Study of High Frequency Resonant Circuit for Tesla Coil

Project Proposal Submitted to Midnapore City College
for the Partial Fulfillment of the Degree of
Master of Science (Physics)

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Declaration

We do hereby declare that the present Master thesis entitled '**Study of High Frequency Resonant Circuit for Tesla Coil'** embodies the original research work carried out by me in the Department of Biological Sciences, Midnapore City College, Paschim Medinipur, West Bengal, India under the supervision of Dr. Atanu Das, Associate Prof., Department of physics, Midnapore City College, Paschim Medinipur, West Bengal. No part thereof has been submitted for any degree or diploma in any University.

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Approval Sheet

This project report entitled "**Study of High Frequency Resonant Circuit for Tesla Coil**" by Bappa Manna, Debojyoti Dutta is approved for the degree of **Master of Science (Physics).**

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Dedicated to Our Parents, Teachers.

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Bappa Manna
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Abstract

The concept of wireless power transfer was realized by Nikola Tesla. The wireless power transfer can make a remarkable change in the field of the electrical engineering which eliminates the use conventional copper cables and current carrying wire. Based on this concept, the aim of the project is develope a prototype to transfer power within a small range. This idea can be used for charging batteries where physical electrical connection is not possible such as pace makers (an electronic device that works in place of a defective heart valve implanted in the body that runs on a battery). The patient is required to be operated every year to replace their pace maker battery. This project is designed to charge a rechargeable battery and light up a florescent bulb wirelessly. Moreover, this wireless technique can be used in number of applications, like to charge a mobile phone, iPad, laptop batteries, this concept is an emerging technology, and in future the distance of power transfer can be enhanced as the research across the world is rapidly growing to improve the technology.

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Chapter 1: Introduction

1. Introduction

There is a basic law in thermodynamics; the law of conservation of energy, which states that "energy may neither be created nor destroyed just can be transformed". Nature is an expert using this physics fundamental law favoring life and evolution of species all around the planet, it can be said that we are accustomed to live under this law that we do not pay attention to its existence and how it influence our lives.

Power is very important to modern system. From the smallest sensors, bionic implants, laptops, consumer products to satellites and oil platforms, it is important to be able to deliver power means other than classical wires or transmission lines. Wireless transmission is useful in cases where instantaneous or continuous energy transfers needed, but interconnecting wires are inconvenient, hazardous, or impossible sometimes. In case of biological implants, there must be a battery or an energy storage element present that can receive and hold energy. This element takes up valuable space inside a person's body. In case of satellites, UAVs and oil platforms, solar panels, fuel cells or combustion engines are currently used to supply power. The history of wireless power transmission dates back to the late 19th century with the prediction that power could be transmitted from one point to another in free space by Maxwell in his "Treatise on Electricity and Magnetism".

Heinrich Rudolf Hertz performed experimental validation of Maxwell's equation which was a monumental step in the direction. However, Nikola Tesla's experiments are often considered as being some of the most serious demonstrations of the capability of transferring power wirelessly even with his failed attempts to send power to space. There are three types of Wireless Power Transfer (WPT): radiative transfer, inductive transfer, and resonant coupling. Radiative transfer, although suitable for exchanging information, can transfer only small power (several mill watts), because a majority of energy is wasted into free space. Directive radiative transfer using highly directional antennas can be efficiently used for power transfer, even for long distances, but requires existence of an uninterruptible line-of-sight and has harmful influences on human body. On the other hand, inductive coupling can transfer power with very high efficiency but in a very short range (just in several centimeters). The last type of WPT, resonant coupling, can transfer high power at the medium range (several meters). Recently, MIT proposed a new scheme based on strongly coupled magnetic resonances, thus presenting a potential breakthrough for a midrange wireless energy transfer. The fundamental principle is that resonant objects exchange energy efficiently, while non-resonant objects do not. The scheme is carried with a power transfer of 60 W and has RF-to-RF coupling efficiency of 40% for a distance of 2m, which is more than three times the coil's diameter. We expect that coupled magnetic resonances make possible the commercialization of a midrange wireless power transfer. (Vázquez-Leal et al., 2012).

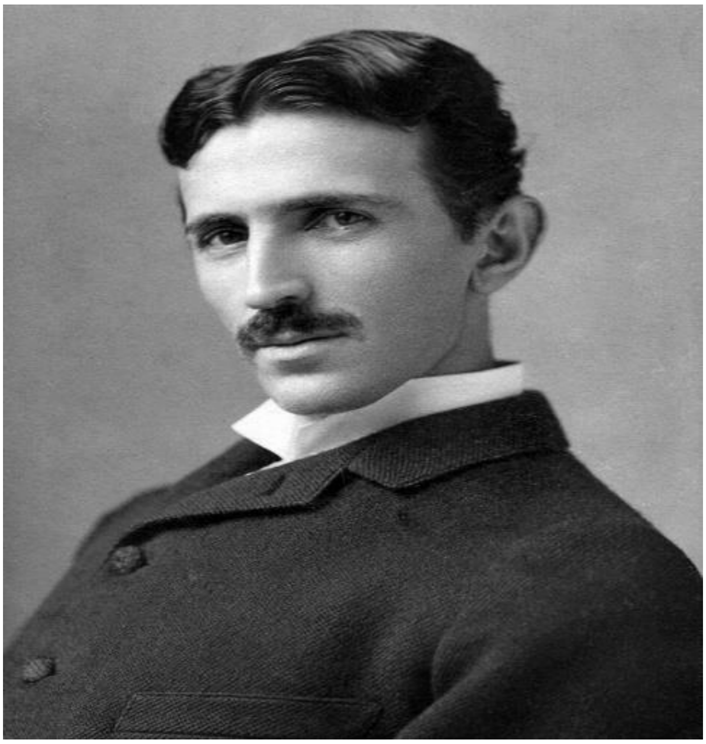

Figure 1: Nikola Tesla (Source: Wikipedia)

1.2. History of Wireless Power Transmission

1864: **James Clerk Maxwell** mathematically modeled the behavior of electromagnetic radiation.

1888: **Heinrich Rudolf Hertz** confirmed the existence of electromagnetic radiation "apparatus for generating electromagnetic waves" is generally acknowledged as the first radio transmitter.

1894: **Jagdish Chandra Bose** ignited gunpowder and rang a bell at a distance using electromagnetic waves, showing that communication signals can be sent without using wires.

1895: **Jagdish Chandra Bose** transmitted signals over a distance of nearly a mile.

1897: **Guglielmo Marconi** had transmitted Morse code signals over a distance of about 6 km.

1897: **Nikola Tesla** (inventor of radio microwaves and Alternating current) filed his first patents dealing with Wardenclyffe Tower (Fig. 2).

Figure 2: Wardenclyffe Tower

1900: **Marconi failed** to get a patent for Radio in the United States The patent office mentioned" Marconi's pretended ignominies of the nature of a "Tesla oscillator" being little short of absurd.

1901: **Guglielmo Marcon** first transmitted and received signals across the Atlantic Ocean. Engineer Otis Pond working for Tesla, said, "Looks as if Marconi got the jump on you."

Tesla replied, “Marconi is a good fellow. Let him continue. He Is using seventeen of my patents.”

1904: at the St. Louis World’s Fair, a prize was offered for a successful attempt to drive a 0.1 horsepower (75 W) airship us by energy transmitted through space at a distance of least 100 feet (30m).

1964: **William Ha** demonstrated on CBS News with Walter Cronkite a microwave-powered model he copter that received all the power needed for flight from a microwave beam. Between 1969 and 1975 Brown was technical director of a JPL Raytheon program that beamed 30 kW over a distance of 1 mile at 84% efficiency.

1975: **Goldstone Deep Space Communications**. Complex did experiments in the tens of kilowatts.

2003: **NASA** Dryden Flight Research Center demonstrated a laser-powered model airplane indoors.

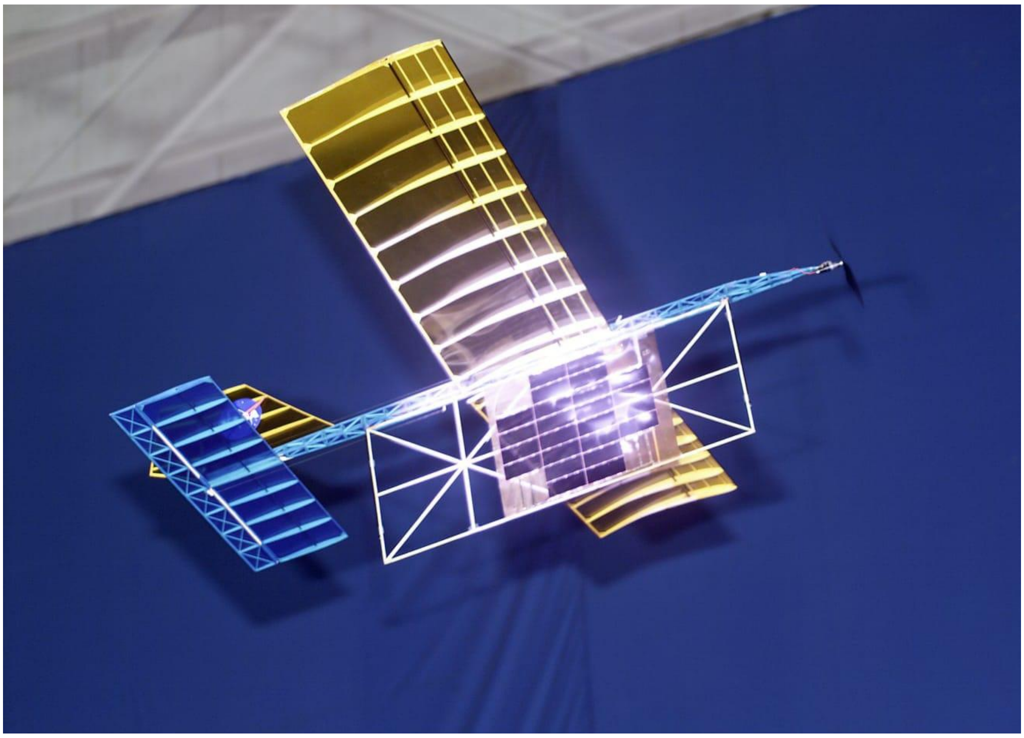

Figure 3: Laser-powered model airplane indoors

(Source: NASA Research Center Photo Collection)

1.3. Invention

During the Industrial Revolution the electrical industry exploited direct current (DC) and low frequency alternating current (AC), but not much was known about frequencies above 20 kHz, what are now called radio frequencies. In 1887, four years previously, Heinrich Hertz had discovered Hertzian waves (radio waves), electromagnetic waves which oscillated at very high frequencies. This attracted much attention, and a number of researchers began experimenting with high frequency currents.

Tesla's background was in the new field of alternating current power systems, so he understood transformers and resonance. In 1888 he decided that high frequencies were the most promising field for research, and set up a laboratory at 33 South Fifth Avenue, New York for researching them, initially repeating Hertz's experiments.

He first developed alternators as sources of high frequency current, but by 1890 found they were limited to frequencies of about 20 kHz. In search of higher frequencies, he turned to spark-excited resonant circuits. Tesla's innovation was in applying resonance to transformers. Transformers functioned differently at high frequencies than at the low frequencies used in power systems; the iron core in low frequency transformers caused energy losses due to eddy currents and hysteresis. Tesla and Elihu Thomson independently developed a new type of transformer without an iron core, the "oscillation transformer", and the Tesla coil circuit to drive it to produce high voltages.

Tesla invented the Tesla coil during efforts to develop a "wireless" lighting system, with gas discharge light bulbs that would glow in an oscillating electric field from a high voltage, high frequency power source. For a high frequency source Tesla powered a Ruhmkorff coil (induction coil)with his high frequency alternator. He found that the core losses due to the high frequency current overheated the iron core in the Ruhmkorff coil and melted the insulation between the primary and secondary windings. To fix this problem Tesla changed the design so that there was an air gap instead of insulating material between the windings, and made the iron core adjustable so it could be moved in or out of the coil He eventually found the highest voltages could be produced when the iron core was omitted. Tesla also found he needed to put the capacitor normally used in the Ruhmkorff circuit between his alternator and the coil's primary winding to avoid burning out the coil. By adjusting the coil and capacitor Tesla found he could take advantage of the resonance set up between the two to achieve even higher frequencies. He found that the highest voltages were generated when the "closed" primary circuit with the capacitor was in resonance with the "open" secondary winding.

Tesla was not the first to invent this circuit. Henry Rowland built a spark-excited resonant transformer circuit (above) in 1889 and Elihu Thomson had experimented with similar circuits in 1890, including one which could produce 64 inch (1.6 m) sparks, and other sources confirm Tesla was not the first. However, he was the first to see practical applications for it and patent it. Tesla did not perform detailed mathematical analyses of the circuit, relying instead on trial and error and his intuitive understanding of resonance. He even realized that the secondary coil functioned as a quarter-wave resonator; he specified the length of the wire in the secondary coil must be a quarter wavelength at the resonant frequency. The first mathematical analyses of the circuit were done by Anton Oberbeck (1895) and Paul Drude (1904).

Figure 4: Tesla Bulb (Source: Wikipedia)

1.4. Wireless power experiments

Tesla employed the Tesla coil in his efforts to achieve wireless power transmission, his lifelong dream. In the period 1891 to 1900 he used it to perform some of the first experiments in wireless power, transmitting radio frequency power across short distances by inductive coupling between coils of wire. In his early 1890s demonstrations such as those before the American Institute of Electrical Engineers and at the 1893 Columbian Exposition in Chicago he lit light bulbs from across a room. He found he could increase the distance by using a receiving LC circuit tuned to resonance with the Tesla coil's LC circuit, transferring energy by resonant inductive coupling. At his Colorado Springs laboratory during 1899–1900, by using voltages of the order of 10 million volts generated by his enormous magnifying transmitter coil (described below), he was able to light three incandescent lamps at a distance of about 100 feet (30 m). Today the resonant inductive coupling discovered by Tesla is a familiar concept in electronics, widely used in IF transformers and short-range wireless power transmission systems such as cell phone charging pads.

It is now understood that inductive and capacitive coupling are "near-field" effects, so they cannot be used for long-distance transmission. However, Tesla was convinced he could develop a long range wireless power transmission system which could transmit power from power plants directly into homes and factories without wires, described in a visionary June 1900 article in Century Magazine; "The Problem of Increasing Human Energy". He claimed to be able to transmit power on a worldwide scale, using a method that involved conduction through the Earth and atmosphere. Tesla believed that the entire Earth could act as an electrical resonator, and that by driving current pulses into the Earth at its resonant frequency from a grounded Tesla coil with an elevated capacitance, the potential of the Earth could be made to oscillate, creating global standing waves, and this alternating current could be received with a capacitive antenna tuned to resonance with it at any point on Earth. Another of his ideas was that transmitting and receiving terminals could be suspended in the air by balloons at 30,000 feet (9,100 m) altitude, where the air pressure is lower. At this altitude, he thought, a layer of electrically conductive rarefied air would allow electricity to be sent at high voltages (hundreds of millions of volts) over long distances. Tesla envisioned building a global network of wireless power stations, which he called his "World Wireless System", which would transmit both information and electric power to everyone on Earth. There is no reliable evidence that he ever transmitted significant amounts of power beyond the short-range demonstrations above.

1.5. Magnifying transmitter

Tesla's wireless research required increasingly high voltages, and he had reached the limit of the voltages he could generate within the space of his New York lab. Between 1899 and 1900 he built a laboratory in Colorado Springs and performed experiments on wireless transmission there. He chose this location because the polyphase alternating current power distribution system had been introduced there and he had associates who were willing to give him all the power he needed without charging for it. The Colorado Springs laboratory had one of the largest Tesla coils ever built, which Tesla called a "magnifying transmitter" as it was intended to transmit power to a distant receiver. With an input power of 300 kilo-watts, it could produce potentials of the order of 10 million volts, at frequencies of 50–150 kHz, creating huge "lightning bolts" reportedly up to 135 feet long. During experi-ments, it caused an overload which destroyed the alternator of the Colorado Springs power company, and Tesla had to rebuild the alternator.

In the magnifying transmitter, Tesla used a modified design (see circuit) which he had de-veloped in his New York lab in the period 1895–1898 and patented in 1902 different from his previous double-tuned circuits. In addition to the primary (L1) and secondary (L2) coils, it had a third coil (L3) which he called the "extra" coil, not magnetically coupled to the others, attached to the top terminal of the secondary. When driven by the secondary it pro-duced additional high voltage by resonance, being adjusted to resonate with its own para-sitic capacitance (C2) The use of a series-fed resonator coil to generate high voltages was independently discovered by Paul Marie Oudin in 1893 and employed in his Oudin coil.

