Analogue Electronics
IE2030

Practical Assignment

Title: Multi-stage amplifier and Filtering Circuit
Batch Number: (Y1S2.WD.CSNE.01)
Group Number: (WD_01)
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Contents

1.Introduction

The design and implementation of the audio output section of a basic AM radio present a practical challenge that brings together key principles of analog electronics, particularly amplification and signal filtering. In this assignment, we developed a multi-stage circuit consisting of a high-pass filter, a common-emitter amplifier using a Bipolar Junction Transistor (BJT), and a low-pass filter, aimed at processing weak incoming radio signals to produce a clear, audible output through a loudspeaker.

The high-pass filter, with a cutoff frequency of 1 kHz, was designed to eliminate low-frequency noise and interference from the incoming signal. This ensured that only the relevant audio frequencies passed through to the amplifier stage. The common-emitter amplifier, constructed using an NPN BJT, was designed to provide a voltage gain of at least 50, boosting the strength of the filtered signal to a usable level. Following this, the low-pass filter with a cutoff frequency of 15 kHz was used to suppress any high-frequency noise and smooth the output for better audio quality.

While the RC-based passive filters offered simplicity and helped reduce unwanted frequency components, they lacked precision in attenuating out-of-band signals due to their limited selectivity. Additionally, the practical performance of the amplifier showed slight deviations from theoretical predictions, including minor distortions, likely caused by real-world component tolerances and biasing variations.

Despite these challenges, the final circuit performed satisfactorily, meeting the key design goals of signal amplification and noise reduction. This report documents the theoretical analysis, component selection, schematic design, dot board implementation, and waveform measurements demonstrating how fundamental electronic concepts are applied to the development of a functional audio signal processing system for AM radios.

2. Stage 1 – High Pass Filter

Stage 1 is a high-pass RC filter designed to remove low-frequency noise from the incoming signal. The cutoff frequency of the filter is set to 1 kHz, allowing only higher-frequency signals to pass through. This filter stage plays a crucial role in removing low-frequency hum and background noise before amplification.

- Theoretical Calculations

Fc = 1KHz

Assuming C = 10nF

In cut off frequency,

Xc = R

$$R = \frac{1}{2\pi f c}$$

$$R = \frac{1}{2\times 3.14\times 10\times 10^{-9}\times 1\times 10^{3}}$$

R = 15915.49Ω Hence,

R ≈ 16kΩ

We used a 10nF(because of cost effectiveness, reduce noise susceptibility) capacitor in series with a 16kΩ resistor to implement the high-pass filter. The components were selected using the standard cutoff frequency formula:

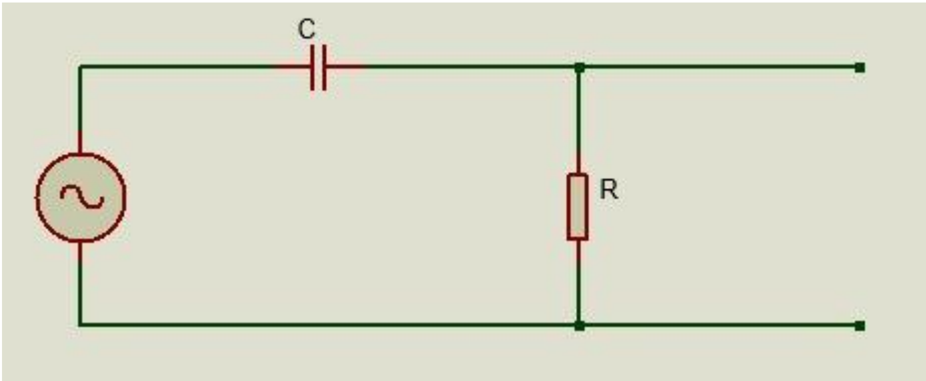
$$Fc = \frac{1}{2\pi RC}$$

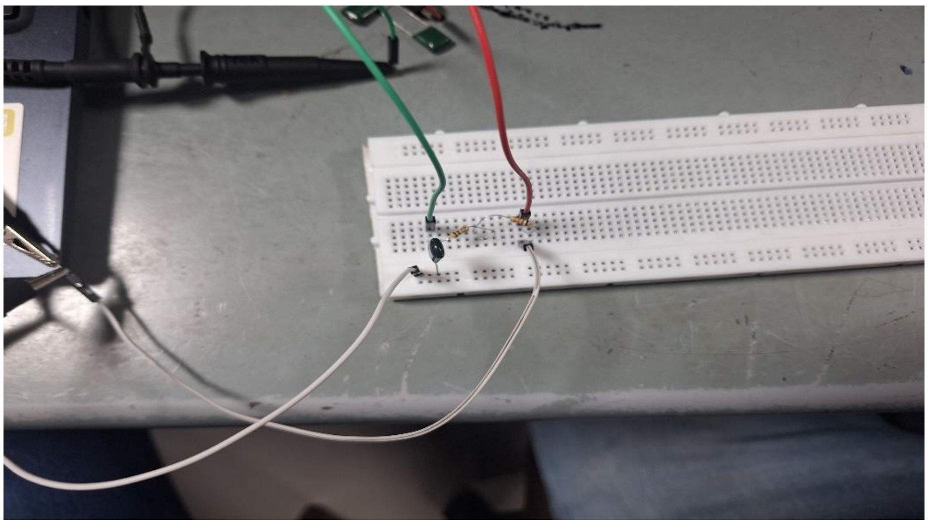
Substituting the values:

$$Fc = \frac{1}{2\pi\times 16\times 10^{3}\times 10\times 10^{-9}} \approx 995 \approx 1\text{kHz}$$

This is sufficiently close to the desired 1 kHz cutoff point.

