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SAN JOSÉ STATE UNIVERSITY | CHARLES W. DAVIDSON COLLEGE OF ENGINEERING

Robust Hard Drive Control

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Summary

This project presents a simulation-based control for the piezoelectric micro-actuator system on the HDD. The piezoelectric actuator on the HDD is based on the desired position to read the data written on the disk. As the head reads the tracks on the HDD the vibrations and disturbances present from the spinning disk can impact the positioning of the piezoelectric actuator creating resonant modes if not properly controlled. The system also faces resonant modes from variations of operating temperatures between the manufacturing tolerances of the drives and as a result demand for a robust control system design that considers all variations. To design a robust controller for the data-driven model we can shape the system's closed-loop frequency responses by using a PI controller with a set of notch filters. Because the desired output of the system is to reach a steady state error of zero and this project is limited to the MA controller, it is necessary to use a PI controller in place of the VCM controller. Notch filters are particularly important as they control the waterbed effect of the system when pushing the gains of the PI controller, and if we were to ignore the system's high-frequency modes, the PI controller would provide below-par performance. Once the controller and the notch filters provide adequate performance for all systems, the controller can be analyzed in the time domain by choosing a single plant, deriving a transfer function using MATLAB's "invfreqz" function, and the complex frequency response data and comparing the bode plots of the plants FRD Model and the identified Controller. The step response can then be simulated with the identified controller, in turn, providing the ability to evaluate the time domain performance and plot tracking results for inputs and various frequencies.

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Results

The first was to simulate the various systems given the provided data of 10 different plant sets such that the dynamics of the uncontrolled system are known **(Figure 1)**.

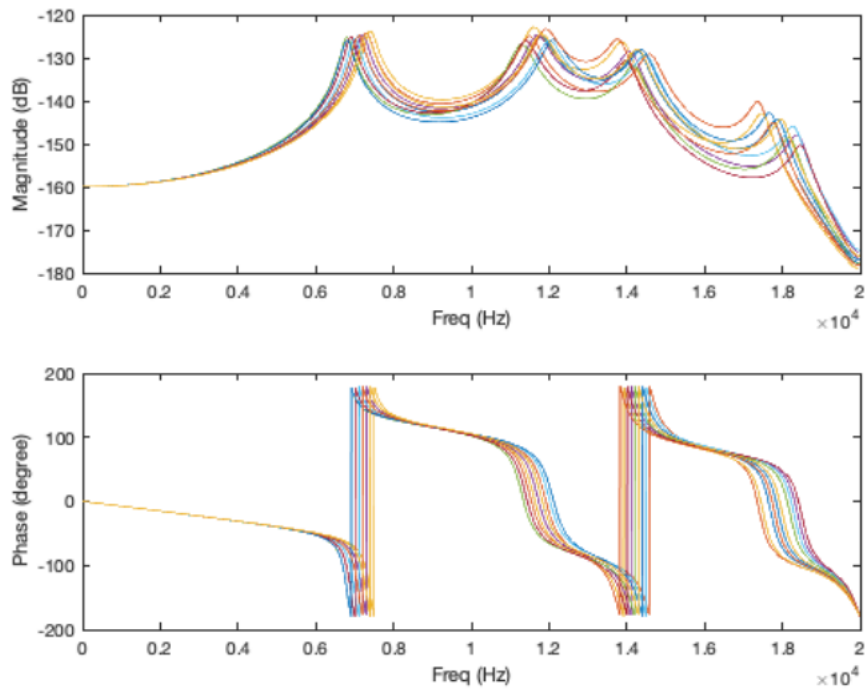

*Figure 1***:** *Open Loop Bode graph.*

From the open-loop Bode diagram, we can then design a controller (**Figure 5)** and place sets of notch filters at the resonant frequencies to achieve desirable performance criteria. By designing multiple notch filters there is an optimization trade that balances the magnitude of the steady-state error and phase loss of the system **(Figure 2,3,4).**