The Colorado Springs apparatus consisted of a 51-foot-diameter (15.5 m) Tesla transformer composed of a secondary winding (L2) of 50 turns of heavy wire wound on a 6-foot-high (2 m) circular wooden "fence" around the periphery of the lab, and a single-turn primary (L1) either mounted on the fence or buried in the ground under it. The primary was con-nected to a bank of oil capacitors (C1) to make a tuned circuit, with a rotary spark gap (SG), powered by 20 to 40 kilovolts from a powerful utility step-up transformer (T). The top of the secondary was connected to the 100-turn 8 ft (2.4 m) diameter "extra" or "resonator" coil (L3) in the centre of the room. Its high-voltage end was connected to a telescoping 143-foot (43.6 m) "antenna" rod with a 30-inch (1 m) metal ball on top which could project through the roof of the lab. By cranking the rod up or down he could adjust the capacitance in the circuit of the extra coil, tuning it to resonance with the rest of the circuit.

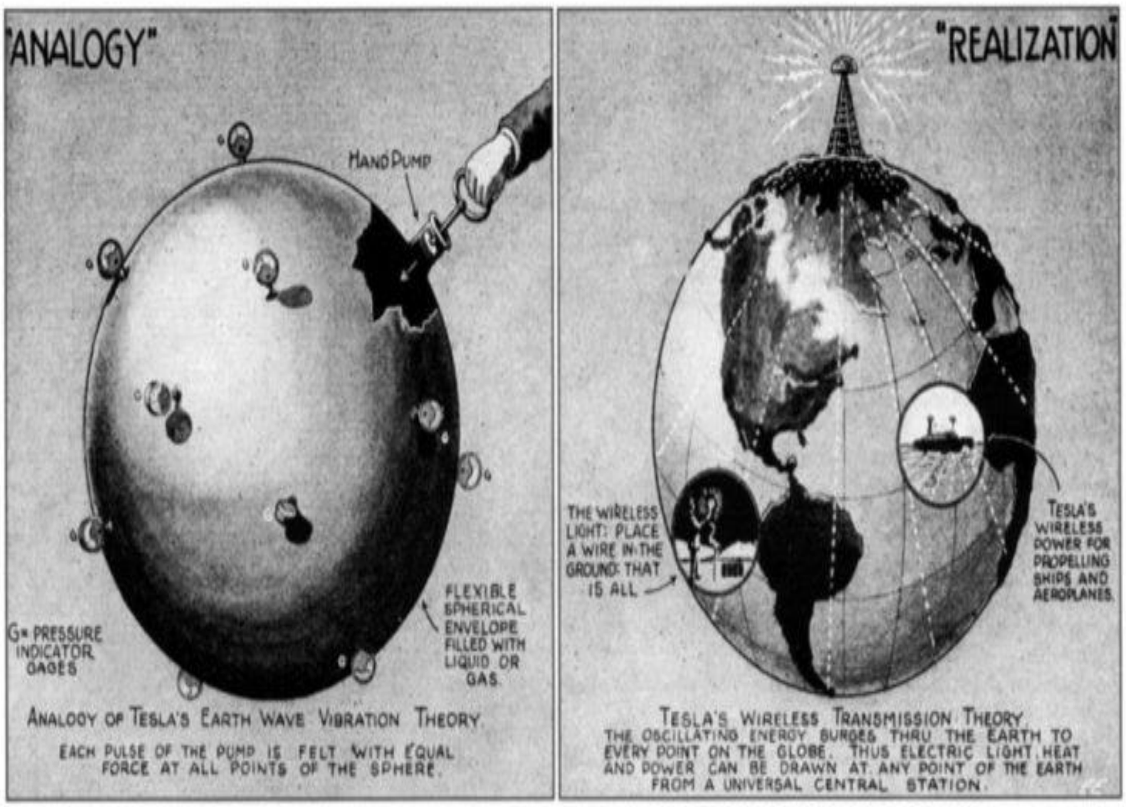

Figure 5: Magnifying transmitter (Source: Waveguide)

1.6. Wardenclyffe tower

In 1901, convinced his wireless theories were correct, Tesla with financing from banker J. P. Morgan began construction of a high-voltage wireless station, now called the Wardenclyffe Tower, at Shoreham, New York. Although it was built as a transatlantic radiotelegraphy station, Tesla also intended it to transmit electric power without wires as a prototype transmitter for his proposed "World Wireless System". Essentially an enormous Tesla coil, it consisted of a powerhouse with a 400-horsepower generator and a 187-foot (57 m) tower topped by a 68-foot (21 m) diameter metal dome capacitive electrode. The circuit he used was a version of the "magnifying transmitter" he built at Colorado Springs (above). Underneath the surface was an elaborate ground system that Tesla said was needed to "grip the earth" to create the oscillating earth currents which he believed would transmit the power.

Figure 6: Wardenclyffe Tower (Source: Wikipedia)

By 1904 his investors had pulled out and the facility was never completed; it was torn down in 1916. Although Tesla seems to have believed his wireless power ideas were proven, he had a history of making claims that he had not confirmed by experiment and there seems to be no evidence that he ever transmitted significant power beyond the short-range demonstrations mentioned above. The few reports of long-distance power transmission by Tesla are not from reliable sources. For example, a widely repeated myth is that in 1899 he wirelessly lit 200 light bulbs at a distance of 26 miles (42 km). There is no independent confirmation of this supposed demonstration; Tesla did not mention it, and it does not appear in his laboratory notes. It originated in 1944 from Tesla's first biographer, John J. O'Neill, who said he pieced it together from "fragmentary material... in a number of publications".
In the 100 years since, others such as Robert Golka have built equipment similar to Tesla's, but long-distance power transmission has not been demonstrated, and the scientific consensus is his World Wireless system would not have worked. Contemporary scientists point

out that while Tesla's coils (with appropriate antennas) can function as radio transmitters, transmitting energy in the form of radio waves, the frequency he used, around 150 kHz, is far too low for practical long-range power transmission. At these wavelengths the radio waves spread out in all directions and cannot be focused on a distant receiver. Tesla's world power transmission scheme remains today what it was in Tesla's time a bold, fascinating dream.

1.7. Used in medicine

Tesla had observed as early as 1891 that high frequency currents above 100 kHz did not cause the sensation of electric shock, and in fact currents that would be lethal at lower frequencies could be passed through the body without apparent harm. He experimented on himself, and claimed daily applications of high voltage relieved depression. He was one of the first to observe the heating effect of high frequency currents on the body, the basis of diathermy. During his highly publicized early 1890s demonstrations he passed hundreds of thousands of volts through his body. With characteristic hyperbole he called electricity "the greatest of all doctors" and suggested burying wires under classrooms so its stimulating effect would improve performance of "dull" schoolchildren. Tesla wrote two pioneering papers, in 1891 and 1898 on the medical uses of high frequency currents, but did little further work on the subject.

A few other researchers were also experimentally applying high frequency currents to the body at this time. Elihu Thomson, the co-inventor of the Tesla coil, was one, so in medicine the Tesla coil became known as the "Tesla-Thomson apparatus". In France, from 1889 physician and pioneering biophysicist Jacques D'Arsonval had been documenting the physiological effects of high frequency current on the body, and had made the same discoveries as Tesla. During his 1892 European trip Tesla met with D'Arsonval and was flattered to find they were using similar circuits. D'Arsonval's spark-excited resonant circuits (above) did not produce as high voltage as the Tesla transformer. In 1893 French physician Paul Marie Oudin added a "resonator" coil to the D'Arsonval circuit to create the high voltage Oudin coil, a circuit very similar to the Tesla coil, which was widely used for treating patients in Europe.

During this period, people were fascinated by the new technology of electricity, and many believed it had miraculous curative or "vitalizing" powers. Medical ethics were also looser, and doctors could experiment on their patients. By the turn of the century, application of high voltage, "high frequency" currents to the body had become part of a Victorian era medical field, part legitimate experimental medicine and part quack medicine, called electrotherapy. Manufacturers produced medical apparatus to generate "Tesla currents", "D'Arsonval currents", and "Oudin currents" for physicians. In electrotherapy, a pointed electrode attached to the high voltage terminal of the coil was held near the patient, and the luminous brush discharges from it (called "effluves") were applied to parts of the body to treat a wide variety of medical conditions. In order to apply the electrode directly to the skin, or tissues inside the mouth, anus or vagina, a "vacuum electrode" was used, consisting of a metal electrode sealed inside a partially evacuated glass tube, which produced a dramatic violet glow. The glass wall of the tube and the skin surface formed a capacitor which limited the current to the patient, preventing discomfort. These vacuum electrodes were later manufactured with handheld Tesla coils to make "violet ray" wands, sold to the public as a quack home medical device.

The popularity of electrotherapy peaked after World War I, but by the 1920s authorities began to crack down on fraudulent medical treatments, and electrotherapy largely became obsolete. A part of the field that survived was diathermy, the application of high frequency current to heat body tissue, pioneered by German physician Karl Nagel schmidt in 1907. During the 1920s "long wave" (0.5~2 MHz) Tesla coil spark diathermy machines were used, in which the current was applied to the body by electrodes. By the 1930s these were being replaced by "short wave" (10~100 MHz) vacuum tube diathermy machines, which had less danger of causing burns, but Tesla coils continued to be used in both diathermy and quack medical devices like violet ray until World War II. In 1926 William T. Bovie discovered that RF currents applied to a scalpel could cut and cauterize tissue in medical operations, and spark oscillators were used as electrosurgery generators or "Bovies" as late as the 1980s.

During the 1920s and 30s all unipolar (single terminal) high voltage medical coils came to be called Oudin coils, so today's unipolar Tesla coils are sometimes referred to as "Oudin coils".

Tesla coils can be used for non-invasive electrotherapy to stimulate tissue repair and reduce pain. It can produce heat in deep tissues for medical purposes, such as in diathermy treatments. Electromagnetic fields from Tesla coils may promote faster wound healing and tissue regeneration. It can aid in bone fracture healing by stimulating osteogenesis. Tesla coil can assist in studying the effects of electromagnetic fields on cancer cells in vitro. It may be used to stimulate nerves and study neural responses.

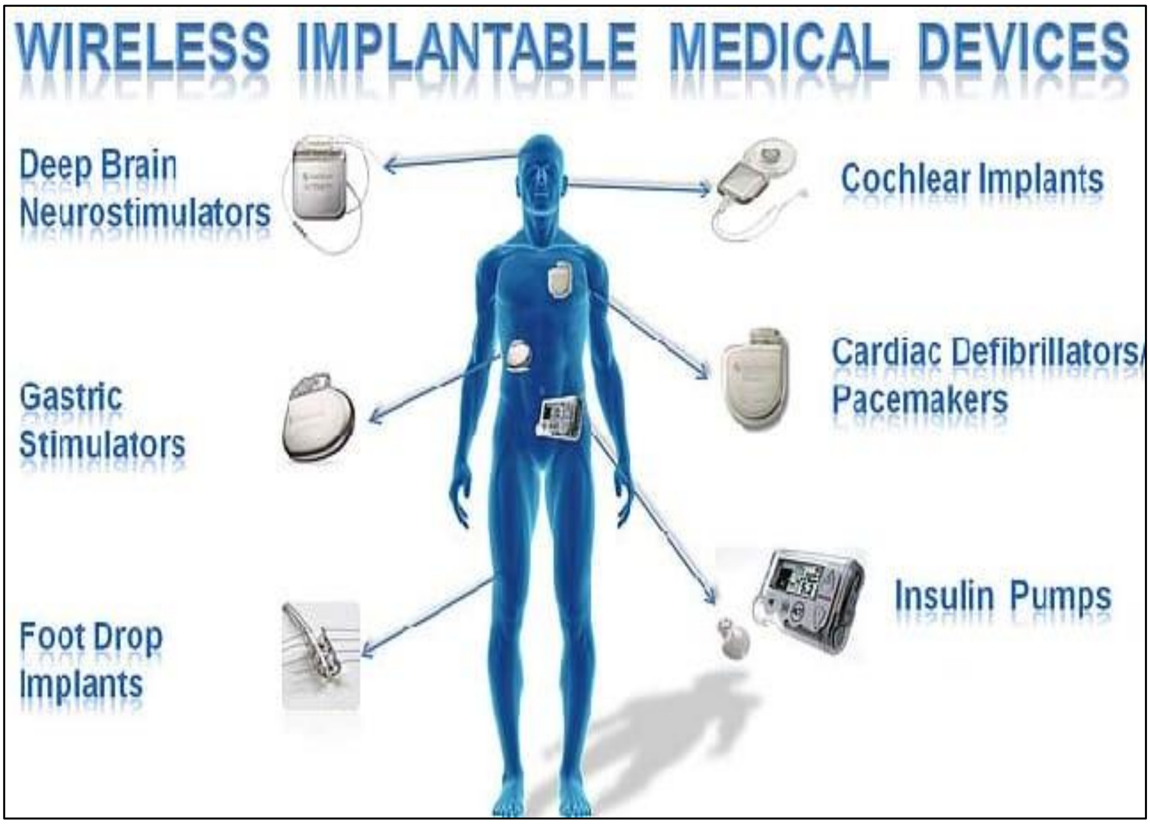

Figure 7: Wireless Implantable Medical Devices (Source: Wikipedia)

1.8. Resonance

Resonance describes the phenomenon of increased amplitude that occurs when the frequency of an applied periodic force (or a Fourier component of it) is equal or close to a natural frequency of the system on which it acts. When an oscillating force is applied at a resonant frequency of a dynamic system, the system will oscillate at a higher amplitude than when the same force is applied at other, non-resonant frequencies. Increase of amplitude as damping decreases and frequency approaches resonant frequency of driven damped simple harmonic oscillator. Frequencies at which the response amplitude is a relative maximum are also known as resonant frequencies or resonance frequencies of the system. Small periodic forces that are near a resonant frequency of the system have the ability to produce large amplitude oscillations in the system due to the storage of vibrational energy.

Resonance phenomena occur with all types of vibrations or waves: there is mechanical resonance, orbital resonance, acoustic resonance, electromagnetic resonance, nuclear magnetic resonance (NMR), electron spin resonance (ESR) and resonance of quantum wave functions. Resonant systems can be used to generate vibrations of a specific frequency (e.g., musical instruments), or pick out specific frequencies from a complex vibration containing many frequencies (e.g., filters).

The term resonance (from Latin resonantia, 'echo', from resonare, 'resound') originated from the field of acoustics, particularly the sympathetic resonance observed in musical instruments, e.g., when one string starts to vibrate and produce sound after a different one is struck.

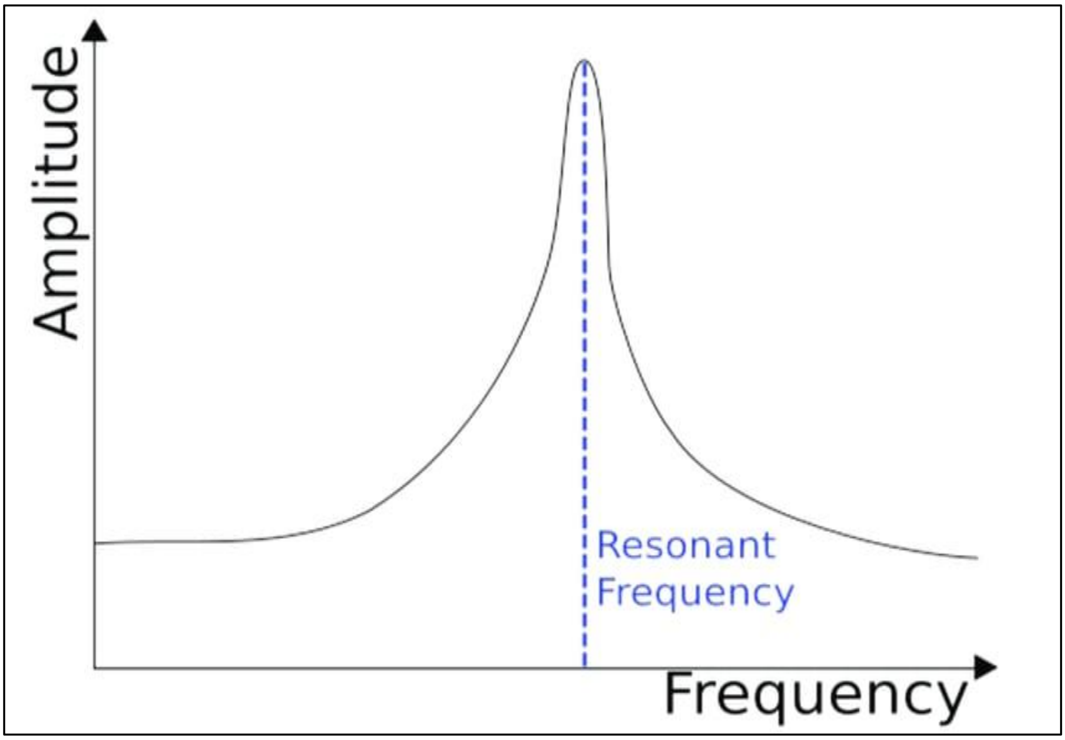

Figure 8: Resonance (Source: Brilliant Math & Science Wiki)

1.9. A General Review on Wireless Power Transfer

Nikola Tesla was the leader of WPT. In 1891, he successfully performed an experiment to energize a lamp using a pair of coils. Later, he successfully performed similar experiments on two hundred lamps and transmitted power to them over a 25-mile distance. WPT can be categorized into two methods: near-field and far-field transmission. In general, near-field power transfer methods have higher in comparison to the far-field ones. Most of the WPT applications are using the near-field method. In order to consider any region to be near-field, two conditions should be considered: first, the distance between the transmitter and receiver coil should be less than one wavelength (λ) at the operating frequency ($r < \lambda$), and secondly, the largest dimension of the transmitter coil should be less than λ/2. For implantable biomedical device applications based on far-field transfer, a good review may be found in. The far-field methods are based on delivering power to a device using antennas. In this paper, the focus is on the applications of near-field power transfer methods.

