ELECTRONICS WORKSHOP 02
PROJECT 01 REPORT

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Contents

1 Introduction to Pre-Amplifier

A **preamplifier (preamp)** is a small amplifier used to boost weak signals before they go to a larger amplifier. It helps improve the quality of the signal by making it stronger and reducing unwanted noise. Preamplifiers are commonly used in microphones, musical instruments, radios, and sensors to ensure the signal is clear and strong.

1.1 Main Functions of a Pre-Amp

- **Makes Weak Signals Stronger:** If a signal is too weak, a preamp boosts it so that it can be processed properly.
- **Prevents Signal Loss:** Helps transfer signals without losing quality by matching the connected devices.
- **Reduces Noise:** It improves clarity by making the actual signal louder while reducing unwanted background noise.
- **Acts as a Buffer:** It protects the next stage of the circuit from being overloaded by the weak signal source.

1.2 Theoretical Circuit Analysis

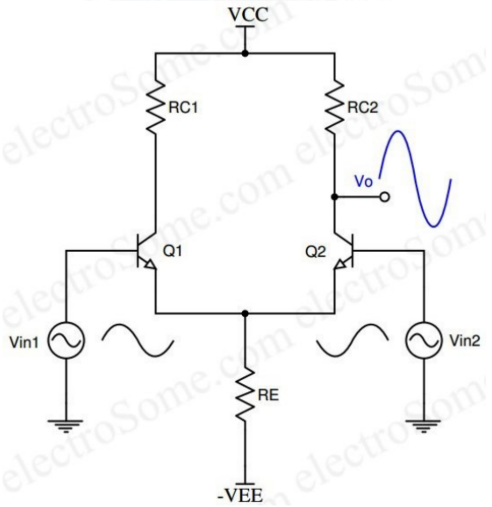


Figure 1: Differential Amplifier Circuit

1.2.1 Differential Mode Analysis

In differential mode, the inputs are equal in magnitude but opposite in phase:

$$V_{in1} = +\frac{V_d}{2}, \quad V_{in2} = -\frac{V_d}{2} \tag{1}$$

where V_d is the differential input voltage.

Step 1: Apply Kirchhoff's Voltage Law (KVL)

For the small signal analysis, we replace BJT transistors (Q_1 and Q_2) with their small-signal equivalent circuits using g_m and r_o models. The emitters of Q_1 and Q_2 are connected to R_E, which introduces a negative feedback mechanism.

The collector resistances are:

$$R_C = R_{C1} = R_{C2} \tag{2}$$

The total emitter resistance seen by the signal is:

$$r_e = \frac{1}{g_m}, \quad \text{where } g_m = \frac{I_C}{V_T} \tag{3}$$

Since the circuit is symmetrical, the emitter voltage will be at AC ground:

$$V_E = \frac{V_{in1} + V_{in2}}{2} = 0 \tag{4}$$

Thus, the small-signal voltages at each base are:

$$V_{BE1} = V_{in1} - V_E = +\frac{V_d}{2}, \quad V_{BE2} = V_{in2} - V_E = -\frac{V_d}{2} \tag{5}$$

Step 2: Emitter Current Calculation

The small-signal emitter currents for Q_1 and Q_2 are:

$$i_{e1} = g_m \cdot V_{BE1} = g_m \cdot \frac{V_d}{2}, \quad i_{e2} = g_m \cdot V_{BE2} = -g_m \cdot \frac{V_d}{2} \tag{6}$$

Since $i_C = \alpha i_E \approx i_E$, the collector currents are:

$$i_{C1} = g_m \cdot \frac{V_d}{2}, \quad i_{C2} = -g_m \cdot \frac{V_d}{2} \tag{7}$$

Step 3: Output Voltage

The output voltage at the collector of Q_2:

$$V_{out} = -i_{C2} R_C = -(-g_m \frac{V_d}{2}) R_C \tag{8}$$

$$V_{out} = \frac{g_m R_C}{2} V_d \tag{9}$$

Step 4: Differential Gain

If the output voltage V_{out} is taken at Q_2's collector, the differential gain is:

$$A_d = \frac{g_m R_C}{2}$$

If the output voltage V_{out} is taken at Q_1's collector, the differential gain is:

$$A_d = -\frac{g_m R_C}{2}$$

1.2.2 Common Mode Analysis

In common mode, the inputs are equal:

$$V_{in1} = V_{in2} = V_c \tag{10}$$

Step 1: Apply KVL to the Base Circuit

Since both transistors receive the same input,

$$V_E = V_c \tag{11}$$

The emitter current for both transistors is:

$$i_{E1} = i_{E2} = \frac{V_E}{2(r_e + R_E)} \tag{12}$$

Total emitter current:

$$I_E = i_{E1} + i_{E2} = \frac{V_E}{r_e + 2R_E} \tag{13}$$

Using transconductance:

$$i_{C1} = i_{C2} = \frac{\beta V_E}{r_e + 2R_E} \tag{14}$$

Step 2: Output Voltage

$$V_{out} = -i_{C2}R_C = -\left(\frac{\beta V_E}{r_e + 2R_E}\right) R_C \tag{15}$$

$$V_{out} = -\frac{\beta R_C}{r_e + 2R_E} V_C \tag{16}$$

Step 3: Common Mode Gain

$$A_c = \frac{V_{out}}{V_C} = -\frac{\beta R_C}{r_e + 2R_E} \tag{17}$$

If R_E is large, $A_c \approx 0$, meaning the circuit rejects common-mode signals effectively.

1.2.3 Common-Mode Rejection Ratio (CMRR)

The CMRR is the ratio of differential gain to common-mode gain:

$$CMRR = \left|\frac{A_d}{A_c}\right| = \frac{g_m R_C/2}{\beta R_C/(r_e + 2R_E)} \tag{18}$$

$$CMRR = \frac{g_m R_C}{2} \cdot \frac{r_e + 2R_E}{\beta R_C} \tag{19}$$

For high CMRR, R_E should be large.

1.3 Simulation Results

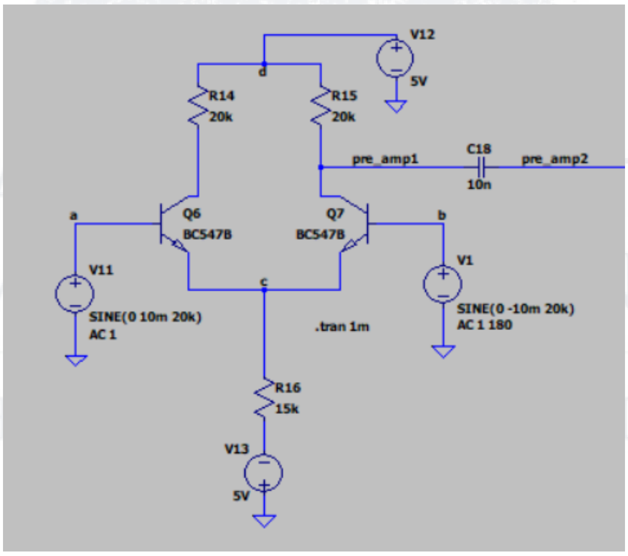


Figure 2: LTSpice Simulation of Differential Amplifier

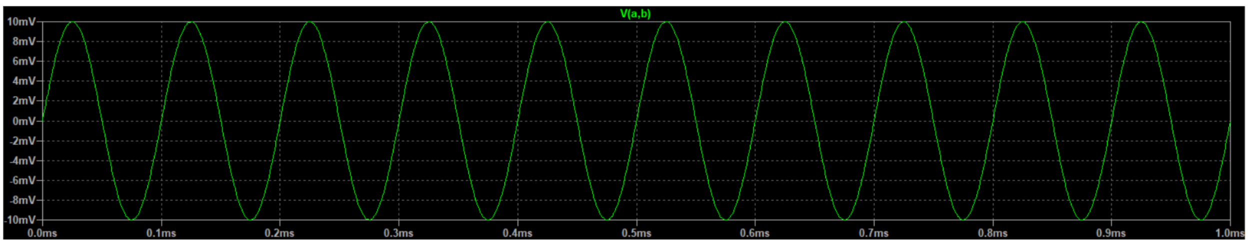


Figure 3: Input Signal

This LTSpice circuit represents a **Differential Amplifier** using two BC547B NPN transistors. Here is a brief explanation of its functionality and key points:

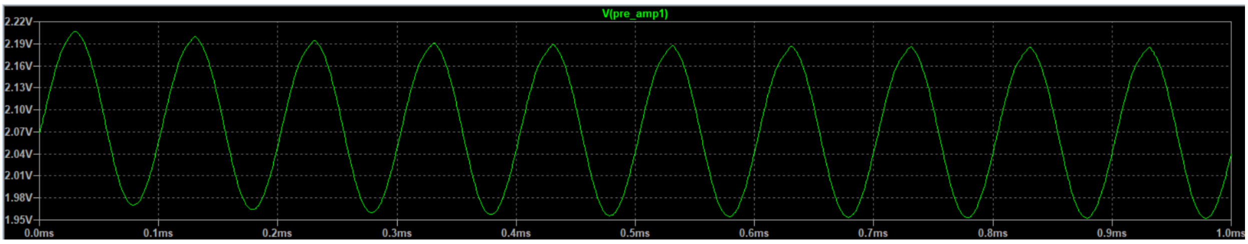


Figure 4: Signal After Pre-Amp and Before Coupling Capacitors

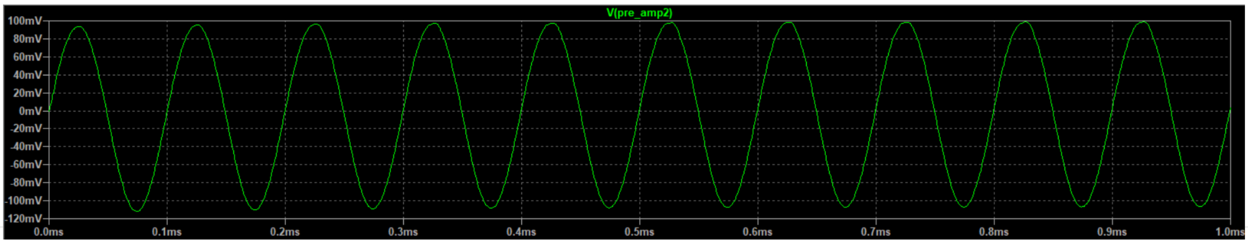


Figure 5: Signal After Coupling Capacitors

1.3.1 Circuit Overview

Differential Pair (Q6 & Q7)

- The two BC547B transistors form a classic differential amplifier configuration.
- Their emitters are connected together and biased by R_{16} (15kΩ) to a 5V DC source (V_{13}).
- This resistor helps set the operating point of the differential pair.

Input Signals (V_{11} & V_1)

- V_{11} and V_1 are sine wave inputs of equal amplitude (10mV peak) but **180° out of phase**.
- This ensures that the circuit is operating in **differential mode**, which is ideal for rejecting common-mode noise.

Collector Resistors (R_{14} & R_{15}, 20kΩ each)

- These resistors convert the differential current changes into output voltage variations.
- The amplified **differential output** appears across these resistors.

Coupling Capacitor (C_{18}, 10nF)

- Used to **filter DC offset** and pass only the AC signal from *pre_amp1* to *pre_amp2*.
- Ensures proper signal coupling for the next stage of amplification or processing.

Expected Simulation Results in LTSpice

Differential Mode Behavior

- The circuit will amplify the voltage difference between V_{11} and V_1.
- Output will be taken from *pre_amp1* and *pre_amp2*.

Common-Mode Rejection

- If both inputs receive the same signal (common-mode), the output should ideally be **zero or minimal** due to **common-mode rejection**.

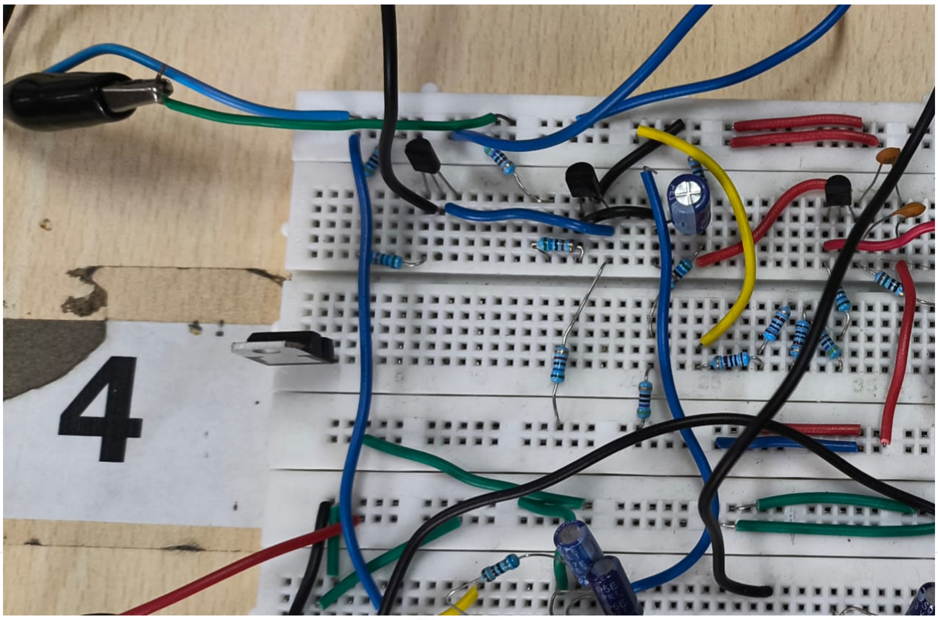


Figure 6: Hardware Implementation of Pre-Amplifier

Figure 7: Hardware implemented output at DSO after pre-amp stage

1.4 Hardware Implementation and Modifications

1.4.1 Differences Between LTSpice Simulations and Hardware Implementations

- **Resistor Adjustments** – Resistor values had to be modified to match expected performance.
- **Output Discrepancies** – Theoretical simulation results did not directly translate to hardware.
- **Component Tolerances** – Variations in real components affected circuit behavior.
- **Gain Deviations** – Expected gain values were not achieved in hardware.
- **Noise Interference** – Unwanted signal fluctuations occurred in the real circuit.
- **Debugging Challenges** – Extensive modifications and testing were required for optimization.

Although initially in the ltspice had an implementation 10 times then 50 times in gain stage but while implementing had to change it to 20 times in pre amplifier stage and around 25 times after gain stage...which really helped in shaping the final hardware circuit differently with proper mechanism compared to what we had in LTspice simulations

2 Stage 2: Gain Stage

2.1 Objective

The Common-Emitter (CE) amplifier is one of the most widely used transistor amplifier configurations due to its high voltage gain and moderate input and output impedance characteristics. It is primarily employed in analog circuits such as audio amplifiers, radio frequency circuits, and signal processing applications.

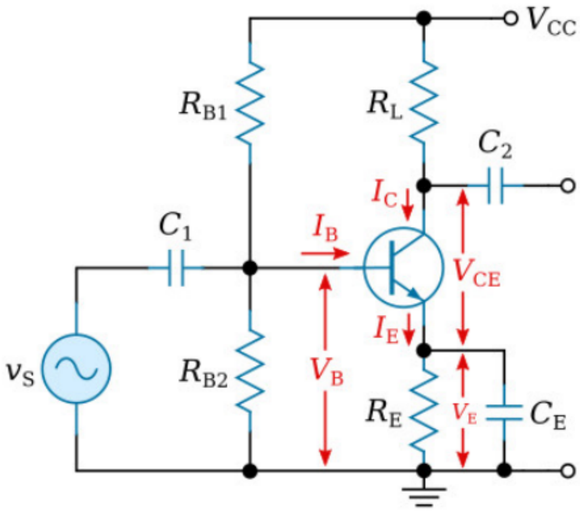


Figure 8: Common-Emitter Amplifier Circuit

2.1.1 CE Amplifier Configuration

- The input signal is applied to the base terminal through a coupling capacitor.
- The output is taken from the collector terminal.
- The emitter terminal is typically connected to the ground via an emitter resistor, which helps stabilize the operating point.

2.1.2 Key Features of CE Amplifier

- **Voltage Gain:** The CE amplifier provides significant voltage amplification, making it suitable for signal amplification applications.
- **Phase Inversion:** The output signal is 180° out of phase with the input signal.
- **Moderate Input Impedance:** It has a moderate input impedance, which is lower than that of a Common-Collector (CC) amplifier but higher than that of a Common-Base (CB) amplifier.
- **High Output Impedance:** The output impedance is relatively high, making it suitable for driving loads with higher impedance.

2.2 Theoretical Circuit Analysis

2.2.1 Small-Signal Analysis

The small-signal model of the CE amplifier is used to derive expressions for voltage gain, input impedance, and output impedance.

Step 1: Small-Signal Equivalent Circuit

The small-signal equivalent model replaces the transistor with its hybrid-π model:

- Base-emitter resistance: $r_\pi = \frac{\beta}{g_m}$

- Transconductance: $g_m = \frac{I_C}{V_T}$, where V_T is the thermal voltage ($\approx 25mV$ at room temperature).
- Output resistance: r_o (due to the Early effect, often neglected for simplicity).

The input voltage v_{in} is applied at the base, and the output voltage v_{out} is taken at the collector. The emitter is grounded (through R_E if present).

