Group 01

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Project Report

High Frequency Amplifier

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Laboratory Practice - II

Module Code :- EN 2090

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ABSTRACT

Our project aim was to design a High Frequency Amplifier (HFA), using analog components such as transistors, resistors and capacitors. We are not allowed to use any sort of prebuilt operational amplifiers. The designed high frequency amplifier should be able to drive a head-phone (8 Ω speaker) without any distortion at the amplified signal. The design must be able to amplify a sine wave of 0.1V. The expected bandwidth of the device is from 20KHz to 100KHz.

The high frequency amplifier was designed with two stages. The first stage was to amplify the voltage while the second stage increases the power gain. The first stage uses one transistor in the Common Emitter (CE) configuration. Second stage uses four transistors in AB push pull amplifier configuration to achieve the power gain needed to drive the load.

This report contains the introduction to the project, the tasks, the requirements given and methods that are followed to tackle the tasks. The report also contains the details about circuitry, theories used, and the final outcome

1.INTRODUCTION

An amplifier is a device that increases the power without any distortion on the output of a given input signal. As per the name, it is designed with the purpose to operate at high frequencies in the kHz range. This part of the report has the target specifications to be met at the completion of the project.

Objectives

The main task was to design a simple high frequency amplifier which is capable of driving a headphone, which has an 8 Ω load.

The main expected outcomes of the project are as follows

- Should be able to drive a load impedance of 8Ω (headphone, speaker)
- Compatible with a supply voltage of 12V
- Design should be fully analog.
- Minimum number of transistors is 3 and no op-amps can be used.
- Working frequency range (Bandwidth requirement) is 20 kHz - 100 kHz
- Must be able to amplify simple sine waves

Input signal - A sine wave of 0.1V (peak-peak voltage) in the frequency range of 20KHz - 100KHz.

Other than these points we are also expected to provide a datasheet with the specifications of the built amplifier.

2. METHODOLOGY

This part of the report describes the theories used to build the amplifier as well as the methods used for the completion of the project.

Initial Design

With initial introduction to the project, the initial circuit was designed as sketch and calculations were made to get the ideal values for the components

Circuit Design

The circuit is a cascade amplifier with analog components.The design consists of two stages. The first stage being the CE amplifier & the second stage being the class AB push-pull amplifier.

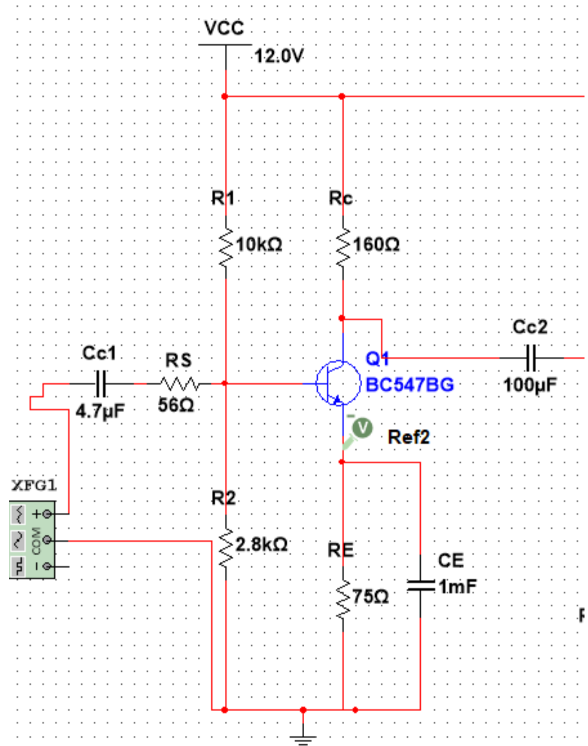
Amplifier Classes

Depending on the operational range of amplifiers they are classified into many types , the main ones are as follows,

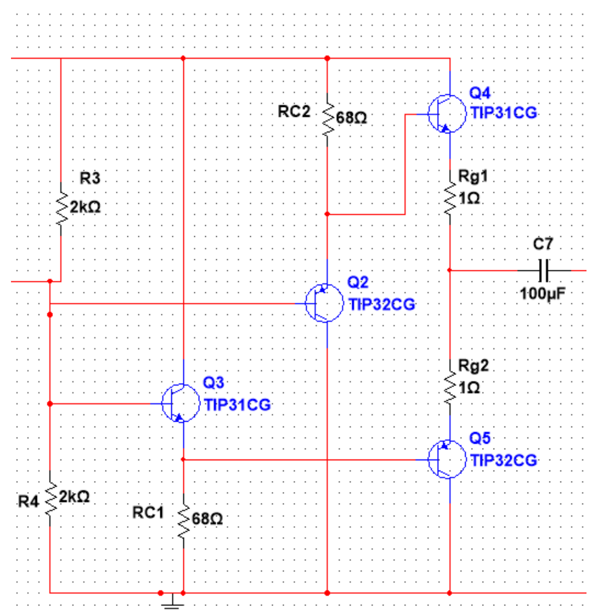
1. Class A amplifiers - The amplifiers' single output transistor conducts for the full 360° of the cycle of the input waveform.
2. Class B Amplifiers - The amplifiers' two output transistors only conduct for one-half, that is, 180° of the input waveform.
3. Class AB Amplifiers - The amplifiers' two output transistors conduct somewhere between 180° and 360° of the input waveform.
4. Class C Amplifiers - The amplifiers' two output transistors conduct less than 180° of the input waveform.
5. Class D-T Amplifiers

