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Course Number ECE-2333

Course Section 003

Laboratory No. 11 Audio Equalizer Design

Due Date:24 April 2020

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I. Objectives and Purpose

By building off the concepts explored in previous labs throughout the semester, this lab's objective is to build a 2-channel audio equalizer with a crossover frequency of 500Hz. Personally, this lab is beneficial in what I would like to do for a living because it is combining low pass and high pass filters to create equalization with independent volume controls, which can be found in all sorts of music equipment from pedal design, amps, to even basic pickup wiring or creating active instrument preamps.

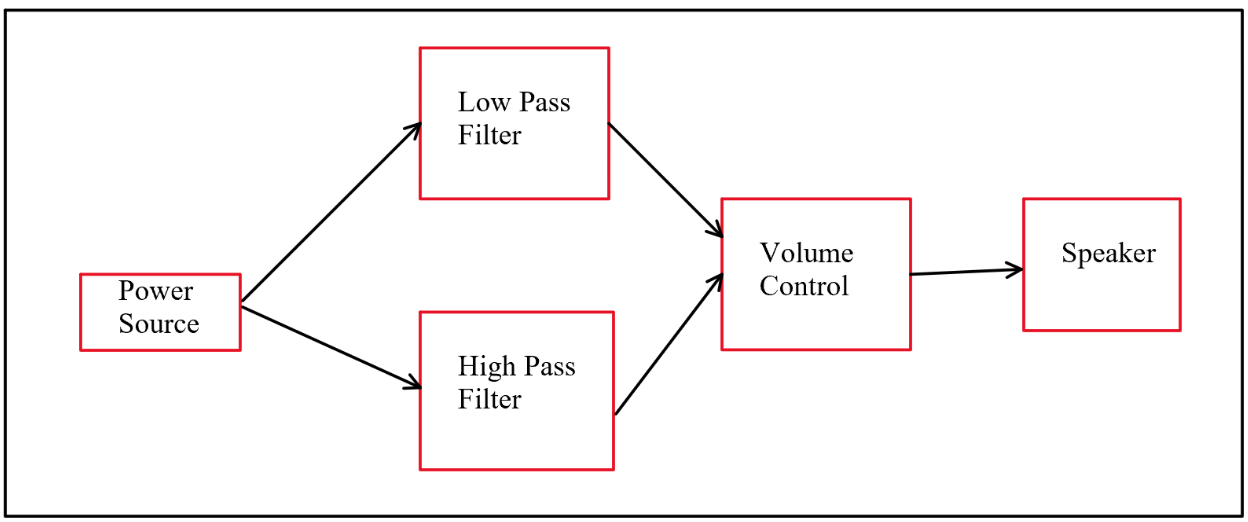
II. Design Procedure

The lab manual states that the 2-channel equalizer must meet three design criteria:

Design goals:

1. Design a circuit that is capable of simultaneously increasing and/or decreasing audio volume at the bass and treble signals (Crossover Frequency at 500Hz)
2. Make the volume adjustable (like a knob on an equalizer)
3. Volume should be adjustable up to 15 dB in both bass and treble frequency bands.

From this, I knew there must be four stages to the circuit to which I drew up in a block diagram, consisting of low pass and high pass filters to create a bandwidth with a crossover frequency of 500Hz.



[Figure 1A: Block Diagram for Audio Equalizer]

Based on the previous labs we have done with frequency response I knew the first thing I should do is consider how I will get a cutoff frequency. To do this I started by examining every capacitor and inductor given in the circuit kit and rearranged their transfer functions to solve for possible resistor combinations that will achieve a cutoff frequency of $500Hz$.

99Y7506					
ECE2333	**Principles Electric Circuit**				
#	Item	Newark#	ECE Stock#	Qty	Alternative
1	100 ohm	58K5000	17	1	
2	330 ohm	58K5042	22	2	
3	680 ohm	58K5068	26	1	
4	1K ohm	58K5001	27	2	
5	1.2K ohm	59K8332	29	1	
6	1.5K ohm	58K5015	30	1	
7	2.2K ohm	58K5030	33	1	
8	3.3K ohm	58K5043	37	1	
9	10K ohm	58K5002	45	2	
10	100K ohm	58K5003	58	2	
11	LM741CN, Op-Amp	41K6294	119	2	
12	47000 pF (47 nF or 0.047 uF)	46P6681	178	1	
13	0.1 uF	46P6667	185	1	
14	1 uF	74AC1306	195	2	
15	Breadboard	71Y9233	n/a	1	56T0249
16	F-F Jumper Wire	31Y3511		1 PK 10	
17	M-F Jumper Wire	31Y3512		1 PK 10	
18	LED	09J9310	303	5	
19	TL072CP, Dual Op-Amp	60K6988	308	1	
20	Tactile switch	14H0928	349	4	
21	3.3 mH	32M9872	n/a	1	14AC4948/74R9996
22	M-M Jumper Wire	31Y3513		1 PK 10	99W1758, 88W2570
23	Photoresistor	54W2650		1	14J5050
24	Piezo buzzer	25R0888	n/a	1	
25	Speaker	18X4918		1	
26	Audio breadboard connector	75Y0814		1	
27	10K ohm Pot	62J2093		2	235/236, 05N1554

[Figure 1B: Circuit Kit Components]

I used the following MATLAB code to perform my calculations and then I cross examined which calculated R values were closest to the ones in the kit. After that I plugged the closest respective resistor into the original transfer function to calculate their respective cutoff frequency to ensure it still filters approximately at $500Hz$.

```
%% Crossover Frequency Calculations
f=500 %[Hz]
Ra=(1/(2*pi*f*.047e-6)) %C=47000 pF
Rb=(1/(2*pi*f*.1e-6)) %C=.1 uF
Rc=(1/(2*pi*f*1e-6)) %C=1uF

%Using Inductor:
Rd=2*pi*f*3.3e-3 %L=3.3mH

% Checking Capacitor
fb=(1/(2*pi*3.3e3*.1e-6)) %R=3.3 KiloOhms C=.1uF
fc=(1/(2*pi*330*1e-6))     %R=330 Ohms      C=1uF
%Based on the previous results, Rb and RC
%comes closest to 500Hz with the closest resistors in our kit
%being 330 Ohms or 3.3kilo Ohms, so the High Pass will be an RC
%circuit
```

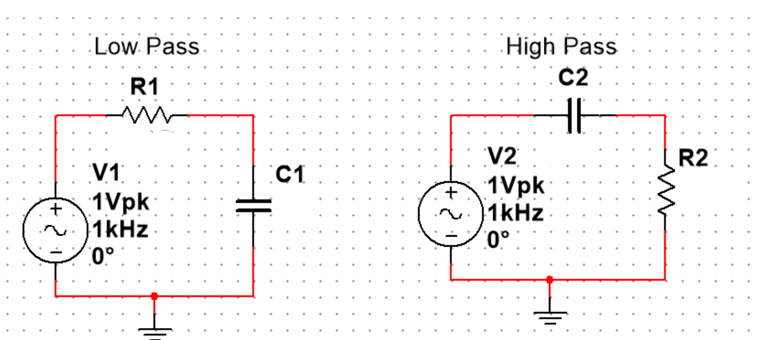
[Figure 1C: Matlab Calculations]

Based on this calculator I discovered that the only two possible outcomes using the resistors in our kit, were to use a 330Ω resistor and a $1\mu F$ capacitor or to use a $3.3k\Omega$ resistor and $.1\mu F$ capacitor since:

$$F = \frac{1}{(2\pi * (330) * (.1 * 10^{-6}))} \approx 482.77\ Hz$$

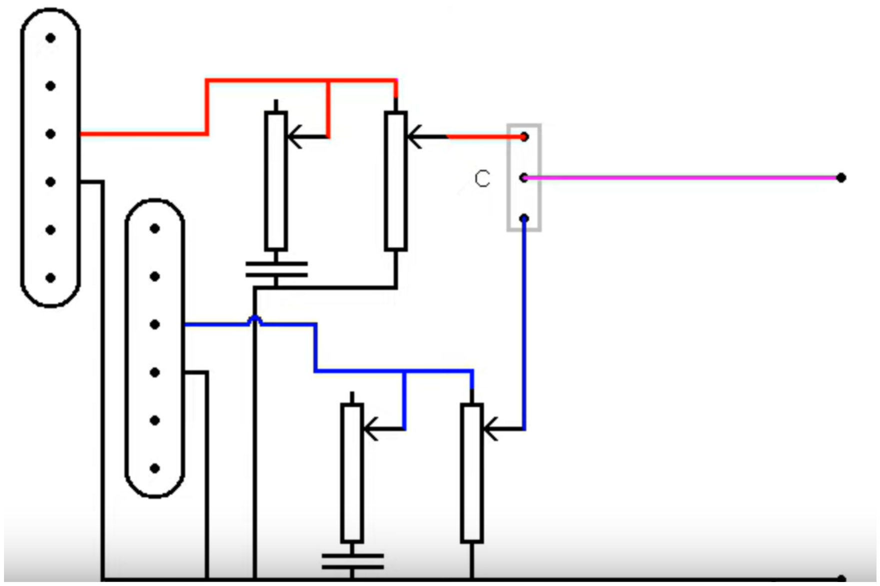
$$F = \frac{1}{(2\pi * (3.3 * 10^{3}) * (1 * 10^{-6}))} \approx 482.77\ Hz$$

Since a low pass and high pass can both be built from a placing a resistor in series with a capacitor, I knew I could use either of these to get the correct bandwidth. Personally, I decided to use one of each.



