Experiment 4

Noise-Cancelling Headphones

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1 Aim

The aim of the experiment was to implement a lag-compensator based controller to reduce the noise that was being received by the microphone of the headphones. The specifications for the setup of the controller and headphones are as follows:

- Forward gain at 100 Hz for **open-loop** has to attenuated to 20 dB.
- Gain margin for **open-loop** has to be greater than 10 dB.
- Phase margin for **open-loop** has to be greater than 20°.
- Forward gain at 100 Hz for **closed-loop** has to be -10 dB.

2 Procedure

- The first step was to obtain the Bode plot of the uncompensated headphones and to find the value of the gain at 100 Hz.
- Using the Bode plot (Figures 1 and 2), we proceeded to simulate a second order system with the transfer function as given in Equation 1. We found approximate values of the resistors and capacitors to be used in the circuit to be connected to the headphone setup.
- We then cascaded the compensator circuit shown in Figure 3 with the headphones setup first in an open-loop circuit. To achieve the open-loop specifications for the gain and phase margins, we tweaked the values of the resistors using potentiometers.
- Finally we connected the entire setup in a closed loop to observe the gain and phase.

$$H(s) = \frac{15(\frac{s}{1000}+1)^2}{(\frac{s}{100}+1)^2} \tag{1}$$

- The gain of the uncompensated system is nearly 5.563342254 at 100Hz frequency

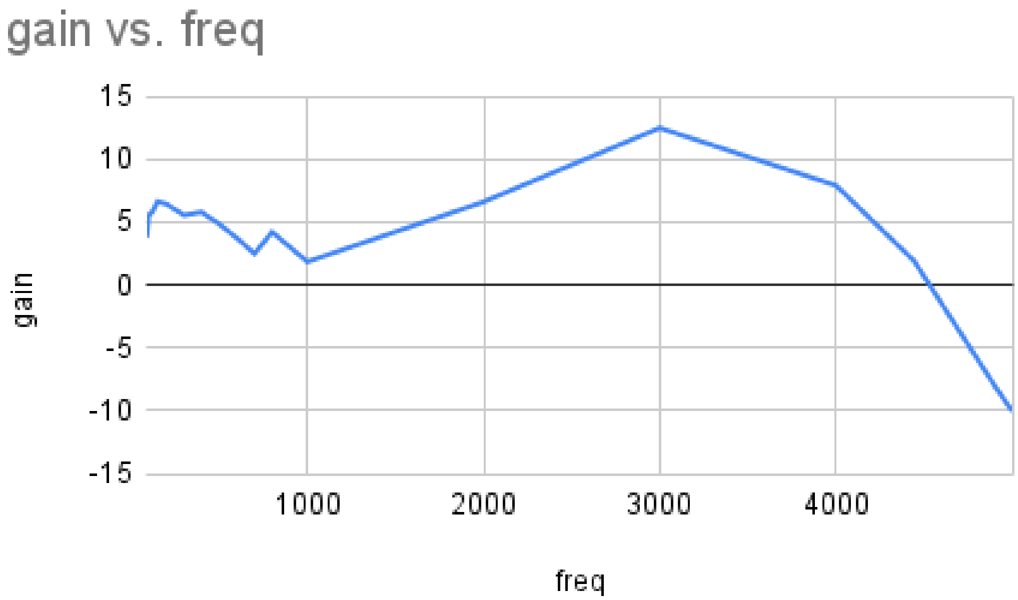

Figure 1: Gain vs Freq plot for Uncompensated System

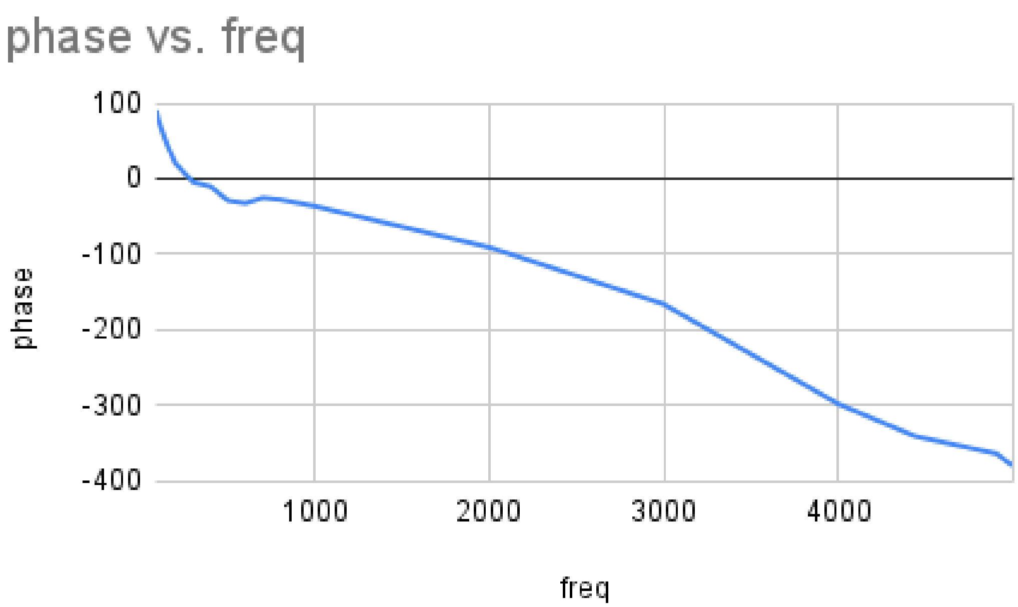

Figure 2: Phase vs Freq plot for Uncompensated System

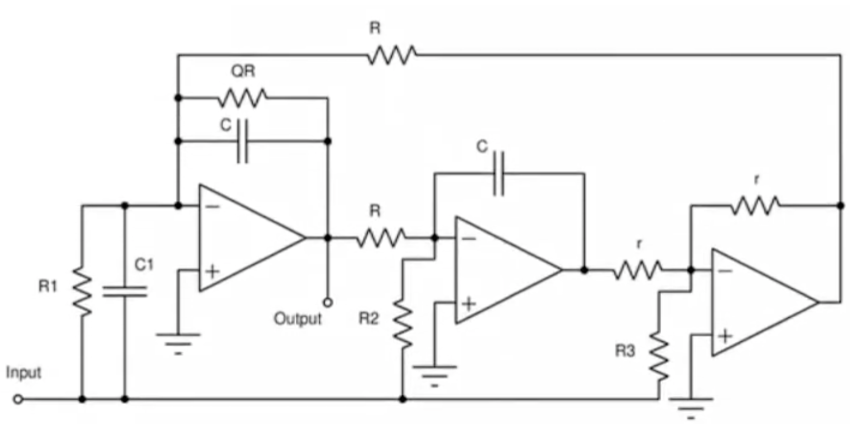

Figure 3: Compensator Circuit

$$T(s)=\frac{V_o(s)}{V_i(s)}=\frac{\left(\frac{C1}{C}\right)^2 s^2+\frac{1}{C}\left(\frac{1}{R1}-\frac{r}{R.R3}\right)s+\frac{1}{C^2.R.R2}}{s^2+\frac{1}{Q.C.R}s+\frac{1}{C^2.R^2}}$$

