Five Band Equalizer

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Table of Contents

List of Figures

List of Tables

I. Introduction:

The objective of this project is to build a five-band equalizer. The equalizer is a hardware filter intended to adjust the volume of specific frequencies of an audio signal. The adjustment works on the audio supply by either increasing or cutting off certain frequency ranges. The purpose of an equalizer is to make the sound louder or softer by varying the notes, or it can keep the same sound of the original.

II. Problem Definition:

The project goal is to design a five-band equalizer. In the first stage, the equalizer has an audio input, which goes through filtering circuits, and each band of the filter has an output that can cut or boost the high and low ranges. In the second stage, the result of summing the signals comes to the output jack, which is connected to a pair of speakers or headphones. To have a more professional and customizable sound, the equalizer provides control of 5 bands to accommodate for the wide range of human hearing spectrum.

A. Background:

To enhance the manufacturability of the high-quality equalizer which can be used in large volumes in cars audio systems, the design of the circuit had to be very easy to build. It gives tone adjustment, which is not exposed by standard treble, midrange, and bass controls. Also, it is combined with portable components like: stereos, tape-recorders, car stereos, radio-cassette recorders, etc.

The basic concept of an equalizer, when applied with an analog circuit board, is to divide the spectrum into different bands, then each band consists of a band-pass filter. The sound comes through all the filters in parallel, and each band-pass filter will output only the sound within its band, cutting off all the others. At that point, it mixes the outputs of all the band-pass filters together again, but then puts them in a circuit with the ability to adjust the amplitude of each first.

B. Client Requirements:

- Operate on frequencies from 0 – 16 kHz
- Filter audio output
- Boost or cut the frequency ranges defined in each band
- Drive a pair of headphones or a set of speakers
- Low cost

The product should be safe, free of static hazards. It must be able to interface with an audio jack and an amplifier, and should be mechanically stable enough to support plugging and unplugging cables, and to be able to be turned on and off via stomp switches. All knobs, buttons, and externally adjustable parts should be in logical positions and should be easy to adjust. The purpose of this device is to serve as a music equalizer with good functionality. In addition, it must have true bypass circuitry to prevent signal loss when the equalizer is off. The product price should be comparable to the prices of analog equalizers of similar style.

III. Project Solution:

To implement the design of the project and to create a working device, it is the object to tweak certain components of the design to help meet the main goals. The goals are as follows: to have a monophonic design, to have the audio range operating in the range of frequencies between 0 – 16 kHz, to boost or cut certain frequency ranges, to have complete gain control, and to have the ability to operate with a pair of headphones or speakers.

The first step of the five-band equalizer design is for the input signal from the audio device to go immediately into the overall gain control. It is necessary to have overall gain control at the input stage to allow the equalizer to work even with small input signals coming from cell phones or small digital recorders. The gain stage then drives into the filter bank, which is considered as the main part of the equalizer. Also, note that the sliding potentiometers are combined into the filter bank as well to provide the cut and boost level of each band. All the five filters used in this design were bandpass two-pole filters and the center frequencies are discussed, and determined based on the audio range from 0-16 kHz. The outputs of all the filters are then recombined and used to drive a set of speakers or headphones. Figure 1 shows a diagram of the overall filter components.

