Phono Preamplifier Documentation

ECE 3155

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Team Activity

Decisions on this project were decided on by the group as a whole. The team leader (Justin) was mainly responsible for calling team meetings and scheduling meetings with the professor, as well as constructing the physical circuit. Lucas originally came up with the idea to investigate the phono preamplifier circuit, and he led the initial research in selecting a specific phono preamplifier circuit as well as constructing the simulation in multisim. Jorge, Toan, and Christian took initiative in learning how the Analog Discovery 2 kit operated, and how it could be incorporated into the project.

Meeting Information

October 3rd	Decide on project - 15 min
October 8th	Summarize/layout tasks - 30 min
October 25th	Finalize simulation - 11 min
November 3rd	Discuss analog discovery - 5 min
November 15th	Discuss the built circuit - 16 min
November 28th	Finalize demo - 40 min

*Note: all meetings were online where we updated each other on our progress and decided on how to move forward

Progress Compared to Milestones

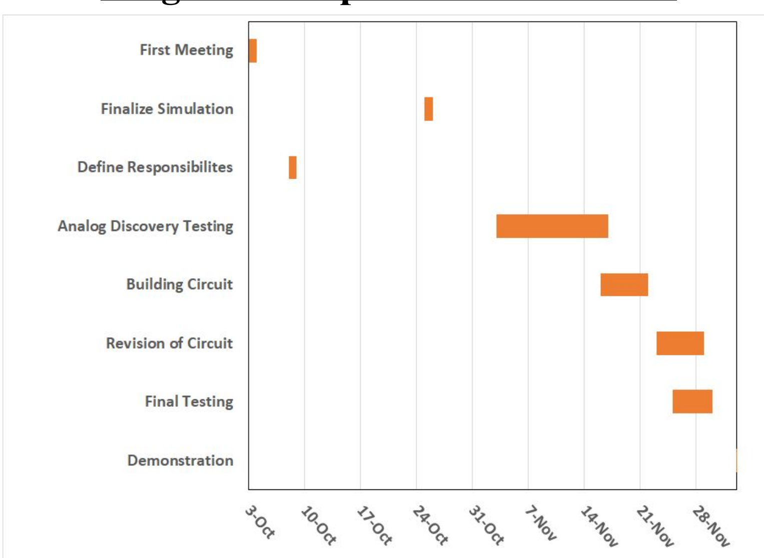

Figure 1: Progress Chart During the Semester

Figure 1 displays the period in which certain tasks were to be accomplished as the semester progressed, beginning from our first meeting on October 3rd. Upon meeting, the team set a general list of milestones that were to be met, which include; research of RIAA phono preamplifiers, physical creation of a phono preamplifier circuit, inputting the correct signal that is RIAA compatible, receiving a desired outputted audio file, final group report, and demonstration of final product. From figure 1, it is shown that production of the phono amplifier began late October as oscilloscope kits were handed out to all students around that time for use of other class labs as well. About a week was reserved to all team members to learn how to utilize the Analog Discovery 2 Oscilloscope for the project. During this time, we sought out how the oscilloscope could take in an audio file and be inputted into a circuit, as well as plot out the outputted files frequency so that we can determine whether this was what should be expected. By around mid-November, construction of the physical circuit began, copying the components shown in Figure 2 below. With plenty of time being allotted during Thanksgiving week, the circuit was revised to fit the desired bode plot from Figure 3, as well as testing white noise audio files found online through the oscilloscope after being put through the RIAA filter and seeing as to whether the desired output could be achieved. After several different iterations of configuring the kit, the outputted audio file would not match what was desired, but from the network analyzer it was shown that the output's frequencies matched what we expected if everything did go well, in which its low frequencies would be strengthened and its high frequencies would be cut off.

What is a Phono Preamplifier?

A phono preamplifier is a specialized amplifier circuit designed for use with phono turntables and vinyl audio disks. The characteristics of the phono preamplifier are designed in such a way that enables high fidelity audio signals to be stored and read from a vinyl disk. The preamplifier increases the input signal coming from the phono needle (a magnet and coil based pickup system similar to a guitar pickup) and applies a filter known as the RIAA Equalization Curve to the audio signal. This standard introduces an original filter curve on the recorded audio that reduces lower frequencies while increasing higher frequencies, allowing more information to be cut into each groove on the disk. The preamplifier then applies the inverse curve or the equalization curve, restoring the incoming signal back to its original recorded fidelity. Information from https://www.audioadvice.com/videos-reviews/what-is-a-phono-preamp/.