Figure 4: Transfer Function for the Compensator Circuit

$$\frac{\frac{15}{100}s^2+300s+15\times10^4}{s^2+200s+10^4}$$

Figure 5: Transfer Function for the Compensator Circuit we achieved

- Comparing the two equations above, the base values of the resistors and capacitors that we obtained were: C = 10 kpF, C1 = 3872 pF, R = 1 MΩ, R1 = 250 kΩ, R2 = 66.67 kΩ, R3 = r = 1 MΩ.
- Then we moved to closed loop system and followed the same. For closed loop system we designed a subtractor circuit and implemented it on hardware.

3 Devised Algorithm and Relevant Code Snippets

- We used MATLAB to obtain the bode plots of the ideal compensated system with the given specifications.

```
A = 15; %15
z1 = 1000; % 2500
z2 = 1000; %2500
p1 = 100; %150
p2 = 100; %150

s = tf('s');
sys = tf(A*((s/z1+1)*(s/z2+1))/((s/p1+1)*(s/p2+1)));

freq = [90,100,120,150,200,300,400,500,600,700,800,
1000,2000,3000,4000,4442,4909,5000];
[gains, phases, freq] = bode(sys, freq);


og_mag =[3.781124724,5.563342254,5.800692227,6.648769198,
6.454984907,5.563342254,5.800692227,4.860760974,
3.741732867,2.498774732,4.217067306,1.855081065,
6.619864381,12.49447952,7.916326301,1.93820026,
-8.190437624,-10.01204701];
og_pha =[90.9,79.2,65,45.5,20.1,-4.32,-10,-28.8,-32.3,
-25.2,-27.6,-36.3,-90.7,-166,-298.1,-340.9,-364,-379.8];

mag = [];
pha = [];

for i = 1:length(freq)
    mag = [mag, gains(i)];
    pha = [pha, phases(i)];
end

mag = 20*log10(mag);


mag = mag + og_mag;
pha = pha + og_pha;

bode(sys)
```

```
figure,
title("Mag")
semilogx(freq, mag, "b")
hold on
semilogx(freq, og_mag, "r")
hold on
semilogx(freq, zeros(length(freq)))
hold off
figure,
semilogx(freq, pha, "b")
hold on
semilogx(freq, og_pha, "r")
hold on
semilogx(freq, -180*ones(length(mag)))
hold on
semilogx(freq, -540*ones(length(mag)))
hold off
```

