SDMAY19-11: MIDI Zeusaphone

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Client and Adviser: Dr. Joseph Zambreno (ISU ECpE)
Website: http://sdmay19-11.sd.ece.iastate.edu/

Problem Statement

- Requested solution is to build a “Zeusaphone” - a singing tesla coil
- Showpiece for Iowa State ECpE Department Demos
- Inspire next generation of ECpE students

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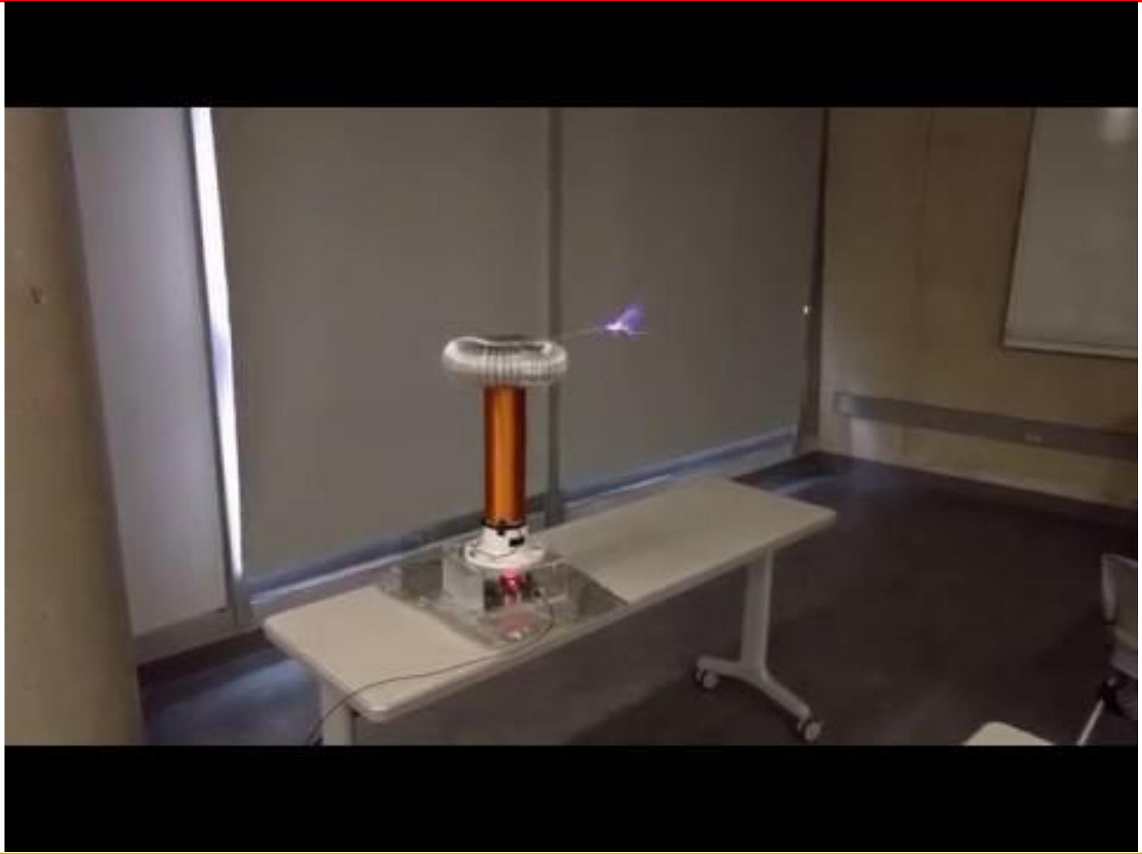

Functional Requirements

- Powered by standard 120V, 60Hz wall outlet
- Generate arcs easily visible to audience
- Capable of playing two notes simultaneously
- MIDI Keyboard input for real-time, live music playing
- Saved MIDI file input for preloaded songs

Non-Functional Requirements

- Total cost less than $1000 - budget given by client
- Safe to operate and observe - safety cannot be compromised for functionality
- Size:
  - Height less than 2 feet
  - 1 foot by 1 foot area
- Easy to move, store, transport, and set up for demonstrations
- Reliable for demonstrations

Market/Literature Survey

- OneTesla is a company that makes Zeusaphones
- Steve Ward and Kaizer Power Electronics have several designs and useful information
- Largely a hobbyist field - little commercial use beyond entertainment

Deliverables

- Transmitter Module with USB MIDI Keyboard
- Tesla Coil Module
- Design Document
- User Manual and Safety Document

