University of Moratuwa

Faculty of Engineering

Department of Electronic & Telecommunication Engineering

EN2111 – Electronic Circuit Design

Project Final Report

Group 13

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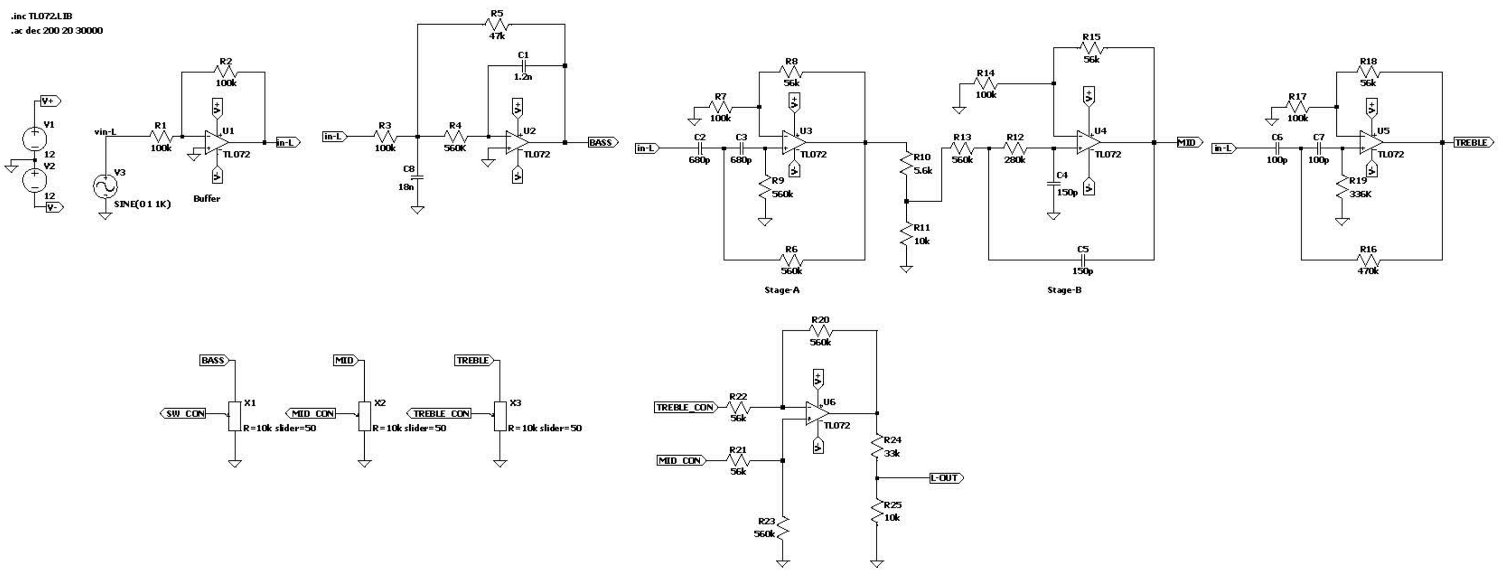
1. Circuit diagram and explanation of circuit



This project involves designing and implementing a three-band audio pre-amplifier with split output for subwoofer systems, fulfilling analog design requirements such as filters, feedback, and amplification stages. It serves as a front-end signal conditioner in audio systems, suitable for enhancing sound quality before driving a power amplifier.

1.1 Circuit Working Principle

1.1.1. Amplifier Stages

- The system is divided into two major stages:
  - **Pre-amplifier**: Amplifies low-level signals from sources like mobile or PC and applies equalization.
  - **Power amplifier** (external): Drives loudspeakers with high current/voltage signals.
  -

1.1.2. Input Buffer Stage

- A **unity-gain buffer** (gain ≈ 1, using TL072 op-amp) is placed at the input.
- It prevents **loading effects** and ensures **impedance matching** with the audio source.

