GEORGIA INSTITUTE OF TECHNOLOGY

SCHOOL of ELECTRICAL and COMPUTER ENGINEERING

ECE 2025 Spring 2003
Problem Set #11

Assigned: 21-Mar-03
Due Date: Week of 31-March-03

Quiz #3 will be given on 11-April.

Reading: In *SP First*, Chapter 8: *IIR Filters*

$\Longrightarrow$ **Please check the "Bulletin Board" often. All official course announcements are posted there.**

ALL of the **STARRED** problems will have to be turned in for grading. A solution will be posted to the web. Some problems have solutions similar to those found on the CD-ROM.

Your homework is due in recitation at the beginning of class. After the beginning of your assigned recitation time, the homework is considered late and will be given a zero.
Please follow the format guidelines (cover page, etc.) for homework.

PROBLEM 11.1*:

Use the most convenient form of these system functions to determine the corresponding impulse responses of the following:

(a) $H_a(z) = \dfrac{1-2z^{-1}}{1-0.5z^{-1}} = \dfrac{1}{1-0.5z^{-1}} - \dfrac{2z^{-1}}{1-0.5z^{-1}} = 4 - \dfrac{3}{1-0.5z^{-1}}$

(b) $H_b(z) = \dfrac{2+0.9z^{-1}}{1+0.9z^{-1}+0.81z^{-2}} = \dfrac{1}{1+0.9e^{j\pi/3}z^{-1}} + \dfrac{1}{1+0.9e^{-j\pi/3}z^{-1}}$

(c) $H_c(z) = \dfrac{18+24z^{-2}}{1+0.75z^{-2}} = 32 - \dfrac{7}{1-j\frac{1}{2}\sqrt{3}z^{-1}} - \dfrac{7}{1+j\frac{1}{2}\sqrt{3}z^{-1}}$

PROBLEM 11.2*:

For each of the difference equations below, determine the poles and zeros of the corresponding system function, $H(z)$. Plot the poles **(x)** and zeros **(o)** in the complex z-plane. In most cases, you should be able to obtain the poles and zeros by inspection, but you could use MATLAB's `roots` function to find them.

$$\mathcal{S}_1: \quad y[n] = 0.5y[n-1] + x[n] - 2x[n-1]$$

$$\mathcal{S}_2: \quad y[n] = -0.9y[n-1] - 0.81y[n-2] + 2x[n] + 0.9x[n-1]$$

$$\mathcal{S}_3: \quad y[n] = 0.75y[n-2] + 18x[n] + 24x[n-2]$$

$$\mathcal{S}_4: \quad y[n] = -y[n-2] + x[n] - x[n-4]$$

PROBLEM 11.3*:

A causal LTI system has the following system function:

$$H(z) = \frac{18 + 24z^{-2}}{1 + 0.75z^{-2}}$$

The following questions cover most of the ways available for analyzing IIR discrete-time systems.

(a) Plot the poles and zeros of $H(z)$ in the z-plane.

(b) Use inverse z-transforms to determine the impulse response $h[n]$ of the system; i.e., the output of the system when the input is $x[n] = \delta[n]$.

(c) Determine if the system is stable.

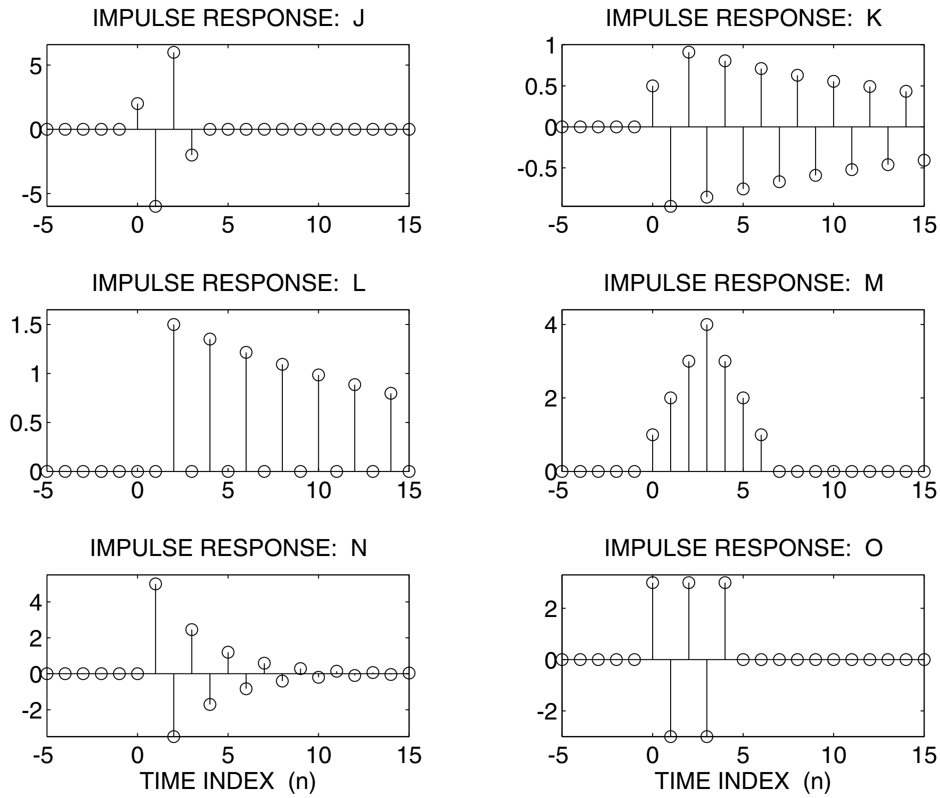
(d) Determine a simple expression for the frequency response $H(e^{j\hat{\omega}})$ of the system.

