Tesla Final Project Documentation

By Edwin Almeida (Project Manager)

Objective

The CSULB Tesla coil project provides its group members, who are all emphasizing in power systems, with the opportunity to design and implement power electronics systems into a working project. A Tesla coil is an electronic device which produces high voltage discharges (sparks). The aim of this project is to create a Tesla coil which can read MIDI music files and create sound output using the electrical discharges. The design being implemented utilizes solid state power electronics to drive the Tesla coil.

Level 1 Requirements

In order to complete our mission objective of constructing a safe, Tesla coil that is capable of producing sound from MIDI files, the following Level 1 requirements have been set:

- Project must be completed by 12/9/2014, which is the date of last class meeting of EE400D according to the CSULB Fall 2014 Academic Calendar.
- The total cost of the Tesla Coil project must not exceed $700. This value has been set by the customer.
- Create a Tesla Coil that has the ability to play monophonic (one note played at a time) MIDI files. The Tesla coils sound output level shall be between 62 and 98 dB at the minimum NFPA clearance distance of 8 ft. These sound levels were found by the National Center for Biotechnology Information to be the sound levels an average person qualifies as low and very loud respectively when listening to music.
- Project must be safe to operate, as determined by the CSULB COE Health and Safety Policy.
- For ease of use, the device will only have one external power cable connected to a household power outlet. According to article 210.52 of the National Electric Code, the typical household outlet supplies 15 A RMS at 120V AC RMS.

Information on how these requirements will be verified can be found here.

