ME Ph.D. Qualifying Examination — System Dynamics and Controls, Fall 2007

Choose **3** of the following **4** questions to answer.

Problem 1

The *poles* and *zeros* are very important characteristics of a transfer function. It is certainly interesting to investigate their roles in affecting the system response.
Consider a single-input-single-output system which can be represented by the following transfer function

$$G(s) = \frac{s+2}{s^2+2s+1}.$$

The transfer function has one *zero* at -2 and two *poles* at -1.

(1) Find an initial condition of the dynamic system such that the response $y(t) = 0$ for all $t \geq 0$ if the input $u(t) = \mathrm{e}^{-2t}\,1(t)$, where $1(t)$ stands for the unit-step function. (This means the input, which is chosen based on the *zero*, can compensate for the influence of the initial condition so that the system produces no output.)

(2) Find an initial condition of the dynamic system so that its zero-input (or free) response is $y(t) = 5e^{-t}$ for all $t \geq 0$. (This means the output is triggered only by the pole.)

Problem 2 (two pages)

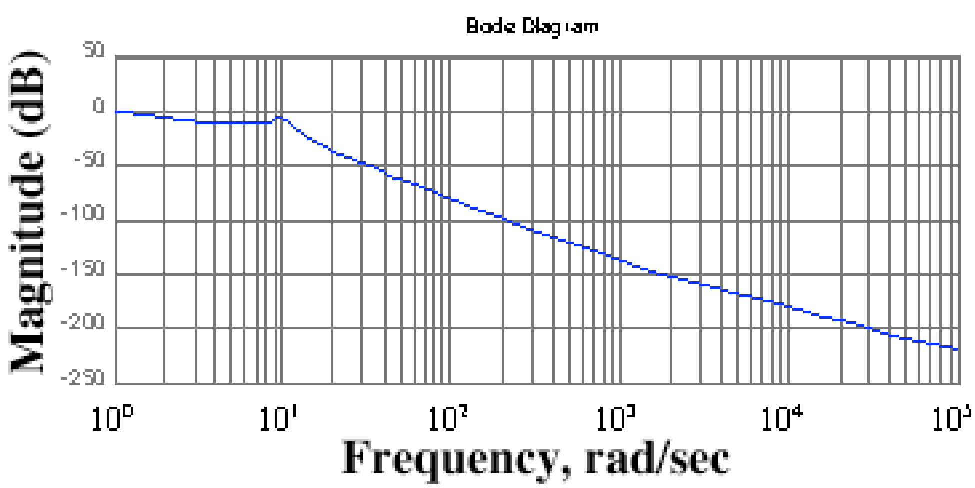
Given below is the magnitude plot of a Bode diagram for a linear system represented by the transfer function G(s) where the substitution s = jω has been made for ω a real positive number in calculating the plot. The phase plot is not given.

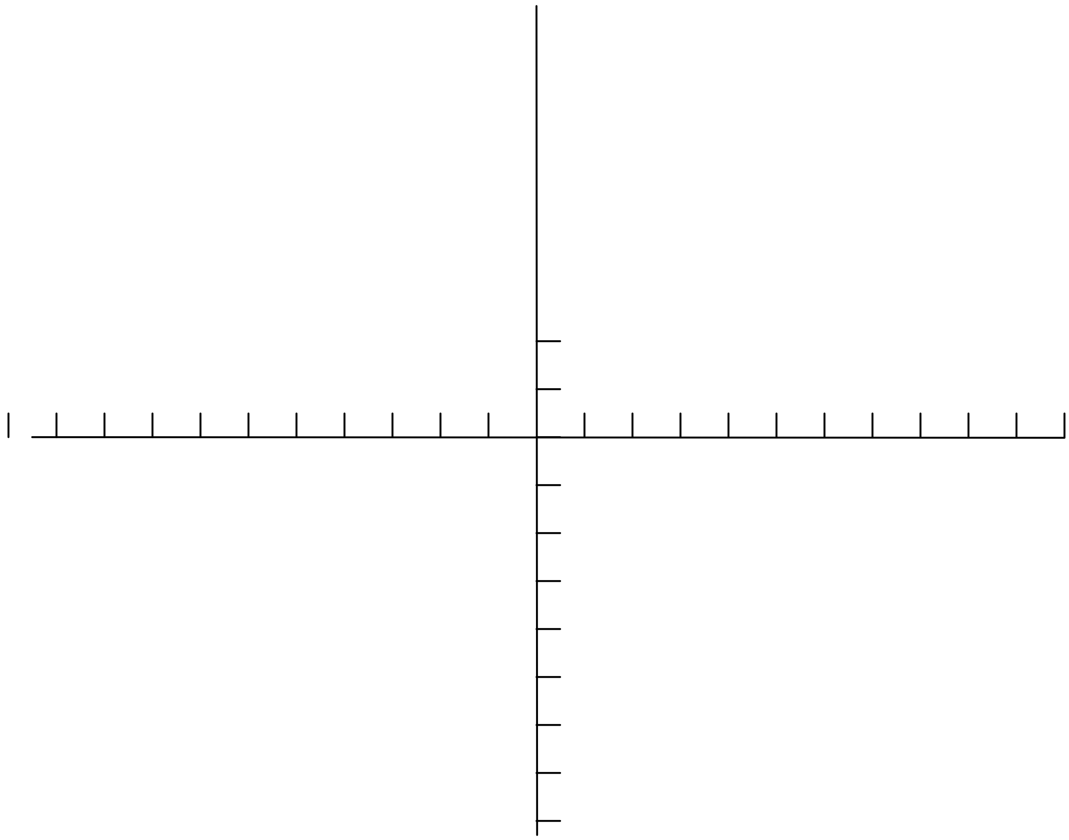
(a) Using the axes on the next page, show all of the possible pole and zeros that would be consistent with that Bode diagram magnitude plot. Take care to group the possible combinations of positions that would belong together in establishing the possible poles and zeros of G(s). Denote the systems as system A, system B, etc.

