10-Band Equalizer using active adjustable filters

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***Abstract*— In this paper we will discuss a study on an equalizer circuit. The study involves a theoretical analysis and a simulation of a 10-band equalizer, a simulation and circuit implementation of a 3-band equalizer. An equalizer equipment or circuit used to strengthen or weaken energy of specific frequency bands or "frequency ranges". There are different circuit topologies that can achieve this frequency suppressions; this paper aims to demonstrate the multiple feedback bandpass active filter configuration to build an equalizer from scratch.**

I. INTRODUCTION

The process of weakening or strengthening energy of specific frequency bands is called equalization. Equalization works by adjusting the balance between frequency components within certain electronic signals.

People use equalizer in recording studios, radio studios and production control rooms and for live sound reinforcement. Equalizers are famously known in the music industry, they can be used for instrument amplifiers, such as guitars and bass instruments. They can also be used to correct and adjust the response of microphones and loudspeakers. Music producers and musicians use this tool to manipulate the frequency content of their music mix so that everything is balance clearly.

Filters on the other hand are devices that pass electric signals at certain frequencies or frequency ranges while preventing the passage of other frequencies.

All types of filters usually consist of passive component such as resistors, capacitors, and inductor; the combination of these passive components form passive filters. In contrast, active filters contain active components such as operational amplifiers, transistor, or FETs within their circuit design. Passive filters have several advantages over an active filter; they guaranteed stability. Passive filters scale better to large signals, whereas active filter devices can have a gain due to its operational amplifier, they can increase the power available in a signal compared to the input. Active filters also have good isolation between each stage of a design circuit, and they can provide high input impedances and low output impedances.

There are many types of filters and they are like each type of filter; passive and active. There are low pass filters which passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. High pass filters pass signals with frequency higher than the selected cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. Another type of filter is the bandpass filter which passes frequencies withing a certain range and rejects other frequencies outside that range. The bandpass filter is a combination of a low pass and high pass filters. For this design project this type of filter is ideal because the requirement for this project is to try cover the frequency range of 20 Hz to 20 kHz. This paper will explain the design of an audio equalizer with 10 bands using active adjustable bandpass filters. To adjust each bandpass, we can use a potentiometer to be placed at the negative feedback portion of each bandpass filter to provide gain or attenuation for that specific band.

The purpose for this paper is to describe the goal of designing, simulating, building, and testing an audio equalizer from scratch. There are three different phases involved in this study, first we will discuss the design methodology and hand calculations of the equalizer, second an LTSpice simulation for a 10-band equalizer will be performed, finally we will build and test a 3-band equalizer circuit.

The following image, Figure 1 provides a block diagram of a 10-band equalizer. This block diagram will work to have a visualization of the desire equalizer circuit.

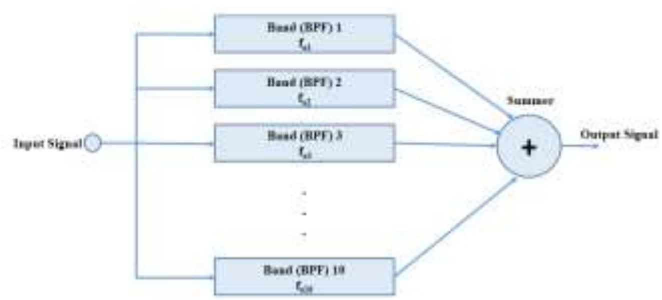

FIGURE 1: 10-BAND EQUALIZER BLOCK DIAGRAM

II. METHODS AND MATERIALS

A. *Circuit topologies*

The circuit topology used to successfully design a functioning equalizer is the multiple feedback bandpass filter. The multiple feedback bandpass filter is a very simple design, but it might be difficult to calculate the values for given set of parameters. These filters are very popular for equalization, analysis, and other tasks such as sound to light converter. Figure 2 presents a multiple feedback bandpass active filter use to create the equalizer.

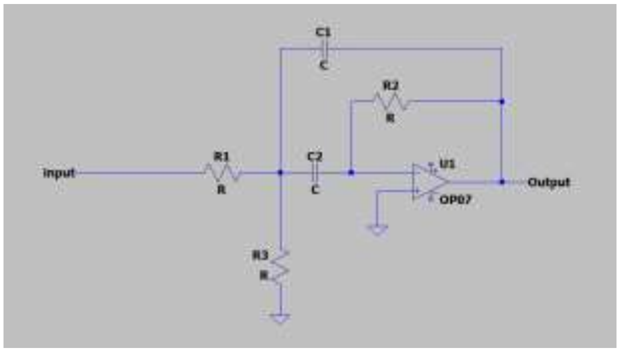

FIGURE 2: MULTIPLE FEEDBACK BANDPASS ACTIVE FILTER CIRCUIT TOPOLOGY

There are multiple advantages to this active band-pass filter configuration. First, there is no need to use an inductor to create the band-pass shape. Another advantage is that it only needs one operational amplifier device. The disadvantage for this configuration is that the nature of adjusting the center frequency, meaning that the adjustments are not independent. This center frequency can be tune by a resistor or potentiometer, but the quality factor will change.

Keep in mind that the component tolerances alter the tuning frequencies. Therefore, the operational amplifier is used, the use of enough horsepower will not spoil the frequency response of the filter.

We can describe the filter shape by, the center frequency is the center of the band which is typically the peak of the frequency response of the curve. The bandwidth is the upper and lower frequencies that are defined as the frequencies where the gain has dropped to 0.707 of the mid-band gains. The quality factor describes the width of the passband. Finally, the mid-band gain describes the voltage gain at the center frequency.

The following Figure, Figure 3 provides the frequency response of a bandpass filter. This image gives an insight idea of the center frequency, fo, As well the lower and high frequency, fl and fh.

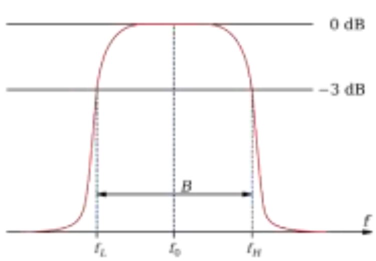

FIGURE 3: MFB BANDPASS ACTIVE FILTER FREQUENCY RESPONSE

Another circuit topology to consider for the equalizer is the summing op amp. As we can see from Figure 1, the block diagram provides 10 bandpass filters all connected to a summing operational amplifier. We can use a summing amplifier circuit to sum all the bandpass active filters use in the equalizer. The following image, Figure 4 provides a non-inverting operational summing amplifier.

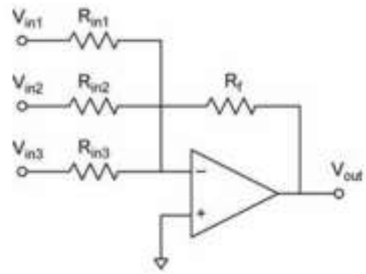

FIGURE 4: NON-INVERTING OPERATIONAL SUMMING AMPLIFIER

The summing amplifier combine several inputs into one common signal without noise or interference. This comes handy because we have 10 bandpass active filters that needs to be added or combine into a single signal. Another name the summing amplifier has is the Voltage Adder as its output is the addition of voltages present at its input terminal.

The figure describing the summing amplifier, Figure 4; has 3 input signals, the difference with our equalizer project is that the summing amplifier will have 10 input signals.

