New York City College of Technology

Department of Electrical & Telecommunications Engineering Technology

EET 2171 - E244 - Projects Laboratory

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Final Project: Audio Power Amplifier

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Table of Contents

Objective

For this project we will be building an audio power amplifier with a DC power source, AC Input, and AC output section, using many components that include resistors, capacitors, a TDA 2003 chip, a fuse and fuse holder, a switch, a banana jack, an RCA jack, a potentiometer, a speaker jack, different color wires, and a heat sink. We also will be measuring voltage gain, power gain, output power, and lower and upper cutoff frequencies. Lastly, we will be researching the different types of amplifiers and their different purposes.

Theory of Operation

1. An amplifier is an electronic device that takes a weak signal and sends out a stronger one. This only increases the amplitude without affecting the frequency or waveshape. This can include increasing a voltage, current, or the power of a given signal. Some applications for an amplifier include wireless communications, broadcasting, and in audio equipment. Some amplifier examples consist of audio frequency amplifiers, intermediate frequency amplifiers, radio frequency amplifiers, ultrasonic amplifiers, wideband amplifiers, DC amplifies, video amplifiers, buffer amplifiers, operational amplifiers, and transistor amplifiers.

2. First, we have the audio frequency amplifier. These operate in the range of 20Hz to 20kHz. These are usually used to operate loudspeakers. Next, we have the intermediate frequency amplifier which are often used in TV's, radios, and radar. This amplifier provides the maximum voltage amplification before the video or audio signal is demodulated. The frequency that they operate at is decided by the type of equipment being used. Then, we have the radio frequency amplifier. This amplifier increases the power of low-frequency radio signals. The frequency is controlled by the tuned circuit. An advantage of this amplifier is that it has low noise performance, so they are often used in the earlier stages of the receiver. Next, we have the ultrasonic amplifier. This amplifier operates in the frequency of 20kHz to 100kHz. This amplifier can be used in products for ultrasonic cleaning, ultrasonic scanning, remote control systems and many more. Now, we have the wideband amplifier. They amplify from DC to tens of MHz's. This amplifier can be found in lab equipment such as an oscilloscope. The purpose of this amplifier is used to measure over a very wide range of frequencies. Next, we have the DC amplifiers. This amplifier can only work at very low frequencies. This amplifier amplifies DC frequency which we know is 0Hz. Then, we have the video amplifier. This amplifier turns a video signal into a high resolution. This amplifiers frequency operates at what the equipment operates at. In the case of TV's this can be from 0Hz to 6MHz. Next, we have buffer amplifiers. This amplifier is mostly used for electrical impedance transformation from one circuit to a different one. The amplifier gain here is 1. Then we have the operational amplifier which we would be using for this project. This amplifier is a high gain voltage amplifier. The two inputs on this op amp are an inverting and non-inverting. Lastly, we have the transistor amplifier. This amplifier amplifies the voltage or the current of the input signal. The two types of transistor amplifiers we have are the bipolar junction transistor (BJT) and the field effect transistor (FET).

In the BJT we have a small current at the base that controls the current at the emitter and the collector and for the FET we have a small voltage at the gate that controls the voltage at the source and drain.

3. An audio power amplifier is an amplifier that amplifies low power audio signals to a high enough level for hearing through a device such as a loudspeaker or headphone. This amplifier is usually found in sound systems and is the final stage in an audio playback chain before it is sent to the loudspeaker or headphone.

An audio amplifier is an amplifier that enhances the strength of signals passing through by reproducing the signal. This amplifier also adjusts tone, effectiveness, and sharpness of the audio to give you the best sounding sound.

4. The classes of amplifiers we have are measured by the size of the signal, physical configuration, and the output signal compared to the input signal. We have two types of signals, small and large. Then we have three types of configurations, common emitter, common base, and common collector. Next, we have four classifications, class A, class B, class AB, and class C. And lastly, we have four frequency of operations, direct current, audio frequencies, radio frequencies, and VHF, UHF, and SHF frequencies.

A simple signal amplifier should always have three main things. An input resistance, output resistance, and the amplification (Gain or A). The gain is measured by output signal divided by the input signal. There are three types of gains that can be measured. This is the voltage gain, current gain, and power gain. We can also measure these gains in dB. To measure the voltage gain in dB we use a_v = 20*log (Av), for current gain in dB we use a_i = 20*log (Ai), and lastly for power gain in dB we use a_P = 10log (Ap). (Note for ex. Av=output voltage/input voltage).

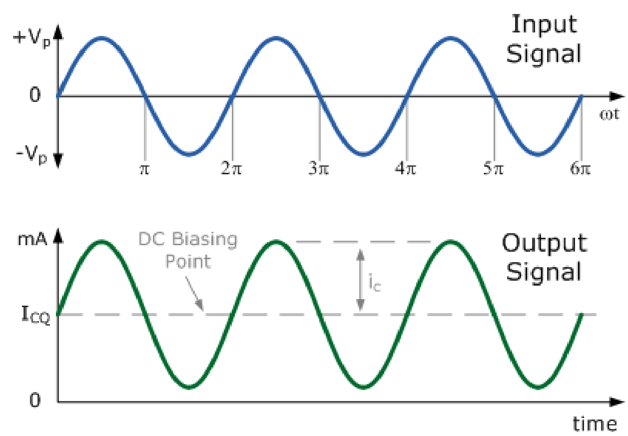
We can also measure the amplifier efficiency using

$$Efficiency\ (\text{ŋ}) = \frac{P_{out}}{P_{In}}$$

We have four classes class A, class B, class AB, and class C which range from near linear output with low efficiency to non-linear output and high efficiency. Class A amplifier has low efficiency (Less than 40%) but has good signal reproduction and linearity. For class B amplifier we have an efficiency of about 70% due to the device only conducting and using power for half the input signal. Next, we have the class AB amplifier, which has an efficiency rating between about 40% and 70%, but worse signal reproduction than class A. Lastly, we have the class C amplifier, which is the most efficient amplifier, but the distortion is very high. This means that the input signal would not look like the output signal.

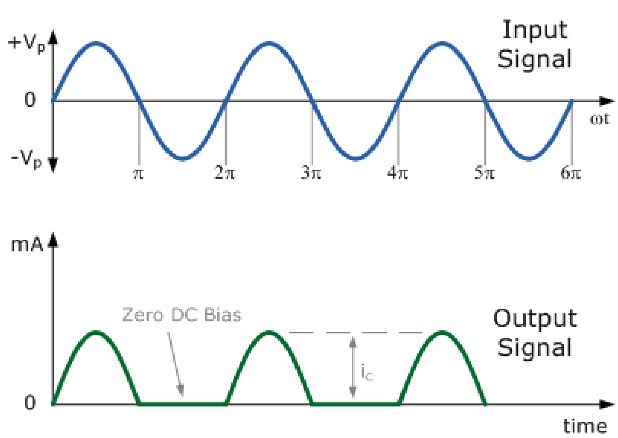
Below are a few graphs of the output waveforms of some of the different class amplifiers.

