DEPARTMENT OF ELECTRONIC & TELECOMMUNICATION ENGINEERING UNIVERSITY OF MORATUWA

EN2091 - Laboratory Practice and Projects

High Frequency Amplifier

Group Analog Mates

Name	Index No.
Maduwantha L.H.H	200370K
Dimagi D.H.P.	210131N
Dissanayaka D.M.P.C.	210140P
Dilshan N.L.	210129P

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Abstract

The objective of the project is to design a high frequency amplifier. The amplifier can drive an 8-ohm load(speaker) without any distortion. The rated frequency for the amplifier is 20kHz to 100kHz.

The amplifier has two stages. The pre-amplifier stage has been designed using a common emitter amplifier which will amplify the voltage. The power amplifier stage consists of a class AB amplifier and two corresponding voltage buffers.

The open terminal voltage gain (theoretical value) of the amplifier is 28.5, and it has a gain around 18.1 with the speaker.

Contents

1. Introduction

The report discusses the method, objective requirements, and challenges of designing the high frequency amplifier.

1.1 Requirements/Outcomes

The high frequency amplifier should be able to amplify a signal with a small amplitude without any distortion. Followings are the design requirements and outcomes of the product:

1. Bandwidth: 20 kHz - 100 kHz
2. Minimum number of transistors: 3
3. Operating voltage: < 12V
4. Input: 0.1Vp-p (MAX)
5. It should be able to drive 8 Ω (headphone) load without significant waveform distortion or amplitude reduction.

There are 6 main parameters in the specification of the product:

1. Open circuit gain
2. Gain with the 8Ω load
3. Bandwidth
4. Input Resistance
5. Output Resistance
6. Power Dissipation

1.2 Summary of Report

The report discusses the design, development, and testing processes of the High Frequency Amplifier. It consists of two stages: a voltage amplification stage and a power amplification stage. Initially, the amplifier circuit was simulated using Proteus. Then, a physical prototype was built and tested using Altium. The final report was created based on the data obtained from testing the ultimate prototype.

2. Design Approach of The Circuit

2.1 Steps of Circuit Designing

The end circuit design was obtained by going through several design steps to meet the required design specifications. First, we used a class A amplifier for the circuit design. Later, to address some amplification issues, we added a class AB stage in the second step. Finally, we used voltage buffers in the last step to achieve a high gain.

2.1.1 Class A Amplifier Stage

Class A amplifiers are widely preferred for their popularity. They provide full amplification of the input signal and have a simple structure. To keep the amplifier active during oscillation, a steady current must flow through the transistor, preventing it from turning off. However, due to this characteristic, class A amplifiers tend to be inefficient and generate significant heat. As a result, they are not suitable for high-power amplification needs.

2.1.2 Class B Amplifier Stage

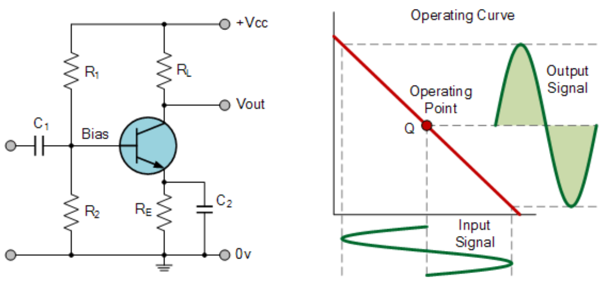
In class B amplifiers, only half of the input signal is conducted due to biasing. To obtain the complete waveform, two of these amplifiers can be configured in a "Push Pull" arrangement where their output signals are combined. Since the amplifier has a quiescent current of 0, there is minimal or no DC current, resulting in reduced power loss. However, the 0.7V required to bias the transistor into the active region can cause a slight distortion called zero crossing distortion, which is still present.

