Building an Active 5-Band Equalizer

Bruno E. Gracia Villalobos

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Professor Lars Hansen

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INTRODUCTION

Equalization: A Brief History

Prior to the 1930's, Bell Labs pioneered equalization to fix audio transmission losses (Rane). However, equalization was used as part of the internal electronics of a system. It was not until John Volkman of RCA used a variable equalizer in a cinema's theater system that equalization served as an external unit of a system—a post-production unit (Rane). At the same time, the passive equalizer, Langevin Model EQ-251A, was created with 'faders' as a pre-production unit—used as part of the recording process and not as a filter unit compared to Volkman's implementation (Rane). Equalization was still passive, however.

To have better control of equalization, Cinema Engineering created the first graphic equalizer—the 7080 Graphic Equalizer with 6 separate bands some time after (Rane). The design implemented the classic equalizer we see today. Although this equalizer was active, further improvement was still to be made concerning feedback.

After World War II, equalization received a boom of improvements beginning with work done by Professor C.P. Boner from the University of Texas at Austin in 1962. Professor Boner created a notch filter that addressed the feedback problem, and this was further improved by Altec-Lansing with the creation of the 1/3 octave, passive notch filter in 1967 (Rane).

With the feedback and bandwidth limitations addressed, the notch filter marked the beginning of an "explosion" of equalization improvements (Rane). From this, equalization branched out into 2 main segments: Passive and Active. The types of equalizers can be seen on Figure 1.

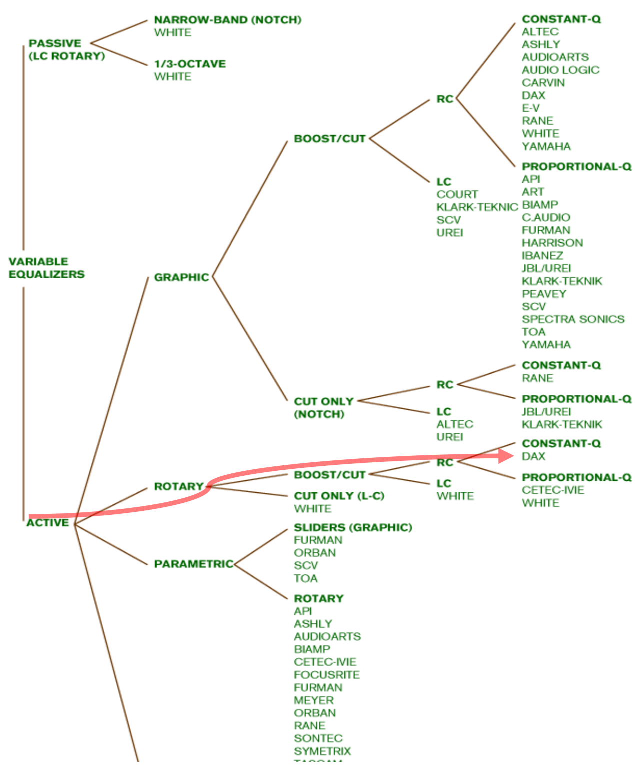


Figure 1 - Types of Equalizers (Rane)

Most importantly, the equalizer built for this project branches out as follows,

Active → Rotary → Boost/Cut → RC → Constant Q

and can be seen in Figure 1. The circuit schematic for this equalizer was found on *bestengineeringprojects.com*, and further improvements to it were made along the way.

Equalizer Operation

This active 5-band equalizer (EQ) behaves like a typical graphic equalizer would. Its main purpose is to take an input signal, “boost” or “cut” gain at the specified center frequencies given by the five “bands”, and then output the equalized signal. The equalizer’s operation is demonstrated in Figure 2.

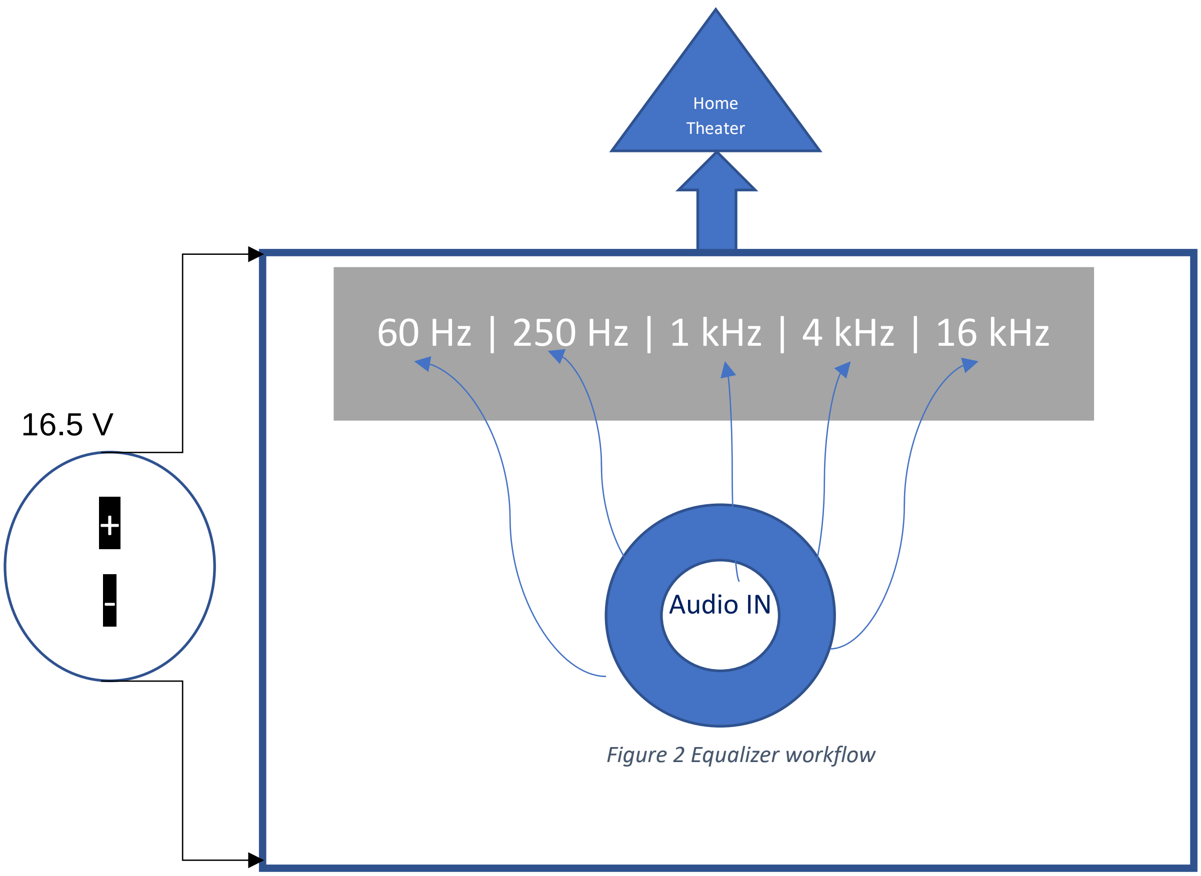


Figure 2 Equalizer workflow

On a high level, the audio signal comes from a 3.5mm jack into the circuit, fed in parallel to the 5 equalization bands, then fed out into the speaker with the given equalization. The circuit is powered by a repurposed 16.5 V, 400mA max wall-wart transformer. However, since the stereo signal is fed into a single input in the circuit the output is forced to be mono.

