Design Review

ECE 445 Senior Design
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Team 12- Musical Instrument: Electronically Resonated Metal

Table of Contents

1. Introduction

1.1 Statement of Purpose

We have chosen this project because each of us has some interest in music and we wanted to apply our knowledge of electrical engineering to develop a new musical instrument prototype. This instrument will produce a unique sound, and when we are finished we will have a working instrument for others to learn and play.

1.2 Objectives

This musical instrument is unique in a way that we have to vibrate the entire metal rod using a powerful driver coil. On the market, there are guitars that use similar mechanism but they vibrate the strings with a less powerful driver coil and a less powerful magnetic pickup coil. Our instrument uses electret mic because it is easier to interface with the rest of our project and easy to see the output on the lab equipment. The main goals of this project are to initiate vibrations in the steel rod when a button is pressed, to sustain vibrations in the steel rod until the button is released, and to create a more powerful driver coil and a pickup coil compared to the ones commercially available.

1.2.1 Conceptual Model

The model for the musical instrument consists of a metal rod made of ferrous material which is electronically resonated using a driver coil via electromagnetic induction. In the initial setup, the rod lies between the rollers which are attached to a chassis such that the rollers hold the rod in place at the midpoint of the rod. Only one end of the rod will be extended to different lengths when using the instrument while the other end will not.

The user of this musical instrument places the instrument on a sturdy surface and positions the instrument in front of him or her such that the rod is aligned parallel to the ground and vibrating end of the rod is pointing to the right for a right hand player or to the left for a left hand player. The user starts off by pressing a button with his or her non playing hand and extends the rod to the desired length while still holding the button down. The arm motion while pulling the rod in and out to the desired length looks similar to a violin player extending and retracting the bow while playing different notes on the violin. The difference in the arm motion compared to a violin is that the user does not lift the arm or the elbow while playing this instrument.

The action of pressing the button when the rod is extended to a certain length will result in the microcontroller detecting a +5V at the digital input pin where the button is connected and it sends an initial control signal from its analog PWM port to the transconductance amplifier. The transconductance amplifier will then convert the voltage signal into amplified current signal and then it will output the amplified current to the driver coil. The driver coil uses the current from the transconductance amplifier to initiate the vibrations in the rod via electromagnetic induction similar to a solenoid. The pickup coil, which is an electret mic in this project, is connected to the analog input of the microcontroller. When the pickup coil detects the sound of the rod vibrating at different frequencies for a particular length of the rod, it internally converts the sound due to the mechanical vibrations of the rod into voltages that the preamp can amplify. The output of the preamp will be the amplified voltage signal from the pickup coil to the microcontroller. The microcontroller will then send out the voltage signal to the input of the transconductance amplifier using the analog PWM output pins as long as the button is still pressed down by the user and the vibrations in the rod will be sustained. The speakers are connected to the output of the transconductance amplifier and the user will be able to hear sound at different frequencies through the speakers.

If the microcontroller detects that the user is no longer pressing the button, then the microcontroller will send a signal of 0V to the Vin the transconductance amplifier via its analog output pin. The transconductance amplifier will then send 0A current to the driver coil and 0W to the speakers when the button is not pressed. This will result in the speakers not producing any sound. Similarly, the driver coil will see the 0A current at its input and will stop vibrating the rod.

1.2.2 Features

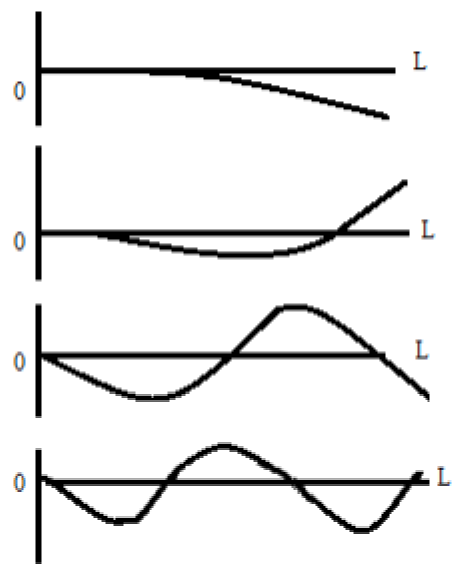
- A microcontroller will be interfaced with the button, the volume and tone potentiometers in the final product to provide additional functionality to the user if the time permits.
- A roller holds the rod in place and makes it slide easily back and forth.
- The response time of the button to initiate vibrations in the rod will be less than 0.5 seconds.
- This instrument is easy to use by both left-handed and right-handed users alike.
- A transconductance amplifier will amplify the current using the voltage signal from the microcontroller to drive the speakers.
- The driver coil will vibrate the entire rod at its resonant frequencies.
- The rod is resonated electronically using transducers and amplifiers.
- An electret microphone will be used to sense the sound that is produced from the vibrations in the rod and will function as a pickup coil. The advantage of an electret microphone is that it will produce voltages in the mV range so it can be safely connected

to the microcontroller’s input pins using a preamp with fixed gain. A preamp will amplify the voltage from the electret microphone.

1.2.3 Benefits

- When a rod clamped at one end vibrates, it produces a fundamental frequency and several frequencies that are not whole number multiples of the fundamental. This is illustrated in the figure below. This creates an interesting sound with which musicians and composers can experiment and add expression to their music.

- This is a musical instrument, so it will provide people with the opportunity to learn how to play it for fun.



The four lowerst modes of the transverse vibration of a clamped, free bar. Note the boundary conditions at each end and the different classes of the nodes

Fig. 1 from *Fundamentals of Acoustics* by Kinsler, Frey, Coppens and Sanders, showing frequencies excited on a rod clamped at one end.

2. Design
2.1 Block Diagram

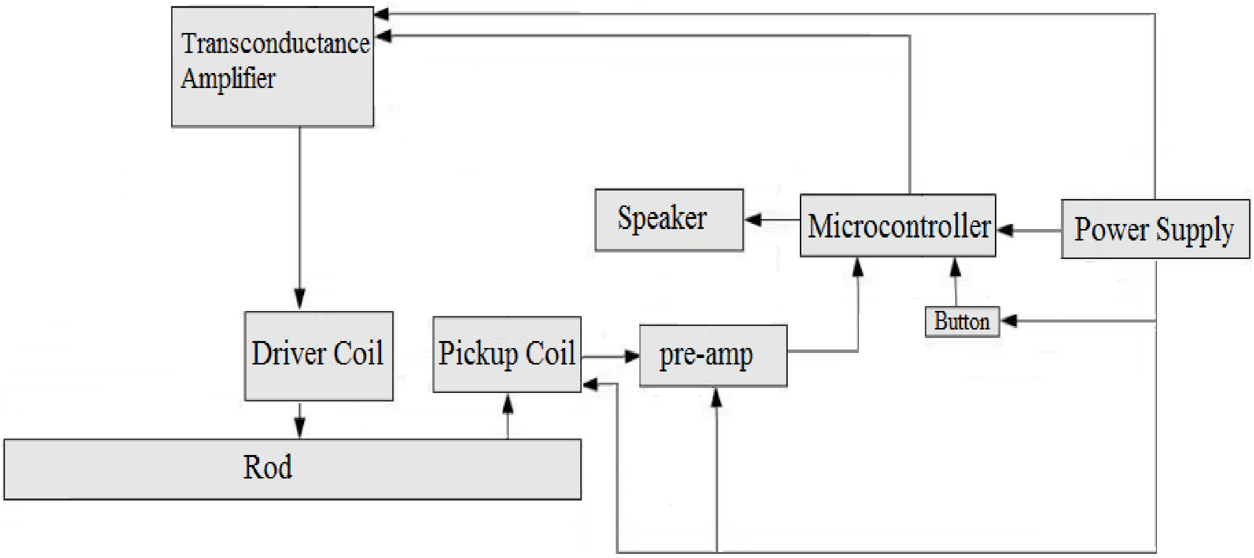


Fig. 2: Top-level block diagram

2.2 Block Descriptions

2.2.1 Rod

The rod is made of magnetic material, and the pitch it produces can be changed by changing the rod's length. The input to the rod comes from the driver coil. The driver coil initiates the rod's vibrations, and based on the feedback from the transconductance amplifier it changes its vibrating frequency to the resonant frequency of the rod. When the player slides one end of the rod back and forth, the effective length of the rod will change. The resonant frequency will increase as the rod's length decreases, and therefore the pitch increases. The output of the rod is mechanical vibrations which will be converted into voltage signal by the pickup coil.

2.2.2 Pickup Coil

The pickup coil will consist of an electroacoustic transducer which converts the sound due to the mechanical vibrations produced by the rod into a voltage signal. The input for the pickup is the sound waves from the vibrating rod. The electret microphone is commonly used to interface with microcontrollers such as Arduino. The disadvantage is that a pre-amp will be needed to connect the electret microphone to the microcontroller because the electret microphones generally output voltages in the range of millivolts. The output of the electret mic will be the voltage signal that will go into the preamp.

2.2.3 Power Supply

An external power supply will consist of +5 V batteries for the electret mic and the opamps used in the pre-amp. The button and the transconductance amplifier can be powered using the +5V pin from the microcontroller. The microcontroller can be powered using a +5V battery or a USB port from the personal computer. If a battery is used, the +V wire will be plugged into the Vin of the microcontroller and the other wire will be plugged into the GND port of the microcontroller.