Step 2: Voltage Gain Derivation

Case 1: Without Emitter Resistor ($R_E = 0$)

Applying Kirchhoff's Voltage Law (KVL) at the base-emitter loop:

$$v_{be} = v_{\text{in}} \tag{20}$$

Applying Kirchhoff's Current Law (KCL) at the collector node:

$$i_c = g_m v_{be} = g_m v_{\text{in}} \tag{21}$$

The output voltage is:

$$v_{\text{out}} = -i_c R_C = -g_m v_{\text{in}} R_C \tag{22}$$

Thus, the voltage gain is:

$$A_v = \frac{v_{\text{out}}}{v_{\text{in}}} = -g_m R_C \tag{23}$$

Case 2: With Emitter Resistor ($R_E \neq 0$)

When R_E is present, the gain is reduced due to negative feedback. The input voltage is divided as:

$$v_{be} = v_{\text{in}} - v_e \tag{24}$$

Since $v_e = i_e R_E$ and $i_e \approx i_c$, we get:

$$v_e = g_m v_{be} R_E \tag{25}$$

Rearranging,

$$v_{be}(1 + g_m R_E) = v_{\text{in}} \tag{26}$$

Thus,

$$v_{be} = \frac{v_{\text{in}}}{1 + g_m R_E} \tag{27}$$

Substituting into the output voltage equation,

$$v_{\text{out}} = -g_m v_{be} R_C = -\frac{g_m v_{\text{in}} R_C}{1 + g_m R_E} \tag{28}$$

So, the voltage gain is:

$$A_v = \frac{v_{\text{out}}}{v_{\text{in}}} = -\frac{g_m R_C}{1 + g_m R_E} \tag{29}$$

If R_E is bypassed by a capacitor (AC shorted), then $A_v = -g_m R_C$, which is the same as the first case.

Step 3: Input and Output Impedance

Input Impedance (Z_{in})

The input impedance is given by:

$$Z_{\text{in}} = R_B \parallel r_\pi \tag{30}$$

where $R_B = R_{B1} \parallel R_{B2}$. Since $r_\pi = \frac{\beta}{g_m}$, the final impedance is:

$$Z_{\text{in}} = (R_{B1} \parallel R_{B2}) \parallel \left(\frac{\beta}{g_m}\right) \tag{31}$$

Output Impedance (Z_{out})

$$Z_{\text{out}} = R_C \parallel r_o \tag{32}$$

For most cases, r_o is large, so:

$$Z_{\text{out}} \approx R_C \tag{33}$$

2.2.2 Large-Signal Analysis

Large-signal analysis deals with the nonlinear behavior of the transistor. Here, we analyze the amplifier under DC operating conditions and high-amplitude input signals.

Step 1: DC Operating Point Analysis

To ensure the transistor operates in the active region:

$$I_B = \frac{V_B - V_{BE}}{R_B} \tag{34}$$

$$I_C = \beta I_B \tag{35}$$

$$V_{CE} = V_{CC} - I_C R_C \tag{36}$$

where $V_{BE} \approx 0.7V$ for a silicon transistor.

Step 2: Large-Signal Voltage Gain

For large signals, the gain depends on the nonlinear behavior of the transistor. The resistance of the emitter r_e plays a crucial role in determining the gain:

$$r_e = \frac{V_T}{I_E} \tag{37}$$

Thus, the voltage gain is:

$$A_v = -\frac{\beta R_C}{R_E + r_e} \tag{38}$$

This shows that the gain is reduced due to R_E, which stabilizes the amplifier.

2.3 Simulation Results

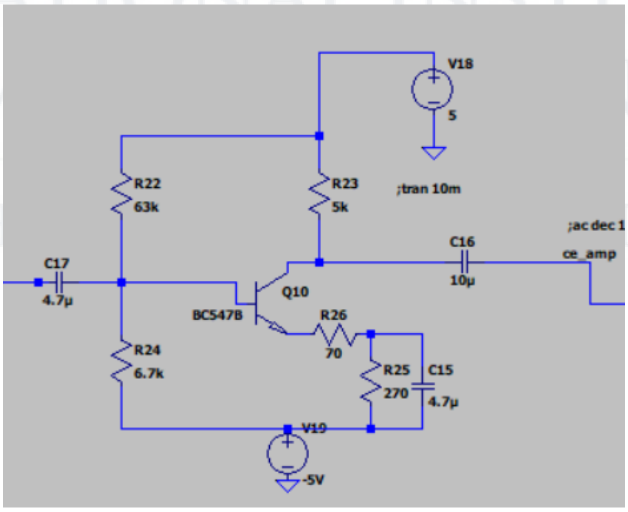


Figure 9: LTSpice Circuit of CE Amplifier

2.3.1 LTSpice Components of the CE Amplifier Circuit

Components:

- **BC547B (Q10)**: NPN transistor used for amplification.
- **R22, R24**: Biasing resistors to set the transistor's operating point.
- **R23 (Collector Resistor)**: Determines the voltage gain.

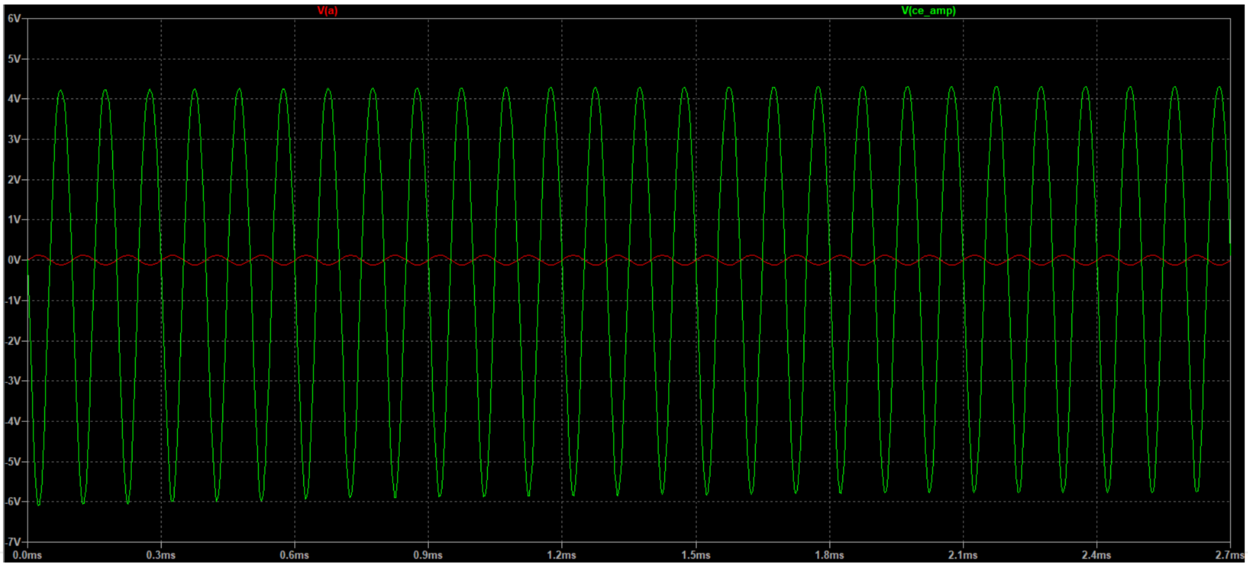


Figure 10: LTSpice Simulation of CE Amplifier

- **R26, R25 (Emitter Resistors)**: Provide stability and negative feedback.
- **C17 (Input Coupling Capacitor)**: Blocks DC and allows AC signal to pass.
- **C15, C16 (Bypass Output Capacitors)**: C15 stabilizes gain, C16 couples output.
- **V18 (+5V) and V19 (-5V)**: Power supply.

Simulation Commands:

- `.tran 10m`: Transient analysis for 10ms.
- `.ac dec 1`: AC analysis to check frequency response.