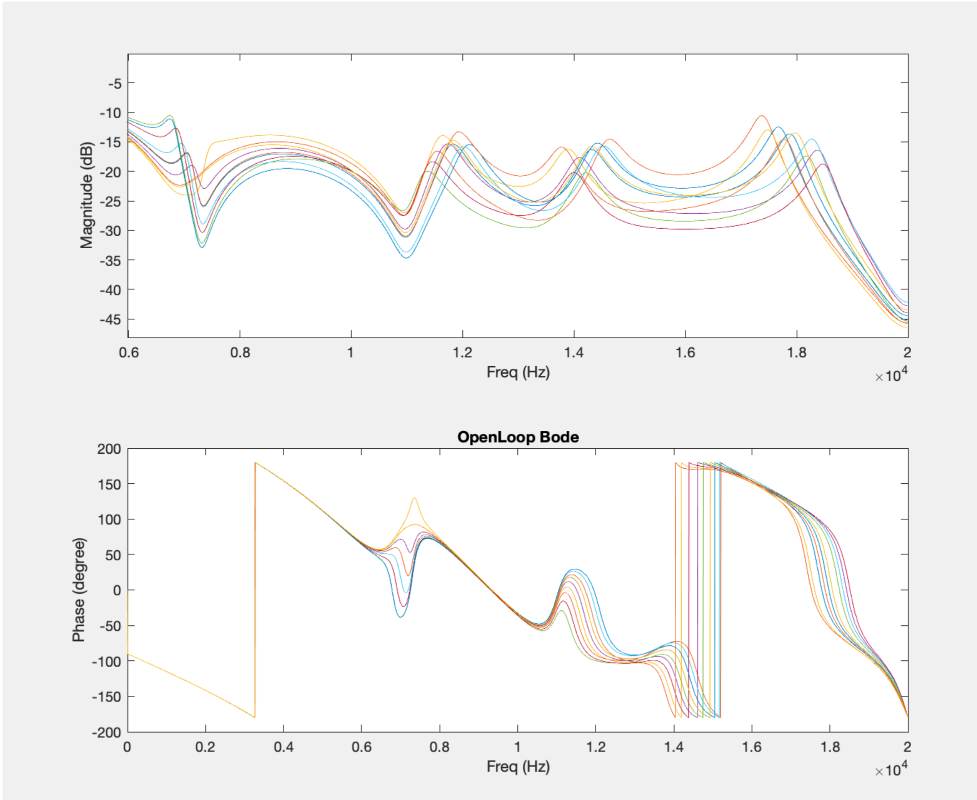

Figure 2: Open Loop Bode Diagram with Notch Filters and PI Controller

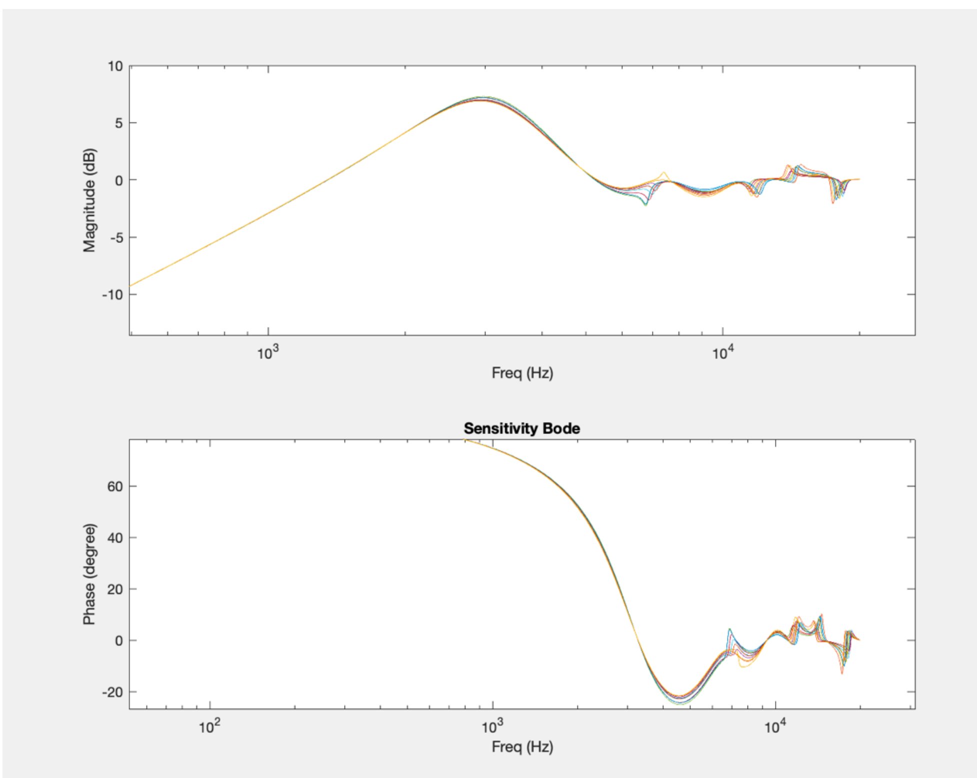

Figure 3: Sensitivity Transfer Function Dynamics

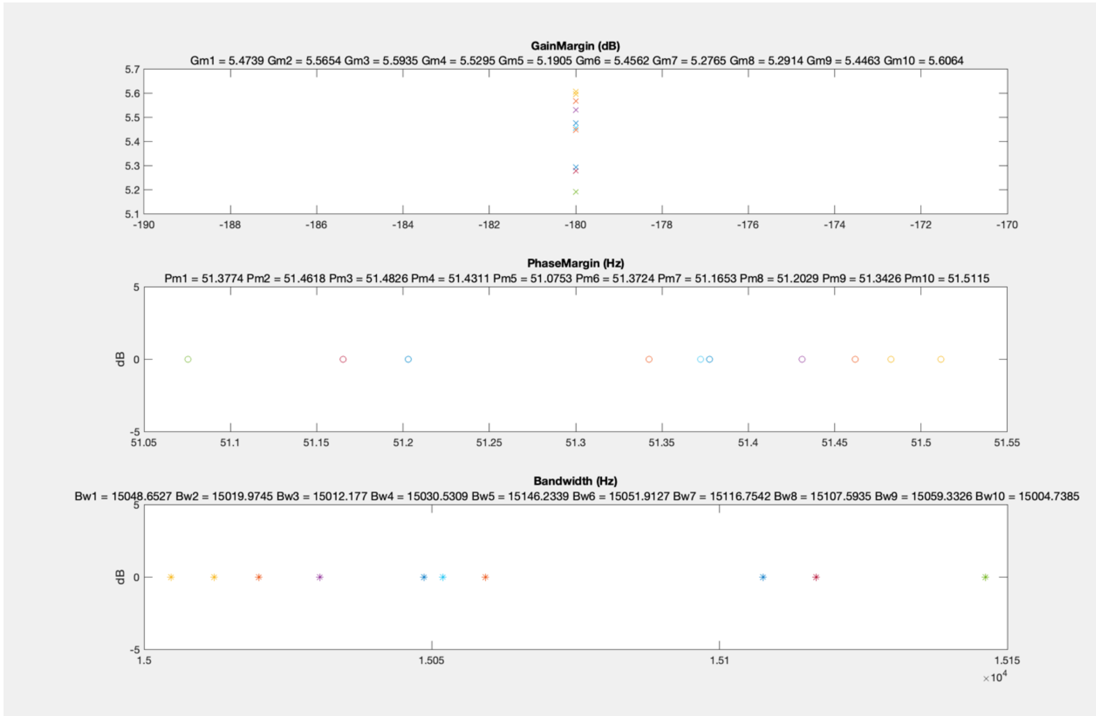

