EE 324: Experiment 4 Lab Report

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24^{th} October 2024
(Thursday Batch)

Experiment 4: Noise cancellation in headphones

Contents

1 Aim

To design and implement an analog circuit for noise cancellation in headphones.

2 Objectives

- To achieve an attenuation of 20 dB when a noise of 100 Hz frequency is applied.
- To design an analog compensator to stabilize the system through loop shaping of the loop transfer function.

3 Open Loop Block Diagram

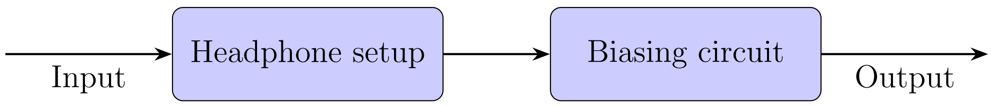

Figure 1: Open Loop Block Diagram

4 Frequency Response Analysis

Frequency response analysis is performed on the headphone setup by applying sinusoidal input waves from the function generator. Both input and output are observed on the DSO, and the magnitude and phase are plotted versus frequency.

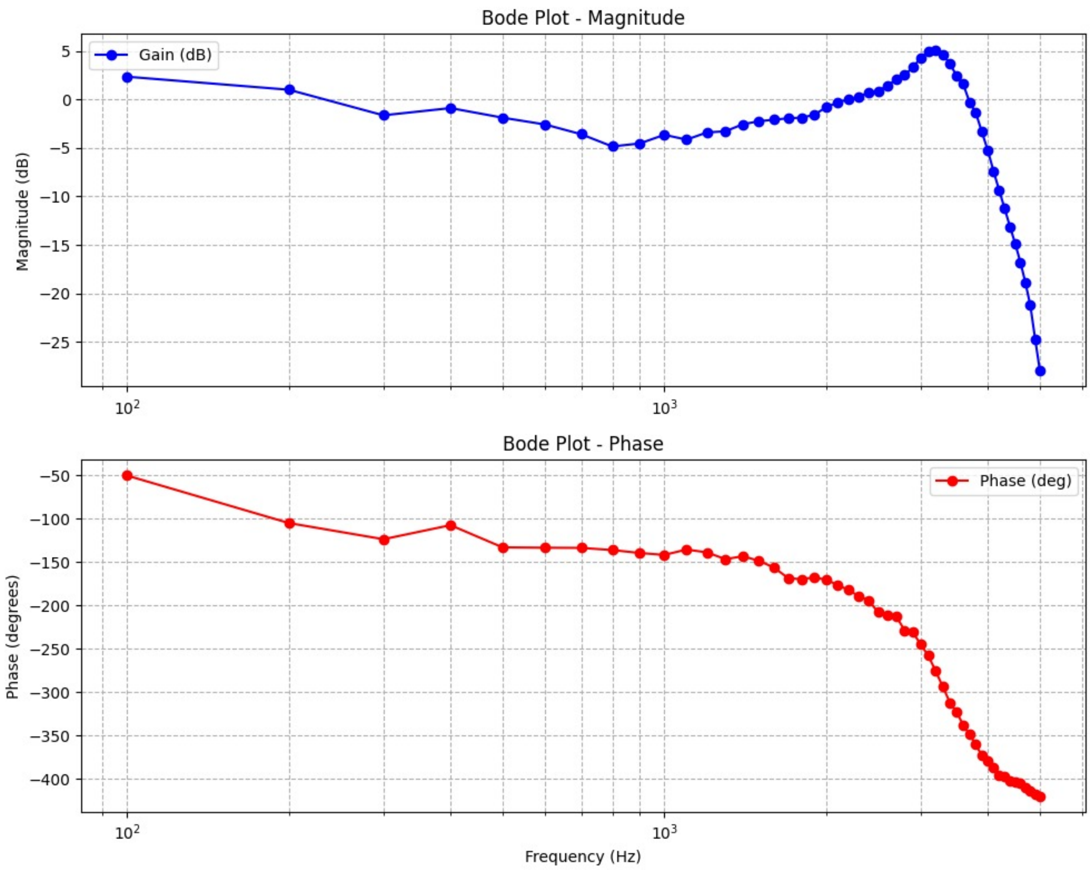

Figure 2: Bode Plot of Headphone Setup

5 Compensator Design

After analyzing the frequency response, a compensator is designed to stabilize the system without deviating from the required specifications. The compensator is then cascaded with the setup, and the loop is closed. Noise is fed into the circuit, and the signal-to-noise ratios (SNR) are measured at frequencies of 100 Hz, 500 Hz, and 1000 Hz.

