Electronic Workshop - 2 :

Project - 1

Table Number **: 37**

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Contents

1 Introduction

The project aims to design and build an audio amplifier consisting of four key stages: a pre-amplifier, a common emitter amplifier, a bandpass filter using an operational amplifier (op-amp), and a power amplifier. The goal is to create a system capable of amplifying audio signals, enabling both a microphone (mic) and a speaker to work effectively in audio applications.

The **pre-amplifier** stage boosts the low-level signal from the microphone to a level that can be processed by subsequent stages. The **common emitter amplifier** stage further amplifies the signal and provides necessary voltage gain. This stage is critical for improving the signal strength while maintaining fidelity. The **bandpass filter**, implemented using an op-amp, serves to filter out unwanted frequencies, ensuring that only the desired audio range passes through to the next stages. This stage enhances the quality of the audio by removing noise or irrelevant frequency components. Finally, the **power amplifier** stage drives the speaker, providing the required power for sound reproduction. This stage is responsible for ensuring the amplified signal can be heard clearly at an adequate volume level.

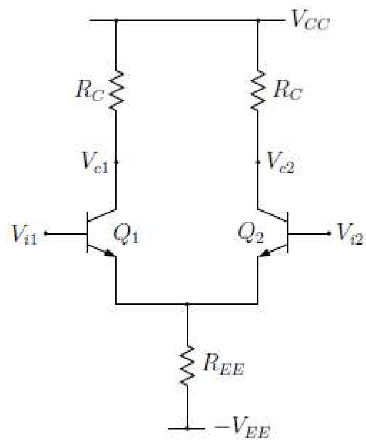
The combination of these stages ensures high-quality sound amplification, enabling seamless communication between the microphone and speaker.

2 Pre-amplifier Circuit

The Pre-amplifier stage is required for initial amplification of audio signal. Ideally, the Input resistance should not be low as this will cause the amplifier to draw high current, which the microphone cannot supply, leading to ineffective operation of the amplifier.
For this reason, the Common-Emitter Differential amplifier can be used as it has a high Input and Output impedance, with good noise performance. If the noise performance of a Pre-amplifier is bad, the already weak signal could be completely overpowered by noise .
In summation, the Pre-amplifier's main purpose is to provide initial amplification to the signal to send it to the gain stage, while also preventing noise from entering the system.

2.1 Design

It is build by using 2 Bipolar Junction Transistors(BJT) in Active Mode



(a)

The Emitter currents from both Emitters of Bipolar Junction Transistors flow through Emitter Resistance R_{EE}.
Let's do **Small signal Analysis**.
When Inputs are different then say Current across first BJT is I_{e1}, while that of second BJT is I_{e2}.
By using V = IR for both internal emitter resistance r_e.

$$V_1 - V_E = I_{e1} * r_e$$

$$\implies I_{e1} = \frac{V_1 - V_E}{r_e}$$

$$V_2 - V_E = I_{e2} * r_e$$

$$\implies I_{e2} = \frac{V_2 - V_E}{r_e}$$

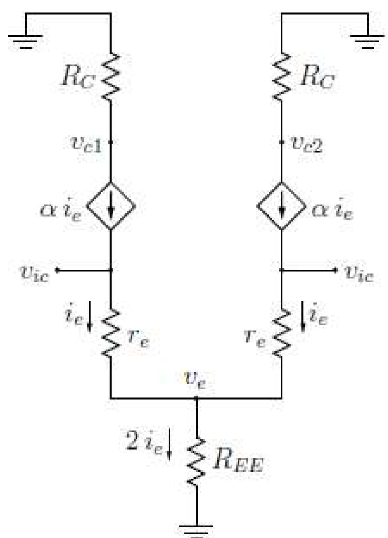
Considering α close to 1. Then Collector current will be approximately equal to Emitter current . Then

$$V_{c1} = R_C \frac{-(V_1 - V_E)}{r_e}$$

$$V_{c2} = R_C \frac{-(V_2 - V_E)}{r_e}$$

$$\implies V_{c1} - V_{c2} = R_C \frac{V_2 - V_1}{r_e}$$

$$Gain = \frac{R_C}{r_e}$$



Let's ground input of second BJT then gain of signal at collector of second BJT will be $\frac{R_C}{2r_e}$. We know that

$$g_m = \frac{1}{r_e}$$

$$g_m = \frac{I_c}{V_{th}}$$

By choosing Gain and Collector resistance we can calculate r_e . From above relation we can calculate DC current I_C .

For Second BJT to act in Active region we need V_E greater than 0.7 . A current of $2*I_C$ flows through Resistor R_{EE}.

Thus Pre amplifier is designed. Note Load of next stage must be considered as that will effect the gain to

$$Gain = \frac{R_C || R_L}{2 * r_e}$$

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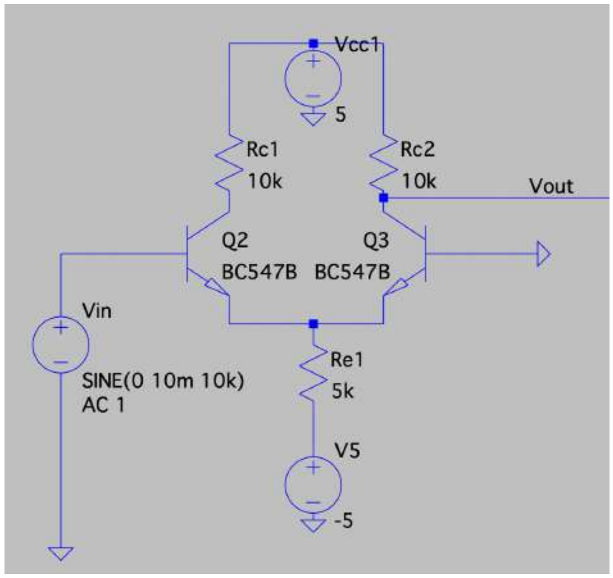