2.2.4 Button

The button is a simple push button that has two states, ON or OFF. ON means the button is pressed and OFF means the button is not pressed. One terminal of the button will be connected to +5V on the microcontroller and the other terminal on the button will be connected to one end of the 10K resistor. The other end of the resistor will be connected to GND on the microcontroller. The terminal of the button which connects to the resistor will be connected to the digital input of the microcontroller. When the button is in the ON state, the circuit closes on the two terminal button and the digital input on the microprocessor will read +5V. If the button is in an OFF state, the circuit of the button is open and the digital input on the microcontroller will read 0V because the button will be connected to GND.

2.2.5 Microcontroller

The microcontroller is the audio signal processor for the musical instrument in this project. For the final product, if the time permits the microcontroller will be interfaced with the volume and tone potentiometers to provide the user with additional features to control the volume and tone for his or her liking. The inputs to the microcontroller are the voltage signal from the button when pressed, the voltage signal from the pre-amp. If the button is not pressed, the digital input where the button is connected to the microcontroller will read 0V. So, the transconductance amplifier will output 0A to the driver coil, whereby the driver coil will not vibrate the rod at all. This will also result in the speaker not outputting any sound for the user to hear.

In the other case when the microcontroller reads a positive voltage of +5V at the digital input terminal of the button, the microcontroller will send a noise signal from its analog PWM output to the transconductance amplifier. The transconductance amplifier will output an amplified current output to the driver coil and will be able to drive the speakers with enough power. The amplified current from the transconductance amplifier will flow through the driver coil and the driver coil will induce magnetic field which will vibrate the rod. The pickup coil will sense the sound due to the vibrations in the rod and then send a positive voltage to the input of the pre-amp and then the pre-amp will send a positive voltage to the microcontroller using the analog input of the microcontroller.

The microcontroller will then make a decision as to whether to output 0V from its analog outputs or a positive voltage based on the state of the button. If the button is pressed, the microcontroller will send a scaled positive voltage mapping 0V to max voltage from the pre-amp to the range 0V to 5V from its analog PWM pin as its output. Otherwise, if the button is not pressed, it will send a 0V to the input of the transconductance amplifier and 0V to the Vcc of the transconductance amplifier. This cycle repeats based on whether the button is in a pressed state or in a unpressed state.

2.2.6 Pre-amp

The pre-amp amplifies the voltage output from the pickup coil which in this project is the electret mic. The pre-amp will consist of an op-amp with two resistors configured in to work like a noninverting amplifier. The input of the preamp is the voltage signal from the electret mic with a gain controlled by the values of the two resistors R1 and R2. The output of the pre-amp will be the amplified voltage signal which is Vout=Vin*(1+(R2/R1)) and this signal will feed into the analog input pin of the microcontroller. If we want a larger gain, we will need R2/R1 to be a very large value. The op-amp chip used for the pre-amp will limit the maximum output voltage for the pre-amp. Also, the supply source voltage for the op-amp will limit how much gain we can have for the pre-amp and in turn limits the maximum output voltage. We cannot output more voltage than the supply source voltage otherwise the op-amp chip will break. If we use a CA31403 chip, the maximum output voltage will be ~3V for Vcc = 5V at 25 degree Celsius room temperature.

2.2.7 Cascaded Transconductance Amplifier

The cascaded transconductance amplifier takes a voltage from the microcontroller as the input signal and outputs a current to the driver coil. Two op-amps and six resistors will control the gain of the output signal. The current output, Iout, will be equal to Vout/R7, where Vout = (1+R2/R1)(1+R6/R5)Vin, and Vin varies from 0 to 5V. Consequently, the output current is proportional to Vin and it will flow through the driver coil. The op-amp chip used for the transconductance amplifier will limit the maximum output voltage for the transconductance amplifier. We cannot output more voltage than the supply source voltage otherwise the op-amp chip will break. If we use a CA31403 chip, the maximum output voltage will be ~3V for Vcc = 5V at 25 degree Celsius room temperature.

2.2.8 Speaker

The audio speaker will be 8 ohms speaker whose + terminal will receive its input from the transconductance amplifier. The other terminal of the speaker will be connected to the ground. The positive terminal of the speaker is connected to the Vout of the transconductance amplifier. The negative terminal of the speaker is connected to the GND.

2.2.9 Driver Coil

The driver coil is basically an electromagnet. It consists of a wire wrapped around an iron core. It receives an input current and voltage from the transconductance amplifier. The input current is time-varying, so this will cause fluctuations in the magnetic field. The purpose of the iron core is to increase the strength of the magnetic field. The driver coil will be placed underneath the steel rod so that it will cause the rod to move up and down via magnetic induction. The frequency of the rod's oscillations will be the same as the frequency of the input current. For the final product, the driver coil coil should be able to vibrate at a range of frequencies that encompasses the steel rod's frequency range.

2.3 Flowcharts

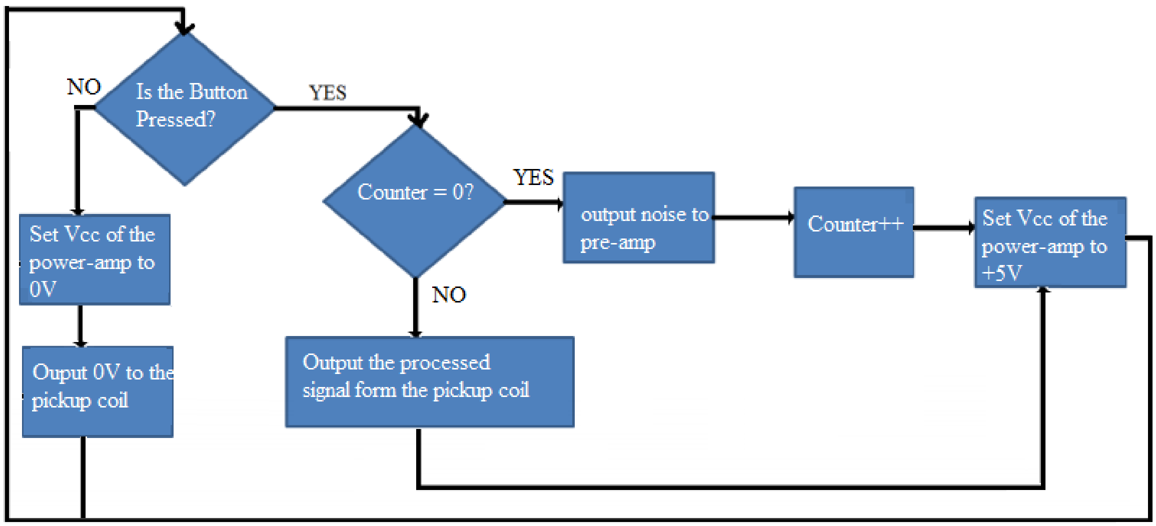


Fig: 3 The Control System Flowchart

2.4 Schematics and Calculations

2.4.1 Steel Rod

After applying boundary conditions on the rod and using numerical techniques (see Kinsler, Frey, Coppens, and Sanders), the frequencies of vibration are given as:

$$f = ((1.94)^2, (2.988)^2, 5^2, 7^2)\frac{\pi K c}{8L^2}$$

where K is the radius (a) of the rod divided by 2, c is the sound speed in steel (5050 m/s), and L is the length of the vibrating end of the rod. The total length of the rod was measured to be 56 centimeters; the radius was estimated to be 0.004 m. When calculating the resonant frequencies what matters is the length of the vibrating portion of the rod, which will change as the player slides it back and forth. When the vibrating portion of the rod is at its longest length, this corresponds to the lowest frequency; conversely, when it is at its shortest length, this corresponds to the highest frequency. However, the lowest frequency of the rod does not correspond to 56 centimeters due to the fact that it needs to be supported at one end; it will actually be a bit shorter. As the length of the side of the rod that is vibrating becomes shorter, there will be a point at which the rod will not be long enough to sustain vibrations. The length of the vibrating end of the rod at this point was estimated to be about 15 centimeters; the longest length of the rod was estimated to be 40 centimeters.

Plugging in these numbers to the above equation, we have, when the rod is the longest:

$$f_1 = \frac{(1.194)^2 \pi \frac{0.004}{2} (5050)}{8\,(0.40)^2} = 35.3 \text{ Hz}$$

$$f_2 = \frac{(2.988)^2 \pi \frac{0.004}{2} (5050)}{8\,(0.40)^2} = 221 \text{ Hz}$$

$$f_3 = \frac{(5)^2 \pi \frac{0.004}{2} (5050)}{8\,(0.40)^2} = 619 \text{ Hz}$$

Where f_1 is the fundamental frequency and f_2 and f_3 are the first two overtones.

When the rod is the shortest, the resulting frequencies are:

$$f_1 = \frac{(1.194)^2 \pi \frac{0.004}{2} (5050)}{8\,(0.15)^2} = 251 \text{ Hz}$$

$$f_2 = \frac{(2.988)^2 \pi \frac{0.004}{2} (5050)}{8\,(0.15)^2} = 1570 \text{ Hz}$$

$$f_3 = \frac{(5)^2 \pi \frac{0.004}{2} (5050)}{8\,(0.15)^2} = 4400 \text{ Hz}$$

The exact frequencies have yet to be measured, but these calculations show that the rod's fundamental frequency range will include frequencies between 40 and 200 Hz, and they give an idea of what the frequencies of the overtones will be. According to Hopkin, usually only the fundamental and the first overtone will be heard.

