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Low-Power Hi-Fi Class-AB Audio Amplifier

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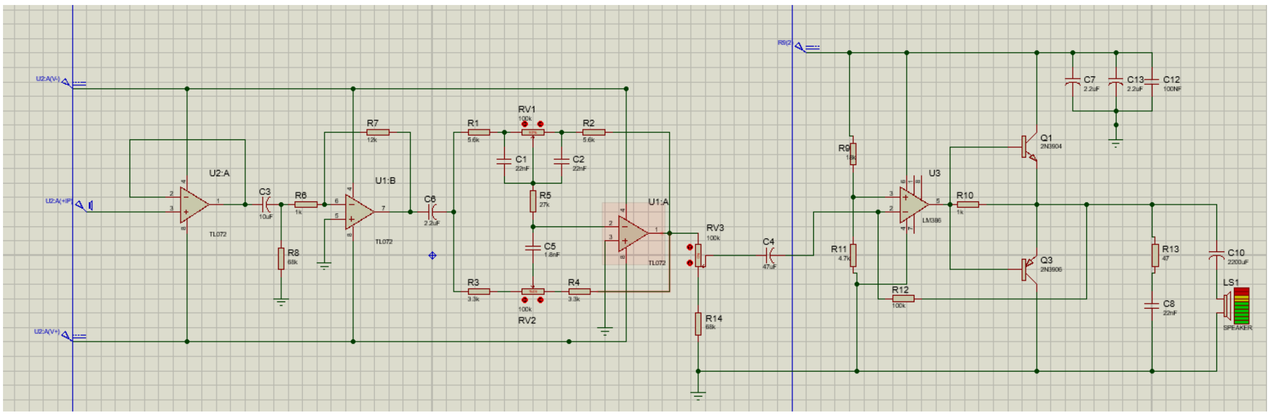
1. Introduction

Audio amplification is a fundamental aspect of analog electronics, with applications in consumer electronics, public addressing systems, and high-fidelity audio equipment. This project focuses on designing and implementing a **low-power Hi-Fi Class AB audio amplifier** for small speaker systems. Class AB amplifiers combine the efficiency of Class B and the low-distortion characteristics of Class A, making them ideal for low-power, high-quality audio applications

We first implement this circuit in **proteus** and simulate the working of it and implement the Baxandall tone controller in **LT spice** for analysing the frequency response. The main components we use here are.

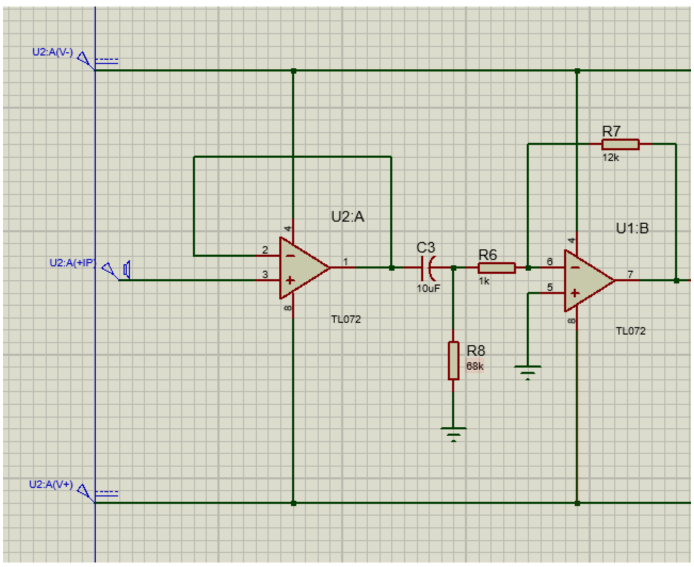
1. TL072 (Buffer, Pre amplifier, Baxandol T.C.)
2. LM386 (Power amplifier)
3. 2N3906
4. 2N3904

2. Circuit Diagram and simulation



2.1. Pre amplifier

A **preamplifier**, or **preamp**, is an electronic circuit used to boost weak electrical signals to a level suitable for further processing or amplification. By increasing the signal strength without significantly adding noise or distortion, the preamplifier ensures that the audio quality is preserved and optimized for playback.



In pre amplifier circuit It contains 3 main parts

Input Buffer
An op-amp buffer circuit, or voltage follower, provides unity gain with high input impedance and low output impedance. This prevents higher current drain from the signal source by isolating it, ensuring accurate signal transfer without loading effects.

High pass filter
The high-pass filter is used after the buffer to block low-frequency noise or DC offset while allowing the desired AC signal to pass through.

Cut off frequency

Fc = 1/(2* pi * R * C)
 = 1/(2* pi * 68 * 10^3 * 10 * 10^-6)
 = 0.234 Hz

Noise free amplifier
This inverting amplifier is a **fixed-gain, low-noise amplifier** used to boost the audio signal to a suitable level for tone control. It provides clean amplification with minimal noise. Here use TL072 opamp IC Due to low noize and higher slew rate. And supply 12V dual voltage supply.

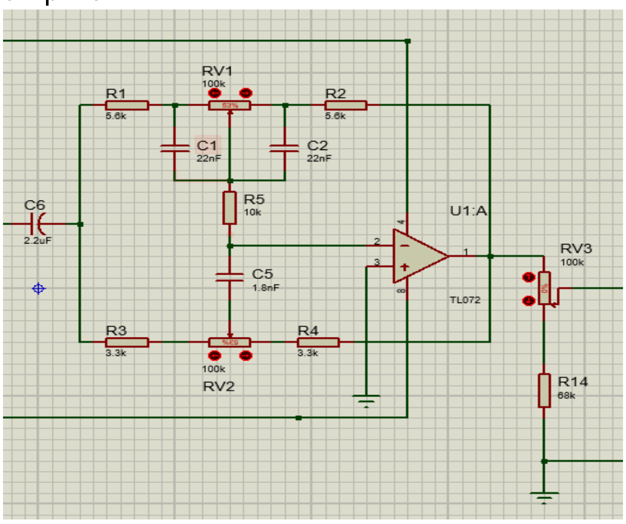
- **Low Noise**
  V_n = 18 nV/√Hz Typ at f = 1 kHz
- **High Input Impedance . . . JFET Input Stage**
- **Internal Frequency Compensation**
- **Latch-Up-Free Operation**
- **High Slew Rate . . . 13 V/μs Typ**
- **Common-Mode Input Voltage Range Includes V_{CC+}**

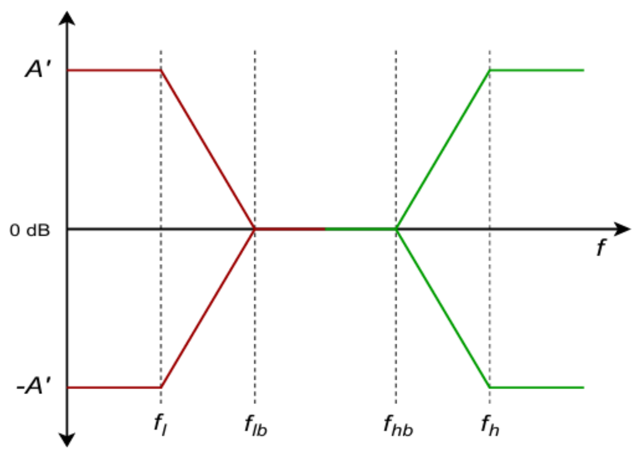
TL072

* Here we set the gain for 21.58 dB that make the signal input to desired voltage level.

2.2. Tone controller

This is a simple bass and treble tone controller circuit based on the Baxandall design. It lets you boost or reduce low (bass) and high (treble) sounds using two knobs (potentiometers). We used the TL072 op-amp, which is a low-noise and good-quality IC commonly used in audio circuits. It gives better sound control compared to passive tone circuits. We also added another potentiometer at the output to adjust the overall tone level before sending the signal to the power amplifier. This helps in setting the final volume or strength of the signal going into the power amplifier





The total filter response is varied as the plots of the graphs. Here we design our Bass - treble tone controller.