Methodology

Stage 1 - Common Emitter configuration



Stage 2 - AB push pull amplification



Stage One

In this stage the main target is to get a high voltage amplitude of the signal such that it can pass through the push-pull part. For this we used a BC 547 transistor model in CE configuration as it is the most effective and suitable method for high frequencies. Among other transistors, this model shows more capabilities for this task. BC 547 has,

- Considerably high h_{FE} (DC Current Gain)
- High Gain Bandwidth product
- Stable h_{FE} with collector current (up to 100mA) and temperature.
- Fast switching / fast responding time

In this step we mainly focused on V_{CE} to be placed at 6V in order to get the full swing of the voltage.

Since absolute maximum rated V_{EBO} is 6V we decided to bias the base around 2.5V, therefore we selected base resistors as R_{B1} = 10k and R_{B2} = 2.8k such that V_B = 2.625V. (Assuming that I_B current is negligible).

Since the typical value of V_{BE} is given as 0.7V,

$$V_B = 0.7V + (\frac{1}{\beta} + 1) I_C R_E$$

According to the datasheet, the maximum collector current for which the h_{FE} is steady, is 100mA. **β**= 345. Therefore, we selected R_E such that I_C to be lower than 30mA. Hence,

$$R_{E\ min} = \frac{V_B - 0.7}{30} \times 10^3 = 64.167\ \Omega$$

Next, we selected R_E to be 75Ω, which makes $I_C \approx 25.67$mA

By deriving the DC load line,

$$12 \approx V_{CE} + I_C(R_E + R_C)$$

Since our target was V_{CE} to be at 6V,by substituting above I_C and R_E values we get

R_C=160Ω.

However, after implementing the circuit on a protoboard, we had to change values in order to get a clear output waveform.

Stage Two

The purpose of this stage is to get sufficient power amplification to drive the 8Ω load without any distortions. This is an AB Push Pull amplifier, one of the most suitable methods for power amplification. Although the conventional AB amplifier consists of a diode, we replaced it with two other transistors, which will act as a diode, as well as improve amplification. After doing some research about power amplifiers, we found that TIP31C/ TIP32C transistor models are good enough for our task.

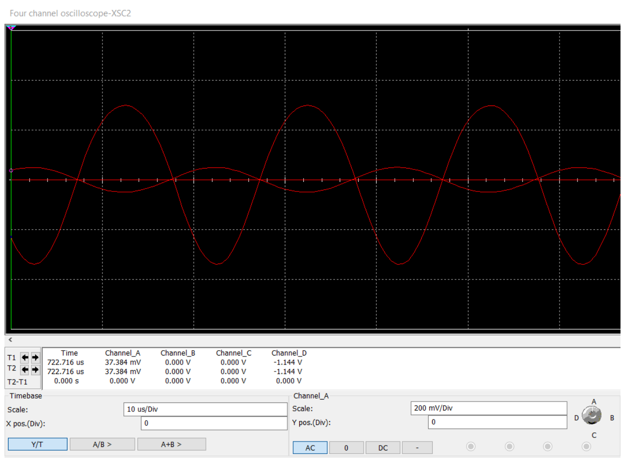
- TIP31C/ TIP32C has a stable DC current gain (h_{FE}) up to collector current = 10A.
- Tolerable for higher temperatures
- Good at audio and other signal amplification requirements.
- These transistors have high switching speed and linear output.
- These transistors give a significant current gain and can handle the large currents that are passing through them.

Development Progress - Simulations

After making the calculations and designing the circuit, the next step was to try it in a simulation. Initially we used “circuit maker” to simulate the circuit but due to the limitations and lack of components in the circuit maker, the final simulation was done on Multisim 15.1.