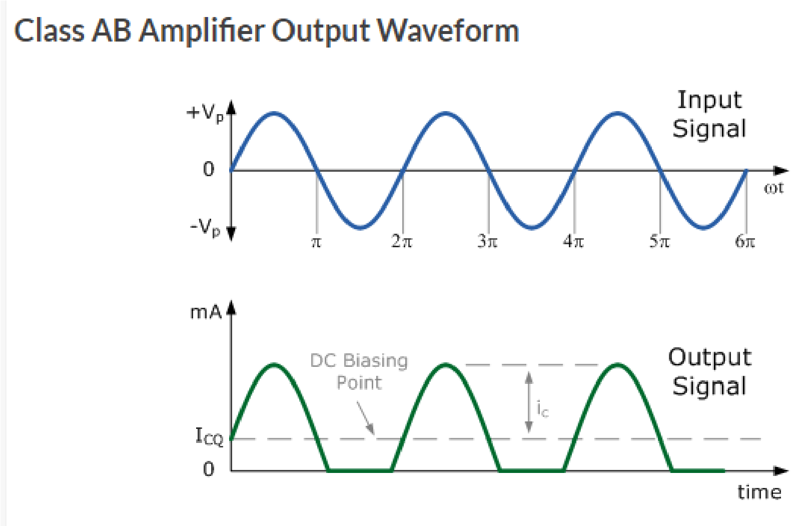
Class A Amplifier Output Waveform



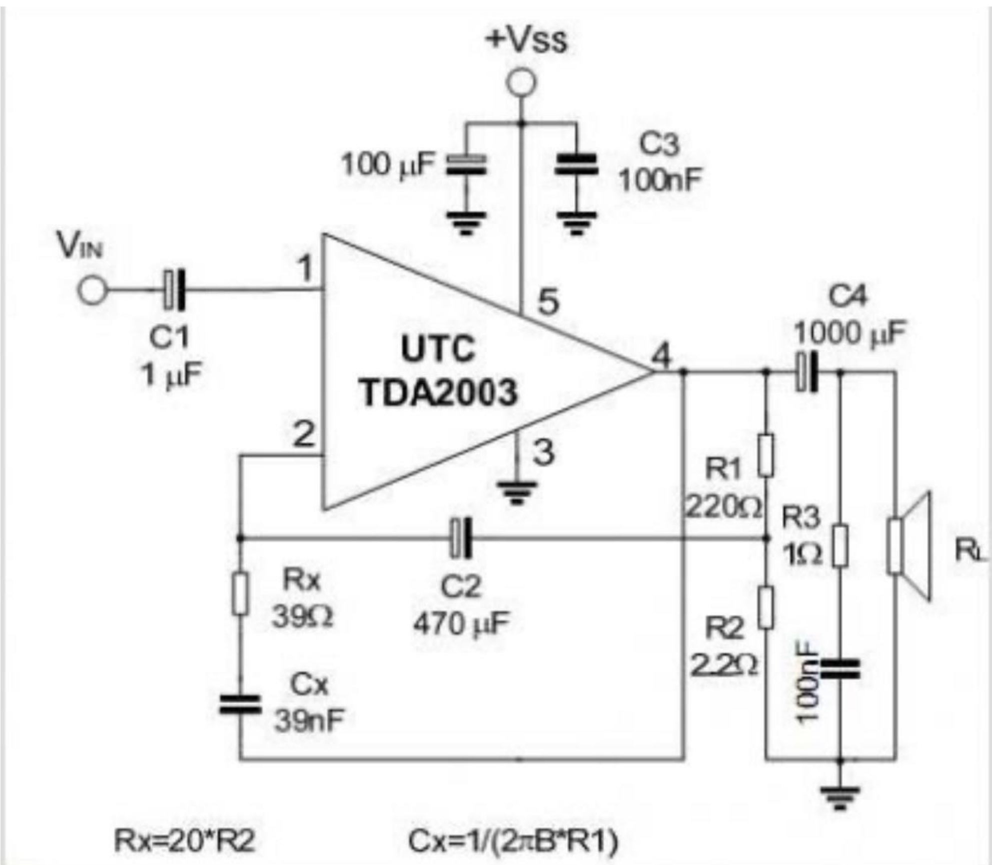
Note: I_CQ is the DC biasing current flowing through the collector of the transistor

Class B Amplifier Output Waveform



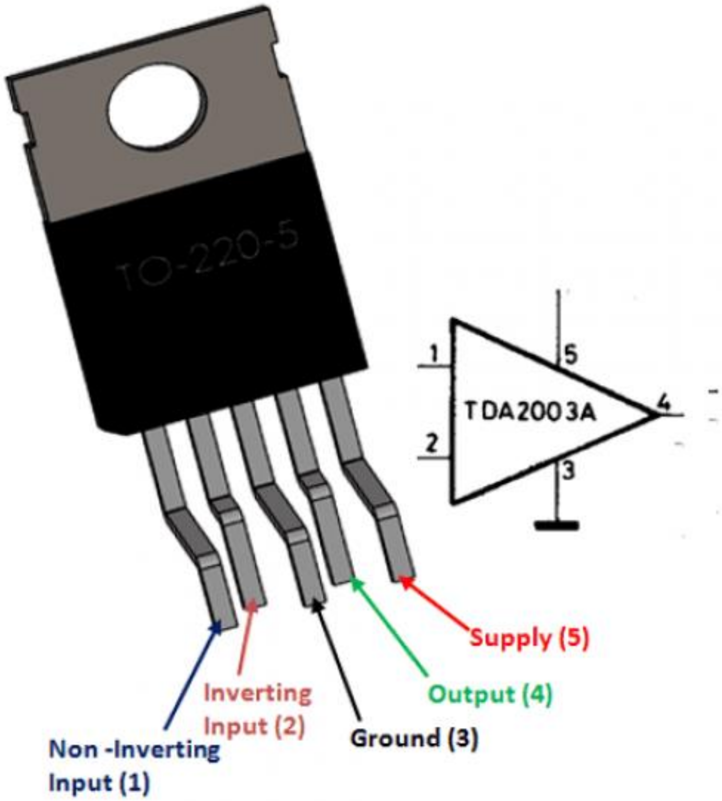


5. For this main project, I selected the following amplifier to build.



The figure above shows a 10W Dual Audio Power Amplifier circuit, which uses a TDA2003 chip.

Below is a picture of the detailed explanation of the TDA2003 chip.



This chip provides many built-in protective systems. First, it has a load dump voltage surge protection on pin 5 up to 40V. Next, it has a short circuit protection for both AC and DC up to 16V. Then, we have polarity inversion protection. This means this chip can withstand up to 5A. Next, we have protection diodes just in case an open to ground is formed. We also have a protection diode between pin 4 and 5 to work with inductive loads. This means we can use a coupling transformer for audio modulation. Lastly, we have thermal shutdown protection. This includes an overload on the output, excessive ambient temperature, or excessive junction temperature.

6. First and most importantly, we have the TDA2003. This is a 5-pin amplifier. The audio signal is sent to pin 1 (non-inverting input) and the audio output is at pin 4 (output). Then we have pin 2 (inverting input) which adjust for gain of the circuit, pin 3 (ground) used for a common return path for the electric current, and lastly pin 5 (supply voltage) which provides the TDA2003 with a power supply.

Next, we have the components Cx and Rx which sets the bandwidth for the amplifier using the formulas …

$$R_x = 20 * R_2$$

and

$$C_x = \frac{1}{2\Omega B R_1}$$

Then we have resistors R1 and R2, which adjust the gain for the amplifier. Next, we have R3 which protects the speaker. We also have the capacitors now. C1 is the input DC decoupling, C2 is the ripple rejection, C3 is the supply bypassing, C4 is the output coupling to load, and lastly C5 is the frequency stability.

7. Theoretical Gain Calculation:

$$A_v = 1 + \frac{220\Omega}{2.2\Omega}$$

$$A_v = 101$$

Maximum Power Availability:

$$V_{In} = 12V_{Peak\ to\ Peak}$$

$$V_{In\ (After\ Voltage\ Drop)} = 11.2V_{Peak\ to\ Peak}$$

$$V_{Out(RMS)} = \frac{1}{2 * \sqrt{2}} * V_{Out\ Peak\ to\ Peak}$$

$$V_{Out(RMS)} = \frac{1}{2 * \sqrt{2}} * 11.2V_{Peak\ to\ Peak}$$

$$V_{Out(RMS)} = 4V_{RMS}$$

$$P_{Max} = \frac{V_{Out(RMS)}^2}{Impedance_{Load\ (Speaker)}}$$

$$P_{Max} = \frac{4V_{RMS}^2}{8\Omega}$$

$$P_{Max} = 2W$$

Test Procedure and Results

Experiment #1 Oscilloscope

Run I: DC Voltage Measurement

Before we start testing our project, we must first run the Oscilloscope Test Procedure. To complete this procedure, we must first turn the oscilloscope on. Next, press the button “2” twice to turn the second output off. Then press the button 1 to see the vertical menu for channel 1. Then we must set coupling to GND, BW Limit to OFF, Probe to 1X, and Invert to OFF. Then we must use the position knob for channel 1 to move the trace in the middle of the screen. Then we will open the vertical menu again and select the coupling DC option. Next, we will use the scale knob for channel 1, and select 2V/Division. Now we will turn the DC power supply on and adjust it to 6V. Then we will connect the scope probe to the power supply and the trace should appear on the screen.