Figure 1: Differential Amplifier Circuit

3 Common Emitter Configuration Amplifier

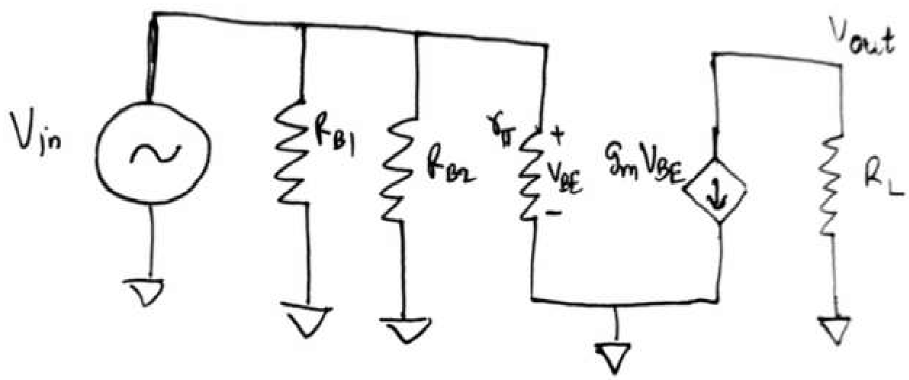
The Amplifier is an electronic circuit that is used to increase the strength of a weak input signal in terms of voltage, current, or power. The process of increasing the strength of a weak signal is known as Amplification. One most important constraint during the amplification is that only the magnitude of the signal should increase and there should be no changes in the original signal shape.

The **Common Emitter Amplifier** is a three basic single-stage bipolar junction transistor and is used as a voltage amplifier. The input of this amplifier is taken from the base terminal, the output is collected from the collector terminal and the emitter terminal is common for both the terminals.

When a signal is applied across the Emitter-Base Junction, the forward bias across this junction increases during the upper half cycle. This leads to an increase in the flow of electrons from the emitter to a collector through the base, hence increases the collector current. The increasing collector current makes more voltage drops across the collector load resistor RC.

The Negative Half cycle decreases the forward bias voltage across the emitter-base junction. The decreasing collector-base voltage decreases the collector current in the whole collector resistor R_C. Thus, the amplified Load resistor appears across the collector resistor.

AC Analysis



From the circuit, we have:

$$v_{BE} = v_{in}$$
$$i_c = g_m \times v_{BE}$$
$$\therefore i_c = g_m \times v_{in}$$
$$v_{out} = -i_c \times R_L = -g_m \times v_{in} \times R_L$$
$$\therefore \text{gain} = \frac{v_{out}}{v_{in}} = -g_m \times R_L$$

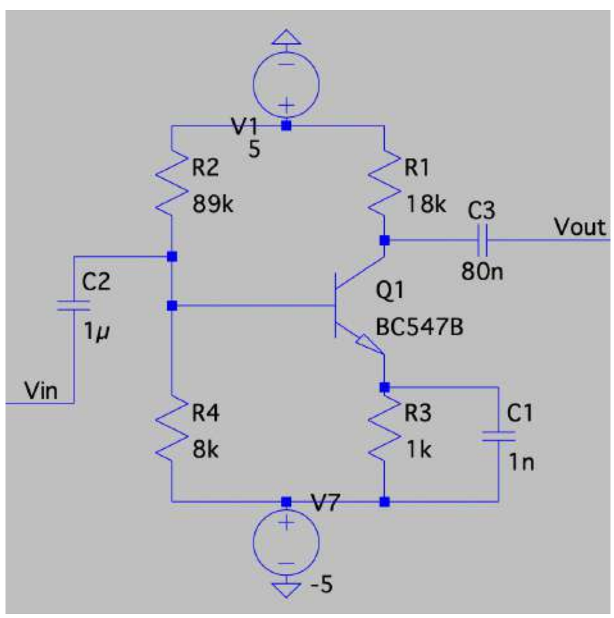
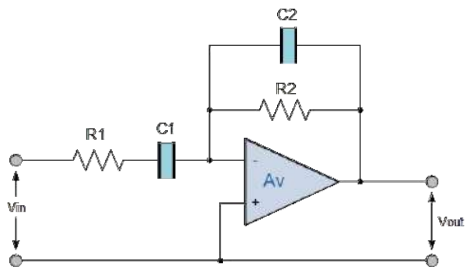


Figure 2: Common Emitter Amplifier Circuit

4 Filter Design



4.1 Circuit Description

The given circuit is an active band-pass filter that uses:

- A Resistor-Capacitor (RC) network for both low-pass and high-pass filtering.
- An operational amplifier (op-amp) to provide gain and buffering.

4.2 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.

4.3 Circuit Analysis

The Non-Inverting terminal of operational amplifier is connected to ground. So due to virtual shorting , Inverting terminal is also virtual grounded.

$$V_{in} - 0 = I * Z_1$$

$$0 - V_{out} = I * Z_2$$

$$Gain = -\frac{Z_2}{Z_1}$$

$$Z_1 = \frac{sR_1C_1 + 1}{sC_1}$$

$$Z_2 = \frac{R_2}{sR_2C_2 + 1}$$

4.4 Transfer Function

The transfer function $H(s)$, describing the frequency-dependent behavior, is given by:

$$H(s) = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{sR_2C_1}{(sR_1C_1 + 1)(sR_2C_2 + 1)}$$

where:

- $s = j\omega$ (Laplace variable),
- R and C are the resistor and capacitor values.

4.5 Key Parameters

1. **Center Frequency (f_0):**

   $$f_0 = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

   This is the frequency where the circuit achieves maximum gain.

2. **Bandwidth (B):**

   $$BW = f_H - f_L$$

   The range of frequencies passed by the filter.

3. **Quality Factor (Q):**

   $$Q = \frac{f_0}{B}$$

   A higher Q indicates a narrower pass band.

4. **Cutoff Frequencies:**

   - Low cutoff frequency (f_L):

     $$f_L = \frac{1}{2\pi R_1C_1}$$

   - High cutoff frequency (f_H):

     $$f_H = \frac{1}{2\pi R_2C_2}$$

4.6 Frequency Response

The frequency response of the circuit exhibits:

- **Attenuation:** For $f < f_L$ (low frequencies) and $f > f_H$ (high frequencies).
- **Passband:** Between f_L and f_H, centered at f_0.
- A **peak gain** at f_0, determined by the op-amp and feedback network configuration.