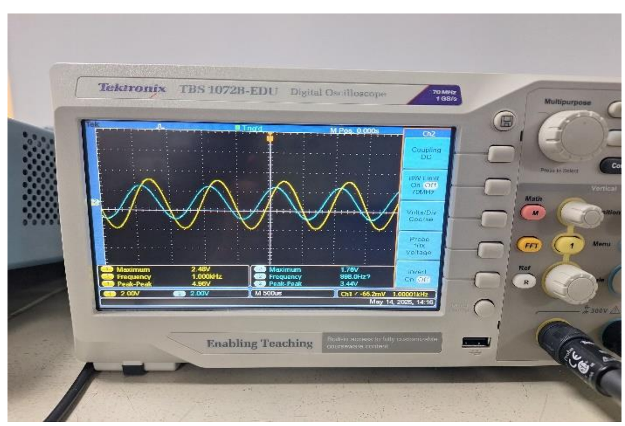
- **High Pass Filter Circuit Diagram**



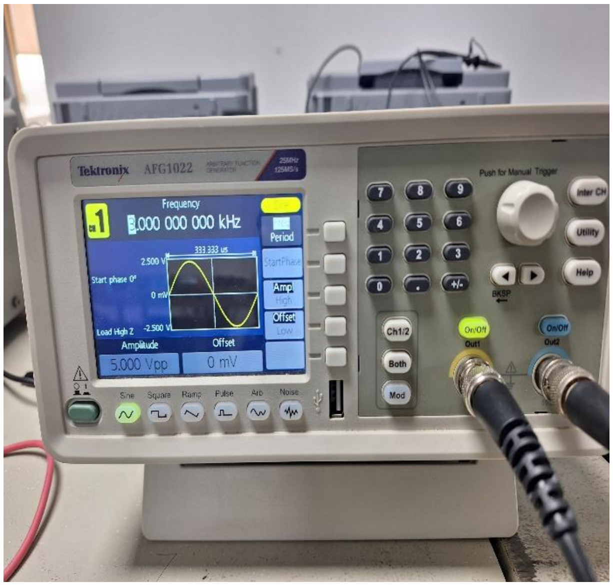


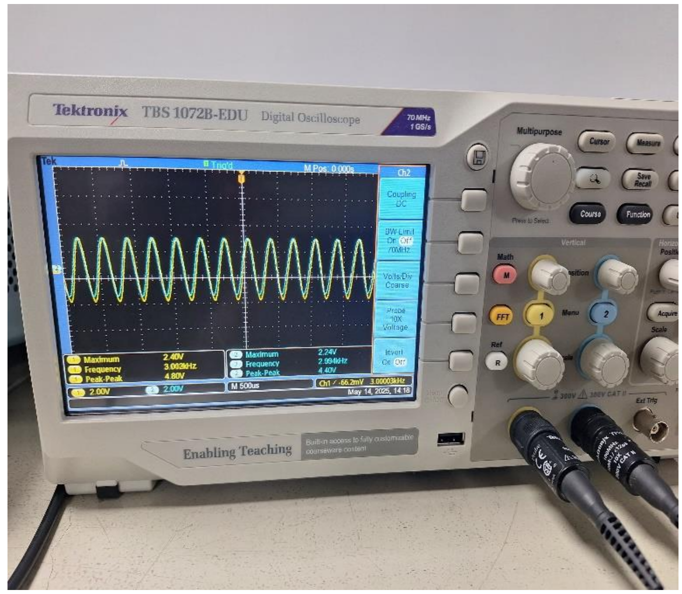
- **High pass Filter Outputs**

1 kHz

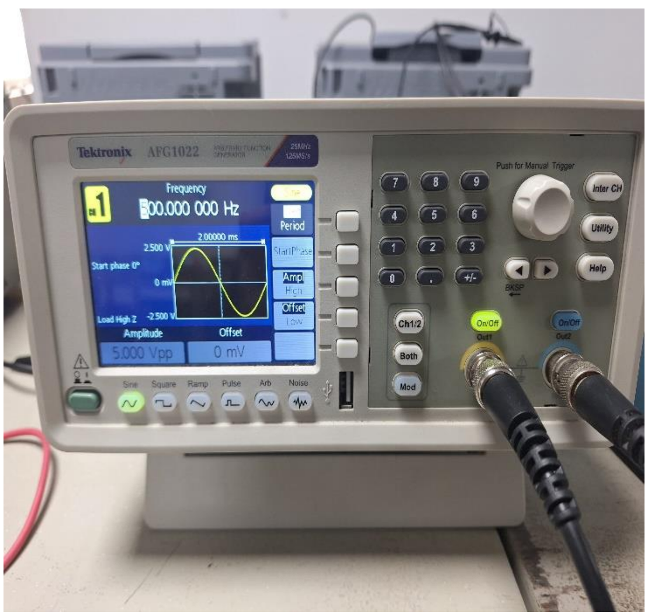


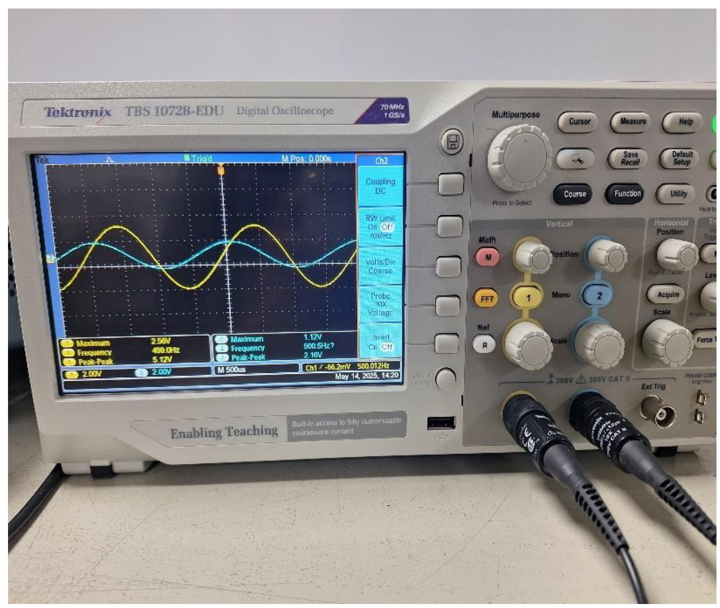
3 kHz





500 Hz





When input frequency is decreased below cut off frequency (1kHz), the attenuation factor of the output signal rapidly increases. Even at the exact cut off frequency, there is a slight attenuation. However, when we increase the frequency further, the attenuation factor becomes extremely negligible.

3. Stage 2-Transistor-Based Common Emitter Amplifier

This stage uses a BC547 NPN transistor in a common-emitter configuration to amplify the filtered signal from Stage 1. The transistor has a DC gain (β) between 110 and 800, and is powered using a 9V DC supply. A voltage divider network is used to bias the transistor in its active region.
The input signal is fed through a coupling capacitor . to prevent DC from entering the base. The amplified output is taken from the collector and passed through another coupling capacitor . to block DC before sending it to Stage 3.
.

- Theoretically calculated values:

Since we selected BC547 transistor, we assumed that $I_C = 2mA$ and started our calculations. For optimum amplification, we found that collector voltage V_C should be
$V_{CC} / 2 = 4.5V$. Also, we set our mid-band voltage gain (A_V) to 50. Diagram related to theoretical calculations is given above.