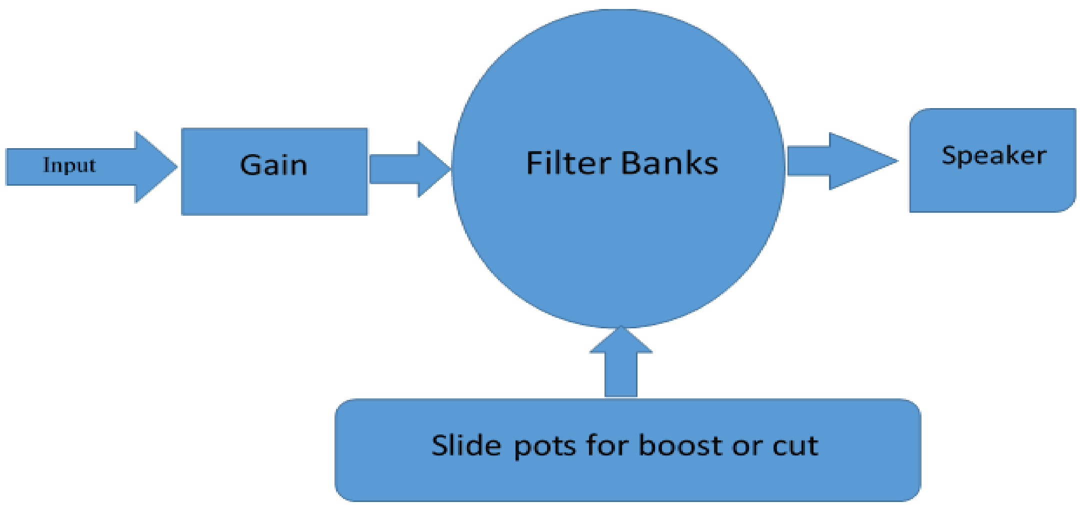


Figure 1. Block Diagram of Design

Building a five-band equalizer requires five separate filters, each with a different center frequency. The frequencies are based on industry standard values which are as follows: 60Hz, 250Hz, 1kHz, 4kHz, and 16kHz. Also, the five-band equalizer needs to utilize multiple feedback (MFB) bandpass filters. The circuit for this filter topology is shown in Figure 2.

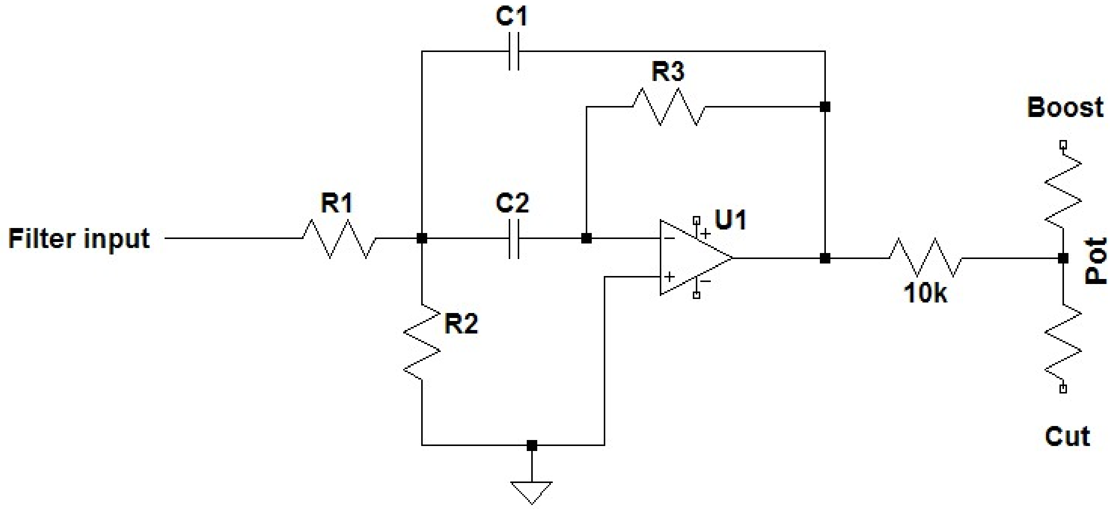


Figure 2 filter design

This design allows a bandpass filter to be made with only an operational amplifier. One disadvantage of the MFB filter is that the design equations can become tedious when calculating for a certain set of design parameters. The following formulas are used to calculate the component values and design parameters of each filter.

$R1 = Q / (G * 2 * \pi * f * C)$

$R2 = Q / ((2 * Q^2 - G) * 2 * \pi * f * C)$ $R3 = Q / (\pi * f * C)$

$G = 1 / ((R1 / R3) * 2)$

$f = (1 / (2 * \pi * C)) * \sqrt{((R1 + R2) / (R1 * R2 * R3)}$

To go through the equations, the required unity gain means (G=1), and the selected value for the capacitors are chosen to give reasonable values for the resistors. Table 1 shows the values calculated for the design of each band.

Table 1 Value for the Resistors and Capacitors

Centre frequency (Hz)	C (µF)	Ra (K - ohms)	Rb (K - ohms)	Rc (K - ohms)	Gain (A)	Quality (Q)
60	C4=C5=0.1	R9=11	R11=27	R10=91	4.1	1.7
250	C7=C8=0.1	R14=2.7	R15=6.3	R13=22	4.1	1.7
1000	C10=C11=0.047	R18=1.5	R19=3.3	R17=11	3.7	1.6
4000	C13=C14=0.0022	R22=7.5	R23=18	R21=63	4.2	1.7
16000	C16=C17=0.0022	R26=2	R27=4.3	R25=15	4.2	1.7

The table lists the component values for different center frequencies of the equalizer. The constant value 'Q' was set to 1.7 and the gain 'A' to 4. The circuit for the 5-band equalizer uses U1 LM833 as the buffer stage for the equalizer. It is a non-inverting amplifier with a gain of '2.' The input signal is divided by '2' by the resistive network comprising R1 and R2. After that the net gain of this amplifier is unity (1). Two 100k resistors (R3 and R11) are used as a voltage divider and the junction voltage is fed to its positive input through R14. This divider has enough power to feed all other op-amps directly.

