Department of Electronic and Telecommunication Engineering

University of Moratuwa

EN2091: Laboratory Practice

High Frequency Amplifier

Group 17

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Contents

1. Abstract

An amplifier is an electronic device which is capable of increasing the power of a signal. The current or voltage or both could be amplified. Depending on the frequencies that constituent the signal, there are different types of amplifiers. High frequency amplifiers are designed to operate with high frequency signals. Applications of high frequency amplifiers include telecommunication, high speed electronic measurements, laser research and photonic research. Factors such as bandwidth, low noise, noise immunity and high gain should be considered during the design process.

2. Introduction

The objective of our project is to design an amplifier that can amplify high frequency signals to a level at which it can drive speaker or a headphone with a load impedance of 8ohms.

The amplifier should meet the following requirements,

1. Bandwidth: 20kHz – 100kHz
2. Operating voltage: 12V
3. Input signal: 0.1V peak-to-peak voltage
4. Should be capable of driving a speaker or a headphone with 8ohm impedance.

Constraints,

1. Only simple analog electronic components such as transistors, resistors and capacitors can be used. Use of integrated circuits such as operational amplifiers is prohibited.
2. Should consists of at least 3 transistors.

A datasheet for our final product can be found at the end of this report (see Appendix D). It consists of the following specifications,

1. Operating Supply Voltage
2. Input Voltage (peak-to-peak)
3. Open Circuit Voltage Gain
4. Gain (with 8ohm load)
5. Input Resistance
6. Output Resistance
7. Average Output Power (with 8ohm load)
8. Bandwidth
9. Maximum Load Current

This report aims to discuss the full design process of our high frequency amplifier. After carrying out a thorough literary review and using Multisim circuit simulation software, we were able to design an amplifier that meets the above requirements. We varied parameters such as resistances and capacitors in Multisim circuit simulation software to find the circuit that meets the above requirements while having a sufficient gain. Then we implemented on our design on a breadboard to verify our simulation results. Then we designed a PCB using Altium PCB Design Software and an enclosure using SolidWorks and made our final product. The specification sheet values were obtained using the final product. Even though there was a slight deviation between our Multisim simulation results and our final product, our final product still had a sufficient gain and met the necessary requirements.

3. Methodology

The procedure of designing the amplifier will be explained broadly in this part followed by the theory of the amplifier circuit.

3.1 Theory of an Amplifier

An amplifier is an electronic device that is used to increase the magnitude of a given input signal. There are plenty of applications of an amplifier related to amplifying various kinds of signals. Among those types of signals, audio signal amplification is an area, targeted as an aspect of this report. Regarding ordinary applications such as music and voice, a maximum of 20kHz is needed to be handled but when it comes to some specific applications, it needs to be considered about the higher frequency signal amplification. So that is where high-frequency amplifiers come into play.

3.1.1 Different Classes of Amplifiers

Based on the operation range amplifiers can be classified into several classes such as A, B, AB, C & D-T.

Amplifier Class	A	B	AB	C	D-T
Operation type	Full cycle conduction	Half cycle conduction	180> conduction(slightly)	180< conduction(slightly)	(linear switching)
Operation angle	2π	π	$\pi<\boldsymbol{\theta}<2\pi$	$<\pi$	0

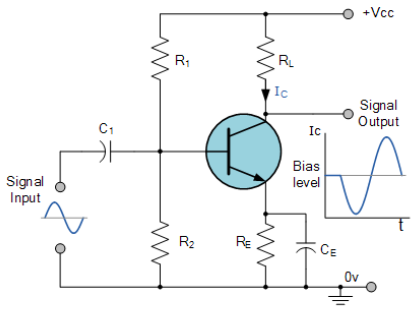
3.1.1.1 Amplifiers of Class A

The class A amplifier is the one primarily used in common. The single switching transistor is used in the standard common emitter circuit configuration as it is the simplest type of power amplifier.

The transistor is always biased "ON" to conducting of the duration of one complete cycle of the input signal waveform, resulting in the least amount of distortion and the highest possible output signal amplitude.

Even in the negative half cycles, there can be no crossover or switch-off distortion to the output waveform. So it can be considered as the ideal operating mode.

Since these type of transistors doesn't switch off during the oscillation, it is less efficient and generates a lot of heat as well. This drives it not to be used in high-power amplification applications.

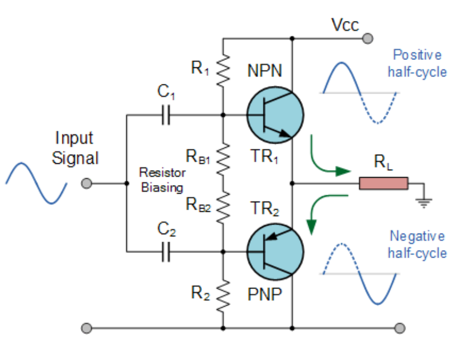


Single Stage Class A Amplifier Circuit

3.1.1.2 Amplifiers of Class B

In class B amplifiers, it is used 2 or more transistors biased in a way that each transistor conducts during a one-half cycle of the input waveform, By using 2 transistors it is possible to make a circuit commonly termed as class B amplifier which is also known as a push-pull amplifier which reduces the wasted power as heat in class A amplifier.

