Griffin Rzonca, David Mengel, Aditya Anand

ECE 445

9/10/23

Tesla Coil Guitar Amp - Project Proposal

I. Introduction

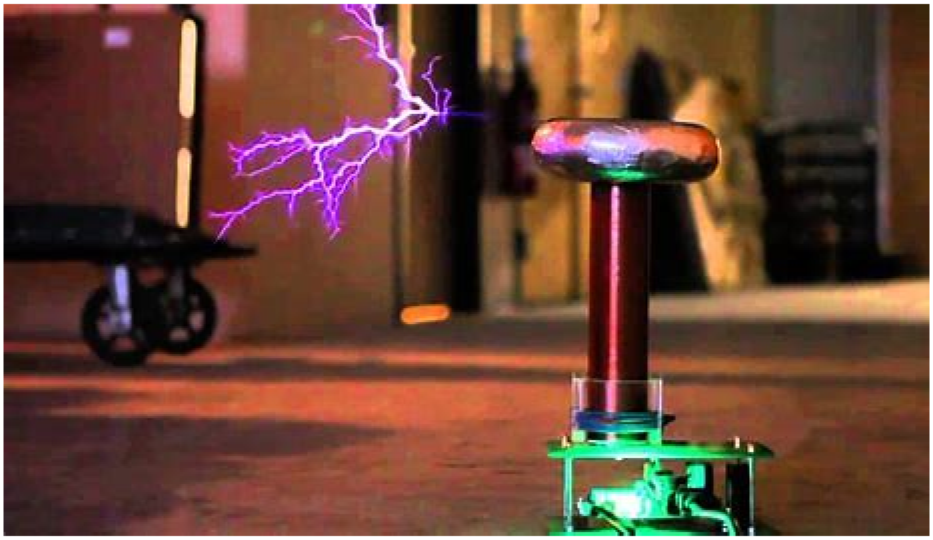
Problem:

Musicians are known for their affinity for flashy and creative displays and playing styles, especially during their live performances. One of the best ways to foster this creativity and allow artists to express themselves is a new type of amp that is both visually stunning and sonically interesting.

Solution:

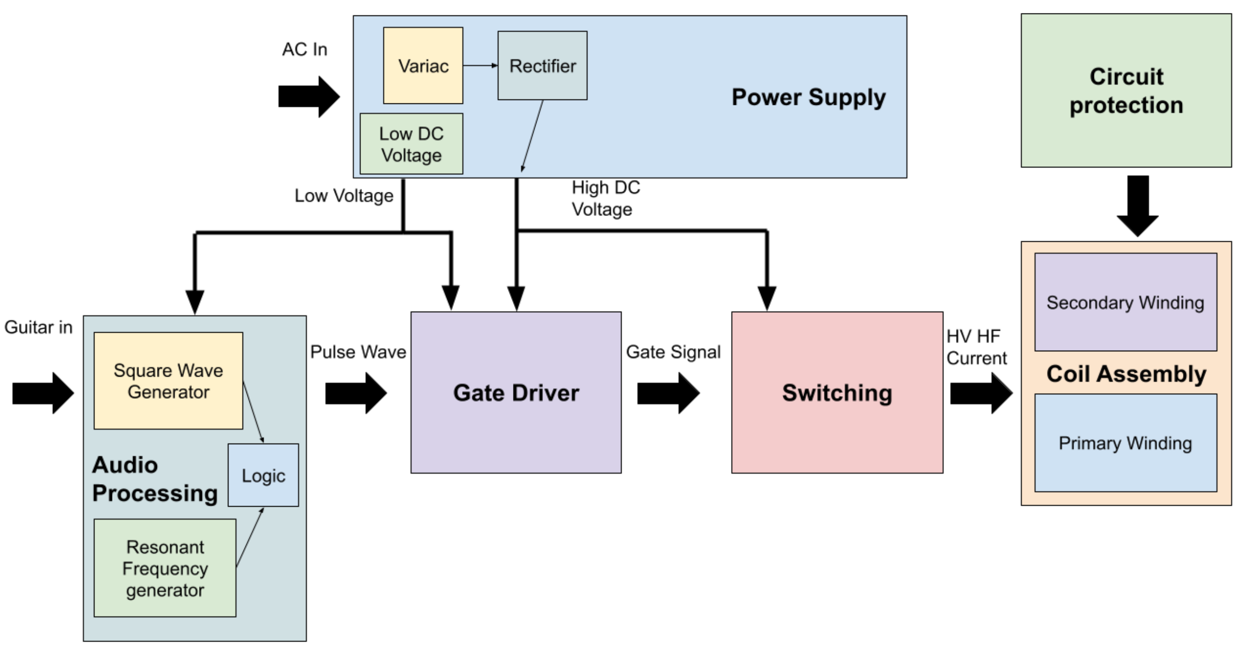
We propose a guitar amp that uses a Tesla coil to create a unique tone and dazzling visuals to go along with it. The amp will take the input from an electric guitar and use this to change the frequency of a tesla coil's sparks onto a grounding rod, creating a tone that matches that of the guitar.