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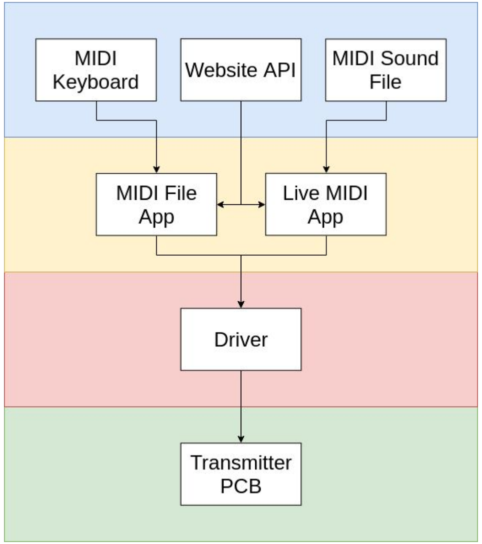
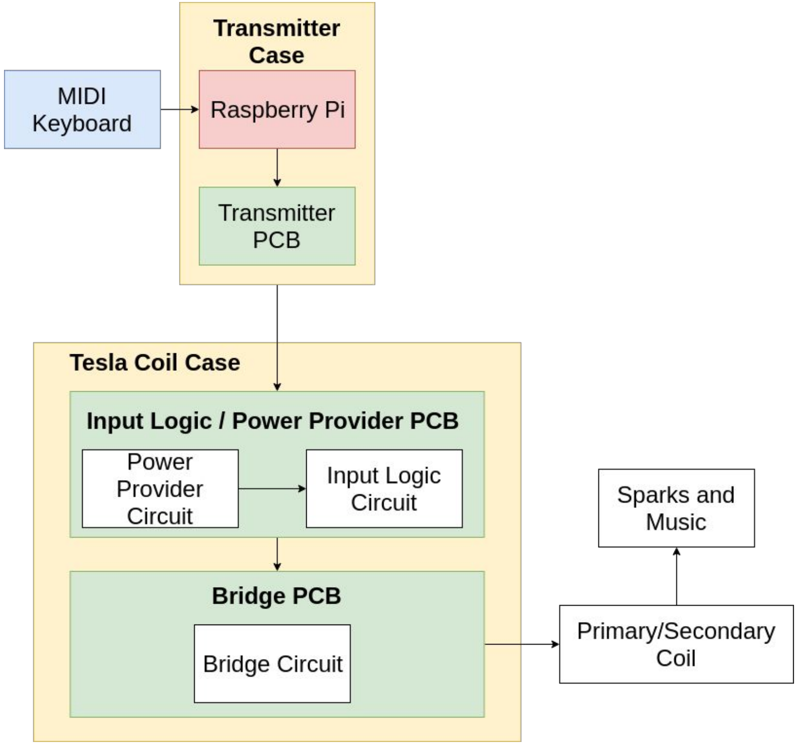
Design Architecture



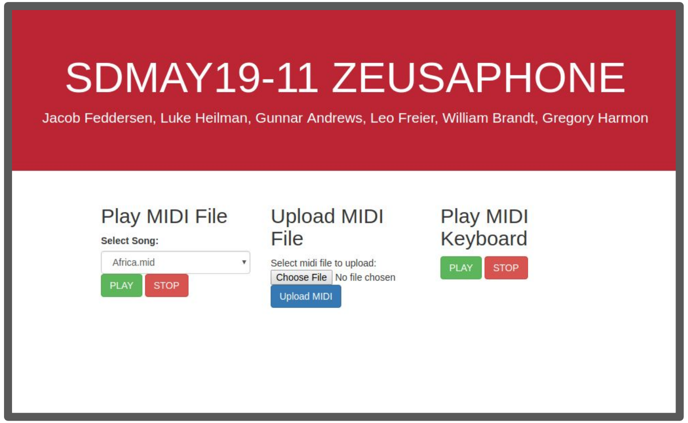
Software Architecture



Hardware Architecture

Software Design - User Interface

- Web Interface hosted by Raspberry Pi
  - Raspberry Pi serves its own WiFi access point, secured with WPA2
  - Upload/Delete MIDI files from Pi
  - Play MIDI files stored on Pi
  - Enable/disable live keyboard input
- Handled with HTML front-end, PHP back-end



Software Design - Application Layer

- Receives MIDI input and transforms the format for the driver layer:

```
C<channel number>F<frequency>;
```

- Two main programs:
    - MIDI file input
        - MidiFile library - read and play stored MIDI files
    - MIDI keyboard input
        - RtMidi library - read live input events from MIDI keyboard

```
Note On: 56 31080
Sending `C0F207.652349;`
Note Off: 56 31199
Sending `C0F0;`
Note On: 58 31200
Sending `C0F233.081881;`
Note Off: 58 31439
Sending `C0F0;`
Note On: 51 31440
Sending `C0F155.563492;`
Note Off: 51 31559
Sending `C0F0;`
Note On: 53 31560
Sending `C0F174.614116;`
Note Off: 53 31679
Sending `C0F0;`
Note On: 55 31680
Sending `C0F195.997718;`
Note Off: 55 31919
Sending `C0F0;`
```

