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

Date: March 13, 2019 Course: EE 445S Evans

Name: ____
Last, First

- The exam is scheduled to last 50 minutes.
- Open books and open notes. You may refer to your homework assignments and the homework solution sets.
- Calculators are allowed.
- You may use any standalone computer system, i.e. one that is not connected to a network. ***Please disable all wireless connections on your computer system(s).***
- Please turn off all cell phones.
- No headphones allowed.
- All work should be performed on the quiz itself. If more space is needed, then use the backs of the pages.
- **Fully justify your answers.** If you decide to quote text from a source, please give the quote, page number and source citation**.**

Problem	*Point Value*	*Your score*	*Topic*
1	28		Filter Analysis
2	24		Sampling & Aliasing
3	24		Filter Design
4	24		Potpourri
Total	100		

Problem 1.1 *Filter Analysis*. 28 points.

Consider the following causal linear time-invariant (LTI) discrete-time filter with input $x[n]$ and output $y[n]$ described by

$$y[n] = a\, x[n] + b\, x[n\text{-}1] - b\, x[n\text{-}2] - a\, x[n\text{-}3]$$

for $n \geq 0$, where a and b are real-valued positive coefficients.

(a) Is this a finite impulse response (FIR) or infinite impulse response (IIR) filter? Why? *3 points*.

(b) What are the initial conditions and their values? Why? *6 points*.

(c) Draw the block diagram of the filter relating input $x[n]$ and output $y[n]$. *6 points*.

(d) Derive a formula for the transfer function in the z-domain and the region of convergence. *4 points*.

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

(f) Give a formula for the phase response vs. discrete-time frequency and the group delay vs. discrete-time frequency. Does the filter have linear phase over all frequencies? Why or why not? *6 points*.

Problem 1.2 *Sampling and Aliasing.* 24 points.

A frequency of 46 kHz is higher than the normal audible range of 20 Hz to 20 kHz for a human being.

Consider a continuous-time signal $x(t) = \cos(2\,\pi\, f_0\, t)$ where $f_0 = 46$ kHz.

Sample the signal using a sampling rate of $f_s = 48$ kHz.

(a) Derive a formula for the discrete-time signal $x[n]$ that results from sampling $x(t)$. *3 points.*

(b) Using only analysis of $x[n]$ in the discrete-time domain, determine the discrete-time frequency to which the continuous-time frequency of f_0 will alias. *6 points.*

(c) What is the equivalent continuous-time frequency for the aliased discrete-time frequency in (b)? *6 points.*

(d) Using only analysis in the continuous-time frequency domain of sampling applied to $x(t)$, determine the continuous-time frequency to which the continuous-time frequency f_0 will alias. The answer should be the same as part (c). *6 points.*

(e) Is the aliased frequency audible? *3 points.*

Problem 1.3 *Filter Design.* 24 points.

An electrocardiogram (ECG) device records the heart's electrical potential versus time for monitoring heart health and diagnosing heart disorders. [1]

Use a sampling rate f_s of 240 Hz for the continuous-time ECG signal for a monitoring application.

Design a third-order discrete-time infinite impulse response (IIR) filter to remove baseline wander noise below 0.5 Hz and powerline interference at 60 Hz in an ECG signal. [1]

Baseline wander noise is induced by electrode changes due to perspiration, movement and respiration.

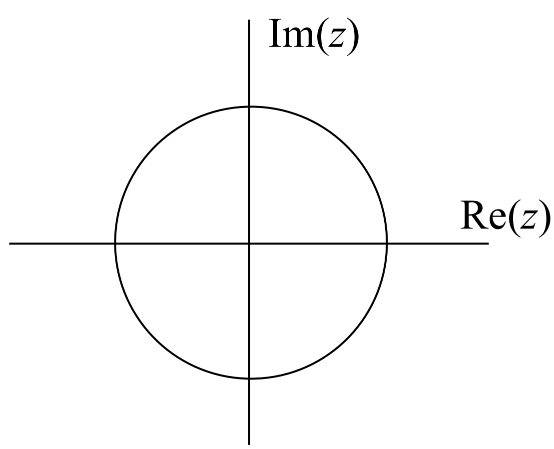
The third-order discrete-time IIR filter will be a cascade of a first-order and a second-order section.

(a) Design a first-order discrete-time IIR filter to remove DC (0 Hz) but pass as many of the other frequencies as possible with a gain of one in linear units. Please give the pole, zero, and gain. *6 points*.

(b) Design a second-order discrete-time IIR filter to remove 60 Hz but pass as many of the other frequencies as possible with a gain of one in linear units. Please give the two poles, two zeros, and gain. *6 points*.

(c) Plot the poles and zeros for the third-order discrete-time IIR filter on the right. The circle on the right has a radius of 1. *6 points*.

(d) What is the response of the discrete-time IIR filter to continuous-time frequencies in the ECG signal that are odd harmonics of 60 Hz, i.e. 180 Hz, 300 Hz, etc.? Why? *6 points*.

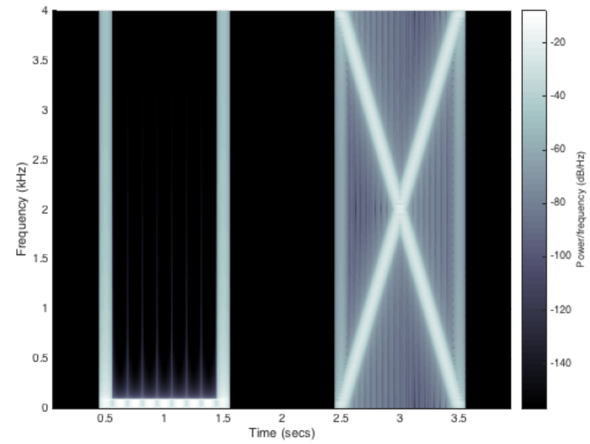


[1] Yong Lian and Jianghong Yu, "A Low Power Linear Phase Digital FIR Filter for Wearable ECG Device", *Proc. IEEE Int. Conf. on Engineering in Medicine and Biology Society*, pp. 7357-7360, 2005.

Problem 1.4. *Potpourri.* 24 points.

(a) A discrete-time signal with sampling rate of f_s of 8000 Hz has the following "UX" spectrogram. The spectrogram was computed using 1000 samples per block and an overlap of 900 samples.

i. Describe the frequency components vs. time. *6 points*.



ii. What would the signal sound like when played as audio signal? *6 points*.

(b) Consider an unknown causal, time-varying, nonlinear, discrete-time system with input $x[n]$ and output $y[n]$. We will model the system as a discrete-time linear time-invariant (LTI) finite impulse response (FIR) filter. Find the FIR coefficients.

i. Give a formula for a finite-length input signal other than an impulse that contains all frequencies. *3 points*.

ii. Using your answer in part i, derive a time-domain algorithm to estimate the FIR filter coefficients. Your algorithm should also be able to determine how many FIR filter coefficients are meaningful. *9 points*.

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