2.1.3 Class AB Amplifier Stage

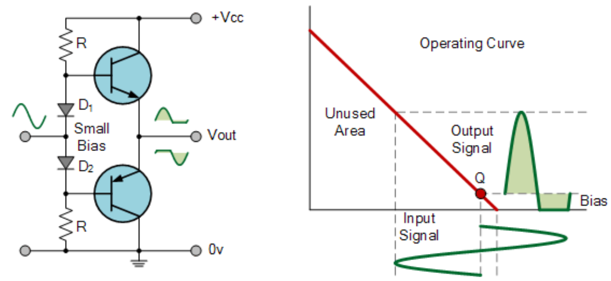
Class AB amplifiers solve the distortion issue found in class B amplifiers by always keeping the two transistors just inside the active region. This eliminates the distortion problem and ensures an undistorted output waveform. However, this approach leads to decreased efficiency compared to class B amplifiers. Despite that, class AB amplifiers have significantly smaller power dissipation due to the DC component, making them more suitable for high power amplification applications.

2.1.4 Voltage Buffer Stage

To address the issue of insufficient gain in Class AB amplifier stages, a common approach is to incorporate voltage buffers using the common collector configuration. This configuration helps to isolate each transistor in a push-pull amplifier setup.



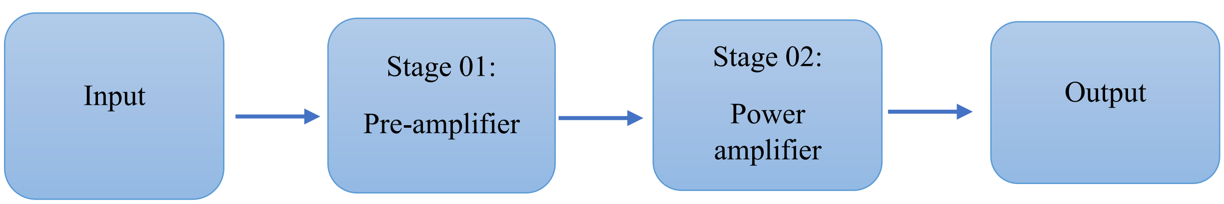
Class A Amplifier



Class AB Amplifier

2.2 Flow of the Circuit

The design utilizes a two-stage amplifier with a cascading setup. In the first stage, a Bipolar Junction Transistor is employed in a common emitter configuration. A capacitor is employed to connect this amplifier stage to the next. The second stage involves four Bipolar Junction Transistors arranged in an AB push-pull configuration. Consequently, the amplifier cascades in the following manner.

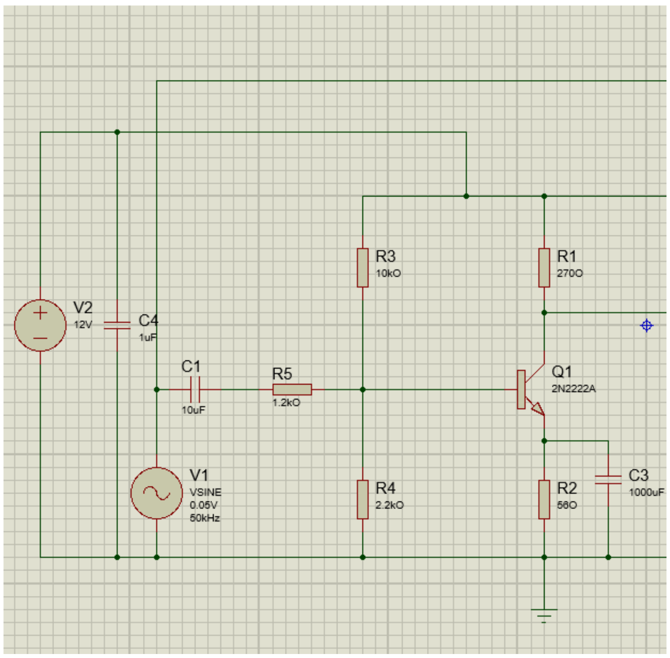


- To prevent the transmission of Direct Current (DC) signals, a 100µF capacitor is employed to establish a connection between the two stages.
- To minimize distortions observed during testing, stage one's input is linked with a 10µF capacitor and a small 2.2kΩ resistor.
- Similarly, for the sake of avoiding DC signals reaching the speakers, a crucial measure is taken by connecting the output with a 1000µF capacitor, serving the same purpose as explained earlier. This is necessary to safeguard the speakers from potential harm caused by the transmission of DC signals.
- 1µF capacitor has been used to prevent instant surges due to power supply.