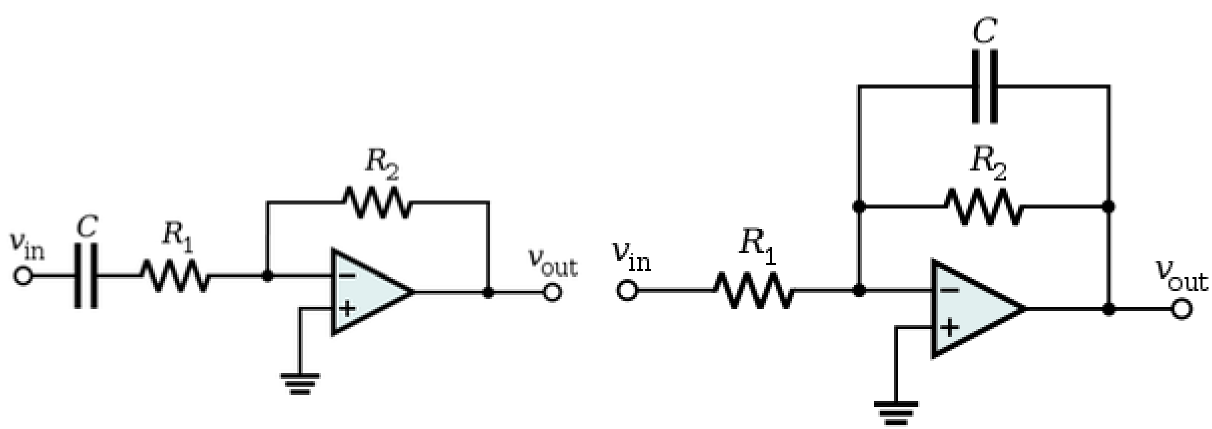
[Figure 1D: Basic RC Low Pass/High Pass configurations]

The next part would be to put them together. I knew I would use some sort of op amp configuration to isolate part of the circuit, but something I thought of was considering how guitars are wired with their Tone potentiometers and Volume potentiometers.



[Figure 1E: Basic 2 Pickup Guitar Wiring]

Knowing previous knowledge that guitars work by putting a low pass filter as a tone knob in parallel with a potentiometer acting as a volume knob that then delivers the signal out of the volume pot's output, I figured that these two filters I created with this lab should be active filters by using non-inverting op amps and set in parallel from each other.

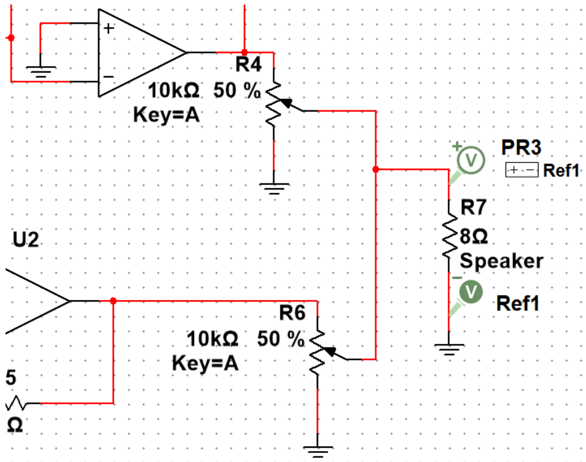


[Figure 1F & 1G: A generic example of an Active High and Low Pass Filter by using Inverting Op Amps. This is how I will rework the filter]

Originally, I tried to also wire the volume potentiometers that will be used in my design to cut or boost by $15dB$ in parallel with the actual filter before the op-amp, however putting a potentiometer before the op-amp will simply mess with the bandwidth instead of the gain since current will follow the path of least resistance. This realization also made me realize that I would need two like resistors to act as Rf for the low pass filter and Rs for the high pass filter so that way the bandwidth will not change, for simplicity sake, I chose two $1k\Omega$ resistors to fill this.

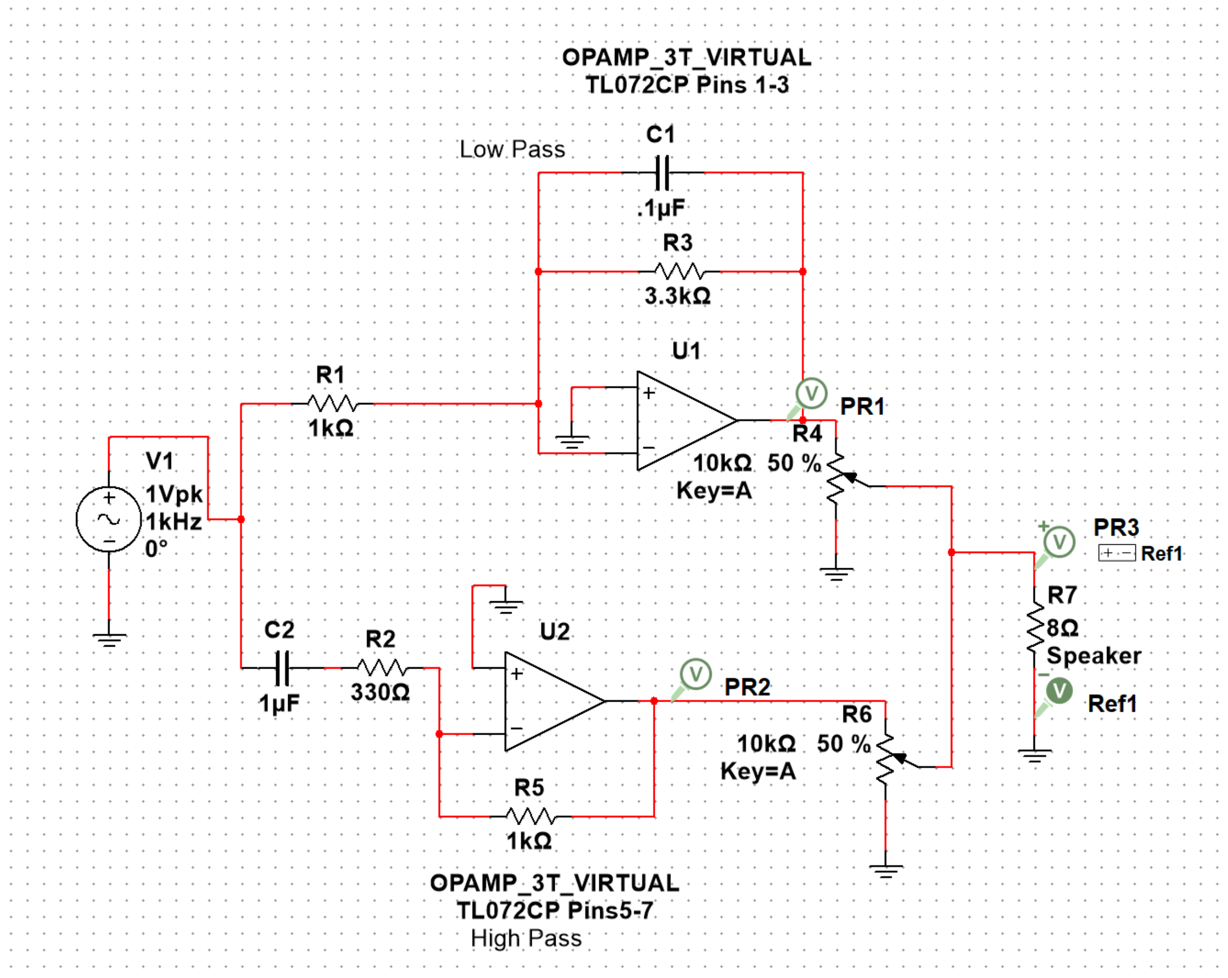
[Figure 1H: Inverting Op-Amp wiring and Gain formula]

To figure out how the volume potentiometer should work, I decided to rework my idea by reading the textbook's chapter on RLC filtering and ultimately realized I can essentially create a voltage divider using the two potentiometers in our lab kit, which are $10k\Omega$ after the op amp. The potentiometers will also amplify or cut by $15dB$ because essentially the overall circuit is flattening out the curve of a bandstop filter to let more current pass through one of filters, which will then boost the respective frequency.



