TUTORIAL 4

Objective:

Design of FIR filters using windowing, frequency sampling technique

Note: Students need to revise the theory covered in this tutorial
Write the code in the observation book (Calculation not required)

Filter structures

1. Determine the Cascade and Parallel form structure for the filter with transfer function

$$H(z) = \frac{0.44z^2 + 0.362z + 0.02}{z^3 + 0.4z^2 + 0.18z - 0.2}$$

```
num = [0 0.44 0.362 .02];
den = [1 0.4 0.18 -0.2];
[cascade_sos,G] = tf2sos(num,den);
[r p k] = residuez(num,den)
```

2. Determine the lattice form structure for the filter transfer functions given below. *Use MATLAB function poly2rc.* Also check the stability of the filters.

$$a)\, H(z) = 1 + 1.2z^{-1} + 1.12z^{-2} + 0.12z^{-3} - 0.08z^{-4}$$

$$b)\, H(z) = \frac{1 + 1.6z^{-1} + 0.6z^{-2}}{1 - z^{-1} - 0.25z^{-2} + 0.25z^{-3}}$$

```
% Sample Solution (2a)

num2a = [1 1.2 1.12 0.12 -0.08];
den2a = [1];
k2a = poly2rc(num2a);
% Sample Solution (2b)
num2b = [1 1.6 0.6];
den2b = [1 -1 -0.25 0.25];
[k2b,v2b] = tf2latc(num2b,den2b);
```

FIR Filters

3. Determine the impulse response of an ideal lowpass filter with linear phase characteristics. Truncate the impulse response at different lengths, say N=11, 21, 31, 41 and observe the magnitude response of the filters. *Gibbs phenomenon*

```
clear;clc;clf;
M=input('enter the length of the filter:');
w_c=pi/3;
Mby2=(M-1)/2;
n=0:M-1;
h_d = sin(w_c*(n-Mby2))./(pi*(n-Mby2));
h_d(Mby2+1) = w_c/pi;
[H,w] = freqz(h_d,1);
```

```
subplot(211), stem(n,h_d);
subplot(212), plot(w/pi,abs(H));
figure
freqz(h_d,1);
```

4. Consider a low pass filter with ω_p=0.2π and ω_s =0.3π. Design a FIR filter using frequency sampling method. Plot the frequency response of the designed filter and determine the ripple in the passband (R_p) and minimum stopband attenuation (A_s). Try for filter length M=20 and M=40.

```
w_p=0.2*pi; w_s=0.3*pi;
M = input('Enter order of filter:');
pass=fix(w_p*M/(2*pi))+1; % kp
stop=fix(w_s*M/(2*pi))+1; % ks
trans=stop-pass;
if rem(M,2)==0,U=M/2 -1;else U=(M-1)/2;end;
if trans==1,
Hr=[ones(1 ,pass),zeros( 1 ,U-pass+1)];
else
tk = pass+ 1 :stop;
trans_mag=0.5*(1+cos(pi*(tk-pass)/trans)); % raised
coosine in transition band
     Hr=[ones(1,pass),trans_mag, zeros(1,U-stop+1)];
end;
k=0:U;
G=(-1).^k.*Hr;
if rem(M,2)==0,
G_M=[G 0 -G(U+1:-1 :2)]; else
G_M=[G -G(U+1:-1 :2)];
end;
I=0:M-1 ;
H=G_M.*exp(pi*I*j/M);
h=ifft(H);
Mag = abs(fft(h,512));
w=[0:255]*pi/256; plot(w,Mag(1:256));
figure;
freqz(h,1,512);
```

5. Design the above filter using Hanning window, Hamming window, Blackmann window, and Bartlett window. Plot the impulse response, amplitude response and zero locations of the designed filter and compare their performance.

