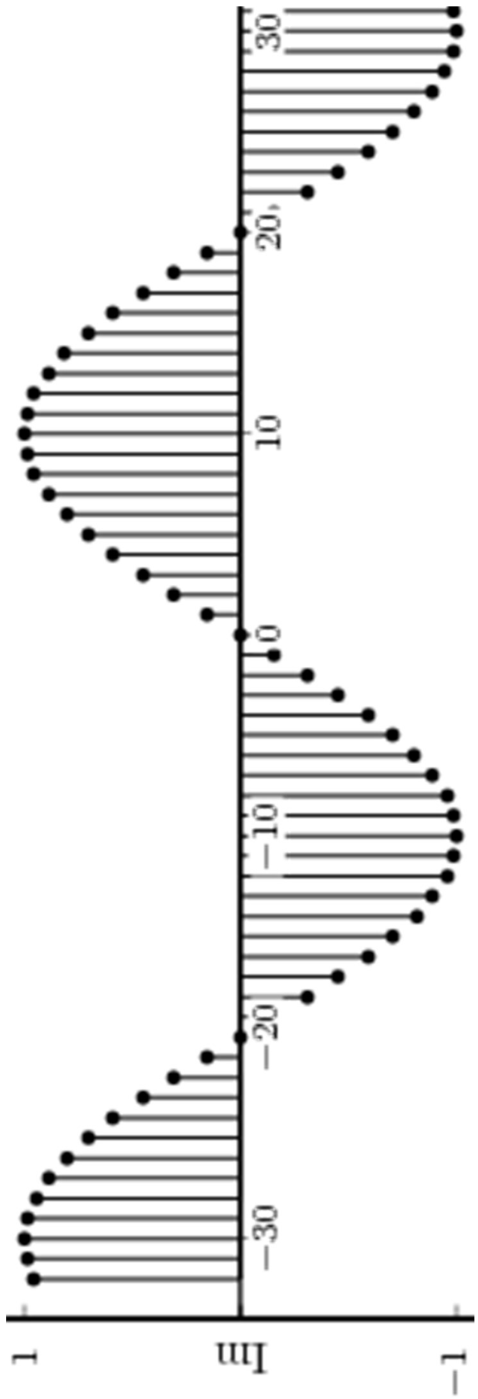

Systems and Random Processes in Discrete Time –

Project

By

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EECS 3602
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TABLE OF CONTENTS

INTRODUCTION

In this design project, we used MATLAB functions to design different filters and plot their frequency responses. We also calculated different parameters like optimum interpolation factor, filter lengths of bandedge shaping filter, upper branch masking filter and lower branch masking filter etc. We also designed two FIR filters to remove noises from an ECG signal.

EQUIPMENT

We used a computer and MATLAB software for this Lab.

RESULTS AND DISCUSSIONS

Part 1: FIR Filter Design

Question 1:

a) $\lambda 1 = \frac{3600}{8000}$ $\lambda 2 = \frac{3200}{8000}$ $\beta = \frac{400}{8000}$

$M = \frac{1}{\sqrt{\beta - \lambda 1 - \lambda 2 + 1}} = 2.68 \simeq 2$ (even for high pass filter)

b) Bandegdes of bandedge shaping filter $H_a(z)$:

$F_{a,p} = M(0.5 - \lambda 1) = 2(0.5 - \frac{3600}{8000}) = 0.1$

$F_{a,s} = M(0.5 - \lambda 2) = 2(0.5 - \frac{3200}{8000}) = 0.2$

Bandegdes of masking filter $H_{Ma}(z)$:

$F_{Ma,p} = \lambda 1 = 0.45$

$F_{Ma,s} = \frac{m-1}{M} + 0.5 - \lambda 2 = 0.1$

c) Filter lengths of bandedge shaping filter and masking filter:

$$L = \frac{-20\,\mathrm{lo}\ \left(\sqrt{\delta p \delta s}\right) - 13}{14.6\ \beta} + 1$$

$L_a = 65.38 \simeq 66$

$L_{Ma} = 10.2 \simeq 11$

d) Filter lengths of bandedge shaping filter and masking filter using "ifir"

$M_{opt} = 2$

Normalized passband = $\frac{3600}{8000}$ = 0.45

Normalized stopband = $\frac{3200}{8000}$ = 0.40

<u>Matlab Code:</u>

```
[h,g]=ifir(2,'high',[0.1 0.2],[.01 .0001]);
Hcas = conv(h,g);
```

L_a = 73 and L_{Ma} = 11 which is about the same as the values calculated in (c).

e) Frequency response of all filters:

<u>Matlab Code:</u>

```
figure
title('Intrpolated Filter Ha(z)')
freqz(h,1);

figure
title('Masking Filter HMa(z)')
freqz(g,1);

figure
title('Overall Filter')
freqz(Hcas,1);
```