Design Process/Measurements

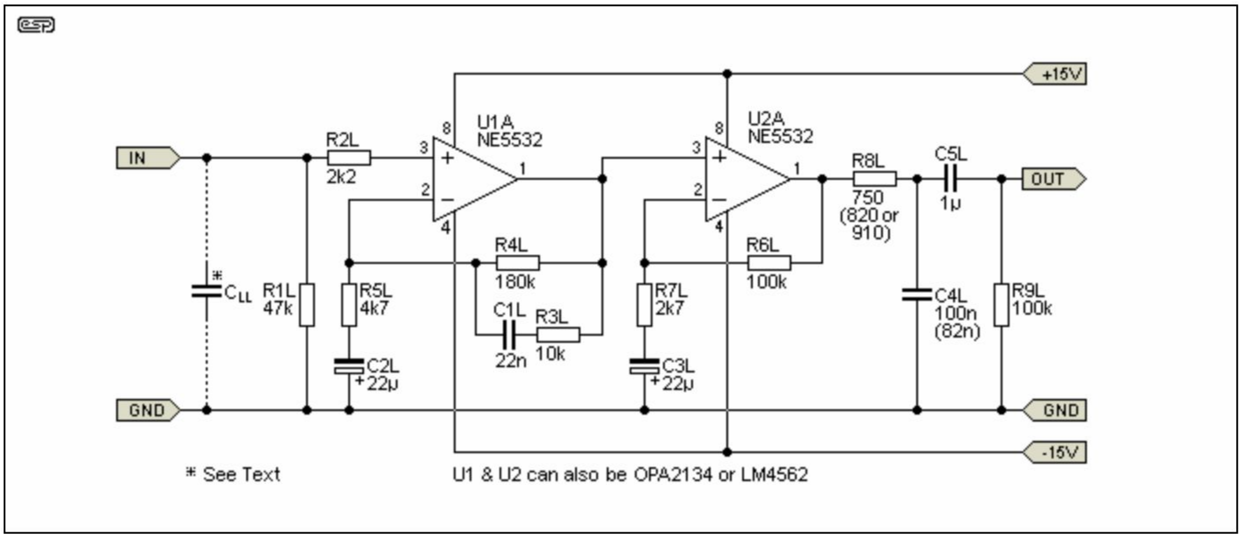

Figure 2: Phono Preamplifier Circuit (from https://sound-au.com/project06.htm)

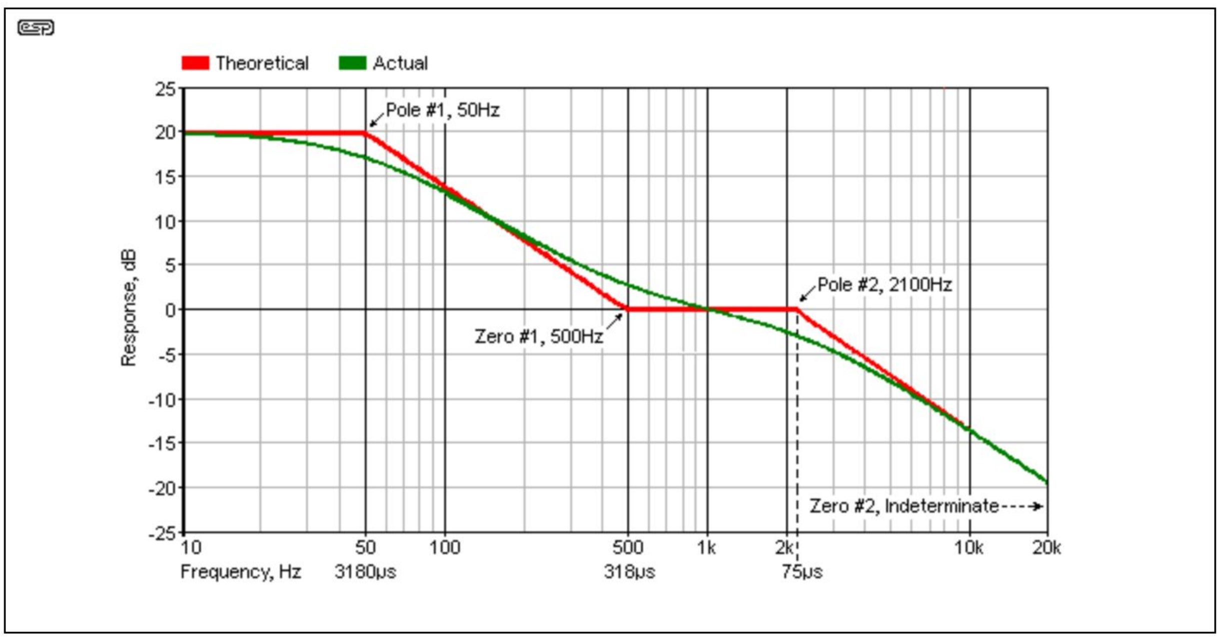

Figure 3: Theoretical Bode Plot for Phono Preamplifier (from https://sound-au.com/project06.htm)

Figure 3 shows the bode plot that we are trying to achieve by building this circuit (Figure 2). This curve is called RIAA Equalization, and it is needed to boost the signal from the record player so that it is ready to be sent to an ordinary speaker. This filter boosts very low frequency signals (10 to 50 Hz) because that is the music stored on the vinyl disk that we want to hear.

After 1 kHz, we start to see the signal be dampened. These high frequencies are typically undesirable and need to be filtered out (typically cracks and pops from the vinyl).

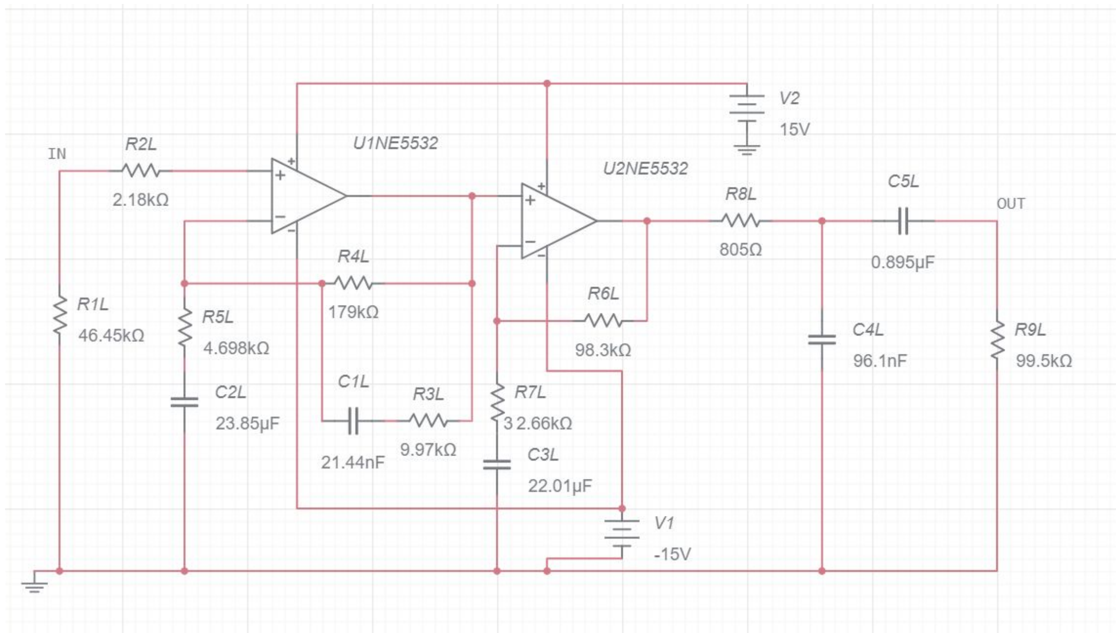

Figure 4: Phono Preamplifier Schematic V1

The Figure 4 circuit is the same as the one from https://sound-au.com/project06.htm by Rod Elliot, but with the actual component values we used on the breadboard instead of the theoretical values. This was our initial test of the circuit.

