DESIGN AND DEVELOP MINIATURE TESLA COIL

WAN MOHD FARID B WAN RAMLI

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'I hereby declared that I have read through this report and found that it has comply he partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature	:	.....
Supervisor's Name	:	Mohd Farriz Bin Hj Basar
Date	:	07 / 05 / 2010

I declare that this report entitle *"Design and Develop a miniature Tesla Coil"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: .....

Name : WAN MOHD FARID B WAN RAMLI

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ABSTRACT

Nikola Tesla is a responsible person that invented Tesla Coil, a type of resonant air core transformer, used to generate high voltage and low current electricity. Even though the Tesla Coil is an old invention, there are useful for developing many devices today. Tesla Coil used to conduct innovative experiments in electrical lighting, fluorescence, x-rays, wireless energy transfer for electrical power transmission and also for educational purposes. Tesla coil designs employed high voltage alternating current power source, high voltage capacitor, and a spark gap to excite the primary side of the Tesla coil system with periodic bursts of high frequency current. The primary and secondary coil is designed in order to resonate at the same frequency. The main purpose of this project is to design a miniature size of tesla coil that use a low dc (direct current) voltage as a primary circuit input instead of ac (alternating current) voltage and will produce an ac high voltage at secondary circuit side. This project will prove that even though the input is only a low DC voltage, this miniature Tesla Coil is able to step up the input voltage and simultaneously generate a high voltage approximately 2kV at the secondary side. The size of Tesla Coil is also one of the main issues, which typical Tesla Coil usually have a large scale of its construction. As a result a miniature Tesla Coil will be use as an impulse generator with low voltage rating. In addition, this project has contributed many advantages rather than typical Tesla Coil which is bulky and has many mobility issues.

ABSTRAK

Nikola Tesla ialah individu yang bertanggungjawab mencipta *Tesla Coil*, sejenis alatan yang menggunakan konsep penguat jenis teras udara resonan yang digunakan untuk menghasilkan voltan tinggi dan arus berfrekuensi tinggi. Walaupun *Tesla Coil* adalah satu ciptaan yang lama, ia tetap menyumbangkan banyak manafaat untuk peralatan dan kegunaan pada zaman sekarang. *Tesla Coil* digunakan dalam ujikaji inovatif pencahayaan elektrik, fluorescence, x-ray, penghantaran kuasa elektrik tanpa wayar dan juga untuk kegunaan pembelajaran. Rekabentuk *Tesla Coil* memerlukan sumber kuasa voltan tinggi, kapasitor voltan tinggi dan juga spark gap (sela percikan) untuk menjana bahagian lilitan utama pada system *Tesla Coil* dengan letusan arus frekuensi tinggi yang berkala. Binaan lilitan (gegelung) memerlukan litar utama (primer) dan kedua (sekunder) selaras supaya ianya resonan pada frekuensi yang sama. Tujuan utama projek ini ialah untuk merekabentuk sebuah *Tesla Coil* berskala kecil yang menggunakan voltan rendah pada bahagian masukannya dan berhasil mengeluarkan voltan tinggi pada bahagian keluarannya. Projek ini akan membuktikan walaupun ianya hanya menggunakan voltan arus terus yang rendah pada bahagian masukan, *Tesla Coil* berskala kecil ini tetap mampu menginjakkan voltan masukan dan menghasilkan voltan tinggi (anggaran 2kV) pada bahagian keluaran. Saiz *Tesla Coil* juga merupakan isu yang penting, dimana kebiasaan *Tesla Coil* mempunyai binaan dengan saiz yang besar. Keputusannya, projek ini akan memajukan *Tesla Coil* bersaiz kecil yang akan menyumbangkan banyak kelebihan daripada kebanyakan *Tesla Coil* yang mana bersaiz besar dan mempunyai banyak isu kesukaran untuk bergerak(berpindah).

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CHAPTER 1

INTRODUCTION

1.1 Overview

Although Tesla Coil is using the concept of transformer, there is some difference between both of it. Transformer usually use metal as its core meanwhile Tesla coil use only air as its core. Unlike low frequency power transformers, no ferromagnetic "core" is used, and the windings are "loosely coupled" which means that typically only 10-20% of the primary's total magnetic field links with the secondary winding [6]. Unlike most transformers, output voltage of Tesla Coil is virtually independent of the turns-ratio of the secondary versus the primary. Instead, it is a function of the relative ratio of inductances or capacitances between the primary and secondary. The result is, extremely high voltages can easily be generated.