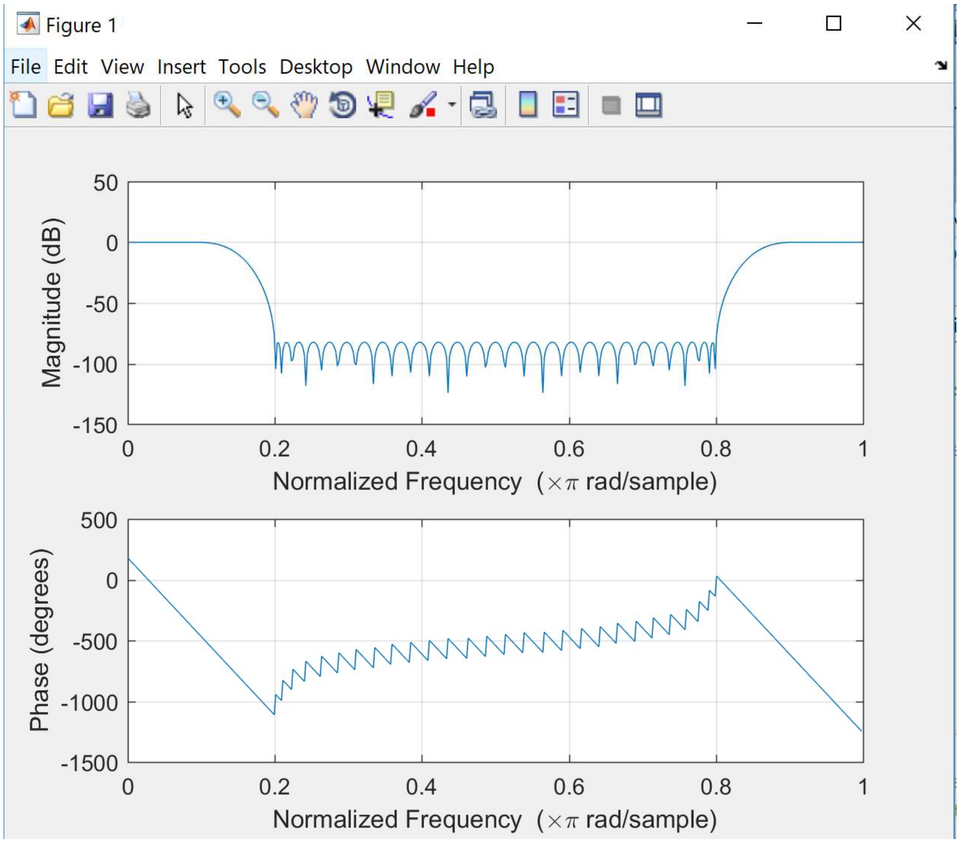


Figure 1
File Edit View Insert Tools Desktop Window Help
Magnitude (dB)
50
0
-50
-100
-150
0
0.2
0.4
0.6
0.8
1
Normalized Frequency (×π rad/sample)
Phase (degrees)
500
0
-500
-1000
-1500
0
0.2
0.4
0.6
0.8
1
Normalized Frequency (×π rad/sample)

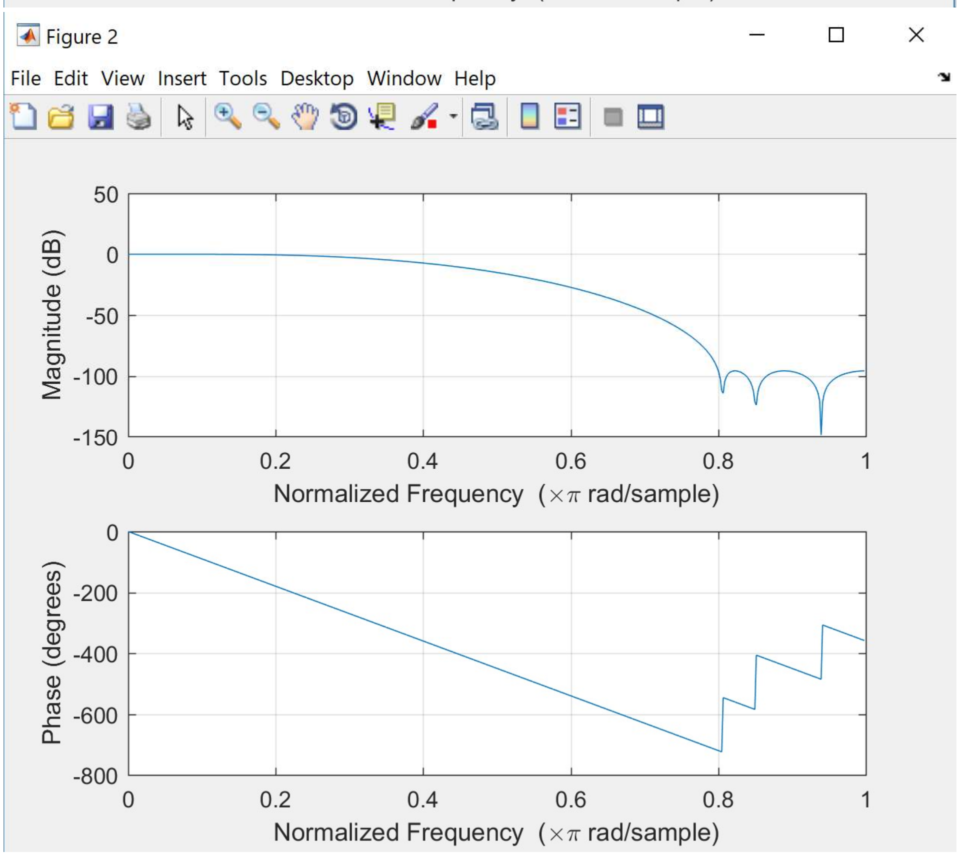
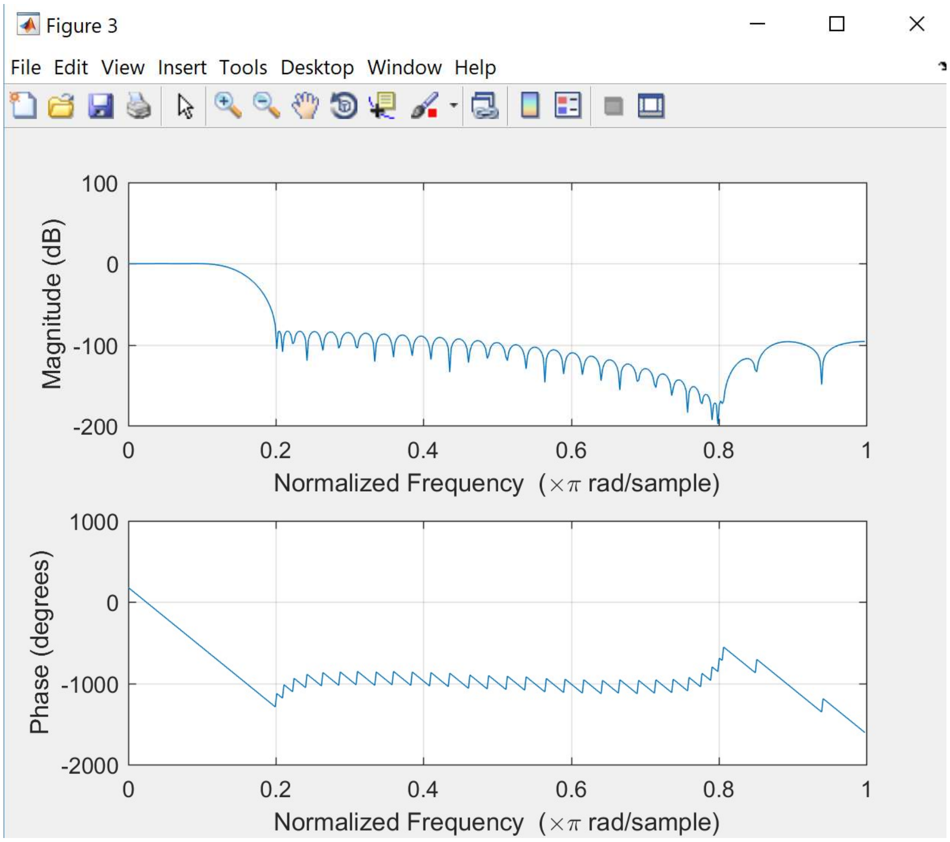