2.4 Hardware Implementation Modifications

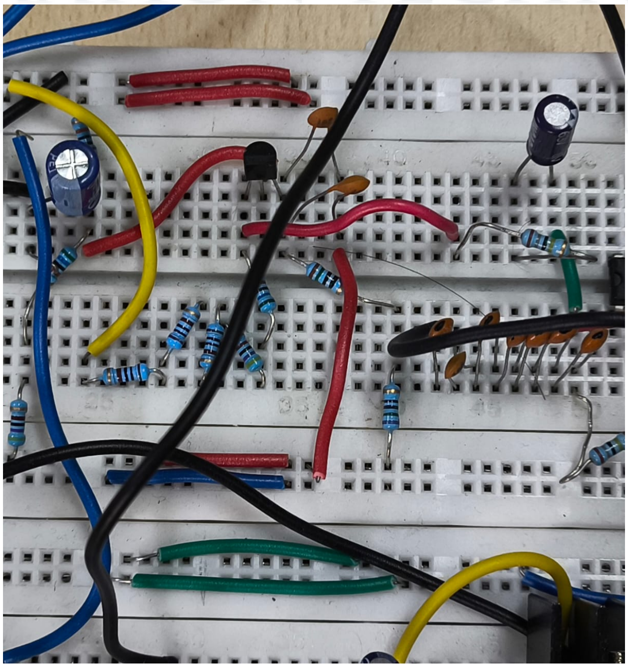


Figure 11: Hardware Implementation of CE Amplifier

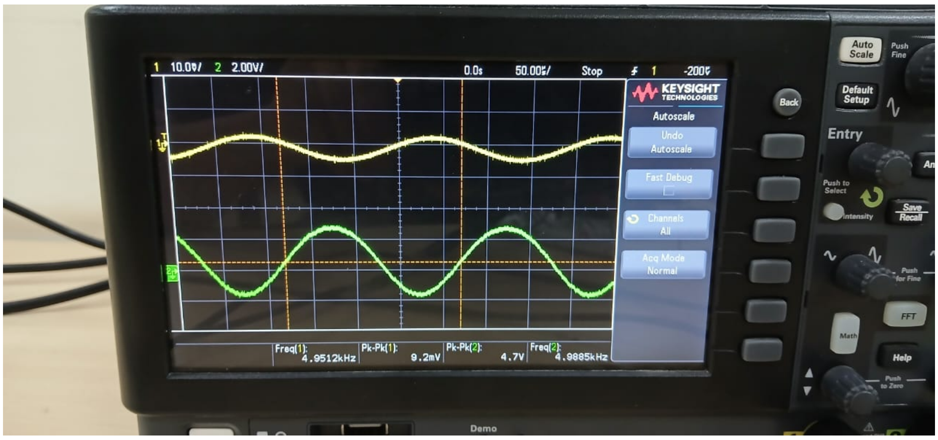


Figure 12: Hardware implemented output at DSO after CE amplifier or gain stage

3 Stage 3: Bandpass Filter

3.1 Objective

A **bandpass filter (BPF)** is a crucial component in audio amplifier circuits, designed to allow signals within a specific frequency range to pass while attenuating frequencies outside this range. It is widely used in audio applications to isolate and enhance certain frequency bands, such as mid-range tones in music or speech signals.

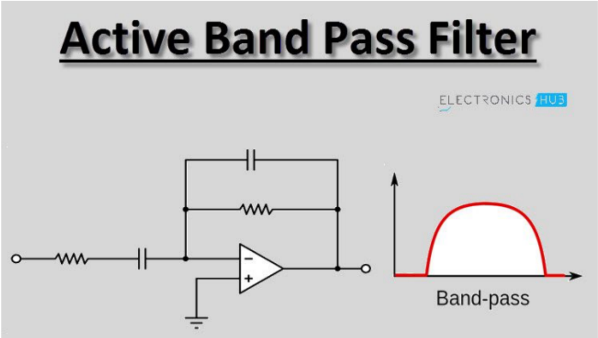


Figure 13: Bandpass Filter Circuit

First and Second Order Bandpass Filters

Bandpass filters can be categorized based on their order, which determines their sharpness and effectiveness.

1. First-Order Band-pass Filter

- Composed of a single capacitor-inductor (LC) or RC network.
- It provides a gentle roll-off of −20 dB/decade outside the passband.
- Suitable for simple applications where precise filtering is not required.

2. Second-Order Band-pass Filter

- Uses two inductor-capacitor (LC) or RC stages, often with an active component (op-amp).
- Provides a sharper roll-off of −40 dB/decade, offering better filtering.
- More effective for audio applications requiring precise band selection.

Why Not Use Low-Pass or High-Pass Filters in Audio Amplifiers?

While low-pass and high-pass filters have their uses, they are not ideal for general audio amplification due to the following reasons:

Low-Pass Filters

- Only allow frequencies below a certain threshold to pass.
- This would remove high-frequency details (e.g., treble sounds in music and speech clarity).
- Not ideal for full-range audio reproduction.

High-Pass Filters

- Only allow frequencies above a certain threshold to pass.
- This would remove bass and low-mid frequencies, making audio sound thin and weak.
- Not suitable for applications requiring a full audio spectrum.

Bandpass filters are preferred in audio amplifiers because they preserve the essential frequency range while removing unwanted noise and interference.

3.2 Theoretical Circuit Analysis

3.2.1 High-Pass Filter (HPF) Derivation

A high-pass filter consists of a series capacitor C_1 and a shunt resistor R_1.

Transfer Function

Using impedance notation:

$$Z_{C_1} = \frac{1}{j\omega C_1} \tag{39}$$

Applying the voltage divider rule:

$$H_{HPF}(j\omega) = \frac{V_{out}}{V_{in}} = \frac{j\omega R_1 C_1}{1 + j\omega R_1 C_1} \tag{40}$$

Lower Cutoff Frequency f_L

Magnitude response:

$$|H_{HPF}(j\omega)| = \frac{\omega R_1 C_1}{\sqrt{1 + \omega^2 R_1^2 C_1^2}} \tag{41}$$

Setting the magnitude to $\frac{1}{\sqrt{2}}$ for -3dB cutoff:

$$\omega^2 R_1^2 C_1^2 = 1 \tag{42}$$

Solving for ω_L:

$$\omega_L = \frac{1}{R_1 C_1}, \quad f_L = \frac{1}{2\pi R_1 C_1} \tag{43}$$

3.2.2 Low-Pass Filter (LPF) Derivation

A low-pass filter consists of a series resistor R_2 and a shunt capacitor C_2.

Transfer Function

Using impedance notation:

$$Z_{C_2} = \frac{1}{j\omega C_2} \tag{44}$$

Applying the voltage divider rule:

$$H_{LPF}(j\omega) = \frac{1}{1 + j\omega R_2 C_2} \tag{45}$$

Upper Cutoff Frequency f_H

Magnitude response:

$$|H_{LPF}(j\omega)| = \frac{1}{\sqrt{1 + \omega^2 R_2^2 C_2^2}} \tag{46}$$

Setting the magnitude to $\frac{1}{\sqrt{2}}$:

$$\omega^2 R_2^2 C_2^2 = 1 \tag{47}$$

Solving for ω_H:

$$\omega_H = \frac{1}{R_2 C_2}, \quad f_H = \frac{1}{2\pi R_2 C_2} \tag{48}$$

3.2.3 Overall Band-Pass Transfer Function

Since a band-pass filter is a cascade of HPF and LPF, the total transfer function is:

$$H_{BP}(j\omega) = H_{HPF}(j\omega) \cdot H_{LPF}(j\omega) \tag{49}$$

Substituting their expressions:

$$H_{BP}(j\omega) = \frac{j\omega R_1 C_1}{1 + j\omega R_1 C_1} \cdot \frac{1}{1 + j\omega R_2 C_2} \tag{50}$$

Simplifying:

$$H_{BP}(j\omega) = \frac{j\omega R_1 C_1}{(1 + j\omega R_1 C_1)(1 + j\omega R_2 C_2)} \tag{51}$$

3.2.4 Resonant Frequency f_0

At the peak frequency, the gain is maximum. Solving for ω_0:

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}, \quad f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \tag{52}$$

3.2.5 Bandwidth B

Bandwidth is given by:

$$B = f_H - f_L \tag{53}$$

Substituting f_H and f_L:

$$B = \frac{1}{2\pi R_2 C_2} - \frac{1}{2\pi R_1 C_1} \tag{54}$$

Factoring $\frac{1}{2\pi R_1}$:

$$B = \frac{1}{2\pi R_1}\left(\frac{1}{C_2} - \frac{1}{C_1}\right) \tag{55}$$

Using $K = \frac{R_2}{R_1}$:

$$B = \frac{1}{2\pi R_1}\left(\frac{1}{KC_2} - \frac{1}{C_1}\right) \tag{56}$$

where the bandwidth can be controlled by K.

3.2.6 Why -3dB is taken?

Step 1: Power and Voltage Relationship

The power in an electrical circuit is given by the following:

$$P = \frac{V^2}{R} \tag{57}$$

where V is the voltage across the load, and R is the resistance.

The gain of a system in terms of power is:

$$G_P = \frac{P_{\text{out}}}{P_{\text{in}}} \tag{58}$$

In decibels (dB), the power gain is expressed as:

$$G_P(\text{dB}) = 10\log_{10}\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right) \tag{59}$$

Since power is proportional to the square of voltage,

$$\frac{P_{\text{out}}}{P_{\text{in}}} = \left(\frac{V_{\text{out}}}{V_{\text{in}}}\right)^2 \tag{60}$$

Thus, the voltage gain in decibels is:

$$G_V(\text{dB}) = 20\log_{10}\left(\frac{V_{\text{out}}}{V_{\text{in}}}\right) \tag{61}$$

Step 2: Defining the -3dB Condition

We define the cutoff frequency as the point where the power is reduced to half of the maximum power:

$$\frac{P_{\text{out}}}{P_{\text{in}}} = \frac{1}{2} \tag{62}$$

Using the power-to-voltage relationship:

$$\left(\frac{V_{\text{out}}}{V_{\text{in}}}\right)^2 = \frac{1}{2} \tag{63}$$

Taking the square root:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{\sqrt{2}} \tag{64}$$

