Audio Amplifier

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***Abstract*—This project aims to design and implement an audio amplifier with the given specifications, performance criteria. The amplifier consists of four main stages: pre-amplification, gain stage, filtering, and power amplification. The pre-amplifier is designed using a differential common-emitter configuration to ensure high input impedance and minimize noise. The gain stage employs a common-emitter amplifier to achieve the required amplification. A band-pass filter is incorporated to limit unwanted frequency components while maintaining signal integrity. The power amplifier, implemented as a Class AB design, ensures efficient power delivery with minimal distortion. The project also includes an analysis of distortion and slew rate to evaluate signal quality and circuit performance. The total harmonic distortion (THD) is minimized using filtering techniques, while the slew rate is optimized to handle high-frequency signals effectively. The final design provides a robust and efficient audio amplification system suitable for various applications.**

Keywords—component, formatting, style, styling, insert (key words**)**

I. Introduction

Amplifiers are essential in modern audio systems, ensuring weak signals are amplified without significant distortion. An ideal audio amplifier should not only increase signal strength but also maintain clarity, efficiency, and minimal noise. This project explores the design and implementation of an audio amplifier tailored for low-power applications while meeting key performance criteria.

The amplifier design is structured into multiple stages, each playing a critical role in enhancing the input signal. The pre-amplifier boosts the weak audio signal while maintaining a high signal-to-noise ratio. The gain stage provides the necessary amplification, while a band-pass filter ensures that only the desired frequency range (20 Hz–20 kHz) is retained. The final stage, a Class AB power amplifier, delivers sufficient power to drive the output without introducing significant distortion.

II. Specifications

The audio amplifier is designed to meet the following technical specifications:

- Supply Voltage: 0–5V
- Input Signal Voltage: 10–40mV (peak-to-peak)
- Voltage Gain: 500 (achieved through pre-amplification and gain stages)
- Frequency Response: 20 Hz to 20 kHz (audible frequency range)
- Output Power: 1.5W
- Filter Design: Must preserve the input signal without attenuation
- Power Amplifier Constraint: Should not introduce additional voltage gain
- Load Resistance: 10Ω

These specifications ensure that the amplifier effectively enhances low-level audio signals while maintaining signal integrity, minimizing distortion, and optimizing power efficiency.

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III. Pre-Amplifier

A pre-amplifier (preamp) is the first stage in an audio amplifier system. Its main function is to increase the strength of a weak input signal so that it can be further amplified without distortion. In this project, the preamp is designed to handle input signals between 10–40mV peak-to-peak while minimizing noise.

To ensure proper operation, the preamp should have a **high input impedance** to avoid drawing too much current from the signal source and a **low output impedance** to efficiently transfer the signal to the next stage. A **common-emitter differential amplifier** is chosen for its ability to provide high gain and reduce unwanted noise. Proper transistor biasing is necessary to keep the amplifier in its active region and prevent signal distortion.

A well-designed preamp helps maintain signal clarity by reducing interference and ensuring the input signal is amplified without unwanted modifications. Once the preamp boosts the signal, it is sent to the next stage for further amplification.

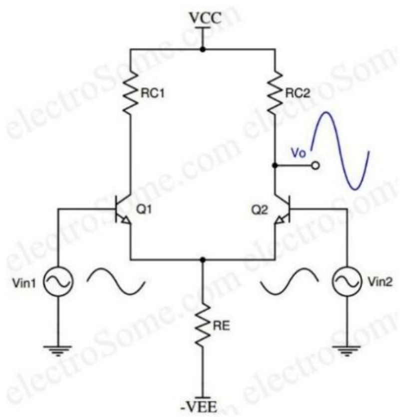


Figure: Pre-Amplifier

The differential amplifier is a fundamental building block in analog electronics, widely used in operational amplifiers and signal processing applications. It amplifies the difference between two input signals while rejecting common-mode noise. This report analyzes the working of a differential amplifier when one of its inputs V_{in2} is grounded.

The circuit consists of two identical NPN transistors Q_1 and Q_2 with a common emitter resistor R_E. The collectors are connected to the power supply VCC via resistors R_{C1} and R_{C2}, and the output voltage V_o is taken from the collector of Q_2. The input signals V_{in1} and V_{in2} are applied at the bases of the transistors, and the circuit operates with a negative power supply $-V_{EE}$ at the emitter resistor.

Biasing and DC Operation:

When $V_{in2}=0$ (grounded), the base-emitter voltage of Q2 is determined as:

$V_E = V_{B2} - V_{BE2} = 0V - 0.7V = -0.7V$

The emitter current I_E is given by:

$I_E = |V_E - (-V_{EE})| / R_E$

Since I_E is shared between Q_1 and Q_2,

$I_{E1} + I_{E2} = I_E$

where I_{E1} and I_{E2} are the emitter currents of Q_1 and Q_2, respectively.

Effect of Input Voltage V_{in1} on Transistor Currents:

When V_{in1} increases:
- The base-emitter voltage V_{BE1} of Q_1 increases, leading to an increase in I_{E1}.
- Since the total emitter current I_E remains nearly constant, an increase in I_{E1} results in a decrease in I_{E2}.
- Since collector current I_C is approximately equal to the emitter current in active mode, we get:

Output Voltage Behavior:

The output voltage V_o is taken from the collector of Q_2 and is given by:
$V_o = VCC - I_{C2} R_C$

As I_{C2} decreases with an increasing V_{in1}, the voltage drop across R_C decreases, leading to an increase in V_o. This indicates that the circuit behaves as an **inverting amplifier**.

Voltage Gain of the Amplifier:

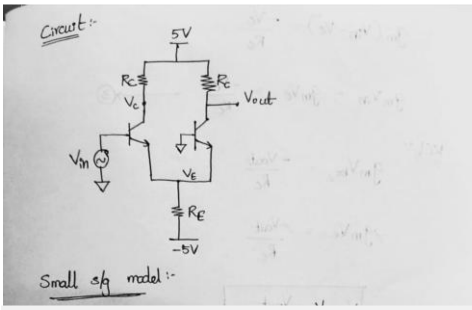
The voltage gain A_v of the amplifier is determined by the transconductance g_m and collector resistance R_C:

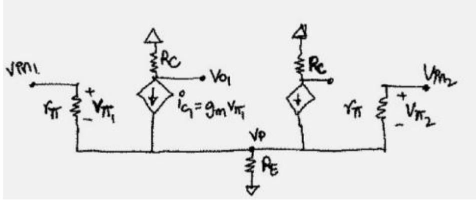
$g_m = I_C / V_T$, $A_v = g_m R_C$

where V_T is the thermal voltage V_T = 25mV at room temperature.

