Digital Signal Processing Laboratory

EXPERIMENT-6

Shorya Sharma
19EE01017

1 Problem Statement 1

1.1 Question

Obtain the coefficients of an FIR low pass filter to meet the specifications given below using the window method.

passband edge frequency	1.5kHz
transition width	0.5kHz
stopband attenuation	$>$ 50 dB
sampling frequency	8kHz

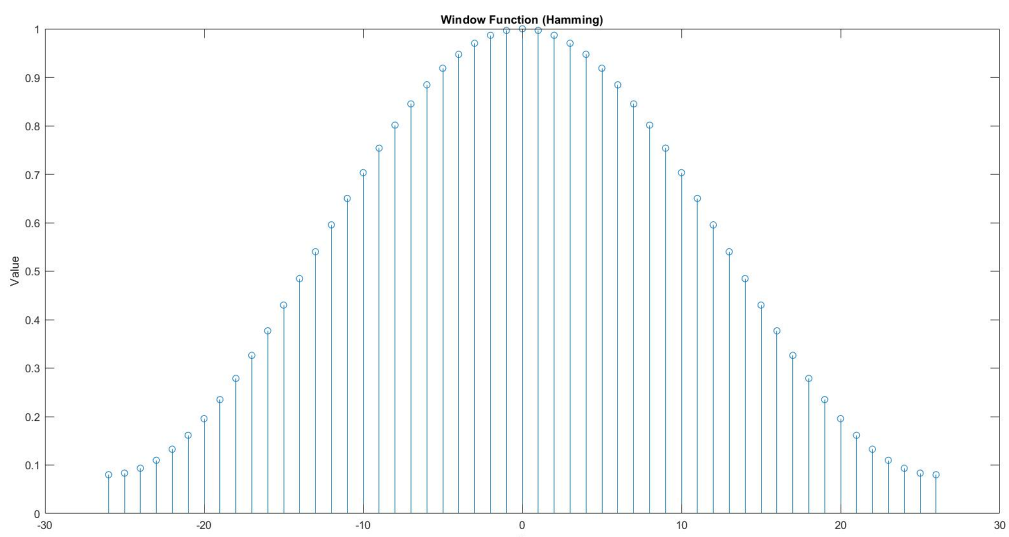
1.2 Choice of window

Since the stopband attenuation should is 50 dB, Hamming filter should be used.
Transition width = 0.5 KHz/8Khz = 0.0625
Length of window = 3.3/Transition width
3.3/0.0625 = 52.8
So,Window length N =53
Ideal Impulse response

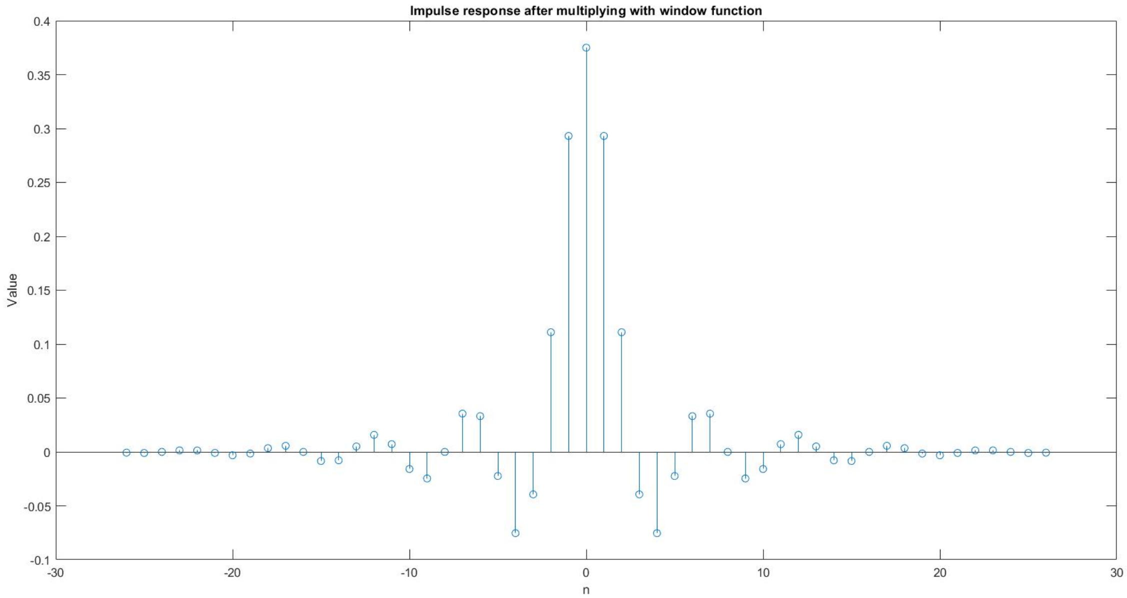
$$h_{LP}[n] = \frac{\sin \omega_c n}{\pi n}$$