Then by $V_{CC} - V_C = I_C * R_C$

$$9 - 4.5 = 2*10^{-3}*R_C$$

$$R_C = 2250\ \Omega$$

$$R_C = 2.25\ k\Omega$$

Since $A_V = \frac{Rc}{Re+r}$; where $A_V = 50$

$r = \frac{25mV}{2mA} = 12.5\ \Omega$

Where r = 12.5Ω (Internal resistor of BJT)

$60 = \frac{2250}{Re+12.5}$

$R_E = 25\Omega$

Since $I_E = I_B + I_C$

Also $I_B << I_C$

Then $I_E \approx I_C$

By $V_E - GND = I_E*R_E$

$V_E - 0 = I_C*R_E$

$V_E = 2*10^{-3}*25$

$V_E = 50mV$

By $V_{BE} = 0.7$ (min)

$= V_B - V_E$

$0.7 = V_B - 0.05$

$V_B = 0.75mV$

To get values for R_{B1} and R_{B2}, lets create a potential divider network. We can consider both resistors being series since I_B current is negligible.

So $R_{B1} = 8k\Omega$ and $R_{B2} = 1k\Omega$

Also $C_I = C_O = 100$ nF $\quad C_I$=Input Coupling capacitor

$C_E = 200\ \mu F$ $\quad C_{O=Output\ Coupling\ Capacitor}$

$C_{E=Emitter\ bypass\ capacitor}$

Although we initially designed the circuit based on our theoretical calculations, the practical implementation did not work as expected. The voltage values we obtained were significantly different from the predicted ones. As a result, we adopted a trial-and-error approach, manually adjusting resistor values to achieve the correct biasing voltages for the transistor. Once proper biasing was established, we also experimented with different capacitor values to achieve a desirable level of signal amplification. Below, we have listed the updated resistor and capacitor values along with the measured voltage readings.