Question A. How many divisions did the trace move up?

The trace moved up 3 Divisions.

Question B. Can you measure the DC input to scope by using the divisions?

Yes, you can measure the DC input to scope by using divisions.

Question C. Calculate the DC voltage on the screen.

*3 Divisions * 2V = 6V*

Now we must press the measurement button. Then for the source we will select Ch1, Voltage, and Vmax.

Question D. What is the measurement value?

The measurement value is 6.081V.

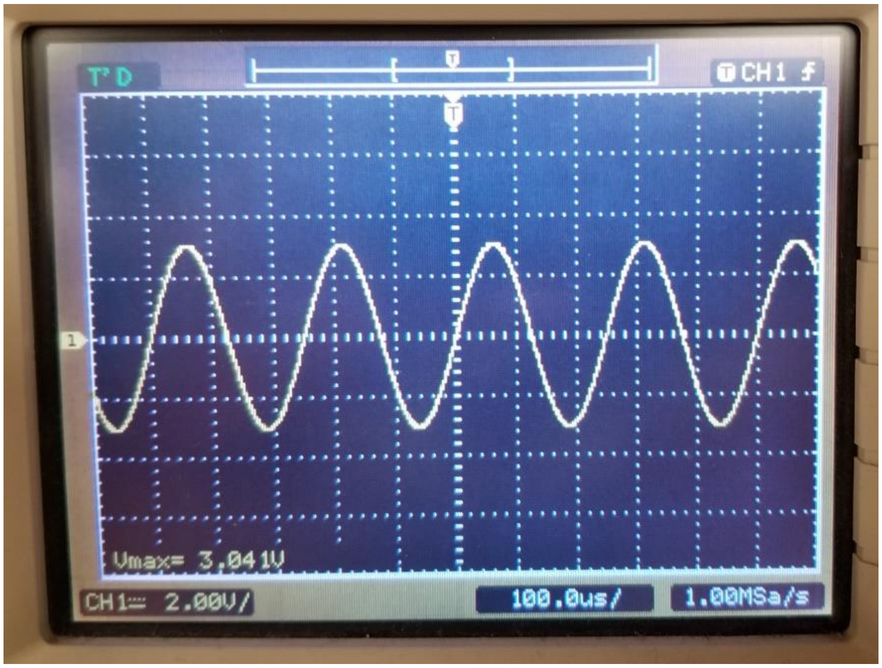
Run II: AC Voltage Measurement

First, we must turn on the generator using the power button the left side. Then, we will press the utility button, output setup button, and select Load/High Z, and then press Done. You should then see High Z Load on the top right. Now, we will have to press Sine, Freq, and then press 4 and select KHz. Then we will select Ampl, 6, and press Vpp. Next, we will press Offset and select 0 and press mVDC. Now we will press the Output button. Next, we must use the scale knob and adjust it to 100µs/Division. Then, we will connect the scope probe to the generator output. Now, to see the trigger menu we will select Mode, and see the mode to Edge, Source to Ch1, Sweep to Auto, and Coupling to DC. Next, we will press the 50% button to select the midpoint triggering level.

Question E. What type of waveform is on the screen?

On the screen there is a Sine Wave.

Question F. Record the waveform (you can take a picture).

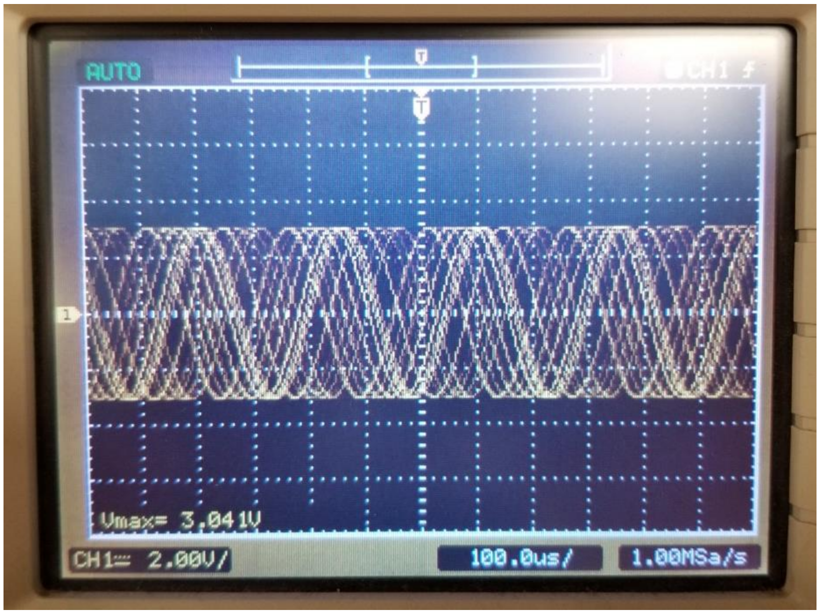


Next, using the trigger level knob, we will increase the trigger level to a line above the positive peak of the waveform.

Question G. Explain your observation of the waveform on the screen?

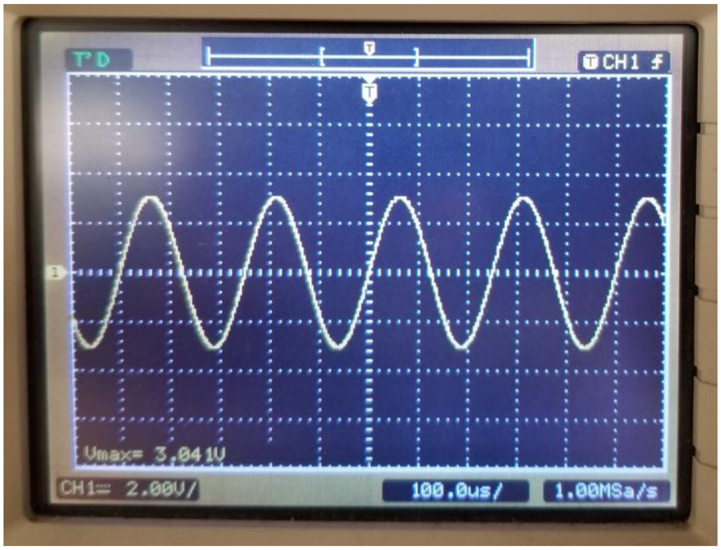
The waveform is moving horizontally.

Question H. Record the waveform (you can take a picture).



Then, we will press the 50% button to select the midpoint triggering level again.

Question I. Record the waveform (you can take a picture).



Now, we will press the measurement button and for the source select Ch1, and voltage to Vpp.

Question J. What is the measurement value?

The measurement value is 6V.

Then, we will press the measurement button again and select Voltage and change it to 2/3 and to Vrms.

Question K. What is the measurement value?