Figure 2
File Edit View Insert Tools Desktop Window Help
Magnitude (dB)
50
0
-50
-100
-150
0
0.2
0.4
0.6
0.8
1
Normalized Frequency (×π rad/sample)
Phase (degrees)
0
-200
-400
-600
-800
0
0.2
0.4
0.6
0.8
1
Normalized Frequency (×π rad/sample)



Question 2:

a) M_{opt} interpolation factor:

$M_{opt} = \frac{1}{2}\sqrt{0.2 - 0.194} = 6.45 \simeq 6$

b) Table:

$$L_{Total} = L_a + L_{Ma} + L_{Mc} \qquad L_0 \approx \frac{\left[-20\log(\sqrt{\delta_p\delta_s}) - 13\right]}{14.6(\lambda_2 - \lambda_1)} \qquad \beta = \lambda_2 - \lambda_1$$

$$\frac{L_0}{M} + \frac{2\pi\beta L_0}{\frac{4m\pi + 2\pi - M\left(\omega_s + \omega_p\right)}{M}} + \frac{2\pi\beta L_0}{\frac{M\left(\omega_s + \omega_p\right) - 4m\pi}{M}} \qquad \text{For Case A, } m_a = \lfloor f_p M \rfloor \qquad \text{For Case B, } m_b = \lceil f_s M \rceil$$

M_{opt}	Case A or B	Band edges of $H_a(z)$		Band edges of $H_{ma}(z)$		Band edges of $H_{mc}(z)$		L_a	L_{Ma}	L_{Mc}	L_{Total}
		$F_{a,\,p}$	$F_{a,\,s}$	$F_{ma,\,f}$	$F_{ma,\,s}$	$F_{mc,\,f}$	$F_{mc,\,s}$				
4	B	0.200	0.224	0.056	0.200	0.194	0.300	111	20	26	157
5	B	0.000	0.030	0.006	0.200	0.194	0.200	89	15	440	544
6	A	0.164	0.200	0.194	0.300	0.139	0.200	75	26	45	146
7	A	0.358	0.400	0.194	0.228	0.091	0.200	64	79	26	169
8	B	0.400	0.448	0.181	0.200	0.194	0.300	56	141	26	223

c) Determining the optimum interpolation factor:

M_{opt} = 6 as that is optimal value as it has the lowest filter length.

