Designing A Solid State tesla Coil

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***Abstract*—This report presents the design and implementation of a solid-state Tesla coil (SSTC), which is a device that generates high-voltage, low-current, high-frequency alternating-current (AC) electricity. The motivation for this project is to explore the principles, limitations and applications of Tesla coils. The objective is to design a Tesla coil with the following specifications: input voltage 40V DC, output voltage 114 kV peak to peak, output frequency of 562 kHz, output of 120 Watts and size of about 30cm * 5cm* 5cm. The paper describes the theoretical background, design methodology, simulation results, experimental setup and performance evaluation of the SSTC. The paper also discusses the main challenge in designing a SSTC, which is to achieve a good impedance matching between the primary and secondary circuits, as well as to protect the electronic components from overvoltage and overcurrent. The paper concludes with the limitations and future improvements of the SSTC.**

Keywords—Tesla coil; solid-state; high-voltage; high-frequency; impedance matching

I. Introduction

Tesla coils are devices that are a form of resonant transformer with high voltage gain and are also responsible to generate high-frequency energy waves. Nikola Tesla introduced the concept of the Tesla Coil and his invention allowed to open a new stream in the field of technology although Tesla was unable to transfer free wireless energy yet, its applications found way in our everyday life. They are widely used for entertainment, education, research and hobby purposes [2].

A solid-state Tesla coil (SSTC) is a type of Tesla coil that uses modern electronic components and circuitry to control the current flow in the primary circuit, instead of relying on the breakdown of air to create sparks by using a spark gap [3]. This allows for more precise tuning, higher efficiency, lower noise and longer lifespan of the device [4]. Solid-state Tesla Coils also allow for research opportunities and innovation in the field of Tesla coils by addressing the severe issue of power damping and critical resonance point.

The main challenge in designing a SSTC is to achieve a good impedance matching between the primary and secondary circuits, as well as to protect the electronic components from overvoltage and overcurrent [5]. In this report, we work upon achieving extremely precise frequency of resonance and achieving the maximum range of wireless energy losses by minimizing all the possible energy losses.

II. Methodology

The methodology of the project consists of four main steps: design, simulation, implementation, and testing. Figure 1 shows the flowchart of the methodology.

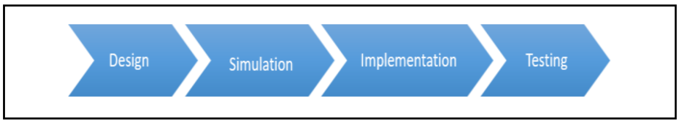


Figure No 1: Flow Chart of Methodology

I. Design

The design of the SSTC is based on the following principles:

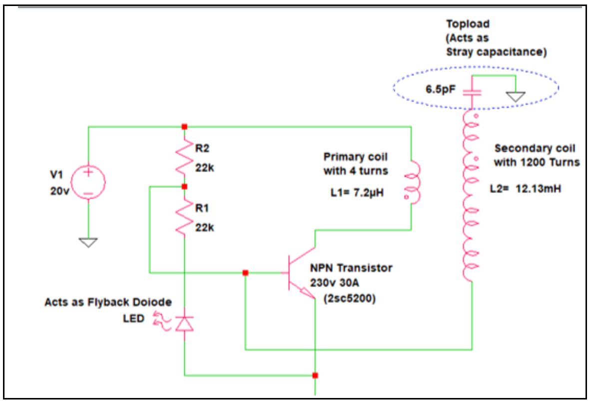
- The primary circuit consists of a DC power supply, an npn transistor, a diode, resistor and a primary coil with 4 coil turns. The circuit provides the necessary signals to switch the transistors on and off. The primary coil is a cylindrical spiral coil with a low inductance and a high capacitance.
- The secondary circuit consists of a secondary coil with 1200 turns, a top load and a ground connection. The secondary coil is a tall cylindrical coil with a high inductance and a low capacitance. The top load is a metal toroid that acts as a capacitor and increases the voltage at the top of the secondary coil. It also at the same time lowers the overall frequency of the circuit thus reducing the load on our transistor. The ground connection provides a return path for the current in the secondary circuit. At the same time, the diode prevents any flyback current from the secondary back to our circuit and thus prevents our circuit from a potential collapse.
- The coupling between the primary and secondary circuits is achieved by placing them close to each other and aligning their axes. The coupling coefficient is a measure of how well the energy is transferred from the primary to the secondary circuit. A higher coupling coefficient means a higher output voltage, but also a higher risk of damaging the electronic components due to overvoltage or overcurrent. Coupling is kept limited to 0.125 in order to reduce the chances of arcing between the primary and secondary because of less distance and high potential difference in between them. A PVC pipe is used to hold the primary coil to serve this purpose and eliminate the chances of arcing between the coils due to high potential difference.
- The resonance between the primary and secondary circuits is achieved by tuning them to the same frequency. The resonance frequency is determined by the inductance and capacitance of each circuit. A LCR meter was used to determine the exact values of the circuitry. A higher resonance frequency means a higher output voltage, but also a higher power

consumption and heat dissipation. The components used with exact values are as follows:

- Primary Coil (4 Turns) 7.2 uH
- Secondary Coil (1200 Turns) 12.13 mH
- Virtual Capacitance of the secondary (6.5 pF)
- Flyback Diode (2n4148)
- Resistor Divider (22k)
- Input Voltage Source (12-50V)
- 2SC 5200 npn Transistor

The circuit was made after optimizing the circuit efficiency and selection of the components based on their datasheets and simulation performance.