(e) Plot the magnitude of the frequency response.

(f) Use the frequency response function to determine the output $y_1[n]$ of the system when the input is

$$x_1[n] = 2\cos(0.5\pi n) \qquad -\infty < n < \infty.$$

PROBLEM 11.4*:



(a) For each of the impulse-response plots (J, K, L, M, N, O), determine which one of the following systems[1] (specified by either an $H(z)$ or a difference equation) matches the impulse response. ***Explain your answers.***

$\mathcal{S}_0$: $y[n] = 0.90y[n-2] + 1.5x[n-2]$

$\mathcal{S}_1$: $y[n] = -0.7y[n-1] + 5x[n-1]$

$\mathcal{S}_2$: $y[n] = -0.7y[n-1] + 7x[n] + 10x[n-1]$

$\mathcal{S}_3$: $H(z) = \dfrac{\frac{1}{2}(1 - z^{-1})}{1 + 0.94z^{-1}}$

$\mathcal{S}_4$: $H(z) = 2(1 - z^{-1})^3$

$\mathcal{S}_5$: $H(z) = 3(1 - z^{-1} + z^{-2} - z^{-3} + z^{-4})$

$\mathcal{S}_6$: $y[n] = 8x[n] - 8x[n-1]$

$\mathcal{S}_7$: $y[n] = 2\sum_{k=0}^{7}(-1)^k x[n-k]$

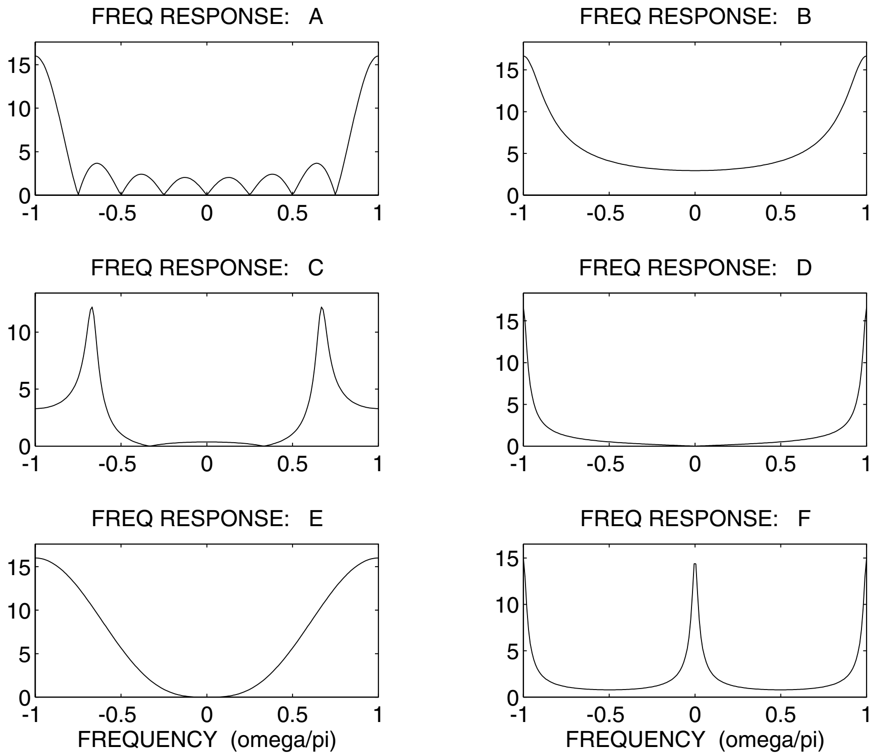
$\mathcal{S}_8$: $y[n] = x[n] + 2x[n-1] + 3x[n-2] + 4x[n-3] + 3x[n-4] + 2x[n-5] + x[n-6]$

$\mathcal{S}_9$: $H(z) = \dfrac{1 - z^{-1} + z^{-2}}{1 + 0.9z^{-1} + 0.81z^{-2}}$

(b) For systems $\mathcal{S}_0$ through $\mathcal{S}_4$ above, make the pole-zero plot of each system in the z-plane.