Visual Aid:



II. Design

Block Diagram:



Subsystem Overview & Subsystem Requirements:

Audio Processing:

This will convert the output of the guitar into a pulse wave to be fed as a driver for the tesla coil. This can be done using a network of op-amps. We will also use an LED and phototransistor to separate the user from the rest of the circuit for safety purposes, so that they have no direct connection to any high voltage circuitry. In order to operate our tesla coil, we need to drive it at its resonant frequency. Initial calculations and research have this value somewhere around 100kHz. The ESP32 microcontroller can create up to 40MHz, so we will use this to drive our circuit. In order to output different notes, we will use pulses of the resonant frequency, with the pulses at the frequency of the desired note. This output will then be passed to the gate drivers.

Criterion for success:

- Audio processing unit must be compatible with the voltage and current levels of an electric guitar input, and line input.
- Audio processing unit must be able to produce a pulse wave from said input signal that is at the same frequency
- Output bandwidth must be well above Tesla Coil Resonant Frequency (~100khz)
- Audio processing unit must be able to produce all outputs that are needed to communicate with gate driver. This means output voltage level must be compatible with gate driver, unit must be able to produce pulses at resonant frequency if needed to drive

coil, unit must be able to provide output that corresponds to acceptable output power of final coil

- Audio processing must operate on a single rail of either 3.3v, 5v, 9v, or 12v. (not necessarily all, but one of the four)

Gate Drivers:

We will use a microcontroller, an ESP 32, to control an IR2110 gate driver IC and two to four IGBTs held high or low in order to complete the circuit as the coil triggers, acting in place of the air gap switch. These can all be included on our PCB. The drivers will take input from the audio processing and pass it along through our switching.

Criterion for success:

- Drivers must be able to reliably switch the chosen power transistors
- Drivers must have at least 1,000 volts isolation from input to power rails
- Drivers must operate at a bandwidth above tesla coil resonance frequency (~1Khz)
- Drivers must be operable with two isolated voltage rails, one low voltage, at 3.3, 5, 9, or 12 volts (same as audio processor), and one, variable high voltage between 50 and 400 volts, preferably going down to 10.

Switching:

We will use semiconductor switching rather than the comparably popular air-gap switching, as this poses less of a safety issue and is more reliable and modifiable. These devices will need to be able to withstand high frequency and power, so we are considering using GaN transistors. This switching will take input from the gate drivers and its output will be passed into the primary coil of our tesla coil.

Criterion for success:

- Transistors must be operable up to 400 volts.
- Transistors must be able to sink [insert large amount here] of current
- Transistors must have switching bandwidth of above coil resonance frequency (~100v)
- Heat sinks must be built to allow transistors to carry rated current.

Power Supply:

We will use a 120V or 240V AC input to power the tesla coil, we'll use a high-voltage transformer, likely a neon sign transformer or a Variac, going into a full bridge rectifier and a filter to get steady DC.

Requirements

- Power supply must supply very low ripple (< .1%) low current (< 100mA) DC power of either 3.3, 5, 9, or 12 volts for gate drivers and audio processing
- Power supply must also supply variable high voltage DC power of range 0V to 170 volts at least with output current of at least an amp.
- Power supply must contain circuit protection to prevent short circuits and voltage surges

Coil:

Consists of a few wire loops on the primary side and a 100-turn coil of copper wire in order to step up voltage for spark generation. Will also require a toroidal loop of PVC wrapped in aluminum foil in order to properly shape the electric field for optimal arcing. These pieces can be modular for easy storage and transport. All sparks will be directed onto a grounded metal rod 3-5cm from the coil. The coil will take input from the switching circuitry and its output will be sparks onto our grounding rod.

Requirements:

- Protections to protect shorts between windings from voltages upwards of 10kV

- 100 to 1000 winding secondary coil
- 1-5 winding primary coil
- Primary coil capable of handling currents upwards of 1000 Amps.

Protection:

See safety section

Tolerance Analysis:

One component particularly susceptible to error is the transistor drivers of the coil trigger circuit. Some transistors cannot handle high frequencies and high duty ratios, and may burn up and break due to the inputs. To mitigate this risk, we plan to do extensive research into transistors that can operate at high switching frequencies. Furthermore, to limit the duty ratio of our transistors, we are using a microcontroller to control the square wave input signal. This gives us control over the input pulse widths, allowing us to shorten the pulse width at high frequencies to avoid turning the transistors on more than necessary, thus preventing our devices from overheating.

III. Ethics and Safety

Ethics:

There aren't too many ethical concerns with this project, but there are some concerns with the use cases of this project. We outlined that we expect this tesla coil to be used in a live music performance setting, and not in other industries such as the military. Other ethical concerns with this project involve user safety, however in the next section we outline our safety concerns and guidelines to make sure there is no harm or injuries.

Safety:

Tesla coils have been built for senior design in the past, and as noted by TAs, there are several safety precautions needed for this project to work. We reviewed guidelines from dozens of recorded tesla coil builds and determined the following precautions:

- The tesla coil will never be turned on indoors, it will be tested outside with multiple group members present using an outdoor wall outlet, with cones to create a circle of safety to keep bystanders away.
- We will keep everyone at least 10ft away while the coil is active.
- The voltage can reach up to 100kV (albeit low current) so all sparks will be directed onto a grounding rod 3-5cm away, as a general rule of thumb is each 30kV can bridge a 1cm gap.
- The power supply (120-240V) components will be built and tested in the power electronics lab.
- The coil will have an emergency stop button and a fuse at the power supply.
- The cable from the guitar will use a phototransistor so that the user is not connected to a circuit with any power electronics.