WIRELESS POWER TRANSFER

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A Thesis
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DECLARATION

We hereby declare that the thesis titled “Wireless Power Transfer”, a thesis submitted to the Department of Electrical and Electronic Engineering of BRAC University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering is our own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

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Abstract

Electric vehicles are making a new era in the world of vehicles and electronics where Bangladesh has just started getting the touch of this technology. It is very efficient and a way of saving our natural resources aiming to modernize these fuel free transports of Bangladesh. This paper is about a wireless charging system for EV and solar vehicles. The purpose of this project is designing and implementation of a system to enhance the performance of wireless power transfer system and to reduce the use of wires by using a Tesla coil as a transmitter to produce high frequency, high voltage with low alternating current in order to produce high density flux to transfer electric power. Power is transferred wirelessly by magnetic field which is created by direct induction followed by resonant magnetic induction which is a form of inductive coupling where the carried flux can be captured by inductive coil at the receiver that coupled to the primary coil. This tesla coil is involved to transfer power at a distance to a load or an electrical equipment that need to be charged or powered wirelessly. This system is developed so as to reduce the use of wire, save natural resources, on going power for electric vehicle and wireless charging. As a core factor, charging for solar vehicle is also mentioned.

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ABBREVIATIONS

WPT - Wireless Power Transfer

AWG - American Wire Gauge

AC - Alternating Current

DC - Direct Current

IMF - International Monetary Fund

SUV - Sport-utility Vehicle

EV - Electric Vehicle

MIT - Massachusetts Institute of Technology

KAIST - Korean Advanced Institute of Science and Technology

LMW - Litz Magneto Plated wire

IC - Integrated Circuit

MRC - Magnetic Resonance Coupling

LC - Inductor-Capacitor Circuit

DWPT - Dynamic Wireless Power Transfer

EMF - Electromotive Force

MMF - Magnetomotive force

NST - Neon Sign Transformer

PFC - Power Factor Correction

PVC - Polymerizing Vinyl Chloride

RMS - Root Mean Square

DIP - Dual-Inline Package

LED - Light-Emitting Diode

MMC - Multi-Mini Capacitors

Chapter 1

Introduction

1.1 Introduction

Nowadays, we cannot even imagine our life without electricity. From the beginning of mankind, there always has been the necessity of power, which brought us to the inventions of fire, steam engines and most importantly, electricity. Majority of today's residences and commercial buildings are powered by alternating current (AC) from the power grid. Electrical power stations generate AC electricity that is delivered to load centers through high voltage transmission lines and step transformers with I^2R losses. At the distribution end the voltage is step down for efficient distribution of transmitted power and the consumers consume at its desired low voltage level[29]. This AC current is a daily necessary for our everyday life, for example, lights, fans, kitchen appliances, chargers, and so on. Almost all the components are standardized with the electrical wire. Any device rated for standard current and voltage will work

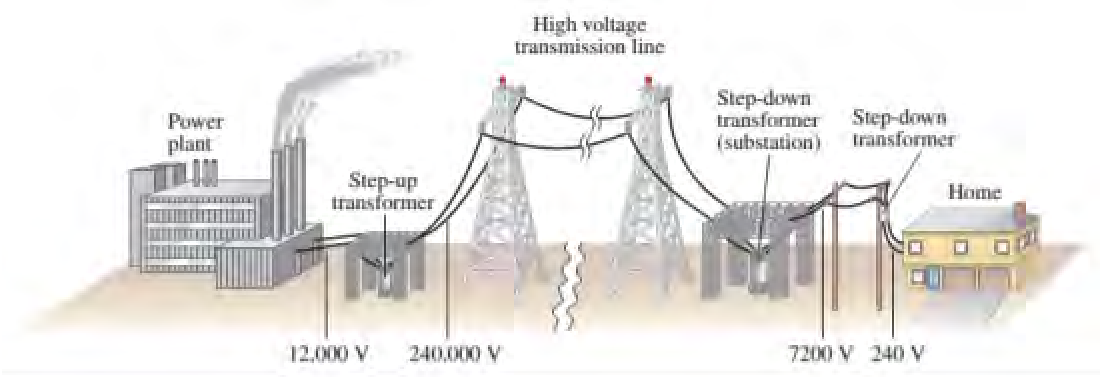


Fig. 1.1 Power transmission from power station [1]

in any of the millions of outlets throughout the country. While standards differ between countries to countries, within the limit of a given electrical system, any perfectly rated device will work. But in this case, the complexity is wire or cord. Problems like short circuited, burning wires, plug in/out, twisting etc. Apart from the conventional transmission system, wireless power transmission is more efficient, modern and really needed technology to be developed [2].

1.2 Introduction to Wireless Power Transfer

Transmission of electrical energy without wires is known as Wireless power transfer (WPT). It is WPT which enables to supply power through an air gap, without the necessity of current carrying wires. WPT can deliver power from an AC source to batteries or other electronic devices without physical connections. Mobile phones and tablets, drones, cars, even transportation equipment can be recharged by WPT. It may even be possible to wirelessly

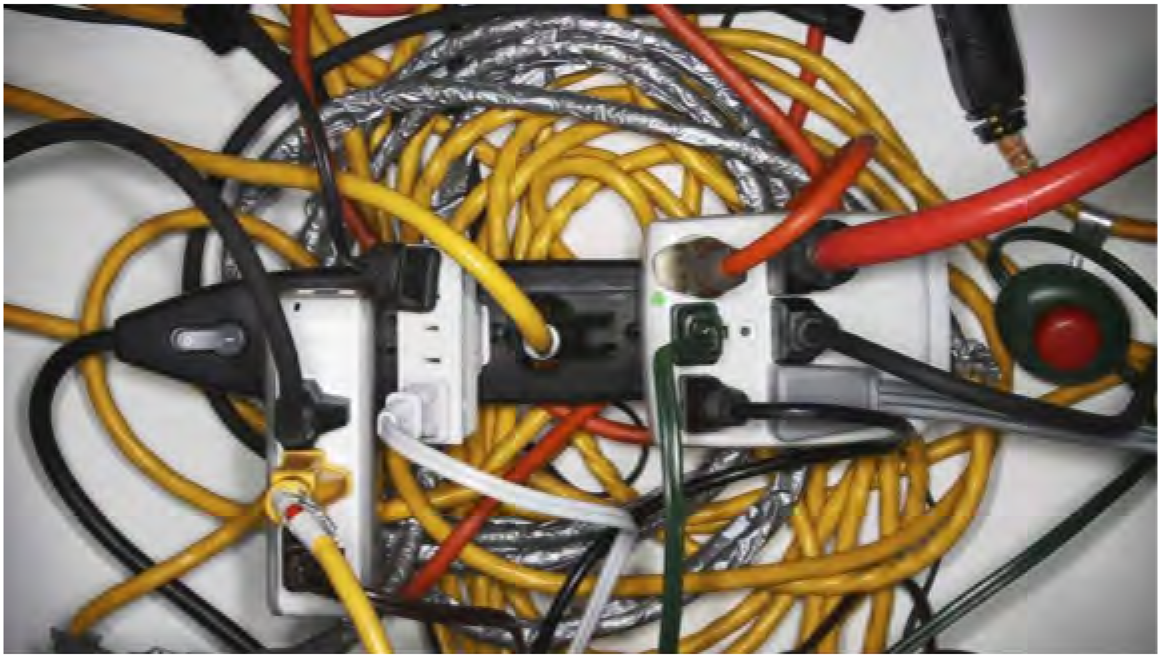


Fig. 1.2 Wired charging system [39]

transmit power gathered by solar panel arrays. WPT has been an exciting development in consumer electronics, replacing wired chargers.

WPT uses fields created by charged particles to carry energy between transmitters and receivers over an air gap. The air gap is bridged by converting the energy into a form that can travel through the air. The energy is converted to an oscillating field, transmitted over the air, and then converted into usable electrical current by a receiver. Depending on the power and distance, energy can be effectively transferred through an electric field, a magnetic field, or electromagnetic waves such as radio waves, microwaves, or even light.

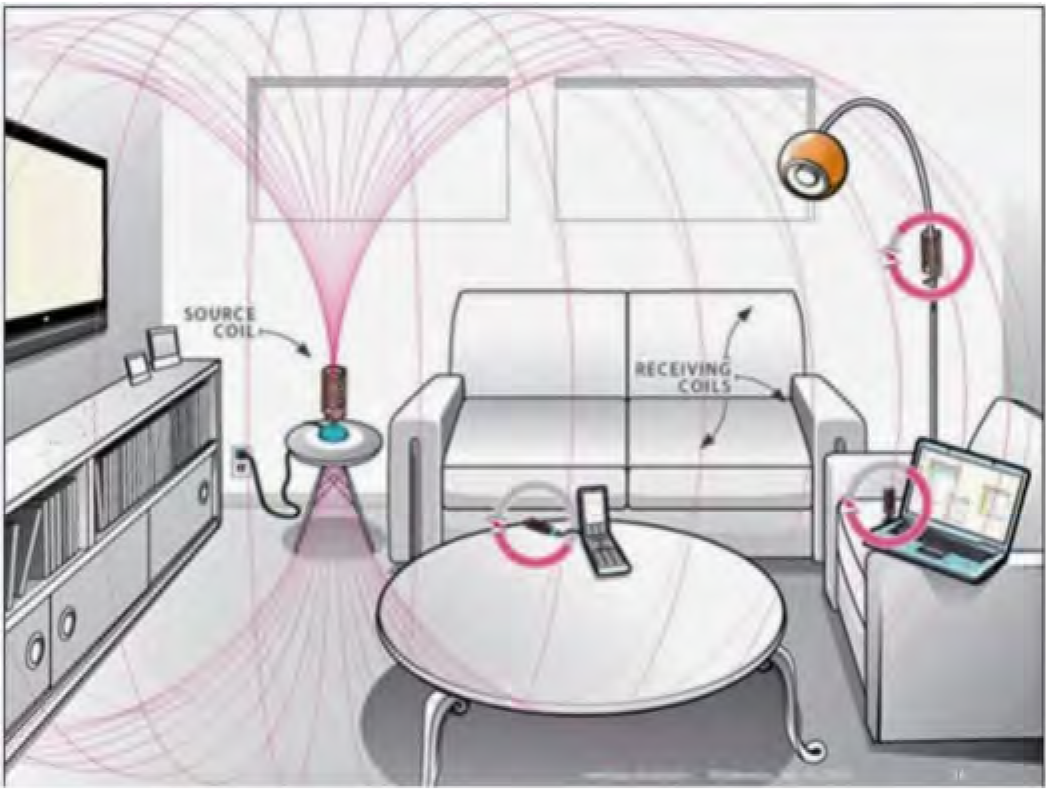


Fig. 1.3 Wireless power system [38]

1.3 Invention of WPT

The concept of transferring power without wires was introduced in the late 1890s. The name, Nikola Tesla is mostly famous in case of wireless power transfer. Nikola Tesla successfully lighted electric bulbs wirelessly at his Colorado Springs Lab. In his experiment he used electrodynamics induction which is also known as resonant inductive coupling.

While he was doing his own experiments in the lab, he invented an electrical resonating transformer in the year 1891. That transformer was also known as the Tesla Coil or Tesla's Coil.

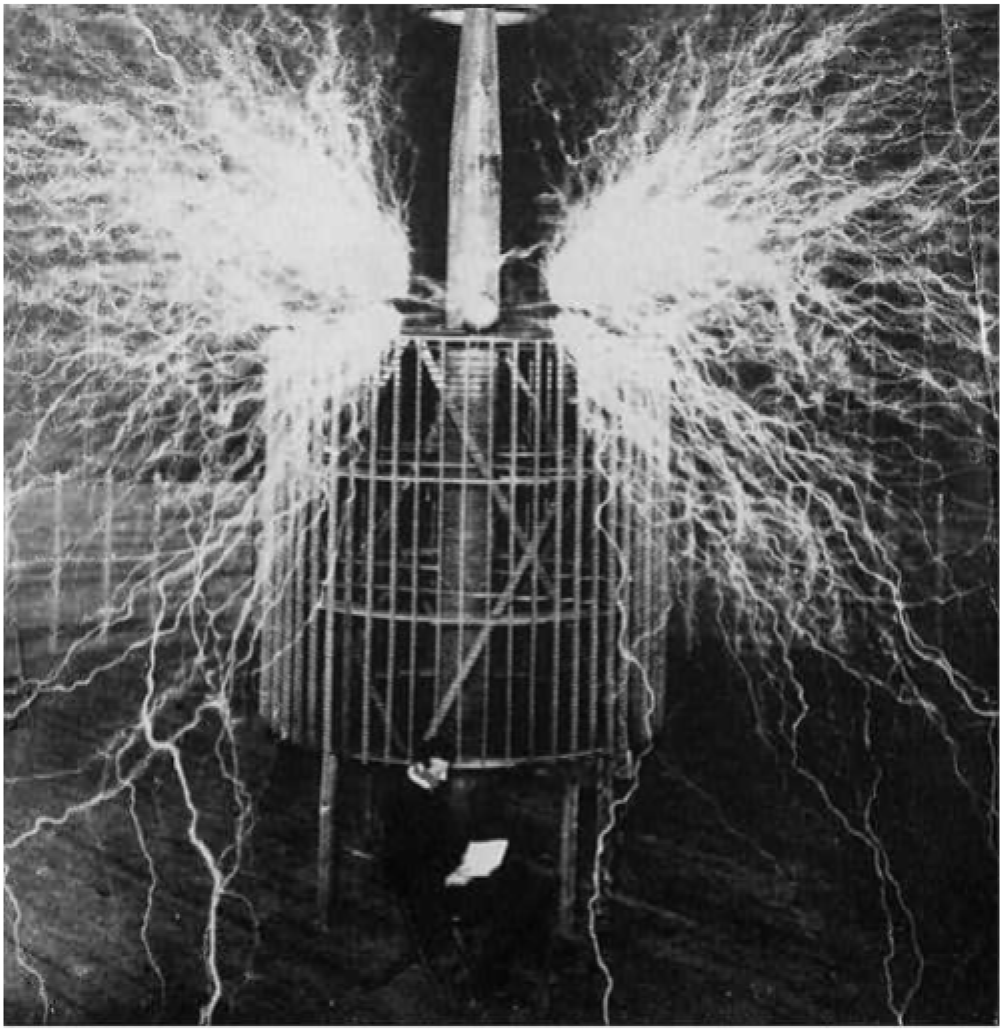


Fig. 1.4 Nikola Tesla's experiment [40]

Nikola Tesla was hopeful that his transformer would deliver power without the connection of wires. At the Pikes Peak, North America the weather was a bit rough. Lightning storms was common there. Tesla observed the natural lightning and analyzed how it acted. He also examined how the lightning traveled to the ground. He found that just after the lightning the air remains charged for some moments. Then he experimented with his transformer and observed how the charges were reflected. He actually found an extra-ordinary result even with a small tesla coil. Though he was not only testing with the small one, but also he built one of the largest coils ever built. The fascinating matter is, the discharges from the large coil in Colorado Spring Lab could be seen from a long distance.

1.4 Motivation

After Nikola Tesla had introduced the concept of wireless power transfer, and experimented for related technology patent in 1902. Since then, many scientists have done research on it. Some of them were able to gain some achievements in induction power transmission at close range. In our case, the main purpose of our analysis was to achieve a brighter output and thus contributing to the transmission of wireless power transfer. In order to keep pace with the modern technologies, the concept of wireless power transfer is needed to be brought to light which was another reason behind choosing this concept.

In modern times, no one wants to use the wire or cord in case of charging any device and there comes the necessity of WPT. According to the IMF, Bangladesh's economy is the second fastest growing major economy of 2016[41]. With the advance growth of economy, the standards of living are getting higher day by day. In that case, the uses of smart devices are getting very popular nowadays. The smart devices have various features but the transmission of power into them wirelessly in one of the spectacular features in recent times. People are much fond of using devices that does not require the connection through wires or cords. It has been mentioned earlier that, to get rid of the annoying wires, WPT is the perfect solution. This paper describes about the design and performance of wireless power transfer using tesla coil technique.

Recently in Bangladesh, there are some manufacturers who have introduced electric motorcycles (also known as E-Cycles). There are also easy bikes (also known as Electric Rickshaw) which usually commute within a fixed area. These vehicles run by rechargeable batteries. To recharge them, wires are needed to be connected from the wall socket to the batteries. WPT can be an improved recharging system in this regard.

1.5 Contribution of this project

We are trying to improve the efficiency of the WPT. For example, if we increase the distance the induced voltage to the load reduces, but we are trying to achieve a certain amount of voltage within a fixed range, so that the load can be operated from a certain distance wirelessly. It will ease the way of life not only in terms or household chores but also in respect of transportation like vehicle charging. In this project, we have succeeded to light an LED wirelessly by a load coil which is around 9.5 inches away from the secondary coil.

Though we have not got the expected brighter output, but it is clear that, if the efficiency is further increased, then this project can become an ultimate smart power grid system which will recharge components like batteries and run the devices which are able to get recharged through WPT.

1.6 Research objective

Previously, those who have worked researched on WPT have faced many challenges. The limitations that the researchers and engineers are recharging batteries, continuation of supplied power, dealing with moving points, optimizing the sensors and so forth. Though these challenges still exist, day by day the limitations and problems are getting minimized because of the continuous research going on WPT. The purpose of our research was to contribute to minimize the limitations of the transmission of power wirelessly.

1.7 Advantages of wireless power transfer

The advantages of wireless power transfer are too many to be described. Some of them are mentioned below:

- First of all, WPT is a safe, secure, waterproof and durable form of power transmission.
- WPT relieves us from using annoying wire connections.
- It allows power transfer system to become portable.
- Wireless technology really allows a network to reach locations that could not be achieved by using a network cable.
- The cost of transmission and distribution becomes less and the cost of electrical energy for the consumer also can be reduced.
- The power failure due to short circuit and fault on cables will never exist in the power transmission system and power theft will not be possible at all.
- Loss of transmission is at negligible level in the Wireless Power Transmission. Therefore, the efficiency of this method is very much higher than the wired transmission.

- One of the major benefits is, wireless power allows a highly expandable power range.[38]
- WPT increases the product life of a device.

1.8 Overview of the project

At first, we wanted to increase the efficiency of the wireless power transmission system. This means that, if we increase the distance between the load coil and the secondary coil, the load will perform comparatively better in the highest possible range.

1.9 Summary of the following chapters

The 1st chapter describes about the basics of wireless power transfer (WPT), the historical background of the invention of WPT and the reason behind choosing this topic for our thesis. It also gives a clear idea about our contribution to this project and purpose of our project. Moreover, the advantages and disadvantages of wireless power are being described here.

The 2nd chapter explains the basic concepts of wireless power transfer. For example: Ampere’s law, Faraday’s law of induction, Lenz’s law. It also describes about the two main types of WPT and they are i) Far field and ii) Near field WPT. The basic differences between wired and wireless power transfer are mentioned here properly. Efficiency of WPT is discussed in the last part of this chapter.

The 3rd chapter is titled as “Existing improvements on Wireless Power Transfer”. Here three techniques of power transmission is described; which are i) inductive coupling, ii) mix-inductive coupling and iii) microwave. At the end of this chapter, some limitations and problems of WPT are being described with explanation.

The 4th chapter of our thesis is mainly focused on the fundamentals of tesla coil, the components that must be required to build an efficient tesla coil. The basic designing of tesla coil is also shown here. This designing includes: neon sign transformer, primary coil, primary capacitor, spark gap, secondary coil and top load. Lastly in this chapter, an overview of the overall system is provided.

The 5th chapter briefly describes about our project implementation. The name of the components and their functions and discussion about the connections among the components are given there. The components include step down transformer, oscillator circuit, primary coil, secondary coil and load coil.

The 6th chapter is completely focuses on the Oscillator circuit. The reason behind putting this component in a separate chapter is to describe the basic functions of this circuit are vast. The uses of oscillator in tesla coil, designing of it, the analysis of the output of the oscillator, the result from simulation are also mentioned here.

The 7th chapter is all about "Result". The analysis of the result we got and the calculated value of efficiency of the system is properly mention in this chapter. The power calculation is also provided here along with necessary values. There is also a description about how the efficiency can be further improved in the last part of this chapter.

The 8th chapter which is certainly the last one puts in the conclusion part. This chapter tells about the summary of the whole project. There were some limitations which he had faced during this project are also described here. There is also a discussion on the future work that can be done on this project later on.

Chapter 2

Wireless Power Transfer

2.1 Introduction

Wireless power transmission (WPT) is not a new technology. Nikola Tesla first introduced the basic concept of wireless power transfer in nineteenth century. Over the years, some researchers continue their works on it. The major disadvantages of wireless power transfer are low efficiency. So, researchers are trying to improve the efficiency using several types of techniques. The advantages of wireless power transfer are many that there has been an increasing interest in wireless power transfer technology. Wireless power transfer technology can eliminate all the charging troublesome. It can make our daily life so smooth and easy. The basic difference between wired and wireless power transfer is the cable. The traditional wired power transfer has the problems of power loss, damaging wire, electric spark and so on. Meanwhile, it is difficult to use cable to transmit electricity in some special occasions. In that case, wireless power transfer technology is a solution.

2.2 Basic concept of wireless power transfer

Wireless power transfer is the process where electric energy is transmitted from power source to an electrical load without any wire connection. Wireless power transfer is based on the magnetic resonance and near field coupling of two loop resonators was reported by Nicola tesla a century ago. Power is wirelessly transfer when magnetic field is transferred over short distance.

The magnetic field is created using inductive coupling between coils of wire or electric fields using capacitive coupling between electrodes. The concept of inductive coupling and magnetic field comes from the following principles [11].

2.2.1 Ampere's law

According to Ampere's law, when current is passed through a closed loop of conductor or coil, a magnetic field is created around it. The magnetic field created by the current is proportional to the size of that current with a constant of proportionality equal to the permeability of free space.

2.2.2 Faraday's law of induction

It states that the instantaneous electromotive force (emf) or voltage induced in a circuit due to changing magnetic field is directly proportional to the change of that magnetic field.

2.2.3 Lenz's law

It states that the induced emf generates current that sets up a new magnetic field which acts to oppose the existing magnetic field.

In wireless power transfer system, these principles are adopted. In general a WPT system consists of a transmitter connected to power source and a receiver which receives the power and deliver it to the load. In the transmitter side, there is a primary coil and in the receiver side there is a secondary coil. When the power is connected to the primary coil a current passed through it and a magnetic field is formed around it. When the secondary coil is brought close to the primary coil a voltage induces in the secondary coil which generates a current that causes another magnetic field around the secondary coil. The current produced in the secondary coil is used by any load without any physical connection [11].

2.3 Types of wireless power transfer

There are mainly two categories of wireless power transfer, radiative and non radiative. Radiative are for far field and non radiative are for near field.

2.3.1 Far field or radiative region

In far field or radiative region, microwave or laser beams is used to transmit power wirelessly. These techniques can transfer high power over distances. But a direct-line of transmission path is required as high level radiation transmits from transmitter to receiver. In microwave radiation system, frequency is very high so the antennas should be large enough to satisfy the power density limits. This technique is mostly used in space and military applications such as solar power satellite [11].

2.3.2 Near field or non radiative region

In near field or non radiative region, there are several techniques to transfer power wirelessly. They are inductive coupling, resonant inductive coupling, capacitive coupling, resonant capacitive coupling and magnetodynamic coupling. In inductive coupling, power is transferred between coils of wire by a magnetic field. From two coils, one is in the transmitter side and another is in the receiver side. This is the oldest and most widely used wireless power technology. It is used to charge phones battery, electric vehicles battery, electric toothbrush battery and turn on a bulb. This technique is highly efficient when two coils are very close together. In resonant inductive coupling, power is transferred between two resonant circuits by magnetic fields. One circuit is in the transmitter side and another circuit is in the receiver side. Each resonant circuit consists of coil of wire connected to a capacitor. The resonant between the coils can highly increase coupling and power transfer. It is most efficient than inductive coupling technique. Power can be transferred over greater distances with high efficiency. Nowadays it is widely absorbed in modern wireless power systems. In capacitive coupling, power is transferred by electric field between electrodes such as metal plates. In this process, a capacitor is formed between the transmitter and receiver electrodes. The capacitive coupling has limitation on charging electric vehicles due to too small coupling capacitance. So, it is basically used in a low power applications. In resonant capacitive coupling, resonance are used with capacitive coupling to extend the range. In magnetodynamic coupling, power is transferred between two rotating armatures. One armature is in the transmitter side and another one is in the receiver side and both rotates synchronously. Both coil are coupled together by a magnetic field generates by permanent magnets on the armatures. It is an alternative process of inductive power transfer for non-contact charging of electric vehicles. It is claimed that this technique can transfer power over distances of 10 to 15 cm (4 to 6 inches) with high efficiency, over 90% [11].

2.4 Functional difference between wired and wireless power transfer

Wired is the term that refers to any physical connection consisting of cables. The cables are copper wire, twisted pair or fiber optic etc. Wired power transfer is the transmission of power through cables. On the other hand, wireless is the term that refers to the medium that is made of electromagnetic waves. All the wireless devices include antenna or sensors. Wireless power transfer is a method of transmitting energy from one physical device to another without any physical connection. The main difference between wireless and wired connection is the physical medium between two devices. For example, the cables can be damaged and require repair or replacement. The cost for the replacement or repair can be high. When compared with cables, wireless are easy to install and no need to worry about the damage of cables. Using wire, we can transfer power from one device to another. In wireless power transfer, one can easily transfer power from one device to different devices. In wired connection, there is a chance of power failure or power loss due to short circuit because of the existence of cables. Sometimes it is hard to manage the interconnecting wires between devices in wired connection. Wireless systems are comparatively maintenance free and if maintenance becomes necessary, they are easy to maintain [16].

2.5 Efficiency

Wireless power transfer (WPT) technology is developing rapidly and its efficiency increasing day by day. It is highly efficient in some cases. Using this technology, one can turn on more than one bulbs at a time. It is also possible to charge several batteries at the same time without using any cable. Many working group have experimented WPT technology using different types of methods. In 1983, Donaldson's research showed that the optimal electromagnetic coupling coefficient of the transmitter and receiver can be achieved by using the S/P capacitance compensation technique. The transmission efficiency can reach 50%. In 2009, KAIST tested on the SUV car and got 17 kw power at the output with a distance of 170mm. The efficiency reached 71%. In 2010, University of Auckland tested on private vehicles and achieved 3kW power for charging the vehicles battery wirelessly [14]. The efficiency was 85% at a distance of 180mm between source and load. A team from MIT has experimented and were able to light up a 60W light bulb from a power source at a distance of 2m. The efficiency of this experiment was 40%. Furthermore, they found that it is possible to increase the efficiency by shorten the distance. Researchers were able to power a 60W light bulb at roughly 90% efficiency at a distance of 3 feet. In 2010, MIT WiTricity tested on private vehicles and achieved 3.3kW power for charging the vehicle's battery at a distance of 180 mm. The efficiency was 90%. In WPT technology, distance is a big tissue and we got to know this through these experimented results. The efficiency of WPT depends on the distance. The efficiency is higher if there is shorter distance between power source and load. The efficiency is lower if the distance between power source and load is longer. On the other hand, the efficiency also depends on the technique [15].

