Digital Signal Processing, Lab 4

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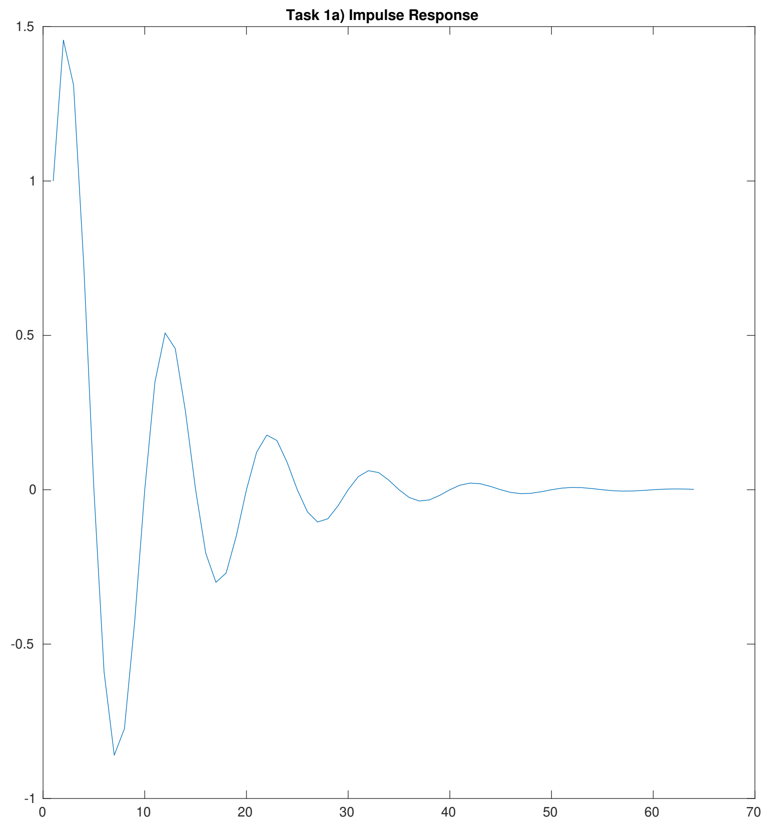
Chapter 1

Task 1

We use this code to generate filter coefficients:

```
j = sqrt(-1);
poles = [0.9 * exp(j*0.2*pi), 0.9 * exp(-j*0.2*pi)];
A = poly(poles);
B = poly(0);
dlt = zeros(1, 64);
dlt(1) = 1;
Y = filter(B, A, dlt);
```