As all we know, typical Tesla Coil usually has been made in large scale size and also using medium voltage or high voltage as an input supply. The bulky size of Tesla Coil commonly have the minimum size as like as human size gives some barrier with the transportation or mobility of Tesla Coil. Beside of that, the high voltage input that implemented to typical Tesla Coil is quite dangerous to the users. Due to that, this research is going to give an innovation for the typical Tesla Coil.

To build a miniature Tesla Coil, the construction of typical Tesla Coil must be well studied. Miniature Tesla Coil still use the same concept and theoretical of typical Tesla Coil, but in a different approach. For an example, the spark gap that used on typical Tesla Coil will be replaced to the relay. This is the different approaches but the aim of using it is still the same which spark gap is used as a switch to initiating the discharge of the tank capacitor into the

primary winding of the Tesla Coil with the periodic time [2],[8]. The capacitor used to store energy from input source and then energy from the capacitors is transferred into the primary winding when the spark gap fires. For the primary and secondary coil ratio, the ratio of 1:100 will be used in order to step up the input voltage of 24 volt dc to 2 kilovolt ac at the output side. The project of design and develop miniature Tesla Coil consists of:

Table 1.1: Works On Project Development

Simulation	Hardware
• Simulation work using Pspice is to verify the circuit that has been designed for the hardware purpose. The circuit of Tesla Coil is simulating using the real component value which is used in developing the hardware.	• The hardware development consists of the design, redesigns, testing and troubleshoots all the circuit involved. • Assemble the component as well as reducing the cost.

1.2 Problem Statement

Generally, the challenges to carry out this research are divided into a few obstacles. First is the way to convert the low dc voltage to the high ac voltage. Then is the ability to attain the high ac voltage at the secondary voltage and finally the transmission of electricity energy through the air medium which can consider as the main barrier to do this project.

Typical Tesla Coil usually using a medium ac voltage or high ac voltage as their input. The employment of medium and high voltage is quite dangerous in terms of safety. Due to that, the miniature Tesla Coil will employ an input of 24Vdc voltage at the primary and this is

the most significant part for this project. The challenge is to convert the low dc voltage at the input to the high ac voltage at the output.

Ordinarily, Tesla Coil gives some of barrier and difficulties to the users as the result of the size of common Tesla Coil which is bulky and heavy. In order to make it more reliable, rugged, and user friendly compare to the present invention, this prototype will be made in the normal size of Tesla Coil. In addition, even though the size of Tesla Coil is miniature, it is still able to produce a high ac voltage at the output.

1.3 Objectives

The following project objectives mannerly had been created to make sure the aim of this project will be achieve at in the end:

1. To develop a miniature Tesla Coil that is small in size compared to the typical Tesla Coil.

2. To generate high voltage approximately 2kV at the secondary side using a low dc voltage (24volt) as an input of the primary circuit.

3. To analyze the electrical characteristics at the output of secondary circuit.

1.4 Scope of Project

1. The computer simulation work by using PSpice software is the preliminary experiment for prior to the hardware development.

2. Generate a high ac voltage at the output of secondary circuit by using the contribution of high voltage capacitor, primary and secondary coil, spark gap and low dc voltage input.

3. Parameters of the electrical characteristic to be studied are voltage, current and frequency of the output.

1.5 Thesis Outline

This project report consists of five chapters which are explained below:

Chapter 1 is the overview of the project research which includes the problem statement, objectives and scope of project to give a clear view of PSM 2.

Chapter 2 explains the literature review and theory background that related to this research. It contributes with the history of Tesla Coil, Tesla Coil circuit and design, component on Tesla Coil and Tesla Coil operational with referring to the previous research and paper. The wireless transmission of electricity and the skin effect myth also discussed in this chapter.

Chapter 3 cover about the methodology that was adapted to this research by explaining the whole project procedure from the beginning to the end and it was presented in a flow chart and explained briefly.