The following figure, Figure 5 provides the proposed circuit design schematic for a 10-bands using the multiple feedback bandpass active filter and the summing op amp.

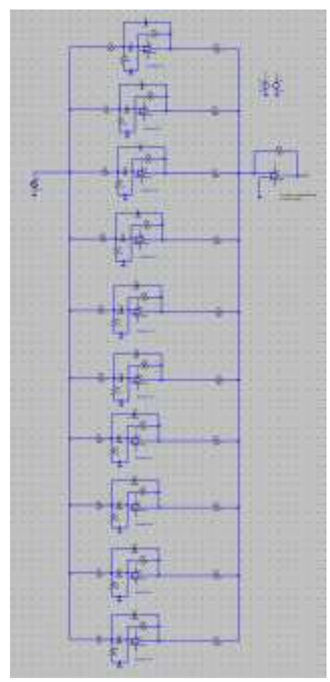

FIGURE 5: 10-BAND EQ CIRCUIT SCHEMATIC

B. *Circuit Design*

The MFB filter are useful for equalization, is a simple looking design, but it is difficult to calculate the values for a given set of parameters. The source impedance must be low with respect to the input resistance, which normally these filters are driven from an operational amplifier buffer.

The transfer function for MFB filter is as follows:

$$\frac{Vout}{Vin} = \frac{-s\frac{1}{R1\ C2}}{s^2 + s\frac{C1 + C2}{C1\ C2\ R3} + \frac{1}{R3\ C1\ C2} \times \left(\frac{1}{R1} + \frac{1}{R2}\right)} \text{ [eq0]}$$

The design flow for this type of circuit is as follows: We can choose one capacitor value because $C = C1 = C2$, by choosing a capacitor value we can determine the rest of the components. We should notice that the following equation requires a desire center frequency.

$$k = 2\pi F_o C$$

Were F_o is the desire center frequency of each bandpass filter. To determine the desire center frequency of each bandpass filter we need to consider frequencies in the logarithmic scale and not linear. This is because the human ear does not perceive sound in linear scale. Therefore, for the desire center frequencies we can discusses a $1/3rd$ octave. To achieve this, we can consider the $\sqrt[3]{10}$ which equals to 2.15427. This number can be multiplied by the lowest frequency the human ear can detect which is 20 Hz. The resulting number will be our second desire center frequency which is 43 Hz. We can multiply this second center frequency by the cube root of ten and obtain our third center frequency which is 93 Hz. By repeating this same process, we can achieve the other seven desire center frequencies.

$$1st\ center\ frequency\ 20\ Hz$$

$$2nd\ center\ frequency\ 43\ Hz$$

$$3rd\ center\ frequency\ 93\ Hz$$

$$4th\ center\ frequency\ 200\ Hz$$

$$5th\ center\ frequency\ 430.8\ Hz$$

$$6th\ center\ frequency\ 928.1\ Hz$$

$$7th\ center\ frequency\ 2\ kHz$$

$$8th\ center\ frequency\ 4.3\ kHz$$

$$9th\ center\ frequency\ 9.28\ kHz$$

$$10th\ center\ frequency\ 20\ kHz$$

Once all the desire center frequencies have been founded, we can proceed with the design flow of the MFB active filter. To find each resistor value, consider the following equations.

$$R1 = \frac{1}{H \times K}\ [eq1]$$

$$R2 = \frac{1}{(2Q - H)k}\ [eq2]$$

$$R3 = \frac{2Q}{k}\ [eq3]$$

Were Q being our quality factor and H cannot be bigger than 1. If we use these equations and find a capacitor value, we can find the appropriate resistance for the desire center frequency. An Excel spreadsheet can help ease the calculations when performing trial and error to compute the capacitance of the circuit topology.

By performing the equations: eq1, eq2, and eq3, we can determine the capacitance and resistance values for each bandpass. We can let $H = 1$ and $Q = 1$ for all bandpass filter specifications. These equations have been created in an Excel spreadsheet to calculate the desire components that will output the desire frequency. Given all the information above the equations lead us to the component values of each bandpass to be the following,

Bandpass 01:
When the center frequency, $F_o = 20\ Hz$

$$\text{Let } C1 = C2 = 6.7\ \mu F$$

$$k = 2\pi F_o C = 8.42\ \times 10^{-4}$$

$$R1 = \frac{1}{H \times K} = 1.2\ k\Omega$$

$$R2 = \frac{1}{(2Q - H)k} = 1.2\ k\Omega$$

$$R3 = \frac{2Q}{k} = 2.4\ k\Omega$$

Bandpass 02:
When the center frequency, $F_o = 43\ Hz$

$$\text{Let } C3 = C4 = 2.2\ \mu F$$

$$k = 2\pi F_o C = 5.95\ \times 10^{-4}$$

$$R4 = \frac{1}{H \times K} = 1.6\ k\Omega$$

$$R5 = \frac{1}{(2Q - H)k} = 1.6\ k\Omega$$

$$R6 = \frac{2Q}{k} = 3.3\ k\Omega$$

Bandpass 03:
When the center frequency, $F_o = 93\ Hz$

$$\text{Let } C5 = C6 = 1\ \mu F$$

$$k = 2\pi F_o C = 5.84\ \times 10^{-4}$$

$$R7 = \frac{1}{H \times K} = 1.7\ k\Omega$$

$$R8 = \frac{1}{(2Q-H)k} = 1.7\ k\Omega$$
$$R9 = \frac{2Q}{k} = 3.4\ k\Omega$$

Bandpass 04:
When the center frequency, $F_o = 200\ Hz$

$$\text{Let } C7 = C8 = 0.22\ \mu F$$

$$k = 2\pi F_o C = 2.76\ \times 10^{-4}$$
$$R10 = \frac{1}{H \times K} = 3.6\ k\Omega$$
$$R11 = \frac{1}{(2Q-H)k} = 3.6\ k\Omega$$
$$R12 = \frac{2Q}{k} = 7.2\ k\Omega$$

Bandpass 05:
When the center frequency, $F_o = 430\ Hz$

$$\text{Let } C9 = C10 = 0.22\ \mu F$$

$$k = 2\pi F_o C = 5.94\ \times 10^{-4}$$
$$R13 = \frac{1}{H \times K} = 1.7\ k\Omega$$
$$R14 = \frac{1}{(2Q-H)k} = 1.7\ k\Omega$$
$$R15 = \frac{2Q}{k} = 3.7\ k\Omega$$

Bandpass 06:
When the center frequency, $F_o = 928\ Hz$

$$\text{Let } C11 = C12 = 0.1\ \mu F$$

$$k = 2\pi F_o C = 5.83\ \times 10^{-4}$$
$$R16 = \frac{1}{H \times K} = 1.7\ k\Omega$$
$$R17 = \frac{1}{(2Q-H)k} = 1.7\ k\Omega$$
$$R18 = \frac{2Q}{k} = 3.4\ k\Omega$$

Bandpass 07:
When the center frequency, $F_o = 2\ kHz$

$$\text{Let } C13 = C14 = 0.022\ \mu F$$

$$k = 2\pi F_o C = 2.76\ \times 10^{-4}$$
$$R19 = \frac{1}{H \times K} = 3.6\ k\Omega$$
$$R20 = \frac{1}{(2Q-H)k} = 3.6\ k\Omega$$
$$R21 = \frac{2Q}{k} = 7.2\ k\Omega$$

