classmate
Date :
Page :

SECTION - 1

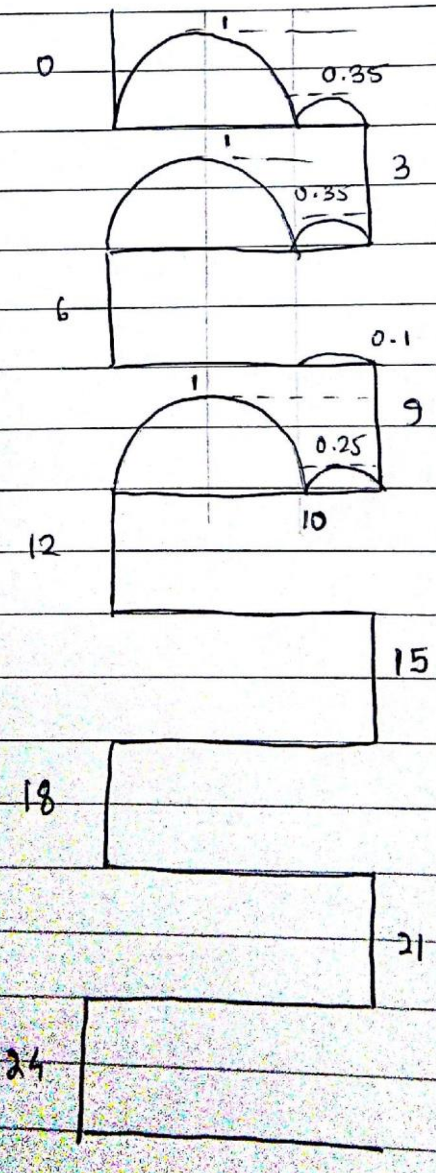
1) For Nyquist criteria,

$$f_s \geq 2\,(\text{max frequency in bandwidth})$$
$$\therefore\ f_s \geq 2\,(12)\ \text{kHz}$$
$$\therefore\ f_s \geq 24\ \text{kHz}$$

So, $T_s = \dfrac{1}{f_s} = \dfrac{1}{24\times10^{3}}$

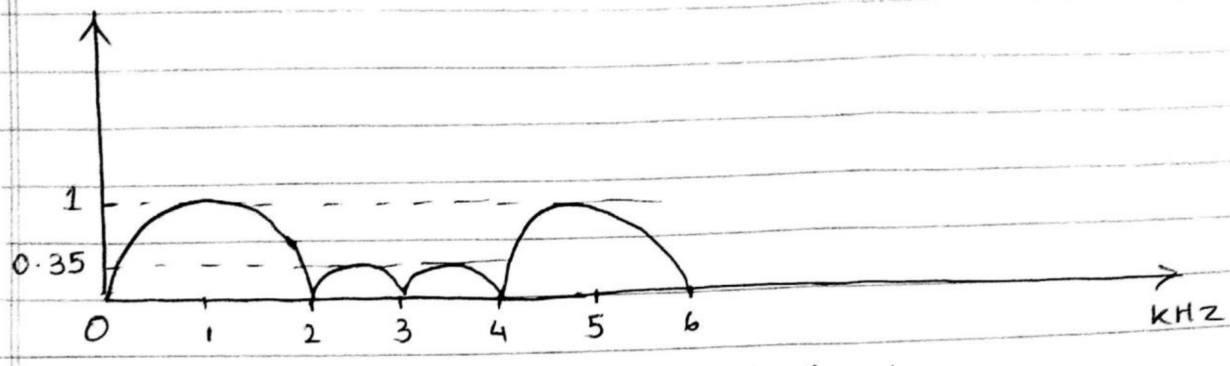
$$\therefore\ T_s = 4.167\times10^{-5}\ \text{sec}$$

2) $f_s = 6$ kHz



So, aliasing occurs here due to the overlapping of the spectrum.

Hence, the sampled signal is as drawn in the final page.



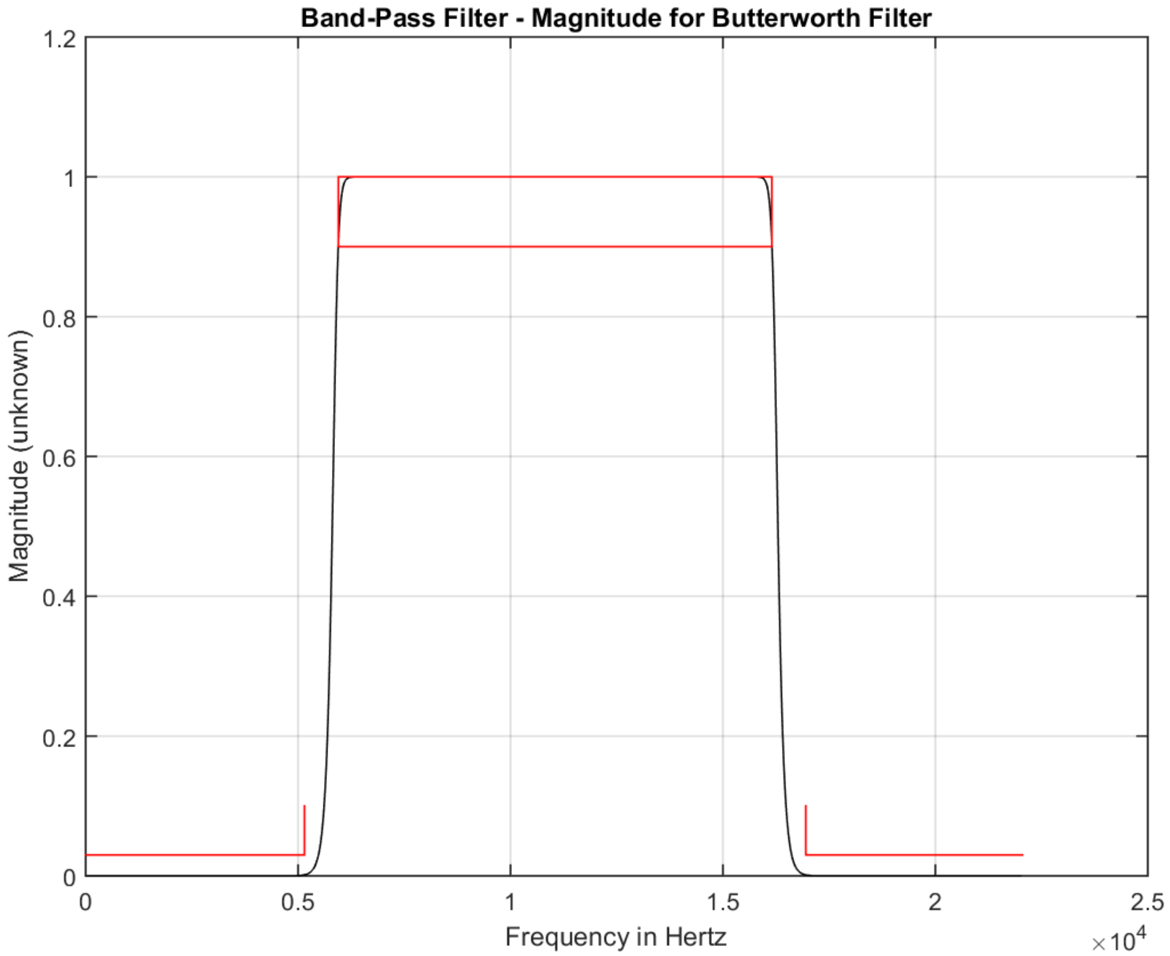
spectrum of sampled signal.