Software Design - Driver Layer

- Provides server for application layer
  - Listen for note events on local UNIX socket
- Designed to be modular
  - Works for keyboard and file input
- Output an analog square wave at frequency specified
  - Two pins - one for each channel
  - Hardware PWM pins - precise waveform generation

Hardware Design - Transmitter Circuit

- Takes Pi output and merges the two waveforms
- Uses 555 timers to filter overlapping pulses
  - Raspberry Pi output triggers both timers
  - First timer outputs pulse to tesla coil
  - Second timer creates “dead period” during which the first cannot be activated again
- Outputs over the fiber optic cable
- Switch to turn on/off fiber optic output
- Power-off push button to shut down software

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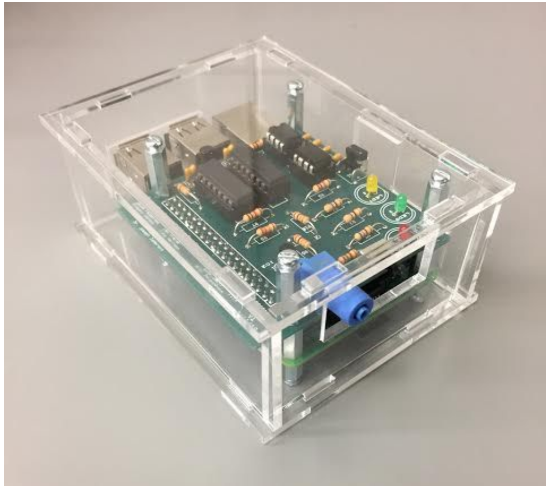
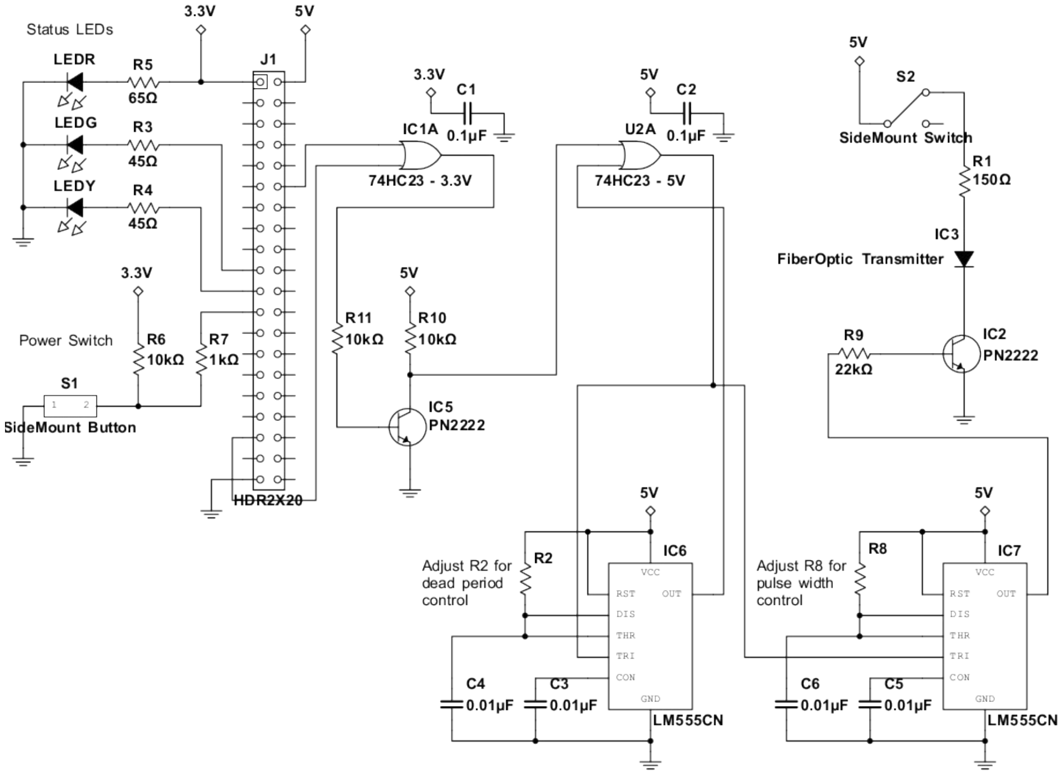
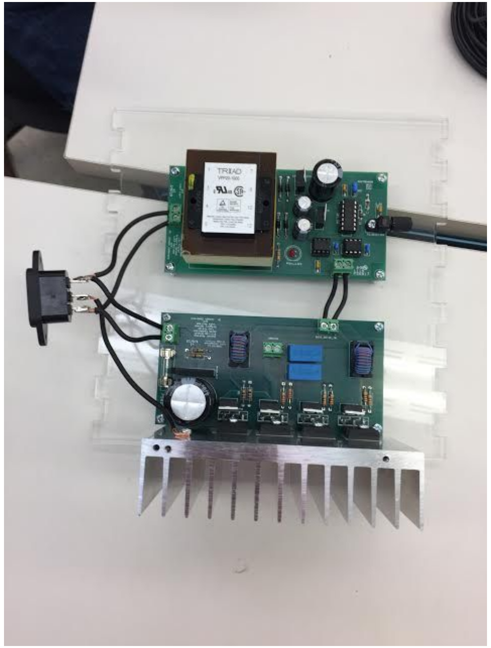
Hardware Design - Transmitter Circuit