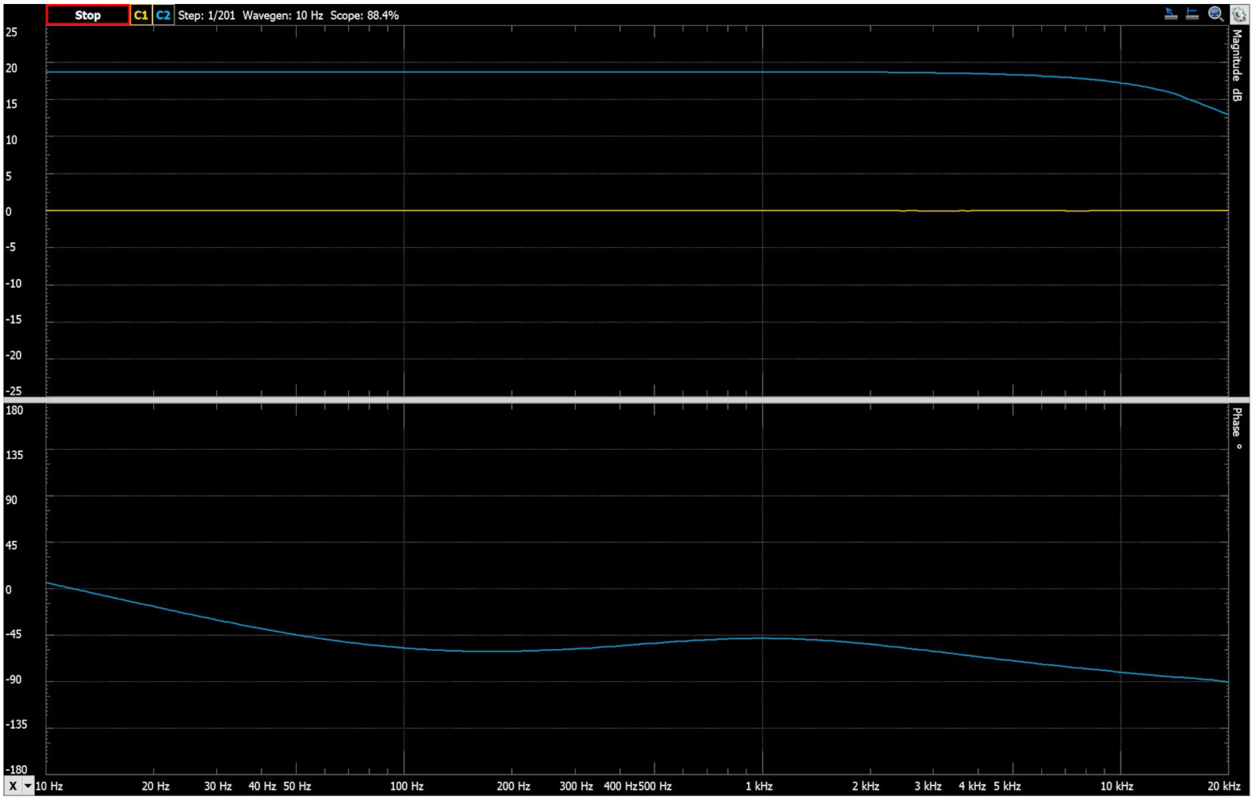

Figure 5: Phono Preamplifier V1 Bode Plot

Our bode plot of the circuit in Figure 4 did not match the theoretical one from Figure 3. This discrepancy is shown in Figure 5. Here we see there are no poles around 50 Hz, and we only have 1 pole around 10 kHz. This circuit does not filter out the undesired snaps and pops that are characteristic at the high frequencies. We think this discrepancy may have been due to the tolerances of our components.