2.2.1 Stage 01 : Pre-Amplifier

The main goal of the initial stage is to achieve a significant amplification in voltage. To accomplish this, we opted for a class A common emitter amplifier. It is a simple common emitter BJT amplifier. We obtained an approximate voltage gain of 20. After comparing it with other options, we ultimately selected the 2N2222A transistor for this purpose.

This transistor was chosen primarily for its ability to handle high frequency signals, thanks to its higher bandwidth and fast switching characteristics. These features were the key factors in its selection. Now let's dive into the design details of the first stage.



Stage 01: Pre-Amplifier

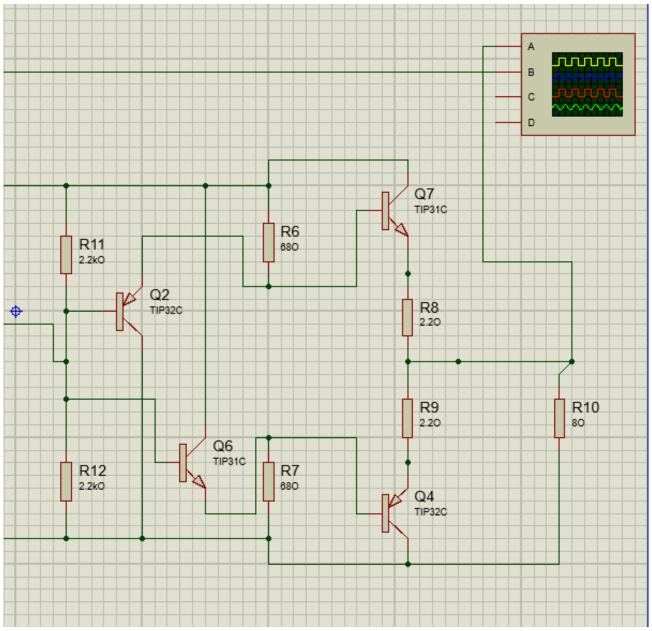
- The base was biased at the base voltage is 1.9V. Therefore, the base resistors, R_3=10kΩ and R_4=2.2kΩ.
- V_B = 1.9V. (Base current is negligible)
- V_E = 1.2V. (Assuming VBE is equal to 0.7V)
- We selected the emitter resistor such that $I_E \approx 20$ mA.
- Therefore, R_E = 56Ω (R2), $I_C \approx$ 20mA.
- $V_{CE} \approx$ 6V.
- Therefore, $R_C = \frac{12-(6+1.2)}{20\times10^{-3}} = 240\Omega$ (We used 270Ω based on the observations in the testing)

Calculation of resistors

2.2.2 Stage 02: Power Amplifier

The AB Push Pull stage serves as the amplifier's second stage. Its purpose is to achieve the required power amplification to drive an 8-ohm load (speaker) while minimizing any substantial reduction in the output amplitude.

After careful analysis of the datasheets, we opted to choose the TIP 31C/TIP 32C power transistor pair. These transistors were selected due to their ability to handle the present high currents flowing through them, as well as their significant current gain.