A negligible amount of DC current flows since there is no quiescent current present which drives it to generate a lesser amount of heat i.e. power dissipation is much lesser. Due to the bias point of nearly 0.7V, a slight waveform distortion called zero crossing distortion occurs.

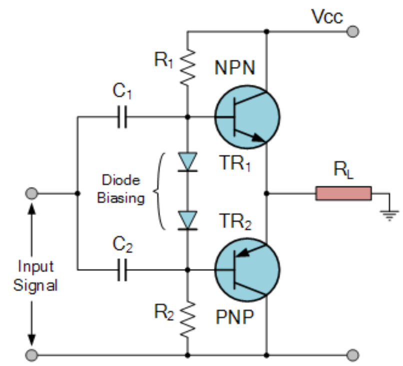


Class B Push-Pull Amplifier Circuit

3.1.1.3 Amplifiers of Class AB

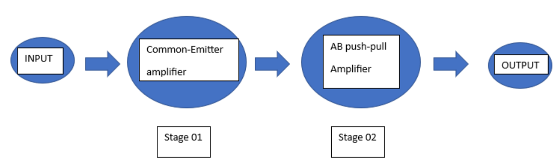
In class AB amplifiers, the issue of distortion we had earlier within the class B amplifier is completely solved by taking them into active regions permanently. although it reduces the efficiency by a little, the undistorted output waveform it gives is more significant.

Furthermore, the power dissipation due to the DC component is much lesser than class A amplifiers which makes this more appropriate for high-power applications.



4. Circuit Design

Amplification of the high-frequency signal is done by two stages of the amplifier circuit which increases the voltage followed by the power. The first stage uses a Bipolar Junction Transistor (BJT) in a Common Emitter configuration and the second stage uses 4 BJTs in AB push-pull configuration.

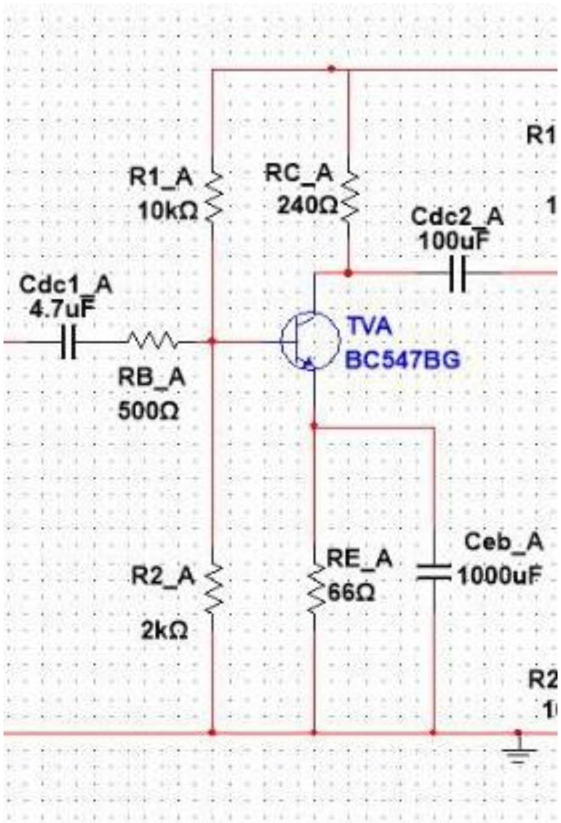


A 100uF coupling capacitor is used to couple each stage in order to refrain from propagation of DC signals and input is coupled using a 4.7µF capacitor upon the very reason discussed above. As a result of the readings & observations obtained in testing rounds, a 500Ω resistor is used to reduce distortions that were present in the initial design. Also, the output is coupled with a 1000µF capacitor for the same reason above because if DC signals are propagated into the speaker, it would damage the speaker.

4.1 Stage 01 - Voltage amplifier in Common Emitter configuration

This stage aims to get a voltage gain enough to pass through the circuitry next to it. In order to get a larger voltage gain it is decided to go with a class A common emitter amplifier. As a result it was given a gain approximately equal to 20.

Based on the forward voltage gain(h_{fe}) value BC547BG transistor is selected after a comparison with other transistors because it has a higher forward current gain and additionally, the higher bandwidth and the faster switching ability make it some steps closer to enabling the ability of handling high frequencies.