Here we select the components as the flb as 1000Hz and fhb as 3000Hz. Then the above frequencies are

Bass Tuner

Assume $R_2 >>> R_1$

$$f_\ell = \frac{1}{2\pi\,(RV1)\,C_1} = \frac{1}{2\pi \times 100 \times 10^3 \times 22 \times 10^{-9}} = 72.34\ \text{Hz}$$

$$f_{\ell b} = \frac{1}{2\pi \times R_2 C_1} = \frac{1}{2\pi \times 5.6 \times 10^3 \times 22 \times 10^{-9}} = 1291.84\ \text{Hz}$$

$$\text{Mid Band gain} = 20\log_{10}\left(1 + \frac{R_2}{R_1}\right) = 20\log_{10}\left(1 + \frac{100}{5.6}\right)$$

$$(\text{Max}) = 25.51\ \text{dB}.$$

Treble Tuner

$RV2 >>> R_3 + 2R_5 + R_2$

$$f_h = \frac{1}{2\pi \times 3.3 \times 10^3 \times 1.8 \times 10^{-9}} = 26.79\ \text{kHz}$$

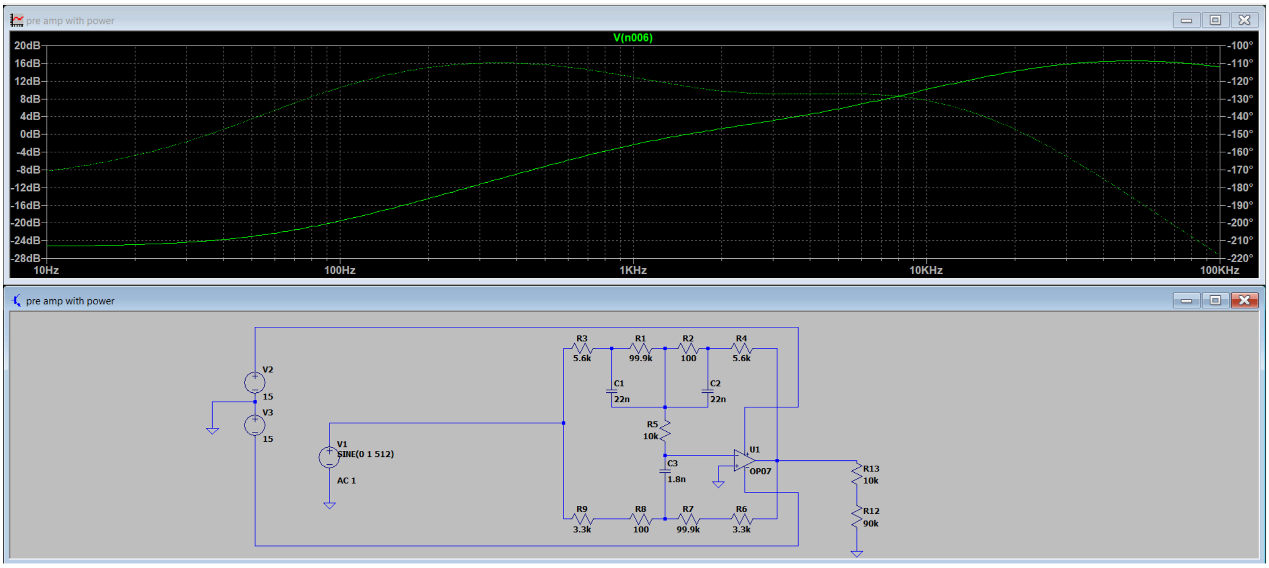
$$f_{hb} = \frac{1}{2\pi \times 28.9 \times 10^3 \times 1.8 \times 10^{-9}} = 3.059\ \text{kHz}$$

$$\text{Mid band gain} = 20\log_{10}\left(1 + \frac{R_2 + 2R_5}{R_3}\right) = 20\log_{10}\left(1 + \frac{5.6 + 20}{3.3}\right)$$

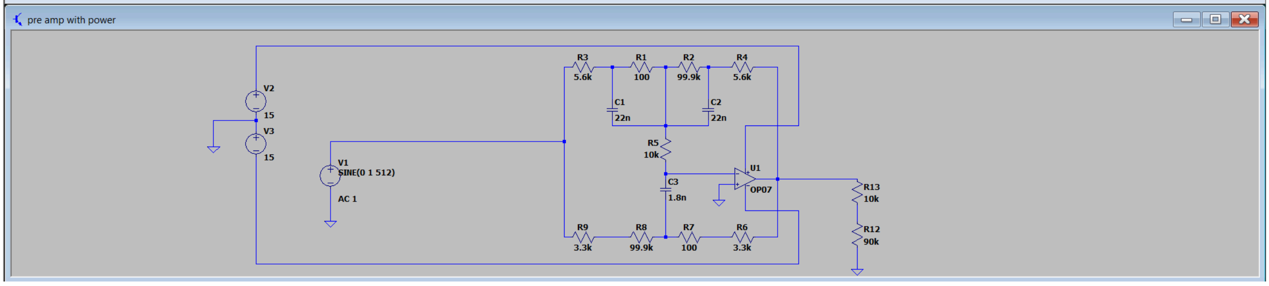
$$(\text{Max}) = 18.847\ \text{dB}$$

Simulation test results for bass treble tone controller circuit response

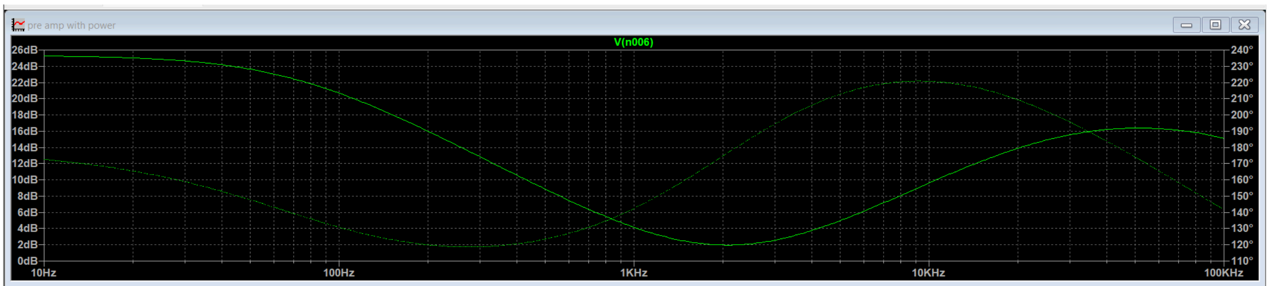
When Bass resistor(RV1) ratio 999:1 and Treble(RV2) 1:999

