University of Moratuwa

Department of Electronic and Telecommunication Engineering

EN2111

Electronic Circuit Design

Project Report - Team 22

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1 Abstract

This report presents the design, development, and analysis of a headphone amplifier circuit constructed for the Electronic Circuit Design module. The amplifier consists of two main stages: a pre-amplifier to boost low-level audio signals and a Class AB power amplifier to drive standard headphones with minimal distortion. The design aims to achieve high-fidelity audio output while maintaining efficiency and thermal stability. The report details the circuit description, including schematic explanations, component selection, and design rationale. Simulations were performed to validate the amplifier's performance, and analytical calculations were conducted to determine key parameters such as gain, cutoff frequencies, and power efficiency. Furthermore, frequency response analysis was carried out to evaluate the total harmonic distortion across the audio bandwidth. The project demonstrates a practical application of analog design principles and highlights critical aspects of amplifier performance relevant to audio applications.

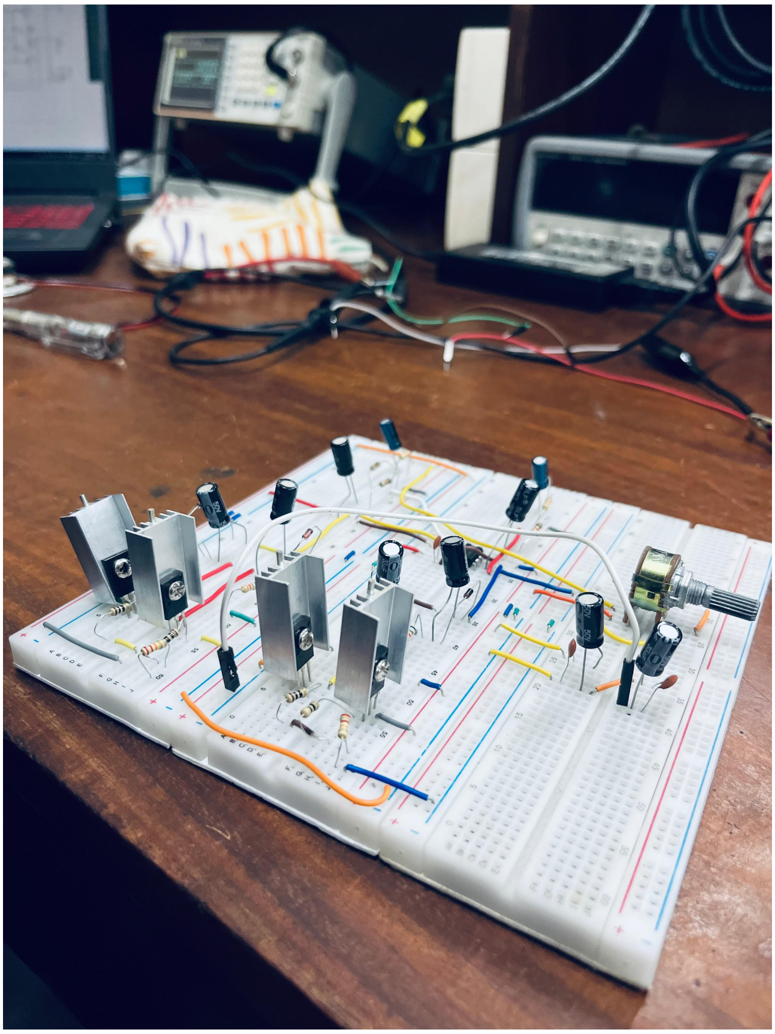

Figure 1: Physical implementation of the circuit

2 Circuit Description

2.1 Block Diagram

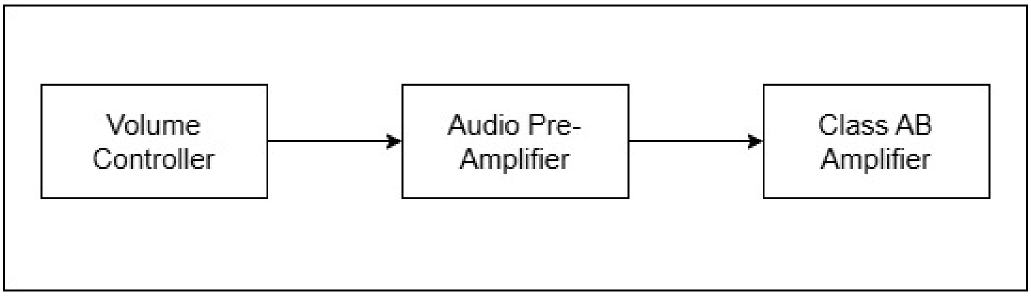

Figure 2: Block Diagram of the Circuit

The circuit consists of 3 main parts:

- The volume controller : For user to control the volume as desired.
- Audio pre-amplifier : To amplify weak audio signals to line level.
- Class AB amplifier : To provide high current and voltage gain to drive speakers