Equalization bands

The equalizer has 5 different bands as can be seen in the diagram. Each of these are 2 octaves apart, since 60 Hz * 2^2 = 250 Hz, 250 Hz * 2^2 = 500 Hz, and so on; multiplying a frequency band by 2 would give the frequency an octave above. Although the industry standard is 1/3 octave, this equalizer is for Hip-Hop production due to 3/5 of the bands centered around the lower and mid band range, and the last band at high end: the lower bands cover the drum and bass heavy qualities of hip-hop, and the 16kHz band is where the hi-hats would hit as well. The 5 bands are a limitation to other genres, but to the author's musical preference serve quite useful.

CIRCUIT OVERVIEW

The schematic was taken from *bestengineeringprojects.*com. The circuit implementation is split into three distinct stages: the first stage receives and outputs the signal from the 3.5mm jack and outputs a voltage rail ½ of the power supply; the second stage consists of the 5 frequency bands, which are implemented as multiple feedback bandpass filters (MFB's); the third stage consists of the summing amplifier, which is fed in the output of the 5 different MFB's and outputs the signal to the home theater system. The entire circuit is shown in Figure 3.

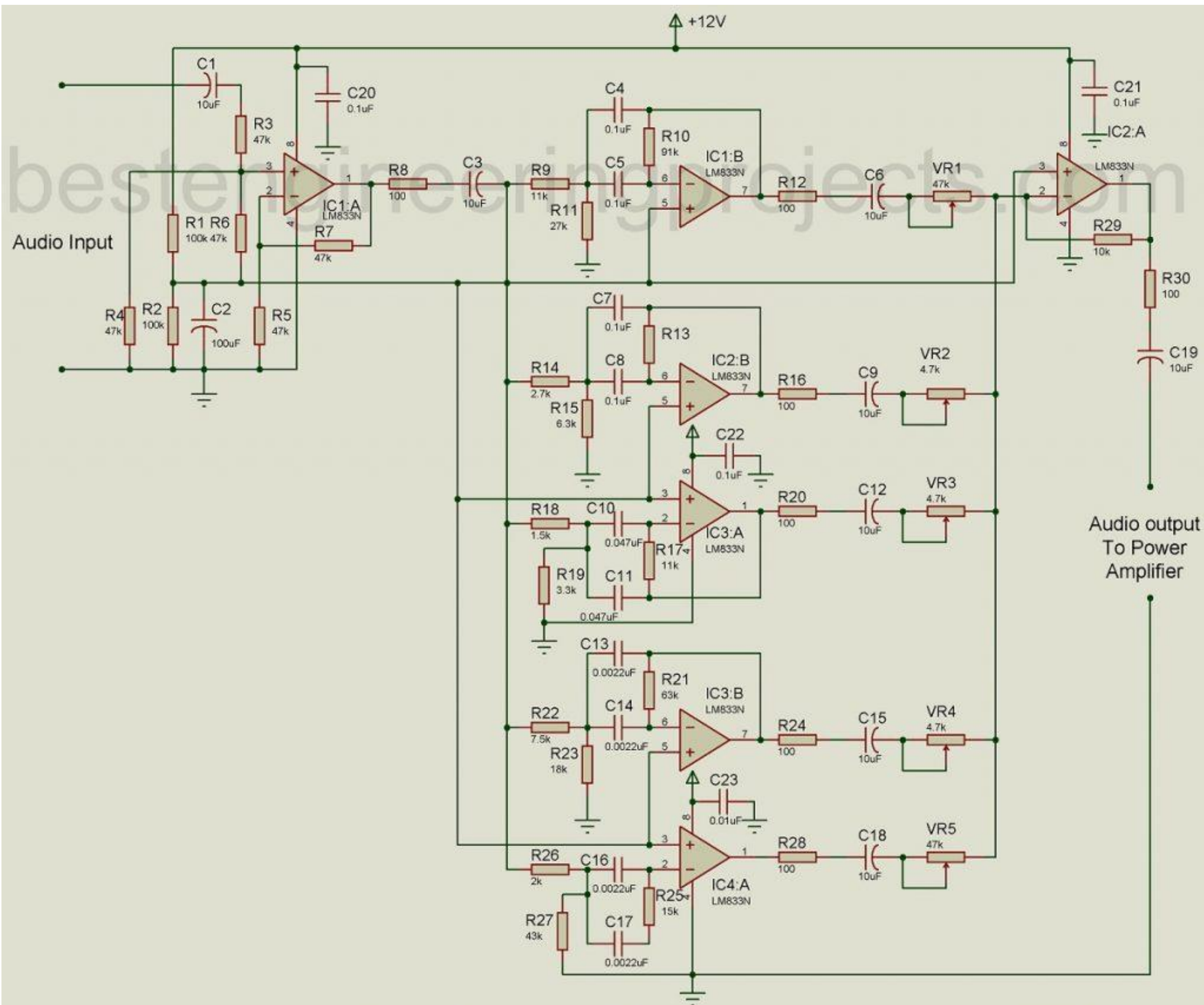


Figure 3 The Circuit Schematic for the Active 5-Band EQ

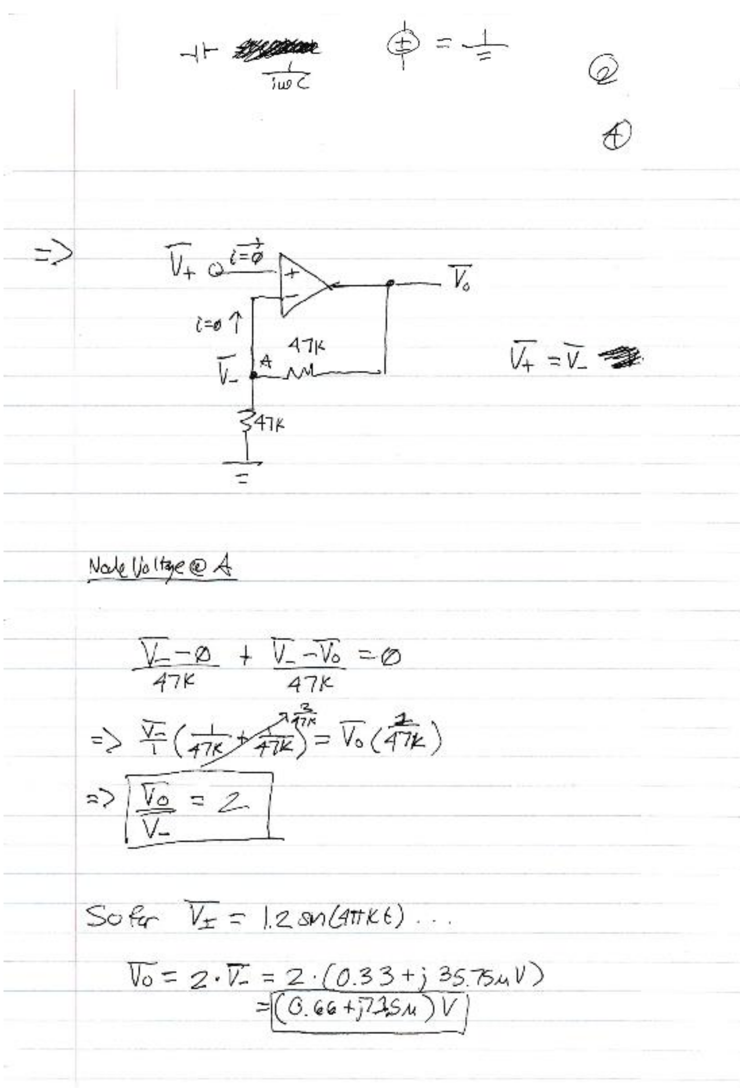
The First Stage