Bandpass 08:
When the center frequency, $F_o = 4.3\ kHz$

$$\text{Let } C15 = C16 = 0.022\ \mu F$$

$$k = 2\pi F_o C = 5.95\ \times 10^{-4}$$
$$R22 = \frac{1}{H \times K} = 1.6\ k\Omega$$
$$R23 = \frac{1}{(2Q-H)k} = 1.6\ k\Omega$$
$$R24 = \frac{2Q}{k} = 3.3\ k\Omega$$

Bandpass 09:
When the center frequency, $F_o = 9.28\ kHz$

$$\text{Let } C17 = C18 = 0.01\ \mu F$$

$$k = 2\pi F_o C = 5.83\ \times 10^{-4}$$
$$R25 = \frac{1}{H \times K} = 1.7\ k\Omega$$
$$R26 = \frac{1}{(2Q-H)k} = 1.7\ k\Omega$$
$$R27 = \frac{2Q}{k} = 3.4\ k\Omega$$

Bandpass 10:
When the center frequency, $F_o = 20\ kHz$

$$\text{Let } C19 = C20 = 0.001\ \mu F$$

$$k = 2\pi F_o C = 1.26\ \times 10^{-4}$$
$$R28 = \frac{1}{H \times K} = 8\ k\Omega$$
$$R29 = \frac{1}{(2Q-H)k} = 8\ k\Omega$$
$$R30 = \frac{2Q}{k} = 16\ k\Omega$$

Once all the component values for the capacitors and resistors have been found we can proceed to simulate each bandpass filter in LTSpice to obtain each frequency response and determine the low and high frequencies of each bandpass frequency response.

The desire center frequencies for each bandpass has been discuss we can proceed to LTSpice and simulate each bandpass. Once the center frequency has been found using the cursor provided in the simulation, we can navigate this cursor to -3dB. Take note that we must consider the magnitude present at the center frequency. This magnitude present at the center frequency is the magnitude consider finding the low corner frequency and high corner frequency. By adding -3dB per decade we can determine each low and high frequency.

The following table, Table 1 provides all the value components for the 10-band equalizer, as we as some additional information that will be further discuss under simulations.

Bands	fo	fl	fh	Q	A	BW
1st	20.1 Hz	11.9 Hz	33.3 Hz	1.02	0.5	21.4
2nd	43 Hz	26.37 Hz	75.23 Hz	1.02	0.5	48.86
3rd	93 Hz	56.9 Hz	154.2 Hz	1.02	0.5	97.3
4th	200 Hz	119.8 Hz	333 Hz	1.02	0.5	213.2
5th	430.8 Hz	231.8 Hz	719.02 Hz	1.02	0.5	487.22
6th	928.1 Hz	573.3 Hz	1.53 kHz	1.02	0.5	956.7
7th	2 kHz	1.21 kHz	3.33 kHz	1.02	0.5	6020
8th	4.3 kHz	2.74 kHz	7.23 kHz	1.02	0.5	4490
9th	9.28 kHz	5.73 kHz	15.3 kHz	1.02	0.5	9570
10th	20.2 kHz	11.6 kHz	33.9 kHz	1.02	0.5	22300

TABLE 1: 10-BAND EQUALIER DESIGN PARAMETERS

All the component values for the 10-band equalizer circuit are provided in Table 1. By recalling [eq0], we can perform the transfer function for each individual bandpass filter. The transfer function equation will lead us to the following transfer function results for each bandpass.

Bandpass 01 TF: $\frac{61.9s}{s^2+123.8s+15.9E03}$

Bandpass 02 TF: $\frac{132.4s}{s^2+264.8s+72.9E03}$

Bandpass 03 TF: $\frac{286.4s}{s^2+572.8s+34.14E04}$

Bandpass 04 TF: $\frac{615.9s}{s^2+1232s+1.57E05}$

Bandpass 05 TF: $\frac{1326.8s}{s^2+2653s+7.32E05}$

Bandpass 06 TF: $\frac{2858.5s}{s^2+5715s+34.05E06}$

Bandpass 07 TF: $\frac{6159.9s}{s^2+12319.9s+1.58E08}$

Bandpass 08 TF: $\frac{13243s}{s^2+26487s+7.3E08}$

Bandpass 09 TF: $\frac{28582.3s}{s^2+57164.6s+3.4E09}$

Bandpass 10 TF: $\frac{62277.4s}{s^2+124554.9s+1.61E10}$

C. Simulations

To understand the behavior of multiple feedback bandpass active filter a simulation on LTSpice can be simulated to obtain the frequency response of the bandpass filters. Building the circuit schematic using LTSpice components can make the simulation a lot easier and free of errors. By performing a transient analysis of each filter, we obtained the frequency response for these bandpass filters. Given an AC signal as an input and probing the output of the bandpass will result in the desire frequency response. The following images figures, Figure 6 through Figure 15 will provide the circuit schematic for bandpass 01 simulated in LTSpice. As a reference, Table 1 provides all the value components use for each MFB bandpass active filter.

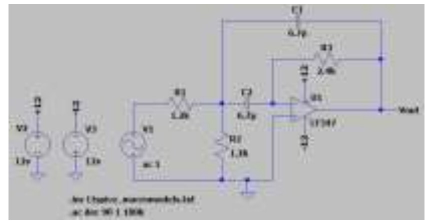

FIGURE 6: MFB BANDPASS 01 CIRCUIT SCHEMATIC

The desire center frequency for the first bandpass filter is of 20 Hz, by simulating the circuit schematic in LTSpice we obtained the following frequency response.

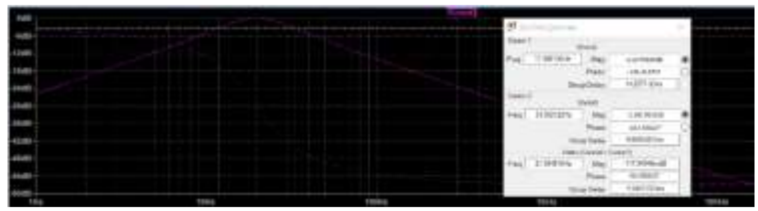

FIGURE 6A: MFB BANDPASS 04 FREQUENCY RESPONSE

This frequency response shows the low corner frequency and high corner frequency of the first bandpass for the equalizer, the $F_{Low} = 11.908\ Hz$ and $F_{High} = 33.302\ Hz$ while the $F_{Center} = 20.01\ Hz$.

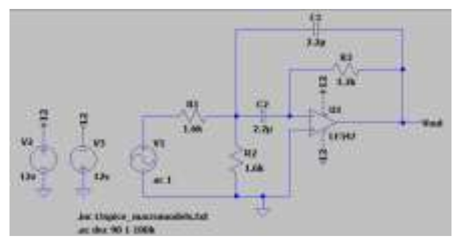

FIGURE 7: MFB BANDPASS 02 CIRCUIT SCHEMATIC

The desire center frequency for this bandpass filter is of 43 Hz, by moving around the cursor on the frequency response simulation we can see that the $F_{Low} = 26.364\ Hz$ while the $F_{High} = 75.232\ Hz$ and the simulated center frequency of $F_{Center} = 43.321\ Hz$.