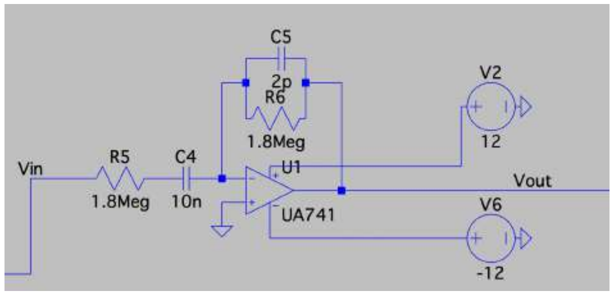


Figure 3: Filter Circuit

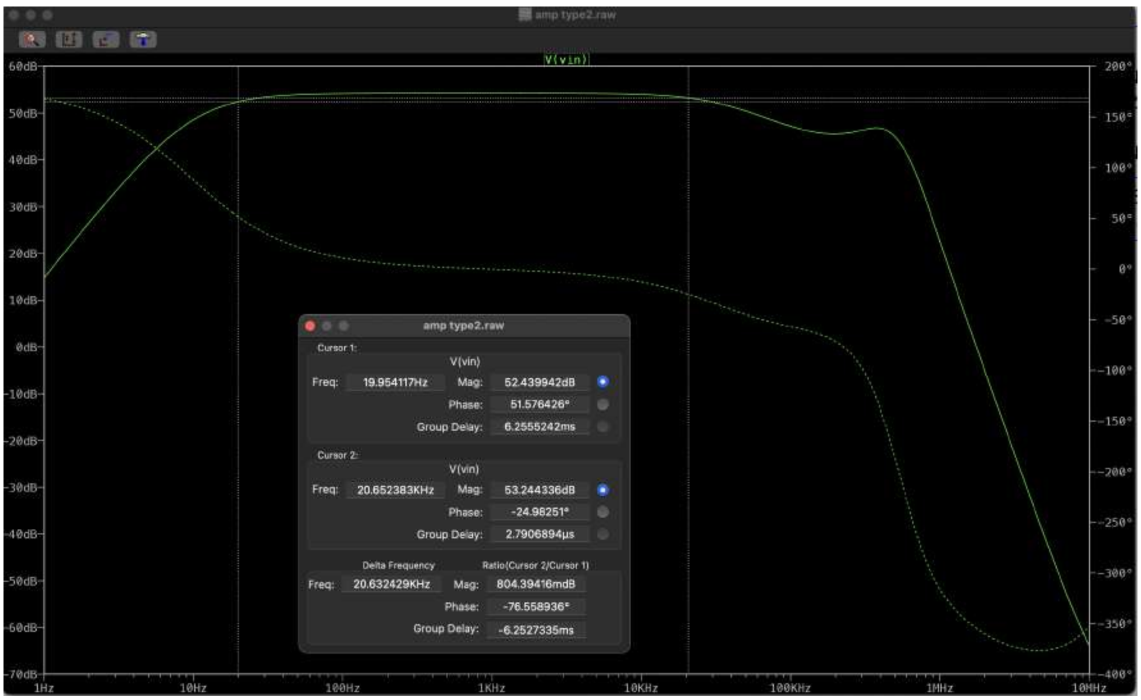


Figure 4: Filter Frequency Response

5 Power Amplifier

Power amplifiers are used to increase the power level of a signal and are commonly classified into Class-A, Class-B, and Class-AB based on their operating point, conduction angle, and efficiency.

5.1 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.

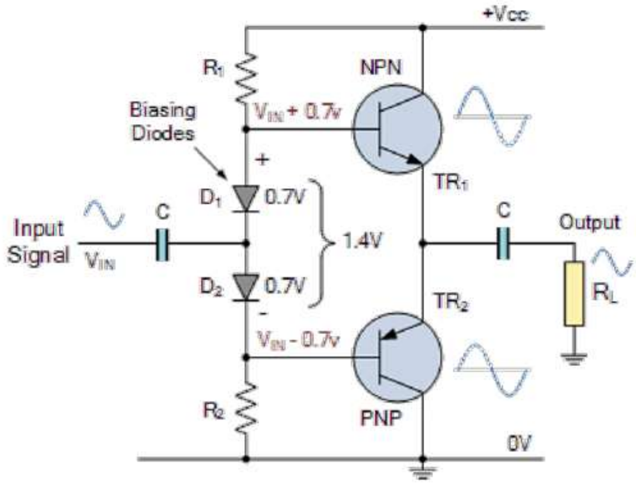
5.2 Class-B Power Amplifier

- **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).

5.3 Class-AB Power Amplifier

- **Operating Principle:** Combines the features of Class-A and Class-B by biasing the transistors slightly above cutoff, allowing both transistors to conduct for slightly more than half of the signal cycle (greater than 180° but less than 360° conduction angle).
- **Features:**
  - Improved linearity compared to Class-B, reducing crossover distortion.
  - Higher efficiency than Class-A, typically around 50%.
  - Moderate heat dissipation, balancing efficiency and linearity.

Circuit Explanatory and Theory



The amplifier uses two transistors: one NPN (top) and one PNP (bottom). During positive half-cycles of the input signal, the NPN transistor conducts, driving current into the load. During negative half-cycles, the PNP transistor conducts, sinking current from the load. Each transistor is biased so that it conducts for slightly more than 180° of the signal cycle. This small overlap in conduction prevents a dead zone at the zero-crossing point, thereby reducing crossover distortion that is typical of Class B amplifiers.

Two diodes D1 and D2 have forward voltage drops of 0.7V across them. They provide a small forward bias voltage between bases, keeping both transistors on verge of conduction even when input signal is absent or zero. When the input signal goes positive, the bias arrangement plus the input voltage makes the NPN transistor conduct more, while the PNP transistor is driven closer to cutoff (but not fully off). When the input goes negative, the roles reverse: the PNP transistor takes over conduction, while the NPN transistor is partially cut off. NPN handles the positive portion of the input waveform while PNP handles the negative portion of input waveform.