Resistor Roy (R6=R8=R19=R23=R28=R15=R33=100Ω) has the dual function of noise reduction and resistive isolation of capacitive load. It may be varied between 50 and 150 ohms depending on the noise in the circuit. The potentiometers (R9, R20, R29, and R34) are in the signal path so these are should be of the best quality possible. The body of the pots was wrapped with bare copper wire and the other end of the wire was soldered to ground. Since the filters are very sensitive, all resistors used were metal-film type and the capacitors were ceramic type. Each stage of the op-amp was capacitively coupled to the next stage so that the DC does not get propagated and amplified. For a good low-frequency response, this coupling capacitor was chosen to be greater than 1 μF. A 10μF, 16V capacitor is used in each stage of the circuit here. The circuit is powered by a 12V DC regulated supply. The Vcc pin of each op-amp was grounded with a 0.1μF ceramic disk capacitor to bypass the noise. Decreasing the capacitor values increases the resistor values for any specific frequency and care was taken, especially when using multiple filters, that the resistor values were not too low to cause loading on the input op amp.

After the filters are arranged, each filter output was recombined to form the result overall output. The electronical total of the filters of the output is recombined together, taking into account the individual boot or cut gains of each specific filter. Two inverting summing amplifiers were used to recombine all the filter outputs. A slider potentiometer was used to feed the output of each filter section to the first summing amplifier for cutting or the second summing amplifier for boosting. Leaving the potentiometer in the middle results in an output that is neither cut or boosted.

Because we used the MFB bandpass filter, which is an inverting filter, the input into each of the filters needs to be inverted back by adding an inverter in series with the inputs of the filters. The final design can be seen in Figure 3.