Many readings and testings were done on the software itself. The following are the circuit parameters we got from the simulations

Simulation Results



Simulations parameters

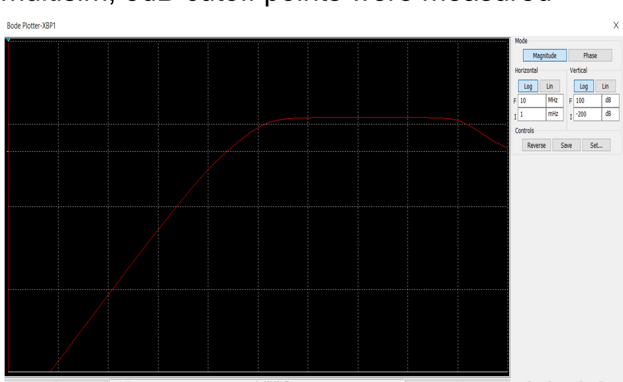
Gain

$$A_v = \frac{3.17V}{0.1V} = 31.7$$

$$A_i = \frac{395mA}{180uA} = 2194.44$$

Power Gain = 48.46 dB

By using the blode plotter available in multisim, 3dB cutoff points were measured



Higher cutoff =1.169MHz
Lower cutoff = 191.8Hz
Bandwidth = 1.1688MHz

Input Resistance = 555.56 ohm
Output Resistance = 2.8 ohm
Max load current = 143mA(rms)
THD : measured by the Distortion Analyzer tool in the multisim
20kHz – 7.874%
50kHz – 7.856%
100kHz – 7.818%

Development Progress - Prototype

After the successful simulations with satisfactory results we moved to the physical prototype design stage. The physical prototype was built on the breadboards with the following components

List of components used

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

Along with these components the following equipment is used for testing purposes.

1. DC Power Supply
2. Function Generator
3. Oscilloscope
4. Digital Multimeter
5. Connectors

When the calculated values of the simulations were brought into the physical prototype, there were a significant number of challenges we had to overcome

The physical prototype built with the calculated values for components, didn't give the same output in the physical context as the simulation.

The output waveform was distorted and the gain was way lower.

Even though stage 1 voltage amplification of the circuit properly translated into the physical context, the above mentioned issue continuously occurred for stage 2 power amplification. So in order to overcome the issue we calculated how the values should change (either decrease or increase) and used a trial and error method to adjust the component values to get the expected outcome. But we maintained the required values for the transistor thresholds.

Another issue was components getting heated, due to the high currents passing. We used power resistors as well heatsinks to overcome this issues

Sometimes there were moments where the prototype would work well on one day, and not working on the next day. There were problems with jumper wires as well.

Development Progress - PCB

The PCB was designed using Altium designer. The schematic diagram, and the pcb layout is attached in the appendix. While soldering, we had to face some issues like the disconnection of routes. We continuously did continuity checks and used solder in places where it was needed more to overcome this issue.

Development Progress - Enclosure

The main idea our team had when designing the enclosure was providing enough ventilation for the amplifier.

Also since the device was a high frequency amplifier the team decided to go with the shape of the OP AMP

The enclosure is designed with air vents in the top and side panels for proper ventilation and it is lifted slightly above the ground level using legs which would represent the op amp junctions and also will promote more ventilation

There are a switch for turning on/off the amplifier, a port for 12V power supply for the device and two 3.5mm audio jacks for audio in and audio out as the amplifier is designed to drive a 8ohm speaker

3. RESULTS

The evaluation of the circuit occurred in 3 phases ,

1. Calculated Values
2. Simulation Values
3. Prototype Values

The calculated values and the simulation values are already mentioned above

Using the physical prototype the values for the data sheet are calculated. The calculations along with the methods are as follows,

Parameters of the tested circuit

<u>Open circuited voltage Gain - 32.2dB</u>

The open circuit voltage gain is obtained from output(pk-pk) voltage is divided by input(pk-pk) voltage when output is open circuited.

Voltage Gain(with load) - 26.44dB

The voltage gain is calculated the same as above but load (8Ω) is connected across the output.

Bandwidth - 325Hz to 920kHz

As the overall power gain is known, when the gain value becomes half of it, find the value of frequency.

Bandwidth(open circuited) - 325 Hz to 920kHz

This is measured same as above but open circuited the output.

Input Resistance - 420.17 Ω

The peak voltage is divided by the input peak current, giving the input resistance. Measure the current drawn by the input circuit using an ammeter, with the open circuited output.

Output Resistance = 2.4Ω

Output resistance is measured by short circuiting the input and measuring the current and voltage across the output using a multimeter.

Max load current = 256.1mA

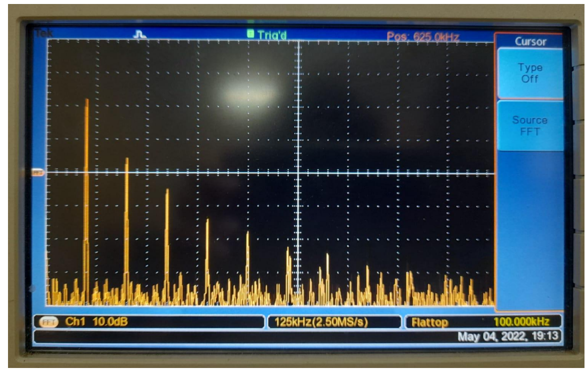
Max. load current is measured by connecting a multimeter through the load and reading the output current for 0.1V (pk-pk) input signal.