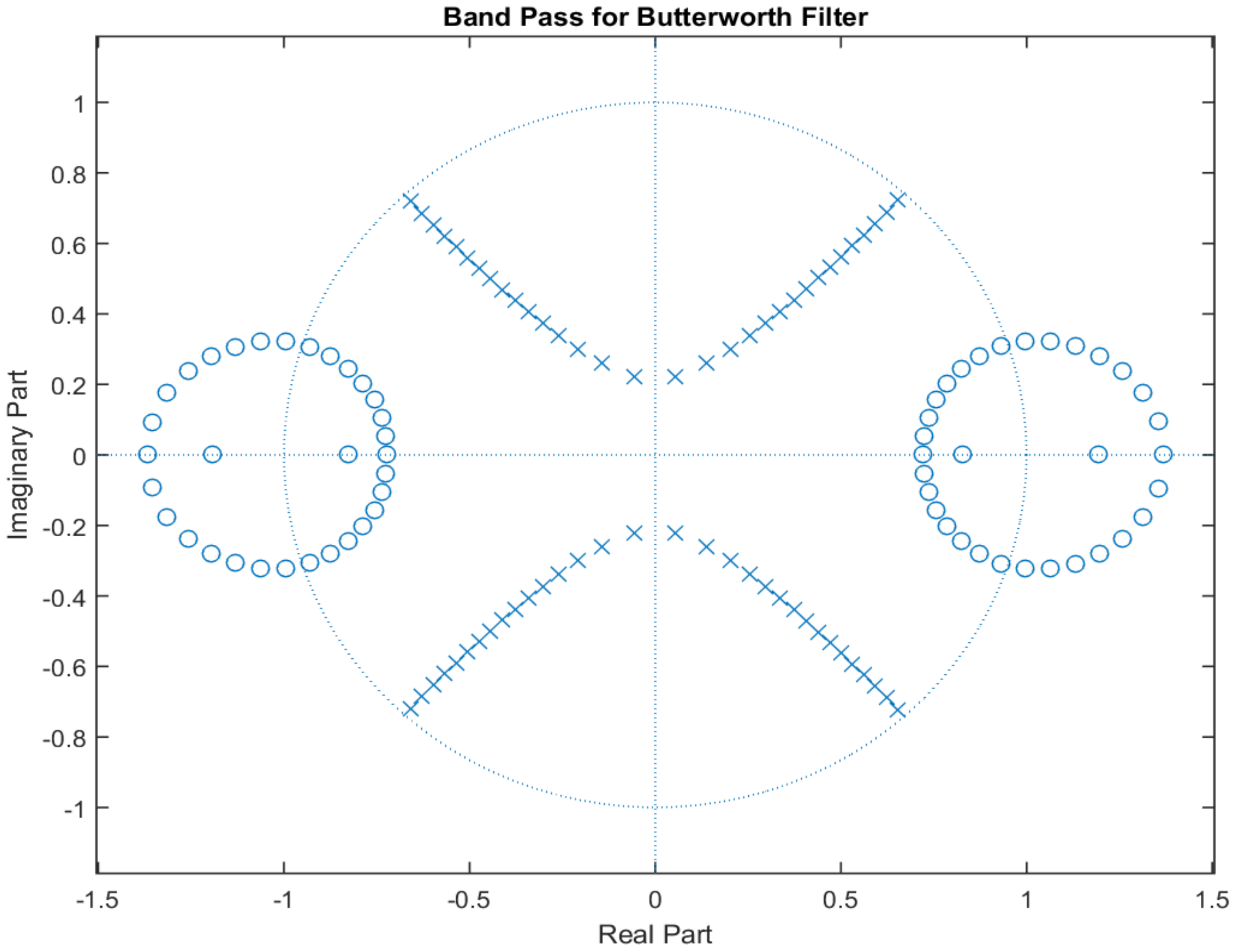
Section – 2

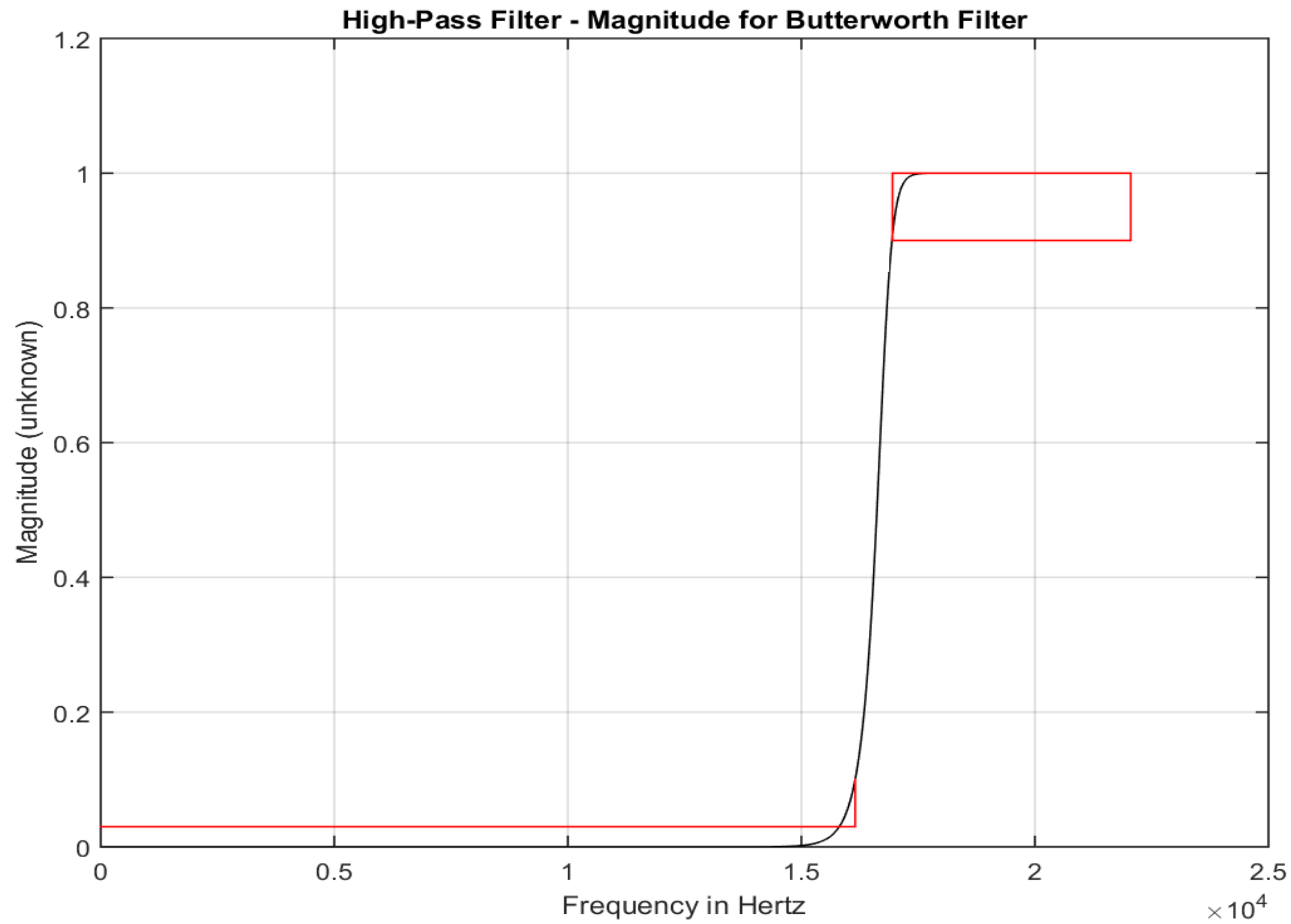
Question 1 and 2

```
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
-- -- -
% TITLE: Section II - Filter Design
%
% Purpose: To design a set of Butterworth IIR filters that matches the
% specifications.
% Date created: 07/14/2016 Author: Tamoghna Chattopadhyay
% Date modified: rev1 - 07/18/2016
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
-- -

% Filter Specifications
% Butterworth Bandpass Filter
[ nbwbp, wbwbp ] = buttord( [ 5.95/22.05 16.15/22.05 ], [ 5.15/22.5 16.95/22.5 ], -1, -30 )

% Butterworth Highpass Filter
[ nbwhp, wbwhp ] = buttord( 16.95/22.05, 16.15/22.5, -1, -30 )

% Butterworth Lowpass Filter
[ nbwlp, wbwlp ] = buttord( 5.15/22.5, 5.95/22.5, -1, -30 )

%Creating array of coefficients for Bandpass Butterworth Filter
[ bwbpnz, bwbpdz ] = butter( nbwbp, wbwbp);

%Creating array of coefficients for Highpass Butterworth Filter
[ bwhpnz, bwhpdz ] = butter( nbwhp, wbwhp, 'high');

%Creating array of coefficients for Lowpass Butterworth Filter
[ bwlpnz, bwlpdz ] = butter( nbwlp, wbwlp);

% Producing Plots of frequency response

% Bandpass Butterworth Filter
[a_bp,f1] = freqz ( bwbpnz, bwbpdz, 1024,44100);
figure(1);
plot(f,abs(a_bp),'k',...
    [0 5150 5150], [0.03 0.03 0.1],'r-',...
    [5950 5950 16150 16150 5950],[0.9 1 1 0.9 0.9],'r-',...
    [22050 16950 16950],[0.03 0.03 0.1],'r-');
title('Band-Pass Filter - Magnitude for Butterworth Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;
figure(2);
zplane( bwbpnz, bwbpdz );
title( 'Band Pass for Butterworth Filter' );

% Highpass Butterworth Filter
[a_hp,f2] = freqz ( bwhpnz, bwhpdz, 1024,44100);
figure(3);
plot(f2,abs(a_hp),'k',...
    [0 16150 16150],[0.03 0.03 0.1],'r-',...
    [16950 16950 22050 22050 16950],[0.9 1 1 0.9 0.9],'r-');
title('High-Pass Filter - Magnitude for Butterworth Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;
figure(4);
zplane( bwhpnz, bwhpdz );
title( 'High Pass for Butterworth Filter' );

% Lowpass Butterworth Filter
[a_lp,f3] = freqz ( bwlpnz, bwlpdz, 1024,44100);
figure(5);
```

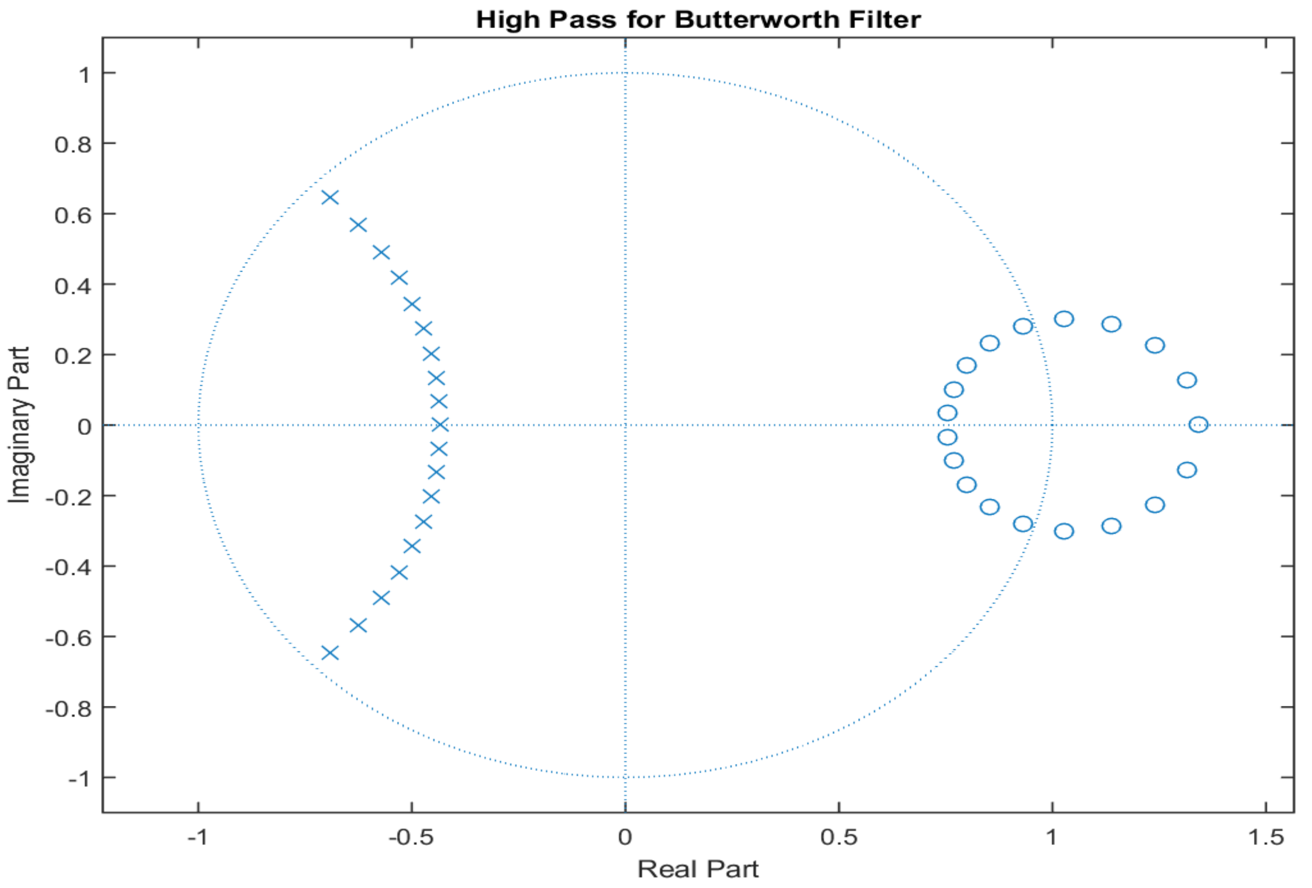
```
plot(f3,abs(a_lp),'k',...
    [0 5150 5150 0], [1 1 0.9 0.9], 'r-',...
    [22050 5950 5950], [0.03 0.03 0.1], 'r-' );
title('Low-Pass Filter - Magnitude for Butterworth Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;
figure(6);
zplane( bwlpnz, bwlpdz );
title( 'Low Pass for Butterworth Filter' );

% Generate impulse response of system.
d = zeros( 2048, 1 );
d(64) = 1.0;

llp = filter( bwlpnz, bwlpdz, d );
hlp = filter( bwhpnz, bwhpdz, d );
blp = filter( bwbpnz, bwbpdz, d );

% Produce a plot of the frequency responses overlaid on one another.
figure(7);
subplot( 311),plot( llp );
title( 'Impulse Response of Low Pass' );
xlabel('Length of filter');
ylabel('Response of filter');
subplot( 312),plot( blp );
title( 'Impulse Response of Band Pass' );
xlabel('Length of filter');
ylabel('Response of filter');
subplot( 313),plot( hlp );
title( 'Impulse Response of High Pass' );
xlabel('Length of filter');
ylabel('Response of filter');
```