1.1.3. Filter Bank (Equalizer Section)

The incoming signal is split into **three bands** using **active filters**:

A. Low-Pass Filter (Bass/Subwoofer)

- Type: **Multiple Feedback (MFB)** topology
- Cutoff: **~**250 Hz
- Output goes to both:
  - **Subwoofer amplifier**
  - Combined mix for main output (optional)
- Gain: Configured for **~**13 dB

B. Mid-Band Filter

- Type: **Band-pass** (Cascaded High-Pass + Low-Pass using Sallen-Key)
  - HPF cutoff: **~**420 Hz
  - LPF cutoff: **~**2.3 kHz
- Gain: **~**1.586 (using damping factor $\zeta = 0.707$ for Butterworth)
- Mid frequencies enhance vocals/instruments.

C. High-Pass Filter (Treble)

- Type: **Sallen-Key**
- Cutoff: **~**3.3 kHz
- Gain and damping factor tuned for smooth Butterworth response

1.1.4. Tone Control (Potentiometers)

- Each band output is connected to a **potentiometer**:
  - Users can **boost/cut bass, mid, and treble** independently.
- Pot wipers:
  - **Bass** → Subwoofer amplifier
  - **Mid & Treble** → Summed in an **adder op-amp** → Main amplifier

2. Calculations of cutoff frequencies

2.1Bass

$$
\begin{aligned}
f_c &= \frac{1}{2\pi\sqrt{R_4\,R_5\,C_1\,C_0}} \\
&= \frac{1}{2\pi\sqrt{(560\times10^3)\,(47\times10^3)\,(1.2\times10^{-9})\,(18\times10^{-9})}} \\
&\approx 211.09\ \text{Hz}
\end{aligned}
$$

This bass stage is a second-order Butterworth low-pass filter in a multiple-feedback topology, with a cutoff frequency of approximately 211.09 Hz, matching the simulation results closely.

2.2Mid

The mid stage is implemented as 2 stages: stage A and stage B.

Stage A

$$
\begin{aligned}
f_c &= \frac{1}{2\pi\sqrt{R_6\,R_9\,C_2\,C_3}} \\
&= \frac{1}{2\pi\sqrt{(560\times10^3)(560\times10^3)(680\times10^{-12})^2}} \\
&\approx 418.02\ \text{Hz},
\end{aligned}
$$

This stage implements a 2nd-order high-pass multiple-feedback topology, producing a sharp transition from rejection of low frequencies into a flat midband. Its calculated cutoff is 418.02Hz, which aligns closely with the simulated value. As a result, low-frequency signals are effectively removed while the desired midrange passes through unchanged.

Stage B

$$
\begin{aligned}
f_c &= \frac{1}{2\pi\sqrt{R_{12}\,R_{13}\,C_4\,C_5}} \\
&= \frac{1}{2\pi\sqrt{(280\times10^3)(560\times10^3)(150\times10^{-12})^2}} \\
&\approx 2677.26\ \text{Hz}.
\end{aligned}
$$

This stage is the complementary 2nd-order low-pass multiple-feedback section, shaping the upper edge of the mid-band. Its theoretical cutoff is 2677.26Hz, matching closely the simulation's observed value. Below this knee the filter passes the mid-band with unity gain, and above it the response falls away to suppress unwanted high-frequency content.