2.4.2 Driver Coil

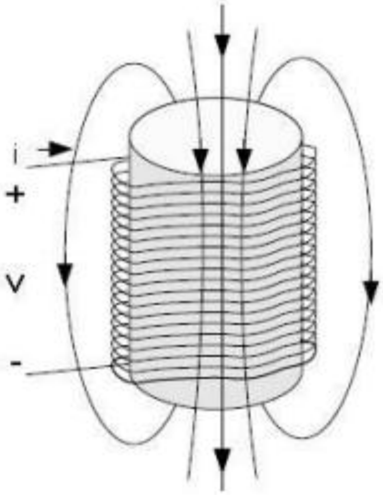


Fig. 4: Diagram of driver coil showing magnetic field lines

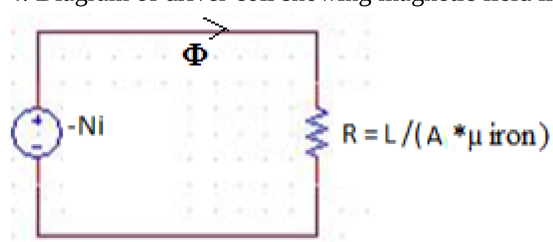


Fig. 5: Magnetic equivalent circuit of the driver coil in Fig 4

Fig. 5 above shows a magnetic equivalent circuit to model the driver coil in Fig. 4. **N** is the number of turns of the coil, **i** is the input current, ***R*** is the magnetic reluctance, ***l*** is the length of the coil, **μ** is the magnetic permeability of the iron core, **A** is the cross-sectional area of the core, and **Φ** is magnetic flux. Using Kirchhoff's voltage law, $\mathbf{Ni + \Phi \mathit{l} / \mu A = 0}$, so the magnitude of N is $\Phi l / i\mu A$. The maximum magnitude of Φ is equal to the magnetic field strength (B) times the area of the core. Therefore, $N/l = BA\Phi / i\mu A$, and this expression for the number of turns per unit length can be simplified as $N/l = B/i\mu$. To increase the strength of the magnetic field, the number of turns of the wire must be increased. However, doing this may also require a smaller wire gauge. The resistance of the wire is given by $R = \rho L / A$, where ρ is the resistivity of the wire, L is the length, and A is the cross-sectional area. Having a smaller wire would decrease the area, and therefore increase the resistance of the wire, causing the dissipation of more heat.

2.4.3 Preamp

For the pre-amp in an inverting closed-loop configuration, Vout = Vin*(1+(R2/R1) where Vin is the voltage from the electret mic and Vout is the output of the preamp. For the CA3140E op-amp chip with supply source voltage at 5V, the maximum Vout is ~3V at 25 degrees Celsius. Assuming the maximum output voltage of the electret mic will be around 100 mV max, then gain would be around 30. So we can choose R2/R1 = Gain-1 and the ratio to be around 29. We can choose R1 to be a value ~1 ohm, R2 to equal around ~29 ohms.

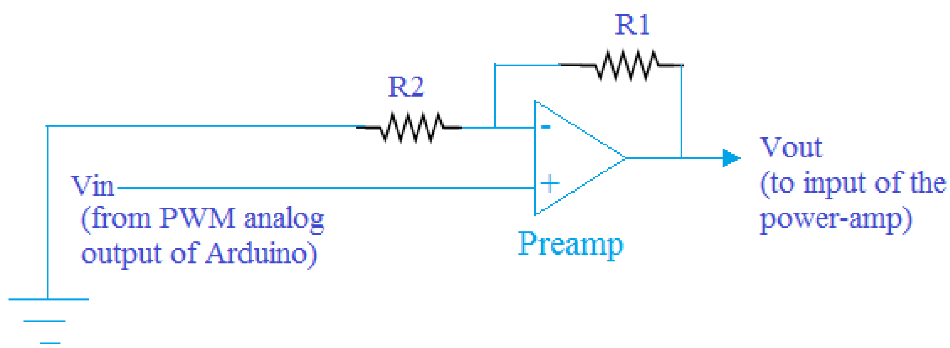


Fig 6: Schematic of a preamp in an inverting closed-loop configuration
(Refer: Sedra and Smith pg 59)

The closed loop gain G= Vout/Vin = 1/(R2+R1). We will choose R1 and R2 based on additional testing using the pickup coil and the microcontroller analog PWM outputs.

2.4.4 Cascade Amplifier

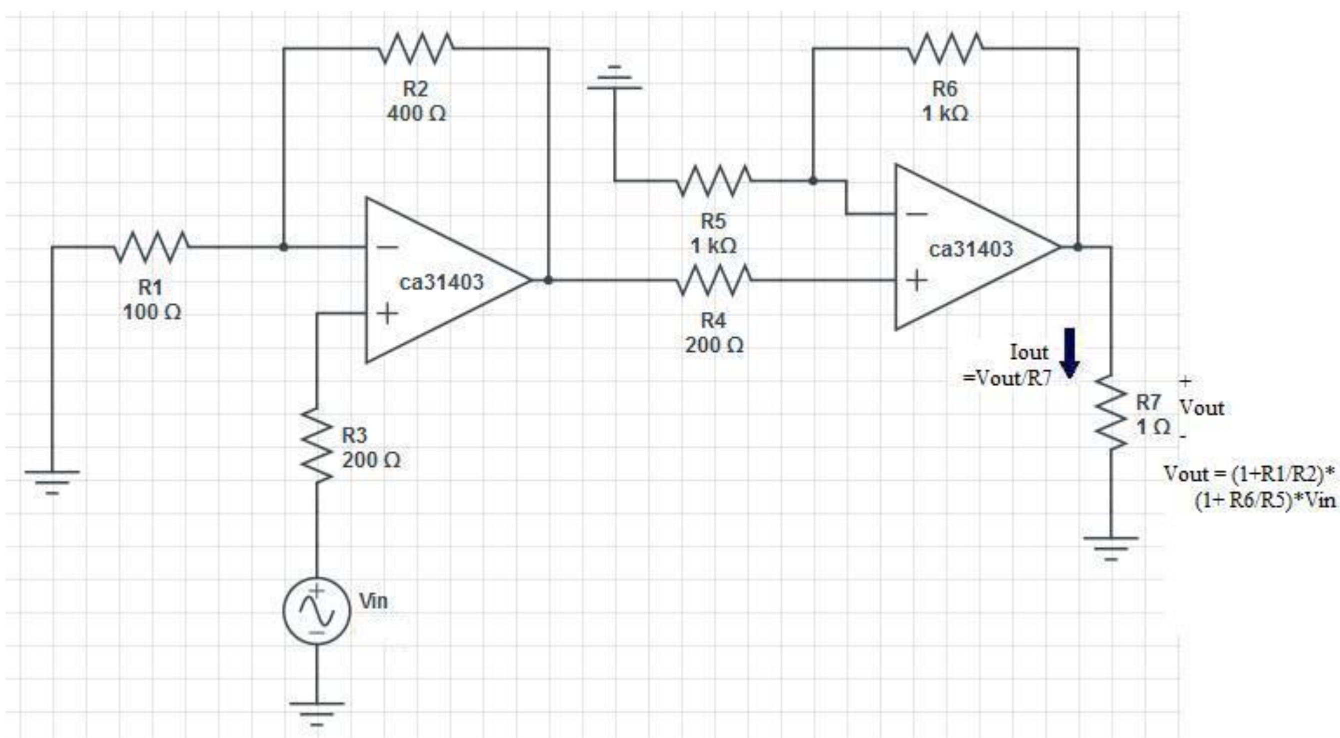
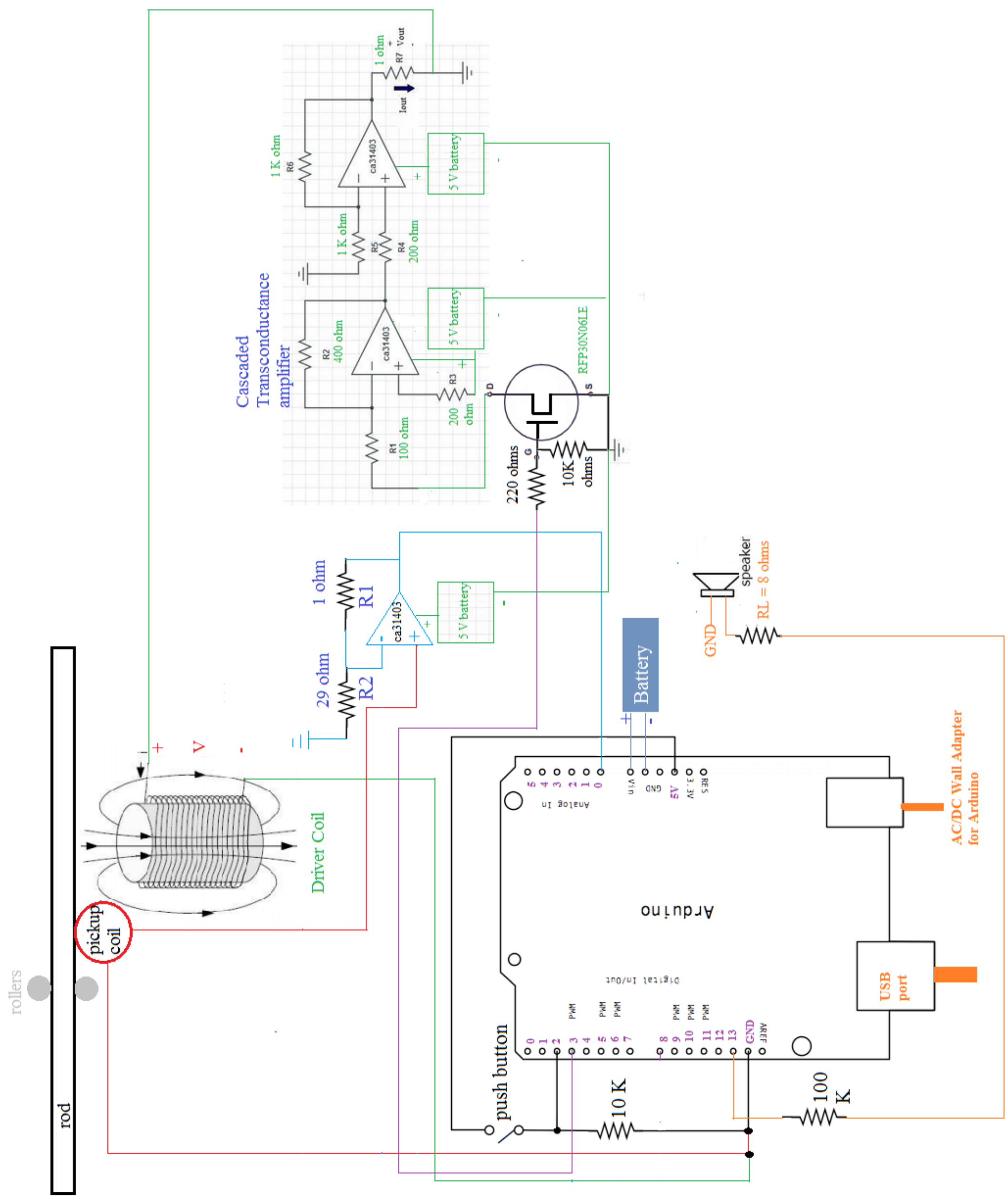