Step 3: Expressing in Decibels

We now convert this voltage ratio into decibels:

$$G_V(\text{dB}) = 20\log_{10}\left(\frac{1}{\sqrt{2}}\right) \tag{65}$$

Since $\sqrt{2} \approx 1.414$, we compute:

$$\log_{10}(1.414) \approx 0.15 \tag{66}$$

Thus,

$$G_V(\text{dB}) = 20 \times (-0.15) = -3 \text{ dB} \tag{67}$$

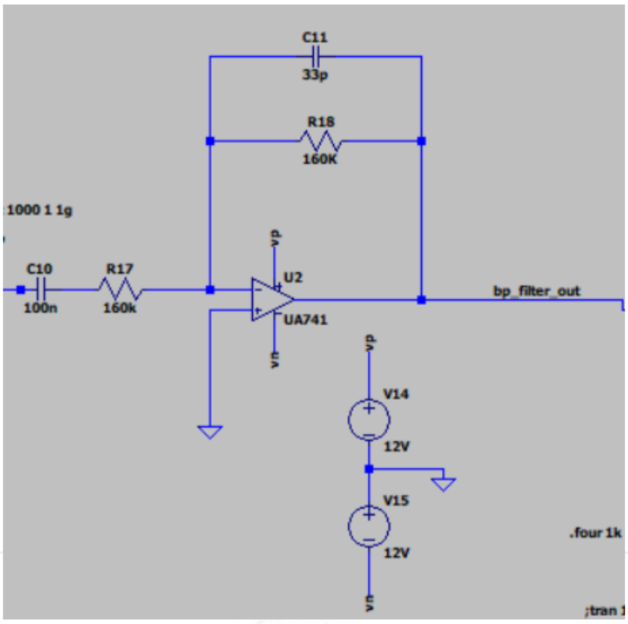


Figure 14: LTSpice Circuit of Bandpass Filter

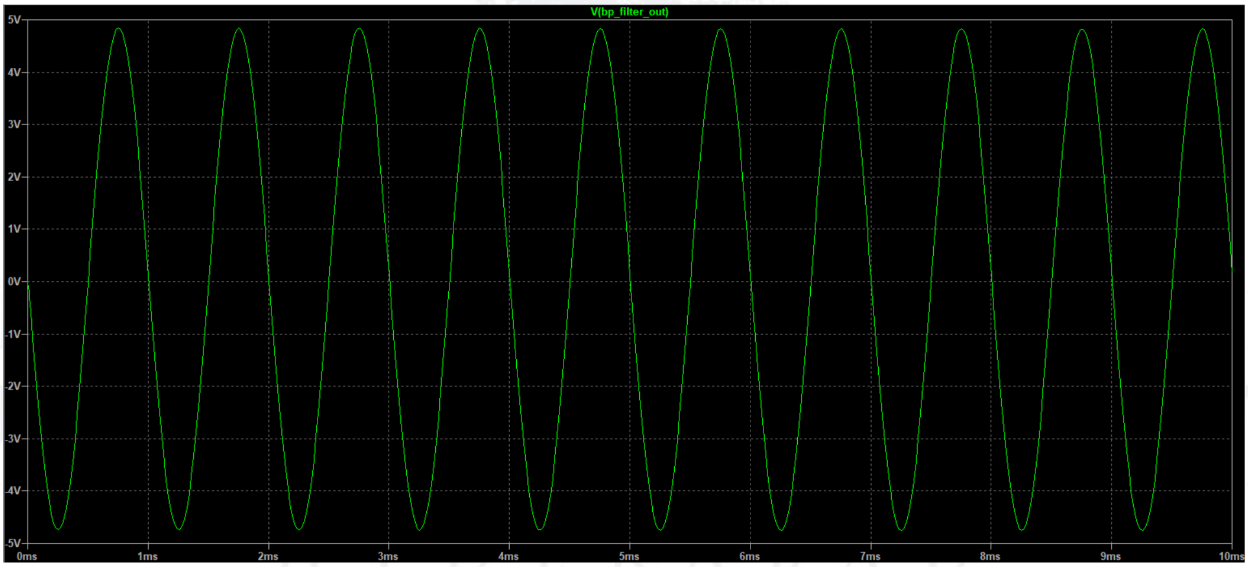


Figure 15: LTSpice Simulation of Bandpass Filter

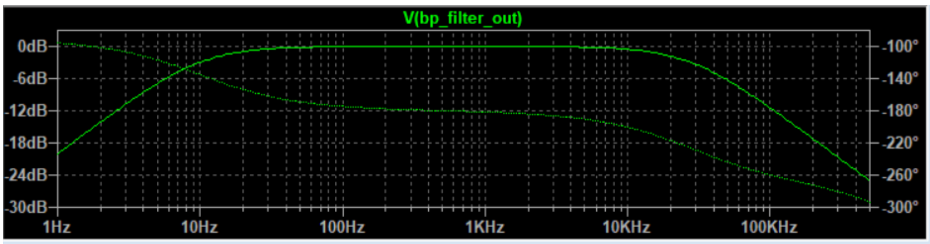


Figure 16: AC Analysis of Bandpass Filter

3.3 Simulation Results

3.3.1 LTSpice Components

Components:

- **UA741 (U2)**: Operational amplifier used for active filtering.

- **R17, R18 (Resistors)**: Define gain and frequency response.
- **C10, C11 (Capacitors)**: Set cutoff frequencies for the band-pass filter.
- **V14, V15 (±12V Supplies)**: Provide power to the op-amp.

Simulation Commands:

- `.tran 2m`: Transient simulation for 2ms.
- `.four 1k`: Fourier analysis at 1kHz to analyze harmonic content.

3.4 Hardware Implementation Modifications

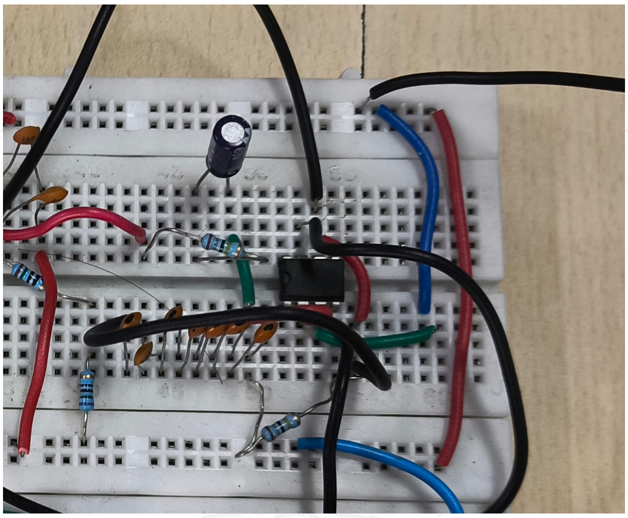


Figure 17: Hardware Implementation of Bandpass Filter

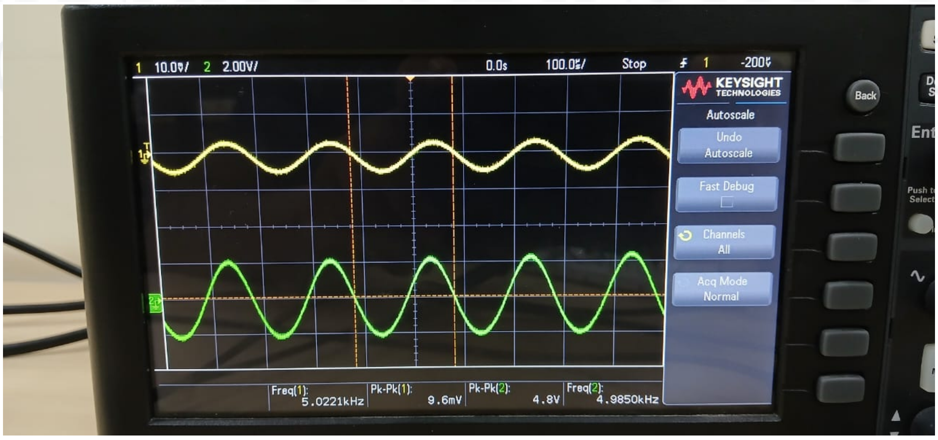


Figure 18: Hardware implemented output at DSO after bandpass filter

4 Stage 4: Power Amplifier

4.1 Objective

A **power amplifier** is designed to increase the power level of an input signal while maintaining its waveform characteristics. It is commonly used in audio systems, RF communication, and other applications where high power output is needed.

- **High Efficiency** – Convert DC power into AC power with minimal loss.
- **High Gain** – Provide a significant increase in signal amplitude.
- **Low Distortion** – Preserve the integrity of the input signal without introducing noise or harmonic distortion.
- **Wide Bandwidth** – Operate over a range of frequencies as required.
- **Thermal Stability** – Prevent excessive heating to avoid damage to the circuit components.