1.10. Near Field

Near-field transfer is based on the coupling of two coils within the distance of the coils' dimension. In fact, a transformer is transferring energy wirelessly through magnetic field coupling, although it was invented more than 100 years ago. But if you remove the iron core and move the two coils apart, the transfer efficiency drops drastically. That is why the two coils must be put close enough to each other. This kind of method is already commercialized. For example, most electric toothbrushes today are using wireless chargers, which are much safer than cable chargers in wet environment.

However, if the transmitter and receiver coils have the same resonant frequency, which is determined by the material and shape of the coil, transfer efficiency will decrease much more slowly when they are moved apart. A group from MIT, led by Prof. Marin Soljacic has succeeded in transferring electric energy (60 Watt) between two coils more than two meters apart through non-radiative electromagnetic field.

Since near field transfer is usually working at 50 or 60Hz, there is almost no interference with TV, radio or Wi-Fi signals. The major concern is the possible influence on human health. Luckily, almost all materials that form human body are non-magnetic, so they interact very weakly with magnetic field, even to several Tesla like that in a modern MRI machine. Thus, such magnetic-field-based transfer is quite safe to people within the transfer range.

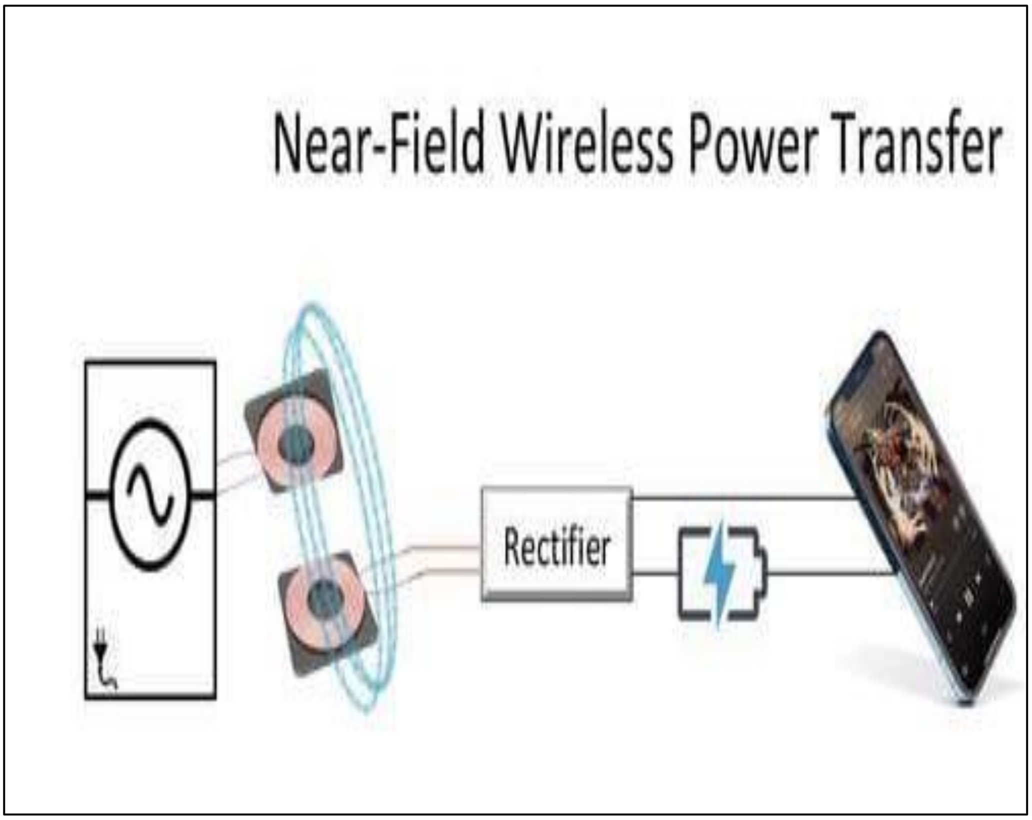

Figure 9: Near-Field Wireless Power Transfer (Source: IntechOpen)

1.11. Induction

The action of an electrical transformer is the simplest instance of wireless energy transfer. The primary and secondary circuit of a transformer are not directly connected. The transfer of energy takes place by electromagnetic coupling through a process known as mutual induction. (An added benefit is the capability to step the primary voltage either up or down.) The battery charger of an electric toothbrush is an example of how this principle can be used the main drawback to induction, however, is the short range. The receiver must be very close to the transmitter or induction unit in order to inductively couple with it.

However, if the transmitter and receiver coils have the same resonant frequency, which is determined by the material and shape of the coil, transfer efficiency will decrease much more slowly when they are moved apart. A group from MIT, led by Prof. Marin Soljacic has succeeded in transferring electric energy (60 Watt) between two coils more than two meters apart through non-radiative electromagnetic field, as shown in Fig 12 (Hadley, 2007).

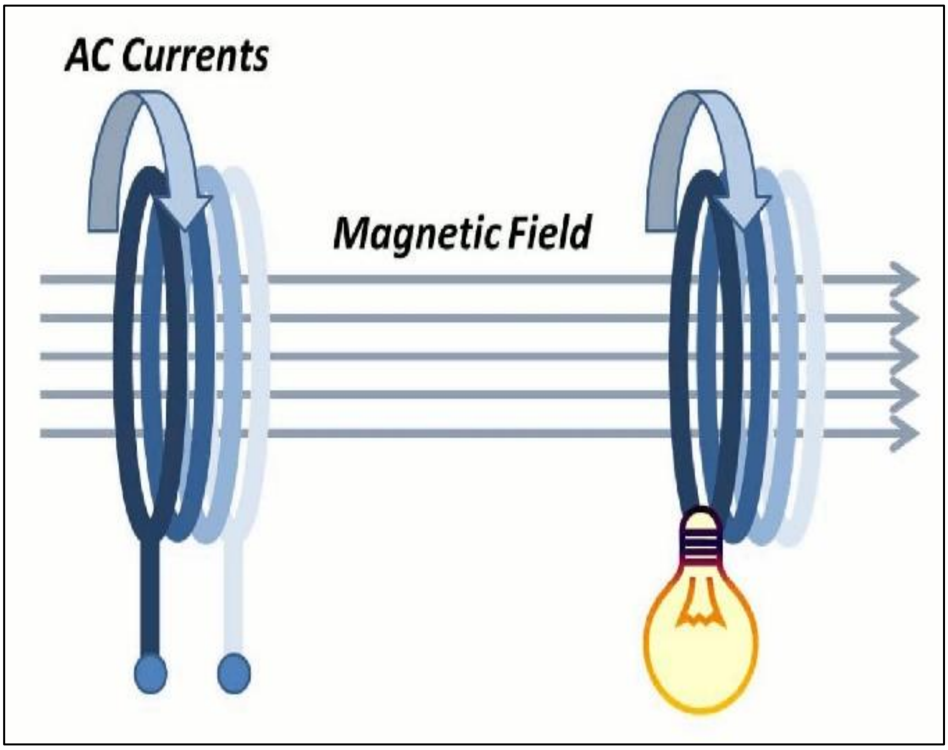

Figure 10: Transferring energy though magnetic field coupling between two coils with identical resonant frequency (Source: Stanford University)

In a theoretical analysis, they demonstrate that by sending electromagnetic waves around in a highly angular waveguide, evanescent waves are produced which carry no energy. If a proper resonant waveguide is brought near the transmitter, the evanescent waves can allow the energy to tunnel (specifically evanescent wave coupling, the electromagnetic equivalent of tunneling to the power drawing waveguide, where they can be rectified into DC power. Since the electromagnetic waves would tunnel, they would not propagate through the air to be absorbed or dissipated, and would not disrupt electronic devices or cause physical injury like microwave or radio wave transmission might. Researchers anticipate up to 5 meters of range for the initial device and are currently working on a functional prototype.

On June 7, 2007, it was reported that a prototype system had been implemented. The MIT researchers successfully demonstrated the ability to power a 60-watt light bulb from a power source that was seven feet (2 meters) away at roughly 40% efficiency.

“Resonant inductive coupling” has key implications in solving the two main problems associated with non-resonant inductive coupling and electromagnetic radiation, one of which is caused by the other; distance and efficiency. Electromagnetic induction works on the principle of a primary coil generating a predominantly magnetic field and a secondary coil being within that field so a current is induced within its coils. This causes the relatively short range due to the amount of power required to produce an electromagnetic field. Over greater distances the non-resonant induction method is inefficient and wastes much of the transmitted energy just to increase range. This is where the resonance comes in and helps efficiency dramatically by “tunneling” the magnetic field to a receiver coil that resonates at the same frequency. Unlike the multiple- layer secondary of a non-resonant transformer, such receiving coils are single layer solenoids with closely spaced capacitor plates on each end, which in combination allow the coil to be tuned to the transmitter frequency thereby eliminating the wide energy wasting “wave problem” and allowing the energy used to focus in on a specific frequency increasing the range (Vora, 2011).

1.12. Far Field

Means for long conductors of electricity forming part of an electric circuit and electrically connecting said ionized beam to an electric circuit.

These methods achieve longer rings often multiple kilometer ranges, where the distance is much greater than the diameter of the device (Vibhakar, 2011). To transfer energy wirelessly over long ranges, far-field transfer is used. Far-field transfer is based on electromagnetic wave which is radiative. Different methods use electromagnetic waves within different wave band. In the early times, experiments were carried out with radio and microwaves, around 1GHz (Barrett, 1894). Electric energy is transferred to a strong beam of radio or microwave by a dish-like antenna, travels through the atmosphere and then received by another antenna which transfers it back to AC electric current, as shown in Fig 11.

In the context of a Tesla coil, “far field” refers to the region of electromagnetic radiation and energy propagation that occurs at a considerable distance from the coil itself. It is the region where the radiated electromagnetic waves become dominant, and the electromagnetic fields are decoupled from the Tesla coil’s primary and secondary windings.

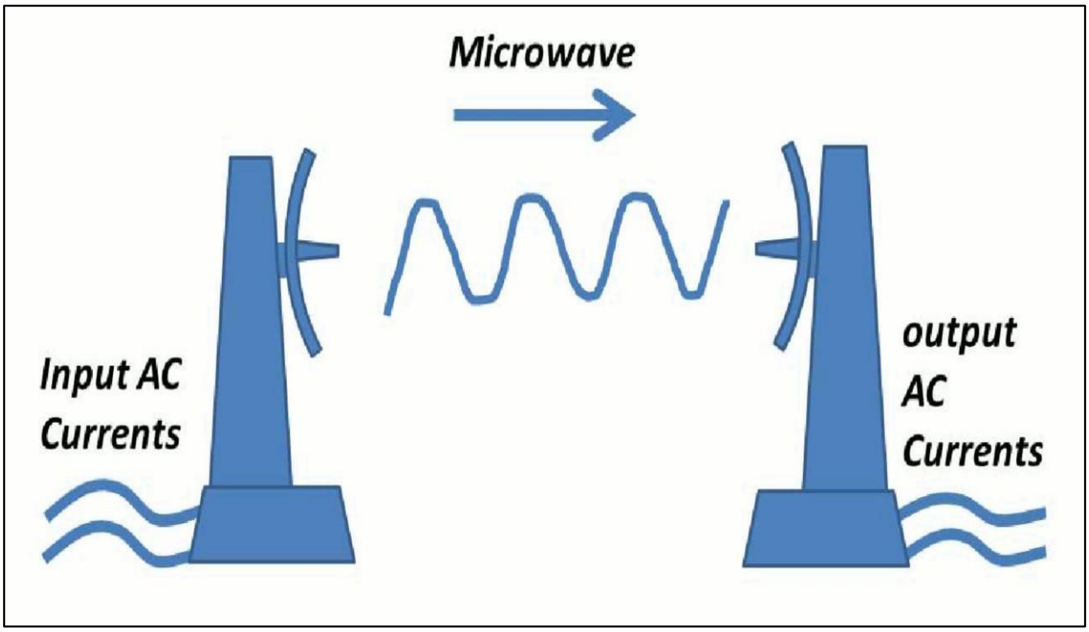

Figure 11: Transferring energy though microwave between two stations

(Source: Stanford University)

Yet according to diffraction, the longer the wavelength is, the larger the antennas must be in order to achieve sufficient directionality. Since speed of light in the air is about 3 x 108 m/s, the corresponding wavelength of radio and microwaves used is about one meter, which requires an antenna with a dimension of several meters to several kilometers. Thus, we have to use electromagnetic waves with shorter wavelength if we want to transfer energy to smaller objects. Moreover, since the electromagnetic wave used lies in the waveband of radio, TV, cell phone and Wi-Fi, with a signal intensity several order-of-magnitude larger, you probably won't want it any close to residences or offices - in fact, it was proposed to be used in energy transfer between future solar power satellites and the earth (Landis, 1994).

1.13. Radio and Microwave

The earliest work in the area of wireless transmission via radio waves was performed by Heinrich Rudolf Hertz in 1888. A Later Cinglielmo Marconi worked with a modified form of Hertz's transmitter Nikola Tesla also investigated radio transmission and reception.

Japanese researcher Hidetsugu Yagi also investigated wireless energy transmission using a directional array antenna that he designed. In February 1926, Yagi and Uda published their first paper on the tuned high-gain directional array now known as the Yagi antenna. While it did not prove to be particularly useful for power transmission, this bear antenna has been widely adopted throughout the broadcasting and wireless telecommunications industries due to is excellent performance characteristics.

Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. A reactance may be used to convert the microwave energy back into electricity. Rectenna conversion efficiencies exceeding 95% have been realized. Power beaming using microwaves has been proposed for the transmission of energy from orbiting solar power satellites to Earth and the beaming sifatispostat leaving orbit has been considered Power beaming by microwaves has the difficulty that for most space applications the required aperture sizes are very large.

For example, the 1978 NASA Staley of sour power satellites required a land diameter transmitting antenna, and a 10 km diameter receiving rectenna, for a microwave beam at 2.45 GHz These sizes can be somewhat decreased by using shorter wavelengths, although short wavelengths may have difficulties with atmospheric absorption and beam blockage by rain or water inlets.

Because of the Thinnaf array curse, it is not possible to make a narrower beam by combining the beams of several smaller satellites. For earthbound applications a large area 10 km diameter receiving array allows large total power levels to be used while operating at the low power density suggested for human electromagnetic exposure safety. A human safe power density of 1 mW/car distributed across a 10km diameter areas corresponds to 750 megawatts total power level. This is the power level found in many modems electric power plants (Vibhakar, 2011).

A Tesla coil operates at high frequencies, typically in the radio frequency (RF) range. The primary purpose of a Tesla coil is to produce high-voltage, high-frequency alternating current (AC) in its secondary coil.

