Analog Electronics

IE2034

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Multi-Stage Amplifier and Filtering Circuit

Submitted to Sri Lanka Institute of Information Technology (SLIIT)

BSc (Hons)Computer Systems Engineering

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1. Introduction

Analog signal processing is important for electronic systems, especially in audio and communication. Signals often have unwanted noise that can reduce quality. To fix this, analog circuits use filtering and amplification.

This project focuses on designing, building, and testing a multi-stage amplifier and filtering circuit that simulates the audio output of a basic AM radio. The circuit has three parts: a high-pass RC filter to remove low-frequency noise, a common-emitter BJT amplifier to increase signal strength, and a low-pass RC filter to limit high-frequency interference. Each part is made to meet specific frequency and gain needs.

This project reinforces key ideas in analog electronics, like frequency response and multi-stage amplification. We evaluate performance using oscilloscope measurements. This report shows the methods, results, and important aspects of circuit design and testing.

2.1 High-Pass Filter

The circuit's first stage is to implement a high-pass RC filter to remove low-frequency noise from the incoming signal. The audio quality can be degraded if the low-frequency components (below 1 kHz) are not filtered out. Therefore, a high-pass filter is used to allow frequencies above the cutoff point to pass. For this design, the cutoff frequency is set to 1 kHz, and the high-pass filter ensures that only frequencies greater than 1 kHz pass through.

Theoretical Calculations

- Firstly, we chose the capacitor value to be 10nF(0.01μF).
- Then, we calculate the resistor value using frequency and capacitor values.

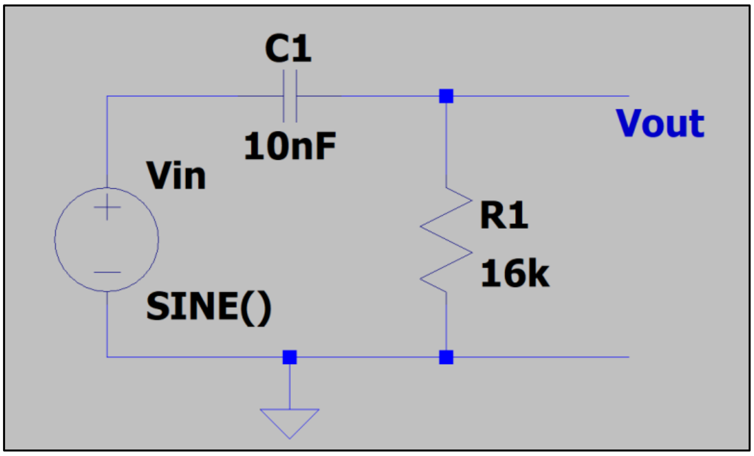
$$\text{the cutoff frequency(fc)} = \frac{1}{2 \times \pi \times R \times C}$$

$$1000 = \frac{1}{2 \times \pi \times R \times 10 \times 10^{-9}}$$

$$\mathrm{R} \sim 15.92k\Omega$$

$$\mathrm{R} = 16k\Omega$$

Schematic design

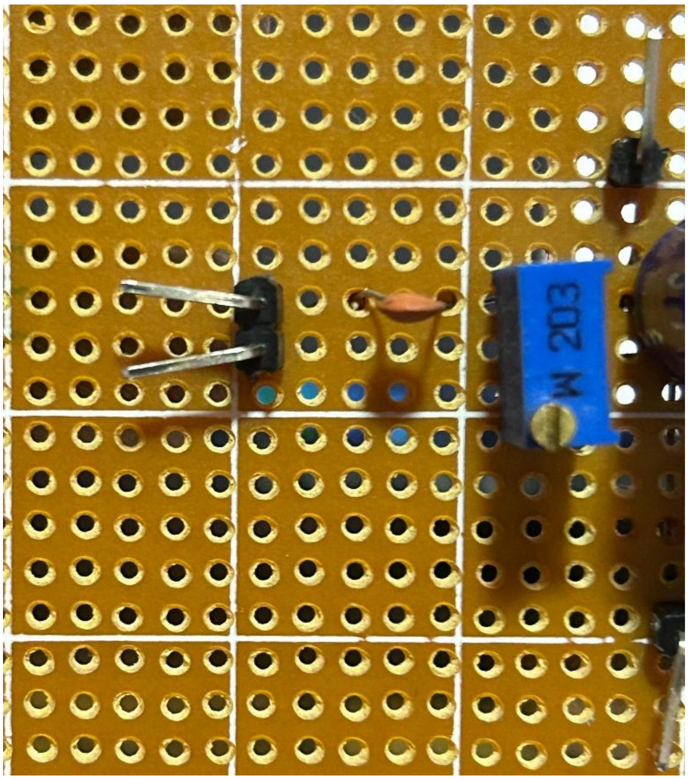


Used Components

- W203 Variable resistor (16kΩ) 