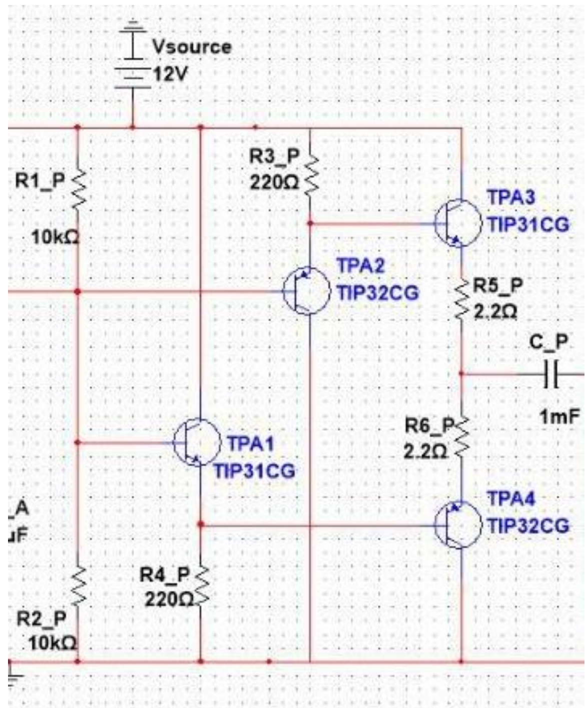
Stage 01 circuit diagram

Procedure of designing the first stage

- The BC547BG was needed to be biased first so it was decided to go with according to potential divider bias method, and bias voltage was needed to exceed the voltage barrier of the BE junction (0.7 V), so it was selected as 2V. Since we have 12V power supply, it was easier to divide into 10V & 2V by using 10kΩ and 2kΩ resistances.
- Since base current is very low it is assumed as zero. Hence V_B is 2V.
- Because of the 0.7V drop through the BE junction. V_E = 1.3V.
- Emitter resistance is selected as I_E happens to be 18mA.(approximately)
- Therefore R_E 72.2 kΩ and IC ≈ 18mA.
- For the allowance of the fullest swing of the voltage during operation of amplification to get the maximum gain without any distortion, V_{CE} is taken as half of V_{CC} (6V)
- Hence R_c can be calculated as [12-(6+1.3)] /18 = 261.11Ω.
- Considering the availability in the market components with approximately equal values have been chosen.

4.2 Stage 02 - Power Amplifier in Push-Pull Configuration

The next stage is a push-pull amplifier of AB class. Necessity of this stage is to get the expected power amplification without having a more considerable decrement of the output amplitude to drive a small load of range 4-8 ohms



TIP31C & TIP32C NPN & PNP power transistor pair is what we decided to choose after going through datasheets and later with the recommendations found and the results shown online, persuaded to confirm the decision.

There is some information obtained by the comparison of datasheets such as the ability of handling large currents and the significant current gain of the selected transistors.

To handle the large currents passing through them, 220Ω power resistors have been used.

Even though this stage has a voltage gain of unity the current gain is higher, and it does what it was assigned in the circuit.

The load is also connected with a capacitor to make sure that the absence of a DC component in the output.

5. Components Used & Equipment Required

The list of components used in the circuit,

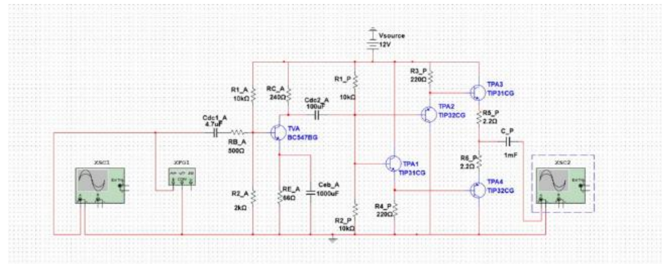
Name	Quantity
• BC547BG NPN BJT transistor	1
• TIP31C power transistors	2
• TIP32C power transistor	2
• Heat Sinks	4
• Capacitors	
○ 1000uF	2
○ 100uF	1
○ 4.7UF	1
• Resistors	
○ 250mW	
▪ 10kΩ	3
▪ 1kΩ	4
▪ 33Ω	2
▪ 120Ω	2
○ 1W	
▪ 220Ω	2
▪ 2.2Ω	2
• Switches	1
• 1W 8Ω speaker	1
• Connecting clips	6
• Barrel connector	1