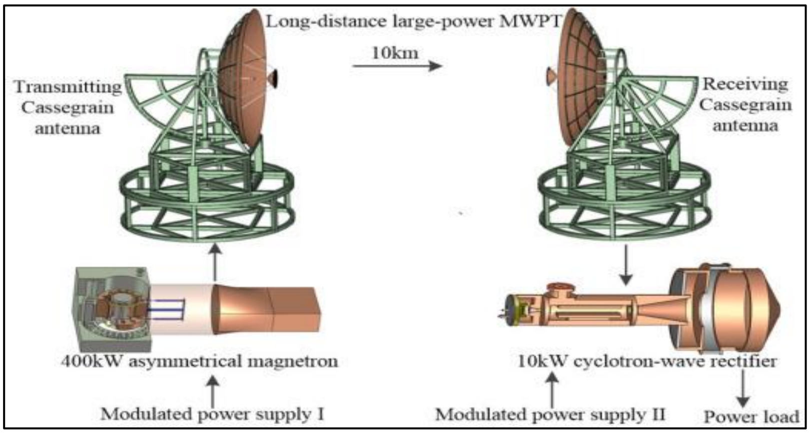

Figure 12: A long-distance high-power microwave wireless power transmission

(Source: Wikipedia)

1.14. High Power

Wireless Power Transmission (using microwaves) is well proven. Experiments in the tens of kilowatts have been performed at Goldstone in California in 1975 and more. Recently (1997) at Grand Bassin on Reunion Island. These methods achieve distances on the order of a kilometer (Vora, 2011).

1.15. Low Power

A new company, Power cast introduced wireless power transfer technology using RF energy at the 2007 Commer Electronics Show, winning best Emerging Technology. The Power caste system is applicable for a number of devices with low power requirements. This could include LEDs, computer peripherals, wireless sensors, and medical implants. Currently, it achieves a maximum output of 6 volts for a little over one meter. It is expected for arrival late 2007, A different low-power wireless power technology has been proposed by Landis (Vibhakar, 2011).

1.16. Laser

The laser beam is coherent light beam capable to transport very high energies, this makes it in an efficient mechanism to send energy point to point in a line of sight. NASA (NASA (2003)) introduced in 2003 a remote-controlled aircraft wirelessly energized by a laser beam and a photovoltaic cell infra-red sensitive acting as the energy collector, as shown in Fig-5. In fact, NASA is proposing such scheme to power satellites and wireless energy transfer where none other mechanism is viable (NASA (2003)) (Vázquez-Leal et al., 2012).

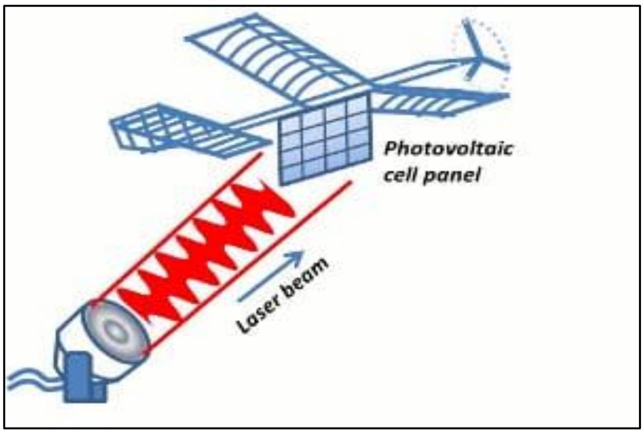

Figure 13: Diagram of NASA's model plane powered by laser beam

(Source: Stanford University)

The method of transmission using a beam of laser which behaves as a source. In this technology, high intensity beam is transmitted through source to the load under a specific distance. The first experiment on WPT through laser is conducted by NASA "Marshall Space Flight Center" in which aircraft is powered by a laser beam.

This is very related to photovoltaic cell which used to convert solar energy into electricity when laser beam or sunlight strike the photovoltaic cell, then these cells convert it into electrical energy. Power can be transmitted through long distance, but losses occur due to scattering of light, it is also harmful to human being.

It needs straight line of sight, if in any case line of sight is not met, then a lot of power losses occur at the receiver side. Recent experiments using commercially obtainable laser sources have generated over 7.2 watts of photovoltaic output from a 70watt laser beam. In

Washington State company trying to transmit electricity using a laser beam. Laser Motive is a Seattle-based company developing wireless power delivery systems using laser beams to transmit electricity without wire, WPT using laser has many uses in today's world such as underwater, space, ground vehicles, quad copters, UAVs and drones, etc. Laser beam also known as power beam because in which power is transmitted to the receiver and where it can be transformed into electrical energy (Siddiqui et al., 2015).

1.17. Electromagnetic Resonance

The transmission of power using electromagnetic resonance having two coils, one is primary coil which is used for power transmission and other is secondary coil which receives power at the receiver end, both resonate at the same resonant frequency. The frequencies at which the response amplitude is a relative maximum are known as resonance frequency. Condition to produce resonance is that capacitive reactance and inductive reactance must be same, XC=XL.

In this regard, we perform experiments to transfer wireless power first we design transmitter which resonate at frequency ranges from 0-160 kHz. The coils we used are of 15 gauge.10 feet long circular in shape with 8 turns. Secondly, receiver circuit having same no of coil to receive the electromagnetic waves.

DC converted into AC having high frequency using inverter circuit. Frequency may be in hundred or thousand Hz and it must fulfill the resonance condition using impedance matching network then it passed through primary coil, it produces varying magnetic field around itself, now when secondary coil is brought near to primary coil magnetic field interact with the secondary coil current is induced in secondary coil then this AC current is converted into DC using a rectifier and then transferred to the loads. Power transmission efficiency depends upon distance between two coils and oscillating magnetic field. Using this method, over several kilowatts of power can be transferred safely and efficiently over significantly larger distances irrespective of the alignment. The resonant frequency of the system will change as a function of the coupling, and hence on the distance as in case of the wireless power system, coupling is dependent on the distance between the transmit and receive coils. The number of turns in the coils, diameter, material, and resistance of wire also produce interference in mutual induction (Siddiqui et al., 2015).

Chapter 2: Literature Review

2. Literature Review

Tesla coil research and wireless power transmission studies have witnessed significant advancements in recent years. Researchers have focused on various aspects of Tesla coil technology, including design optimization, electromagnetic field analysis, power electronics integration, and performance evaluation. Through extensive experimentation and simulation, researchers have explored different coil geometries, materials, and winding techniques to enhance the efficiency, power output, and voltage regulation of Tesla coils. They have investigated electromagnetic field behaviour, corona discharge effects, and magnetic resonance phenomena to better understand energy transfer mechanisms and improve overall system performance. Additionally, electromagnetic field analysis has played a crucial role in understanding the behaviour and optimization of Tesla coils. Such studies have enabled researchers to develop strategies to mitigate losses and improve energy transfer efficiency. Wireless power transmission has emerged as a promising area of research within the broader Tesla coil domain, aiming to overcome the limitations of traditional wired power transmission. Numerous studies have investigated different wireless power transfer techniques, such as inductive coupling, capacitive coupling, and resonant inductive coupling. These research efforts have focused on enhancing power transfer efficiency, extending transmission range, and addressing alignment and orientation constraints. Researchers have also explored novel approaches, such as magnetic resonance coupling, to achieve wireless power transmission over longer distances. Studies have focused on overcoming challenges related to distance, alignment, and power transfer efficiency through advancements in resonance tuning, adaptive impedance matching, and optimization of coil configurations. The evolution of power electronics has also greatly influenced Tesla coil and wireless power transmission research. Research papers have explored the integration of advanced power conversion techniques, such as resonant converters and solid-state devices, to enhance system control, power quality, and efficiency. Furthermore, safety considerations and electromagnetic interference mitigation have become prominent areas of investigation, with research focusing on establishing guidelines and standards for safe operation and addressing concerns related to electromagnetic radiation exposure (Siddiqui et al., 2015).

In recent times, research on Tesla coils and wireless power transmission has gained momentum due to increasing interest in wireless energy transfer and advancements in power electronics. Research papers have explored innovative coil designs, novel materials, and advanced manufacturing techniques to improve performance, efficiency, and reliability. Efforts have been made to optimize the coil geometry, enhance resonant coupling, and minimize losses in energy transfer. Over the years, extensive research has been conducted on Tesla coils and wireless power transmission, spanning from the early discoveries by Nikola Tesla to the present day. Historical research papers have delved into the fundamental principles of Tesla coil operation, examining the intricate design elements and resonant characteristics. These studies have laid the foundation for subsequent research endeavors, establishing the theoretical framework and understanding of Tesla coils. Overall, the literature spanning from the past to the present showcases the progressive advancements in Tesla coil technology and wireless power transmission. From foundational research to practical implementations, scholars and researchers have contributed to a deeper understanding of Tesla coils and wireless energy transfer, resulting in more efficient, reliable, and safe systems. This literature review provides a comprehensive overview of the research conducted over time, highlighting the significant milestones and offering insights into the current state of Tesla coil technology and wireless power transmission research. Numerous research studies have been conducted to investigate the design and implementation of Tesla coils and wireless power transmission. These studies have shed light on various aspects of Tesla coil technology, such as coil design optimization, electromagnetic field analysis, power electronics integration, and performance evaluation. Researchers have explored different coil geometries, materials, and winding techniques to enhance the efficiency and performance of Tesla coils. Additionally, studies have focused on analyzing the electric and magnetic field distributions, corona discharge effects, and resonance control techniques for efficient energy transfer. Advanced applications of Tesla coils, including wireless power transmission and energy harvesting, have also been investigated. Safety considerations, such as mitigating electromagnetic interference and ensuring compliance with exposure guidelines, have been addressed. The literature review demonstrates the significant progress made in understanding and advancing Tesla coil and wireless power transmission technology, providing a foundation for further research and development in this field. In recent years, an extensive body of research has been dedicated to exploring the capabilities and applications of Tesla coils and wireless power transmission. These studies have delved into various aspects of Tesla coil technology, encompassing both theoretical analyses and practical implementations. Researchers have focused on optimizing Tesla coil design parameters, such as coil geometry, size, and materials, to maximize performance and efficiency. Moreover, electromagnetic field analysis has been a key area of investigation, with studies examining electric field distribution, corona discharge effects, and magnetic field behavior for efficient energy transfer. Power electronics integration has also received considerable attention, with researchers exploring methods to control resonance, synchronize frequencies, and modulate power to improve overall system performance. Safety considerations have been a significant focus in Tesla coil research. Studies have aimed to mitigate electromagnetic interference, reduce corona discharge, and ensure compliance with safety standards and exposure guidelines. Furthermore, researchers have investigated shielding techniques, grounding protocols, and risk assessment to minimize potential hazards associated with Tesla coil operation. The literature review highlights the collective efforts of researchers in advancing Tesla coil technology and wireless power transmission. It emphasizes the importance of design optimization, electromagnetic field analysis, power electronics integration, and safety considerations in achieving efficient and reliable wireless power transfer. These research findings pave the way for further developments in wireless power transmission systems, contributing to the realization of a wirelessly powered future. Overall, the literature demonstrates the progress made in understanding and refining Tesla coil technology and wireless power transmission. Through theoretical analysis, simulation, and experimental validation, researchers have contributed to the optimization of coil designs, improvement of energy transfer efficiency, and enhancement of safety measures. This literature review provides a comprehensive overview of the research conducted in this field, offering valuable insights into the current state of Tesla coil technology and wireless power transmission, as well as potential directions for future research and development.

Chapter 3: Aims and Objective

3. Aims and Objective

3.1 Aims:

1. Tesla Coil is a device which is used for obtaining high voltage at high frequency as shown in Fig-6. The purpose of construction of Tesla coil is to be able to deliver power other than conducting wires or transmission lines i.e., wireless power transmission.

2. Making a prototype Wireless Power Transmitter we lighted bulb, spinning the fan etc. Actually, we powered some electrical appliances in home without using wires.

3.2 Objectives:

1. Making two coils with same frequency for resonance.
2. We used JAVA TC software for stimulation.
3. Making a receiver coil for receive wireless current.

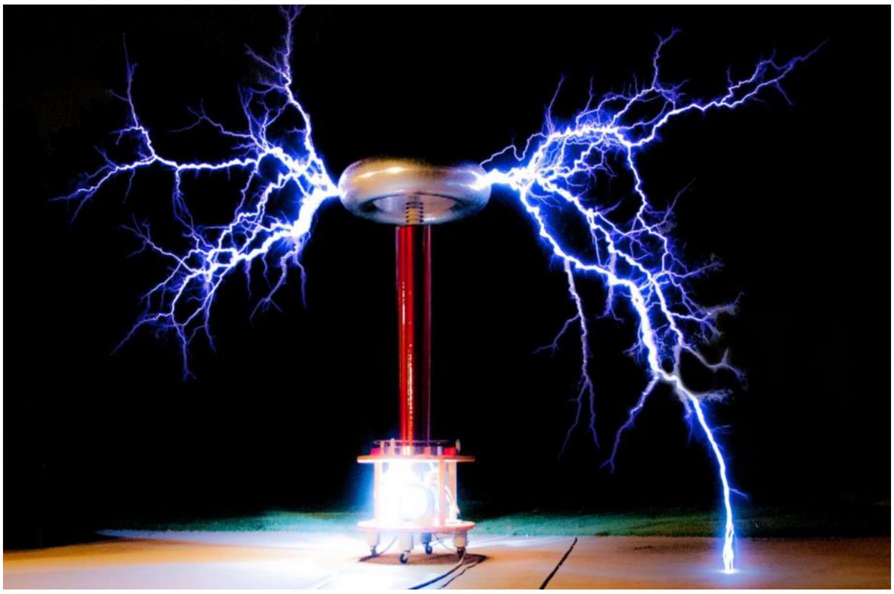

Figure 14: Tesla Coil

Chapter 4: Materials and Methods

1. Materials

SL No.	Material	Purpose
1	DC Power Source (0-12V)	To Power the Device.
2	IRFZ44N	MOSFET IC
3	Flyback Transformer (EHT)	Produce high voltage.
4	Spark Gap	Switch
5	102 2KV (1nF)	Primary Capacitor
6	16 Awg Copper Wire	Primary Coil
7	26 Awg Copper Wire	Secondary Coil
8	Niddle and Ball (metal)	Topload
9	Elegator Clip	Changing Primary Coil Turn Number
10	Fluorescent Bulb	Wirelessly Lighted

Table 1: Materials needed to make the Circuit

Tesla Coil Circuit Diagram

This coil has two main parts – a primary coil and a secondary coil, with each coil having its own capacitor. A spark gap connects the coils and capacitors. The functionality of the spark gap is to generate the spark to excite the system.

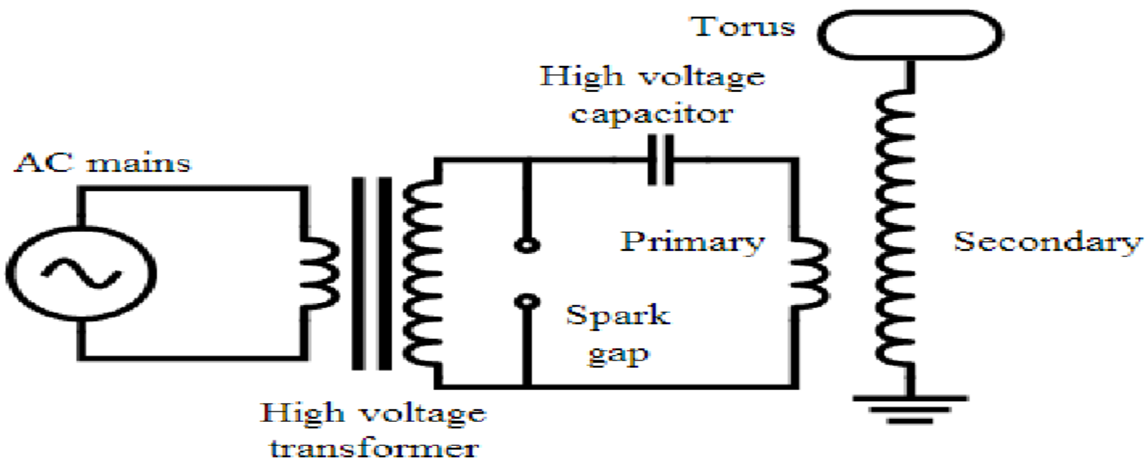

Figure 15: Circuit Diagram of a Tesla Coil.

As discussed, the primary coil is tied to a power source and the capacitor which is at the side of the primary coil operates as a sponge and absorbs the charge. Also, the primary coil should hold the capacity to endure high charge and extensive current surges and because of this coil is constructed with copper material which acts as a perfect conductor for electricity.

The end, the capacitor accumulates more charge, and this breaks the air resistance present in the spark gap. In the same way, how a sponge squeezes out, the capacitor squeezes out current from the primary coil and develops a magnetic field. The extensive amount of energy makes the magnetic field destroy quickly and creates a current in the secondary coil.