[Figure 1I: Volume Controls]

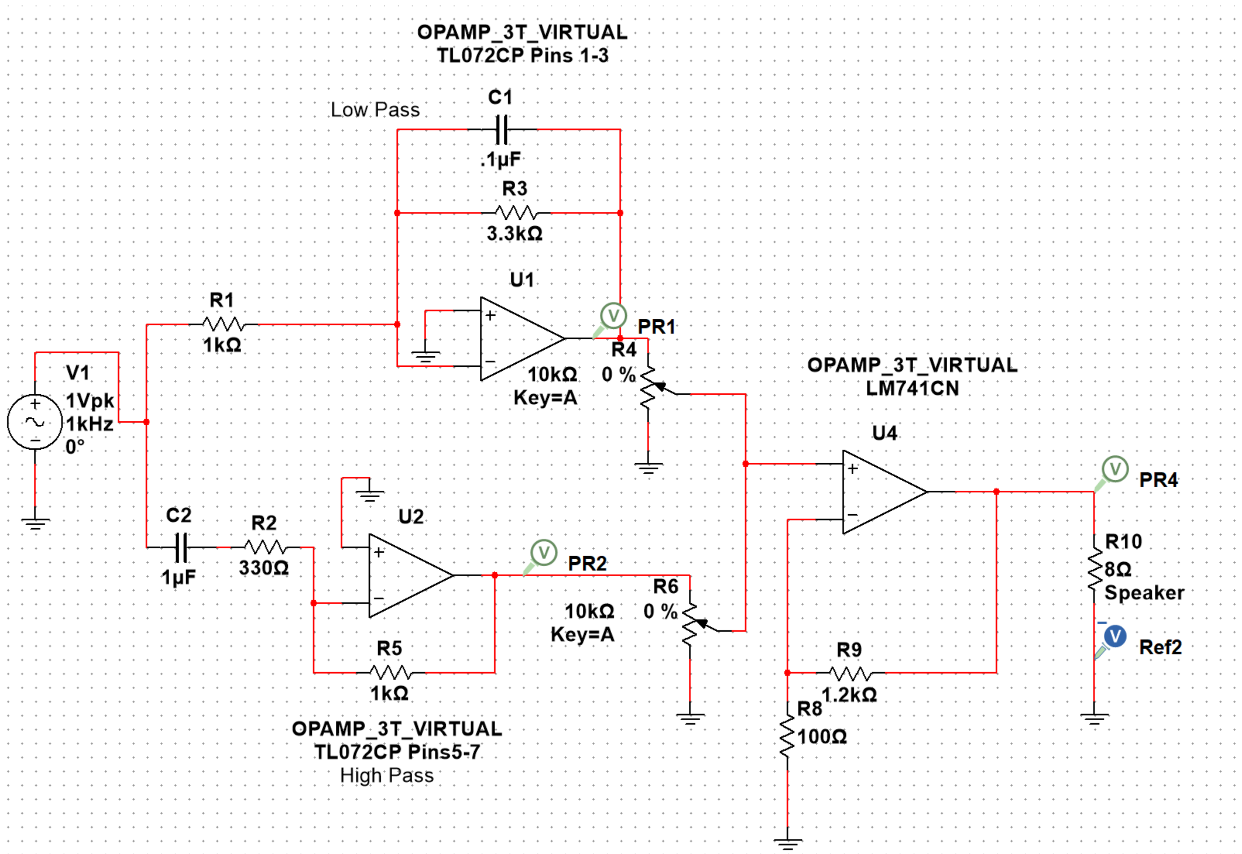
$R4$ will be the output of the active low pass, and $R6$ will be the output of the active high pass, which due to KCL will then meet at a node and go into the speaker. To show this, I will show my final design below which follows the block diagram:



[Figure 2: Final Design with 8Ω resistor modelling the speaker]

It is worth noting that to wire this on a breadboard, the TL072CP Dual Op Amp should be used for both filters instead of the LM741CN that we have used throughout the semester.

Something I thought worth mentioning is while this circuit will fill all requirements, I decided that another amplifier could be brought in to act as a master volume, since as a musician who owns a 7-band graphic eq pedal on his bass's pedal board, I know that an overall gain boost or limit can sometimes be necessary. While the kit would need to contain another potentiometer, theoretically I could use the same Non-Inverting Op Amp by using the LM741CN I used to boost in Lab 9 and still use the individual volume controls to control the gain, or if I had another potentiometer I could replace one of the resistors with a potentiometer to make a master volume knob:



[Figure 2B: Final Design with Optional Master Volume using LM741CN]

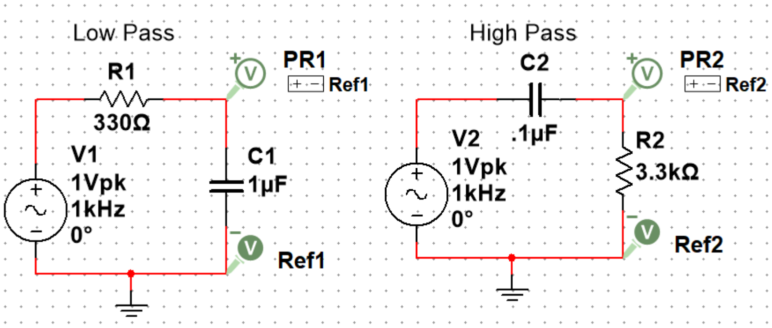
The Gain calculation for the Op Amp follows as:

$$G = 1 + \frac{R1}{R2} => 1 + \frac{1.2k\Omega}{100\Omega} = 13$$

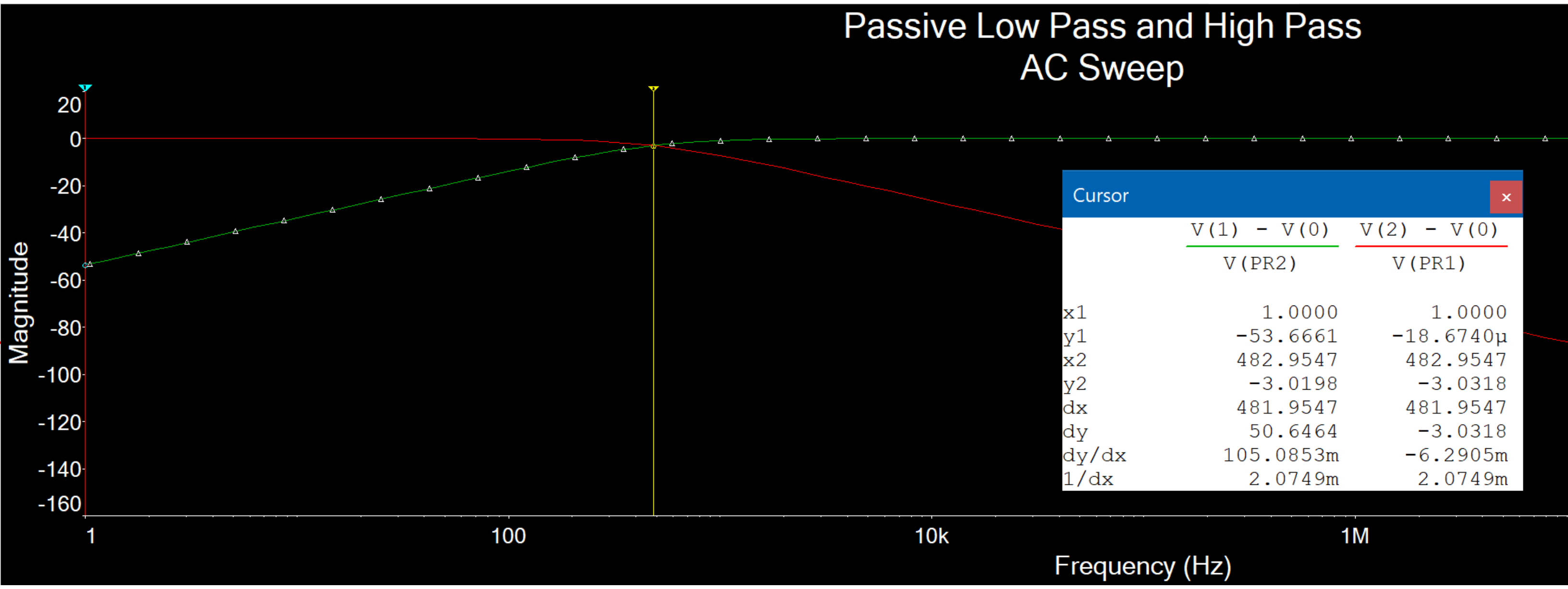
$$G_{dB} = 20 * log_{10}(13) \approx 52dB$$

Alternatively, transistors could also be used to replace any of the op amps above but that would require some reworking.