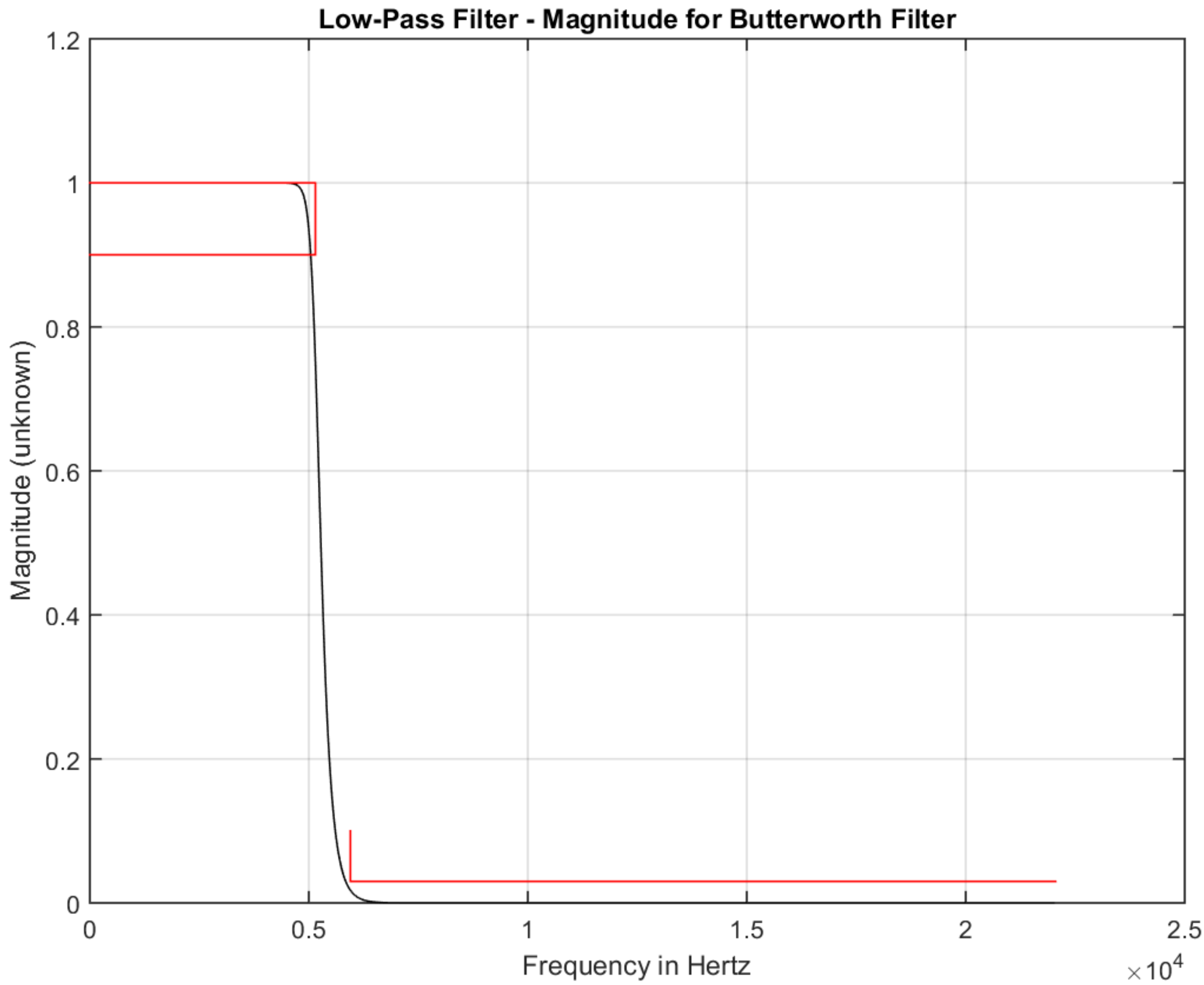


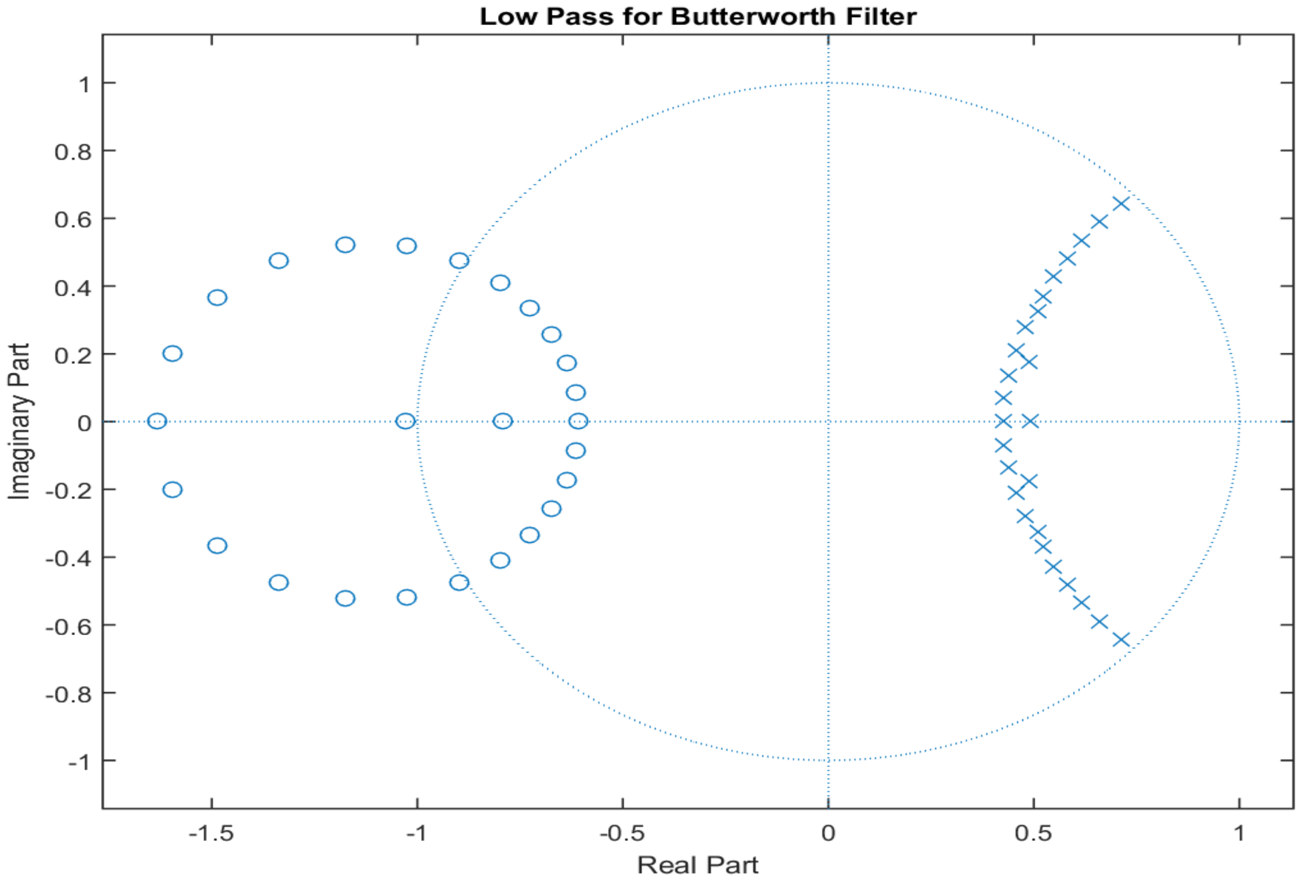


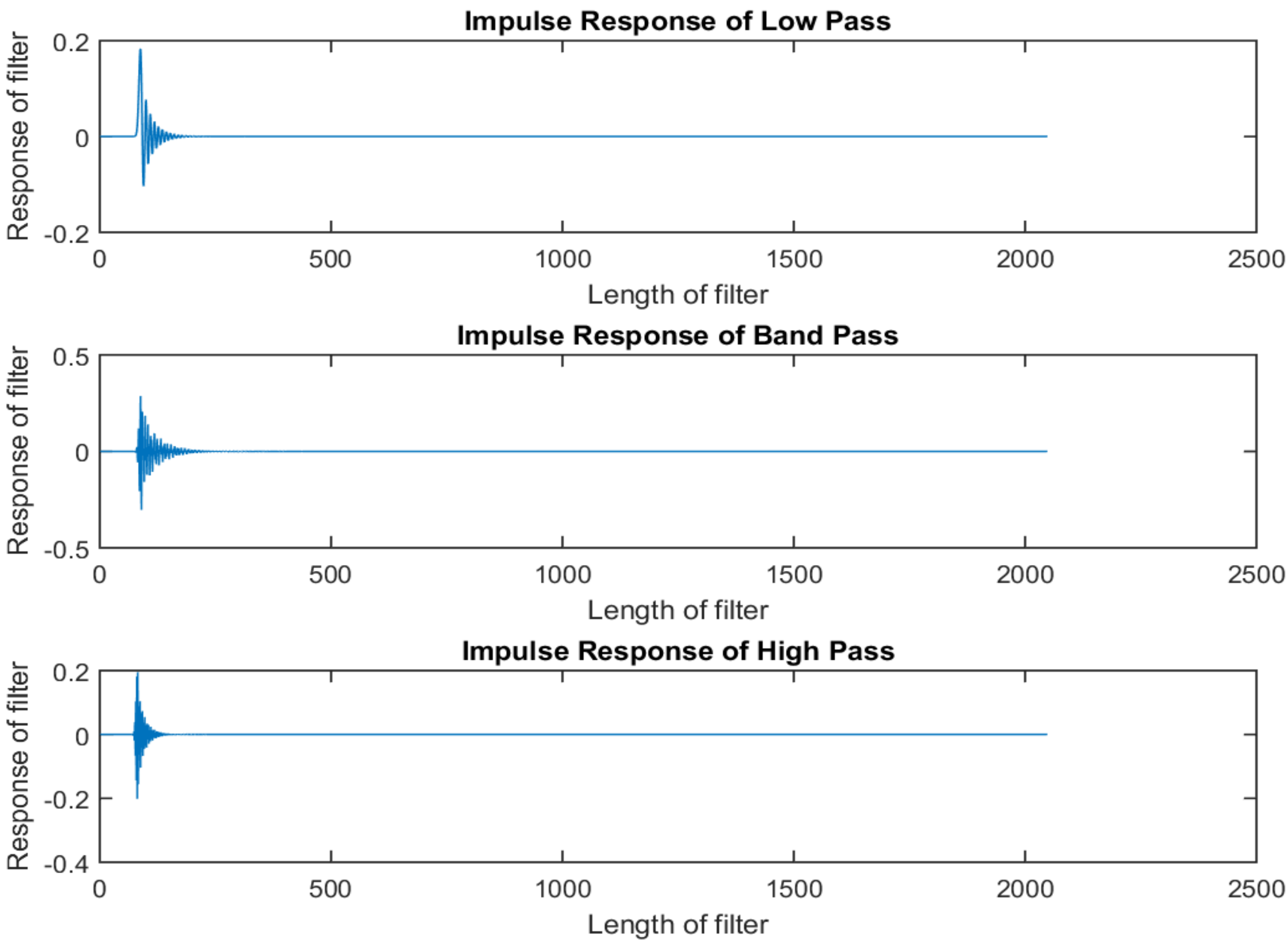


Scanned by CamScanner


High Pass for Butterworth Filter
Imaginary Part
Real Part
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1
1.5


Low-Pass Filter - Magnitude for Butterworth Filter
Magnitude (unknown)
Frequency in Hertz
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
×10^4

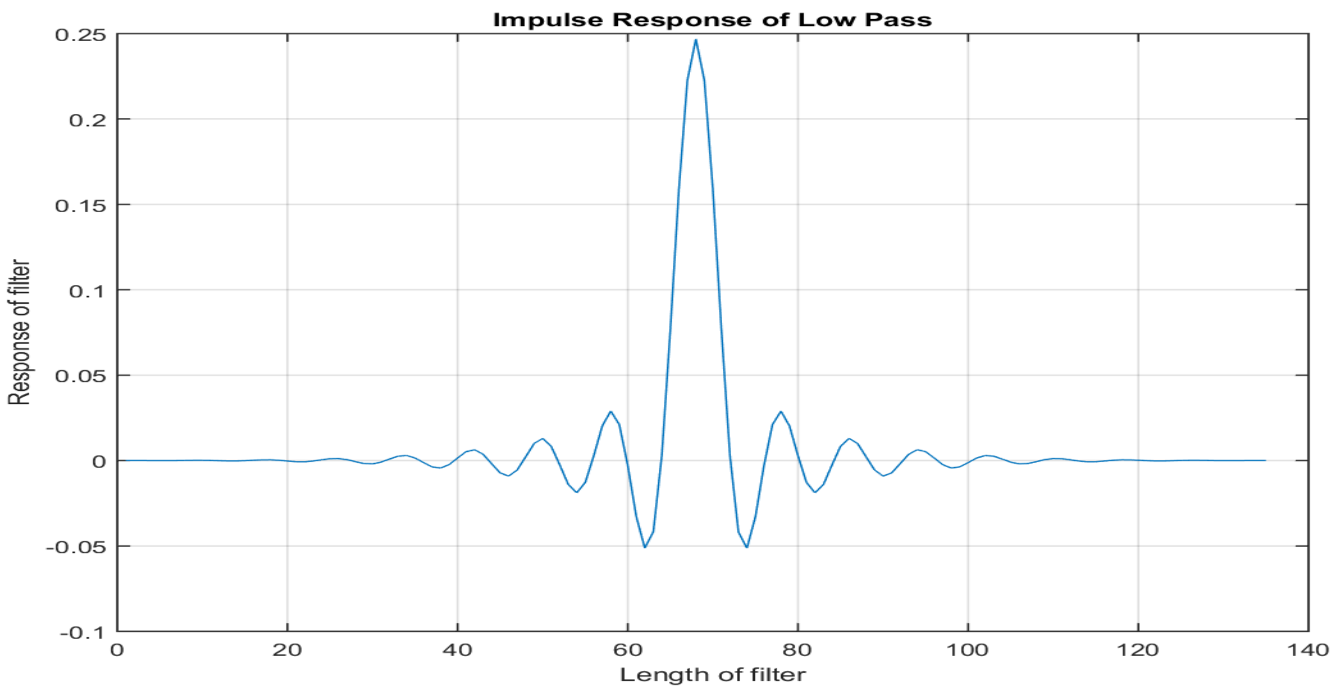

Low Pass for Butterworth Filter
Imaginary Part
Real Part
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.5
-1
-0.5
0
0.5
1

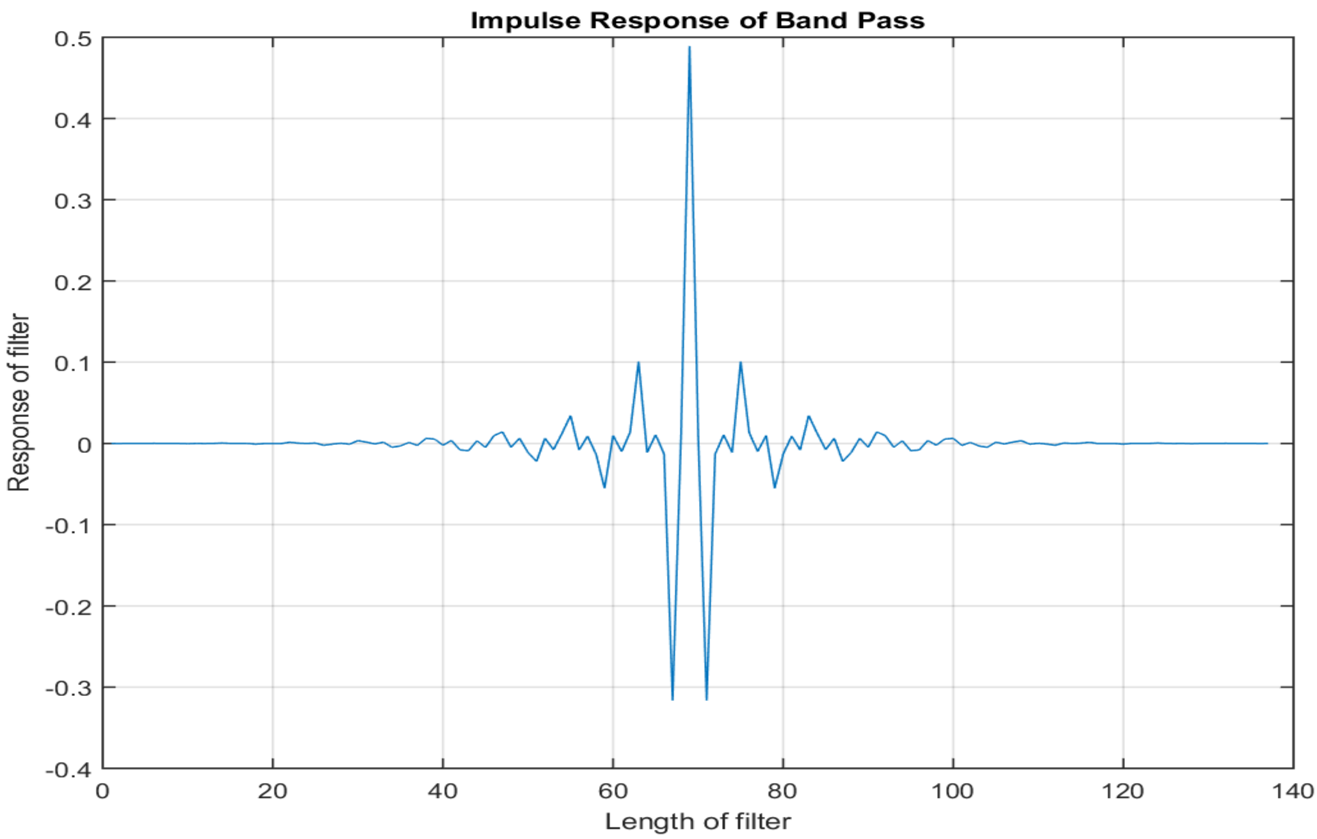

Impulse Response of Low Pass
Response of filter
Length of filter
0.2
0
-0.2
0
500
1000
1500
2000
2500
Impulse Response of Band Pass
Response of filter
Length of filter
0.5
0
-0.5
Impulse Response of High Pass
Response of filter
Length of filter
0.2
0
-0.2
-0.4