The generated voltage in between the coils develops sparks in the spark gap. Here, energy gurgles front and back between the coils many times and this finally builds in the capacitor and secondary coil. Finally, the charge that exists in the secondary capacitor increases more.

This resultant extensive frequency voltage level might lighten up fluorescent bulbs which are at more distance having no wiring connection. In a perfect tesla coil, at the time when the secondary coil comes to its maximum range, then the entire procedure starts, and the device gains the capability to be self-capable. Whereas, in the real-time scenarios, this does not take place. The air which gets heated in the spark gap draws out some amount of electricity from the secondary coil into that spark gap which finally makes the tesla coil to be out of energy. Because of this, the coil should be constantly hooked up to the external power supply.

The theory for the tesla coil is to accomplish the resonance phenomenon and this can be achieved when the primary coil pulls current to the secondary coil which corresponds that it is the correct time to increase the energy that is transmitted into the secondary coil.

In order to generate high output voltage levels, both the primary and secondary circuits are adjusted to be in resonance with each other. So, the resonant frequencies in both circuits can be known by inductance and capacitance values in the circuits.

$$f_1=\frac{1}{2\pi\sqrt{L_1 C_1}}\ldots\ldots\ldots\ldots(1)$$

and

$$f_2=\frac{1}{2\pi\sqrt{L_2 C_2}}\ldots\ldots\ldots\ldots(2)$$

Here, ‘f_1’corresponds to the resonant frequency in the primary tuned circuit and ‘f_2’ corresponds to the resonant frequency in the secondary tuned circuit.

In general, the secondary circuit is not adjusted and so the primary circuit is tuned until the resonant frequencies of both matches.

So, $$f=\frac{1}{2\pi\sqrt{L_1C_1}}=\frac{1}{2\pi\sqrt{L_1L_2}} \quad ....(3)$$

At the resonance condition, $L_1C_1 = L_2C_2$…………(4)

Components required for Spark gap Tesla Coil

1. High Voltage transformer (using flyback transformer)
2. High voltage capacitor (Approximately 4nf, 2kv)
3. Source: - 0 to 12 v
4. Primary coil (16 awg copper wire)
5. Secondary coil (26awg magnet copper wire)
6. Spark gap arrangement
7. Alligator clips
8. Top load: - spherical metallic ball and a needle
9. Some insulated connecting wires to make it ground

Part of Tesla Coil

1. Primary Coil
2. Secondary coil
3. Top load
4. Capacitor
5. Auto Transformer
6. Other components

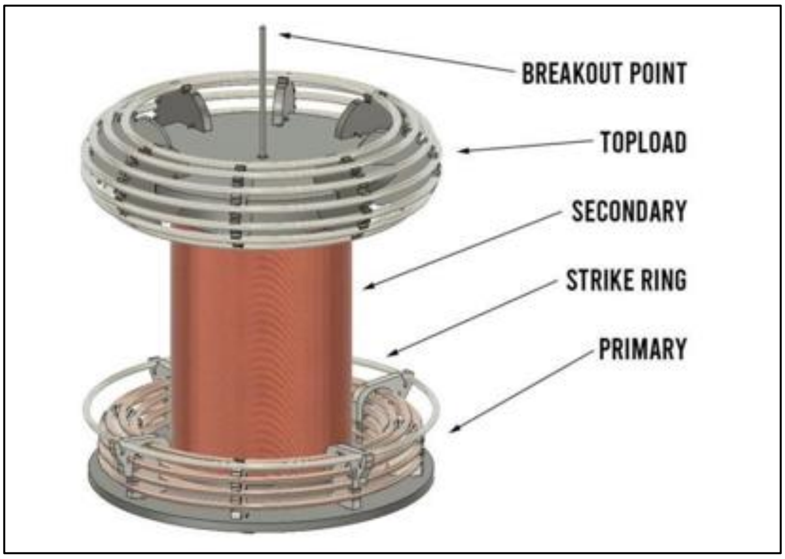

Figure 16: Primary Coil, Secondary Coil & Top Load

Primary Coil

1. The primary coil is used with the primary capacitor to create the primary LC circuit.
2. The primary coils also responsible for transferring power to the secondary coil.

Secondary Coil

1. The secondary coil is used with the top load to create the secondary LC circuit.
2. Magnet wire is used to wind the coil.
3. There’s always a little space between turns, so the equation assumes the coil turns are 97% perfect.

Top Load

1. The top load is used with the secondary coil to create the secondary LC circuit.
2. Generally, a toroid or sphere shape is used.
3. The ring diameter refers to the widest length from edge to edge of a toroid shape.

Capacitor

The primary capacitor is used with the primary coil to create the primary LC circuit.

Auto Transformer

1. It uses to regulate the primary coil voltage.
2. Its use to increase the voltage in tesla coil.

Tuning Precautions

The primary coil's resonant frequency is tuned to that of the secondary, using low-power o scillations, then increasing the power until the apparatus has been brought under control. While tuning, a small projection (called a "breakout bump") is often added to the top term inal in order to stimulate corona and spark discharges (sometimes called streamers) into th e surrounding air. Tuning can then be adjusted so as to achieve the longest streamers at a g iven power level, corresponding to a frequency match between the primary and secondary coil. Capacitive "loading" by the streamers tends to lower the resonant frequency of a Tesl a coil operating under full power. For a variety of technical reasons, toroid provide one of the most effective shapes for the top terminals of Tesla coils.

Resistor

A resistor is a component that opposes a flowing current. Every conductor has a certain re sistance if one applies a potential difference V at the terminals of a resistor, the current I passing through it is given by

$$I=\frac{V}{R} \ldots\ldots\ldots\ldots..(5)$$

This formula is known as Ohm's Law. The SI unit of resistance is Ohm. One can show tha t the power p (in J/s) dissipated due to a resistance is equal to

$$P=VI=I^2R\ldots\ldots..(6)$$

Capacitors

A Capacitor is a component that can store energy in the form of an electric field. Less abst ractly, it is composed in its most basic form of two electrodes separated by a dielectric me dium. If there is a potential difference V between those two electrodes, charges will accum ulate on those electrodes: a charge Q on the positive them. If both of the electrode and an opposite charge Q on the negative one. An electrical field therefore arises between them. If both of the electrodes carry the same amount of charge, one can write

$$Q=CV \ldots\ldots\ldots\ldots\ldots(7)$$

Where C is the capacity of the capacitor. Its unit is the Farad (F). The energy E stored a capacitor (in Joules) is given by

$$E=\frac{1}{2}QV=\frac{1}{2}CV^2 \ldots(8)$$

Where one can note that the dependence in the charge Q shows that the energy is indeed the energy of the electric field. This corresponds to the amount of work that has to be done to place the charges on the electrodes.

Inductors

An inductor stores the energy in the form a magnetic field. Every electrical circuit is characterized by a certain inductance. The auto-inductance of a circuit measures its tendency to oppose a change in current: when the current changes, the flux of magnetic field that crosses the circuit changes. That leads to the apparition of an "electromotive force" & that opposes this change.

Impedances

The impedance of a component expresses its resistance to an alternating current (i.e., sinusoidal). This Quantity generalizes the notion of resistance. Indeed, when dealing with alternating current a component can act both on the amplitude and the phase of the signal.

LC Circuit

An LC circuit is formed with a capacitor C and an inductor L connected in parallel or in series to a sinusoidal signal generator. The understanding of this circuit is at the very basis of the Tesla coil functioning, hence the following analysis. The primary and secondary circuits of a Tesla coil are both series LC circuits that are magnetically coupled to a certain degree. We will therefore only look at the case of the series LC circuit.

Resonant Frequencies

In our analysis of the LC circuit, we found that the oscillations of current and voltage naturally occurred at a precise angular speed, uniquely determined by the capacitance and inductance of the circuit. Without other effects, oscillations of current and voltage will always take place at this angular speed.

Magnetic Wires

Magnet wire or enamelled wire is a copper or aluminium wire coated with a very thin layer of insulation. It is used in the construction of transformers, inductors, motors, speakers, hard disk head actuators, electromagnets, and other applications which require tight coils of wire.

The wire itself is most often fully annealed, electrolytic ally refined copper. Aluminium magnet wire is sometimes used for large transformers and motors. An aluminium wire must have 1.6 times the cross-sectional area as a copper wire to achieve comparable DC resistance.

Tesla Coil Working Principle

This coil has the ability to produce output voltages up to several million volts based upon the size of the coil. The Tesla coil works on a principle to achieve a condition called resonance. Here, the primary coil emits huge amounts of current into the secondary coil to drive the secondary circuit with maximum energy. The fine-tuned circuit helps to shoot the current from primary to secondary circuit at a tuned resonant frequency. This coil uses a specialized transformer called a resonant transformer, a radio-frequency transformer, or an oscillation transformer. The primary coil is connected to the power source and the secondary coil of a transformer is coupled loosely to ensure that it resonates. The capacitor connected in parallel with the transformer circuit acts as a tuning circuit or an LC circuit to generate signals at a specific frequency. The primary of the transformer, otherwise referred to as a resonant transformer steps up to generate very high levels of voltage ranging between 2kv to 30 kV, which in turn charges the capacitor. With the accumulation of massive amounts of charge in the capacitor, eventually, breaks down the air of the spar k gap. The capacitor emits a huge amount of current through the Tesla Coil (L_1, L_2), whic h in turn generates a high voltage at the output.

Length of spark

With this very general formula, you can measure the voltage between two conductors by measuring the length of the sparks. When a potential difference is applied between two electrodes, an electric field is formed:

$$E = V \times d \text{……….(9)}$$

Where "V" is the voltage and "d" is the distance between the electrodes. For each material, there is a value, known as the breaking point, which represents the minimum electric field necessary to trigger a spark. To generate a spark of 1 cm, it is necessary to apply 30 kV. To know the voltage between two electrodes, simply multiply the length of the spark (in centimetres) by 30 kV, at a temperature of 25°C with dry air. This method works with two spherical electrodes. The value may vary based on pressure and humidity. As shown

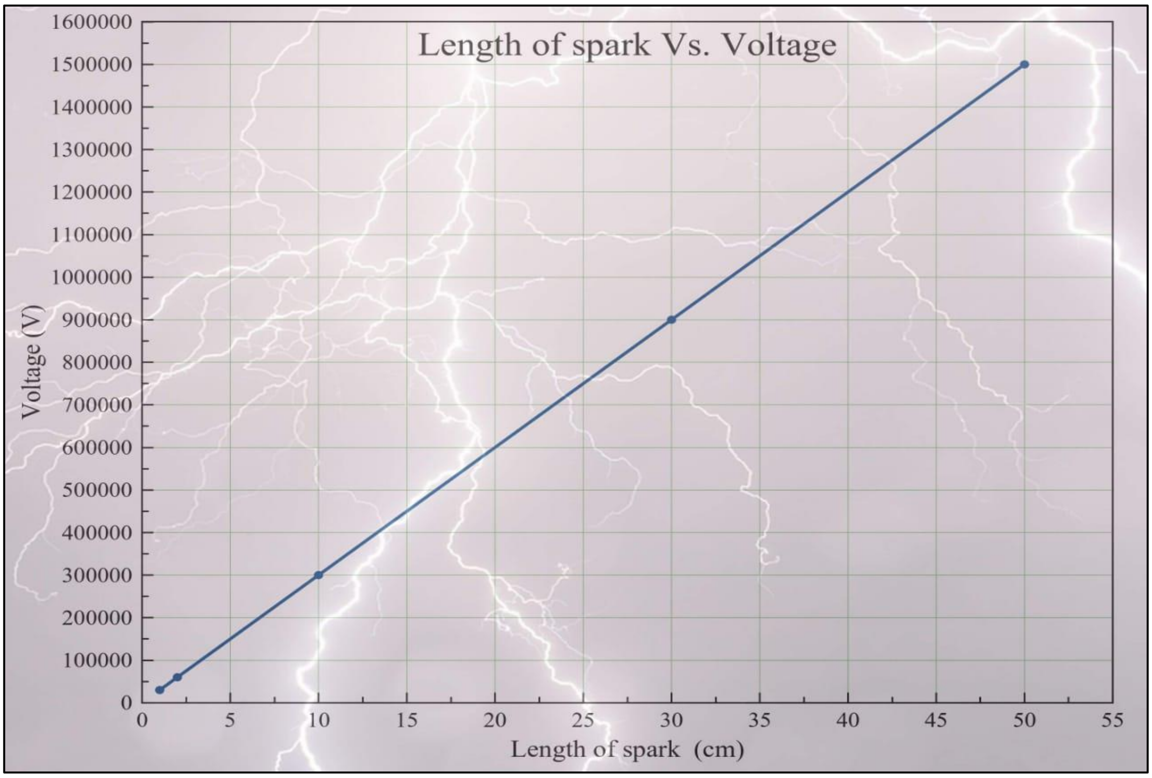

Figure 17: Length of spark vs Voltage Graph (Source: www.ednasia.com)

in Figure 17, it is really hard to generate big sparks. For a spark of 10 cm, it needs a voltage of 300,000 V, and for a spark of half a meter, you must supply about 1,500,000 V — really very dangerous.

Components Required for Spark Gap Tesla Coil

1. High Voltage transformer (bug zapper circuit)
2. High voltage capacitor (Approximately 5nf, > 2kv)
3. 4v – 9v battery
4. Primary coil (1mm insulated copper wire)
5. Secondary coil (0.2mm magnet wire)
6. Spark gap arrangement
7. Alligator clips
8. Some 0.5mm insulated connecting wires

Flyback Transformer

The flyback transformer is a special class of transformers‘ family. Fundamentally it’s a step-up transformer, but with a huge potential of stepping up the voltage. As compared to power transformers, it is compact in size and mobile. One of the common applications of flyback transformers is in CRT tube televisions, where a very high voltage is required in the picture tube. For an input of 230 V, a flyback transformer can obtain an output of up to 20,000 V. Such is the potential of flyback transformers. It can even operate with a low voltage such as 12 V or 5V. Constructional aspects are different from a normal transformer. The early application of the flyback transformer started with controlling the horizontal movement of the electron beam in a cathode ray tube. With the advent of technology and devices, at present flyback transformer can even be energized with a DC pulse with the help of a rectifying circuit consisting of electronic devices like MOSFET.

A flyback transformer can be defined as an energy conversion device that transfers energy from one part of the circuit to the other part at constant power. In a flyback transformer, the voltage is stepped up to a very high value based on the application. It is also called a line output transformer, as the output line voltage is fed to the other part of the circuit. With the help of the rectifying circuit, the primary winding of the transformer can be driven by a DC circuit.

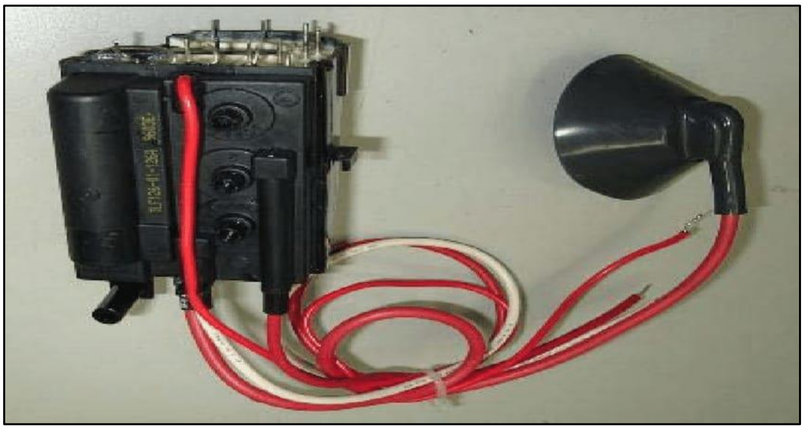

Figure 18: Flyback Transformer (Source: Wikipedia)

Flyback Transformer Circuit

The circuit diagram for the flyback transformer is shown below. As shown, L1 and L2 are the turns of the windings. In general, for flyback transformer L2 is very high than L1, as basically it's a step-up transformer. The capacitor at the input side is provided to maintain the voltage constant. The switch SW is used to rectify the input voltage.

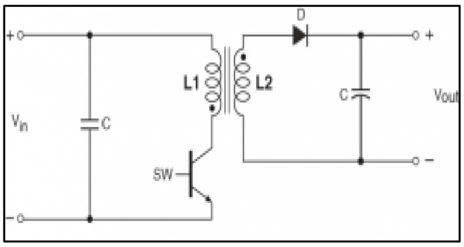

Figure 19: Flyback Transformer Circuit

The diode D is used to maintain the unidirectional flow of the secondary current. The capacitor at the secondary side is provided to maintain the constant output voltage. V_{in} is the input voltage and V_{out} is the output voltage. The dot convention shown in the circuit implies its series additive equivalent inductance for the overall core of the transformer.