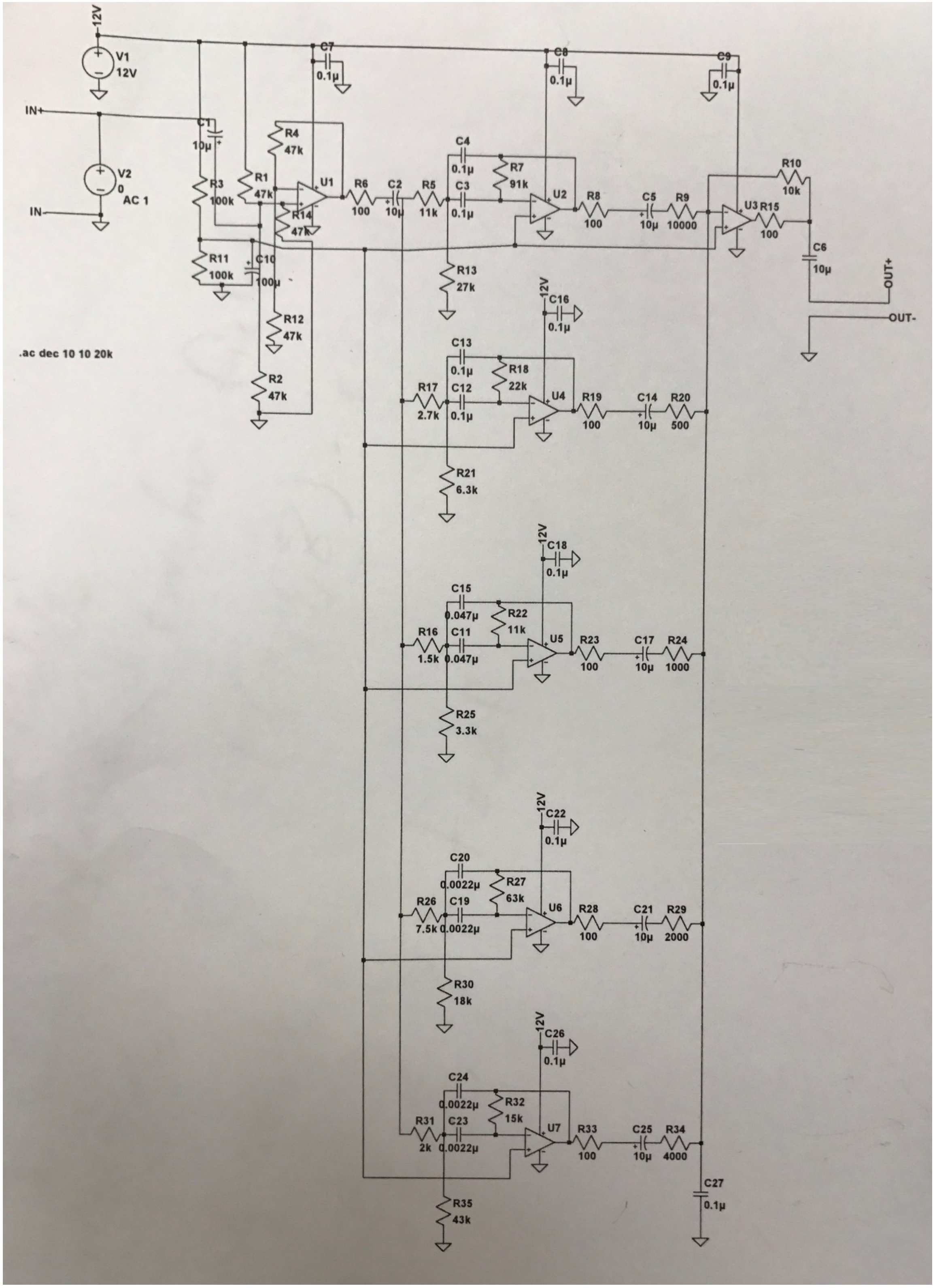


Figure 3 Final Design

This equalizer uses low-cost and good-quality op-amps. It is powered by a single voltage supply. The op-amp has a noise value of less than 24nV/√Hz, and the LM833 used in this circuit meets these requirements. Equalizer circuits typically divide the audio spectrum into separate frequency bands and each band has independent gain control. The output of each band is mixed at U3 and then fed to an audio power amplifier. Appropriate quality factor (Q) is selected to avoid overlap in adjacent bands as this introduces coloration into the audio signal.

Figure 4 shows the multiple-feedback bandpass filter topology.

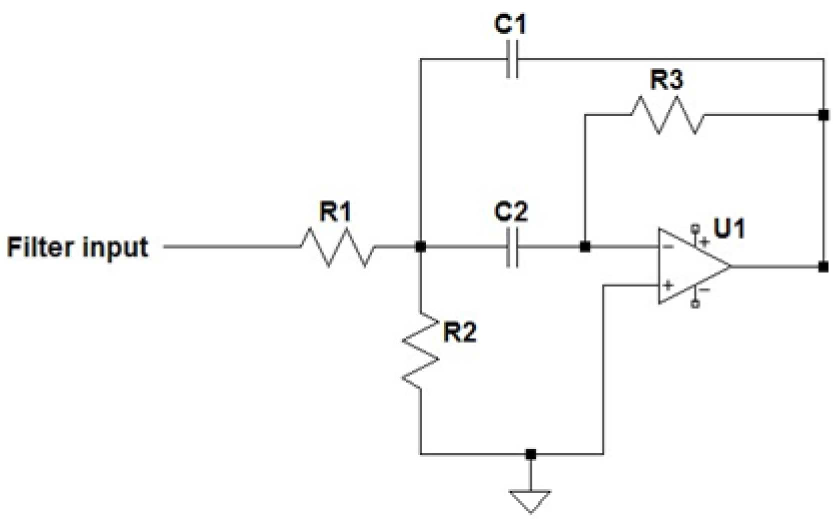


Figure 4: multiple-feedback bandpass filter

The calculations began by choosing a large value of capacitance (~0.1F) and smaller value of resistances. Increasing the capacitance decreased the resistance (R1, R2 and R3). Care was taken to avoid overloading on the input buffer op-amp. Note that stray capacitances on the board reduces the value of ‘C.’ The bandwidth and gain do not depend on R2. So, R2 can be used to modify the mid-frequency without affecting the bandwidth and gain. A balance between the number of filters and bandwidth was observed. It is possible to use a wider bandwidth and fewer filters, or narrower bandwidth and more filters. Anything narrower than 1/3 octave is rare, since the complexity of the filters increases for higher values of ‘Q.’ This can become expensive and limited of use for most applications in audio systems.