Chapter 3

Existing improvements of wireless power transfer

3.1 Introduction

Communication technologies are providing ubiquitous and cable free communication to the users but user's devices are still battery limited and need wires to charge them. The recent advances are promising to charge devices without the help of wires or battery replacement. Nowadays, wireless power transfer is being utilized in IC cards, portable telephones and electric automobiles [9]. It is necessary to improve the quality factor of the receiving coil and the transmitting coil for high efficiency and long distance transmission [9]. Many research is taking place to improve the efficiency and distance at the same time. Nikola Tesla has invented tesla coil to transfer power wirelessly in 1891. He was a bit over ambitious as he dreamed to have a wireless power grid. At present, wireless power transfer is taking place in charging electric vehicles, mobiles and other devices. In this field, the contribution of Nikola Tesla is irreplaceable. Modern techniques of transferring power wirelessly includes tesla coil. With the passage of time, the construction of tesla coil is modified. Though it will be just a dream to have a wireless power grid in future, but, wireless charging system is developing all over the world. Wireless power system is costly, but it is safe. It will eliminate the loss of the wires, it will prevent users from electrocution.

3.2 Overview

Wireless power transmission technologies use time-varying electric, magnetic, or electromagnetic fields [11]. Wireless transmission is useful to power electrical devices where interconnecting wires are inconvenient, hazardous, or are not possible [11]. It is more secure for people. As the system becomes wireless, people will have no physical contacts with the transmission process. So, it will be safer for people. Moreover, it will be time saving, easy for people as it does not require any cable connection. It is very much user friendly as devices will be charged at the same time when they are being used. Thus it saves time.

Different research group used a Litz Magneto Plated wire (LMW) structures as transmission coils for wireless power transmission in electric vehicle charging system [10]. Litz wire is generally used to decrease the ac resistance due to skin effect of a coil [9]. However, the decrease in ac resistance caused by the proximity effect is difficult, and there is a limit in increasing the quality factor using a litz wire [9].

In wireless power transfer, there are mainly two categories, radiative and non-radiative . Non-radiative technique is used to deliver power wirelessly in near fields. This technique uses magnetic fields created by inductive coupling between coils of wire, or by electric fields using capacitive coupling using metal electrodes. Non-radiative technique is used to deliver power wirelessly in far fields. In this technique, power is transferred by beams of electromagnetic radiation, like microwave or laser beams.

3.2.1 Inductive coupling

The coupling between two wires can be increased by winding them into coils and placing them close together on a common axis, so the magnetic field of one coil passes through the other coil [12]. The mutual inductance of two conductor is used to measure the amount of inductive coupling between them. The coupling between two wires can be increased by winding them into coils and placing them close together on a common axis, so the magnetic field of one coil passes through the other coil [12]. The two coils may be physically contained in a single unit, as in the primary and secondary windings of a transformer, or may be separated. Coupling may be intentional or unintentional. Unintentional inductive coupling can cause signals from one circuit to be induced into a nearby circuit, this is called cross-talk, and is a form of electromagnetic interference [12].

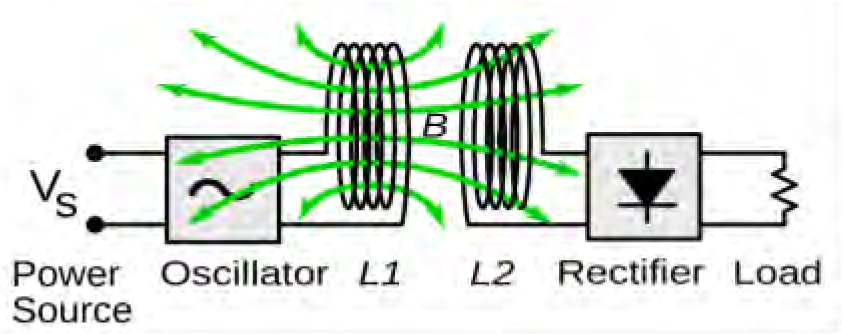


Fig. 3.1 Inductive coupling [12]

3.2.2 Mix inductive coupling

Wireless power transfer system via magnetic resonance coupling (WPT/MRC) is used for its higher efficiency, longer range and greater power output [17]. Up to now, diverse circuit architectures are widely utilized in wireless power transfer system [17]. There are four basic topologies: series-series, series-parallel, parallel-parallel, parallel-series.

Tesla coil also follows the mechanism of magnetic resonance coupling. Direct induction followed by magnetic resonance induction is used for wireless power transmission. The flux produced from the primary coil is received by the coupled secondary coil and voltage is induced in the secondary coil. The overall technique is using magnetic field, so the primary coil should have a high enough frequency, high flux density. So, the tesla coil is used as a transmitter to produce high voltage, high, low alternative current and high density flux.

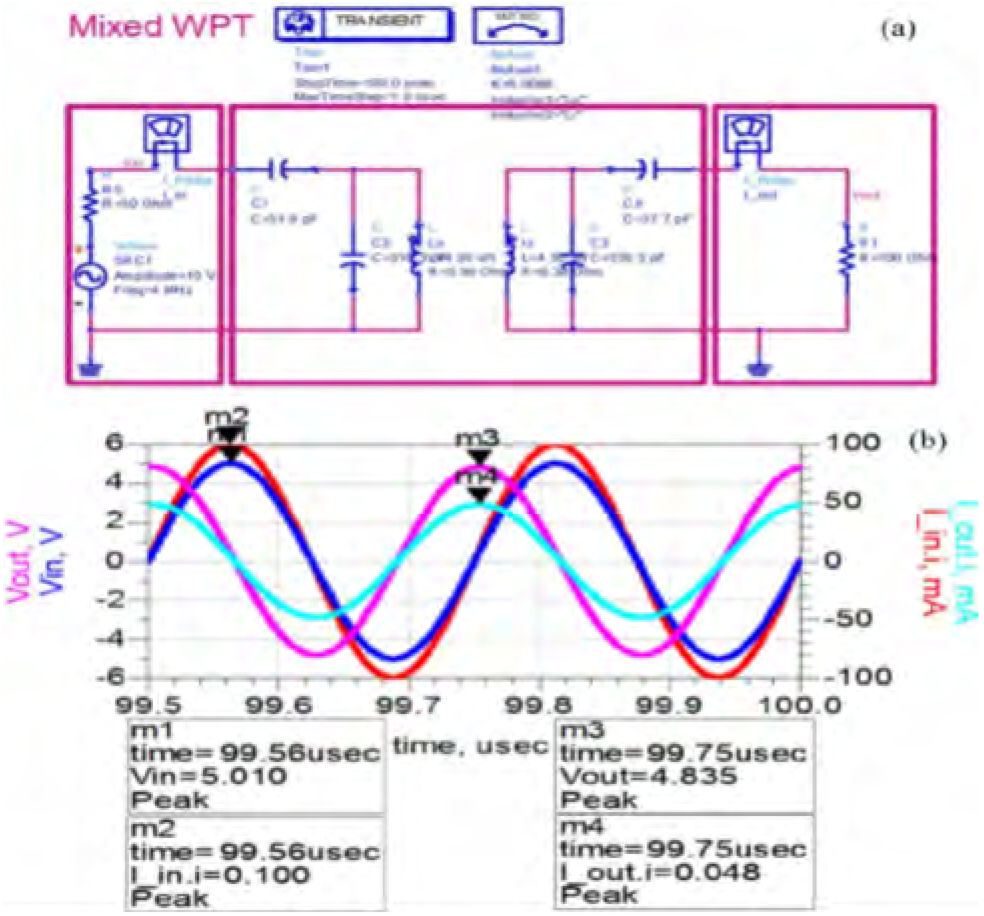


Fig. 3.2 Mixed resonant coupling circuit [18]

3.2.3 Microwave

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 [11]. A rectenna 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 of power to spacecraft leaving orbit has been considered [11]. 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 [11]. Wireless high power transmission using microwaves is well proven. Experiments in the tens of kilowatts have been performed at Goldstone in California in 1975 [11].

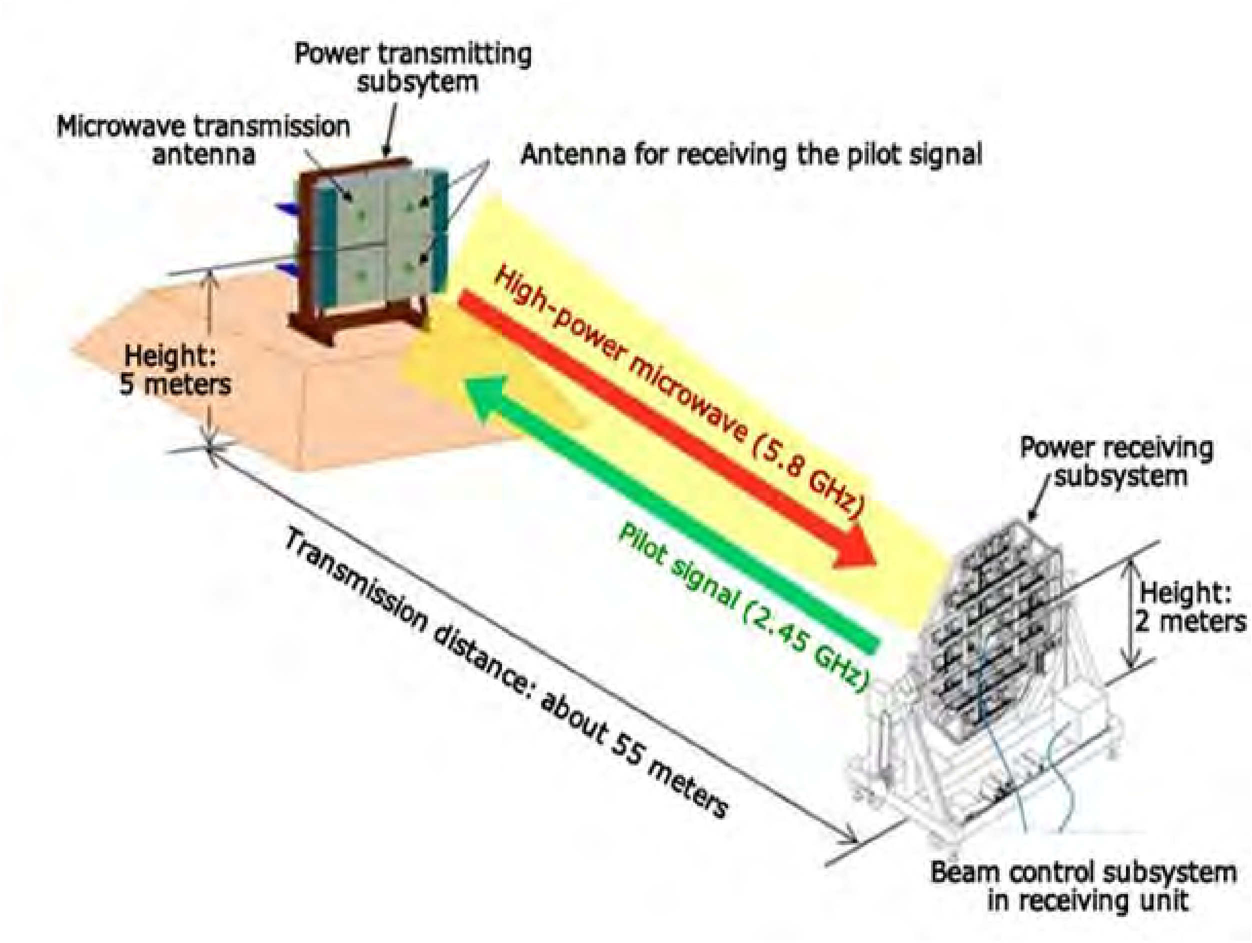


Figure 3.3 : Microwave wireless power transmission [23]

Tesla coil also follows the mechanism of magnetic resonance coupling. Direct induction followed by magnetic resonance induction is used for wireless power transmission. The flux produced from the primary coil is received by the coupled secondary coil and voltage is induced in the secondary coil. The overall technique is using magnetic field, so the primary coil should have a high enough frequency, high flux density. So, the tesla coil is used as a transmitter to produce high voltage, high, low alternative current and high density flux [26].

Figure 3.4 : Tesla coil [26]

3.3 Limitations and problems

When wireless power transfer is in band with information transfer, there will be interruption in connectivity.

The wireless power density is hard to estimate and control. The radio exposure can be over the limit due to reflection and refraction of the signals originated from other wireless devices.

Ensuring safety where end-users are allowed to deploy new power transmission and modify the locations of existing energy transmission and energy receiver at run-time is difficult. The more ETs are deployed, end users might be exposed to more radiation . Determining a power transfer schedule for ETs in order to maximize power transfer and ensure EMR safety is a hard problem . In such a dynamic system, one should guarantee the exposure safety considering run-time influence of unpredictable end-user actions. For scenarios where ERs are wearable, body movements might lead to unpredictable exposure influence on different parts of the body .

Wireless power transfer through microwave involves biological effects due to high frequency [19]. Moreover, it will be very much costly. The transmission of electric power through this method is susceptible to security risks like cyber warfare [19].

Chapter 4

Wireless Power Transfer Using Tesla Coil

4.1 Introduction

In 1891 Nikola Tesla invented his Tesla Coil in order to transmit electricity through air, indeed he spent majority of his career lifetime attempting to achieve his ultimate goal of wireless power transmission[4]. Whenever power was needed one would need a receiver coil to convert the power into a useful form according to individual needs [5]. Nikola Tesla had some success in this area but the investors found it impractical and refused to support in further research, so he has to stop this research. His research on wireless power transfer was not a loss as he used tesla coil to experiment in radio transmission, build death rays and other wild inventions[5].

So inspired from his experiments, we decided to use tesla coil for wireless power transmission and to materialize his dream of transfer power wirelessly. For wireless power transfer, tesla coil is used as a transmitter where tesla coil is used high voltage, high frequency transformer. Working procedure and designing of a tesla coil will be described later the chapters.

4.2 Working principle of Tesla Coil

Tesla coil is used basically as a transmitter for wireless power transmission where the tesla coil is a high voltage transformer. Tesla coil is a resonant transformer containing a primary and a secondary LC circuits where this two LC circuits are loosely coupled together [3]. It is a kind of transformer but its operation is different than conventional transformer and this is why we are using it as a transmitter which will give us high voltage, high frequency output for better induction in the load side.

Tesla coil charges a capacitor (Primary capacitor) with a high voltage transformer and temporarily store the charges, when the capacitor is charged with sufficient voltage which is connected to a special type of switch named spark gap, ionized in the air between the electrodes and it conducts [7]. The spark gap is placed between the primary capacitor and primary coil and the other end of the capacitor is connected with the high voltage transformer whereas the primary capacitor can be connected in series or parallel combination. The other end of the primary coil is the RF ground.

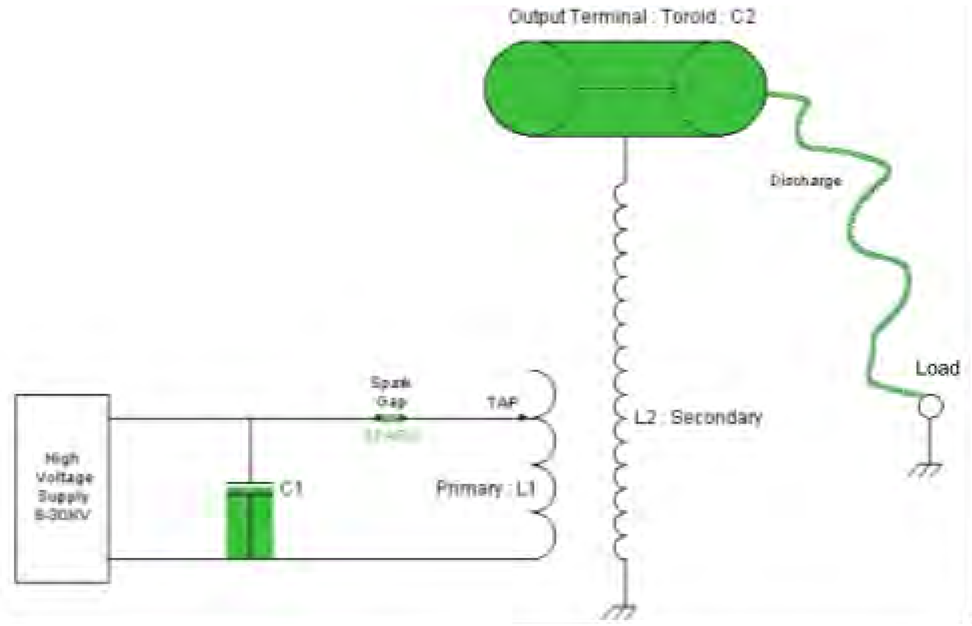


Fig. 4.1 Tesla coil operation [6]

In the above figure we can see the tesla coil operation where power is transferring wirelessly to a load. Previously mentioned that a high voltage power supply is used to charge the primary capacitor, here the capacitor C1 is charged through a high voltage power supply, when the capacitor reaches to a high enough voltage, the switch like spark gap fires and the energy stored in the capacitor dumps into a 1:100 step up transformer as primary and secondary coil turns ratio is approximately 1:100 means, if primary coil is about 10 turns, the secondary turns is 1000 that gives 1:100 ratio which means if feed in 10,000 volts, get out 1,000,000 volts [6].

The actual operation of the tesla coil is bit more complicated as it is based more on resonance than on turns ratio. Resonance is basically, when the spark gap fires, the capacitor get electrically charged and then the charge in C1 dumps into L1, and then back into C1, and then back into L1 where C1 and L1 make up resonator and they are changing electric field into a magnetic field, and back again, at a rate (frequency) determined by the value of C1xL1 [6]. The primary side will deliver energy and the secondary side will receive that energy during the charging and discharging session. The secondary coil (L2) picks up some energy from primary coil (L1) each time charges up and in the output terminal, secondary capacitor (C2) gets an electric charge from the L2 each time L2 discharges. In the secondary side it is necessary to maintain the resonance as well, the resonance is determined by L2xC2 and it will work when this condition appears,

L1xC1 = L2xC2 or both resonator resonance at a same rate. The energy in L2 builds by a little bit from L1 on each cycle when both resonator are at a same rate and this is called resonant rise than the output voltage gets higher on each cycle until it gets too high to hold and then it delivers to the load wirelessly [6]. This is how a tesla coil operates basically. In the following chapters we will be describing all the components and their functionality in detail.

4.3 Advantages of using Tesla Coil

In direct electromagnetic induction, it delivers power at 10 cm with 80% efficiency along with 20 cm with 45% efficiency, which is not up to the mark. In addition to that there was low flux density which results in low induced voltage in the primary coil as well as the secondary coil. An Massachusetts Institute of Technology (MIT) report which says, in urban areas the electric vehicles will get charged while going through the streets. In this case, the streets are working as the primary coil, this process is known as Dynamic Wireless Power Transfer (DWPT). In developing countries like Bangladesh, it is almost impossible to build this kind of street.

Wireless power transfer is based on electromagnetic induction between primary and secondary coil where these induction depends on the change of flux and the change of flux depends on the flow of current. From the basic concept of induction, we know the Faraday’s law about the electromotive force (EMF) which depends on the change of flux which is basically the basic concept of a typical transformer which induced voltage is proportional to the rate of change of flux linkage. This means that if the coil is stationary relative to the magnetic field, no emf is induced rether to induce emf, either the coil or magnetic field must move. Faraday’s law formula is mentioned below,

$$\varepsilon = - N \frac{\delta\phi}{\delta t}$$

If we integrate both side of the formula and rearrange in terms of ϕ, we would find that the flux depends on the integral of the voltage. This means that it will induce a magnetic field if we put an emf across the coil. The tesla coil also works on this principle, the more the emf the more the induced magnetic field and the more the magnetic field the more voltage induced in the secondary side. Tesla coil is a type of transformer but not the typical transformer which works as a transmitter in wireless power transmission. In tesla coil, the density of induced magnetic field is so high and the induced voltage is also so high that has the more efficiency in transmission of power. Tesla coil works on resonant coupling, so the frequency is also so high.

In tesla coil the induced magnetic field in an inductor captured by another inductor coil and as this technique use magnetic field to transfer energy that is why the flux that is produced in the primary side must be in high density with high frequency. This is one of the the basic problem to transfer electric power wirelessly with a good efficiency rate. Thus, tesla coil is used as a transmitter to produce high frequency, high voltage with low alternating current in order to produce high density of flux for a better transmission of wireless power [8]. Another aspect is to be in under consideration that having an unusually high frequency, high voltage, tesla coil has no health hazards when they passes through a body do not cause any painful situation and muscle contraction of electric shock, as low frequency AC/DC currents do. The nervous system is insensitive to currents with frequencies over 10 - 20 kHz [4].

4.4 Designing of Tesla Coil

In direct electromagnetic induction, the energy is transmitted by electromagnetic coupling but this process requires a close range between the transmitter and receiver in order to couple. To extend the distance between the transmitter and receiver, tesla coil is the best solution. Tesla coil is used as a transmitter to produce high voltage, high frequency, low alternating current to produce high density flux. An extra feature of using Tesla coil is, that is not harmful for human body [3].

In order to produce high voltage, high frequency and high flux density with low alternating current in the secondary coil, flux produced in the primary coil must be in high density with high frequency. The standard voltage ratio between the primary and secondary coil is 1:100. Both coils should have the same resonant frequency coupled to form a great output. The formula of resonant frequency is:

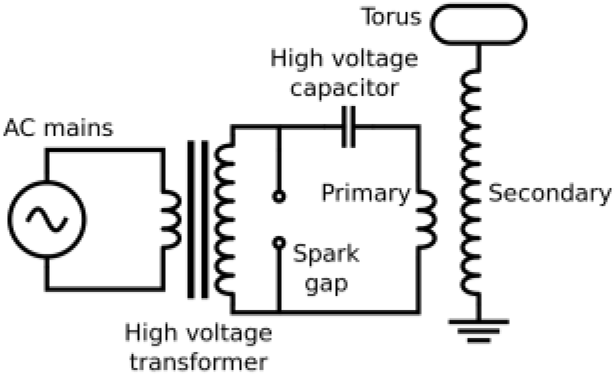


Fig. 4.2 Tesla coil [13]

$$f_r = \frac{1}{2\pi\sqrt{(LC)}}$$

Depending on the value of L and C, we get a resonant frequency at the primary side that has to be equivalent to the secondary resonant frequency. To avoid misuse of electrical energy, parallel resonance can be employed. In parallel resonance, the inductance and the capacitance are in parallel so the impedance of the combination rises to maximum the resonant frequency. Magnetomotive force (MMF) increases when the number of turns and current increases.

$$\text{mmf, } f_m = \mathrm{N} \times \mathrm{I}$$

After saturation, though the number of turns is increased, the MMF will no longer increase as well as the flux. There are some equipments that is necessary to build a tesla coil as it is not just a typical transformer or a simple transmitter. Tesla coil is a bit complicated electrical equipment which needs some complex operating conditions and components as well as to produce perfect output. If any of the equipments get missing or messed up making or faulty construction can make all the things messed up which can cause a great danger. So, it is a very hard job to design a tesla coil and one should be very careful about it and some most important things must be keep in mind which should be in under consideration to construct a tesla coil. All the equipment and their functions are described in detail with their typical values in the following below [3].

4.4.1 Neon Sign Transformer (NST)

A neon sign transformer is slightly different from the conventional transformers which convert line voltages in the range of 2-15 kV and supply between 18-30 mA and 60 mA. In case of choosing the NST, we must ensure that transformer supplies at least 5 kV, otherwise we may have problems with the spark gap not firing. A power factor correction (PFC) can be wired across the NST input terminal to correct the AC power phase and increase efficiency. PFC shifts the VA rating of the transformer closer to actual input and output watts and reduces input current needed. Studying all those papers and some Tesla coil designing sites, we came up with some

Fig. 4.3 Neon Sign Transformer (NST) [3]

estimated values and TeslaMap software shows typical values for designing NST. In the table given below, typical NST values are mentioned using TeslaMap [3].

NST Inputs		NST Outputs	
Input Voltage	220V	Optimum PFC Cap	17.8uF
Input Frequency	50Hz	NST Watts	280W
Output Voltage	9kV	Max Arc Length	28.4 in
Output Current	30mA	MMC Cap for Static Spark Gap	17.2nF

Table 4.1 : NST input-output data in TeslaMap

4.4.2 Primary Coil

The basic functionality of primary coil is to couple to the secondary coil to transfer power form the primary to secondary circuit. It takes the output from the NST and step up the voltage with 1:100 ratio in the secondary coil. In the primary side the flux density must be high enough, so the

Fig. 4.4 Typical Primary Coil [3]

coil AWG must be low. In general, 0.25in diameter of copper tube is used to form the primary coil. There must be a spacing of 0.25in between turns. Primary coil can be constructed in different shapes like pancake, conical or helix. To form conical shape, the coil angle must be less than 45 degree. Helical coils are wound into a helix of equal diameter. We are using pancake shaped primary coil because it is easy to construct and it is preferred to use pancake for medium and large size Tesla coil. We designed estimated primary coil using TeslaMap. TeslaMap shows typical values for designing. For coil wire diameter and wire spacing typical values are 0.06in to 0.25in. Center hole diameter measured between the inside of the innermost turns are 2in larger than the secondary coil diameter. The values are given below [3].