4 Results

- The bode plots for the open-loop compensated system are shown in Figures 6 and 7.

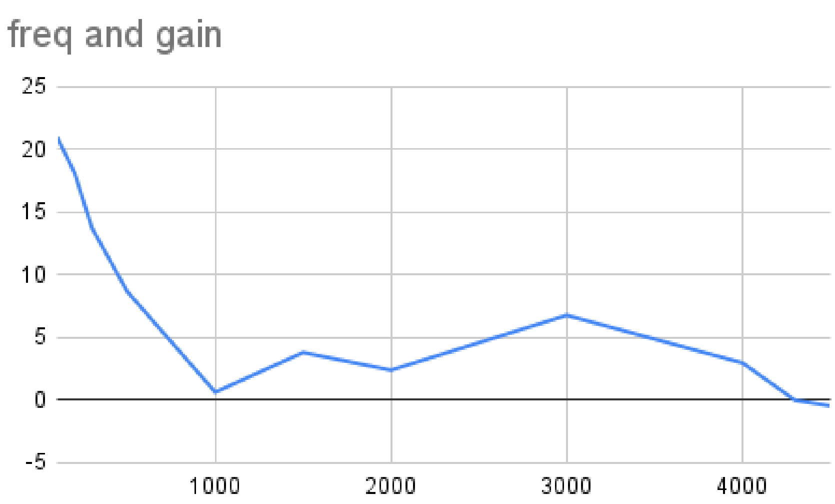

Figure 6: Gain vs Frequency for Open Loop system

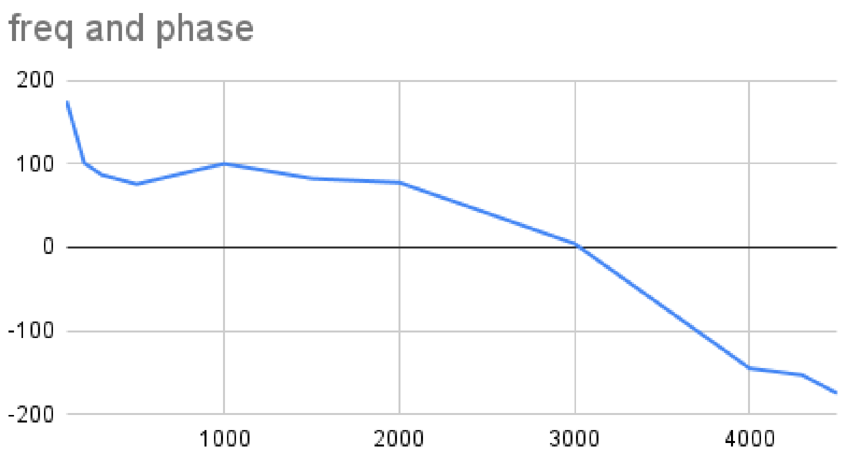

Figure 7: Phase vs Frequency for Open Loop system

- The bode plots for the close-loop compensated system are shown in Figures 8

4.1 System

- Gain Margin : 11.66 dB
- Phase Margin : 160°
- Gain at 100Hz : 5.563342254 dB

4.2 Compensator Transfer Function

- The transfer function is in fig 9.