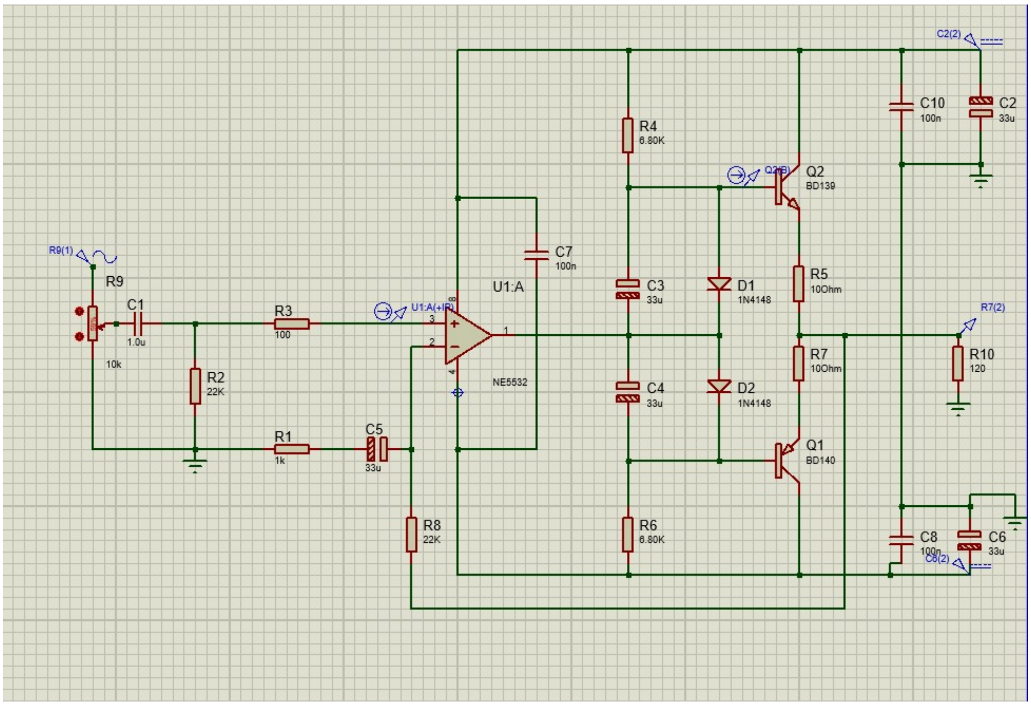

Figure 3: The Complete Schematic

2.2 Volume Controller

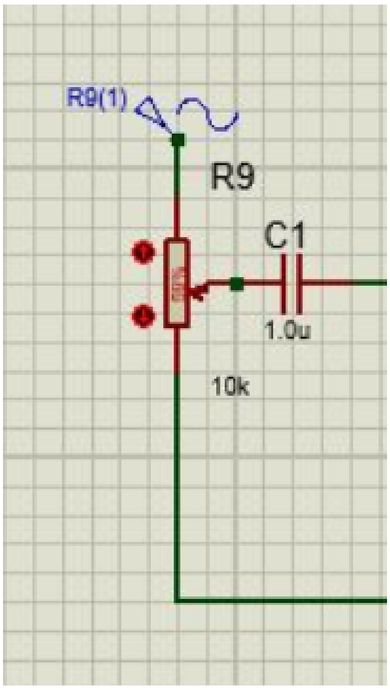

Figure 4: Volume Controller

The volume controller of this circuit is essentially a voltage divider circuit. It consists of a variable resistor connected in series with a capacitor. The audio input is connected between one terminal of the variable resistor and the ground. The capacitor is included to block DC voltage from entering the pre amplifier as well as to cut off high frequency noise.

2.3 Pre Amplifier

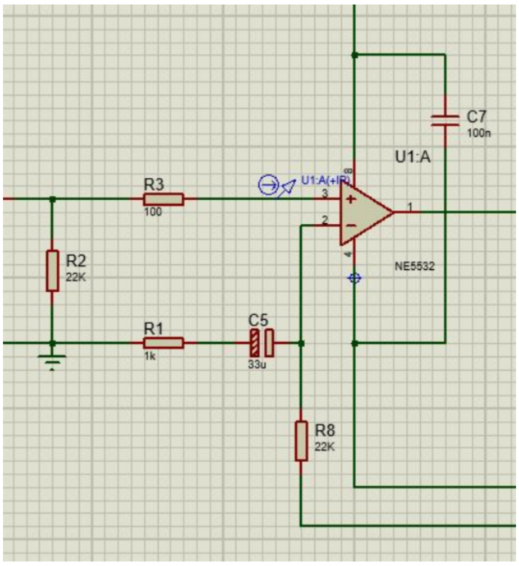

Figure 5: Audio Pre-Amplifier

The pre-amplifier boost weak audio signals from sources like microphones, turntables, or line inputs to a standard line level required by power amplifier. Having this stage between audio helps to improve the sound quality as this amplifies the audio signal more than the noise.

