ECE 345: Introduction to Control Systems
In-Class Exercise #5

`http://www.ece.unm.edu/course/ece345/`

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1 Introduction

The camera in the figure below uses an automatic focusing system based on a charge-coupled device (CCD).

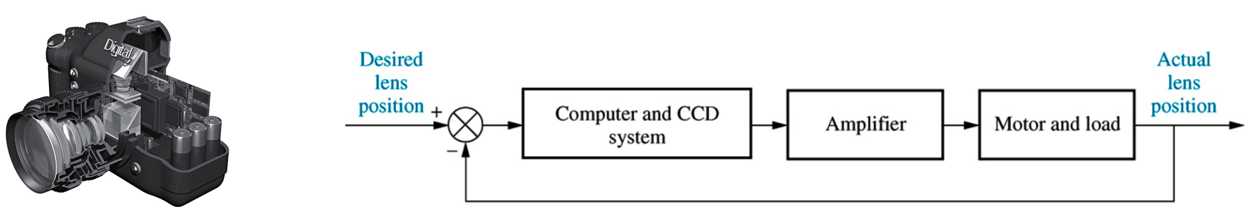


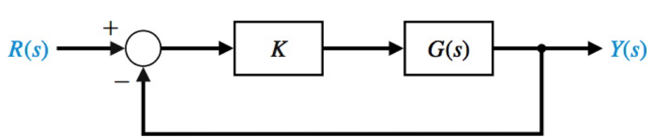
Figure 1: Camera image (left) copyright Steven Sweet / iStockphoto.

A charge-coupled device (CCD) is most often used in video movie cameras to convert images into electrical signals, but can also be used as part of an automatic focusing system in cameras. The automatic focusing system works by focusing the center of the image on a CCD array through two lenses. The separation of the two images on the CCD is related to the focus. The camera senses the separation, and a computer drives the lens and focuses the image.

In essence, the automatic focus system provides a position control, where the desired position of the lens is an input selected by pointing the camera at the subject. The output is the actual position of the lens. The amplifier is represented by the gain K, as shown in the negative unity feedback system below. The computer and CCD system, as well as the motor and the load, are represented by the transfer function

$$G(s) = \frac{10}{s(s+2)(s+10)}$$

The objective of this exercise is to analyze (and compare) the stability of the automatic focusing system through root locus, Bode, and Nyquist diagrams.



2 Pre-Class Work

1. What is the type number of the closed-loop system $\frac{Y(s)}{R(s)}$?

2. Find the characteristic equation $\Delta(s)$ of the closed-loop system.

3. Using Matlab, create the following plots and bring **hardcopies** of the plots to class on Thursday, using the specific instructions below.

   (a) Create a Bode plot of $G(s)$. Use `orient tall` to create a plot you will be able to use in class.

   (b) Create a Nyquist plot of $G(s)$. Use `axis([-1.02 0.02 -1 1])`, to create a plot you will be able to use in class.

4. How many encirclements of -1 are there? *Hint: Consider Nise Example 10.6, Figure 10.31.*

3 In-Class Assignment

1. Roughly sketch the root locus of $G(s)$ (you do not need to hand the sketch in in). What happens as K is increased? *More than one answer may be correct.*

   (a) A complex conjugate pair of poles close to the origin move from the LHP to the RHP.

   (b) The pair of poles closest to the origin is initially undamped, then underdamped, then critically damped, then overdamped.

   (c) A complex conjugate pair of poles in the LHP follows two asymptotes further into the LHP.

   (d) One pole on the negative real line moves farther into the LHP.

2. Consider your answer to Pre-Lecture Question #2. What value of gain K is required to place two of the poles of the closed-loop system on the imaginary axis at a location $\pm j\omega$? (You may assume in this case that the third pole of the closed-loop system is located at $-a$.)

3. Use the Bode diagram from Pre-Lecture Question #3(a) to estimate gain margin G_M and phase margin Φ_M of $\frac{Y(s)}{R(s)}$. Mark clearly on your Bode plot where you calculated these two quantities, and indicate units.

4. Consider the Nyquist diagram from Pre-Lecture Question #3(b) and your answer to Pre-Lecture Question #4. By what factor would you need to increase the gain K in order to destabilize the system?

5. Examine your answers to the above three problems. Comment on any patterns you see between the gain margin and your answer to In-Class Question #2.

6. A phase margin of 20° to 30° is often desirable, to counter against any modeling errors, disturbance forces, or measurement uncertainties in the system. What value should K be in order to achieve this degree of relative stability?

If your group finishes early...

Other points to consider (not necessary to hand in):

- Consider the value of ω solved for in In-Class Question #2. What significant feature on the Bode diagram does this frequency correspond to? *Hint: What is the phase condition of all points on the root locus?*
- Consider the Nyquist diagram from Pre-Lecture Question #3(b). Repeat In-class Question #3 using the Nyquist diagram instead of the Bode diagram.
- Consider the Nyquist diagram below, corresponding to a transfer function $G(s)$ with three poles in the LHP.
  - By what factor should the gain be *reduced* to make the closed-loop system stable?
  - Will increasing the gain change the stability of the closed-loop system?
- Describe the benefit of Nyquist / Bode diagrams in assessing stability. What additional information about stability is provided in the Nyquist or Bode diagrams that is not provided in the root locus?
- If you were given a Bode diagram of an open-loop system based on experimental data, would you be able to assess the stability of the closed-loop system? Why or why not?