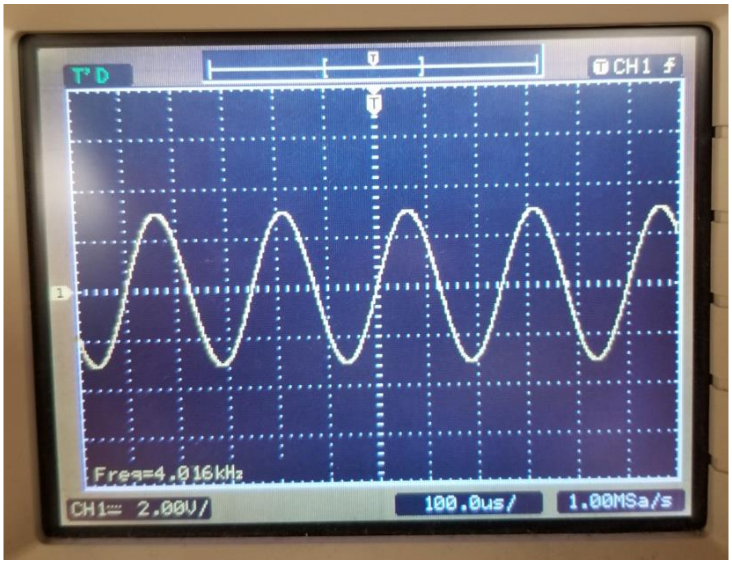
The measurement value is 2.189V.

Next, we will press the measurement button again, and chance the source to Ch1, select time, and then select Freq.

Question L. What is the measurement value?

The measurement value is 4kHz.

Question M. Record the waveform (you can take a picture).

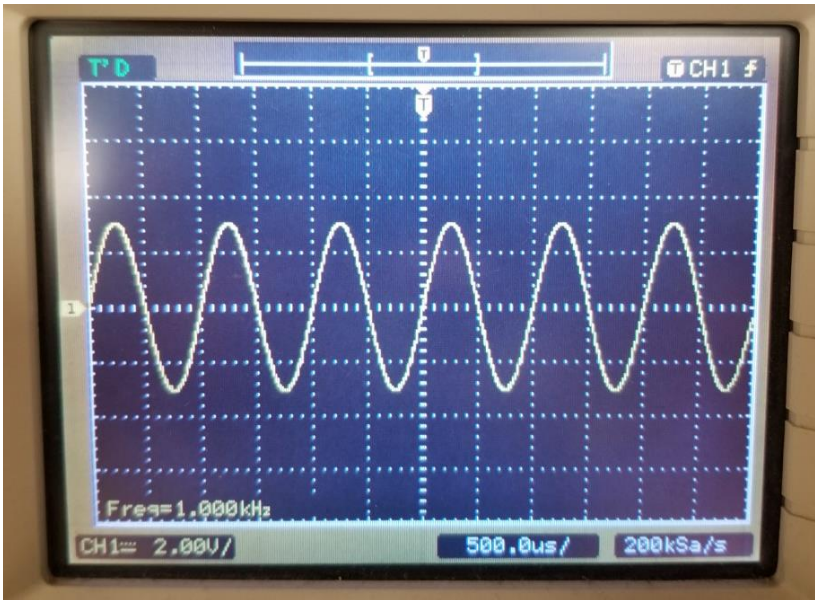


Then, we will select the Freq button on the generator, press 1, press KHz. And verify that it shows 1KHz. Now, using the scale knob on the scope, we will select Time/Division to see a few cycles of the waveform.

Question N. What is the measurement value for the frequency?

The measurement value is 1kHz.

Question O. Record the waveform (you can take a picture).

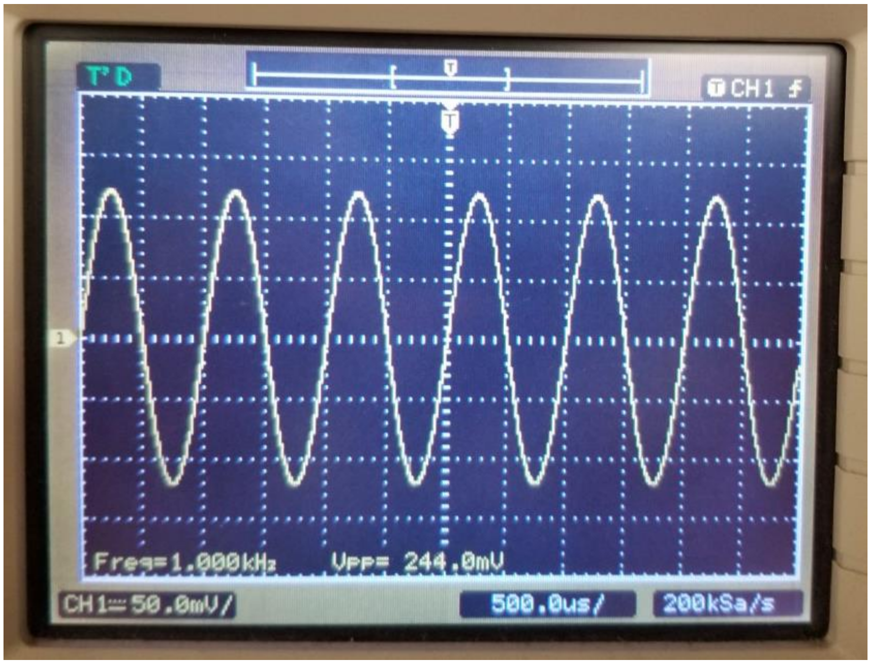


Next, must press the Ampl key on the generator, and press 240, and then mVpp. Then, using the scale knob for channel 1, select V/Division so that we can see the peak-to-peak of the waveform.

Question P. What is the measurement value for the Vpp?

The measurement value is 244mV.

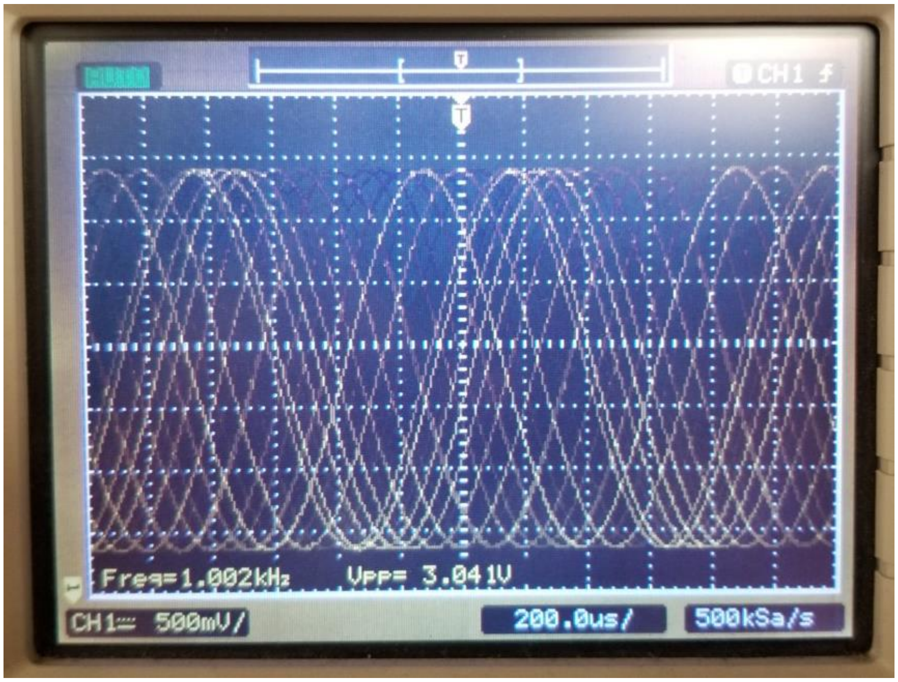
Question Q. Record the waveform (you can take a picture).



Run III: AC Plus DC Measurement

First, we will press the Ampl key on the generator and then press 3, and Vpp. Then, we must press Offset, 2, and V_DC. Then, using the scale knob for channel 1, select proper V/Division to see the peak-to-peak of the waveform.

Question R. Record the waveform (you can take a picture).



Question S. Explain the effect of Offset on the waveform.

The waveform is moving horizontally.

Question T. What is the measurement value for the Vpp? Did the Offset voltage change the value of Vpp?

The measurement value for the Vpp is 3V, and the Offset voltage did not change the value of Vpp.

Question U. What is the DC measurement value?

The DC measurement value is 2V.

Lastly, we must press the Offset key, 0, and then mVDC.

Audio Power Amplifier DC Test

Note: All tests were completed and successful.