Chapter 4 discusses about the major about simulation and hardware construction works. The analysis of the simulation result explains and shows briefly in this chapter. For the

hardware construction and development, the procedure of making hardware is discussed. The expected result of project also stated in this chapter.

Chapter 5 is a discussion of all overall progress and overview for PSM 2. Some of recommendations for PSM 2 will be included in this chapter. The conclusion for this PSM 2 also presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Tesla Coil History

It is very important to know about the history of Tesla Coil to get inspiration and learn how it was built especially when to built a miniature Tesla Coil using the basic fundamental of a typical Tesla Coil. Nikola Tesla (1856 - 1943) was one of the most important inventors in human history. He invented the induction motor and our present system of three-phase power in 1888 and then he invented the Tesla coil, a resonant air-core transformer, in 1891 and in the year of 1893, he invented a system of wireless transmission of intelligence [8]. Tesla also did the fundamental work in power and communications, the major areas of electrical engineering. These inventions have truly changed the course of human history. After Tesla had invented three-phase power systems and wireless radio, he turned his attention to further development of the Tesla coil and he also built a large laboratory in Colorado Springs in 1899 for this purpose [9].

Tesla invented an apparatus that pushed the limits of electrical understanding to investigate high-frequency and high-voltage. None of the circuit's typical components were unknown at the time, but its design and operation together achieved unique results, because of Tesla is very masterful in construction of most particularly of a special transformer or coil which is usually the heart of the circuit's performance [5].

A classical Tesla coil which built by Nikola Tesla (as shown in Figure 2.1) contains two stages of voltage increase. The first is a conventional iron core transformer that steps up the available line voltage to a voltage in the range of 12 to 50 kV, 60 Hz. The second is a resonant air core transformer (the Tesla coil) which steps up the voltage to the range of 200

kV to 1 MV. The high voltage output is at a frequency much higher than 60 Hz, about 500 kHz for the small units and 80 kHz (or less) for the very large units [8].

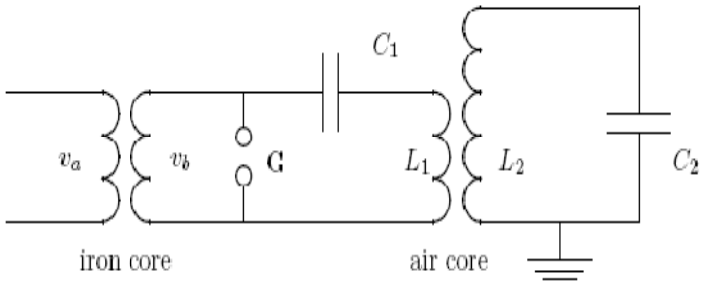

Figure 2.1: Classical Tesla Coil circuit

There were two most common of Tesla Coil circuit. The typical circuit (Figure 2.2), the spark gap's short circuiting action prevents high frequency oscillations from "backing up" into the supply transformer. In the alternate circuit, high amplitude high frequency oscillations that appear across the capacitor also are applied to the supply transformer's winding. This can induce corona discharges between turns that weaken, and eventually destroy, the transformer's insulation [8].

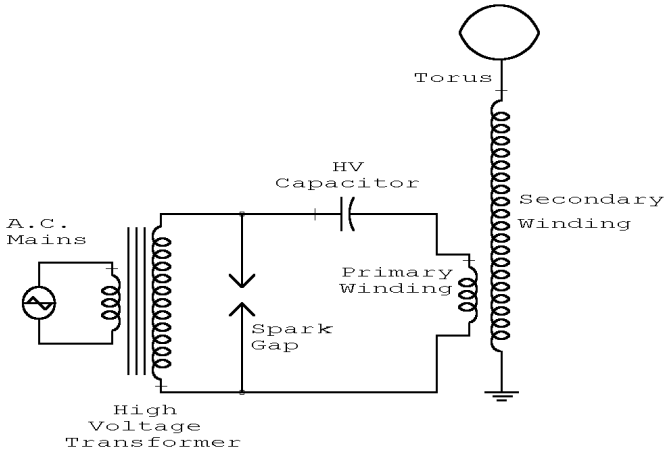

Figure 2.2: Typical Tesla Coil Circuit

In alternative circuit design (Figure 2.3), the Tesla Coil primary winding, spark gap, and tank capacitor are all connected in series. Once the gap fires, the electrical behavior of either circuit

is identical. Experiments have shown that neither circuit offers any marked performance advantage versus the other [2], [8].