- 10nF Ceramic capacitor 

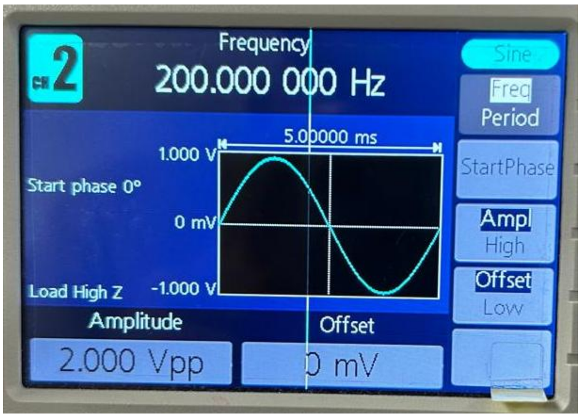
Circuit design on the dot board



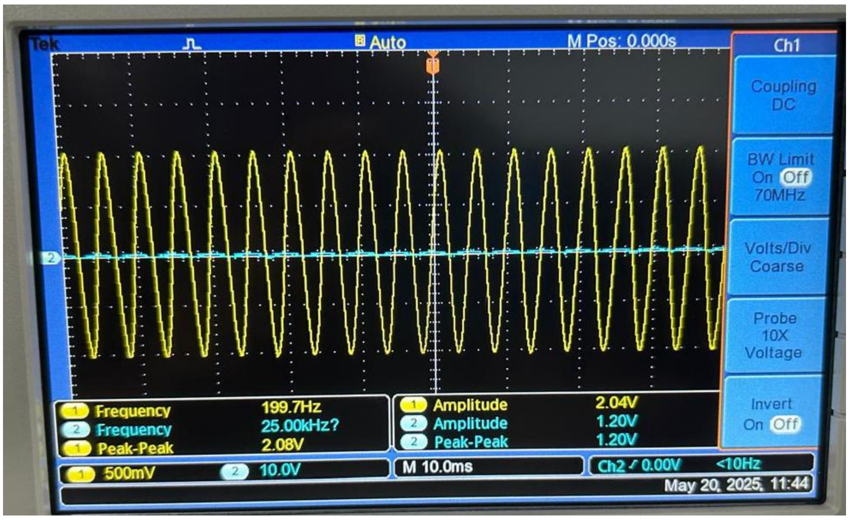
Waveform Measurements

1. When the frequency is set to 200 Hz,

- Input signal in the signal generator



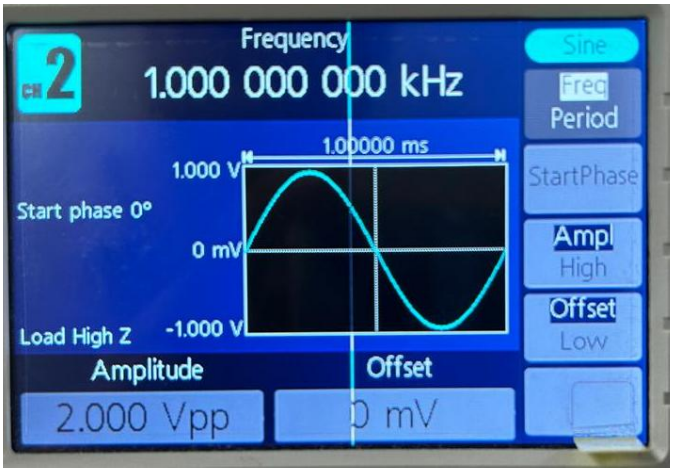
- Output signal using the oscilloscope



If the Input frequency is decreased below the cut-off frequency (1 kHz), the output signal gradually decreases.

2. When the frequency is set to 1 kHz,

- Input signal in the signal generator

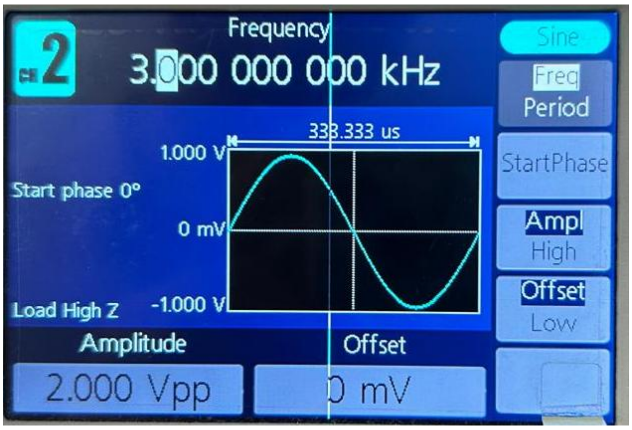


- Output signal using the oscilloscope

Here, the signal passes. Therefore, the high-pass filter appears to be successful.

3. When the frequency is set to 3 kHz,

- Input signal in the signal generator



- Output signal using the oscilloscope

When the cutoff frequency is increased, the signal passes.

2.2 Common-Emitter Amplifier

In a common-emitter amplifier, we use a BJT transistor configured in a common-emitter setup to amplify the signal filtered by the high-pass filter.

Theoretical Calculations

- Base Voltage - (Vb)
- Emitter Voltage - (Ve)
- Voltage Difference between Base and Emitter - (Vbe)
- Emitter Current - (Ie)
- Collector current - (Ic)
- Collector-Emitter Voltage - (Vce)

The voltage division from the R1 and R2 resistors form the base voltage

$$Vb = Vcc \text{ X } \frac{R2}{R1+R2} = 9 \text{ X } \frac{470}{5900+470} = 0.664 \text{ V}$$

Assume Vbe as 0.7 V for the BC547 Transistor

Ve = Vb – Vbe = 0.664 – 0.7 = - 0.036V

Ve cannot be negative, which means there is a problem with the biasing resistors. The low Vb indicates that the transistor might not be turning on correctly. To move forward, let’s assume Ve is 0.5V for our simulation.

Vb = Ve + Vbe = 0.5V + 0.7V = 1.2V

Other than in simulation Adjusting R1 or R2 resistors in a practical approach didn’t work. Assuming Ve as 0.5V

$Ie = Ve/Re = 0.5V/0.8\Omega = 0.625A = 625mA$

The current theoretical values are too high for small signal transistors like the BC547, which has a maximum collector current (Ic) of 100 mA. This makes a low emitter resistor (Re) of 0.8 Ω problematic. Using a more common range of Re, such as 100 to 200 Ω, would be better.