Fig7 : Schematic of a cascade amplifier (voltage to current amplifier)
(Refer: http://www.johnloomis.org/ece201L/lab7/lab7.html)

As shown in the Fig 7, the cascade amplifier consists of a two op-amps in cascading configuration. Vin is the voltage from the microcontroller, which has its range from 0 to 5V; and, Iout is the current output flowing through the driver coil. Based on the cascading amplifier circuit above, Iout results in Vout/R7 where Vout = (1 + R2/R1)(1+R6/R5)Vin; that is, the gain of Iout depends on the resistance values of R1, R2, R5, R6, and R7, and it is proportional to Vin. Assuming the current flowing through the driver coil will be greater than or around 1A, then the gain needs would be 10. Then, the values of resistors (from R1 to R7) would be 100, 400, 200, 200, 1K, 1K, and 1 ohm, respectively. The exact resistor values will be known only after experiments with the microcontroller and the driver coil.

2.4.5 Overall Design



2.5 Simulations (with mathematical models)

2.5.1 Pre-amp

Vout = Vin*(1+(R2/R1)

Partial Matlab Code(with specific values for R1 and R2):

```
t = -10:.01:10; R1 = 1; R2 = 10; % resistor values measured in ohms and t in sec
subplot(3,1,1); Vin = cos(t); plot(t,Vin);
subplot(3,1,2); Vout = Vin*(1+(R2/R1)); plot(t,Vout);
subplot(3,1,3); z= 1+(R2/R1); plot(t,z,'-');
```

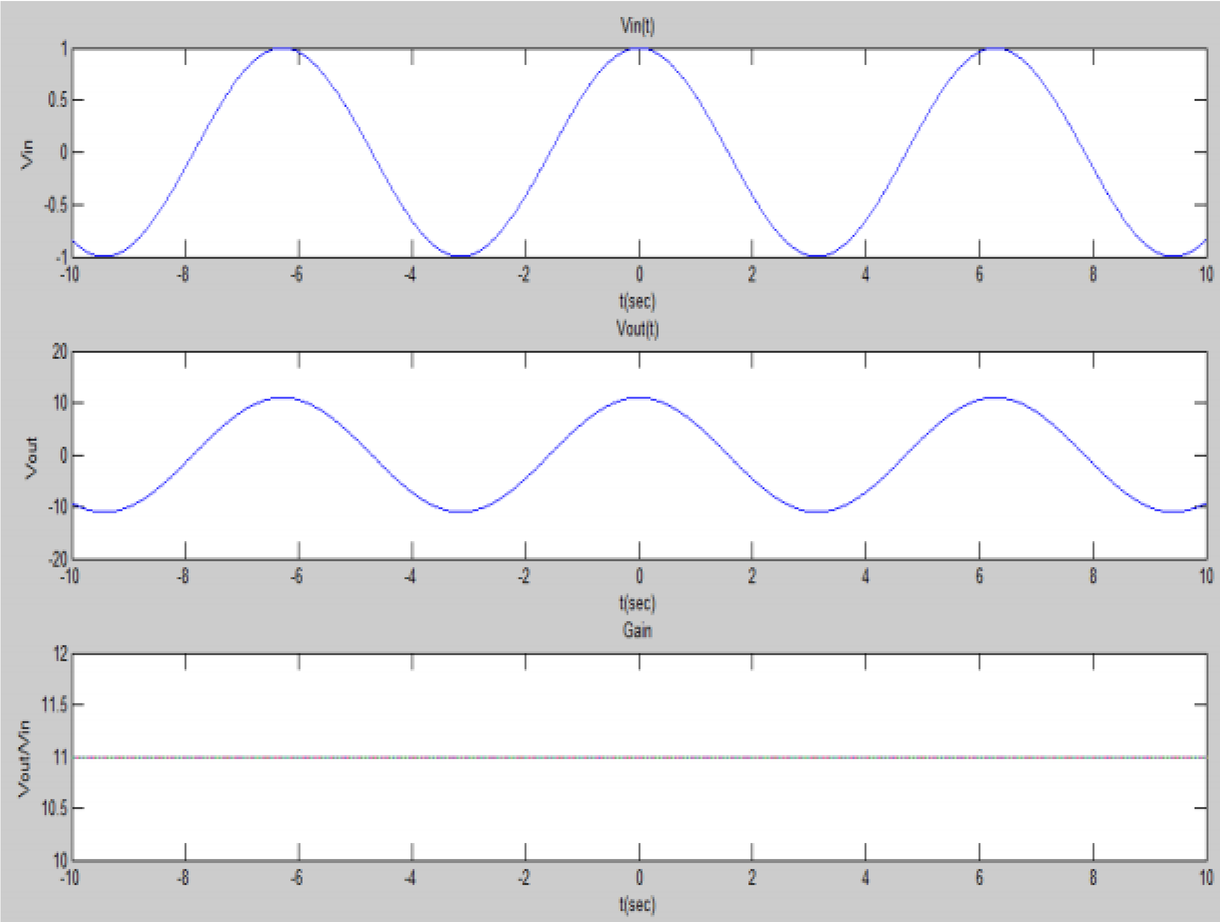


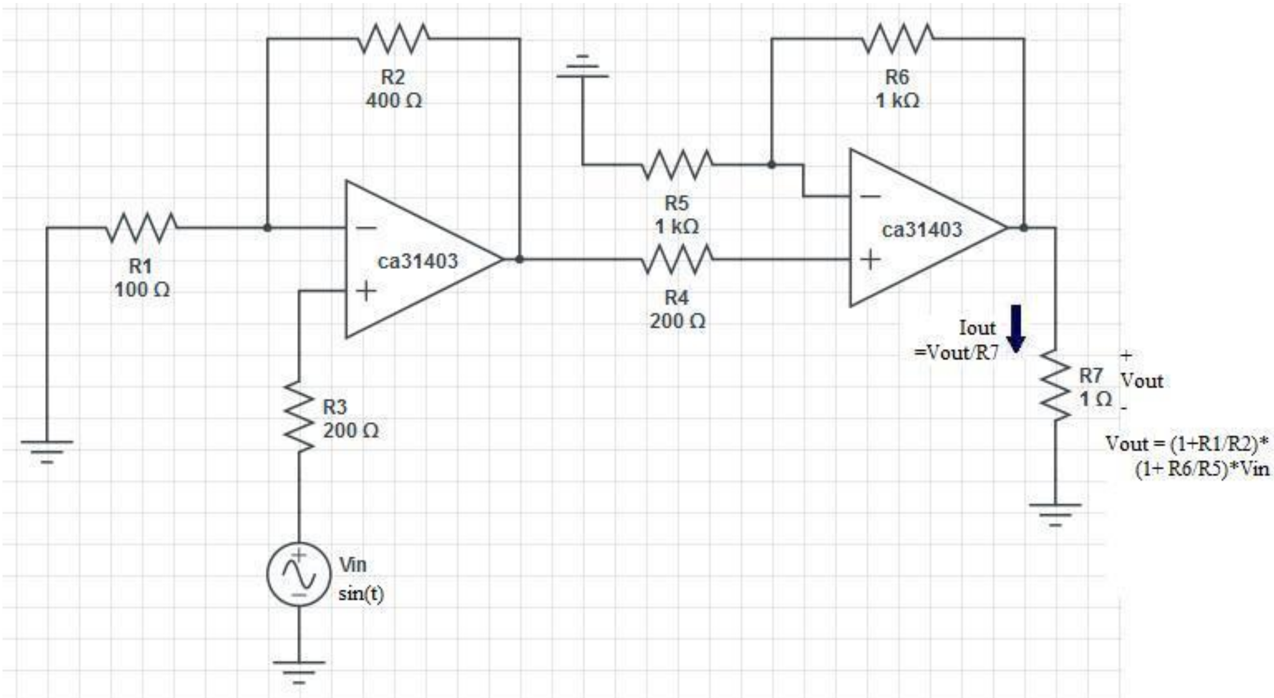
Fig 9. Voltage output and Gain characteristic of the preamp with specific R1 and R2 values

2.5.2 Microcontroller (Pseudo Code)

1. Poll the input of the button and see if the input is at logic high.
2. If so, then send an initial noise signal to the transconductance amplifier,
3. Poll the input of the button again and if the input is 0 V then got to step 8.
4. If the input pin is high, get the input from the pre-amp connected at the analog pin input.
5. Scale the voltage of the pre-amp to maximum of 5V.
6. Output the scaled voltage from the PWM terminals.
7. Poll the input of the button again.