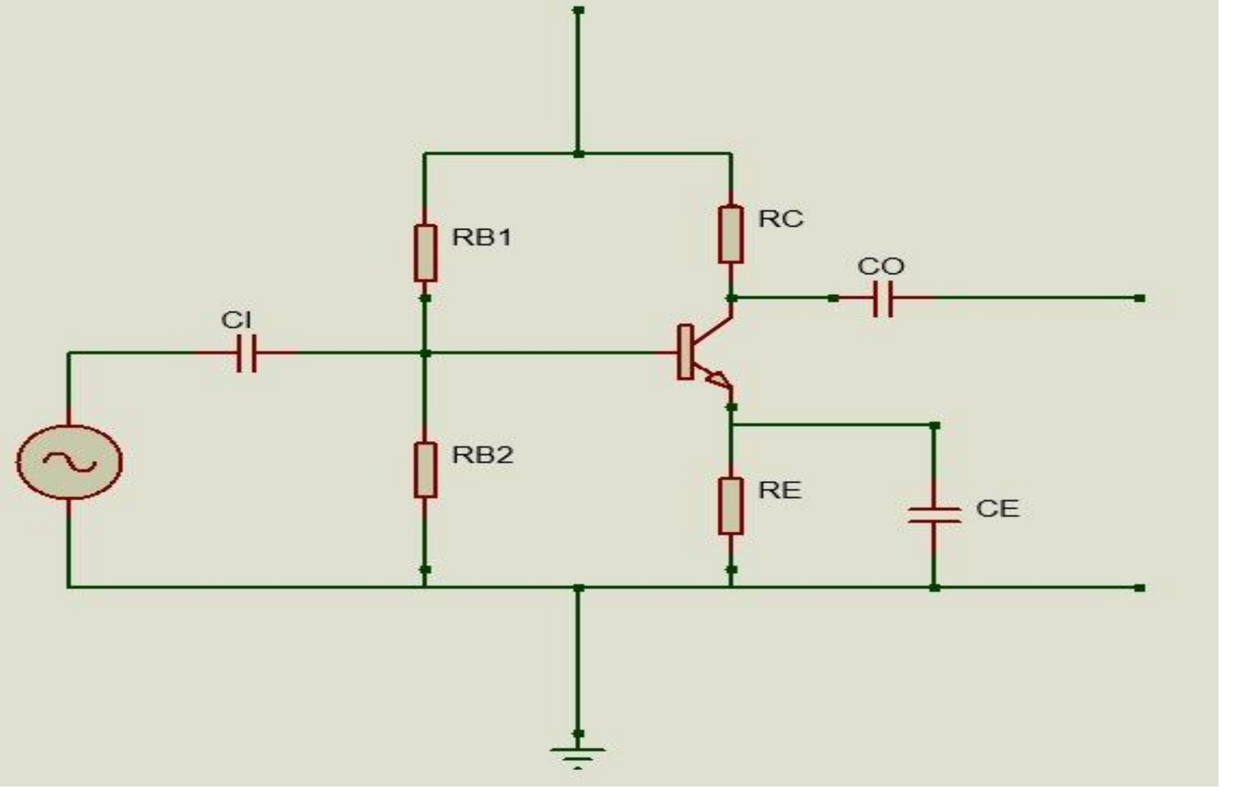
$C_I = \ \ 2.2\mu F$ R_{B1} = 82 kΩ

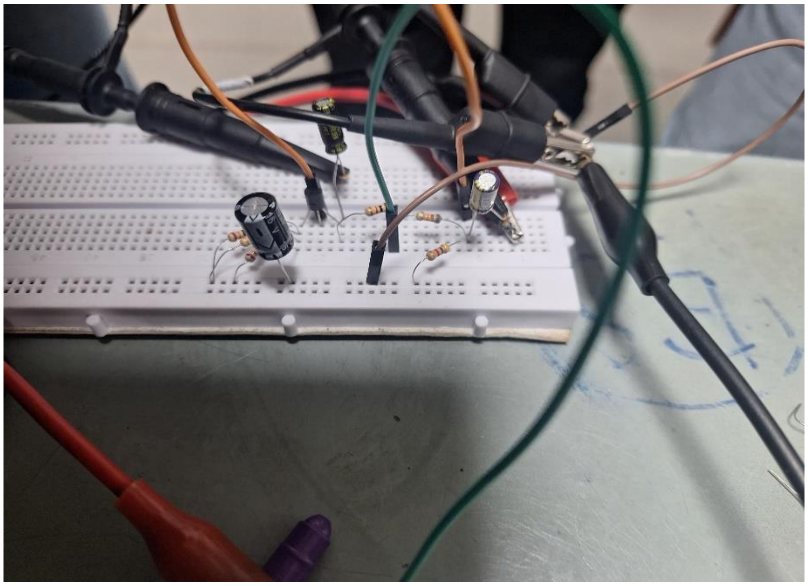
$C_O = \ \ 4.7\mu F$ R_{B2} = 4.7 kΩ

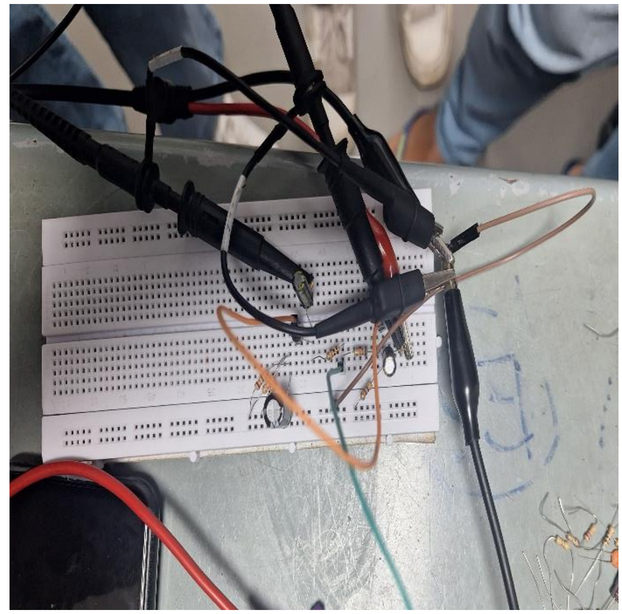
$C_E = \ \ 470\mu F$ R_C = 1 kΩ

R_E = 22 kΩ

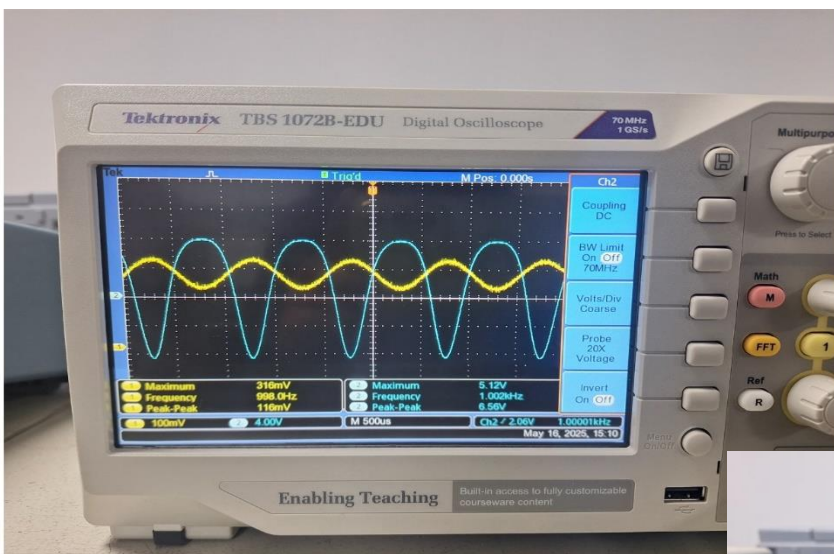
- **Amplifier Circuit Diagram**







- **Transistor-Based Common Emitter Amplifier output**



4. Stage 3 – Low Pass Filter

Stage 3 is designed to remove high-frequency noise from the amplified signal and allow only frequencies below 15 kHz to pass through. This ensures that the final audio output is clean and free from unwanted high-frequency interference. We connected the V_{in} to an sinusoidal AC wave generated by a function generator. Then connected V_{out} to a digital oscilloscope. Since this is a passive filter, we cannot completely remove unwanted frequencies. However, higher frequencies undergo a significant attenuation when passed through the filter.