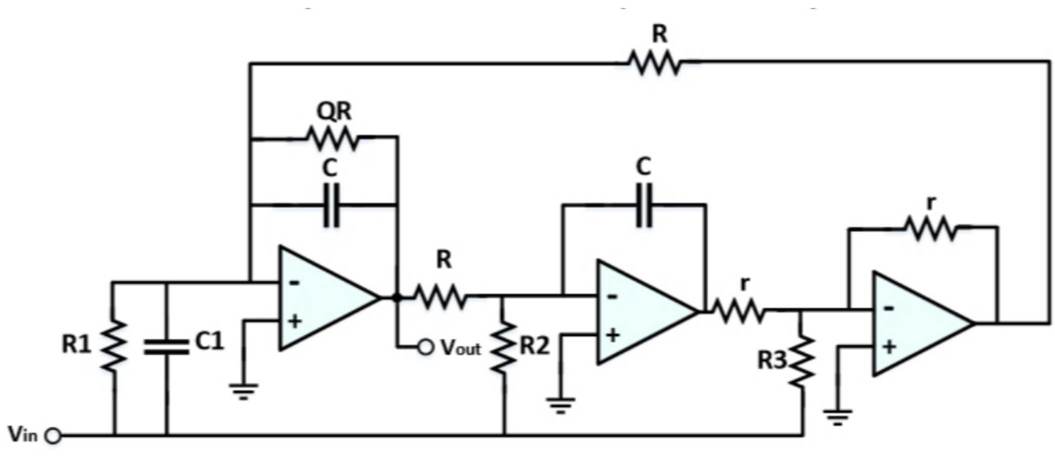

Figure 3: 2nd Order Compensator Circuit

The transfer function of the compensator is:-

$$T(s) = \frac{V_o(s)}{V_i(s)} = \frac{\left(\frac{C_1}{C}\right)^2 s^2 + \frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right) s + \frac{1}{C^2 R R_2}}{s^2 + \frac{1}{QCR} s + \frac{1}{C^2 R^2}}$$

So we modelled this tranfer function in MATLAB to find the values of the required components to satisfy the requirements and we got these values:-

$$C_1 = 1\,\text{nF}, \quad C = 110\,\text{nF}, \quad R_1 = 10\,\text{k}\Omega, \quad R_2 = 51.6\,\text{k}\Omega, \quad R = 1\,\text{M}\Omega, \quad R_3 = 10\,\text{M}\Omega,$$

$$r = 998\,\Omega, \quad Q = 0.5$$

6 Control Algorithm

A noise cancellation control algorithm uses a *cascade compensator* to adjust the system's forward path transfer function. The goal is to stabilize the closed-loop system and reduce disturbances effectively. The compensator helps achieve a large open-loop gain, which is important for proper noise cancellation and accurate input following. For instance, a noise cancellation level of 20 dB is needed at 100 Hz, so the compensator must provide enough gain to meet this target.

To ensure stability at higher frequencies (above 1 kHz), the compensator must lower the gain to avoid instability. The Bode plot of the system, with increased gain by the amplifier (such as 20 dB), may show that the phase approaches 180° at frequencies beyond 1 kHz, which can lead to instability. To prevent this, the compensator design must keep the gain margin at least 5 dB and the phase margin above 30 degrees. A *lag compensator* is often used to reduce the gain at higher frequencies while maintaining system stability.

However, a simple lag compensator may introduce too much phase lag, which could reduce the phase margin and cause instability. To address this issue, a *second-order damped lag compensator* can be used. This type of compensator offers more controlled gain and phase reduction over the frequency range. Its transfer function is:

$$H(s) = K\frac{s^2 + 2\zeta zs + \omega_z^2}{s^2 + 2\zeta ps + \omega_p^2},$$

where ζ is the damping factor, z and p are the zero and pole frequencies, and ω_z and ω_p are their respective natural frequencies. This second-order compensator ensures smoother gain reduction and avoids excessive phase lag, helping the system maintain stability while achieving the desired noise cancellation, even at higher frequencies.