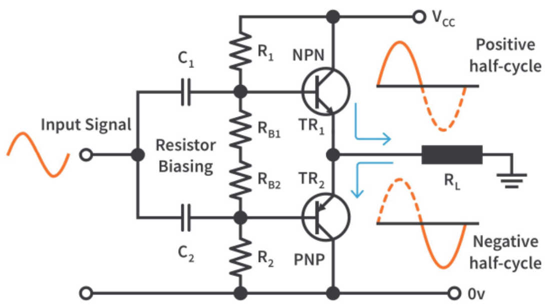


Figure 19: Class AB Power Amplifier Circuit

4.2 Why Not Class A, Class B, Class C, Class D? Why Choose Class AB?

1. Class A Amplifier

Advantages:

- Excellent linearity and low distortion.
- No crossover distortion.

Disadvantages:

- Very low efficiency ($\sim 25\% - 30\%$) as it continuously draws power.
- High power dissipation leads to excessive heat generation.

Conclusion: Class A is not suitable for power amplification due to its poor efficiency.

2. Class B Amplifier

Advantages:

- Higher efficiency ($\sim 70\%$) compared to Class A.
- Less heat dissipation since transistors conduct only during one half-cycle.

Disadvantages:

- Introduces **crossover distortion** due to the dead zone between the switching of transistors.

Conclusion: Class B is more efficient but suffers from crossover distortion, making it unsuitable for high-quality audio amplification.

3. Class C Amplifier

Advantages:

- Very high efficiency ($\sim 80\% - 90\%$).
- Suitable for RF applications.

Disadvantages:

- Extreme distortion makes it unsuitable for audio applications.

Conclusion: Class C is only useful in RF applications, not in power audio amplification.

4. Class D Amplifier

Advantages:

- Extremely high efficiency ($\sim 90\% - 95\%$).
- Uses switching transistors, reducing heat dissipation.

Disadvantages:

- Requires complex filtering to remove high-frequency switching noise.
- May introduce quantization noise in audio signals.

Conclusion: Class D is great for efficiency but is complex and less ideal for high-fidelity audio without extensive filtering.

5. Why Choose Class AB Amplifier?

Advantages:

- Combines Class A's low distortion and Class B's efficiency ($\sim 50\% - 70\%$).
- Reduces crossover distortion by slightly biasing transistors to operate in an overlapping mode.
- Well-suited for **audio amplification**, balancing **efficiency and linearity**.

Conclusion: Class AB amplifiers are widely used in audio applications because they provide a **good compromise** between **efficiency, linearity, and distortion control**.

4.3 Theoretical Circuit Analysis

1. Voltage Transfer Characteristics

In a Class AB amplifier, the output voltage V_{out} is related to the input voltage V_{in} through transistor operation.

$$V_{BE1} + V_{BE2} = V_{D1} + V_{D2}$$

For silicon diodes,

$$V_{BE1} + V_{BE2} \approx 1.4V$$

This prevents crossover distortion.

2. Output Power Calculation

The AC power delivered to the load R_L is:

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

For a sinusoidal peak voltage V_m:

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

Thus,

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

3. DC Power Calculation

The total DC power supplied is:

$$P_{DC} = V_{CC} I_{DC}$$

where,

$$I_{DC} = \frac{2I_m}{\pi}, \quad I_m = \frac{V_m}{R_L}$$

So,

$$P_{DC} = V_{CC} \times \frac{2}{\pi} \times \frac{V_m}{R_L}$$

4. Efficiency Calculation

The efficiency η is:

$$\eta = \frac{P_{out}}{P_{DC}} \times 100\%$$

Substituting values:

$$\eta = \frac{\frac{V_m^2}{2R_L}}{V_{CC} \times \frac{2}{\pi} \times \frac{V_m}{R_L}} \times 100\%$$

$$\eta = \frac{\pi V_m}{4V_{CC}} \times 100\%$$

For maximum efficiency:

$$\eta_{max} = \frac{\pi}{4} \times 100\% \approx 78.5\%$$

5. Crossover Distortion Reduction

Class B suffers from a "dead zone" where no current flows.

$$V_{out} = V_m \sin(\omega t) - V_{BE}$$

For $V_{BE} \approx 0.7V$, biasing keeps transistors slightly on, reducing distortion.

4.4 Simulation Results

This is a Push-Pull amplifier which utilizes complementary transistors TIP31C (NPN) and TIP32C (PNP). The circuit is designed to provide high efficiency and low distortion in power amplification.

4.4.1 Components

- **Diodes:** D_3, D_4 (1N4148) – Provide thermal stability and prevent crossover distortion.
- **Resistors:** R_{19}, R_{20} (2.5kΩ each) – Biasing network for transistors.
- **Coupling Capacitors:** C_{12}, C_{13}, C_{14} – Block DC and pass AC signals.

Operation

- This circuit is designed for **power amplification**.
- It provides **high efficiency** and **low distortion**.
- The output signal is a larger replica of the input with an enhanced power.

4.5 Hardware Implementation Modifications

The output after power amplifies has been added along the final output results.

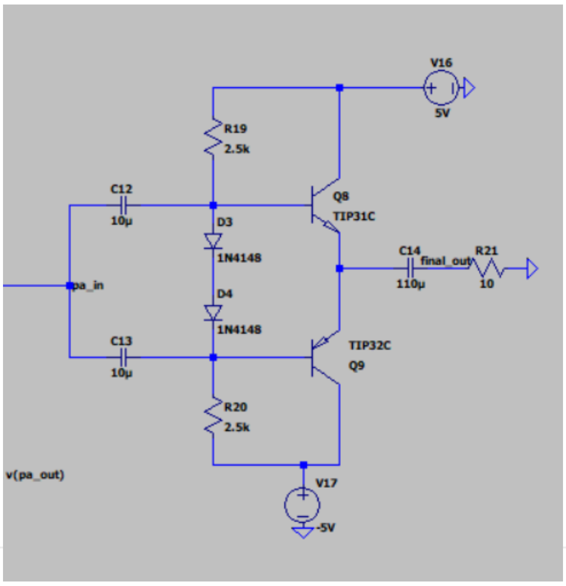


Figure 20: LTSpice Circuit for Class AB Amplifier

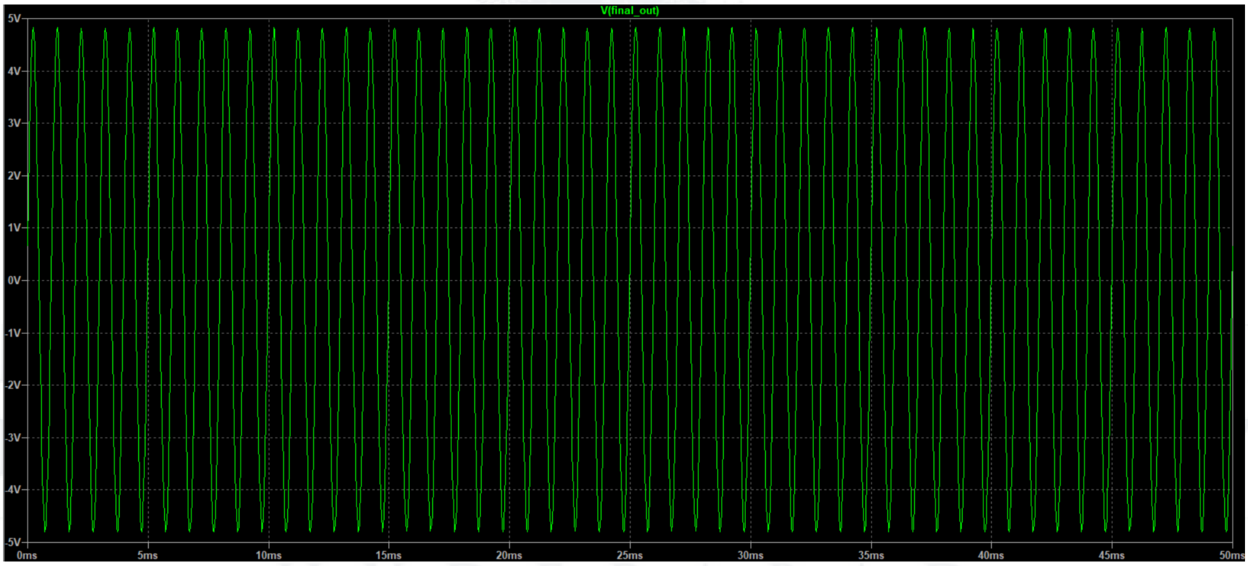


Figure 21: Simulation Result of LTSpice After Power Amplifier

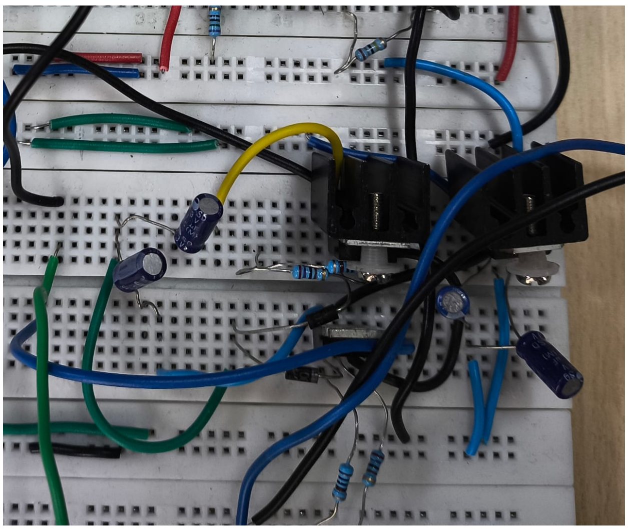


Figure 22: Hardware Implementation of Power Amplifier

5 Combining All Stages

5.1 Simulation Results

This below figures are the Ltspice simulated circuits and its output.

