Department of Electronic and Telecommunication Engineering

University of Moratuwa

EN2091 - Laboratory Practice and Projects

High Frequency Amplifier

Group 15

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Abstract

The design of a high frequency amplifier was the objective of this project. This should be able to drive an 8-ohm load(speaker) without causing any distortion to the output signal. It should be able to amplify signals of frequencies 20kHz-100kHz.

There are two-stage amplifiers. The first stage uses a transistor in the common emitter configuration. The second stage uses an AB Push Pull amplifier configuration to achieve the power amplification needed to drive the speaker.

The amplifier achieved an open terminal voltage gain of around 20.4, and had a voltage gain of around 14.6 with a speaker.

Contents

1 Introduction

This report outlines the challenge that has been assigned as well as the project's objective requirements.

1.1 Objective

The given task is to design a high frequency amplifier with small amplitude loss or waveform distortion that can drive a small speaker.
Design requirements for amplifier :

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.

The parameters to be determined for the specifications sheet for the product :

1. Open Circuit Gain
2. Gain (with 8Ω load)
3. Bandwidth
4. Input Resistance
5. Output Resistance
6. Maximum Load Current

1.2 Summary of report

The High Frequency Amplifier design, development, and testing processes are covered in the report.
There are two stages of amplifier, a voltage amplification stage and a power amplification stage.
The amplifier circuit was first sketched up on paper, then it was simulated using Multisim, and then a physical prototype was created and tested using Altium.
Using data from testing performed on the final prototype, the final specifications sheet was created.

2 Methodology

The method used to create and design the amplifier is described in this section. Before examining the design method, the amplifier's theory will be reviewed.

2.1 Amplifier Theory

In the market, amplifiers are frequently employed. They have many different applications. The amplification of audio signals before they are sent to speakers is one such application. Whereas the amplifier just has to be able to handle signals up to roughly 20kHz for typical applications dealing with music or voice. Nonetheless, some applications might call for amplification of higher-frequency signals. As a result, a high frequency amplifier's design is important.

2.1.1 Amplifier Classes

Depending on their range of action, amplifiers can be divided into different classes.

2.1.2 Class A Amplifiers

The most popular amplifiers are class A amplifiers. They fully amplify the input signal and feature a basic structure. A constant current must flow through the transistor to bias it in a way that prevents it from turning off throughout the oscillation. Nevertheless, because of this characteristic, they are efficient and produce a lot of heat. They cannot, therefore, be applied for high power amplification applications.

2.1.3 Class B Amplifiers

Due to bias, only half of the input signal is conducted by class B amplifiers. The complete waveform can be obtained by using

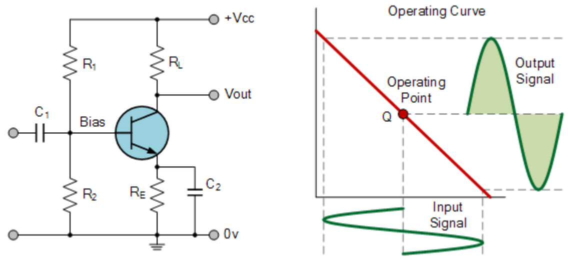


Figure 1: Class A amplifier

two of these amplifiers set up in a "Push Pull" arrangement and combining the output signal.
As this amplifier's quiescent current is 0, there is minimal or no DC current and hence significantly less power loss. Although the 0.7V needed to bias the transistor into the active region causes a small waveform distortion known as zerocrossing distortion, it is still present.

2.1.4 Class AB Amplifiers

By permanently bringing the two transistors just inside the active region, class AB amplifiers get over the distortion problem that plagues class B amplifiers. Although the efficiency is decreased, the output waveform is undistorted as a result.

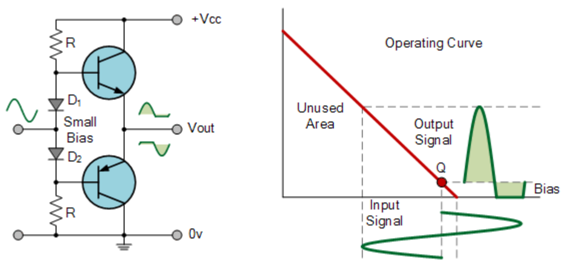


Figure 2: Block of circuit diagram

Although the power dissipation due to the DC component is substantially smaller than class A amplifiers, this is much more suitable for high power amplification applications.

2.2 Circuit Design

The design makes use of a cascading two-stage amplifier. Initially, a Bipolar Junction Transistor is used. It is applied in a common emitter arrangement. A capacitor is used to cascade the amplifier. Four BJTs set up in an AB push pull arrangement are used in the second stage.
The amplifier is cascaded as following manner:

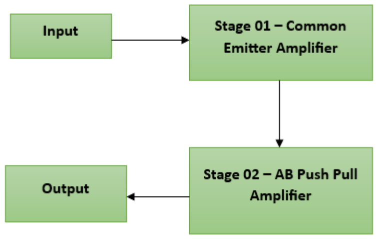


Figure 3: Block of circuit diagram

A 100μF capacitor connects the two stages in order to stop the transmission of Direct Current (DC) signals.