[1]These 8 systems are exactly the same as the next matching problems.

PROBLEM 11.5*:



(a) For each of the frequency response plots (A, B, C, D, E, F), determine which one of the following systems[2] (specified by either an $H(z)$ or a difference equation) matches the frequency response (magnitude only). ***Explain your answers.***
Note: the frequency axis is ***normalized***; it is $\hat{\omega}/\pi$.

$\mathcal{S}_0:\qquad y[n] = 0.90y[n-2] + 1.5x[n-2]$

$\mathcal{S}_1:\qquad y[n] = -0.7y[n-1] + 5x[n-1]$

$\mathcal{S}_2:\qquad y[n] = -0.7y[n-1] + 7x[n] + 10x[n-1]$

$\mathcal{S}_3:\qquad H(z) = \dfrac{\frac{1}{2}(1-z^{-1})}{1+0.94z^{-1}}$

$\mathcal{S}_4:\qquad H(z) = 2(1-z^{-1})^3$

$\mathcal{S}_5:\qquad H(z) = 3(1-z^{-1}+z^{-2}-z^{-3}+z^{-4})$

$\mathcal{S}_6:\qquad y[n] = 8x[n] - 8x[n-1]$

$\mathcal{S}_7:\qquad y[n] = 2\sum_{k=0}^{7}(-1)^k x[n-k]$

$\mathcal{S}_8:\qquad y[n] = x[n] + 2x[n-1] + 3x[n-2] + 4x[n-3] + 3x[n-4] + 2x[n-5] + x[n-6]$

$\mathcal{S}_9:\qquad H(z) = \dfrac{1-z^{-1}+z^{-2}}{1+0.9z^{-1}+0.81z^{-2}}$

(b) For systems $\mathcal{S}_5$ through $\mathcal{S}_9$ above, make the pole-zero plot of each system in the z-plane.

[2]These 10 systems are exactly the same as the previous matching problems.

PROBLEM 11.6:

This problem has been given before. Study it and its solution carefully when preparing for Quiz #3.

We have developed several concepts that are useful in solving problems involving LTI systems. The main concepts are the *difference equation*, the *impulse response*, the *system function*, and the *frequency response* function. Most problem solving demands that you be able to go back and forth among these different mathematical representations of the LTI system because, as simple as it seems, the z-transform is *not* always the best tool for solving problems. Indeed, for a specific problem, one of these representations may be more convenient than the others, or we may need to use more than one of these representations in solving a given problem. The following is a simple problem that might be posed about an LTI system:

Given the input sequence $x[n]$ find the output sequence for all n when the system is an IIR filter:

$$y[n] = 0.8y[n-1] + x[n] + x[n-2].$$

The following is a partial list of possible approaches to solving this problem:

1. *Time-Domain:* Use the difference equation representation of the system to compute the output $y[n]$ for all required values of n. *For example, you could do this using* MATLAB.
2. *Z-Domain:* Multiply the z-transform of the input by the system function and determine $y[n]$ as the inverse z-transform of $Y(z)$.
3. *Frequency-Domain:* Break the input into a sum of complex exponential signals, use the frequency response function to determine the output due to each complex exponential signal separately, and finally, add the individual outputs together to get $y[n]$.

In each of these solution methods you would use one or more of the basic representations of the first-order IIR filter. Which method is easiest will have a lot to do with the nature of the input signal. For example, if you are given the difference equation and you want to use approach #2, you will have to determine the system function $H(z)$ from the difference equation coefficients.

Now in each of the following cases, the input will be given. In each case, determine which representation of the system and which of the above approaches will lead to the easiest solution of the problem, and detail the steps in using that approach to solve the problem. For example, if you choose approach #2 to solve the problem, your answer should be something like the following:

Step 1: Find $X(z)$, the z-transform of $x[n]$.

Step 2: Find $H(z)$, the system function of the first-order IIR filter.

Step 3: Multiply $X(z)H(z)$ to get $Y(z)$.

Step 4: Take the inverse z-transform of $Y(z)$ to get $y[n]$.

Now here are some possible inputs. In each case, state which of the approaches above (#1, #2, or #3) you would use. There may not be a clear cut answer. Give the approach that you *think* will yield the solution with least effort. Then carry out the method to get the output.

(a) $x[n] = u[n]$.

(b) $x[n] = 2\cos(0.5\pi n - \pi/2) + \cos(0.25\pi n - \pi)$ for $-\infty < n < \infty$.

(c) $x[n] = 10\delta[n-5]$.

(d) $x[n]$ is a sampled speech signal. It is represented by a vector of 10000 numbers. In this case, you do not have to find the actual output.