8. If the input is at logic low, then send 0 V as input of the noise signal to the transconductance amplifier.
9. Go to Step 1.

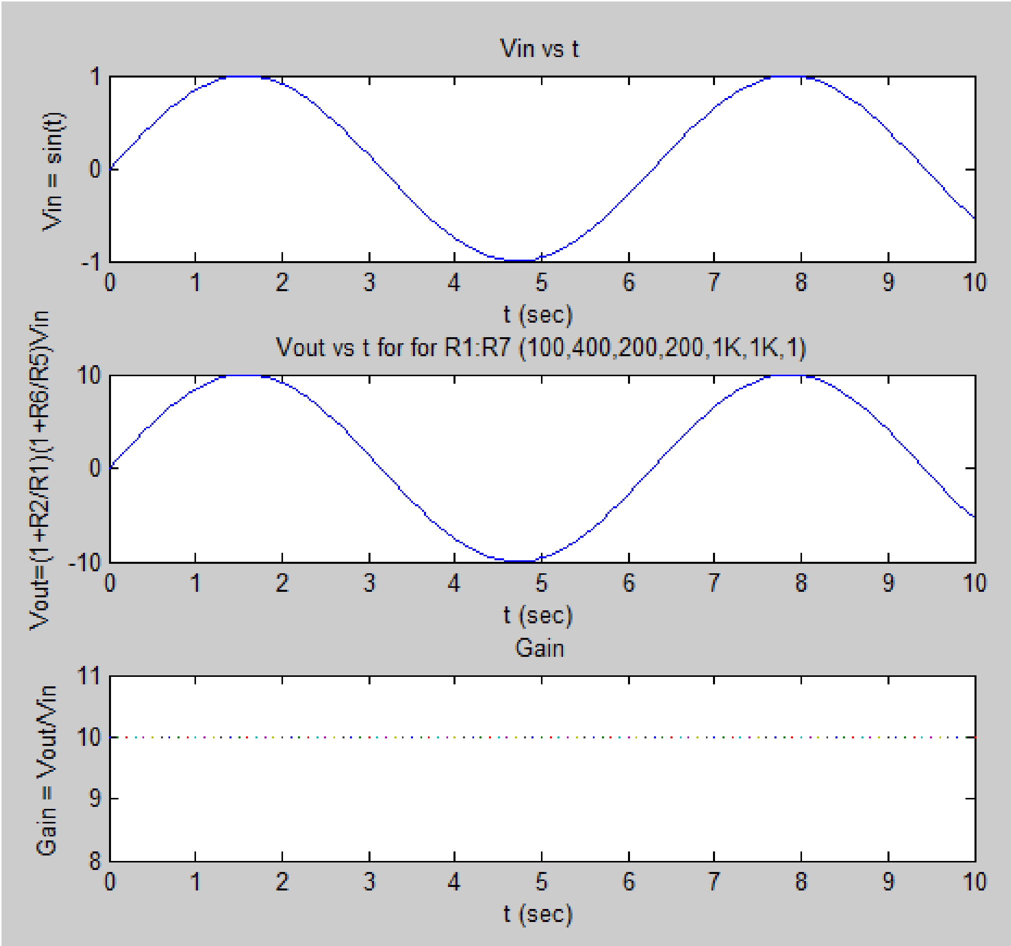
2.5.3 Cascaded Transconductance Amplifier



Vin = sin(t);
% resistor values in ohms
R1 = 100;
R2 = 400;
R3 = 200;
R4 = 200;
R5 = 1000;
R6 = 1000;
R7 = 1;
Vout = (1+R2/R1)*(1+R6/R5)*Vin;

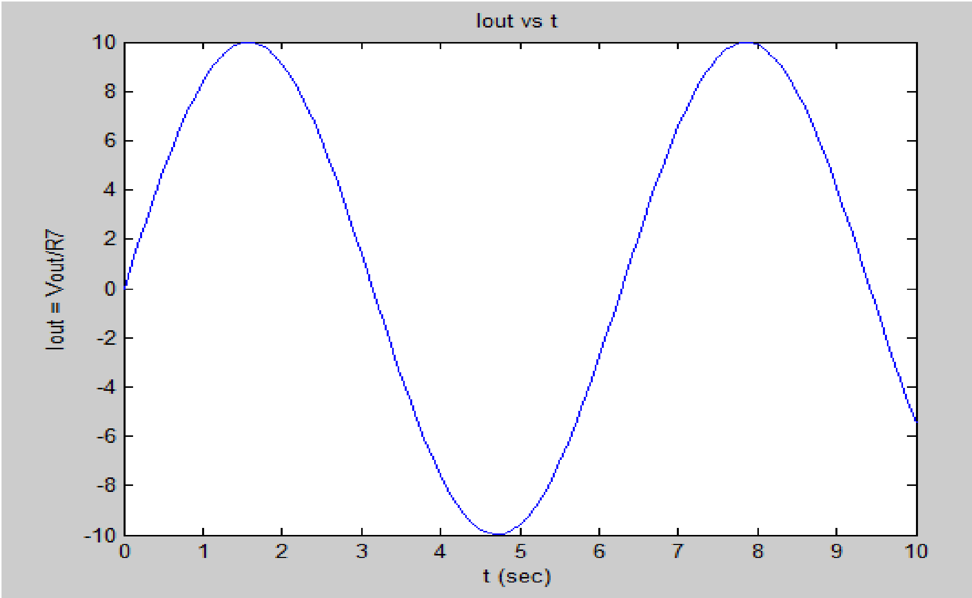
<u>Partial Matlab Code(with specific values for R1:R7):</u>

```
t = 0:.1:10;
Vin = sin(t);
subplot(3,1,1);
plot(t,Vin);
Vout = (1+R2/R1)*(1+R6/R5)*Vin;
subplot(3,1,2);
plot(t, Vout);
subplot(3,1,3)
plot(t,Vout/Vin,'-');
```



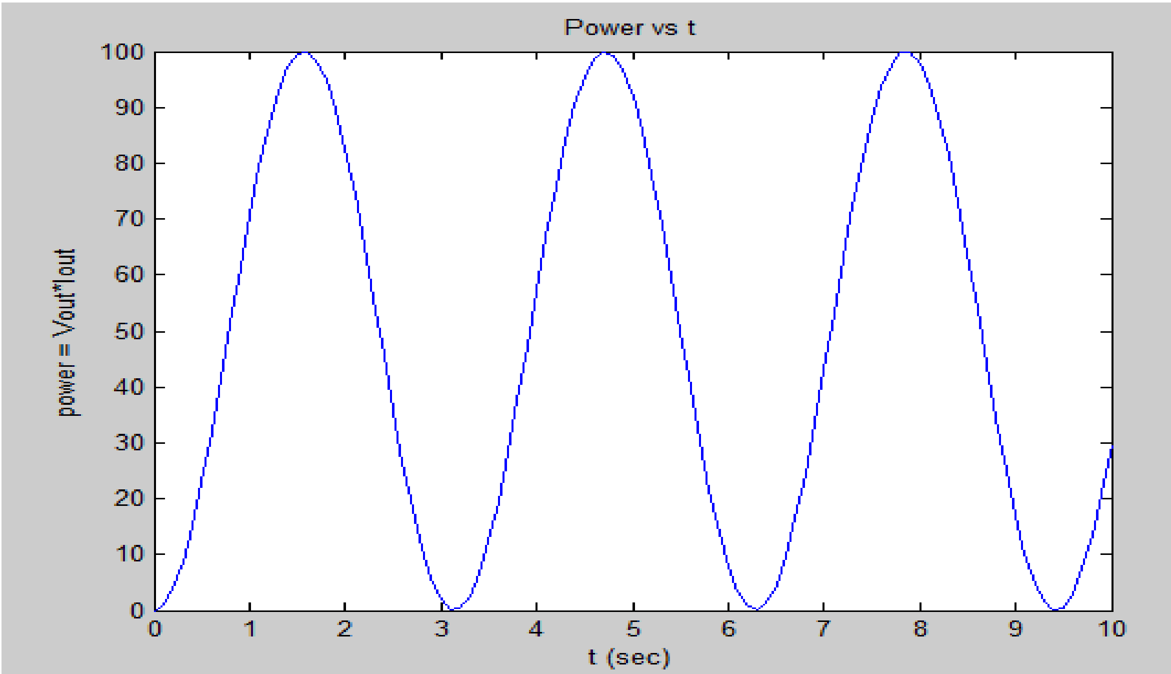
We can see that the voltage gain is 10 for the above mentioned specific R1:R7 values for a sine wave input.

Iout = Vout/R7



Since R7 = 1 ohm, we can see that Iout = Vout at the output terminal of the cascaded transconductance amplifier.