THD - Total harmonic distortion

THD is determined by FFT(fourier transform) of the output signal, using a digital oscilloscope.

$$\text{THD} = \frac{\Sigma\, rms\ values\ of\ harmonics}{rms\ value\ of\ fundamental\ component} \text{ x } 100\%$$

$$\text{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots\ldots}}{V1} \times 100\%$$



Values taken at different frequencies (considering only the first three harmonics) ,

20kHz – 6.724%

25kHz – 6.851%

50kHz – 7.769%

100kHz – 7.703%

4. CONCLUSION

As a team, we were able to finish the project excluding the physical enclosure within the given time period.

Even though we finished the project with almost all required design parameters excluding the bandwidth , we weren't able to meet the parameters we got from the simulations due to physical constraints.

Overall, the parameters of the components obtained by the initial calculations and simulations did not agree with the physical implementation.

Also the amplifier experiences a slight gain reduction when it continuously runs for a long time at the upper cut-off frequency due to the heating of components.

In the final product there is a significant amount of heat dissipation in the TIP Transistors and the resistors close to them. But the heatsinks are attached to reduce the dissipation

5. REFERENCES

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
Amplifier Classes
https://www.electronicstutorials.ws/amplifier/amplifier-classes.html

7. CONTRIBUTIONS

180601T - Shyamal.M.A.L - PCB Design & Initial Calculations

190001M - Aakkash.G - Overall project Report & Data sheet calculations

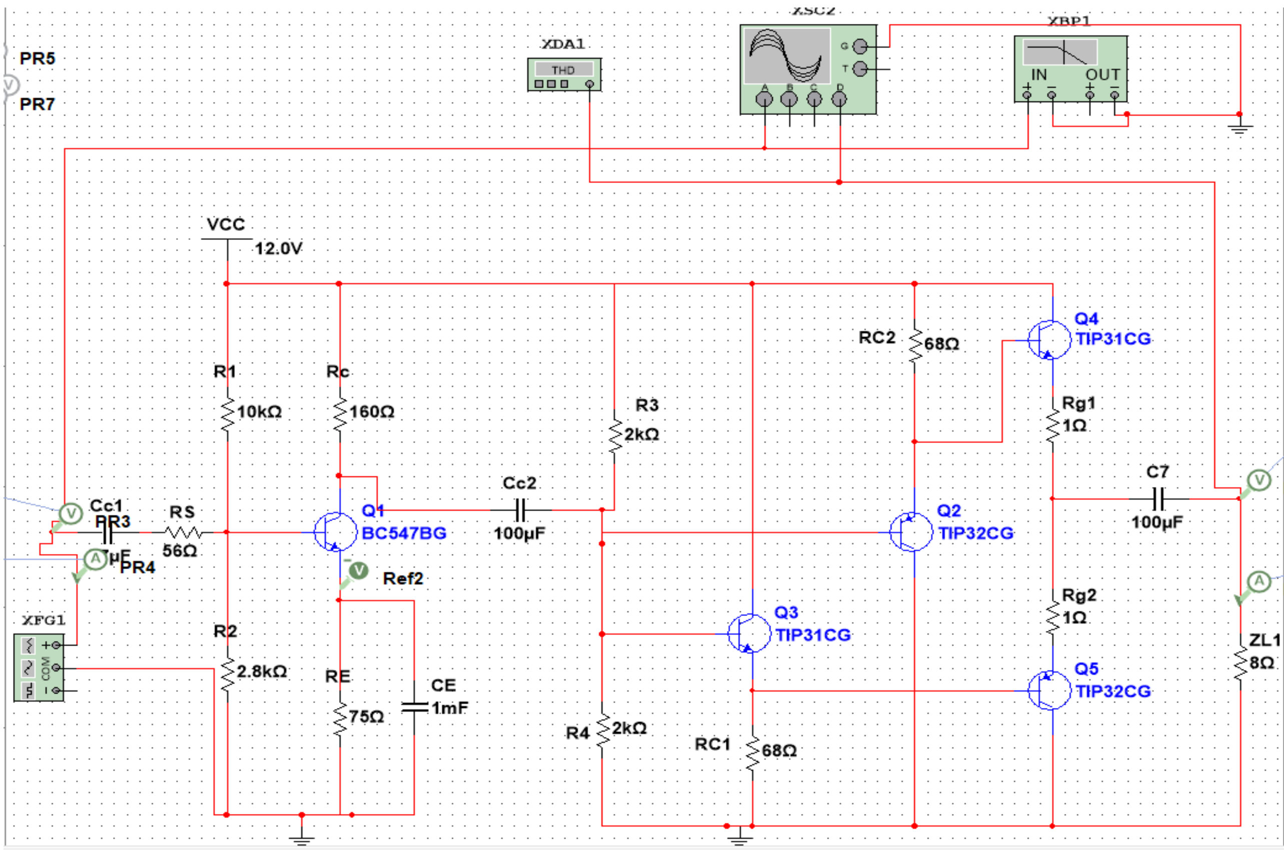
190005E - Abeywansa.C.N - Data Sheet preparation & Initial calculations