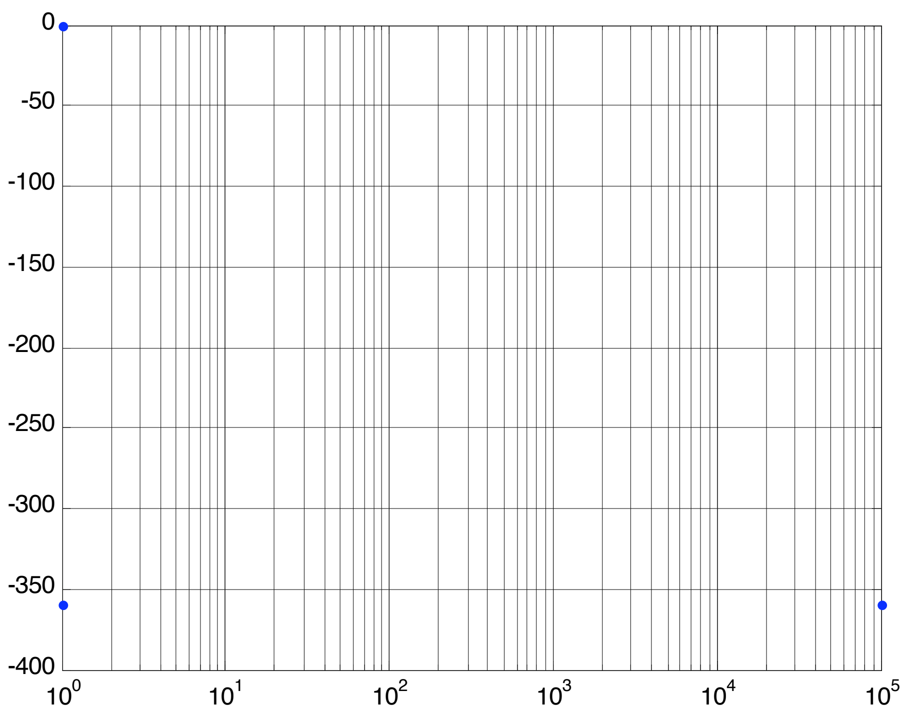
(b) Using the axes provided for the phase plot on the next page, create the phase plot corresponding to a minimum phase system with the given magnitude plot. Indicate the pole-zero pattern that corresponds to this phase plot.

(c) If an experiment is to be performed on the systems identified in part (a), what difficulties could be anticipated for each of the systems A, B, …? The experiment to be performed is the classical one where a sine wave of frequency ω is used to drive the system and the phase and amplitude of the response is measured. Assume first that the systems are perfectly described by the transfer function. Next assume that the inevitable imperfections in the model, sensors, and actuators are present.

(d) Based on the frequency response for that system in part (a) which has no poles or zeros in the right half plane, what would be the steady-state error for a closed loop proportional control of G(s) for a step input. State any restrictions on the values of the proportional gain K_p for which your answer will hold and explain.



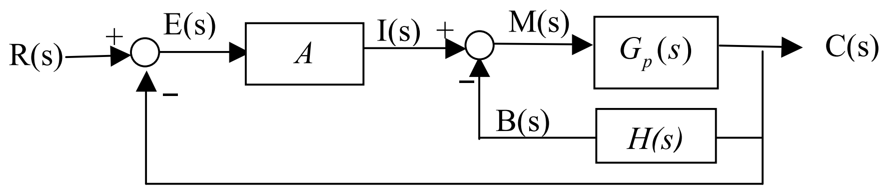




0
-50
-100
-150
-200
-250
-300
-350
-400
10^0
10^1
10^2
10^3
10^4
10^5

Problem 3

Consider the closed-loop compensation system (shown below) with rate feedback $H(s) = K_t s$ and the amplifier gain A not equal to unity, where $G_p(s) = \dfrac{K}{s(s+1)(s+5)}$. The designer has the flexibility in assigning the values of *A, K,* and K_t while maintaining the damping ratio ξ of the complex poles (of the complete system) at 0.45.



