Design Project 21115/L

3ECE-A Group 1

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Abstract—**This paper discusses the design and operation of a tone control circuit, an essential audio equipment component that allows users to adjust the signal for the desired output tone. The paper begins with an overview of tone control, its importance, and its uses in the audio systems we have today. We then constructed a three-tone control circuit, employing operational amplifiers, potentiometers, and passive components. A detailed construction and circuit analysis process is presented, explaining each component's role, why we opted for the design we presented, and how our tone control works. Furthermore, we investigate the impact of different control parameters, such as potentiometer settings, on the overall tone of the audio signal. Simulations, data, and documentation are presented in our paper to validate if our design functions and complies with the given parameters. Lastly, the paper concludes by discussing the overall observations from the project design and potential design improvements.**

Keywords—Tone control circuit, operational amplifiers, peter baxandall, active filters.

I. Introduction

Sounds can be perceived by the human ears with different sensitivity, pitch, and tone. This is due to frequency and amplitude variations in the signals from these sounds or audio we hear. Because of these changes, we were able to compose different music, deliver different intonations of speech, and more audio-related experiences.

In the music and audio production industry, tone control circuits have a big impact on devices such as audio mixing consoles, various guitar amps, portable audio devices, audio applications, and more. A tone control circuit device is used to adjust the tonal balance of an audio signal. This allows the users to freely change such audio signals to increase the audio's bass or treble and even allow them to cut and boost certain frequency bands. Initial designs back then consisted of only a network of passive components such as filters and capacitors to adjust the high and low frequencies of the signal. This results in limited control over the range of the frequency bands (Colloms, 2003).

Op-amps were introduced around the 20th century and integrated into our modern-day tone-control circuits (Jung, 2010). This component offered flexibility towards the frequency range, making it wider due to high gain from amplification, high input impedance, and low output impedance for stability, thus making it possible to control the bass and treble frequencies independently. Op amps can also be treated as inverting and non-inverting, which differ in their gain, phase shifting, and input terminal. Both have the same purpose, but one of which is suitable for a certain type of project (e.g., inverting op amps provides more precise control; non-inverting op amps provide a gain greater than one without any phase shift).

It was named after Peter Banxandall, who developed the Baxandall tone circuit in 1952. It is one of the popular methods in tonal balance due to its simplicity and effectiveness. This type of tone circuit focuses on the three commonly known filters. The low pass filter, also known as the bass filter, and the high pass filter, on the other hand, is the treble filter. The last is the mid-range filter, which uses a band pass filter. Using this specialized designed tone control allows an independent adjustment of these frequencies (Patron, 2004).

This paper will discuss these components in more detail, including how they work together to achieve the desired output from the built tone control circuit. The results would be validated and discussed further through simulations and actual testing, including why such a design was chosen, accompanied by mathematical proof from our obtained values.

II. Design Methodology

A. Process of Building

The required specifications of the tone control circuit is a bass cutoff frequency of 50Hz, a mid-range center frequency of 450Hz, and a treble cutoff frequency of 6kHz. The circuit must have a maximum cut/boost of ±8dB, with an error tolerance of 3%. The frequencies are given an error tolerance of 10%.