$$\omega_c = 1.5/8 = 0.1875$$

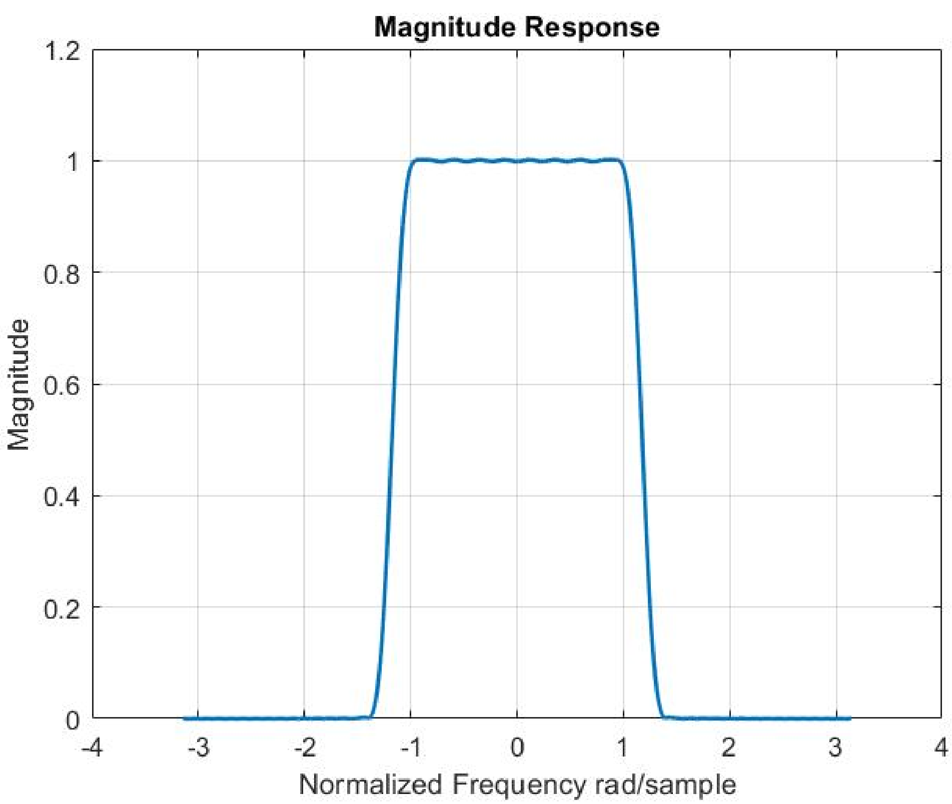
1.3 Window Function

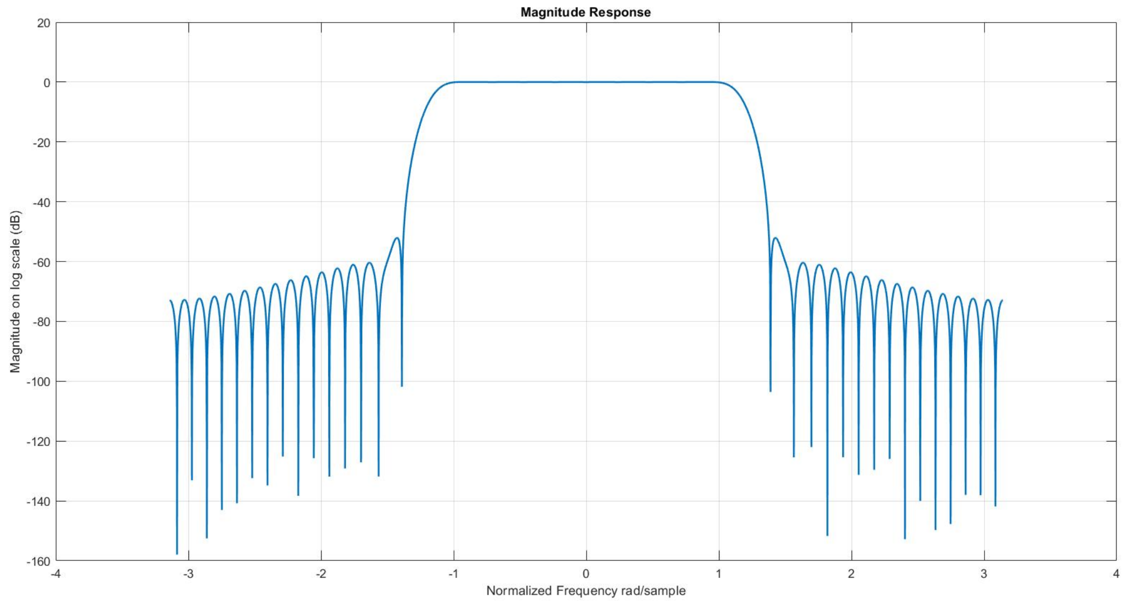


1.4 Impulse Response

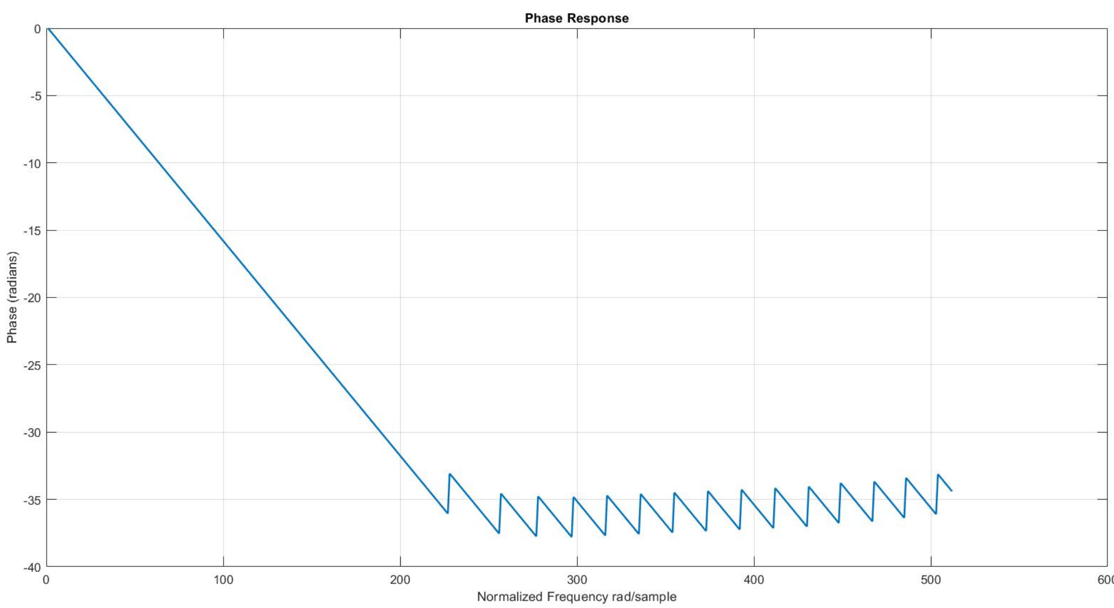


1.5 Magnitude Response





1.6 Phase Response



1.7 Filter coefficients

```
Columns 1 through 13

 -0.0007   -0.0010    0.0000    0.0014    0.0014   -0.0009   -0.0031   -0.0015    0.0035    0.0056   -0.0000   -0.0084   -0.0078

Columns 14 through 26

  0.0051    0.0158    0.0072   -0.0158   -0.0246    0.0000    0.0355    0.0332   -0.0224   -0.0754   -0.0394    0.1110    0.2931

Columns 27 through 39

  0.3750    0.2931    0.1110   -0.0394   -0.0754   -0.0224    0.0332    0.0355    0.0000   -0.0246   -0.0158    0.0072    0.0158

Columns 40 through 52

  0.0051   -0.0078   -0.0084   -0.0000    0.0056    0.0035   -0.0015   -0.0031   -0.0009    0.0014    0.0014    0.0000   -0.0010

Column 53

 -0.0007
```