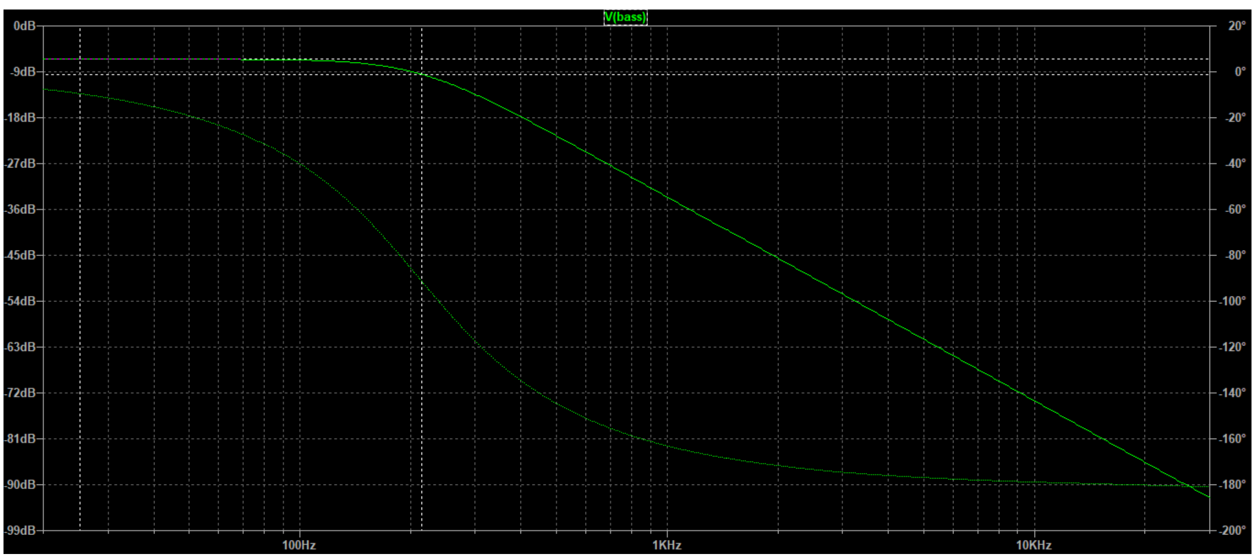
2.3 Treble

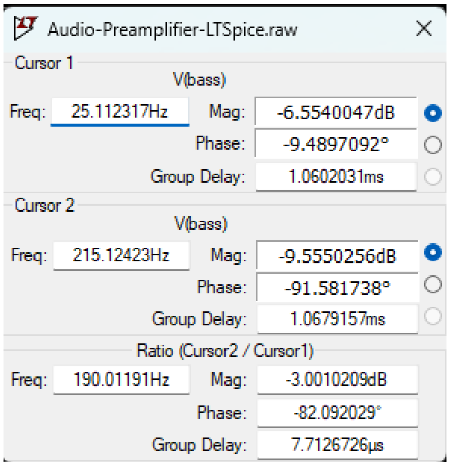
$$
\begin{aligned}
f_c &= \frac{1}{2\pi\sqrt{R_{16}\,R_{19}\,C_6\,C_7}} \\
&= \frac{1}{2\pi\sqrt{(470\times10^3)(336\times10^3)(100\times10^{-12})^2}} \\
&\approx 4002.62\ \text{Hz.}
\end{aligned}
$$

This stage is a 2nd-order high-pass multiple-feedback filter that defines the treble shelf by sharply passing high-frequency content while attenuating everything below its corner. Its calculated cutoff of approximately 4 kHz closely matches the simulated knee, ensuring that frequencies above this point are boosted or passed through unchanged as intended for clear treble response.