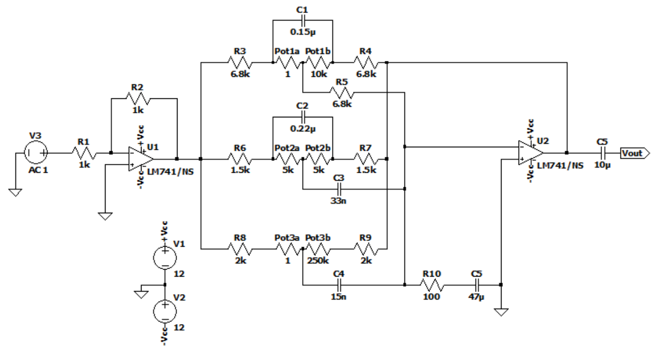


Figure 1: Topology of the Tone Control Circuit

The circuit design uses the Banxandall circuit as reference, which in essence is an inverting summing amplifier with 3 parallel branches that each act as a passive filter for the bass band, mid-range, and treble. While the potentiometer values are held constant, the resistors were first identified by using the formula of an inverting amplifier, with the gain kept constant as 8dB. The computation for capacitances are last in the design approach to set the circuit cutoff frequencies while having minimal effect on the set maximum cut/boost. R_{10} and C_5 are placed to assist in fine tuning the gain and frequency response, and their values were settled experimentally in LTspice simulations. The used active component of the circuit is the UA741 operational amplifier, which is a high performance general-purpose operational amplifier.

Furthermore, this design does not consider the mid-range to achieve maximum cut/boost due to the difficulty of configuring it on an analog device and the inevitability of its gain being constantly affected by bass and treble tone control. Thus, the design approach focuses on the bass and treble frequencies being able to achieve the maximum cut/boost according to the circuit specifications.

An inverting summing amplifier was used in the design to have a less difficult approach in the computations for gain. However, this results in an inverted output. This is corrected by placing a unity gain inverting amplifier before the active tone control network of the circuit. Moreover, a 12V DC supply is used to power the operational amplifiers and would ideally allow a maximum undistorted output of $24V_{pk\text{-}pk}$. This confirms that the voltage ratings of the capacitive components must be equal to or greater than the DC supply. To add, the simulations are used to determine the maximum power of the resistors in the circuit, which ascertains that resistors of at least 1/8W rating can be used.

B. Computations

A Baxandall tone control circuit is an equalizer frequently employed in audio systems for modifying the balance between bass and treble frequencies.

In this circuit, resistor components (R3, R4, R5, R6, R8) and capacitors are crucial in defining the frequency response characteristics. The calculations specify the extent of amplification and attenuation for both bass and treble frequencies based on the values of these resistors. To ensure that the circuit follows the ±8dB maximum cut/boost requirement, the gain formula of an op-amp based inverting amplifier will be used to set the bass and treble resistors. The computed resistances are used to attain the capacitances that will allow the circuit to set the required cutoff frequencies.

1. Bass Network Components

$$MBB(dB) = 8dB\ (Max\ Bass\ Boost)$$

$$MBB = 10^{\frac{8}{20}} \approx 2.5119$$

$$Let\ Pot_1 = 10k\Omega,\ R3 = R4 = R5:$$

$$MBB = 10^{\frac{8}{20}} = \frac{Rf}{Ri} = \frac{Pot1 + R5}{R5} = \frac{10k\Omega + R5}{R5}$$

$$\therefore R3 = R4 = R5 = 6614.2534\Omega$$

$$\approx 6.8k\Omega\ (standard\ value)$$

This formula indicates the maximum boost for bass frequencies. It makes use of the ratio of the feedback resistance to the input resistance to attain the required resistance to meet the specified gain.

$$fc_{bass} = 50Hz = \frac{1}{2\pi(Pot1+R4+R5)C_1}$$

$$C1 = \frac{1}{2\pi(Pot1+R4+R5)fc_{bass}} = \frac{1}{2\pi(10k\Omega+6.8k\Omega+6.8k\Omega)(50Hz)}$$

$$= 0.1349\mu F \approx 0.15\mu F\ (standard\ value)$$

The formula for the cutoff frequency of an RC filter is used to solve for the required capacitance to meet the bass frequency specifications.