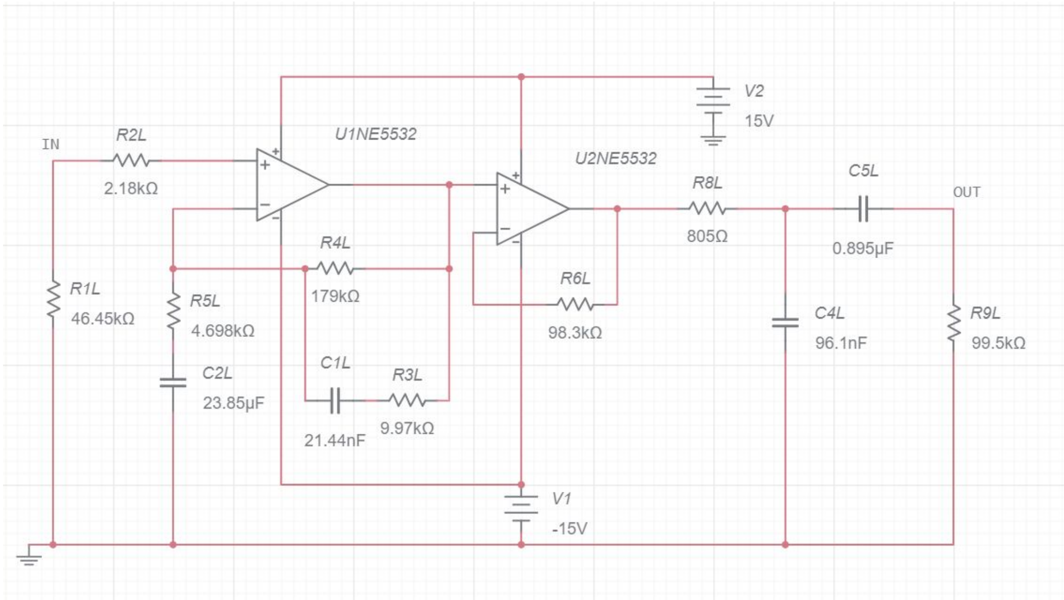

Figure 6: Phono Preamplifier Schematic V2

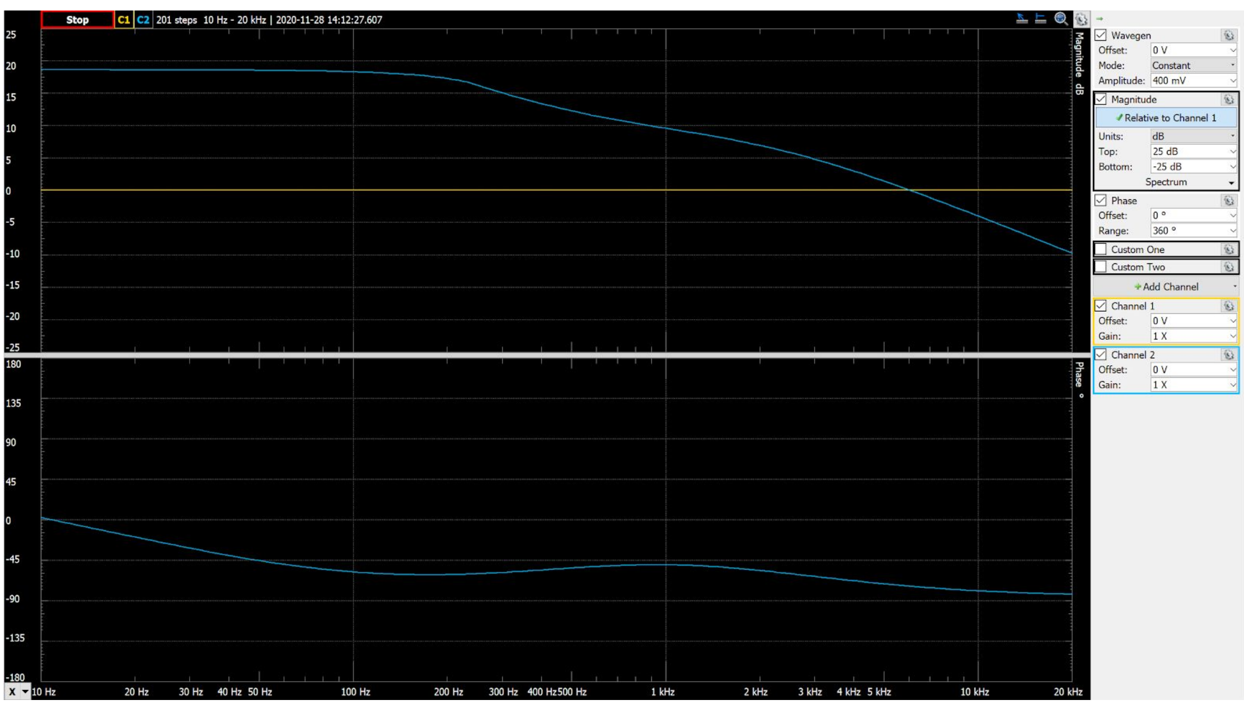

Figure 7: Phono Preamplifier V2 Bode Plot

Figure 6 shows our revised circuit. The difference between Figure 6 and 5 is that resistor R7L and capacitor C3L was removed entirely. Figure 7 then shows the bode plot of this new circuit. This one at least more closely resembles what we are trying to model, but the first pole is at about 200 Hz and it doesn't cross the 0 dB mark until about 5 kHz. Capacitor C3L certainly looks like it controls where the first pole is located.

