EE324: Experiment No. 3
Noise Cancellation Headphones

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1 Overview of the experiment

The aim of the experiment was to design a compensator to minimize the noise at 100Hz by 20dB margin, and also obtain a gain margin of 5dB and phase margin of 30 degrees. This controller was also to be implemented using Opamps and the validity and effectiveness of the controller was to be ascertained experimentally.

2 Theory and Control Algorithm

We were initially given a headphone - microphone setup, which we had to characterize. We found out the transfer characteristics of the headphone setup. Let us call it G(s). The closed loop can be modelled as a unity feedback model. We need to add a controller C(s) in the feedforward path to ensure that the given characteristics are met.

Theoretical transfer function from input to output -

$$G_{cl}(s) = \frac{L(s)}{V_i(s)} = \frac{DH_1C}{1 + AMH_1H_2CD} \tag{1}$$

Theoretical transfer function from noise to output -

$$R_{cl}(s) = \frac{L(s)}{N(s)} = \frac{1}{1 + AMH_1H_2CD} \tag{2}$$

Controller free unity closed loop feedback -

$$\frac{Y(s)}{X(s)} = \frac{1}{1 + G(s)} \tag{3}$$

Closed loop unity feedback transfer function with the controller -

$$\frac{Y(s)}{X(s)} = \frac{1}{1 + C(s)G(s)} \tag{4}$$

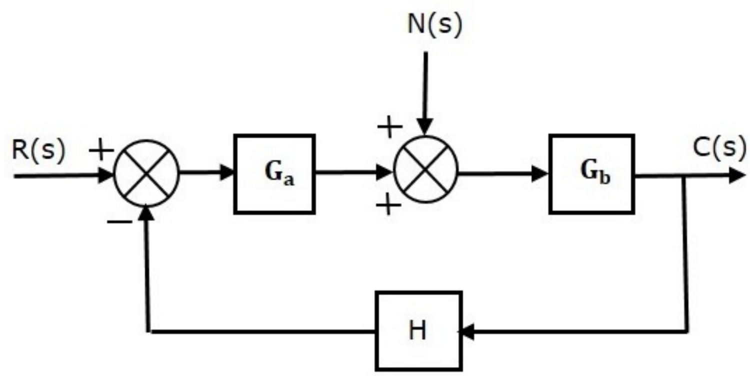

Figure 1: Given System High Level Model, $G_a = C(s), G_b = G(s)$

3 Design

The design of the transfer function and all the deductions and assumptions that we made are listed below.

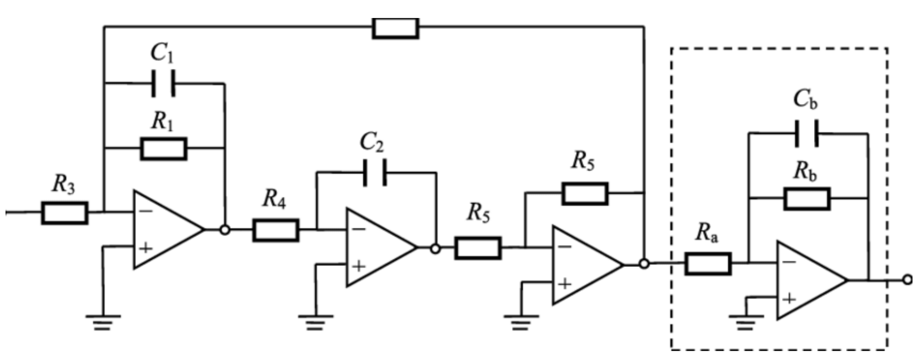

Figure 2: Representative Second Order Controller Circuit

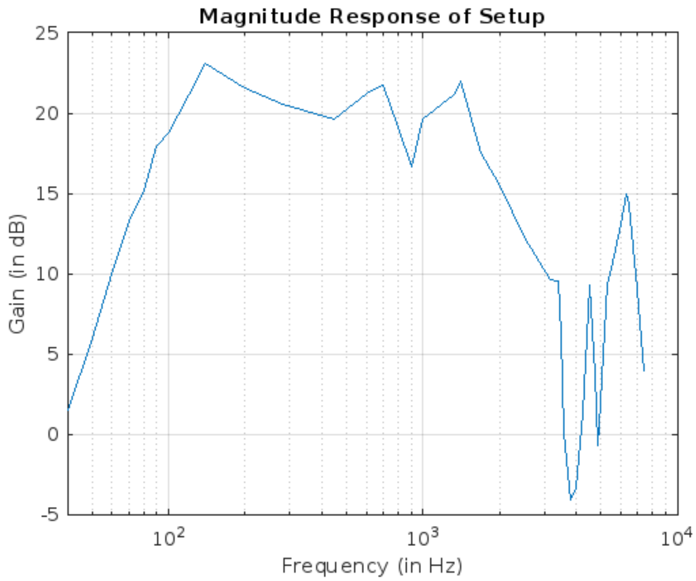

Figure 3: Magnitude Response of Headphone Setup

- Given the controller requirements to be fulfilled, we first try to satisfy the main goal of the compensator - noise reduction of 20dB at 100Hz. This was first obtained by designing the linear compensator and then adding the required gain at 100Hz frequency.