2. Mid-range Components

$$f_{center} = 450Hz,\ e_{tolerance} = 10\%:$$

$$f_{midLow} = 450Hz \cdot (100\% - 10\%) = 405Hz$$

$$f_{midHigh} = 450Hz \cdot (100\% + 10\%) = 495Hz$$

$$Let\ Pot_2 = 10k\Omega,\ R6 = R7 = 1.5k\Omega:$$

$$f_{midHigh} = \frac{1}{2\pi R_6 C_2} \rightarrow C_2 = \frac{1}{2\pi R_6 f_{midHigh}}$$

$$C_2 = \frac{1}{2\pi(1.5k\Omega)(495Hz)} = 0.2144\mu F$$

$$\approx 0.22\mu F$$

$$f_{midLow} = \frac{1}{2\pi(Pot_2+R_7)C_3} \rightarrow C_3 = \frac{1}{2\pi(Pot_2+R_7)f_{midLow}}$$

$$C_3 = \frac{1}{2\pi(10k\Omega+1.5k\Omega)(405Hz)} = 34.1718nF$$

$$\approx 33nF\ (standard\ value)$$

The mid-range frequencies were attained by using the given frequency error tolerance and the specified center frequency. After experimentally deciding on the resistance values that output a reasonable gain, they were utilized in attaining the capacitances necessary to set the mid-range of 405Hz to 495Hz.

3. Treble Network Components

$$MTB(dB) = 8dB\ (Max\ Treble\ Boost)$$

$$MTB = 10^{\frac{8}{20}} \approx 2.5119$$

Let $Pot_3 = 250k\Omega$, $R8 = R9$:

$$R_{TotalBass} = 3R_5 + \frac{Pot1}{2} = (3 \cdot 6.8k\Omega) + \frac{10k\Omega}{2} = 2$$

$$R_{TotalMid} = R_6 + \frac{Pot2}{2} = 1.5k\Omega + \frac{10k\Omega}{2} = 6.5k\Omega$$

$$MTB = 10^{\frac{8}{20}} = \frac{Rf}{Ri} = \frac{R_{TotalBass} \parallel R_{TotalMid} \parallel Pot3}{R9}$$

$$10^{\frac{8}{20}} = \frac{25.4k\Omega \parallel 6.5k\Omega \parallel 250k\Omega}{R9}$$

$$\therefore R8 = R9 = 2018.6329\Omega$$
$$\approx 2k\Omega\ (standard\ value)$$

Similar to the bass network, the ratio of the feedback resistance to the input resistance is used to attain the necessary resistance to achieve the desired gain. However, the resistance of the other branches must be considered in the feedback resistance, which constitutes to the total resistance of the bass and mid-range network being important in the computation process.

$$fc_{treble} = 6kHz = \frac{1}{2\pi R_9 C_4}$$

$$C4 = \frac{1}{2\pi R_9 fc_{treble}} = \frac{1}{2\pi(2k\Omega)(6kHz)}$$
$$= 13.2629nF \approx 15nF\ (standard\ value)$$

Resistances of the tone control network:

- $R3 = R4 = R5 = 6.8k\Omega$
- $R6 = R7 = 1.5k\Omega$
- $R8 = R9 = 2k\Omega$
- $Pot_1 = 10k\Omega$
- $Pot_2 = 10k\Omega$
- $Pot_3 = 250k\Omega$

The attained resistances can be used to recompute for the maximum cut/boost of the bass and treble frequencies:

- Max Bass Boost:

  $$20 \cdot log_{10}(\frac{6.8k\Omega + 10k\Omega}{6.8k\Omega}) = 7.8560dB$$
- Max Bass Cut:

  $$20 \cdot log_{10}(\frac{6.8k\Omega}{6.8k\Omega + 10k\Omega}) = -7.8560dB$$
- Max Treble Boost:

  $$20 \cdot log_{10}(\frac{25.4k\Omega \parallel 6.5k\Omega \parallel 250k\Omega}{2k\Omega}) = 8.0805dB$$
- Max Treble Cut:

  $$20 \cdot log_{10}(\frac{2k\Omega}{25.4k\Omega \parallel 6.5k\Omega \parallel 250k\Omega}) =- 8.0805dB$$

As observed, the maximum cut/boost achieved is approximately equal to the circuit specifications due to the computed resistances.