fc $= \frac{1}{2\pi \times R \times C}$

- Theoretical Calculations

  Fc = 15KHz

  Assuming C = 100nF

  In cut off frequency,

  R = $\frac{1}{2\pi f C}$

  R = $\frac{1}{2 \times 3.14 \times 15 \times 10^{3} \times 100 \times 10^{-9}}$

  R = 106.103 Ω Hence,

  R ≈ 100Ω

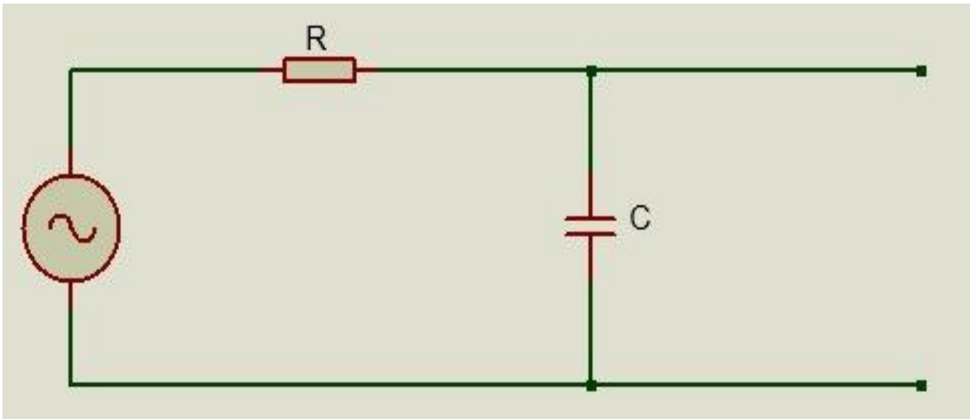
We used a 100nF (because commonly available, smoothing, noise reduction)capacitor in series with a 100Ω resistor to implement the low-pass filter. The components were selected using the standard cutoff frequency formula

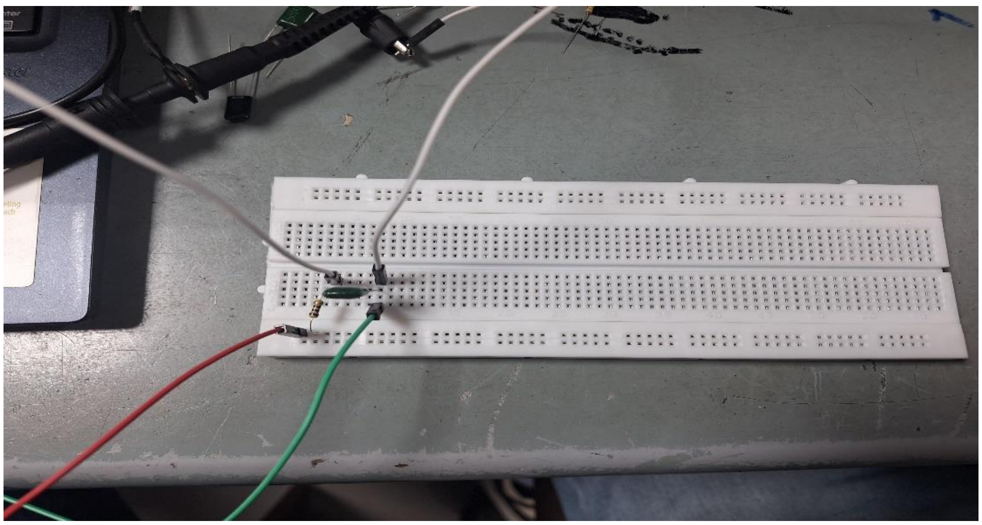
Substituting the values:

Fc = $\frac{1}{2\pi \times 100 \times 100 \times 10^{-9}} \approx 15.9$ kHz ≈ 15kHz

This is sufficiently close to the desired 15kHz cutoff point.