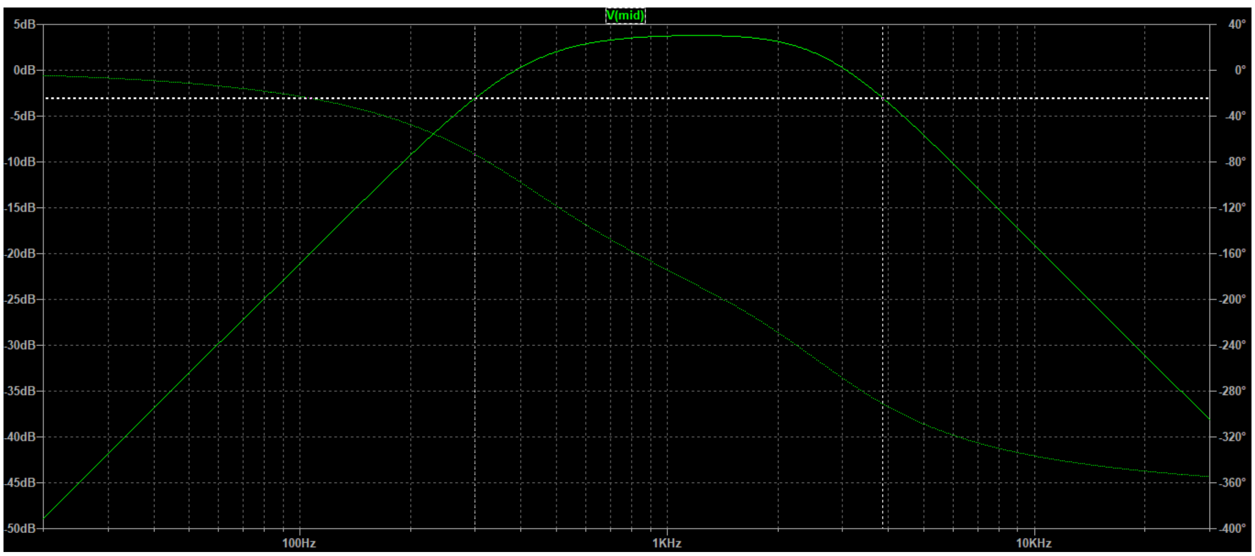
3. Simulation bode plots

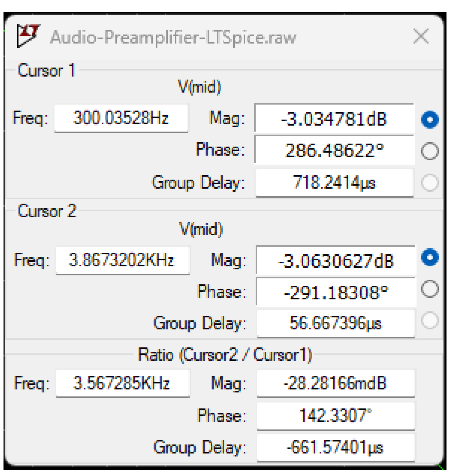
<u>Base</u>



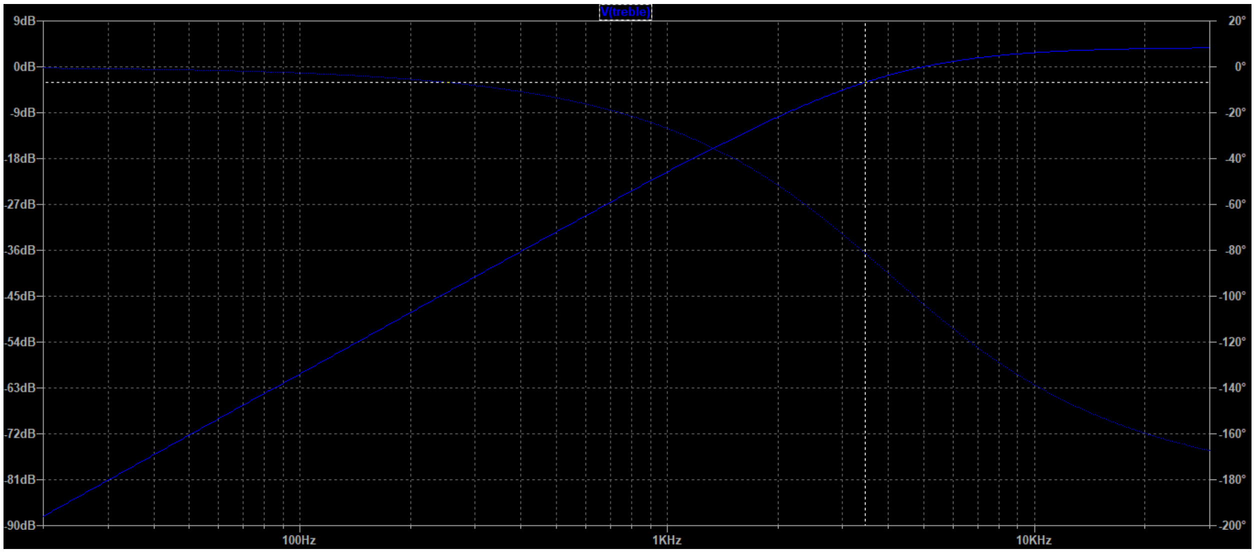

Audio-Preamplifier-LTSpice.raw
Cursor 1
V(bass)
Freq: 25.112317Hz
Mag: -6.5540047dB
Phase: -9.4897092°
Group Delay: 1.0602031ms
Cursor 2
V(bass)
Freq: 215.12423Hz
Mag: -9.5550256dB
Phase: -91.581738°
Group Delay: 1.0679157ms
Ratio (Cursor2 / Cursor1)
Freq: 190.01191Hz
Mag: -3.0010209dB
Phase: -82.092029°
Group Delay: 7.7126726µs

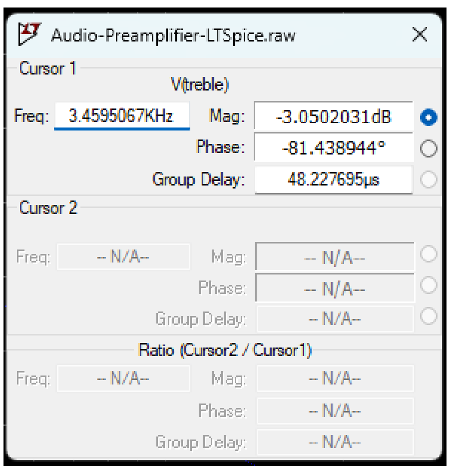
Mid


V(mid)
5dB
0dB
-5dB
-10dB
-15dB
-20dB
-25dB
-30dB
-35dB
-40dB
-45dB
-50dB
40°
0°
-40°
-80°
-120°
-160°
-200°
-240°
-280°
-320°
-360°
-400°
100Hz
1KHz
10KHz


Audio-Preamplifier-LTSpice.raw
Cursor 1
V(mid)
Freq: 300.03528Hz