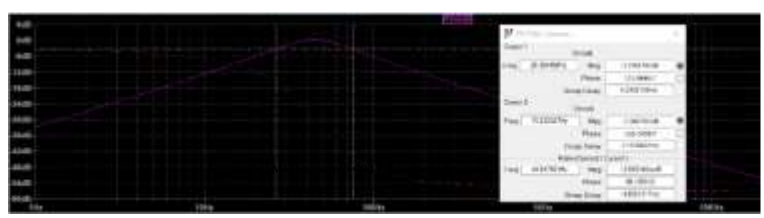

FIGURE 7A: MFB BANDPASS 02 FREQUENCY RESPONSE

The desire center frequency for the third bandpass filter is of 93 Hz, Figure 8. By finding its magnitude and adding -3dB we can find the low and high frequency of the frequency response.

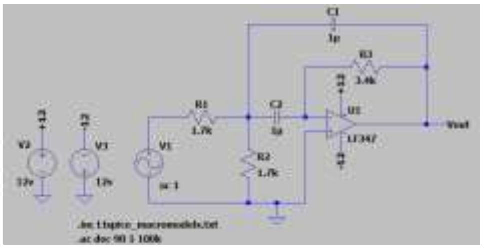

FIGURE 8: MFB BANDPASS 03 CIRCUIT SCHEMATIC

Cursor 1 provides the $F_{High} = 154.24\ Hz$ while Cursor 2 provides the $F_{Low} = 56.99 Hz$ and the simulated center frequency $F_{Center} = 93.012\ Hz$.

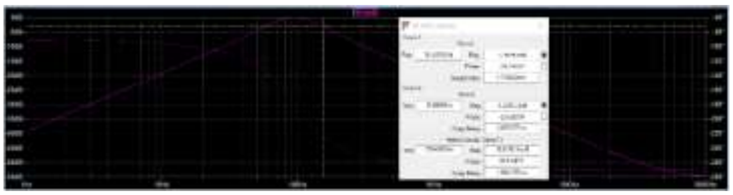

FIGURE 8A: MFB BANDPASS 03 FREQUENCY RESPONSE

For the fourth bandpass filter the desire frequency is of 200 Hz, Figure 9. All the calculated component values have been implemented in the simulation providing a center frequency of $F_{Center} = 200.1\ Hz$. Cursor 1 provides the $F_{Low} = 119.853 Hz$ and Cursor 2 provides $F_{High} = 333.021\ Hz$, refer to Figure 9.

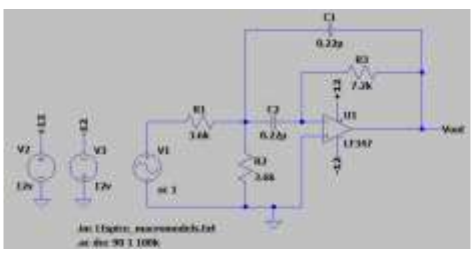

FIGURE 9: MFB BANDPASS 04 CIRCUIT SCHEMATIC

The following image figure, Figure 9a provides the frequency response discuss above for the fourth bandpass filter.

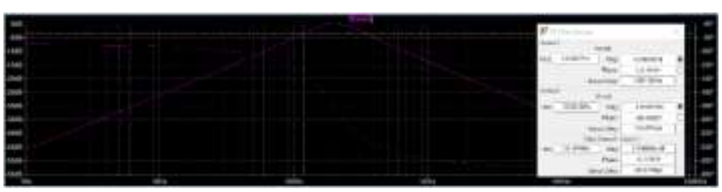

FIGURE 9A: MFB BANDPASS 04 FREQUENCY RESPONSE

For the fifth bandpass filter the desire frequency is of 430.8 Hz, Figure 10. All the calculated component values have been implemented in the simulation providing a center frequency of $F_{Center} = 430.05\ Hz$. Cursor 1 provides the $F_{Low} = 231.82 Hz$ and Cursor 2 provides $F_{High} = 719.021\ Hz$.

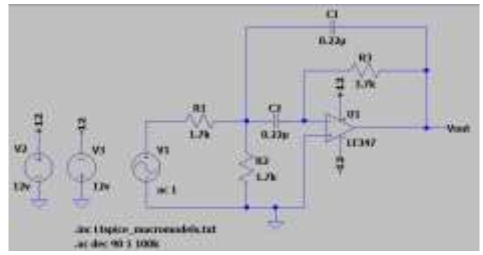

FIGURE 10: MFB BANDPASS 05 CIRCUIT SCHEMATIC

The following image figure, Figure 10a provides the frequency response discuss above for the fifth bandpass filter.

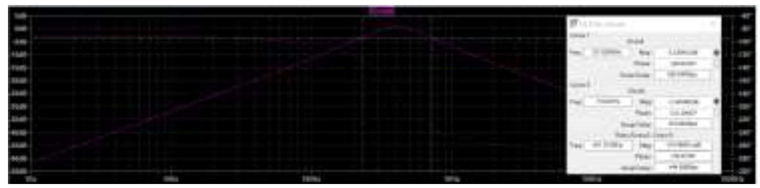

FIGURE 10A: MFB BANDPASS 05 FREQUENCY RESPONSE

The desire center frequency for the sixth bandpass multiple feedback filter is 928.1 Hz, refer to Figure 11. After running the simulation and finding the center frequency at the frequency response we can observe that the simulated center frequency, $F_{Center} = 928.3\ Hz$, while the simulated low frequency can be seen in the picture below and its represented in the first cursor of the frequency response the value for this frequency is $F_{Low} = 573.35\ Hz$, the second cursor shows the high frequency for the sixth bandpass and it's in the $F_{High} = 1.532\ kHz$.

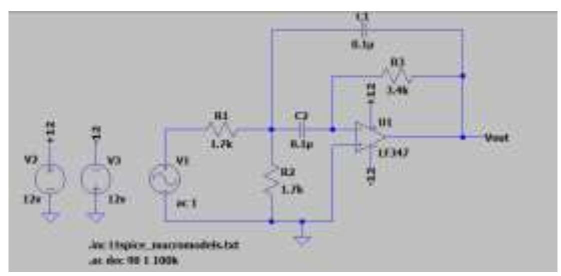

FIGURE 11: MFB BANDPASS 06 CIRCUIT SCHEMATIC

The following image figure, Figure 11a provides the frequency response discuss above for the sixth bandpass filter.

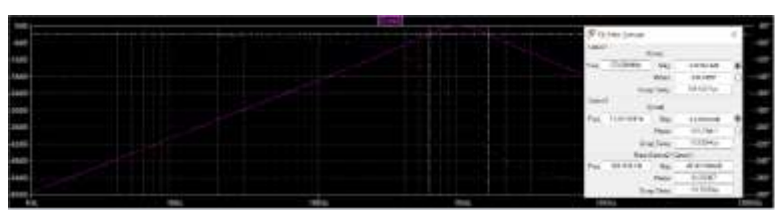

FIGURE 11A: MFB BANDPASS 06 FREQUENCY RESPONSE

The seventh bandpass of the equalizer had different value components for the capacitors and resistance, these value components produce a center frequency of 2 kHz, Figure 12. By simulating this bandpass filter, we can be able to examine the low and high frequency response for this specific bandpass. The simulated low frequency is $F_{Low} = 1.21\ kHz$ and its shown below in the first cursor. From the picture below we can also see that the high frequency of this frequency response is $F_{High} = 3.33\ kHz$ and it is portrayed in the second cursor of the frequency response.