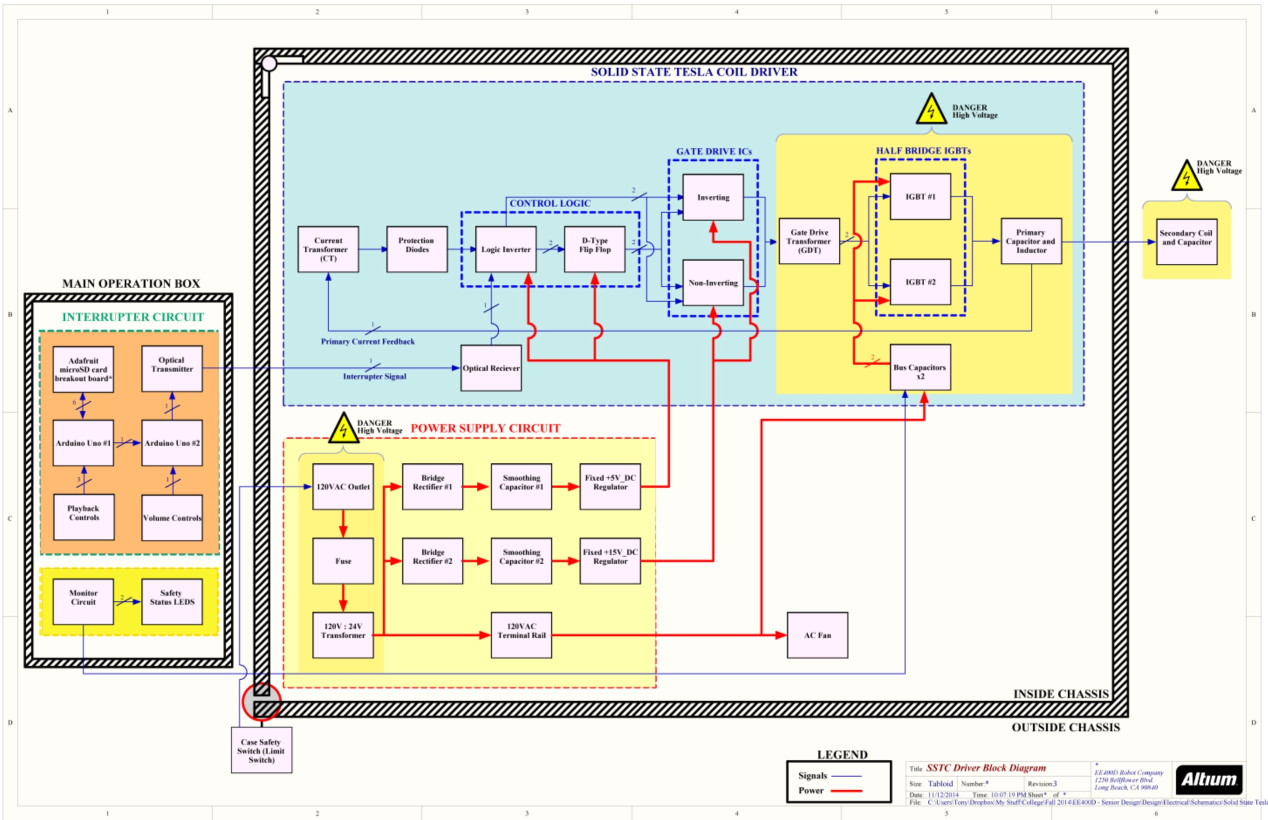
Level 2 Requirements

- For safety purposes, a Tesla Coil controller will be designed to allow MIDI files to be selected remotely by means of an optical cable connected to an Arduino from a distance of at least 8 ft. away from the Toroid of the coil. This is the minimum safety clearance distance as determined by the NFPA.
- CSULB COE states that we need to determine whether safety needs for the department are met (e.g., training, personal protective equipment, and corrective measures including non-mandated items identified in safety inspections).
- CSULB COE states that we need to assure that hazards are proactively identified and corrected by implementing engineering or administrative controls, or by assuring use of necessary personal protective equipment.
- OSHA Electrical Standard 1910.303(h)(2)(iii)(B) states that "equipment shall be marked with appropriate caution signs".
- In order to create the sparks necessary to produce sound, a driving circuit will be designed to utilize 120 Volts RMS AC and less than 15 Amps RMS as the input and convert this to 170 Volt peak-peak pulses which will charge the primary capacitor.
- In order to adjust the sound output level of the coil to remain between 62 and 98 dB from the NFPA safe distance of 8 feet away, the Tesla coil controller will be designed to have a volume control knob.
- In order to use only one external power cable, a DC power supply will be designed to provide 5 VDC and 15 VDC. These values were obtained from the datasheets of the components that they will be powering. These include the 74HCT14N hex inverting Schmitt trigger and 74HCT74N dual D-type flip-flops which require a 5 VDC supply. This also includes the UCC37321P and UCC37322P IC MOSFET drivers which require a 15 VDC supply.
- For ease of use, the Tesla controller will be designed to have at minimum, Play, Stop, & Next Track controls in order to navigate multiple MIDI files stored on a storage device.
- The Tesla controller will be designed to be able to store a minimum of 21.72 KB of data, which equates to 2 minutes 43 seconds of sound per song. The minimum length of a Top 100 Song on iTunes was found to be 2 minutes 43 seconds. According to the MIDI Manufacturer's Association, the size of a MIDI file is about 10 KB per minute of sound.

Information on how these requirements will be verified can be found here.

The Preliminary Project Documentation can be found **here.**

System Block Diagram



The figure above is a system block diagram of the Tesla coil. The Tesla coil can be broken down into three main subsystems. These include the DC power supply, the Tesla coil driving circuit, and the Tesla controller/interrupter. The DC power supply provides 5 VDC and 15 VDC to the driving circuit in order to power on the control and feedback logic. The main blocks of the driving circuit are the control logic and the half-bridge. The interrupter controls the driving circuit by means of light pulses that travel through an optical cable. For a more in depth explanation of the driving circuit, click here. For a more in depth explanation of the DC power supply and its design, click here. A PDF of the system block diagram is available here.

Design Solutions

Spark Gap vs SSTC Design Consideration

Two different designs were initially considered for the Tesla coil. These were a spark gap design, and a solid state design. The final design chosen was the solid state Tesla coil because it was the only design that allowed the output to be modulated. For more information, see this post.

MOSFET vs IGBT Design Consideration

Two different devices were considered for use as solid state switches in the Tesla coil. Despite IGBTs typically being used in lower frequency applications, the benefits of having higher output power as well as higher voltage ratings makes IGBTs the better choice for the Tesla Coil project. Thus, IGBTs were chosen for use in this project. For more information, see this post.

Prototyping, Simulations, & Trade-Off Studies

Transformer Trade-Off

Three different transformers were considered for use in the Tesla coil as part of the DC power supply. The main factors considered were mounting style, current rating, and price. Further details can be found here.

IGBT Trade-Off

Three different IGBTs were considered for use as part of the high voltage driving circuit. The main factors considered were voltage rating, continuous and pulsed current rating, power rating, and price. Further details can be found here.