- But, after designing the basic first order compensator, we found that the slope of the magnitude plot is not enough to satisfy the gain and phase margins. Thus we needed to increase the slope of the magnitude plot to accommodate the gain and phase margins. A desired -40dB/dec slope could be achieved only by using a higher order (second order) controller.

- We then squared our initial controller to make a good enough assumption of the second order actual controller. The gain coefficient was adjusted to give the desired response characteristics, which we assessed by plotting the bode plots and the transfer function of the controller.

Thus, keeping in mind the gain and phase margins, the -40dB/dec fall/slope, and the second order design of the compensator, we came up with the following transfer function after experimenting with and tuning our controller on MATLAB.

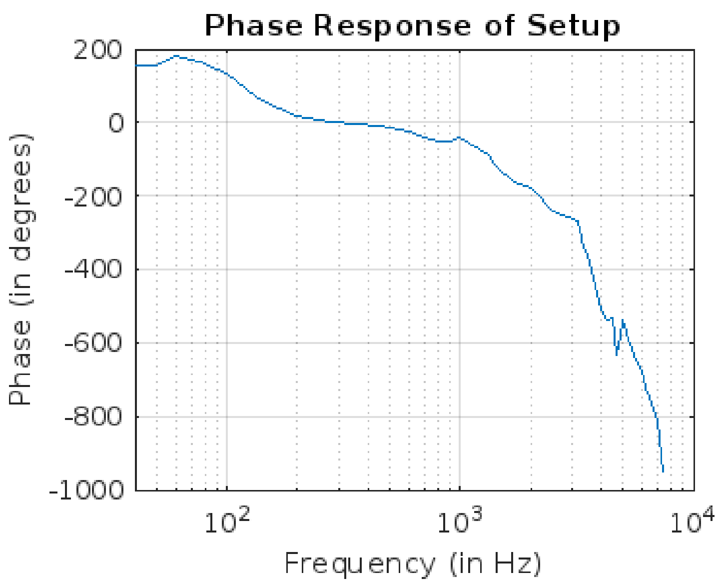

Figure 4: Phase Response of Headphone Setup

$$C(s) = \frac{48(s+11000)^2}{5000(s+450)^2} \tag{5}$$

4 Challenges Faced

- **Noisy Readings** - We had initially obtained noisy readings in our characterisation of the headphone setup, because of ambient disturbances present in the surroundings. Thus, we had to do the experiment again, this time with the setup in a different silent room. Only then could our observational readings be used for controller design.

- **MATLAB Bode plot** - When we were plotting the bode plot in matlab, we were initially unaware that the input parameters to the ***bode()*** function are given in radians, rather than Hertz, which initially caused erroneous results.

- **Optimum Resistance and Capacitance Values** - As the exact values of resistances and capacitances are not available, thus we needed

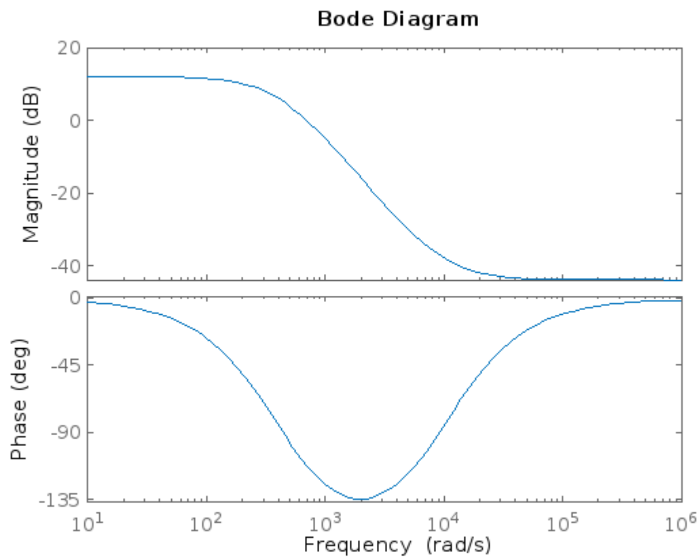

Figure 5: Bode plot of the designed controller

to find a rough match for the R and C values of the circuit implementation.