2 Problem Statement 2

2.1 Question

A requirement exists for an FIR digital filter to meet the following specifications:

Passband	$150 - 250$ Hz
transition width	50 Hz
passband ripple	0.1 dB
stopband attenuation	60 dB
sampling frequency	1kHz

Obtain the filter coefficients and spectrum using the window method.

2.2 Choice of window

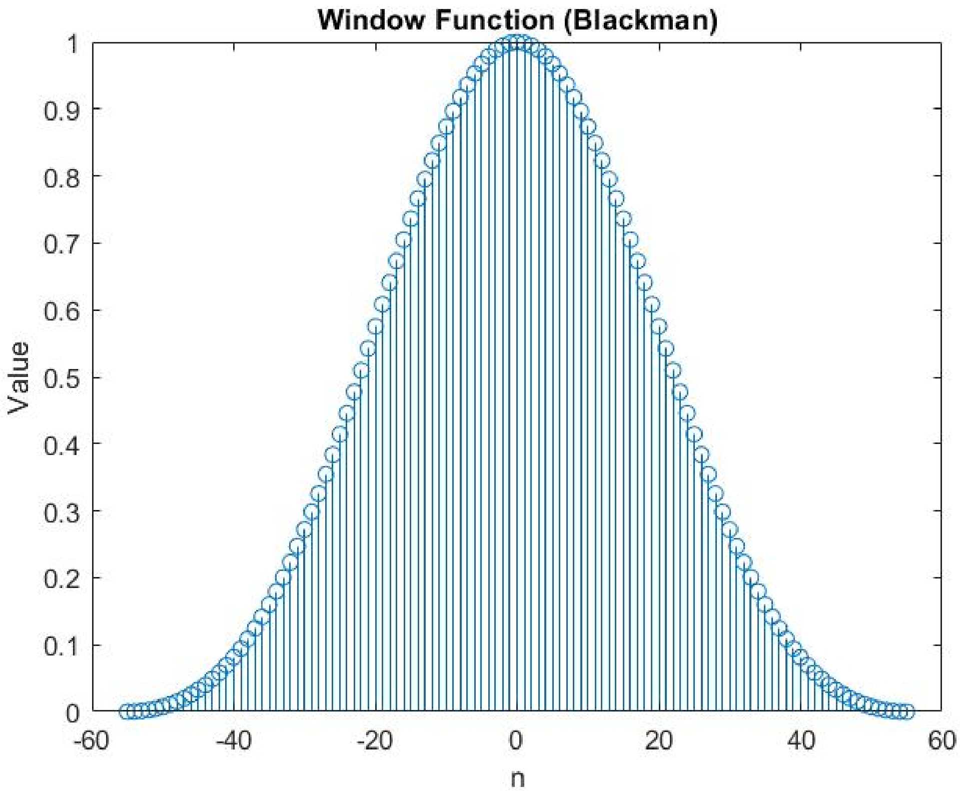
Since the stopband attenuation should is 50 dB, Blackman filter should be used.
Transition width = 50 Hz/1Khz = 0.05
Length of window = 5.5/Transition width
5.5/0.05 = 110
So,Window length N=111 (odd)
Ideal Impulse response

$$h_{BP}[n] = \begin{cases} \frac{\sin(\omega_h n)}{\pi n} - \frac{\sin(\omega_l)}{\pi n}, & n \neq 0 \\ \frac{\omega_h}{\pi} - \frac{\omega_l}{\pi}, & n = 0 \end{cases}$$