Simulation of IGBT Half Bridge

The purpose of this simulation was to determine the current and voltage ratings of the IGBT's (Insulated Gate Bipolar Transistors) used in the driver circuit. In order to determine the ratings needed, the maximum values of voltage and current were found using MatLab's SimuLink. This met the secondary requirement for the peak to peak output DC pulse values. Further information can be found here.

Simulation of Protection Diode Circuitry

This portion of the control logic was simulated to verify that feedback signals would be properly conditioned for use by the digital circuitry. This necessary signal conditioning was verified using MultiSim. Further information can be found here.

Power Supply Simulation

In order to power the control logic and gate drive IC circuit components, the design of a 5V and 15V DC power supply was required. Simulation was needed to prove that the design would output the correct DC voltages. This simulation was needed to verify the level two requirement for the DC power supply. Further Information can be found here.

Power Supply Breadboard Testing

In order to further verify the power supply design before ordering the respective PCB, testing on a breadboard was necessary. This testing was needed to verify the necessary output voltages for the DC power supply level two requirement. Further Information can be found here.

Subsystem Design

Control Logic PCB

The control logic PCB design was needed per the company president's request. It was designed to control the switching of the IGBT half bridge. Further information can be found here.

Arduino Code for MIDI File Playback

The first Arduino used in the project contains the logic for reading/closing MIDI files on an SD card, as well as logic for the playback controls. The code is written in the model of a finite state machine. The finite state machine is implemented by means of a switch statement in the main program loop. This Arduino Uno and code meets the level two requirement for play, stop and next song in this section. Further information can be found here.

Flowchart of Code for Arduino #2 (Serial MIDI to Optical Pulses)

The second Arduino Uno in the Tesla coil project utilizes the Serial-MIDI data that is transmitted from the first Arduino Uno, processes the data, and outputs optical pulses. A flowchart was created to illustrate the program logic. Further information can be found here.

SD Card Data Verification

The successful storage of data for the Tesla controller was verified using checksum hashes, thus meeting the level two requirement for data storage. Further information can be found here.

Tesla Coil Base

The Tesla coil base design had multiple criteria that needed to be met in order to be able to work with the high voltage aspects of this project. The first and foremost design consideration was safety. A two tiered design was chosen to effectively separate the high voltage circuitry from the low voltage circuitry. This design meets multiple safety requirements in addition to the single power cord level one requirement. More information can be found here.

Tesla Controller Interface Definition and Schematic

Two Arduino Unos are being used for the Tesla controller. The first handles MIDI file playback and playback controls, while the second handles conversion from MIDI protocol to optical pulses. The physical pin connections and Fritzing schematic can be found here.

Verification Test Plans

Control Logic PCB Verification

Proper operation of the control logic PCB was verified with point to point tests. Full testing results can be found here.

Power Supply

In order to verify that the DC power supply PCB supplied the correct DC voltages, testing was performed to verify that the necessary level two requirements were met. Further information can be found here.

Project Status

Heat Budget

The heat budget was created to ensure that the inside of out Tesla enclosure did not become exceedingly hot. It was also used to verify that the fan used was of an adequate CFM rating. Further information can be found here.

Power Budget

The power budget was created to ensure that the Tesla coil did not draw more than the 15A available from a household outlet. The calculated current draw is 7.5 Amps. For more information, see the blog post here.

Task Assignments

The assignments listed below are some of the major tasks that each group member has completed.

- Matt Maniaci
  - Design DC Power Supply
  - Simulate DC Power Supply
  - Perform Output Voltage Calculations
  - Test DC Power Supply (Breadboard the circuit)
  - Build Power Supply PCB
  - Build Tesla Coil Base Enclosure
  - Transformer Trade-off
- Tony Huynh
  - Design Driver Circuit
  - Simulate Diode Protection Circuit
  - Design PCB for Driver Circuit Control Logic
  - Design Monitoring Circuit for Driver Circuit
- Tommy Tang
  - Maintain Bill of Materials
  - Assist Project Manager with Level 1 and Level 2 Requirements
  - Perform Secondary Coil Inductance Calculations
  - Write Code for Tesla Controller

- Perform RC Circuit Calculations for Driver Circuit
- Varnish Secondary Coil
- Power Budget
- Heat Budget
- IGBT Trade-off