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

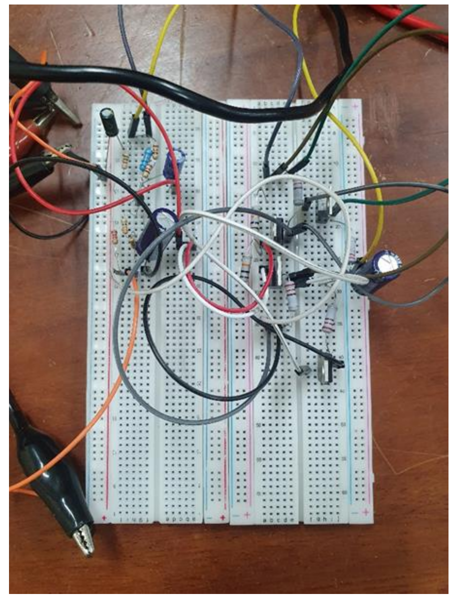
- Protoboards
- Digital Multimeter
- Power supply
- Function Generator
- Digital Oscilloscope
- 4Ω, 8Ω resistors
- Connectors
- Materials required for screen printing and soldering the PCB.
- Jumper wires for connectivity

6. Prototyping & Final Product Design

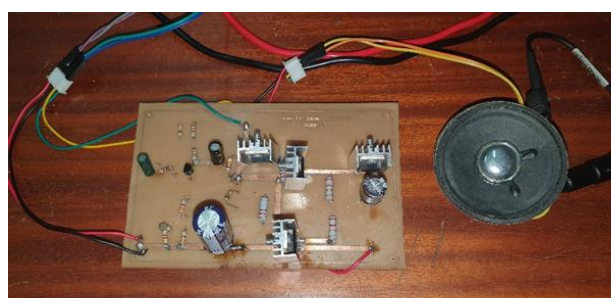
The virtual prototype was designed using Multisim Circuit Simulation Software. Parameters such as resistances and capacitances were varied in order to improve the performance of our circuit. The schematic of our final circuit is shown below.



Then we carried our breadboard implementation and were able to get results that deviated only slightly from the simulation (see Appendix A for simulation results).



After designing and printing the PCB (see Appendix B for PCB Design), we soldered the components and made the final circuit that would be placed inside the enclosure of our final product (see Appendix C for enclosure). The PCB implementation has a slight deviation from breadboard implementation. Nevertheless, it met the necessary requirements and had a sufficient voltage gain.



Then the product was finished by placing the final circuit inside the enclosure and making necessary connections to the external probes for giving inputs, obtaining outputs and taking measurements.

7. Results

7.1. Requirements

- Create a high-frequency amplifier that can support an 8Ω load impedance.
- A functional 12V must be supported by the design.
- A sine wave of 0.1V must be amplified by the construction.
- The design must operate in the 20 kHz to 100 kHz frequency band (Bandwidth requirement)
- The configuration must use a minimum of three transistors; the use of op-amps is not permitted.

- In addition to the demonstration, a datasheet for the design must be supplied.

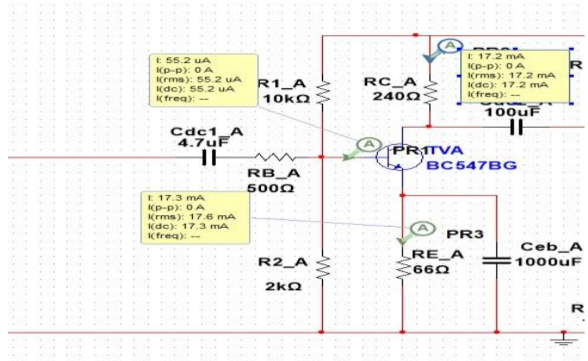
7.2. Testing and results

The design specifications were examined, and the datasheet's necessary parameters were acquired using the physical prototype and the simulation. Below is a way for obtaining those parameters.

7.2.1 Simulation results

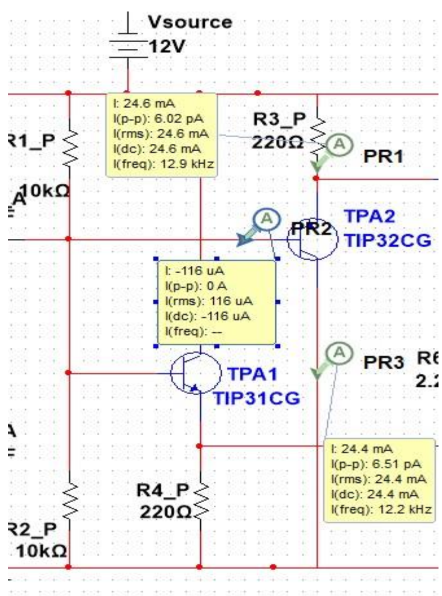
NI Multisim 14.2 was used to model the amplifier circuit. The following are the values that the simulation yielded:

1. Stage 1 – amplifier in common emitter configuration(BJT -BC547)



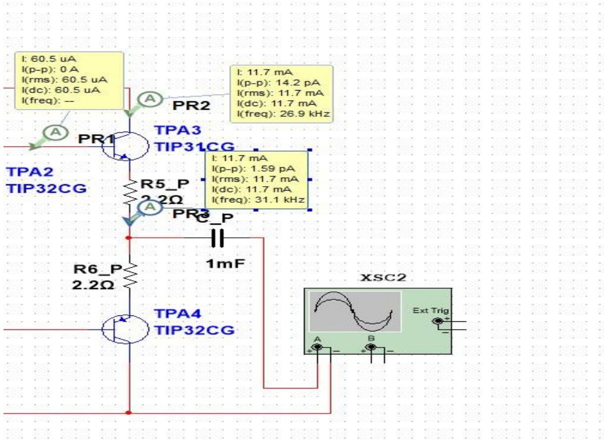
- Base current = 55.2 uA
- Collector current = 17.2 mA
- Emitter current = 17.3 mA
- Beta = 17.2*1000/55.2 = 311.594
- $r_\pi = V_T/I_B$ = 26000/55.2 = 471.014 Ω
- Input impedance = 367 Ω
- Voltage gain(A_{vo}) = -240*311.594/471.014 = -158.769

2. Stage 2 – emitter follower (buffer)

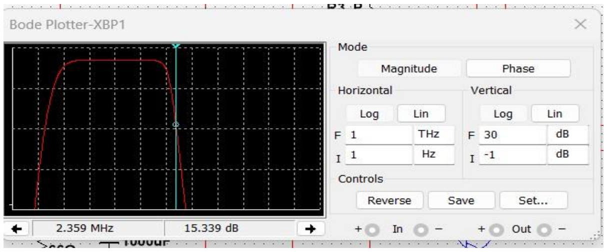


- Base current = 116 uA
- Collector current = 24.2 mA
- Emitter current = 24.6 mA
- Beta = 24.2*1000/116 = 208.62

3. Stage 3 – push pull circuit



1. Base current = 60.5 uA
2. Collector current = 11.7 mA
3. Emitter current = 11.7 mA
4. Beta = 11.7*1000/60.5 = 193.88
5. Open circuit gain = 20*log(30) = 29.542 dB
6. Current gain with load = 20*log(22.97) = 27.223 dB
7. Bandwidth – 20.153 Hz to 2.359 MHz
   a. Using the Bode Plotter tool in Multisim, the amplifier's spectrum was evaluated. Half power points were chosen as the cutoff frequencies (15dB).The measured bandwidth complies with the bandwidth's design specifications.
   b. Bode plot



8. Maximum load current – 140.25 mA
9. Total Harmonic Distortion (THD) –

Utilizing Multisim's Total Harmonic Distortion Tool, the harmonic distortion was determined. When tested at various frequencies, it ranged from 2.8% at low frequencies to 33% at high frequencies.

Initial Designs

The amplifier was originally designed with three stages including a medium current amplification stage using an emitter follower amplifier. After removing the intermediate current amplification stage, it was observed that the voltage gain of the amplifier does not decrease. This is because the input impedance of the amplifier is significantly reduced with the elimination of the emitter follower stage. To reduce this problem, we decided to increase the base resistance of the first and last stages. This resulted in a higher input impedance, which improved the amplifier's performance.

However, this increase in base resistance created a new problem. Low input resistance caused distortion of the input signal when a load was connected. This was due to the loading effect, which occurs when the load impedance is much smaller than the amplifier's input impedance. To prevent this distortion, we connected a 500Ω resistor in series with the input coupling capacitor. This increased the input impedance of the amplifier and eliminated the distortion caused by the loading effect.

Even after addressing the input distortion, there was still a slight distortion in the output signal when a load was connected. This was due to the relatively high output impedance of the amplifier. To reduce the output distortion, we could have added an output buffer stage to the amplifier. However, this will increase the complexity of the circuit and add additional cost. Alternatively, the output impedance of the amplifier can be reduced by increasing the collector resistance of the final stage. This improves the output performance of the amplifier without adding additional stages.

8. Conclusion

The successful completion of the amplifier project is a significant achievement and demonstrates effective engineering design and project management. Meeting the high cut off requirement of 100kHz and the low cut off requirement of 20kHz is an important success criterion, as it ensures that the amplifier can handle a wide range of frequencies. Additionally, the output is free of distortion, indicating that the design of the amplifier is robust and can perform well under a variety of conditions. The amplifier can deliver good gain even with a load and in an open loop, suggesting that it is able to handle a range of loads and signal amplitudes. The success of the project can be attributed to a combination of effective planning, good design, and effective execution.

8.1. Discussion

An inability to experience significant gain loss or distortion when the amplifier is driving small loads is a positive sign, suggesting that the amplifier is well matched to the load. This can be important in applications where the load impedance may vary or where the amplifier is required to drive a low impedance load.