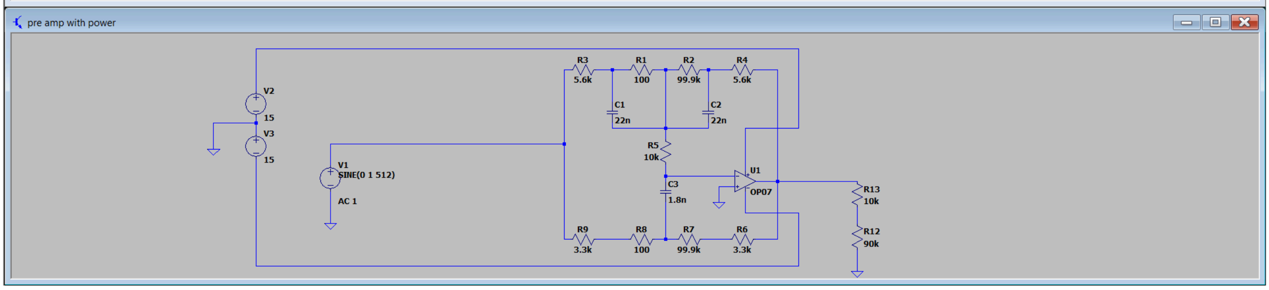


When Bass resistor(RV1) ratio 1:999 and Treble(RV2) 999:1

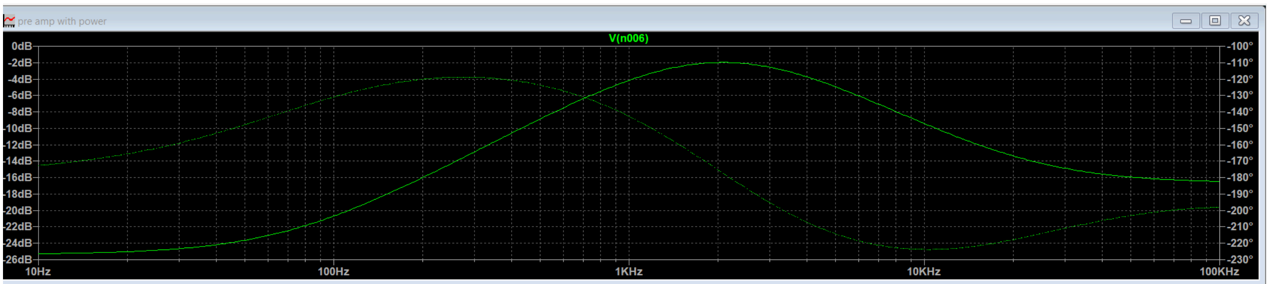


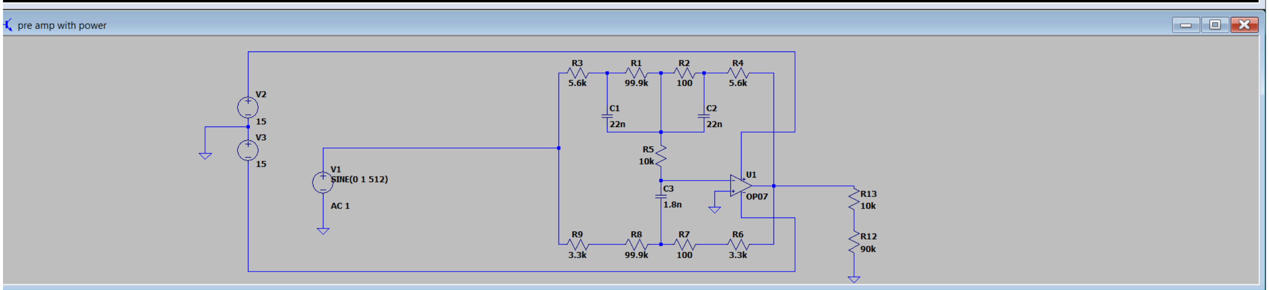
When Bass resistor(RV1) ratio 1:999 and Treble(RV2) 1:999





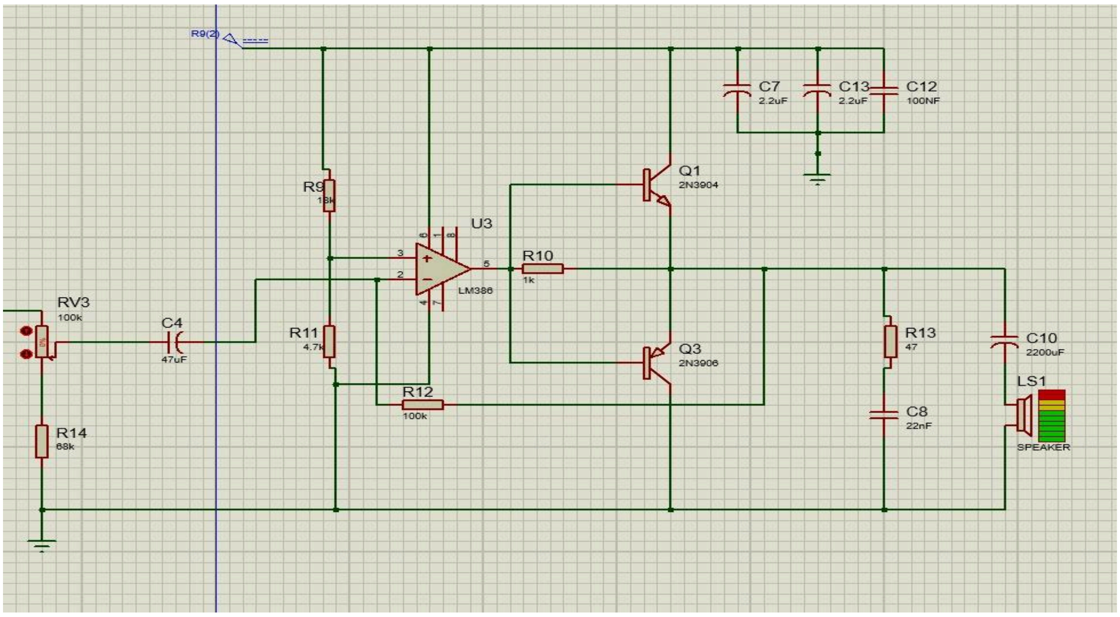
When Bass resistor(RV1) ratio 999:1 and Treble(RV2) 999:1





2.3 Power Amplifier

A power amplifier is a circuit that increases the power level of a small input signal in order to drive a high power load, such as speakers and [motors.](motors) This is a **Class AB power amplifier** circuit built around a **single power supply LM386** low voltage audio power amplifier and a complementary pair of BJTs for driving 8Ω speaker.



This power amplifier circuit contains 3 main parts,

1.Pre Amplifier(LM386)
  ·The LM386 amplifies the low-level audio signal.
  ·R12 provides negative feedback, setting the gain.

2.Class AB amplifier
  ·Transistors Q1 (NPN) and Q3 (PNP) amplify the signal from the LM386.
  ·Capacitors C7, C13, C12 provide power supply filtering.
  ·Capacitor C10 decouples DC from the speaker.
  ·Capacitor C8 ensures high-frequency stability.

3.Speaker

Voltage Gain

According to LM386 datasheet,

Gain = 20

With feedback resistors,

$$Av = 1 + R11/R12 = 1 + 4.7k/100k \approx 22.3$$

Power Gain

Speaker load = 8Ω
Peak output voltage = 5V → RMS = 3.54V

$$Pout = Rload/Vrms^2 = 8/3.54^2 \approx 1.57W$$

If the input signal is 100 mV

$$Power\ gain\ (linear) = 1.57/(0.1^2/8) = 1.57/0.00125 \approx 1256$$
$$Power\ gain\ (dB) = 10log(1256) \approx 31dB$$

Power Efficiency

Class AB typical efficiency = 50–70%.
Supply voltage = 12V, total current drawn ≈ 200 mA (peak):

$$Pin = Vcc \times I = 12 \times 0.2 = 2.4W$$
$$\eta = Pin/Pout \times 100 = 1.57/2.4 \times 100 \approx 65.4\%$$

Frequency Analysis

C4 = 47 µF: Input coupling → sets lower cutoff with R11:

$$flow = 1/2\pi RC = 1/2\pi \cdot 4.7k \cdot 47\mu F \approx 0.72Hz$$

C10 = 2200 µF with 8Ω load:

$$flow = 1/2\pi \cdot 8 \cdot 2200\mu F \approx 9.1Hz$$

C8 = 22 nF with R13 = 47Ω:

$$fhigh = 1/2\pi RC = 1/2\pi \cdot 47 \cdot 22nF \approx 154kHz$$

Estimated bandwidth: ~10 Hz to 150 kHz

Problems We Faced when implementing on the breadboard

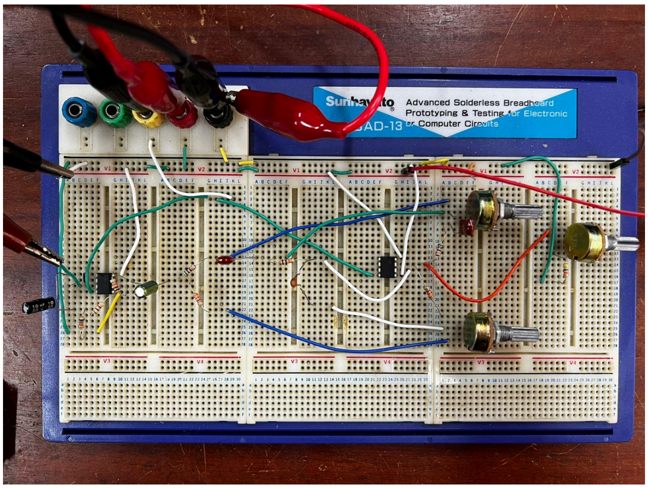
1. LM386(U3) transistor was not biased

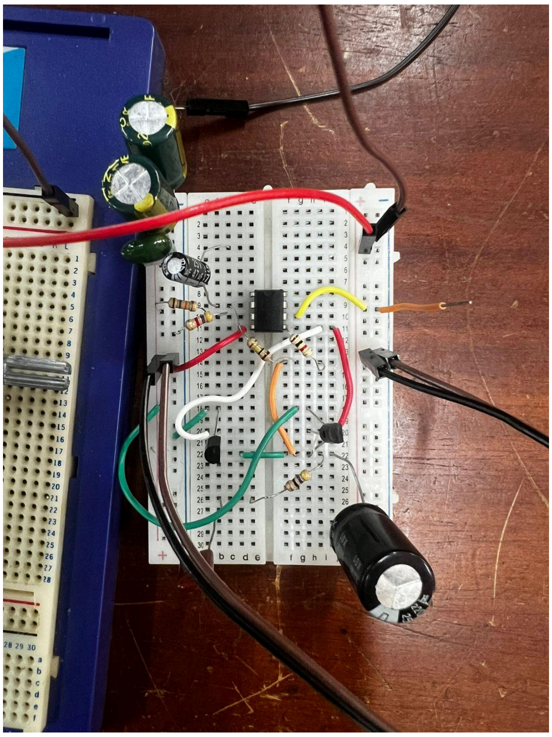
Although we planned to bias both transistors by taking R11 and R9 with equal resistance(100k) and setting the midpoint at 6V, we were unable to do so because of the current flowing into the op-amp. So we chose the resistors such that both transistors were biased and gave the necessary output signal.(18k, 4.7k)

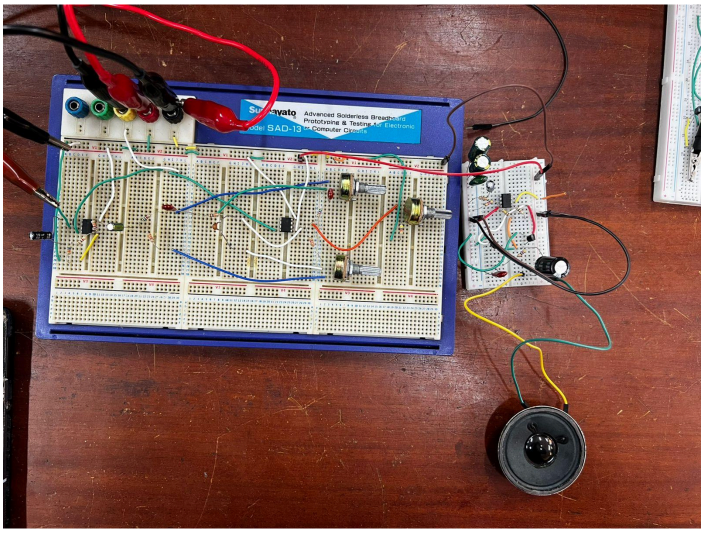
2. Crossover Distortion

We used a class AB amplifier in order to reduce crossover distortion, but when we went to high frequencies above 5kHz, there was crossover distortion, and in frequencies like 15kHz-20kHz, waveforms were distorted not only in the zero level but also at higher levels, we saw notches in the waveforms.

3. Breadboard implementation





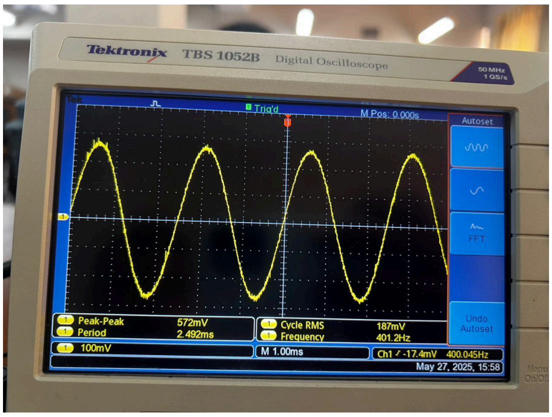


4. Oscilloscope output

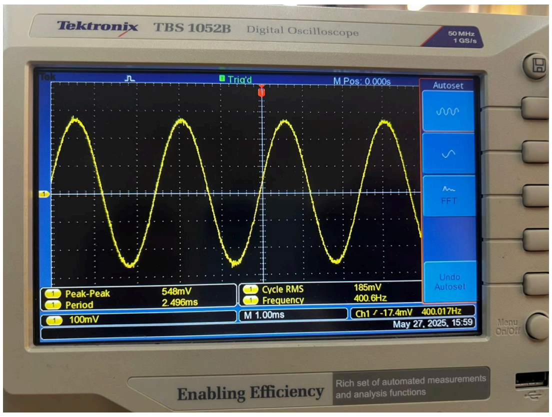
4.1 Point to point output waveform

Here we give 400Hz as input wave and take the oscilloscope result at each point of the circuit. Make the Bass potentiometer, treble potentiometer and volume control potentiometer at the minimum point.