Figure 4: Open Loop Gain margin, Phase Margin, Phase Crossover Frequency

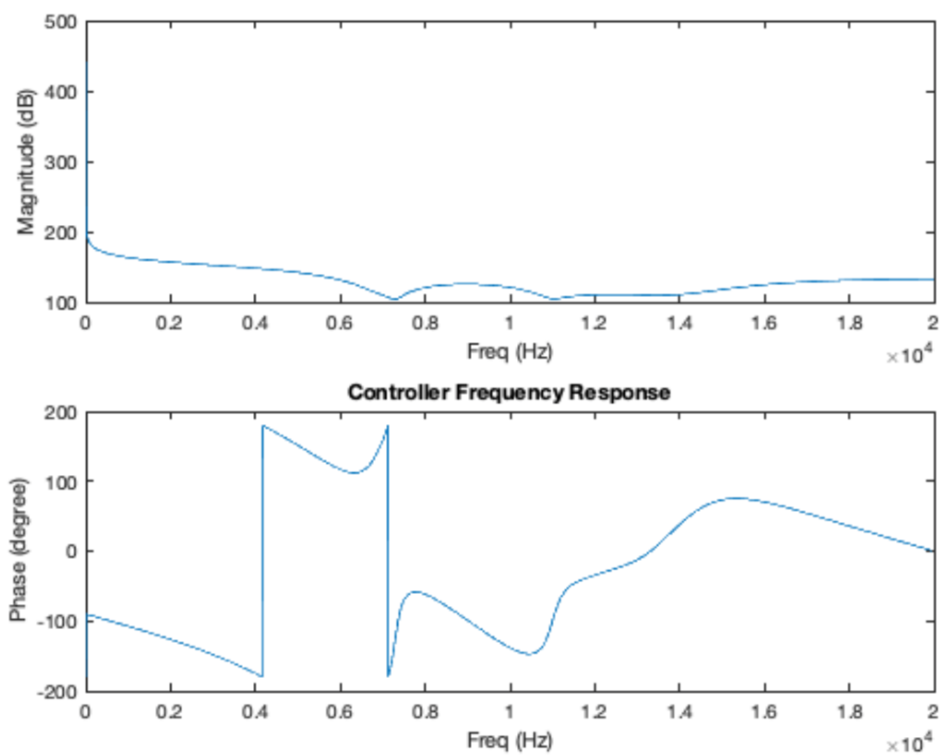

Figure 5: Controller Bode Plot

After the desired performance criteria are met for all underlying variables a discrete transfer function can then be identified using MATLAB's "Invfreqz" function by fitting it against a single plant's frequency response data. We check the validity of the identified transfer function by comparing the bode plots of the selected FRD Plant and the identified z-domain plant. **(Figures 6,7,8)**