III. Design Verification and Results

A. *Design Verification.*

The results and analysis of each part will be discussed to understand further the three-band tone control system that the group has made. Analysis of the three different filters will be thoroughly discussed here, namely the lowpass for the bass, bandpass for the mid-band, and highpass for the treble. We also used an inverting amplifier that helps obtain the dB gain for the circuit. We opted to use a UA741 as our op-amp due to its versatility for having low noise, high gain, and decent audio frequency characteristics perfect for a tone control system.

Low Pass Filter

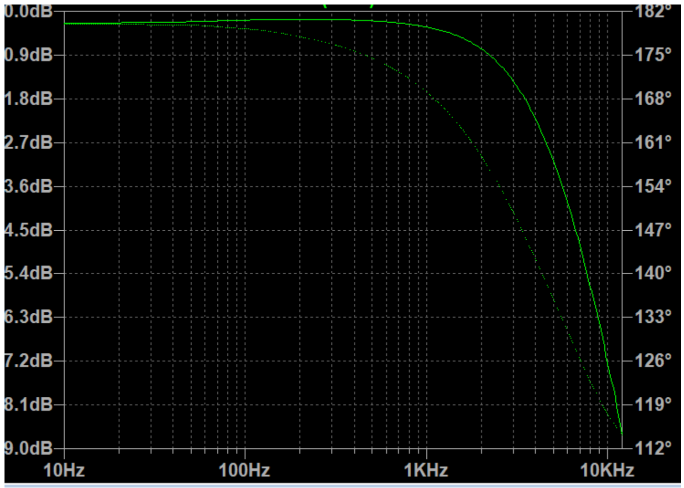


Figure 1.0: Low Pass Filter Waveform

The bass region makes sure that it emphasizes the low frequency to make it more focused in the signal. The low pass filter is used for the bass to attenuate higher frequencies and allow low frequencies to pass. The computed cut off frequency is equal to 50 hz. This will be the required value for the bass of the circuit.

Band Pass Filter

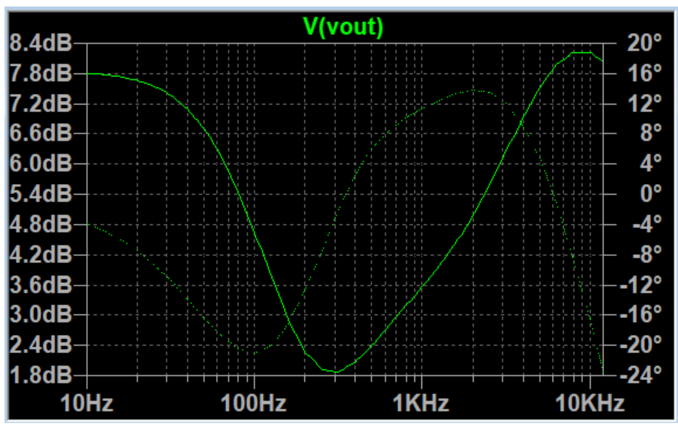


Figure 1.1: Band Pass Filter Waveform

A bandpass filter may not be visibly apparent, and its attenuation is influenced by the interplay of gain and attenuation from both bass and treble frequencies. Unlike low-pass or high-pass filters, a bandpass filter operates by selectively allowing a range of frequencies, known as the passband, to pass through while attenuating frequencies outside this range. The subtlety of its effects lies in its selectivity, making the impact less immediately noticeable. The interaction between gain and attenuation factors, particularly with bass and treble frequencies, influences the overall response of the bandpass filter. The interplay of gain and attenuation within the passband shapes the treatment of frequencies, contributing to the filter's role in tonal modification and overall tone shaping in audio systems.