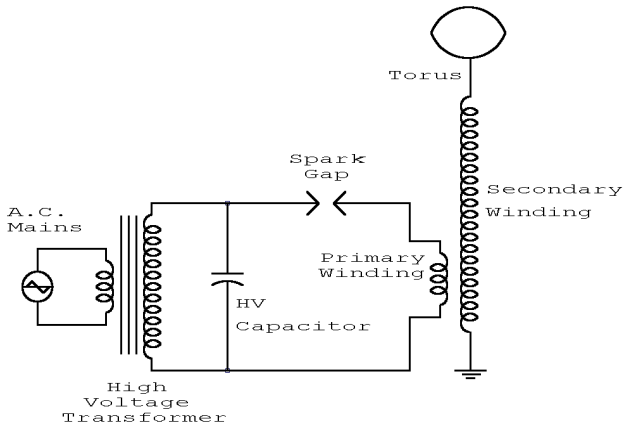

Figure 2.3: Alternate Tesla Coil Circuit

2.2 Typical Tesla Coil

Figure 2.4 show the most typical Tesla Coil design. However, there was another various Tesla Coil design that has been built beside than this.

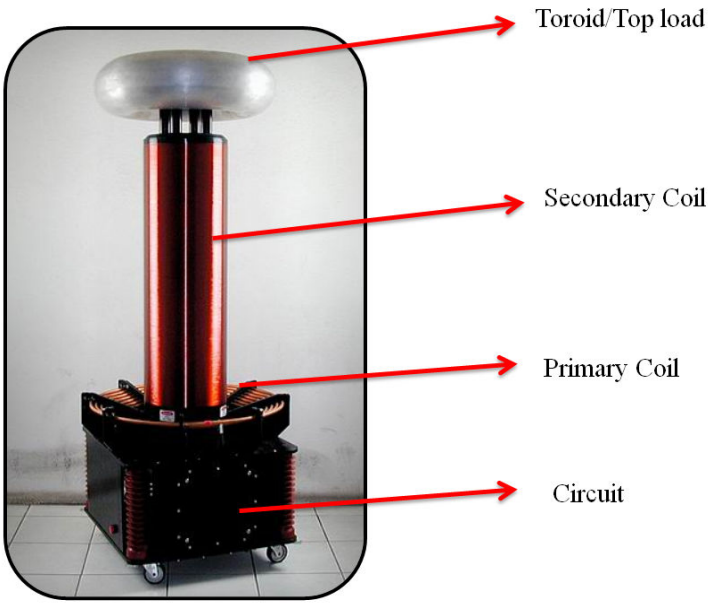

Figure 2.4: Typical Tesla Coil Design

2.3 Tesla Coil Component

Tesla Coil consists of some component in its construction. This subchapter will discuss about the Tesla Coil generally.

2.3.1 Toroid

Toroid also known as top loads form the capacitor for the secondary circuit. Along with the secondary coil they form a resonant circuit at the same frequency as the primary circuit. As the secondary inductor is so large (500-2500 turns) and the primary inductor is so small (2-10 turns), the secondary capacitance can be small (8-100pf) Any lump of metal will form a capacitance, but to allow as much energy to be stored in the Toroid without the power "breaking out" the Toroid needs to be as smooth as possible. Any sharp point will accumulate electrical charge and discharge to the atmosphere [8].

2.3.2 Primary Coil

Primary Coil forms is the inductive part of the primary circuit, along with the primary capacitor these two components form a resonant circuit. As the primary coil handles all of the stored power in the primary capacitance and is almost a short circuit, it has to be capable of withstanding large current pulses. For this reason it is usually constructed from copper tubing or heavy gauge wire. For tuning purposes the primary coil is tapped to allow its inductance to be changed and therefore the resonant frequency of the primary circuit as a whole. It is generally easier to vary the inductance than the size of the primary capacitor [2], [8].