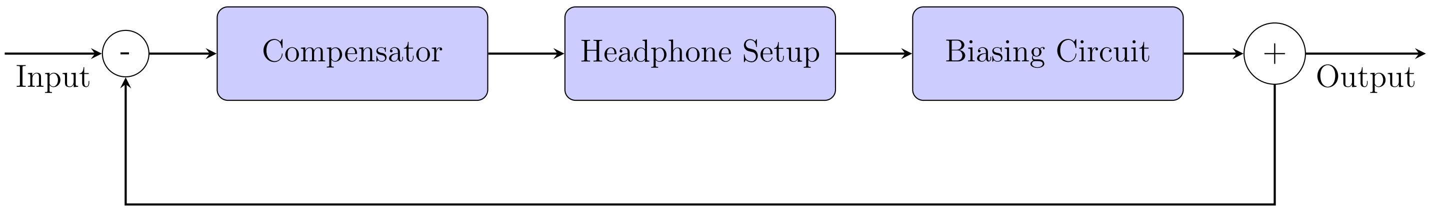

Figure 4: Closed Loop Block Diagram

7 Challenges Encountered

During the implementation of the noise cancellation circuit for headphones, the following challenges were encountered:

1. **System Identification and Frequency Response Analysis:** Precise frequency response analysis required careful calibration of equipment, particularly in managing phase shifts and ensuring the function generator's accuracy. Minor setup errors led to discrepancies in frequency readings, making it difficult to accurately plot magnitude and phase.

2. **Design and Tuning of the Compensator:** Designing an effective compensator to achieve the desired attenuation at 100 Hz was challenging. Tuning the compensator to provide adequate stability and meet loop shaping requirements without affecting other parts of the frequency spectrum required multiple iterations and adjustments.

3. **Component Limitations:** The analog components, including amplifiers and passive elements, introduced parasitic effects and noise that complicated the circuit's behavior. Variations in resistor and capacitor tolerances affected the performance, making it challenging to achieve the precise 20 dB attenuation target.

4. **Equipment Noise and Environmental Interference:** External noise sources, such as electrical interference from nearby equipment, impacted the experiment results. Shielding the setup and using twisted pair wires for connections was necessary to mitigate interference.

5. **Measurement and Data Accuracy:** Capturing precise data from the Digital Storage Oscilloscope (DSO) was essential, but slight adjustments in probe placement or grounding introduced inconsistencies. Additionally, accurately measuring signal-to-noise ratios at different frequencies required careful calibration.

6. **Integration with Headphone Setup:** Ensuring the noise cancellation effect was audible and effective through the headphones was complex, as slight variations in frequency response across different headphones could affect the perceived noise cancellation.

Each of these challenges provided valuable insights into the practical aspects of analog circuit design for noise cancellation and enhanced the understanding of frequency response and compensator design.

8 Results

From Headphone Bode Plot

$$\text{Gain Margin} \quad : 0\,\text{dB}$$
$$\text{Phase Margin} \quad : 58^\circ$$

Final components used for compensation

$$C_1 = 1\,\text{nF},$$
$$C = 110\,\text{nF},$$
$$R_1 = 10\,\text{k}\Omega,$$
$$R_2 = 51.6\,\text{k}\Omega,$$
$$R = 1\,\text{M}\Omega,$$
$$R_3 = 10\,\text{M}\Omega,$$
$$r = 998\,\Omega,$$
$$Q = 0.5$$