A 4.7μF capacitor and a small 2.2kΩ resistor are used to connect the input to stage one in order to reduce the distortions that were detected during testing.

For the same reason as previously, a 1000μF capacitor is used to connect the output. This is crucial because DC signals that are transmitted into speakers run the risk of doing so.

2.2.1 Stage 01 - Common Emitter

The objective of the first stage is getting a high voltage amplification. Then we decided to use class A common emitter amplifier for this purpose. We got 22 of voltage gain roughly. We used BC547BG transistor after comparing with others.
Higher bandwidth and fast switching, enabling it to handle high frequency signals are the main reasons to select this transistor.

The design of the first stage was determined as follows:

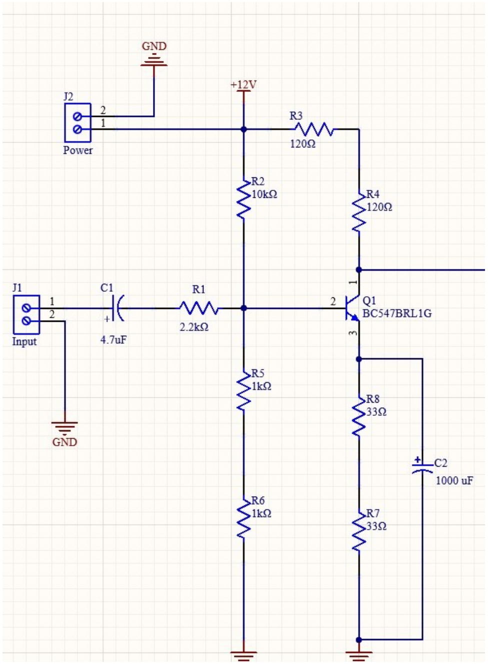


Figure 4: Stage 1 Circuit Diagram

- The base was biased at the base voltage is 2V. Therefore the base resistors, R_2=10kΩ and R_5=R_6=1kΩ.
- V_B = 2V. (Base current is negligible)
- V_E = 1.3V. (Assuming V_{BE} is equal to 0.7V)
- We selected the emitter resistor such that Ie ≈ 20 mA.
- Therefore, $R_E = 66\Omega$ $(R_7 + R_8)$, $I_C \approx$ 20mA.
- $V_{CE} \approx 6$V.
- Therefore, $R_C = \frac{12-7.3}{20} k\Omega \approx 240\Omega$ $(R_3 + R_4)$.

2.2.2 Stage 02 – AB Push Pull Amplifier

AB Push Pull stage is the second stage of amplifier. This stage is used to obtain the necessary power amplification for driving the 8 ohm load (speaker) without significantly reducing the output amplitude.

We made the decision to select the TIP 31C/TIP 32C power transistor pair after reviewing the datasheets. These transistors are capable of handling the high currents that are currently flowing through them and provide a sizable current gain.

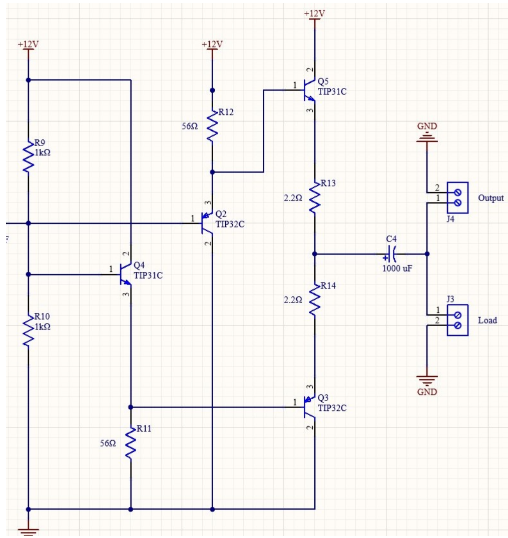


Figure 5: Stage 2 Circuit Diagram

Because of the high currents flowing through them, the 56Ω resistors are power resistors.

The circuit has a large current gain but a voltage gain of one, which is sufficient for the application.

To guarantee that no DC component reaches the output, the load is connected via a capacitor.

2.2.3 Initial Designs

An emitter follower amplifier was used in the early design of the amplifier to create three stages, including a middle current amplification stage. However, this step generated a distortion, and after it was removed, the voltage gain did not decrease. As a result, we choose to eliminate this stage.
The base resistors' initial values were substantially lower (1kΩ and 200Ω). However, when a load was attached, there was an input distortion because of the low input resistance. As a result, we multiplied the input resistors by 10.
Finally, when a load was connected, there was a small distortion of the output signal. We connected a 2.2kΩ resistor in series with

the input coupling capacitor to solve this problem.