The emitters of both NPN and PNP transistors are connected. The speaker or output load is connected to this common emitter node. Resistor R1 and R2 are connected to bias between Vcc and VEE. R1 is equal to R2 so that when input is absent, voltage between the two diodes is zero. Also these resistors control the base current and provide stability.

The input and output coupling capacitor blocks DC component.

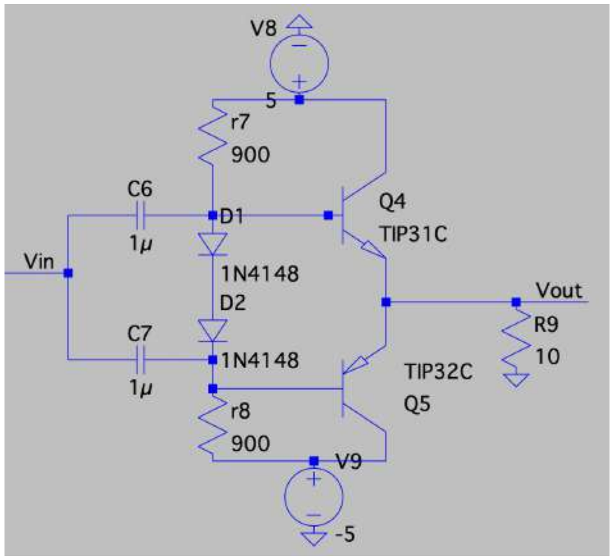


Figure 5: Power Amplifier Circuit

6 Complete Circuit Results

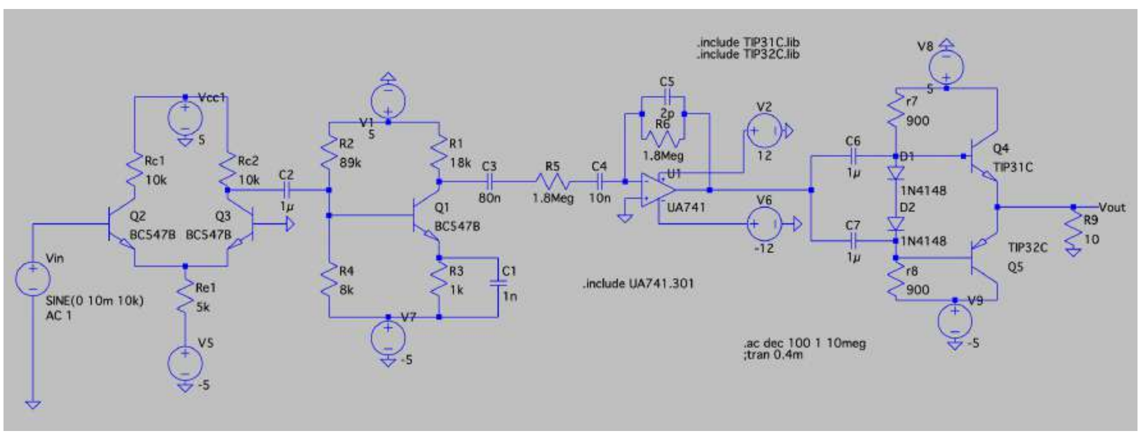