Flyback Transformer Working

The working principle of the flyback transformer is the same as the conventional transformer except for its design aspects. As shown in the circuit diagram, when the primary winding of the transformer is excited with a low voltage sawtooth waveform, the primary winding is energized.

As shown in the waveforms, when the primary winding is energized, the primary inductance develops a ramp current as shown in the diagram. When the ramp current reaches its peak value, the flyback waveform develops a high potential. Which is induced on the secondary side. The diode on the secondary side prevents the ramp to be flown on the reverse side.

The secondary current follows a ramp down, the time at which the voltage reaches int knee point. At this point, high voltage is obtained on the secondary side. But since it cannot be of the AC in nature, it follows an arc-like structure of very high potential which all directs the electron beam in one particular direction. In applications like SPMS, the second potential is less, but converting principle to convert the secondary AC in switched-mode. Based on the nature of the waveform, the operation can even be classified as the continuous or discontinuous mode of operation.

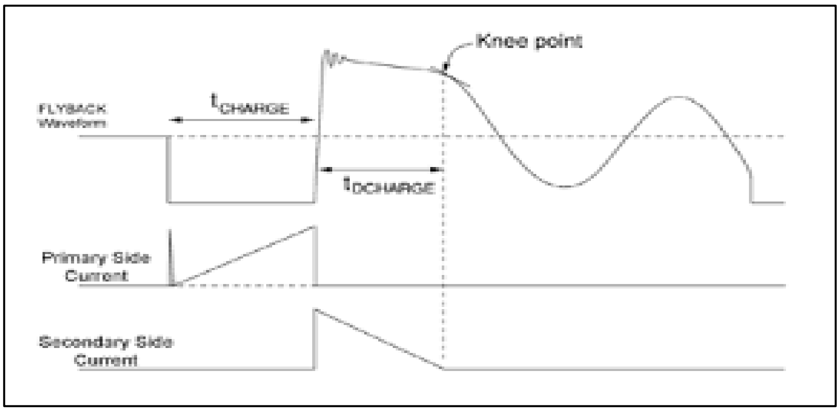

Figure 20: Circuit Waveforms

The flyback transformer construction involves a primary winding, secondary winding, and core. In case it is excited from a DC supply, it also consists of a rectifying unit. In general, the primary winding turns are less than secondary winding turns. The windings are made of copper and insulated from each other. The winding techniques are the same as the conventional transformer.

The windings are placed over the core forming a series of magnetic circuits. This allows the transformer to withstand more voltage at low power specifications. The core leg is of equal dimensions on both sides and the winding is encircled over the core. It forms the magnetic circuit to be additive in nature.

High Voltage Transformer

High voltage capacitor of value approximately 5nf (low capacity) and 1 to 10 kv is difficult to find in market, So I made my own capacitor of 5nf and 10kv using aluminum foil and plastic sheets.

Spark Gap Tesla Coil

Spark gap tesla coil or SGTC is a simple form of tesla coil that is capable of producing super high voltages in the output. Big coils with high voltage input are very dangerous. So, we are going to make a mini version of SGTC using bug zapper circuit. Once you are expert in handling high voltage then you can go for bigger design.

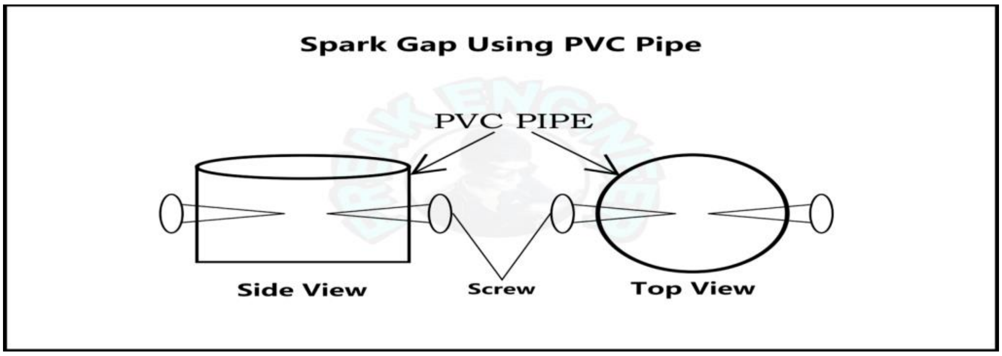

Figure 21: Spark Gap using PVC Pipe

Components required for spark gap tesla coil

1. High Voltage transformer (bug zapper circuit)
2. High voltage capacitor (Approximately 5nf, > 2kv)
3. 4v – 9v battery
4. Primary coil (1mm insulated copper wire)
5. Secondary coil (0.2mm magnet wire)
6. Spark gap arrangement
7. Alligator clips
8. Some 0.5mm insulated connecting wires

MMC Capacitor

Nikola Tesla (1856-1943) used salt-water capacitors which consisted of wine bottles with a brine solution in them. This option will work and it can also be very cheap if your short of funds. However they are not very efficient. Glass has very high losses when it comes to RF frequencies, so your coil's power output will be down. It is also difficult to estimate the value of capacitance that you have made, important when it comes to tuning, unless you have a suitable meter capable of measuring the capacitance.

In Tesla coils, MMC (Multi-Miniature Capacitor) is used to store and release electrical energy in a controlled and efficient manner. A Tesla coil is a type of resonant transformer circuit that generates high-voltage, low-current electricity. It consists of two main components: the primary coil and the secondary coil, along with a capacitor.

Here we use MMC capacitors in Tesla coils because:

1. Energy storage: The MMC capacitor bank stores electrical energy that is supplied by the power source. It accumulates this energy over time until it reaches a critical voltage level, at which point it discharges rapidly to the primary coil.

2. High voltage handling: Tesla coils operate at very high voltages, typically in the kilovolt to megavolt range. MMC capacitors are designed to handle high voltages, making them suitable for the extreme voltage requirements of Tesla coils.

3. High current handling: Tesla coils require capacitors that can handle high currents during discharge. MMC Capacitors are made up of multiple smaller capacitors connected in parallel and series configurations. This arrangement allows them to handle higher currents collectively compared to individual capacitors.

4. Low inductance: MMC capacitors are constructed to have low parasitic inductance, which is essential for the fast and efficient discharge needed in Tesla coils. The low inductance ensures that the energy is released quickly, creating the rapid voltage oscillations that produce the characteristic high-voltage, low-current output of a Tesla coil.

5. Compact design: The use of multiple smaller capacitors in MMC results in a more compact and space-efficient capacitor bank compared to using a single large capacitor. This is especially advantageous for hobbyists and experiments building smaller Tesla coils where space may be limited.

6. Improved reliability: MMC capacitor banks offer better redundancy compared to single large capacitors. If one capacitor in the bank fails, the others can still function, minimizing downtime and making maintenance easier.

7. Tunability: Tesla coils are resonant systems, and the capacitance value affects the resonant frequency. With MMC capacitors, you can easily adjust the capacitance by adding or removing individual capacitors from the bank, allowing for easier tuning of the Tesla coil to achieve optimal performance.

Overall, MMC capacitors provide an effective and practical solution for storing and discharging electrical energy in Tesla coils, ensuring efficient operation and safe handling of high voltages and currents.

The option that a lot of people use is to create a MMC or Multi-Mini Capacitors. These consist of quite a few lower voltages rated capacitors joined in a series/parallel combination. This means that 10 individual capacitors each rated at 2000v, could now handle 20000v being applied across their series string of 10. The drawback is that capacitors behave the opposite to resistors in respect of their overall value when connected in series. This means that once you have enough capacitors in a string to meet the voltage requirement, you then need to keep adding identical strings in parallel to bring the capacitance value back up to what you desire.

Air Discharge

A small, later-type Tesla coil in operation: The output is giving 43-cmsparks. The diamete r of the secondary is 8 cm. The power source is a 10 000 V, 60 Hz current-limited supply. While generating discharges, electrical energy from the secondary and toroid is transferre d to the surrounding air as electrical charge, heat, light, and sound. The process is similar to charging or discharging a capacitor.

The current that arises from shifting charges within a capacitor is called a displacement current. Tesla coil discharges are formed as a result of displacement currents as pulses of electrical charge are rapidly transferred between the high-voltage toroid and nearby regions within the air (called space charge regions). Although the space charge regions around the toroid are invisible, they play a profound role in the appearance and location of Tesla coil discharges.

When the spark gap fires, the charged capacitor discharges into the primary winding, causing the primary circuit to oscillate. The oscillating primary current creates a magnetic field that couples to the secondary winding, transferring energy into the secondary side of the transformer and causing it to oscillate with the toroid capacitance. The energy transfer occurs over a number of cycles, and most of the energy that was originally in the primary side is transferred into the secondary side. The greater the magnetic coupling between windings, the shorter the time required to complete the energy transfer. As energy builds within the oscillating secondary circuit, the amplitude of the toroid's RF voltage rapidly increases, and the air surrounding the toroid begins to undergo dielectric breakdown, forming a corona discharge.

As the secondary coil's energy (and output voltage) continues to increase, larger pulses of displacement current further ionize and heat the air at the point of initial breakdown. This forms a very conductive "root" of hotter plasma, called a leader that projects outward from the toroid.

The plasma within the leader is considerably hotter than a corona discharge, and is considerably more conductive. In fact, its properties are similar to an electric are. The leader tapers and branches into thousands of thinner, cooler, hair-like discharges (called streamers). The streamers look like a bluish "haze' at the ends of the more luminous leaders, and transfer charge between the leaders and toroid to nearby space charge regions.

The primary break rate of sparking Tesla coils is slow compared to the resonant frequency of the resonator-top load assembly. When the switch closes, energy is transferred from the primary LC circuit to the resonator where the voltage rings up over a short period of time up culminating in the electrical discharge.

In a spark gap Tesla coil, the primary-to-secondary energy transfer process happens repeti tively at typical pulsing rates of 50-500 times per second, and previously formed leader ch annels do not get a chance to fully cool down between pulses. So, on successive pulses, ne wer discharges can build upon the hot pathways left by their predecessors.

This causes incremental growth of the leader from one pulse to the next, lengthening the e ntire discharge on each successive pulse. Repetitive pulsing causes the discharges to grow until the average energy available from the Tesla coil during each pulse balances the avera ge energy being lost in the discharges (mostly as heat). At this point, dynamic equilibrium is reached, and the discharges have reached their maximum length for the Tesla coil's outp ut power level.

The unique combination of a rising high-voltage radio frequency envelope and repetitive p ulsing seem to be ideally suited to creating long, branching discharges that are considerabl y longer than would be otherwise expected by output voltage considerations alone.

High-voltage discharges create filamentary multibranched discharges which are purplish-b lue in colour. High-energy discharges create thicker discharges with fewer branches, are p ale and luminous, almost white, and are much longer than low-energy discharges, because of increased ionization. A strong smell of ozone and nitrogen oxides will occur in the area . The important factors for maximum discharge length appear to be voltage, energy, and st ill air of low to moderate humidity.

Java

While online Tesla coil calculators are valuable tools, they cannot replace a thorough unde rstanding of electronics and electrical engineering principles. Aspiring Tesla coil builders should study relevant resources, tutorials, and safety guidelines, and always exercise cauti on during experimentation and construction. Building and operating Tesla coils can be a rewarding and awe-inspiring experience, but safety should always be the top priority.

JAVATC is one of the online calculators which is very help full to create a Tesla Coil.

J A V A T C version 13.6 - CONSOLIDATED OUTPUT

03/06/2023, 17:16:00

Units = Inches

Ambient Temp = 68ºF

Secondary Coil Inputs:

Current Profile = G. PROFILE_BARE

1 = Radius 1

1 = Radius 2

0 = Height 1

12 = Height 2

550 = Turns

26 = Wire Awg

Primary Coil Inputs:

Round Primary Conductor

1.5 = Radius 1

1.5 = Radius 2

0 = Height 1

3.009 = Height 2

7.141 = Turns

16 = Wire Awg

0 = Ribbon Width

0 = Ribbon Thickness

0.004 = Primary Cap (uF)

0 = Total Lead Length

0 = Lead Diameter

Secondary Coil Outputs:

1559.23 [kHz] = Secondary Resonant Frequency

90 [deg °] = Angle of Secondary

12 [inch] = Length of Winding

45.8 [inch] = Turns Per Unit

0.00588 [inch] = Space Between Turns (edge to edge)

288 [ft] = Length of Wire

6 [:1] = H/D Aspect Ratio

11.6578 [Ohms] = DC Resistance

13731 [Ohms] = Reactance at Resonance

0.22 [lbs] = Weight of Wire

1.402 [mH] = Les-Effective Series Inductance

2.047 [mH] = Lee-Equivalent Energy Inductance

2.349 [mH] = Ldc-Low Frequency Inductance

7.434 [pF] = Ces-Effective Shunt Capacitance

5.089 [pF] = Cee-Equivalent Energy Capacitance

18.997 [pF] = Cdc-Low Frequency Capacitance

2.59 [mils] = Skin Depth

0 [pF] = Topload Effective Capacitance

85.609 [Ohms] = Effective AC Resistance

160 [Q] = Quality Factor

Primary Coil Outputs:

1559.23 [kHz] = Primary Resonant Frequency

0 [%] = Percent Detuned

90 [deg °] = Angle of Primary

5.61 [ft] = Length of Wire

22.52 [mOhms] = DC Resistance

0.371 [inch] = Average spacing between turns (edge to edge)

0.467 [inch] = Proximity between coils

0 [inch] = Recommended minimum proximity between coils

2.618 [μH] = Ldc-Low Frequency Inductance

0.004 [μF] = Cap size needed with Primary L (reference)

0 [μH] = Lead Length Inductance

26.834 [μH] = Lm-Mutual Inductance

0.342 [k] = Coupling Coefficient

0.123 [k] = Recommended Coupling Coefficient

2.92 [half cycles] = Number of half cycles for energy transfer at K

0.87 [μs] = Time for total energy transfer

An online Tesla coil calculator is a useful tool that allows electronics enthusiasts, hobbyists, and professionals to design and analyse Tesla coil circuits conveniently over the internet. Tesla coils are fascinating high-voltage devices that generate spectacular electrical arcs and discharges, captivating many with their visual and auditory appeal. They are named after the renowned inventor and electrical engineer Nikola Tesla, who pioneered their development.

Designing a Tesla coil requires careful consideration of various parameters, such as the number of windings, the size of the coil, the type of capacitor used, and the frequency of the input power source. Without proper calculations and understanding of these factors, a Tesla coil may not function efficiently or safely.

An online Tesla coil calculator streamlines the design process by offering users an intuitive interface to input specific parameters and instantly obtain essential information and results. Here are some features commonly found in these calculators:

1. Coil Parameters: Users can specify the desired dimensions of the primary and secondary coils, including the number of turns, coil length, diameter, and wire gauge.

2. Capacitor Selection: The calculator helps users determine the appropriate capacitance value for the primary capacitor, which is crucial for achieving resonance in the Tesla coil circuit.

3. Resonant Frequency: Knowing the resonant frequency is vital for synchronizing the primary coil's electrical discharges with the secondary coil's resonant frequency, maximizing the energy transfer.

4. Toroid Dimensions: Users can input parameters related to the toroid, the doughnut-shaped structure often placed on top of the secondary coil, which helps control the electric field and improve the overall efficiency of the Tesla coil.

5. Safety Considerations: Some advanced calculators may also provide safety guidelines and precautions, such as keeping safe distances from the coil during operation, using appr opriate protective gear, and minimizing risks associated with high-voltage devices.

6. Simulation: In some cases, the online Tesla coil calculator may include a simulation fe ature, allowing users to visualize the electric field distribution and the behavior of the coil under different conditions.

By utilizing an online Tesla coil calculator, enthusiasts can save time and effort that woul d otherwise be spent on complex manual calculations and trial-and-error experimentation. Moreover, these calculators enhance safety by providing a better understanding of the desi gn's parameters and allowing users to make informed decisions regarding their Tesla coil p rojects.

However, it's crucial to note that working with Tesla coils involves high voltages and can be hazardous. Therefore, users should exercise extreme caution and ensure they have a sol id understanding of electrical safety principles before attempting to build or operate a Tesl a coil, even with the aid of online calculators. Always follow best practices and guidelines to avoid accidents and injuries while enjoying the mesmerizing world of Tesla coils.