d) <u>Matlab Code:</u>

```
% Ha(z)
F = [0.164 0.2];
A=[1,0];
Dev=[0.0085,0.00085];

[N,Fi,Ai,W]=firpmord(F,A,Dev,1);
ha=firpm(N+1,Fi,Ai,W);

% HMa(z)
F = [0.194 0.3];
A=[1,0];
Dev=[0.0085,0.00085];

[N,Fi,Ai,W]=firpmord(F,A,Dev,1);
hma=firpm(N,Fi,Ai,W);
hma = [0 0 0 0 0 0 0 0 0 0 hma 0 0 0 0 0 0 0 0 0 0];

% Hmc (z)
F = [0.139 0.2];
A=[1,0];
Dev=[0.0085,0.00085];

[N,Fi,Ai,W]=firpmord(F,A,Dev,1);
hmc=firpm(N+1,Fi,Ai,W);
```

e) Matlab Code:

```
% Ha
sf1 = 0.164;
pf1 = 0.2;
pb = linspace(pf1,sf1,512)*pi;
[haf,w] = freqz(ha,1);
haf1 = freqz(ha,pb);
figure;
plot(w/pi,abs(haf))
ylabel('Magnitude')
title('Ha(z) in linear scale')
% Hma
sf1 = 0.194;
pf1 = 0.3;
pb = linspace(pf1,sf1,512)*pi;
[hmaf,w] = freqz(hma,1);
hmaf1 = freqz(hma,pb);
figure;
plot(w/pi,abs(hmaf))
ylabel('Magnitude')
title('Hma(z) in linear scale')
% Hmc
sf1 = 0.139;
pf1 = 0.2;
pb = linspace(pf1,sf1,512)*pi;
[hmcf,w] = freqz(hmc,1);
hmcf1 = freqz(hmc,pb);
figure;
plot(w/pi,abs(hmcf))
ylabel('Magnitude')
title('Hmc(z) in linear scale')
```

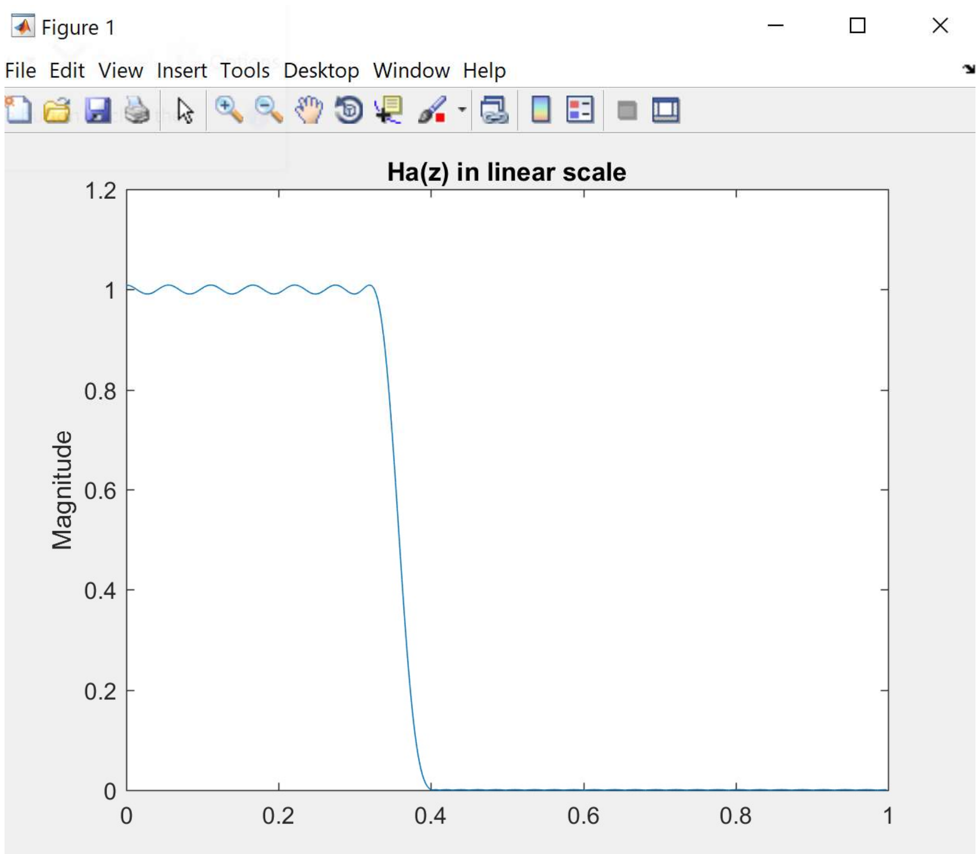


Figure 1
File Edit View Insert Tools Desktop Window Help
Ha(z) in linear scale
Magnitude
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1