Using the *root locus* technique, discuss the effect of ξ_i (the damping ratio of the inner loop) on the undamped natural frequency, the ramp error coefficient, and the settling time of the complete system. You may focus on the range $0.4 < \xi_i < 0.8$ in your discussion. Then, choose a set of values for *A, K,* and K_t which would yield the shortest settling time.

Problem 4

Researchers at the Tokyo Institute of Technology have developed a mobile manipulator that detects landmines using a metal detector and ground penetrating radar at the end of a 3m long robot arm. The arm is mounted on an all-terrain vehicle (ATV). A picture of the device is shown below.

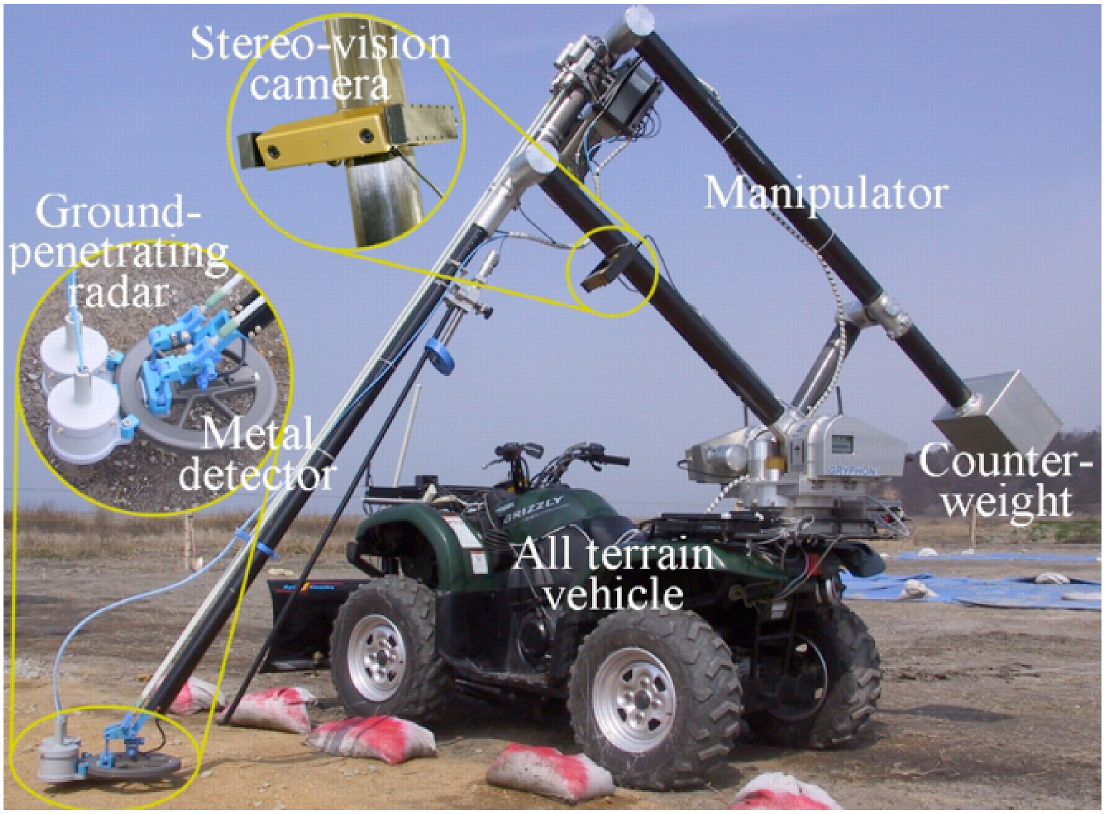


Figure 1: Gyphon the Landmine Detector.

Given that the robot arm is long and the tires and suspension of the ATV are flexible, the endpoint of the arm tends to vibrate when it moves around. The landmine sensors give poor measurements when the arm vibrates. So, it is important to understand these vibrations and develop a control system to suppress the vibration.

1) Assume the ATV is not moving and that the end point of the arm only moves in a horizontal plane (no vertical motion). Create a model of the system that would reveal the oscillatory dynamics of the system.

2) How would the model need to be changed to account for vertical motions of the endpoint?

3) How would the dynamics change when the ATV is moving?

4) What type of control system would you use to control the system? What sensors would be needed by your controller?