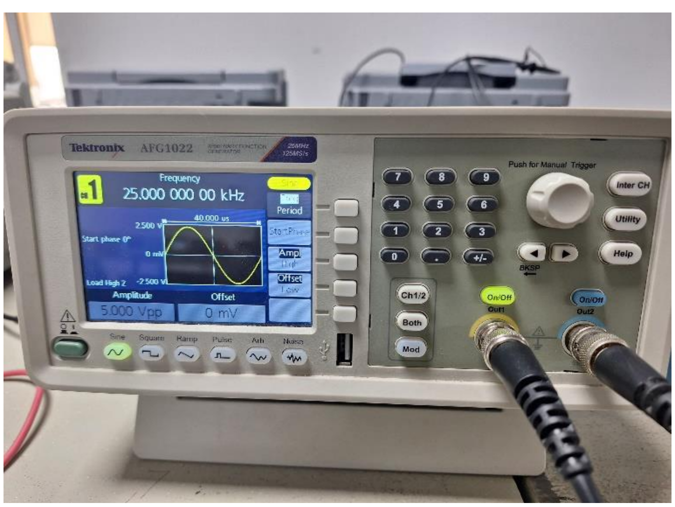
- **Low Pass Filter Circuit Diagram**

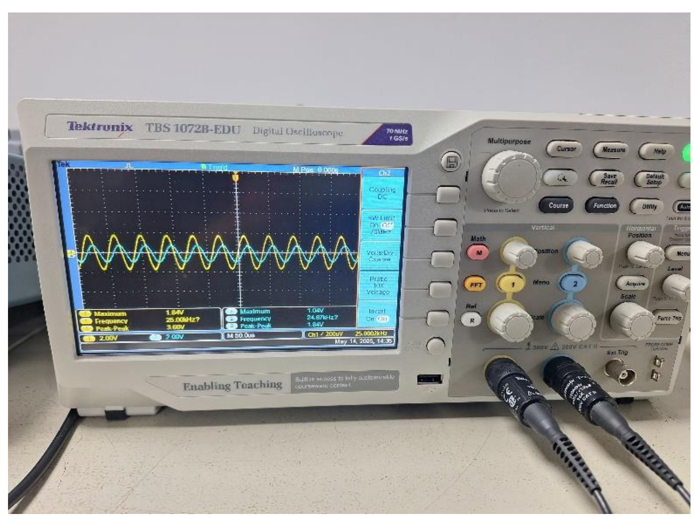




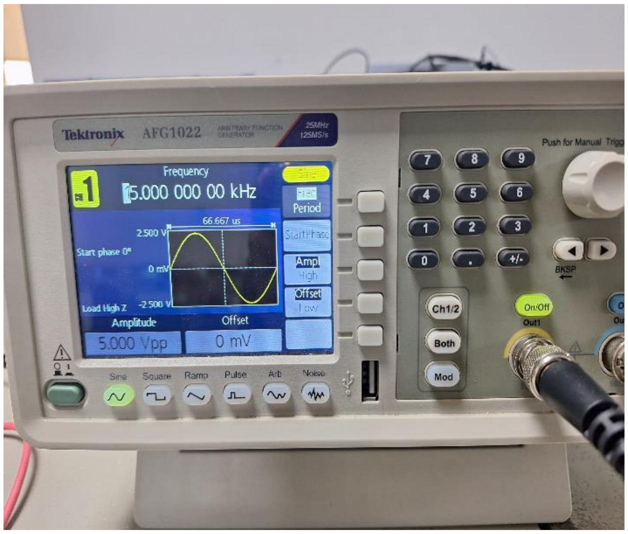
- **Low pass Filter Outputs**

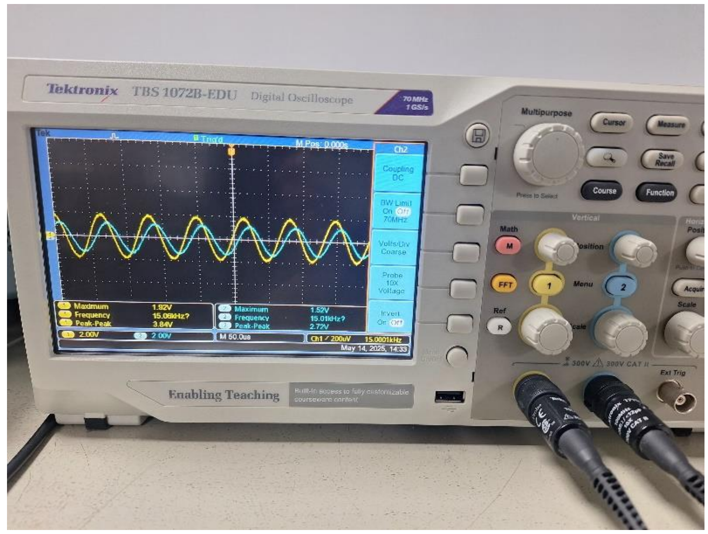
25kHz



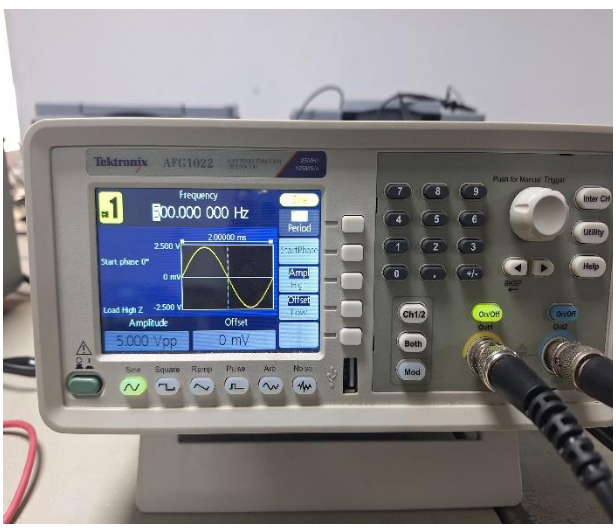


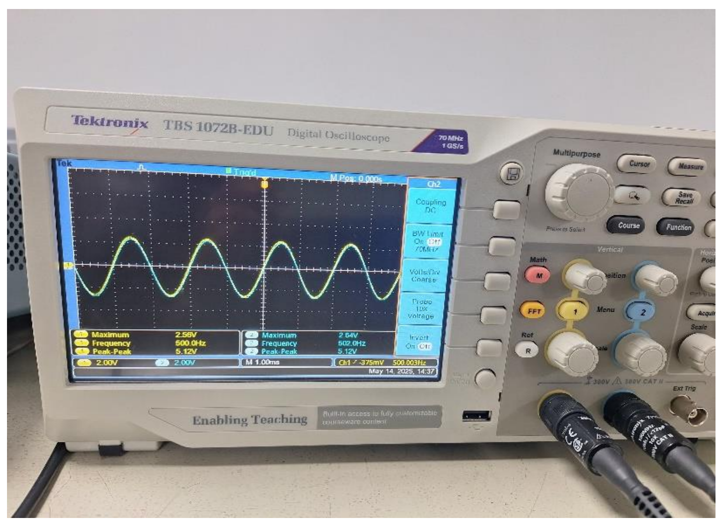
15 kHz