The first stage takes input from the 3.5 mm jack into the circuit and biases both the inverting and noninverting input. The signal first is routed through a 10uF electrolytic capacitor, then after reaching the two 47k resistor junction, routes itself to the noninverting input. After this, the signal then continues down the 47k resistor to an RC network to ground.

In between the 47k resistor after the noninverting junction and ground, there is a power rail that feeds down from the 16.5V supply. Upon testing, the potential must have been at around 8.25 V due to the voltage divider by the two 100k resistors, but after testing, this junction was at around 4V due to the divider connected coupled with the noninverting input. This rail feeds into the rest of the noninverting inputs for the rest of the 5 bands.

For AC analysis, the following signal was used based on oscilloscope measurements of the output from an Android phone playing a sine wave:

Vin = 1.2sin(4k*pi*t) [V] → 1.2*phase(-90)



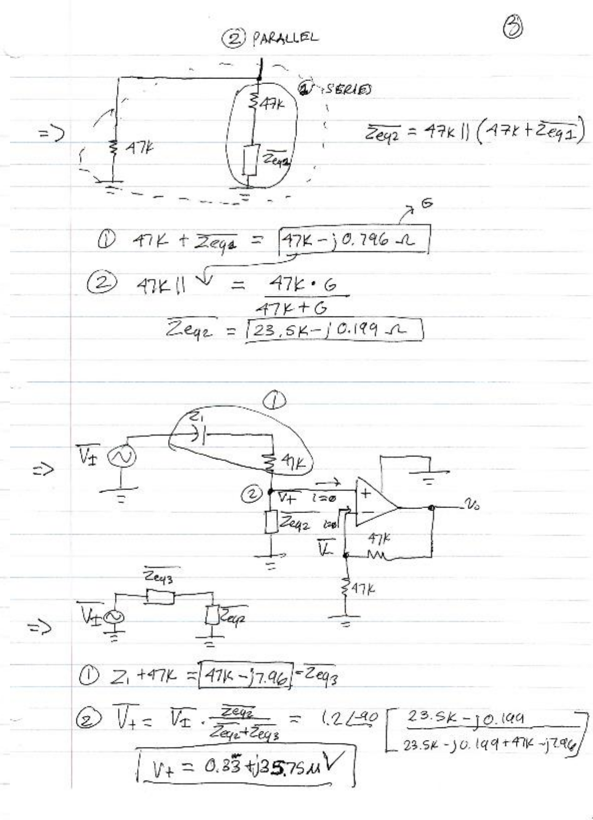


Figure 4: Starting from the top right, counter-clockwise

In Figure 4, the circuit is simplified for AC analysis: DC sources are set to ground. To begin, the signal is fed into the RC network. The capacitors are represented as impedances Z1 and Z2, and these are put in parallel and series recursively until the circuit becomes a simple noninverting amplifier. Here, nodal analysis is performed at node A, and the gain is confirmed to be:

Av = R2/R1 = 2.

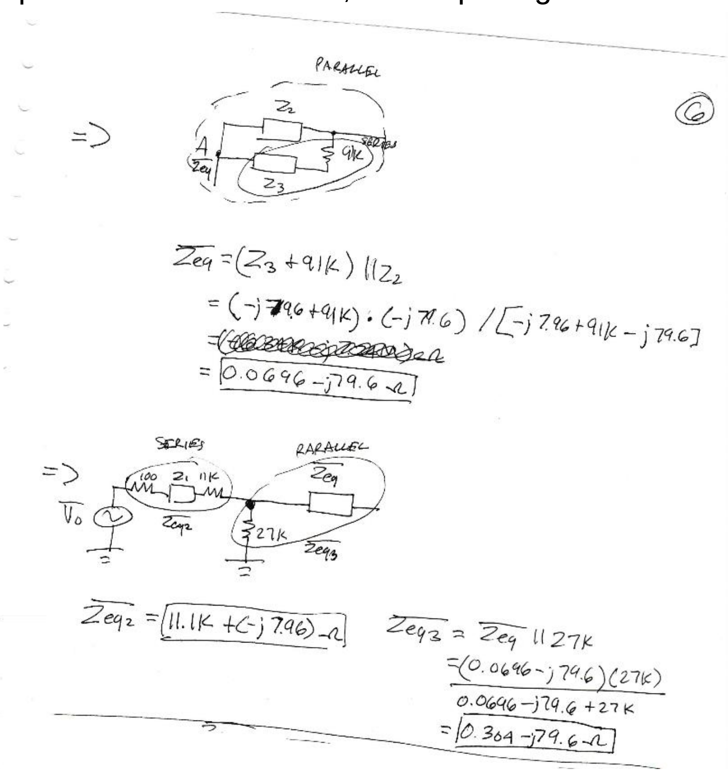
The output signal is found to be:

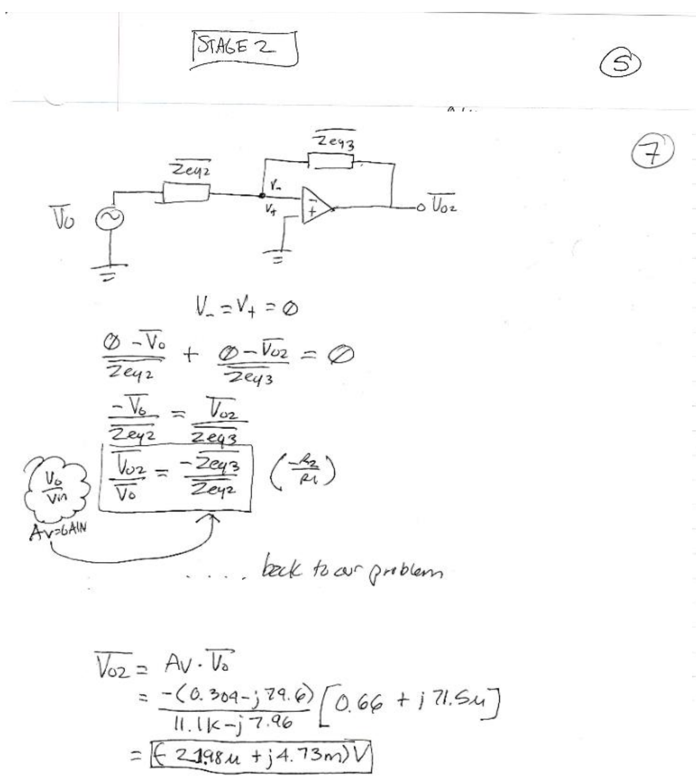
Vo = (0.66 + j71.5x10^-6) [V]