Primary Inputs

Coil wire diameter	0.25 in
Coil wire spacing	0.25 in
Coil hole diameter	8 in
Coil incline angle	0 in

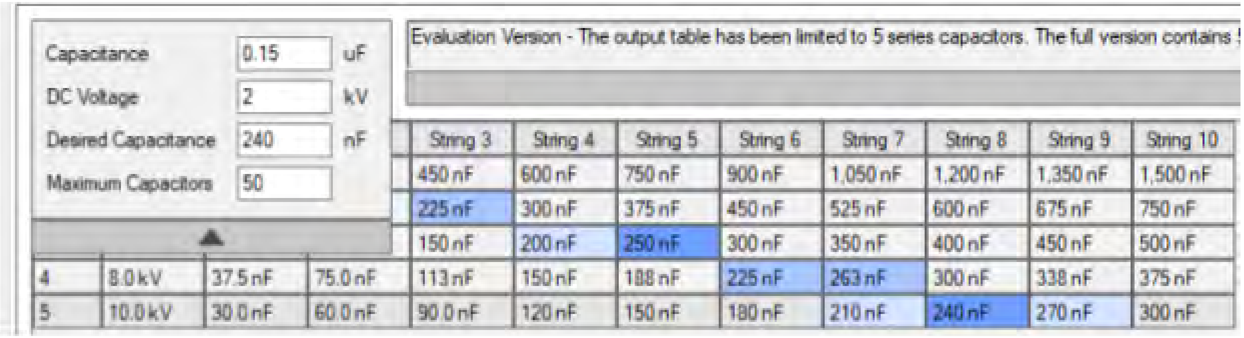
Primary Outputs

Turns	Diameter	Height	Length	Inductance
1	9 in	0.25in	2.36 ft	0.457uH
2	10 in	0.25in	4.97 ft	1.72uH
3	11 in	0.25in	7.85 ft	3.73uH
4	12 in	0.25in	11 ft	6.45uH
5	13 in	0.25in	14.4 ft	9.91uH

Table 4.2 : Primary coil input-output data in TeslaMap

4.4.3 Primary Capacitor

Primary capacitor is very important component for construction of tesla coil. The primary coil gets input through the primary capacitor as power can not be supplied directly to the primary coil of a tesla coil because it won’t work until the resonant frequency matches. Basically, to create a primary LC circuit primary capacitor is used. This primary capacitor isn’t just the ceramic or cylindrical capacitors that are used is lab works rather it is made of several dozen of capacitors wired in series and parallel configuration creating an array of capacitors, this type of configured capacitors are called Multi-Mini capacitors (MMC). The advantage of using MMC for primary coil is, it is easy to replace if any of those fails to work. To construct an array of capacitors it is recommended to use factory capacitors as they are labeled with a perfect capacitance and easy to get desired capacitance and safe as well as this capacitors exposed to high voltage and very short charge/discharge cycle times and this factory capacitors have a high tolerance level. This capacitors are chosen with the VDC rating as it requires very short charged and discharged time and VAC is ignored. Normally, 1.6 kV to 2 kV capacitors are used to make a MMC array wiring several capacitors series and parallel connection to provide a desired voltage rating [3].


Capacitance 0.15 uF
DC Voltage 2 kV
Desired Capacitance 240 nF
Maximum Capacitors 50

Evaluation Version - The output table has been limited to 5 series capacitors. The full version contains

				String 3	String 4	String 5	String 6	String 7	String 8	String 9	String 10
				450 nF	600 nF	750 nF	900 nF	1,050 nF	1,200 nF	1,350 nF	1,500 nF
				225 nF	300 nF	375 nF	450 nF	525 nF	600 nF	675 nF	750 nF
				150 nF	200 nF	250 nF	300 nF	350 nF	400 nF	450 nF	500 nF
4	8.0 kV	37.5 nF	75.0 nF	113 nF	150 nF	188 nF	225 nF	263 nF	300 nF	338 nF	375 nF
5	10.0 kV	30.0 nF	60.0 nF	90.0 nF	120 nF	150 nF	180 nF	210 nF	240 nF	270 nF	300 nF

Fig. 4.5 MMC designing in TeslaMAp

Primary capacitors are chosen depending on the rating of the NST like, if 15 kV rating RMS power supply the capacitors are chosen 40 - 60 kV voltage rating which is 2 - 3 times the peak voltage of the NST. A typical MMC will have a dozen of capacitors in each series string, it is better to calculate the strings and the number of capacitors with rows and columns with a certain valued capacitors [3]. TeslaMap can be used to calculate and designing of the MMC array. **Fig. 4.5** is a typical MMC calculation in TeslaMap with some typical values for medium sized tesla coil. Here it shows 2 kV VDC rating maximum 50 capacitors with 0.15 uF capacitance combining in strings, desired 240 nF can be obtained. In **Fig. 4.6** is a typical primary capacitor array.

Fig. 4.6 Typical MMC array [3]

4.4.4 Spark Gap

The spark gap is actually a switch that momentarily connects the primary capacitor to the primary coil. It is basically two conductor separated in a box filled with inert gas. When the capacitor is charged enough to fire the spark gap, it shorted between the primary coil and capacitor. It is important to match the resonance frequency of the two LC circuits of primary and secondary side. It is of two types, one is static gap and another is rotary gap. A spark gap is a must for big and medium sized tesla coil [3]. **Fig. 4.7** shown a typical static spark.

Fig. 4.7 Static spark gap [3]

4.4.5 Secondary Coil

The secondary coil is coupled with primary coil. It is actually a white PVC pipe covered by a lot of enamel wire. One side is connected to ground and high voltage comes through the other side. PVC pipe standard size is about 4.4-6.6in. Two flanges (Flat rim) are needed in two sides of the secondary coil. 22 AWG to 28 AWG enameled copper wire is needed to form winding. Greater than 28 AWG is considered loss. The magnet wire is typically sold by weight. Magnet wire is copper wire with thin enamel insulation. Both wires are same by conduct, but the magnet copper wire is specially coated with thin and high heat absorbing material. There must not be any spaces between winding wires and no overlapping as well. Height to width ratio of secondary coil is 5:1 for small, 4:1 for average sized, and 3:1 for large Tesla coil. The typical values of the winding are 800-1200 turns. We designed estimated secondary coil using TeslaMap. It shows typical values for designing [3].

Secondary coil Inputs

Magnet wire AWG	22
Coil winding weight	26 in
Coil form diameter	5.5 in

Secondary coil Outputs

Secondary coil turns	923
Secondary H/W ratio	4.7:1
Secondary wire length	1330 ft
Secondary wire weight	1.17 kg
Optimal top load cap	22.4pF

Table 4.3 : Secondary coil input-output data in TeslaMap

4.4.6 Top Load

It is a metallic object at the top of the secondary coil. It provides a capacitance to the Tesla coil. Top load is preferred doughnut or toroid shaped. To construct a top load, there must be aluminum duct, a flange and wires. The flange is covered by the aluminum duct. There are two ways to construct it. The first way is to bend the wire to bring the two edges of the aluminum duct as close as possible. The wire must be inside the toroid. The other way is to use hot glue to add the aluminum duct and the flange together. After calculating the values of the primary and secondary coil in the TeslaMap, we found that the preferable value of the optimal top load capacitance is 22.4 pF [3]. **Fig. 4.8** is a typical top load.

Fig. 4.8 Top load [3]

4.5 Overview

Here in this chapter the details of all the components of tesla coil with their functions are described. The typical values and measurements are also given for a medium sized tesla coil construction. In the later chapters, the implementation of tesla coil used in our project will be described with concrete values, measurements and specifications.

Chapter 5

Project Implementation

5.1 Introduction

Tesla coil is very dangerous as we know it requires very high voltage to drive and it step up voltage at the secondary side with a 1:100 ratio. So it is very dangerous and need skills to handle carefully, actually experts are needed to handle this tesla coil. So it is easier to handle a mini or small sized tesla coil instead of the typical or middle sized tesla coil as in this mini sized tesla coil, the input is low voltage with a higher frequency. The construction of the primary and the secondary coil will also be different as with a lower turns, diameter, height and also the other parameters will have different ratio. Basically, the designing of the whole tesla coil will be slightly different but the main intention and basic properties will remain the same. In typical tesla coil, input is giver through NST but we can not use it as it give output of 15 kV (typically) which is very high voltage and dangerous to handle. NST step up the voltage with a very high frequency that goes to the primary coil through a high voltage capacitor array and a spark gap. In our case, we can not use any of them because of the dangerousness and unavailability in markets. To avoid the danger issues, we used low input voltage with high frequency as is it required to induce more voltage in the secondary side in order to get efficient voltage. In order to increase voltage a oscillator circuit has to be constructed with a low voltage. That’s why we have constructed a oscillator circuit which generates a very high frequency and that is supplied to the primary coil the tesla coil through a capacitor. The tesla coil gets power from the oscillator circuit output. Then from the primary coil, voltage induced in the secondary coil which supply power wirelessly in air. Electromagnetic waves are in the air and a load coil is there to induce voltage in it then it is converted to a usable form. **Fig. 5.1** illustrates the whole flow of the project in a block diagram. This is the basic concept of our construction and in the following chapters all the equipment, design and functionality will be described in detail. Here we will describe the construction of the whole experimental setup with proper measurement of the coil construction, specification of equipments used. The designing of the coils and the whole process will be described in this chapter.

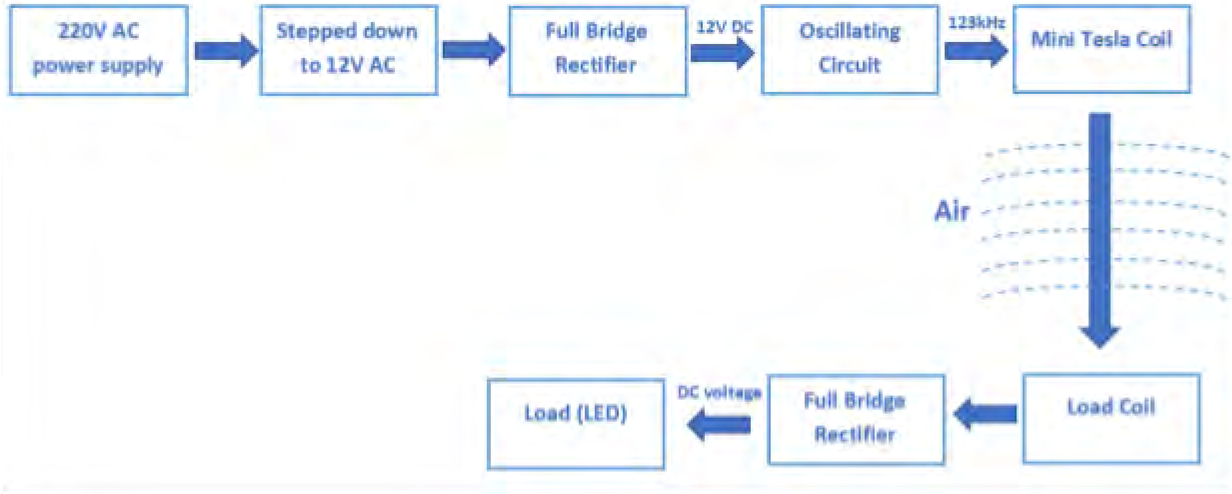


Fig. 5.1 Block diagram of the overall process

5.2 Step-down transformer

A transformer that decreases voltage from primary to secondary is called a step down transformer. In a step down transformer, primary turns are higher than secondary transformer. The transformer converts high voltage, low current power into low voltage high current power. The more details about step down transformer are discussed in chapter 6. **Fig. 6.1** shows the step down transformer used in our transformer. In our thesis project, we have used step down transformer to convert 220V AC voltage to 12V AC. Step down transformers output is directly connected to the full bridge rectifier to convert 12V AC to 12V DC. The output of the rectifier is connected to oscillating circuit. The 220V AC can damage or burned the oscillator circuit. This is the reason we chose a step down transformer to avoid the risk of the damage.

5.3 Oscillator Circuit

An oscillator circuit is an electronic circuit that makes a periodic signal often a sine wave or square wave. Oscillator circuit convert DC voltage to AC voltage. It also produce high frequency. The main purpose of using an oscillator circuit is to generate a high frequency voltage. We have given 220V AC as input with 50Hz frequency. In making of Tesla coil, the primary coil resonant frequency should be approximately 20 kHz to 100KHz or more. To increase the frequency from 50Hz to higher, we used an oscillator circuit. In our thesis project, we made the circuit using resistors, capacitors and a NE555P Timer IC. **Fig. 6.6** and **Fig. 6.8** shows the schematic and practical implementation of the oscillator circuit used in our project. The details of the oscillator circuit and the functioning of that circuit will be described in chapter 6. We have used 46Ω, 216Ω and 547Ω resistors, and 0.001uF, 0.02uF, 0.1uF capacitors. We successfully got 123 kHz frequency with 6V peak at the output of the oscillator circuit. The output voltage was a square wave but we needed a pure sinusoidal wave. To convert the square wave to a sinusoidal wave, we added a low pass filter with the oscillator circuit shown in **Fig. 6.13**. The job of the low pass filter is to pass the sinusoidal waveform of the pulse wave. The low pass filter is a RLC circuit. We have used 300 mH inductor, 15Ω resistor and 15nF capacitor in series connection. After connecting the low pass filter with the oscillator output, we got a pure sinusoidal wave with a frequency of 121kHz. The peak voltage of the sinusoidal wave was 8.35V in our oscillator circuit which perfectly worked. There is a slight difference between simulation and practical implementation. In simulation, we got 100 kHz frequency at the output of the filter whereas in practical its 121 kHz. This happened because we made 15Ω resistor using some resisters connected in series-parallel connection and also is for capacirors. Later, the output of the oscillator circuit with low pass filter was connected to the primary coil capacitor.

5.4 Primary Coil

In our wireless power transfer process, we have used tesla coil technique to transfer power wirelessly and the tesla coil is used as a transmitter of wireless power transfer. Tesla coil is a sort of transformer but different from the conventional transformers. As we know and discussed in chapter 4 about the basic theory of transformer and Faraday's law, transformer is consists of primary and secondary coils in primary and secondary sides respectively. Primary coil stays in primary side which induces voltage in the secondary side through electromagnetic induction. The primary coil creates magnetic flux in the primary side and induces secondary coil through flux lines. The primary coil creates electromagnetic flux with the change of alternating current in a coil. In the secondary coil the voltage is induced and the induced voltage dependent upon the rate of change of flux within the primary and secondary side. All the formulas and laws are mentioned in chapter 4. We need to know how induction works to design the coil in which the induction, electromagnetic flux, induced voltage rate of change of flux depend. Making slight mistakes or error in the measurement of the construction of coils, the tesla coil won't work. So it is very sensitive work that has to done carefully.

We have discussed earlier that the primary coil wire must be thicker than the secondary coil wire. That means, primary coil wire diameter is greater than the secondary coil wire diameter. That is why we have used a very thick or larger diameter wire for primary coil construction. Our constructed primary coil is shown in **Fig. 5.2**. The best use for primary coil is to use copper tube wire which is thicker and cylindrical shape tube. We have taken 1 mm diameter copper tube for our primary coil. We made helix shaped primary coil as we know primary coil can be in different

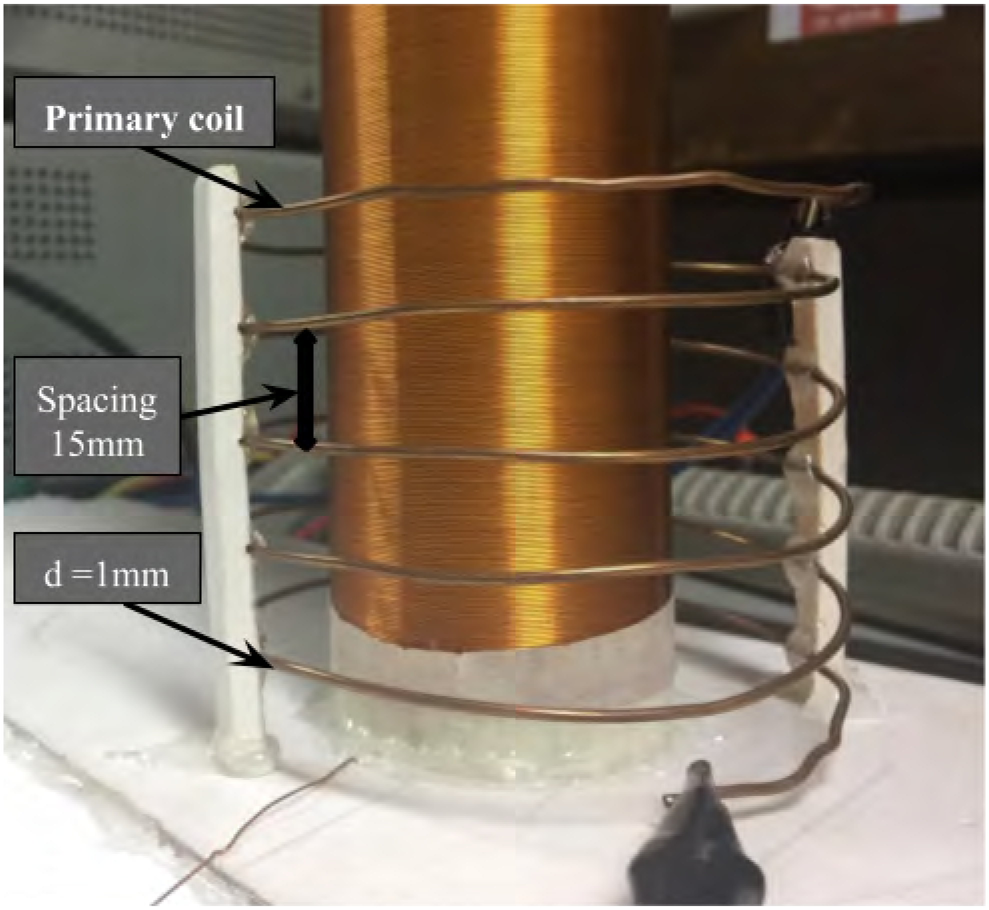


Fig. 5.2 Primary coil

shapes. As we were making mini sized tesla coil, it is better to use helix shape primary coil for better induction in secondary coil. The inner diameter of the helix primary coil is 68 mm. We have discussed in the chapter 4 about the typical turns for the primary coil and spacing between turns. We have taken 5 turns in primary coil with 15 mm spacing between turns. Approximately 1.068 m long copper tube is used in the construction of the coil. As the coil diameter is 70 mm and 5 turns were used so, $\pi \times 70 \times 5 = 1.099$ m. So, we took approximately 1 m long wire tube length according to the availability in the market. All the measurement of the primary coil is given in **Table: 5.1**.

Coil wire diameter	1 mm
Coil diameter	70 mm
Spacing between turns	15 mm
Number of turns	5 turns
Length of the wire	1.2 m

Table 5.1 : Primary coil measurement

5.5 Secondary Coil

The primary coil induces voltage in the secondary coil to transfer power wirelessly with a 1:100 ratio. Secondary coil steps up the voltage to a high enough voltage that can be transferred maintaining the resonance frequency. The load coil receives power from the secondary coil and from the top load of the secondary coil.

Tesla coil is an electrical resonant transformer designed by Nicola Tesla which has both primary and secondary side like other conventional transformers. In secondary side, secondary coil is used with top load to create secondary LC circuit. It is responsible for generating the very high voltage in secondary side of Tesla coil. In tesla coil technique as we mentioned earlier that the oscillator circuit gives input to the primary coil with a very high frequency, magnetic field produce in between primary and secondary coil and this magnetic field induces an electric current in the secondary coil. This current later produce an induced voltage in the secondary coil and also in the secondary coil a magnetic field is induced in a certain are centering this secondary coil. So, secondary coil basically creates a range where it can transfer power to the loads and this voltage converted to a usable form is used to power devices. In the designing process, secondary coil should be design first before designing the primary coil. It is easier to match the resonant frequency of both coils. The first thing to decide when constructing a secondary coil is what form to use. Secondary coil usually have 800-1200 turns. In some cases, 2000 turns can be acceptable. The more number of turns creates more magnetic flux. In that case, saturation is the biggest problem. Saturation occurs when increase the number of turns have no longer effect on the magnetic flux. This is the reason of the limitation of the number of turns in secondary coil. Copper wire or magnet wire is used to wind the coil. There should be no space between wires while winding the coil. The secondary coil is wound onto an insulator former, usually PVC pipe. White PVC pipe is a better choice. White PVC are plastics and they are good insulators. The height and diameter of the PVC pipe are important as well. There is a limitation of the AWG of the wire. The AWG of the copper/magnet wire should be in between 22 to 28. More than 28AWG can create arc problem and considered as a loss. Tesla CAD software can be used to calculate the winding calculation and other parameters. This software is also used to maintain the resonant frequency of both primary and secondary coils. The diameter and height of the coil is also given by Tesla CAD software.

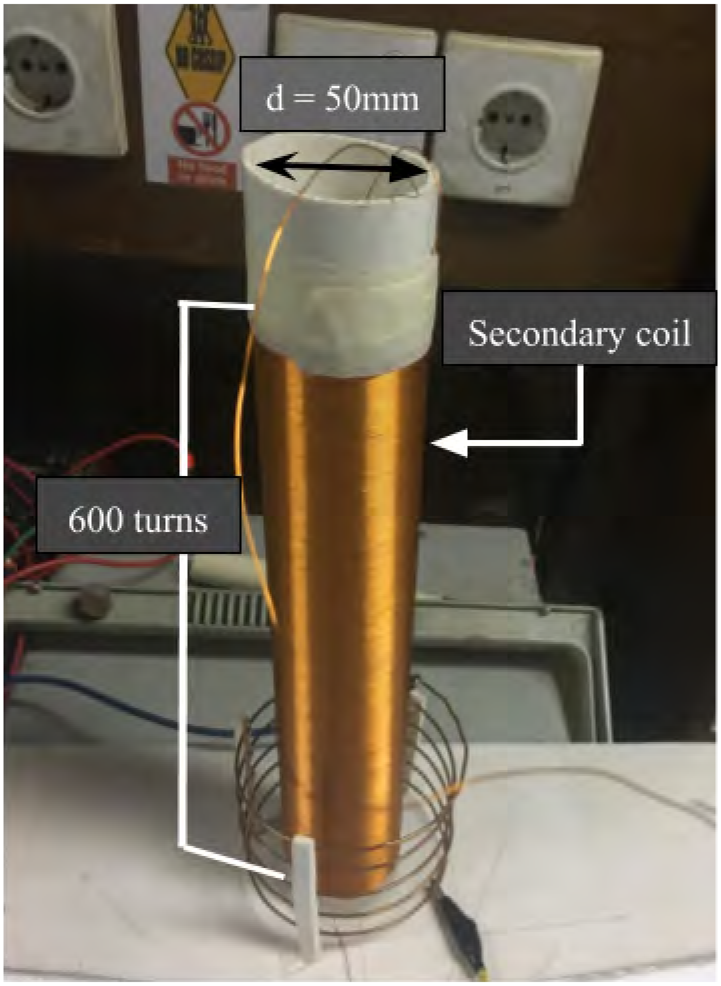


Fig. 5.3 Secondary coil

In our Tesla coil for wireless power transfer project, we have taken 600 turns as we were making a mini Tesla coil. To winding the coil, we used 28AWG copper wire. A white PVC pipe of 50 mm diameter with a height of 18 inch is covered by the windings of the coil. **Fig. 5.3** shows the secondary constructed for this thesis purpose and **Table: 5.2** contains all the measurements used for secondary coil. For secondary coil, 100 gm of 28 AWG wire were bought. The length was approximately, $600\times\pi\times50 = 94.23$ m.

So, approximately 100 m long wire were used to wind the 600 turns for secondary coil.

Coil wire diameter	0.3211 mm
Coil wire AWG	28
Coil diameter	50 mm
Number of turns	600
Coil height	18 inch
Length of the wire	100 m

Table 5.2 : Secondary coil measurement

5.6 Load Coil

Tesla coil creates magnetic field surrounding in a certain area centering the secondary coil. In that area there are electromagnetic waves with very high frequency. This high frequency power in electromagnetic form can not be used in any of the electronic or electric devices. So after the transfer of power wirelessly it is mandatory to receive that energy in which form it is than it is needed to convert in a usable form. Load coil is such a coil that receives that energy and induces a voltage and than convert it to another form.

To construct a load coil for our project to receive power wirelessly from tesla coil, 20 turns of 32 AWG copper wire is taken. It was winded in a plastic syringe of approximately 1 inch diameter. The two terminals of the load coil is connected to the full bridge rectifier circuit to convert it into a DC voltage. One terminal goes to the input (positive terminal) of the rectifier circuit and another goes to the ground. Before connecting to the circuit the terminals of the coil wire was scratched to eliminate the coating of the surface for batter conduction. **Fig. 5.4** is the load coil that is used to catch power wirelessly and power up devices wirelessly. The rectifier circuit gets power from this load coil. Basically, the load coil works as a voltage source for the rectifier circuit.

Fig. 5.4 Load coil

5.7 AC to DC conversion circuit

As mentioned earlier, electric power is needed in a usable form to drive any electronic or electric devices. Tesla coil drives in a very high frequency voltage but most our daily life appliances runs in 50 or 60 Hz of frequency. Tesla coil runs at a high frequency and produces higher frequency to maintain the LC resonance frequency. Whatever the power tesla coil produces wirelessly can not be used directly to any devices rather it is necessary to convert that received power to a usable form. We know from the law of conservation of energy that the summation of the energy is constant, it just can be transformed from one form to another. This concept is used here also. That high frequency electromagnetic intensity is captured with the load coil and transferred to the AC to DC converting circuit which is the full bridge rectifier. In chapter 6 the details of the full bridge rectifier is discussed elaborately. **Fig. 6.3** is the schematic diagram of the full bridge rectifier and the **Fig. 6.5** is the circuit setup of the full bridge rectifier which converts AC voltage to DC voltage. This AC to DC conversion is used two times in our project, one in the oscillator circuit and another in the receiving side to supply the DC voltage to the the load LED.

Chapter 6

Oscillator circuit

6.1 Introduction

There are many ways to transfer power wirelessly with various efficiency. The types of wireless power transfer was discussed earlier chapters with their advantages and disadvantages. Use of tesla coil in wireless power transfer was also mentioned earlier. Tesla coil is bit complicated to operate though it is type of transformer but not like a typical transformer. Functionality of a tesla coil is so complicated that it has very complicated operating conditions and property. The construction of a tesla coil is also very complicated and one has to be very careful about it else all the hard work will go in vain. A slight error in calculation or carelessness in construction can destroy all the work you have done so far. Operating tesla coil is also a big issue as it requires many complicated and dangerous conditions. It requires high voltage, high frequency with low alternating current. Now the question arise why it is so complicated and why it requires so many conditions to operate tesla coil. As mentioned earlier, it is not just a typical step up transformer as it has many more turns in the secondary side compared to the primary side with 1:100 turns ratio. Unlike a typical transformer, all its properties not only depend on turns ratio rather it depends on many more things like operating frequency, voltage or resonant frequency. Tesla coil is a high voltage, high frequency transformer and it needs very high frequency to operate. The basic working procedure of induction according to Faraday’s law that induced voltage depends on rate of change of flux linkage, rate of change of flux depends on the current flow in per unit time cycle. If the frequency is so high, the rate of change of flux will also be high which increase the induced voltage in the secondary side as the input high frequency alternating voltage applied. On the basis of the logic or property it is necessary to give high frequency voltage in the primary side of the tesla coil as it bumps up the voltage unusually high with the 1:100 ratio. So if one wants a tesla coil to function perfectly fine, the operating voltage and frequency has to be high enough. This is why we built a oscillating circuit to increase the frequency of the input voltage of the tesla coil. Later in the chapter the whole oscillating circuit will be described with the output diagram of that circuit.