190009U - Abeyratne . M.A.D.J - Enclosure Design & Soldering

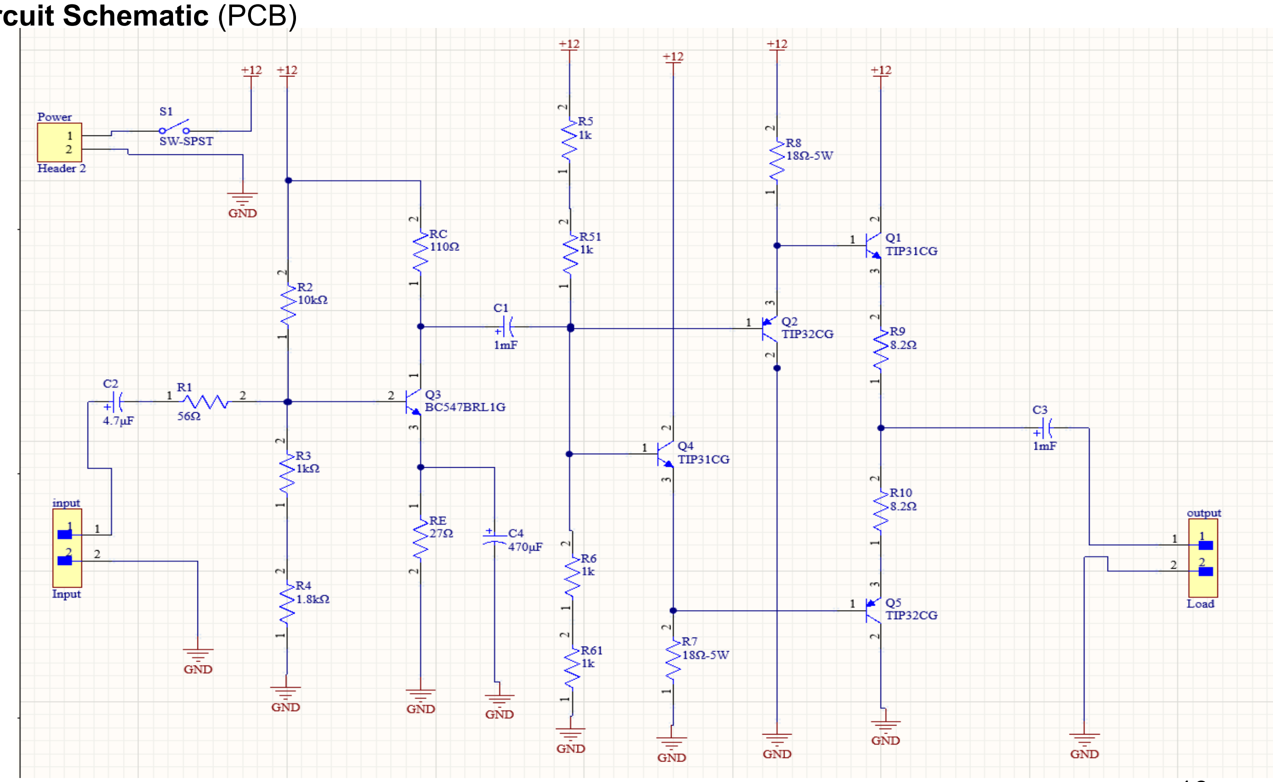
All four team members contributed in testing the simulations and calibrating the physical prototype

8.APPENDICES

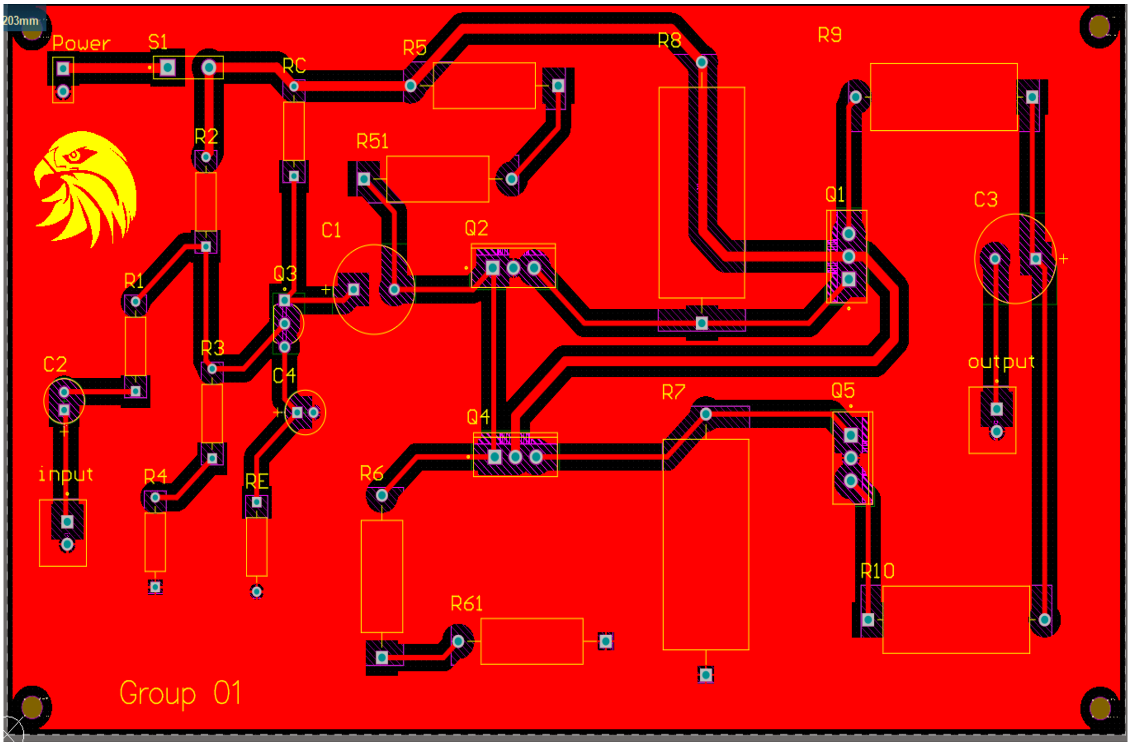
Circuit Schematic (Simulation)