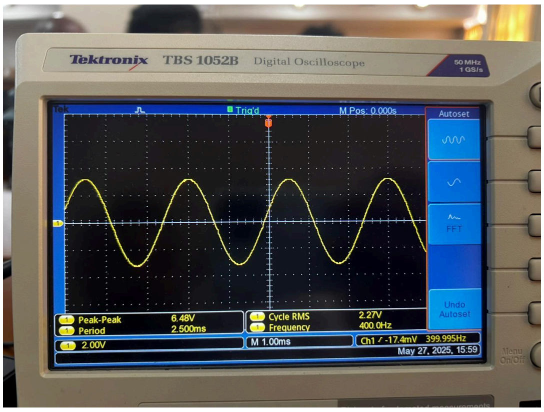
Input



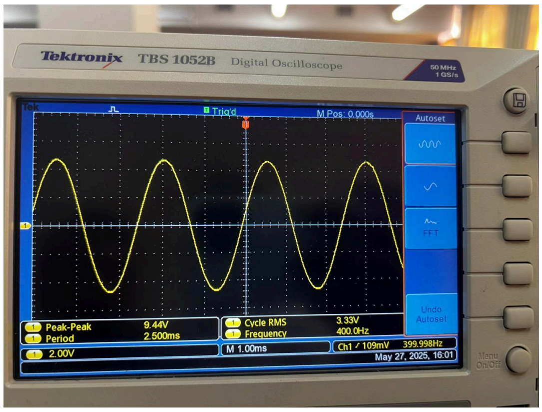
After the Buffer



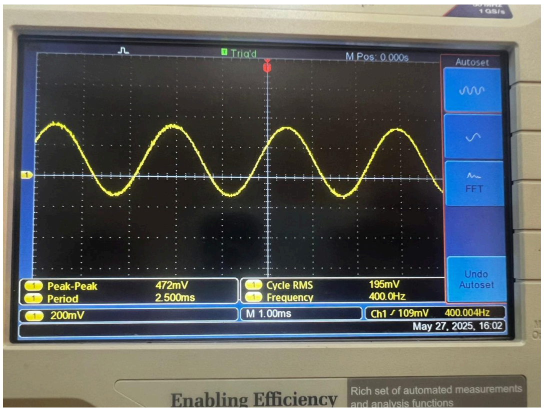
After pre amplifier



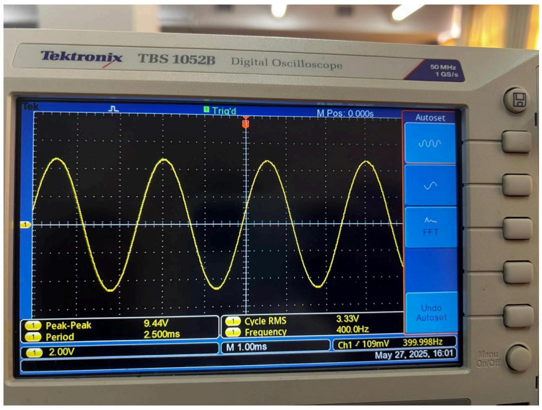
Before volume controller



Power amplifier input



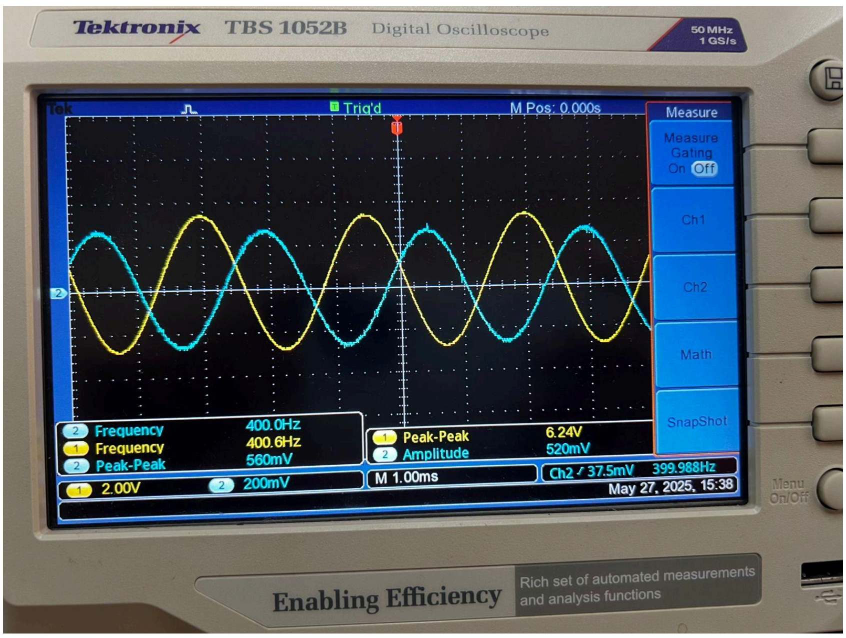
At the output



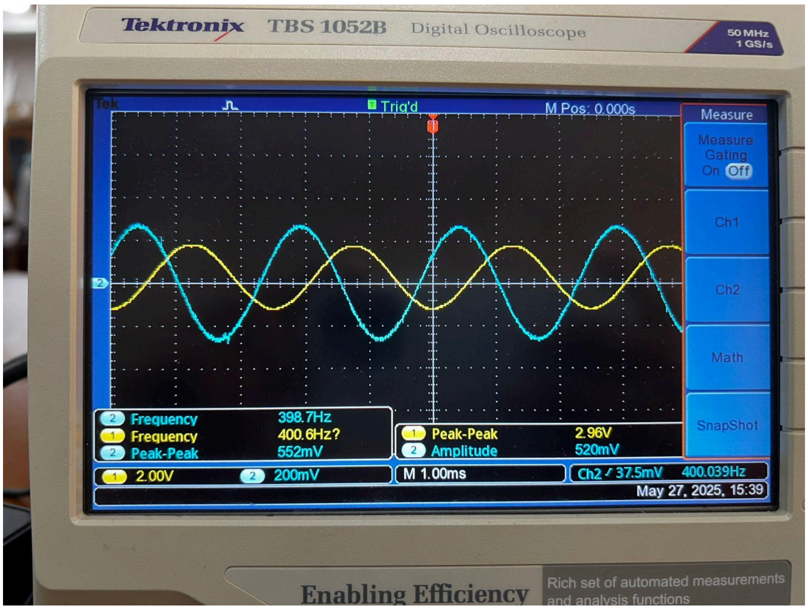
5. Waveform analysis

In this section we see how the Output wave varies with potentiometer adjusting. Here we analyse 400Hz, 1000Hz and 3000Hz sine waves as inputs. Blue is the input wave and yellow is the output wave. Between Input and output waves, there is a phase shift due to capacitors and opamps adds phase shifts to the input wave and that does not make sense to human ears.