Figure 6: Full Circuit

6.1 LT SPICE Results

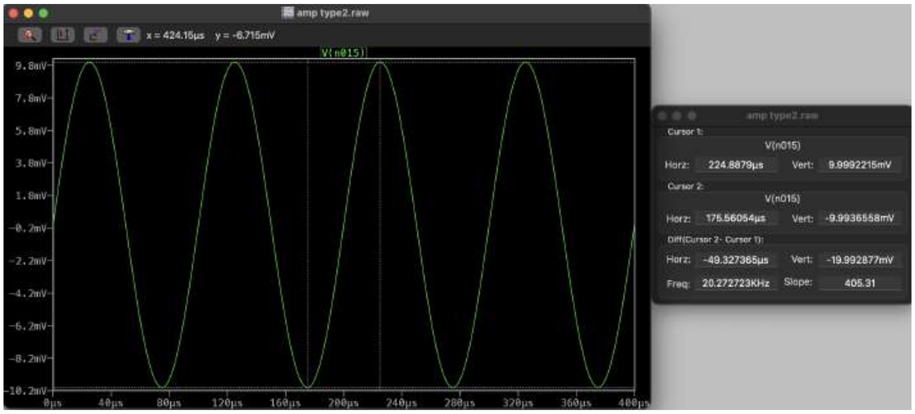


Figure 7: Input Signal

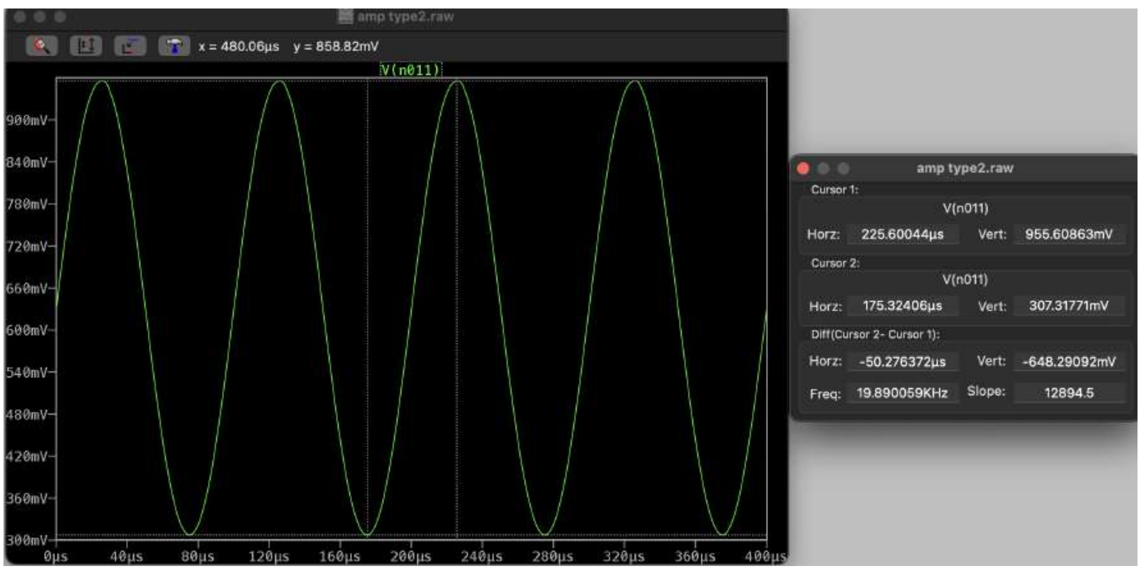


Figure 8: Differential Amplifier Output

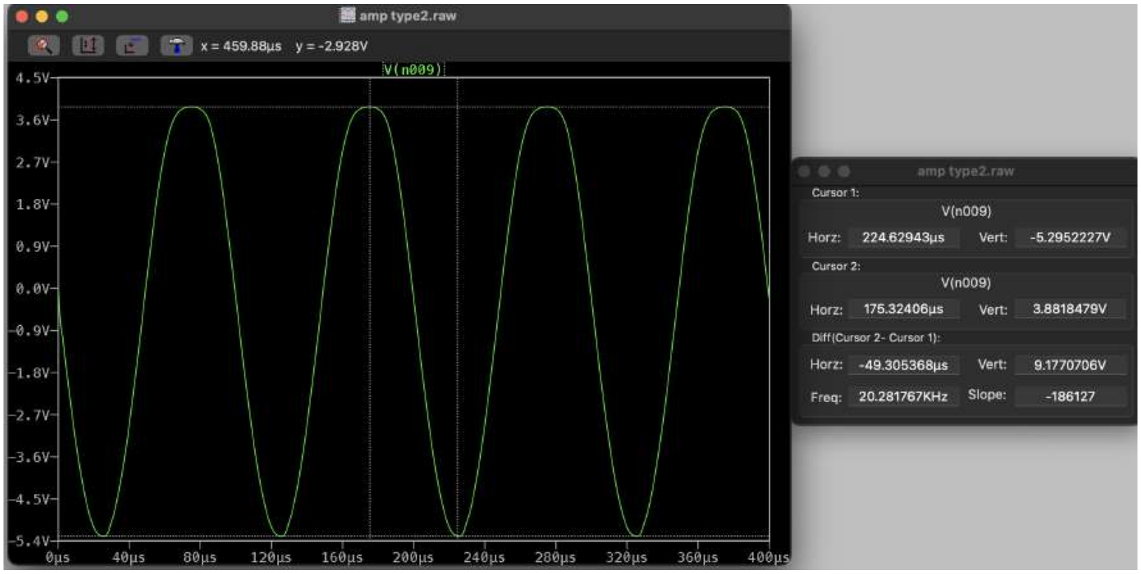


Figure 9: Common Emitter Amplifier Output

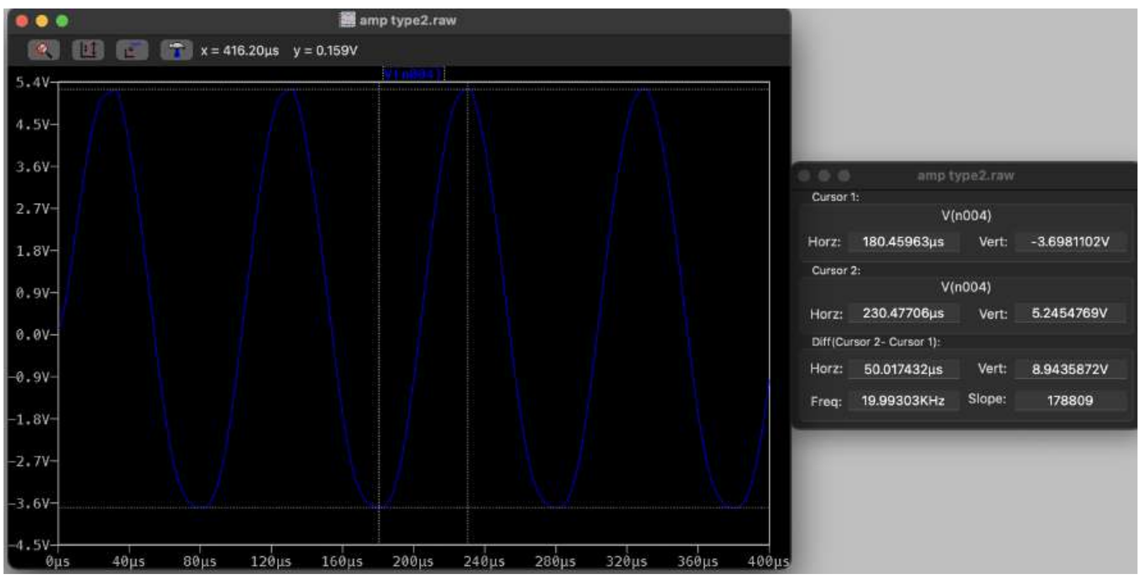


Figure 10: Filter Output

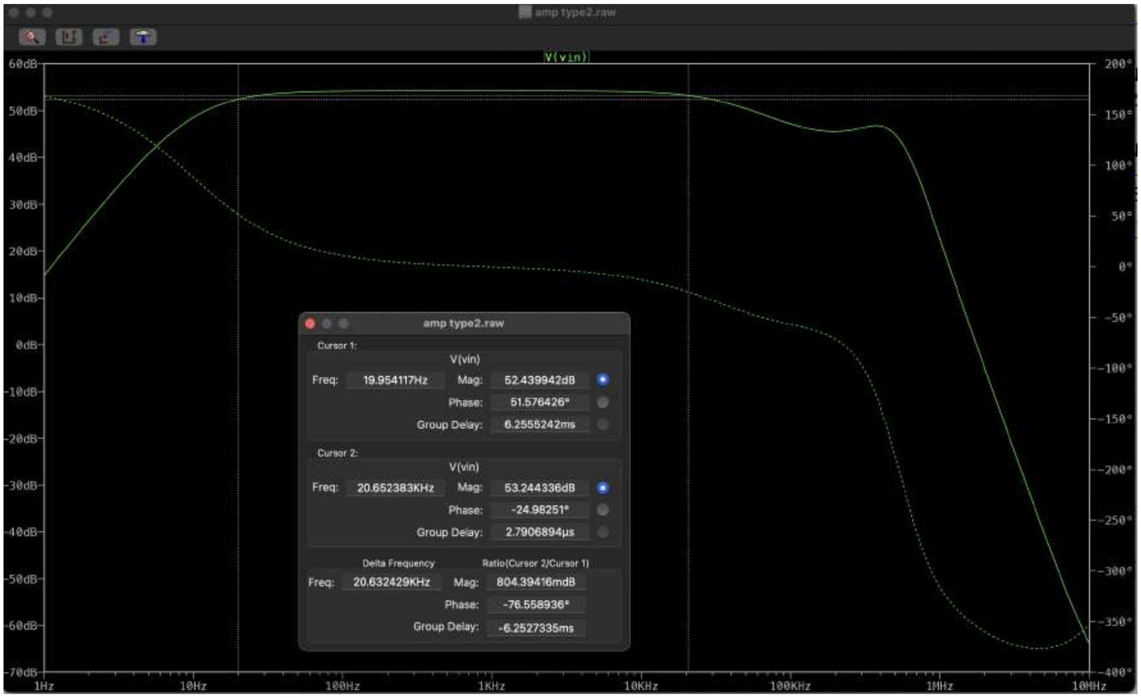


Figure 11: Frequency Response

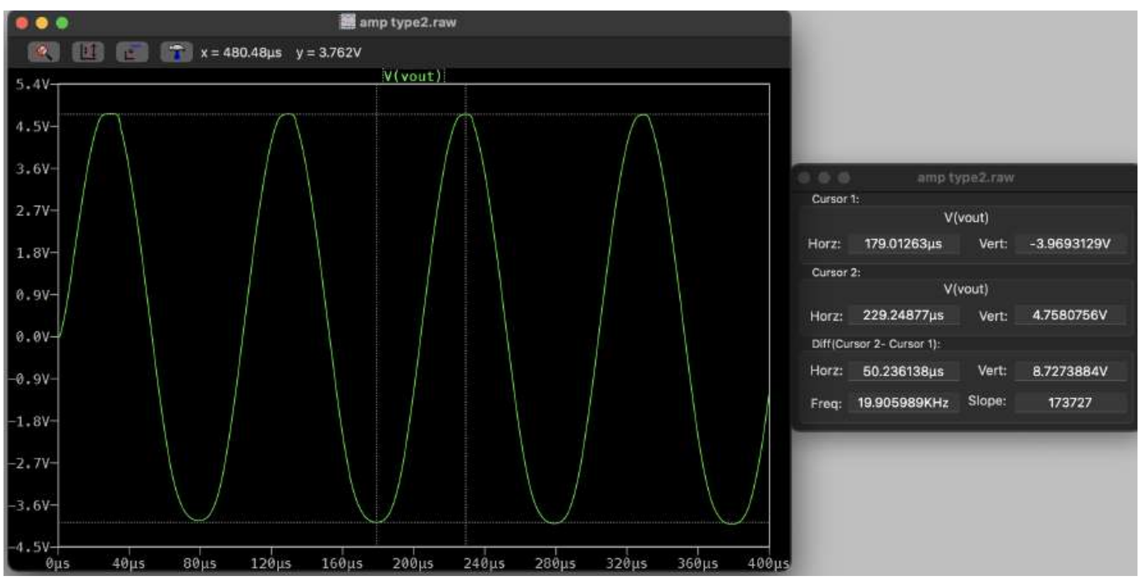


Figure 12: Power Amplifier Output

Figure 13: RMS Voltage

Figure 14: RMS current

6.2 Circuit Results