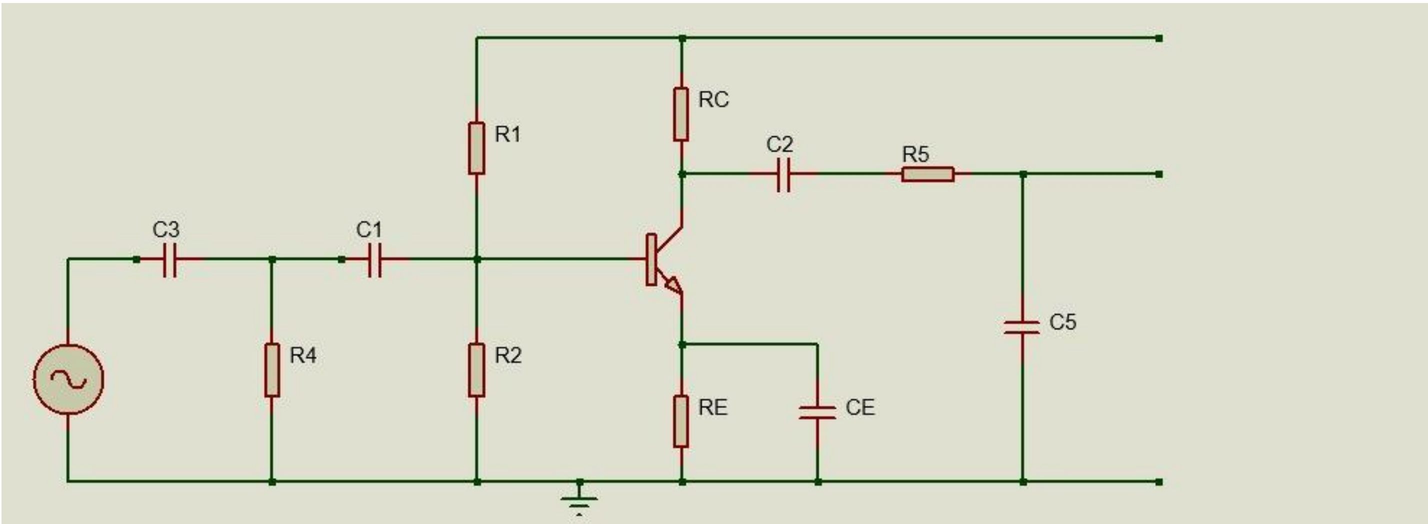
500 Hz

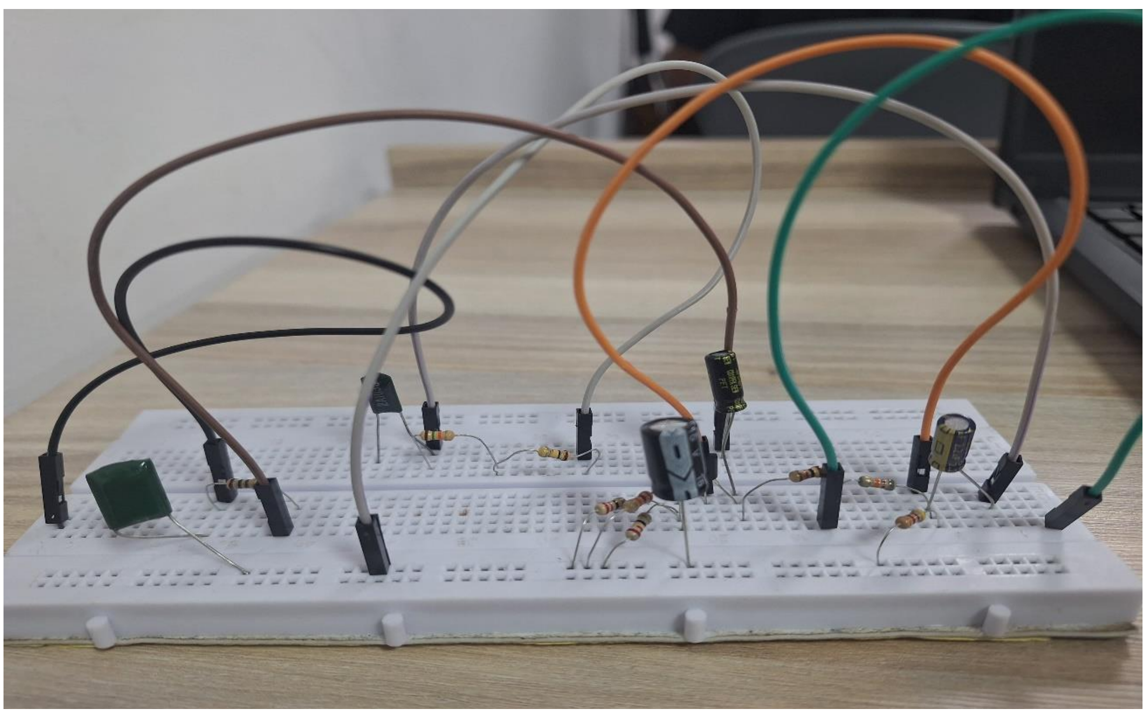




When input frequency is increased above cut off frequency (15kHz), the attenuation factor of the output signal increases. Although there seems to be a significant attenuation at the exact cut off frequency, it decreases rapidly when we decrease the input frequency further.