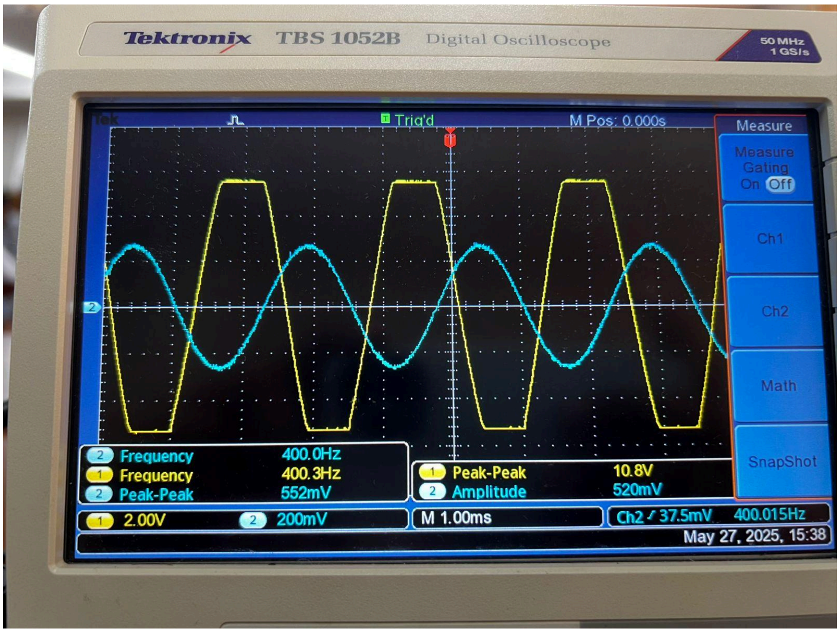
5.1. 400Hz



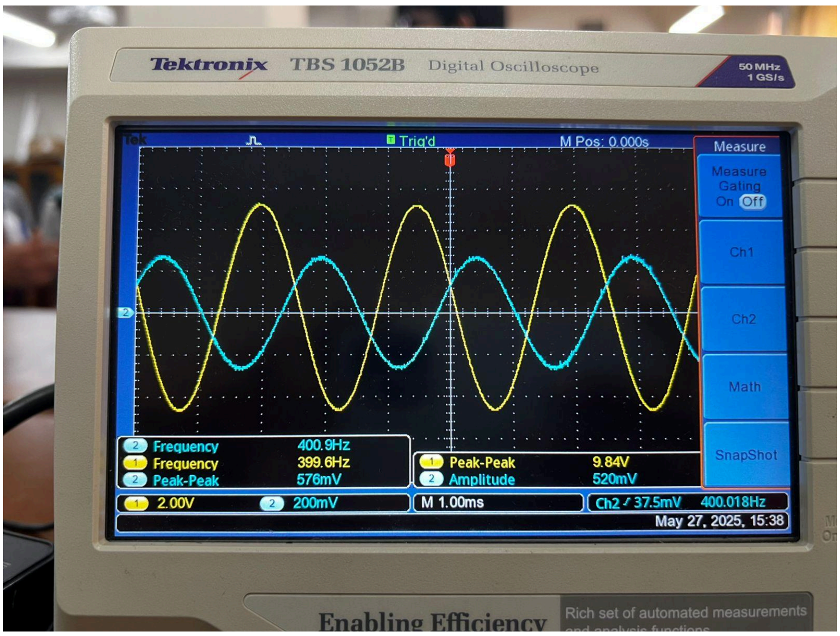
5.1.1 Volume decreased



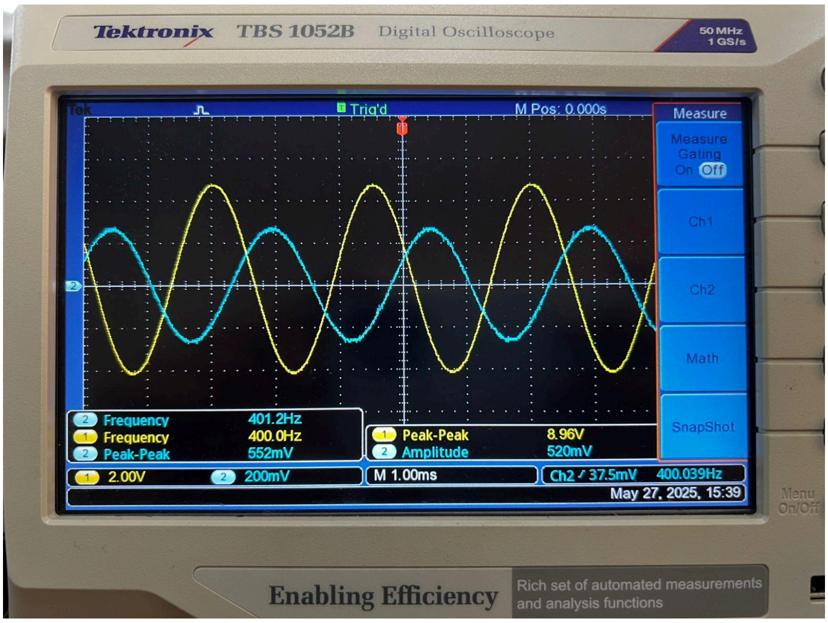
5.1.2 Volume Increased



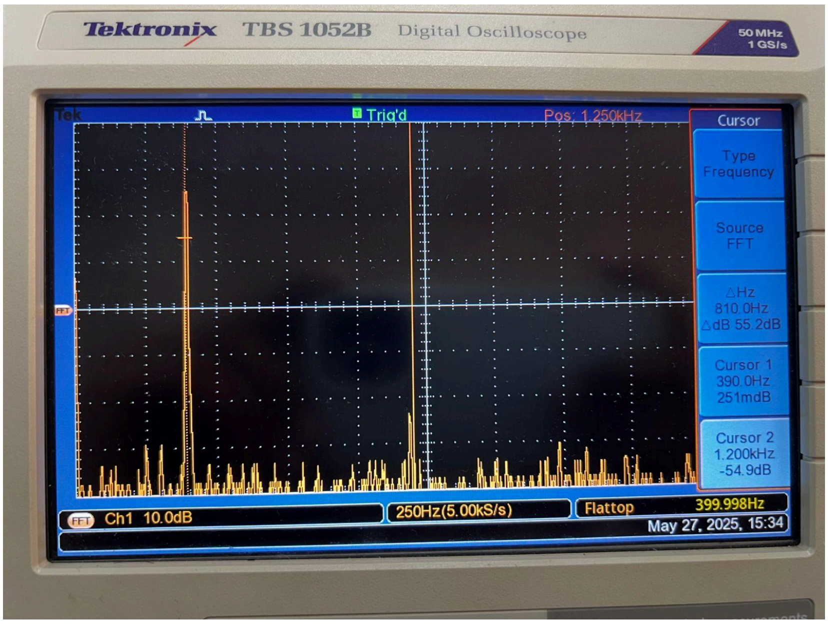
5.1.3 Bass controller increased



5.1.4 Bass controller decreased

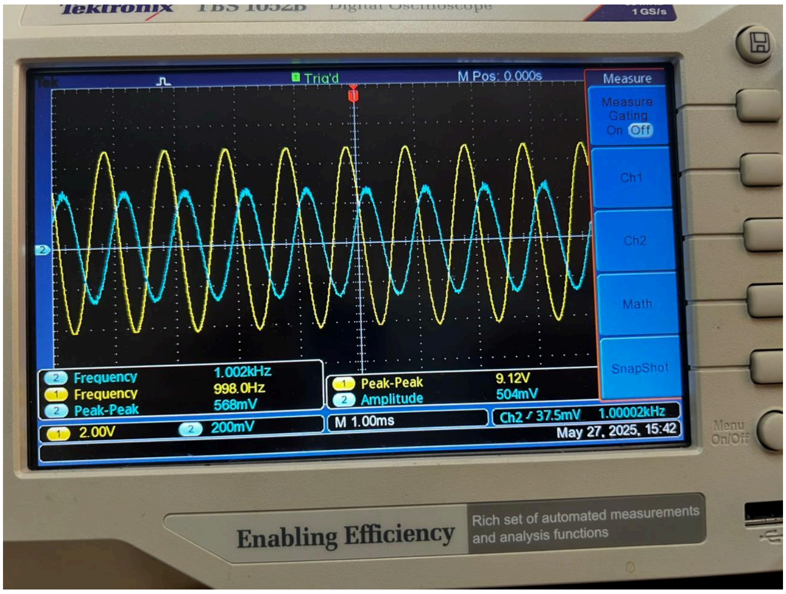


5.1.5 FFT

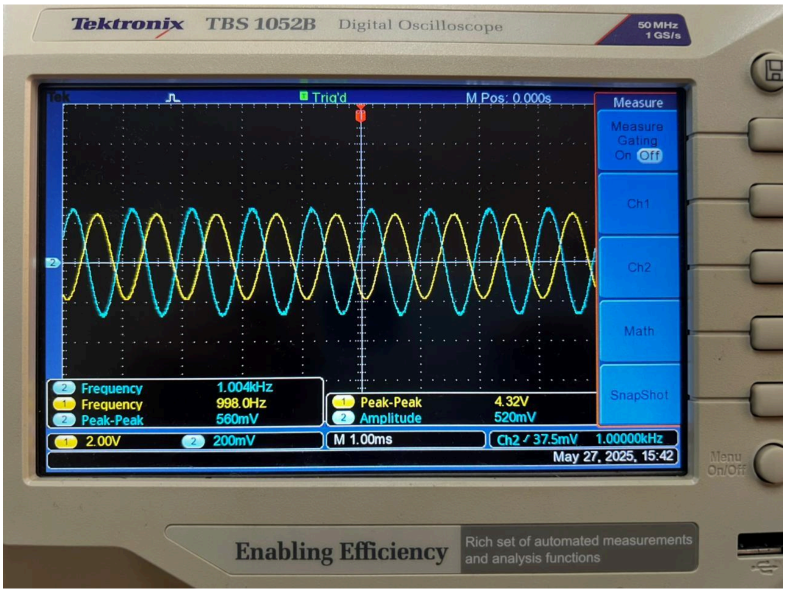


According to the FFT analysis, there are two peaks at **400 Hz** and **1200 Hz.** The 400 Hz is the input (supply) signal frequency. The 1200 Hz peak is the third harmonic, which is amplified because the crossover distortion was not fully removed in the power amplifier. Since 400 Hz is in the bass range we selected, changing the bass potentiometer (RV1) affects its amplitude. When we increase the bass knob, the amplitude increases. When we decrease it, the amplitude goes down. Also, when we raise the volume too much, the waveform gets clipped because it cannot go beyond the op-amp's supply voltage in the power amplifier.