This part consists an NE5332 op-amp in non inverting configuration. The gain of the op-amp was calculated to be 23. The R_2 resistor and C_1 capacitor forms a high-pass filter with cutoff frequency of 7.2 Hz. The R_1 resistor and C_5 capacitor forms a high-pass filter with cutoff frequency of 4.8 Hz. This helps to reduce the low frequency feedback. This has the effect of "boosting bass".

2.4 Power Amplifier

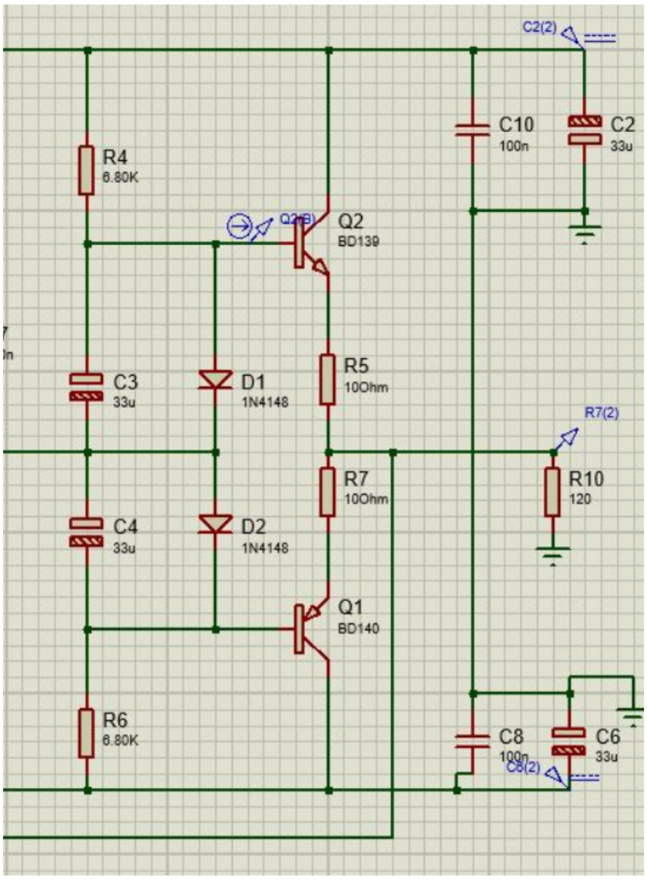

Figure 6: Class AB Amplifier

This part is a class AB amplifier made using 2 complementary transistors (BD 140 & BD 139) in push-pull configuration.

D1 & D2 diodes help mitigate crossover distortion due to transistor biasing. C3 & C4 are bootstrap capacitors which helps maintain the bias.

R4 & R6 resistors provide the bias current. They also limit the current through diodes. R5 & R7 resistors prevent thermal runaway by providing negative feedback.

C2 & C6 capacitors are for power supply filtering (reservoir capacitors). They filter the low frequency noise from power supplies. C8 & C10 capacitors filter out the high frequency noise from power supply.

This part of the circuit has several functionalities.

- **Voltage & Current Amplification :** The pre-amp stage increases voltage, but the power amp increases both voltage and current to provide sufficient power to the speaker. Speakers typically need high current to move the coil and diaphragm efficiently.
- **Impedance Matching :** Matches the high-impedance output of the preamp to the low-impedance load of the speaker (usually 8 Ω, 4 Ω, etc.)
- **Driving Loads Efficiently :** Must handle varying speaker loads without overheating or clipping.

3 Simulations

Before constructing the circuit, simulations were carried out using Proteus simulation software. The waveforms at input and output were observed after providing a sinusoidal waveform. This helped to verify the functionality of the circuit before purchasing components or building the circuit.