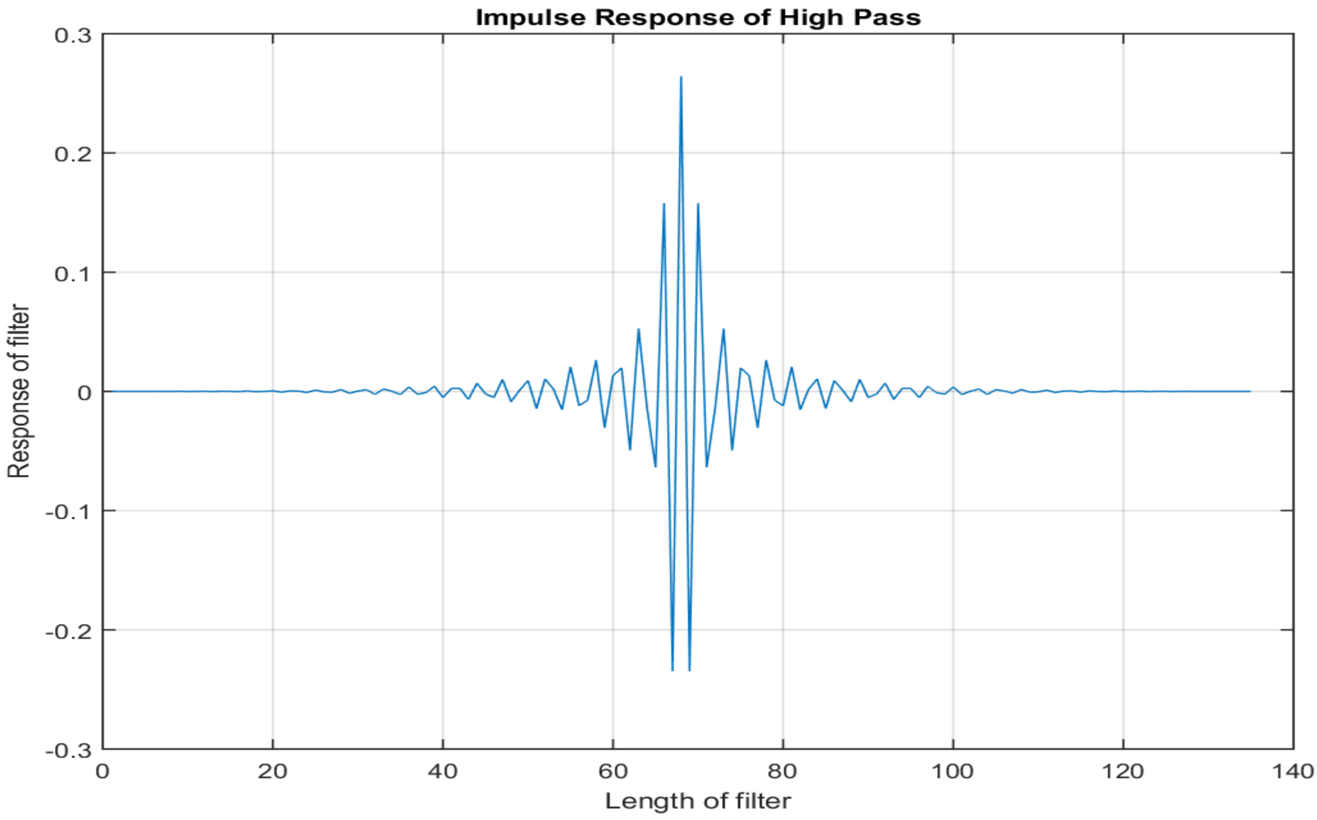
Question 3

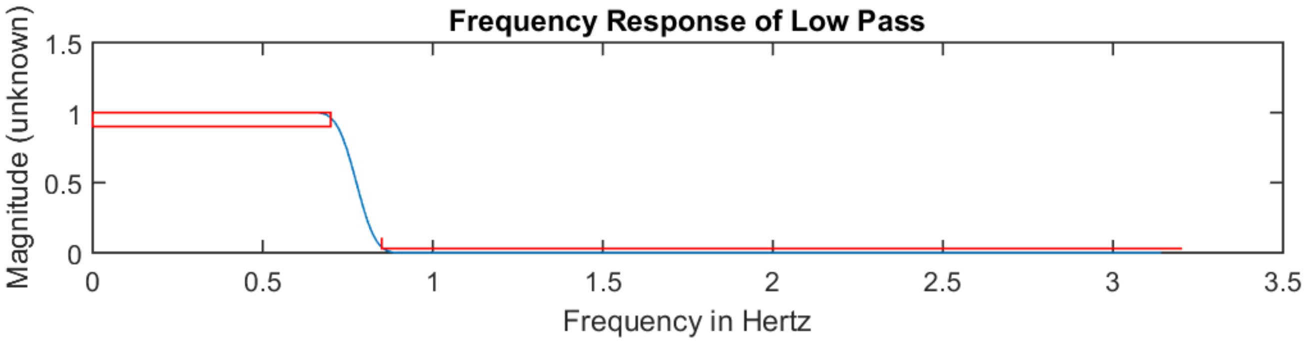
```
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -
- -- -
% TITLE: Section II - Filter Design
%
% Purpose: To design a set of FIR filters that matches the
% specifications.
% Date created: 07/25/2016 Author: Tamoghna Chattopadhyay
% Date modified: rev1 - 07/25/2016
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
-- -

% Filter Specifications

% Lowpass Filter
lp = firls_hamming_search( [0 5.15/22.5 5.95/22.5 1], [ 1 1 0 0], 0.1 );
figure(1);
plot(lp);
title('Impulse Response of Low Pass');
xlabel('Length of filter');
ylabel('Response of filter');
grid on;

% Bandpass Filter
bp = firls_hamming_search( [0 5.15/22.5 5.95/22.5 16.15/22.5 16.95/22.5 1], [ 0 0 1 1 0 0],
0.1 );
figure(2);
plot(bp);
title('Impulse Response of Band Pass');
xlabel('Length of filter');
ylabel('Response of filter');
grid on;

% Highpass Filter
hp = firls_hamming_search( [0 16.15/22.5 16.95/22.5 1], [ 0 0 1 1 ], 0.1 );
figure(3);
plot(hp);
title('Impulse Response of High Pass');
xlabel('Length of filter');
ylabel('Response of filter');
grid on;

% Create Frequency Response of each filter.
w = [0:pi/256:pi];
lpfr = freqz( lp, 1, w );
bpfr = freqz( bp, 1, w );
hpfr = freqz( hp, 1, w );

% Produce a plot of the frequency responses overlaid on one another.
figure(4);
subplot( 311),plot( w, abs(lpfr),[0 0 0.7 0.7 0],[0.9 1 1 0.9 0.9],'r-',...
    [0.85 0.85 3.2],[0.1 0.03 0.03],'r-');
title( 'Frequency Response of Low Pass' );
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
subplot( 312),plot( w, abs(bpfr), [0 0.65 0.65], [0.03 0.03 0.1],'r-',...
    [0.75 0.75 2.3 2.3 0.75],[0.9 1 1 0.9 0.9],'r-',...
    [2.4 2.4 3.15],[0.1 0.03 0.03],'r-');
title( 'Frequency Response of Band Pass' );
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
subplot( 313),plot( w, abs(hpfr), [0 2.2 2.2], [0.03 0.03 0.1], 'r-',...
    [2.35 2.35 3.2 3.2 2.35],[0.9 1 1 0.9 0.9], 'r-');
title( 'Frequency Response of High Pass' );
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
```

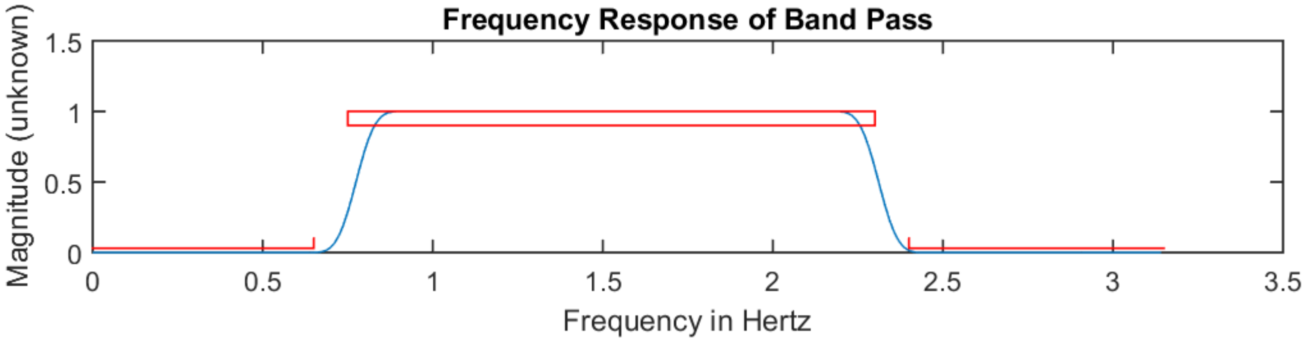
```
% Plot the pole zero plot
figure(5);
zplane( lp, 1 );
title ('Pole Zero Plot - Low Pass Filter');

figure(6);
zplane( bp, 1 );
title ('Pole Zero Plot - Band Pass Filter');

figure(7);
zplane( hp, 1 );
title ('Pole Zero Plot - High Pass Filter');
```

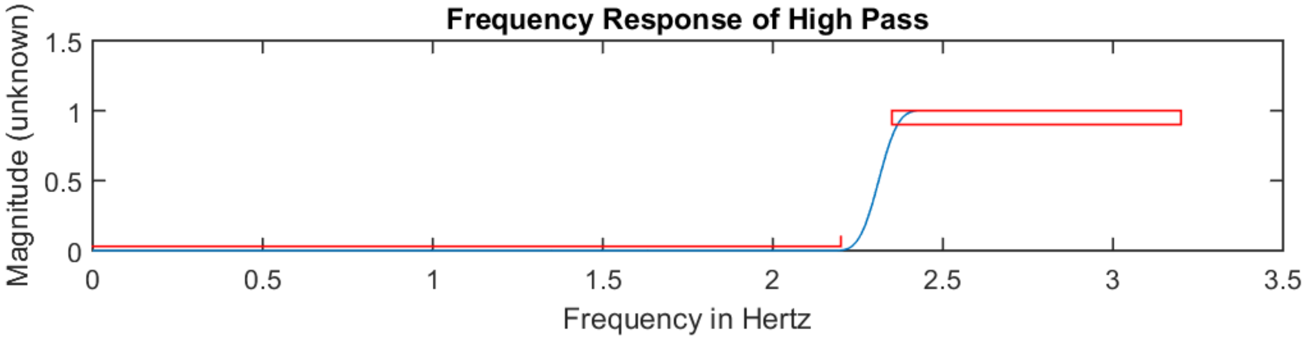


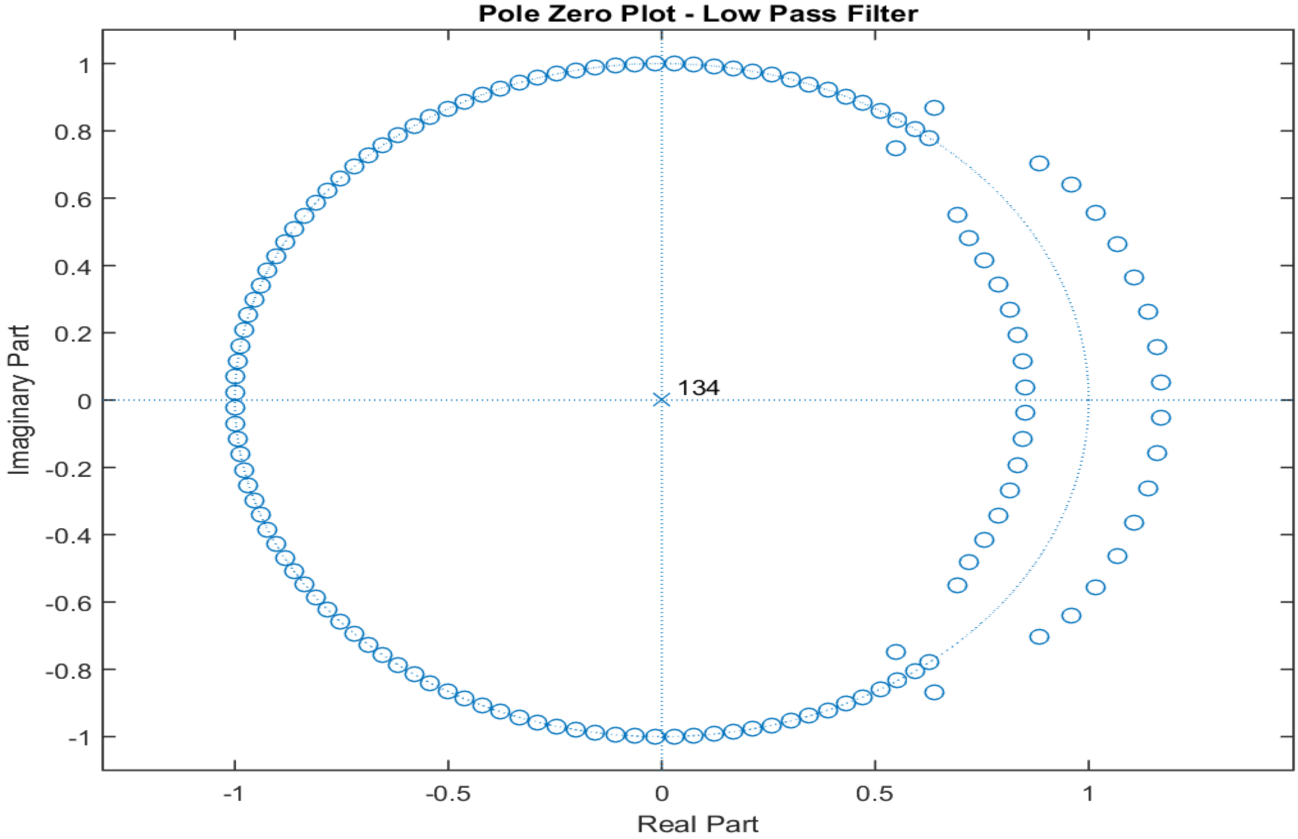


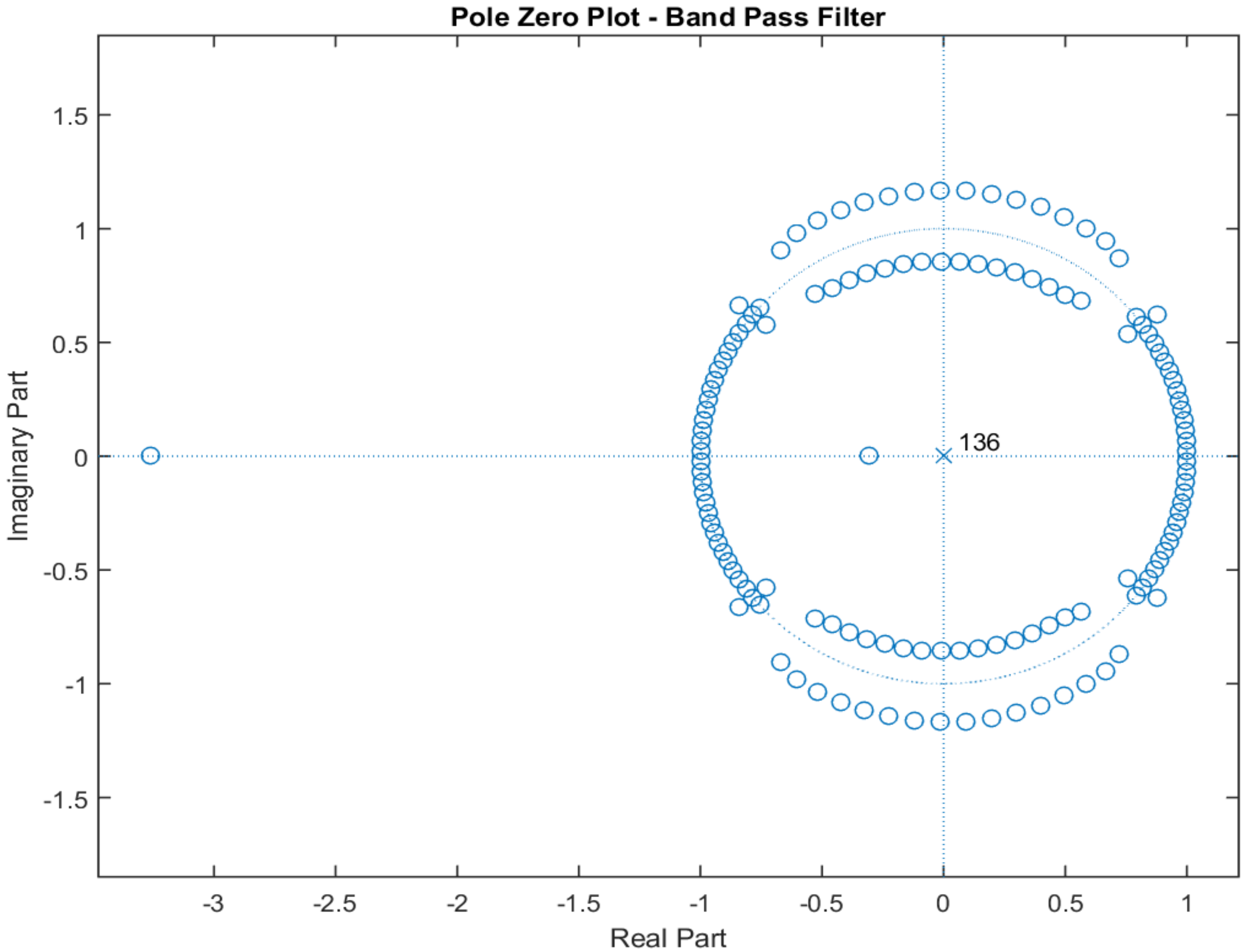

Impulse Response of High Pass
Response of filter
Length of filter
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
20
40
60
80
100
120
140