$Ie = 0.5V/100\Omega = 5mA$

For our calculations, let's assume that Re is 100 Ω. This is like a theoretical simulation, but it might not work in real-life situations.

Assuming Ic = Ie = 5mA,

$Vrc = Ic.Rc = 5mA.770\Omega = 3.85V$

$Vc = Vcc – Vrc = 9V – 3.85V = 5.15\ V$

$Vce = Vc – Ve = 5.15V – 0.5V = 4.65\ V$

The Q-point is set at Ic = 5mA and Vce = 4.65V. This means the transistor is in the active region, close to the middle of the power supply, which allows for a better signal swing.

Voltage Gain

- The mid band voltage gain - (Mv)
  Mv = Rc / re

- When re = 25mV/Ie
  re = 25mA / 5 mA = 5Ω
  Mv = 770 Ω / 5 Ω = 154

This is over the needed gain of 50, but the actual gain might be lower because,

- When Emitter Bypass Capacitor Impedance is at 1kHz
  $Xce = \frac{1}{2\pi.1kHz.100nF} = 1592\ \Omega$

This value is high compared to Re = 5 Ω, which significantly lowers the effective gain because Xce does not fully bypass Re. We need a larger Ce; theoretically, we should use 47µF, which results in Xce = 3.4Ω.

- Loading Effects: The low-pass filter has an input impedance of 1,060 Ω, which puts a load on Rc and reduces the gain.

  Rload,eff = Rc || Rlpf = 770 || 1060 ≈ 440Ω

$$Mv \approx 440\Omega/5\Omega \approx 88$$

Initial tests indicated a practical gain of 8 to 9, likely due to the high Xce and loading conditions. It is recommended to increase Ce to 47 µF or higher. When Ce is set to 47 µF, Xce equals 3.4 Ω.

Coupling Capacitors

When Input Coupling (Cin) is at 1kHz,

$$Xcin = \frac{1}{2\pi.1kHz.220\mu F} = 0.724\ \Omega$$

This level is low, which helps the high-pass filter work well.

When Output Coupling (Cout) is at 1kHz,

$$Xcout = \frac{1}{2\pi.1kHz.100\mu nF} = 1592\ \Omega$$

The impedance is high compared to the low pass filter's impedance (1060Ω), which may weaken the signal. A larger capacitor, like 1µF, decreases the impedance to Xc = 159 Ω, but this approach does not work well in practice.

Input and Output impedance

Input impedance,

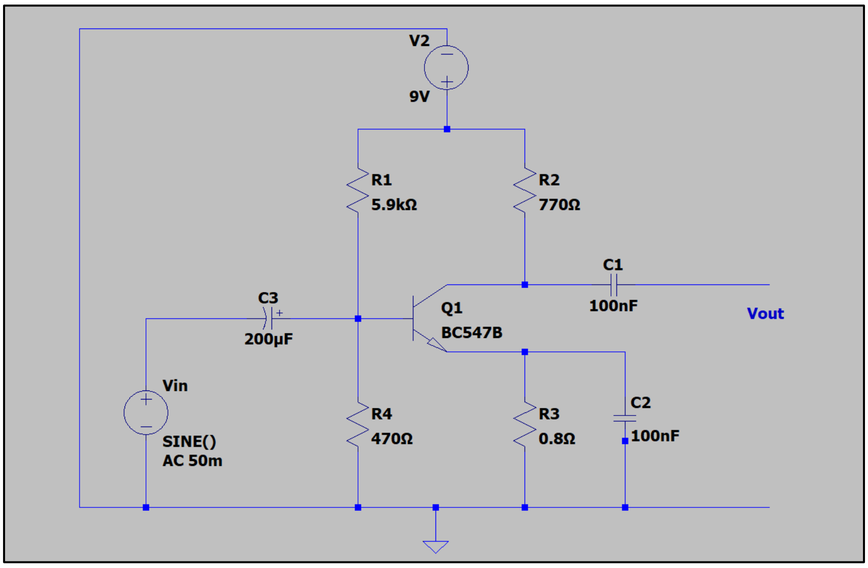
$$Zin = \beta \times (re + Re) \approx 200 \times (5 + 200) \approx 21k\Omega$$

(Assuming β ≈ 200 for BC547, and Re = 100Ω)

Output impedance,

$$\approx Rc = 770\Omega$$

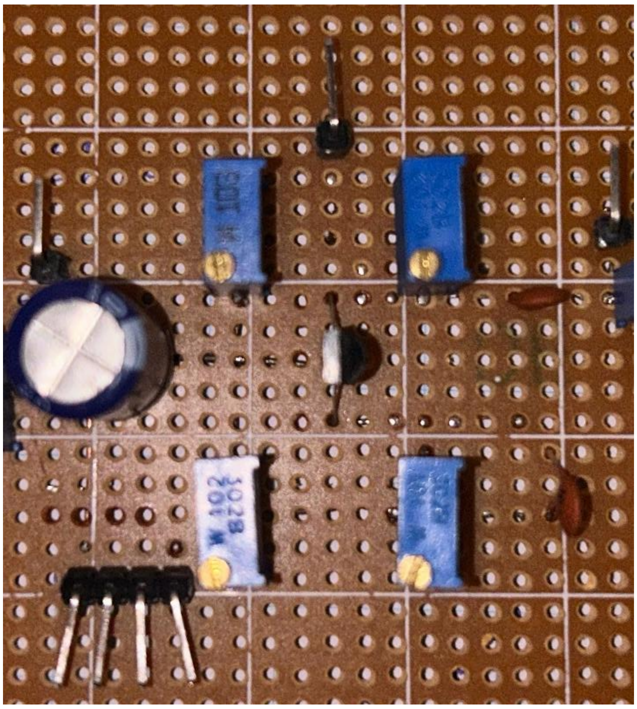
Schematic design for Theoretical Calculations