System parameters:
Attenuation at 100 Hz = 2.35 dB

Lag compensation-cum-amplification:
Attenuation at 100 Hz = 17.8 dB

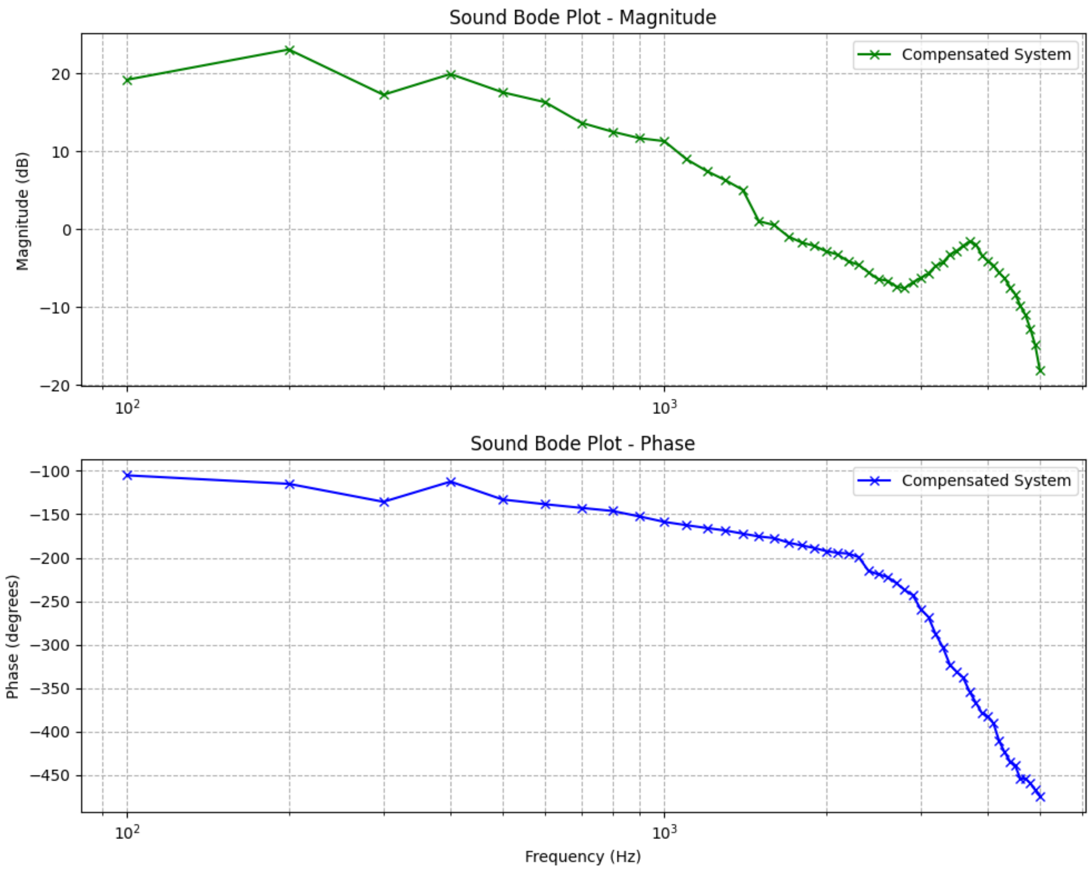

Figure 5: Bode Plot post Compensation

9 Observations and Inferences

When we plotted the input versus output on the XY plane, we observed a 90-degree phase-shifted ellipse. This elliptical pattern confirmed that our system was successfully cancelling the noise, as the 90-degree phase shift indicates effective noise attenuation at the target frequency.
A photo of the observed plot is provided above for reference, showcasing the successful implementation of noise cancellation in the designed circuit.