2.3 Prototype Design

Multisim, which was used to create the virtual prototype (see Appendix A), was the foundation for several of the testing.
Using Altium, the PCB for the physical prototype was created (See Appendix B for layout). Following screen printing (Figure 6), the necessary parts were soldered to the PCB.

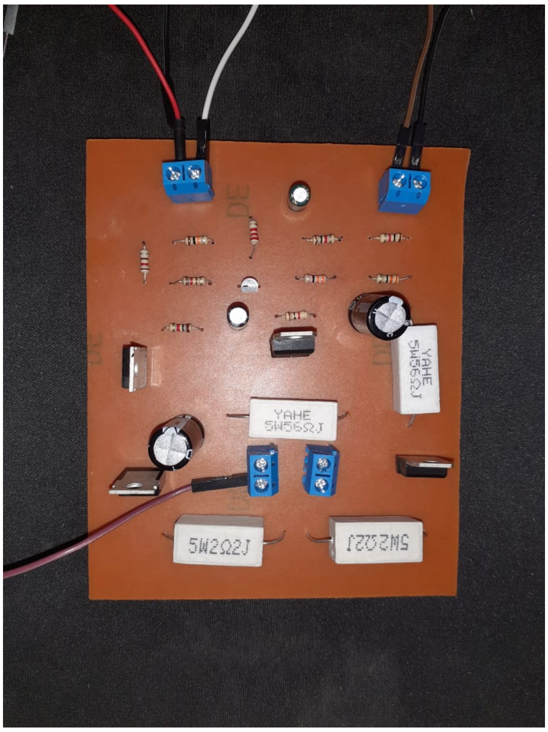


Figure 6: PCB

SolidWorks was used to create the Enclosure. To allow for heat dissipation and prevent the amplifier from overheating, the enclosure has a perforated cover (see Appendix C).

2.3.1 List of Components and Equipment Used

The list of components used in the circuit:

1. BC547BG NPN BJT transistor
2. TIP31C power transistor (2)
3. TIP32C power transistor (2)
4. Heat Sinks (4)
5. Capacitors (4.7uF – 1, 100uF – 1, 1000uF – 2)
6. Resistors (33Ω - 2, 120Ω - 2, 1kΩ - 4, 10kΩ - 1, 2.2kΩ - 1)
7. Power resistors (56Ω - 2, 2.2Ω - 2)

The list of other components and equipment used in the development process:

1. Breadboard
2. Digital Multimeter
3. Power supply
4. Signal Generator
5. Digital Oscilloscope
6. 8Ω speaker
7. Connectors
8. Materials required for screen printing and soldering the PCB

3 Results

Three steps made up the evaluation of the amplifier, with the first step being the basic calculations made by hand during circuit design. The simulation of the circuit was second and the prototype was eventually constructed and tested.
Requirements and methods used to test:

3.1 Testing and Results

The design requirements were examined and the parameters required for the datasheet were obtained using the actual prototype and the simulation.
The methods of obtaining those parameters are given below.

Design Requirement	**Testing Method**
Bandwidth	Simulation
Min No. of transistors	Simulation / Circuit Design
Operating Voltage	Initial Calculations
Allowable Input Voltage	Prototype
Allowable load without distortion	Prototype
Data sheet	Prototype / Simulation

3.1.1 Initial Calculations

The Hybrid model was initially used to generate some of the parameters for stage one. However , lot of these parameters were eventually discarded because they did not match the observed values.
For the first stage:
Find r_π:

$$r_\pi = \frac{V_T}{I_B} = \frac{26mV}{20mA/300} = 390\Omega$$

Input resistance:

$$R_{in} = R_{b1}//R_{b2}//r_\pi \approx r_\pi = 390\Omega$$

Open circuit voltage gain:

$$A_{vo} \approx \frac{\beta * R_c}{R_{in}} \approx 180 \approx 22.55dB$$

3.1.2 Simulation

Multisim was used to simulate the amplifier circuit. The following are the parameters that the simulation obtained:

1. **Open circuit gain - 18.986 dB**
The oscilloscope tool in Multisim was used to test the Open circuit gain. As seen in Figure 7, the value mentioned above is accurate for the mid frequency values.

2. **Gain with 8Ω load - 17.167dB**
By placing an 8Ω load across the output, the gain with an 8Ω load was

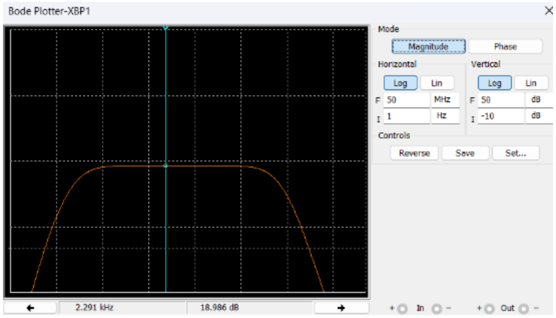


Figure 7: Bode plot of simulated circuit

evaluated. Then the oscilloscope tool was used to test the gain.