The Second Stage

The Second stage consists of the middle part of the circuit. Here, the output signal from the input stage as well as the 4V power rail are fed into the inverting and noninverting inputs of the op-amp. There are 5 op-amps connected to the input stage, with each serving as one of the bands of the equalizer. From top to bottom, the op-amps represent the 60 Hz, 250 Hz, 1 kHz, 4 kHz, and 16 kHz bands.

From reference, each of these op-amp circuits are bandpass filters (whsites.net). More specifically, they are MFBs. First, the analysis will be continued from Figure 6 below.





In Figure 5, the 60 Hz band is analyzed with the AC output of the First stage. Once the DC sources are set to ground, the capacitors are represented as impedances Z1, Z2, and Z3. These are combined with the resistors in parallel and series recursively until a simple inverting amplifier is realized. Once again, the gain is found to be -Zeq3/Zeq2, and the output Vo2 is shown in the bottom left hand corner.

AC analysis aside, the primary focus of each of these bands is the center

Figure 5: Starting from the top right, counter-clockwise

frequency and bandwidth given the circuit application. The following sections present each of the bands with hand calculations and circuit operation.

60 Hz Band

In Figure 6, the 60Hz band is analyzed for its gain, center frequency, and bandwidth. Given the bandwidth is 34.98 Hz, this is a good MFB filter. This means the lower pole is at:

$$f_o - BW/2 = 42.18 \text{ Hz},$$

and the upper pole is at:

$$f_o + BW/2 = 77.16 \text{ Hz}.$$

As stated before, this band is useful for boosting or cutting the sub frequency range of the bass in the hip-hop track due to its narrow bandwidth. This is the frequency which is most famous for "rattling" subwoofers.

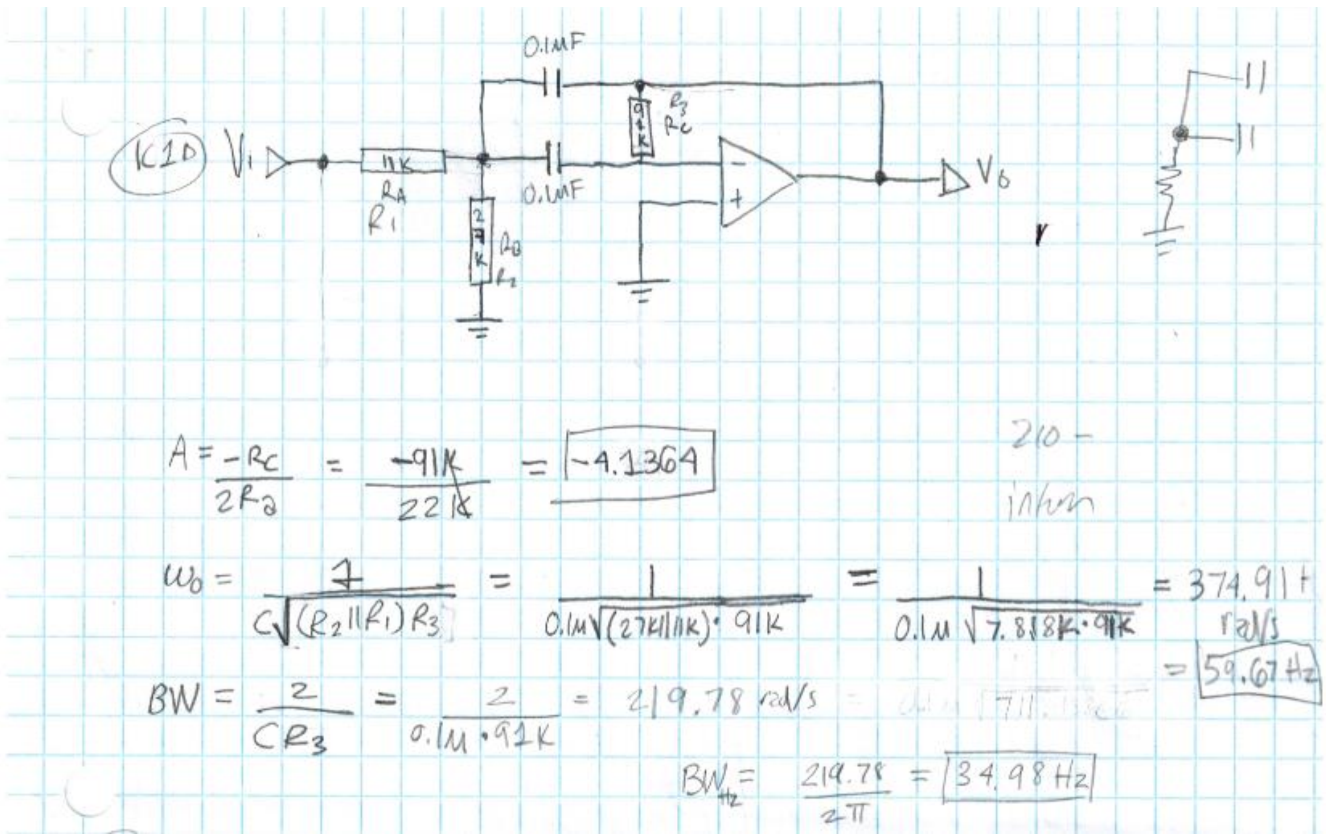


Figure 6: The 60 Hz band

250 Hz Band

In Figure 7, the 250 Hz band is analyzed for bandwidth, gain, center frequency, and upper and lower poles. In this band, the gain is slightly lower than the 60 Hz band. The bandwidth is also larger than the 60 Hz band, but still low enough to provide accurate adjustments. The lower and upper poles are also presented in the form of fc1 and fc2. Interestingly, this bandwidth is critical for the famous "808 Kick drum" used in most of the songs in Hip-hop today, and therefore proves useful for producing Hip-hop.