Hardware Design - Power Provider & Input Logic

- Power provider steps down 120VAC to 10VAC, regulators give 12V and 5V DC rails
- Input logic receives signal from transmitter
- Transmitter signal synced with coil through antenna feedback
- Outputs gate drive signals to bridge circuit



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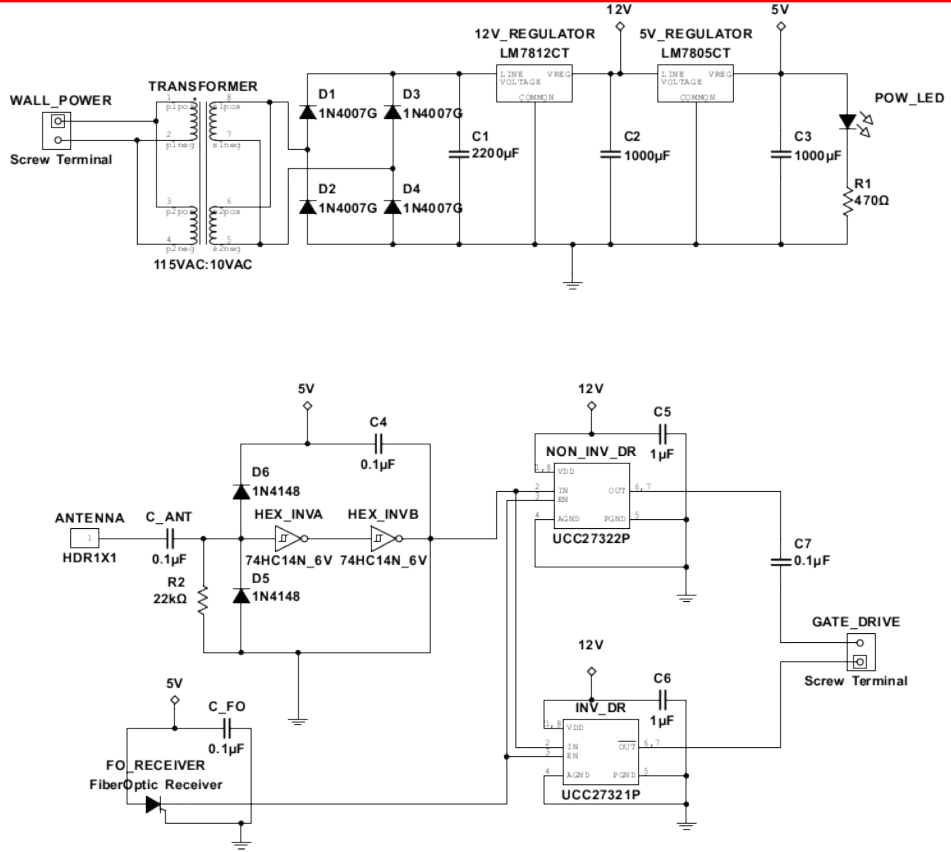
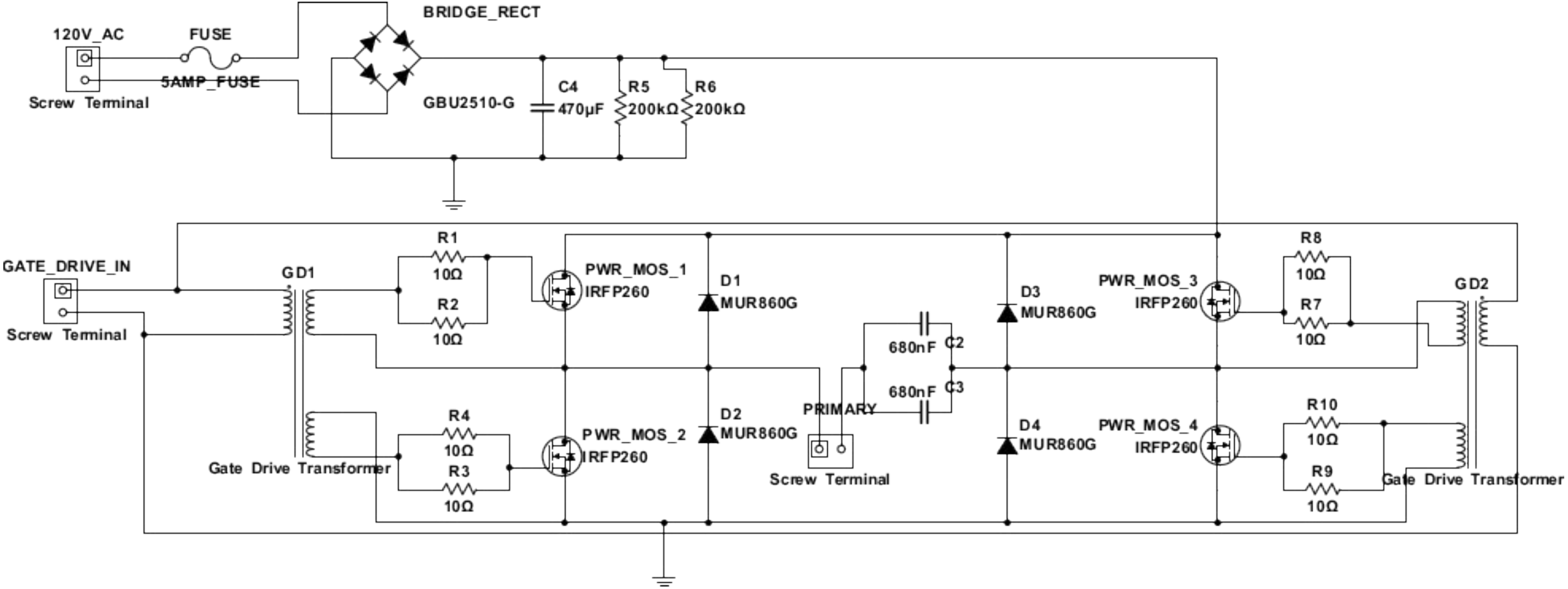
Hardware Design - Power Provider & Input Logic