2.3.3 Secondary Coil

A secondary coil is where all of the voltage multiplication is achieved. Essentially the secondary coil is a single air cored inductor wound with 500-2500 turns of insulated wire. The wire size and turns are usually dictated by the required size of the secondary. The secondary is wound onto an insulating former, usually PVC, but many other formers are used including cardboard, glass & polypropylene. To help insulate and to prevent corona discharge the secondary is coated with many layers of varnish, ideally until it has a smooth finish [2].

2.3.4 Spark Gap

The spark gap is basically a high power switch. It is the spark gap which is responsible for initiating the discharge of the tank capacitor into the primary winding of the Tesla Coil. It turns on when sufficient voltage exists across the spark gap. The air in the gap ionizes and begins to conduct electricity like a closed switch. The spark gap turns-off when the current flowing through it drops to a low level, and the air gap regains its insulating properties. Spark gap supplying energy with fraction of time and it can reduce the electromagnetic interference.

[2]. The best way to describe spark gap in Tesla Coil construction is; spark gap function is much like a brain to Tesla Coil.

In the typical Tesla Coil construction, there is several type of spark gap that has been used. Figure 2.5 show the design of simple static spark gap. However, there was a Tesla Coil design using rotary spark gaps which need a motor to operate.

Figure 2.5: Static Spark Gap Design

Figure 2.6 show the example of rotary spark gap. The rotary spark gap operated in air using modern materials with speed control device to achieve the best possible arc quenching and minimizing the jitter in the timing of the primary coil [2]. A rotary spark gap has the advantage of being able to control the rate of firings.

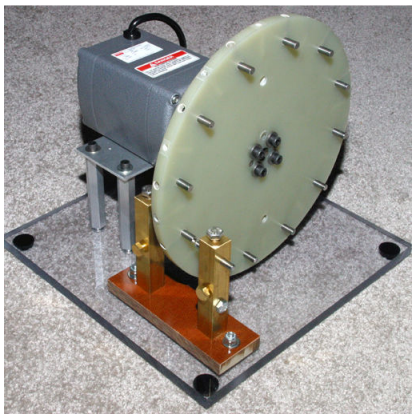

Figure 2.6: Rotary Spark Gap Design

2.3.5 Capacitor

A capacitor or also known as condenser is a passive electronic component consisting of a pair of conductors separated by a dielectric. A typical capacitor is a two-terminal device consisting of two conductors separated by a dielectric. When a voltage difference *Vo* is applied to the conductors, a charge of $+Q$ will appear on one conductor and an equal and opposite charge $-Q$ on the other conductor. The capacitance *C* is defined as the ratio of the charge on one conductor to the potential difference [8].

$$C = \frac{Q}{V_o} \tag{2.1}$$

Tesla Coil capacitance is much more difficult to calculate or to estimate with any accuracy. The capacitance value used to determine the resonant frequency of the Tesla coil is a combination of the capacitance of the coil and the capacitance of the top load, usually a sphere or a toroid, with respect to ground [8]. Usually values of primary capacitor are 6nF - 10uF depending on coil size and primary voltage.

2.4 Basic Operation of the Typical Tesla Coil

A Tesla Coil is an air-cored resonant transformer. It has some similarities with a standard transformer but the mode of operation is somewhat different. A standard transformer uses tight coupling between its primary and secondary windings and the voltage transformation ratio is due to turns ratio alone. In contrast, a Tesla Coil uses a relatively loose coupling between primary and secondary, and the majority of the voltage gain is due to resonance rather than the turns ratio. A normal transformer uses an iron core in order to operate at low frequencies, whereas the Tesla Coil is air-cored to operate efficiently at much higher frequencies [2], [6], [8].

A typical Tesla Coil circuit diagram is shown on Figure 2.7 below.