6.2 Use of oscillator circuit in Tesla coil

Tesla coil is very complicated electrical device which needs a complicated operating system. It is a type of transformer but a way different from the typical conventional transformer. Normally a typical transformer is either a step-up or step-down with some variation in functions. Tesla coil is always a step up transformer with unusual rise of voltage and frequency. Tesla coil is a resonant transformer containing a primary and secondary LC circuit which is loosely coupled together. A high voltage power is supplied to the primary side through a transformer which charges a capacitor and then it will discharge through a spark gap into the primary coil. The energy will oscillate back and forth between the primary capacitor and primary coil inductor at high frequencies (typically 100 - 300 kHz). As the primary circuit oscillates, power is induced in the secondary coil where the voltage is multiplied many times. The primary and the secondary LC circuit must oscillate at the same frequency to achieve the maximum power transfer [3]. The oscillation or resonance frequency depends on the inductance (L) and the capacitance (C) of both of the primary and secondary side of a tesla coil. The formula for the resonance frequency (f) was mentioned earlier.

Now the question arise, how to calculate and match the resonance frequency for a particular tesla coil. As we know this resonance frequency depends on the value of L and C, a software name Tesla CAD would do it by the value of the inductance, L of the secondary coil by the AWG, number of turns , input voltage and frequency and the diameter of the coil. Here comes the main part, what should be the input frequency of the tesla coil and why. The tesla coil works on the induction property, from the basic formula about induction, Faraday's law we know that the induced voltage is proportional to the rate of change of flux linkage. The more the change of flux ,the more the induced voltage. The change of flux depends,on the frequency of the flow of current. The increase in the frequency of the flow of the current , the increase in the rate of change of flux and thus increase in the induced voltage. Usually in Bangladesh our AC is in 50Hz but a tesla coil works typically in 100 - 300 kHz which is really a very high frequency. So it really a sensitive work which must be done carefully.

6.3 Designing of oscillator circuit

Tesla coil to operate it is necessary to increase frequency of the input voltage. The whole process of designing a oscillator circuit can be divided into several parts like,

1: Step down process

2: AC to DC conversion process

3: Oscillating process

4: Filtering process

First of all, AC 220V is stepped down to 12V AC with a step down transformer. After that, with a full bridge rectifier circuit, 12V AC is converted into a 12V DC which will be the input for the oscillator circuit. The oscillator circuit will give the pulse wave with a very high frequency. Finally, with a RLC filter circuit we will get the sinusoidal voltage waveform which will be the input of the primary coil of the tesla coil through a capacitor.

The first job is to step down the 220V AC to 12V AC with a small step down transformer which is available in the market or one can order in the market with their specification. To avoid a lot of complicacy it is wiser to use a ready made transformer available in the market with proper specification. We bought a step down transformer form the market and its specification is,

I/P: 220V ~ 50Hz

O/P: 12Vx2 1000mA

Fig. 6.1 Step-down transformer

Fig. 6.1 shows the step down transformer what is used during our project. Here 12Vx2 means that we can either get 12V or 24V in the output. With the proper combination of two from the three wires in the output side can give the desired output. For example, if one take the output from the black and yellow wires, will get 12V AC as an output, if an output is taken from the two black wires, 24V AC they will get. We took 12V AC with the black and yellow combination from the output.

After getting the stepped down AC voltage, we converted the AC to DC voltage with the rectifier circuit and smooth is with a capacitor. **Fig 6.2** shows a full bridge rectifier circuit which converts the 12V AC to 12V DC that goes to the oscillator input. A full bridge rectifier is consist of four diodes which converts both of the cycles of a AC voltage into a pure DC voltage. The four diodes are connected in series pairs with only two diodes conducting during each half cycle.

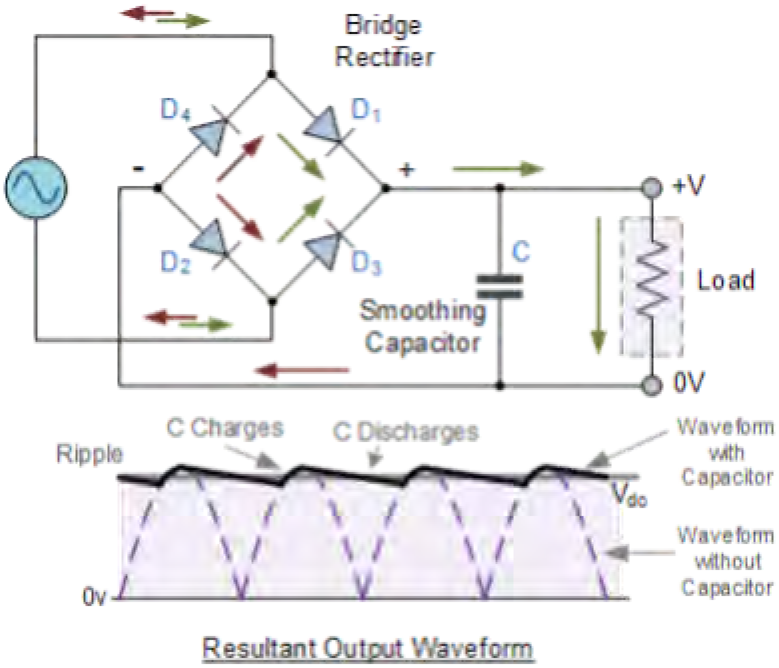


Fig. 6.2 Full bridge rectifier [20]

During the positive half cycle the diodes labelled D1 and D2 (**Fig. 6.2**) are conducting in series connection while the other diodes are in reverse biased and current is flowing in a direction. During the negative half cycle, the diodes D3 and D4 are conducting in series connection while the other diodes are in reverse biased and the current is flowing in the same direction as before. As the current flowing through the load is unidirectional, the voltage developed across the load is also unidirectional. However in reality, each diodes drops 0.7V, so during each cycle current flows through two diodes, so the amplitude of the output voltage is two voltage drops (2X0.7V = 1.4V) less than the input voltage Vmax amplitude. There is also a capacitor parallel to the load. This capacitor is called the smoothing capacitor as it smooths the output DC voltage to a pure DC voltage. The smoothing capacitor reduces the AC variation of the rectified output. This smoothing capacitor converts the full wave DC ripple voltage into a more smooth DC voltage. We need to be careful choosing the perfect capacitor. If the capacitance value is too low has the little effect on the output voltage. If the smoothing capacitance value is sufficiently large enough, the output voltage is as smooth as pure DC [20].

We have constructed our full bridge rectifier circuit to convert 12V AC to 12V DC voltage. A voltage regulator IC LM7812CT is used to regulate voltage. **Fig. 6.3** shows our full bridge rectifier circuit simulated in multisim. In our rectifier circuit 1N4007 series four diodes are used

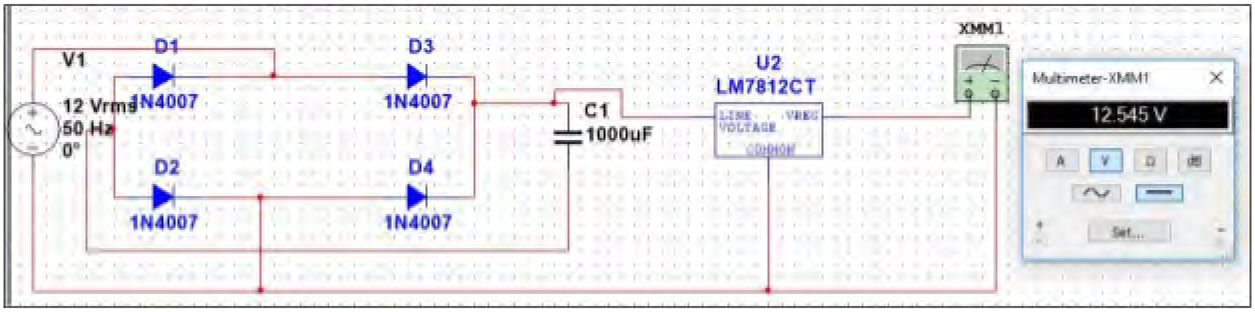


Fig. 6.3 Schematic diagram of full bridge rectifier

along with smoothing 1000µF capacitor. In each half cycle there is a drop of 1.4V as two diodes are in series in different combinations (D1 & D2 or D3 & D4) in every cycle. IC LM7812CT is a voltage regulator to maintain the 12V DC at the output side of the rectifier circuit. In **Fig. 6.3.3**, the output of the rectifier circuit is shown which goes to the input of the oscillator circuit. **Fig. 6.4** is the IC we have used to regulate. There are three pins with serial 1,2 & 3 from left where 1 is line voltage, 2 is common and 3 is vreg or the regulated output. Output is taken from the 2 & 3 number pin of the IC as no.1 pin is for input. Voltage across the pin no. 2 & 3 goes to the input of the oscillator circuit. The practical implementation is done and the **Fig. 6.5** shows the whole full bridge rectifier circuit which is the a part of the whole oscillation process of the oscillator circuit. We can see that the circuit is implemented practically on breadboard, the input is supplied from the transformer which stepped down 220V AC to 12V AC. The 12V AC is supplied across parallel diodes in order to pass the half wave of a half cycle and then again pass the half wave of the other half cycle in a same direction. This circuit is constructed in the same

Fig. 6.4 LM7812CT IC [21]

way and got approximately same output voltage, as simulated in Multisim. Here 1000µF cylindrical capacitor is used to smooth the output voltage to make it pure DC voltage. All the connections are shown in that figure as well.

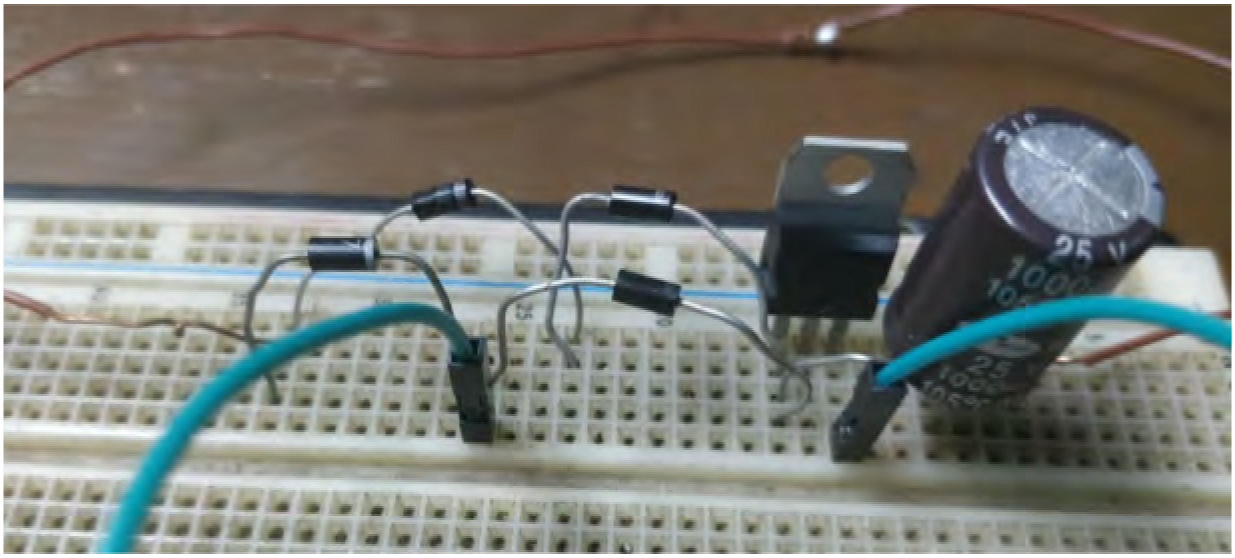


Fig. 6.5 Circuit setup of full bridge rectifier

The output from the full bridge rectifier is supplied to the oscillator circuit which increases the frequency high enough to drive this tesla coil as we know tesla coil needs a very high frequency to induce high voltage in the secondary coil from the high density flux. We have simulated our oscillator circuit in Multisim and than constructed practically to drive our tesla coil. **Fig. 6.6** shows the schematic diagram of our oscillator circuit and **Fig. 6.7** is the output waveform of the oscillator circuit. Input from the full bridge rectifier circuit is 12V DC and the oscillator circuit gives 123 kHz frequency square wave with 5.99V AC RMS peak voltage. All the component used to construct this oscillator circuit is given in the **Table 6.1**. The main component used in the circuit is the 555 timer IC which is the integrated circuit used pulse generation and oscillator application. This 555 timer basically generates pulse waveform in different frequencies. The frequency of the output pulse wave of the 555 timer IC can be varied with the combination of the

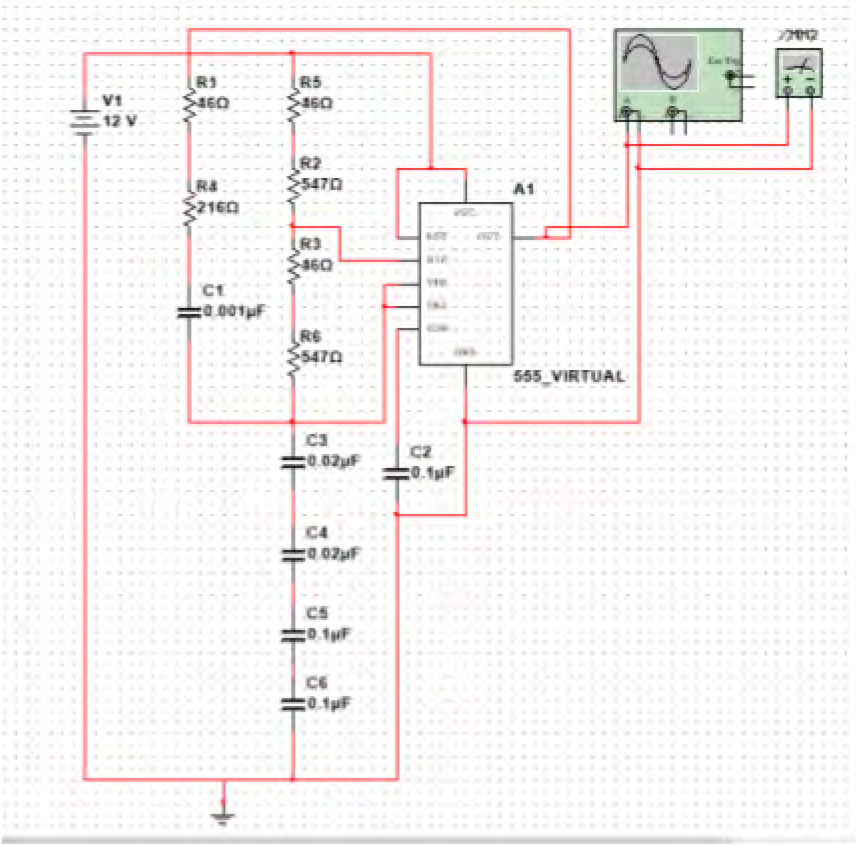


Fig. 6.6 Oscillator circuit schematic diagram

other components like resistors and capacitors with proper connection the pins of the timer IC. Timer IC have several pins with their different functions for different

Resistors	46Ω, 216Ω, 547Ω
Capacitors	0.001µF, 0.02µF, 0.1µF
IC	555 Timer

Table 6.1 : Components of oscillator circuit

purposes. In our circuit we have this particular combinations of resistors and capacitors connected with the timer IC to get our desired frequency. The 12V DC from the full bridge rectifier circuit is the input for the timer IC that goes to the Vcc and RST pin of the 555 timer IC. Resistors R5 and R2 are in series and connected to the input and DIS pin of the timer. THR and TRI pins are shorted and connected with the R3 and R6. R1, R4 and C1 are in series and connected with the OUT and shorted node of THR. C3,C4, C5 and C6 are in series connected in THR and ground. CON pin is connected to the ground through C2 and GND pin is also grounded. Output is measured from the OUT pin with respect to the ground with the virtual oscilloscope on the Multisim. A virtual multimeter is also connected in series with the oscilloscope to measure the RMS peak of the high frequency pulse wave of the oscillator circuit.

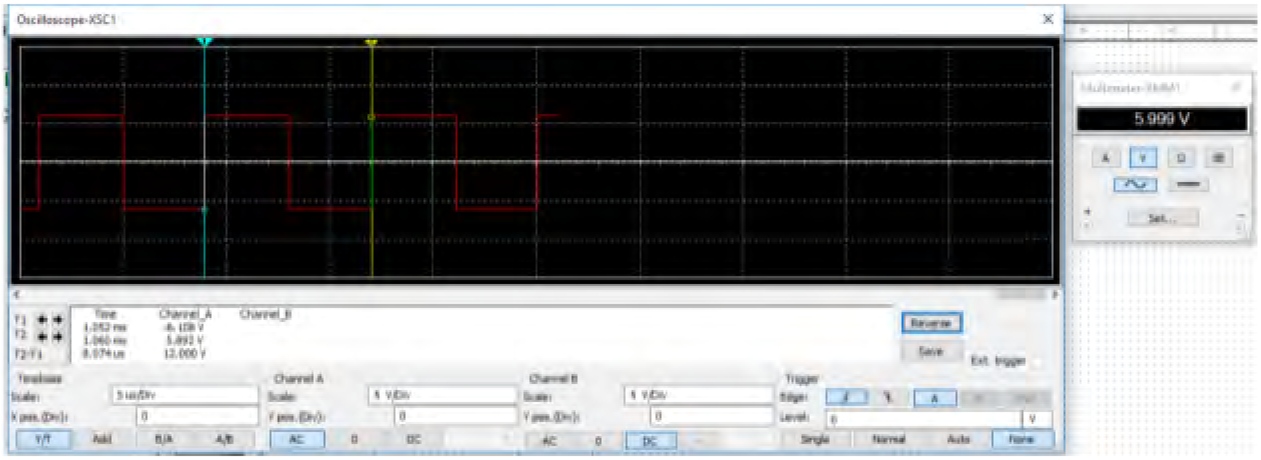


Fig. 6.7 Pulse waveform of the oscillator circuit output in Multisim

Fig. 6.7 is the output pulse waveform of the oscillator circuit simulated in Multisim measures with the virtual oscilloscope. Here in the virtual multimeter we measured the RMS of the peak value is 5.99V AC. Frequency can be calculated from the time period (T) of one cycle. In the virtual oscilloscope, using the cursor function we can measure the starting and end point of a cycle T1 and T2. We measured T2-T1 = 8.074 µs. We know, $f = \frac{1}{\Delta T}$, so with this equation we calculated our frequency, f = 123 kHz (ΔT = T2-T1 = 8.074 µs). This is the simulated result frequency we got in Multisim. We have constructed this oscillator circuit practically and measured the output AC voltage along with frequency. **Fig. 6.8** shows the practical implementation of the oscillator circuit. We have used exactly the same valued resistors and capacitors simulated in Multisim. Basically, we simulated with this combination of resistors and capacitors because of their availability. The timer IC is used to oscillate the voltage and the IC will be described with the inner diagram later in this chapter. **Fig. 6.9** is the output pulse waveform of the oscillator circuit with high frequency in the oscilloscope. Here also in the

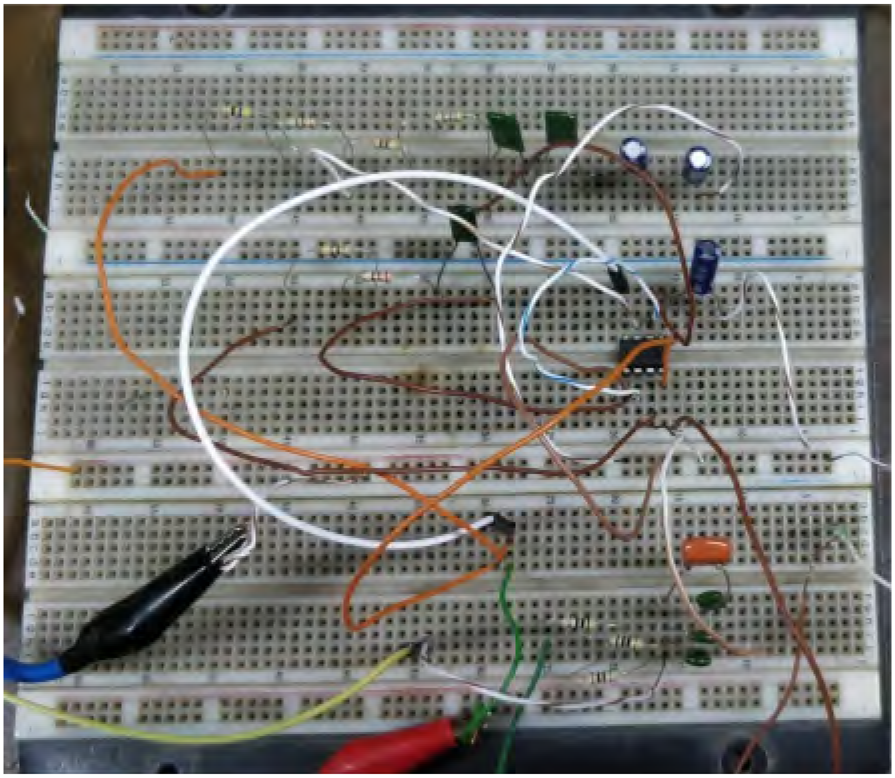


Fig. 6.8 Oscillator circuit setup

oscilloscope, cursor function is used to measure the frequency. Two different methods are used to calculate the frequency, one is from the period (T) of a cycle and another is directly frequency (*f*) and everytime time we got approximately the same result which is, *f* = 123 kHz with 6V peak approximately. This is a square wave we got from the oscillator circuit which can not be used directly in the tesla coil. A filter circuit is needed to make it sinusoidal waveform which will be passed to the tesla coil through a capacitor.

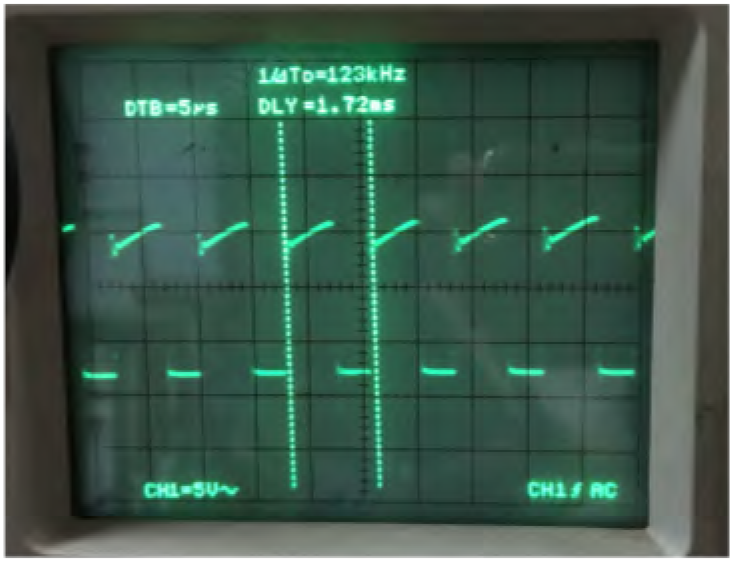


Fig. 6.9 Oscillator circuit output in oscilloscope

This oscillator circuit is designed with a NE555P timer IC. This IC is used to produce various types of output waveform in addition of an external RC circuit. It is very commonly used as it is very cheap, popular and useful device that can be used as either a simple timer to generated a single pulses or long time delays, or as a relaxation oscillator producing stabilized waveform of varying duty cycle from 50 - 100% [22].

This 555 timer is extremely robust and stable 8-pin device that can be operated either as a very accurate monostable, bistable or astable multivibrator to produce a variety of applications. The single 555 timer chip in its basic form is a bipolar 8-pin mini dual-inline package (DIP) consisting of some 25 transistors, 2 diodes and about 16 resistors arranged to form two comparators, a flip-flop and a high current output stage [22]. **Fig. 6.10** shows the NE555P timer IC that is used in the construction of the oscillator circuit for driving the tesla coil. In **Fig. 6.11** the block diagram and the pin configuration of the 555 timer IC is given and will be described the functionality of the individual pins.

Fig. 6.10 NE555P timer IC

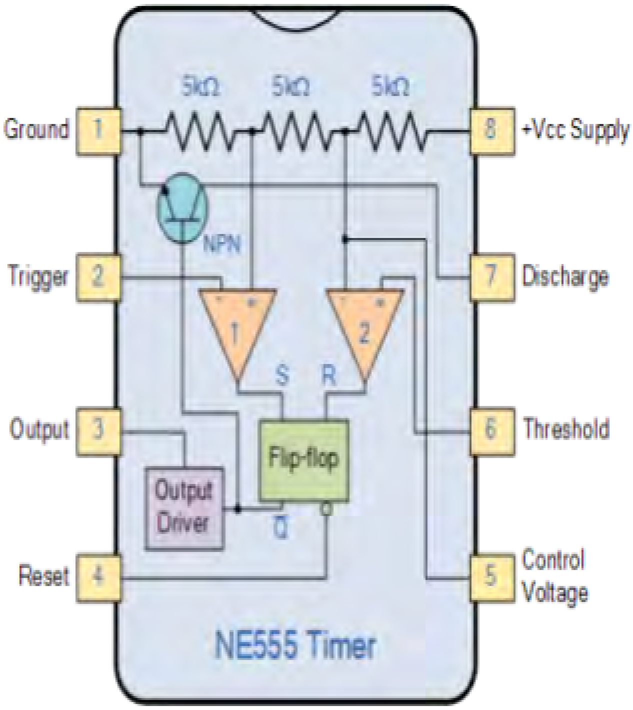


Fig. 6.11 NE555P timer IC block diagram [22]

As the name suggest, the 555 timer gets its name from the three 5 kΩ resistors it uses to generate the two comparators reference voltage. The block diagram of the 555 timer in **Fig. 6.11** is the simplified diagram representing the internal circuitry, a brief explanation of each of its connecting pins will be given to understand batter of its functions.

- Pin 1 - Ground: The ground pin connects the 555 timer chip to the negative (0V) tarminal of the supply.
- Pin 2 - Trigger: It is the negative input to the comparator no.1 in which a negative pulse “sets” (S) the internal flip-flop when the voltage drops below ⅓ Vcc causing the output to switch from a “LOW” to a “HIGH” state.
- Pin 3 - Output: The output is connected to the output driver which is connected to the flip-flop and the base of the NPN transistor and this pin can drive any TTL circuit which is capable of sourcing up to 200mA of current at an output voltage equal to approximately Vcc - 1.5V.
- Pin 4 - Reset: This pin is used to “reset” the internal flip-flop controlling the state of the output at pin 3 as it is connected to the flip-flop. This is an active-low input and is generally connected to a logic “1” when not used to prevent any unwanted resetting of the output.
- Pin 5 - Control Voltage: This pin controls the timing of the 555 by overriding the ⅔ Vcc level of the voltage divider network. Applying the voltage to this pic the width of the output signal can be varied independently of the RC timing network. When not used it is connected to ground via a 10 nF capacitor to eliminate any noise.
- Pin 6 - Threshold: The positive input of the 2nd comparator is in this pin and this pin is used to reset the flip-flop when the voltage is applied to it exceeds ⅔ Vcc causing the output to switch from “HIGH” to “LOW” state. This pin connects directly to the RC timing circuit.