However, slight wave distortion is a concern for all frequencies within a given bandwidth. This indicates that the Total Harmonic Distortion (THD) of the amplifier is higher. THD is a measure of the amount of distortion introduced into a signal by an amplifier and is a key performance parameter. High THD can cause loss of signal quality and affect amplifier performance. It may be necessary to adjust the amplifier design to reduce the THD and improve the overall performance of the amplifier.

Also of note is the large amount of heat dissipated by the TIP transistors, which suggests that the amplifier may not be working efficiently. However, the fact that amplifiers are fitted with heat sinks and use power resistors to handle the large currents passing through them indicates that steps have been taken to manage heat dissipation. Further optimization of the amplifier design may be necessary to reduce heat dissipation and improve the overall efficiency of the amplifier.

Since there are often differences between theoretical calculations and practical implementations it is not unexpected that values obtained by preliminary calculations do not agree with values obtained through simulation. However, it is important to carefully analyse these differences to ensure that the amplifier design is accurate and reliable.

Further optimization of the amplifier design may be required to reduce heat dissipation and improve the overall efficiency of the amplifier.

However, the fact that the specification sheet is based on prototype values implies that the specification sheet will be an accurate representation of the amplifier's performance.

9. References

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10. Contribution by Members

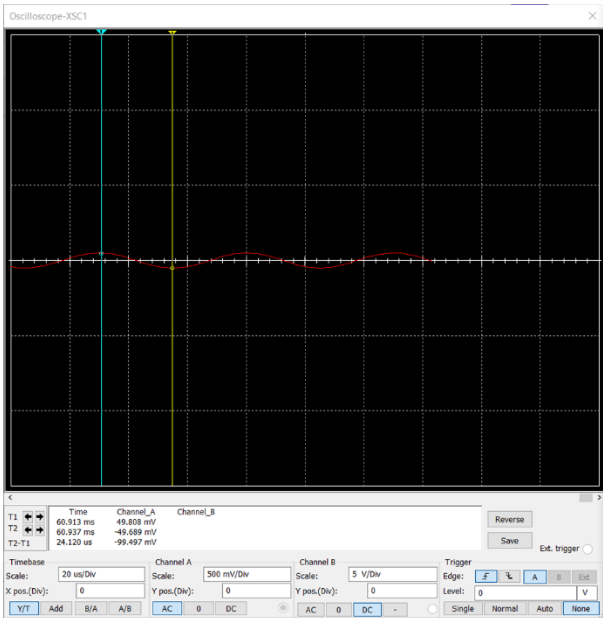
Index Number	Name	Contribution
200118X	DESHAPRIYA G.I.	Circuit Design, Prototyping & Testing, PCB Design using Altium, Final Assembly.
200306X	KISHOKKUMAR R.	Circuit Design, Prototyping & Testing, Enclosure Design using SolidWorks.
200462U	PERERA N.W.P.R.A.	Circuit Design, Circuit Simulation, Prototyping & Testing, Final Assembly, Documentation.
200702H	WEERASINGHE P.D.G.U.M.B.	Circuit Design, Prototyping & Testing, Final Assembly, Documentation.

11. Annex

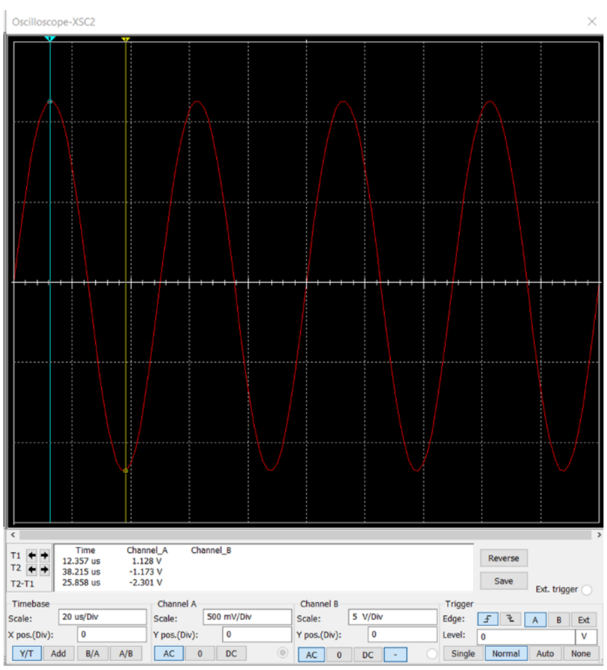
Appendix A – Multisim Simulation Results