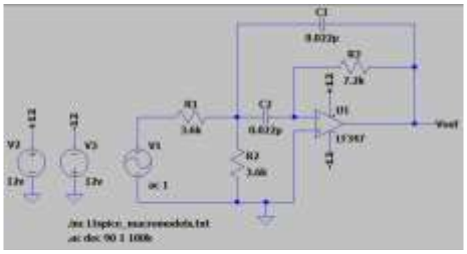

FIGURE 12: MFB BANDPASS 07 CIRCUIT SCHEMATIC

The following image figure, Figure 12a provides the frequency response discuss above for the seventh bandpass filter.

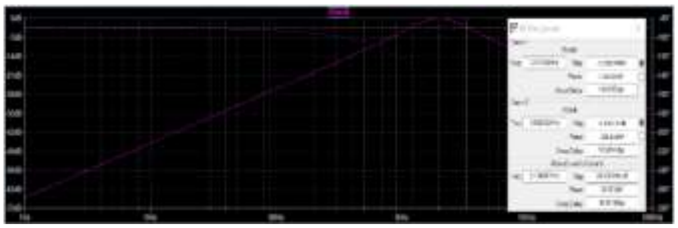

FIGURE 12A: MFB BANDPASS 07 FREQUENCY RESPONSE

For the eight bandpass filter the desire frequency is of 4.3 kHz, Figure 13. All the calculated component values have been implemented in the simulation providing a center frequency of $F_{Center} = 200.1\ Hz$. Cursor 1 provides the $F_{Low} = 2.74\ kHz$ and Cursor 2 provides $F_{High} = 7.23\ kHz$

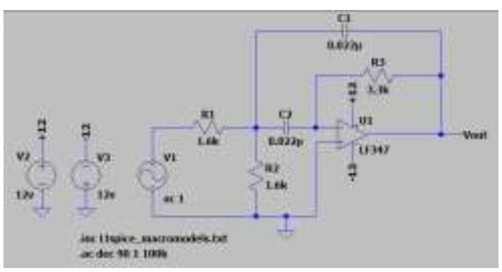

FIGURE 13: MFB BANDPASS 08 CIRCUIT SCHEMATIC

The following image figure, Figure 13a provides the frequency response discuss above for the eight bandpass filter.

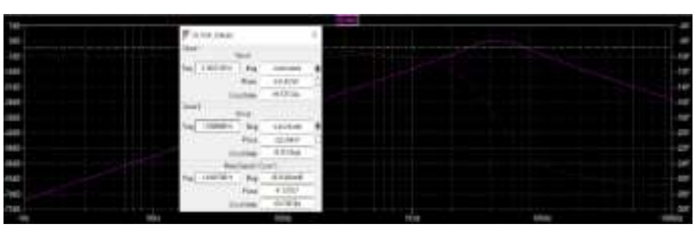

FIGURE 13A: MFB BANDPASS 08 FREQUENCY RESPONSE

For the ninth bandpass filter the desire frequency is of 9.28 kHz, Figure 14. All the calculated component values have been implemented in the simulation providing a center frequency of $F_{Center} = 9.1851\ kHz$. Cursor 1 provides the $F_{Low} = 5.733\ kHz$ and Cursor 2 provides $F_{High} = 12.324\ kHz$.

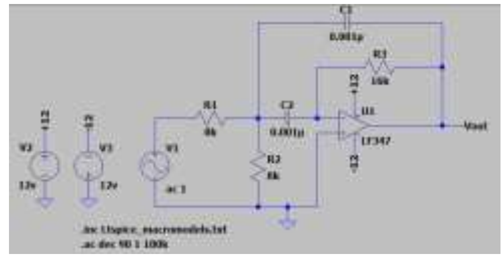

FIGURE 14: MFB BANDPASS 09 CIRCUIT SCHEMATIC

The following image figure, Figure 14a provides the frequency response discuss above for the eight bandpass filter.

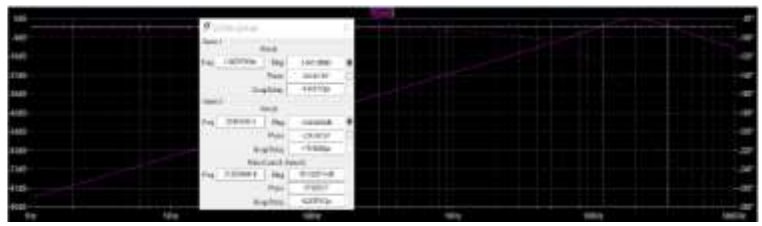

FIGURE 14A: MFB BANDPASS 09 FREQUENCY RESPONSE

The tenth bandpass of the equalizer had different value components for the capacitors and resistance, these value components produce a center frequency of 20 kHz, Figure 15. By simulating this bandpass filter, we can be able to examine the low and high frequency response for this specific bandpass. The simulated low frequency is $F_{Low} = 11.603\ kHz$ and its shown below in the first cursor. From the picture below we can also see that the high frequency of this frequency response is $F_{High} = 33.95\ kHz$ and it is portrayed in the second cursor of the frequency response.

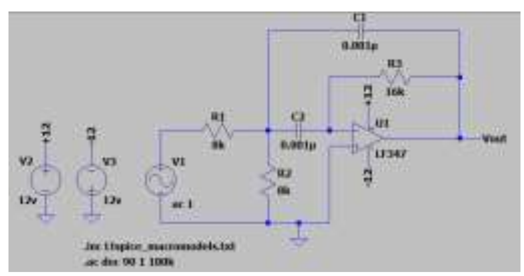

FIGURE 15: MFB BANDPASS 10 CIRCUIT SCHEMATIC

The following image figure, Figure 15a provides the frequency response discuss above for the eight bandpass filter.

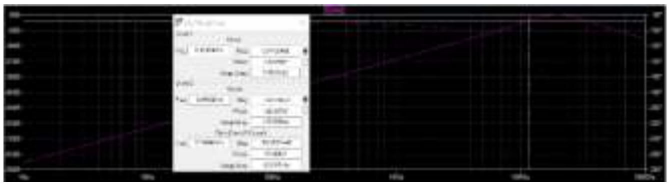

FIGURE 15A: MFB BANDPASS 10 FREQUENCY RESPONSE

To build and simulate the 10-band equalizer circuit we can consider all the previous discuss bandpass filters, we can also refer to Figure 5. By connecting each one of them in parallel to one another we can achieve an audio equalizer from the 20 Hz to 20 kHz frequency range. Each bandpass filter has its appropriate components values to cover the human ear frequency range.

The following image figure, Figure 5a provides the frequency response discuss above for the 10-band equalizer circuit. By probing the output of the summing op amp, the frequency response obtained is the summation of all frequency response discuss from Figure 6 to Figure 15.

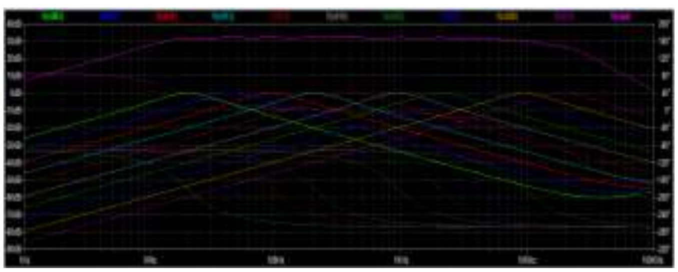

FIGURE 5A: 10-BAND EQUALIZER FREQUENCY RESPONSE

This image figure, Figure 5A provides the frequency response of the 10-band equalizer, while the pink line is the summation of each bandpass filter forming a wide bandpass for the equalizer system. To add all the bandpass filter for the equalizer a summing op amp is added into the 10 bandpass output. This will provide the pink frequency response observe in the image below.