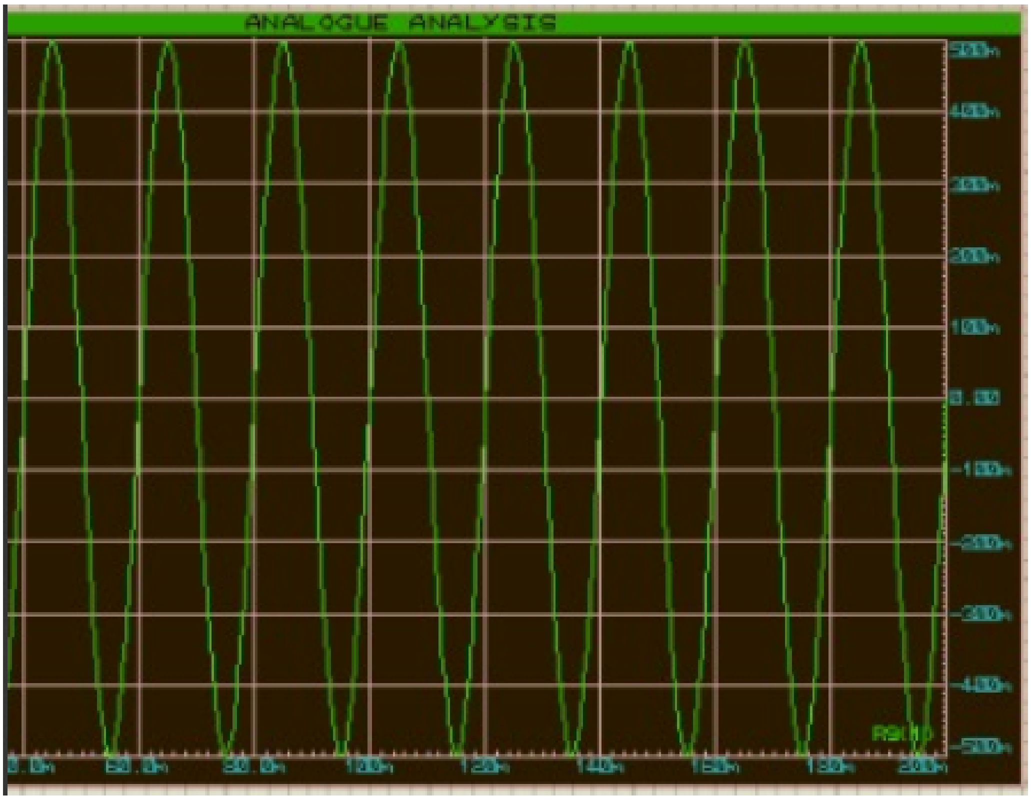

Figure 7: Simulated Waveform at the Input

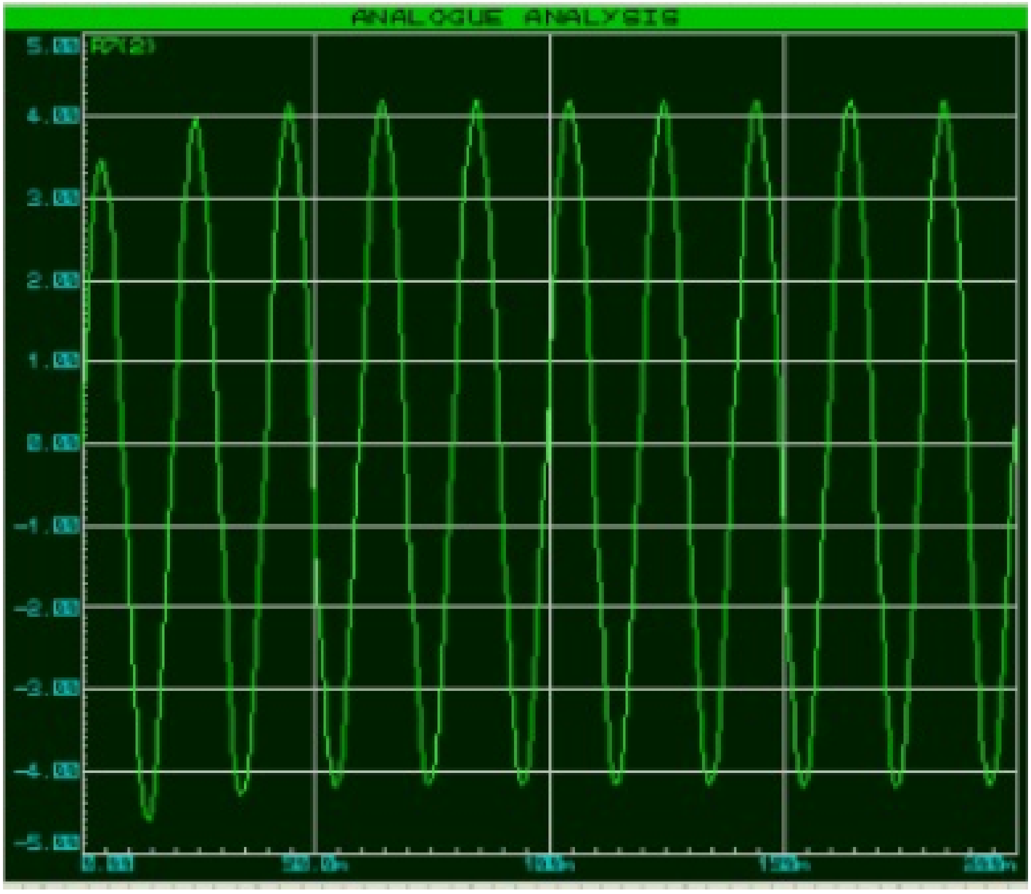

Figure 8: Simulated Waveform at the Output

4 Component Selection

4.1 Op-Amp

Chosen Op-Amp : **NE5532**

Specifications

Parameter	**Min**	**Typ**	**Max**	**Units**
Input Noise Voltage (30Hz)		8		nV/$\sqrt{Hz}$
(1kHz)		5		nV/$\sqrt{Hz}$
Input Noise Current (30Hz)		2.7		pA/$\sqrt{Hz}$
(1kHz)		0.7		pA/$\sqrt{Hz}$
Slew Rate		9		V/μs
Gain Bandwidth Product		10		MHz
Power Supply Rejection Ratio		10	50	μV/V

Table 1: NE5532 Op-Amp Specifications

High slew rate, very low input noise current & voltage and high GBP makes this op-amp suitable for audio applications. It is also a widely available op-amp which makes it ideal for a project like this.