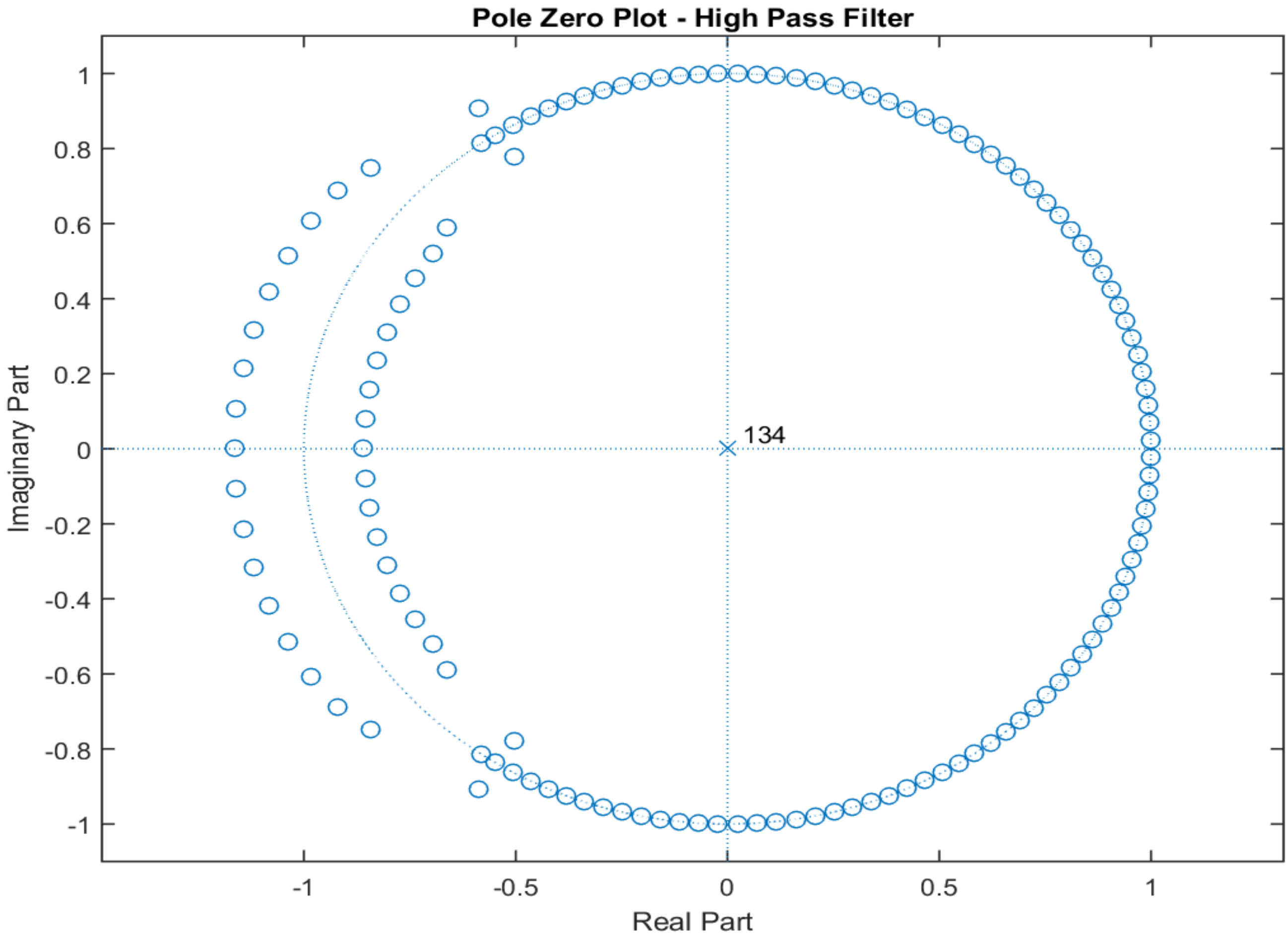

Frequency Response of Low Pass
Magnitude (unknown)
Frequency in Hertz
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5


Frequency Response of Band Pass
Magnitude (unknown)
Frequency in Hertz
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5


Frequency Response of High Pass
Magnitude (unknown)
Frequency in Hertz
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5


Pole Zero Plot - Low Pass Filter
Imaginary Part
Real Part
134
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1


Pole Zero Plot - Band Pass Filter
Imaginary Part
Real Part
136
1.5
1
0.5
0
-0.5
-1
-1.5
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1



Pole Zero Plot - High Pass Filter
Imaginary Part
Real Part
134
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1

QUESTION 4

Classmate Date : Page :

SECTION - 2

4) • For FIR Low Pass Filter, from plot of impulse response, x axis varies till almost 135. So, number of MAD's required for FIR Low Pass Filter = 135

• For FIR Band Pass Filter, from plot of impulse response, x axis varies till almost 138. So, number of MAD's required for FIR Band Pass Filter = 138

• For FIR High Pass Filter, from plot of impulse response, x axis varies till almost 135. So, number of MAD's required for FIR High Pass Filter = 135

• For IIR Band Pass Filter, we can see that the values of the numerator and denominator variables bwbpdz and bwbpnz vary to 1X65 double. Thus M = 65. So,
Number of MADS = $2m+1 = 2(65)+1 = 131$

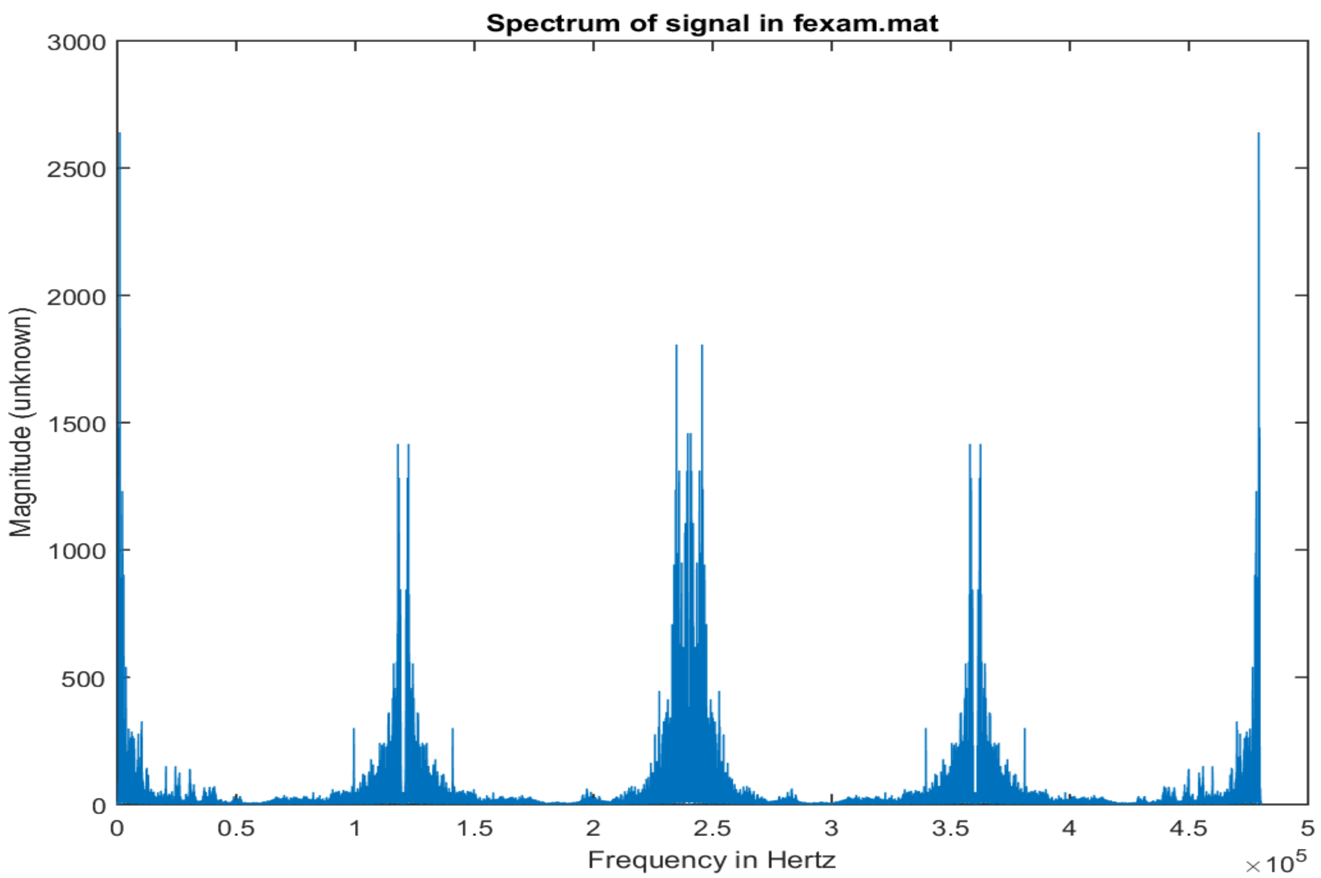
• For IIR High Pass Filter, we can see that the values of the numerator and denominator variables bwhpdz and bwhpnz vary to 1X20 double. Thus M = 20. So,
Number of MADs = $2m+1 = 2(20)+1 = 41$

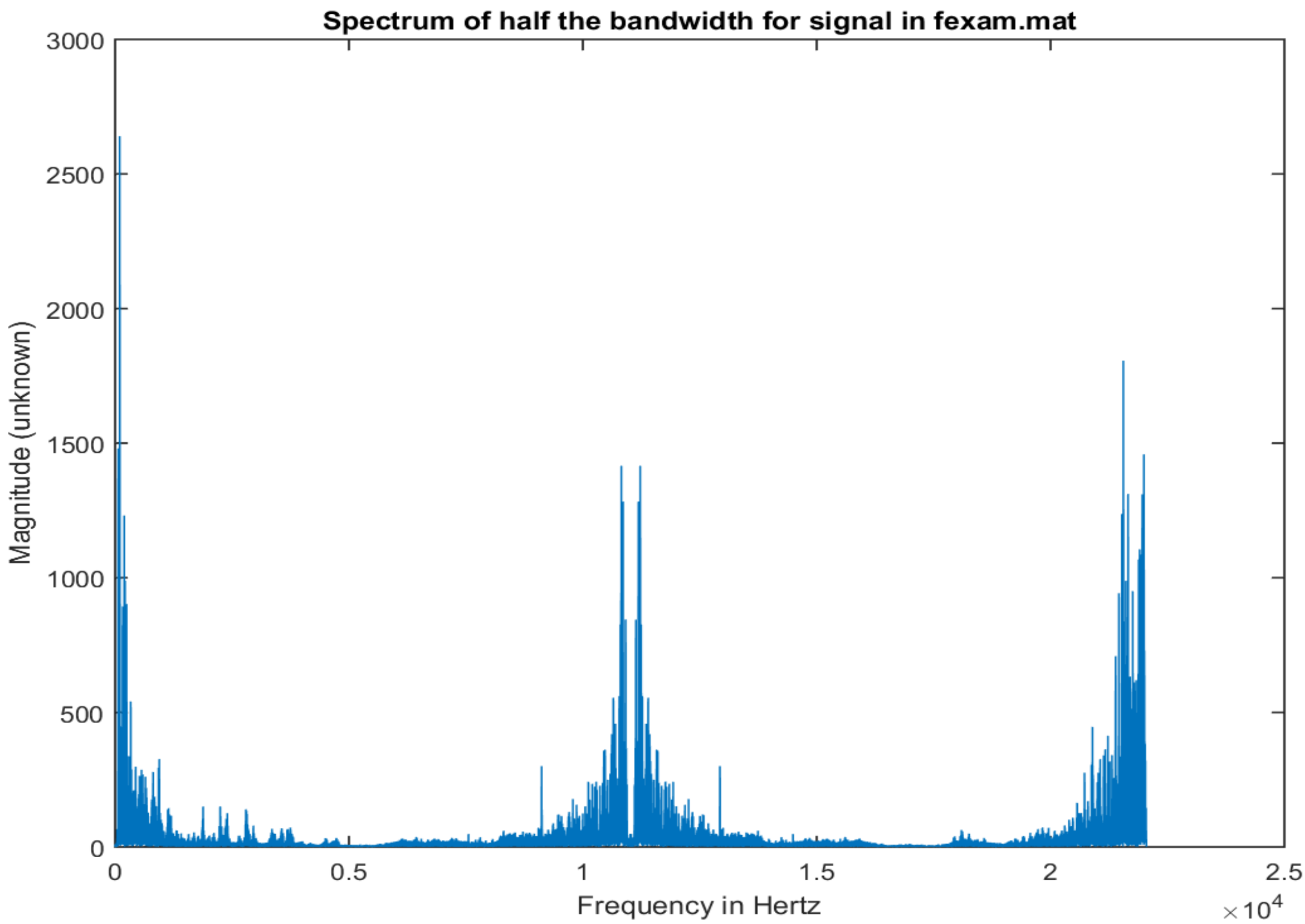
• For IIR Low Pass Filter, we can see that the values of the numerator and denominator variables bwlpdz and bwlpnz vary to 1X27 double. Thus M = 27. So,
Number of MADs = $2m+1 = 2(27)+1 = 55$