Visual Inspection

First, we must perform a visual inspection. This consist of checking the board with our eyes for any open gap on the traces, any soldering done incorrectly, any solder between the pads, and that none of the pads are connected.

Ground Line Test

Next, we will perform the ground line test. First, we must check the continuity from the black terminal of the banana jack to the pin 3 of the IC chip. Then we will check the continuity from the black terminal of the banana jack to the ground side of the RCA jack. Now, we will check the continuity from the black terminal of the banana jack to the ground terminal of the speaker jack. Next, we will check the continuity from the black terminal of the banana jack to the ground terminal of the switch (with indication).

Positive Line Test

Then we will check the continuity from the red terminal of the banana jack to the fuse terminal. Next, we must check the continuity from the other terminal of the fuse to the switch terminal. Now, we will check the continuity from the switch terminal to the pin 5 of the IC. Next, we must turn the switch to the “ON” position and then check the continuity from the red terminal of the banana jack to the pin 5 of the IC. The DMM should show continuity. Now, we will turn the switch to the “OFF” position. The DMM should show open circuit.

Power Line Test

Lastly, we will place the ohmmeter between positive and negative terminals of the banana jack, and we should not see any value. And when the switch is on, the meter reading should be larger than 10K.

Audio Power Amplifier Test and Measurement Procedure

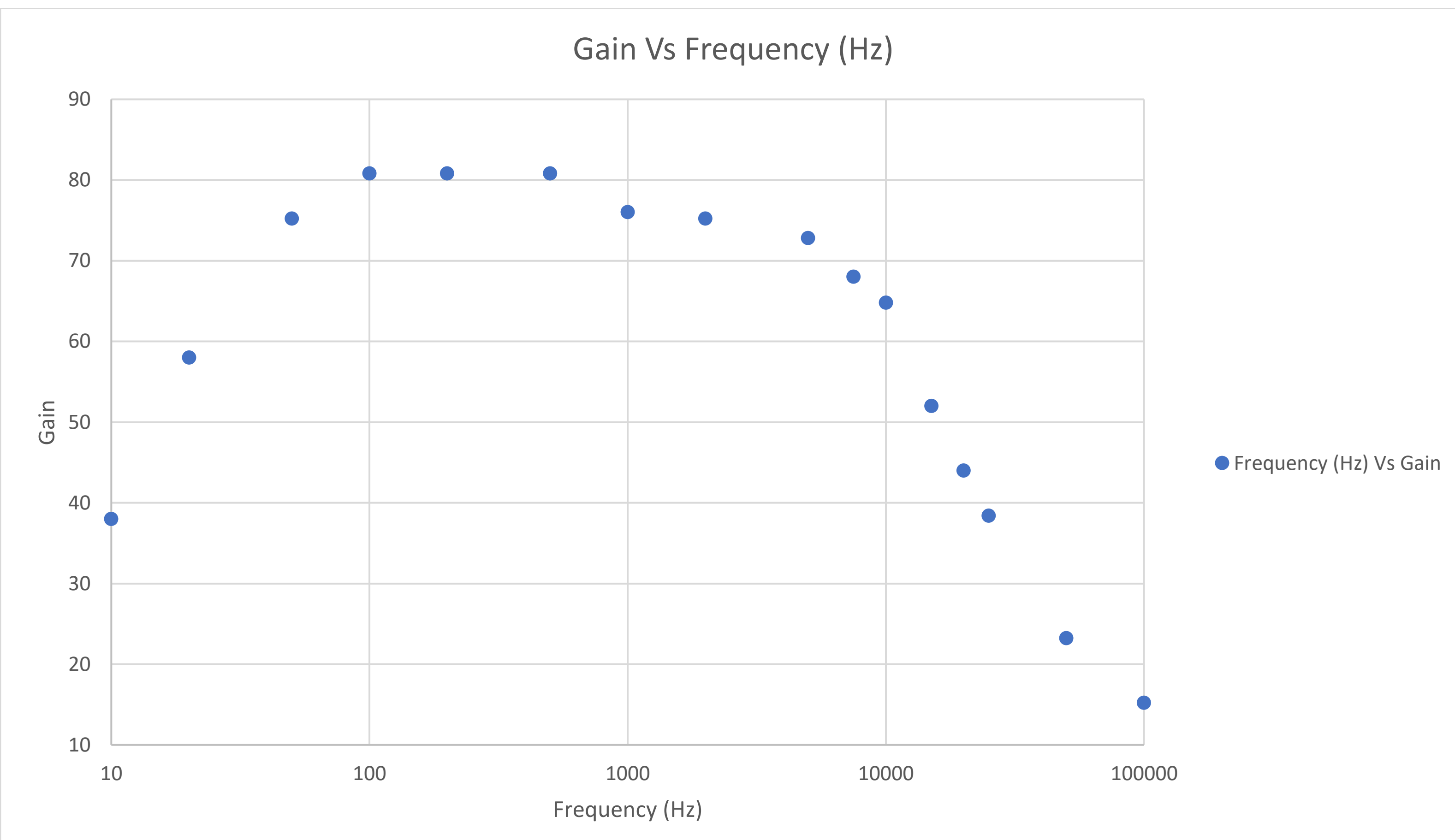
Test and Measurement Procedure

Note: All tests were completed and successful.

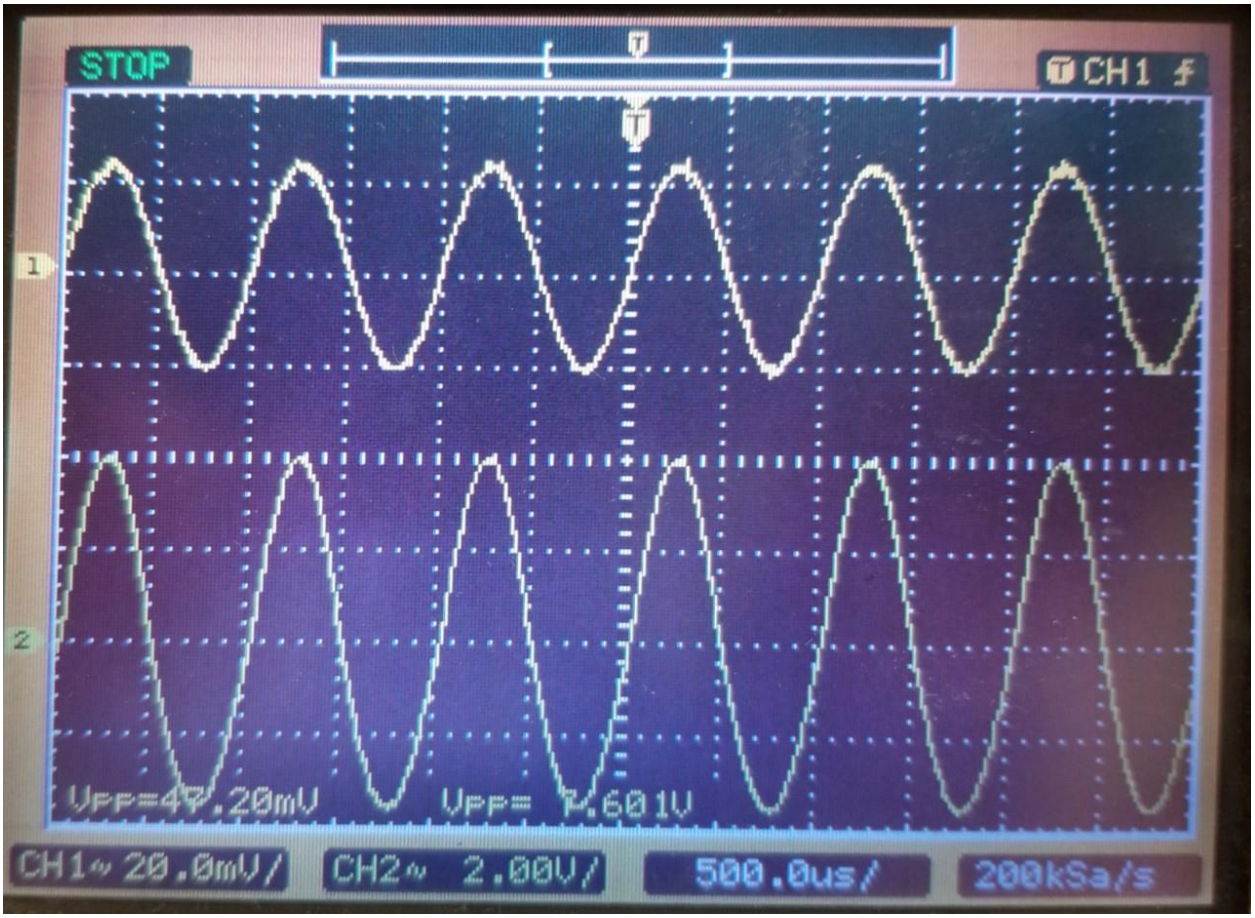
First, we will connect an 8Ω resistor to the speaker jack. Next, we will connect one of the scope's probes to the functional generator output and to the provided RCA cable leads. And connect the second probe to the RCA cable leads and the channel "1" of the oscilloscope. Now, we will connect the third probe to channel "2" of the oscilloscope and across the 8 Ω load resistor. Next, set the Oscillator to 1 kHz and 100mv (PP) output level. Then, set the vertical of channel 1 to 50 mV/div and channel 2 to 1V/div. And the horizontal time base to 500 µs/div. We must verify that the waveform is visible on the scope's channel 1. Now, we can connect the RCA plug to the project and verify that the waveform on the screen did not change. Next, we can set the volume control of the Audio Power Amplifier to the maximum. Then we can turn the power supply to the "ON" position, set it to 12V and turn the output "OFF". Now, using banana plugs, we can connect the power supply to the banana jack of the project. Now we can turn the power supply output "ON". We can also know turn the switch of the project to the "ON" position. We must now verify that the voltage of the power supply did not change. The output waveforms should now be visible on the oscilloscope channel 2. We can now measure the input and output levels on the oscilloscope and compute the gain. This is the Amplifier's mid-band gain. Now we can also compute the Amplifier's output power. To now complete the Frequency Response table of the Audio Power Amplifier, we can vary the frequency of the oscillator as shown in Table 1 starting at 1 kHz and measure the amplifier's gain for each of the frequencies listed in the table 1. On the table we must also find the lower and upper cut off frequencies and record them in the table. To find the upper and lower cutoff frequencies, vary the frequency of the oscillator until the gain is 0.7 times of the mid-range gain. Lastly, we must use excel spreadsheet to plot the curve of the frequency response. The plot should have the length as frequency with logarithmic scale from 10 Hz to 100 kHz and its width as gain with linear scale.