The op-amp IC has 2 amplifiers inside, which were used as pre-amplifiers for the 2 stereo circuits (left & right)

Calculations for required slew rate and the bandwidth provided by the op-amp is given in the calculations section.

4.2 Transistors

Chosen Transistors : **BD 140, BD 139**

These 2 complementary power transistors were used for the push-pull output stage. Complementary design is essential for push-pull Class AB output stages.

Specifications

Parameter	Value	Units
Collector-Emitter Voltage	80	V
Collector Current	1.5	A
Power Dissipation	12.5	W
DC Current Gain	40-250	-

Table 2: BD139/BD140 Transistor Specifications

These are well suited for the given application because:

- 80 V rating provides adequate headroom for typical ±35V audio supply rails
- 1.5 A current capacity enables ∼10-15W output power into 8 loads
- 12.5 W power dissipation handles Class AB thermal requirements with proper heat sinking
- 40-250 current gain reduces drive requirements and improves efficiency

4.3 Capacitors

For C2 and C6 (33 μ F) , ceramic capacitors were chosen over electrolyte capacitors. This is because C2 & C6 are used for high frequency noise filtering on power supply. Ceramic apacitors have low ESR and ESL values, which makes them suitable for faster operations.

4.4 Diodes

Regular diodes were chosen for transistor biasing.

Power diodes were not chosen because:

- Their forward voltage is too low.
- This causes distortion around the crossover region.

5 Calculations

Gain calculation of the pre-amplifier stage

$$\begin{aligned}\text{Gain of the Op–Amp} &= \frac{R_{4L}}{R_{3L}} + 1 \\ &= \frac{22}{1} + 1 \\ &= 23\end{aligned}$$

Cutoff frequencies of the filters

Considering R_{1L} and C_{1l}:

$$\begin{aligned}\text{Cutoff Frequency} &= \frac{1}{2\pi RC} \\ &= \frac{1}{2\pi \cdot 22\,\mathrm{k\Omega} \cdot 1\,\mu\mathrm{F}} \\ &= 7.2\,\mathrm{Hz}\end{aligned}$$

Considering R_{3L} and C_{2L}:

$$\begin{aligned}\text{Cutoff Frequency} &= \frac{1}{2\pi RC} \\ &= \frac{1}{2\pi \cdot 1\,\mathrm{k\Omega} \cdot 33\,\mu\mathrm{F}} \\ &= 4.8\,\mathrm{Hz}\end{aligned}$$

This helps reduce low frequency feedback. Which improves "bass boost".

Calculating required slew rate

Considering maximum voltage swing to be ± 14 V, allowing for some headroom from the supply rails,

The slew rate (SR) is given by:

$$SR = 2\pi f V_{peak} \tag{1}$$

where:

- $f = 20,000\,\mathrm{Hz}$ (maximum audio frequency),
- $V_{peak} = 14\,\mathrm{V}$ (peak voltage).

$$\begin{aligned}SR &= 2\pi \times 20,000 \times 14 \\ &\approx 6.28 \times 20,000 \times 14 \\ &\approx 1,753,600\,\mathrm{V/s} \\ &\approx 1.75\,\mathrm{V/\mu s}\end{aligned}$$

Therefore, the op-amp needs a slew rate of at least $1.75\,\mathrm{V/\mu s}$ to pass a 20 kHz signal without distortion.

Calculating the bandwidth of the op-amp

Bandwidth of the op-amp is given by,

$$\text{Bandwidth} = \frac{\text{GBWP}}{\text{Gain}} \tag{2}$$

Gain was calculated to be 23 and GBP is given as 10MHz.

$$\begin{aligned}\text{Bandwidth} &= \frac{10 \times 10^6}{23} \\ &\approx 434,782\,\text{Hz} \\ &\approx 434.78\,\text{kHz}\end{aligned}$$

Therefore, the op-amp bandwidth is approximately 434.78 kHz.

Power Efficiency Calculation

Input DC Power

0.054 A drawn from $\pm 15\,\text{V}$

$$P_{\text{DC}} = 30\,\text{V} \times 0.054\,\text{A} = 1.62\,\text{W}$$

Output Voltage

Output Voltage (peak-peak) = 11.4 V

$$\text{output Voltage (RMS)} = \frac{11.4}{2\sqrt{2}} \approx 4.03\,\text{V} \tag{3}$$

Headphone Resistance

Headphone resistance = 16 Ω

Output Power Dissipation

$$\text{Output power dissipation} = \frac{(4.03\,\text{V})^2}{16\,\Omega} \approx 1.015\,\text{W}$$

Power Efficiency

$$\text{Power Efficiency} = \frac{\text{Output}}{P_{\text{DC}}} = \frac{1.015}{1.62} \approx 0.6265$$

As a percentage: 62.65%

6 Frequency Analysis

The circuit's response to various frequencies in the audio range was analyzed by using the function generator to supply sinusoids of those frequencies to the input terminal of the circuit. Then, the input and output waveforms were simultaneously analysed using the oscilloscope. It was done to see if there is noise present in the output or if the circuit clips the peaks of the sinusoids.