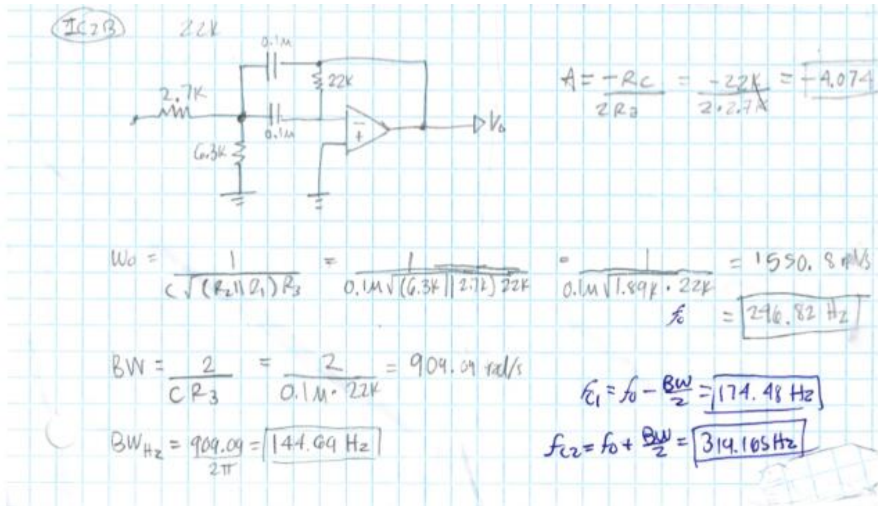


Figure 7: 250 Hz band

1 kHz Band

As the frequency increases from band to band, given contiguous bands are 2 octaves apart from each other, the bandwidth also increases. However, the gain is relatively the same across the bands. Depending on the targeted operation of this equalizer and for what it will be used, this wide bandwidth can be useful. For targeting single snare drums this bandwidth might not be too useful since it is too wide, but for targeting vocals it will because it encompasses a large part of the frequency range of human voice. Nevertheless, if targeting vocals, they should be isolated from the entire mix to prevent attenuating or boosting other instruments in the mix.

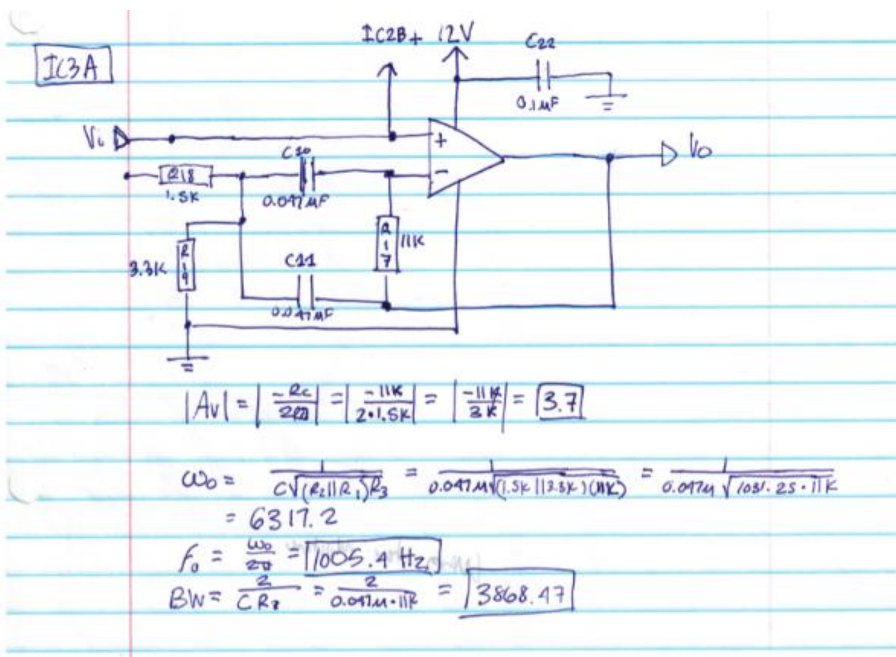


Figure 8: The 1 kHz band

4 kHz Band

In the 4kHz band shown in Figure 9, the gain is once again close to other bands'. Here too, the bandwidth is increasing, which limits the amount of accuracy needed to further control the instruments to be mixed. At this band, the snare drum is highly prominent, but the bandwidth renders this band close to useless for engineering the sound of the instrument. On a separate note, this band is once again useful for editing vocals in a mix: the 4 kHz band can add some prominence to female vocals over a drum heavy track. Nevertheless, this must also be done in isolation from the rest of the instruments—the vocals must be the only thing running through the EQ.

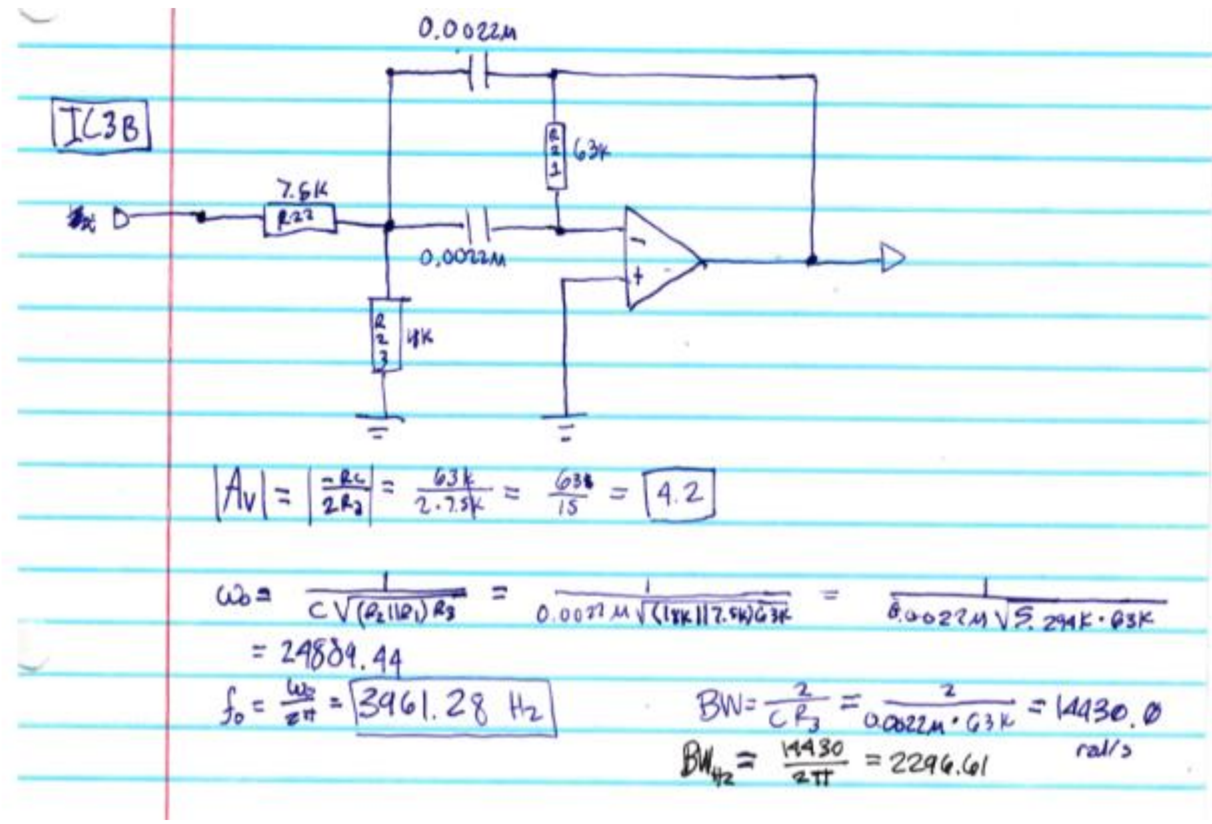


Figure 9: The 4 kHz band

16 kHz Band

The schematic claims this MBF has a center frequency of 16 kHz, but the analysis proved fo to be 13.5 kHz. Also, the bandwidth came out to be around 60 kHz which would be highly useless as it would attenuate or boost the entire spectrum of human hearing. In the following sections of this report, this explains the high amount of noise the band caused within the implementation of the circuit.