Used Components

- W101 Variable resistor (0.8Ω)
- W102 Variable resistors (470Ω, 770Ω)
- W103 Variable resistor (5.9kΩ)
- Ceramic capacitors (2× 100nF)
- Electrolytic Capacitor (220uF)

Circuit design on the dot board



Waveform Measurements

1. When the frequency is set to 10 kHz and the amplitude is set to 40 mV,

- Input signal in the signal generator

- Output signal using the oscilloscope

V_{in} = 140 mV

V_{out} = 5.68 V

Amplifier gain is;

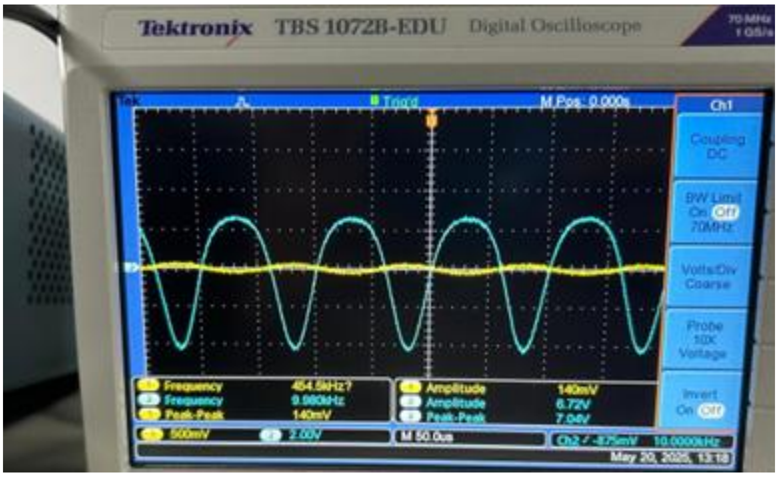
$$\text{Gain} = \frac{5680\ mV}{140\ mV}$$

Gain = 40.6

2. When the frequency is set to 10 kHz and the amplitude is set to 50 mV,

- Input signal in the signal generator

- Output signal using the oscilloscope



V_{in} = 140 mV

V_{out} = 7.04 V

Amplifier gain is;

$$\text{Gain} = \frac{7040\ mV}{140\ mV}$$

Gain = 50.3

When comparing the 2 outputs, the voltage has increased from 5.68V to 7.04V.

Then the gain has also increased.

Therefore, our amplifier is working correctly.

2.3 Low-Pass Filter

In the final stage of the circuit, we use a low-pass RC filter to remove high-frequency noise from the amplified signal. This filter has a cutoff frequency of 15 kHz, which helps ensure smooth audio output. If the signal goes above this cutoff frequency, the low-pass filter reduces the higher frequencies to minimize unwanted noise.

Theoretical Calculations

- We selected the capacitor value to be 10nF(0.01µF).
- We calculate the resistor value using frequency and capacitor values.

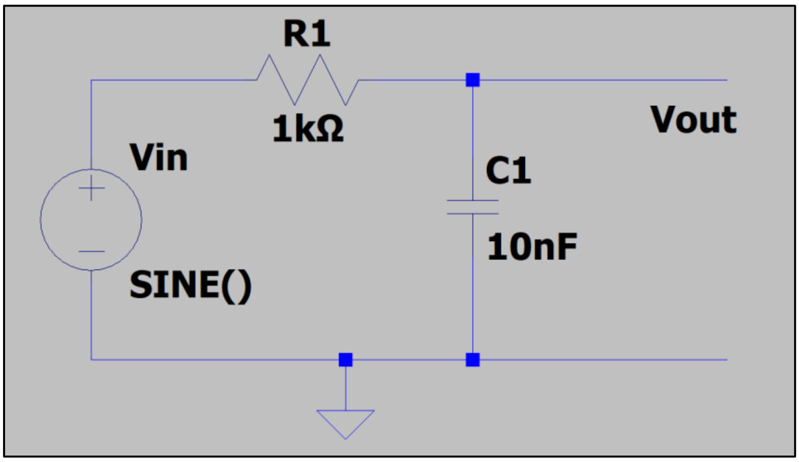
$$\text{the cutoff frequency(fc)} = \frac{1}{2 \times \pi \times R \times C}$$