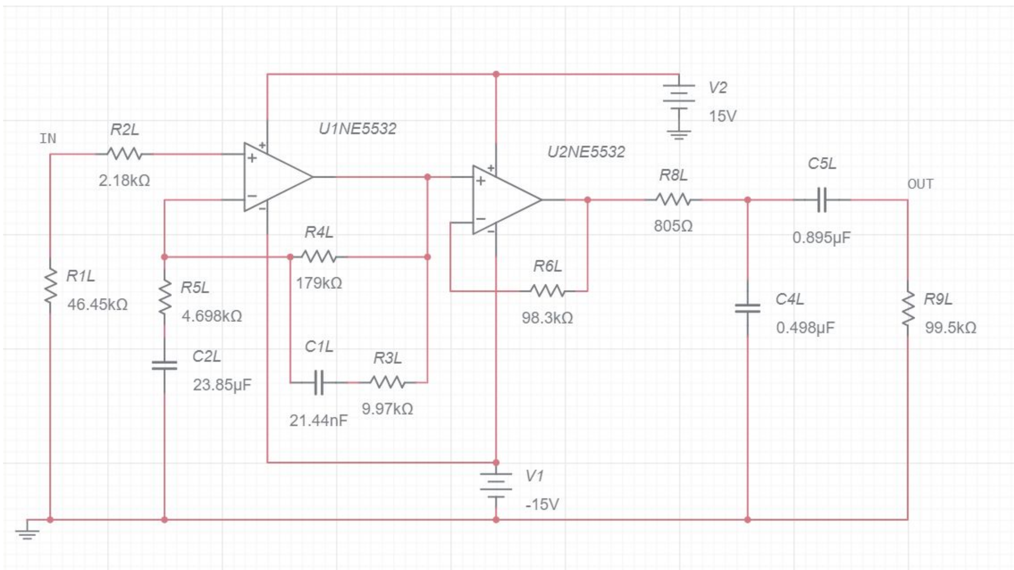

Figure 8: Phono Preamplifier Schematic V3

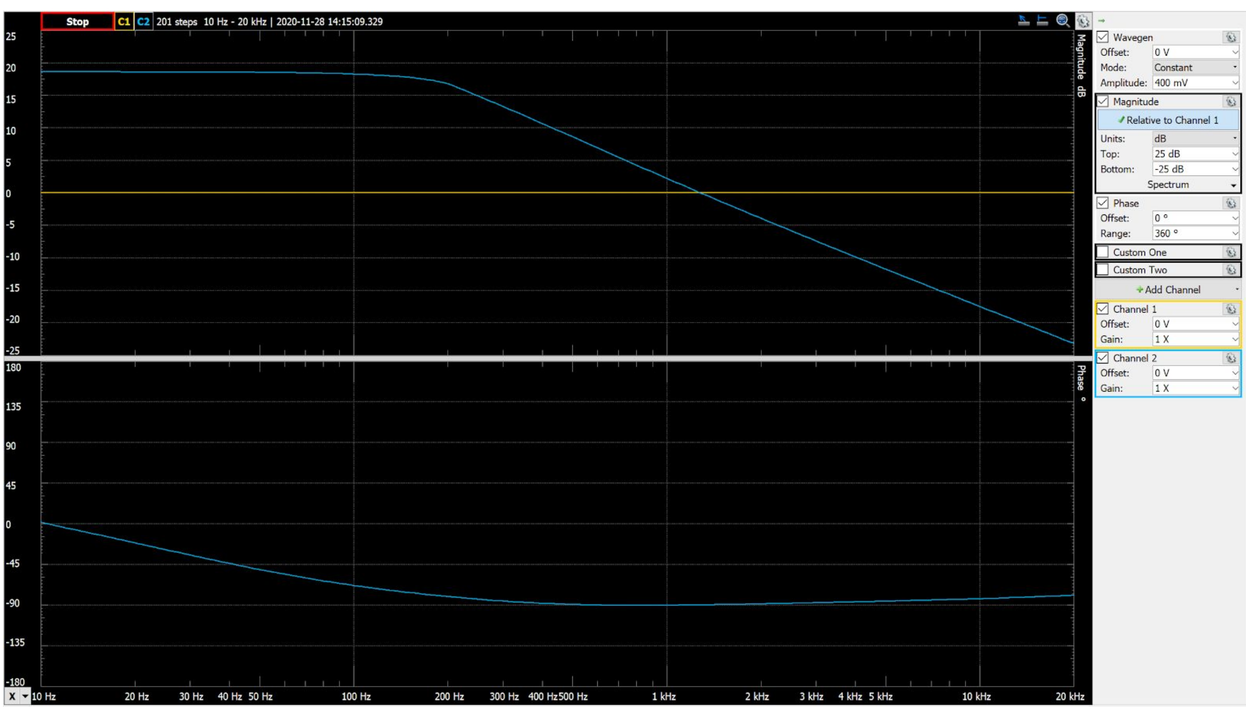

Figure 9: Phono Preamplifier V3 Bode Plot

Figure 8 is again a revision of the circuit. R7L and C3L are still removed, however this iteration changes the value of C4L from 96.1 nF to 0.498 µF. Figure 9 shows the bode plot of the physical circuit we built that is represented by Figure 7. This plot looks much better in terms of the slope. Here the output of the circuit crosses the 0 dB line at around 1 kHz, which is what is supposed to look like. However, our first pole is not starting at 50 Hz, and instead around 200 Hz.