- Pin 7 - Discharge: The discharge pin is directly connected to the collector of an internal NPN transistor which is used to discharge the timing capacitor to ground when the output at pin 3 switches “LOW”.
- Pin 8 - Supply +Vcc: This is the power supply pin and for general purpose TTl 555 timer is between 4.5V and 15V.

In the 555 timer there are three 5 KΩ resistors connected together internally producing a voltage divider network between the supply at pin 8 and ground pin 1, this is why its name is given 555 timer. The voltage across this resistive network holds the negative inverting input of comparator two at ⅔ Vcc and the positive non-inverting input to the comparator one at ⅓ Vcc [22]. The two comparator produce an output voltage dependent upon the voltage difference at their inputs which is determined by the charging and discharging action of the externally connected RC network. The output from both comparators are connected to the two inputs of the flip-flop which in turn produces either a “HIGH” or “LOW” level output at Q’ based on the states of its inputs. The output from the flip-flop is used to control a high current output switching stage to drive the connected load producing either a “HIGH” or “LOW” voltage level at the output pin. The most common and extensive use of the 555 timer oscillator is as simple astable oscillator by connecting two resistor and a capacitor across its terminals to generate a fixed pulse train with a time period determined by the time constant of the RC network and the frequency can also be calculated. The 555 timer oscillator chip can also be connected in a variety of different ways to produce monostable or bistable multivibrator as well as the more common astable multivibrator [22].

The 555 oscillator ia a type of relaxation oscillator for generating stabilized square wave output waveform of either a fixed frequency of up to 500 kHz or of varying duty cycles from 500 to 100% . The 555 timer monostable circuit stopped after a preset time waiting for the next trigger pulse to start over again in order to get then oscillator to operate as an astable multivibrator it is necessary to continuously re-trigger the 555 IC after each timing cycle. This re-triggering is basically achieved by connecting the trigger input, pin 2, and the threshold input, pin 6, together. In this case, the oscillator continuously changes its state from one state to another state. This is how 555 timer create oscillation and generates a high frequency pulse waveform [22].

6.4 Filtered output

The oscillator circuit generates a very high frequency pulse wave at its output pin but tesla coil required a very high frequency sinusoidal waveform voltage. This constructed oscillator circuit using 555 timer, described above, gives us 6V, 123 kHz pulse wave voltage. So, it is required to make this pulse wave to a sinusoidal waveform. We have constructed a RLC low pass filter to make this a sinusoidal waveform. This simple RLC circuit will make this pulse wave to a sinusoidal wave but the frequency will remain constant. The output from this filter will be

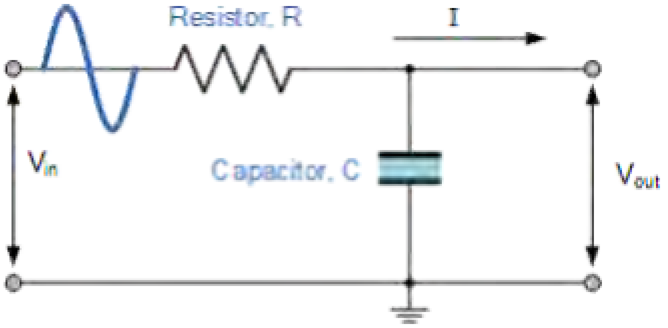


Fig. 6.12 RC filter [24]

supplied to the primary coil of the tesla coil through a capacitor. Designing and the function of a filter circuit is described below.

The RLC low pass filter is consist of resistor, inductor and capacitor connected in series and this name consist of the letters being the usual electrical symbolic representation of resistor, inductor and capacitor respectively. The filter circuits are used to modify, reshape or reject all the unwanted signals with high frequency and only to accept the signals wanted or in other way we can say that it filters out the unwanted signals and ideal filters will separate and pass sinusoidal inputs based upon their frequency. Generally in low frequency application (up to 100 kHz) low pass filter is designed with only resistor and capacitor (RC) and in high frequency case (higher than 100 kHz) it is constructed with resistor, inductor and capacitor (RLC) components. This type of filter is called passive filter as it is constructed with passive components like resistor, inductor and capacitors [24].

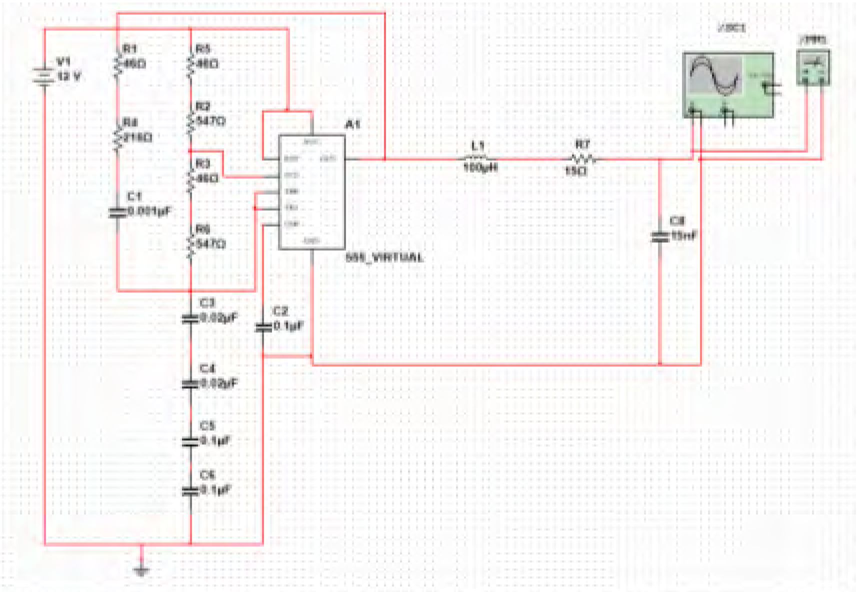
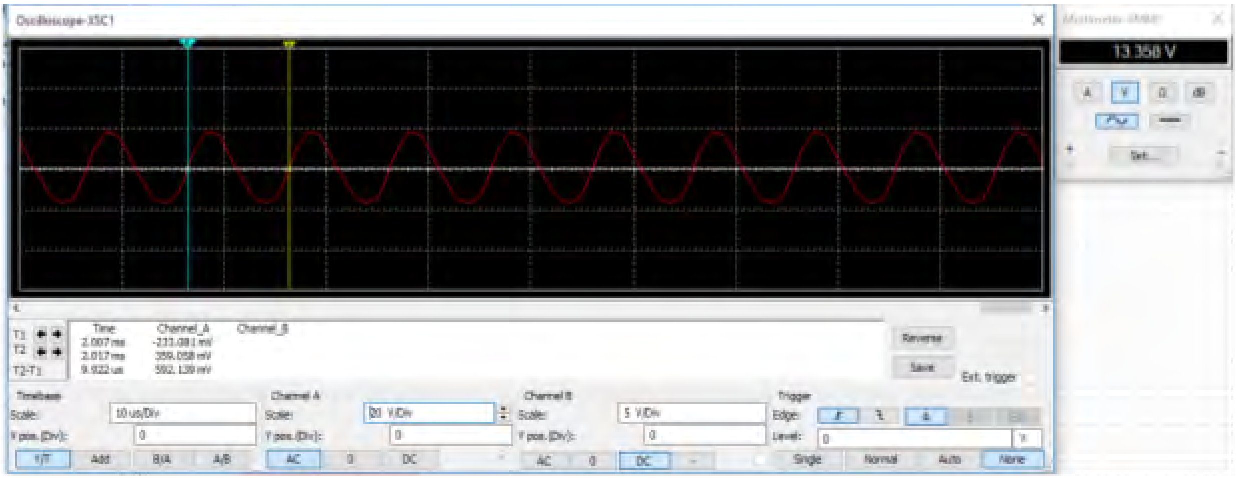


Fig. 6.13 Oscillator circuit with RLC low pass filter schematic diagram

As our constructed oscillator circuit generates 123 kHz frequency which is above 100 kHz and is supplied to the low pass filter to make it a sinusoidal waveform, we need to construct a RLC low pass filter. Here in **Fig. 6.12** shows a RC low pass filter which is required only for below 100 kHz frequency. In low pass filter the filtered output is taken across the capacitor with respect to the ground. We have simulated the whole circuit in multisim where the output from the oscillator circuit is supplied to the RLC low pass filter and then the output is taken across the capacitor shown in the **Fig. 6.13**. The RLC low pass filter is consist of resistor, R = 15 Ω, inductor, L = 100 µH and capacitor, C = 15 nF. These values are chosen to get the best desired result as a output. Using trial and error method we have constructed our low pass filter. The output waveform of the filtered oscillator circuit from the low pass filter is shown in **Fig. 6.14** which is multisim using the virtual oscilloscope across the capacitor. The peak RMS value is 13.358V in the virtual multimeter and the frequency is calculated from measuring the time period of a cycle is the same as measured earlier which is 123 kHz from the oscillator circuit without the low pass filter. The practical circuit set is also done with the same parameters having



13.358 V

	Time	Channel_A	Channel_B
T1	2.007 ms	-233.081 mV	
T2	2.017 ms	359.058 mV	
T2-T1	9.922 us	592.139 mV	

Timebase Scale: 10 us/Div
Timebase Y pos.(Div): 0
Channel A Scale: 20 V/Div
Channel A Y pos.(Div): 0
Channel B Scale: 5 V/Div
Channel B Y pos.(Div): 0
Trigger Level: 0 V

Fig. 6.14 Filtered sinusoidal waveform of oscillator circuit in Multisim the same values and got approximately the same result as simulated result in multisim. The **Fig. 6.15** is the practical circuit setup of the whole oscillator circuit with low pass filter. The output goes to the primary coil of the tesla coil through a capacitor which is a sinusoidal voltage waveform. The input of the low pass filter is from the oscillator circuit which is from the output pin of the 555 timer goes through inductor box then the series connection with the resistor and capacitor with the values mentioned earlier to get the desired output. The output from the low pass filter is measured across the capacitor with the oscilloscope which is shown in **Fig. 6.16**. The peak to peak voltage is measured with the cursor function in the oscilloscope and also the frequency is measured directly from the cursor function and calculate from the time period of one cycle. The peak to peak voltage we got is 38.45V and the frequency is same as before which is 123 kHz in both of the methods. This is the input for the primary coil of the tesla coil as required with a very high frequency for the mini tesla coil.

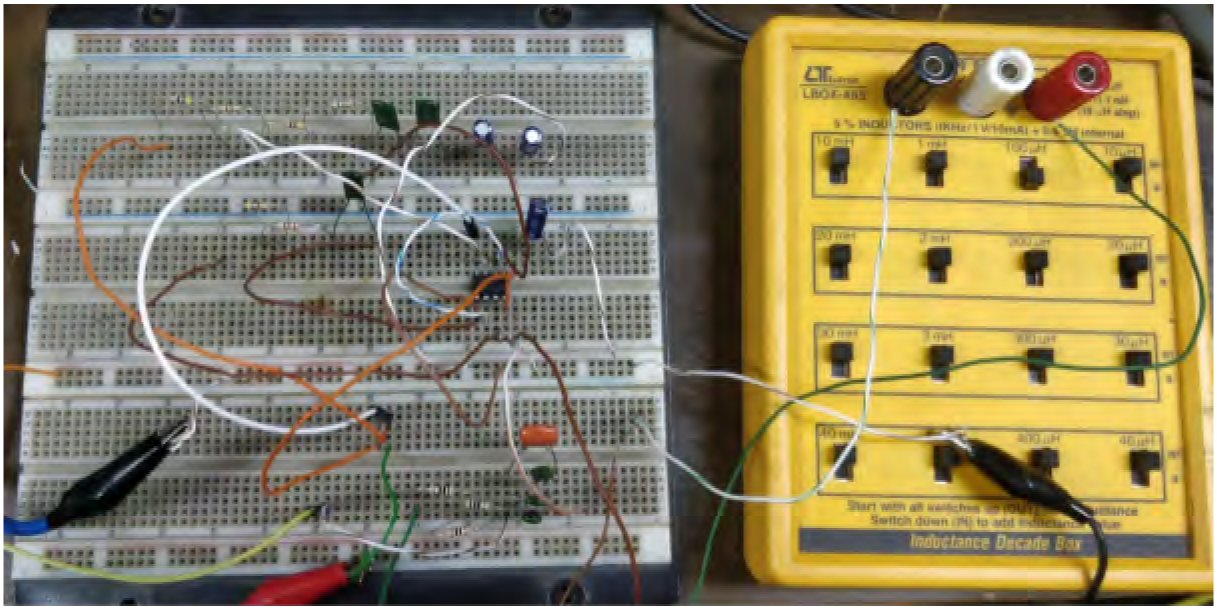


Fig. 6.15 Oscillator circuit setup with low pass filter

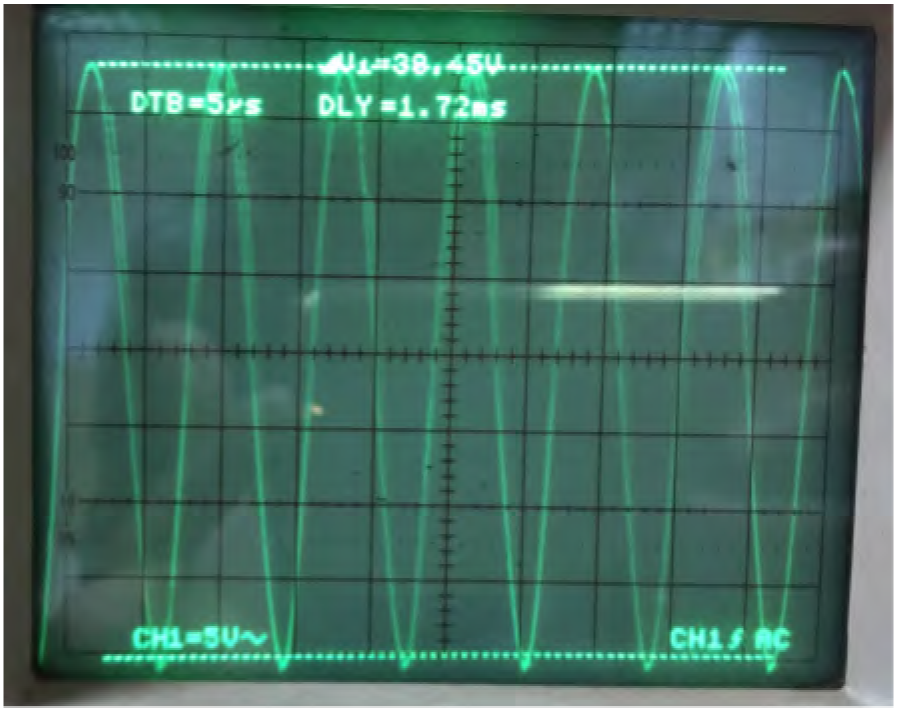


Fig. 6.16 Filtered output waveform of the oscillator circuit in oscilloscope

6.5 Result

To drive the tesla coil it is essential to increase the input frequency of the voltage because a typical medium sized tesla coil requires at least 100 - 300 kHz frequency and the mini or small sized tesla coil requires at least 80 - 100 kHz frequency. As we were constructing a mini sized tesla coil, driving frequency must be approximately 100 kHz. In the simulation process for the oscillator circuit in multisim we got 123 kHz frequency with peak RMS voltage of the pulse wave is 5.99V. In the practical implementation we got the same value for the frequency which is 123 kHz and the peak voltage is 6V approximately. After connecting the filter circuit at the end of the oscillator circuit frequency is same as before 123 kHz and the voltage peak RMS 13.358V in the multisim simulation. In practical implementation, frequency is 123 kHz and the voltage peak was 19V approximately. Al the results we got in simulation and practically is mentioned down below in the **Table: 6.5**.

Simulation result	Practical result
Frequency 123.85 kHz	Frequency 123 kHz
Voltage peak 5.892 V	Voltage peak 8.35 V

Table 6.2 : Simulation vs. practical result of oscillator circuit

Chapter 7

Results

7.1 Introduction

Tesla coil is used for wireless power transfer all over the world. But, to make it work, the frequency has to be more than 50 kHz, otherwise it will not work. There are many ways to increase the frequency. For large tesla coil and large output power, Neon Sign Transformer (NST) is used. The output voltage of NST is 20-30 kV which is used as the input of the primary coil through a primary capacitor. We worked with the mini tesla coil and for mini tesla coil, the input voltage is very low with a high frequency. So, we used oscillating circuit to increase the frequency. The idea of our project based thesis is to transfer power wirelessly, and to get an idea of efficiency. The detailed result is discussed in section 7.2.

7.2 Result analysis

The frequency of our mini tesla coil model was 121 kHz. To measure the output voltage of the secondary voltage, we couldn't use multimeter, because multimeter does not work when the frequency is so high. It gives a voltage rating which fluctuates between 0 - 1V. So, we made a receiver coil which was connected to a full bridge rectifier circuit, to convert the AC output to DC. Then we measured the DC output voltage with a multimeter varying the distance of the receiver coil from the secondary coil. We got output voltage up to 9 inch distance. After that the voltage drops to zero. The voltage we got from the receiver circuit at different distances are given below in the **Table 7.1**.

Distance (Inch)	O/P DC Voltage (V)
0	2.803
1	2.803
2	2.803
3	2.803
4	2.803
5	2.803
6	2.803
7	2.802
8	2.80
9	2.7
9.5	0

Table 7.1 : DC output voltage at different distances

From the table, we can see that, the output voltage is inversely proportional with distance. As the distance increases, the output voltage decreases. At zero distance, the output voltage is maximum. It remains constant up to 6 inch distance. After that, it starts decreasing. The graph from the table is given below:

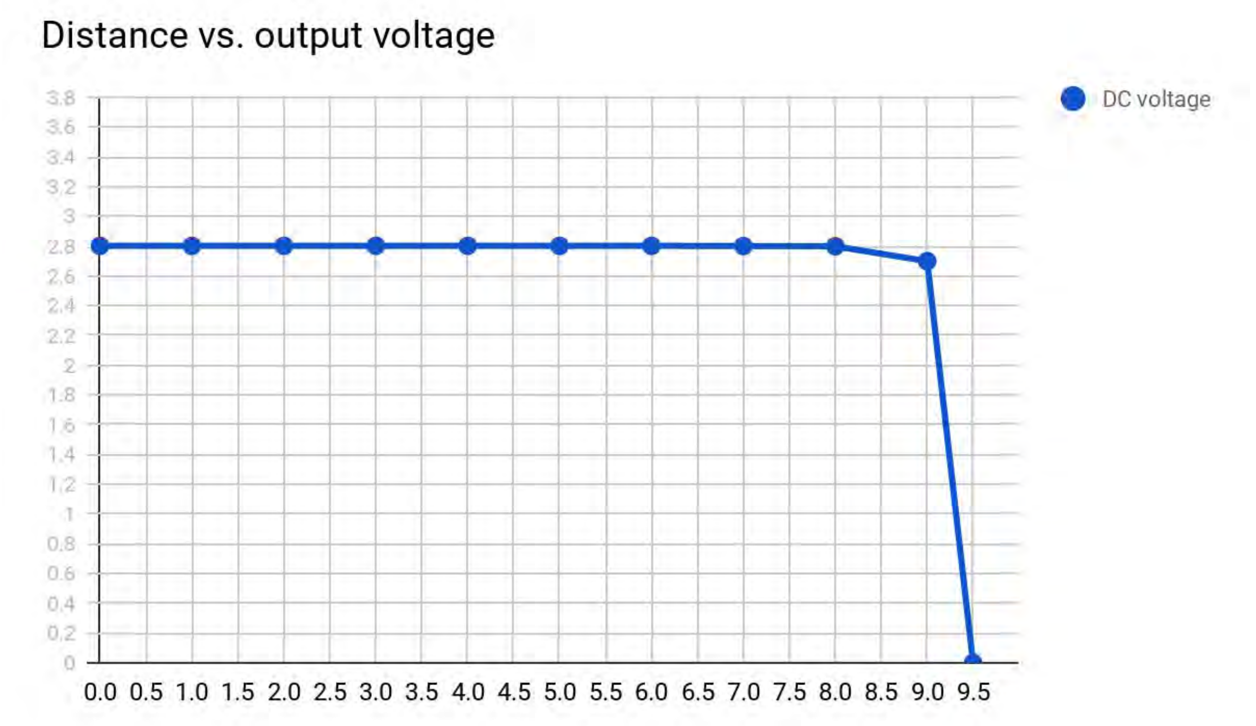


Fig. 7.1 Distance vs output voltage graph

This is the distance vs voltage graph from the table 7.2.1. From the graph, we can see that, when the distance is 0, we get 2.803 volts. Then, up to 9 inch distance, the voltage curve is almost linear. Then suddenly after 9 volts, it starts decreasing rapidly and at 9.5 inch distance, the voltage goes to zero. So, from the overall discussion and the table and also the graph,we can say that the range of our tesla coil is 9 inch.

7.3 Power calculation

In our proposed wireless power transfer system, the input is given through a step down transformer. So the input power must be calculated from the transformer. We know from the basic concept of transformer that is the power is constant in the both of the sides of transformer. In transformer the voltage is stepped up or down altering the current. From the power calculation formula,

$$P = VI\cos\boldsymbol{\theta}$$

That means, voltage, V is inversely proportional to the current, I. So, in step down transformer the voltage is stepped down and rising the current to maintain the power constant. The power in the primary side is the same as the power in the secondary side even if the voltage is either stepped up or down. Thes, if any one desire to calculate power for a transformer, they can either measure power from the primary side or from the secondary side, both of the cases they will get the exactly same result and either way is correct. We calculated the input power from the

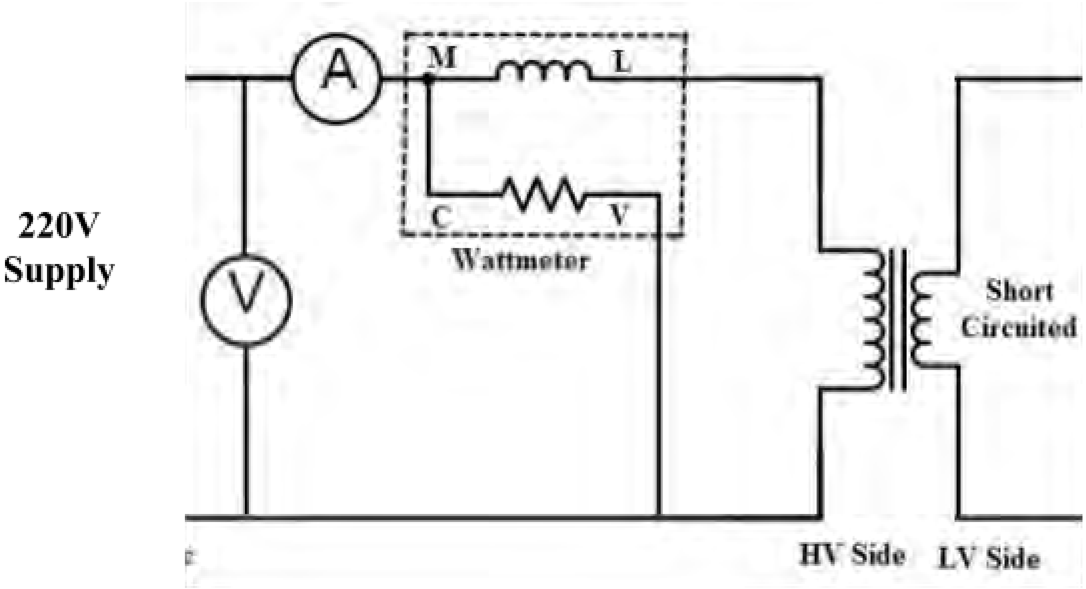


Fig. 7.2 Wattmeter connection to the transformer [30]

primary side of the transformer. We connected the wattmeter in the primary side of the transformer like in **Fig. 7.2**. The wattmeter was shorted as required before connecting to the transformer. The wattmeter gave the reading of P_{in} = 2 watt power at the input side. **Fig. 7.3** is the reading of the wattmeter measuring the input power.

Fig. 7.3 Wattmeter reading of input power

We measured the output voltage from the receiver circuit, across the LED connected to the full wave rectifier circuit. We measured the current across the LED as well. The maximum output voltage we got is 2.803V. So, with 2.803V DC the LED draws 10 mA of current. **Fig. 7.4** is the DC ammeter reading of output current drawn by LED at the full bridge rectifier. The maximum output power we got is,

P_{out} = VI

= 2.803×0.01

= 0.02803 watt

So, the maximum output power we got wirelessly is 0.02803 watt. The output power is very low, as there is a power loss in the receiver coil, across the diodes used in the rectifier circuit. There is a power loss across each component of the oscillator circuit as well. As a result, we got very low output power, just enough to light up LEDs. The maximum power loss is through the air during the transmission wirelessly. In large scale wireless power transfer system, large tesla coils are used where oscillating circuit is replaced by neon sign transformer. As a result, no power loss across the neon sign transformer. So, the output power is much higher.

Fig. 7.4 Ammeter reading of output current

7.4 Efficiency

Efficiency means the ratio of the useful work performed by a machine or in a process to the total energy expended or heat taken in [31]. In our proposed wireless power transfer system, efficiency indicates how well we could deliver power wirelessly.

Our input power was 2 watt and the output power from the receiver circuit was 0.02803 watt. So, the overall efficiency is,

N = (0.02803/2*100)%

= 1.4%

The efficiency we got from our proposed wireless power system is very low. But, there are some ways which we found out from the research and practical experiment.

First of all, the input power we used is very low. As we worked with the mini tesla coil, we used oscillating circuit to increase the frequency. There is a loss in every equipment of the oscillating circuit. But, if we go for large scale wireless power, we have to make a large tesla coil. In large tesla coil, neon sign transformer is used, and the output voltage of the transformer is 15-30 kV which is used as the input to the primary tesla coil. More importantly, no power loss occurs across the transformer [25].

Secondly, in large tesla coil, spark gap is used in between the neon sign transformer and primary coil of the tesla coil [25]. Capacitor bank is also used with the primary coil. Topload works as the secondary coil capacitor to match resonance [25]. We didn’t use any of this things in our mini tesla coil circuit.