$$15 \times 10^3 = \frac{1}{2 \times \pi \times R \times 10 \times 10^{-9}}$$

$$\mathrm{R} = 1.061k\Omega$$

$$\mathrm{R} = 1k\Omega$$

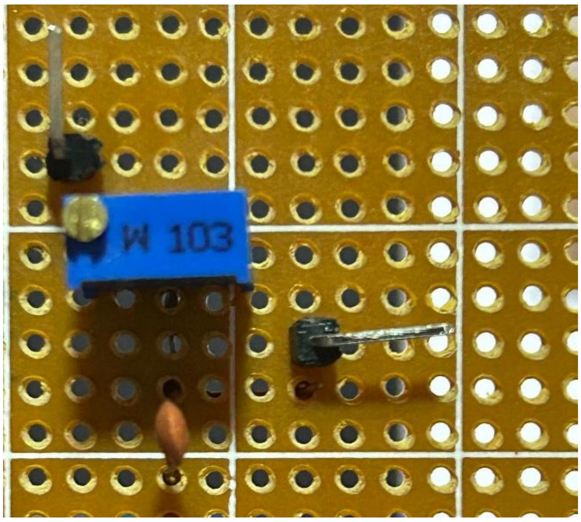
Schematic design



Used Components

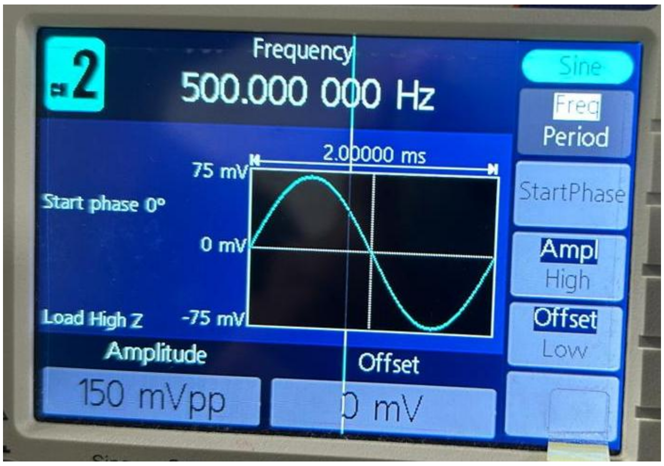
- W103 Variable resistor (1kΩ) 
- 10nF Ceramic capacitor 

Circuit design on the dot board



1. When the frequency is set to 500 Hz,

- Input signal in the signal generator

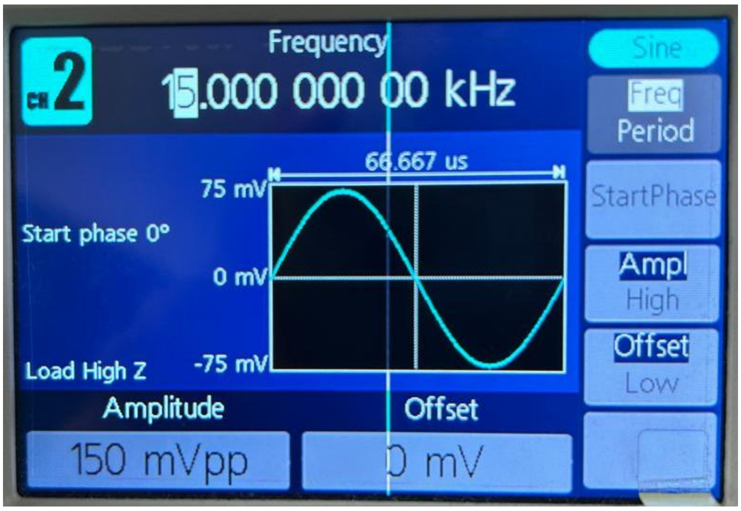


- Output signal using the oscilloscope

If the input frequency drops below the cut-off frequency of 15 kHz, the output signal will pass through.

2. When the frequency is set to 15 kHz,

- Input signal in the signal generator

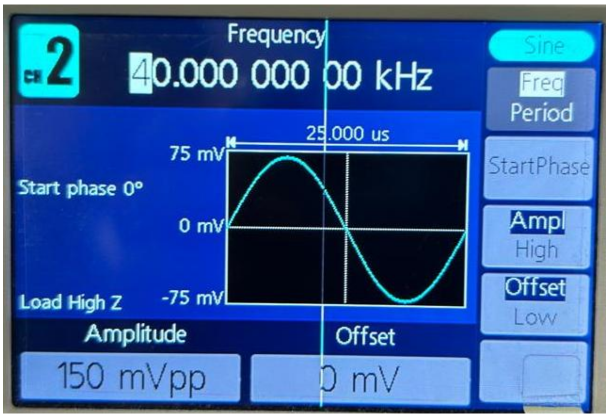


- Output signal using the oscilloscope

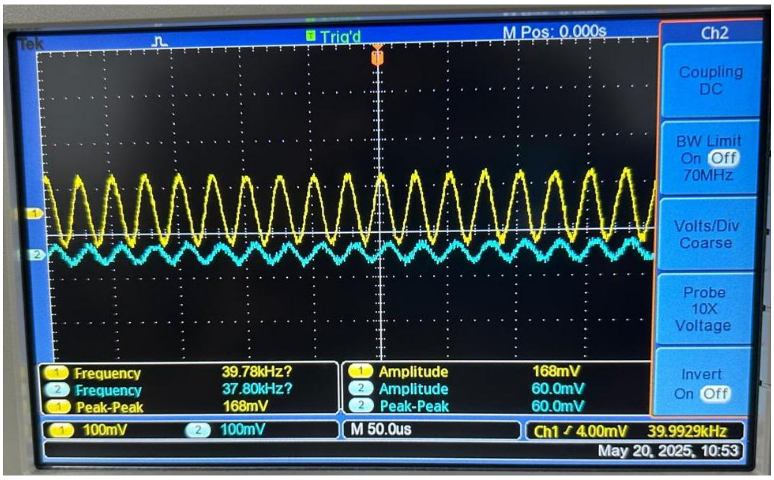
This is the cutoff frequency. Beyond this frequency, the output signal begins to gradually decline.