Power = Vout*Iout

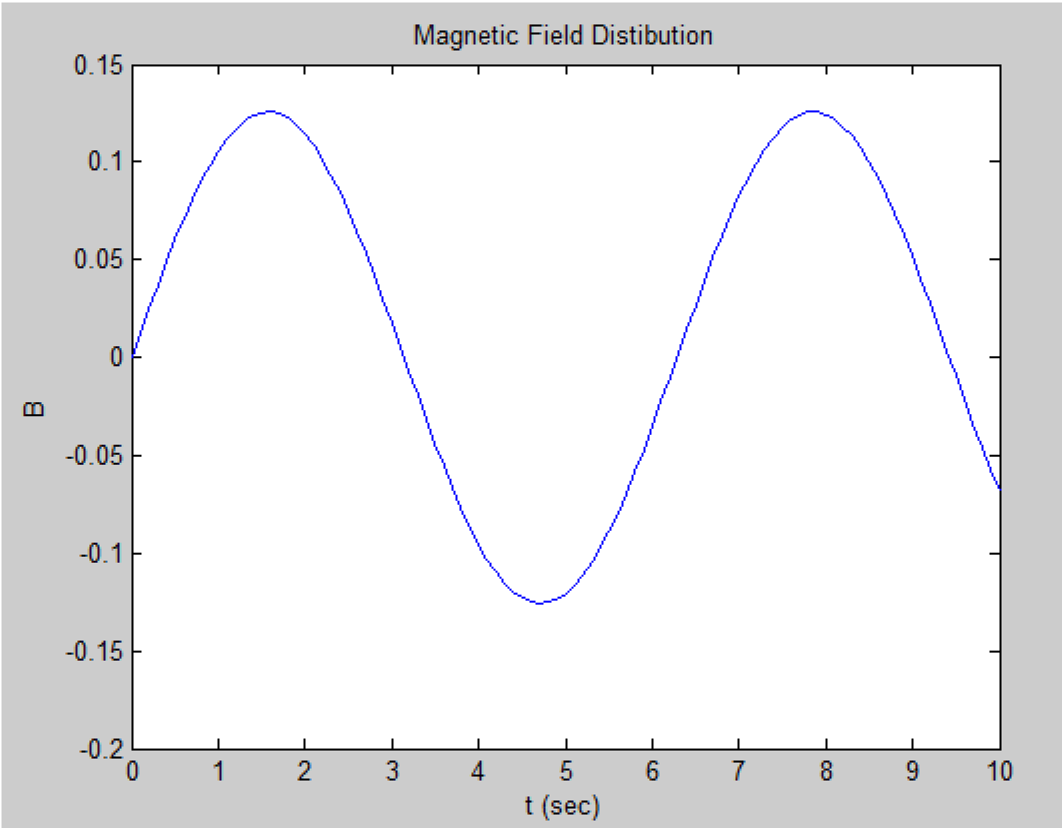


Since Vout = Iout, the amplitude of power is twice the amplitude of Vout and Iout.

2.5.4 Driver Coil: Magnetic Field Distribution

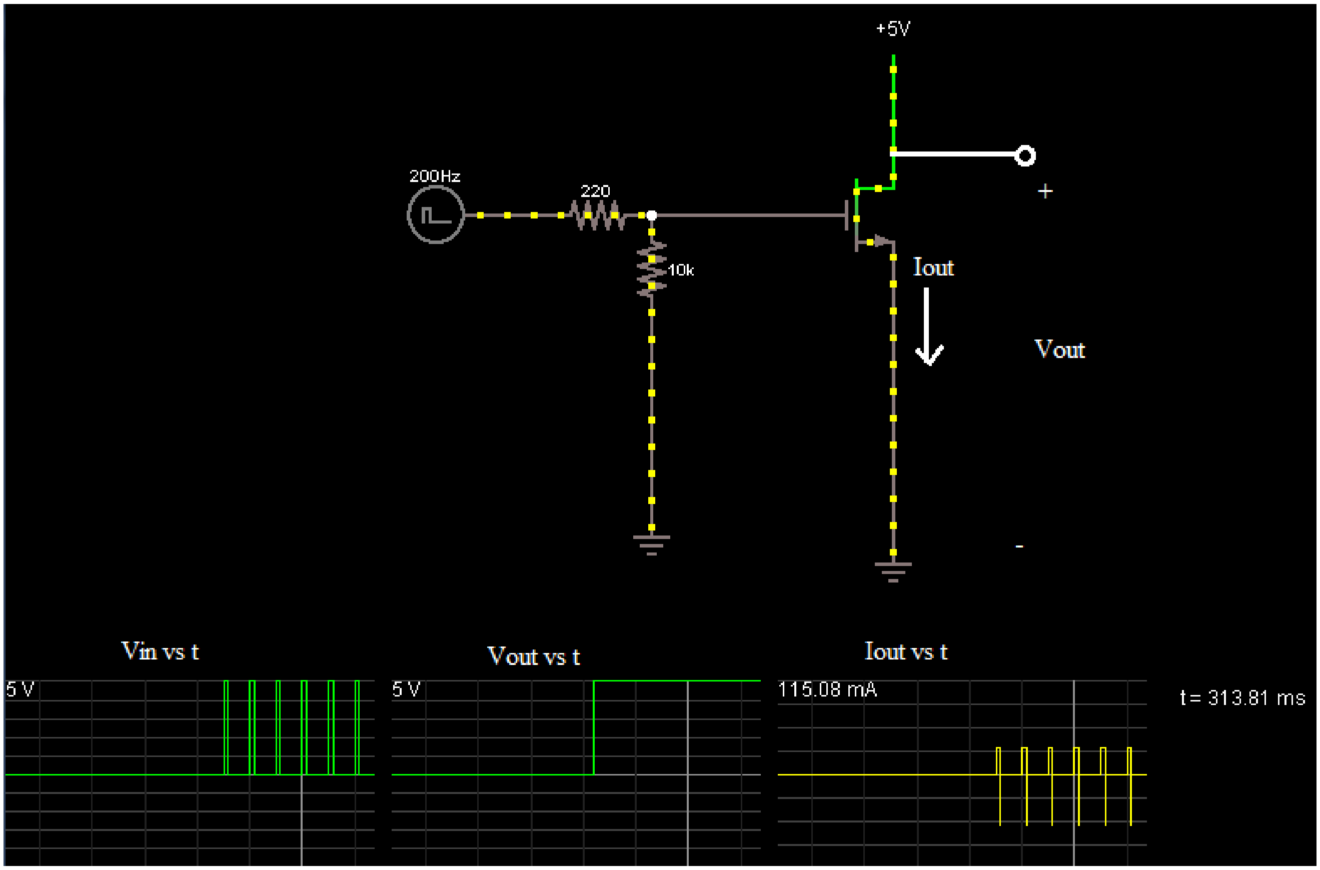
$$B = \mu_0 \frac{Ni}{l}$$

where N = 100, i = sin(t), l = 0.1 m and mu = 100*mu_o



The B field of the driver coil is oscillating because we get an AC current as the output of the transconductance amplifier. Using Biot-Savart's Law for the solenoid, we have used with specific values for N, i, μ, and L for the driver coil. We will test our driver coil in the lab by plotting the actual current through the driver coil after we build it.

2.5.5 MOSFET with PWM input from the microcontroller

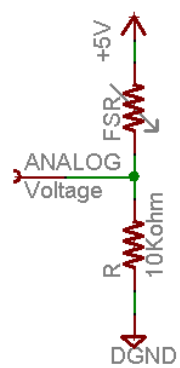


We can see that for the PWM input coming from the Arduino, the Vout is stable for the n-type MOSFET so we can in fact drive the transconductance amplifier with the PWM output of the Arduino. There is some internal resistance in the wires connecting the n type mosfet that is why we were able to observe the current flow in the above simulation.

3. Requirements and Verification

3.1 Testing Procedures

Button Requirement	The button should have a very fast response time of less than 0.5 seconds when it is pressed.
Sub Requirements	**Verification/Testing**
1. The button should be finger-friendly such that the user should not use force > 40 N to get a reading on the multimeter between 3.9 V and 5 V.	**Testing the Force applied on a button** 1. Place a touch sensor specifically a 0.5" diameter force sensitive resistor on the surface of the push button. 2. Connect the positive terminal of FSR to Arduino's

	5V pin. 3. Connect the negative terminal of the FST to the the Arduino's Analog Pin 0. 4. Also connect a 10K resistor to the GND pin on the Arduino and the other end to the Arduino's Analog Pin 0. 5. Run a C Programming Code in the Arduino which displays in the console the amount of force used to press the button. The following the pseudo code for the Arduino code: a) map analog reading 0 to 1023 to 0V to 5000 mV using map funciton in Arduino. b) use voltage divider to write the FSR_V across the 10 ohms resistor as Vcc*R/(R+FSR) c)rearrange terms to get FSR_R = (Vcc-FSR_V)*R/FSR_V d) use the FSR graphs from the product manual for 10 ohms resistor used in this procedure to figure out how much force is applied.  http://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr **Testing the Voltage reading when a button is pressed** 1. Turn on the multimeter and plug the positive and negative wires into the multimeter Voltage measurement terminals. 2. One terminal of the button is connected to +5V on the power supply 3. The other terminal on the button is connected to one end of the 10K resistor and the other end of the resistor is connected to GND on the power supply. 4. The terminal of the button which connects to the

	resistor is connected to the positive terminal of the multimeter. of the microcontroller. 5.Connect the negative terminal of the multimeter to the GND of the power supply 6. Observe the voltage reading on the multimeter when force less than 40 N is applied to determine if the button passed the test or not. 7. For a force of less than 40 N if the voltage is between 3.9 V and 5v then the button passed the test. Else, the button failed the verification test.
2. The button should not have hard edges on the surface.	Visually inspect that the button does not have hard edges on the pressing portion of the button in order to pass this test.
3. The button should have sufficient surface area such that the user can press the button using at least two fingers on the same hand.	1. Measure the diameter of button such that it is greater than 3 inches 2. If the diameters if greater than 3 inches then the button passes this test 3. Otherwise, the button fails the verification test.
4. Response Time of the button is less than 0.5 seconds	The setup is similar to sub requirement 2 for the button. Instead of a multimeter, use an oscilloscope to plot the Vout vs. Time(sec) using channel 1. 1. Start a timer on the cellphone when the user presses a button. 2. Compare how long it takes for the output voltage of the oscilloscope to change after the button pressed. 3. If the time for the change in output on the oscilloscope is less than 0.5 seconds then the button passed the test. 4. Otherwise, the button failed the test.