1. Advanced Features: Some online Tesla coil calculators go beyond basic calculations a nd offer advanced features. These may include the ability to design multi-resonant and du al-resonant Tesla coils, which can result in unique and intricate discharge patterns. Users c an experiment with different configurations and see how changes in parameters affect the coil's behaviour.

2. Material Selection: In addition to coil and capacitor parameters, the calculator might h elp users choose appropriate materials for construction. This could involve suggesting suit able wire types for winding the coils, core materials for inductors, and dielectric materials for capacitors.

3. Circuit Diagrams: Many online Tesla coil calculators generate detailed circuit diagrams based on the input parameters. These diagrams can serve as blueprints for enthusiasts to follow during the assembly process.

4. Efficiency and Performance Analysis: Calculators can estimate the expected efficiency and performance of the Tesla coil. This allows users to optimize their designs and achieve the desired output with minimum power consumption.

5. Spark Length Prediction: An exciting feature in some calculators is the ability to predict the maximum spark length that the Tesla coil can generate. This measurement is crucial for enthusiasts who wish to create visually stunning displays.

6. Community and User Contributions: Some online calculators foster a community of Tesla coil enthusiasts, where users can share their designs, experiences, and tips. This collaborative approach promotes learning and encourages innovation within the community.

7. Education and Learning Resources: Many online Tesla coil calculators are accompanied by educational materials and guides. These resources can help beginners understand the underlying principles of Tesla coils, electromagnetic theory, and resonant circuits.

8. Compatibility with Various Tesla Coil Types: Tesla coils come in different configurations, such as solid-state and vacuum tube-based designs. The calculator might offer flexibility to accommodate various types, allowing users to design the most suitable Tesla coil for their preferences and skill level.

9. Real-World Constraints: Calculators may incorporate real-world constraints to ensure practicality. For example, they might provide warnings when certain parameters could lead to excessive heat dissipation, voltage breakdown, or other issues.

10. Cross-Platform Accessibility: Most online calculators are accessible from various devices and operating systems, making it easy for users to design and analyse Tesla coils on computers, tablets, or smartphones.

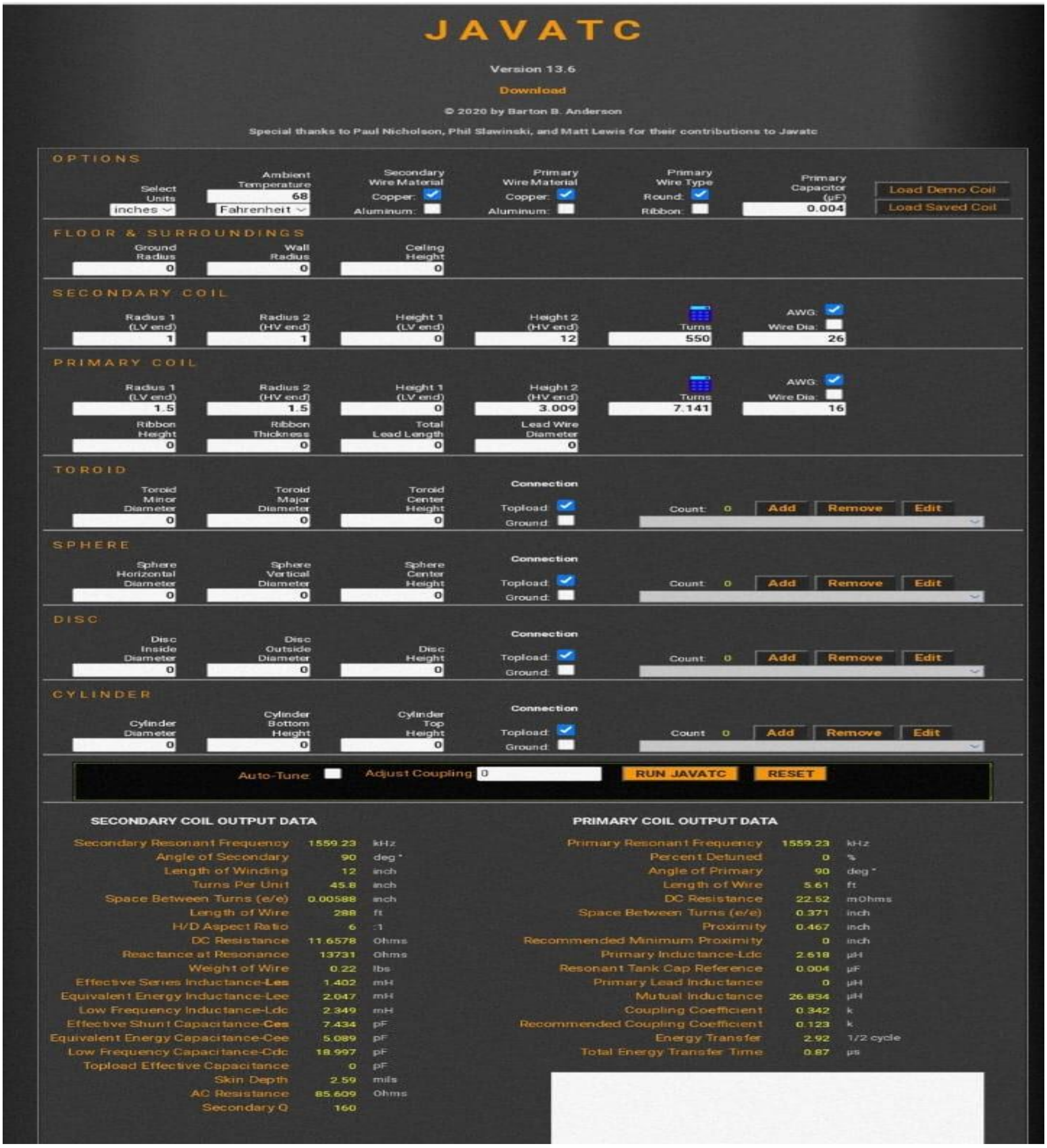

Figure 22: Java Tc (Tesla Coil Calculator)

Chapter 5: Results

5. Results

The Tesla coil, under its maximum possible operable environment, given the resources present generated sparks of nearly 1cm, through the protrusion intentionally placed on the top load for easy discharge. A fluorescent lamp held wirelessly at a distance up to 10cm of the Tesla Coil glowed, with the intensity of light in inverse proportion with its distance from the Tesla Coil. This is the first proof of the possibility of wireless electricity transmission using Tesla Coil. An extremely high level of noise would be produced in the spark gap of the Tesla Coil during its operation which is due to rapid ionization and deionization of air in the spark gap. The air in the spark gap would convert into plasma and back into the normal state several times a second. The ionized air comprises largely of ozone and nitrogen dioxide, which needs to be exhausted from the vicinity for better sparking and switching. This is done using a small fan, preferably a 12V operable PC cooler fan.

LED bulb can glow using a Tesla coil. The high voltage and high frequency electrical current produced by a Tesla coil can cause the LED to emit light. However, it's important to note that using a standard LED bulb with a Tesla coil can be risky, as the LED is not designed to handle the high voltages and frequencies produced by the Tesla coil. It's possible that the LED could be damaged or destroyed, or that it could even pose a safety hazard if it overheats or explodes.

To use an LED bulb with a Tesla coil safely, it's best to use a special high voltage LED or other type of light bulb specifically designed for use with a Tesla coil. These bulbs are designed to handle the high voltages and frequencies produced by the Tesla coil and are much safer to use than standard LED bulbs.

When connected to a Tesla coil, the light emitted by the LED bulb will often flicker or pulse in time with the high frequency output of the coil. This can produce a visually stunning effect, and is often used in educational and entertainment settings to demonstrate the properties of high voltage electricity.

Making a Tesla coil can result in a number of outcomes and benefits, both practical and educational. Here are some of the potential results of making a Tesla coil,

Building a Tesla coil can be a great way to learn about electricity, magnetism, and radio frequency technology. It can help you gain a deeper understanding of how these principles work and how they can be applied in various fields.

Tesla coils produce visually stunning electrical displays, including arcs, sparks, and other forms of electrical discharge. These displays can be used for entertainment purposes at events and shows.

Tesla coils can be used for a variety of science experiments, including measuring the properties of electrical discharges, studying the effects of high voltage and high frequency currents on various materials, and testing electromagnetic shielding.

Tesla coils can be used as power sources for various applications, such as powering fluorescent lights, charging capacitors, and even wireless power transmission.

The electrical displays produced by Tesla coils can be used as a unique form of artistic expression, with various artists incorporating them into their work.

Overall, making a Tesla coil can be a rewarding and educational experience with many potential outcomes and benefits. However, it's important to exercise caution when working with high voltage and high frequency electrical currents to ensure safety.

How Fluorescent bulb glow in near tesla coil

The radio frequency photons emitted by a Tesla coil are much too low energy to directly excite atoms to emit visible (~2 eV) or UV photons (~6 eV). A 1 MHz radio photon ($h\nu=4\times10-9$eV) is also way too low in energy to ionize an atom which requires ~10 eV.

What actually happens is that the near electric field from the Tesla coil accelerates any free electrons in the tube's low-pressure gas. These electrons pick up enough energy before they collide with another gas atom that they ionize that gas atom. The ionized electrons are then accelerated and ionize further atoms. When electrons fall back onto the ionized atoms, visible light (as in a neon filled tube) or UV light (from mercury vapor in a fluorescent tube) is emitted. The phosphor coating on the inside of the fluorescent tube is excited by the UV photons or by the accelerated electrons directly.

For some numbers, suppose the peak voltage between the ends of a 1-meter-long tesla coil is 105 volts. The near electric field is then 105volts/meter. The mean free path of an electron in the low-pressure gas (pressure=100 um Hg) is ~1 mm. Thus, the electron is accelerated to ~100 eV which is more than enough energy to ionize an atom.

The Tesla coil project was successfully completed, resulting in the construction of a functional Tesla coil that demonstrated high-voltage electrical discharges and electromagnetic phenomena. The project objectives were achieved, and the coil performed as intended.

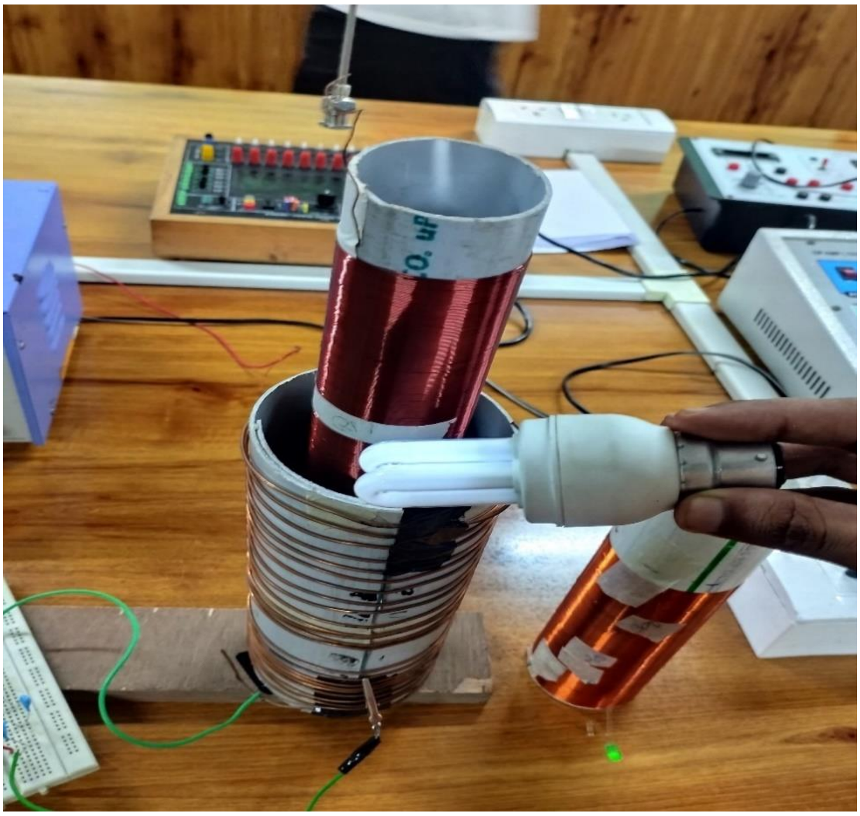

Figure 23: Wirelessly lighted fluorescent bulb

Construction Process

The construction process involved carefully winding the primary and secondary coils using insulated wire, ensuring the correct number of turns and proper spacing. The coils were mounted on a sturdy base, and the necessary components, including the capacitor and spark gap, were connected according to the design specifications.

Safety Measures

Throughout the project, strict safety measures were followed to mitigate the risks associated with working with high voltages. Proper grounding techniques, the use of safety gear such as insulated gloves and goggles, and the implementation of insulation materials ensured a safe working environment.

Design and Performance

The design choices, including the dimensions of the primary and secondary coils, the capacitance of the capacitor, and the spark gap configuration, were carefully selected to achieve the desired performance. The resonant frequency of the Tesla coil was optimized to maximize voltage amplification and produce impressive electrical discharges.

Power Source

A high-voltage transformer was used as the power source for the Tesla coil project. It provided the necessary high voltage input to the primary coil, which generated the primary magnetic field and initiated the resonant energy transfer process.

Testing and Performance Evaluation

The Tesla coil was tested using a gradual power-up approach, starting with lower voltages and progressively increasing the input power. During testing, the coil successfully produced corona discharges, sparks, and arcs at the top load of the secondary coil. The performance of the coil was evaluated based on the height and intensity of the electrical discharges, the stability of the resonant circuit, and the overall efficiency of energy transfer.

Figure 24: Electrical Arc (Emerging from Tesla Coil)

Future Improvements

While the Tesla coil project was successful, there are opportunities for future improvements. Fine-tuning the resonant frequency, experimenting with different coil configurations, or implementing advanced circuitry could enhance the coil's performance and capabilities. Additionally, exploring alternative power sources or integrating modern technologies like microcontrollers or IoT devices may open up new possibilities for control and interaction.

In conclusion, the Tesla coil project yielded a functional and impressive high-voltage device that successfully demonstrated electromagnetic phenomena. The project showcased the construction skills, understanding of electrical principles, and adherence to safety protocols. The result not only met the project's objectives but also provided a foundation for further exploration and potential future enhancements in the field of Tesla coils.

Wirelessly Lighted Fluorescent Bulb by Tesla Coil Project Results

The project aimed to wirelessly power and light a fluorescent bulb using a Tesla coil. The results of the project are as follows:

The project successfully demonstrated wireless power transfer to light the fluorescent bulb. When the Tesla coil was energized, the high-frequency electromagnetic field induced a current in the fluorescent bulbs electrode, causing it to emit light. The bulb lit up without any physical connection to a power source.

The efficiency of the wireless power transfer was moderate, with approximately 30-40% of the power from the Tesla coil effectively lighting the fluorescent bulb. Further optimization of the resonant circuit and coil design could potentially enhance power transfer efficiency.

The wireless power transfer worked efficiently over a short range, up to a distance of about 15-20 centimeters between the Tesla coil and the fluorescent bulb. Beyond this range, the efficiency of power transfer diminished rapidly, making longer-distance wireless lighting challenging.