D. Materials

The following table: Table 2, will provide the list of components use to build the 3-band equalizer. Some of the materials needed some adjustments. The audio input jack pin was to small, this did not let the input signal to reach the circuit equalizer. By soldering cables into the pins of the audio input we were able to let the circuit have an appropriate signal. The soldering for the audio input had to be done for both the input jack and the output jack.

Components	Part specification	Quantity
Resistors	Refer to table 1	13
Capacitors	Refer to table 1	6
Operational Amplifier	LF347	2
Potentiometer	10 kΩ linear potentiometer	3
Breadboard Audio Jack	3.5 mm jack input	2
PowerBrick	+12 V power supply	1
Speaker	YSFCTSPPU Multimedia Speaker	1
Auxiliary cable	Normal media aux cables	2
Breadboard	WB-104-1	1

TABLE 2: LIST OF COMPONENTS NEEDED TO BUILD THE 3-BAND EQUALIZER

III. 3-BAND EQUALIZER EXPERIMENTAL PROCEDURE

This experimental procedure involves a circuit topology very similar to the one discusses before. The exemption for this experimental is that the equalizer uses a 3-Band active filter equalizer; and that we are using three potentiometers. The three different pots would be the input resistors for the non-inverting summing op amp. This will let us adjust the gain of each bandpass filter.

In this section we will discuss similar procedure such as finding the component values for each filter, simulation, and the actual circuit implementation for the 3-band equalizer circuit.

The Figure 2 provides the multiple-feedback bandpass active filter use in the 3-band equalizer build in this experiment. To build a 3-band equalizer we are going to need three circuit configurations of the MFB circuit. Each MFB circuit provides a nominal center frequency of 43 Hz, 470 Hz, and 5.5 kHz. Each of the BPFs should have a nominal quality factor of 1.5 ± 10%. The overall voltage gain is adjustable between 0.4 and 8 for the bass band, centered frequency at 43 Hz, a 0.2 and 4 for the midrange band, centered at 470 Hz, and a 0.1 to 2 for the treble band centered at 5.5 kHz. This idea is slightly different from the 10-Band EQ simulation; were we had a quality factor of 1 for all active filters. By providing this quality factor of 1.5, we saw a different outcome for the frequency response for each bandpass filter. This approach gave better simulation results for the 3-band equalizer.

Using equations eq0, eq1, eq2, and eq3 we can conclude each capacitor value and resistor value, refer to table 4.

Something learned through experimenting with the component values for a desire frequency response for a bandpass filter was that one can set the center frequency, Quality factor, and maximum gain at the center frequency.

Bands	fo	fl	fh	Q	A	BW
1st	43	30 Hz	63.12 Hz	1.5	3.33E+06	30.12 Hz
2nd	470	337 Hz	657.6 Hz	1.5	2.98E+06	320.6 Hz
3rd	5000	7070 Hz	14402 Hz	1.5	2.53E+08	7332 Hz

TABLE 3: 3-BAND EQUALIER DESIGN PARAMETERS

Bands	R1	R2	R3	Capacitor
1st	3.70E+03	1.80E+03	1.10E+04	1.00E-06
2nd	3.50E+03	1.70E+03	1.00E+04	1.00E-07
3rd	3.18E+04	1.59E+04	9.54E+04	1.00E-09

TABLE 4: 3-BAND EQUALIER DESIGN SPECIFICATION

By choosing the capacitors to be equal, we are giving up the ability to independently choose the gain at the center frequency of each band. Something else to consider is that this filter design is driven by low impedance source for accuracy, therefore we need to place a potentiometer in front of each bandpass before adding all the filters into a buffer. By having this in mind we can consider the 4th operational amplifier as an inverting summer after all these stages, this will provide independent gain controls for the three channels. The three potentiometers would be the input resistors for this summing stage, connected as variable resistors. Refer to Figure 16 for a better comprehension of all three active filter stages following through a summing inverting op amp with potentiometers as input resistors.

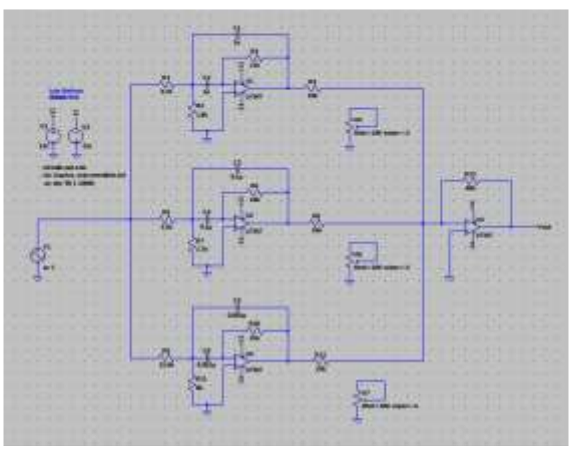

FIGURE 16: 3-BAND EQ CIRCUIT SCHEMATIC

All the component values for the 3-band equalizer circuit are provided in Table 4. By recalling [eq0], we can perform the transfer function for each individual bandpass filter. The transfer function equation will lead us to the following transfer function results for each bandpass.

Bandpass 01 TF: $\frac{61.9s}{s^2+123.8s+15.9E03}$

Bandpass 02 TF: $\frac{132.4s}{s^2+264.8s+72.9E03}$

Bandpass 03 TF: $\frac{286.4s}{s^2+572.8s+34.14E04}$

Figure 16A provides the actual circuit topology use to implement the 3-band equalizer. As we can see from this figure is that we are adding three different potentiometers. By simulating each individual band pass filter, we can conclude that our simulated center frequencies match our calculated center frequencies. The following figure provide just that, each bandpass frequency response with their center frequencies.

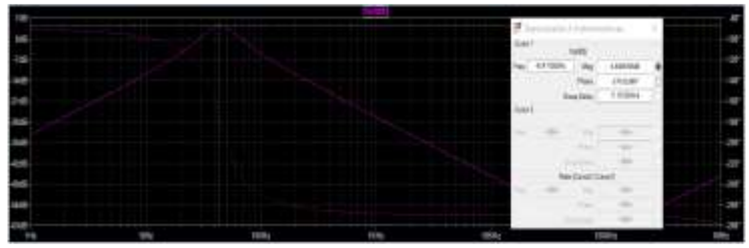

FIGURE 16A: 3-BAND EQUALIZER FREQUENCY RESPONSE FOR BAND 01 WITH CENTER FREQUENCY OF 43 HZ

Figure 16B, provides the frequency response of the first bandpass filter; it shows the center frequency to be 470.13 Hz. This frequency response is under the bass band of the equalizer. This means that by moving the wiper from the potentiometer we would be able to manipulate the bass sound from the input signal or music signal.