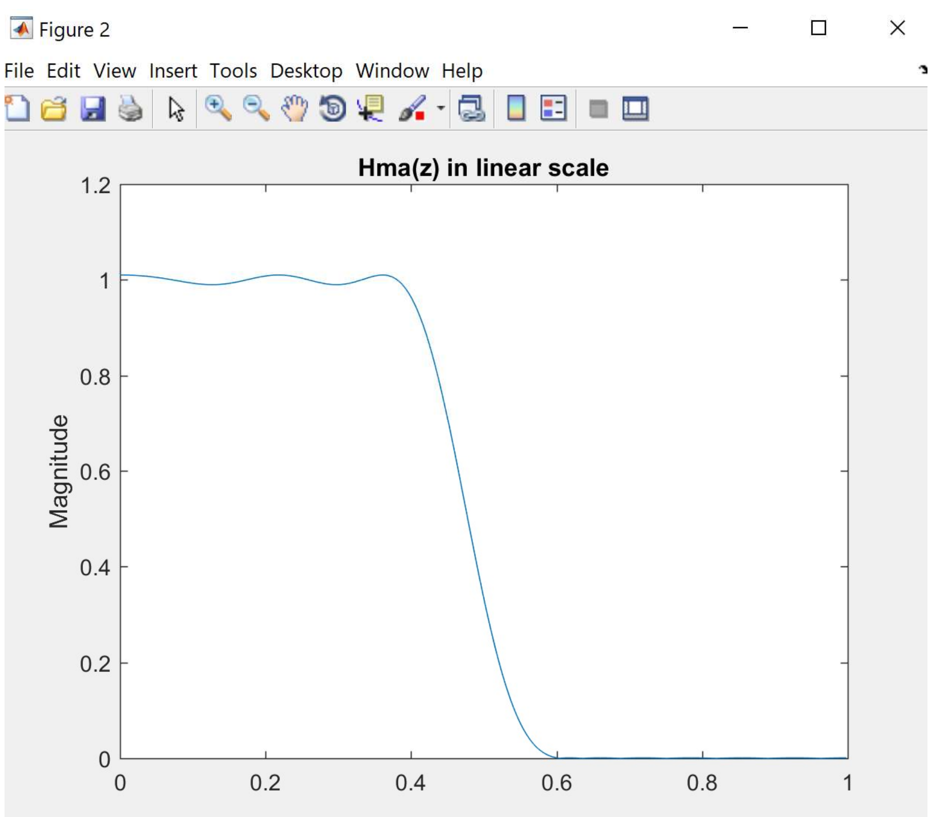
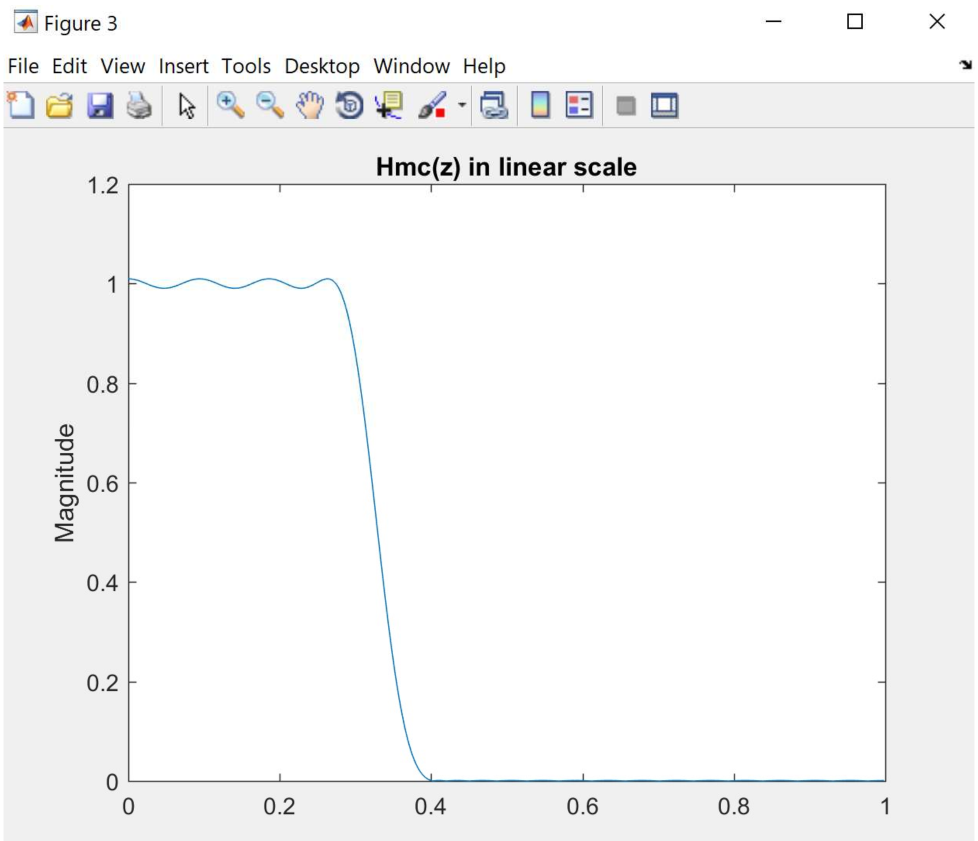


Figure 2
File Edit View Insert Tools Desktop Window Help
Hma(z) in linear scale
Magnitude
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1



f) <u>Matlab Code:</u>

```
%% f)
% h = (ha.*hma)+ (hc-ha)hmc;
t = 1:75;
hc = zeros(1,75);
hc(1,38) = 1;
% Frequency response of the overall filter
Ha = upsample(ha,6);
Hc = upsample(hc-ha,6);
H1 = conv(Ha,hma);
H2 = conv(Hc,hmc);
H = (H1+H2);
figure;
freqz(H);
ylabel('Magnitude')
title('Overall Filter')
sf1 = 0.139;
pf1 = 0.2;

pb = linspace(pf1,sf1,512)*pi;
[overh,w] = freqz(H,1);
overh1 = freqz(H,pb);
figure;
plot(w/pi,abs(overh))
ylabel('Magnitude')
title('Overall Filter')
```