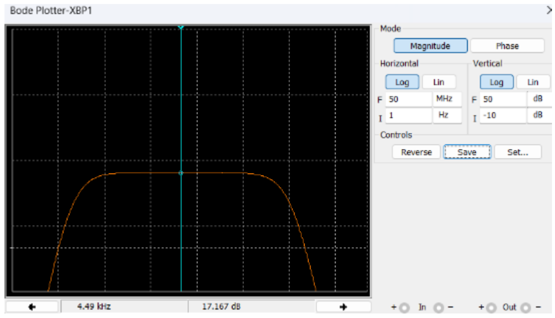


Figure 8: Bode plot of simulated circuit with 8Ω load

3. **Bandwidth – 19.302 Hz to 1.117 MHz**
The bode plotter tool which is available in the Multism was used to test the bandwidth of amplifier. Cutoff frequencies were taken as the half power points.

4. **Input Resistance – 2.772kΩ**
The multimeter was used to test the input resistance for measure the current drawn from the source.

5. **Output Resistance – 8.44Ω**
The input circuit was shorted to measure the output resistance. Then connecting a current source across the output and using the multimeter to measure the voltage across the output.

6. **Maximum Load Current – 31.6mA (for 8Ω load)**

The multimeter was used to measure the current through the load

3.1.3 Tested Circuit

The Prototype Amplifier was tested, and the results revealed the following useful parameters.

1. **Open Circuit Voltage Gain – 13.096dB**
   By attaching the input and output to an oscilloscope and determining the voltage gain between the two, the open circuit gain was evaluated. The voltage gain was evaluated for frequencies between 20Hz and 100kHz, and the value above is the highest voltage gain that was consistently present throughout the mid-frequency ranges.

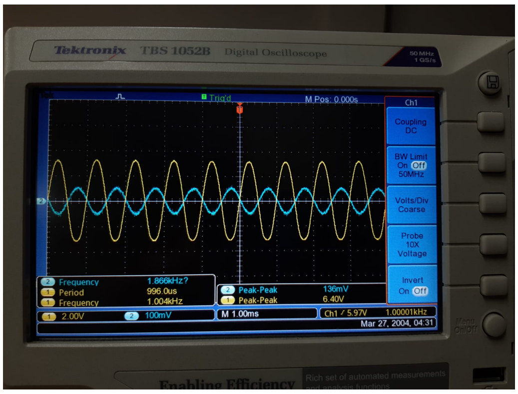


Figure 9: Output waveform with 8 Ω load

2. **Gain (with 8Ω load) – 11.64dB**
   The same procedure as before was used to test the voltage gain with an 8-volt load attached across the output.

3. **Bandwidth – 18.986Hz to 1.087MHz**
   The half power value(14dB) was obtained as the circuit's gain.
   Until the gain dropped to 14dB, the upper and lower cutoff values were calculated by slowly changing the input frequency.
   The lower cutoff frequency does not adhere to the design specifications, although the upper cutoff frequency complies.

4. **Input Resistance – 2.3kΩ**
   An ammeter was used to measure the current drawn from the input for an input voltage of 0.1V (peak to peak), with the output open circuited, in order to estimate the input resistance. The input resistance was then calculated by dividing the peak voltage (0.05V) by the peak current.

5. **Output Resistance – 7.9Ω**
   Two ways were used to determine the output resistance. First, we steadily decreased 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.
   The following equation was applied for a few different load resistances in order to validate this result:

$$R_{out} = \frac{A_o * R_L}{A} - R_L$$

   R_L = Load resistance
   A_o = Open circuit voltage gain
   A = Gain with given load resistance

6. **Maximum Load Current – 28mA (for 8Ω load)**
   Connecting an ammeter through the load and measuring the output current for a 0.1V peak to peak input signal to determine the maximum load current.

4 Individual contributions

Croos J.J.S.E	Circuit design, Soldering PCB, Breadboard Implementation
Kaushalya K.W.K	Circuit design, Documentation
Pathirana K.P.T.R	Circuit design, PCB design, Component Selection
Wanigathunga W.A.S.S	Circuit design, Enclosure design, Simulation in Multisim

5 Conclusion

Within the allotted time, we succeeded in finishing this project.
The amplifier falls short of entirely satisfying the bandwidth requirement. The lower cutoff(20kHz) is significantly lower than the specified requirement even though it satisfies the upper cutoff requirement (100kHz).

5.1 Discussion

- While driving a small load, the amplifier does not significantly lose gain or distortion.
- Within the specified bandwidth, there is a minor waveform distortion at all frequencies. This indicates an excessively high Total Harmonic Distortion.
- The values received during the simulation did not match the values obtained from the calculations.
- The TIP transistors produce a lot of heat that is dispersed. To prevent burning, heat sinks have been affixed to the amplifiers. In order to make sure that they can withstand the high currents flowing through them, power resistors have also been used.
- The simulation's settings came near to, but weren't exactly, the final values discovered after testing the physical prototype. The specification sheet, however, was created using prototype values. As a result, the performance of the amplifier will be accurately represented on the specification sheet.