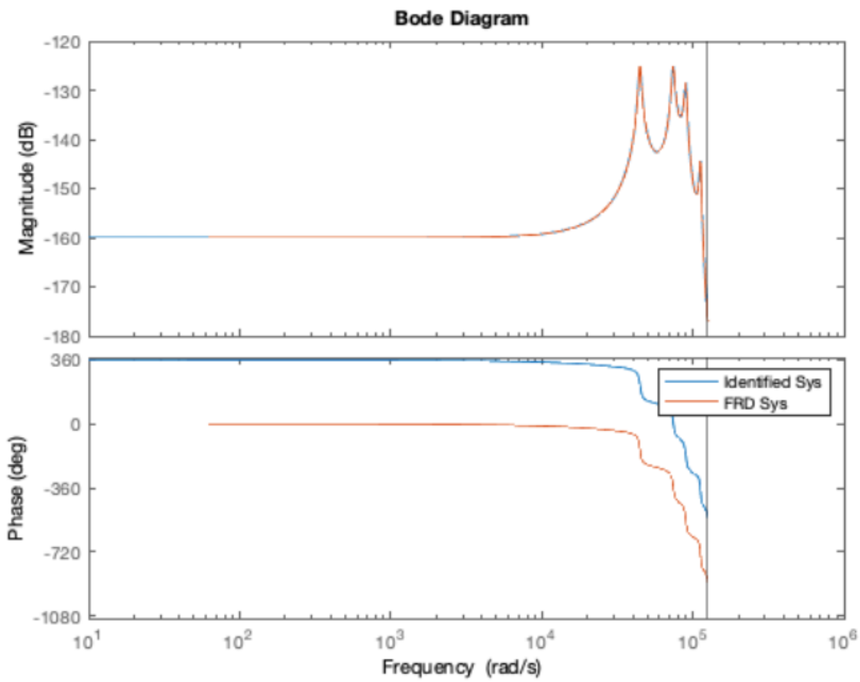

Figure 6: Identified and FRD of Open Loop Bode of Plant 1

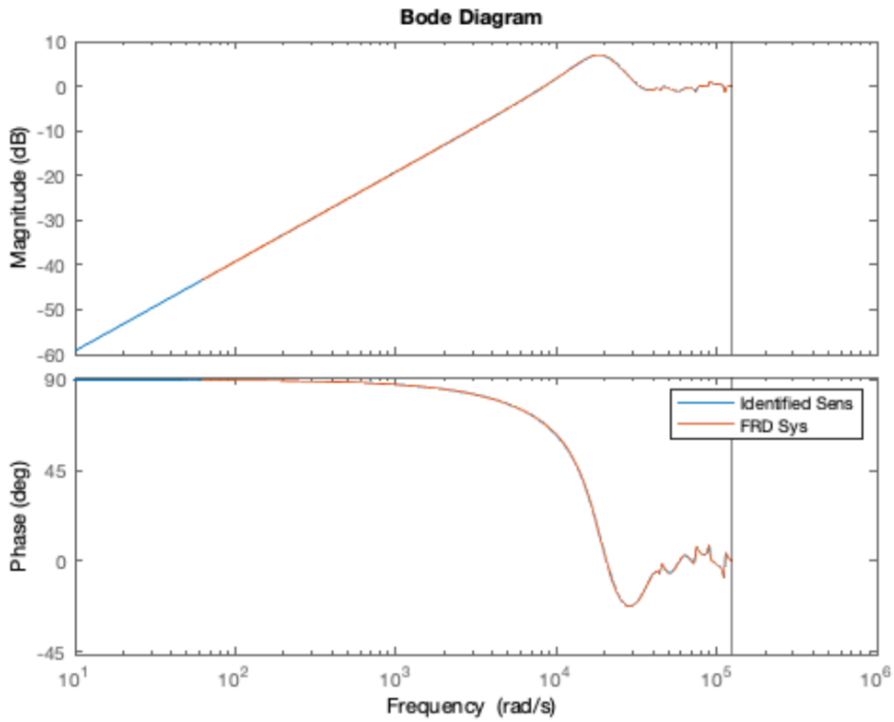

Figure 7: Identified and FRD Sensitivity Bode of Plant 1

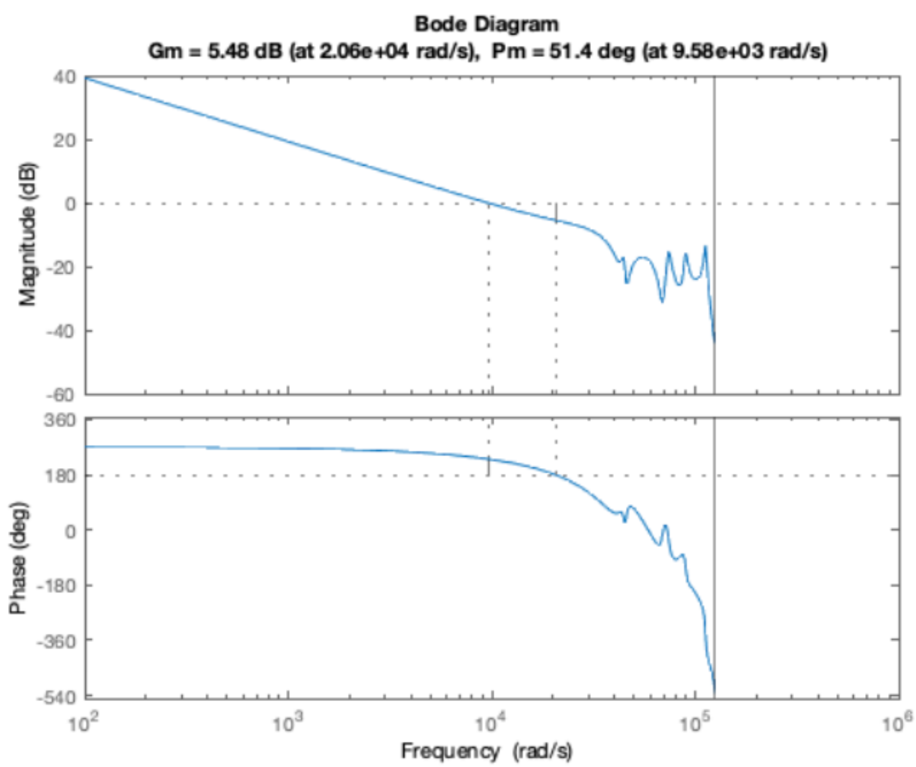

Figure 8: Bode Diagram of the built controller and identified Plant 1

As a Final Check of controller design, using MATLAB's "lsim" command and "step" function is helpful to investigate the dynamics in the time domain. "lsim" can be called on to plot the tracking of controller dynamics with various