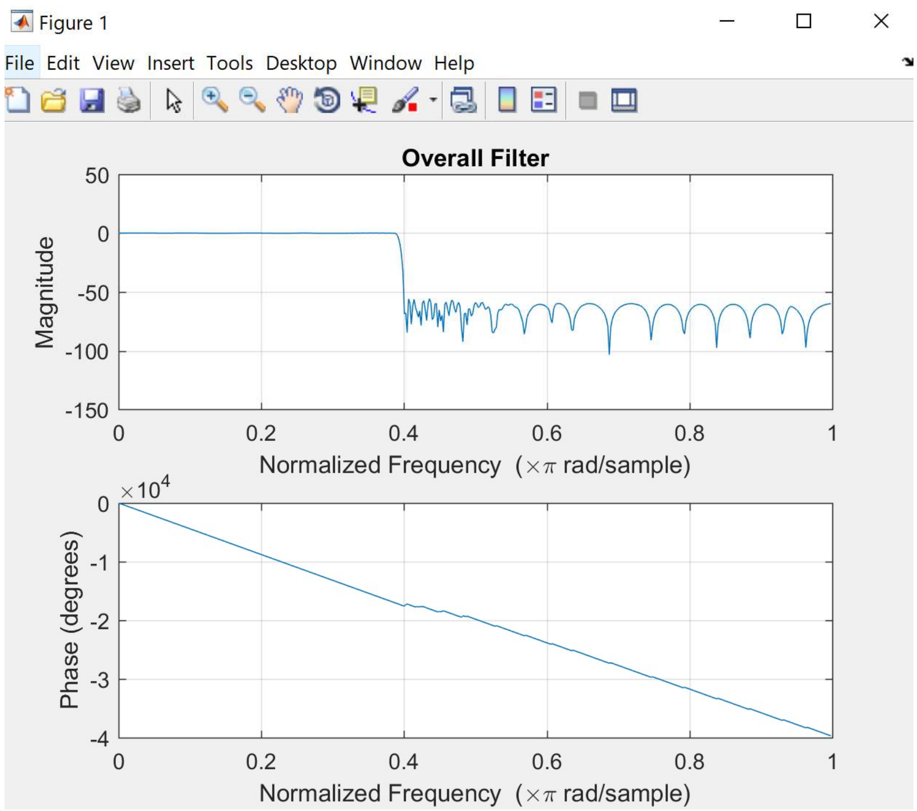


Figure 1
File Edit View Insert Tools Desktop Window Help
Overall Filter
Magnitude
Normalized Frequency (×π rad/sample)
×10^4
Phase (degrees)
Normalized Frequency (×π rad/sample)

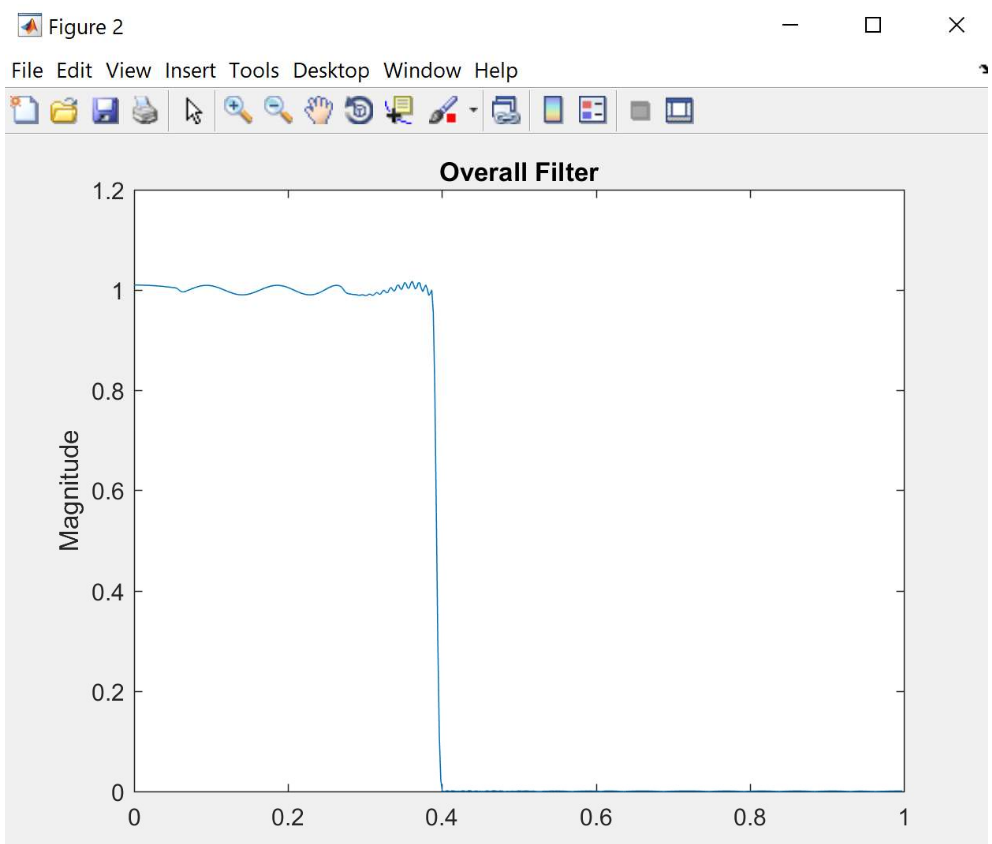
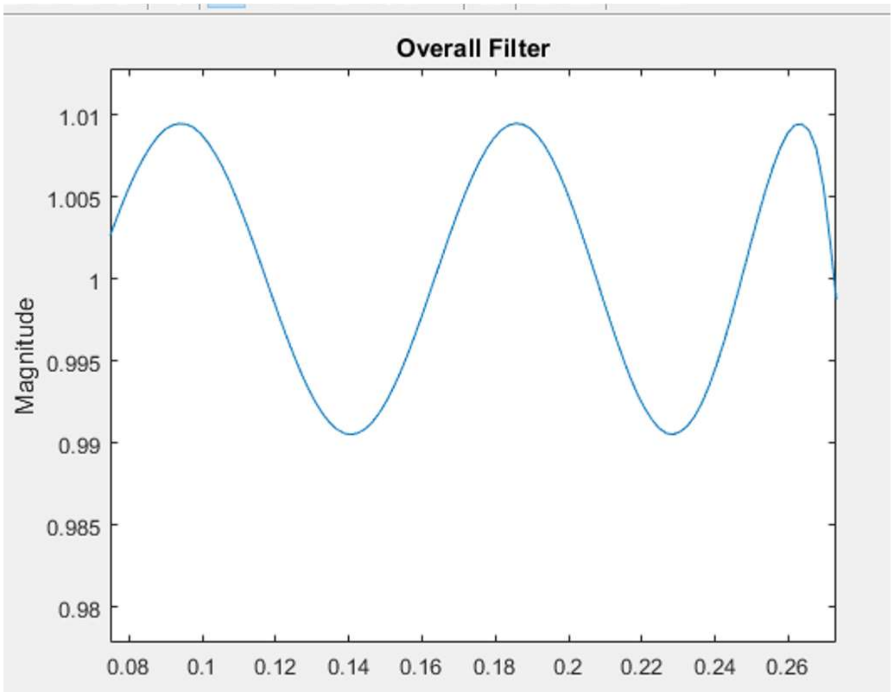