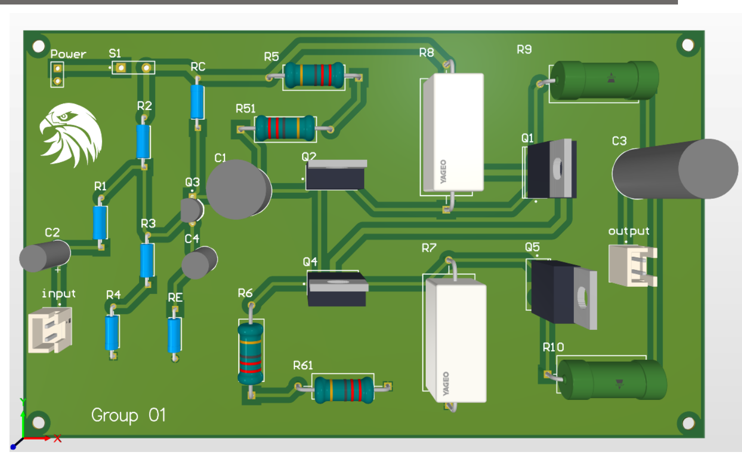
Circuit Schematic (PCB)



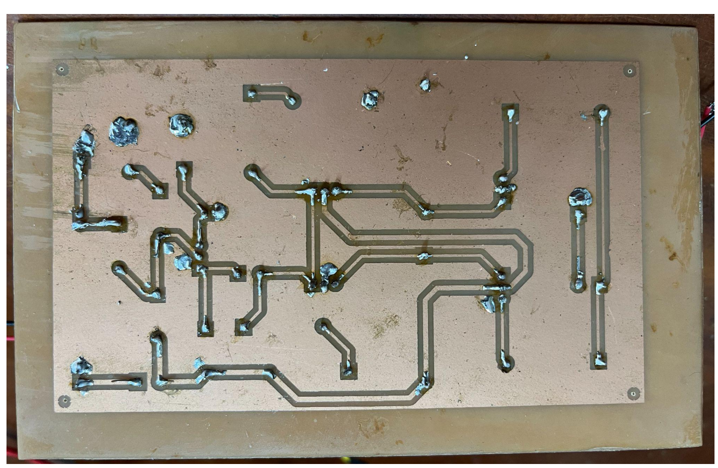
PCB Design (2D)



PCB Design (3D)



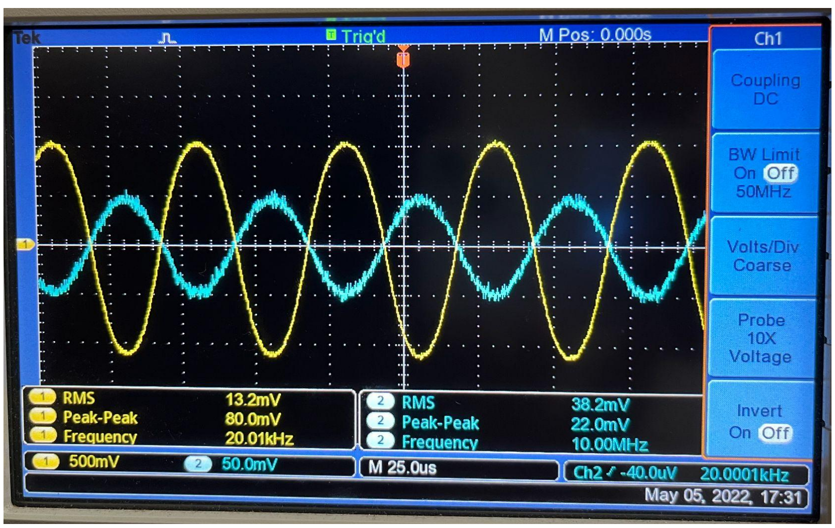
Physical Soldered PCB (Bottom)