For 20kHz,

Input Signal



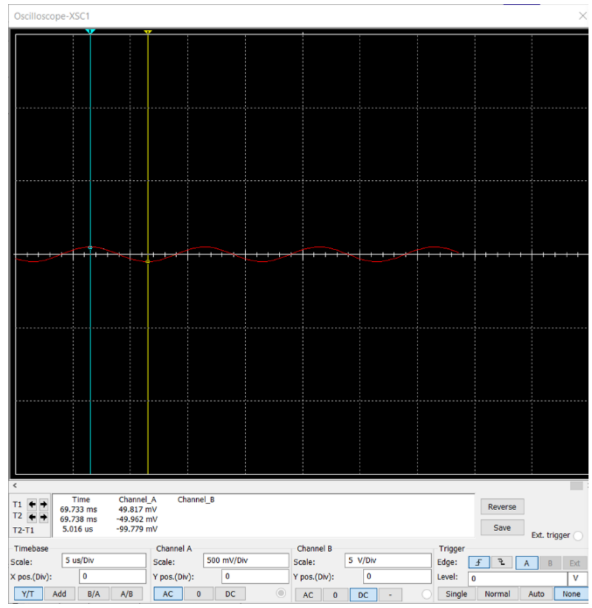
Output Signal



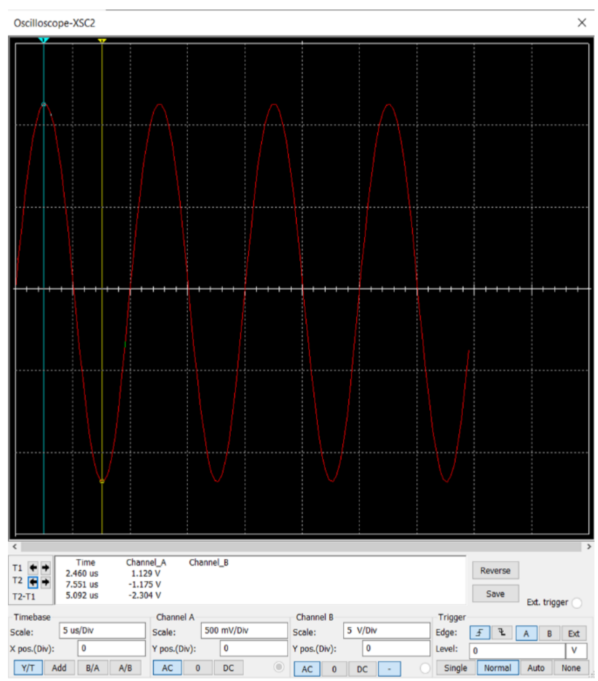
Gain = 27.24dB

For 100kHz,

Input Signal



Output Signal

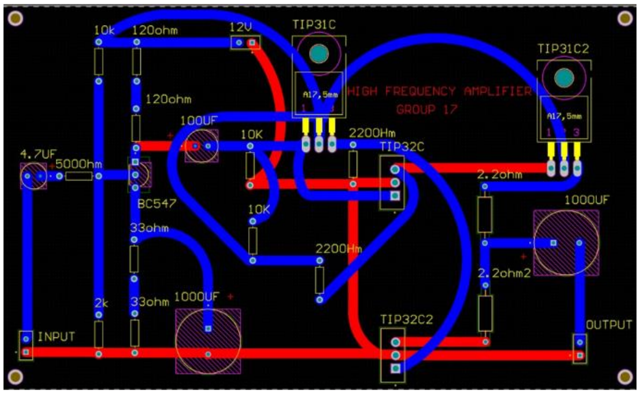


Gain = 27.24dB

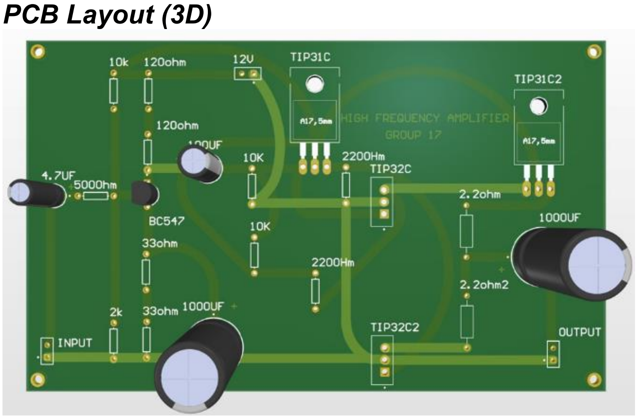
Appendix B – PCB Design

We designed the PCB using Altium PCB Design Software. We decided to use a two-layer design to make the PCB more compact to reduce the size of the final product.