5.Final Circuit





6.The Design Choices for Components

Here, when frequency and capacitor values decrease the capacitor resistance increases. Then, the output voltage also increases. So, we used the lowest valued capacitor for the high pass filter from the recommended range 10nF – 100nF.

For the low pass filter, we used the higher recommended value 100nF capacitor to cut off higher frequencies as when C decreases output voltage also increases according to the opposite of the above theory.

10nF 103 Mylar capacitor / 100nF 104 Mylar capacitor

- Commonly available
- Cost effective
- Reduce noise susceptibility
- Easier calculations

When, reducing the capacitance we should use a higher resistance to get the required output.

So, we used 16kΩ resistor for our high pass filter.

As, we used a higher capacitance we should use a small resistance in order to get a higher output voltage by cutting of higher frequencies. In case, 100Ω resistor is used for the low pass filter.

16kΩ resistor

- Precision and stability
- Current limiting
- Noise reduction
- Reduces low-frequency noise

100Ω resistor

- Lower power Dissipation
- Versatility
- low-cost resistor
- Helps block unwanted high-frequency noise > 15 kHz

BC547

- High Gain: The BC547 has a high current gain (β), typically between 100 and 800, making it suitable for amplification applications.
- Low Noise: It has a low noise figure, which is important in audio and RF applications where signal clarity is crucial.
- Moderate Frequency Response: The transistor has a maximum frequency (f_T) of around 300 MHz, which is adequate for many amplifier designs.
- Small Size: The BC547 comes in a compact package (TO-92), which is convenient for breadboarding and prototyping.
- Low Cost: It's widely available and inexpensive, making it an economical choice for hobbyists and professionals alike.
- Robustness: The transistor can handle moderate power levels, making it reliable for various applications without requiring extensive heat management.
- Easy to Work With: It has straightforward pin configurations and characteristics, making it easier to integrate into designs.
- Versatility: The BC547 can be used in various configurations (common emitter, common collector, etc.) for different amplification needs.

7.Observations and explanations of signal behavior at different stage of the circuit

Step 1: High-Pass Filter

Observation:
The high-pass filter allows signals with frequencies above the cutoff point (1 kHz) to pass through, effectively eliminating low-frequency noise.

Explanation:
In this stage, the capacitor blocks low-frequency components below 1 kHz while allowing higher frequencies to pass. The cutoff frequency is determined by the RC (resistor-capacitor) combination. As a result, unwanted low-frequency noise is filtered out, yielding a cleaner signal for amplification.

Step 2: Transistor-Based Common Emitter Amplifier

Observation:
The signal output from the high-pass filter is significantly amplified by the common-emitter amplifier. The output voltage is much greater than the input.

Explanation:
The BJT, configured in common-emitter mode, amplifies the input voltage. The amplifier's gain is primarily determined by the ratio of the collector resistor to the emitter resistor . With a gain of at least 50, the amplifier strengthens weak radio signals to a usable level. The biasing network ensures the transistor remains in the active region for stable and consistent amplification.

Step 3: Low-Pass Filter

Observation:
After amplification, the signal is passed through a low-pass filter, which attenuates high-frequency noise, resulting in a smoother audio output.

Explanation:
This stage permits frequencies below the 15 kHz cutoff while attenuating higher-frequency components. The RC network determines the cutoff frequency. This final stage removes any high-frequency interference introduced during amplification, ensuring the output is clean and suitable for audio playback.

Overall Signal Behavior

- **Original Signal:** Weak input signal containing both high and low-frequency noise.
- **After High-Pass Filter:** Low-frequency noise is removed; higher-frequency content remains.
- **After Amplifier:** Filtered signal is significantly amplified.
- **After Low-Pass Filter:** Remaining high-frequency noise is filtered out, producing a clear and smooth audio signal ready for output.

8.Performance of the Amplifier and Effectiveness of the Filtering Stages

Amplifier Performance

- **Voltage Gain:**
  The common-emitter amplifier is designed to deliver a mid-band voltage gain of 50 or higher, effectively boosting weak radio signals to a usable amplitude. The actual gain is determined by measuring and comparing the amplitudes of the input and output waveforms.
- **Bias Stability:**
  The biasing network ensures that the transistor operates within the active region, promoting stable and distortion-free amplification. This prevents the transistor from entering saturation or cutoff, which could otherwise result in signal distortion or loss.
- **Frequency Response:**
  The amplifier is expected to maintain a flat frequency response across the desired range of 1 kHz to 15 kHz. This allows all audio frequencies within that range to be amplified uniformly, preserving the fidelity of the original signal.

Effectiveness of the Filtering Stages

High-Pass Filter (Stage 1):

- **Cutoff Frequency:**
  The high-pass filter is designed with a 1 kHz cutoff frequency, which effectively suppresses low-frequency noise such as electrical hum and environmental interference.
- **Signal Clarity:**
  By eliminating unwanted low-frequency components, the filter ensures that only relevant high-frequency signals proceed to the amplification stage, significantly improving the clarity and quality of the signal.

Low-Pass Filter (Stage 3):

- **Cutoff Frequency:**
  Configured with a 15 kHz cutoff, the low-pass filter blocks high-frequency noise and interference—such as static—thereby preventing them from reaching the output stage.
- **Smooth Audio Output:**
  By filtering out high-frequency disturbances, this stage helps produce a clean and smooth audio output, improving the overall listening experience.