When V_{in2} is grounded, the differential amplifier functions as a single-ended inverting amplifier. The output voltage increases when the input V_{in1} increases, and the voltage gain depends on the transconductance and the collector resistance. This configuration is widely used in differential signal processing and operational amplifier designs.

Applications:
- Operational amplifier input stages
- Signal amplification and processing
- Common-mode noise rejection
- Comparator circuits





Applying KCL at V_p:

$$\frac{V_{\pi1}}{r_\pi} + \frac{V_{\pi2}}{r_\pi} + g_m V_{\pi1} + g_m V_{\pi2} = \frac{V_p}{R_E}$$

$$(V_{\pi1} + V_{\pi2}) g_m r_\pi + 1 \cdot \frac{R_E}{r_\pi} = V_p$$

$$(V_{in1} + V_{in2})(g_m r_\pi + 1)\frac{R_E}{r_\pi} = V_p \left[1 + 2g_m r_\pi + 2\frac{R_E}{r_\pi}\right]$$

$$V_p = (V_{in1} + V_{in2})\frac{(g_m r_\pi + 1)}{\frac{r_\pi}{R_E} + 2(g_m r_\pi + 1)}$$

Assuming $r_\pi \ll R_E$,

$$V_p = \frac{V_{in1} + V_{in2}}{2} \quad \rightarrow (1)$$

$$V_{\pi1} = V_{in1} - V_p \quad \rightarrow (2)$$

$$V_{\pi2} = V_{in2} - V_p \quad \rightarrow (3)$$

$$V_{o2} = \Theta g_m V_{\pi2} R_C = -g_m (V_{in2} - V_p) R_C \quad \rightarrow (4)$$

Applying (1) in (4),

$$V_{o2} = -g_m (V_{in2} - V_{in1}) R_C \quad \rightarrow (5)$$

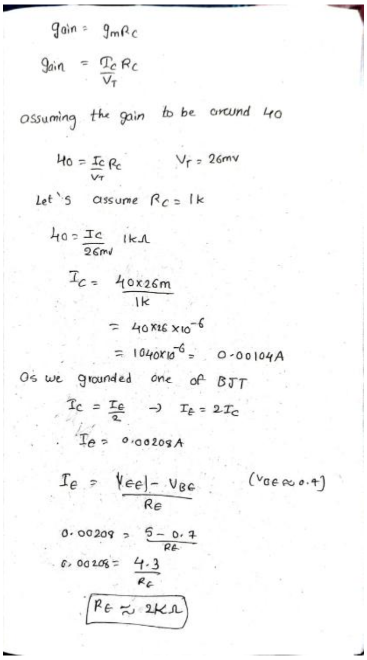
$$V_{o1} = -g_m \left(\frac{V_{in1} - V_{in2}}{2}\right) R_C \quad \rightarrow (6)$$