Rod Requirement	Rod should have vibration frequencies within the range of 40-200 Hz
Sub Requirements	**Verification/Testing**
1. The rod should be magnetic	1.Hold a magnet near the rod. 2.If the magnet attracts to the rod, then this test is passed. 3. Else, the test fails.
2. The diameter of the rod should be less than 1”.	1. Measure the rod’s diameter using a ruler 2. If the diameter of the rod is less than 1” then this test is passed 3. Else, the test is failed.
3.There should be minimum vibrations	1. Visually, make sure that there are rollers holding the rod in

(less than 1V) at the other end of the rod where the vibrations are not initiated.	place. 2. Measure using a multimeter a). Clamp the rod to the table. b). Place the pickup coil underneath the rod near the non-vibrating end and connect the pickup's positive lead to the positive terminal on the multimeter c). The input to the pickup will be the voltages that are sensed when the rod is excited on the other end of the rod where the pickup coil is not placed. d) Pluck the rod with the finger to initiate vibrations in the rod. e).If the output voltage of the pickup coil measured on the multimeter is greater than 1 V, then the rod fails this test. f) Else, the rod passes this test.
4. Frequency range of the rod is within 20-200 Hz.	The range of frequencies will depend on the type of metal, length, and thickness of the rod. 1. Clamp the rod to the table. 2. Place the pickup coil underneath the rod near the vibrating end and connect the pickup to the oscilloscope's channel 1. 3. The input to the pickup will be the voltages that are sensed when the rod is excited by hitting it on one end with a finger. 4.The fundamental frequency and overtones can be determined by using the FFT function on the oscilloscope for the output voltages from the pickup coil. 5. The lowest frequency occurs when the rod is at its longest length, and the highest frequency will occur when the rod is the shortest it can be while still being able to freely vibrate. 6. By measuring the frequencies we can verify that the rod will vibrate within the desired range of 40 to 200 Hz. 7. If the measured frequencies do not fall in the desired range of 40-200 Hz then the rod fails this test. 8. Else, the the rod passes this test.

Driver Coil Requirement	The driver coil should be able to vibrate at the same range of frequencies as the rod.
Sub Requirements	**Verification/Testing**
1. Driver coil should produce a magnetic field.	1. Connect a battery to the driver coil. 2. Place small metal objects such as paper clips or staples on a surface and use the coil to attempt to pick them up. 3. If the objects are attracted to the coil, then the driver coil passes the

	test.
2. Driver coil should produce a time-varying magnetic field strong enough to vibrate the rod.	1. Use a function generator to generate an input current to the driver coil. 2. Place the driver coil underneath the rod. 3. If the rod is observed to vibrate, the driver coil passes the test.
3. Driver coil should be able to sustain the rod's vibrations at the same frequency as the input current.	1. Use a function generator to generate a sinusoidal wave that has a frequency between 40 and 200 Hz. This will be the input of the driver coil. 2. The rod will be placed on a roller above the driver coil, and the coil will cause it to vibrate. As before, a pickup will be placed underneath the rod and connected to an oscilloscope. The frequency of the rod's vibration can be determined by using the FFT function. 3. This should match the frequency of the input signal. Otherwise, this test has been failed.
4. Driver coil should be able to sustain the rod's vibrations at frequencies between 40 and 200 Hz.	1. Repeat the test for requirement 3 above for several different frequency values within the specified range. 2. If the frequency measured on the oscilloscope does not match the frequency of the input signal for all of the frequencies tested, the driver coil does not pass the test.

Pickup Coil Requirement	The pickup coil should convert the mechanical vibrations of the rod into a voltage signal.
Sub Requirements	**Verification/Testing**
1. The output of the pickup coil circuit connected to the microcontroller's input should not exceed 5V.	1. Using alligator clips, connect the positive lead of the pickup coil to the positive lead of the multimeter. 2. Connect the negative leads of the pickup coil and the multimeter together using alligator clips. 3. Place the pickup coil under the rod and excite the rod at different lengths of 2"", 4", 6", and 8" using a finger. 4. The pickup coil passes this test if the voltage read from the multimeter at those above lengths is less than or equal to 5V. 5. Otherwise the microcontroller will break if the input voltage is greater than 5V so this test will fail.
2. The pickup coil should be not be placed more than 6" from the rod.	1. Measure how far away the pickup coil is from the rod using a ruler. 2. If the length measured is greater than 6" then the test fails.

	3. Else, the test passes.
3. IFor an electret microphone, the voltage at the output of the mic should meet the voltage specifications of the input it is being connected to.	1. When the electret mic is used with a microcontroller: a) Visually verify that an amplifier circuit is used when an electret mic is used as a pickup. The maximum voltage of the electret mic is in the range of 100 mv so a pre-amp circuit is definitely needed. b) If the electret mic is connected directly to the microcontroller input, then this test fails. c) Otherwise, measure the voltage at the output of the preamp of the mic using a multimeter. d) The input of the electret mic will be the rod when it is excited to vibrate at one end using a finger. e) If the multimeter reads greater than 1V the test passes else the test fails. 2. If the electret mic is not connected to the microcontroller or an electret mic is not used as the pickup coil, this test is not applicable.

Power Supply Requirement	Adequate power supply is needed for the microcontroller and the power-amp to operate.
Sub Requirements	**Verification/Testing**
1. power supply(battery)	1. If an external battery is used as the power supply, make sure the battery is not dead or the battery is not drained to the 50% of the indicated max voltage for the battery. 2.Connect the + terminal of the battery to the multimeter's positive terminal and the - terminal of the battery to the negative terminal of the multimeter. 3.If the battery reads less than the 50% of its DC voltage, then the battery test fails. 4. Else, the battery test passes.
2. power supply(Microcontroller connected via USB port to the personal computer)	1. Make sure that the input voltage at the 5V terminal of the microcontroller is able to draw > 4.5 V. 2. To test this, connect a multimeter to the input terminal of 5V on the microcontroller and the ground. 3. If the multimeter reads a voltage > 4.5 V then this test is passed. 4. Else, this test is failed.

Pre-amp Requirement	The pre-amp should be working properly: If all of the tests below are passed then the pre-amp circuit is working fine.
Sub Requirements	**Verification/Testing**
1. The pre-amp should amplify voltage based on the formula Vout = Vin*(1+R2/R1) formula for specific R1 and R2.	1. The input of the pre-amp will be a Square wave of +5V peak to peak from a multimeter. 2. R1 would be chosen to be 10+-0.5 ohms and R2 would be chosen as 10+-0.5 ohms also. 2. The output of the pre-amp will be plotted on channel 1 of the oscilloscope. 3. Then Vout = 2*Vin 3. If Vout on the oscilloscope shows amplitude of ~10 V peak to peak with tolerance within + or - 1 V of 10 V then the pre-amp passes this test. 4. Otherwise, the pre-amp fails the test.
2. The values chosen for R1 and R2 for the pre-amp circuit should not result in calculated Vout = Vin*(1+R2/R1) to be greater than 5 V.	1. Calculate Vout = Vin*(1+R2/R1) for the R1 and R2 values used in the final design using paper and pencil for max Vin of 5 V. 2. If Vout > 5 V then the test fails. 3. Otherwise, this test is passed.

Transconductance Amplifier Requirement	The cascaded transconductance amplifier should take the voltage as the input and output the amplified current, larger or around 1A, to the driver coil.
Sub Requirements	**Verification/Testing**
1. The cascade amplifier should output the current based on the formula Iout = Vout/R7, where Vout = (1+R2/R1)(1+R6/R5)Vin	1. A sine wave of +1V peak to peak from a function generator will be the amplifier input. 2. The values of resistors (from R1 to R7) will be 100, 400, 200, 200, 1K, 1K, and 1 ohm, respectively with + or - 10 ohm tolerance. 3. Vout will be measured by using a multimeter. Vout should be ~10V with + or - 1V tolerance. 4. When the Iout is displayed on one channel of the oscilloscope, and the scope shows a sine wave of +10A peak to peak with + or - 1A tolerance, this test is passed. 5. Else, the cascaded amplifier test fails.
2. The calculation of Iout should result in a value larger than or around 1A.	1. Calculate Iout = Vout/R7, where Vout = (1+R2/R1)(1+R6/R5)Vin with the resistor values

	(R1 to R7) chosen for the cascade amplifier. 2. If Iout >= 1A, then the test is passed. 3. Else, the cascaded amplifier fails the test.

Microcontroller Requirement	Microcontroller should be working properly
Sub Requirements	**Verification/Testing**
1. The duty cycle of the PWM output pin should agree with the duty cycle set in the Arduino Code	1. Connect the output of the PWM pin from the Arduino to the oscilloscope channel 1. 2. If the PWM has the duty cycle set by the Arduino code with the tolerance of +-2% then the microcontroller passes the test 3. Else the test is failed.
2. When the button is pressed, the console of the microcontroller should display a logic high value > 4V.	1. Run the arduino code with the button connected as shown on the logic diagram to the microcontroller. 2. When the button is pressed observe that the microcontroller is indeed reading a voltage >4V. 3. If it does, the test is passed; otherwise, the test is failed.

Speaker Requirement	If the speaker is working properly then it will output sound.
Sub Requirements	**Verification/Testing**
1. The speaker is outputting sound when the rod is vibrating.	1. Place the electret microphone under the rod. 2. Connect the speaker as shown on the logic diagram to the microcontroller. 3. Vibrate the rod at one end. 4. If the speaker can produce sound then the test is passed. 5. Else the speaker fails the test.