High Pass Filter

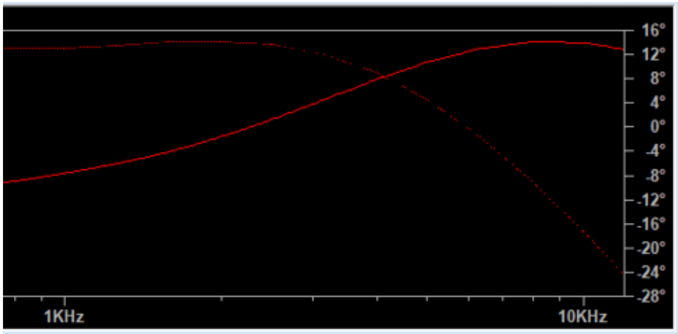


Figure 1.2: Low Pass Filter Waveform

The high pass filter is used for the treble to attenuate or block the lower frequencies and allow high frequencies to pass. It focuses also on the adjustments made for the treble, as this region emphasizes enhancing higher frequencies in the signal. The higher frequency above the cut-off frequency have a flat response, the change from low to high can be emphasized when applied in the audio device.

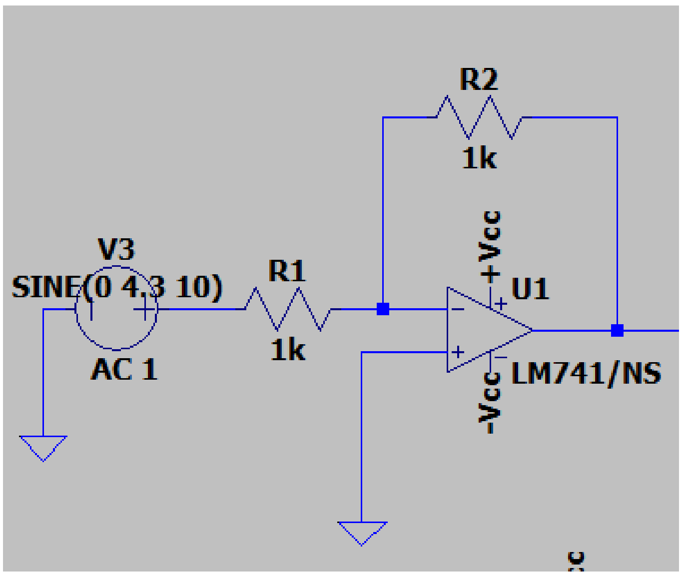


Figure 1.3: Unity Gain Inverting Amplifier

Inverting amplifiers are used for their significant advantages in audio applications, particularly tone control circuits. The inherent 180-degree phase reversal manipulates frequency components, allowing for cancellation or emphasis similar to equalization. Inverting amplifiers stand out for their simplicity, requiring fewer components and offering cost-effectiveness. Their compatibility with feedback networks in tone control circuits aids in frequency response shaping. The flexibility in gain adjustment, achieved by altering feedback resistor values, adapts to specific circuit requirements. Additionally, the standard ground reference simplifies integration into audio systems. In summary, inverting amplifiers in tone control circuits are favored for their advantages in addressing phase relationships, frequency response, and overall design goals.

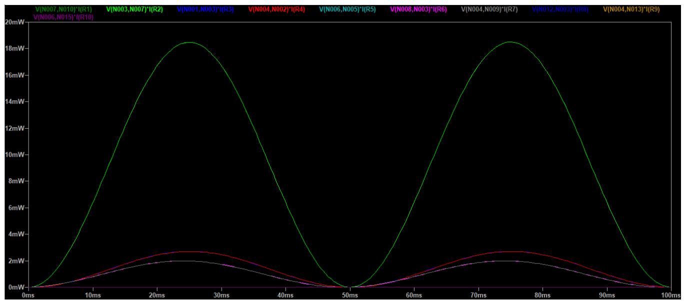


Figure 1.5. Max power and Max Input

From these output waveforms we can observe how the max power and max input is 18.4785mW. With this, the maximum power we are still permitted to use a resistor that has 1/8W as it is part of the minimum power rating a resistor should have.