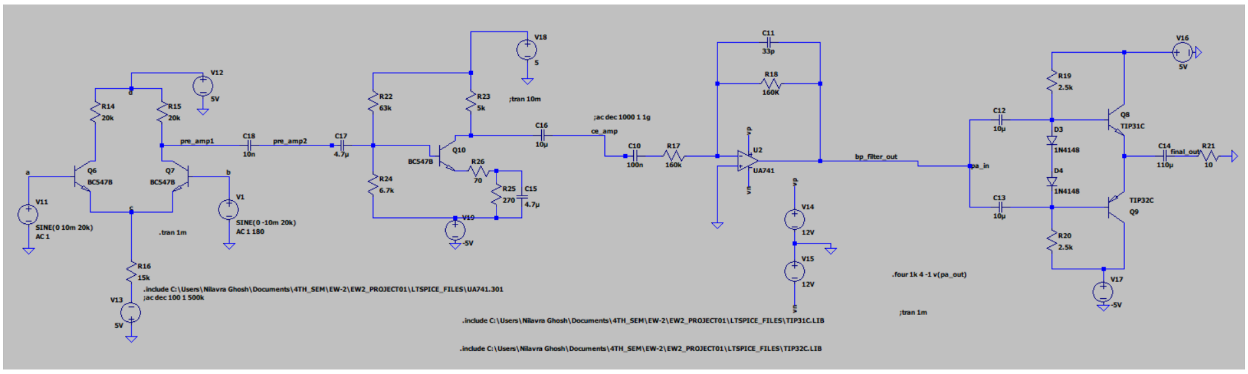


Figure 23: Final LTSpice Circuit of the Audio Amplifier

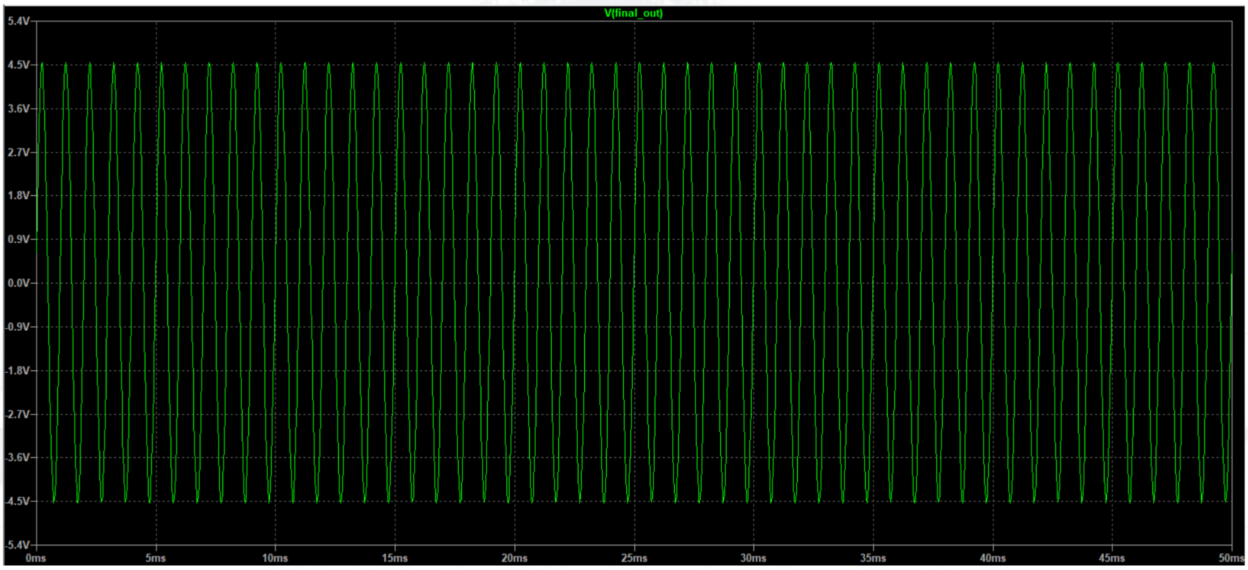


Figure 24: Final Output with 10mV Input

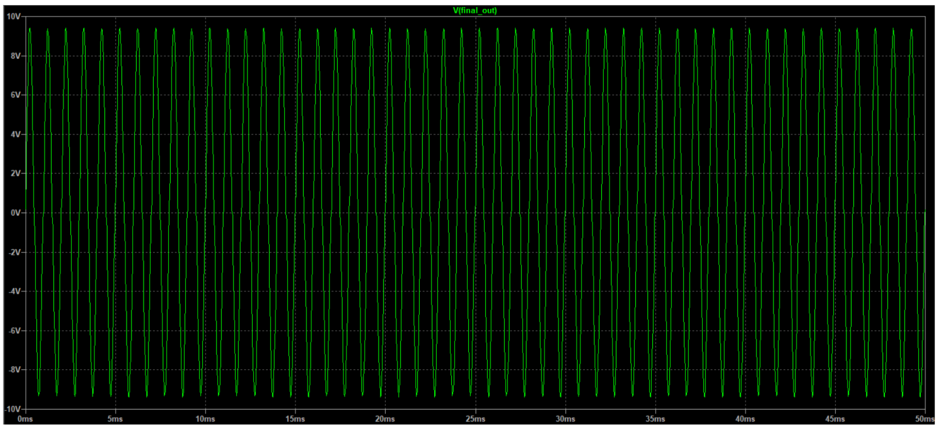


Figure 25: Final Output with 20mV Input

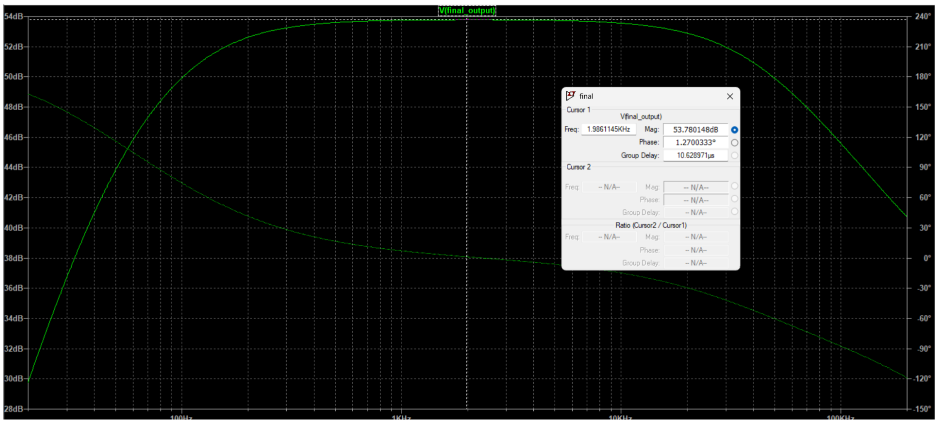
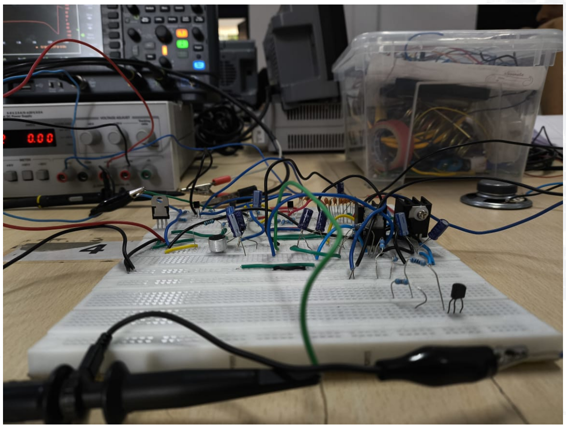


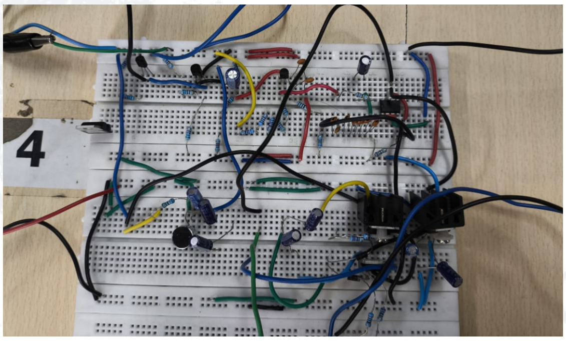
Figure 26: Frequency Response After Combining the Whole Circuit

5.2 Final Outputs

This below figures are the hardware circuit figure and its output.