Hardware Design - Bridge Circuit

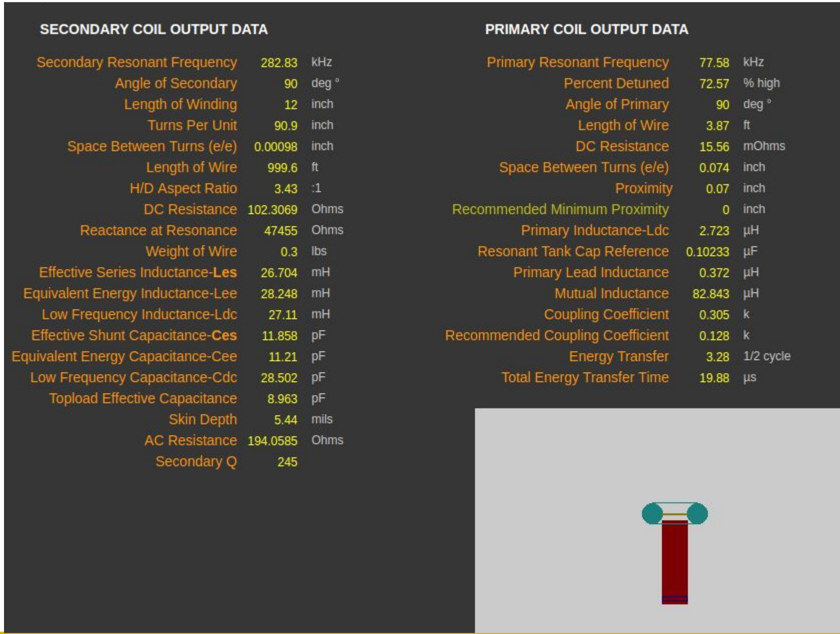
- Input: +/- Gate Drive Wires
- Output: Tesla Coil Primary Connection
- Rectifier for 120VAC mains connection with fuse
- Full bridge of IRFP260 Power MOSFETs
- Gate Drive Transformers for MOSFET gate isolation

Hardware Design - Bridge Circuit



Hardware Design - Tesla Coil Simulation

- Used JavaTC to get ballpark performance parameters
  - Commonly used for tuning tesla coils
- Also included calculators for number of turns, gauge of wire, etc.