5 Code Snippets

```
figure
semilogx(freq,dBgain)
title('Magnitude Response of Setup')
xlabel('Frequency (in Hz)')
ylabel('Gain (in dB)')
grid on
figure
semilogx(freq, phase_mod)
title('Phase Response of Setup')
xlabel('Frequency (in Hz)')
ylabel('Phase (in degrees)')
grid on
```

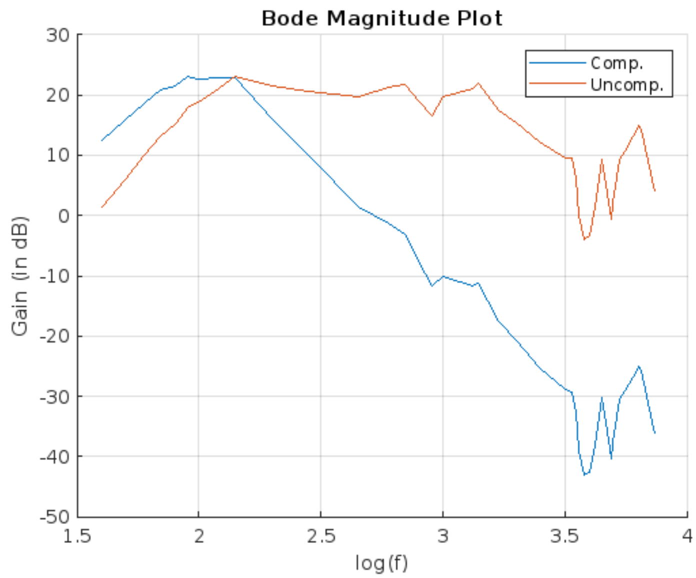

Figure 6: Magnitude Responses

```
syms s
C(s) = 48*((s + 11000)/(5000(s + 450))^2)
Cs = 48/5000*tf([1  22000 121000000],[1 900 202500])
bode(Cs)
syms f
```

6 Results

The designed controller was meeting the given requirements of attenuation, gain and phase margins. The results are summarized as follows -

- Attenuation at 100Hz - 23dB
- Gain Crossover Frequency - 500Hz
- Phase Crossover Frequency - 1580Hz
- Gain Margin - 8dB
- Phase Margin - 39 degrees

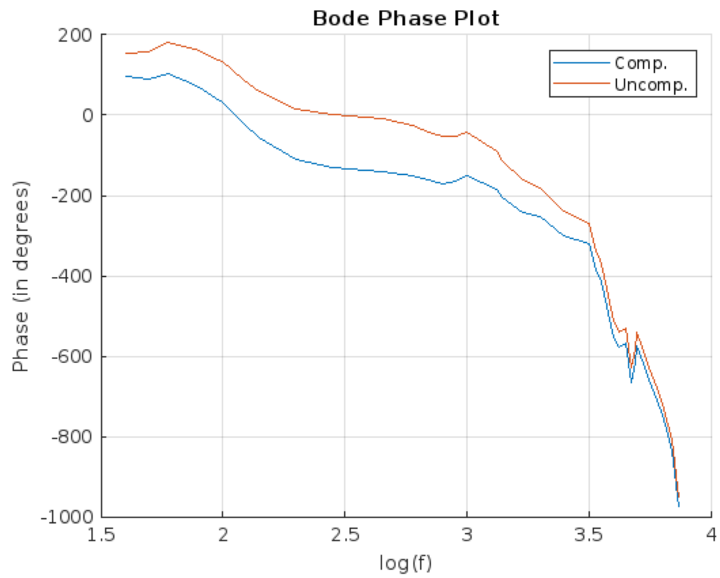

Figure 7: Phase Responses

- Resistance and Capacitance Values (for circuit given in video)-
  1. $r = 470\Omega, R = 1M\Omega, C = 10nF$
  2. $R_1 = 8.9M\Omega, C_1 = 200pF$
  3. $R_2 = 50k\Omega, R_3 = 10k\Omega$
  4. Quality Factor $= 0.465$

CONTROL & COMPUTING LAB
RESULT SHEET

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Group No -

$$C(s) = \frac{48}{5000} \frac{(s+11000)^2}{(s+450)^2}$$

Attenuation 100Hz = 23dB

Gain C.F. = 500Hz   G.M. = 8dB

Phase C.F. = 1580Hz   P.M. = 39°

$r = 470\Omega$ $C_1 = 200pF$

$R = 1M\Omega$ $R_3 = 10k\Omega$

$C = 10nF$ S.F = 0.465

$R_1 = 8.9M\Omega$

$R_2 = 50k\Omega$

	TA Name	Date	Signature
1	Rishabh Kumar Singh	08/11/22	[signature]
2			