	Frequency (Hz)	Measured Input Level (V)	Input Level (For Calculations) (V)	Measured Output Level (V)	Gain (Output/Input)
	10	0.082	0.1	3.801	38.01
	20	0.07	0.1	5.801	58.01
	50	0.046	0.1	7.521	75.21
	100	0.032	0.1	8.081	80.81
	200	0.032	0.1	8.081	80.81
	500	0.032	0.1	8.081	80.81
	1000	0.0472	0.1	7.601	76.01
	2000	0.0512	0.1	7.521	75.21
	5000	0.0608	0.1	7.281	72.81
	7500	0.0656	0.1	6.801	68.01
	10000	0.0664	0.1	6.481	64.81
	15000	0.0744	0.1	5.201	52.01
	20000	0.08	0.1	4.401	44.01
	25000	0.084	0.1	3.841	38.41
	50000	0.088	0.1	2.321	23.21
	100000	0.092	0.1	1.521	15.21
Lower Cutoff…	16	0.072	0.1	5.6	56
Upper Cutoff…	14000	0.0692	0.1	5.8	58

Table 1

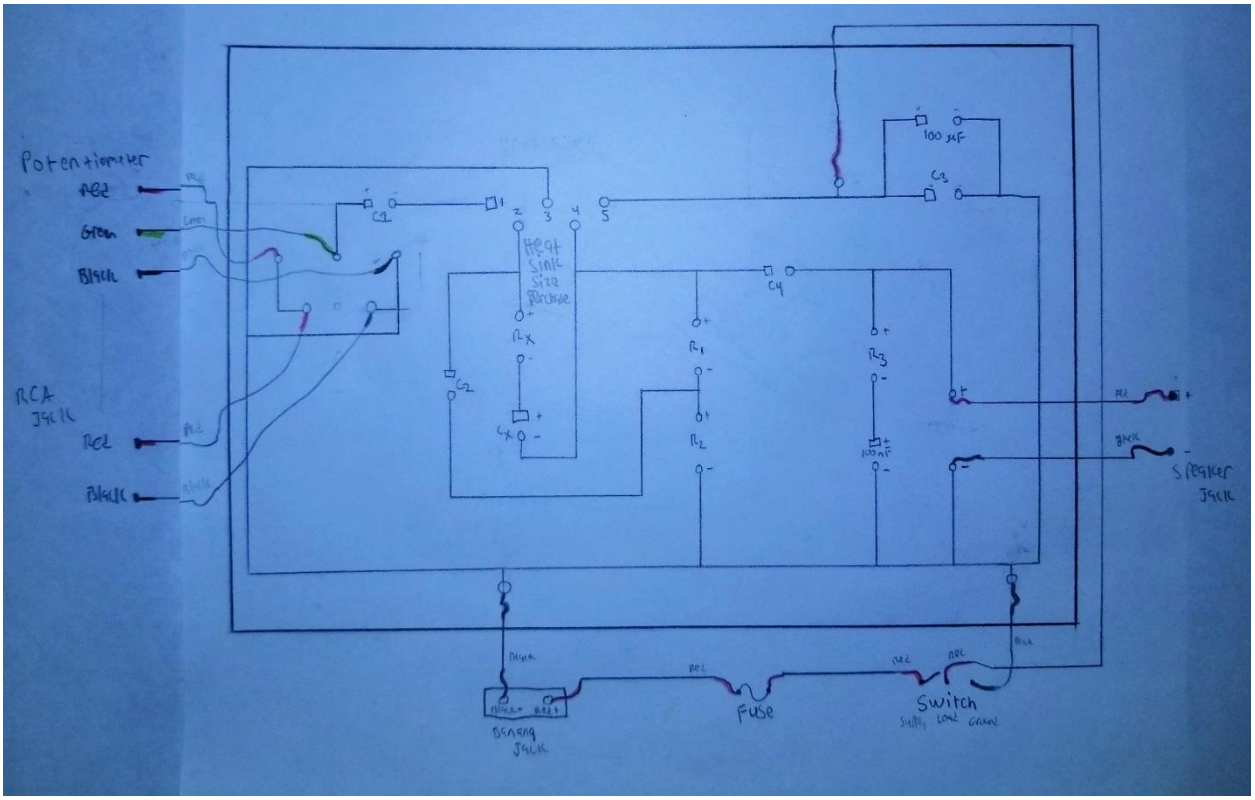


To find the lower and upper cutoff frequency, I took the mid-range gain, and multiplied it by .7 (80.81 * .7 = 56.567). Knowing this, I was able to figure out that the lower cutoff frequency should be in between 10Hz and 20Hz. And the upper cutoff frequency should be in between 10kHz and 15kHz. After finding the right frequencies, I was able to get an output level which would give me a gain for the lower cutoff frequency and upper cutoff frequency of 56 and 58 respectively. These two levels are very close to 56.567 with a precent difference of 1.0074% and 2.501593%.