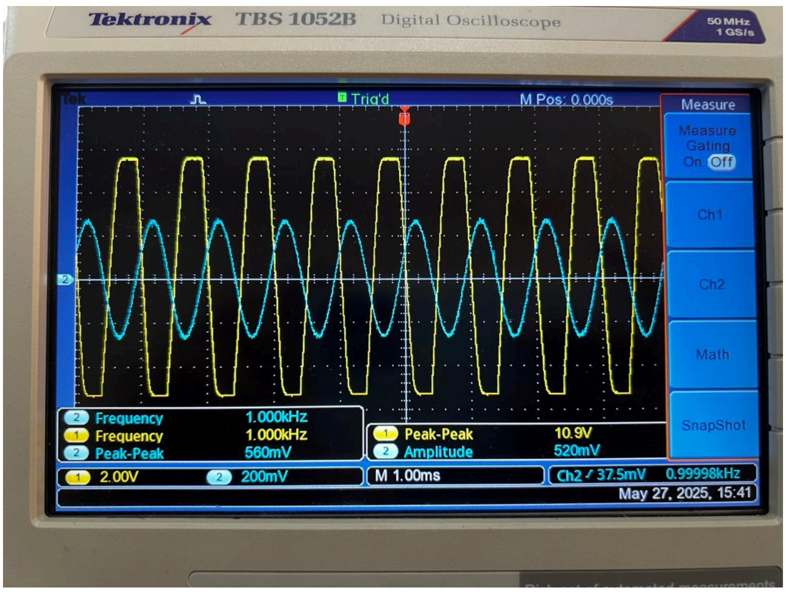
5.2. 1000Hz



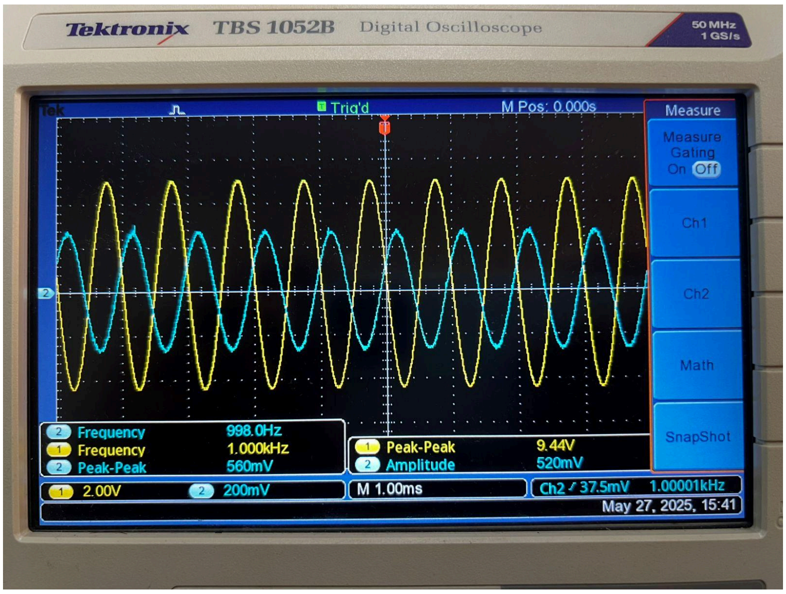
5.2.1 Volume decreased



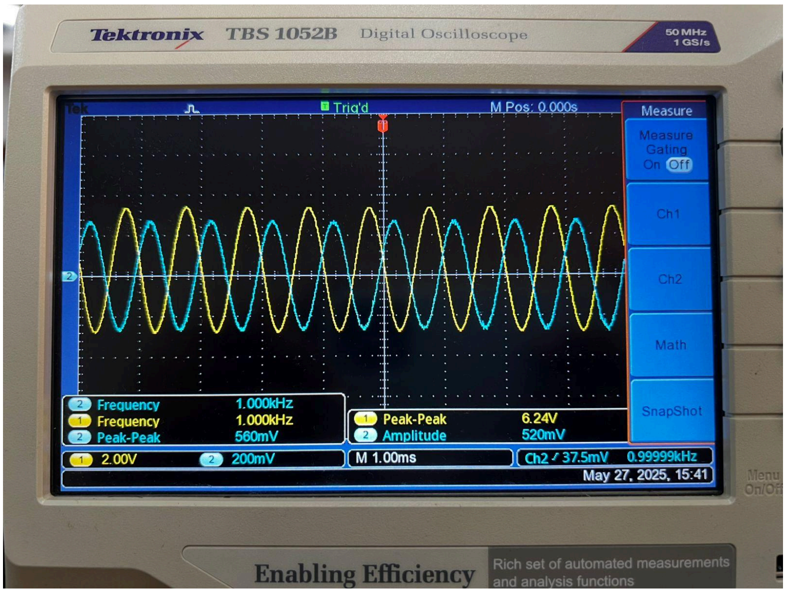
5.2.2 Volume Increased



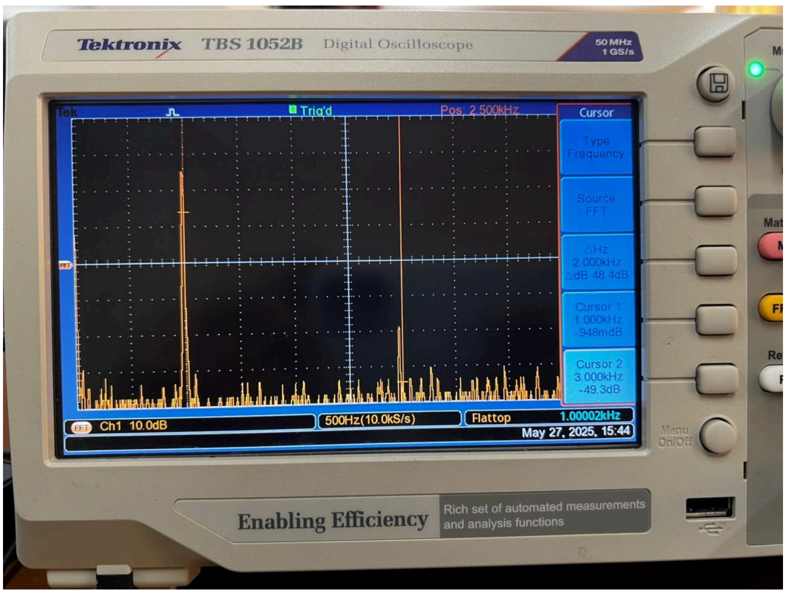
5.2.3 Bass controller increased



5.2.4 Bass controller decreased

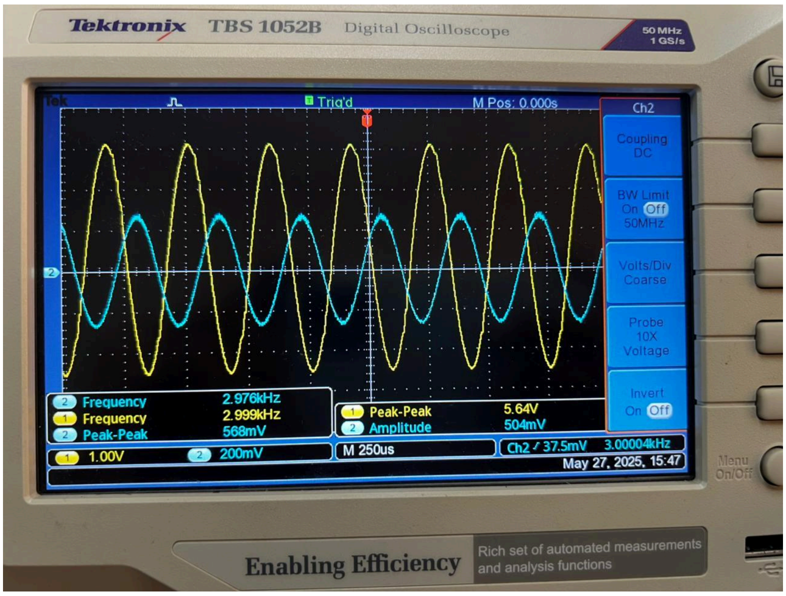


5.2.5 FFT

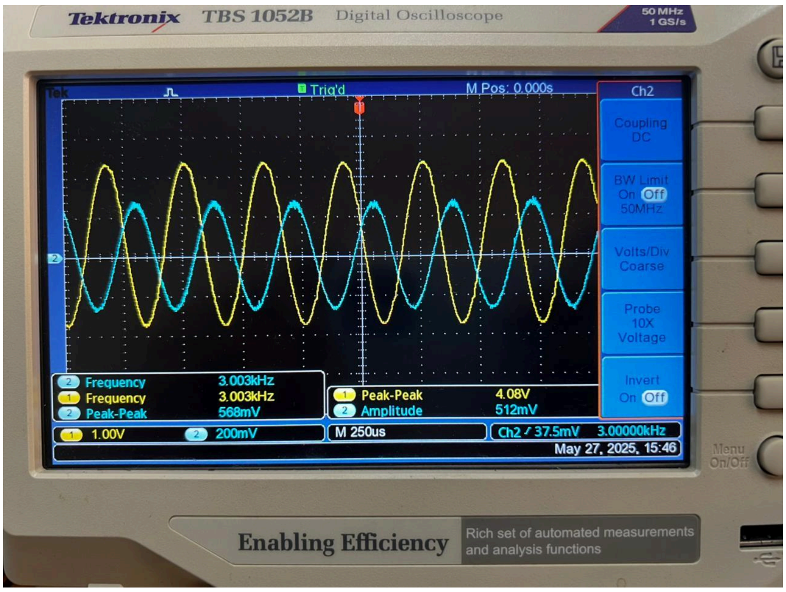


According to the FFT analysis, there are two peaks at **1000 Hz** and **3000 Hz**. The 1000 Hz is the input (supply) signal frequency. The 3000 Hz peak is the third harmonic, which is amplified because the crossover distortion was not fully removed in the power amplifier. Since 400 Hz is in the edge of the bass range we selected, changing the bass potentiometer (RV1) affects its amplitude. When we increase the bass knob, the amplitude increases. When we decrease it, the amplitude goes down. Also, when we raise the volume too much, the waveform gets clipped because it cannot go beyond the op-amp's supply voltage in the power amplifier.