Resulting waveforms are shown below. The input waveform is shown in yellow while the output is in blue.

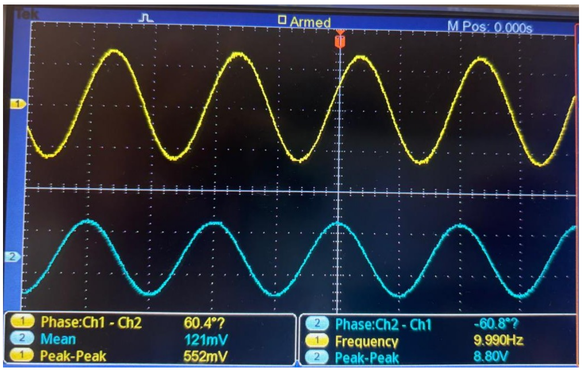

Figure 9: 10 Hz

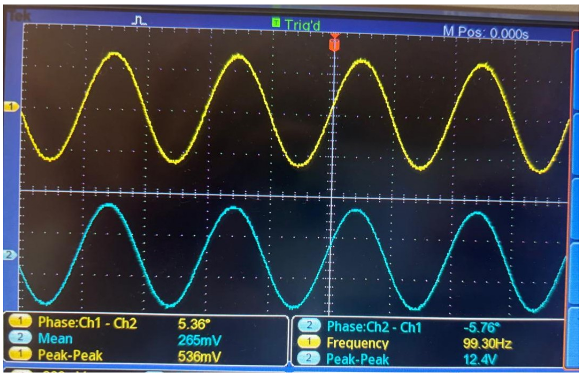

Figure 10: 100 Hz

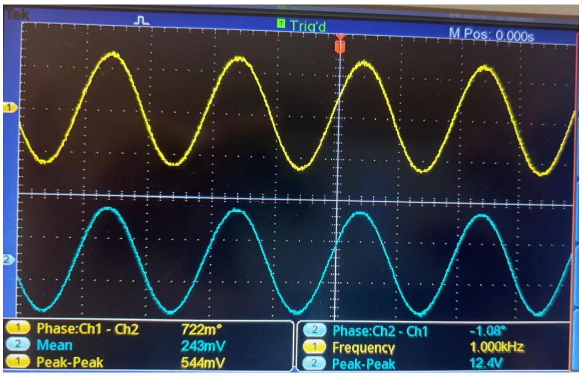

Figure 11: 1 kHz

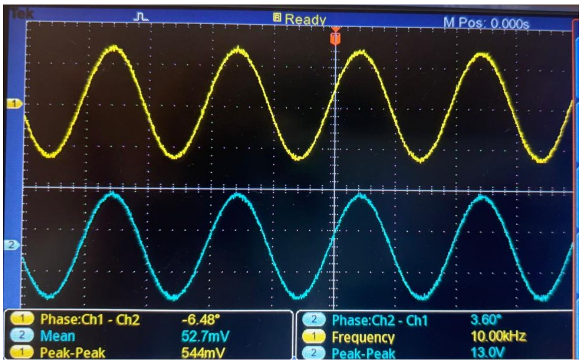

Figure 12: 10 kHz

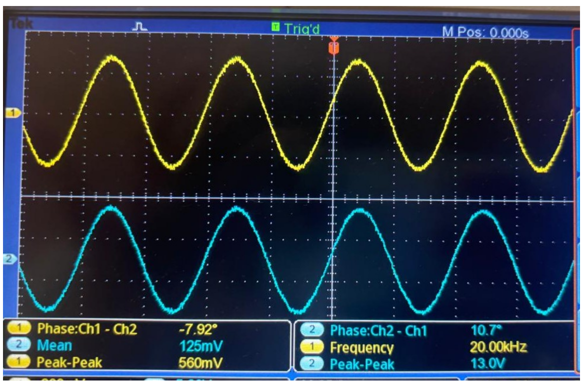

Figure 13: 20 kHz

It can be observed that there is no noise visible in the output waveform for all frequencies.