Another important parameter is the turns ratio. For large tesla coil, higher turns are used in the secondary coil. The ratio of the primary coil and secondary coil is normally 1:100 [25].

Moreover, we measured the output across the LED from the rectifier circuit which was connected with the receiver coil. As a result, there was power loss across each component of the receiver circuit, an air loss in between the secondary coil of the tesla coil and the receiver coil.

For large scale wireless power transfer, we have to make the whole circuit in a different way, and the large tesla coil circuit diagram is given below:

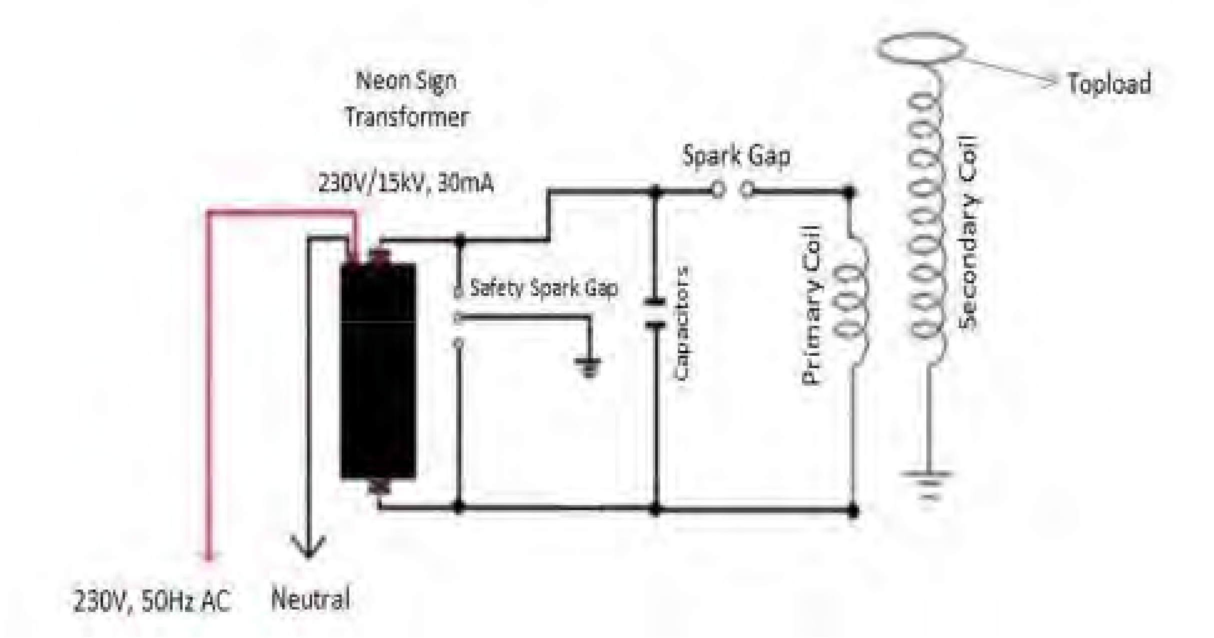


Fig. 7.5 Large tesla coil cct diagram [25]

This is the circuit diagram of a large tesla coil, with a higher efficiency and higher range as well. In this way, we will develop our design and increase the efficiency.

Chapter 8

Conclusion and Summary

8.1 Summary

The proposed wireless power transfer using tesla coil showed a promising result as our main intention was to develop a wireless power transfer system. We got some output voltage to the receiver coil at a distance up to 9 inch which drops at 9.5. We converted the output power from AC to DC and finally were able to light up an LED. We used mini tesla coil for this experience and found that it is possible to transfer more power to a longer range using large tesla coil.

The oscillating circuit was the main part of this experience. We have to increase the frequency more than 50 kHz to make the tesla coil work. The efficiency of wireless power transfer mostly depends on the capacitor values of the oscillating circuit. The simulation part shows that, if we change the capacitor value, the frequency changes and with higher frequency, we can transfer more power wirelessly to higher distances. This indicates that the efficiency and the range can be improved.

The experimental result shows very good agreements with the theoretical background. If we increase the number of turns of the secondary coil, both the efficiency and the range increase. We used 600 turns for our experiment. Turns can be used 900,1000 or more to get better result so that the proposed model can be used in practical applications.

8.2 Limitations

The major problem of wireless power transfer using tesla coil is, the efficiency is inversely proportional to the distance. As a result, it can transfer very low power at higher distances. So, the overall efficiency is low.

Measuring the output voltage is another problem we faced. As the frequency is more than 50 kHz, the multimeter does not work properly. The output voltage rating from the multimeter fluctuates from zero to one volt. The main problem is that, the output is pulsed. So, using an oscilloscope will not be appropriate. Using a voltage divider, we can get the output from the oscilloscope or multimeter [27]. The receiver coil should be in proper alignment to get maximum power at the load.

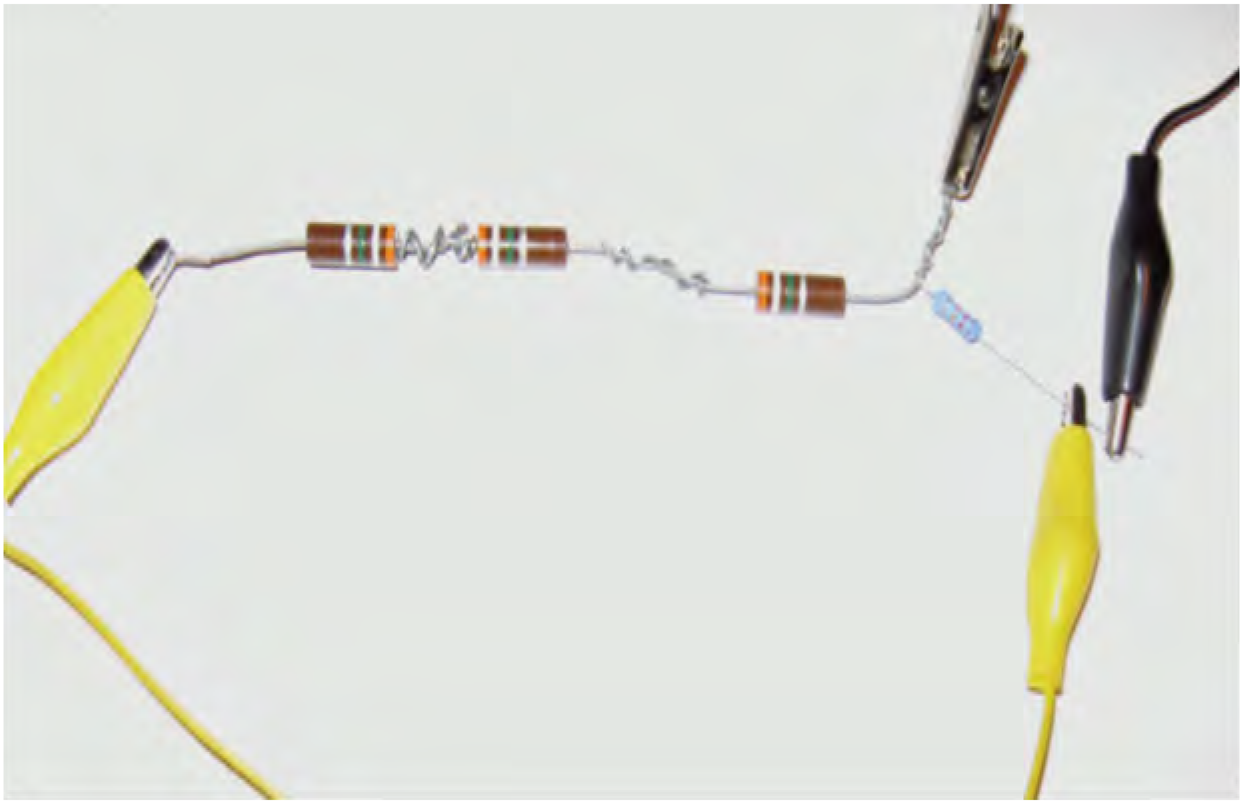


Fig. 8.1 Output measurement using voltage divider [27]

Another major problem of wireless power transfer is, all devices, which are in the range of the tesla coil, will act as a receiver and draw a load. Every device, which will be charged wirelessly, should have built in over current protection as the current in the air will be high enough to transfer power efficiently [32]. The wireless system is easy and safe, comparing to the previous system. But, it is costly. Our body can resist to low frequency voltages which can harm us our life to death. As tesla coil operates at a very high frequency and produces even more higher frequency which our body can not resist and doesn't harmful at all. So it can be said that tesla coil has no health hazard.

8.3 Proposed Researching Infrastructure

We got a promising result from our proposed wireless power transfer using tesla coil. However, the efficiency is low. We propose to develop the model to increase the efficiency and the range. Our main target is to charge electric vehicles wirelessly and to minimize the charging time. Fast charging is another feature we want to include in our future development. The oscillating circuit we made will be modified so that we can get higher frequency and get the maximum power induced from the primary coil to the secondary coil. Changing the capacitor values of the oscillating circuit will be the initiative to increase the frequency. Another improvement that we will work on is the primary and secondary coil and the number of turns. From our practical experiment and theoretical research, we found that if we increase the number of turns of the secondary coil, we will get more output voltage. Another thing is the type of coils. To make larger tesla coils, different wires are used to get the maximum induction in the secondary coil. Our main target area of research is the on road charging for electric vehicles.

When the electric vehicles are moving on the road, it will recharge automatically. For this system, the efficiency and the range of tesla coil have to be increased. There will be a receiver connected with the battery of the electric vehicle. It will receive the transmitted power from the secondary coil via magnetic resonant induction. Our final goal is to support the green energy system. So far, the main electric power sources are burning fossil fuels, water and wind. These systems are polluting environment. We want to generate electricity using solar panel and build the model of large scale wireless transmission grid. If we can develop the on road charging system for electric vehicles, than it will be a great achievement toward the green energy system.

Fig. 8.2 Largest solar power plant [37]

Vehicles, which run by burning fuels, will be replaced by electrical vehicles and as a result, emission of carbon-dioxide and other greenhouse gas will be reduced. But, wireless transmission grid requires high voltage, 25-30 kV as the input of the tesla coil. So, the solar panel should be large enough to be able to supply the required input voltage. This is the largest solar power plant of the world, known as the “Great Wall of Solar” in china. It covers 1200 km and the capacity of this plant is 1500 MW [37].

If we can implement large scale wireless power transmission grid for this kind of large solar plants, we will be able to support the green energy system and will be able to make this world a better place for living.

8.4 Future work

Wireless power transfer has a very promising future. We will be over ambitious if we say that wireless power transfer will be used in the transmission grid because, first of all, it will cost a lot to plant this system. Secondly, maintaining transmission schedule of wireless power transfer will be tough. Thirdly, all devices should have built in protection.

But, in the near future, on road wireless charging for electric vehicles will be introduced. Electric cars will get charged up while moving through the road. There will be a receiver at the bottom of the electric vehicle, which will receive power through magnetic induction from the road and the road will be modified in such a way that it will deliver power from the tesla coil.

Another way of this on road charging is, wireless power will be transferred from beams, which will be located at the side of the road. This time, the receiver will be placed at the top of the electric vehicle. Each beam has its range. When an electric vehicle comes in the range of a beam, the receiver of that car will receive power from that beam. The beams will be placed in such a way that, when an electric vehicles moves out of the range of a beam, it will be in the range of another one. So, it will be getting power consistently through the road.

Fig. 8.3 On road charging for electric vehicles [33]

Normal devices will be replaced by devices with the feature of wireless charging system. People will be more dependable on these devices.

Devices like mobiles and laptops will get charged up while being used. People do not have to be tensed about the charging issue of these devices anymore. It will be time saving and less hazardous for people. Moreover, the charging will be faster.

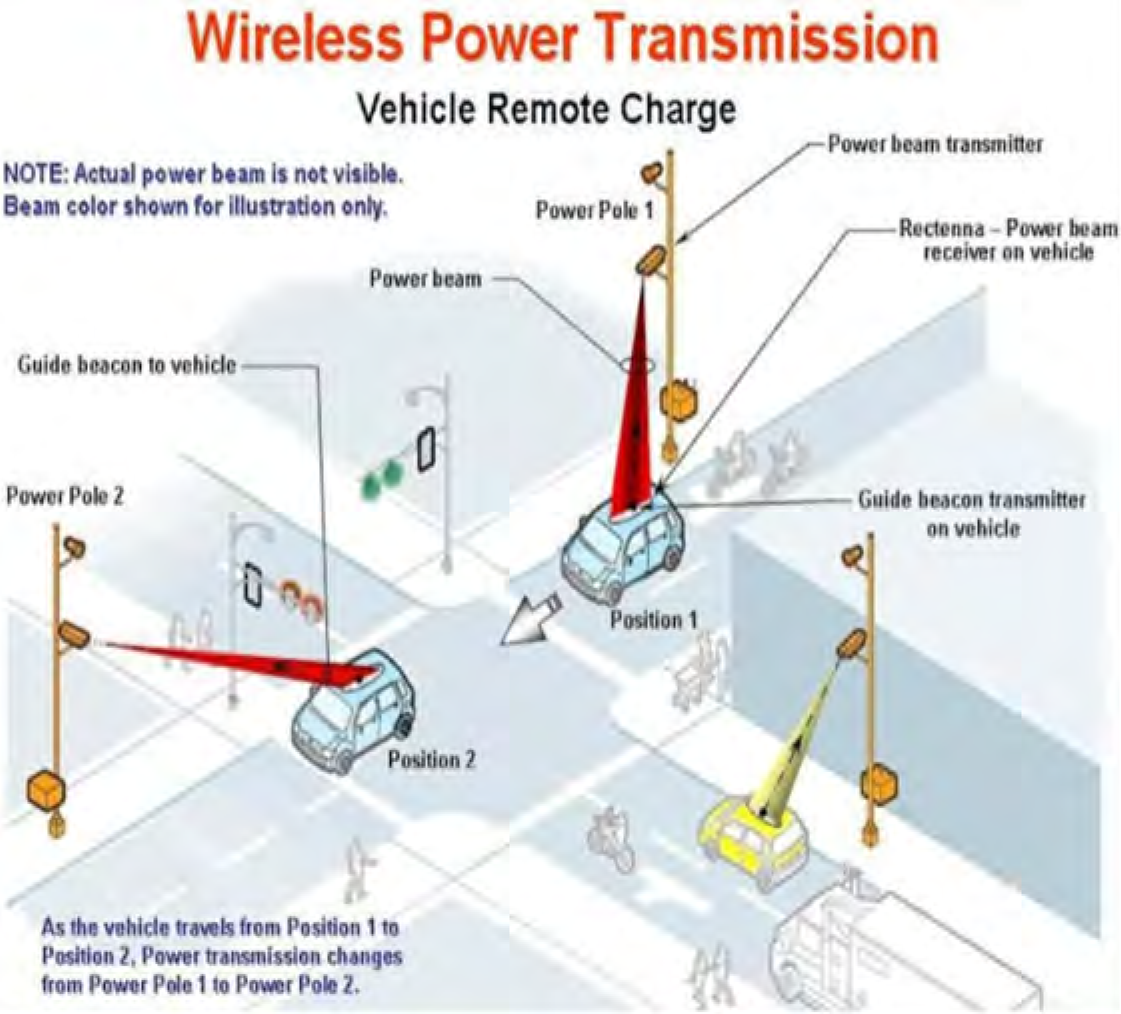


Fig. 8.4 On road charging for electric vehicles [36]

The whole lifestyle will be changed. Life will be more easy and comfortable for people. Wireless power transfer is safe because it prevents physical contact of people with wires.

Industry will be more likely to produce products which will be tuned to consumption and utilization of wireless power.

Fig. 8.5 Wireless mobile charging [35]

8.5 Conclusion

The proposed thesis based project was to deliver power wirelessly. Our research and practical implementation showed positive results. We were able to transfer power wirelessly and the efficiency was 1.4% which is very low. But, from the research, we found that, the efficiency can be increased. As the output power is inversely proportional with the distance, it is very much challenging to improve the efficiency. Many research is going on to improve the efficiency.

This project shows many promises to the green energy system. But, to do so, we have to increase the efficiency first. If we can develop this design to get a high enough efficiency, we might be going for the large scale wireless power transmission grid, which was the dream of Nikola Tesla when he first invented tesla coil. Though it seemed that, he was a bit over ambitious at that time, recent research results shows that, it can be possible.

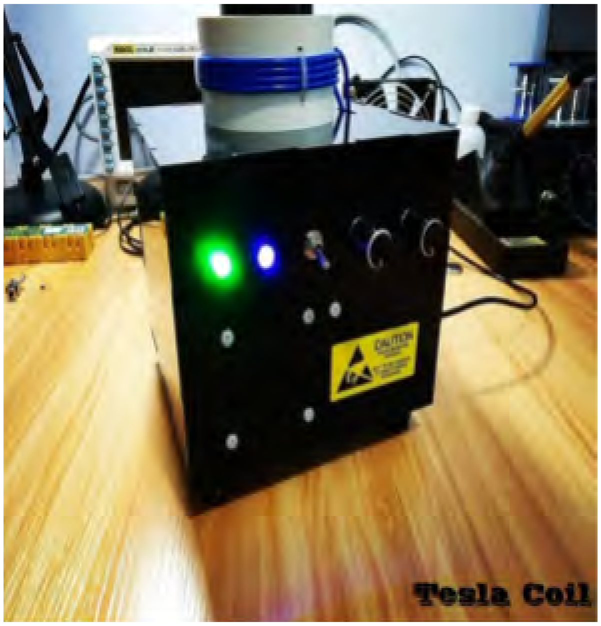


Fig. 8.6 Devices having wireless charging system [34]