SECTION – 3

QUESTION 1

```
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -
% TITLE: Section III - Decimation and Frequency shifting.
%
% Purpose: To plot a signal in the file fexam.mat and it's spectrum
%
% Date created: 07/25/2016 Author: Tamoghna Chattopadhyay
% Date modified: rev1 - 07/25/2016
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -

load('fexam.mat');
sound(sig,44100);
SIG = fft(sig); % Computes the Fourier Transform of sig
figure(1);
plot( abs( SIG ) ); % Plot the spectrum
title('Spectrum of signal in fexam.mat');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');

N=length(SIG);
figure(2);
plot(([0:N/2 - 1]/N)*44.1e3,abs(SIG(1:N/2)));
title('Spectrum of half the bandwidth for signal in fexam.mat');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
```



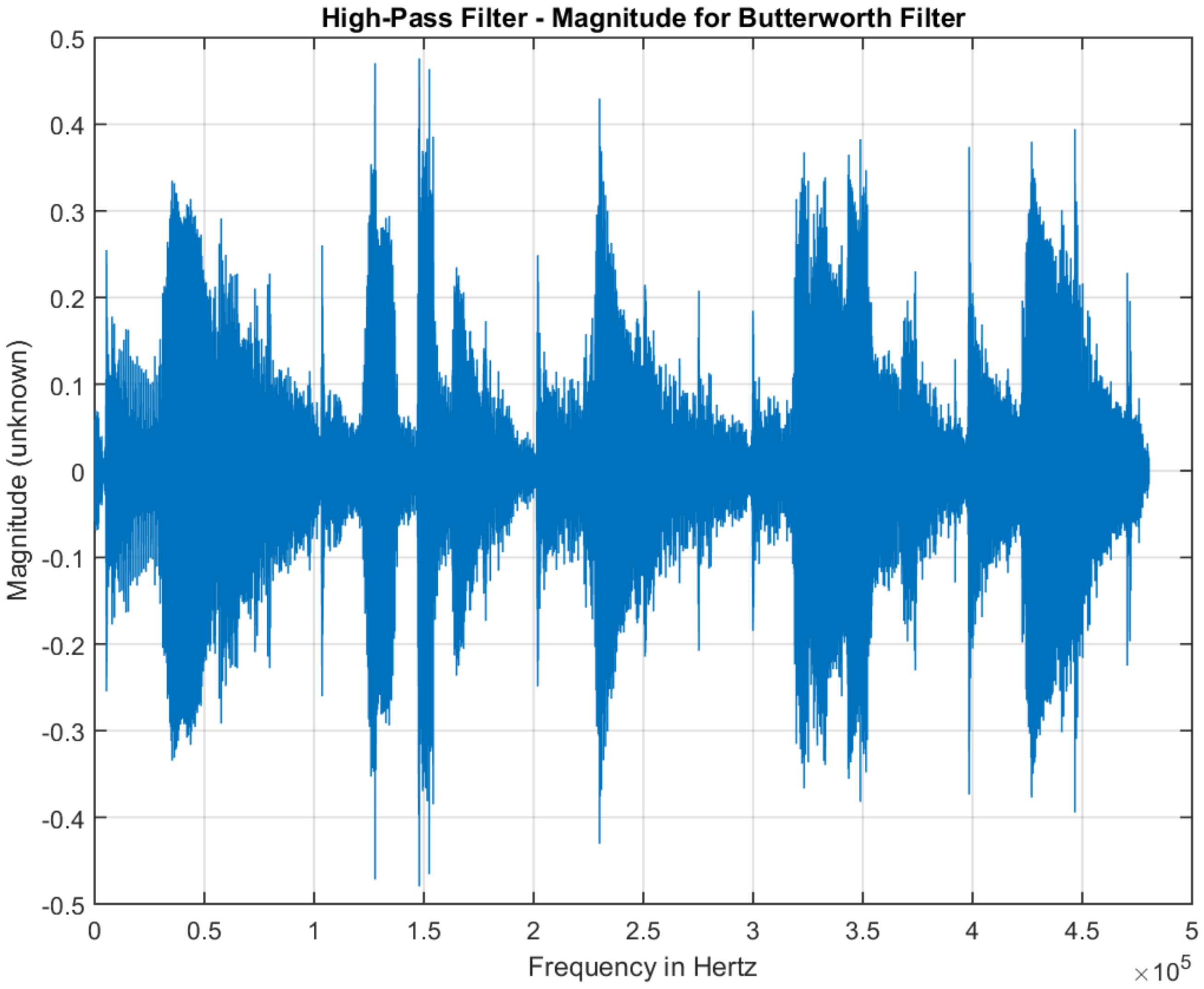


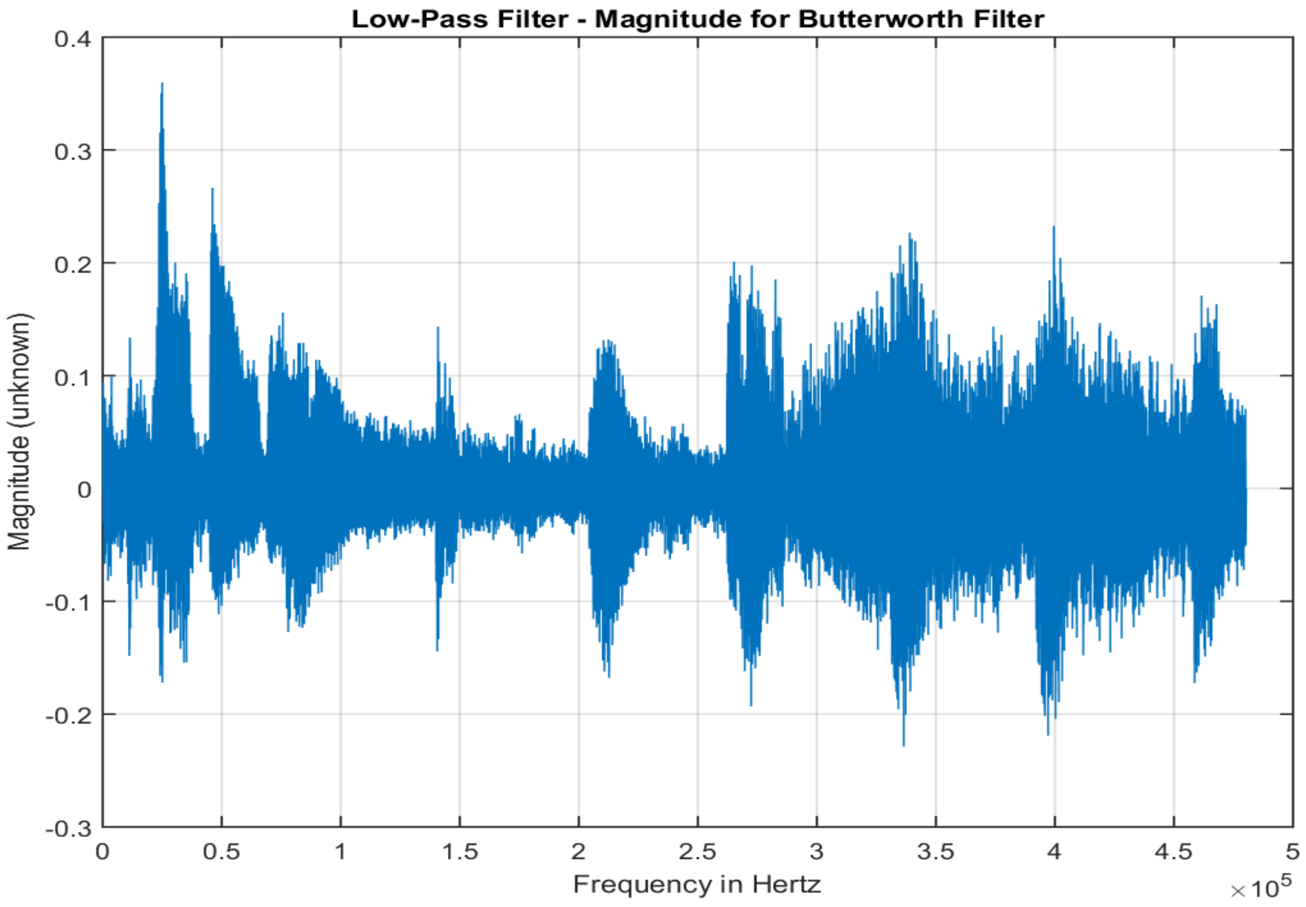
QUESTION 2, 3 AND 4

```
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -
- -- -
% TITLE: Section III - Decimation and Frequency shifting.
%
% Purpose: Apply IIR Filters from Section II to signal in fexam.mat
%
% Date created: 07/25/2016 Author: Tamoghna Chattopadhyay
% Date modified: rev1 - 07/25/2016
% -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
-- -

% Filter Specifications
% Butterworth Bandpass Filter
[ nbwbp, wbwbp ] = buttord( [ 5.95/22.05 16.15/22.05 ], [ 5.15/22.5 16.95/22.5 ], -1, -30 )

% Butterworth Highpass Filter
[ nbwhp, wbwhp ] = buttord( 16.95/22.05, 16.15/22.5, -1, -30 )

% Butterworth Lowpass Filter
[ nbwlp, wbwlp ] = buttord( 5.15/22.5, 5.95/22.5, -1, -30 )

%Creating array of coefficients for Bandpass Butterworth Filter
[ bwbpnz, bwbpdz ] = butter( nbwbp, wbwbp);

%Creating array of coefficients for Highpass Butterworth Filter
[ bwhpnz, bwhpdz ] = butter( nbwhp, wbwhp, 'high');

%Creating array of coefficients for Lowpass Butterworth Filter
[ bwlpnz, bwlpdz ] = butter( nbwlp, wbwlp);

%Load the signal in fexam.mat
load('fexam.mat');
```

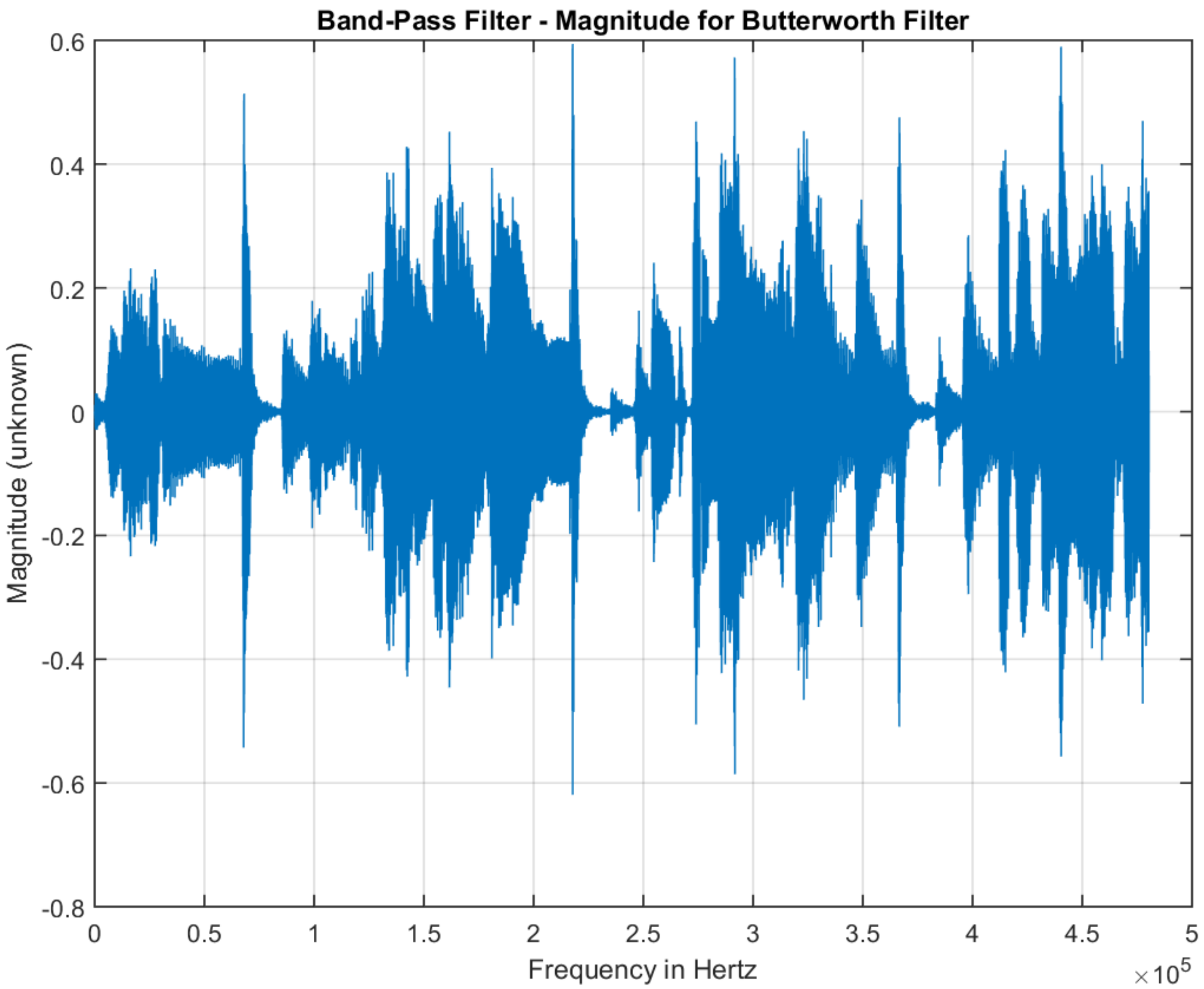
```
sound(sig,44100);
pause;
SIG = fft(sig); % Computes the Fourier Transform of sig

% Filter the signal using Butterworth Highpass Hilter
b_hp = filter ( bwhpnz, bwhpdz, sig);
figure(1);
plot(b_hp);
title('High-Pass Filter - Magnitude for Butterworth Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;

% Filter the signal using Butterworth Lowpass Hilter
b_lp = filter ( bwlpnz, bwlpdz, sig);
figure(2);
plot(b_lp);
title('Low-Pass Filter - Magnitude for Butterworth Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;

% Filter the signal using Butterworth Bandpass Hilter
b_bp = filter ( bwbpnz, bwbpdz, sig);
figure(3);
plot(b_bp);
title('Band-Pass Filter - Magnitude for Butterworth Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;

%Decimate signals to one-fourth sampling rates
Dec_b_hp=b_hp(1:4:end);
Dec_b_lp=b_lp(1:4:end);
Dec_b_bp=b_bp(1:4:end);

%Plot the output signal after decimation
%High Pass Filter output
figure(4);
plot(Dec_b_hp);
title('High-Pass Filter - Magnitude for Butterworth Filter for Decimated Signal');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;

%Low Pass Filter output
figure(5);
plot(Dec_b_lp);
title('Low-Pass Filter - Magnitude for Butterworth Filter for Decimated Signal');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;

%Band Pass Filter output
figure(6);
plot(Dec_b_bp);
title('Band-Pass Filter - Magnitude for Butterworth Filter for Decimated Signal');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
grid on;

%Fourier Transforms of filtered signals
B_HP = fft(Dec_b_hp);
B_LP = fft(Dec_b_lp);
B_BP = fft(Dec_b_bp);
%Plot the Spectrum
figure(7);
subplot( 311),plot( abs( B_HP ) );
```

```
title('Spectrum of the signal passed through High Pass Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
subplot( 312),plot( abs( B_LP ) );
title('Spectrum of the signal passed through Low Pass Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');
subplot( 313),plot( abs( B_BP ) );
title('Spectrum of the signal passed through Band Pass Filter');
xlabel (' Frequency in Hertz ' );
ylabel (' Magnitude (unknown) ');

%Play the signals as sound
sound(Dec_b_hp,11.025e3);
pause;
sound(Dec_b_lp,11.025e3);
pause;
sound(Dec_b_bp,11.025e3);
pause;
```