There are a few important things to note with the final circuit design. The topology used allows the cut and the boost to be symmetrical. The addition of the inverting amplifier at the beginning is added to meet the gain specification of 12 dB and sets the input impedance at 100 kΩ. The 500Ω feedback resistor shown in the circuit is a potentiometer and can be used as a volume control. The cut summing amplifier and the boost summing amplifier allow the input signal to pass-through with unity gain, although with a 180-degree phase shift. It is also worth noting that the inverting amplifier that feeds the filter inputs sets the overall cut and boost magnitudes. The feedback resistance of 500Ω allows a cut or boost of 12 dB. The following two graphs are computer simulations done in Linear Technology's LT-Spice, showing all bands under full boost and cut, respectively

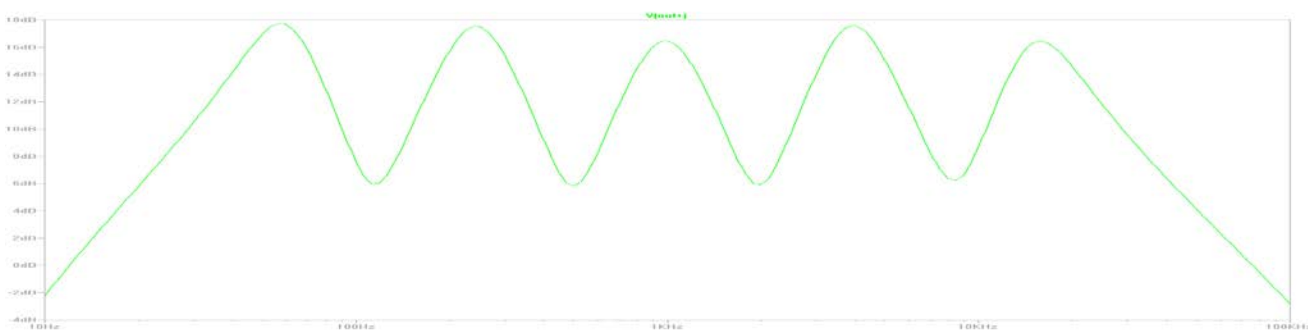


Figure 5: Simulation 1

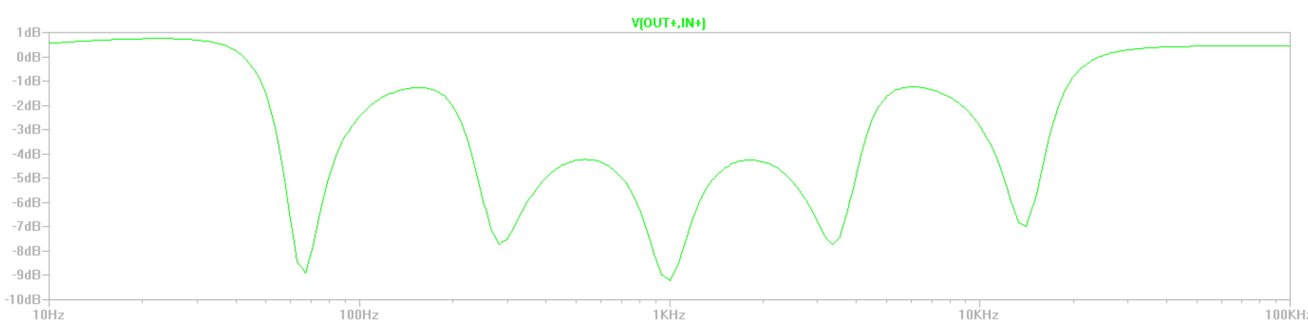
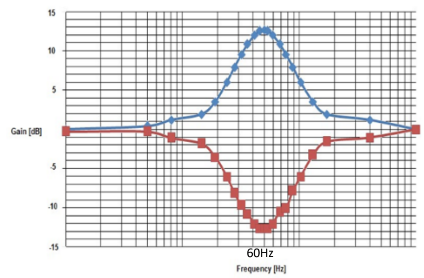
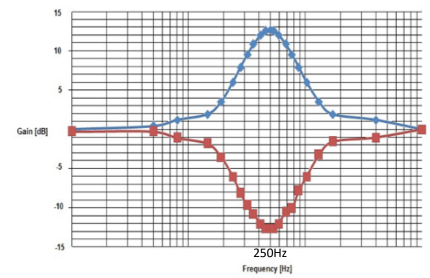