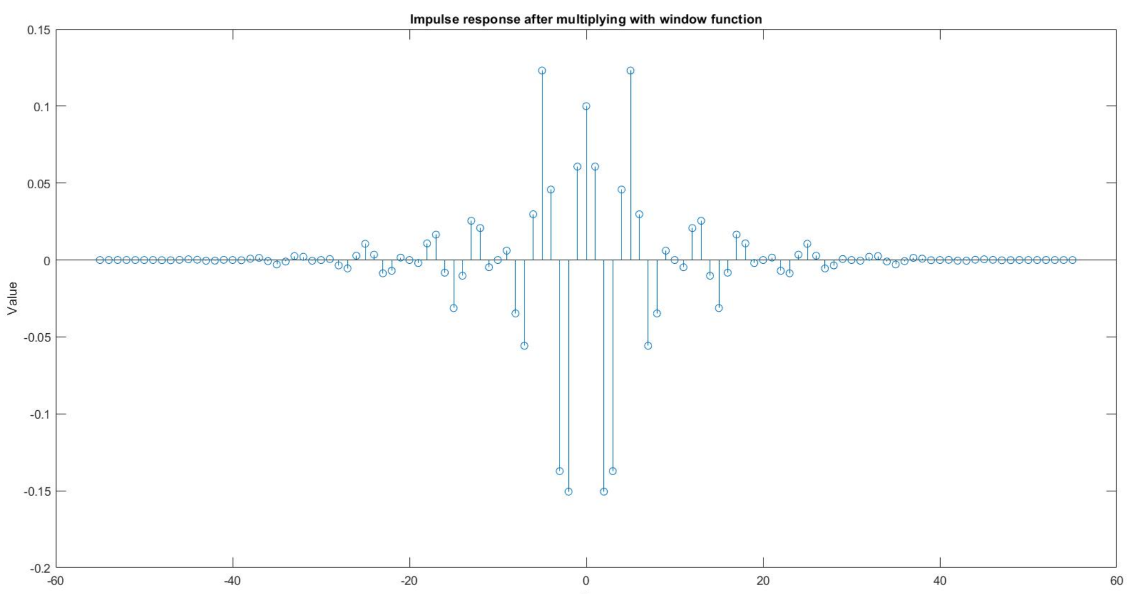
$$\omega_h = 250/1000 = 0.25$$

$$\omega_l = 150/1000 = 0.15$$

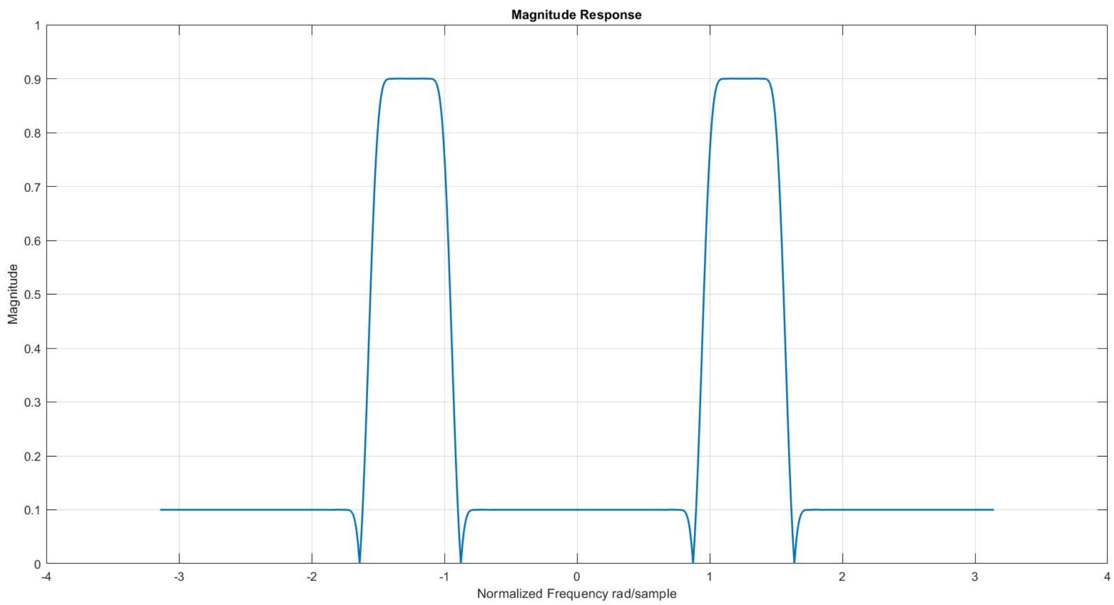
2.3 Window Function

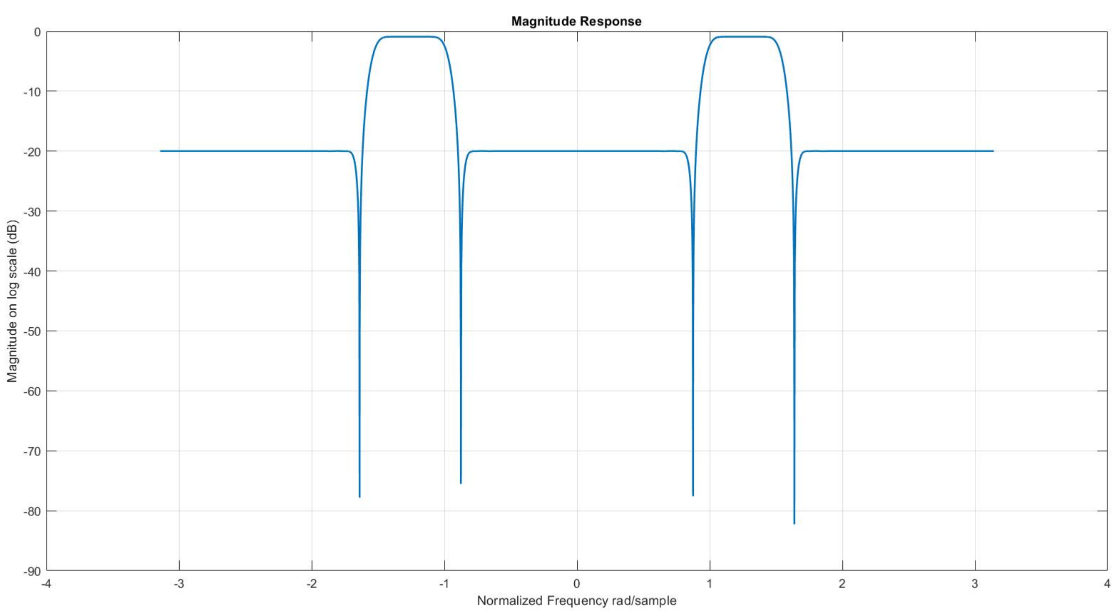


2.4 Impulse Response

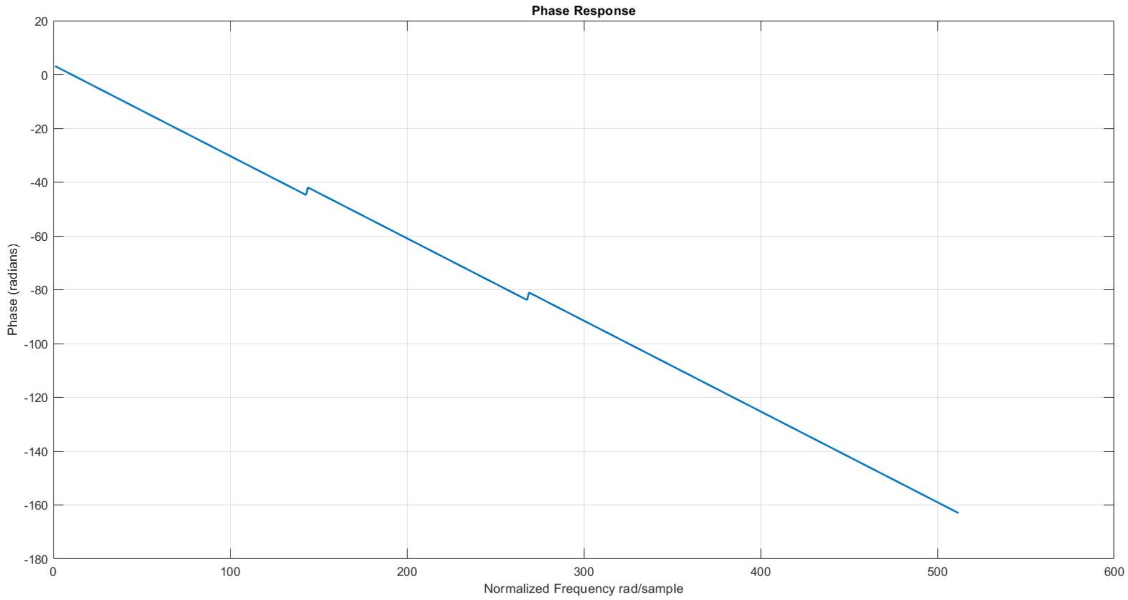


2.5 Magnitude Response


Magnitude Response
Magnitude
Normalized Frequency rad/sample
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-4
-3
-2
-1
0
1
2
3
4


Magnitude Response
Magnitude on log scale (dB)
Normalized Frequency rad/sample
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-4
-3
-2
-1
0
1
2
3
4

2.6 Phase Response



2.7 Filter coefficients

```
h_n =

  Columns 1 through 13

    0.0000   -0.0000    0.0000    0.0000   -0.0000   -0.0000    0.0000   -0.0001   -0.0002    0.0001    0.0005    0.0002   -0.0005

  Columns 14 through 26

   -0.0004    0.0001   -0.0000   -0.0001    0.0009    0.0014   -0.0007   -0.0029   -0.0010    0.0025    0.0021   -0.0005    0.0000

  Columns 27 through 39

    0.0006   -0.0035   -0.0055    0.0028    0.0106    0.0035   -0.0086   -0.0070    0.0016   -0.0000   -0.0019    0.0108    0.0165

  Columns 40 through 52

   -0.0082   -0.0312   -0.0102    0.0255    0.0208   -0.0047    0.0000    0.0061   -0.0347   -0.0557    0.0297    0.1231    0.0458

  Columns 53 through 65

   -0.1372   -0.1506    0.0607    0.1000    0.0607   -0.1506   -0.1372    0.0458    0.1231    0.0297   -0.0557   -0.0347    0.0061