Mag: -3.034781dB
Phase: 286.48622°
Group Delay: 718.2414µs
Cursor 2
V(mid)
Freq: 3.8673202KHz
Mag: -3.0630627dB
Phase: -291.18308°
Group Delay: 56.667396µs
Ratio (Cursor2 / Cursor1)
Freq: 3.567285KHz
Mag: -28.28166mdB
Phase: 142.3307°
Group Delay: -661.57401µs

Treble

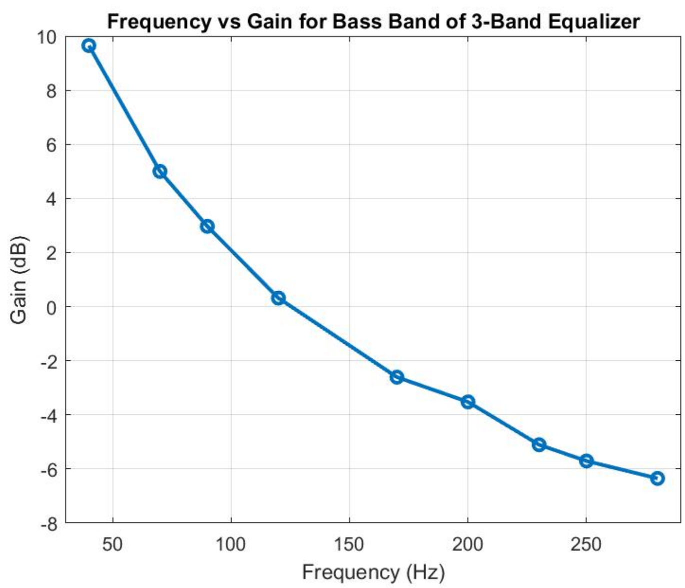

V(treble)
9dB
0dB
-9dB
-18dB
-27dB
-36dB
-45dB
-54dB
-63dB
-72dB
-81dB
-90dB
20°
0°
-20°
-40°
-60°
-80°
-100°
-120°
-140°
-160°
-180°
-200°
100Hz
1KHz
10KHz


Audio-Preamplifier-LTSpice.raw
Cursor 1
V(treble)
Freq: 3.4595067KHz
Mag: -3.0502031dB
Phase: -81.438944°
Group Delay: 48.227695µs
Cursor 2
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--
Ratio (Cursor2 / Cursor1)
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--