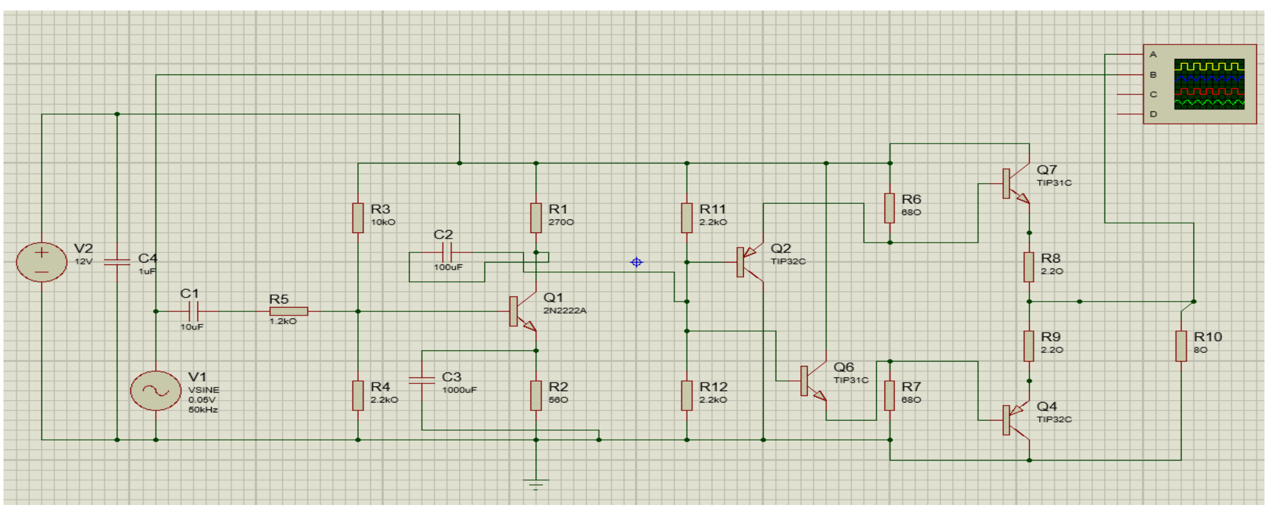


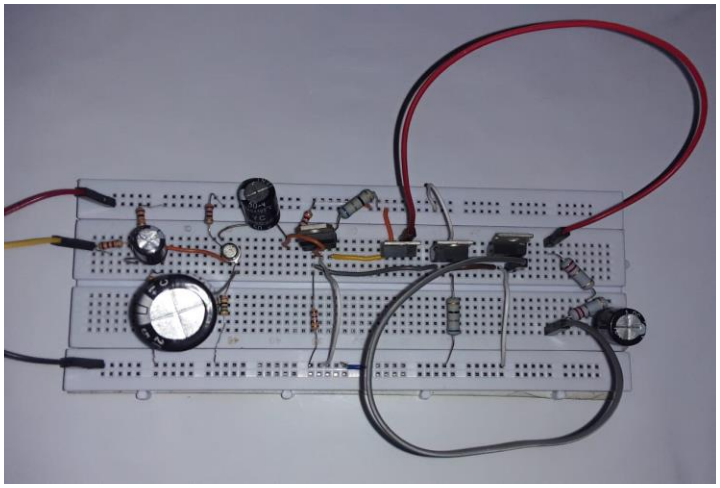
Stage 02: Power Amplifier

- Due to the considerable current flowing through, the 56Ω resistors are classified as power resistors. In this circuit, the current gain is significant, while the voltage gain is only one, which is satisfactory for the intended purpose.
- To ensure that no direct current (DC) reaches the output, the load is connected to a capacitor in the circuit.