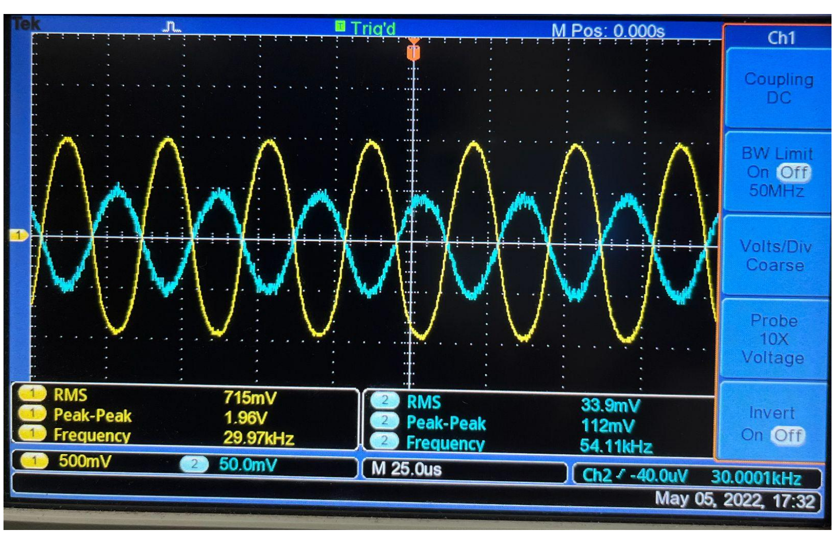
Physical Soldered PCB (Top)