SECONDARY COIL OUTPUT DATA

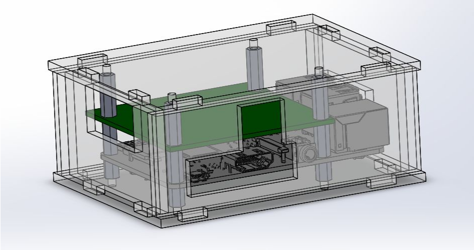
Secondary Resonant Frequency	282.83	kHz
Angle of Secondary	90	deg °
Length of Winding	12	inch
Turns Per Unit	90.9	inch
Space Between Turns (e/e)	0.00098	inch
Length of Wire	999.6	ft
H/D Aspect Ratio	3.43	:1
DC Resistance	102.3069	Ohms
Reactance at Resonance	47455	Ohms
Weight of Wire	0.3	lbs
Effective Series Inductance-**Les**	26.704	mH
Equivalent Energy Inductance-Lee	28.248	mH
Low Frequency Inductance-Ldc	27.11	mH
Effective Shunt Capacitance-**Ces**	11.858	pF
Equivalent Energy Capacitance-Cee	11.21	pF
Low Frequency Capacitance-Cdc	28.502	pF
Topload Effective Capacitance	8.963	pF
Skin Depth	5.44	mils
AC Resistance	194.0585	Ohms
Secondary Q	245	

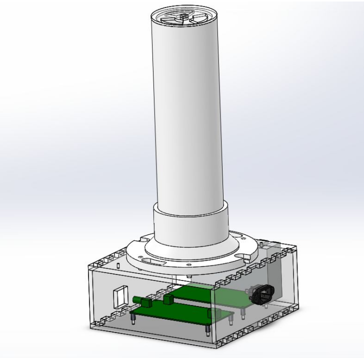
PRIMARY COIL OUTPUT DATA

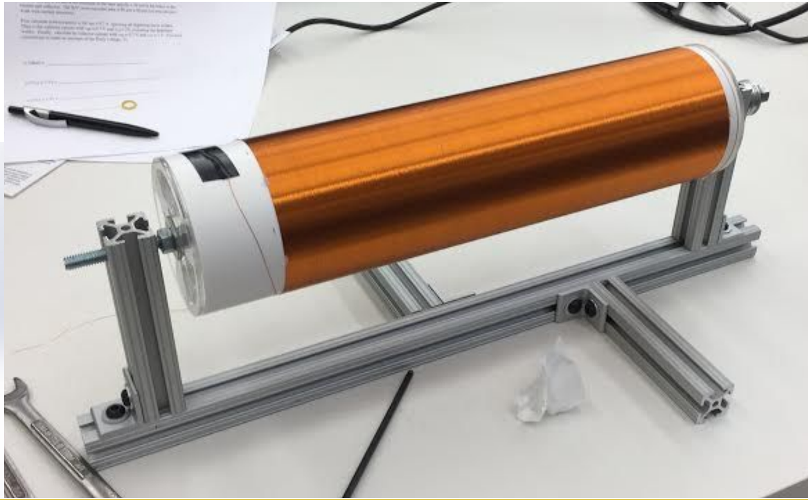
Primary Resonant Frequency	77.58	kHz
Percent Detuned	72.57	% high
Angle of Primary	90	deg °
Length of Wire	3.87	ft
DC Resistance	15.56	mOhms
Space Between Turns (e/e)	0.074	inch
Proximity	0.07	inch
Recommended Minimum Proximity	0	inch
Primary Inductance-Ldc	2.723	µH
Resonant Tank Cap Reference	0.10233	µF
Primary Lead Inductance	0.372	µH
Mutual Inductance	82.843	µH
Coupling Coefficient	0.305	k
Recommended Coupling Coefficient	0.128	k
Energy Transfer	3.28	1/2 cycle
Total Energy Transfer Time	19.88	µs

Hardware Design - Construction

- Transmitter Case and Tesla Coil Base - Laser Cut Acrylic
  - Modeled in Solidworks
- Tesla Coil Secondary
  - Built custom rig to wind secondary with a drill
  - ~1000 turns







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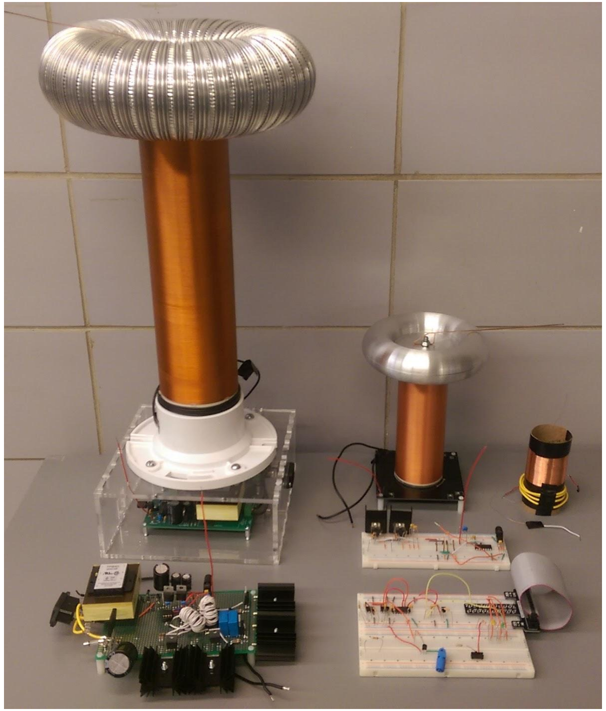
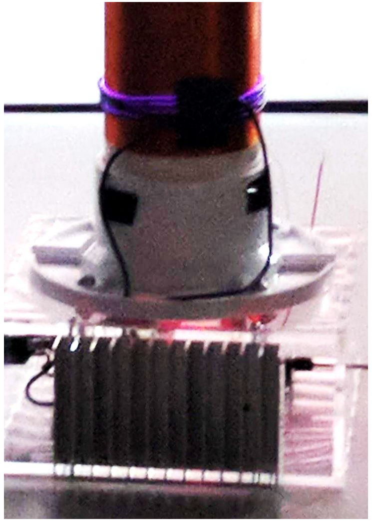
Testing