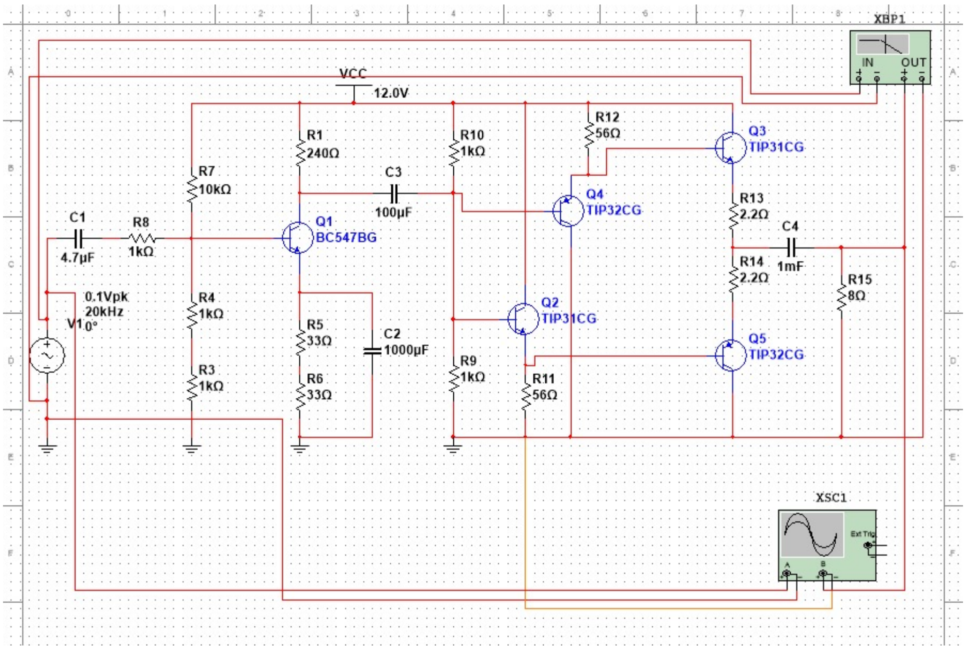
6 References

- Amplifier classes - https://www.electronics-tutorials.ws/amplifier/amplifier-classes.html
- BC546/547 Datasheet - https://www.sparkfun.com/datasheets/Components/BC546.pdf
- TIP31C Datasheet - https://www.st.com/resource/en/datasheet/tip31c.pdf
- TIP32C Datasheet - https://www.st.com/resource/en/datasheet/tip32c.pdf
- 2N2222 Datasheet - https://www.farnell.com/datasheets/296640.pdf

