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Musical Tesla Coils- Meeting 3/Design Review 1

Agenda:

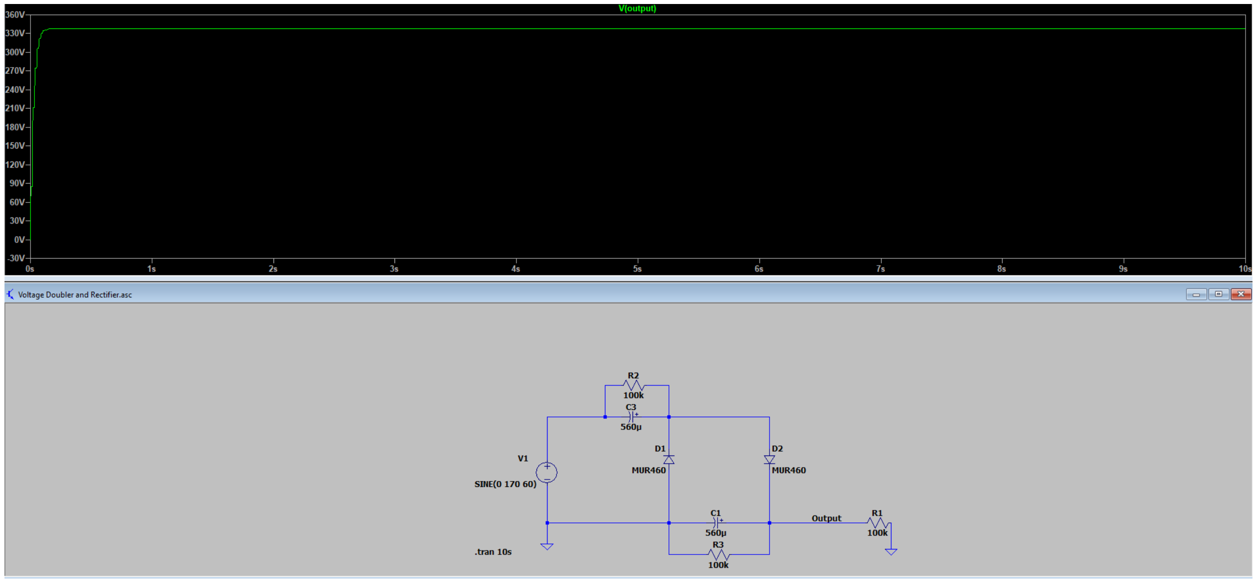
- What we have done since last time
- Go through each of the requirements that we were asked to meet for this Design Review 1
    - Design of each subsystem
    - Description of major components
    - Essential connections
    - Questions
    - Website link where our team documents are posted already

Since last time:

- Selected op-amp mosfet drivers for our design
    - UCC27425 - capable of very fast switching speeds with lots of sink current. Specified for applications of high frequency switching of driver circuits -- exactly what we're looking for
- Designed Tesla coils
- Spec breaker
    - https://www.digikey.com/en/products/detail/weidm%C3%BCller/9926251010/1788798 from wall outlets to coils
- Spec optocoupler
    - Between microcontroller and driver
    - https://www.digikey.com/en/articles/microcontrollers-and-fiber-optics
    - Between remote and microcontroller
    - https://www.digikey.com/en/articles/microcontrollers-and-fiber-optics

Provide a detailed design of each major subsystem

Voltage doubler and rectifier:



~339 V rectified DC signal from 120 V_{RMS} mains wall voltage.

Mosfet driver:
Selected UCC27425 for our mosfet drivers. These are quite cheap ($1.05) per unit and we only need two, one for each of our tesla coils. This will be wired in a simple non-inverting configuration which is capable of switching well above our desired frequency of ~125 kHz and can output up to 18V, which is plenty more than the ~7V max that we need to drive the gates of our IGBTs.

Inverter:
Industrial IGBT packages:
https://www.digikey.com/en/products/detail/littelfuse-inc/MG12150S-BN2MM/5034253
This is a high quality IGBT industrial module that is professionally built to handle high frequency switching operation at large voltages. A significant chunk of the overall size of these modules is due to built in heat sinks that sink the moderately high temperatures that can be produced at frequencies, currents, and voltages that we are going to be operating them at.

Tesla Coils: *designed using JavaTC (a tesla coil secondary/primary design website)* (secondary - primary cannot be designed completely until secondary is actually built. Our first next step is to begin construction so we have plenty of time to adjust primary design as needed based on final product for secondary. Preliminary numbers for primary given based on numbers that we have designed for our secondary.)

- Secondary coil:

- Wire size = 30 AWG
- Turns: 1650
- Radius= 2.25 inches
- Height = 18 inches
- Resonant frequency = 147.83 kHz
- Capacitance = 13.3 pF

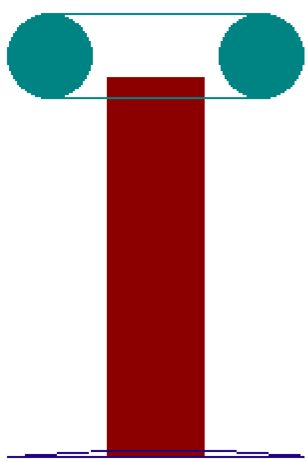
- Primary coil (preliminary):
    - Wire size = .25 inch diameter
    - Turns = 8
    - Radius = 3 inches
    - Height = .25 inches
    - Capacitance = 0.088
        - 940C20S22K-F (polypropylene): VDC- 2kV; C- 0.022uF
        - Four of them in parallel