$$(V_{o2} - V_{o1}) = -g_m (V_{in2} - V_{in1}) R_C \quad \rightarrow (7)$$

$$\frac{V_{o2}}{(V_{in2} - V_{in1})} = -g_m R_C$$

$$\frac{V_{o2} - V_{o1}}{V_{in2} - V_{in1}} = -\frac{g_m R_C}{2}$$

Figure: Derivation of Gain



gain = $g_m R_c$

gain $= \frac{I_c}{V_T} R_c$

assuming the gain to be around 40

$40 = \frac{I_c}{V_T} R_c$ $\quad V_T = 26mV$

Let's assume $R_c = 1k$

$40 = \frac{I_c}{26mV} \; 1k\Omega$

$I_c = \frac{40 \times 26m}{1k}$

$= 40 \times 26 \times 10^{-6}$

$= 1040 \times 10^{-6} = 0.00104A$

as we grounded one of BJT

$I_c = \frac{I_E}{2} \rightarrow I_E = 2I_C$

$I_e = 0.00208A$

$I_e = \frac{|V_{EE}| - V_{BE}}{R_E}$ $\quad (V_{BE} \approx 0.7)$

$0.00208 = \frac{5 - 0.7}{R_E}$

$0.00208 = \frac{4.3}{R_E}$

$\boxed{R_E \approx 2k\Omega}$

Figure: Calculations for pre-amplifier

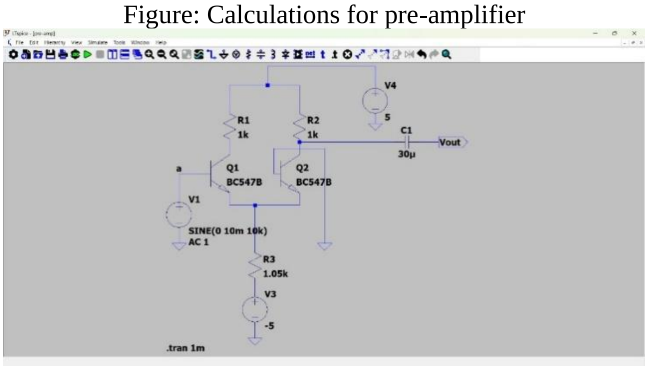


Figure: Circuit Diagram

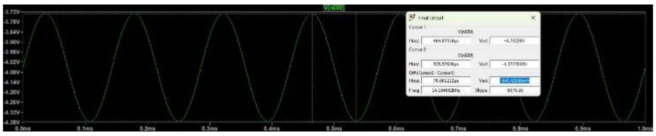


Figure: LTSPICE Output

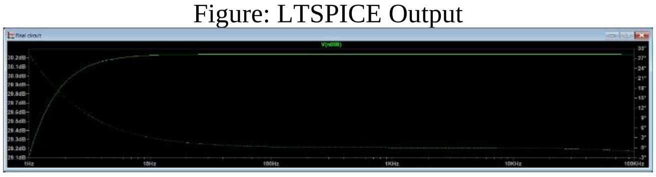


Figure: Bode plot

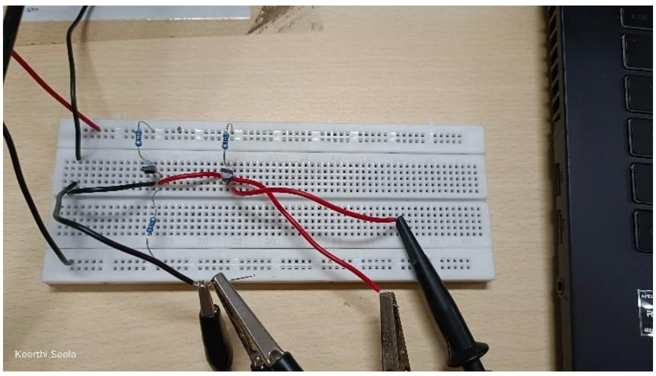


Figure: Hardware

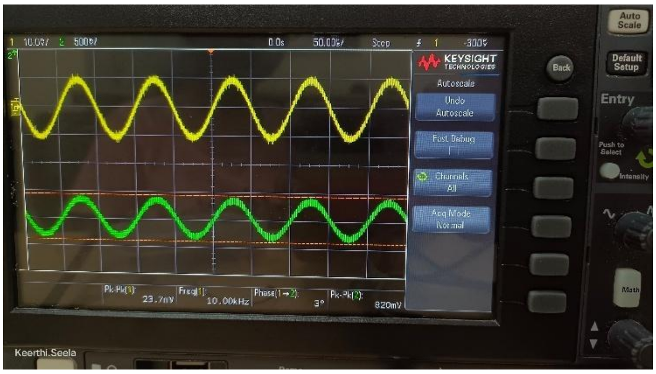


Figure: Hardware Output

Hardware Gain of preamp stage = 820 mV/20mV =41

Figure: Hardware Bode Plot

Common mode Rejection Ratio:

Common-Mode Rejection Ratio (CMRR) is a measure of a differential amplifier's ability to reject common-mode signals (noise) while amplifying differential signals. A higher CMRR indicates better noise rejection, making the amplifier more effective in reducing interference. The mathematical expression for CMRR is given by:

$$\mathrm{CMRR} = \frac{\mathrm{A_d}}{A_{CM}}$$

where:

• A_d = Differential Gain (gain for the desired signal)

• A_{cm} = Common-Mode Gain (gain for noise or unwanted signals)

In decibels (dB), CMRR is expressed as:

$$CMRR(dB) = 20log10\left(\frac{|A_d|}{|A_{cm}|}\right)$$

Example: (CMRR = 10,000)

If CMRR is 10,000, it means the amplifier amplifies the differential signal 10,000 times more than the unwanted noise.

In decibels:

CMRR = 20 log10(10, 000) = 80 dB

This indicates that the amplifier significantly reduces noise and interference, ensuring clean signal amplification.

Stability Factor in Audio Amplifiers:

The stability factor in audio amplifiers measures how stable the amplifier is against changes in parameters, particularly temperature variations and component aging. It is crucial because unstable amplifiers can lead to unwanted effects like thermal runaway, oscillations, or distorted output.

a) *Definition*: The stability factor (S) quantifies how much the collector current (I_C) changes with changes in current gain (β). It is commonly defined as:

$$S = \frac{dI_C}{d\beta}$$

The ideal value of S is 1, which indicates no change in collector current despite variations in β. Higher values indicate less stability.

Stability Important in Audio Amplifiers because:

- Temperature Variations:
  - Amplifiers generate heat during operation, causing changes in transistor parameters, especially (β).
  - A high stability factor can cause thermal runaway, leading to distorted audio output or damage to the amplifier.
- Component Aging:
  - As components age, their parameters may change, particularly transistors and capacitors.
  - An amplifier with a low stability factor is more robust against these changes.
- Feedback and Stability:
  - Audio amplifiers often use negative feedback to improve stability and reduce distortion.
  - Proper feedback design reduces the sensitivity of the output to variations in transistor parameters.

IV. GAIN STAGE

The gain stage is responsible for further amplifying the signal received from the pre-amplifier to achieve the required total gain of 500. This stage must be designed carefully to ensure signal integrity while minimizing distortion and instability.

A **common-emitter (CE) amplifier** is used due to its high voltage and current gain. It has a **low input impedance, allowing efficient signal reception, and a high output impedance**, making it suitable for driving the next stage.

To ensure stable operation, **biasing resistors** keep the transistor in its active region, preventing signal distortion. **Coupling capacitors** remove unwanted **DC components**, allowing only AC signals to pass. Additionally, proper impedance matching is necessary to ensure efficient signal transfer between stages, preventing signal loss and unwanted reflections that could degrade performance.

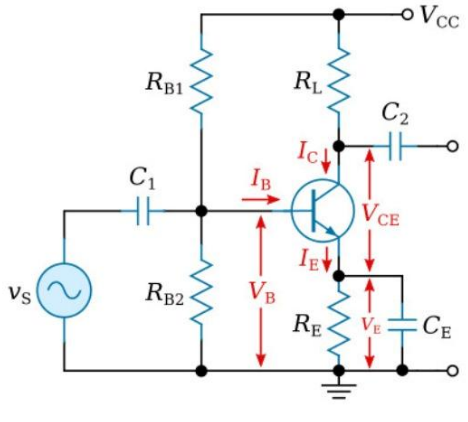


Figure: CE-Amplifier

Key Components of CE Amplifier:

The CE amplifier consists of the following key components:

- Biasing Resistors (R_{B1}, R_{B2}):
  - Provide proper DC biasing to set the transistor's operating point.
- Emitter Resistor (R_E):
  - Stabilizes the operating point and improves linearity.
- Collector Resistor (R_L):
  - Converts the amplified current into an output voltage.
- Coupling Capacitors (C_1, C_2):
  - Block DC and allow AC signals to pass.
- Bypass Capacitor (C_E):
  - Enhances gain by bypassing AC signal currents around RE.
- Power Supply (VCC):
  - Provides the necessary operating voltage.

Input and Output Impedance:

The CE amplifier exhibits moderate input impedance (typically 1-10 k) and relatively high output impedance (10-50 k).The input impedance is given by:

$$Z_{in} = R_B \parallel (h_{ie} + (1 + h_{fe})R'_E)$$

And the output impedance is approximately:

$$Z_{out} \approx RC$$

Operating Principle:

The CE amplifier operates in the active region of the transistor, ensuring amplification. The working mechanism is as follows:

1. **DC Biasing:**

   The resistors R_{B1} and R_{B2} form a voltage divider network to set the base voltage (VB). The emitter voltage is given by:

   $$V_E = V_B - V_{BE}$$

   where $V_{BE} \approx 0.7V$ for a silicon transistor.
   The collector-emitter voltage is:

   $$V_{CE} = V_{CC} - I_C R_L - I_E R_E$$

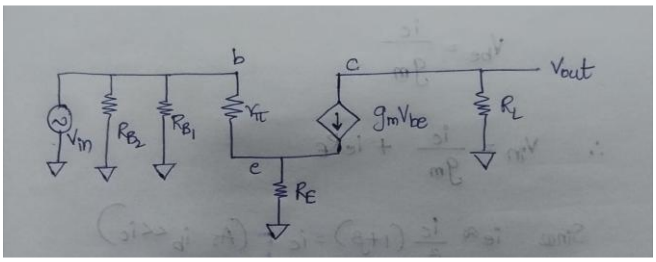
2. **Signal Amplification:**

   When an AC input signal (v_S) is applied, it modulates the base voltage (V_B). A small increase in V_B results in a larger increase in collector current (I_C) due to transistor current gain (β). This increased I_C causes a larger voltage drop across R_L, leading to an inverted and amplified output voltage at the collector.