  Columns 66 through 78

    0.0000   -0.0047    0.0208    0.0255   -0.0102   -0.0312   -0.0082    0.0165    0.0108   -0.0019   -0.0000    0.0016   -0.0070

  Columns 79 through 91

   -0.0086    0.0035    0.0106    0.0028   -0.0055   -0.0035    0.0006    0.0000   -0.0005    0.0021    0.0025   -0.0010   -0.0029

  Columns 92 through 104

   -0.0007    0.0014    0.0009   -0.0001   -0.0000    0.0001   -0.0004   -0.0005    0.0002    0.0005    0.0001   -0.0002   -0.0001

  Columns 105 through 111

    0.0000   -0.0000   -0.0000    0.0000    0.0000   -0.0000    0.0000
```

3 Problem Statement 3

3.1 Question

Obtain the coefficients of a linear phase FIR filter using the Kaiser window to satisfy the following amplitude response specifications:

stopband attenuation	40 dB
passband ripple	0.01 dB
transition width	500 Hz
sampling frequency	10kHz
ideal cutoff frequency	1200 Hz

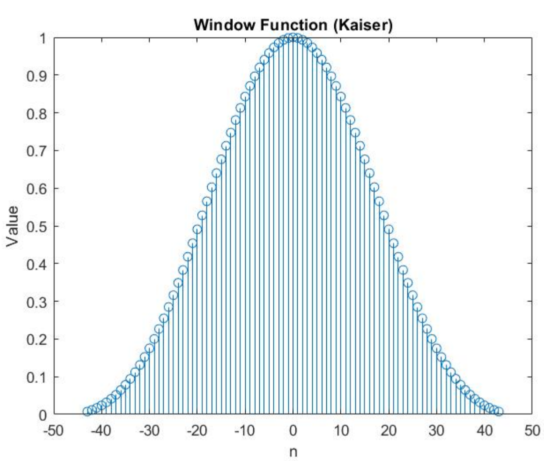
3.2 Choice of window

As given in the question, we have to use Kaiser window. Since the passband ripple is given as 0.01 dB, we should use $\beta = 6.76$
Transition width = 500 Hz/10 Khz = 0.05
Length of window = 4.32/Transition width
4.32/0.05 = 86.4
So,Window length N=87
Assuming Highpass filter Ideal Impulse response

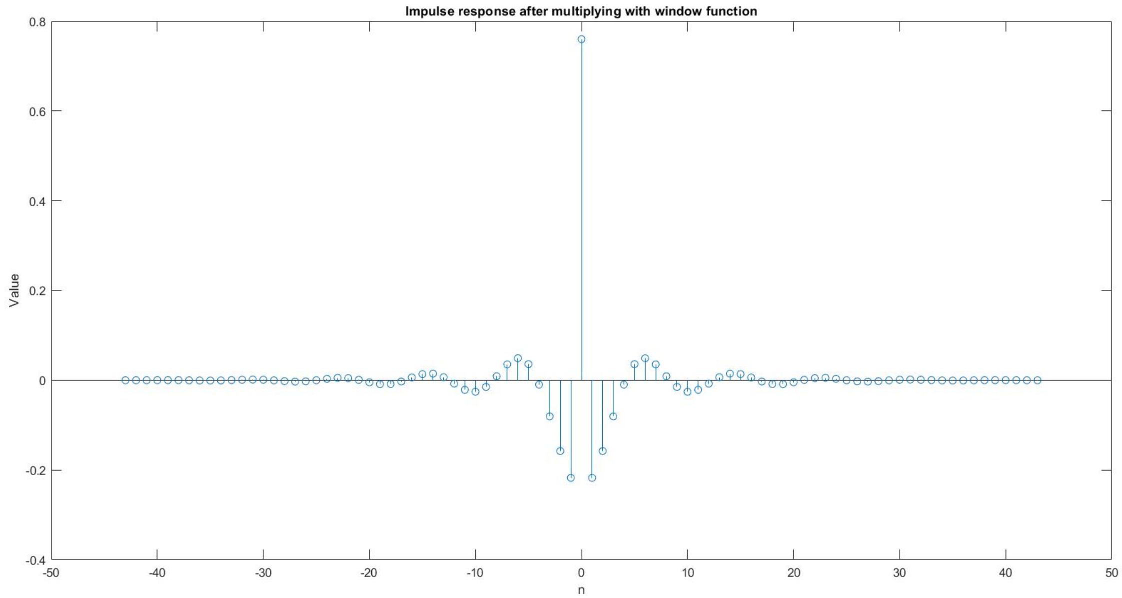
$$h_{HP}[n] = \begin{cases} 1 - \frac{\omega_c}{\pi}, & n = 0 \\ -\frac{\sin(\omega_c n)}{\pi n}, & n \neq 0 \end{cases}$$