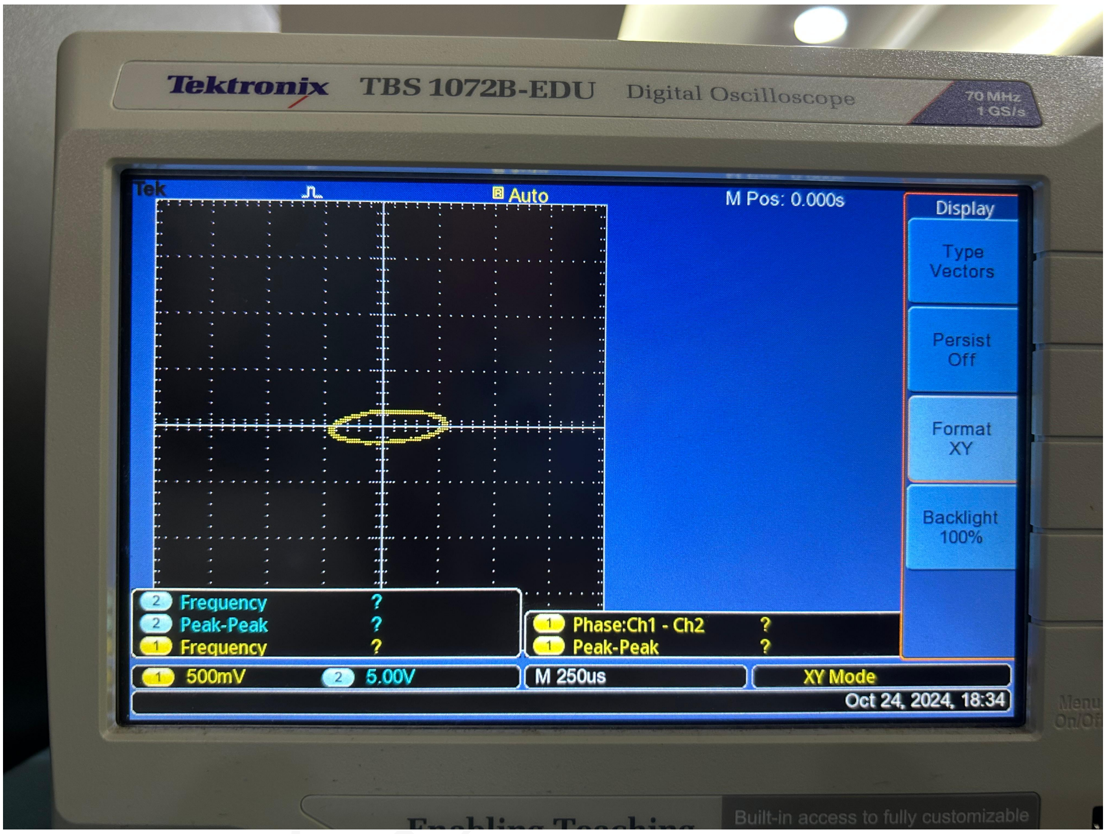

Figure 6: XY plot

We later fed a noise via a function which is available in the AFG, where we set the spectrum of frequencies to be used to demonstrate the noise cancellation abilities of the Headphone.

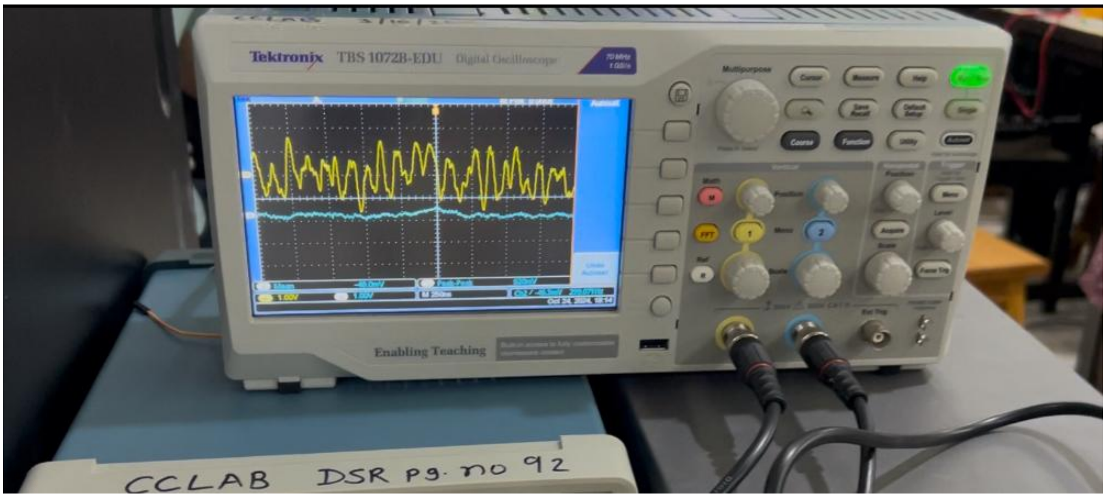

Figure 7: Noise Cancellation in action

The yellow waveform is the noise with different frequencies and the blue waveform is the canceled noise via the setup constructed.