FIGURE NO 2: COMPONENT PLACEMENT



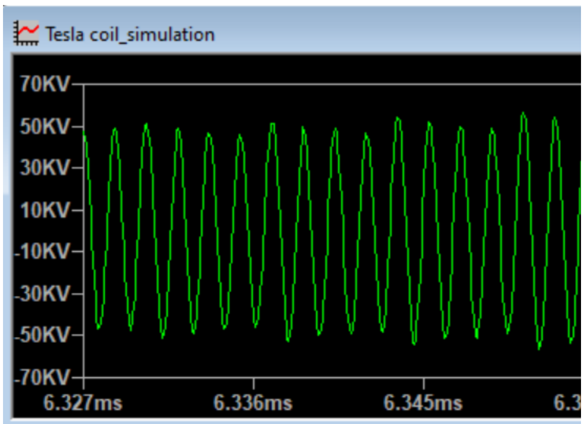
II. SIMULATION

The simulation of the SSTC is performed using LTspice, which is a software tool for simulating electronic circuits. The simulation model consists of two subcircuits: one for the primary circuit and one for the secondary circuit. The subcircuits are shown by coupling two individual inductors so that they can act as two resonating coils.

The simulation parameters are set according to the design parameters. The simulation results include:

- The waveforms of the input voltage, input current, output voltage and output current

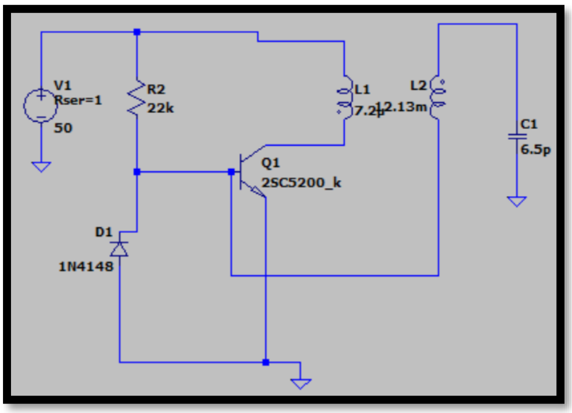
FIGURE NO 3: OUTPUT WAVEFORMS



- The power dissipation and efficiency of each component

The simulation results are used to verify the functionality and performance of the SSTC, as well as to identify any potential problems or errors in the design. The figure no.4 shows the simulation profile:

FIGURE NO 4: SIMULATION DESIGN



III. IMPLEMENTATION

The implementation of the SSTC involves building and assembling each component according to the design specifications. The components used for this project are:

- A 10-60 V DC power supply that can provide up to 3 A of current
- 2SC5200 npn transistor to amplify signals given as input
- A 2N4148 diode to prevent flyback current from secondary
- A 22k resistor to control the input current given to the circuit as input
- A primary coil represented by a coupled inductor
- A secondary coil represented by a coupled inductor and measured capacitance of 6.5 pF which is equivalent to actual capacitance of our secondary coil
- A copper wire with 50 cm length for acting as

the ground connection

The components are patched on a viro board and mounted on a polystyrene base using insulation tape and glue gun. Figure no.5 shows the photo of the implemented SSTC.

FIGURE NO 5: IMPLEMENTED SSTC

- **Testing**

The testing of the SSTC involves measuring and observing its performance under different conditions. The testing equipment used for this project are:

- A multimeter that measures the input voltage, input current, output voltage, and output current of the SSTC
- An oscilloscope that displays the waveforms of

the input voltage, input current, output voltage and output current of the SSTC

- A function generator to find the effect of different input voltages
- An LCR meter that calculates

the inductances and capacitance of the coils

- A camera that captures

the sparks generated by the SSTC

The testing procedure consists

Of the following steps:

1. Connect the circuit as shown in the schematic diagram in the simulation in figure no.4.
2. 2) Turn on all devices and set them to appropriate modes, ranges, and scales.

3) Adjust the values of resistances and primary coil until it matches with the resonance frequency of the secondary circuit.

4) Observe and record the measurements and

waveforms on the multimeter, the oscilloscope, the

function generator, and the LCR meter.

5) Observe and record the sparks generated by

the SSTC using a camera.