7 Appendices

Appendix A - Simulation Diagram

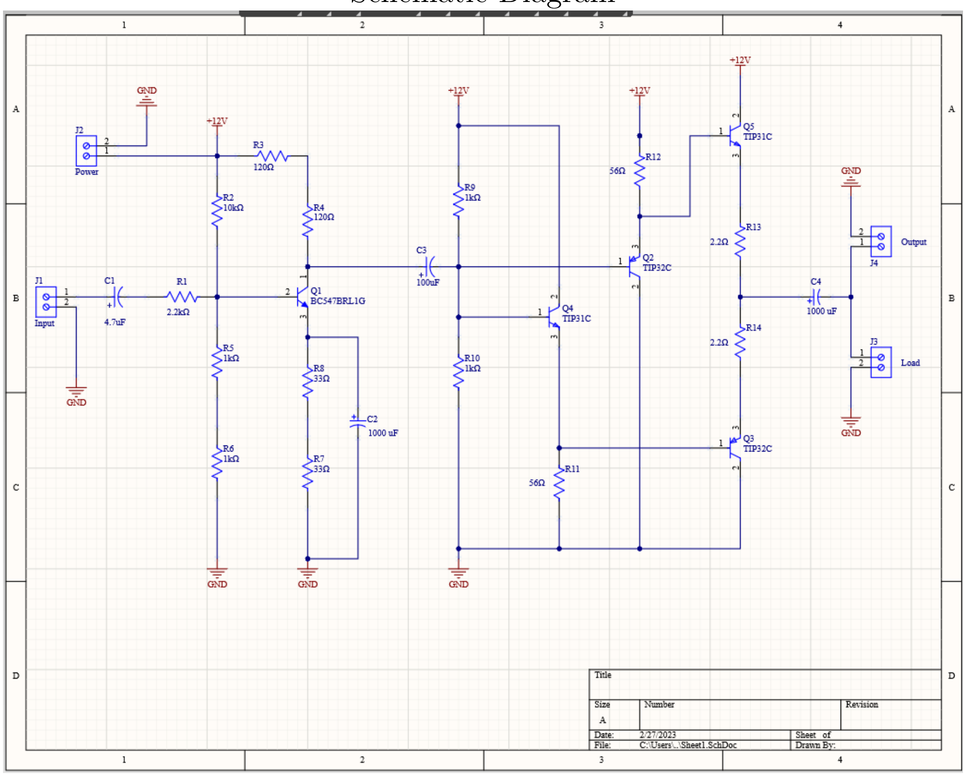
Circuit was design using Multism



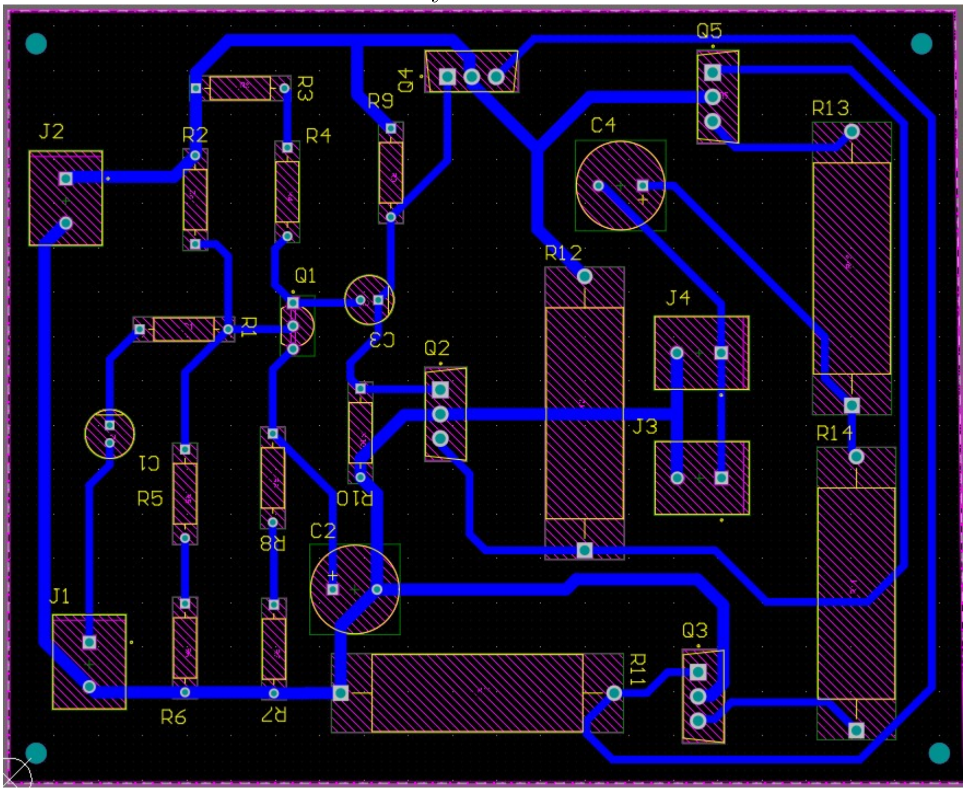
Appendix B - PCB Schematic Diagram

PCB layout was designed using Altium

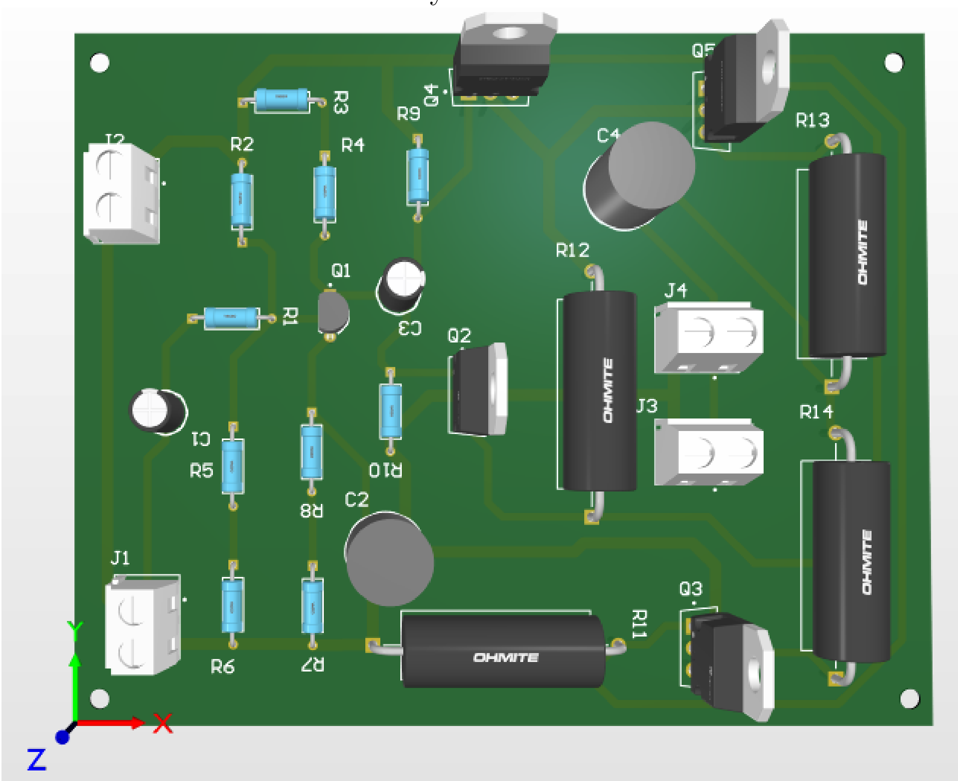
Schematic Diagram



PCB layout - 2D view

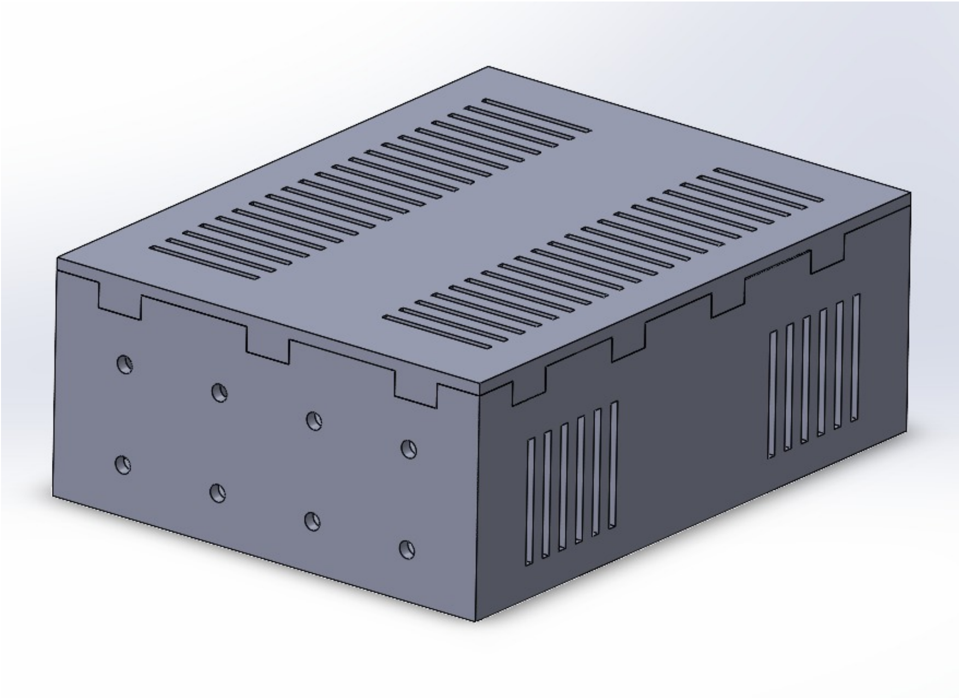


PCB layout - 3D view

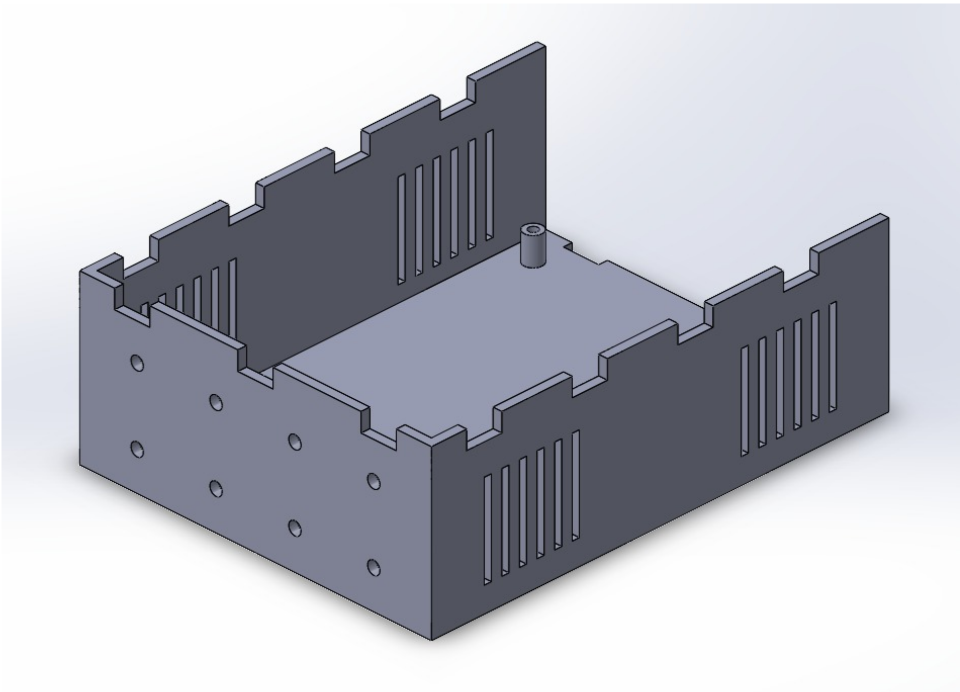


Appendix C – Enclosure

The enclosure was design using Solid Works