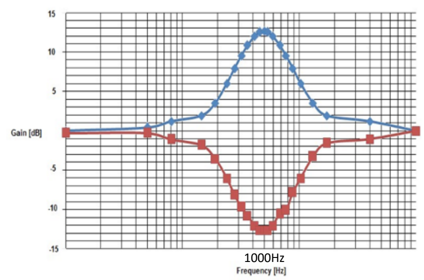
Figure 6: Simulation 2

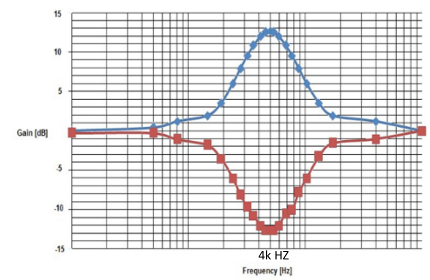
Table 7 shows the curves from the actual design from points showing the equalizer under full boost and the cuts that were measured with an oscilloscope under the same conditions that are described above.

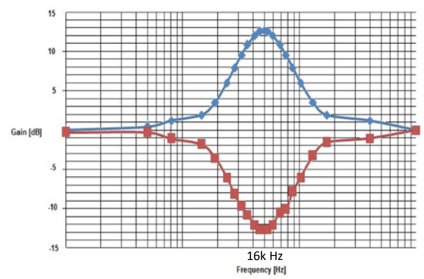
Table 7: actual design











A. Safety and Standards

The product meets the applicable functional safety standards and requirements, as the customer would expect the device will be safe. To consider environmental factors and comply with the IEEE Standard for Environmental Assessment, there is a rule called “protective grounding or physical isolation of non-current-carrying metal parts.” The 2007 NESC states that “all metallic guards including rails, screen fences, etc. about electric equipment shall be effectively grounded" (NESC, 39). To eliminate any static hazards to the user, the box was grounded from the inside. Also, the box edges will also be rounded to avoid sharp edges that could possibly be harmful to the user. Most potentiometers are made from plastic that is strong enough to handle being repetitively stomped on, and light enough to still be portable. It should be strong enough to support the input and output cables and stomp switches. Since the device is analog, it will consist only of analog components (resistors, capacitors, operational amplifiers, etc.). The signal from an audio jack will just start to clip to the voltage ranges between 0 to 5V. The NESC also states that components should be "of suitable voltage and ampere rating for the circuit in which they are installed," so it is a safe amount for usage, and it is easy to control the isolation (NESC, 63). The device should be user-friendly, with knobs placed in a logical configuration. Any stomp switches should be located on the bottom of the box facing the user. At the top of the box there are adjustable gain, volume, and tone knobs.

B. Cost:

Table 3: list of the costs of components needed to build the five-band equalizer.

NO.	components	Quantity	Total
1	Resistors	24	$2.00
2	Capacitors	9	$5.00
3	Potentiometers	5	$2.50
4	Op-amps(LM833)	2	$1.00
5	Perfboard	1	$9.85
6	Audio Jack	1	$6.00
7	Wires	-	$3.75
		Total	**$30.10**

The device should be competitively priced to succeed in the current market. It should be of equal price or cheaper than the combined prices of a five-band equalizer. Prices of comparable range between $50 and $86 of equalizers. The total cost of parts to build an equalizer was $30 to combine the required functions.

To meet the project expectations and requirements several components needed to be acquired. In order to lower the cost of the project and reduce the amount of requested fund, multiple components, such as resistors, wiring, and capacitors were obtained from the UE Electrical Engineering stockroom and from other old projects.

IV. Capabilities:

I have an appropriate background with analog work, because I have done this type of work in the digital system class EE 311. I have had an experience with the filtering sound project which filters the undesired noise. I have learned about how the filters are designed and manufactured, and the different filter types in linear systems class EE 310. Besides, I have personal interest in this field of devices that work to improve the sound. Also, I have access at the UE facilities to complete the work of this project.

V. Conclusion

The five-band equalizer project was successfully implemented. During the design process, I attempted to meet all the filter band requirements 60 Hz, 250 Hz, 1 kHz. 4 kHz, 16 kHz design in the original project requirements. Overall, the goal was met and was proven using a simulation I build in the Lt-spice, and the result was given correctly for both full boost and full cut. The final product was clear from noise and the output sound was smooth. The project was user friendly and the filter response was easy to adjust using the potentiometer. Also, some specifications of the project were improved, like using ceramic capacitors instead of electric capacitors to reduce noise. The final design of the five-band equalizer was developed and met all the requirements set by the instructor. The equalizer has a reliable performance and is able to deliver the necessary results under at all settings.

VI. References:

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Five band EQ
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