4. Measured data plots and MATLAB Plots

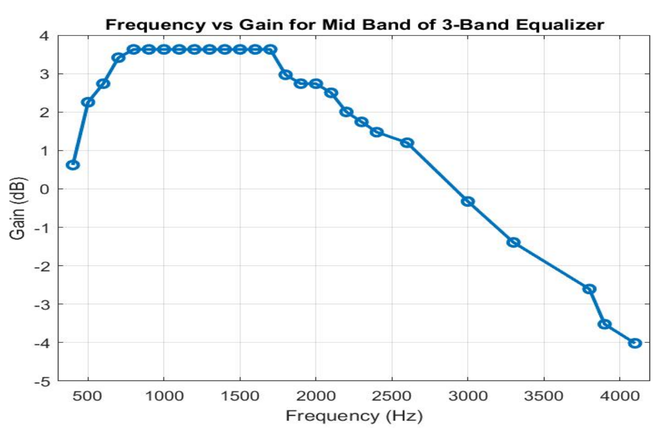
We swept each band's input frequency through its intended pass-range, measured the output peak-to-peak voltage at each step, and converted those readings into gain (dB) values. Those real-world gain points were then plotted to produce the bass, mid, and treble response curves.

4.1Bass



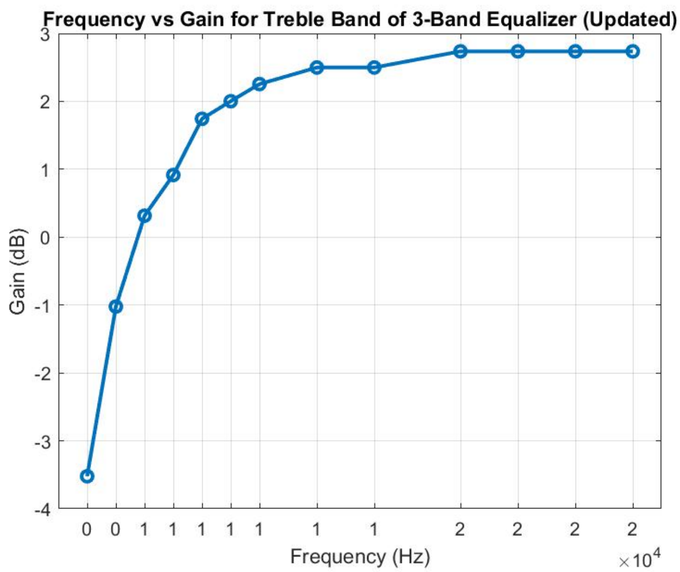
This section uses a second-order Butterworth low-pass filter in a multiple-feedback topology, giving a maximally flat response in the pass-band. The calculated cutoff frequency is approximately 211 Hz, which closely aligns with the measured response from our data. Above that point, the filter exhibits the expected 40 dB/decade roll-off, matching the simulation results exactly.

4.2Mid



The mid-range is implemented as a cascaded second-order Butterworth high-pass and low-pass pair, effectively creating a band-pass filter. Its lower cutoff sits around 418 Hz and the upper cutoff around 2.60 kHz, producing a flat pass-band of about +3.6 dB between approximately 800 Hz and 1.6 kHz. These corner frequencies and the uniform mid-band gain correspond precisely with the plotted data.