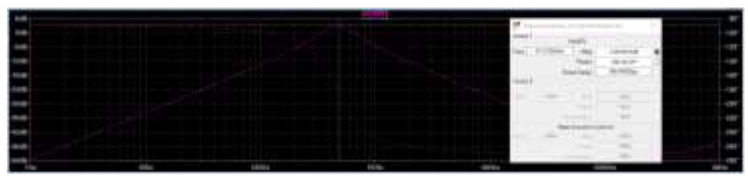

FIGURE 16A: 3-BAND EQUALIZER FREQUENCY RESPONSE FOR BAND 02 WITH CENTER FREQUENCY OF 470 HZ

This figure provides the frequency response for the second bandpass filter. Figure 16C, gives an insight for the frequency response for the second filter. It shows that the center frequency is at around 5.5 kHz, which means that this filter is in the midrange band.

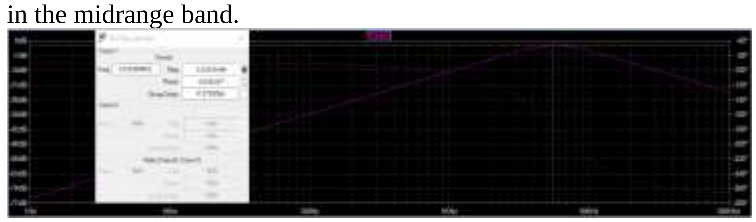

FIGURE 16C: 3-BAND EQUALIZER FREQUENCY RESPONSE FOR BAND 03 WITH CENTER FREQUENCY OF 5.5 KHZ

The actual experiment consisted in implementing Figure 16 on a breadboard. The input signal will be provided from an electronic device such as a computer or a smartphone. This input signal comes in the form of music and by connecting a speaker at the output of the equalizer we will experiment the effects of the 3-band equalizer on the input music signal.

The first step to build the equalizer was to find all the resistors and capacitors values shown in Table 4. Once all the component values have been found we can connect all its resistors in their individual op amp provided by the LF347 microchip. The first bandpass filter was connected in the op amp 3 from the connection diagram of the LF347 provided in Figure 17.

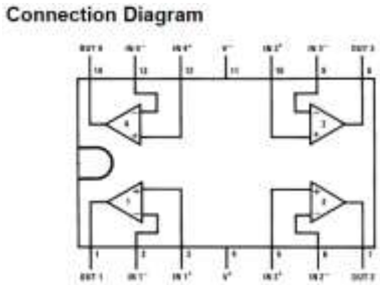

FIGURE 17: LF347 OPERATIONAL AMPLIFIER CONNECTION DIAGRAM

Note that pin 11 and pin 4 provided power to the op amp, where this power comes from the power brick of 12V. The following image, Figure 18 provides an actual picture of how resistor 1 and resistor 2 are connected into pin 9 of the LF347 microchip.

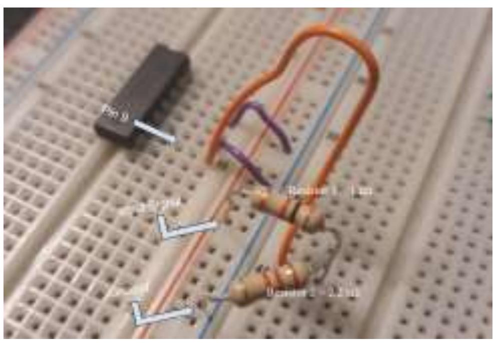

FIGURE 18: RESISTOR INPUTS FOR THE INVERTING INPUT OF LF347

Figure 18, provides an insight of how each bandpass will be recreated to build the full equalizer. The first two resistors are connected into the inverting input signal of the op amp. This figure demonstrates just that. The following image will provide the full active filter implementation. This procedure has been repeated two more times to build the 3-band equalizer.

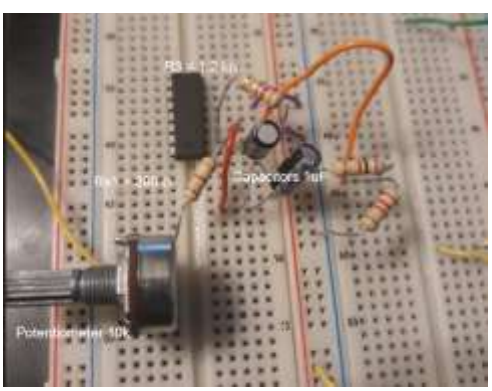

FIGURE 19: FULL FIRST MFB ACTIVE BANDPASS FILTER CIRCUIT IMPLEMENTATION

Figure 19 provides the full first bandpass filter, this filter produces a center frequency of 43 Hz with the help of the linear potentiometer we can adjust the band to a desireble output. Figure 18 and Figure 19 provide an idea of how the other 2 bandpass filter will be connected. The following images will provided how each bandpass filter have been implemented on the circuit breadboard.

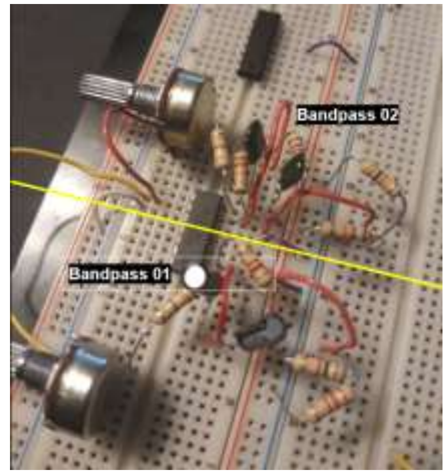

FIGURE 20: FULL FIRST MFB ACTIVE BANDPASS FILTER CIRCUIT IMPLEMENTATION

Figure 20 provides the actual circuit implementation for the first two bandpass. Bandpass 01, has been discuss in Figure 18 and Figure 19. The yellow line divides the two filters from each other. As we can see from this figure is that two input resistors for bandpass 02 are connected to pin 13 from the LF347, refer to the connection diagram on Figure 17.

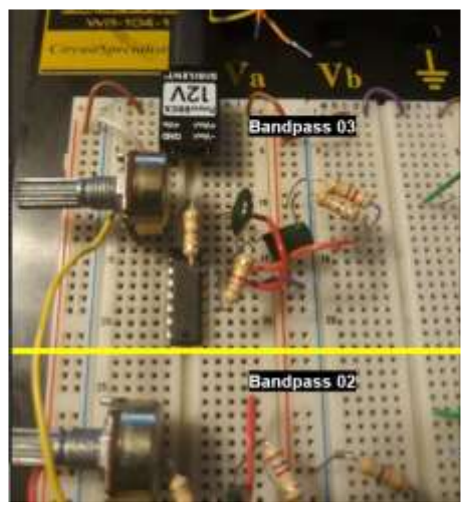

FIGURE 20: : BANDPASS THREE ON A SINGLE LF347 OP AMP CHIP

Figure 20 provides the last bandpass active filter needed to build the 3-band equalizer. This last MFB bandpass filte provides a center frequency of 5.5 kHz. One of the last things to consider when building this equalizer is to give power to the operational amplfiers, we can see from Figure 17 that the connection pins to power the op amps are pin 11 for a negative voltage of -12 V and pin 4 for a positive voltage of +12 V. Another thing to consider is to connect all the output cables into an inverting summin op amp. Figure 21, will provide the full 3-band equalizer connected into the summing op amp. For this summing op amp we are using op amp 1 from the first

LF347 used for bandpass one and two. The output for the summing op amp was connected to a speaker were we would be able to apreciate the adjustable bandpass filters provided by the equalizer.