The gain of the amplifier for different frequencies was also observed. The results are depicted in the table below.
The gain (dB) against frequency graph is depicted below.

f (Hz)	v_{in} (V)	v_{out} (V)	Gain (dB)	f (Hz)	v_{in} (V)	v_{out} (V)	Gain (dB)
10	0.5	8.8	24.91025336	20	0.5	11.2	27.00496037
50	0.5	12.2	27.74779653	100	0.5	12.4	27.88903362
200	0.5	12.4	27.88903362	500	0.5	12.4	27.88903362
1k	0.5	12.4	27.88903362	2k	0.5	12.4	27.88903362
5k	0.5	12.6	28.02801082	10k	0.5	12.6	28.02801082
15k	0.5	12.6	28.02801082	20k	0.5	12.6	28.02801082
25k	0.5	12.6	28.02801082	30k	0.5	12.6	28.02801082

Table 3: Frequency response data.

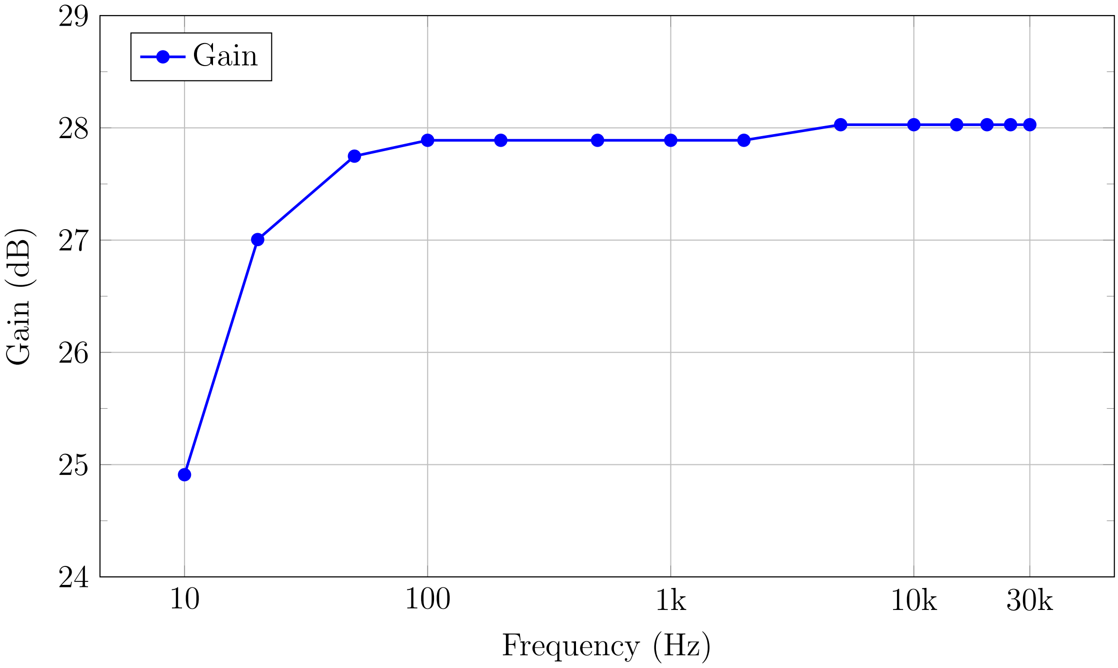

Figure 14: Gain (dB) vs Frequency (Hz).

It can be observed that the gain of the amplifier increases rapidly with frequency at first and displays only a minute rise in the higher frequencies. The circuit provides an average of 28 dB gain consistently across audio frequencies which is good for distortionless audio.

After this, harmonic analysis was conducted for different frequencies using the FFT function of the oscilloscope. It was done to observe the frequency spectrum of the output and see if there are harmonics of the input frequency present in the output signal.

The results of the spectrum analysis are shown below.