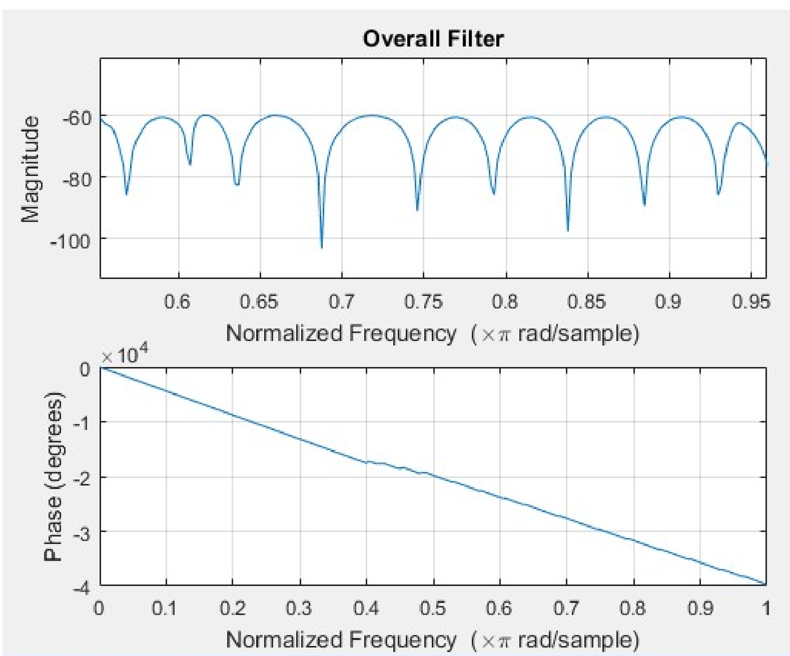
Figure 2
File Edit View Insert Tools Desktop Window Help
Overall Filter
Magnitude

g) Zoomed in values:

As we can see below that the filter meets the required specification.



Passband within 0.01



Stopband Below -60dB which is 0.001 stopband ripple

Part II: Remove noises in ECG signal.

sampling frequency = 360Hz

passband ripples = 0.010

stopband ripples = 0.001

Highpass filter:

Stopband edge: 0.17Hz

Passband edge: 1.0Hz

LowPass filter:

Stopband edge: 40Hz

Passband edge: 54Hz

Matlab Code:

```
plot(t,ecg);

F = [0.17,1];
A = [0,1];
Dev = [0.01,0.001];
fs = 360;
[N,Fi,Ai,W] = firpmord(F,A,Dev,fs);
h = firpm(N,Fi,Ai,W);

y1 = conv(h,ecg);

F = [40,54];
A = [1,0];
[N,Fi,Ai,W] = firpmord(F,A,Dev,fs);
h1 = firpm(N,Fi,Ai,W);

y2 = conv(h1,y1);

figure
plot(t,y2(1:7201));
```