PCB Layout

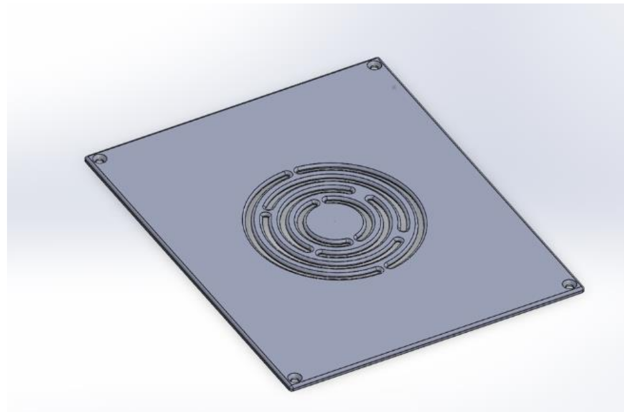


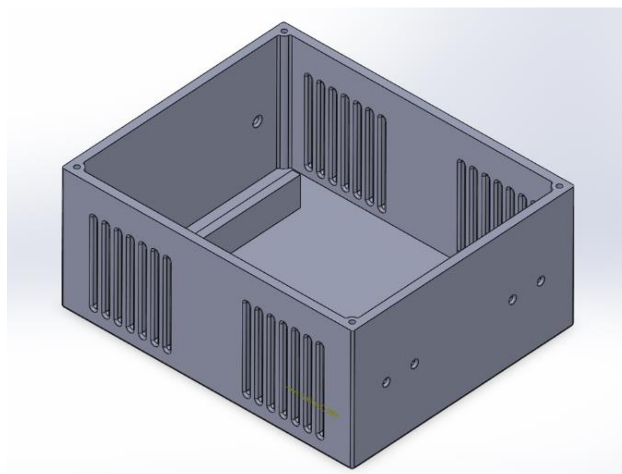
PCB Layout (3D)



Appendix C – Enclosure

We designed the enclosure using SolidWorks and used 3D printing to make the enclosure. Perforated holes are present on the enclosure for better heat dissipation by the power transistors.



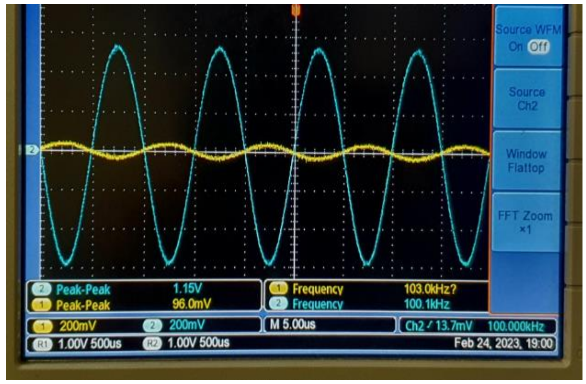


Appendix D – Oscilloscope Results of Final Product

For 20kHz (Open Loop)

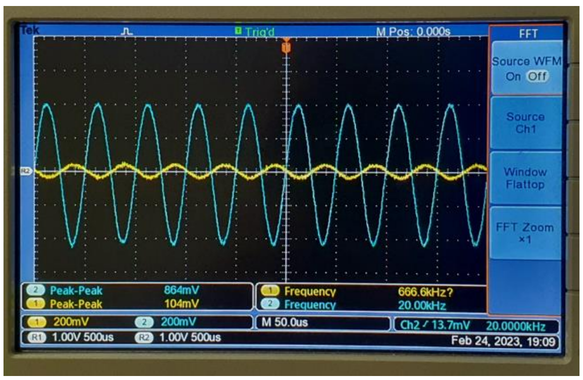
Gain = 21.42dB

For 100kHz (Open Loop)



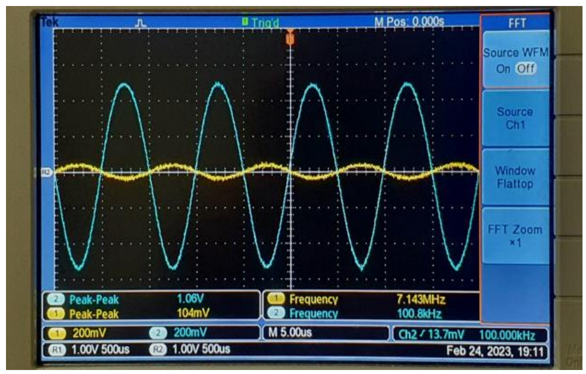
Gain=21.57dB

For 20kHz (with 8Ω load)



Gain=18.39dB

For 100kHz (with 8Ω load)



Gain=20.17dB

Appendix E – Specification Sheet

Parameter	Conditions	Typical	Maximum	Units
Supply Voltage			12	V
Input Voltage (peak-to-peak)			100	mV
Open Circuit Voltage Gain	$R_L \to \infty$	21	22	dB
Voltage Gain	$R_L = 8\Omega$	19	21	dB
Input Resistance	$R_L \to \infty$	175		MΩ
Output Resistance	Vs=0V	10		Ω
Bandwidth		1.176		MHz
Load Current	$R_L = 8\Omega$		288 (pk-pk)	mA
Power Output	$R_L = 8\Omega$		84.4	mW

Appendix F – Frequency Response