frequency inputs as well as showing the magnitudes of the steady-state error. MATLAB's step function can be used to look at time domain performance such as overshoot, settling time, and steady-state error.

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    SettlingTime: 6.2500e-04
     SettlingMin: 0.9213
     SettlingMax: 1.2678
       Overshoot: 26.7784
      Undershoot: 3.8736e-06
            Peak: 1.2678
        PeakTime: 2.2500e-04
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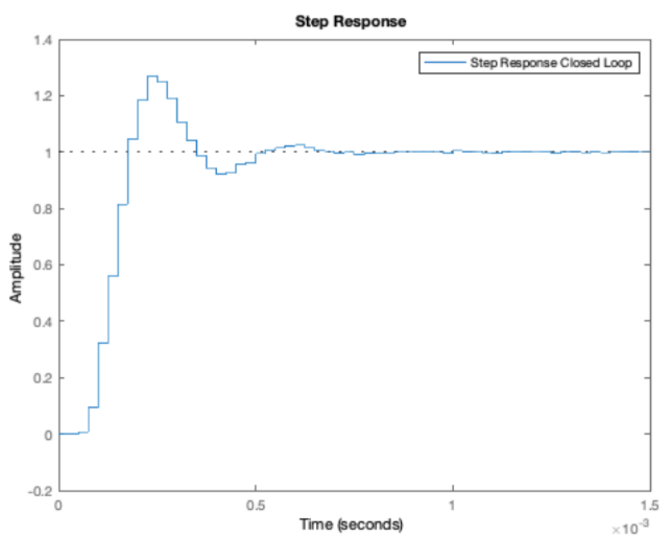