3. **Voltage Gain:**

   The voltage gain (A_v) of the CE amplifier (without bypass capacitor C_E) is:

   $$A_v = -g_m R_L / (1 + g_m R_E)$$



$$\boxed{\begin{aligned} g_m &= \frac{I_c}{V_T} \\ V_{be} &= V_{in} - i_e R_E \end{aligned}}$$

$$V_{out} = -i_c R_L$$

KVL at input side

$$V_{in} = V_{be} + i_e R_E$$

$$i_e = i_b + i_c \Rightarrow i_e \approx i_b(1+\beta) \quad \text{and} \quad i_c \approx \beta i_b$$

Since $i_c = g_m V_{be}$, we have :-

$$V_{be} = \frac{i_c}{g_m}$$

$$\therefore \quad V_{in} = \frac{i_c}{g_m} + i_e R_E$$

Since $i_e \approx \frac{i_c}{\beta}(1+\beta) = i_c$ (As $i_b << i_c$)

$$V_{in} = \frac{i_c}{g_m} + i_c R_E$$

$$V_{in} = i_c\left(\frac{1}{g_m} + R_E\right)$$

$$V_{out} = -i_c R_L$$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{-R_L}{\frac{1}{g_m} + R_E}$$

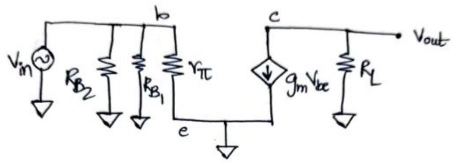
$$\boxed{A_v = \frac{-g_m R_L}{1 + g_m R_E}}$$

where g_m is the transconductance of the transistor, given by:

$g_m = I_C / V_T$, (where $V_T \approx 25mV$ at room temperature)

If C_E is present, the gain simplifies to:

$$Av \approx -gmRL$$



$$i_c = g_m V_{be}$$

$$V_{out} = -i_c R_L$$

$$V_{out} = -g_m V_{be} R_L$$

$$\frac{V_{out}}{V_{in}} = -g_m R_L$$

4. Phase Relationship

The CE amplifier inverts the phase of the input signal, meaning that the output is 180° out of phase with the input.

5. Frequency Response

- *Low-Frequency Response:* Limited by coupling capacitors (C_1, C_2) and bypass capacitor (C_E).
- *Midband Response:* The amplifier operates with stable gain.
- *High-Frequency Response:* Limited by internal transistor capacitances.

Phase Inversion Happens in CE amplifier due to:

1. Base-Emitter Voltage (V_{BE}) controls Collector current (I_C)
   - When the input signal at the base increases, the base-emitter voltage V_{BE} also increases.
   - This increases the base current I_B, which in turn increases the collector current I_c (since $I_c = ß\ I_B$, where ß is the current gain of the transistor).
2. Collector voltage drops due to increased current.
   - The collector resistor R_c is connected to Vcc, and the voltage at the collector is given by:

     $$V_c = Vcc - I_c R_c$$
   - Since I_C increases, the voltage drop across R_C increases, which means the collector voltage Vc decreases.
3. Result: **Output is Inverted**
   - If the input signal rises, the output voltage at the collector falls.
   - If the input signal falls, the output voltage at the collector rises.
   - This results in a 180° phase shift between input and output.

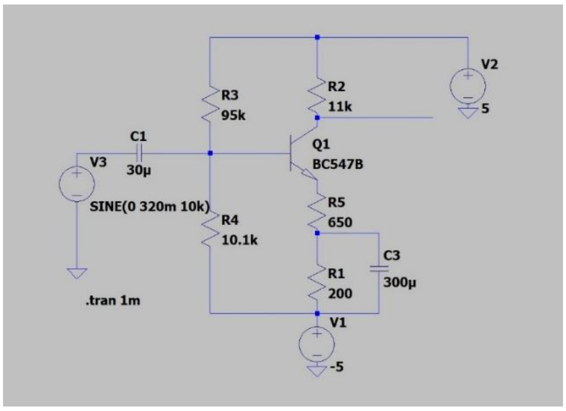


Figure: Circuit Diagram

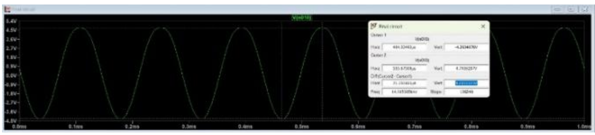


Figure: LTSPICE Output

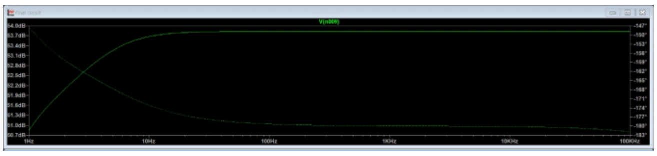


Figure: Bode Plot

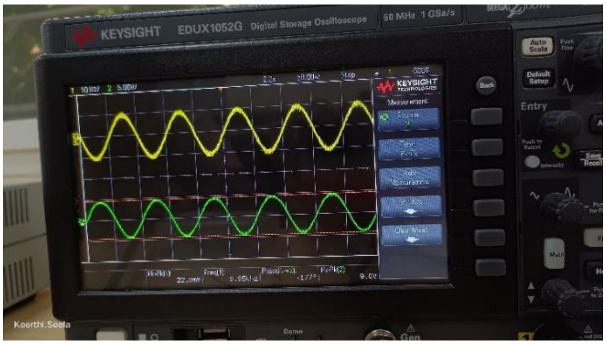


Figure: Hardware Output

Total Gain = 9V / 20mV=450

Figure: Bode Plot

V. Filter Stage

The filter stage is responsible for shaping the frequency response of the amplifier by allowing only the desired range of frequencies to pass while blocking unwanted signals. In this project, the filter ensures that the amplifier operates effectively within the audible frequency range of 20 Hz to 20 kHz without attenuating the input signal.