3. Prototype Design

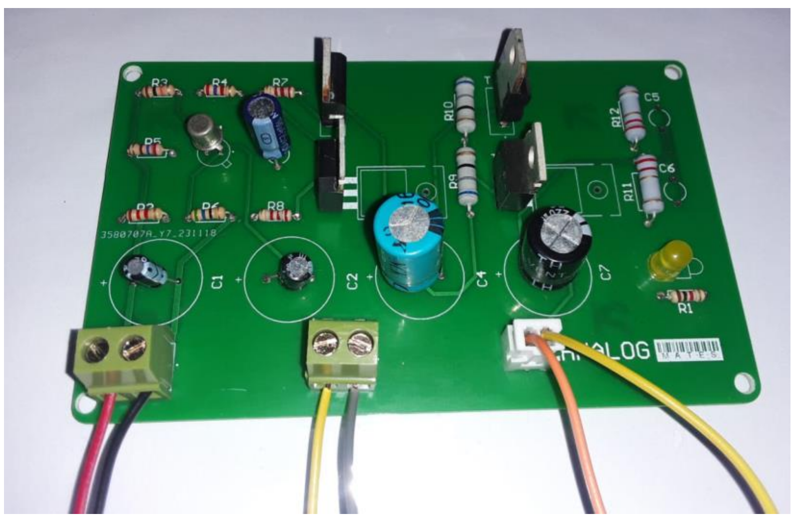
Proteus, the software utilized to develop the virtual prototype, served as the basis for conducting various tests and experiments.



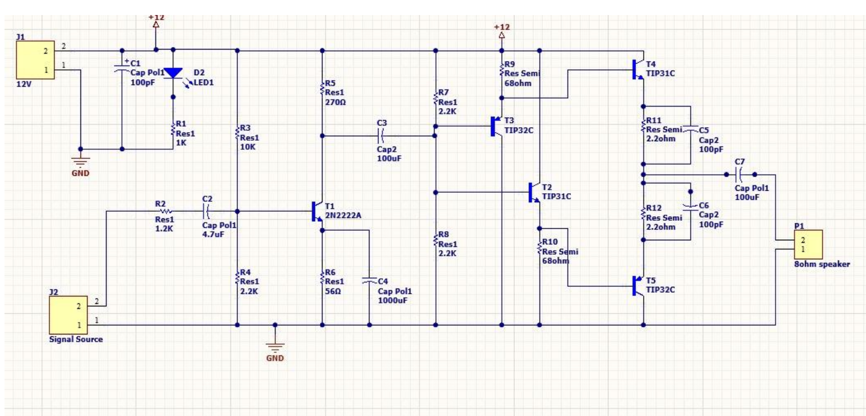


Bread-board Implementation

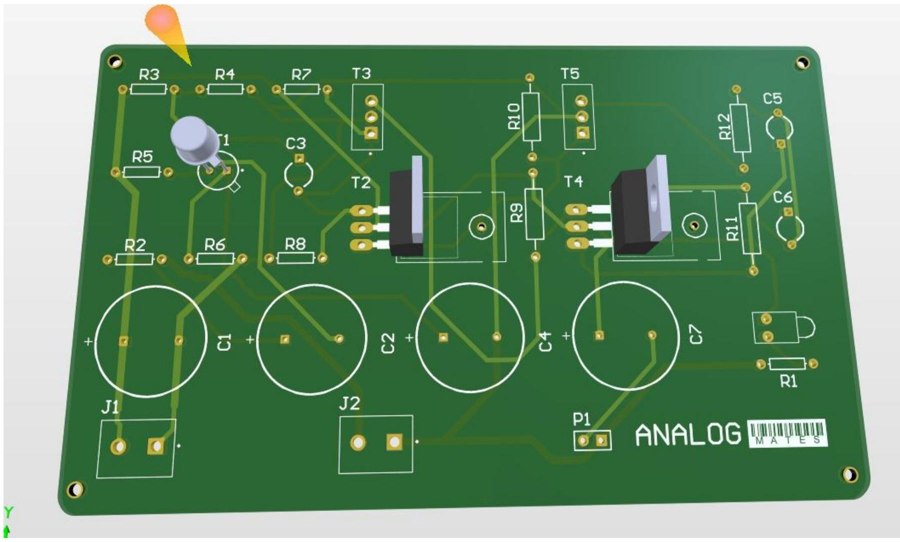
The physical prototype's PCB (Printed Circuit Board) was designed using Altium software. After screen printing, the components required were then soldered onto the PCB.