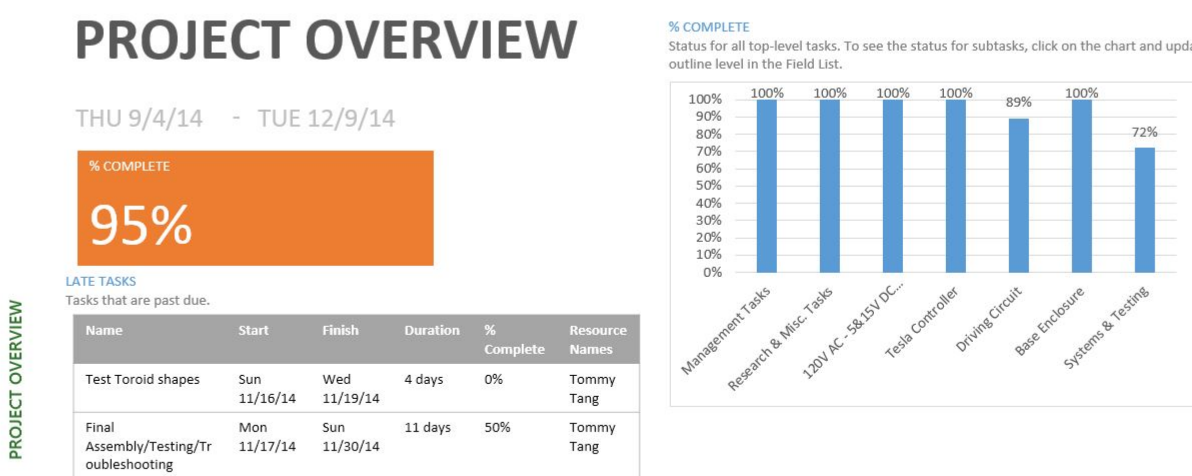
Budget

The project costs are currently $599.55. The DC power supply cost a total of 103.21. The driver circuit cost a total of $171.55. The Tesla controller cost was $143.29. Miscellaneous costs were $181.51. This leaves the project with a budget margin of 16.75%. This meets the level one requirement of staying below $700. For more information, see the bill of materials post here.

Schedule

The project schedule has been broken down by the subsystems of the project. These include the DC power supply, the coil driver, and the Tesla controller. The DC power supply has a design phase, a simulation phase, a PCB design phase, and a test and assembly phase. The coil driver schedule has been broken down in a similar manual, it includes a design phase, a simulation phase, a PCB design phase, and a test and assembly phase. Due to the fact that an Arduino is being used as the base for the Tesla controller, the majority of the time for the controller was spent on writing code. Outstanding tasks that have yet to be completed include final troubleshooting, and testing different toroid shapes. The reason for this is that the Tesla coil is currently non-operational. For further information on the project schedule, see the post here.

Project Percent Completion and Burndown Diagram



Name	Start	Finish	Duration	% Complete	Resource Names
Test Toroid shapes	Sun 11/16/14	Wed 11/19/14	4 days	0%	Tommy Tang
Final Assembly/Testing/Troubleshooting	Mon 11/17/14	Sun 11/30/14	11 days	50%	Tommy Tang

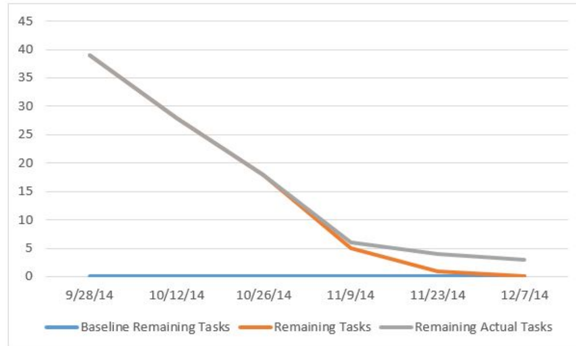
Thu 9/4/14 - Tue 12/9/14

BURNDOWN

BURNDOWN

WORK BURNDOWN

Shows how much work you have completed and how much you have left. If the remaining cumulative work line is steeper, then the project may be late. Is your baseline zero?



TASK BURNDOWN

Shows how many tasks you have completed and how many you have left. If the remaining tasks line is steeper, then your project may be late.

The project is currently at 95% completion. This is due to the fact that troubleshooting was not completed, and so it remains at 50%. Due to troubleshooting not being completed, the toroid shape tradeoff study could not be completed to measure the effect of different shapes on output spark length.