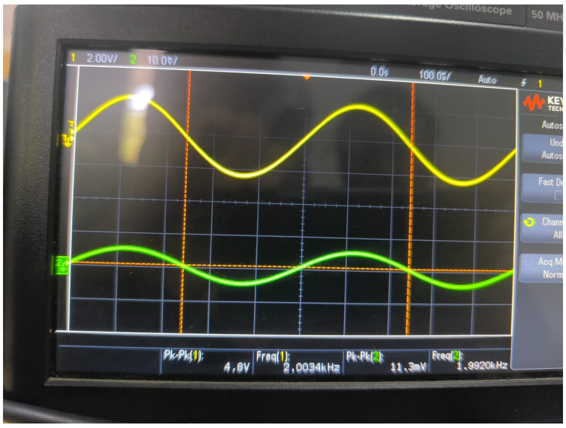


(a) Final Circuit

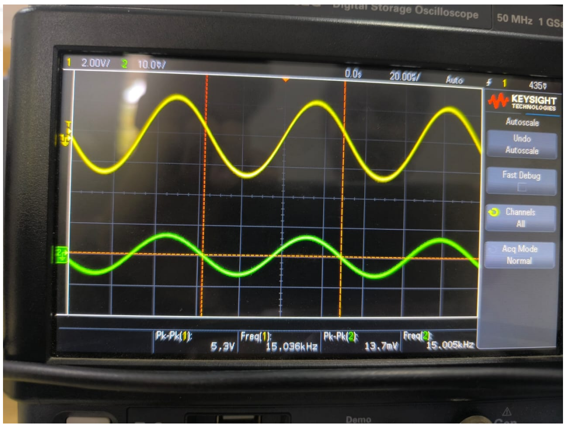


(b) Final Circuit's Top View

Figure 27: Final Circuit Views

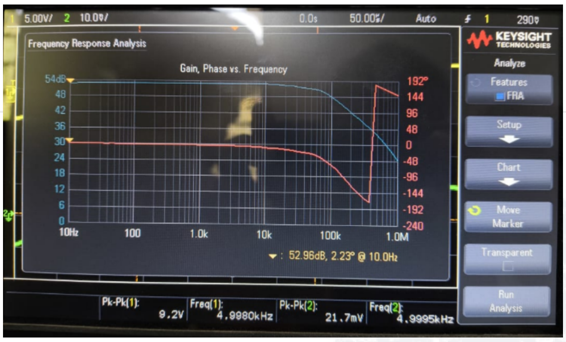


(a) Final Output at the DSO with 10mV Input at Low Frequency

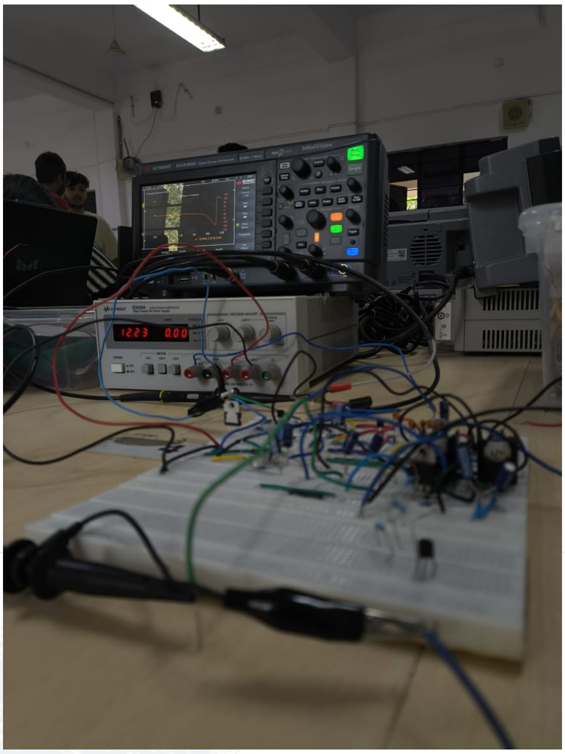


(b) Final Output at the DSO with 10mV Input at Higher Frequency

Figure 28: Final Outputs at Different Frequencies

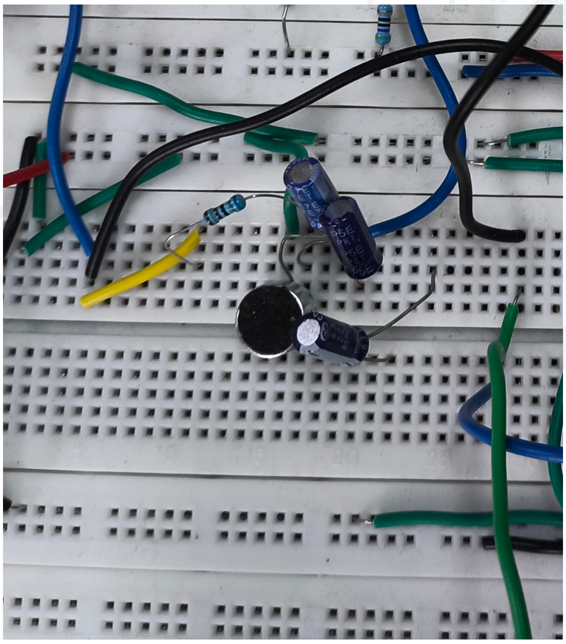


(a) Frequency Response of the Circuit

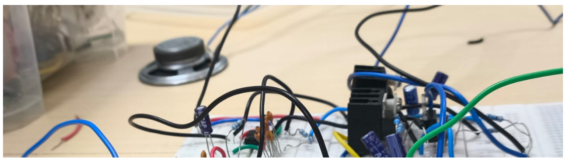


(b) Final Circuit Along with the DSO and Power Supply

Figure 29: Frequency Response and Final Setup



(a) Mic Connected to the Circuit



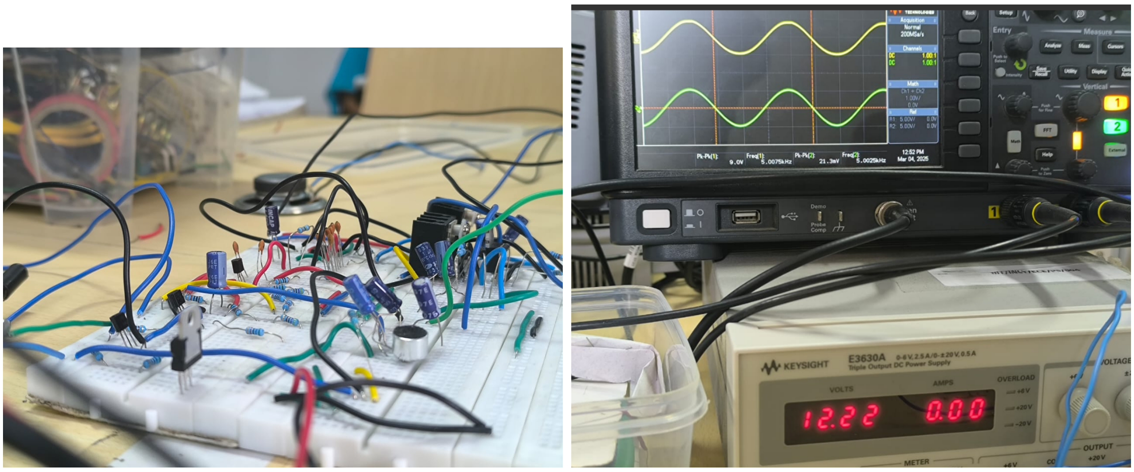
(b) Final Circuit Along with Speaker

Figure 30: Final Circuit with Mic and Speaker

6 Conclusion

This project successfully designed and implemented a **multi-stage audio amplifier system**, incorporating a **pre-amplifier, common-emitter (CE) amplifier, bandpass filter, and power amplifier** to ensure high-quality signal amplification.

- **Pre-Amplifier:** Boosted weak input signals while maintaining signal integrity.



(a) Side View of the Final Circuit

(b) Final Output at the DSO with 20mV Input

Figure 31: Final Circuit and Output

- **CE Amplifier:** Provided voltage gain with moderate distortion control.
- **Bandpass Filter:** Allowed only the desired frequency range, enhancing audio clarity.
- **Power Amplifier Selection:** After evaluating different classes, **Class AB** was chosen for its superior balance between efficiency (78.5%) and reduced crossover distortion compared to Class A, B, C, and D.

This setup ensures **high-fidelity audio amplification with optimized power efficiency**, making it suitable for practical audio applications.

Key Learnings from the Project

- Understanding different **amplifier stages** and their role in signal processing.
- The importance of **filtering techniques** (bandpass filter) to improve audio clarity.
- Evaluating and comparing **power amplifier classes** to balance efficiency and distortion.
- Practical circuit implementation, including **biasing, thermal stability, and signal amplification**.
- Application of **real-world components** like transistors, diodes, and capacitors in designing amplifiers.