III. Simulation Results

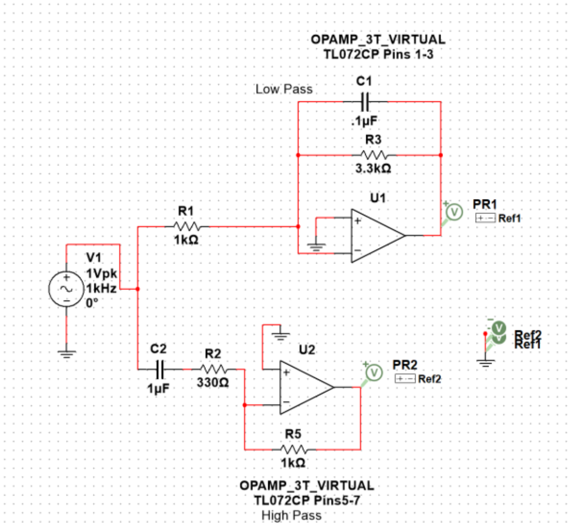


[Figure 1D: Passive RC Filters]

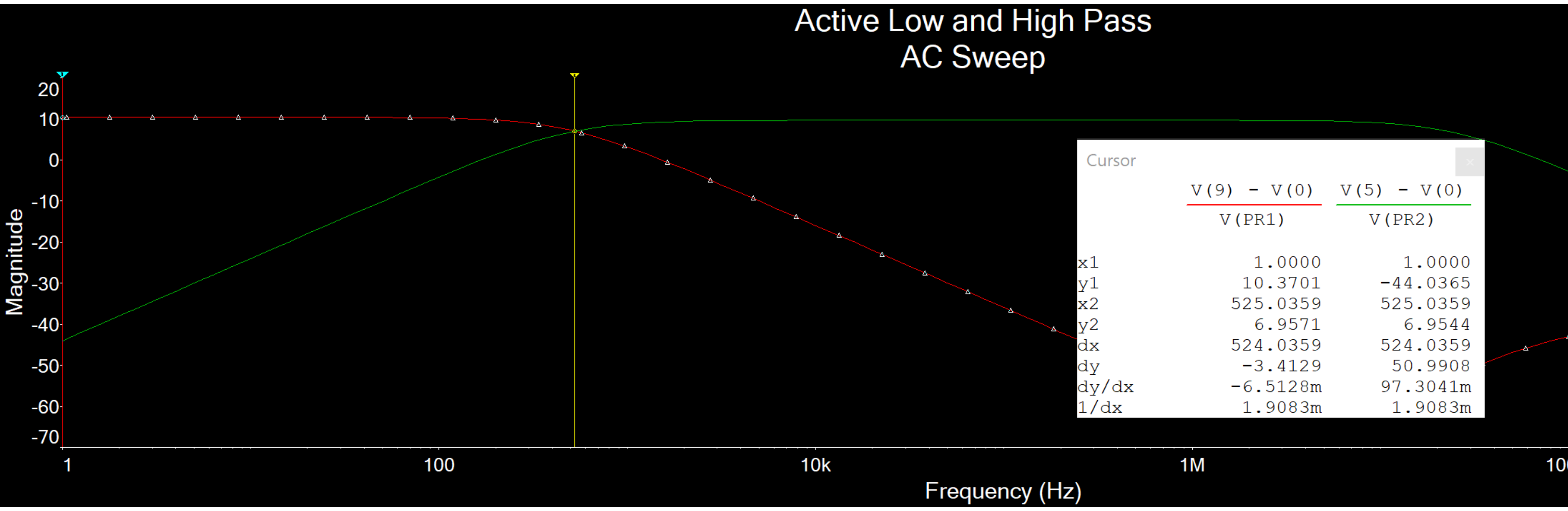


[Figure 3A: Passive Low & High Pass AC Sweep]

Combining the two filters by turning them into active filters without the volume control.

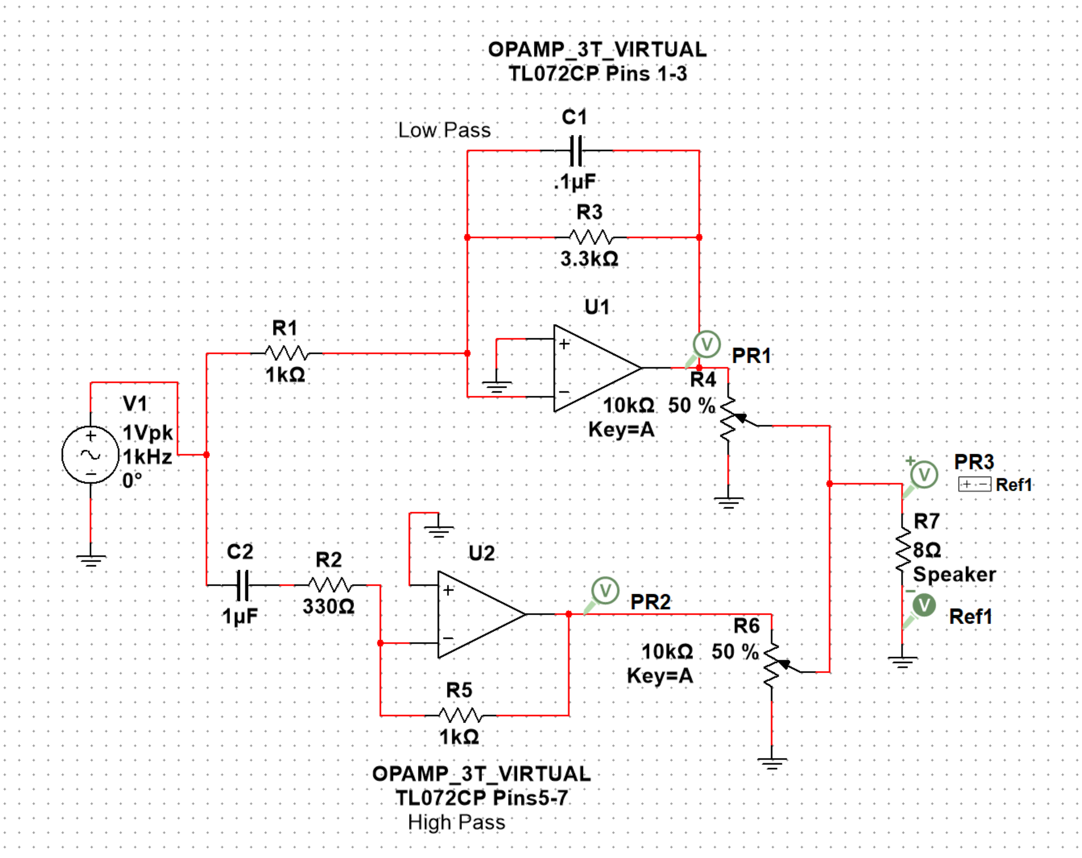


[Figure 1Da: Active Low & High Pass Circuit]



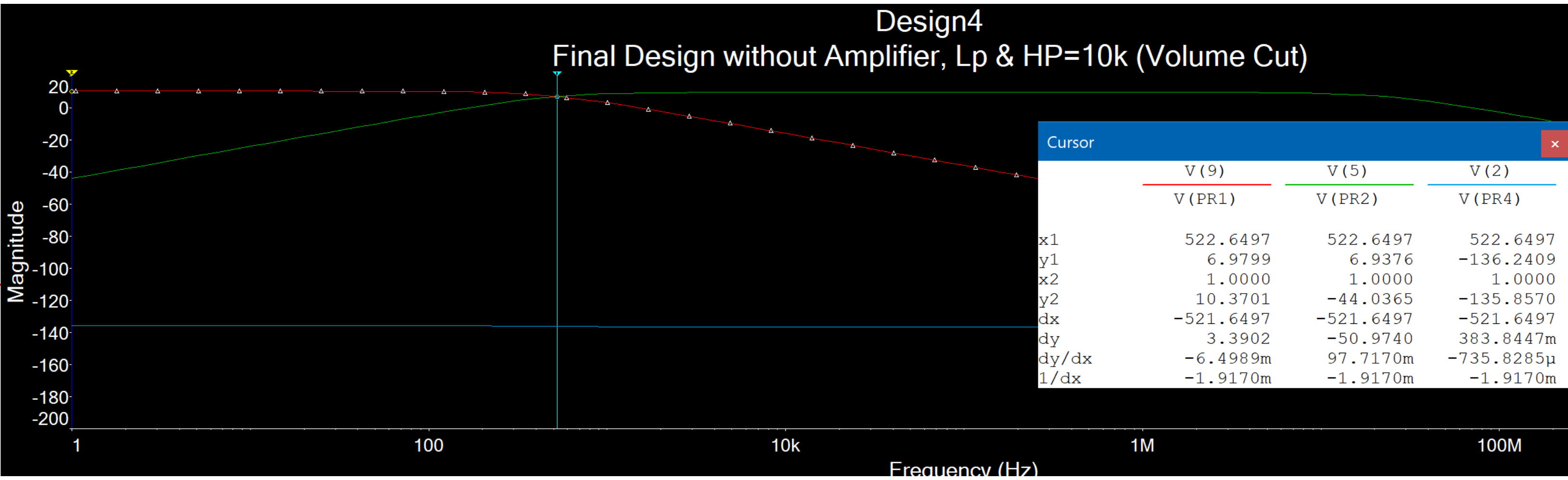
[Figure 3B: Active Low & High Pass AC Sweep]

Adding the Volume Controls to create the final design without the amplifier:

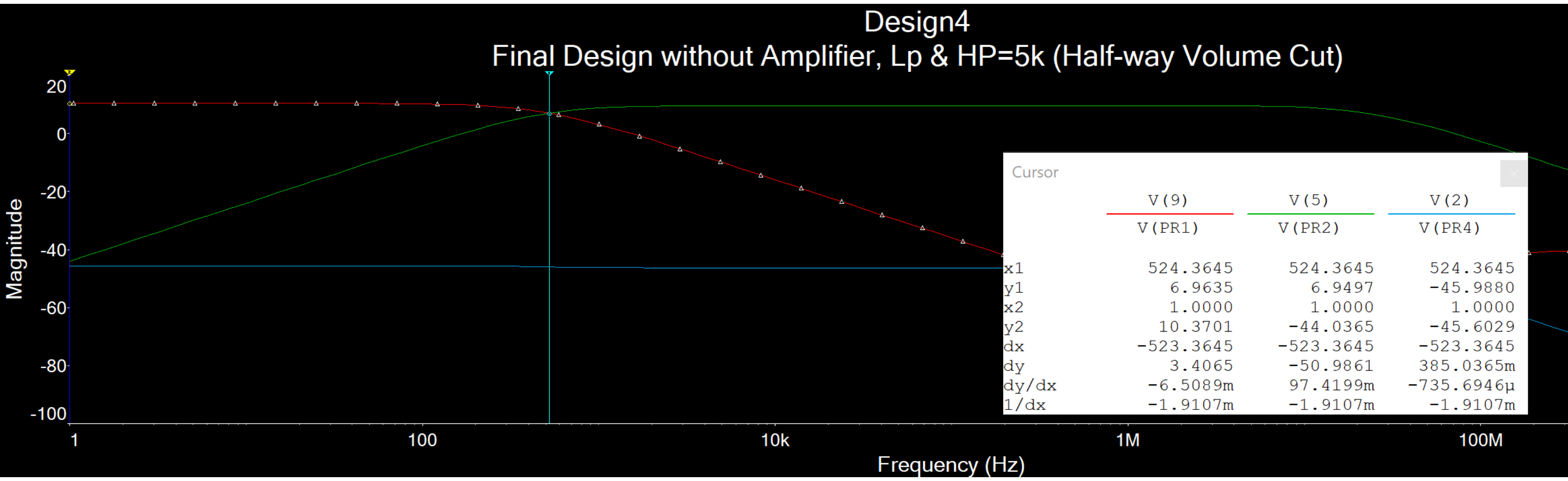


[Figure 2: Final Design without Amplification]

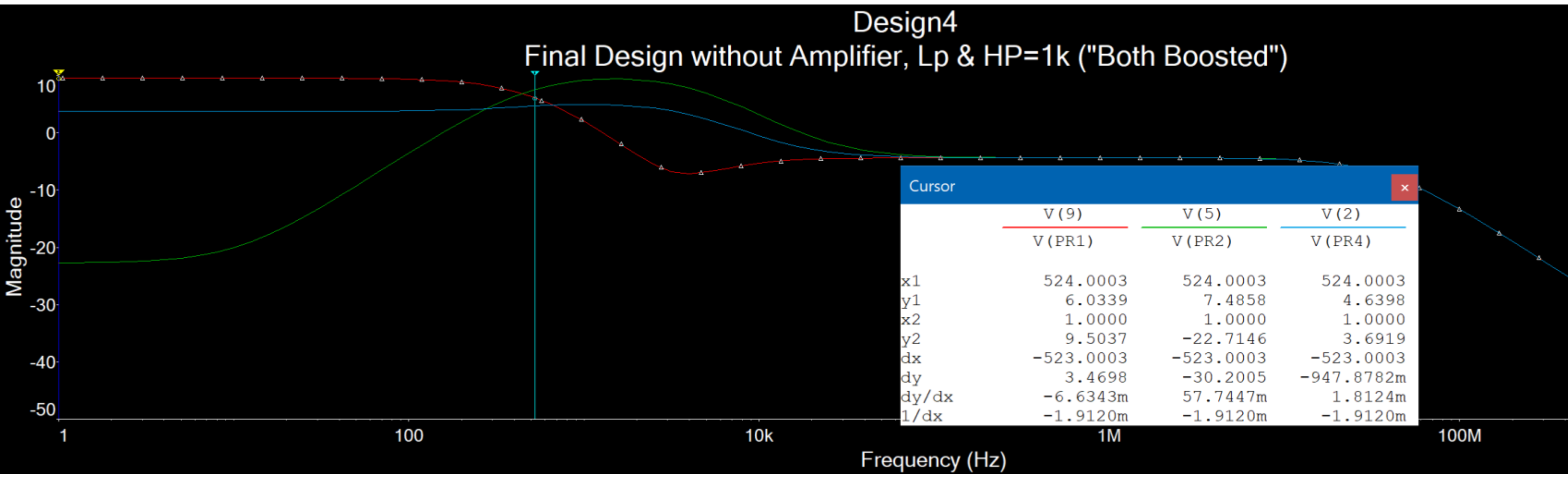
The Red line is the lowpass, the Green line is the high pass, the Blue line is the Final Design. Please read all of what I have to say about these graphs on the next page.



[Figure 4A: Final Design: Volume cut, both pots=10k]

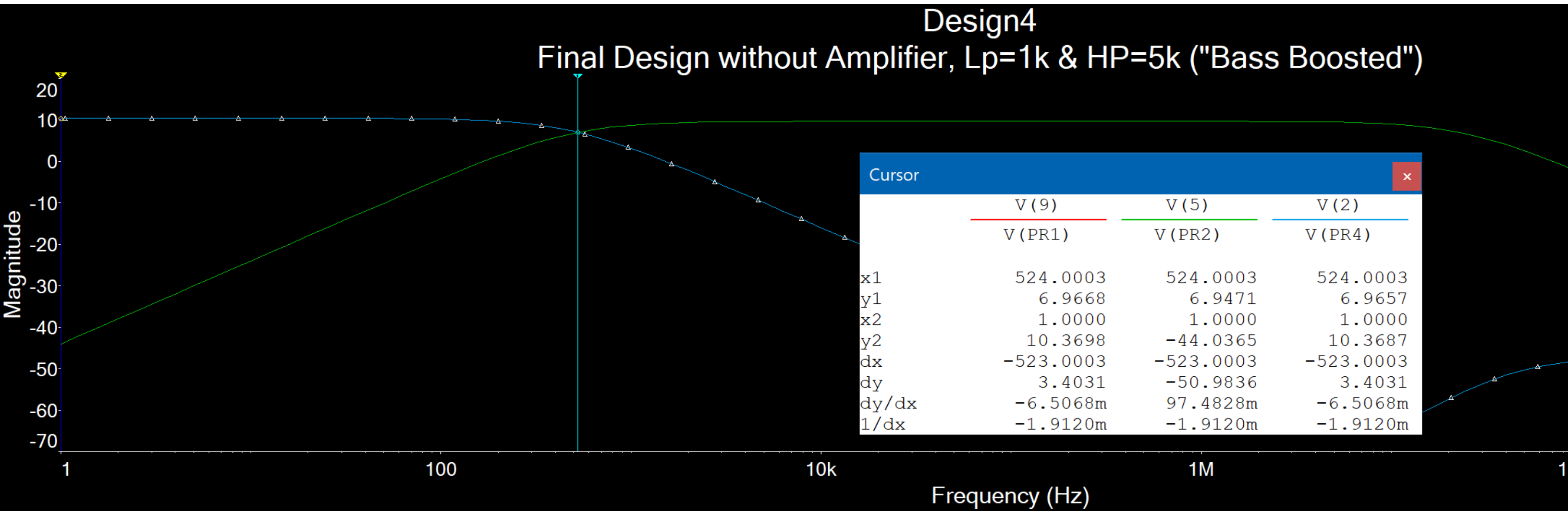


[Figure 4B: Final Design: Volume cut, both pots=5k]

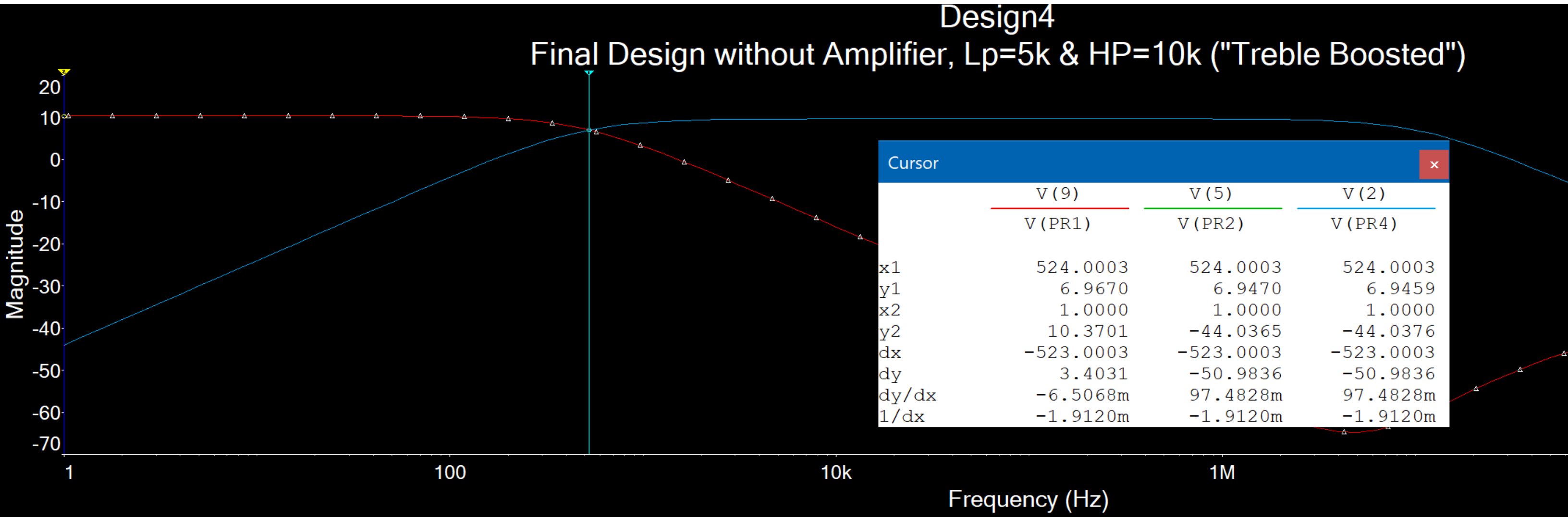


[Figure 4C: Final Design: Both Pots=1k]

Notice the potentiometer actually has such a large range, treble seems to be cut entirely, but in this setting the treble is on halfway, compared to Figure 4A where the treble would be cutting around -140dB, I do fix this later on in the report. Really when comparing any of figures 4C, 4D, 4E to the original 4A, you can see that this circuit “boosts” or “cuts” way more than 15dB and can easily boost or cut 15dB depending on how you set both knobs.