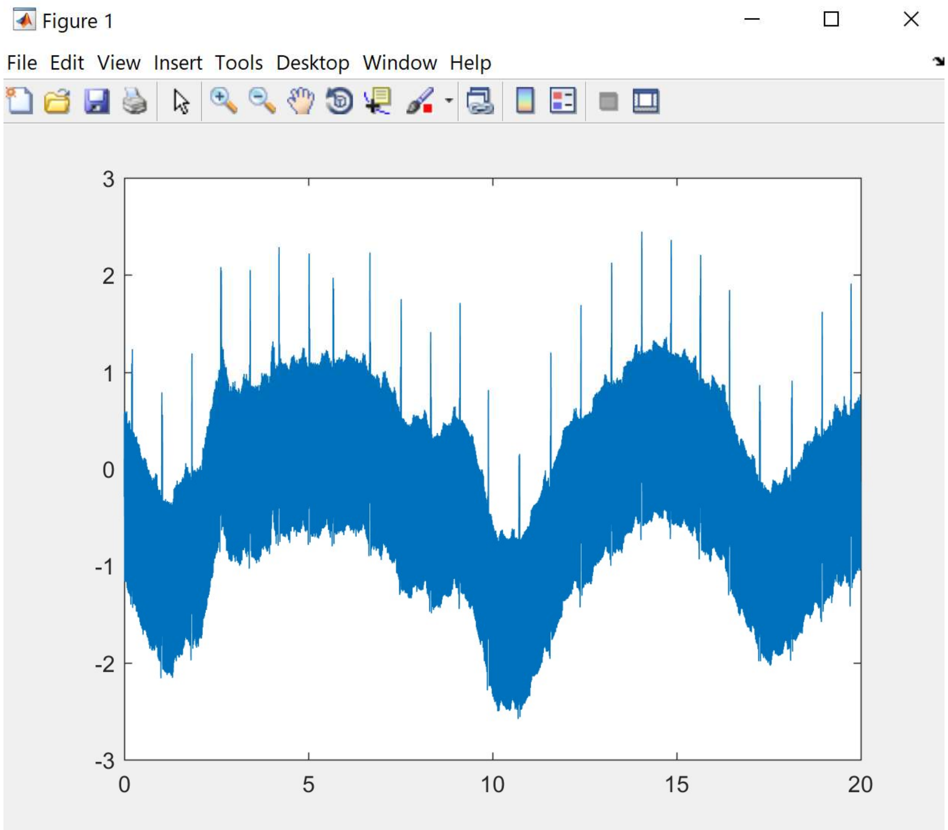


Figure 1
File Edit View Insert Tools Desktop Window Help
3
2
1
0
-1
-2
-3
0
5
10
15
20

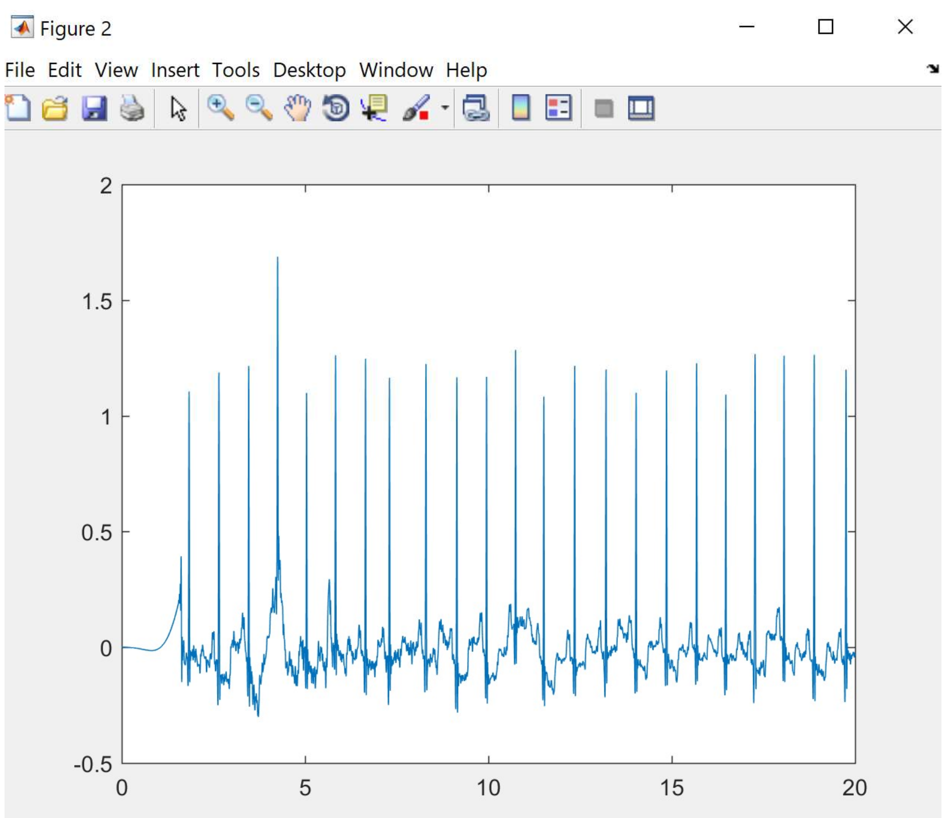


Figure 2
File Edit View Insert Tools Desktop Window Help
2
1.5
1
0.5
0
-0.5
0
5
10
15
20

Due to the Finite impulse response, we have a small delay due to different frequency components. Plus, it's common for that to happen when we use filters to reduce noise.

Additional, the function grpdelay(firf,N,Fs) can be used to check the group delay.

CONCLUSION

This lab helped us understand techniques of advanced filter design really well. We also used a real life application of filters, where we filtered out the noise in an ECG signal. Personally, I think this lab was really interesting as we saw an actual application of this and I think it benefited us all doing the lab.

BIBLIOGRAPHY

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