A band-pass filter is commonly used in audio applications to remove low-frequency noise (such as DC offsets) and high-frequency interference that could distort the output. This filter consists of a combination of capacitors and resistors, which define the cutoff frequencies and determine the overall response of the system.

To ensure stable and regulated power supply to various circuit components, a voltage regulation system is implemented. The filter stage operates with a ±12V power supply, which is then regulated to ±5V using a **voltage regulator**. This regulated voltage is supplied to other stages of the amplifier, ensuring consistent operation and preventing fluctuations that could impact performance.

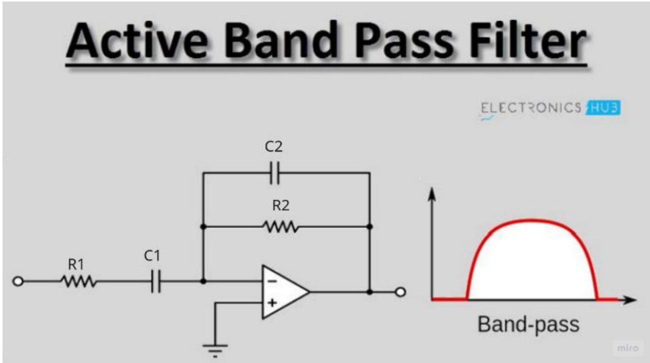


Figure: Band pass filter

Working principle:

1) *Input RC Network (High-Pass Filter):*

The first RC network at the input acts as a high pass filter, blocking low-frequency components below its cutoff frequency(f_L) and allowing higher frequencies to pass.

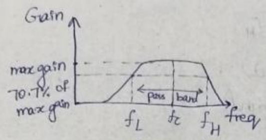
2) *Feedback RC Network (Low-Pass Filter):*

The second RC network in the feedback loop acts as a low-pass filter, allowing frequencies below its cutoff frequency (f_H) to pass while attenuating higher frequencies.

3) *Band-Pass Filtering:*

The combination of the two RC networks results in a band-pass filter, allowing frequencies within the band ($f_L < f < f_H$) to pass while attenuating frequencies outside this range.

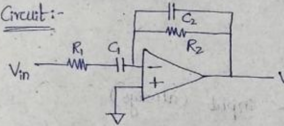
* Active Band Pass filter:-



$\leftarrow$ freq response

$BW = f_H - f_L$

* Circuit:-



$\longrightarrow$ Inverting configuration

$$\frac{V_{in}}{Z_1} + \frac{V_{out}}{Z_2} = 0$$

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{-Z_2}{Z_1}}$$

$$Z_1 = R_1 + \frac{1}{sC_1} = \frac{sC_1R_1 + 1}{sC_1}$$

$$Z_2 = \left(\frac{1}{R_2} + sC_2\right)^{-1} = \frac{R_2}{1 + sC_2R_2}$$

$$\frac{V_{out}}{V_{in}} = \frac{\dfrac{-R_2}{1+sC_2R_2}}{\dfrac{sC_1R_1+1}{sC_1}} = \frac{-sC_1R_2}{(1+sC_2R_2)(1+sC_1R_1)}$$

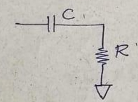
* Quality factor $Q = \frac{f_c}{BW}$

$$f_c = \sqrt{f_L f_H}$$

$Q < 10$ (wideband)

$Q > 10$ (narrow band)

*



$\longrightarrow$ Passive HPF

Limitations:-

$\rightarrow$ output $<$ input (always)

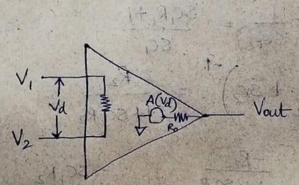
$\rightarrow$ cutoff frequency depends on load

So, we use active filters.

* Opamp:-

High input impedance ($M\Omega$)

Low output impedance (Ω)



$$H(s) = \frac{-sR_2C_1}{(1+sC_1R_1)(1+sC_2R_2)}$$

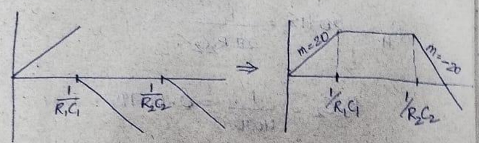
$$\boxed{H(s) = \frac{-j\omega R_2C_1}{(1+j\omega R_1C_1)(1+j\omega R_2C_2)}} \quad (1)$$

$$20\log|H(j\omega)| = 20\log|j\omega R_2C_1| - 20\log|(1+j\omega R_1C_1)| - 20\log|(1+j\omega R_2C_2)|$$

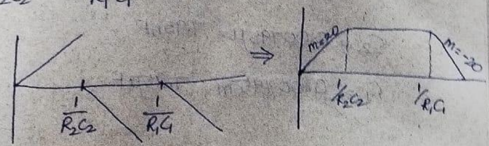
$$20\log|H(j\omega)| = 20\log(\omega R_2C_1) - 20\log\sqrt{1+\omega^2R_1^2C_1^2} - 20\log\sqrt{1+\omega^2R_2^2C_2^2}$$

Cases:-

(1) $\frac{1}{R_1C_1} < \frac{1}{R_2C_2} \Rightarrow R_1C_1 > R_2C_2$



(2) $\frac{1}{R_2C_2} < \frac{1}{R_1C_1} \Rightarrow R_1C_1 < R_2C_2$

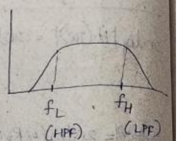


(3) $R_1C_1 = R_2C_2$

This is All pass filter

$f_H = \frac{1}{2\pi R_2C_2}$ $\quad f_L = \frac{1}{2\pi R_1C_1}$

$f_c = \sqrt{f_L f_H}$



$\text{Gain} = \frac{-R_2}{R_1} = 1$

$R_1 = R_2$

$$f_L = 20\,kHz = \frac{1}{2\pi R_1C_1}$$

$$R_1C_1 = \frac{1}{40k\pi} = 0.00795m$$

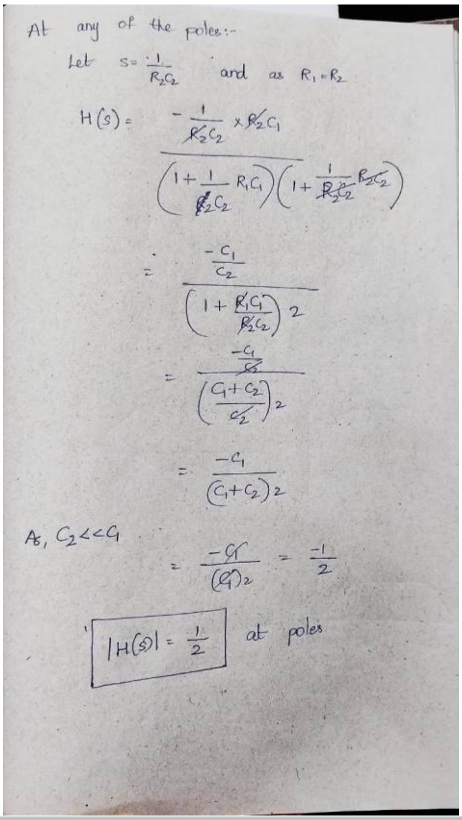
$$f_H = 20\,Hz = \frac{1}{2\pi R_2C_2}$$

