The University of Texas at Austin
Dept. of Electrical and Computer Engineering
Midterm #1

Date: March 6, 2024 Course: EE 445S Evans

Name: ____
Last, First

- **Exam duration**. The exam is scheduled to last 75 minutes.
- **Materials allowed**. You may use books, notes, your laptop/tablet, and a calculator.
- **Disable all networks**. Please disable all network connections on all computer systems. You may not access the Internet or other networks during the exam.
- **No AI tools allowed**. As mentioned on the course syllabus, you may not use GPT or other AI tools during the exam.
- **Electronics.** Power down phones. No headphones. Mute your computer systems.
- **Fully justify your answers**. When justifying your answers, reference your source and page number as well as quote the particular content in the source for your justification. You could reference homework solutions, test solutions, etc.
- **Matlab**. No question on the test requires you to write or interpret Matlab code. If you base an answer on Matlab code, then please provide the code as part of the justification.
- **Put all work on the test**. All work should be performed on the quiz itself. If more space is needed, then use the backs of the pages.
- **Academic integrity.** By submitting this exam, you affirm that you have not received help directly or indirectly on this test from another human except the proctor for the test, and that you did not provide help, directly or indirectly, to another student taking this exam.

Problem	*Point Value*	*Your score*	*Topic*
1	25		FIR Filter Analysis
2	24		Predistortion
3	27		Detection of Radar
4	24		Mystery Systems
Total	100		

Problem 1.1 *FIR Filter Analysis*. 25 points.

Consider a causal linear time-invariant (LTI) discrete-time finite impulse response (FIR) filter with input $x[n]$ and output $y[n]$ observed for $n \geq 0$. The transfer function in the z-domain is

$$H(z) = a + b\,z^{-1} + c\,z^{-2} \quad \text{for } z \neq 0$$

where $a, b,$ and c are real-valued constants.

(a) Give the equation for output $y[n]$ in terms of the input $x[n]$ in the discrete-time domain for $n \geq 0$. *6 points*.

(b) What are the initial condition(s) and their value(s)? Why? *3 points*.

(c) In managing the memory for storing the previous input values, would you advocate for a linear buffer or a circular buffer? Why? *3 points*

(d) Derive a formula for the discrete-time frequency response of the filter. *3 points*.

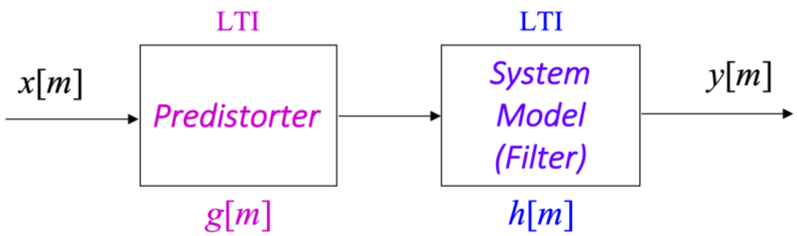
(e) Give all possible conditions on the constants $a, b,$ and c so that the FIR filter has constant group delay. *10 points*.

Problem 1.2 *Predistortion.* 24 points.

Predistortion is a technique used to compensate the distortion in another system.

An example is applying predistortion to an audio signal before being played by an audio speaker.

The block diagram below illustrates the use of predistortion when the predistorter is a linear time invariant (LTI) system and the other system is modeled as LTI:

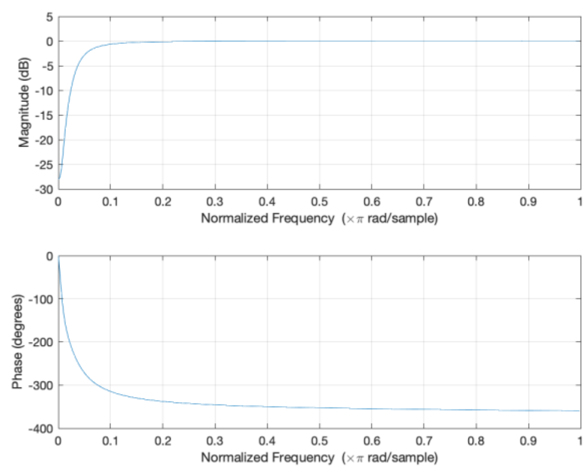


In this problem, $g[m]$ is the impulse response of the discrete-time LTI predistorter, and $h[m]$ is the impulse response of a discrete-time LTI model of an audio speaker.

Each LTI system is a second-order infinite impulse response (IIR) filter with two zeros and two poles.

The sampling rate f_s is 44100 Hz.

(a) The LTI model of the audio speaker $h[m]$ has the frequency response on the right. *12 points*.



i. The two poles are located at $p_0 = 0.9\, e^{j\omega_p}$ and $p_1 = 0.9\, e^{-j\omega_p}$. Please give the value for discrete-time frequency ω_p that corresponds to continuous-time frequency 441 Hz.

ii. The two zeros are located at $z_0 = 1.02\, e^{j\omega_z}$ and $z_1 = 1.02\, e^{-j\omega_z}$. Please give the value for discrete-time frequency ω_z that corresponds to continuous-time frequency 100 Hz.

(b) Give the two poles and two zeros for a bounded-input bounded-output (BIBO) stable LTI predistorter $g[m]$ to compensate the distortion $h[m]$. *12 points*.