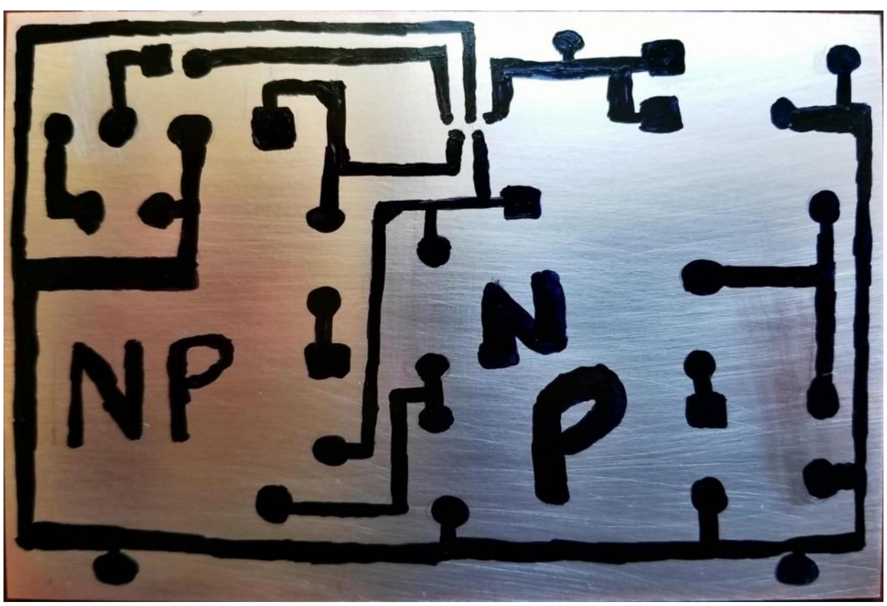


Input on top, and output on the bottom, for frequency at 1000Hz

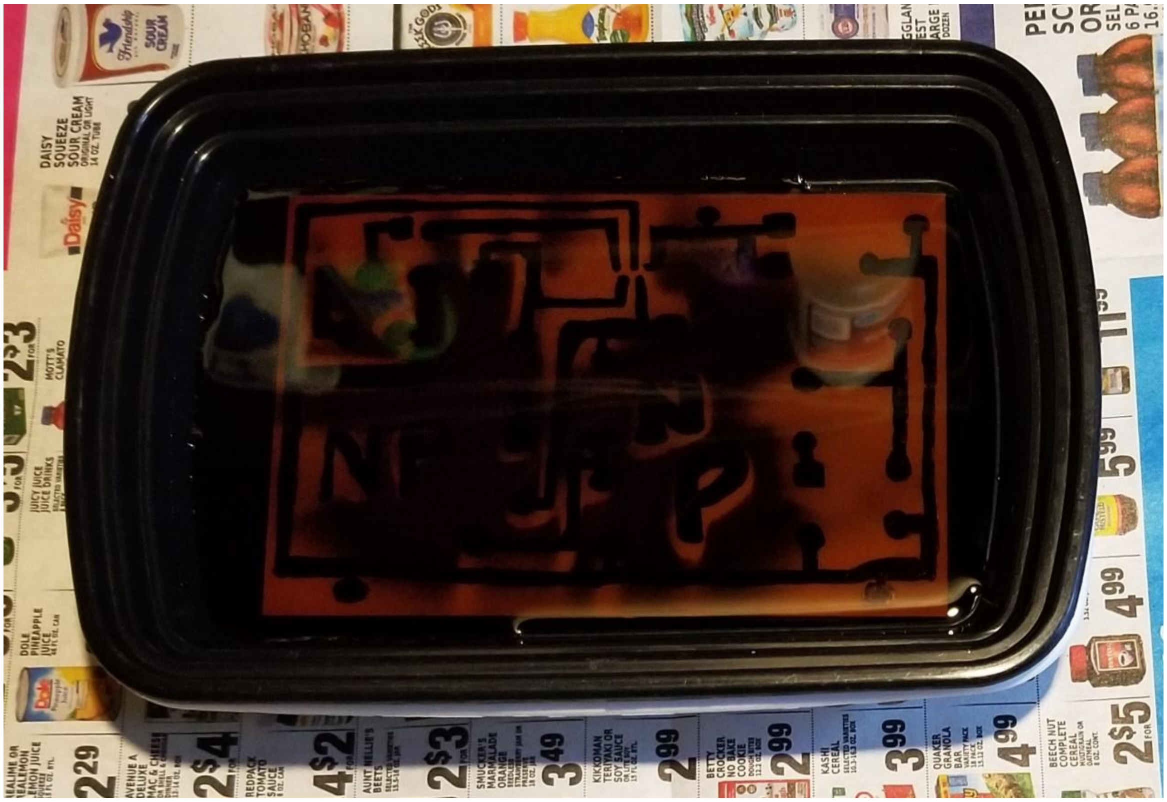
Manufacturing and Assembly Procedure



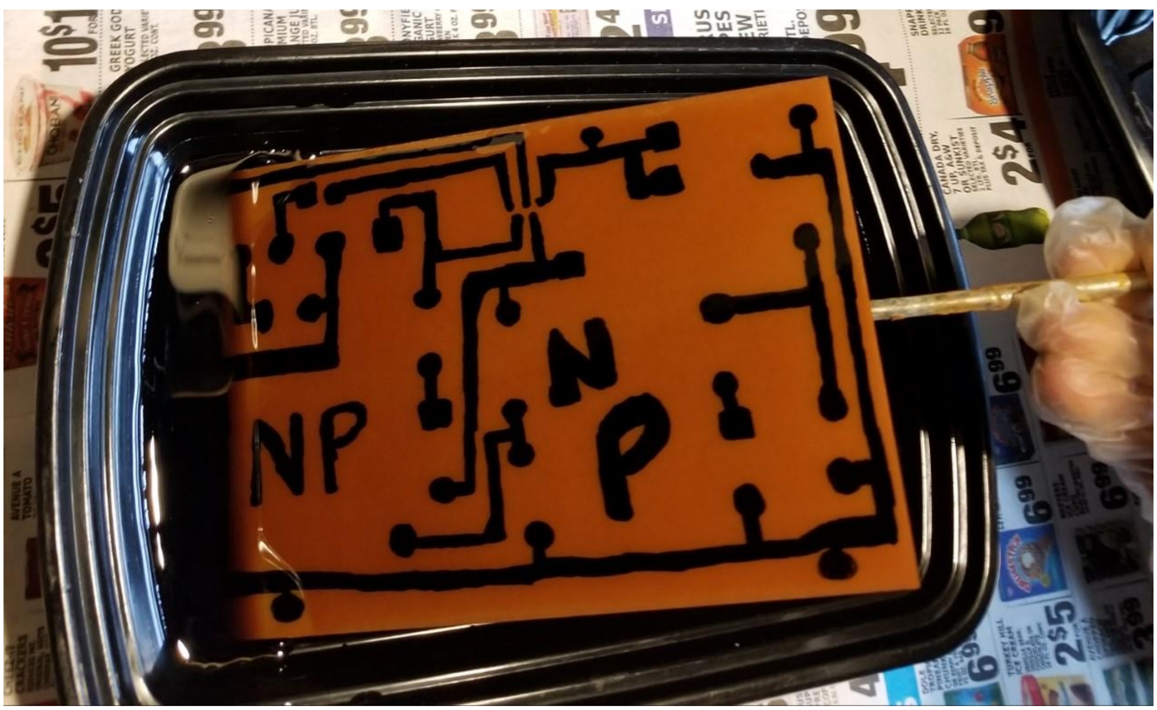
The first phase of designing and building a PCB is always the drawing to make sure we have no issues when transferring it to the board. Above is my schematic for my Audio Power Amplifier circuit.