4.3 Open Loop

- Gain Margin : -0.44 dB
- Phase Margin : 30°
- Gain at 100HZ : 20.98 dB

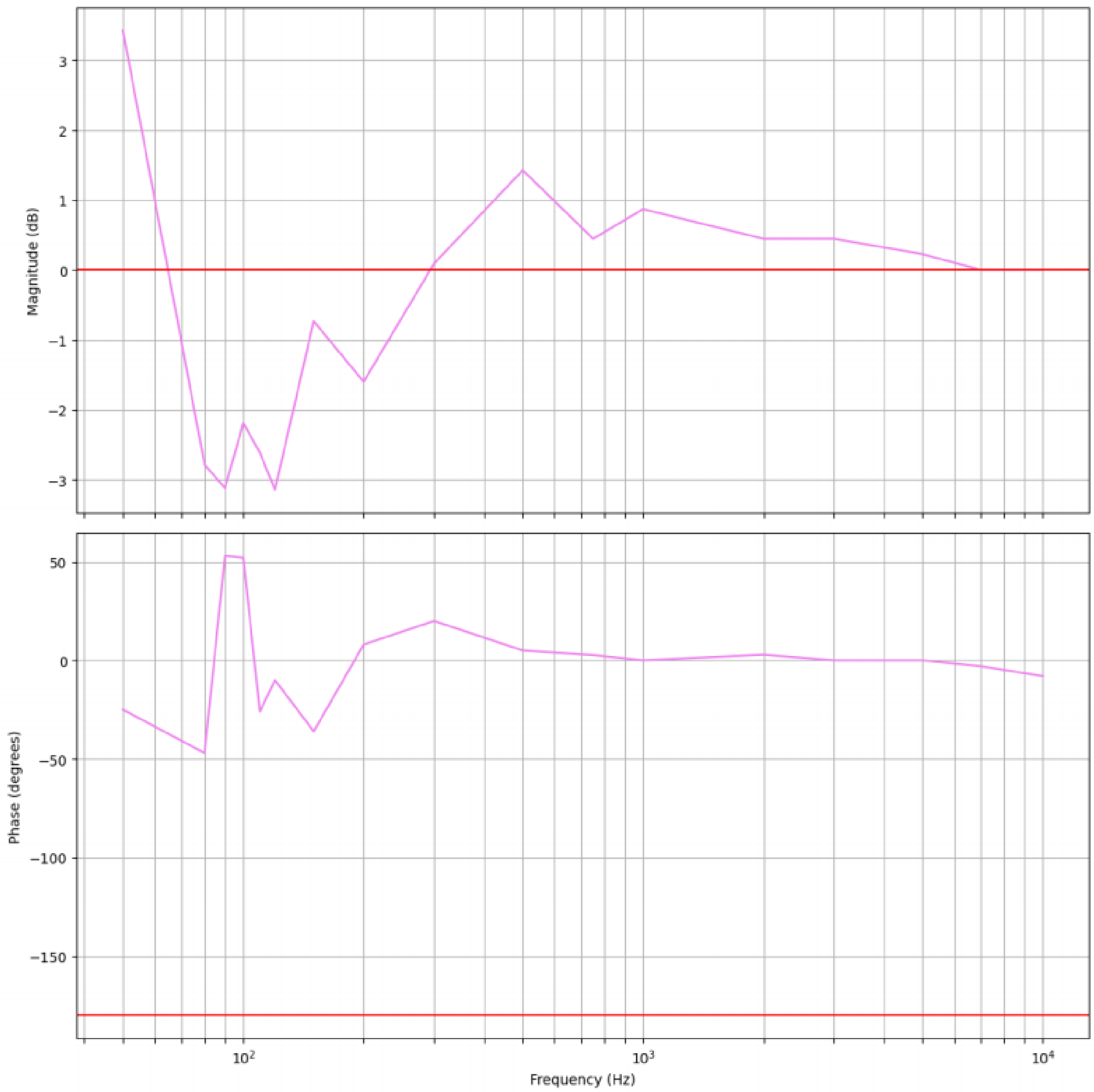

Figure 8: Close loop Bode plots

5 Problems Faced

- The setup for the headphones is quite delicate; we had to take the readings 5 to 6 times to obtain an accurate Bode plot for the uncompensated design.
- The compensator circuit had too many connections making it hard for us to properly debug. Finally we made the circuit again to get the accurate

$$\frac{\frac{15}{100}s^2 + 300s + 15\times 10^4}{s^2 + 200s + 10^4}.$$

Figure 9: Transfer Function for the Compensator Circuit

readings.

- Since phase on the DSO always stays inside $+180^\circ$ to -180 , whenever phase overflowed from negative to positive numbers, we had to ensure we note down the readings ensuring the phase is just decreasing and going below 180..