Characteristics of commonly used window functions

Window function	*Approximate Transition width $\Delta\omega$*	*Exact Transition width $\Delta\omega$*	*Minimum stop band attenuation A_s dB*
Rectangular	4π/M	1.8π/M	21
Hamming	8π/M	6.2π/M	44
Hanning	8π/M	6.6π/M	53
Bartlett	8π/M	6.1π/M	25
Blackmann	12π/M	11π/M	74

```
% lowpass design using window functions clear;close all;
        w_p=0.2*pi;
        M = input('Enter order of filter:');
        h_hann=fir1 (M,w_p/pi,hann(M+1));
        h_hamm=fir1 (M,w_p/pi,hamming(M+1));
        h_blackman=fir1 (M,w_p/pi,blackman(M+1));
        h_bartlett=fir1 (M,w_p/pi,bartlett(M+1));
        freqz(h_hann, 1,512);title(['Hanning window, M='
        ,int2str(M)]);
        figure;
        freqz(h_hamm,1,512);title(['Hamming window, M='
        ,int2str(M)]);
        figure;
        freqz(h_blackman,1,512);title(['Blackman window,
        M=',int2str(M)]);
        figure;
        freqz(h_bartlett,1 ,512);title(['Bartlett window,
        M=' ,int2str(M)]);
        figure;
        n=0:M;
        subplot(2,2,1 ),stem(n,h_hann);
        title(['Hanning window, M=',int2str(M)]);
        subplot(2,2,2),stem(n,h_hamm);
        title(['Hamming window, M=' ,int2str(M)]);
        subplot(2,2,3),stem(n,h_blackman);
        title(['Blackman window, M=' ,int2str(M)]);
        subplot(2,2,4) ,stem(n ,h - bartlett);
        title(['Bartlett window, M=' ,int2str(M)]);
        figure;
        subplot(2,2,1 ),zplane(h_hann,1 );
        title(['Hanning window, M=' ,int2str(M)]);
        subplot(2,2,2),zplane(h_hamm,1 );
        title(['Hamming window, M=' ,int2str(M)]);
        subplot(2,2,3),zplane(h_blackman,1 );
        title(['Blackman window, M=' ,int2str(M)]);
        subplot(2,2,4 ),zplane(h_bartlett,1 );
        title(['Bartlett window, M=' ,int2str(M)]);
```

6. Design a FIR low pass filter of order 20 with the following frequency response using Remez exchange algorithm

$$H(\omega) = 1;\ 0 \le \omega \le 0.4\pi.$$
$$0;\ 0.5\pi \le \omega \le \pi.$$

Problem may be extended for the design of high pass, band pass and band reject filters.

```
% FIR filter design using Remez Exchange method
n = 20;   % length of filter
f = [0  0.4  0.5  1];    % filter specs
m = [1  1    0    0];
bfir = remez(n,f,m)
[hfir,wfir] = freqz(bfir);
plot(f,m,wfir/pi,abs(hfir),'-');
title(' n=20 FIR LPF');
```

7. Design a linear phase FIR bandpass filter to satisfy the following specifications:

Passband	8-12 kHz
Stopband ripple	0.001
Peak passband ripple	0.0015
Sampling frequency	44.14 kHz
Transition width	3 kHz

Obtain the filter coefficients and compare the frequency response for the filter using (a) window method (b) frequency sampling method and (c) optimal method

```
clear; clc; close all;
h=fir1(82,[0.3624 0.5437],blackman(83));
freqz(h,1,512)
figure
% mod5_7b
f = [0 5 8 12 15 22.07]/22.07;
m = [0 0 1 1 0 0];
b = fir2(80,f,m);
[h,w] = freqz(b,1,128);
plot(f,m,w/pi,abs(h));
legend('ldeal','fir2 Designed')
title('Comparison of Frequency Response
Magnitudes');
figure
% mod5_7c
rp = 0.0015;   % Passband ripple
rs = 0.001;  % Stopband ripple
fs = 44140; % Sampling frequency
f = [5000 8000 12000 15000]; % Cutoff frequencies
a = [0 1 0 ]; % Desired amplitudes
dev=[rs rp rs]; % deviations
[n, fo, mo, w]=remezord(f, a, dev, fs);
hopt = remez(n,fo,mo,w);
[H ,W]=freqz(hopt,1,1024);
```