5.3. 3000Hz

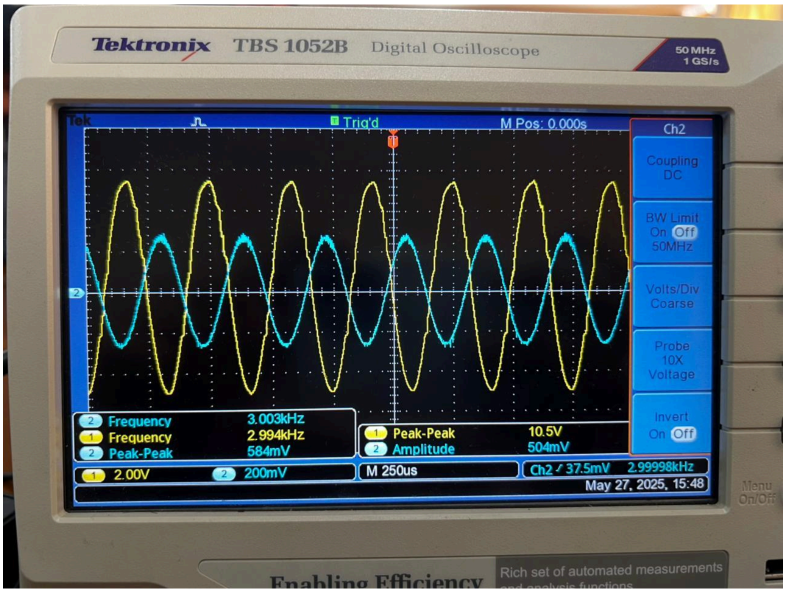


5.3.1 Volume decreased

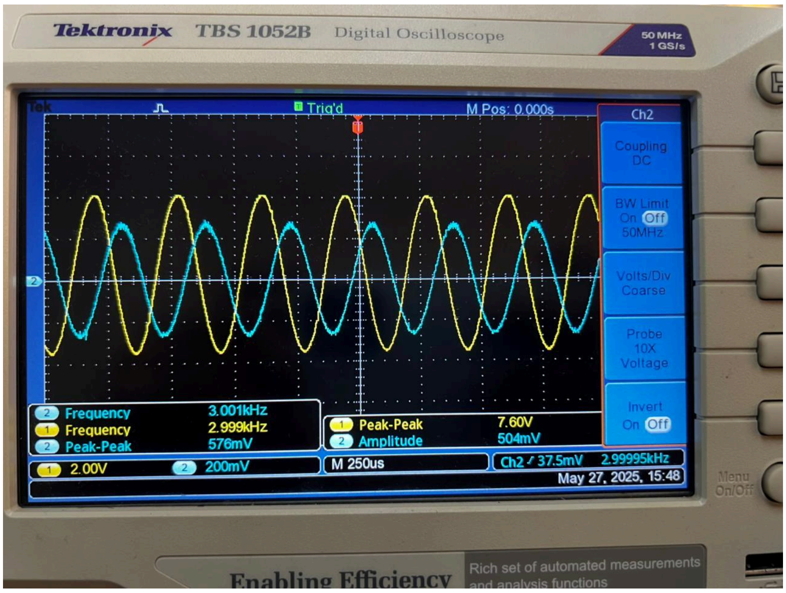


5.3.2 Volume Increased

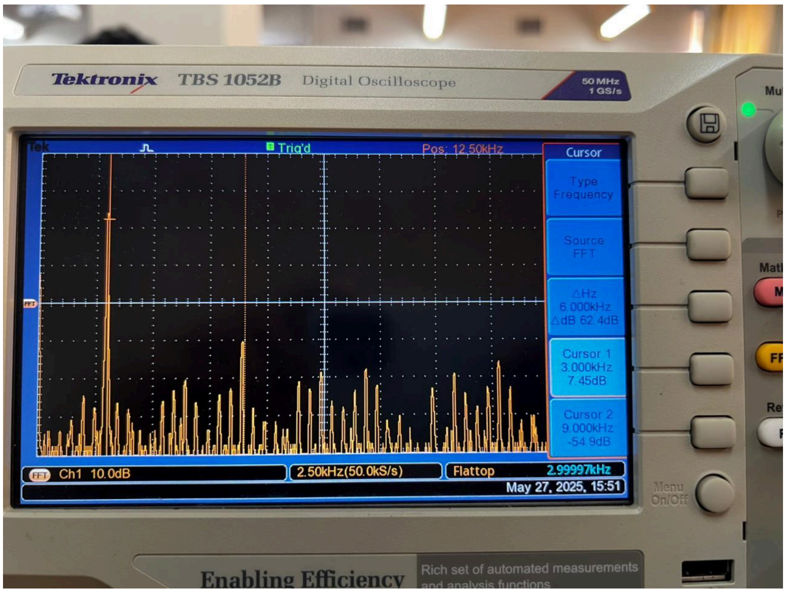
5.3.3 Bass controller increased



5.3.4 Bass controller decreased



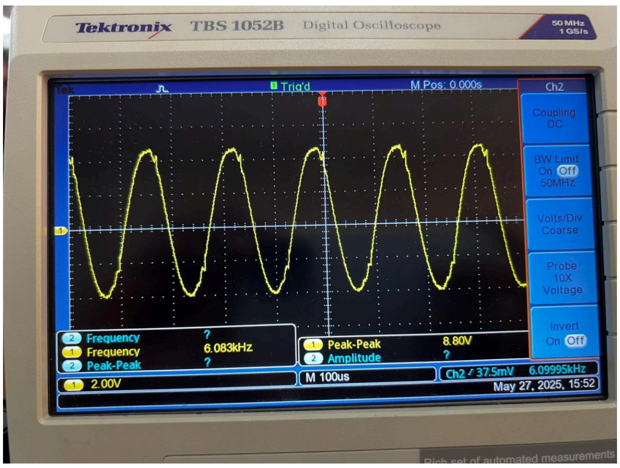
5.3.5 FFT

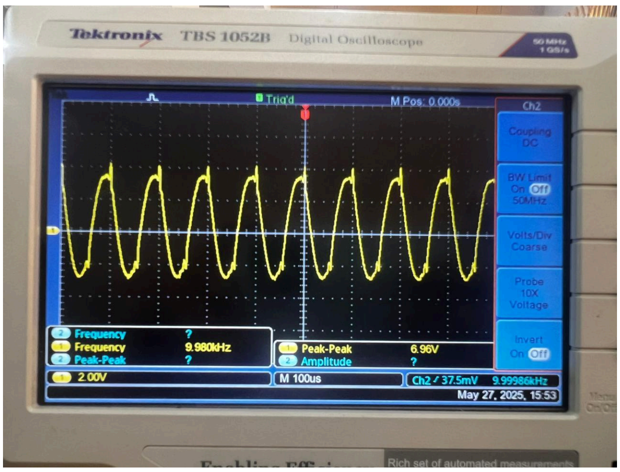


According to the FFT analysis, there are two peaks at **3000 Hz** and **9000 Hz**. The 3000 Hz is the input (supply) signal frequency, and the 9000 Hz peak is the third harmonic. This third harmonic is amplified because crossover distortion becomes more noticeable at higher frequencies, especially when the power amplifier cannot switch cleanly between the positive and negative halves of the waveform. Since 3000 Hz falls within the treble range we selected, adjusting the treble potentiometer (RV2) changes the amplitude of this frequency. When we increase the treble control, the amplitude of the 3000 Hz signal increases. When we reduce it, the amplitude decreases. Also, if the overall volume is raised too much, the waveform may become clipped because it cannot exceed the supply voltage limits of the op-amp in the power amplifier stage.

5.4 Cross over distorsions

In the power amplifier, we use an op-amp (LM386) to bias two BJTs: Q1 handles the upper half of the waveform, and Q2 handles the lower half. The op-amp creates the required voltage through a 1kΩ resistor (R10) to bias the transistors. However, this voltage does not evenly bias both BJTs because they have different base-emitter voltage requirements. The 2N3904 (NPN) needs about **0.65V**, while the 2N3906 (PNP) needs about **0.72V**. This mismatch causes crossover distortion in the waveform. Need to add an ideal pair of transistors.





6. Conclusion

In this project, we designed and tested a Hi-Fi audio tone controller using a Baxandall tone control circuit and a Class AB power amplifier. The tone controller allowed us to adjust bass and treble frequencies effectively using potentiometers, providing a smooth and clear audio response. Through this work, we learned how to properly bias NPN and PNP BJTs (2N3904 and 2N3906) in a Class AB amplifier using a single-supply op-amp (LM386). We also observed that if the biasing is not matched properly, crossover distortion can occur. One key lesson was that current can be unintentionally drawn into the op-amp output when improper resistor values are used. To reduce this, we learned to minimize the values of voltage divider resistors and to use unequal resistors when setting the bias point for the incoming signal. This helped us to achieve better linearity and reduce distortion in the final amplified audio output.