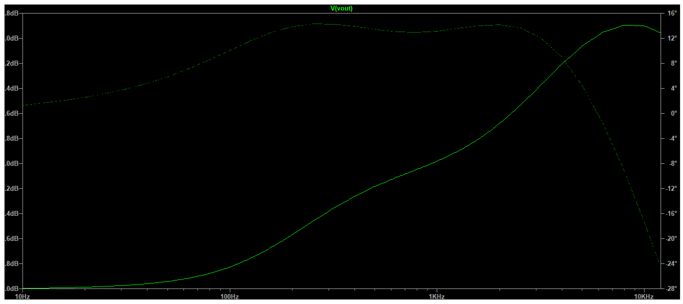


Figure 1.4: Treble Boost

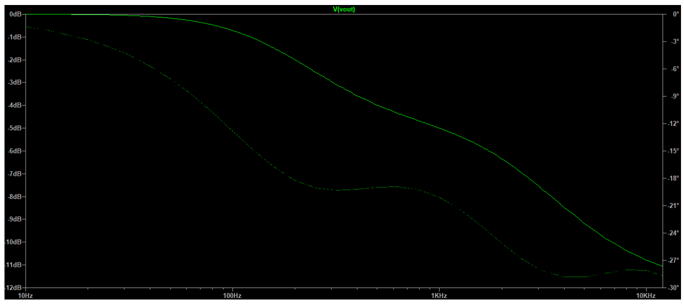


Figure 1.5: Treble Cut

The Treble boost and cut has a limit of positive or negative 8db only. The function of the treble boost Treble boost increases the amplitude or gain of higher-frequency components in an audio signal. For the treble cut, treble cut decreases the amplitude or gain of higher-frequency components in an audio signal. Both the treble boost and cut are integral tools in audio equalization, allowing the users to filter or control the sound to their preferences or to compensate for the characteristics of audio sources and playback systems. These adjustments are part of a broader spectrum of equalization controls that aim to achieve a desired tonal balance in audio reproduction.

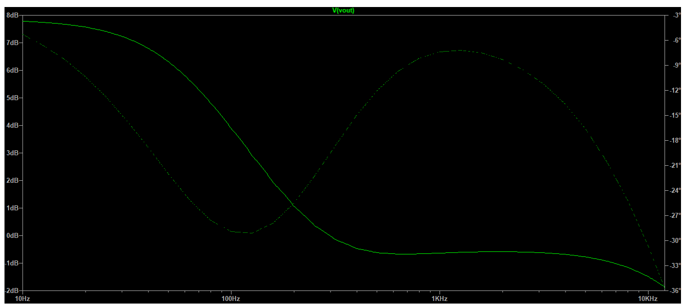


Figure 1.6: Bass Boost

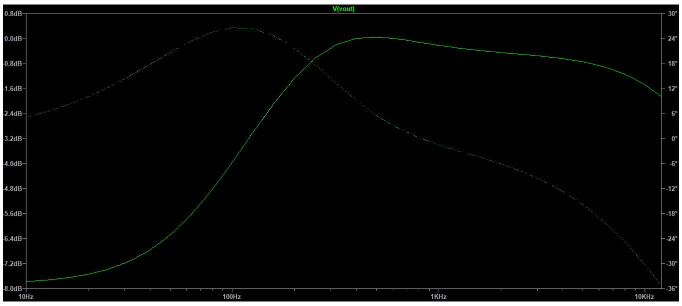
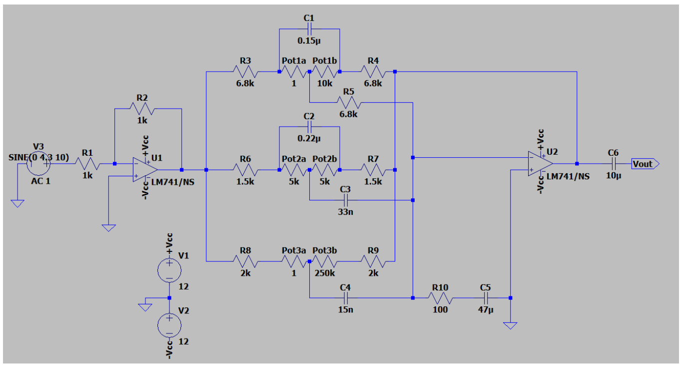


Figure 1.7: Bass Cut

To achieve a specific bass adjustment within our group, it is necessary to implement both a bass boost and a bass cut, totaling an 8dB change. This entails enhancing the bass frequencies using a boost and attenuating them through a cut to achieve the desired overall adjustment. The combination of these two actions contributes to a nuanced and precisely tailored bass response in our audio system.