- Oscilloscope was our friend
- Started with the mini coil and breadboard circuits
- Analyzed the OneTesla coil
- Used the secondary coil of the OneTesla with our perfboard circuit
- Lastly put together our PCBs and own coil



Major Challenges

- Overlapping pulses when playing multiple notes
  - Caused an extra long pulse, which resulted in a very long spark and a loud “pop” in the music
  - Debugged using oscilloscope
  - Solved using filtering circuit on transmitter
- Electrical noise interfering with input logic of tesla coil
  - Noise started when stepping up to full bridge driving circuit
  - Traced noise back to the antenna input using oscilloscope
  - When antenna input was attached to oscilloscope, noise disappeared
  - Added pull-down resistor to input; noise was solved
- Sparks and glow around primary coil on final design
  - Primary was too high on secondary coil; voltage differential was too great



Risks and Mitigation

- Obviously a high-voltage device
  - Is safe from a distance - stay about 10 feet away
  - Wait 5 minutes after power-off for tank capacitors to discharge
- Hardware-intensive for team composition
  - 4 CprEs and 2 EEs
  - Hardware design was behind this semester
  - Lots of time invested to learn and understand hardware, PCB design, and physical construction

Conclusions and Future Work

- We successfully completed the project
- Future work
  - Redesign the transmitter for variable pulse lengths
  - Include an arduino or FPGA for better pulse control
  - Better top load construction
  - Upgrade to a DRSSTC
  - Use secondary coil current feedback instead of antenna

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Questions?