Figure 9: Step Response of Closed Loop System

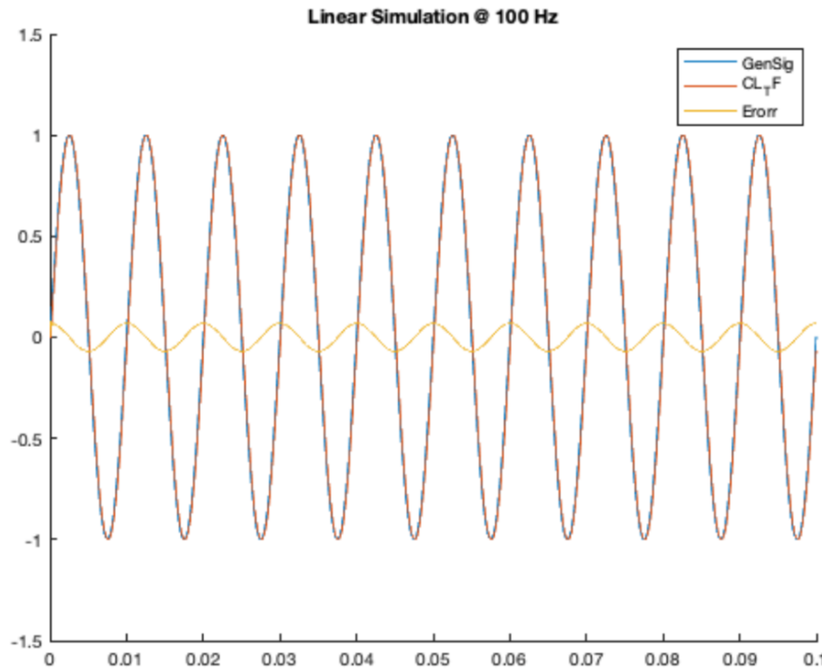

Figure 10: Simulated Response and Error Tracking

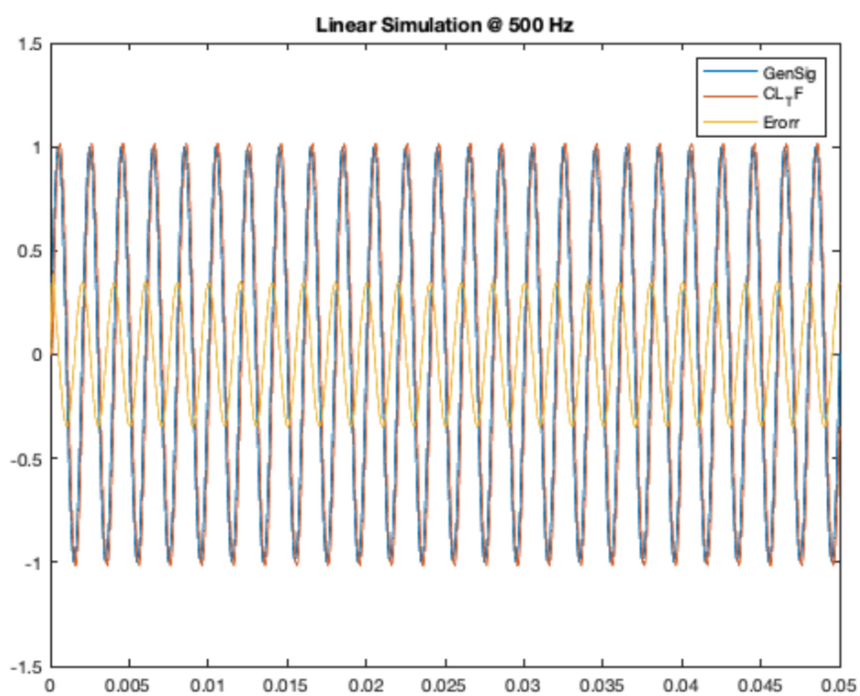

Figure 11: Simulated Response and Error Tracking at 500 Hz

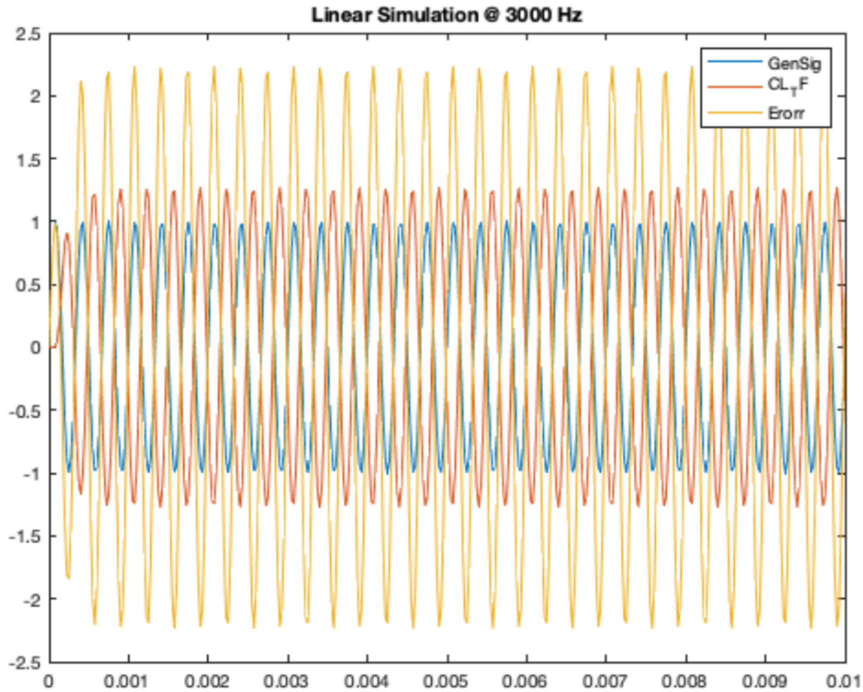

Figure 12: Simulated Response and Error Tracking at 3000 Hz

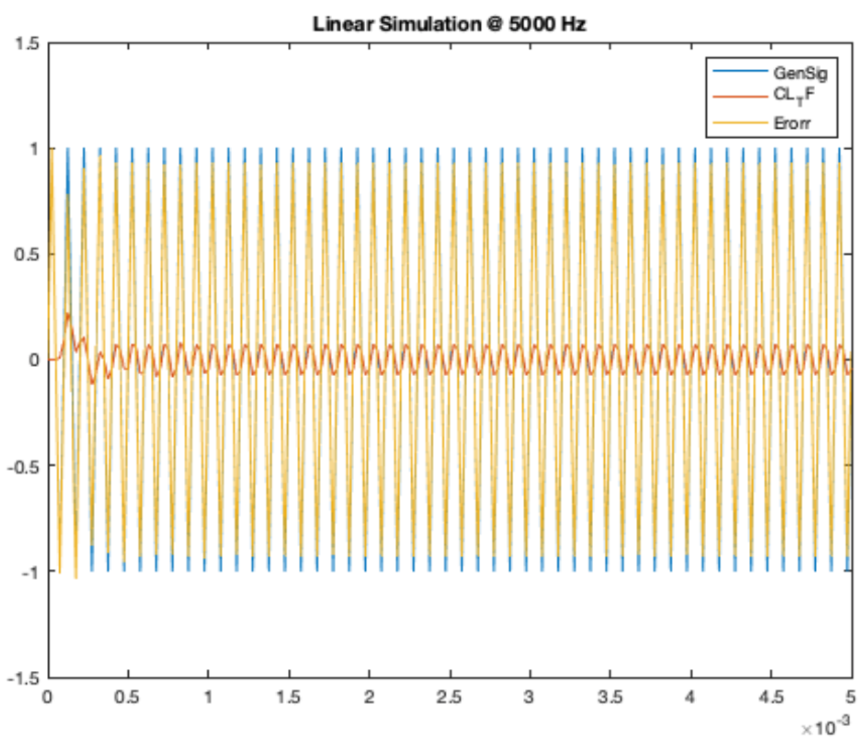

Figure 13: Simulated Response and Error Tracking at 5000 Hz

Conclusions

This project was extremely helpful in understanding the use of notch filters to build robust digital controllers for a data set of frequency responses. With MATLAB, I was able to simulate and design a single controller that met various types of performance dynamics that were important to the HDD position-sensing mechanism. Although the controller is not directly applicable to real HDD positioning mechanisms the control design process is, as we were able to retrieve data and build a controller around that data. I learned a lot about building a discrete controller in the frequency domain as doing so is much more intense than in the continuous domain due to the number of variables that are dependent upon each other. A lot of intuition was built while tunning the controller and setting different size notch filters at respective frequencies as there was an immense number of tradeoffs taking place while changing one aspect of the controller. Overall, this project was extremely helpful and insightful in learning about robust controller design and learning about HDD dynamics.