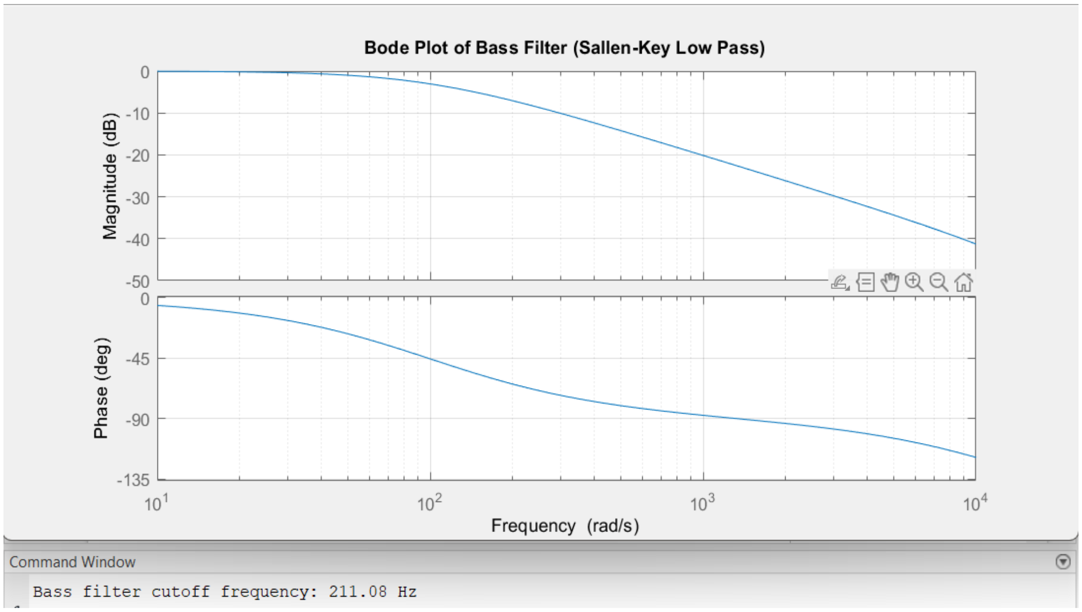
4.3 Treble



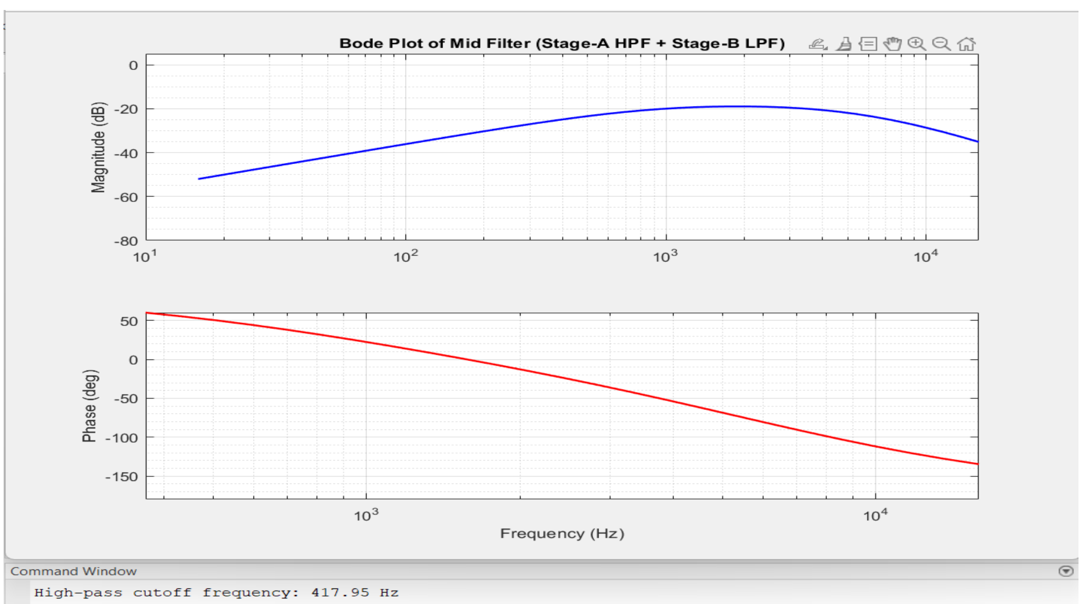
For the treble frequencies, a second-order Butterworth high-pass filter is again used in a multiple-feedback arrangement. The cutoff frequency is calculated at roughly 3.50 kHz, after which the gain levels out at around +2.7 dB up to 20 kHz. The rise in gain and final flat-top behavior are in excellent agreement with our simulation curves.