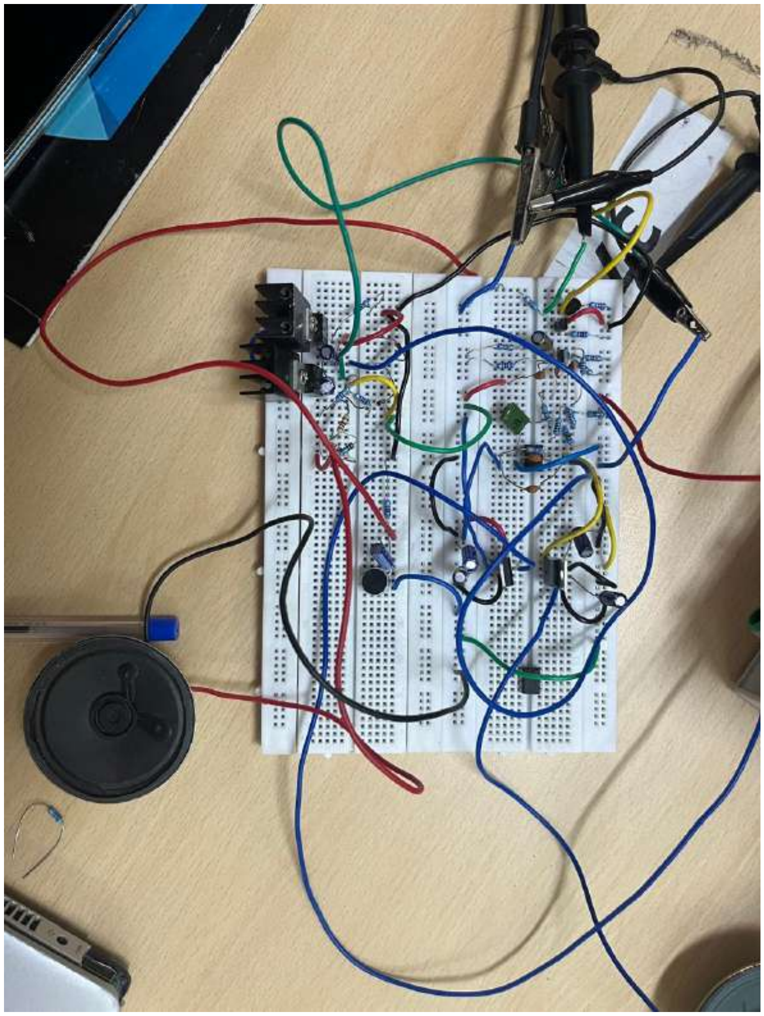


Figure 15: Full Circuit

6.2.1 Differential Amplifier

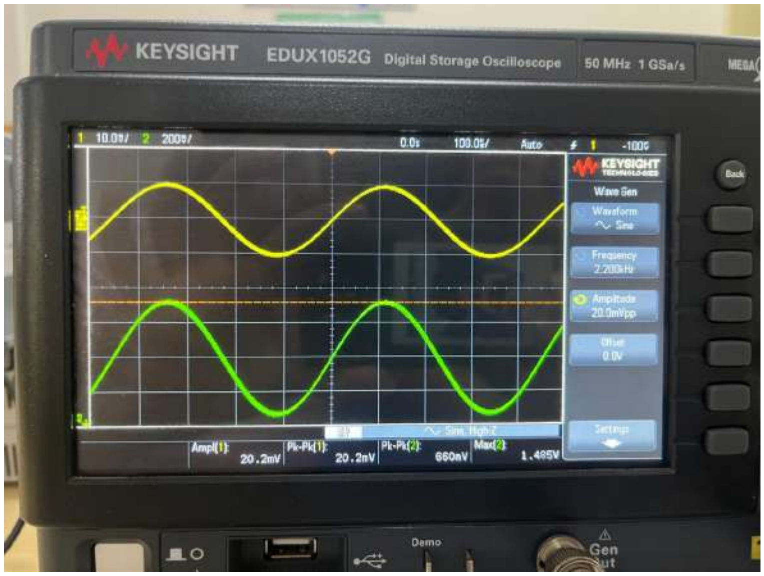


Figure 16: Differential Amplifier Output for 2.2kHz

Figure 17: Differential Amplifier Output for 10kHz

6.2.2 Common Emitter Amplifier

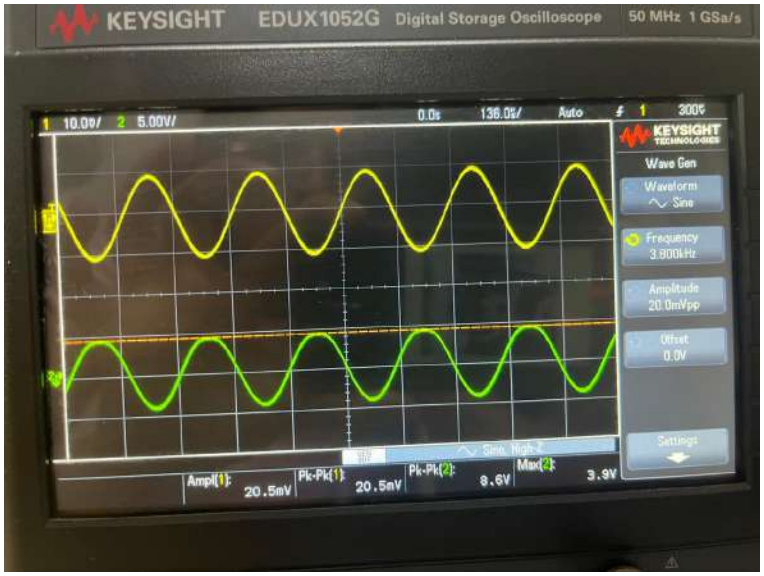


Figure 18: Common Emitter Amplifier Output for 3.8kHz

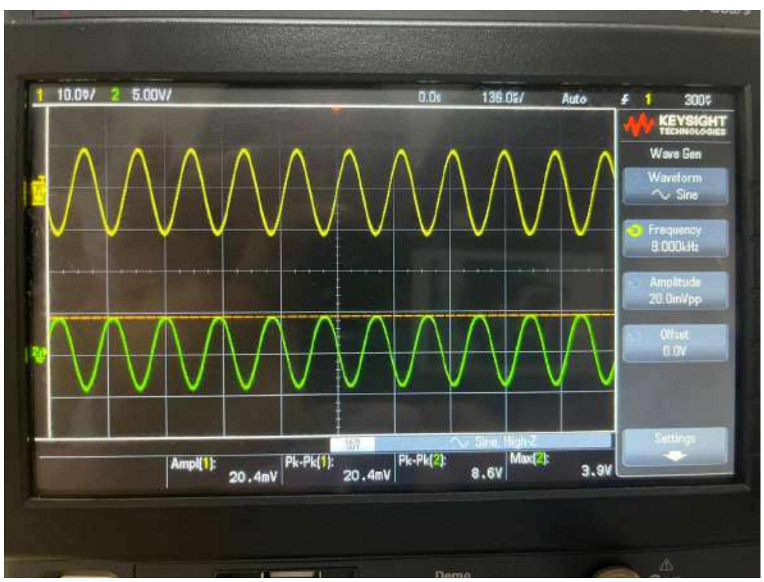


Figure 19: Common Emitter Amplifier Output for 8kHz

6.2.3 Bandpass Filter

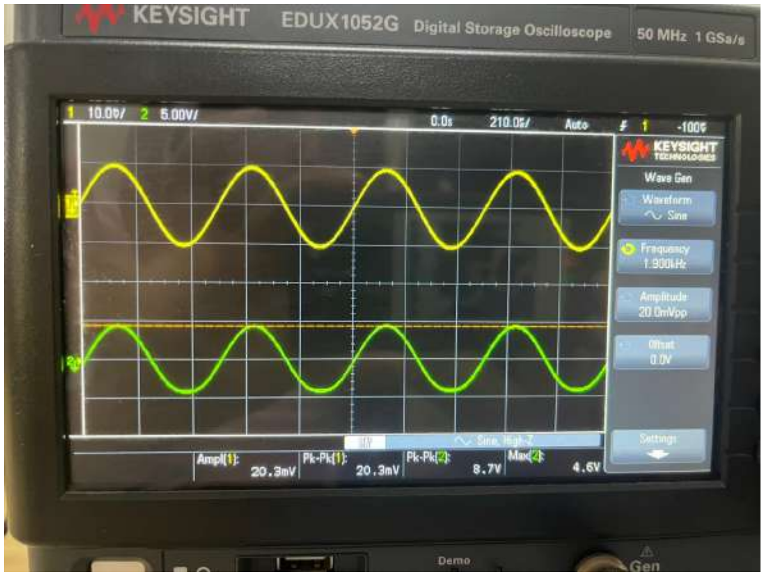