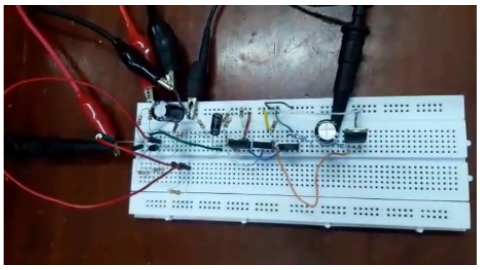


Top view

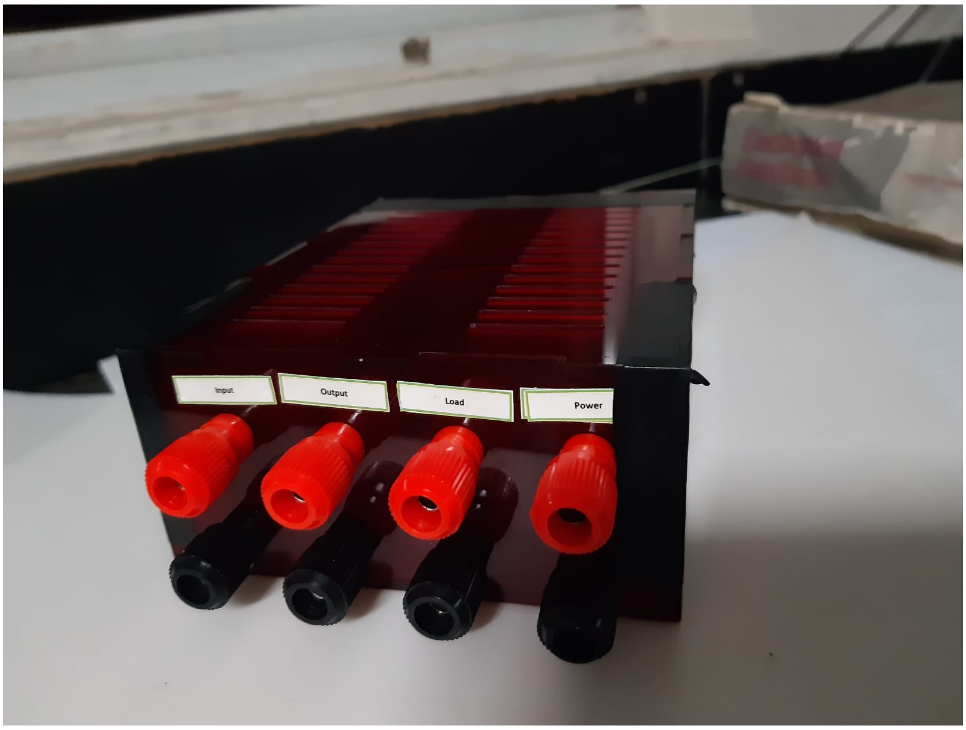


Inside view

Testing and Breadboard Implementation



Final Product



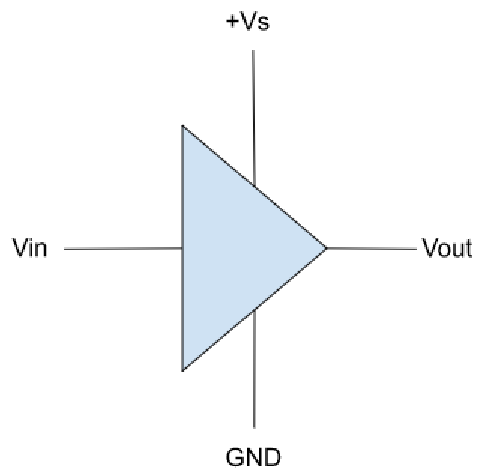
Appendix D – Specification Sheet

HIGH FREQUENCY AMPLIFIER

Specification Sheet

- **Description**
  The High Frequency Amplifier is an amplifier that can be used for high frequency applications. The design enables the amplifier to drive a small load, making it ideal for amplification of audio signals etc.

- **Functional Block Diagram**



- **Electrical Specifications**

Parameter	Conditions	Minimum	Typical	Maximum	Units
Operating Supply Voltage	-	-	-	12	V
Input Voltage (pk-pk)	Sine wave	-	-	0.1	V
Open Circuit Voltage Gain	$R_L \to \infty$	-	18.986	-	dB
Voltage Gain	$R_L \to 8\Omega$	-	17.167	-	dB
Bandwidth	-	-	1.117	-	MHz
Power Output	$R_L \to 8\Omega$	-	7.97	-	mW
Input Resistance	$R_L \to \infty$	-	2.787	-	kΩ
Output Resistance	V_s=0V	-	7.975	-	Ω
Load Current	$R_L \to 8\Omega$	-	31.6	-	mA