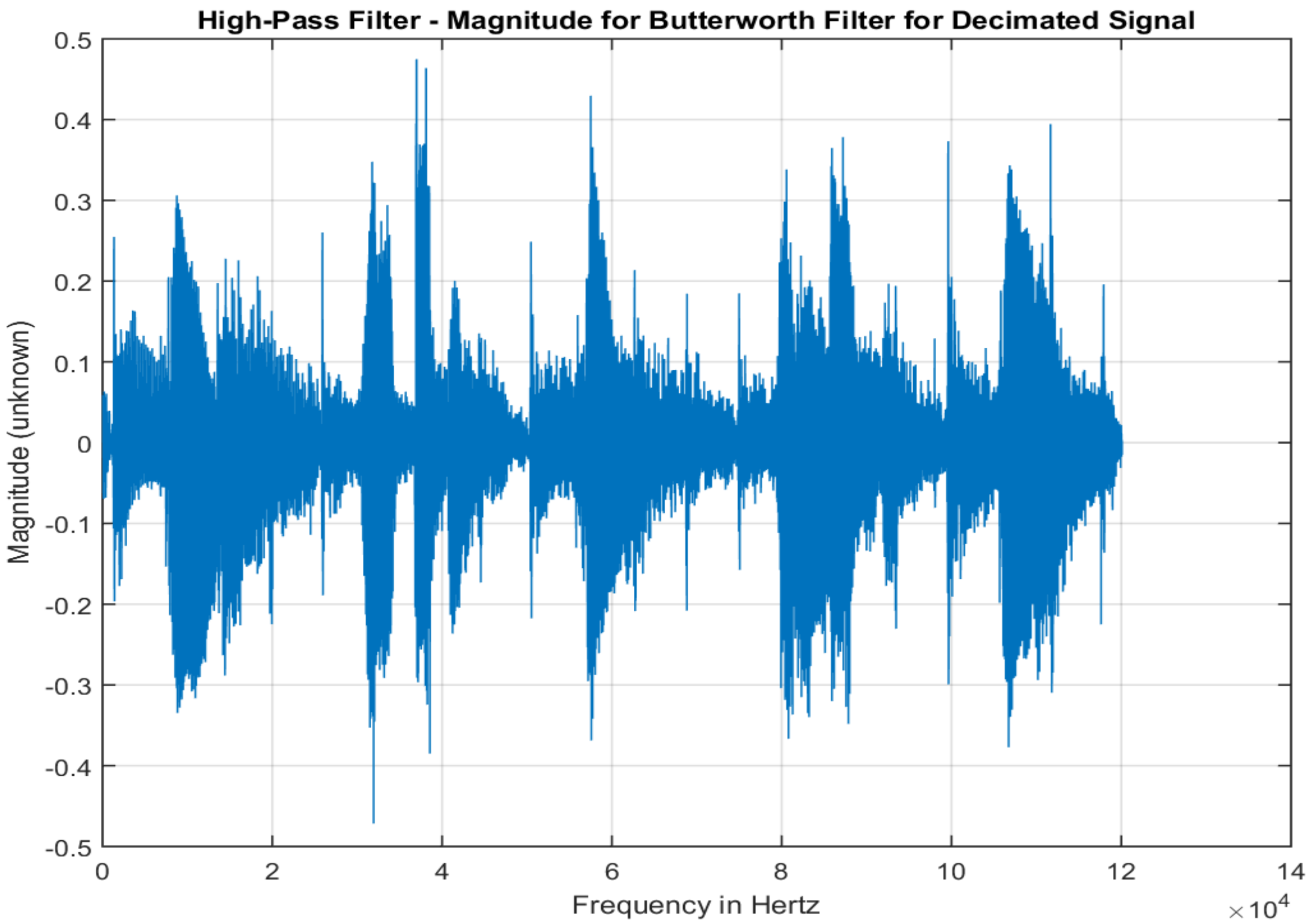


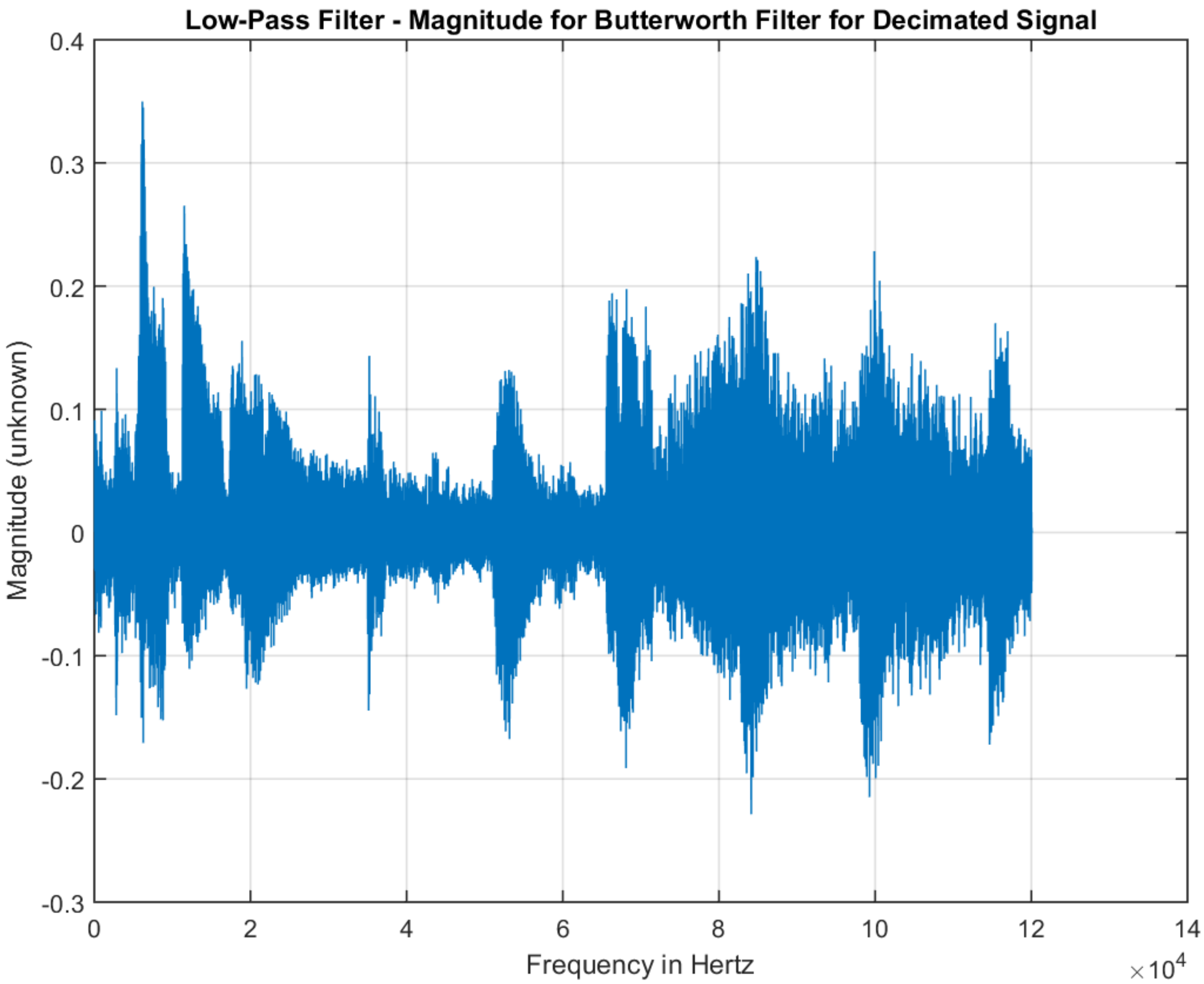


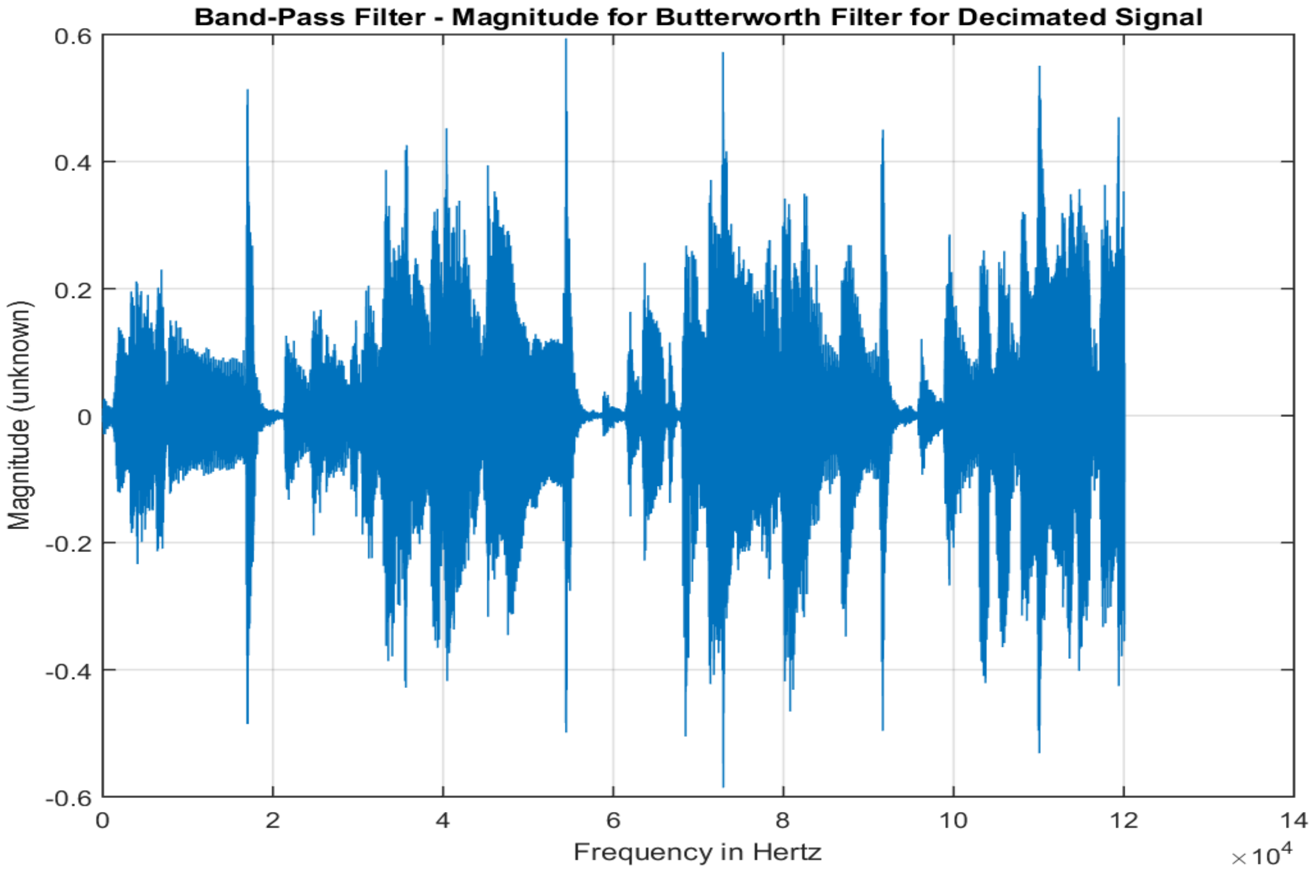
Low-Pass Filter - Magnitude for Butterworth Filter
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Magnitude (unknown)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Frequency in Hertz
$\times 10^5$