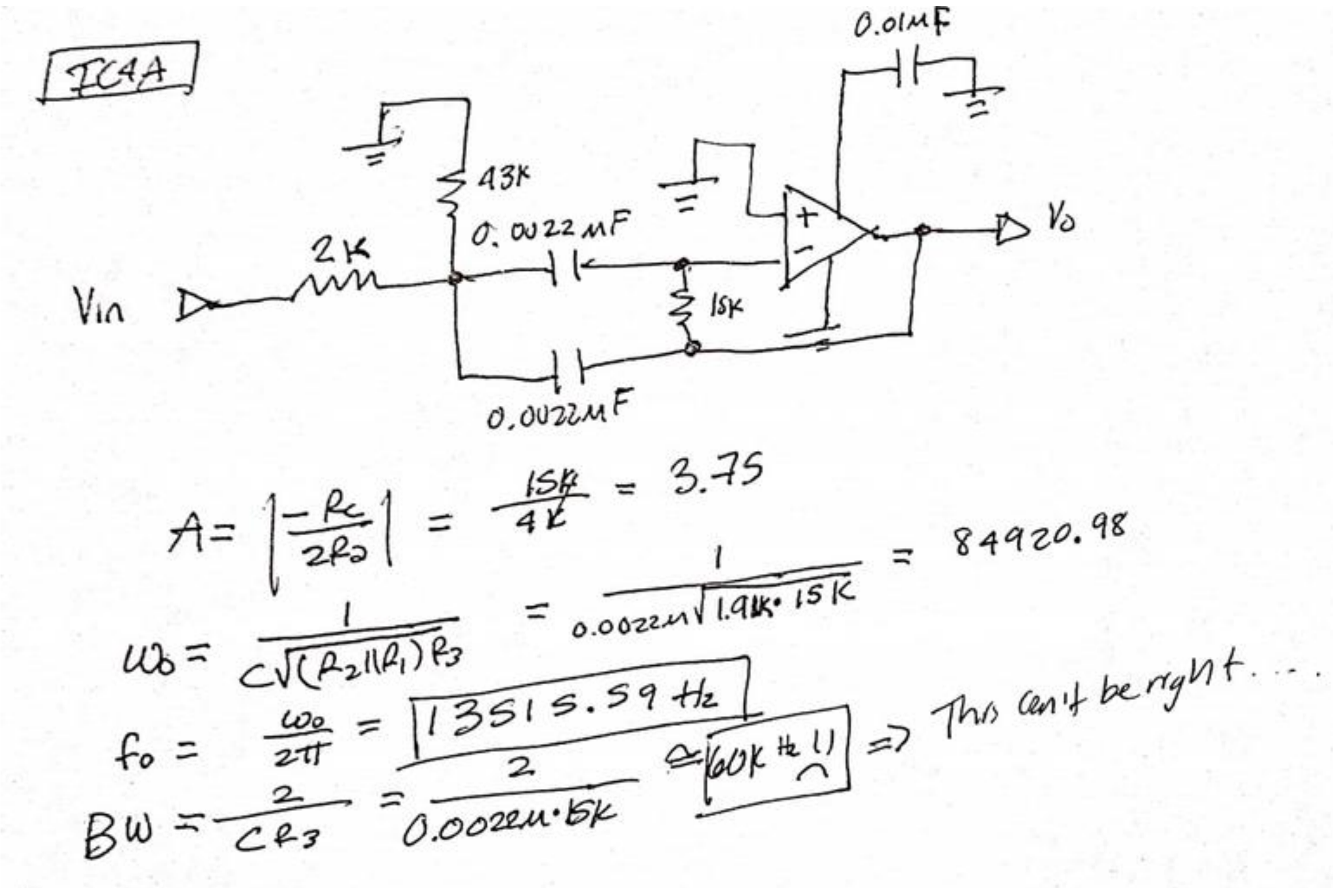


Figure 10: 16 kHz band

The Third Stage

The last stage of the circuit uses a summing amplifier to input the bands' outputs and outputting the equalized signal with gain. Primarily, this amplifier is used to output the signal with a low output impedance for the home theater system to play the signal on the speakers. AC analysis is performed on this stage, and the DC input to the noninverting input is sent to ground.

Given the output of this stage is in micro Volts, this reaffirms the need for an audio amplifier to drive the speakers. This is where the repurposed home theater came in handy.

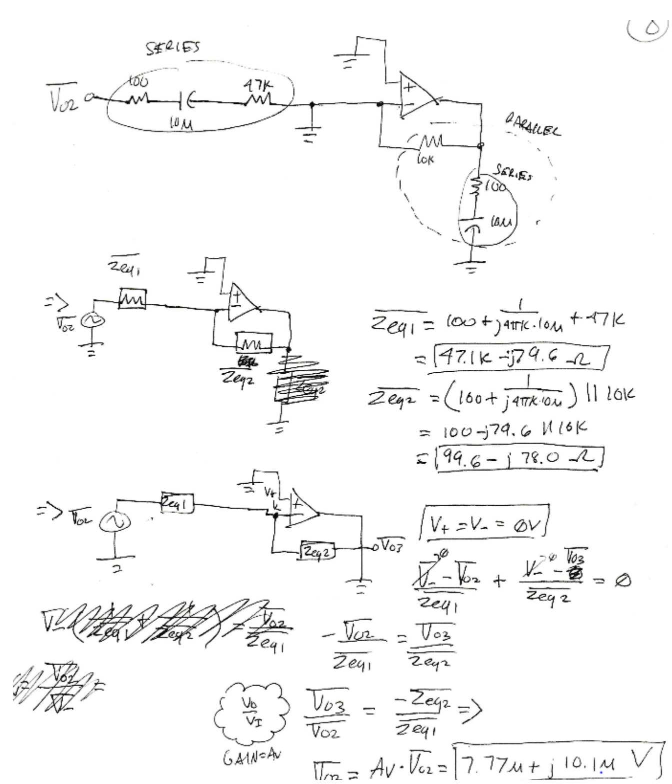


Figure 11: The third stage

MATERIALS

The circuit was built with components considering the needs for a signal with as less noise as possible. For this reason, metal film resistors were used, in addition to JFET input op-amp IC's. Precautionary measures such as AC coupling capacitors were used, and the signal routing was carefully shielded through ground in its input and output points of the circuit. The following table shows the materials list for the implementation of the equalizer obtained from *Mouser.com*.