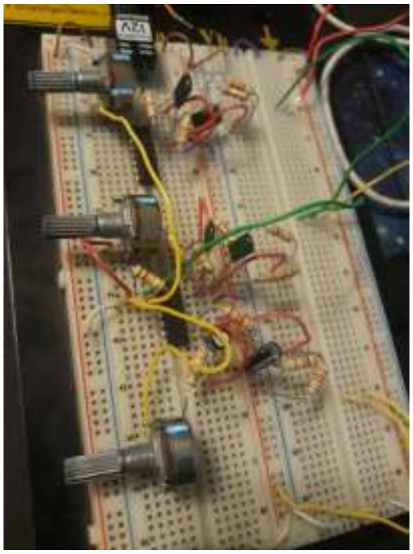

FIGURE 21: 3-BAND EQUALIZER USING MFB CIRCUIT TOPOLOGY

Figure 21 shows the full 3-band equalizer, the output is connected to a speaker and signal is coming from the computer. After connecting the M2k to the equalizer circuit we were able to determine the input and output oscilliscope traces. The input signal comes in the form of a sinewave and the output signal is a square wave. In the following section images will provided the oscilliscope traces for the input and output signals of the equalizer.

A. *Results*

Unfortunately, the results provided in this section are not right. This is because when I first built the 3-band equalizer some problems with the speaker were present. The video that will be provided demonstrates functioning equalizer with low quality sound. I tried to fix this problem with several methods and by trying to fix it I accidentally made it worse.

However, I tried different stuff and recorded my attempts and will be submitted as well as the figure provided in this section give an insight of my failed attempts.

Figure 22 provides the sine wave input signal yellow line and the purple square wave signal which is the output for the equalizer. A video will be submitted provided a live experiment on the equalizer. Everytime one of the potentiometers as been turn the output signal (squarewave) moves either making it narrower, wider, or thinner. The video will provided a better insight of the output behaviour once the potentiometers are wiped.

Figure 22: Input and Output oscilliscope traces for the 3-band equalizer

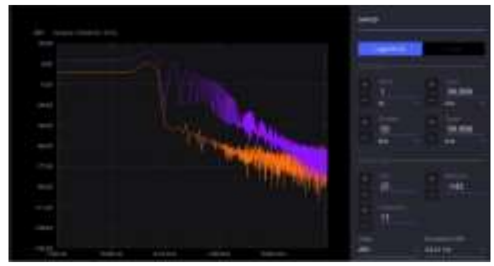

FIGURE 23: PROVIDES THE SPECTRUM ANALYZER OF THE 3-BAND EQUALIZER

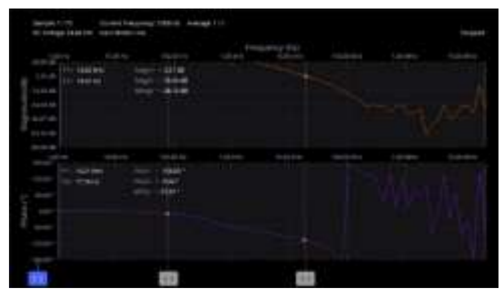

FIGURE 24: PROVIDES THE MAGNITUDE AND PHASE RESPONSE OF THE 3-BAND EQUALIZER

IV. CONCLUSION

Some of the obstacles face during the experimental procedure was giving an amplification for the output signal. Even though the equalizer does work, and we can adjust the filters for sound equalization, the output signal is too low. This can be because of the wattage of the speaker. A guess will be that the op amps use in the equalizer cannot produce sufficient current to take on the speaker. A solution for this problem can be to add a transistor amplifier to the end of the summing op amp. This way the transistor can handle a lot of current and perhaps give a better and high output. A video will be provided demonstrating the functionality of the equalizer, note that this second video demonstrates how the equalizer works but the speaker is too low to hear it clearly. Building a transistor or an inverting amplifier may help with the low volume produce at the speaker.

Somethings to notice from this report is that Figure 18 and Figure 19 provides the actual MFB bandpass active filter. The resistors provided in these images are from a past circuit implementation.

The results obtained from the M2k device are not correct. Even though we get some tweaking output signals by swiping the potentiometer knobs. The results were not as expected. The results provided below Figures 22, 23 and 24, are images from failed attempts to recreate the first 3-band circuit, that is on the video. One of the main problems with the video that is going to be submitted is that the volume is very low. Because of this, there are several things to improve the design.

First, we can try the basic stuff for improvements, trouble shooting the circuit by checking grounds, signal inputs, and making sure resistors and capacitors are not touching each other. Second improvement for the 3-band equalizer is to add a simple transistor amplifier at the end of the summing stage or the output of the equalizer. This addition of a transistor amplifier will be provided sufficient current to the speaker and giving a better sound quality. Next, another solution for this problem is to look for a better speaker that is more suitable for the equalizer parameters. Finally, another way to fix this problem is to go back and double check resistors and capacitors values; making sure all the connections are properly connected.

This final "solution" brought more problems, first all figure from 22 through 24 are the results of failed attempts. The results obtained by recreating the equalizer were not has positive has the first equalizer built. Which is the equalizer presented in the video.

From the video we can hear that the last potentiometer closer to the PowerBRICK has a center frequency of 5.5 kHz. This is important because it is one of the most notable bands that can be heard from the demonstration demo of 3-Band equalizer.

Another detail is that the quality for the simulation is not the same has the implementation. In the begging my simulation mid bands were quite larger. I tried to play a little with the quality factor hoping to bring a better result for the equalizer. By changing the quality factor all capacitors and resistor values changed. Therefore Table 4 and the values for the 10-Band simulation are not the same component values.

REFERENCES

[1] *Active Band Pass Filter - Op-amp Band Pass Filter*. Basic Electronics Tutorials. (2018, February 10). https://www.electronics-tutorials.ws/filter/filter_7.html.

[2] Administrator. (2019, February 26). *Active Band Pass Filter Circuit Design and Applications*. Electronics Hub. https://www.electronicshub.org/active-band-pass-filter/.

[3] Administrator. (2019, February 26). *Active Band Pass Filter Circuit Design and Applications*. Electronics Hub. https://www.electronicshub.org/active-band-pass-filter/.

[4] Engineer), R. T. (E. (2021, April 23). *Inverting and Non Inverting Summing Amplifier: Voltage Adder*. Electronics Hub. https://www.electronicshub.org/summing-amplifier/.

[5] Michael Hahn is an engineer and producer at Autoland and member of the swirling indie rock trio Slight. (2020, December 21). *EQ 101: Everything You Need to Know About Equalization*. LANDR Blog. https://blog.landr.com/eq-basics-everything-musicians-need-know-eq/.

[6] Multiple Feedback Bandpass Filter. (n.d.). http://www.ecircuitcenter.com/Circuits/MFB_bandpass/MFB_bandpass.htm.

[7] Rod Elliott - Elliott Sound Products. (n.d.). Multiple Feedback Bandpass Filter. https://sound-au.com/project63.htm.

[8] Wikimedia Foundation. (2021, May 10). *Band-pass filter*. Wikipedia. https://en.wikipedia.org/wiki/Band-pass_filter.

[9] Wikimedia Foundation. (2021, May 3). *Equalization (audio)*. Wikipedia. https://en.wikipedia.org/wiki/Equalization_(audio).