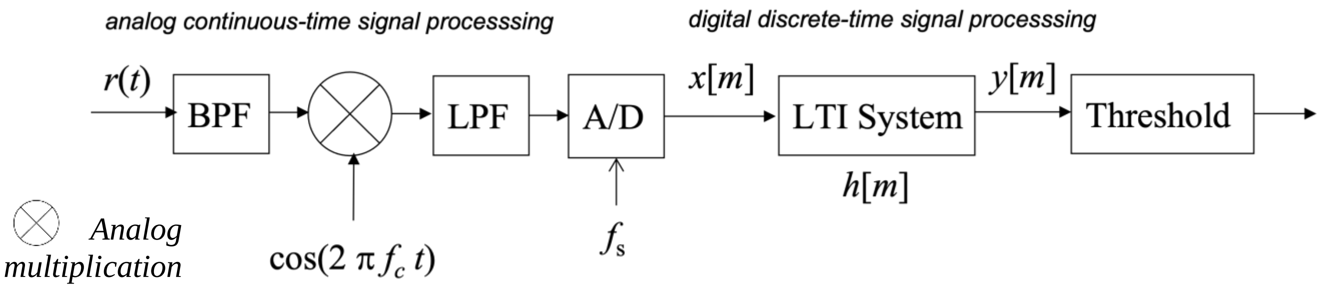
Problem 1.3 *Detection of Radar*. 27 points.

In certain wireless communication bands, radar systems might also be operating from time to time.

The Citizens Broadband Radio Service (CBRS) band, which is between 3550 MHz and 3700 MHz, is used for cellular communications and US military radar, including shipborne radar off the US coasts.

If a communication system in the CBRS band in the US detects radar operating in the transmission band, then the communication system must stop transmitting within one second.

In this problem, you'll design a system to the detect the presence of an SPN-43 radar operating at a center frequency of 3570 MHz with a bandwidth of 1.6 MHz based on the block diagram below:



A/D: *Analog-to-digital converter operating at sampling rate* f_s. BPF: *Bandpass filter*. LPF: *Lowpass filter*. LTI System: *linear time-invariant system*. $r(t)$: *received radio frequency signal*.

The threshold block will compare its input $y[m]$ to a constant and output true or false to indicate whether or not there is an SPN-43 radar operating at a center frequency of 3570 MHz.

In your answers below, please explain why you chose the numerical values that you did.

(a) Give passband and stopband frequencies for the bandpass filter (BPF). *6 points*.

(b) Give a value for f_c. *3 points.*

(c) Give the passband and stopband frequencies for the lowpass filter (LPF). *3 points*

(d) Give a sampling rate f_s for the analog-to-digital (A/D) converter. *3 points.*

(e) Design a second-order LTI system with infinite impulse response $h[m]$ by giving the formulas for the two poles and two zeros to enable detection of an SPN-43 radar system if one is operating. *12 points*

Problem 1.4. *Mystery Systems*. 24 points.

You're trying to identify unknown discrete-time systems.

You input a discrete-time chirp signal $x[n]$ and look at the output to figure out what the system is.

The discrete-time chirp is formed by sampling a chirp signal that sweeps 0 to 8000 Hz over 0 to 5s

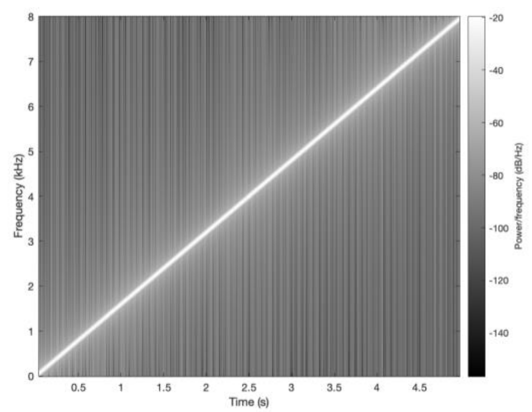
$$x(t) = \cos(2\pi f_1 t + 2\pi \mu t^2)$$

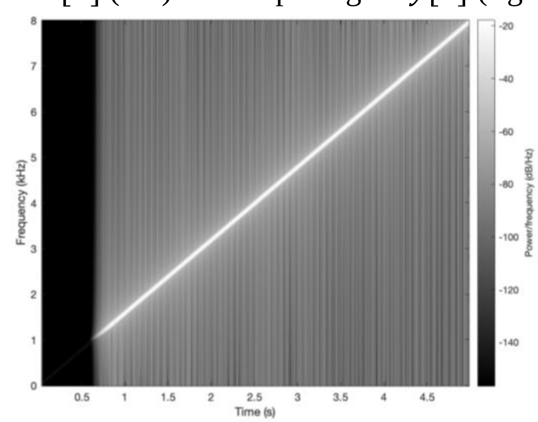
where $f_1 = 0$ Hz, $f_2 = 8000$ Hz, and $\mu = \frac{f_2 - f_1}{2\, t_{\max}} = \frac{8000 \text{ Hz}}{10\, s} = 800 \text{ Hz}^2$. Sampling rate f_s is 16000 Hz.

In each part below, identify the unknown system as one of the following **with justification**:

1. filter – give selectivity (lowpass, highpass, bandpass, bandstop) and passband/stopband frequencies
2. upsampler – give upsampling factor
3. downsampler – give downsampling factor
4. pointwise nonlinearity – give the integer exponent k to produce the output $y[n] = x^k[n]$

(a) Given spectrograms of the chirp input signal $x[n]$ (left) and output signal $y[n]$ (right). *12 points*.





(b) Given spectrograms of the chirp input signal $x[n]$ (left) and output signal $y[n]$ (right). *12 points.*