Signal Outputs

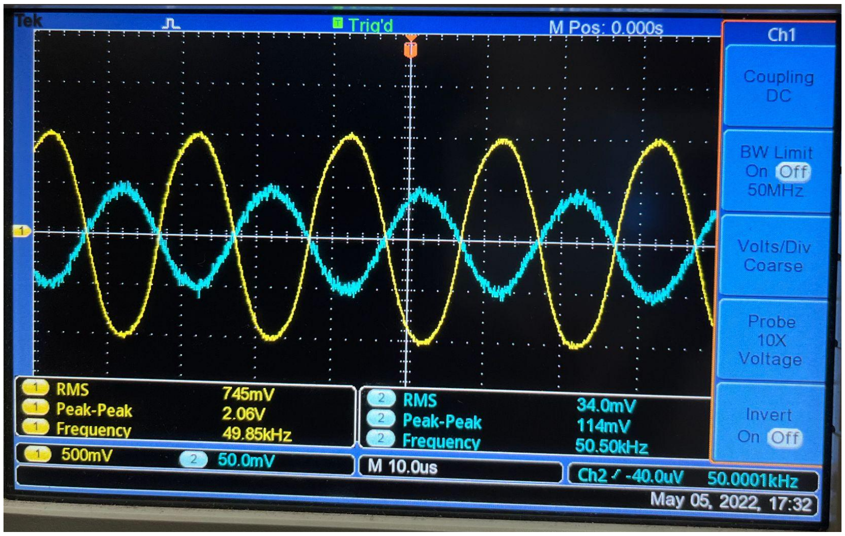
20kHz



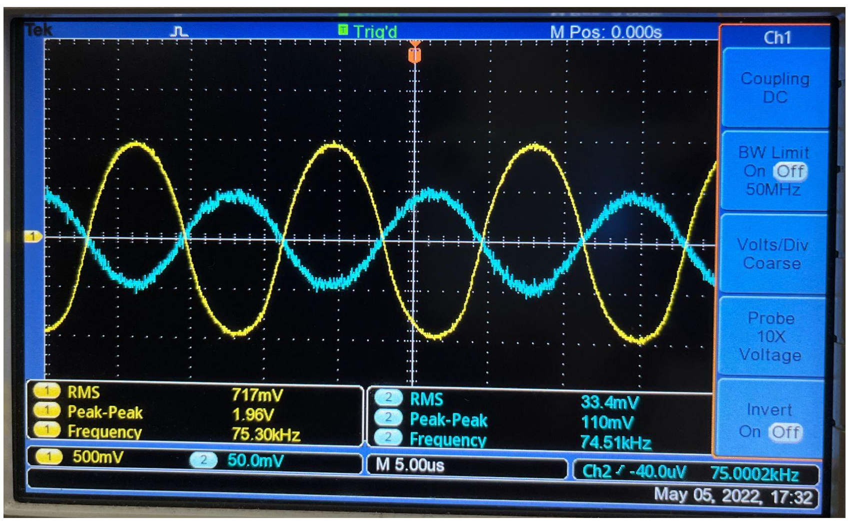
30kHz



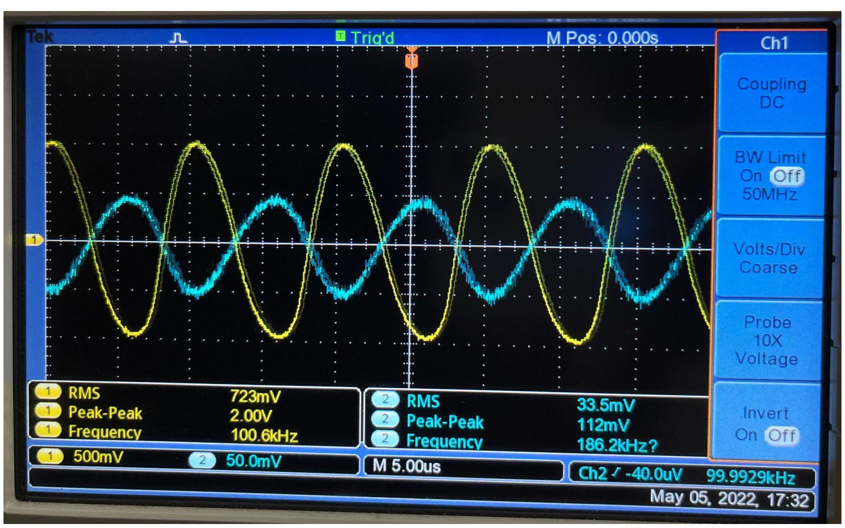
50kHz



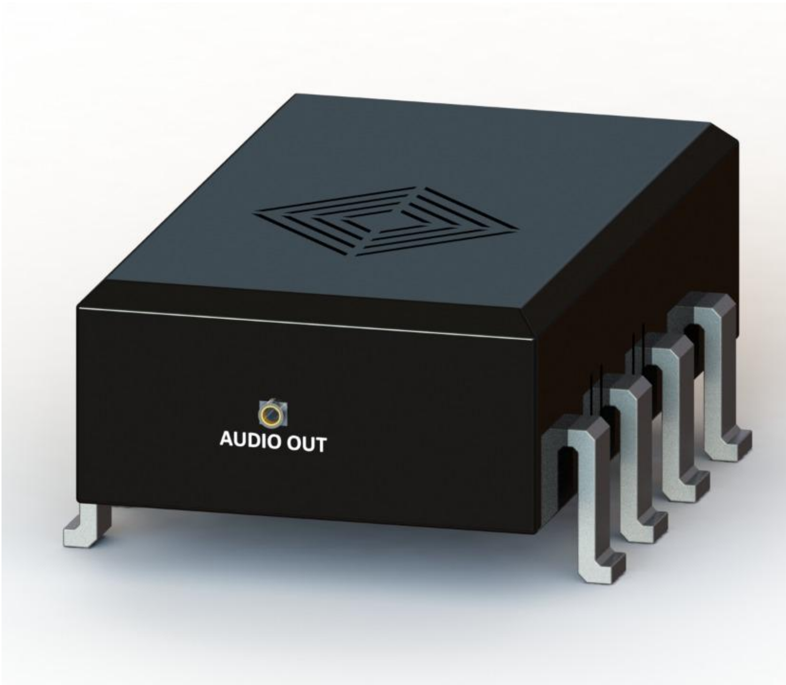
75kHz



100kHz



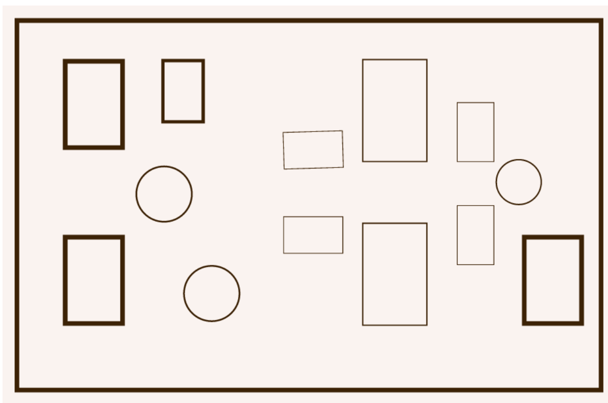
Enclosure Design



HIGH FREQUENCY POWER AMPLIFIER

Specification Sheet

Pin Diagram



Features

Low noise output

Simple sine wave amplification

Load resistor 8Ω

Electrical Characteristics

Parameter	Conditions	Min	Max	Type	Units
Operating Supply Voltage			12		V
Input Voltage(pk-pk)			0.1		V
Voltage Gain	$R_L = 8\Omega$			26.44	dB
Current Gain	$R_L = 8\Omega$			30.43	dB

Input Resistance	$R_L \rightarrow \infty$			420.17	Ω
Output Resistance	Vs =0			2	Ω
Power Gain	R_L = 8Ω			43.65	dB
Load current	R_L = 8Ω			256.09	mA
Total harmonic distortion	f=20kHz			7.7034%	
	f=25kHz			7.769%	
	f=50kHz			6.8513%	
	f=100kHz			6.724%	
Load		8	8.2		Ω