Figure 20: After Filter Output for 1.9kHz

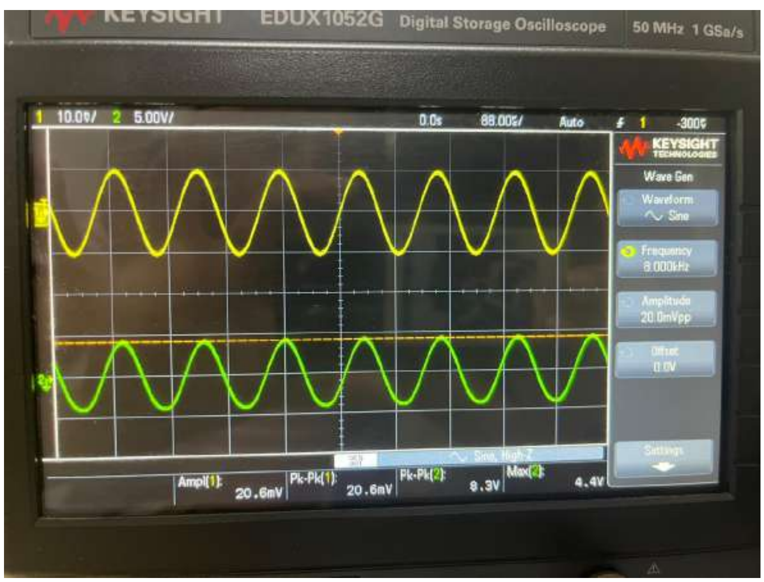


Figure 21: After Filter Output for 8kHz

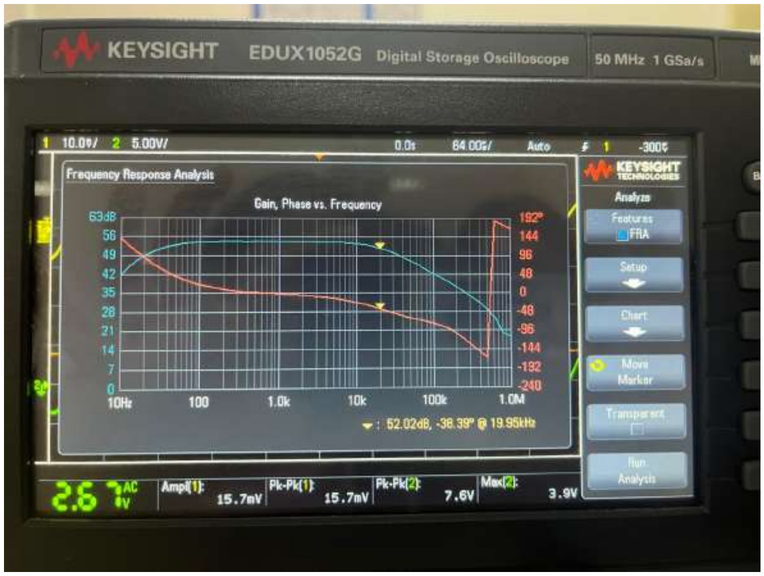


Figure 22: Frequency Response (Low pass Cutoff)

Figure 23: Frequency Response (For 10kHz)

Figure 24: Frequency Response (High pass Cutoff)

6.2.4 Power Amplifier

Figure 25: Power Amplifier for 1.9kHz

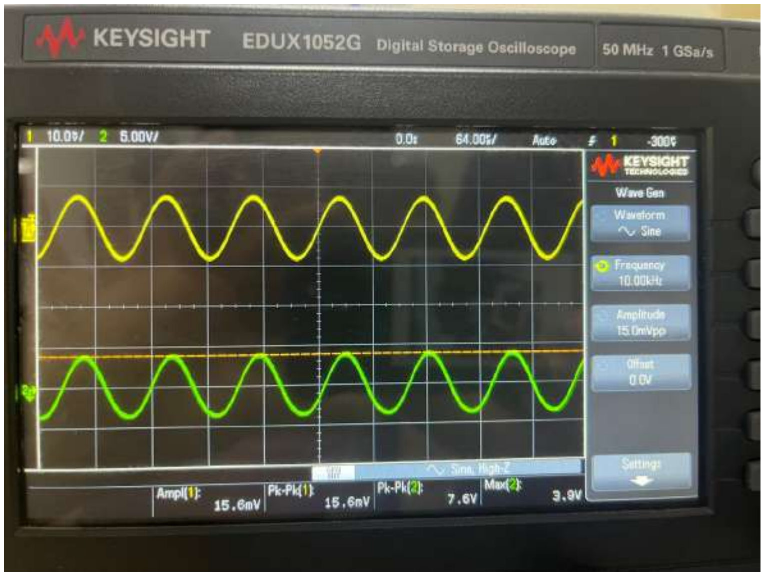


Figure 26: Power Amplifier for 10kHz

Comparison Table

	Simulated Circuit	**Physical Circuit**
Only Pre-amp Gain	32.4	33
After CE amp Gain	460	415
Complete Circuit gain	436	420
Flat Band Gain	54dB	54.1dB
3dB Bandwidth	35KHz	19.95KHz

Problems Faced & Limitations

- Introduction of unwanted noise at every stage from the electrical components such as DSO and Wave-generator. Also thermal noise due to heating of resistors and ICs.
- Frequent heating of voltage divider ICs and MOSFETs led to inaccurate output and hence circuit breakdown.
- Power supply was limited to ±15V except for the filter stage, which caused obstruction in reaching higher gain as further increasing gain without increasing supply led to clipping of output.