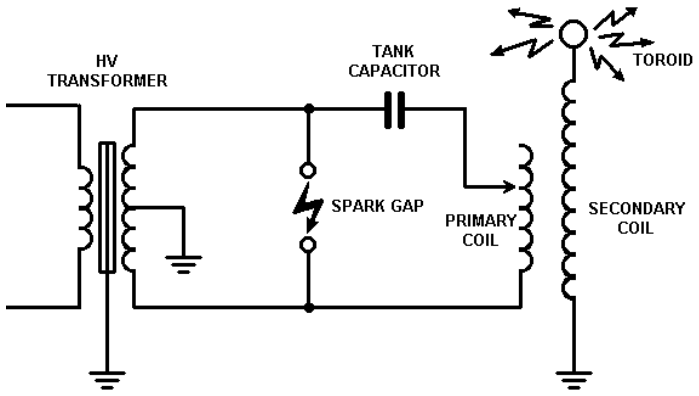

Figure 2.7: Tesla Coil Circuit

The operation of the Tesla Coil is as follows:-

The spark gap initially appears as an open-circuit. Current from the power supply flows through a ballast inductor and charges the primary tank capacitor to a high voltage as shown on Figure 2.8. The voltage across the capacitor increases steadily with time as more charge is being stored across its dielectric.

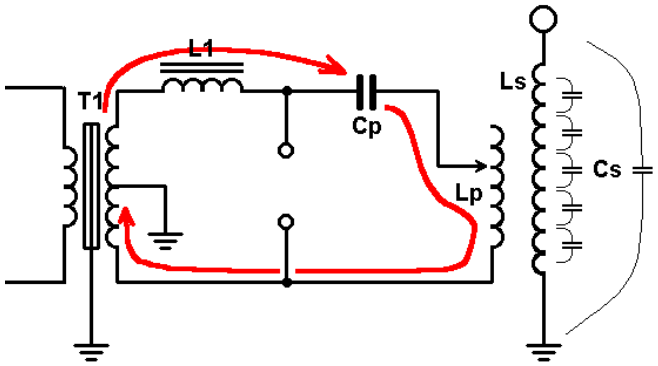

Figure 2.8: Capacitor charging condition

Eventually the capacitor voltage becomes so high that the air in the spark gap is unable to hold-off the high electric field and breakdown occurs. The resistance of the air in the spark gap drops dramatically and the spark gap becomes a good conductor. The tank capacitor is

now connected across the primary winding through the spark gap. This can be explained in Figure 2.9. This forms a parallel resonant circuit and the capacitor discharges its energy into the primary winding in the form of a damped high frequency oscillation. The natural resonant frequency of this circuit is determined by the values of the primary capacitor and primary winding, and is usually in the low hundreds of kilohertz [8].

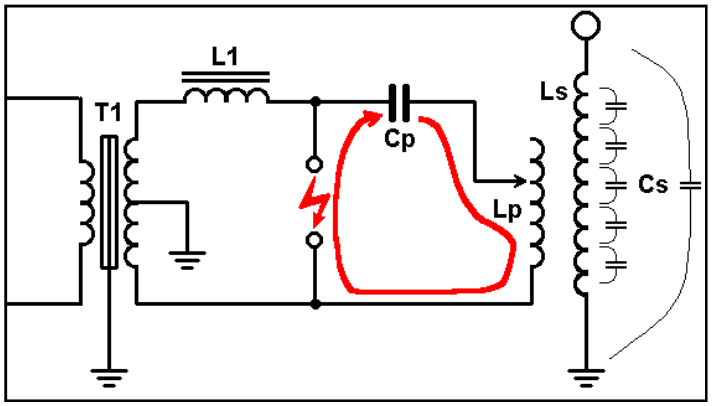

Figure 2.9: Capacitor discharged into primary coil (Lp) when spark gap closed

During the damped primary oscillation, energy passes back and forth between the primary capacitor and the primary inductor. Energy is stored alternately as voltage across the capacitor or current through the inductor. Some of the energy from the capacitor also produces considerable heat and light in the spark gap. Energy dissipated in the spark gap is energy which is lost from the primary tank circuit, and it is this energy loss which causes the primary oscillation to decay relatively quickly with time [8].

The close proximity of the primary and secondary windings causes magnetic coupling between them. The high amplitude oscillating current flowing in the primary causes a similar oscillating current to be induced in the nearby secondary coil [8].

The self capacitance of the secondary winding and the capacitance formed between the Toroid and ground result in another parallel resonant circuit being made with the secondary inductance. Its natural resonant frequency is determined by the values of the secondary inductance and its stray capacitances. The resonant frequency of the primary circuit is