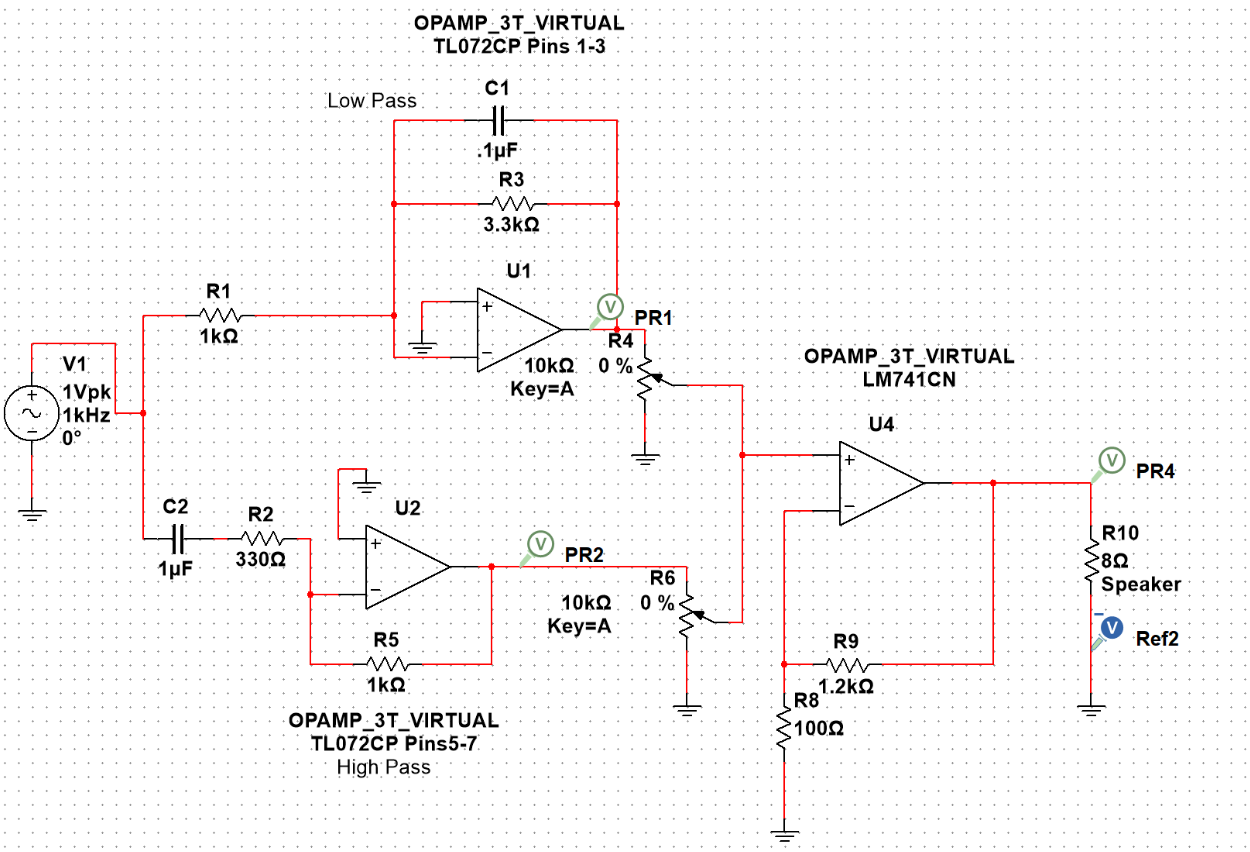


[Figure 4D: Final Design: Bass Boost]



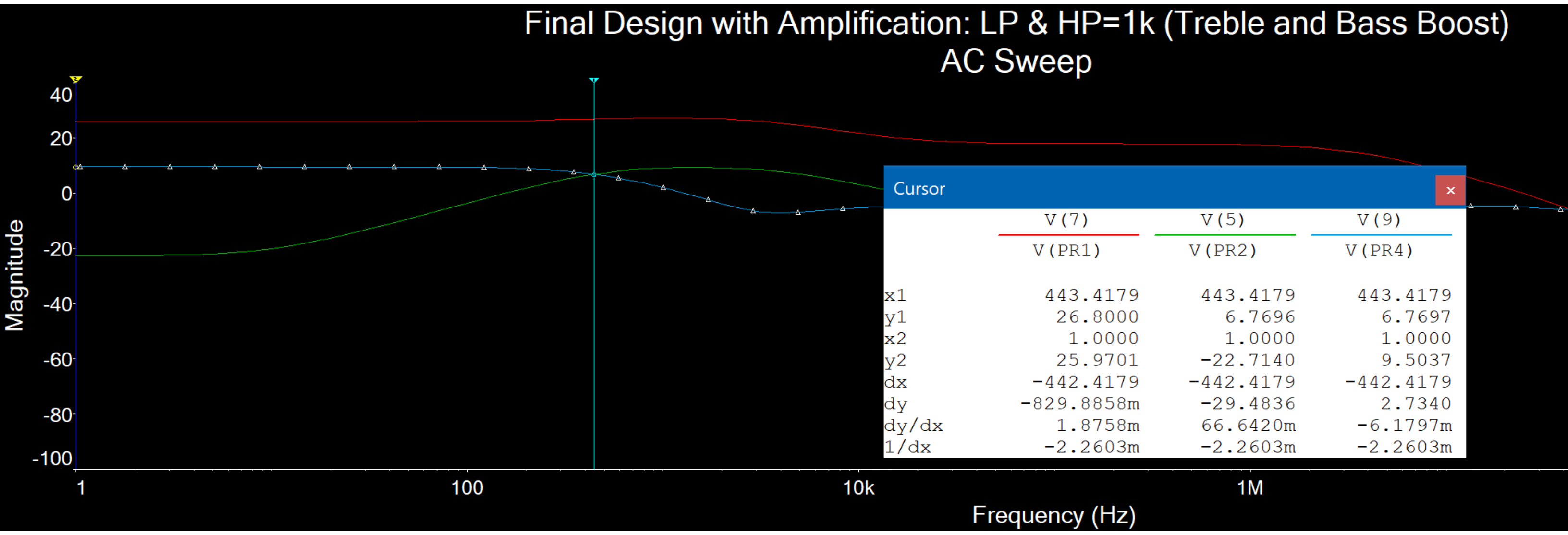
[Figure 4E: Final Design: Treble Boost]

As you can see by the last two AC sweeps, these boosts are actually cutting because the combined filter shown in Figure 4C can not surpass the Ymax of both filters, because the combined filter creates a flat curve at the crossover frequency which portrays a sort of band stop filter. If I wanted to boost past Ymax, I can add the amplifier I was talking about in Figure 2B to keep the same range of how much the circuit can boost or cut due to the potentiometers, but since I amplify the entire circuit, I can boost over the Ymax of the original filters more than $15dB$:

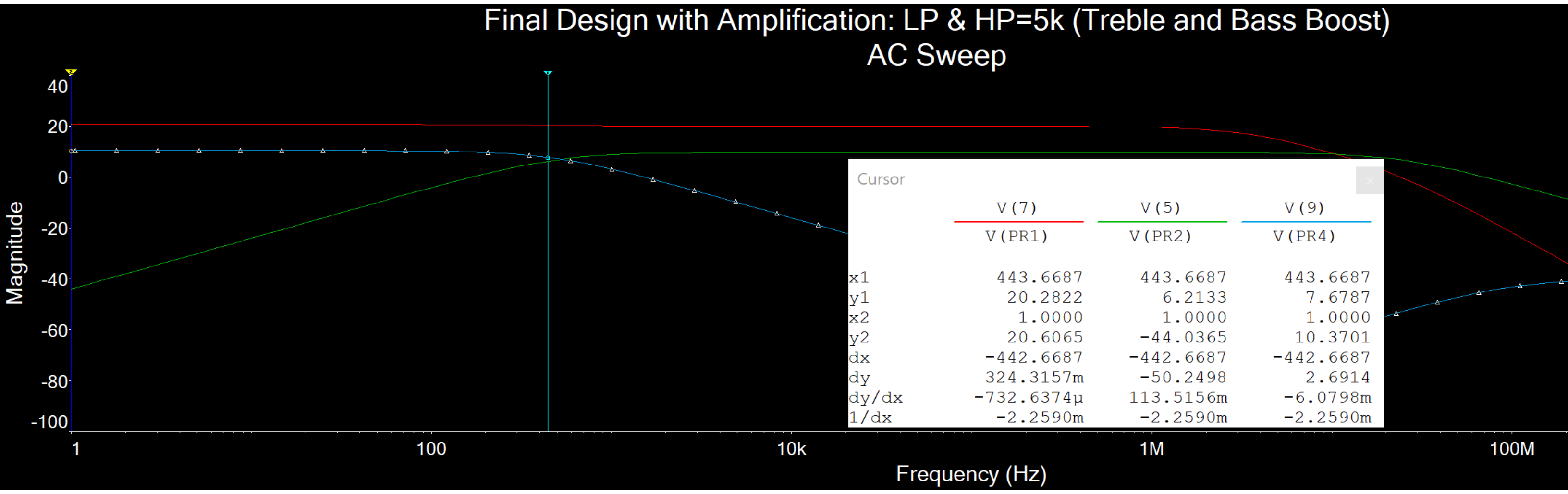


[Figure 2B: Final Design with Amplification]

The crossover frequency does change slightly due to the amplification without a buffer before it. These simulations were also done on a separate multisim file, so the Red Line is the final design, the Blue Line is the low pass and the Green Line is the High Pass.

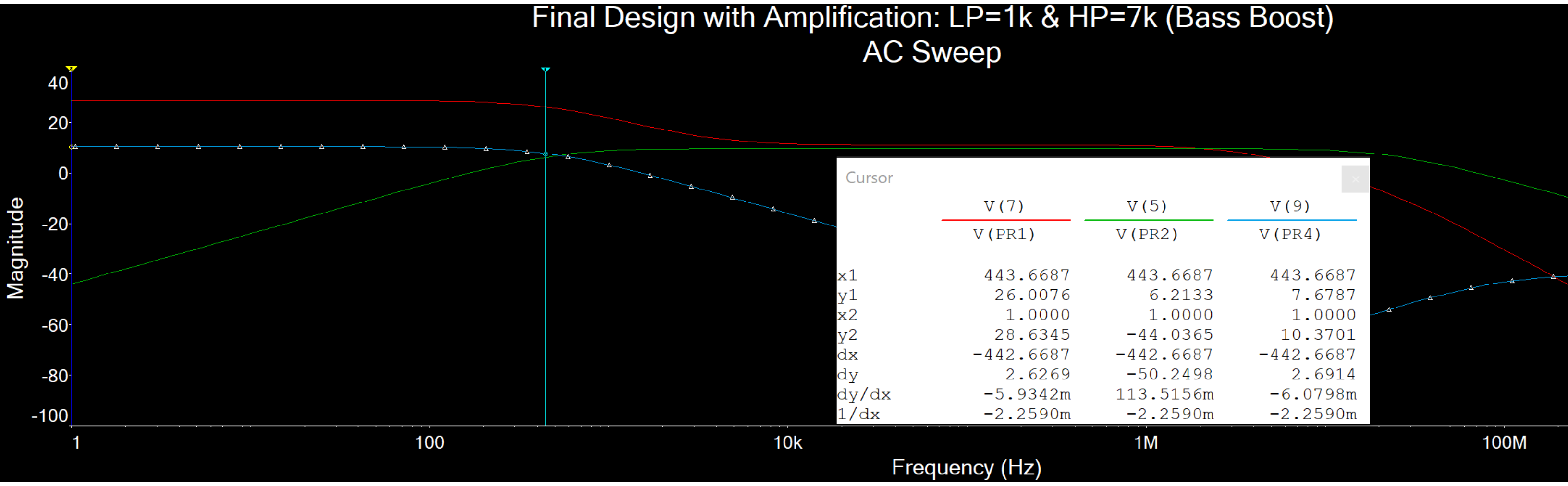


[Figure 5A: Final Design with Amplification, both frequencies boosted]

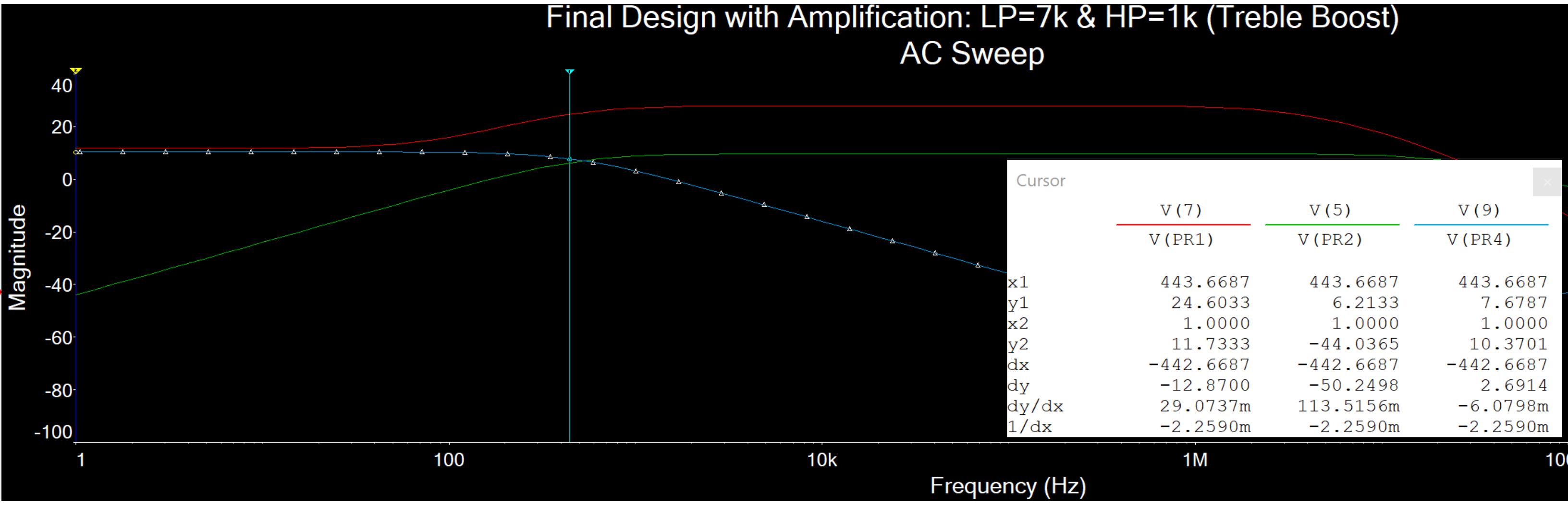


[Figure 5B: Final Design with Amplification both potentiometers at 5k still boosts beyond the Ymax of the original filters]

I will not show the AC Sweep but when both potentiometers are set to about $6.5k\Omega$ the filter matches about the Ymax of both filters, and when the potentiometer is set to $9k\Omega$ or higher the signal is approximately $0dB$ or less. To show a reasonable bass and treble boost of at least $15dB$, I set the both knobs in the following sweeps:



[Figure 5C: Final Design with Amplification, LP Pot=1k, HP Pot=7k Bass Boosted by at least 15dB]



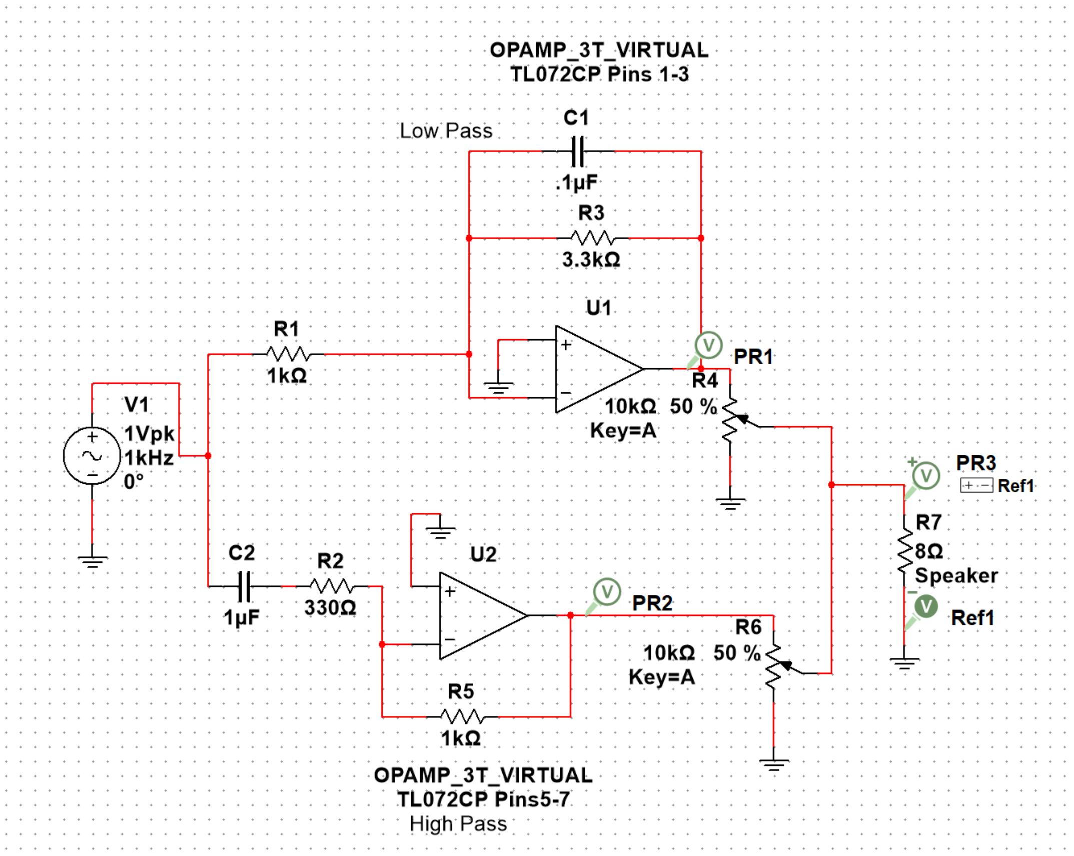
[Figure 5D: Final Design with Amplification, LP Pot=7k, HP Pot=1k Treble Boosted by at least 15dB]