$$\omega_c = 1200/10000 = 0.12$$

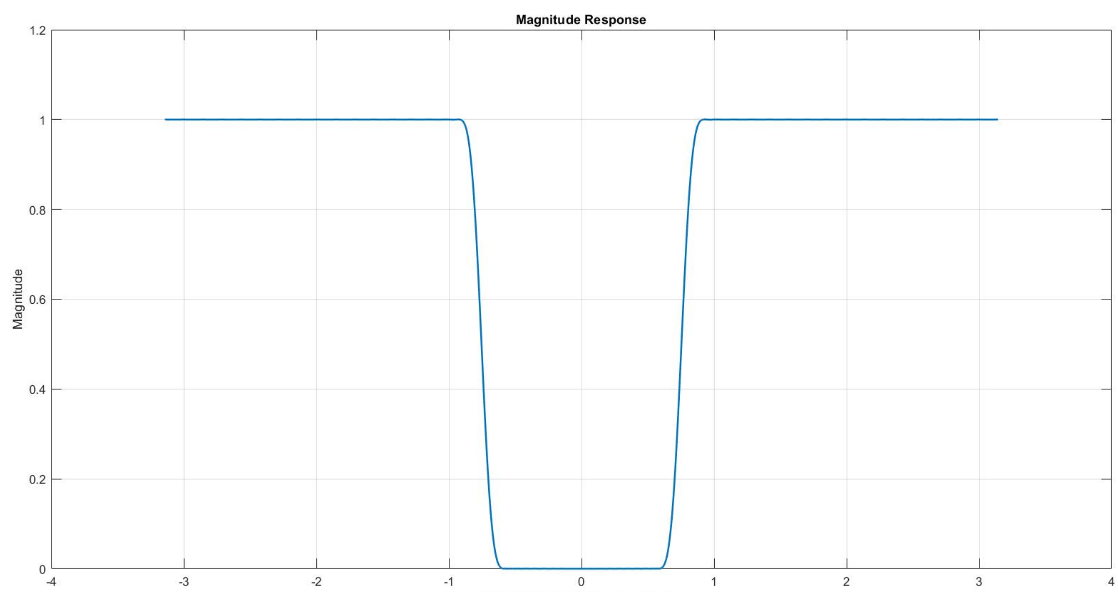
3.3 Window Function

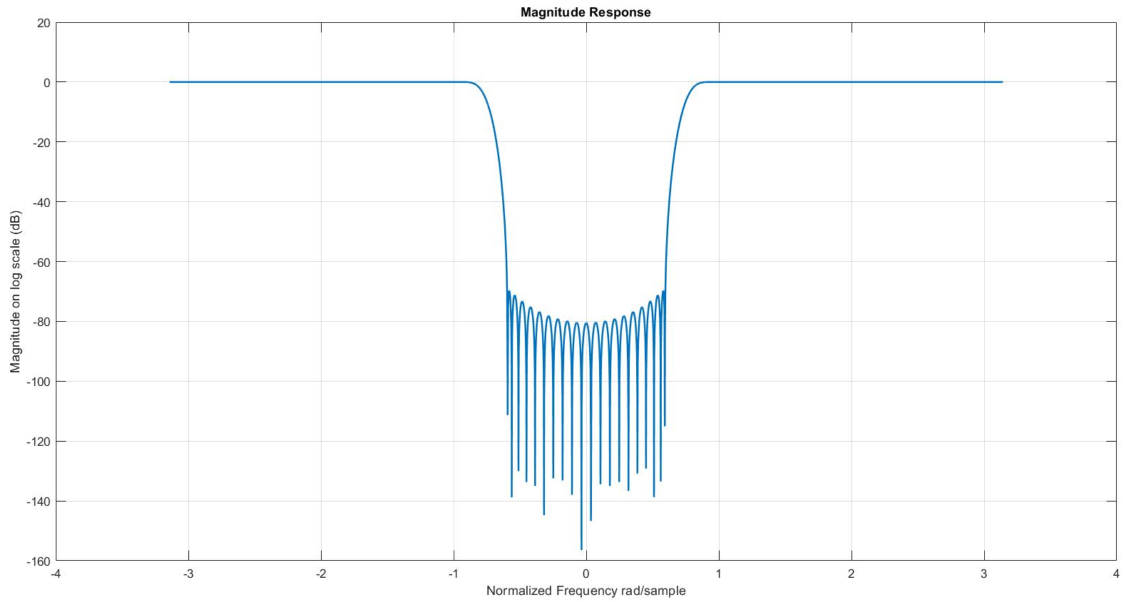


3.4 Impulse Response

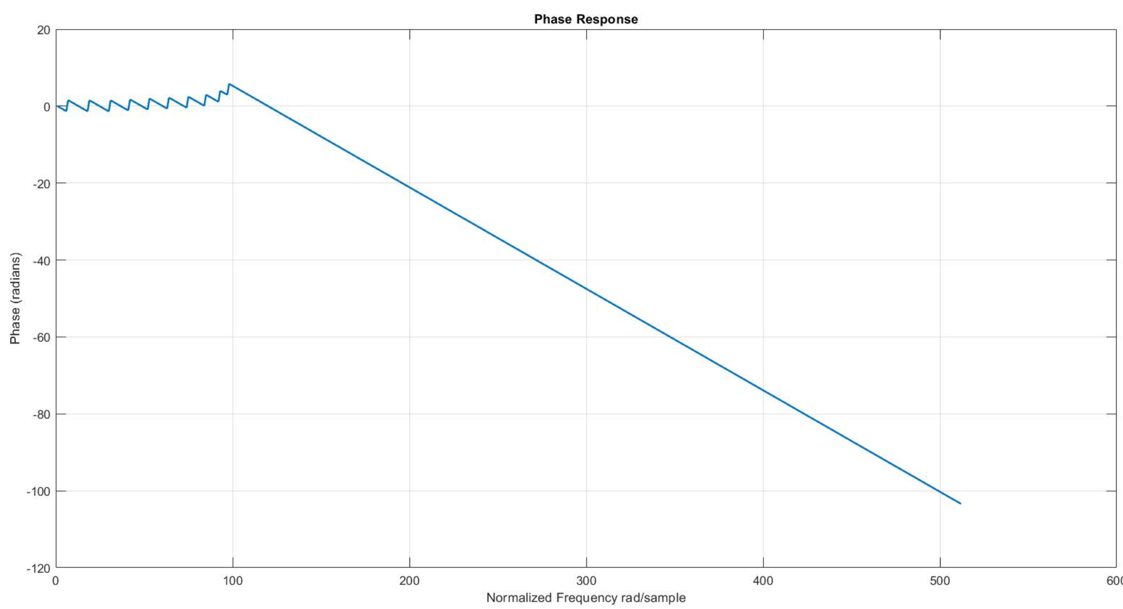


3.5 Magnitude Response





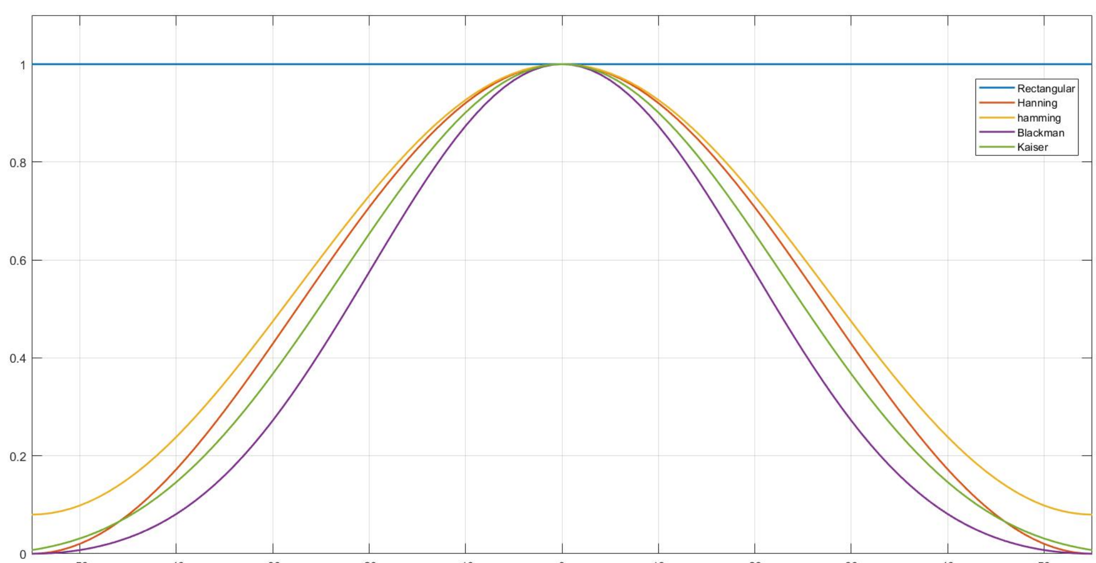
3.6 Phase Response



3.7 Filter Coefficients

```
Columns 1 through 13

 -0.0000   -0.0000    0.0001    0.0002    0.0002    0.0001   -0.0002   -0.0005   -0.0007   -0.0004    0.0003    0.0011    0.0015

Columns 14 through 26

  0.0011   -0.0003   -0.0020   -0.0030   -0.0024    0.0000    0.0032    0.0053    0.0047    0.0009   -0.0046   -0.0087   -0.0084

Columns 27 through 39

 -0.0028    0.0061    0.0137    0.0147    0.0067   -0.0076   -0.0213   -0.0255   -0.0148    0.0089    0.0353    0.0490    0.0359

Columns 40 through 52

 -0.0097   -0.0805   -0.1578   -0.2175    0.7600   -0.2175   -0.1578   -0.0805   -0.0097    0.0359    0.0490    0.0353    0.0089

Columns 53 through 65

 -0.0148   -0.0255   -0.0213   -0.0076    0.0067    0.0147    0.0137    0.0061   -0.0028   -0.0084   -0.0087   -0.0046    0.0009

Columns 66 through 78

  0.0047    0.0053    0.0032    0.0000   -0.0024   -0.0030   -0.0020   -0.0003    0.0011    0.0015    0.0011    0.0003   -0.0004

Columns 79 through 87

 -0.0007   -0.0005   -0.0002    0.0001    0.0002    0.0002    0.0001   -0.0000   -0.0000
```

4 Windows



5 Conclusion

Digital Filters are among the most common DSP applications, being found in a large variety of embedded systems. This experiment involves the design, simulation and implementation of a digital filter.There is no feedback path and therefore this filter is always stable. In problem statement 1, the designed filter was a lowpass filter and the window used was Hamming.In the problem statement 2, we used a blackman window to design the bandpass filter.In problem statement 3, a Kaiser window was employed. In part 3, we also had to design zero-order modified Bessel function of the first kind for the implementation.50 terms were calculated in the Bessel's function.All the phase responses obtained were Linear, a characteristic of FIR filters. We noticed how the undesirable ripples and overshoots (Gibb's phenomenon) were almost eliminated for all the three filters designed with the help of different types of windows.