Marking	**Value**	**QTY**
R1, R2	100 KΩ	2
R3 – R7	47 KΩ	5
R8, R12, R16, R20, R24, R28, R30	100 Ω	7
R9, R17	11 KΩ	2
R10	91 KΩ	1
R11	27 KΩ	1
R13	22 KΩ	1
R14	2.7 KΩ	1
R15	6.3 KΩ	1
R18	1.8 KΩ	1
R19	3.3 KΩ	1
R21	63 KΩ	1
R22	7.5 KΩ	1
R23	18 KΩ	1
R25	25 KΩ	1
R26	2 KΩ	1
R27	43 KΩ	1
R29	10 KΩ	1
C1, C3, C6, C9, C`12, C15, C18, C19 (Electrolytic Capacitors)	10 µF	8
C2 (Electrolytic Capacitors)	100 µF	1
C4. C5, C7, C8, C20 – C23 (Ceramic Disc)	0.1 µF	8
C10, C11 (Electrolytic Capacitors)	0.047 µF	2
C13, C14, C16, C17 (Electrolytic Capacitors)	0.0022 µF	4
7 Op Amps (TL074CN)		2
VR1, VR2, VR3, VR4	4.7 KΩ	4
TOTAL = ~$35.00		

With $35 dollars, the circuit proved to be rather affordable given some equalizers start at $70 dollars. Most importantly, this equalizer is highly customizable which also was an appealing factor of this project.

In addition to these active and passive components, the equalizer implementation also utilized a 16.5V wall-wart, in addition with an old LG home theater system with an amplifier connected to 6 ohm impedance left and right channel speakers. The home theater system also includes a subwoofer which proved useful when testing the 60 and 250 Hz bands of the equalizer.

PROTOTYPING

Audio Interfacing

To begin, two 3.5mm to RCA cables were stripped and carefully soldered to breadboarding wires for easier interfacing into the equalizer. Each wire had 4 individual wires stemming out from it: the left and right channels with each a single grounding wire. These grounding wires had to be grounded otherwise the speakers would output distortion all the time with inaudible audio.

For the audio in wire, the 3.5mm jack was left intact and the RCA endpoints were stripped. Conversely, for the audio out wire, the 3.5mm jack was stripped and the RCA endpoints were left intact. To bring in audio to the board, the audio in wire was connected to an Android phone through the 3.5mm jack and to the breadboard through the leads on the other end. As for outputting audio from the board, the audio out wire was connected to the speakers through the RCA endpoints and to the breadboard through the leads.

Powering the equalizer

The equalizer needs a 12V supply as specified by the schematic. However, given to design complications, the power rail as previously mentioned did not output the necessary 1/2 voltage rail for the noninverting inputs. Nevertheless, a 16.5V wall-wart transformer was used to power the positive and negative rails of the circuit without any further components.

Setting up the Rotary interface

Four 5k ohm potentiometers were used to manage the 250, 1k, 4k, and 16 k Hz bands; The 60 Hz band was implemented without a potentiometer. These were soldered with three breadboarding wires each for easier implementation into the board. To the mistake of the author, the 60 and 16k Hz bands required a 47k ohm potentiometer, but after testing these proved futile. They did not boost or cut the gain more than 10mV.

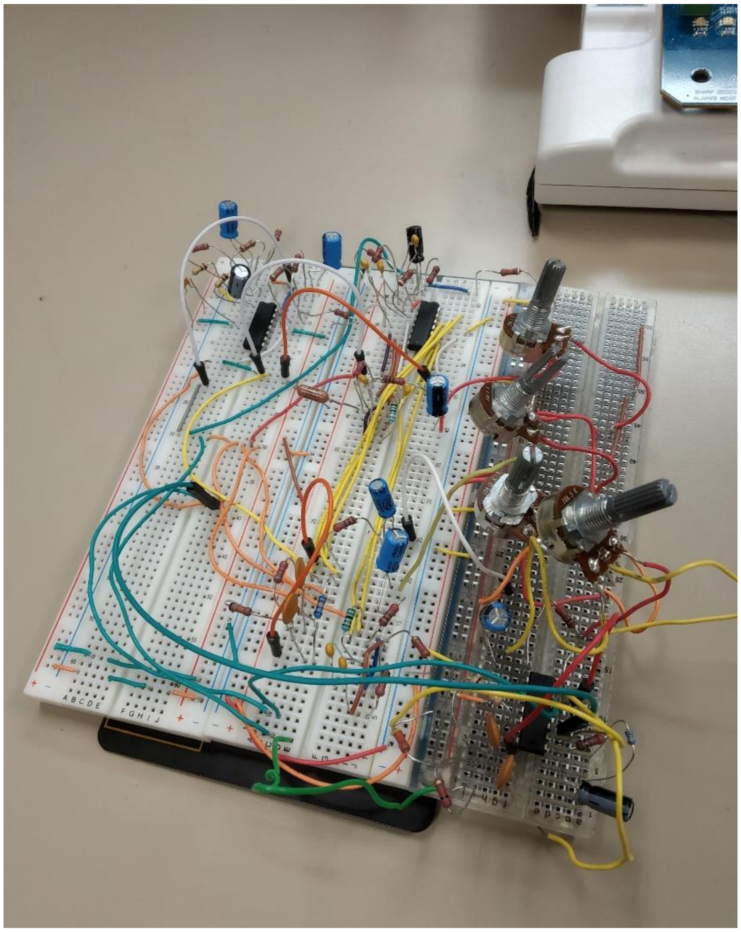


Figure 12: The equalizer without the wall-wart, and audio cables

TESTING AND OPERATION

Each of the circuit's stages was individually tested prior to breadboarding the next. For example, to test the input stage, the inverting amp was built and tested with both music and sine wave signals. Next, the second stage was built band by band, leaving the input stage intact. Finally, once each band was tested in isolation from each other, the final stage was built and tested.

Oscilloscope Tests of the Second Stage

During each test, both music and sine wave signals were fed into the equalizer and both analyzed in the oscilloscope and listened to from the speakers. For example, in the 60 Hz band testing, the bass-heavy instrumental version of the song "Jumpman" by artist "Future" incredibly attenuated the rest of the bands and boosted the bass to a noticeable degree. This band was also tested with a 60 Hz sine wave, sweeped to the lower pole point and upper pole point to check if the oscilloscope showed attenuation. Within these tests, the output was also administered before and after the 47k ohm resistor to test the levels of boost/attenuation.

The preceding methodology was further used for testing the rest of the bands, but it increased in complexity the higher the frequency range of the band went. This may be due to the amount the complexity of the circuit prototyping process—where tens of wires would and components so close to each other proved it difficult to debug. For the first few times of testing the circuit, the following oscilloscope images show different operation compared to the attached final video demonstrations.