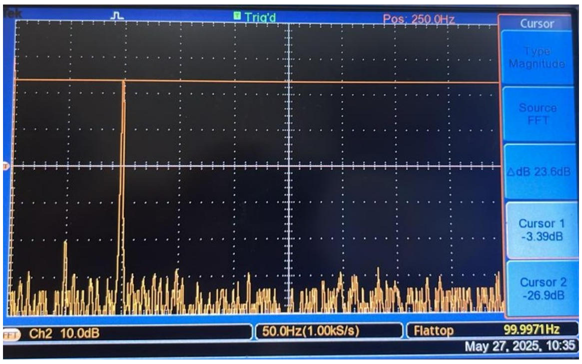

Figure 15: 100 Hz

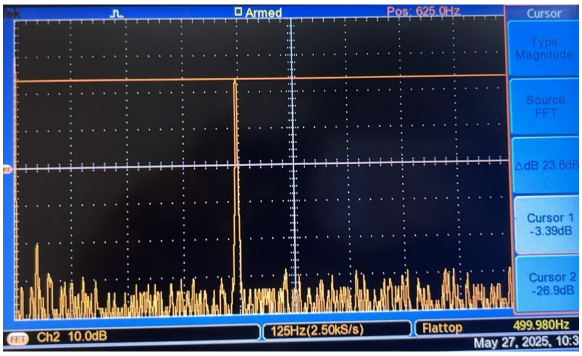

Figure 16: 500 Hz

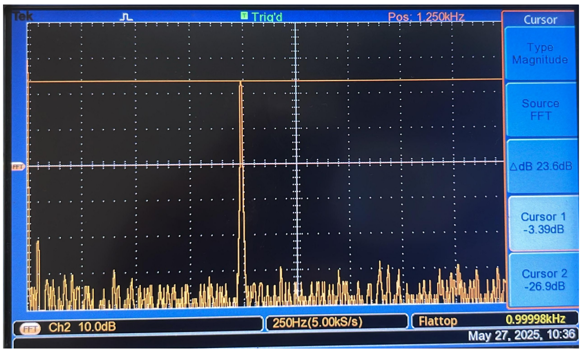

Figure 17: 1 kHz

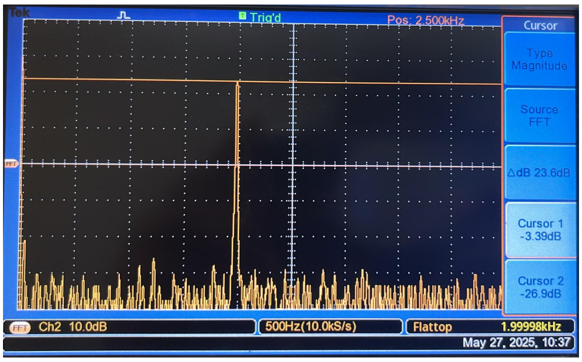

Figure 18: 2 kHz

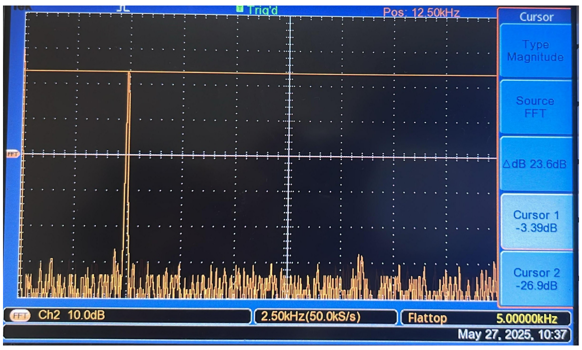

Figure 19: 5 kHz

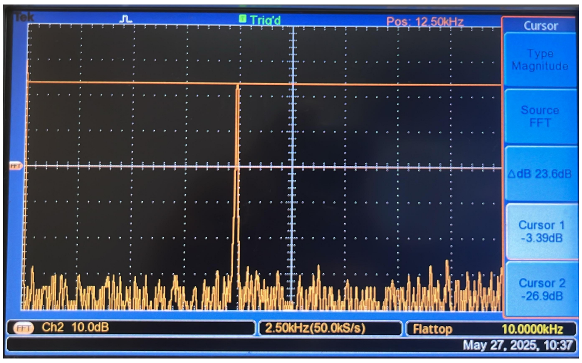

Figure 20: 10 kHz

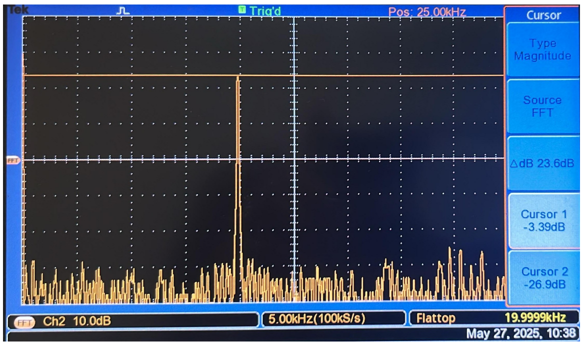

Figure 21: 20 kHz

Figures 14–20 show the frequency spectra of the output signal for input sine waves at various frequencies (100 Hz to 20 kHz). The key observations from the FFT plots are as follows:

- **Low Harmonic Content:** Across all tested frequencies, the FFT plots indicate that the fundamental frequency dominates the spectrum, with second and third harmonics appearing at significantly lower amplitudes. This confirms low harmonic distortion in the amplifier output.

- **Noise Floor:** The spectral plots show a consistent noise floor, with no significant spurious frequency components, validating the clean operation of both the pre-amplifier and power amplifier stages.

- **High-Frequency Performance:** Even at higher input frequencies such as 10 kHz and 20 kHz, the output signal remains spectrally clean with minimal high-order harmonic distortion, indicating that the bandwidth and slew rate of the NE5532 op-amp are sufficient for high-fidelity audio reproduction.

Total Harmonic Distortion (THD) is mathematically defined as:

$$\text{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots}}{V_1}$$

where V_1 is the RMS voltage of the fundamental frequency and $V_2, V_3, \ldots$ are the RMS voltages of the respective harmonic components.

However, in this analysis, explicit calculation of THD is not required since the FFT plots clearly show that the harmonic components are significantly lower than the fundamental, confirming the amplifier's low-distortion performance qualitatively.

This spectral analysis confirms that the designed amplifier maintains high linearity and low total harmonic distortion (THD) across the entire audio frequency range, making it suitable for high-quality headphone audio applications.