6 Appendix (Code)

Part 1

```
clc
clear all
close all
%DSP LAB
%Experiment 6
%QUestion 1 : FIR Low Pass filter

t_w = 0.5/8;
N= 3.3/t_w;
N = floor(N);
if(mod(N,2)==0)
    N=N+1;
end
M = floor((N-1)/2);
n = -M:M;
w_n = 0.54 + 0.46.*cos(pi.*n/M);
fe = 1.5/8;
we = 2*pi*fe;

h_d_n = sin(we.*n)./(pi.*n);
h_d_n(round(N/2)) =2*fe;


h_n = w_n.*h_d_n;
figure()
stem(n,w_n);xlabel('n');ylabel('Value');tit
le('Window Function (Hamming)');
figure()
stem(n,h_n);xlabel('n');title('Impulse
response after multiplying with window
function');ylabel('Value');

ff = -pi:0.0001:pi;

q=0;
for q = 1:length(ff)
 w = ff(q);
 temp = h_n.*(exp(-j*w.*n));
 h(q) = sum(temp);
end

figure()
plot(ff,abs(h));grid on;xlabel('Normalized
Frequency
rad/sample');ylabel('Magnitude');title('Mag
nitude Response');

figure()
plot(ff,mag2db(abs(h)));grid
on;xlabel('Normalized Frequency
rad/sample');ylabel('Magnitude on log scale
(dB)');title('Magnitude Response');

figure()
plot(phasez(h_n));grid
on;xlabel('Normalized Frequency
rad/sample');ylabel('Phase
(radians)');title('Phase Response');
```

Part 2

```
clc
clear all
close all
%DSP LAB
%Experiment 6
%QUestion 2 : FIR Band Pass filter

t_w = 50/1000;
N = floor(5.5/t_w);
if(mod(N,2)==0)
    N=N+1;
end
M = (N-1)/2;
n = -M:M;
w_n = 0.42 + 0.5.*cos(pi.*n/M) + +
0.08.*cos(2*pi.*n/M);


wl = 2*pi*150/1000;
wh = 2*pi*250/1000;
h_d_n = (sin(wh.*n)-sin(wl.*n))./(pi.*n);
h_d_n(round(N/2)) = (wh-wl)/(2*pi);


h_n = w_n.*h_d_n;
figure()
stem(n,w_n);xlabel('n');ylabel('Value');tit
le('Window Function (Blackman)');
figure()
stem(n,h_n);xlabel('n');title('Impulse
response after multiplying with window
function');ylabel('Value');

ff = -pi:0.0001:pi;

q=0;
for q = 1:length(ff)
 w = ff(q);
 temp = h_n.*(exp(-j*w.*n));
 h(q) = sum(temp);
end

figure()
plot(ff,abs(h));grid on;xlabel('Normalized
Frequency
rad/sample');ylabel('Magnitude');title('Mag
nitude Response');

figure()
plot(ff,mag2db(abs(h)));grid
on;xlabel('Normalized Frequency
rad/sample');ylabel('Magnitude on log scale
(dB)');title('Magnitude Response');

figure()
plot(phasez(h_n));grid
on;xlabel('Normalized Frequency
rad/sample');ylabel('Phase
(radians)');title('Phase Response');
```

Part 3

```
clc
clear all
close all
%DSP LAB
%Experiment 6
%QUestion 3 : FIRHigh Pass filter

t_w = 500/10000;
N = floor(4.32/t_w);
if(mod(N,2)==0)
    N=N+1;
end
M=(N-1)/2;
n = -M:M;
beta = 6.76;
w_n = inot(beta*((1-((2.*n/(N-
1)).^2)).^0.5))./inot(beta);
fe =1200/10000;
h_d_n = (-2*fe*sin(n*2*pi*fe))./(n*2*pi*fe);
h_d_n(round(N/2)) =1 - 2*fe;

h_n = w_n.*h_d_n;
figure()
stem(n,w_n);xlabel('n');ylabel('Value');title('Wind
ow Function (Kaiser)');
figure()
stem(n,h_n);xlabel('n');title('Impulse response
after multiplying with window
function');ylabel('Value');

ff = -pi:0.0001:pi;
q=0;
for q = 1:length(ff)
 w = ff(q);
 temp = h_n.*(exp(-j*w.*n));
 h(q) = sum(temp);
end

figure()
plot(ff,abs(h));grid on;xlabel('Normalized
Frequency
rad/sample');ylabel('Magnitude');title('Magnitude
Response');

figure()
plot(ff,mag2db(abs(h)));grid on;xlabel('Normalized
Frequency rad/sample');ylabel('Magnitude on log
scale (dB)');title('Magnitude Response');

figure()
plot(phasez(h_n));grid on;xlabel('Normalized
Frequency rad/sample');ylabel('Phase
(radians)');title('Phase Response');
```

Zero order modified bessel's function for Kaiser window for 50 terms code (used as function inot in code)

```
function out = inot(x)
out = zeros(1,length(x));
for i=0:50
    out = out +
1*((0.25*(x.^2)).^i)./(factorial(i)^2);
end
end
```

Code for plotting all types of windows

```
clc
clear all
close all
M=55;
n=-M:M;
N=111;beta=6.76;
w_n_r = ones(1,length(n));
w_n_han = 0.5 + 0.5.*cos(pi.*n/M);
w_n_ham = 0.54 + 0.46.*cos(pi.*n/M);
w_n_b = 0.42 + 0.5.*cos(pi.*n/M) + +
0.08.*cos(2*pi.*n/M);
w_n_k = inot(beta*((1-((2.*n/(N-
1)).^2)).^0.5))./inot(beta);


plot(n,w_n_r,'DisplayName','Rectangular')
;
hold on;
plot(n,w_n_han,'DisplayName','Hanning');
hold on;
plot(n,w_n_ham,'DisplayName','hamming');
hold on;

plot(n,w_n_b,'DisplayName','Blackman');
hold on;
plot(n,w_n_k,'DisplayName','Kaiser');
 grid on; axis([-M M 0 1.1]);legend;
```