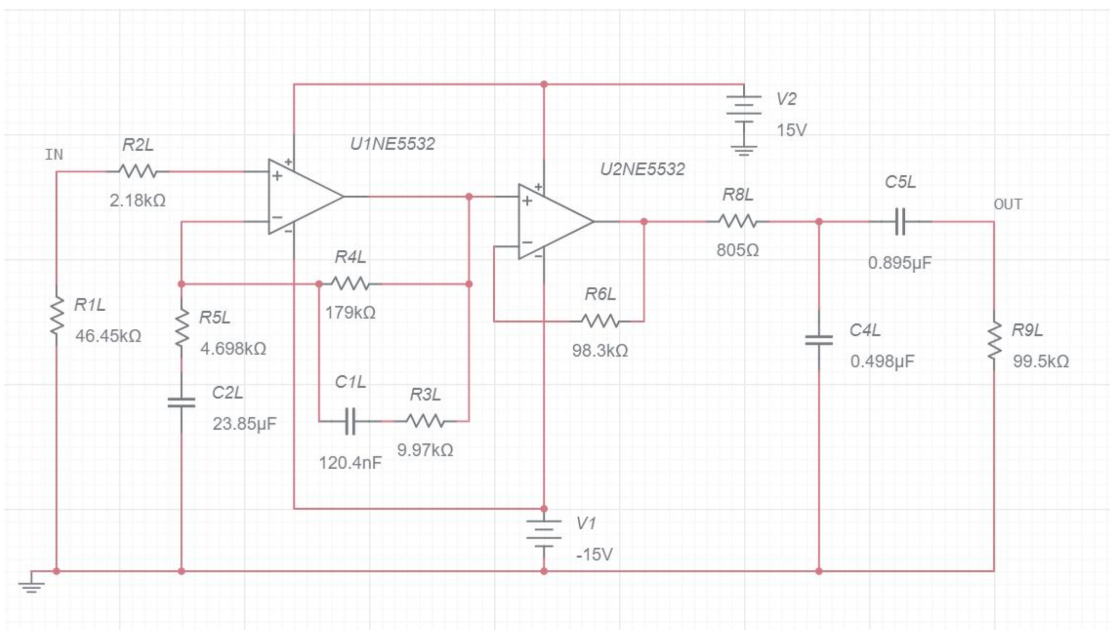

Figure 10: Phono Preamplifier Schematic Final

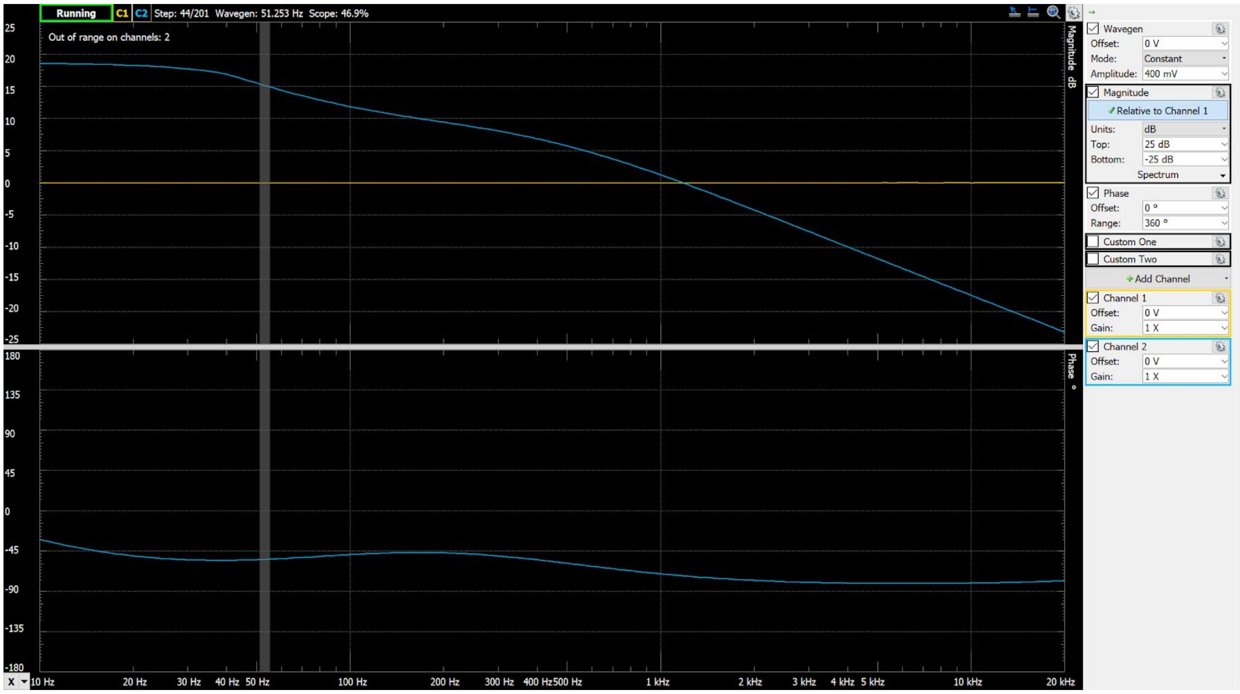

Figure 11: Phono Preamplifier Final Bode Plot

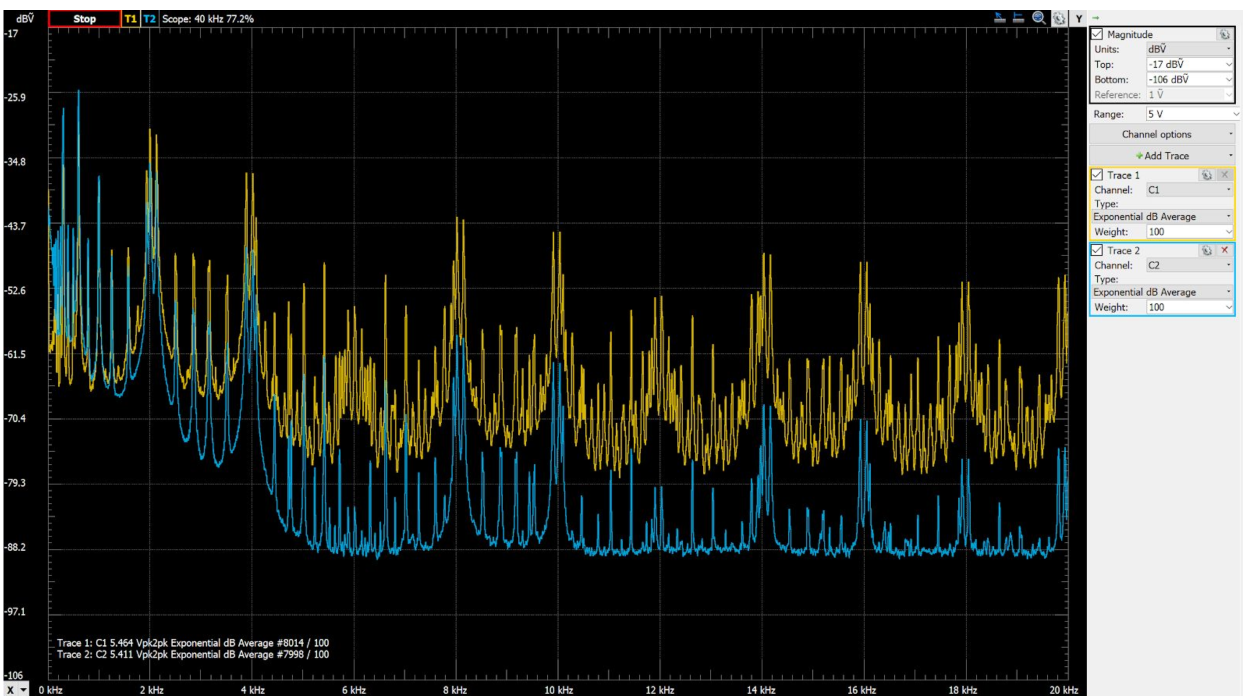

Figure 12: Spectrum Analysis of 30multitone_IRIAA_48.wav

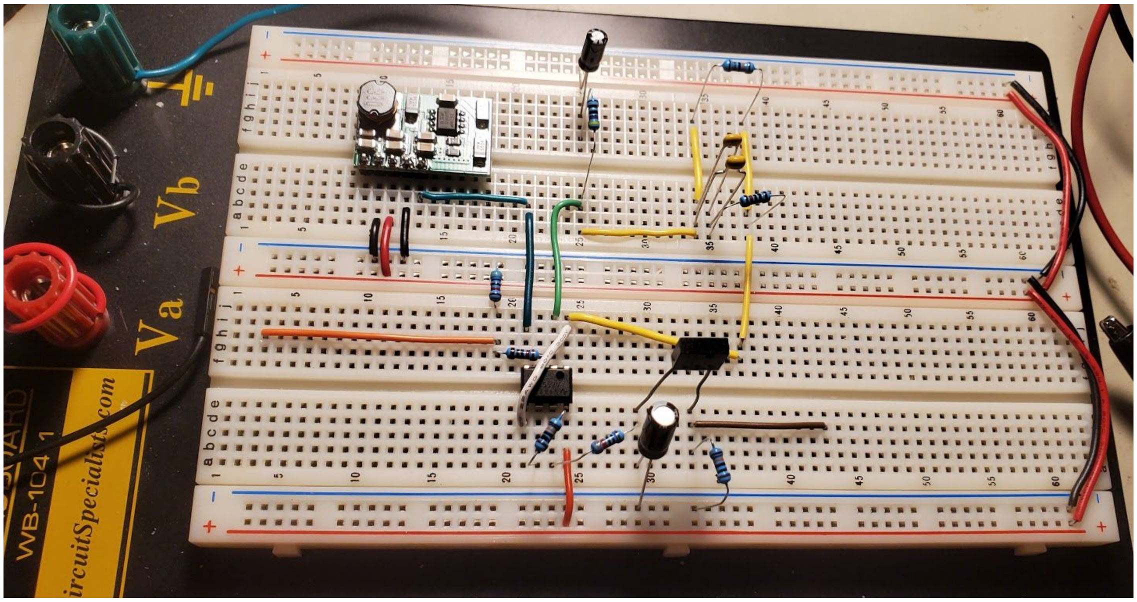

Figure 13: Final Phono Preamplifier on Breadboard

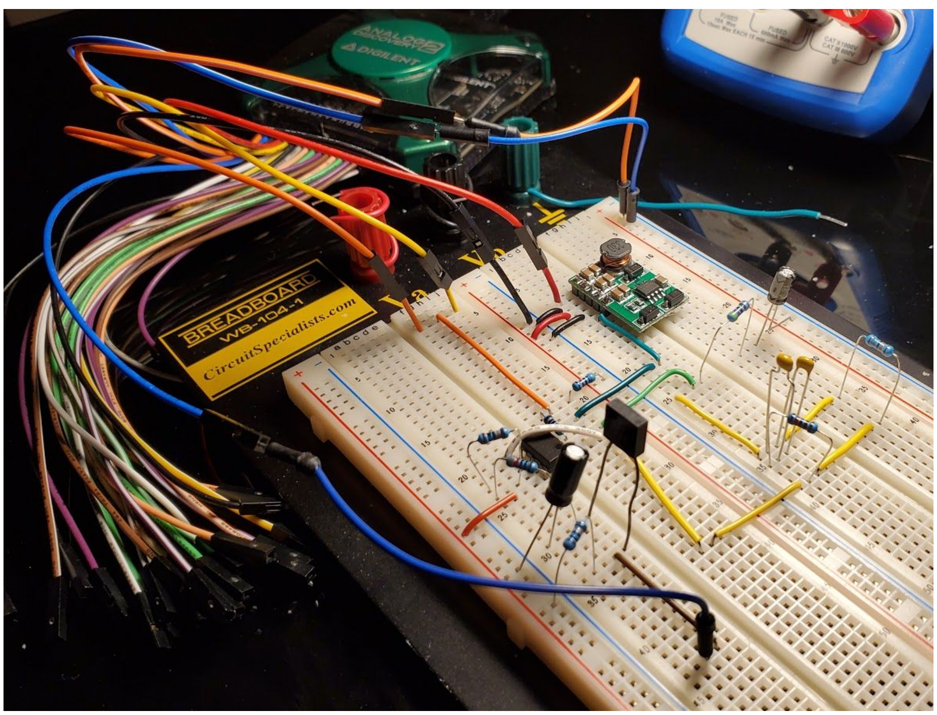

Figure 14: Final Phono Preamplifier Connected to AD2

Figure 10 shows our final schematic representation. All previous changes to the circuit were kept with the addition of one more value change. Capacitor C1L was changed from 21.44 nF to 120.4 nF. This change in the first stage of the circuit gave us the bode plot seen in Figure 10. The first pole is seen at around 50 Hz and the line crosses the 0 dB mark at around 1kHz, which matches the theoretical curve very well. The physical circuit that produced the bode plot in Figure 11 is shown in Figure 13. The purpose of the preamplifier is to read in a signal from the phono needle, boost it, and apply the RIAA equalization curve so that it is ready to be amplified by a regular speaker. Unfortunately we were not able to connect ours to a real record player, but we were able to simulate a vinyl disc by using a WAV file that had an inverse RIAA filter applied to it. The file itself is called 30multitone_IRIAA_48.wav and was borrowed from https://linearaudio.net/downloads.