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APPENDIX

Appendix A

Block Diagram

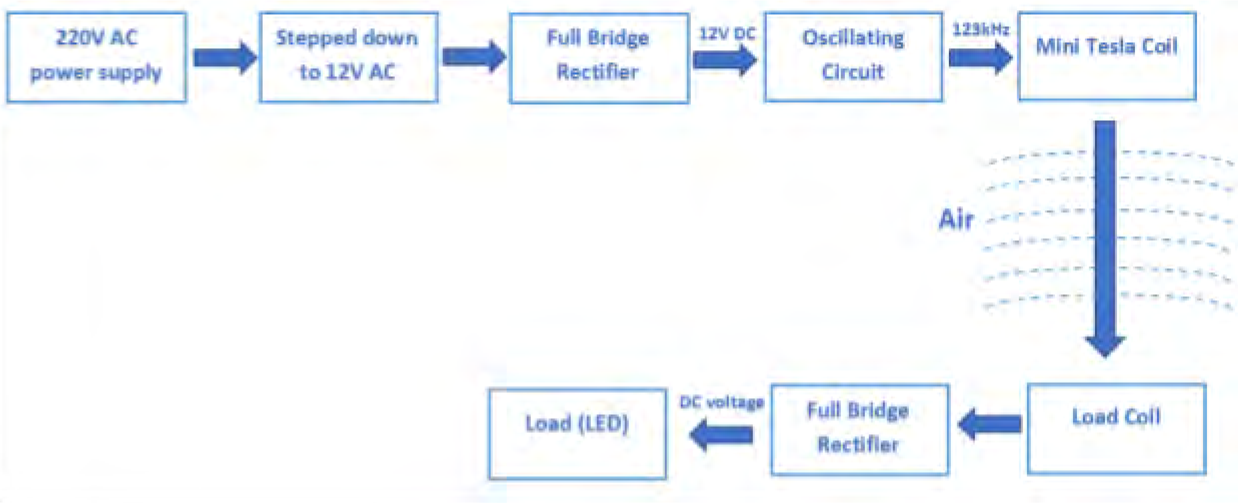


Fig. Block diagram of the overall system

Appendix B

Schematic Diagram

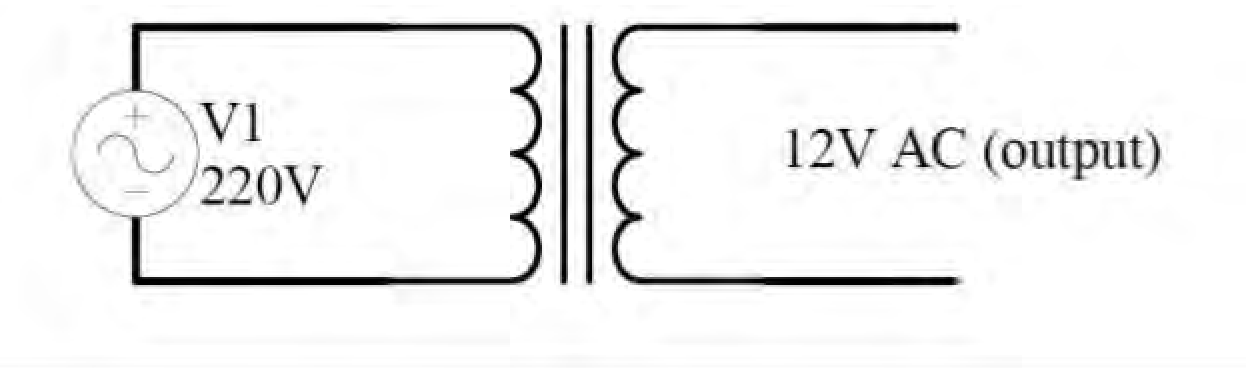


Fig. Step down Transformer

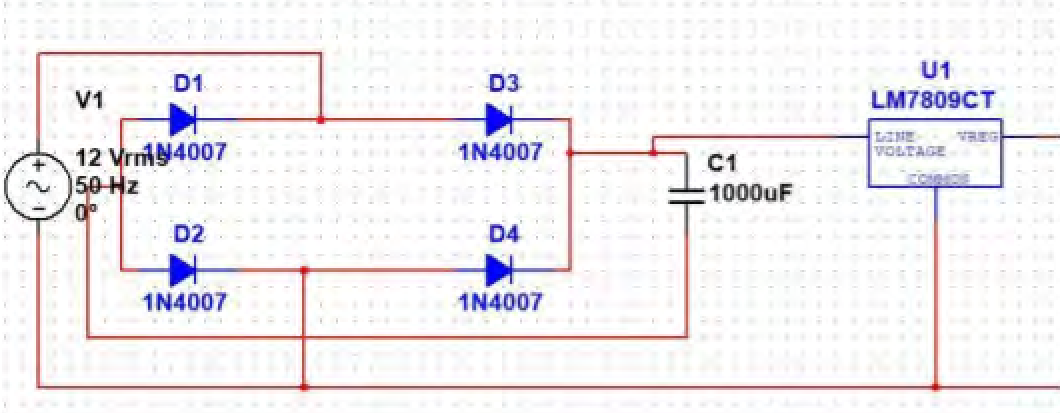


Fig. Full Bridge Rectifier

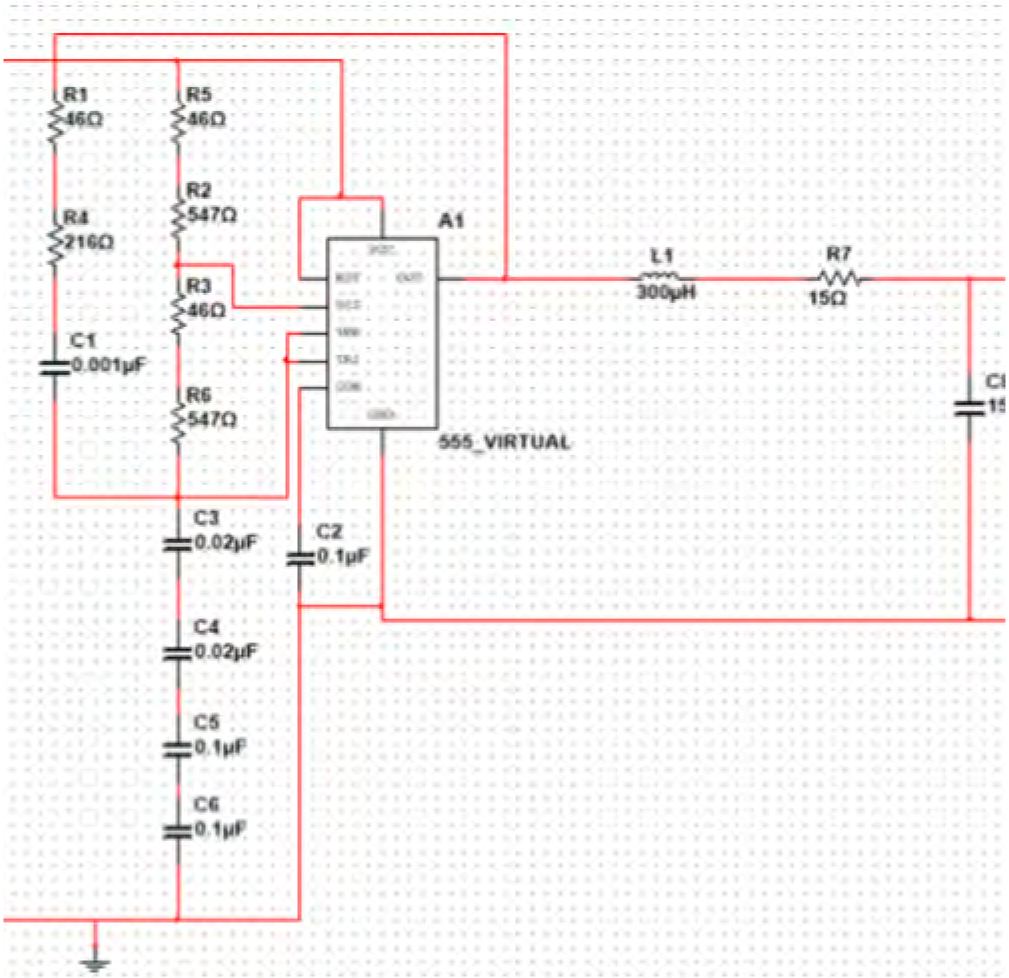


Fig. Oscillator Circuit with Low Pass Filter

Fig. Primary Capacitor

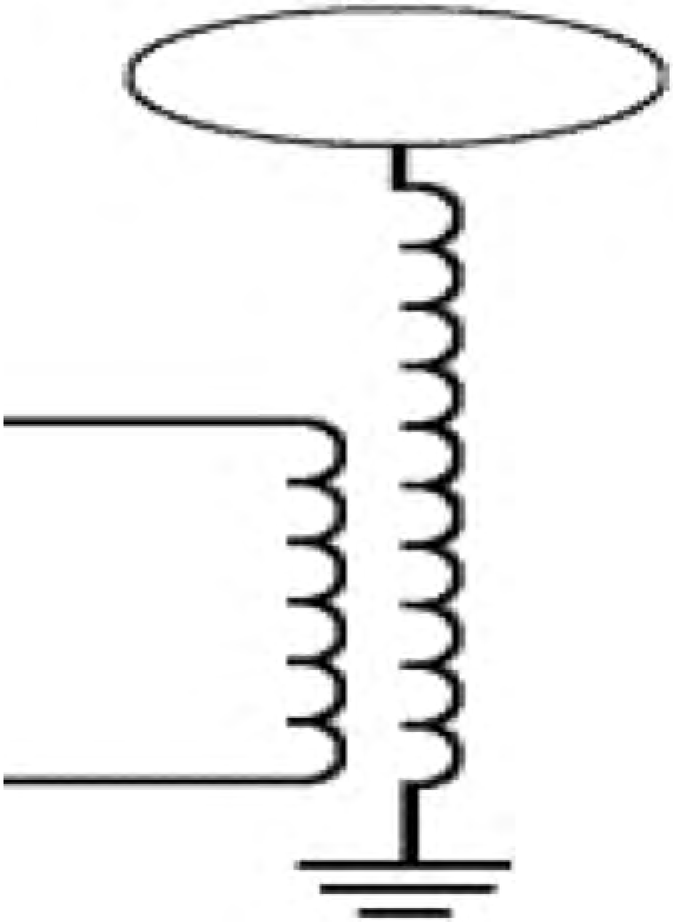


Fig. Mini Tesla Coil

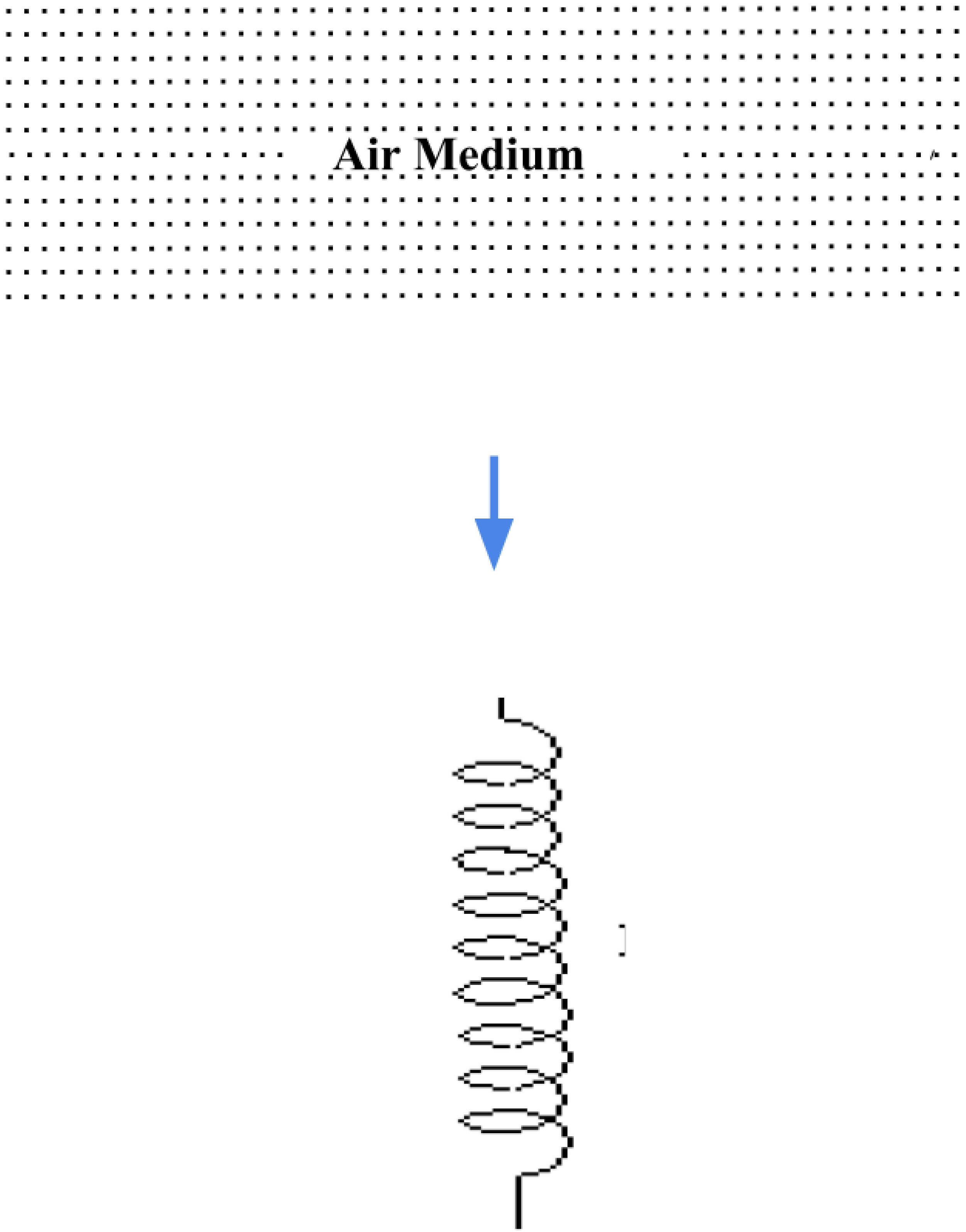


Fig. Load Coil

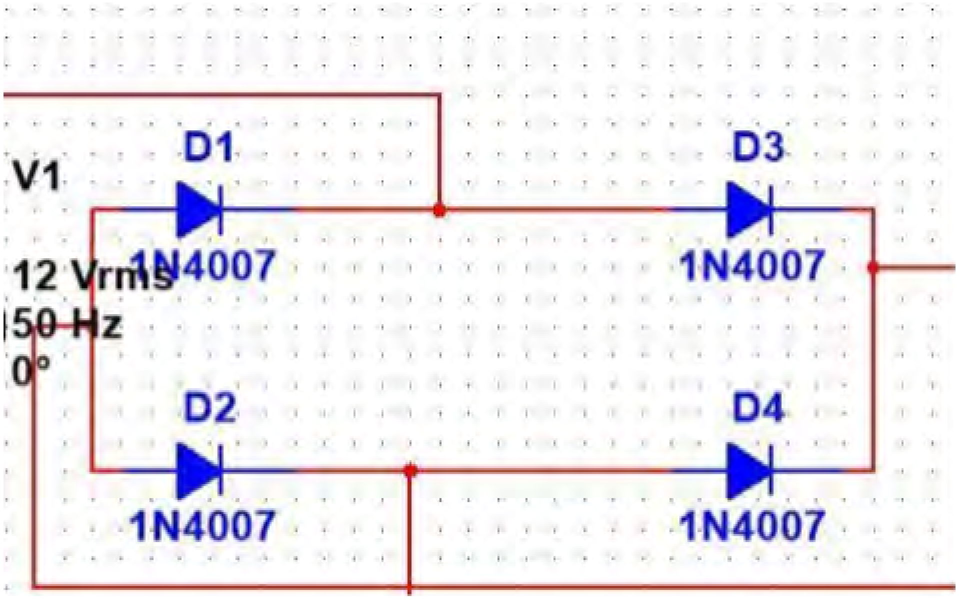


Fig. Full Bridge Rectifier

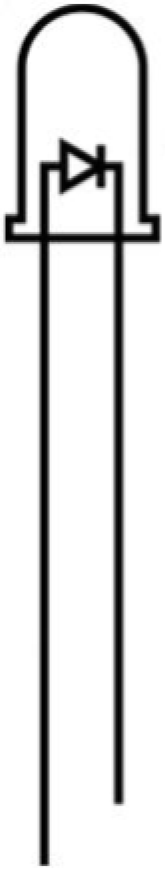
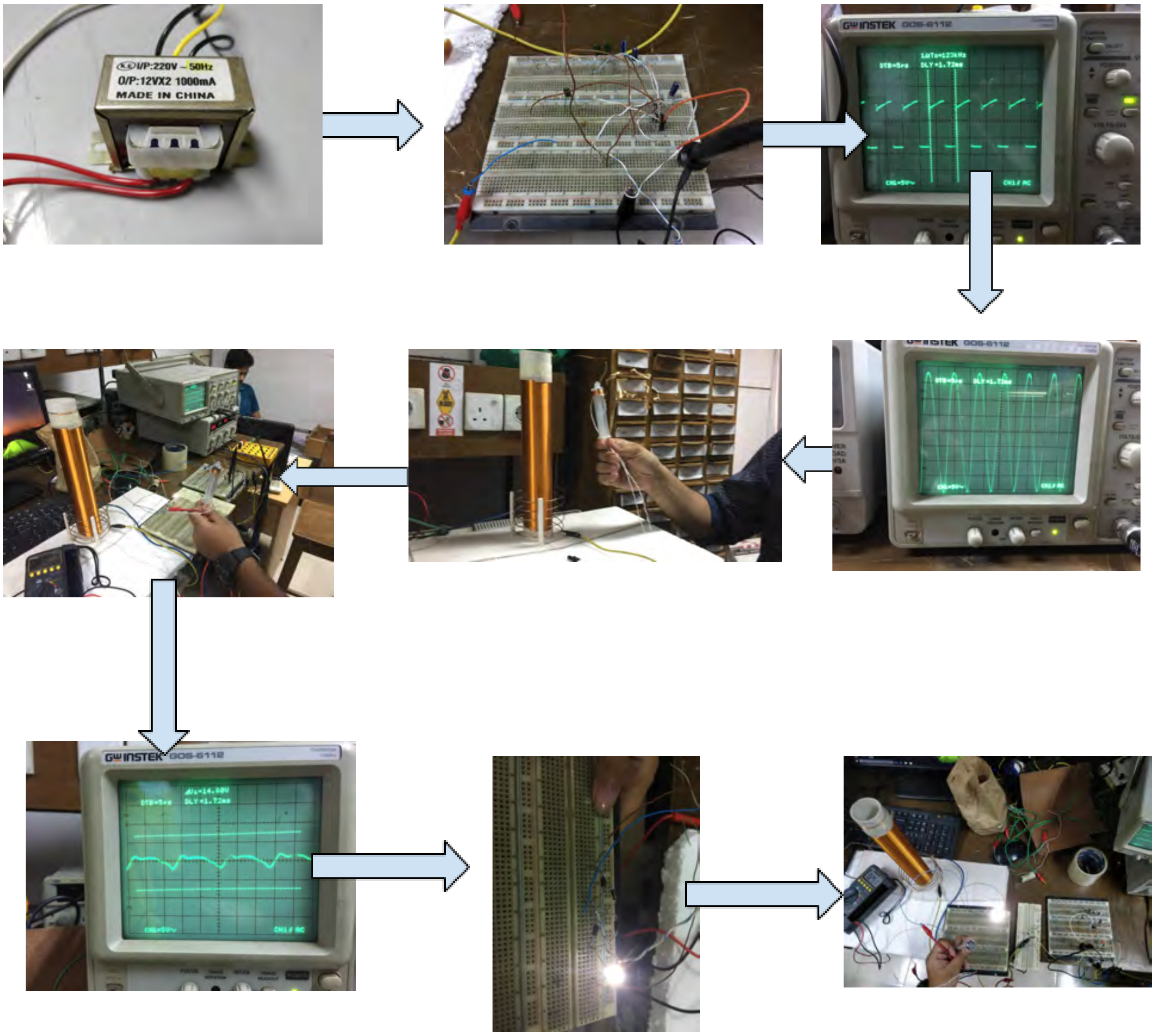


Fig. Light-emitting diode

Appendix C

Chronological Development of Mini Tesla Coil



Appendix D

The Tesla Coil at a glance

Fig. Experimental setup of the overall project

Appendix E

Components

The Step down transformer

Fig: Step down transformer

Step down transformer has been used to convert the 220V ac into 12V ac. One black wire is connected to the oscillator circuit and yellow wire is connected to ground. It supplies 12V ac voltage to the oscillator circuit.

555 Timer IC

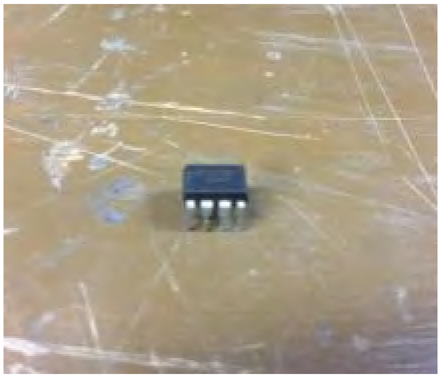


Fig: 555 Timer IC

This IC is used for pulse generated signals. It is an 8 pin configuration IC and without this chip, the oscillator circuit cannot perform properly as it will not generate pulse signals. Without these pulse signals, the oscillator circuit will not work. This IC is also known as the driver of the oscillator circuit.

Oscillator Circuit

Oscillator circuit has been used to increase the frequency from 50Hz to 123kHz. The reason for using oscillator circuit in our project is that the resonant frequency of the coils should be 60 kHz to 100kHz or more than it.

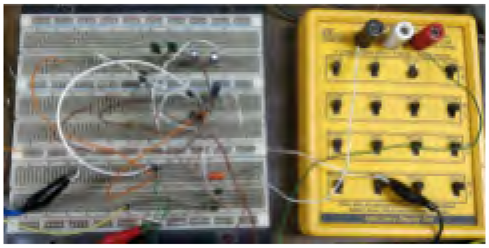


Fig: Oscillator circuit

Primary Coil

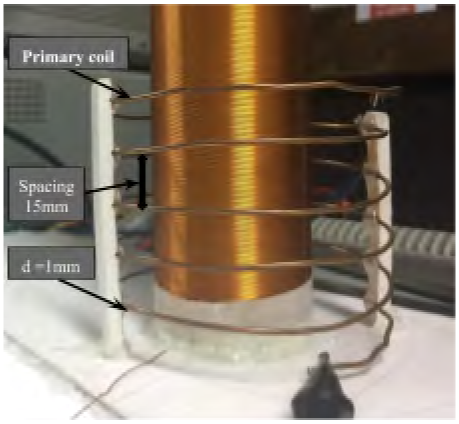


Fig: Primary Coil

The output of the oscillator circuit is given as the input of the primary coil. The primary coil is nothing but a copper tube with a diameter of 1mm. It has 5 number of turns and 15mm spacing. The purpose of using the primary coil is to induce the voltage in the secondary coil.

Secondary Coil

The secondary coil, according to the number of turns perform differently. The primary coil induces voltage to the secondary coil. The secondary coil steps up the voltage and this voltage is received by the load coil. Without the secondary coil, the wireless power transfer cannot be possible specially for the stepping up of the voltage.

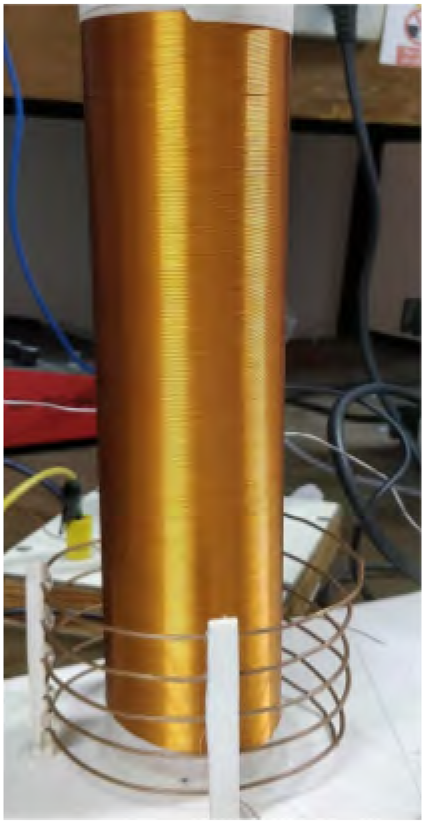


Fig: Secondary Coil

Load Coil

The tesla coil creates magnetic field and this high frequency magnetic fields are to be received by the load coil. To convert the received magnetic field to a usable form, load coil is a mandatory.

Fig: Load Coil

Primary Capacitor

In parallel with the primary coil, there is a capacitor. It is also necessary to use this capacitor.

Fig: Primary Capacitor

Appendix F

Datasheet

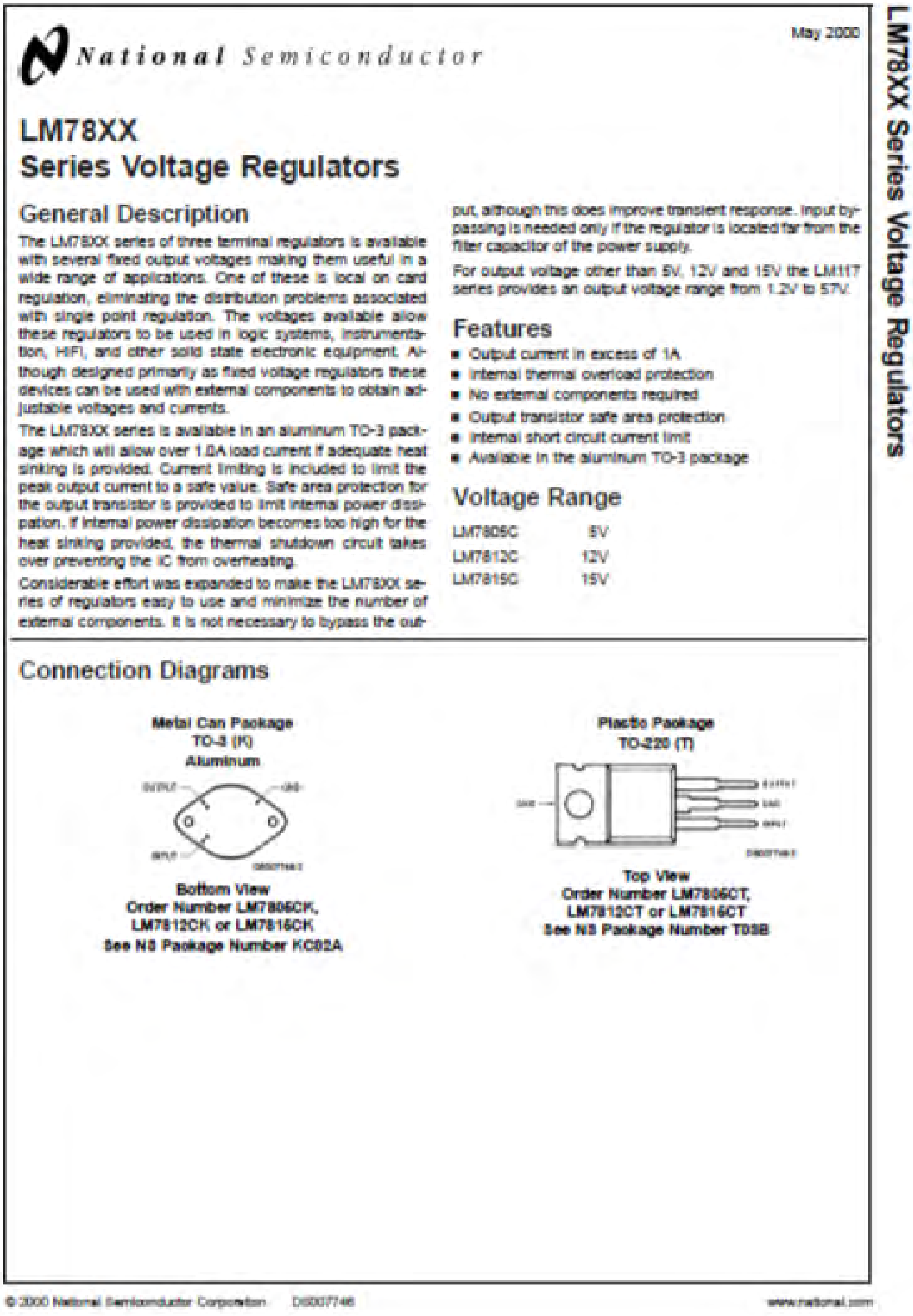
LM78XX Series Voltage Regulators

General Description

The LM78XX series of three terminal

Specifications

Product Attribute	Attribute Value	Search Similar
Manufacturer:	Texas Instruments	☐
Product Category:	Linear Voltage Regulators	☑
RoHS:	N	
Mounting Style:	Through Hole	☐
Package / Case:	TO-220	☐
Number of Outputs:	1 Output	☐
Polarity:	Positive	☐
Output Voltage:	12 V	☐
Output Current:	1 A	☐
Output Type:	Fixed	☐
Input Voltage MAX:	35 V	☐
Minimum Operating Temperature:	0 C	☐
Maximum Operating Temperature:	+ 70 C	☐
Load Regulation:	120 mV	☐
Line Regulation:	120 mV	☐
Quiescent Current:	8 mA	☐
Series:	LM340-N	☐
Packaging:	Tube	☐
Brand:	Texas Instruments	
Dropout Voltage - Max:	2 V	
Factory Pack Quantity:	45	
Unit Weight:	0.081130 oz	



National Semiconductor

May 2000

LM78XX
Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum

Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)

Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

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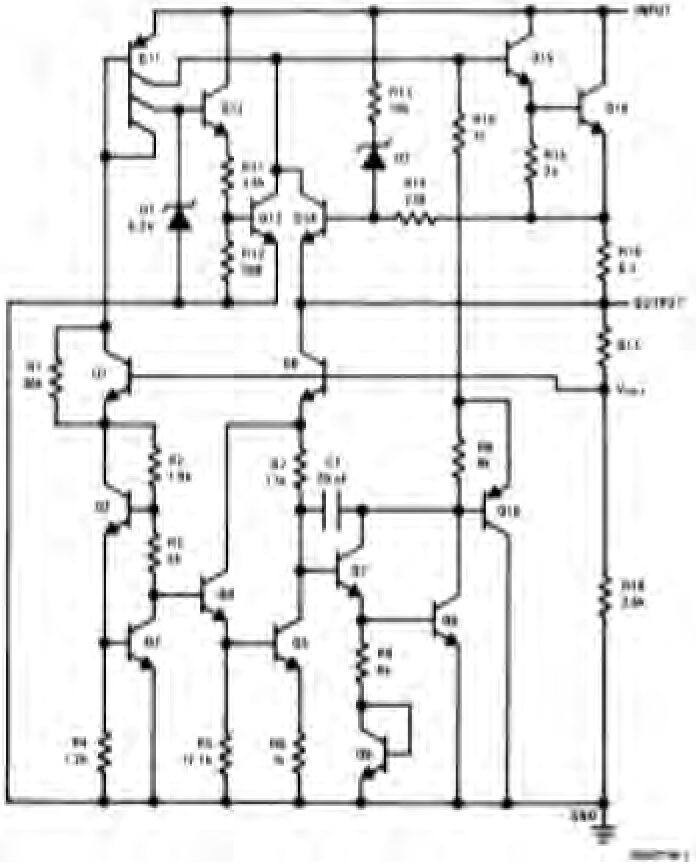
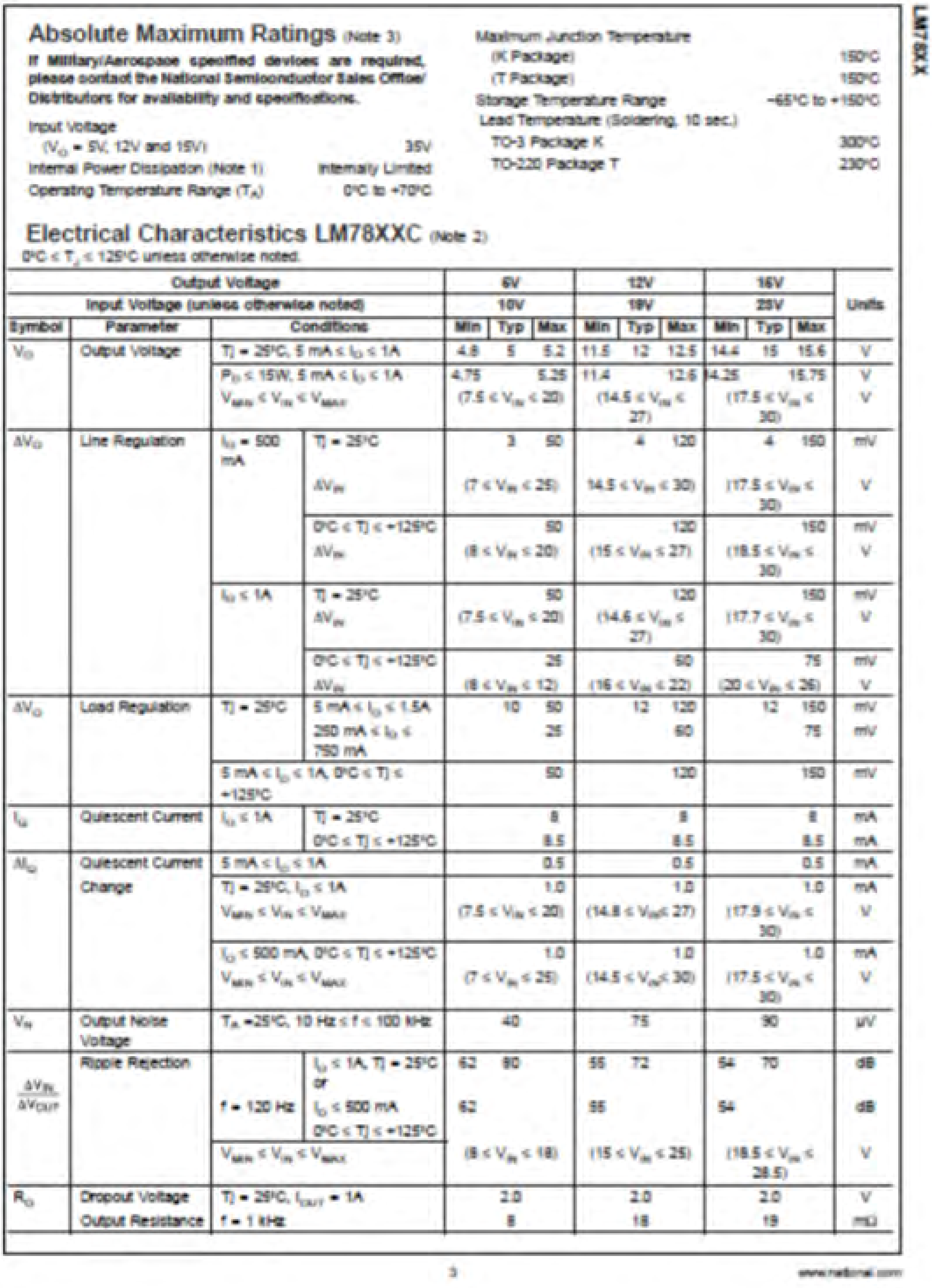
LM78XX Series Voltage Regulators

Schematic





LM78XX

Absolute Maximum Ratings (Note 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