	Passive Filter Cross Over Frequency	Active Filter Cross Over Frequency	Final Design Cross Over Frequency	Final Design with Amplification Cross Over Frequency	Op Amp Amplification For Final Design with Amplification
Calculated	482.2877 Hz	482.2877 Hz	482.2877 Hz	482.2877 Hz	52 dB
Simulated	482.2877 Hz	525.0359 Hz	524 Hz	443.6687 Hz	Depends on how you set the potentiometers

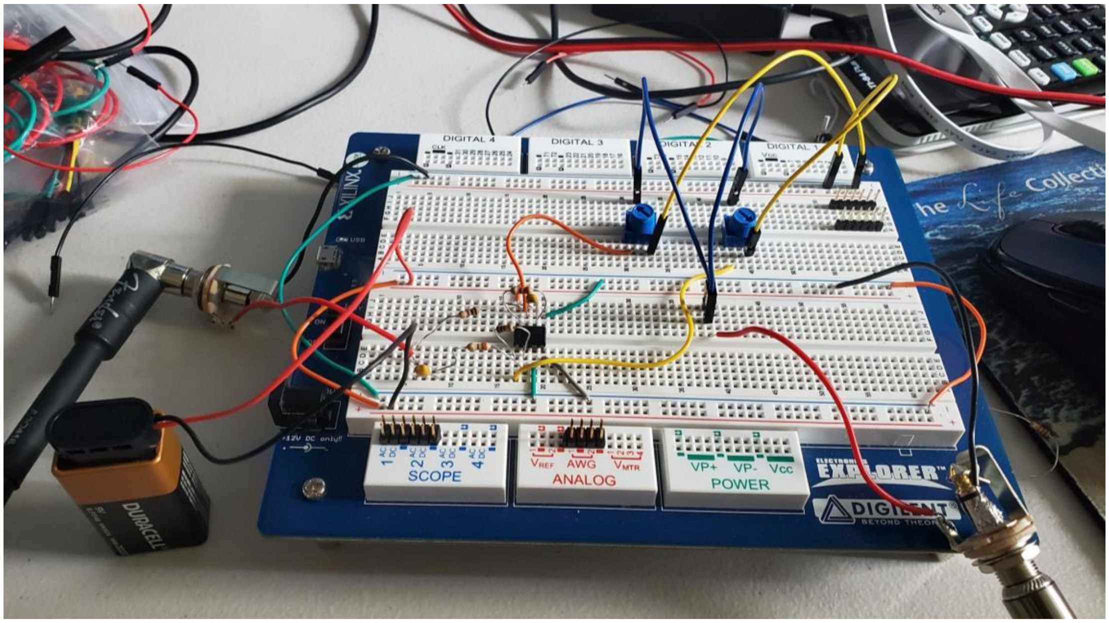
IV. Conclusion and Reflection

Using my knowledge of Low Pass and High Pass Filters, I was able to build a crossover filter that attenuates or rejects frequencies above or below $500\ Hz$ by at least $15dB$. Due to bleed between filters it is probable that discrepancies between my calculations and simulation could be because of the limitations of the components found in the circuit kit. Given that I was one of the students that was able to pick up a board before we went into quarantine, and since I'm still stuck in Philly waiting for my next class to start, I decided to take an hour to build this circuit and see how it reacts as if it were a 2-band EQ pedal for a bass guitar. I decided to try to limit myself by using only a $9V$ battery to power the Op Amps, since typically guitar and bass pedals are run off of $9V$ batteries or $9V$ DC power supply to plug into the wall. Given time constraints I was not able to figure out how to properly power the both the LM741 and TL072 from the same $9V$

battery, I think I would have had to pull out some more resistors to do some kind of input biasing. The LM741 Op amp and that would have extended the range of the boost/cut as well as act like a master volume if added an additional potentiometer, so instead I settled with building the circuit from Figure 2:

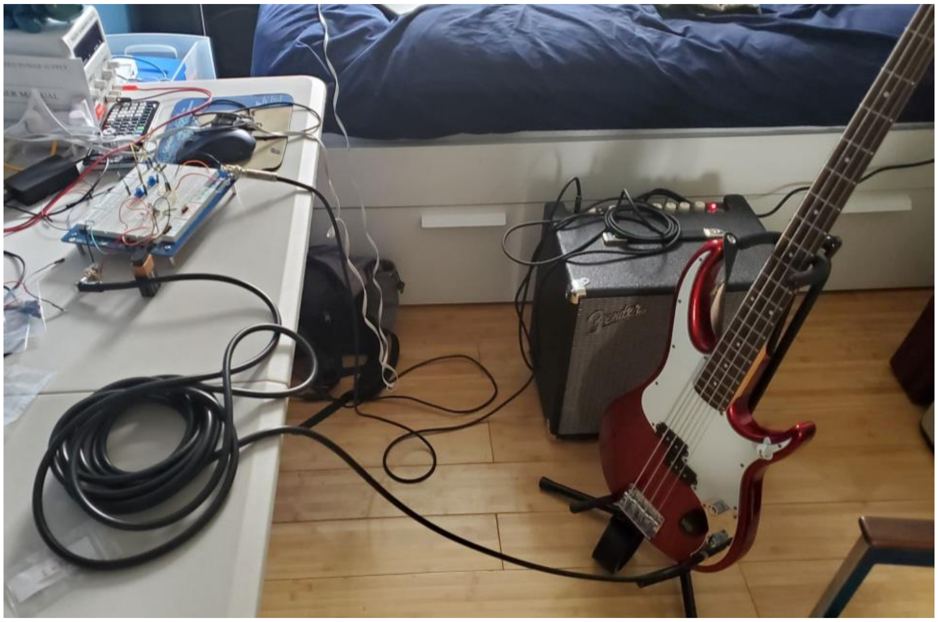


[Figure 2: Final Design without Amplification]



[Figure 2A: Breadboarded Final Design]

I plugged a 4 String Peavey P-Bass into the circuit using a soldered output jack and ran the output of the same way into a Fender Rumble $40 Watt$ Bass Combo.



[Figure 6: Signal Chain of Breadboard Experiment]

By doing this I was able to confirm that the filters do indeed work, however, when one potentiometer cuts all of the way, it completely rejects all of the input signal despite the other potentiometer's setting, instead of just completely cutting the bass or treble. This might have been resolved if I could have figured out powering the master volume part of the circuit, which is something I will revisit by biasing the $9V$ with additional components, once finals are over. This circuit was also extremely helpful to me in terms of future designs because I was able to plug in an additional potentiometer instead of the using one of the resistors on the filter, and essentially change the bandwidth which is how a tone knob on a basic three knob drive pedal would function. Furthermore, I experimented by placing a Way Huge Swollen Pickle Fuzz pedal in between the bass and breadboard, thus experimenting with how an EQ could change the character of a drive pedal before the circuit clips the signal, as well as after the circuit clips the signal, which I did by placing the pedal after the breadboard as well as messing with the amps' overall overdrive. Doing this I was able to conclude how filtering can change the intensity of clipping, and if I wanted to design an overdrive/distortion/fuzz pedal, I could probably add an additional filter for the mid-range and just focus on clipping before, after, or in between the filter part of the circuit. Alternatively, I could reduce the number of filters and use one bandpass with a potentiometer to design a one knob filter sweep. Besides working with drive pedals, this setup can also be worked into building a bigger amplifier by finalizing the frequencies, their crossovers making anywhere from a three-seven band EQ, and adding a master volume that would go into the overall speaker(s). This also made me realize the gain knob controlling the amount of feedback versus a master volume on an amplifier, are probably two potentiometers wired to an Op-Amp.