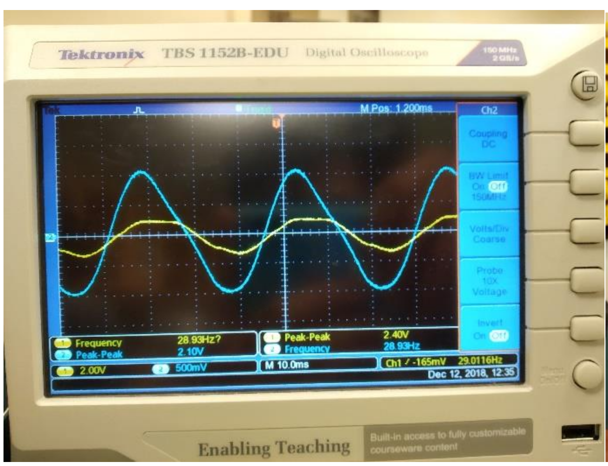


Figure 14: The center frequency of the 60Hz band

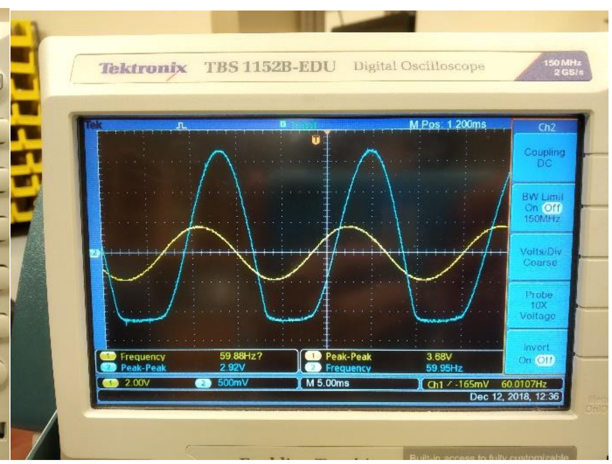


Figure 15 The lower pole of the 60Hz band

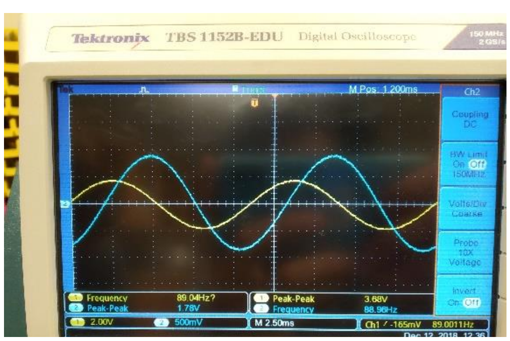


Figure 13: The upper pole of the 60 Hz band

In Figures 14-16, the oscilloscope shows how the 60 Hz band boosted the signal at its center frequency but stayed flat at the lower and upper frequencies. These claim the op amp was saturating at its power rails, given the voltage divider as explained before output around 4V due to poor circuit design.

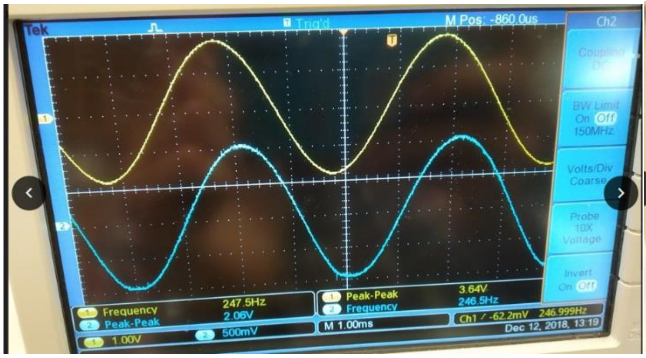


Figure 16: Lower pole of the 250 Hz band

Figure 17 Center frequency of the 250 Hz band

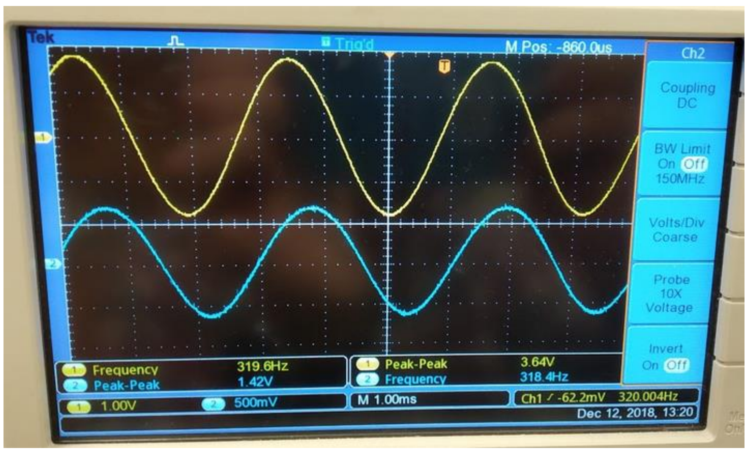


Figure 18 Upper pole of the 250 Hz band'

In these images, the oscilloscope showcases the same behavior for the 250 Hz band as the 60 Hz band: the output saturates around the center frequency on the negative part of the sine wave. It is worth mentioning these images were taken at points before and after the band's potentiometers; this might explain why the signal did not attenuate or boost the frequencies properly.

LESSONS LEARNED

After testing the rest of the bands and seeing unfavorable results, the circuit was rebuilt from the ground up after seeking advice and reference from classmates and faculty. The following problems were fixed or attempted to be fixed:

- The 16.5V wall-wart powered the entire circuit and two 6V PSU's—previously used to power the ½ voltage rail—were removed due to spikes every 10 kHz (phone chargers)
- The circuit was powered by a voltage divider using the 16.5 V to output 12V but it caused the power supply to collapse when powering the op-amps

- The 47k resistor voltage divider at the input stage was replaced by two 100 ohm resistors but the wattage was too high and started to melt the resistors. The op-amp also did not operate properly.
- The audio cables were grounded properly when too much noise drowned out the speakers
- The ½ * 16.5 volt supply rail was coupled with the output from the first stage. Before, these were not wired together and the noninverting input of the op amp was fed only DC when AC was fed to the inverting input
- The three breadboards proved difficult to debug and often caused shorts in the wiring. This was fixed by decoupling the breadboard of interest and testing the stage by itself
- The signal was traced with the RCA to leads wire coming from the home theater system touching the circuit at points of interest. This proved more useful than the oscilloscope at times.

REFERENCES

- **http://www.rane.com/note122.html**
- **http://sound.whsites.net/project63.htm**

FINAL RESULTS ARE ATTACHED IN VIDEO FORMAT FOR EACH BAND IN GOOGLE DRIVE:

https://drive.google.com/drive/folders/1omRAz-ClZ-2A80dkT7Ml-47XwhZCimlo?usp=sharing

Thank you Professor Hansen for your instruction and mentorship.