EE324: Control Systems Lab

Experiment 4: Noise Cancellation in Headphones

Group 11 - Monday Batch
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DEMO VIDEO LINK:
`https://drive.google.com/drive/folders/16PG2q71JDVtlyDyfErBQwEVc9pOXzFTx?usp=sharing`

1 Objective

The goal of the experiment was to design and implement an analog circuit for noise cancellation in headphones. The specific objectives were:

- Achieve an attenuation of 20 dB when a noise of 100 Hz frequency is applied.
- Design an analog compensator to stabilize the system, focusing on loop shaping of the loop transfer function.

2 Control Algorithm

For the given headphone-microphone setup, we characterized the transfer function of the headphone system, denoted as $G(s)$. The closed-loop model was represented as a unity feedback model with a controller $C(s)$ in the feedforward path. The transfer function of the closed-loop system is given by:

$$\frac{Y(s)}{X(s)} = \frac{1}{1 + C(s)G(s)}$$

3 Methodology

We first examined the headphone setup to understand its open-loop output transfer characteristics. Using MATLAB, we modeled the compensated system using a second-order approximation. Our aim was to find suitable values for the resistors and capacitors in the compensator $C(s)$ to achieve approximately 20 dB attenuation at 100 Hz while ensuring stability.

3.1 Procedure

Frequency response analysis was performed on the headphone setup with sinusoidal input from a function generator. Both the input and output were observed on a digital storage oscilloscope (DSO), and magnitude and phase bode plots were generated to represent the open-loop characteristics of the headphones.

3.2 Compensator Design

The compensator is designed as a second-order system, with parameters chosen to meet the required attenuation at 100 Hz. The circuit diagram for the compensator is shown below.

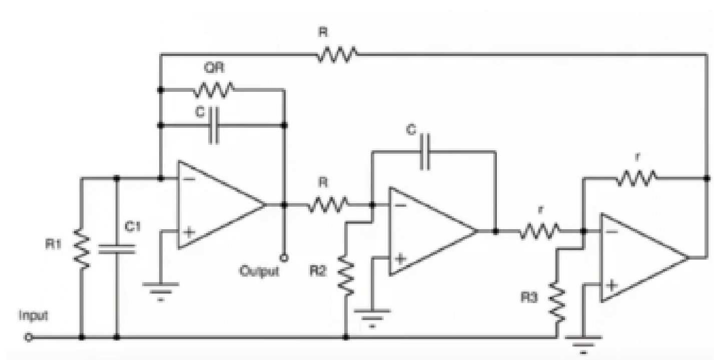

Figure 1: Second Order Compensator Circuit Diagram

The transfer function of the compensator is given by:

$$C(s) = \frac{as^2 + bs + c}{ds^2 + es + f}$$

In terms of circuit components, it is expressed as:

$$C(s) = \left(\frac{C_1}{C}\right)^2 s^2 + \frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{R \cdot R_3}\right) s + \frac{1}{C_2 \cdot R \cdot R_2} s^2 + \frac{1}{Q \cdot C \cdot R} s + \frac{1}{C_2 \cdot R_2}$$

The chosen values of the circuit components are shown in Table 1.

4 Challenges Faced

- **Noisy Readings:** Initial readings were affected by ambient disturbances. *Solution:* Repeated the experiment in a quieter environment for stable readings.

Parameter	Value
C_1	410 pF
C	680 pF
R_1	50kΩ
R	1500Ω
R_3	1Ω
R_2	1MΩ
Q	0.5
r	3MΩ

Table 1: Circuit Component Values

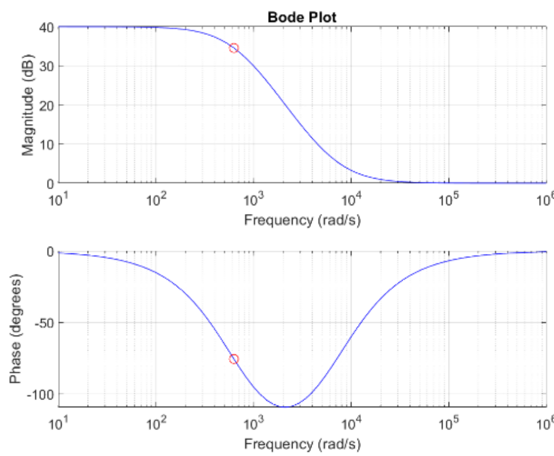

Figure 2: Bode Plot of the Compensator

- **MATLAB Bode Plot:** Input parameters for the `bode()` function in radians caused incorrect results.
  Solution: Converted frequency from Hertz to radians before plotting.
- **Optimum Component Values:** Exact resistances and capacitances were unavailable.
  Solution: Closest available values were used to achieve a functional circuit.

5 Results

The designed compensator achieved the targeted noise attenuation and improved stability. Key results observed:

- **Compensator Transfer Function:** $C(s) = \frac{(s+6500)^2}{(s+650)^2}$
- **Gain Margin (Before Compensation):** -50.8 dB .

- **Phase Margin (Before Compensation):** 90.17degrees .
- **Gain Margin (After Compensation):** 5.68 dB .
- **Phase Margin (After Compensation):** 49.2 degrees.

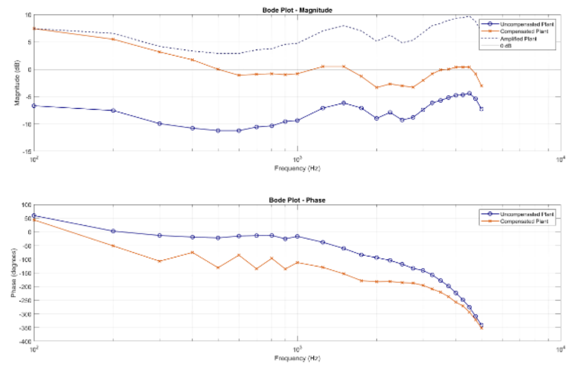

Figure 3: Bode Plot of the Open-Loop Compensated System

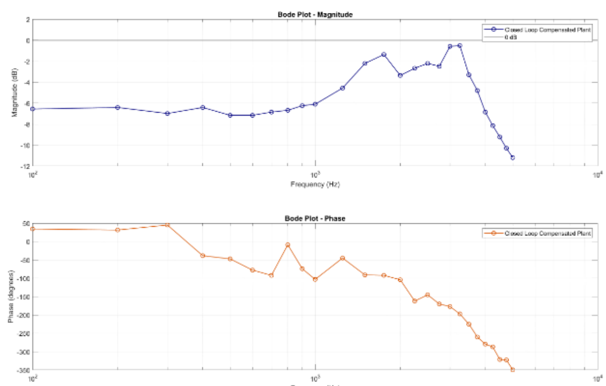

Figure 4: Bode Plot of the Closed-Loop Compensated System

6 Observations and Inference

- The compensator achieved the desired attenuation at 100 Hz, effectively reducing noise interference.
- The reduction in gain from 7.43 dB to approximately -7 dB after closed-loop compensation indicates successful noise reduction.

- The compensator shaped the loop transfer function, as shown in the smoother gain and phase transitions in the Bode plots.
- This design could be applied in various analog noise reduction applications.