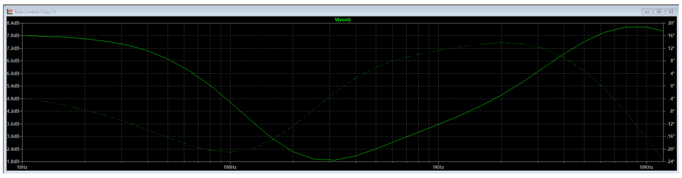


Figure 1.8. Overall output of the 3-band Control System

From this overall output, we can clearly see how the three\band control system affects each part of the signal depending on what they do. In the first half of the wave we can see the Bass in action or the low pass filter, attenuating the signal as it should. On the other hand we noticed how the Treble gives gain on the signal serving its purpose and finally observing the band pass in the middle of them but not that visible due to proper gain and attenuation happening it both the bass and treble.

B. Documentation

The figures presented below are the proof or verification for our actual circuit design.

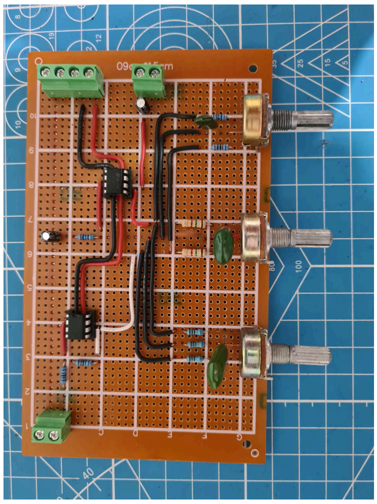


Figure 2.0: Top View of Tone Control Circuit

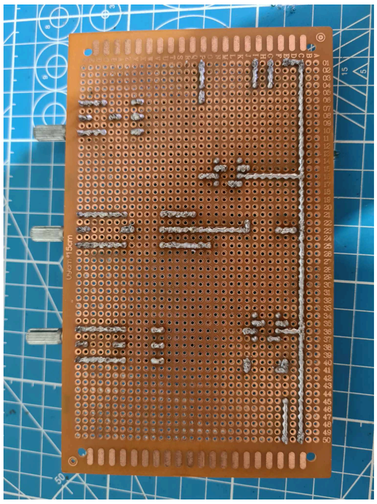


Figure 2.1 Back view of the Tone Control Circuit

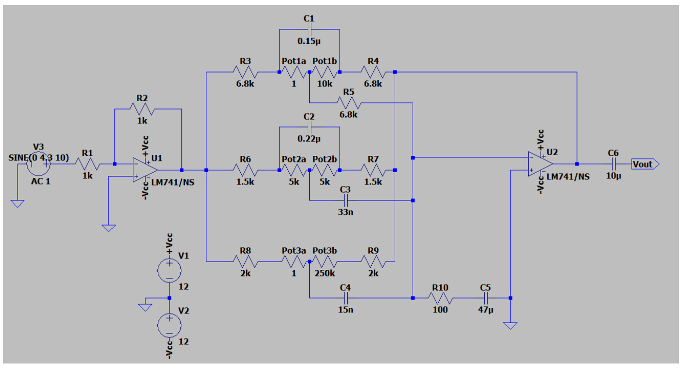


Figure 2.2. LTSpice Circuit of the 3-band control system

Figures 2 and 2.1 present our physical device containing different resistors, capacitors, potentiometers, and op-amps connected on a PCB with the use of copper wires soldered to connect the given components. Figure 2.2 represents the final output of our LTSpice circuit, where tests and analyses were done before implementing and bringing our circuit to life.