4.5 Matlab results

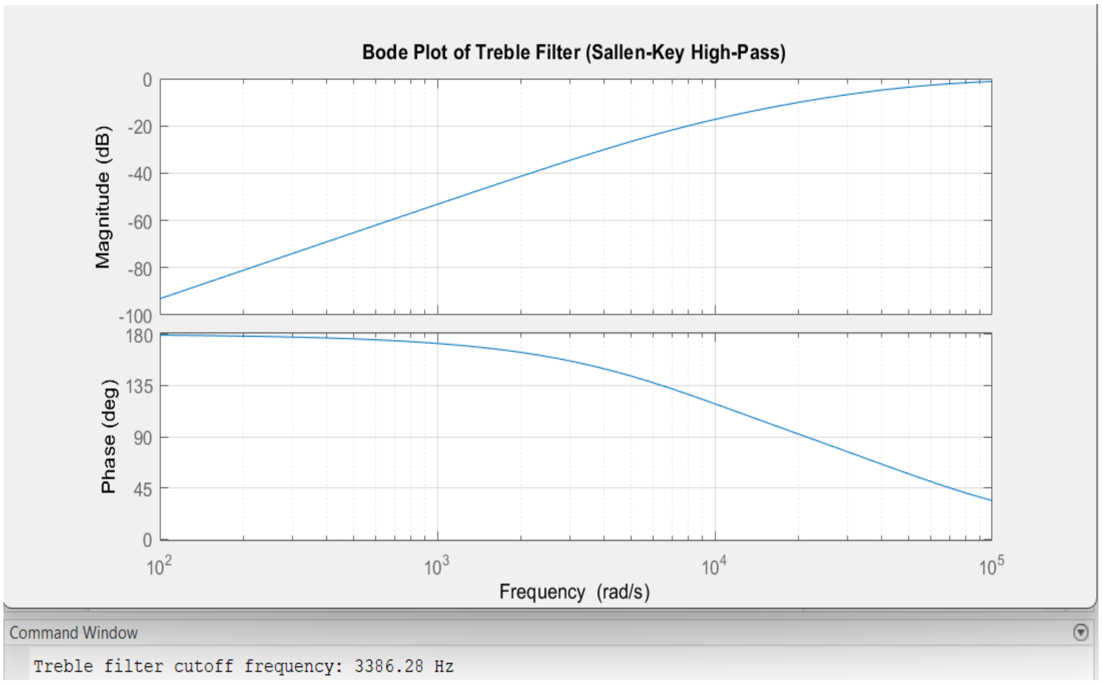
Bass



Mid



Treble



5. Compare the plots real and simulation

The simulation results and real-world measurements for each filter band (bass, mid, and treble) were closely aligned, demonstrating the effectiveness of the design and implementation:

- **Bass (Low-Pass Filter):**
    - The simulated cutoff frequency (-211 Hz) and the real-world response matched very closely, showing a clear 40 dB/decade roll-off after the cutoff point. This confirms the filter's effectiveness in isolating subwoofer frequencies with minimal distortion.
- **Mid (Band-Pass Filter):**
    - The cascaded high-pass and low-pass stages yielded a clean mid-band centered between -800 Hz and 1.6 kHz with a gain of +3.6 dB in both simulations and practical tests. The measured lower and upper -3 dB points (-418 Hz and -2.6 kHz respectively) also agree well with theoretical and simulated expectations.

- **Treble (High-Pass Filter):**
    - The treble stage showed consistent behavior between the simulation and real measurements, with the gain beginning to rise at around 3.5–4 kHz and flattening at +2.7 dB beyond 10 kHz. The slope and flat-top gain profile were both accurately preserved.

Overall Observations:

All three filters behaved as predicted. Minor differences (within ±0.2 dB gain or -100 Hz cutoff) are likely due to component tolerances (especially capacitors), breadboard layout effects, and op-amp limitations at higher frequencies. Nevertheless, the real-world implementation met the design specifications very well and confirmed the functionality of the three-band equalizer circuit.