$$R_2C_2 = \frac{1}{40\pi} = 0.00795$$

Let $R_1 = 1k = R_2$

$C_2 = 0.00795\mu = 7.95nF$

$C_1 = 0.00795\,m = 7.95\mu F$



At any of the poles:-

Let $s = \frac{1}{R_2C_2}$ and as $R_1 = R_2$

$$H(s) = \frac{-\frac{1}{\cancel{R_2}C_2} \times \cancel{R_2}C_1}{\left(1+\frac{1}{\cancel{R_2}C_2}R_1C_1\right)\left(1+\frac{1}{\cancel{R_2C_2}}\cancel{R_2C_2}\right)}$$

$$= \frac{-\frac{C_1}{C_2}}{\left(1+\frac{\cancel{R_1}C_1}{\cancel{R_2}C_2}\right)2}$$

$$= \frac{\frac{-C_1}{\cancel{C_2}}}{\left(\frac{C_1+C_2}{\cancel{C_2}}\right)2}$$

$$= \frac{-C_1}{(C_1+C_2)2}$$

As, $C_2 << C_1$

$$= \frac{-\cancel{C_1}}{(\cancel{C_1})2} = \frac{-1}{2}$$

$\boxed{|H(s)| = \frac{1}{2}}$ at poles

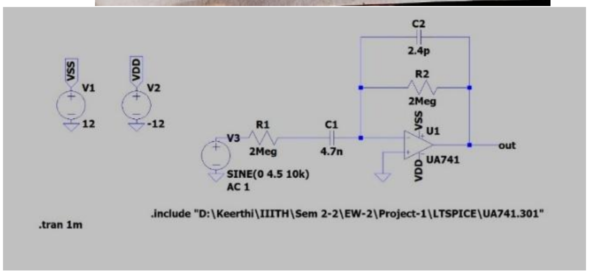


Figure: Circuit Diagram

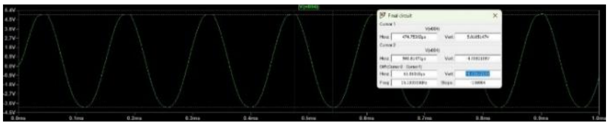


Figure: LTSPICE Output

Figure: Bode Plot

Figure: Hardware Output

Figure: Frequency Response at 20 Hz

Figure: Frequency Response at 20 kHz

VI. Power Amplifier

The power amplifier is the final stage of the audio amplification system, responsible for delivering sufficient power to drive the output load without introducing distortion. Unlike previous stages that focus on voltage amplification, the power amplifier is designed to provide the necessary current and power gain while maintaining signal integrity.

In this project, a Class AB power amplifier is used due to its efficiency and low distortion characteristics. Class AB amplifiers combine the advantages of Class A (low distortion) and Class B (high efficiency) amplifiers, ensuring better performance for audio applications. The design ensures that the amplifier does not introduce additional voltage gain while efficiently driving the 10Ω load.

Class-A Power Amplifier:

• Operating Principle: The transistor in a Class-A amplifier is biased so that it remains active (in the linear region) throughout the entire input signal cycle (360◦ conduction angle).

• Features:

– High linearity, making it suitable for low-distortion amplification.

– Poor efficiency, typically around 25% − 30%.

– High heat dissipation due to continuous current flow even without input signal.

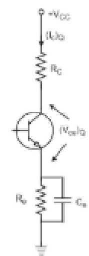


Figure: Class A amplifier

Class-B Power Amplifier:

• Operating Principle: The transistor is biased at cutoff, and each transistor in a push-pull configuration conducts for half of the input signal cycle (180◦ conduction angle).
• Features:
– Higher efficiency compared to Class-A, typically around 50% − 70%.
– Introduces crossover distortion due to the transition between transistors.
– Requires a complementary pair of transistors (NPN and PNP or MOSFETs).

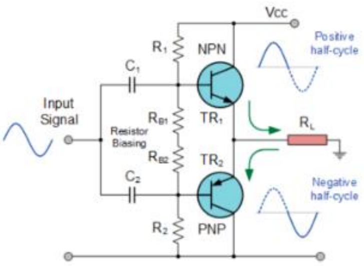


Figure: Class B amplifier

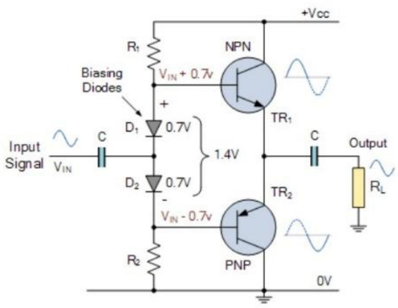


Figure: Class AB Power Amplifier

Working of Class AB Power Amplifier:

A small constant current flows through the series circuit of R1-D1-D2-R2, producing voltage drops which are symmetrical either side of the input. With no input signal voltage applied, the point between the two diodes is zero volts. As current flows through the chain, there is a forward bias voltage drop of approximately 0.7V across the diodes which is applied to the base-emitter junctions of the switching transistors.

Therefore, the voltage drop across the diodes, biases the base of transistor TR1 to about 0.7 volts, and the base of transistor TR2 to about –0.7 volts. Thus, the two silicon diodes provide a constant voltage drop of approximately 1.4 volts between the two bases biasing them above cut-off.

As the temperature of the circuit rises, so too does that of the diodes as they are located next to the transistors. The voltage across the PN junction of the diode thus decreases diverting some of the transistors base current stabilizing the transistors collector current.

If the electrical characteristics of the diodes are closely matched to that of the transistors base-emitter junction, the current flowing in the diodes and the current in the transistors will be the same creating what is called a current mirror. The effect of this current mirror compensates for variations in temperature producing the required Class AB operation thereby eliminating any crossover distortion.