COMPONENT INVENTORY

Component Inventory		
Name of Component	***Values***	***Description***
Resistor (R3, R4,R5)	6.8kΩ	1/2W
Resistor (R6, R7)	1.5kΩ	1/4W
Resistor (R8, R9)	2kΩ	1/2W
Resistor (R10)	100Ω	1/2W
Resistor (R1, R2)	1kΩ	1/2W
Voltage Source (V1, V2)	12V	DC Source
Potentiometer (Bass)	10kΩ	3-terminal
Potentiometer (Mid-band)	10kΩ	3-terminal
Potentiometer (Trable)	250kΩ	3-terminal
Capacitor (C1)	0.15uF	Mylar
Capacitor (C2)	0.22uF	Mylar
Capacitor (C3)	33nF	Ceramic
Capacitor (C4)	15nF	Mylar
Capacitor (C5)	47uF	Electrolytic
Capacitor (C6)	10uF	Electrolytic
2x OPAMP	UA741	General Purpose Op-amp
Universal PCB		9x15cm
4x 2P Terminal Block		

DISTRIBUTION OF TASKS

Distribution of Tasks	
Name of the members	***Tasks Assigned***
Joshua Carlo C. Aguarin	Abstract, Introduction, Component Inventory, Design Verification
John Rene D. Almero	Conclusion, Design Verification
Raleigh Christian P. Cabe	Circuit Design, Design Methodology, Computations, Assembling of Tone Control Circuit
Daryll Aaron Camato	Conclusion, Design Verification

IV. CONCLUSION AND RECOMMENDATION

In conclusion, the paper provides a comprehensive overview of tone control circuits, highlighting their crucial role in shaping the tonal balance of audio signals. The evolution from early designs with passive components to operational amplifiers (op-amps) integration in the 20th century has significantly enhanced flexibility and control over frequency ranges. The introduction of the Baxandall tone circuit in 1952 further contributed to the field, offering a simple yet effective method for independently adjusting low, mid-range, and high frequencies.

The discussion emphasizes the significance of op-amps in modern tone control circuits, detailing their attributes, such as high gain, input impedance, and output impedance, that contribute to expanded frequency manipulation possibilities. The distinction between inverting and non-inverting op-amps is also explored, highlighting their advantages in specific applications.

The paper further explores these components, delving into their collaborative functioning within a tone control circuit. The upcoming sections aim to validate and elaborate on the design choices through LTspice simulations and practical testing supported by mathematical proof derived from obtained values. The document sets the stage for a thorough understanding of tone control circuits, their historical development, and the rationale behind their contemporary designs.

REFERENCES

[1] R. Vargas Patron, "The James-Baxandall Passive Tone-Control Network." , 2004. http://www.tubebooks.org/file_downloads/Baxandall.pdf

[2] K. Saleem, "Active Baxandall Tone Control Circuit," Circuits DIY, 2023. https://www.circuits-diy.com/active-baxandall-tone-control-circuit/

[3] L. Davis, "Dictionary of Electronic and Engineering Terms. 3-Band Active Audio Tone Control Circuit Design,"*www.interfacebus.com, 2016* http://www.interfacebus.com/tone-control-3-band-tlo82-opamp-design.html

[4] D. Harris, "Application Report Audio Tone Control Using The TLC074 Operational Amplifier," 2000. https://www.ti.com/lit/an/sloa042/sloa042.pdf?ts=1702033168172&ref_url=https%253A%252F%252Fwww.google.com%252F

[5] W. Jung, "Op Amp Applications Handbook," 2005. https://ia601607.us.archive.org/23/items/fe_Op_Amp_Applications_Handbook_Newnes_Walt_Jung/Op_Amp_Applications_Handbook_Newnes_Walt_Jung.pdf

[6] [1]H. Harun, "Audio Power Amplifier Design Handbook," *www.academia.edu*, 2002. https://www.academia.edu/25190781/Audio_Power_Amplifier_Design_Handbook