3. When the frequency is set to 40 kHz ,

- Input signal in the signal generator



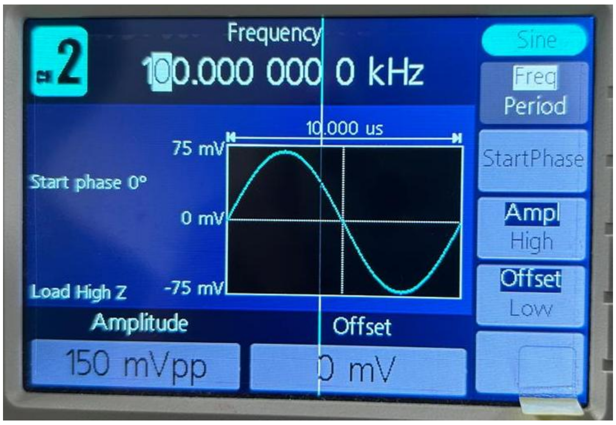
- Output signal using the oscilloscope



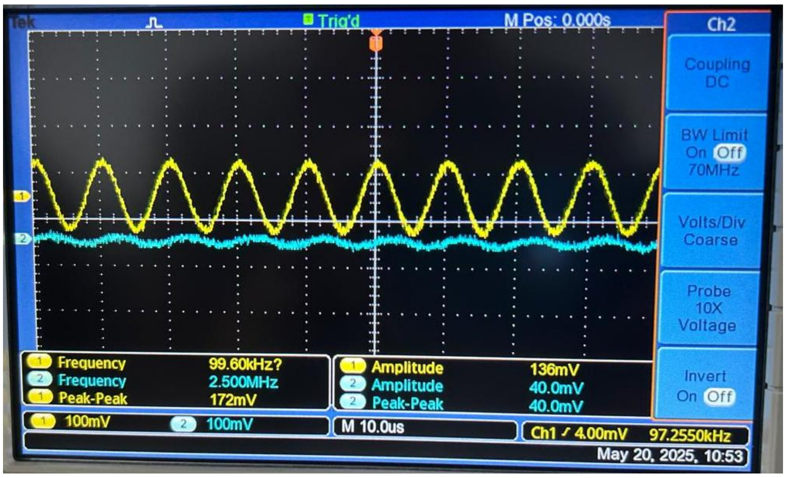
The voltage has decreased from 168 mV to 60 mV.

4. When the frequency is set to 100 kHz ,

- Input signal in the signal generator



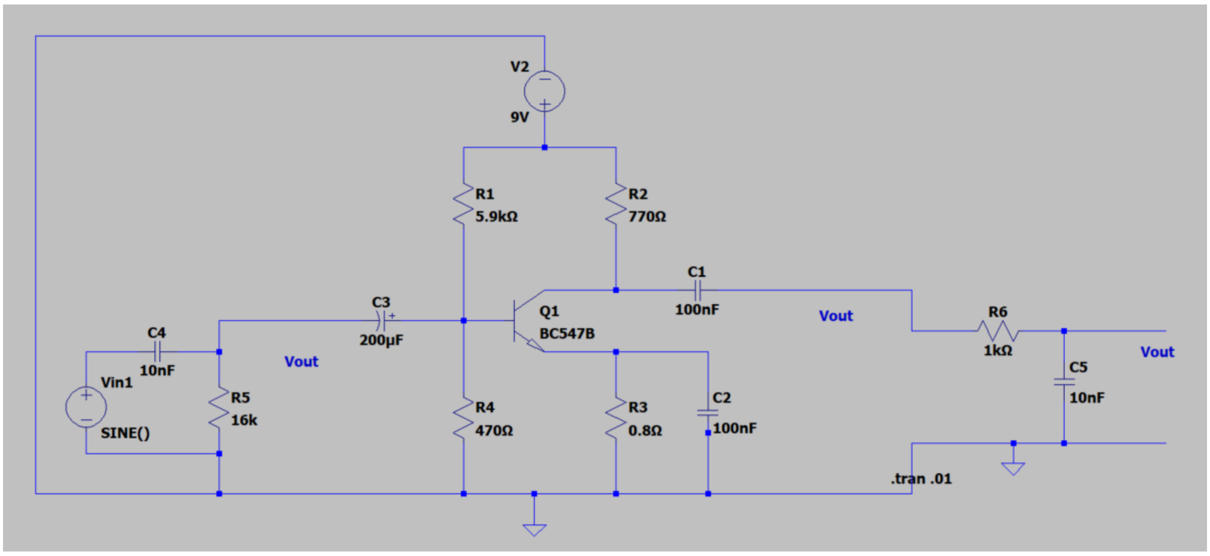
- Output signal using the oscilloscope



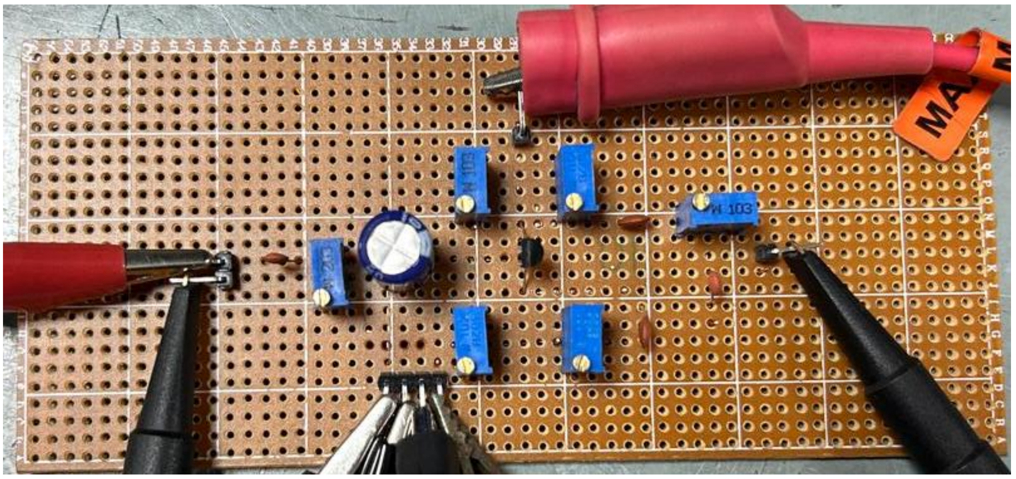
Now, we see that the output frequency has become much smaller.