In practice, diode biasing is easily accomplished in modern day integrated circuit amplifiers as both the diode and switching transistor are fabricated onto the same chip, such as in the popular LM386 audio power amplifier IC. This means that they both have identical characteristics curves over a wide temperature change providing thermal stabilization of the quiescent current.

The biasing of a Class AB amplifier output stage is generally adjusted to suit a particular amplifier application. The amplifiers quiescent current is adjusted to zero to minimize power consumption, as in Class B operation, or adjusted for a very small quiescent current to flow that minimizes crossover distortion producing a true Class AB amplifier operation.

Calculations:-

Using KVL

$$I_d = \frac{V_{cc} - 1.4}{R_1 + R_2}$$

for $I_d \approx 2mA$ (assumption)

$$R_1 + R_2 = \frac{V_{cc} - 1.4}{2mA} = \frac{3.6}{2mA} = 1.8k\Omega$$

Assuming $R_1 = R_2$

$$R_1 = R_2 = 900\Omega$$

We chose 2mA Bias current because:
1. Reduced Crossover Distortion:
In a Class-AB amplifier, we slightly bias the transistors into conduction to avoid the dead zone where both transistors are off. A higher bias current (like 2mA) ensures that the transistors turn on smoothly, reducing crossover distortion.
2. Ensures Proper Operation of the Diodes:
Diodes require a small current to stay in conduction and maintain their 0.7V drop. At very low currents (<1mA), diodes may not operate consistently, leading to variations in base-emitter voltages (V_{be}).
3. Faster response and Better Linearity:
A slightly higher bias current allows the transistors to switch on/off faster, improving the amplifier's frequency response. It helps achieve better linearity in signal amplification.

Output Power (P_{out})

The output voltage is an AC signal that swings between V_{cc} and 0V (assuming ideal conditions).

The RMS value of the output voltage is:

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

The output current is:

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

The power delivered to the load R_L is:

$$P_{out} = \frac{V_{rms}^2}{R_L} = \frac{V_m^2}{2R_L}$$

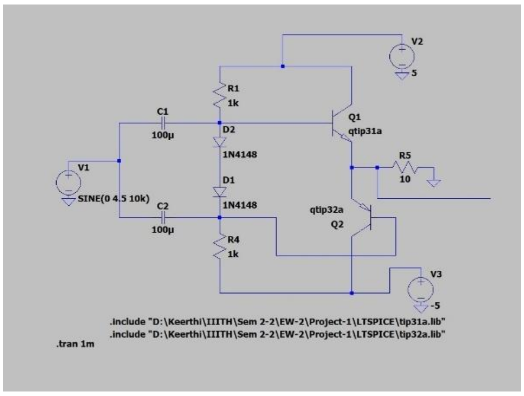


Figure: Circuit Diagram

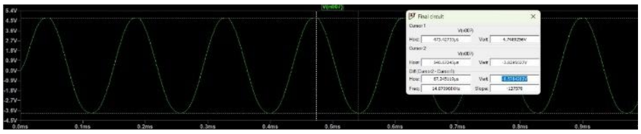


Figure: LTSPICE Output

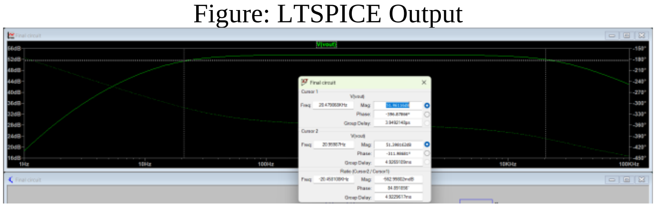


Figure: Bode Plot

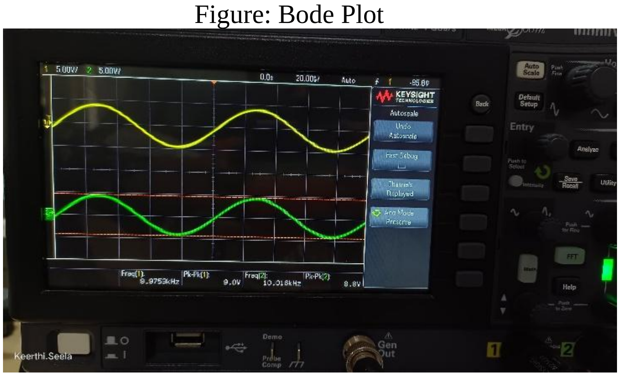


Figure: Hardware Output

Figure: Bode Plot

VII. Complete Circuit

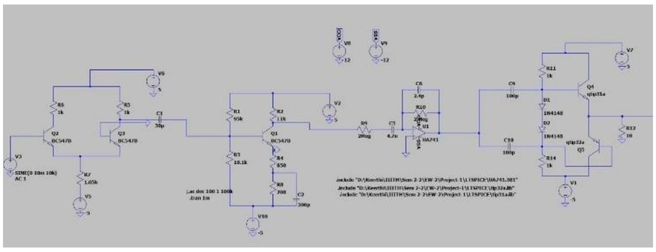


Figure: Complete Circuit Simulation

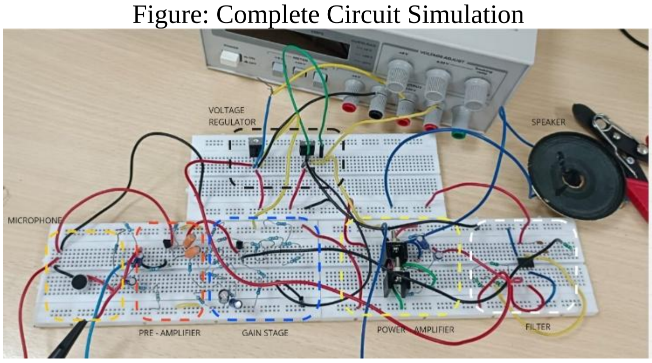


Figure: complete circuit

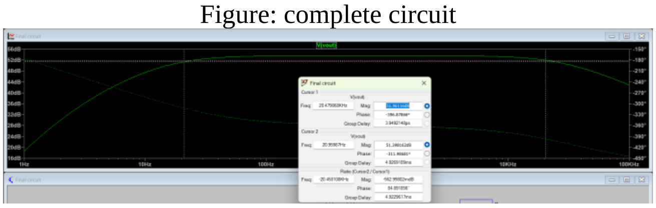


Figure: Final Bode Plot

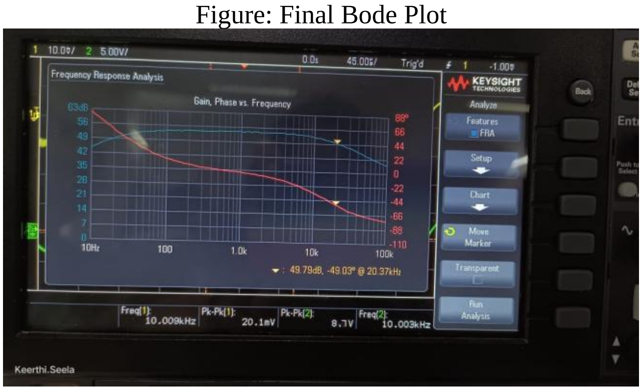


Figure: Final Bode plot

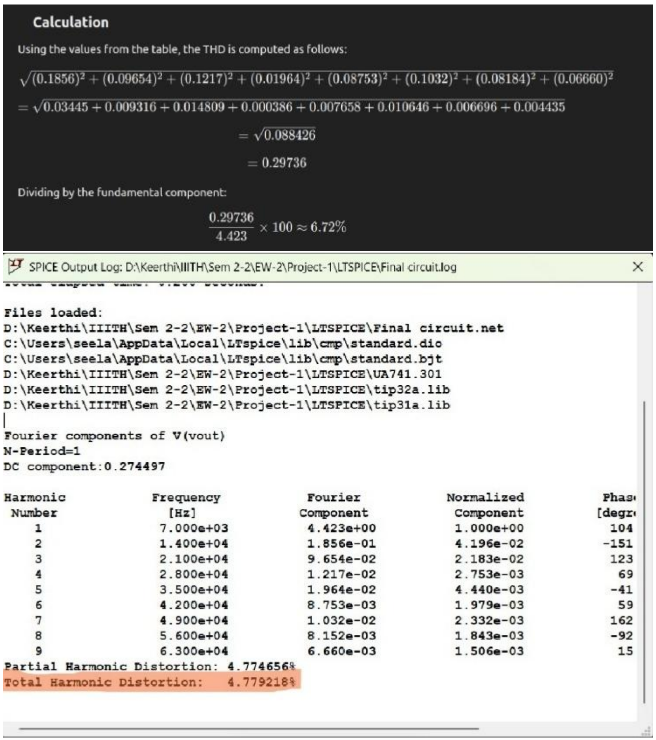
Link of the result: https://drive.google.com/file/d/1z4bTa2ttW6Lfy7q3CHzi1b1uVaFAGL7o/view?usp=sharing

VIII. Distortion Analysis

Distortion in an amplifier circuit refers to the presence of unwanted harmonic content in the output signal, which alters the original waveform. This can occur due to nonlinearities in the circuit components, leading to harmonic distortion. To quantify distortion, Total Harmonic Distortion (THD) is used:

$$\textbf{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_{nRMS}^2}}{V_{fRMS}}$$

V_{nRMS} is the RMS Voltage of the n^{th} harmonic
V_{fRMS} is the voltage of the fundamental frequency



Calculation

Using the values from the table, the THD is computed as follows:

$$\sqrt{(0.1856)^2 + (0.09654)^2 + (0.1217)^2 + (0.01964)^2 + (0.08753)^2 + (0.1032)^2 + (0.08184)^2 + (0.06660)^2}$$
$$= \sqrt{0.03445 + 0.009316 + 0.014809 + 0.000386 + 0.007658 + 0.010646 + 0.006696 + 0.004435}$$
$$= \sqrt{0.088426}$$
$$= 0.29736$$

Dividing by the fundamental component:

$$\frac{0.29736}{4.423} \times 100 \approx 6.72\%$$

SPICE Output Log: D:\Keerthi\IIITH\Sem 2-2\EW-2\Project-1\LTSPICE\Final circuit.log

```
Files loaded:
D:\Keerthi\IIITH\Sem 2-2\EW-2\Project-1\LTSPICE\Final circuit.net
C:\Users\seela\AppData\Local\LTspice\lib\cmp\standard.dio
C:\Users\seela\AppData\Local\LTspice\lib\cmp\standard.bjt
D:\Keerthi\IIITH\Sem 2-2\EW-2\Project-1\LTSPICE\UA741.301
D:\Keerthi\IIITH\Sem 2-2\EW-2\Project-1\LTSPICE\tip32a.lib
D:\Keerthi\IIITH\Sem 2-2\EW-2\Project-1\LTSPICE\tip31a.lib

Fourier components of V(vout)
N-Period=1
DC component:0.274497
```

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phas [degr
1	7.000e+03	4.423e+00	1.000e+00	104
2	1.400e+04	1.856e-01	4.196e-02	-151
3	2.100e+04	9.654e-02	2.183e-02	123
4	2.800e+04	1.217e-02	2.753e-03	69
5	3.500e+04	1.964e-02	4.440e-03	-41
6	4.200e+04	8.753e-03	1.979e-03	59
7	4.900e+04	1.032e-02	2.332e-03	162
8	5.600e+04	8.152e-03	1.843e-03	-92
9	6.300e+04	6.660e-03	1.506e-03	15

```
Partial Harmonic Distortion: 4.774656%
Total Harmonic Distortion:   4.779218%
```

Figure: THD

The THD was determined using the Fast Fourier Transform (FFT) of the amplified output signal. A lower THD indicates minimal unwanted harmonics, resulting in better audio quality. High THD can lead to noticeable distortion, affecting the clarity and fidelity of the sound.
To reduce THD, low-pass filtering was applied to attenuate higher-order harmonics, minimizing circuit interference. Additionally, optimizing the biasing and feedback networks helped improve linearity, reducing unwanted distortions.

IX. SLEW RATE

The Slew Rate (SR) of an amplifier defines the maximum rate of change of the output voltage with respect to time:

$$\text{S.R.} = \max\left(\frac{\partial V_{OUT}}{\partial t}\right)$$

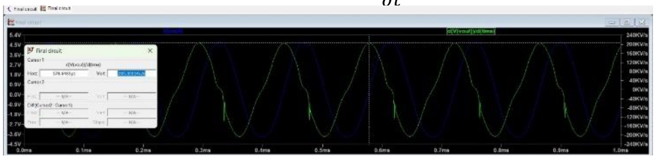


Figure: Slew rate

A high slew rate is desirable, ensuring the circuit can accurately reproduce high-frequency signals without distortion. If the slew rate is too low, the amplifier may fail to keep up with rapid voltage changes, resulting in slew-induced distortion, where sharp signal transitions appear rounded or delayed.