Output Voltage				5V			12V			15V			
Input Voltage (unless otherwise noted)				10V			19V			23V			Units
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	T_J = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)			V
ΔV_O	Line Regulation	I_O = 500 mA	T_J = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}	(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
			0°C ≤ T_J ≤ +125°C			50			120			150	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 1A	T_J = 25°C			50			120			150	mV
			ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)			V
			0°C ≤ T_J ≤ +125°C			25			60			75	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)			V
ΔV_O	Load Regulation	T_J = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ T_J ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	T_J = 25°C			8			8			8	mA
			0°C ≤ T_J ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		T_J = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 500 mA, 0°C ≤ T_J ≤ +125°C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
V_N	Output Noise Voltage	T_A =25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, T_J = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0°C ≤ T_J ≤ +125°C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)			V
R_O	Dropout Voltage	T_J = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

3

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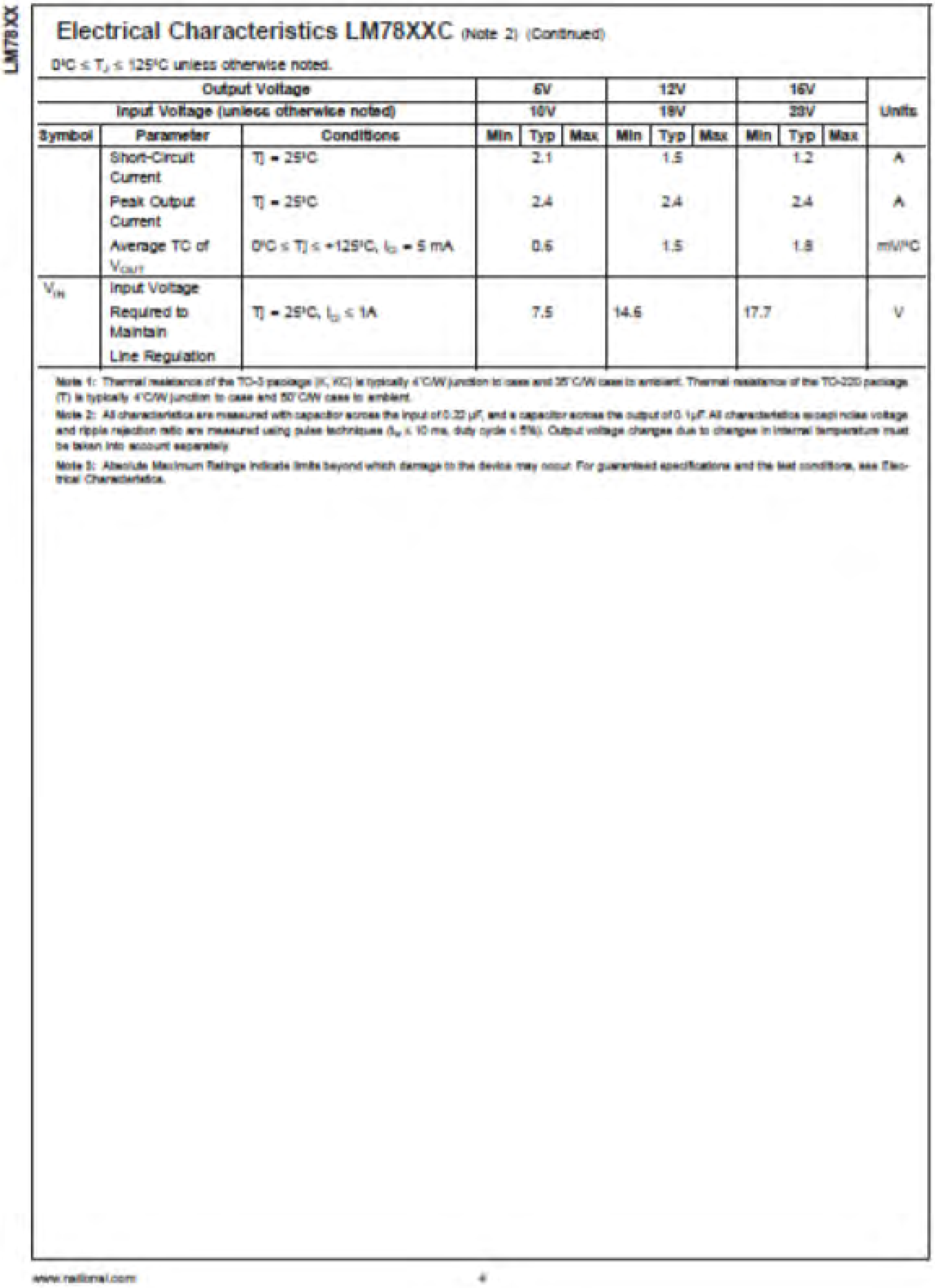


Electrical Characteristics LM78XXC (Note 2) (Continued)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Short-Circuit Current	TJ = 25°C		2.1			1.5			1.2		A
	Peak Output Current	TJ = 25°C		2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ TJ ≤ +125°C, I_O = 5 mA		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	TJ = 25°C, I_O ≤ 1A		7.5		14.6			17.7			V

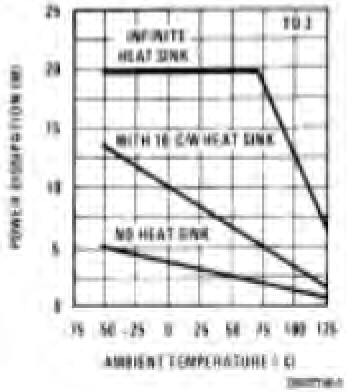
Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 μF, and a capacitor across the output of 0.1μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

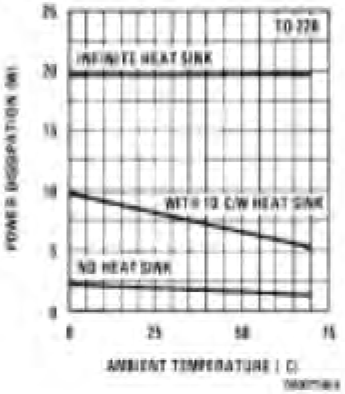
Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

Typical Performance Characteristics

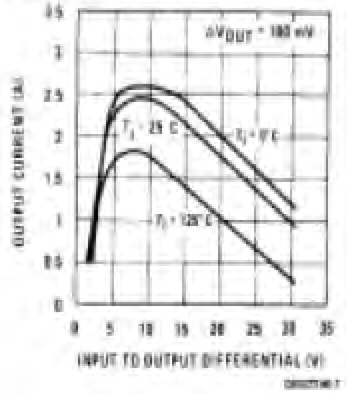
Maximum Average Power Dissipation



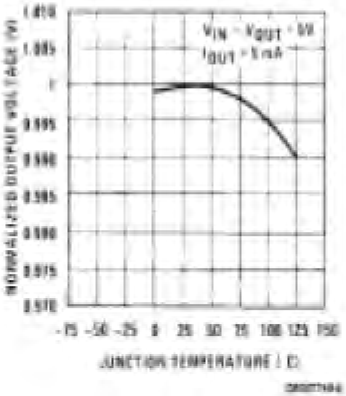
Maximum Average Power Dissipation



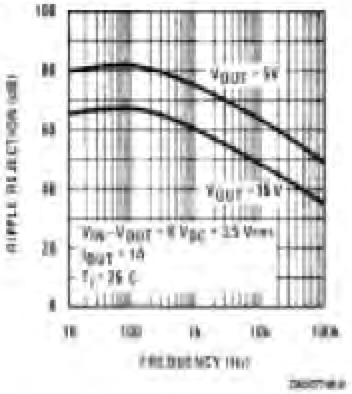
Peak Output Current



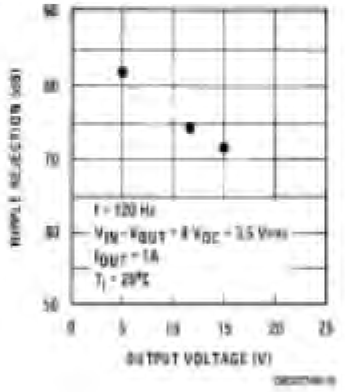
Output Voltage (Normalized to 1V at T_J = 25°C)



Ripple Rejection

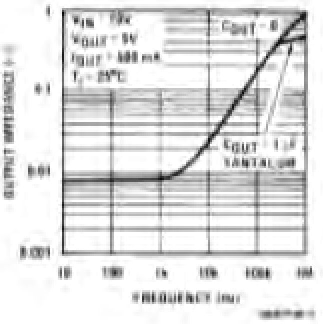


Ripple Rejection

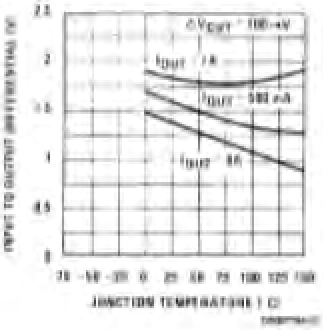


Typical Performance Characteristics (Continued)

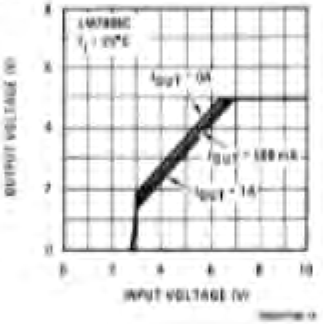
Output Impedance



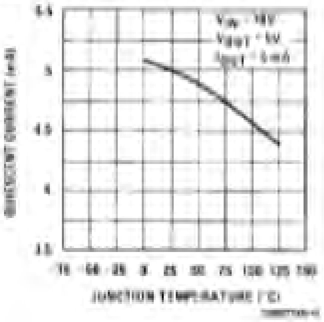
Dropout Voltage



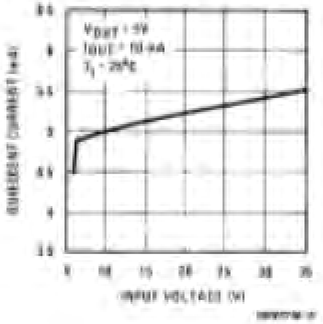
Dropout Characteristics



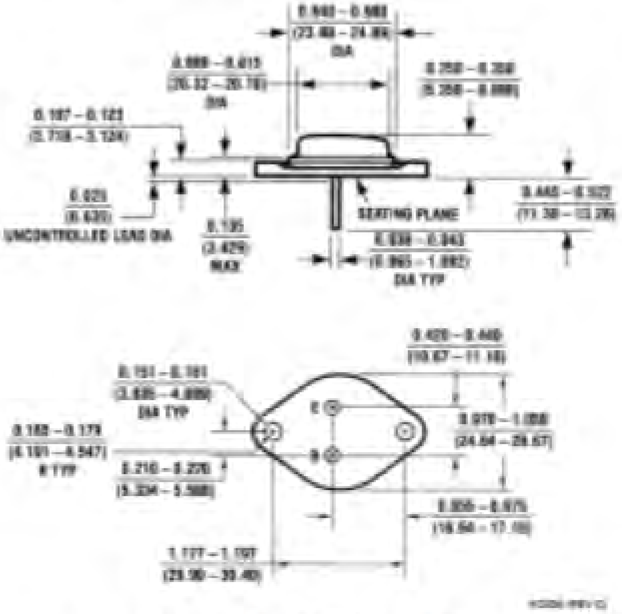
Quiescent Current



Quiescent Current



Physical Dimensions inches (millimeters) unless otherwise noted



Aluminum Metal Can Package (KC)
Order Number LM7805CK, LM7812CK or LM7815CK
NS Package Number KC02A

Product Folder
Sample & Buy
Technical Documents
Tools & Software
Support & Community

TEXAS INSTRUMENTS

LM555

SNAS548D – FEBRUARY 2000 – REVISED JANUARY 2015

LM555 Timer

Features
- Direct Replacement for SE555/NE555
- Timing from Microseconds through Hours
- Operates in Both Astable and Monostable Modes
- Adjustable Duty Cycle
- Output Can Source or Sink 200mA
- Output and Supply TTL Compatible controlled with two external resistors and one
- Temperature Stability Better than 0.005% per °C
- Normally On and Normally Off Output
- Available in 8-pin VSSOP Package or sink up to 200 mA or drive TTL circuits.

Applications
- Precision Timing
- Pulse Generation
- Sequential Timing
- Time Delay Generation
- Pulse Width Modulation

Device Information

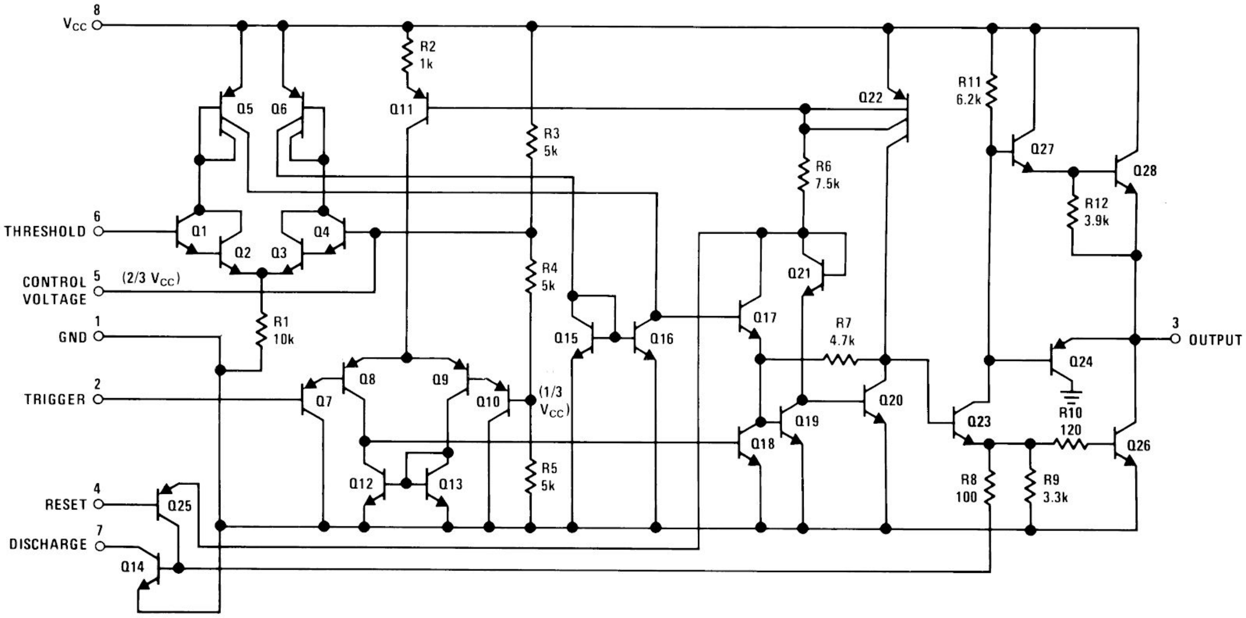
PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM555	SOIC (8)	4.90 mm × 3.91 mm
	PDIP (8)	9.81 mm × 6.35 mm
	VSSOP (8)	3.00 mm × 3.00 mm

- Pulse Position Modulation
- Linear Ramp Generator

Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200 mA or drive TTL circuits.

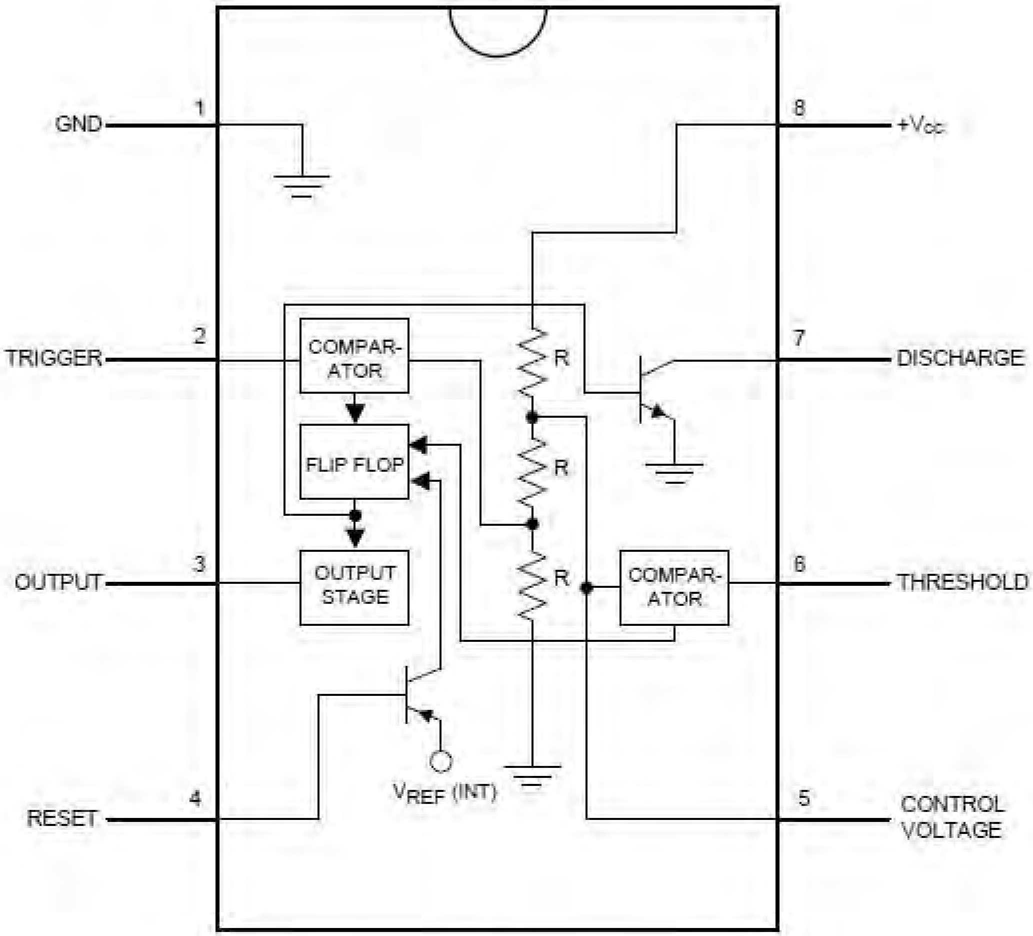
Schematic Diagram



5 Pin Configuration and Functions

Pin Configuration and Functions

D, P, and DGK Packages
8-Pin PDIP, SOIC, and VSSOP
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
5	Control Voltage	I	Controls the threshold and trigger levels. It determines the pulse width of the output waveform. An external voltage applied to this pin can also be used to modulate the output waveform
7	Discharge	I	Open collector output which discharges a capacitor between intervals (in phase with output). It toggles the output from high to low when voltage reaches 2/3 of the supply voltage
1	GND	O	Ground reference voltage
3	Output	O	Output driven waveform
4	Reset	I	Negative pulse applied to this pin to disable or reset the timer. When not used for reset purposes, it should be connected to VCC to avoid false triggering
6	Threshold	I	Compares the voltage applied to the terminal with a reference voltage of 2/3 Vcc. The amplitude of voltage applied to this terminal is responsible for the set state of the flip-flop
2	Trigger	I	Responsible for transition of the flip-flop from set to reset. The output of the timer depends on the amplitude of the external trigger pulse applied to this pin
8	V^+	I	Supply voltage with respect to GND

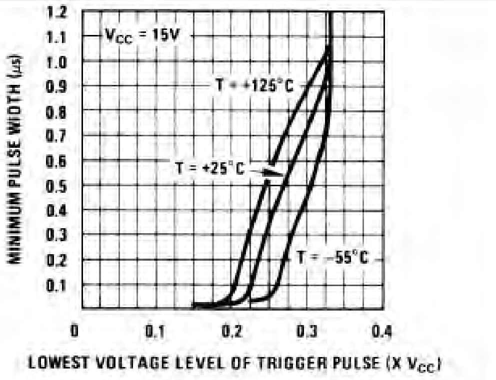


Figure 1. Minimum Pulse Width Required For Triggering

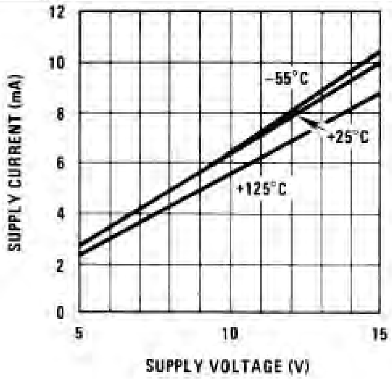


Figure 2. Supply Current vs. Supply Voltage

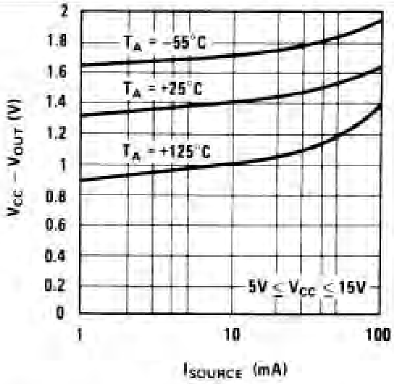


Figure 3. High Output Voltage vs. Output Source Current

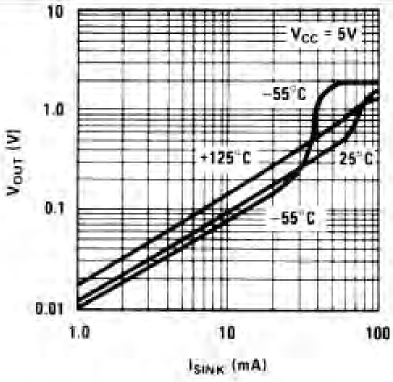
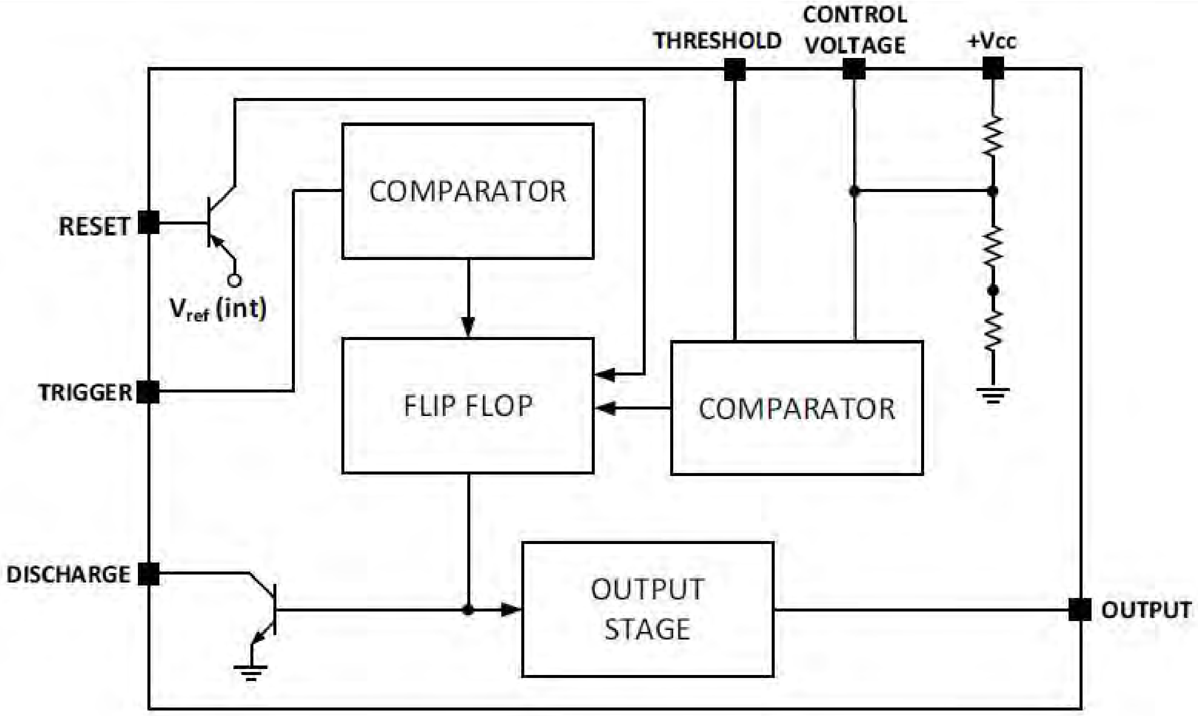


Figure 4. Low Output Voltage vs. Output Sink Current

Functional Block Diagram



Appendix G

Safety Measurements

Careful while using the Step down transformer

Fig. Step down transformer

I/P:220V ~ 50Hz step down transformer has been used in the making of Tesla coil. The input voltage is very high. Anyone can get electric shock while using it. So, we have to be very careful while plugged it into to the socket. Other thing is that the two red wire should not be touched. It can cause a short circuit problem in the transformer and burn the transformer.

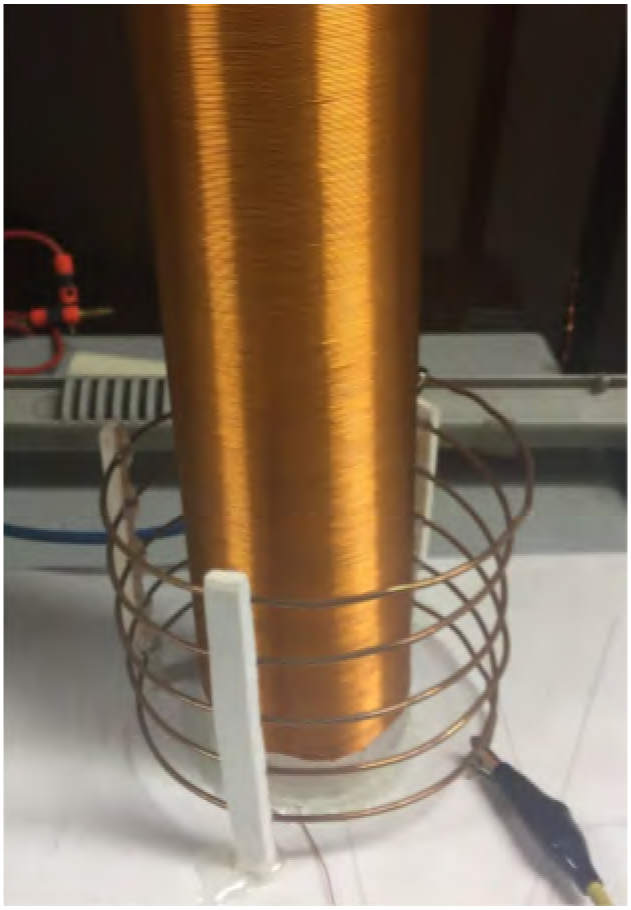


Fig. Primary & secondary coil

Primary and Secondary Coil winding direction

The coil winding direction is very important. If the direction is wrong, then the Tesla coil will not be working. Primary and secondary winding direction should be opposite.

Do not touch the open wire of the winding section

When magnetic coupling happens between primary and secondary coil, one should not touch the open wire. One can get shock while touching the wire as high voltage is present.