Figure 12 shows the spectrum analysis of how our circuit responded to that WAV file. The blue line is the output of the circuit and the yellow line is the input of the circuit (the WAV file itself). This spectrum analysis shows that our preamp is working like it should. At very small frequencies, the output signal is boosted (high positive gain) and at higher frequencies the output signal is smaller than the input (negative gain).

That WAV file was fed into the input of the preamp through the Analog Discovery 2's (AD2) wave generator tool. Scopes from the AD2 were placed on the input and output of the preamp circuit to monitor the response (the physical wiring between the AD2 and the preamp is depicted in Figure 14).

Physical Board Components

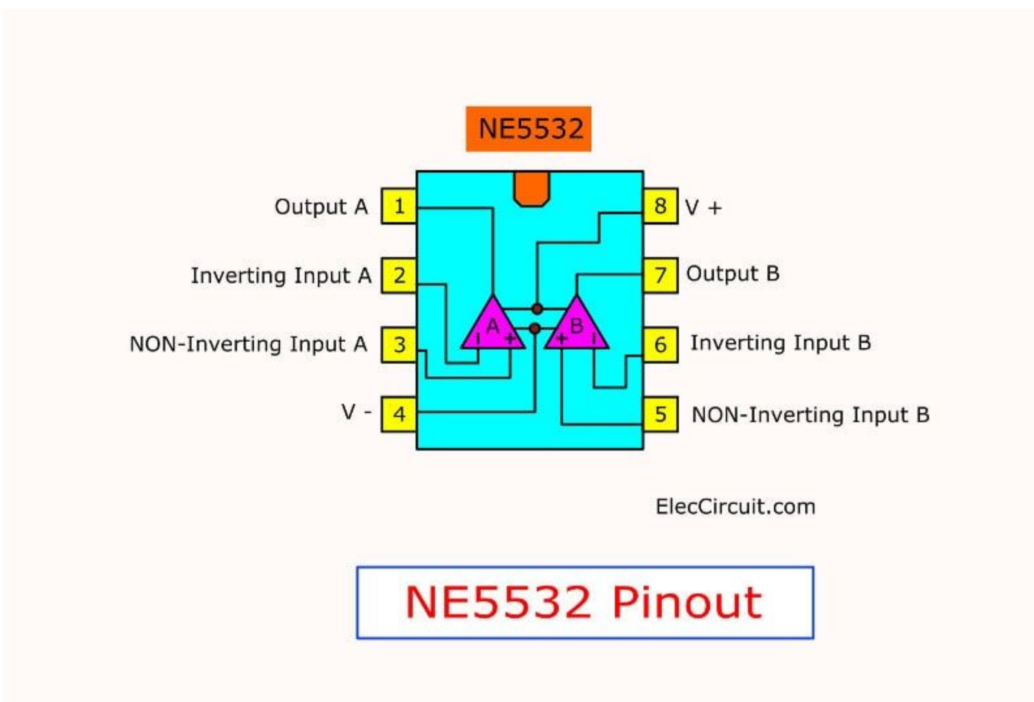

Figure 15: Pinout of NE5532 op-amp (from: https://www.eleccircuit.com/ne5532-datasheet/)

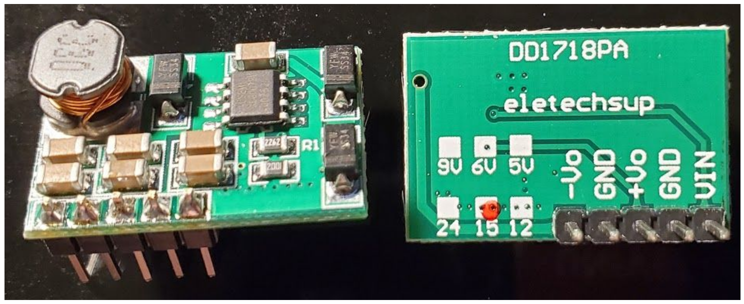

Figure 16: DC to DC Step-up Converter (from: https://www.amazon.com/Converter-3-3V-13V-Positive-Negative-Step-up/dp/B07PDO6R3C/ref=sr_1_37?dchild=1&keywords=Boost+Converter&qid=1607237320&sr=8-37#descriptionAndDetails)

The op-amp used in this design and seen as the black IC on the breadboard of Figure 13 is an NE5532, which was recommended by the original designer of this preamp Rod Elliott (https://sound-au.com/project06.htm). Figure 15 shows the schematic of the NE5532, and as you can see it has two op-amps packed into one IC. This was convenient for this project because the preamplifier needed exactly two stages.

The NE5532 was powered with +15V to pin 8 and -15V to Pin 4. We used the AD2 kit to power and test the circuit. However, the AD2 can only supply a power up to 5V when running off of a computer's USB port. This 5V supply was boosted up to 15V through the DC to DC step-up converter as depicted in Figure 16. The 5V input from the AD2 is connected to VIN, which then steps the voltage up to 15V at pin +Vo and -15V at pin -Vo. Those voltages are then fed into the correct pins to power the NE5532 op-amp as discussed above.

Conclusion

Although we did not get to physically connect our preamplifier to a record player, this project still taught us a lot about how phonographs work and how different capacitor values can affect the bode plot of an op-amp circuit. The physical circuit's bode plot matched the theoretical one produced by Rod Elliott, and the spectrum analysis of the WAV file showed our preamplifier to be functioning correctly. As for why we had to modify the circuit heavily to obtain the correct values is most likely attributed to the tolerances of the capacitors used in this design. As stated in Rod Elliott's original documentation, "The low value capacitors should be 2.5% tolerance if obtainable, otherwise you may be able to measure a selection of standard tolerance caps to find those which are closest to the required value - preferably to within 1%" (source: https://sound-au.com/project06.htm). The resistor values on the circuit were within 1% tolerance, however the capacitors were in the 5% tolerance range. This aspect of the circuit was overlooked when constructing it.