Appendix

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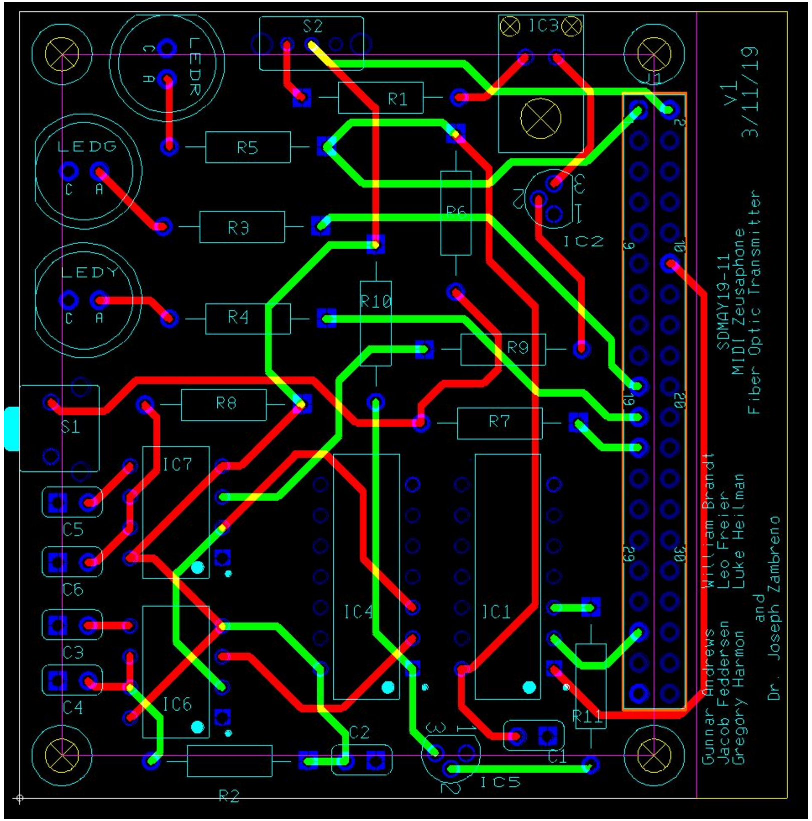
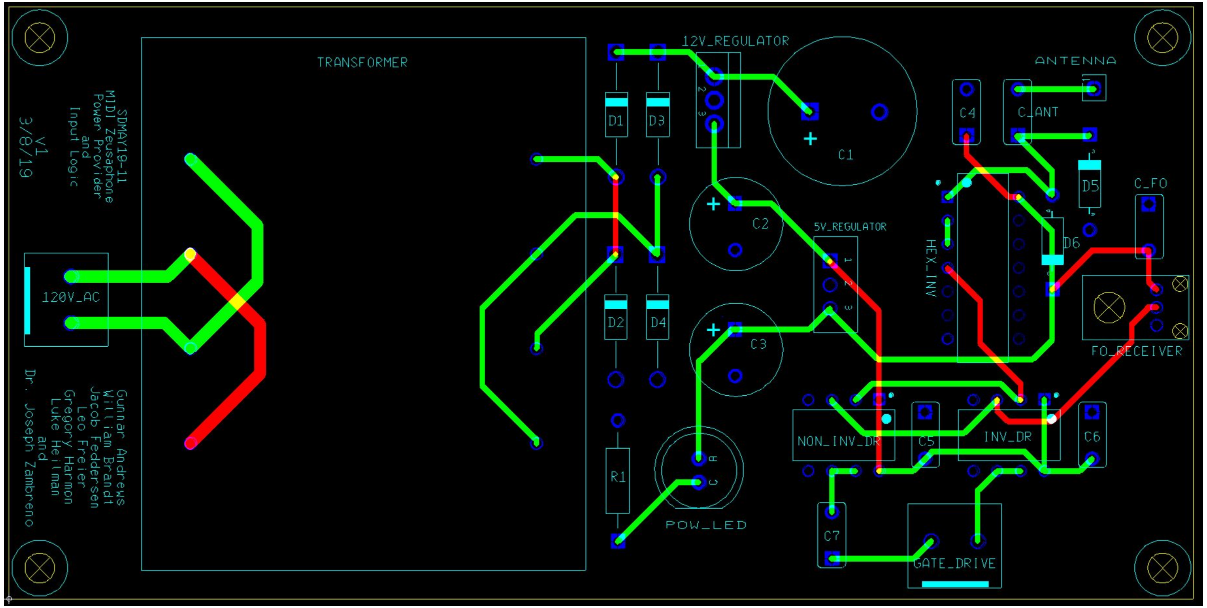
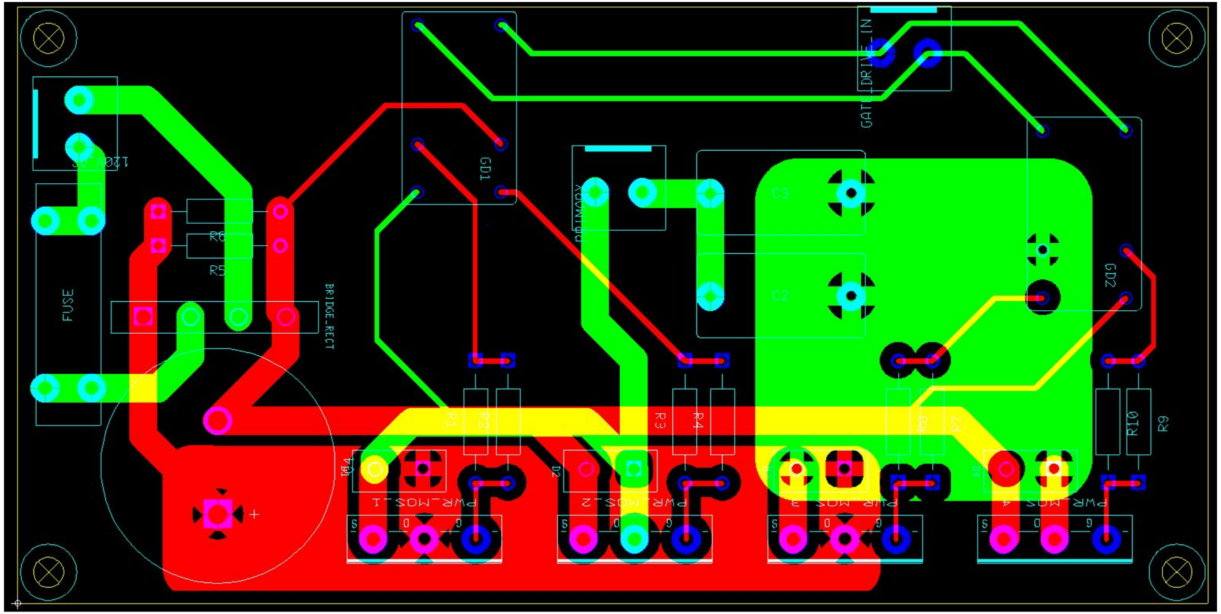
Transmitter Circuit PCB



PP/IL Circuit PCB



Bridge Circuit PCB



555 Timer Waveforms