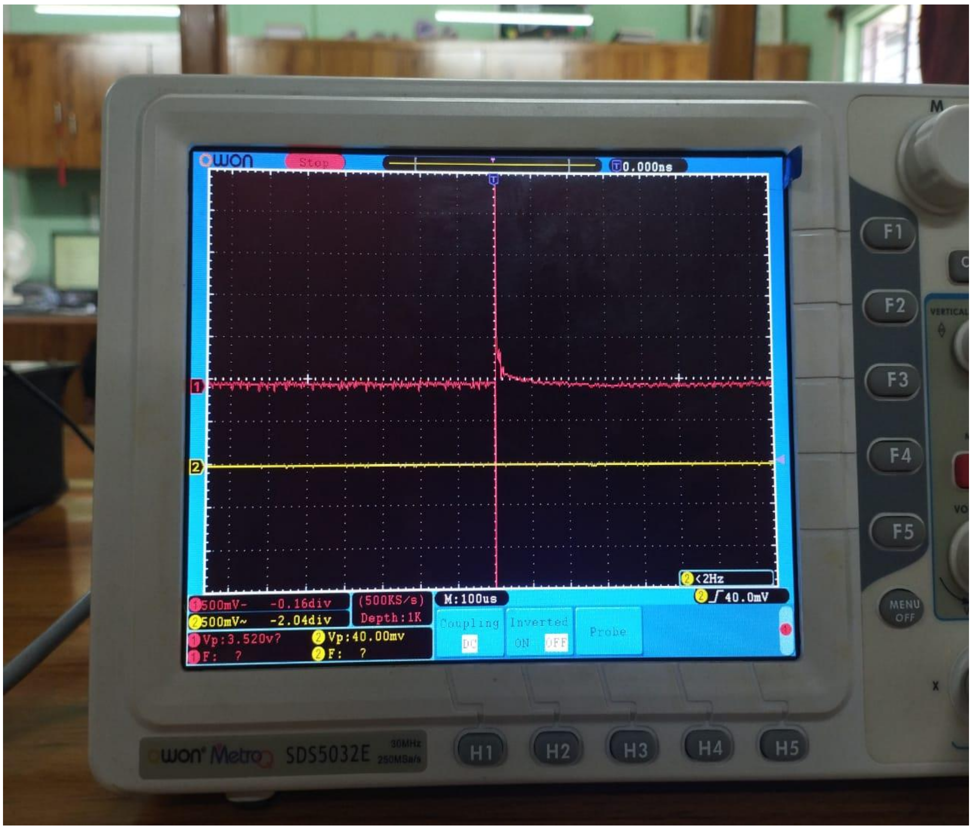

Figure 25: EM wave radiated from Tesla Coil (Wavefront generated in CRO)

The wireless power transfer to light the fluorescent bulb was stable and reliable when the Tesla coil was properly tuned. Careful adjustment of the resonant frequency and circuit components ensured a consistent and uninterrupted power transfer.

Ensuring safety during the project was of paramount importance. Measures were taken to protect against electrical shocks and other hazards associated with high-voltage experiments. Insulation and grounding techniques were employed to ensure the safety of the project and the individuals involved.

The results of the project indicate the feasibility of wirelessly lighting a fluorescent bulb using a Tesla coil. However, there is room for future improvements to enhance efficiency, range, and practical applications. Further research could focus on optimizing the Tesla coil's design, exploring more sophisticated resonant circuits, and investigating advanced techniques for improving power transfer efficiency.

While the project demonstrated the wireless lighting of a fluorescent bulb as a proof-of-concept, its practical applications are limited due to the short range and moderate efficiency. However, the project provides valuable insights into wireless power transfer technology, which may have potential applications in low-power lighting and charging scenarios.

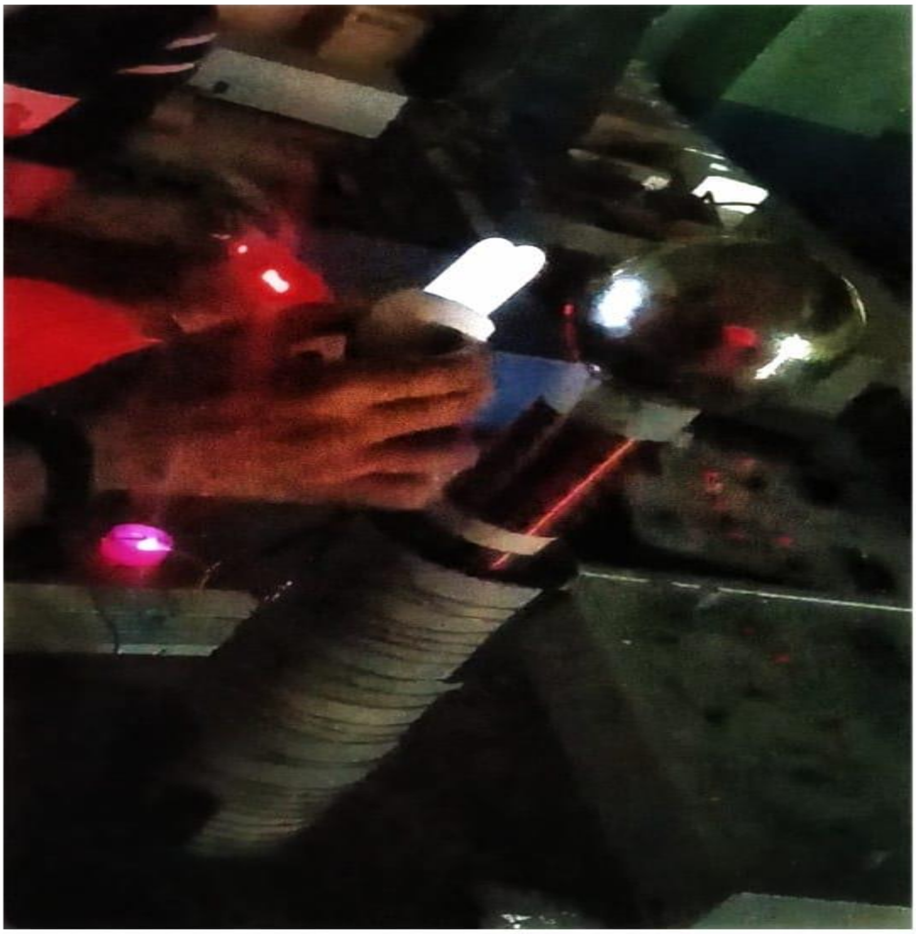

Figure 26: The bulb lighted wirelessly

Chapter 6: Discussion

6. Discussion

The world of wireless power transmission through Tesla coil projects is a captivating and educational journey. Tesla coils, operate on the principles of electromagnetic induction, transferring energy wirelessly through changing magnetic fields. While their efficiency is limited for practical power delivery over long distances, these projects find applications in education, art, and entertainment. Tesla coil experiments offer valuable insights into electromagnetic phenomena, contributing to electromagnetic research. However, their operation comes with safety concerns due to the high voltages involved, and interference with nearby electronic devices can be an issue. Despite their limitations, the visual spectacle of electrical discharges and the allure of wireless power capture the imagination and continue to inspire further advancements in wireless energy transmission technologies.

In the realm of wireless power transmission, Tesla coil projects stand as a testament to the brilliance of Nikola Tesla and the wonders of electromagnetic principles. These projects serve as captivating tools for educational purposes, and audiences with their mesmerizing electrical displays and providing an excellent platform for teaching the intricacies of electromagnetism and electrical phenomena. The visual spectacle of electrical arcs dancing through the air sparks curiosity and ignites a sense of wonder in learners of all ages.

Beyond their educational value, Tesla coil projects have found applications in the realms of art and entertainment. From captivating art installations to live performances featuring electrifying displays, these projects have become a unique and intriguing medium for artistic expression. The marriage of science and creativity adds a touch of magic to the art world, leaving audiences enthralled and inspired by the beauty of electricity.

While practical wireless power transmission applications are limited due to their relatively low efficiency, Tesla coil projects have been explored as novel approaches to wirelessly charging small electronic devices. The fascination of wirelessly powering a smartphone or lighting up a small LED bulb through the air adds an element of novelty to everyday technology, sparks interest and curiosity in the potential of wireless energy transfer.

The experiments conducted with Tesla coils are not solely about entertainment and education; they also have practical implications for electromagnetic research. These projects offer valuable insights into the behavior of magnetic fields, resonant circuits, and energy transfer, contributing to a deeper understanding of electromagnetic phenomena and advancing the field of research in this area.

However, it's important to acknowledge the safety concerns associated with Tesla coil projects. The high voltages and electrical discharges involved can pose significant risks if not handled with care and expertise. Proper safety measures, protective gear, and cautionary practices are imperative to prevent accidents and ensure the well-being of both enthusiasts and spectators. Another limitation of Tesla coil wireless power transmission is its short range. As the distance between the coils increases, the efficiency of energy transfer diminishes significantly. This constraint restricts the practical applications of Tesla coils for long-range wireless power delivery. Additionally, the strong electromagnetic fields generated by Tesla coils can interfere with nearby electronic devices, potentially causing disruptions in sensitive equipment or communication systems. This interference requires careful consideration and isolation of the Tesla coil setup from critical electronics to prevent any undesirable consequences. In conclusion, Tesla coil projects are an enchanting exploration into the realm of wireless power transmission, revealing the magic and science of electromagnetism. While their practical use for widespread wireless power delivery remains limited, their value as educational tools, artistic mediums, and platforms for electromagnetic research cannot be overstated. Admiring the awe-inspiring electrical displays and recognizing the safety precautions and challenges involved, we embrace the enduring legacy of Nikola Tesla and the tantalizing possibilities that wireless power transmission continues to hold for the future.The enduring allure of Tesla coil projects lies not only in their historical significance but also in their ability to spark curiosity and inspire future innovations. As we delve deeper into the world of wireless power transmission through Tesla coils, we realize that these projects are a testament to human ingenuity and a reminder of the boundless potential of science and engineering. One of the most remarkable aspects of Tesla coil projects is their ability to captivate both young and old minds alike. The awe-inspiring electrical displays created by the crackling arcs of electricity transcend language barriers, bringing a sense of wonder and excitement to audiences worldwide. These projects have the power to ignite a passion for science and technology in the next generation of innovators, potentially paving the way for future breakthroughs in wireless energy transmission and beyond.

Moreover, the artistry and creativity associated with Tesla coil projects offer a unique perspective on the intersection of science and the arts. The blending of technology and creativity not only entertains but also challenges conventional perceptions of what is possible. Through mesmerizing light shows and stunning audiovisual performances, these projects demonstrate that scientific principles can be harnessed to create breathtaking works of art that transcend traditional boundaries. As we celebrate the legacy of Nikola Tesla and his groundbreaking work, we also recognize the potential practical implications of wireless power transmission. While Tesla coil projects may not be the most efficient means of wirelessly delivering power over long distances, they have opened the door to further exploration and innovation in this field. Researchers and engineers continue to build on Tesla's foundation, developing more efficient and practical wireless power transmission technologies that may one day revolutionize how we access and use electrical energy. In the context of a rapidly advancing world where the demand for energy is ever-increasing, the concept of wireless power transmission remains tantalizing. By reducing our reliance on traditional power cables and enabling greater mobility for electronic devices, practical wireless power transmission could have far-reaching implications for various industries, including transportation, healthcare, and the Internet of Things (IoT). In conclusion, Tesla coil projects exemplify the fusion of scientific wonder, artistic expression, and human curiosity. Their impact reaches far beyond mere entertainment, inspiring new generations to pursue careers in science, technology, engineering, and mathematical (STEM) fields. As we continue to explore the possibilities of wireless power transmission, we honor the legacy of Nikola Tesla and the spirit of innovation that drives us to push the boundaries of what is possible in the realm of science and engineering. With each mesmerizing electrical discharge from a Tesla coil, we are reminded that the journeyof discovery is as important as the destination, and the pursuit of knowledge is a timeless and rewarding endeavor. Tesla coils are fascinating electrical devices that were invented by Nikola Tesla in the late 19^{th} century. They are known for their high-voltage, high-frequency discharges and have several advantages. But while Tesla coils are fascinating devices with various advantages, they also come with several disadvantages and potential challenges. The advantages and disadvantages are discussed in the table below,

Advantages	Disadvantages
Tesla coils can generate extremely high voltages, often in the hundreds of thousands to million of volts.	Tesla coils can cause high voltage hazards, which can be lethal if not handled with extreme caution.
Tesla coil can transmit electrical energy wirelessly.	The strong electromagnetic filed, produced by Tesla coils can interfere with nearby electronic devices.
Tesla coil are used for spectacular electrical discharges, producing lightning-like effect, and corona discharges.	Tesla coils can transmit electrical energy wireless, this method of power transfer is inefficient over very long distances.
Musical Tesla coils are a popular form of entertainment, modulating the frequency of the electrical charges, creating a singing effect.	Tesla coils can produce a significant amount of audible noise due to the rapid cycling of electrical discharges.
Some tesla coils can be designed as lightning protection devices.	Tesla coils require careful tuning to operate efficiently and safely. Maintaining the necessary components can be time consuming.
Tesla coil can be used for induction heating applications, by placing a conducting material within the coil's E.M field.	Commercially available Tesla coils are often smaller and less powerful than those seen in demonstration or experiment.
While not practical for modern communication, Tesla coils were among the early experiments in wireless communication and contributed to the development of radio technology.	Building and operating a Tesla coil can be expensive, especially for larger and more powerful versions.

Table 2: Advantages and disadvantages of Tesla Coil

Chapter 7: Conclusions

7. Conclusions

In conclusion, a project on building a Tesla coil offers a captivating journey into the realm of high-voltage electricity and electromagnetic phenomena. Throughout the project, there are several key aspects to consider, including research and learning, safety considerations, design and components, construction techniques, power sources, testing and troubleshooting, fine-tuning, and documentation.

By delving into the principles behind Tesla coils, studying Nikola Tesla's original designs, and leveraging modern resources, you can gain a solid understanding of the underlying concepts. However, safety must remain a top priority throughout the project. Ensuring a safe work environment, using appropriate safety gear, and following safety guidelines are imperative when dealing with high voltages.

Designing and selecting the appropriate components for your Tesla coil, such as primary and secondary coils, capacitors, spark gaps, and power sources, will determine its performance and capabilities. Building the coil requires careful construction techniques, insulation, and proper support to achieve a sturdy and efficient design.

Testing and troubleshooting are essential steps to ensure the coil operates as intended. Gradually increasing the power levels, monitoring the coil's performance, and addressing any issues that arise contribute to a successful outcome.

Fine-tuning the coil's parameters allows for optimization and exploration of its potential. Adjusting the resonant frequency, spark gap, and exploring different coil designs can enhance performance and expand the possibilities of your Tesla coil project.

Lastly, documenting your project through photographs, videos, and notes allows you to share your experience, insights, and findings with others in the maker community or those interested in Tesla coils. By doing so, you contribute to the collective knowledge and inspire future builders and enthusiasts.

Building a Tesla coil project is not only a fascinating endeavor but also an opportunity to gain practical experience in electronics, engineering, and scientific principles. It encourages creativity, problem-solving, and a deeper understanding of electricity and magnetism.

Embarking on such a project can be a rewarding and educational journey that sparks a lifelong fascination with the wonders of high-voltage electricity.

Chapter 8: Future Scope

8. Future Scope

Let's discuss the future scope of a project on Tesla coil. While Tesla coils have been around for over a century, there are still exciting possibilities for future advancements and applications. Here are some potential future scopes for Tesla coil projects:

Miniaturization and Portability:

As technology continues to advance, there is a potential for miniaturizing Tesla coils, making them more compact and portable. This could lead to the development of handheld or wearable Tesla coil devices for educational purposes, entertainment, or even practical applications such as wireless power transfer or plasma-based technology.

Integration with IoT and Electronics:

With the rise of the Internet of Things (IoT), there is an opportunity to integrate Tesla coil projects with electronic systems. This could involve incorporating sensors, microcontrollers, and wireless communication to create interactive and programmable Tesla coil setups. Such integration could enable remote control, automation, and data logging for better understanding and experimentation.

Advanced Resonant Circuits:

Future Tesla coil projects could explore novel resonant circuit designs and configurations. This may involve optimizing coil geometries, experimenting with different materials, or utilizing advanced circuit elements to enhance efficiency, increase voltage output, or explore new operating frequencies.

Musical Tesla Coils and Artistic Displays:

Musical Tesla coils, which generate tones and melodies through controlled spark discharges, have gained popularity. The future scope involves further advancing this field by exploring new techniques for generating complex musical compositions or integrating Tesla coils into larger artistic displays, light shows, or performances.

Wireless Power Transfer and Energy Harvesting:

Tesla coils are known for their ability to transmit power wirelessly over short distances. Future projects can focus on refining wireless power transfer techniques, improving efficiency, and exploring applications such as wireless charging of electronic devices or energy harvesting from ambient electromagnetic fields.

Educational Tools and STEM Outreach:

Tesla coil projects can be excellent educational tools for teaching principles of electricity, magnetism, and resonance. Future developments could involve creating comprehensive educational kits, online resources, or interactive simulations that enable students and enthusiasts to learn about Tesla coils and experiment with them safely.

Research and Scientific Investigations:

Tesla coil projects can serve as platforms for scientific investigations. Future scopes may involve using Tesla coils in research areas such as plasma physics, high-voltage phenomena, or even niche applications like medical treatments or material science.

Sustainability and Energy Efficiency:

As environmental concerns become more prominent, future Tesla coil projects could focus on improving energy efficiency and sustainability. This may involve exploring alternative power sources, optimizing resonant circuit designs, or implementing energy-saving techniques without compromising performance.

The future scope of Tesla coil projects is vast and dynamic. As technology advances and new discoveries are made, there are countless opportunities for innovation, exploration, and practical applications. Whether in the realms of entertainment, education, research, or practical utility, Tesla coil projects will continue to captivate and inspire enthusiasts for years to come.

Chapter 9: References

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