SECONDARY COIL OUTPUT DATA

Secondary Resonant Frequency	147.49	kHz
Angle of Secondary	90	deg °
Length of Winding	18	inch
Turns Per Unit	91.7	inch
Space Between Turns (e/e)	0.00088	inch
Length of Wire	1943.9	ft
H/D Aspect Ratio	4	:1
DC Resistance	198.9521	Ohms
Reactance at Resonance	63179	Ohms
Weight of Wire	0.59	lbs
Effective Series Inductance-**Les**	68.175	mH
Equivalent Energy Inductance-Lee	71.455	mH
Low Frequency Inductance-Ldc	69.429	mH
Effective Shunt Capacitance-**Ces**	17.08	pF
Equivalent Energy Capacitance-Cee	16.296	pF
Low Frequency Capacitance-Cdc	29.449	pF
Topload Effective Capacitance	13.341	pF
Skin Depth	7.51	mils
AC Resistance	284.3694	Ohms
Secondary Q	222	

PRIMARY COIL OUTPUT DATA

Primary Resonant Frequency	130.13	kHz
Percent Detuned	11.77	% high
Angle of Primary	4	deg °
Length of Wire	20.94	ft
DC Resistance	3.48	mOhms
Space Between Turns (e/e)	0.251	inch
Proximity	0.62	inch
Recommended Minimum Proximity	0	inch
Primary Inductance-Ldc	18.699	μH
Resonant Tank Cap Reference	0.06227	μF
Primary Lead Inductance	0	μH
Mutual Inductance	185.621	μH
Coupling Coefficient	0.163	k
Recommended Coupling Coefficient	0.131	k
Energy Transfer	6.13	1/2 cycle
Total Energy Transfer Time	23.18	μs



Microcontroller: Simple control programming. Encode output square wave at resonant frequency of coil circuitry and output this to the mosfet drivers. For songs, turn square wave off and on at frequency of the musical note we want to play. The square wave output will be a constant value in the ballpark of ~150 kHz and the musical note information will be contained in vector sequenced in the order that we want them to be played in (according to the song.)

Wired Remote: 5 position rotary switch to select 5 songs which are connected through optocoupler to the microcontroller. Microcontroller analog reads this input and outputs electrical signal to driver circuitry depending on input received from remote. This is a simple selection line. (i.e. song 0, song 1, ..., song 4).

Give a detailed description of all major componentsand describe the function they serve in your design and how the devices work:

Voltage doubler: Doubles wall voltage and rectifies to a usable DC voltage through use of diodes and capacitors. (simple electronics design)

Mosfet driver: Takes input from the microcontroller and outputs the same square wave with increased magnitude (operating as a very efficient, high frequency non-inverting amplifier). This will give us the necessary ~7V to drive the operation of our IGBT gates. We need these because the microcontroller will not be outputting enough voltage on its square wave output signal by itself to drive the gates of the IGBTs.

Inverter: Switches output of mosfet driver to energize the Tesla coils. This creates a square wave which is sent to the Tesla coils. This is matched to the resonant frequency of the coil circuitry in order to build up massive amounts of voltage (~100s kV) on the surface of the toroid so that the air is ionized and plasma freely flows, creating music.

Tesla Coils: Build up electromagnetic energy. The creation of plasma from the toroid happens as a result of simply building up large voltages on the surface of the toroid. When RLC circuit operates at resonance with an AC current source, the electromagnetic energy builds up and we can produce the 100s of kV needed to ionize the air and create the plasma that we are going to use to play our music.

Microcontroller: Microcontroller will do 3 things. (1) Read analog input from remote. (2) Output square wave with a frequency that matches the resonant frequency of our Tesla coil circuitry. This is a very simple logical high low output at a specific frequency that isn't changing. (3) Turning the output square wave on and off a certain number of times per second corresponding with the frequency of the musical note that we want to play.

Wired Remote: 5 position rotary switch will output signal to optocoupler which connects to microcontroller. This will change input based on position and we can read it at the microcontroller as an analog input in order to select our song.

<u>Specify essential connections on all major components.</u>

- Wall outlet 120 V_{RMS} which goes to voltage doubler circuit which outputs 340 V_{DC}
- Doubler circuit goes to + bus for IGBT
- GND from wall outlet goes to - bus for IGBT inverting circuitry
- Wallwart connected to wall outlet 120 V_{RMS} to power the board which will be around 5 V after step down.
- Remote to microcontroller (0-3.3 V)
- Power to microcontroller from wallwart (either 3.3V or 5V)
- GND to microcontroller from wallwart
- Microcontroller to mosfet driver (1-3 V)
- Mosfet driver to IGBT (up to 7.5 V)
- IGBT to primary coil (340 or 0 V)
- Primary coil not physically connected but near secondary
- Secondary coil to toroid
- Secondary coil physically to ground
- Most current we expect to draw is on the order of 10s of Amps in inverting switching circuitry and our IGBTs are rated for 100s of Amps

<u>There are likely to be a set of problems that you are not clear on how you will solve them. Give a list of these items and an action plan to reduce them to solved problems</u>:

No questions at this time. Only thing we are a bit uncertain of is if the optocoupler is sufficiently isolating the remote. If the optocoupler is far enough away from the coils (closer to the remote side) then we don't think there should be a problem but we need to continue to research this (primarily a safety concern, but given that it is electrically isolated there is nowhere for the current to go).

<u>Voltage isolation.</u>

Demonstrate that the team has successfully accessed the team web site by placing Proposal and High Level design documents on the team web site with links:

Done. See website here: http://seniordesign.ee.nd.edu/2021/Design%20Teams/musical/index.html