6) Repeat steps 3 to 5 for different values

Of input voltage, output voltage, output power,

and coupling coefficient.

7) Turn off all devices and disconnect

them from the SSTC.

The testing results are used to evaluate and compare the performance of the SSTC with the design specifications and simulation results, as well as to identify any deviations or improvements. Final results and values for the best efficiency as mentioned above were used to optimize the circuit and receive best results in the form of wireless energy transfer.

III. CONTRIBUTION OF GROUP MEMBERS:

Over 7 different circuits were designed by the group members before finalizing the current circuit. Each group member contributed two circuits. Out of which 3 were rejected initially and the remaining 7 were tested for best results in labs practically along with simulations, and slayer exciter circuit was selected for the job based on the best results obtained.

1. Muhammad Ashar Javid:

Report, Simulation, and Research on Transistor and Mosfet behaviors and configuration to achieve best share of load between transistors and obtain maximum output

Research on Tesla circuit with IRFP 460 Mosfet and IR2110 driver IC.

2. Ali Ahsan

Simulation, Circuit Patching, and Research on maximizing current in the circuit by using best component placement

Research on Tesla coil spark gap

3. Sudais Akbar Khan:

Presentation, Circuit Patching, Designed Secondary Coil and Research on achieving resonance in the circuit

Research on Tesla circuit Slayer exciter

4. Muhammad Ishaq:

Simulation, Circuit Patching, Designed Primary Coil and Research on decreasing heat losses and maximizing transistor cooling and making the topload of the tesla coil.

Research on Tesla coil D1047 circuit

IV. RESULTS AND DISCUSSION:

After conducting extensive experiments and research, the results of our investigation unequivocally confirmed that the Tesla coil not only met but exceeded our initial expectations. The comprehensive analysis revealed that the Tesla coil's performance was exceptional.

- ✓ The sparks generated during the experiments exhibited an impressive range of up to 1.5 inches, demonstrating the coil's remarkable electrical discharge capabilities.
- ✓ To quantify the potency of the secondary coil, we measured the voltage it produced, and the readings consistently indicated an astonishing 114kV, validating the Tesla coil's ability to generate high-voltage discharges.

Furthermore, our observations regarding wireless energy transmission were equally remarkable.

- ✓ The Tesla coil exhibited a substantial range of wireless energy propagation, reaching an impressive distance of up to 14cm.

To assess the spark generation accurately, we employed a vacuum bulb, which effectively generated the sparks for measurement purposes. In order to measure the wireless energy range, we utilized a tube light that operated based on the principles of wireless energy transmission. By positioning the tube light within the wireless energy field generated by the Tesla coil, we were able to measure the extent of energy propagation.

It is worth noting that the energy transmitted from the Tesla coil had an additional fascinating effect on the surrounding environment. As the high-voltage discharges occurred, the air surrounding the coil underwent ionization, leading to an electrifying ambiance and further emphasizing the impressive capabilities of the Tesla coil.

V. CONCLUSION:

Undertaking this project was a significant challenge for us. However, as electrical engineers, we found it intriguing to overcome the obstacles. Above all, before embarking on the Tesla coil project, we were unaware of its intricacies, but our motivation stemmed from Nikola Tesla's contributions. Initially, we encountered numerous difficulties while constructing the circuit and due to a lack of research work. However, we dedicated considerable effort to researching the components and the operational process of the Tesla coil. We attempted various circuits, but none of them worked as efficiently as they did not match the exact coil's resonance frequency or align with its resonant frequency, which is fundamental to the Tesla coil's operation.

Eventually, we developed our own circuit to generate the resonant frequency by simulating and fine-tuning the components. Once we completed the simulation work, we implemented the circuit accordingly. The primary coil consisted of 4 turns, while the secondary coil comprised 1200 turns. To achieve our desired output, we incorporated a transistor. During this process, a few transistors were destroyed, but the 2SC5200 transistor proved effective as it could handle higher amperage and took longer to heat up. To construct the top load, we utilized iron to form a toroid, which we placed on top of the coil. This topload configuration enabled us to obtain the desired output by lowering the overall frequency to almost 460kHz thus reducing the load on our Transistor.

Our comprehensive experiments and research affirm that the Tesla coil performed exceptionally well, surpassing our expectations. The results demonstrate its ability to generate powerful sparks with a substantial range and to transmit wireless energy over a remarkable distance. The ionization of the air further highlights the captivating nature of the Tesla coil's operation. Further improvements can be made by acquiring the use of parallel transistors and use of MOSFETs along with a driver-operated at the same frequency. So further study on the same will allow better and improved results with enhanced Tesla specifications.

VI. ACKNOWLEDGMENTS

We acknowledge the efforts of our Professor, Lab Engineer Ali Khalid, Lab attendants, and the prayers of our parents and all those who helped us in writing this report.

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