EL 6113 : Digital Signal Processing I **Fall 2016**
Section B (Selesnick)

Outline

13 Lectures + Midterm exam + Final exam

(The outline is subject to change.)

LECTURE 1
Discrete-time signals
System properties
LTI systems - convolution
    MATLAB function: conv
Connections of systems
BIBO stability condition
If time: Z-transform (definition, FIR examples)

Homework 1
From Signals packet
System classification
FIR convolution
one sided convolution
two-sided convolution
convolution as a matrix
MATLAB: plotting signals, convolution

LECTURE 2
Z-transform
    ROC
    Right-sided and left-sided signals
    Inverse Z-transform
    Partial fraction expansion
    MATLAB functions: roots, poly, residue
    Transformations of z (1/z, -z, -1/z, z^2)
Transfer functions
    Poles/zeros
Inverse systems
    non-causal systems
    stable inverses on non-minimum-phase systems
    MATLAB demo - Inverse System
If time allows:
Difference equations
    basic example
    difference equation -> transfer function

Homework 2
From Signals packet
MATLAB: inverse systems

LECTURE 3

- Difference equations
  - MATLAB function: filter
- Complex poles
  - MATLAB demo: difference equation -> impulse response, for system with complex poles [complex_poles_demo]
  - Matching pole/zero and impulse responses diagrams
- DC gain
- Frequency response
  - Periodicity of frequency response
  - Response of LTI systems to sinusoidal inputs and frequency response
  - evaluation of frequency response as a polynomial
  - MATLAB demo: frequency response
  - MATLAB functions: freqz, polyval
- Normalized frequency
- Z-transform / frequency response / unit circle
  - Relationships between time domain and frequency domain characteristics
  - poles-zeros <-> frequency response (pdf file animation)

Homework 3
From Signals packet
Difference equations
Complex poles
Frequency response
MATLAB functions: filter, freqz, polyal

LECTURE 4

- DTFT
  - Definition
  - Ideal LPF / impulse response using inverse DTFT
  - sinc function
  - impulses
  - cosine
  - properties (shift, multiplication, periodicity, Parseval, etc.)
  - real-valued signals, symmetries
  - example spectra of signals (e.g., voiced and unvoiced speech)

Homework 4

- frequency response
  - matching with pole-zero diagrams

Simple system design
    real and complex poles and zeros
DTFT problems from Oppenheim and Schafer
MATLAB: simple system design - verify them.

LECTURE 5

Simple system design (review HW 4)
    low-order systems, specified dc gain and nulls
Notch filters
    Motivation: removing 60 Hz hum, baseline drift correction
    second-order recursive filter
    tonal noise suppression
    baseline drift correction
    MATLAB demo: notch filter demo
N-point moving-average filter
    roots of unity
    digital sinc function
    roots of unity equally spaced on unit circle
        <-> nulls of digital sinc function equally spaced
Phase delay of system
    delay of sine through LTI system
    MATLAB demo: filter delay demo

Homework 5
From Signals packet
From DSP packet
    Filters related to N-point moving average
transfer functions / filters / roots of unity
Matlab:
    baseline drift using dc notch filter
    tonal noise speech filtering
    higher-order notch filters

LECTURE 6

DFT
    definition
    properties
    periodic and linear convolution
    connection with DTFT
    matching
    MATLAB functions: fft, ifft
DFT as a matrix
Circular convolution as a matrix
    relation to linear convolution

Using the DFT
- DFT to evaluate DTFT
- zero-padding
- MATLAB: fftshift

MATLAB demo: phase distortion demo
ideal fractional-sample delay

Homework 6
DFT problems from DSP packet.
MATLAB:
- spectra of speech
- notch filter
- 'anti-notch' filter

LECTURE 7

DFT/DTFT
- evaluation of spectra
- frequency leakage

Filtering
- general concepts
- ideal filters
- recursive/non-recursive filters
- approximation problem

Linear-phase FIR filters
- why linear-phase?
- the four types
- properties

Homework 7
From DSP packet
- DFT
- Filters
- Linear-phase FIR filters

LECTURE 8

FFT
- radix-2

Windows
- Standard windows
  - Hamming, Hann, Blackman, Kaiser
- MATLAB functions: hamming, kaiser

FIR filter design using windows
- MATLAB functions: kaiserord, fir1

Frequency measurement using windows

FIR filter design using interpolation (DFT)
STFT (Maybe postponed to later lecture)
- definition
- parameters: frame size, hop, DFT length
- influence of parameters
- MATLAB function: specgram

Homework 8
From DSP packet
- Windows
- FIR filter design using windows
- FIR filter design by interpolation (DFT)
- STFT

Matlab: STFT

LECTURE 9
Recursive filters
- Standard types: Butterworth, Cheby1, Cheby2, Elliptic
- MATLAB demo: recursive filters demo
- MATLAB functions: butter, cheby1, cheby2, ellip

Optimal FIR filter design
- Least square linear-phase
- MATLAB function: firls
- Parks-McClellan (Remez)
- MATLAB demo: firpm demo

Homework 9
From DSP packet
- Least squares filter design
- Recursive filter design (classic methods)

Matlab:
- firls, firpm, butter, cheby1, cheby2, ellip
- low-pass filtering of noisy speech

LECTURE 10
Zero-phase filtering
- forwards-backwards filtering
- MATLAB function: filtfilt

Conversion of analog systems to digital systems
- Bilinear transformation (BLT)
- MATLAB function: bilinear
- Impulse Invariance method

Magnitude Characteristics of LTI systems
- Factorization of Desired Magnitude functions for system synthesis

All Pass Systems
Characterizations and Delay Properties
Minimum Phase Systems
Definition
Minimum Delay Property
Factorization of H(z) into minimum phase, all pass product

<u>Homework 10</u>
From DSP packet
zero-phase filtering
Problems - Oppenheim and Schafer?
Matlab:
compare causal IIR with zero-phase (non-causal) filtering (Matlab filter vs filtfilt)

LECTURE 11
Filter transformations
LPF->HPF, LPF->BPF, LPF->BSF, etc.
Least squares
overdetermined and underdetermined systems of linear equations
differentiation wrt vectors
normal equations
constrained least squares
polynomial approximation
banded systems
extrapolation, linear prediction
smoothing
deconvolution
system identification
interpolation

<u>Homework 11</u>
Least squares packet

LECTURE 12
Least squares (cont.)
Least squares smoothing as an LTI filter
Least squares deconvolution as an LTI filter
Fourier transforms (continuous-time)
Fourier Series and Orthogonal Functions
Sampling theorem

<u>Homework 12</u>
Problems - Oppenheim and Schafer..

LECTURE 13

Catch up
- if behind schedule

Special filters
- differentiators
- Hilbert transform
- fractional delay
- comb filters

Selected topics
- Convolution using overlap-add and overlap-save
- Discrete Cosine Transform (DCT)
- Stability triangle for second-order systems
- Periodogram
- Group delay
- Prony method

<u>Homework 13</u>

None (last lecture)