3.2 Tolerance Analysis

The critical component in our design that the transconductance amplifier can provide enough current for the driver coil to vibrate the rod. To test if the the cascaded amplifier is producing adequate current for the driver coil, we can use the following procedure:

Procedure:

1. Send a square wave as the input to the Cascaded transconductance amplifier with 5 V peak to peak at a frequency of 150 Hz.
2. Calculate the Vout and Iout on paper using the formulas mentioned in above.
3. Measure the Vout and Iout using the oscilloscope at Channel 1 and Channel 2 respectively.
4. If the Vout and Iout on the oscilloscope agree with the hand calculations for Vout and Iout within the tolerance range of + or - 2V and + or - 5A then the driver coil should be able to vibrate the rod without any problems.
5. If it does not work, then we have to test the output voltages at each node in the cascaded amplifier circuit to see if there are any wiring problems and fix those if any.
6.If there are no wiring problems then the op-amp chip might be broken so it should be replaced with a new one.
6. Power = Vout * Iout so the tolerance for the power using the hand calculations should be + or - 10 W.

4. Cost and Schedule

4.1 Cost Analysis

4.1.1 Labor

Name	Hourly Rate	Total Hours Invested	Total = Hourly Rate x 2.5 x Total Hours Invested
Venkata Geetha Bijjam	$35.00	150	$13,125
Jin Kim	$35.00	150	$13,125
Rachel Pashea	$35.00	150	$13,125

4.1.2 Parts

Part	Part Number	Vendor	Unit cost	Quantity	Total
Electret	COM-08635	Sparkfun	$0.95	2	$1.9

Microphone					
100 ohm Resistor	271-1108	Radioshack	$0.238	5	$1.19
200 ohm Resistor	CF1/4LT52R201J TAPE	KOA Speer	$0.75	4	$3.00
400 ohm Resistor	016-400	Xicon	$0.64	1	$0.64
1K ohm Resistor	271-1321	Radioshack	$0.238	5	$1.19
1 ohm Resistor	271-131	Radioshack	$1.08	2	$2.19
10K ohm Resistor	271-1335	Radioshack	$0.238	5	$1.19
22 ohm Resistor	271-1339	Radioshack	$0.238	5	$1.19
Iron Core	-	machine shop	$2	1	$2
Copper wire for driver coil	-	ECE Electronics Shop	$10	1 spool	$10
N channel Mosfet	RFP30N06LE	Fairchild Semiconductor	$1.13	1	$1.13
Opamp	CA3140E	Intersil	$22.08	3	$66.24
Push Button	COM-09181	Sparkfun	$9.95	1	$9.95
Speaker	S120	Logitech through Amazon	$10.26	1	$10.26
Arduino Mega	2560	Amazon	$49.99	1	$49.99
Total					$162.06

4.1.3 Grand Total

Labor	$39,375.00
Parts	$162.06
Total	$39,537.06

4.1.4 Status of the Parts

We asked the machine shop to do the mechanical parts related to the chassis of the instrument such as the rollers and the base for mounting the rod. We will get the rest of the parts from the parts shop. We will buy the Arduino board after we get the basic components like the preamp and the driver coil working.

4.2 Schedule

Deadline	**Week (Date)**	**Tasks**	**Member**
	1 (9/14)	Research (how a driver coil works and how to measure the resonant frequencies of the rod at different lengths)	Rachel
		Research (how an amplifier works and how to sustain the vibrations in the rod when the button is pressed)	Jin
		Research (how a pickup coil works, the different types available in the market, their applications and then use an magnetic pickup coil to measure the frequency range of the rod using an oscilloscope when the rod is clamped on one end and vibrated on the free end)	Venkata
Proposal	2 (9/17)	Use mathematical models to determine the theoretical resonant frequencies of the rod and compare them with the actual measured frequencies from last week and choose an initial design for the driver coil	Rachel
		Choose an initial design of an amplifier	Jin
		Purchase 2 piezo discs and modify the design for the pickup coil to include the volume and tone controls.	Venkata
Design Review Sign-Up	3 (9/24)	Sign-Up for design review Choose an initial design driver coil and model the circuit	Rachel

		as an equivalent magnetic circuit and write out KVL equation for the circuit.	
		Research about pre-amps and choose a basic design and plot Vin, Vout, and gain using matlab for specific input voltage and resistor values.	Venkata
		Improve the designs for the amplifier based on the feedback from the TA	Jin
Design Review	4(10/1)	Finalize driver coil design and figure out the number of turns of wire needed based on the current from the transconductance amplifier	Rachel
		Start building the preamp circuit and measure the input and output voltages on the oscilloscope	Venkata
		Design the amplifier circuit which takes the voltage input from the microcontroller and outputs the current (larger or around 1A) to the driver coil.	Jin
	5 (10/8)	Start building the driver coil by wrapping the wire around the core using the calculated number of turns for the wire.	Rachel
		Verify the output of the pre-amp with the simulations in Pspice for the specific R values and start integrating the electret mic with the pre-amp	Venkata
		Gather materials needed for the cascaded amplifier and start building it	Jin
	6 (10/15)	Test and debug the driver coil and verify that the number of wires used to wrap around the core do indeed produce the calculated B field.	Rachel
		Write the code for Arduino to modulate the output voltage from the pre-amp and debug the code.	Venkata
		Build the cascaded amplifier and debug it by connecting it to the oscilloscope and observing the Vin, Vout and Iout.	Jin
Individual Progress Reports	7 (10/22)	Continue testing and debugging the driver coil	Rachel

		Integrate the Arduino with the rod, the pre-amp, the switch and the button and verify the outputs for Vout and I out for each component using the oscilloscope based.	Venkata
		Debug the pickup coil and the amplifier as a connected circuit	Jin
	8 (10/29)	Integrate the driver coil with the pickup and the amplifier and test the circuit	Rachel
		Integrate the amplifier with the other main components and test the final circuit	Jin
		Add the Nmos to the PWM pin of the Arduino and integrate it with the rest of the components already built. Test the input and output voltages on the oscilloscope after the NMOs are added.	Venkata
Mock-Up Demos and Mock Presentation Sign-Up	9 (11/5)	Sign up for mock-up demo/mock presentation and gather and put together all the materials needed for the amplifier to use in the mockup demo	Jin
		Gather and put together all the materials needed for the pickup to use in the mockup demo. If a component is not working properly, replace it and test the Vin, Vout, Iin, Iout for the components using the oscilloscope.	Venkata
		Gather and put together all the materials needed for the driver coil to be used in the mock up demo.	Rachel
Mock Presentation	10 (11/12)	Prepare documentation and notes for the driver coil circuit and make sure to create an outline for the driver coil.	Rachel
		Prepare notes and documentation for the pickup coil circuit and finish the programming part for the Arduino.	Venkata
		Prepare for the mock presentation by collecting the documentation for the amplifier and put come up with an outline for the amplifier part to be used in the mock presentation.	Jin
Demo and Presentation Sign-Up	12 (11/26)	Sign up for demo and presentation and work on the circuit diagrams for the final paper. Make sure all the programming part is integrated perfectly with the rest of	Venkata

		the circuit.	
		Gather documentation for the Appendix and also Work on Abstract for the Final paper.	Jin
		Work on the requirements and the verification table for each block and make sure that the each requirement has a corresponding verification.	Rachel
Demos and Presentations	13 (12/3)	Edit First Draft of the Final Paper and go through the checklist for the Final paper to make sure none of the required components are missing.	Jin
		Ensure all sources are cited in the Final Paper and make sure that the descriptions for each block make sense and are grammatically correct.	Rachel
		Verify all Data and Simulations are included in the Final Paper. Also, verify that the software part in the Final paper is correct.	Venkata
Presentations, Lab Notebook Due, and Final Paper Due	14 (12/10)	Edit the Second Draft of the Paper and make sure all the data is entered in the Final paper. Also, verify that the requirements and verifications are correct for the Final paper.	Rachel
		Upload the Final Paper to PACE after ensuring that the formatting is correct and all of the Figures are labeled in the Final Paper.	Jin
		Incharge of Checkout and make sure the tool box is returned with all of the materials provided at the beginning of the semester.	Venkata

5. Ethical Considerations

The IEEE code of ethics is listed in the left column; the right column lists how we will adhere to each item of the code during this project.

To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment	Our project is intended to be used by the public when it is finished, so it is our responsibility to write clear instructions for using the instrument.
To avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist	We will immediately inform our TA of possible conflicts of interest if they arise.
To be honest and realistic in stating claims or estimates based on available data	All of our statements and estimations will be backed up by calculations; we will not make a claim without reason. Data will not be fabricated.
To reject bribery in all its forms	We will not accept bribes.
To improve the understanding of technology; its appropriate application, and potential consequences	We will do our best to inform the public about the correct use of this instrument, predict the consequences of misuse, and develop a prototype that minimizes the negative consequences.
To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations	Each of us is more knowledgeable in a certain area than the others, which is how we divided up our work, and yet we must all have an understanding of the project as a whole. This requires us to communicate and teach each other to improve our knowledge.
To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others	This is a team project, so each of us will review the others' work, give feedback, and give each team member credit for her contributions.
To treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin	We will treat everyone involved with this project with the same respect.
To avoid injuring others, their property, reputation, or employment by false or malicious action	We will not injure others, their property, reputation, or employment.
To assist colleagues and coworkers in their professional development and to support them in following this code of ethics	We will make sure that everyone working on this project adheres to this code of ethics, and we will support and encourage one another to live up to Illinois engineering standards.

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