PCB Implementation

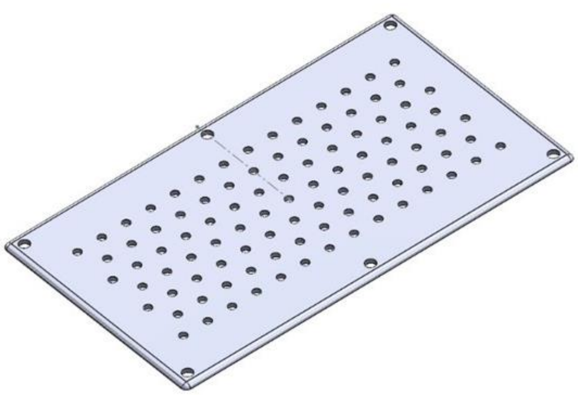


PCB Schematic

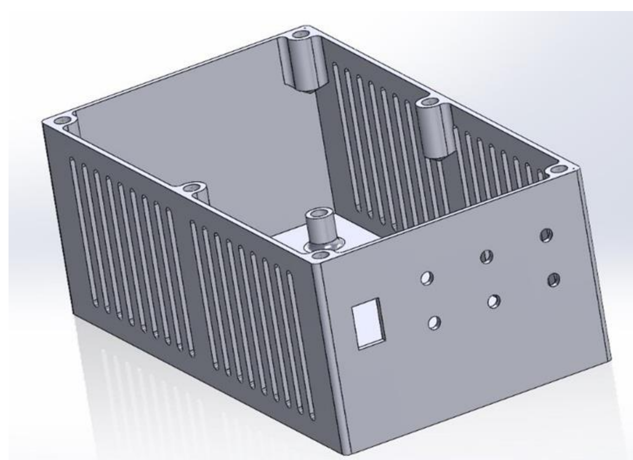


2D and 3D views of the PCB

The Enclosure, created using SolidWorks, incorporates a perforated cover for effective heat dissipation and prevention of amplifier overheating. Crafted from PLA+ material, it boasts low brittleness. Additionally, its eco-friendly nature stems from being produced with recyclable materials.



Top View



Inside View

3.1 List of Components and Equipment

Components used in the circuit:

1. 2N2222A NPN BJT transistor
2. TIP 31C power transistor (2)
3. TIP 32C power transistor (2)
4. Capacitors (1µF, 10 µF, 100 µF, 1000 µF, 220 µF)
5. Resistors (1.2kΩ, 10kΩ, 2.2kΩ, 270 Ω, 56 Ω, 2.2k Ω)
6. Power resistors (68 Ω, 2.2 Ω)

Here is a rundown of the additional components and equipment utilized during the testing process:

1. Power Supply
2. Digital multimeter
3. Signal generator
4. Digital Oscilloscope
5. Breadboard
6. 8 Ω speaker

4. Results

The design specifications were reviewed, and the necessary data for the datasheet were acquired by analyzing both the physical prototype and the simulation results.

Open circuit gain, gain with the 8Ω load, Bandwidth, Input Resistance, Output Resistance, Power Dissipation are the six parameters we focused. All the parameters were examined using both simulation and prototype testing.