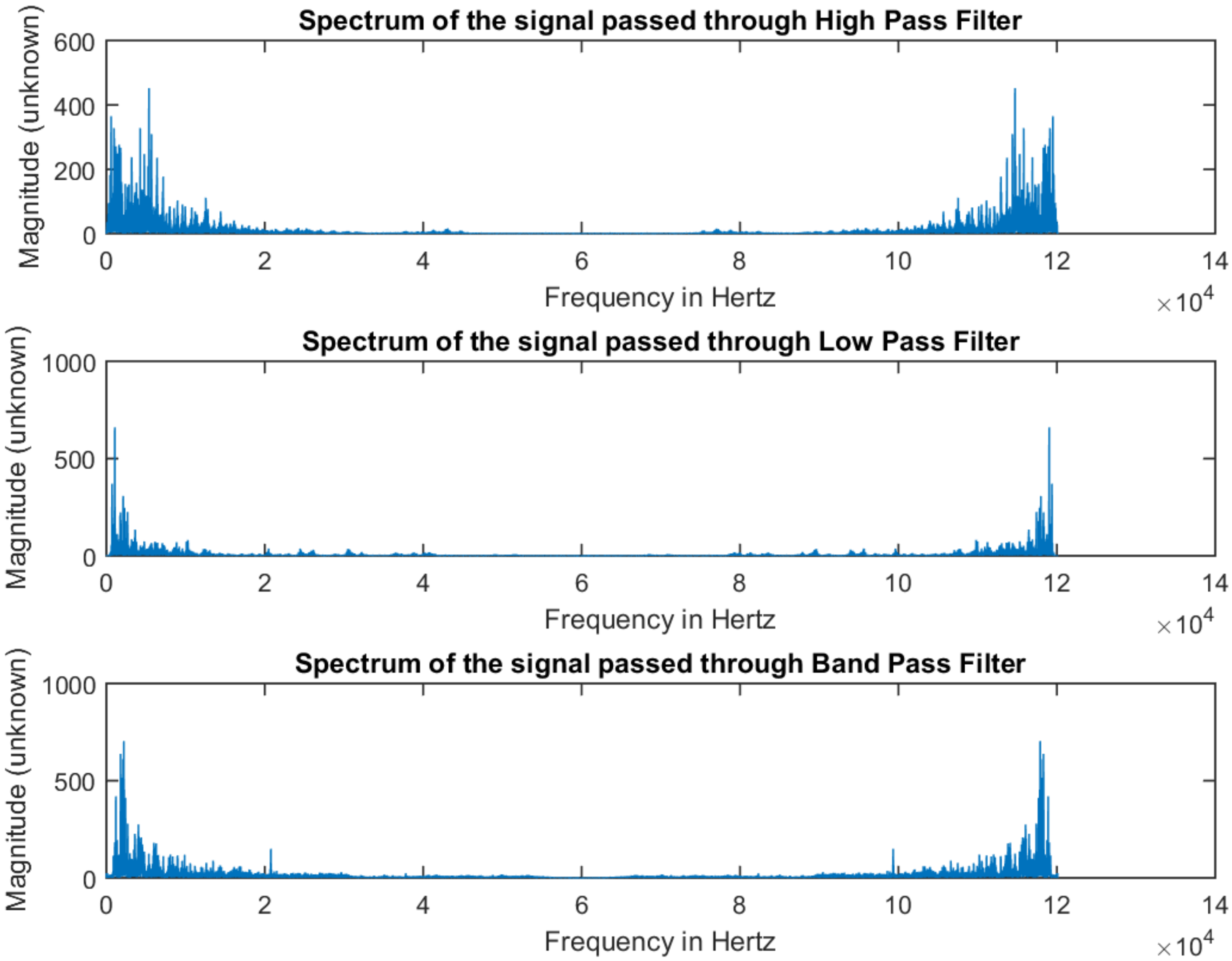


Band-Pass Filter - Magnitude for Butterworth Filter
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Magnitude (unknown)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Frequency in Hertz
$\times 10^5$


High-Pass Filter - Magnitude for Butterworth Filter for Decimated Signal
Magnitude (unknown)
Frequency in Hertz
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
2
4
6
8
10
12
14
$\times10^4$

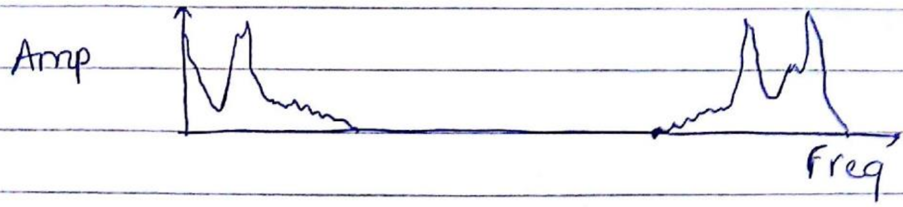

Low-Pass Filter - Magnitude for Butterworth Filter for Decimated Signal
Magnitude (unknown)
Frequency in Hertz
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
2
4
6
8
10
12
14
$\times10^4$


Band-Pass Filter - Magnitude for Butterworth Filter for Decimated Signal
Magnitude (unknown)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
2
4
6
8
10
12
14
Frequency in Hertz
$\times 10^4$

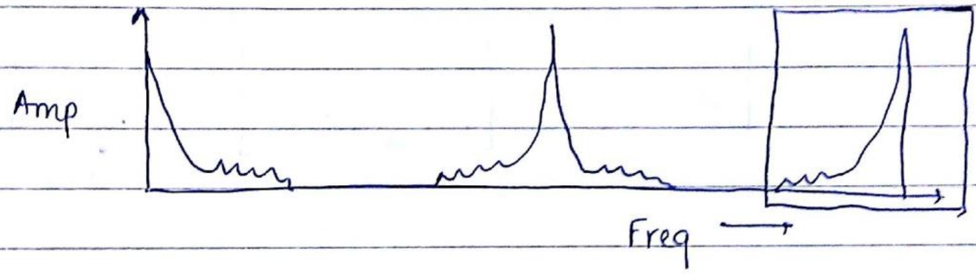

Spectrum of the signal passed through High Pass Filter
Magnitude (unknown)
600
400
200
0
0
2
4
6
8
10
12
14
Frequency in Hertz
$\times 10^4$
Spectrum of the signal passed through Low Pass Filter
Magnitude (unknown)
1000
500
0
0
2
4
6
8
10
12
14
Frequency in Hertz
$\times 10^4$
Spectrum of the signal passed through Band Pass Filter
Magnitude (unknown)
1000
500
0
0
2
4
6
8
10
12
14
Frequency in Hertz
$\times 10^4$

SECTION - 3

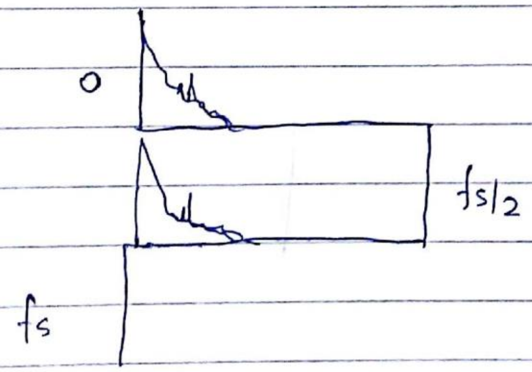
4) The spectrum of the signal passed through High Pass Filter is



This shows that only the high frequency components from the original signal are allowed to pass through.

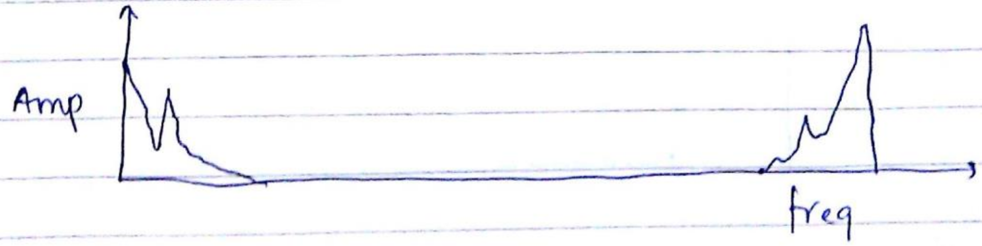


So

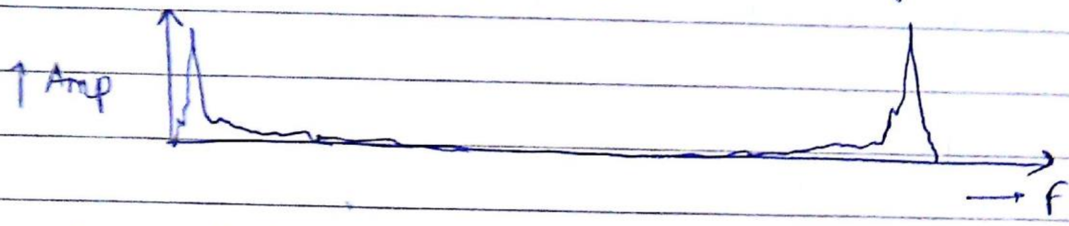


Aliasing diagram

So, spectrum becomes

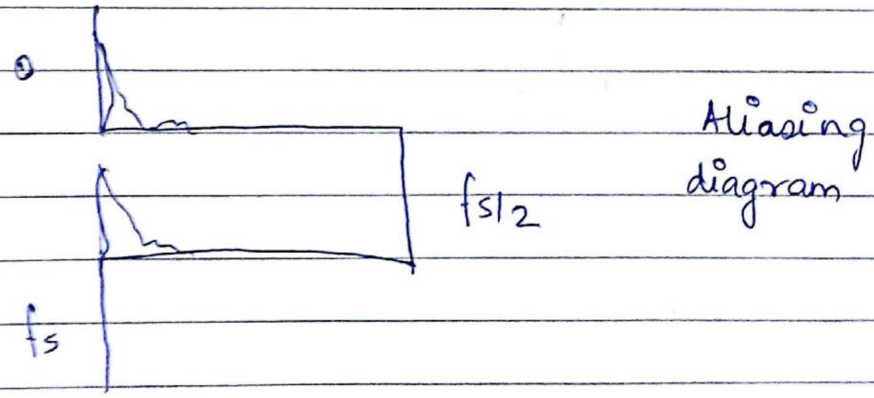


The spectrum of the signal passed through Band Pass Filter is

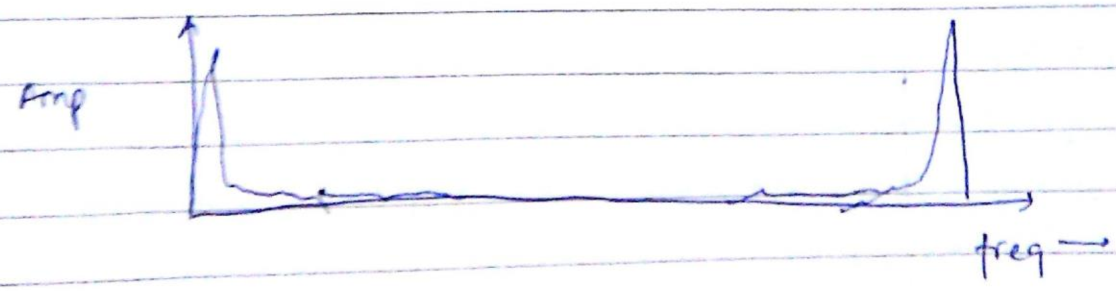


This shows that only the frequencies in the middle of the original signal are allowed to pass through.

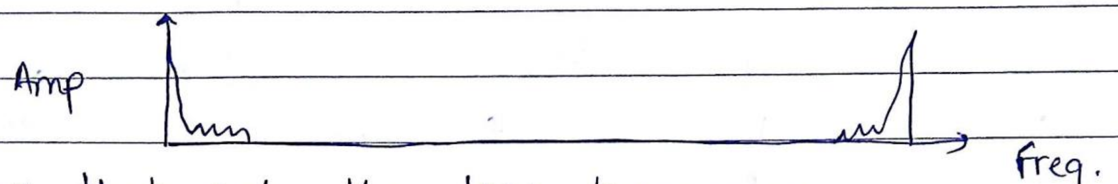
So,



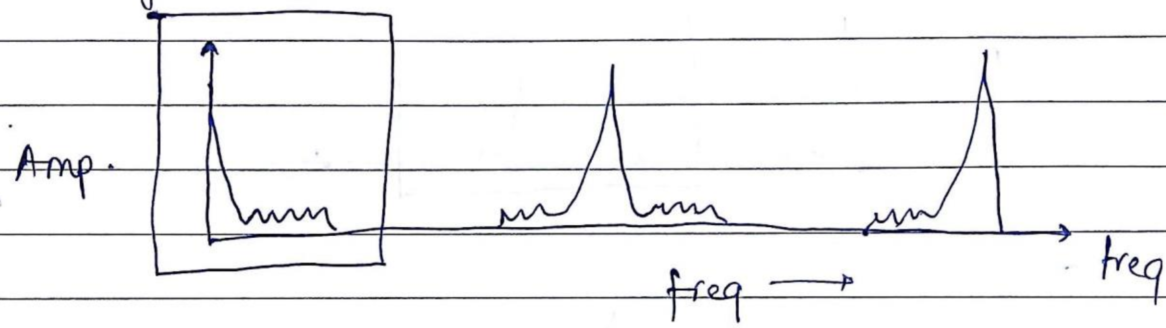
So, spectrum becomes



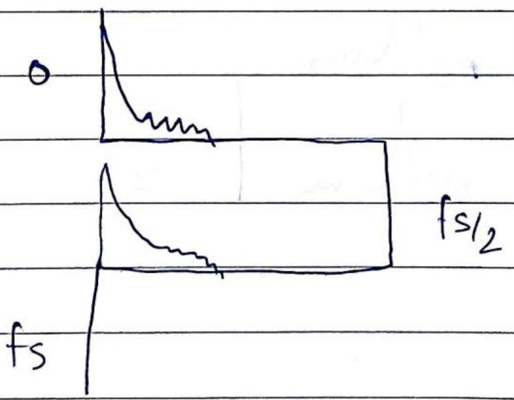
The spectrum of the signal passed through Low Pass Filter is



This shows that only the low frequency components from the original signal are allowed to pass through.



So,



Aliasing diagram

So, spectrum becomes