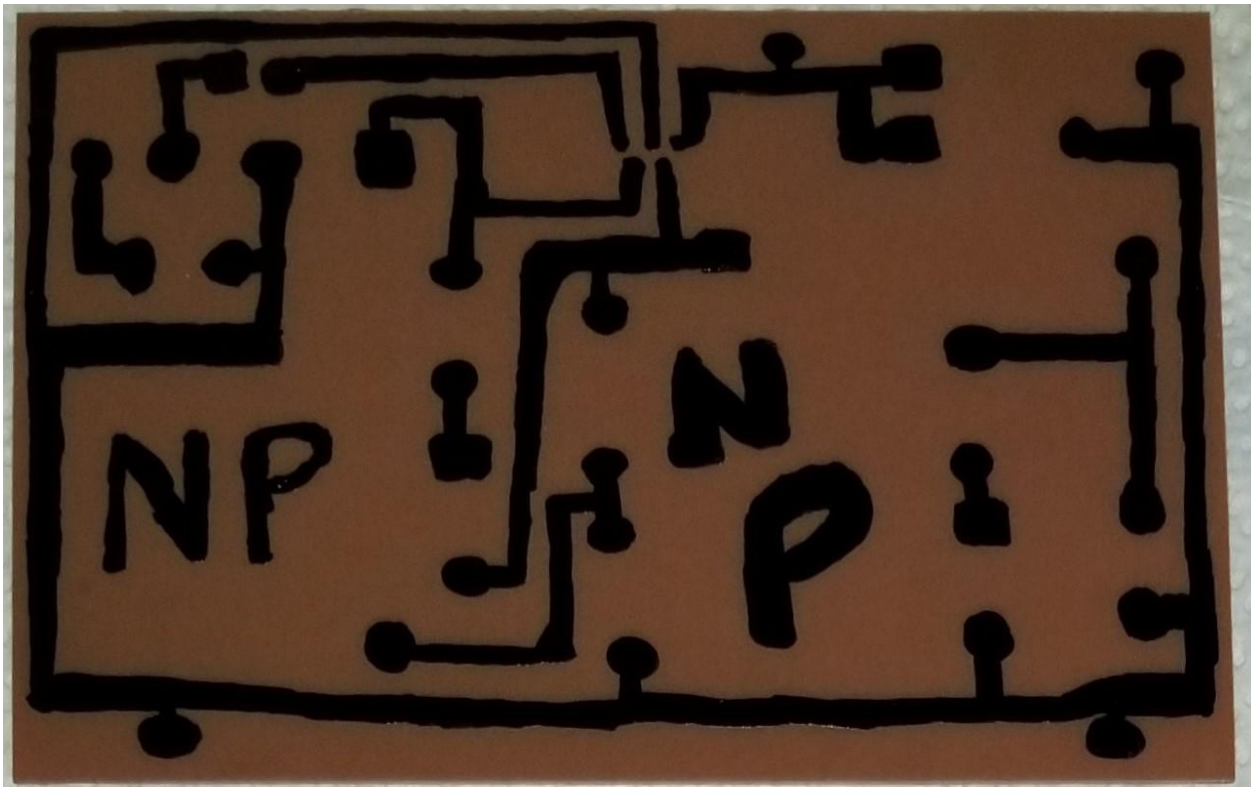
Next, we must transfer the schematic from the paper to the board. This involves using a waterproof marker to draw on a cleaned board. Above is my PCB board after drawing on it.



Then, we must etch our board to remove the extra copper around our traces. This is my board in the solution after about 16 minutes.



As you can see, after 26 minutes my board is still not complete yet because there is still cooper in the center of the board.



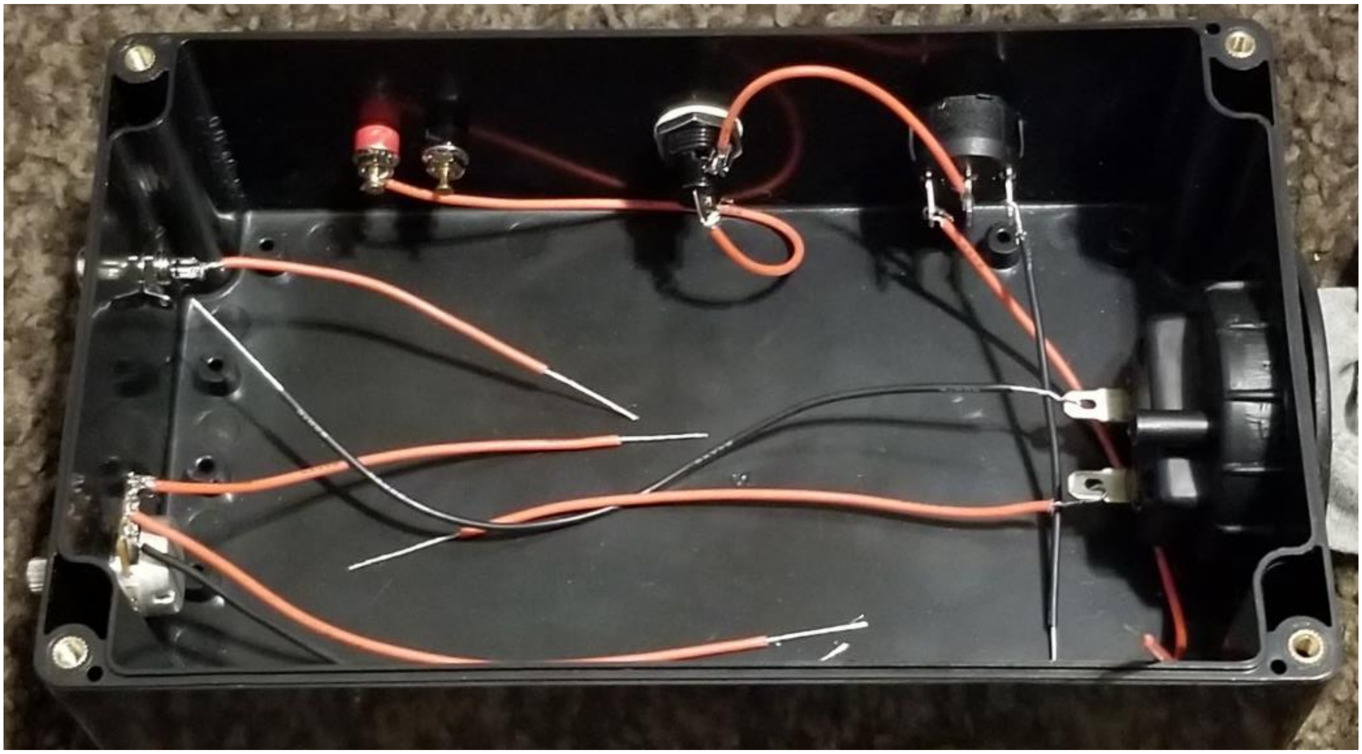
After 45 minutes, my board is now complete. I have taken the board out and washed it with water and then dried it with a paper towel. After this I must use rubbing alcohol to wipe off the marker.

Now, I must prepare my enclosure. The first step is to drill the holes for each part and fit each part in. Above is the Switch (With Indication), Fuse Holder, and Banana Jack. (Left to right)

Above is the RCA Jack and Potentiometer. (Left to right)

Above is the Speaker Jack installed in the enclosure.

Above is the view from all the parts installed in the enclosure.



After installing all the parts I know must connect the wires to each terminal. This is shown above.

Lastly, I must solder the components onto the board, place the board in the enclosure and connect all the wires to the proper terminals.

Above is a view of the completed board with all proper connections.

Conclusion and Comment

Therefore, this experiment has taught me a lot about designing a PCB for an audio power amplifier, etching it, soldering components onto the board, enclosing the PCB into an enclosure, troubleshooting it, and running test on it. Some difficulties I ran into when performing this experiment, was figuring out how long to etch the board for, soldering the wire onto the devices with close terminals (potentiometer), and troubleshooting my project (eventually figuring out that my wire wasn't soldered with a good connection onto the speaker jack). My progress with this experiment was that I successfully built a working audio power amplifier which taught me the basics of using a PCB for various designs. The reason I know my audio power amplifier is working is because, when I ran my test, my table of Gain Vs Frequency (Hz) ended up looking identical to what I predicted. One negative outcome is, when I measured the input level, the level was very low. So, I was instructed to use .1V for my calculations. But I would say my project had many great outcomes. Of which, consist of the amplifier successfully amplifying the signal, and the graph of Gain Vs Frequency (Hz) looking as expected.

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