Open Circuit Gain of the Pre-amplifier:

$$r_\pi = \frac{v_T}{I_B} = \frac{26mV}{20mA\,/\,75} = 97.5\ \Omega$$

Input resistance:

$$R_{in} = R_{b1} \,//\, R_{b2} // r_\pi \approx r_\pi = 97.5\ \Omega$$

Open circuit voltage gain:

$$A_{vo} \approx \frac{\beta * R_C}{R_{in}} \approx 207.692 = 23.17\text{dB}$$

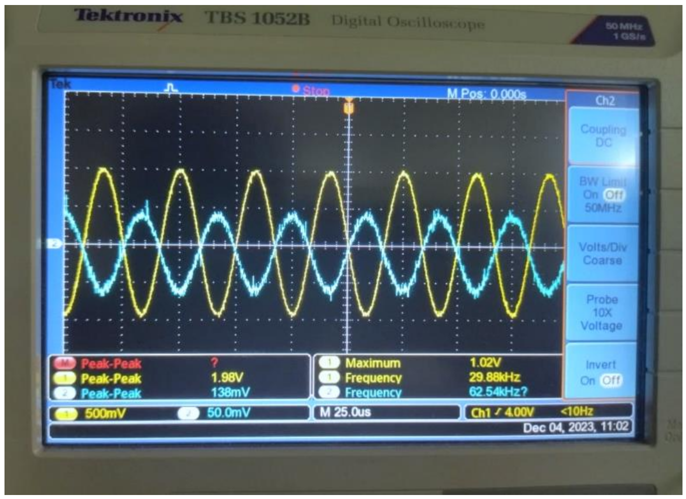
4.1 Open Circuit Gain – 21

The open circuit gain was assessed by connecting the input and output to an oscilloscope and measuring the voltage gain between them. The evaluation covered frequencies ranging from

20Hz to 100kHz. The provided value represents the highest consistently observed voltage gain across the mid-frequency ranges during the assessment.

4.2 Gain with 8Ω load – 16.393

We replaced the load with a 8Ω speaker and tested the voltage gain.



Output waveform with 8Ω load

4.3 Bandwidth – 700kHz

The half power value was obtained as the circuit's gain. Until the gain dropped to that value, the upper and lower cutoff values were calculated by slowly changing the input frequency.

4.4 Input Resistance – 2.188 kΩ

To estimate the input resistance, the current drawn from the input was measured using an ammeter. This measurement was conducted with an input voltage of 0.1V (peak to peak) and the output open-circuited. The input resistance was then determined by dividing the peak voltage (0.05V) by the peak current.

4.5 Output Resistance – 8.0108 Ω

We determined this by steadily decreasing the load starting at 8Ω until the amplifier's gain fell to half its initial value. This occurred with a load resistance that is equal to the output voltage.

4.6 Power Dissipation – 12 * 0.2 = 2.4 W

5. Individual Contributions

Maduwantha L.H.H	PCB design, Component Selection
Dimagi D.H.P.	Enclosure design, Breadboard Implementation
Dissanayaka D.M.P.C.	Enclosure design, Soldering PCB, Breadboard Implementation
Dilshan N.L.	Circuit design, Simulation in Proteus

6. Conclusion

We could successfully complete the project within the given timeframe. However, the amplifier does not fully meet the bandwidth requirement, with the lower cutoff (20kHz) notably falling below the specified threshold, despite meeting the upper cutoff requirement (100kHz).

6.1 Discussion

- We used power resistors with a 56-ohm resistance to accommodate the observed high current flow through TIP transistors.
- Within the specified bandwidth, there is minor waveform distortion at all frequencies, suggesting an excessively high Total Harmonic Distortion (THD).
- Values obtained during simulation did not precisely match calculated values. Discrepancies may arise from non-ideal component characteristics or variations in beta values due to temperature changes.
- Despite challenges, the project was successfully completed within the allocated time, showcasing effective project management and problem-solving skills.

Images of our final product are shown below.

7. References

- Amplifier classes
  https://www.electronics-tutorials.ws/amplifier/amplifier-classes.html

- 2N2222A NPN transistor Datasheet
  https://pdf1.alldatasheet.com/datasheet-pdf/download/956542/FCI/2N2222A.html

- TIP31C Datasheet
  https://www.st.com/resource/en/datasheet/tip31c.pdf

- TIP32C Datasheet
  https://www.st.com/resource/en/datasheet/tip32c.pdf