Full circuit

Schematic design



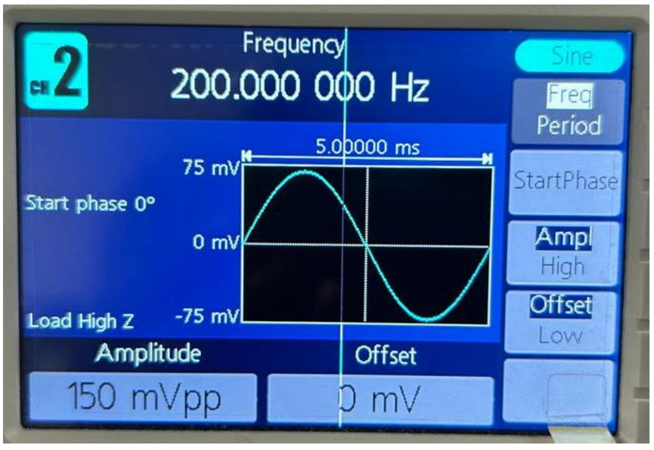
Circuit design on the dot board



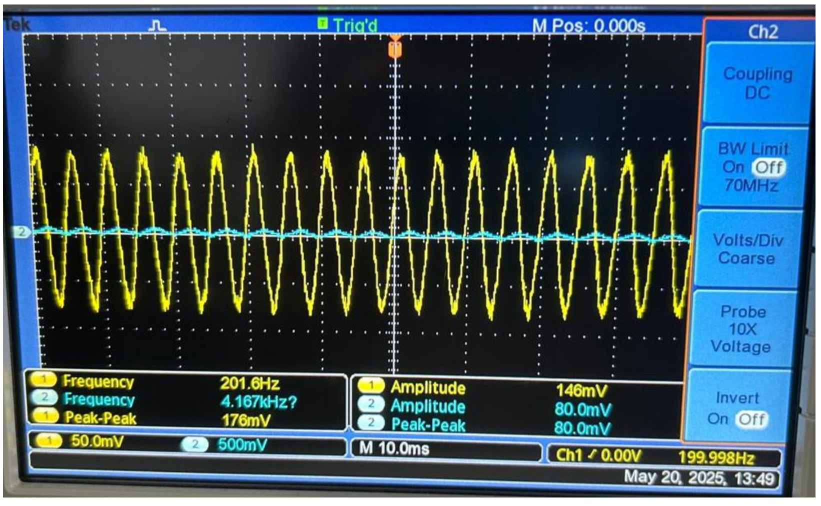
Waveform Measurements

1. When the frequency is set to 200 Hz,

- Input signal in the signal generator



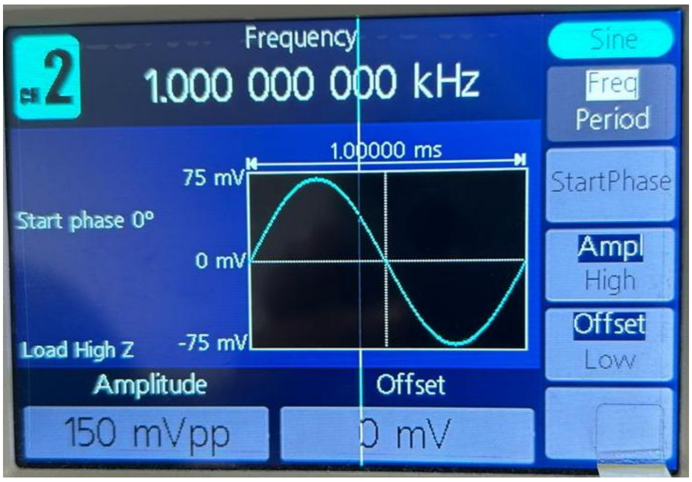
- Output signal using the oscilloscope



This produces a small output because the signal is lower than the cutoff of the high-pass filter.

2. When the frequency is set to 1 kHz,

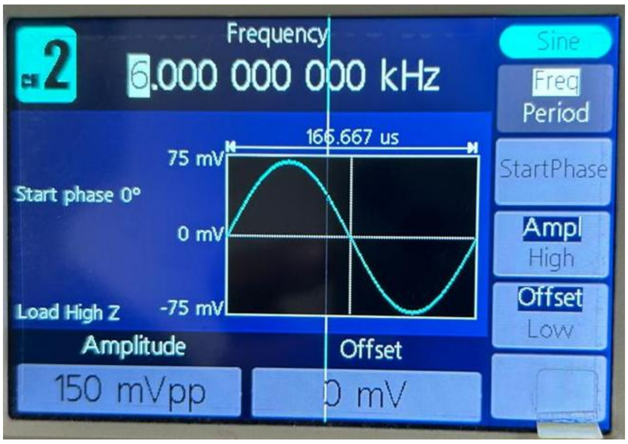
- Input signal in the signal generator



- Output signal using the oscilloscope

3. When the frequency is set to 6 kHz,

- Input signal in the signal generator



- Output signal using the oscilloscope

When the frequency is 7 kHz, the sent signal is amplified.

V_{in} = 220 mV

V_{out} = 1.17 V

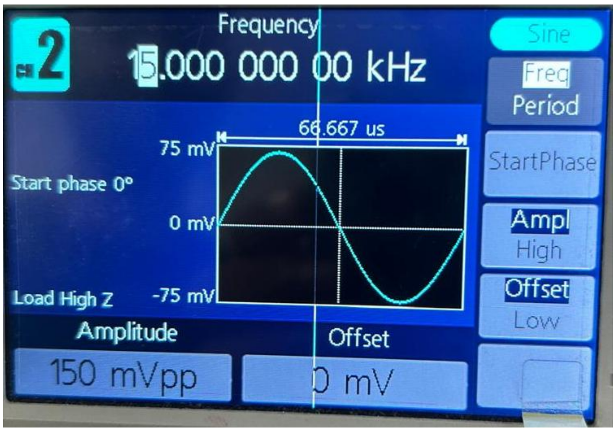
Amplifier gain is;

$$\text{Gain} = \frac{1170\ mV}{220\ mV}$$

Gain = 5.32

4. When the frequency is set to 15 kHz,

- Input signal in the signal generator



- Output signal using the oscilloscope

When the frequency is 7 kHz, the sent signal is amplified.

V_{in} = 220 mV

V_{out} = 1.58 V

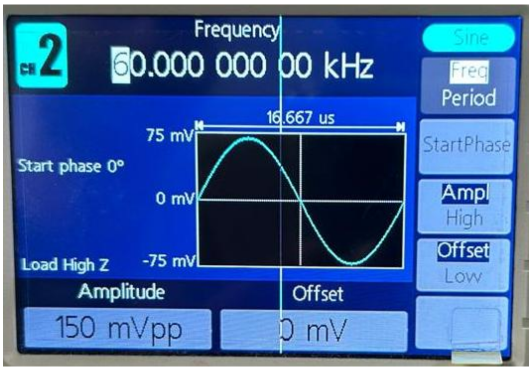
Amplifier gain is;

$$\text{Gain} = \frac{1580\ mV}{220\ mV}$$

Gain = 7.2

5. When the frequency is set to 60 kHz,

- Input signal in the signal generator



- Output signal using the oscilloscope

When the frequency is 60 kHz, the gain decreases because the frequency is higher than the low-pass cutoff frequency.

6. Observations

- **High-Pass Filter:**
  - When the frequency is below 1 kHz, such as at 200 Hz, the output is much lower. This shows that the filter effectively blocks low-frequency noise.
  - At the cutoff frequency of 1 kHz, the output amplitude increased. Frequencies above this point, like 3 kHz, passed through with little loss. This shows that the filter is working correctly.
- **Common-Emitter Amplifier:**
  - For a 10 kHz input signal at 40 mV amplitude, the output amplitude measured was 5.68 V, resulting in a voltage gain of approximately 40.6.
  - Increasing the input amplitude to 50 mV at the same frequency raised the output to 7.04 V, with a measured gain of 50.3.
  - The amplifier provided significant signal amplification, with gain values close to the theoretical target, though practical gain was sometimes lower due to loading and bypass capacitor effects.
- **Low-Pass Filter:**
  - At frequencies below 15 kHz (e.g., 500 Hz, 1 kHz, 6 kHz), the output signal passed with little attenuation.
  - At the cutoff frequency (15 kHz), the output began to decrease, and above this frequency (e.g., 40 kHz, 100 kHz), the output amplitude dropped sharply, confirming effective suppression of high-frequency noise.
- **Full Circuit Measurements:**
  - For low-frequency inputs (200 Hz), the output was minimal due to the high-pass filter.
  - For mid-range frequencies (6 kHz, 7 kHz, 15 kHz), the circuit provided clear amplification, with gains measured between 5.3 and 7.2.
  - At high frequencies (60 kHz), the gain decreased, as expected from the low-pass filter's action.

7. Discussion

The practical results align closely with theoretical expectations for each stage:

- **Filter Performance**

  The high-pass and low-pass filters worked well at their cutoff frequencies of 1 kHz and 15 kHz. The high-pass filter got rid of low-frequency noise, while the low-pass filter reduced high-frequency interference. This kept the output signal within the desired audio range.

- **Amplifier Behavior**

  The common-emitter amplifier provided a strong voltage gain, with measured values coming close to what theory predicted. Some differences, like lower gain in certain situations, were explained by real-world factors.

  - **Bypass Capacitor Sizing**

    The gain was limited when the emitter bypass capacitor's reactance was not sufficiently low at the signal frequency, reducing the effective gain. Increasing the bypass capacitor value improved performance.

  - **Loading Effects**

    The interaction between the amplifier's collector resistor and the input impedance of the subsequent low-pass filter reduced the voltage gain below the ideal value calculated in isolation.

  - **Biasing Challenges**

    The initial calculations for biasing showed that the selected transistor had very high current levels. To fix this, we needed to adjust the resistor values and our assumptions. This helped us find a stable operating point that kept the transistor within safe limits.

- **Components election:**

  We checked the values of the resistors and capacitors using calculations and measurements. It was important to adjust the capacitor values, especially for coupling and bypass functions, to get the right frequency response and gain.

- **Overall Circuit Functionality:**

  The circuit amplified signals effectively in the frequency range of 1 kHz to 15 kHz and reduced signals outside this range. This shows that the multi-stage design works well for processing audio signals.

8. Conclusion

The multi-stage amplifier and filtering circuit reached its design goals. The high-pass and low-pass filters clearly defined the passband, removing unwanted low and high-frequency sounds.

The common-emitter amplifier provided enough gain to strengthen weak audio signals. Its actual performance matched theoretical expectations after we properly selected components and adjusted the bias.

We measured the circuit's frequency response and gain, confirming it is suitable for the audio output stage of an AM radio. It delivers clear and amplified audio within the right frequency range.

This project highlighted the importance of careful component selection, biasing, and considering real-world effects in analog circuit design.