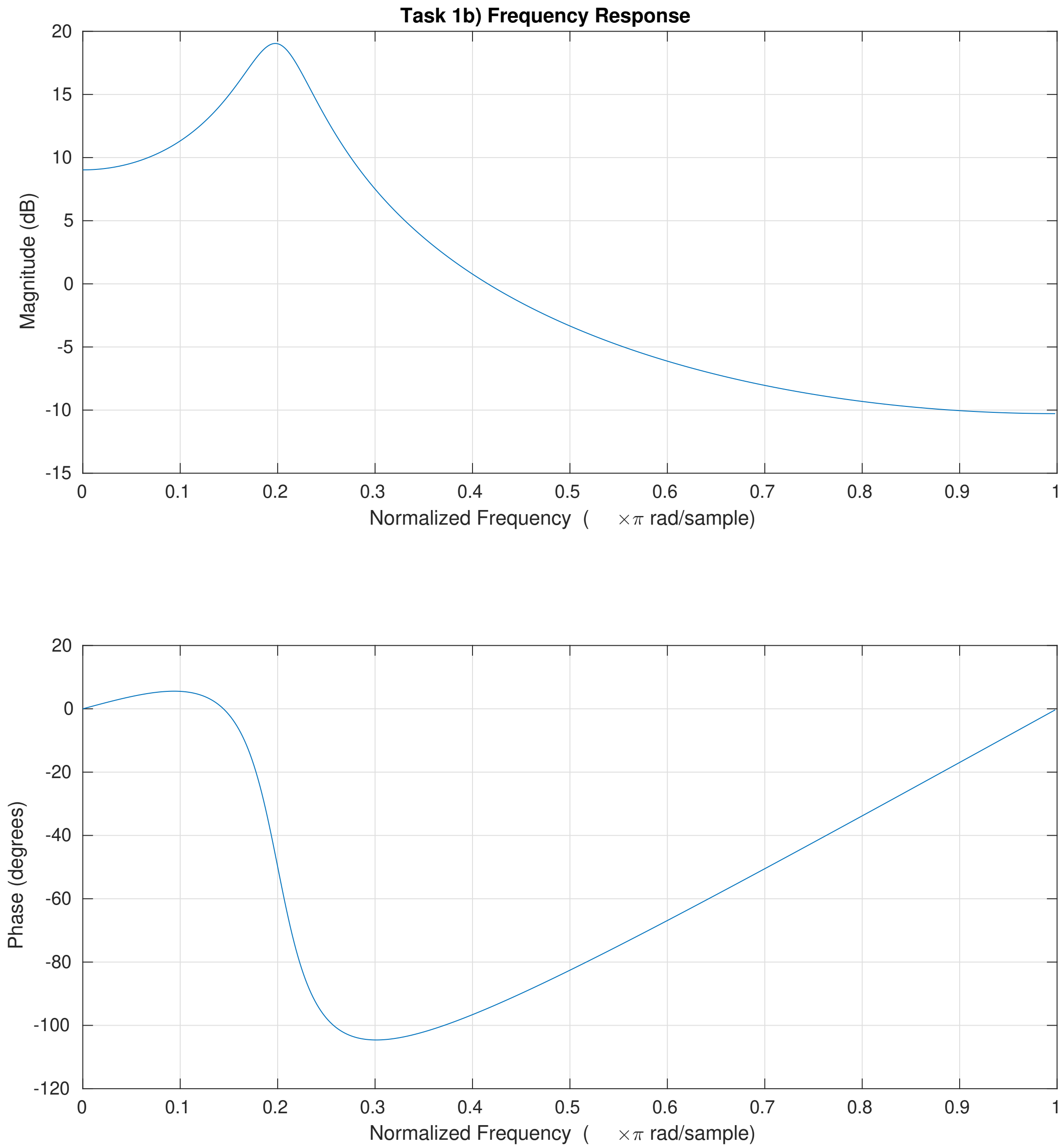
1.1 Impulse Response



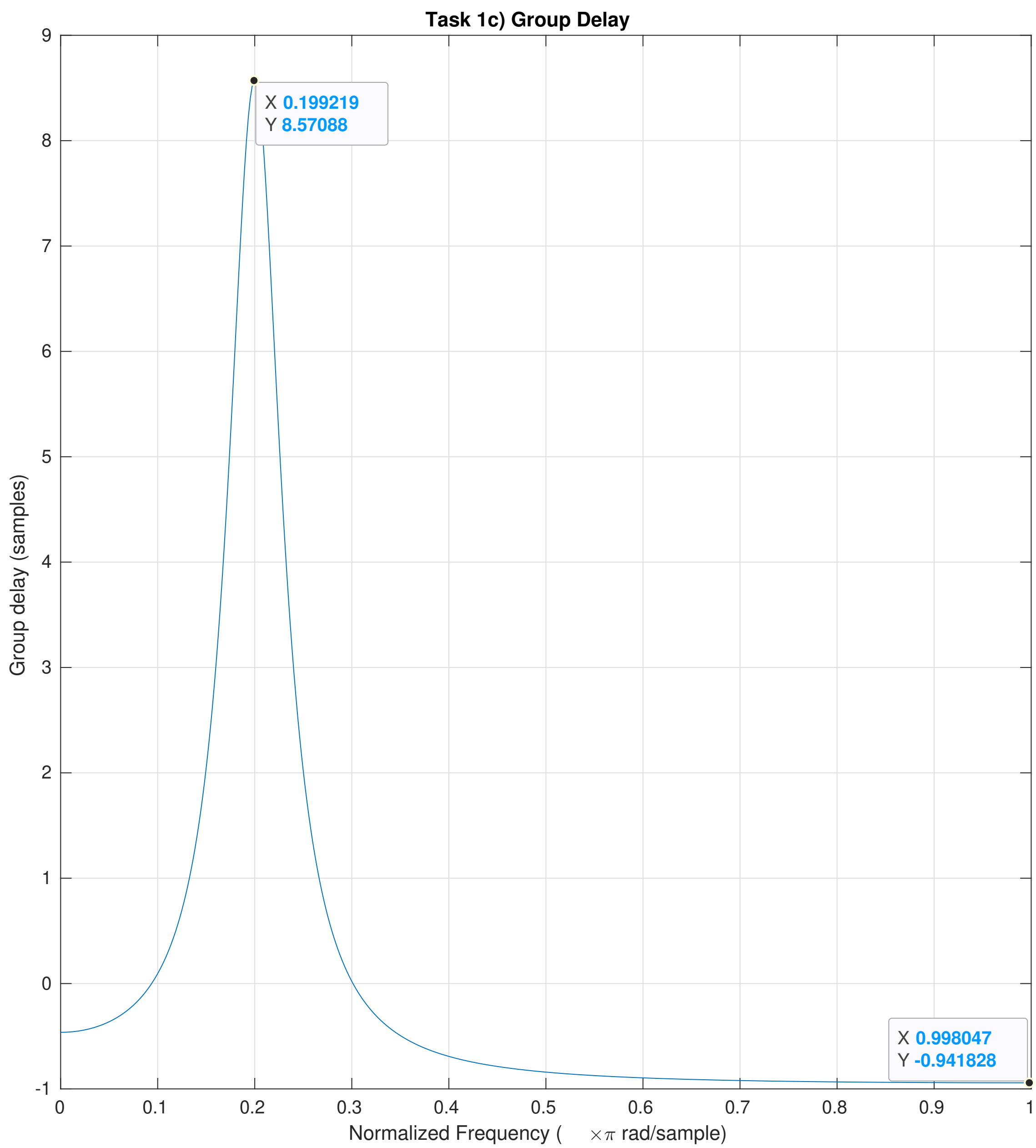
As we can see from the image:

- Period of oscillation is equal to around 10 samples
- Decay rate is equal to around 7 samples (notice how after the 9th sample the value of the signal does not reach more than $\frac{1}{2}$ of it's original value)
- Signal is not oscillating fastly and it diminishes quite fast.

1.2 Frequency Response

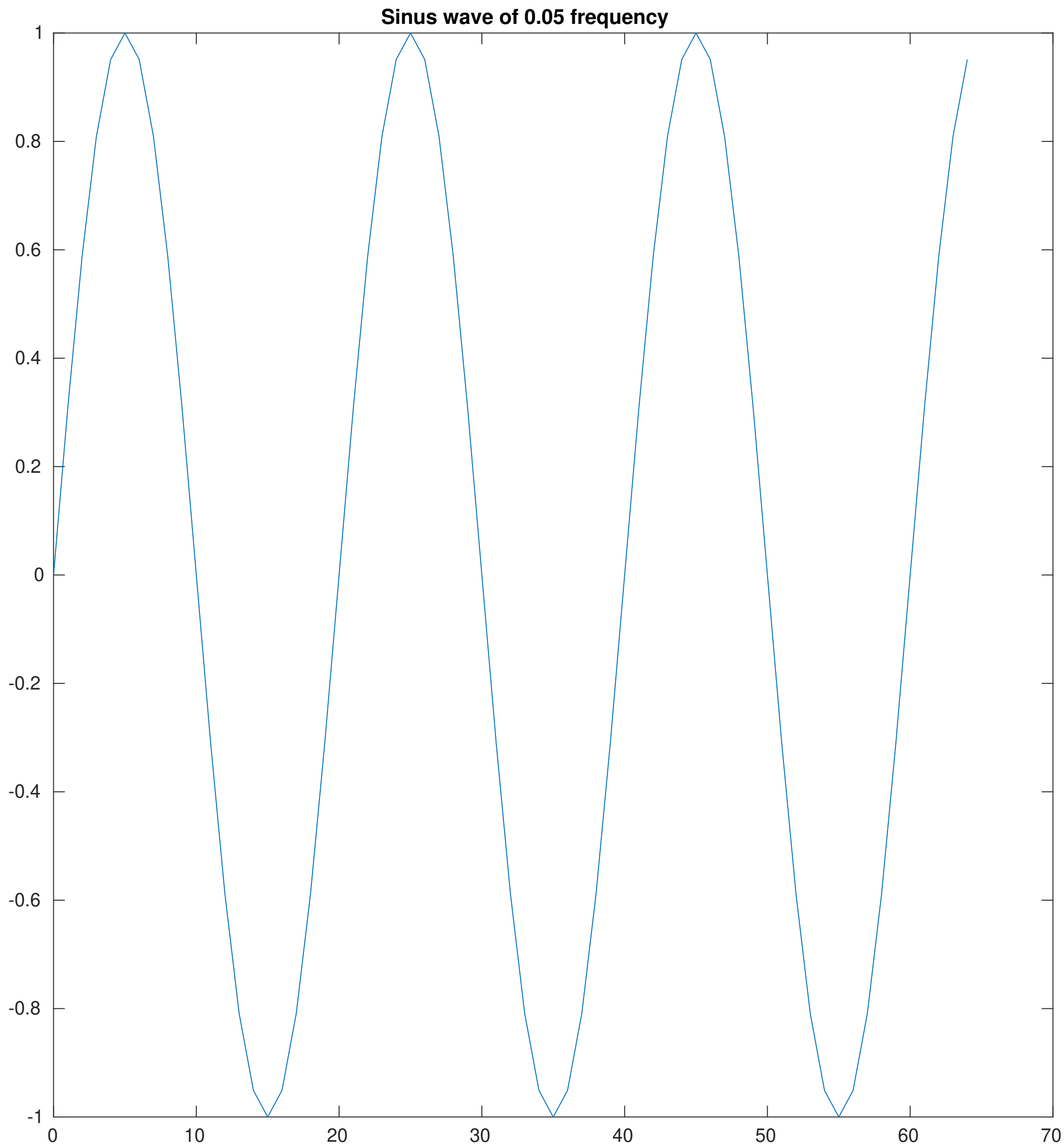


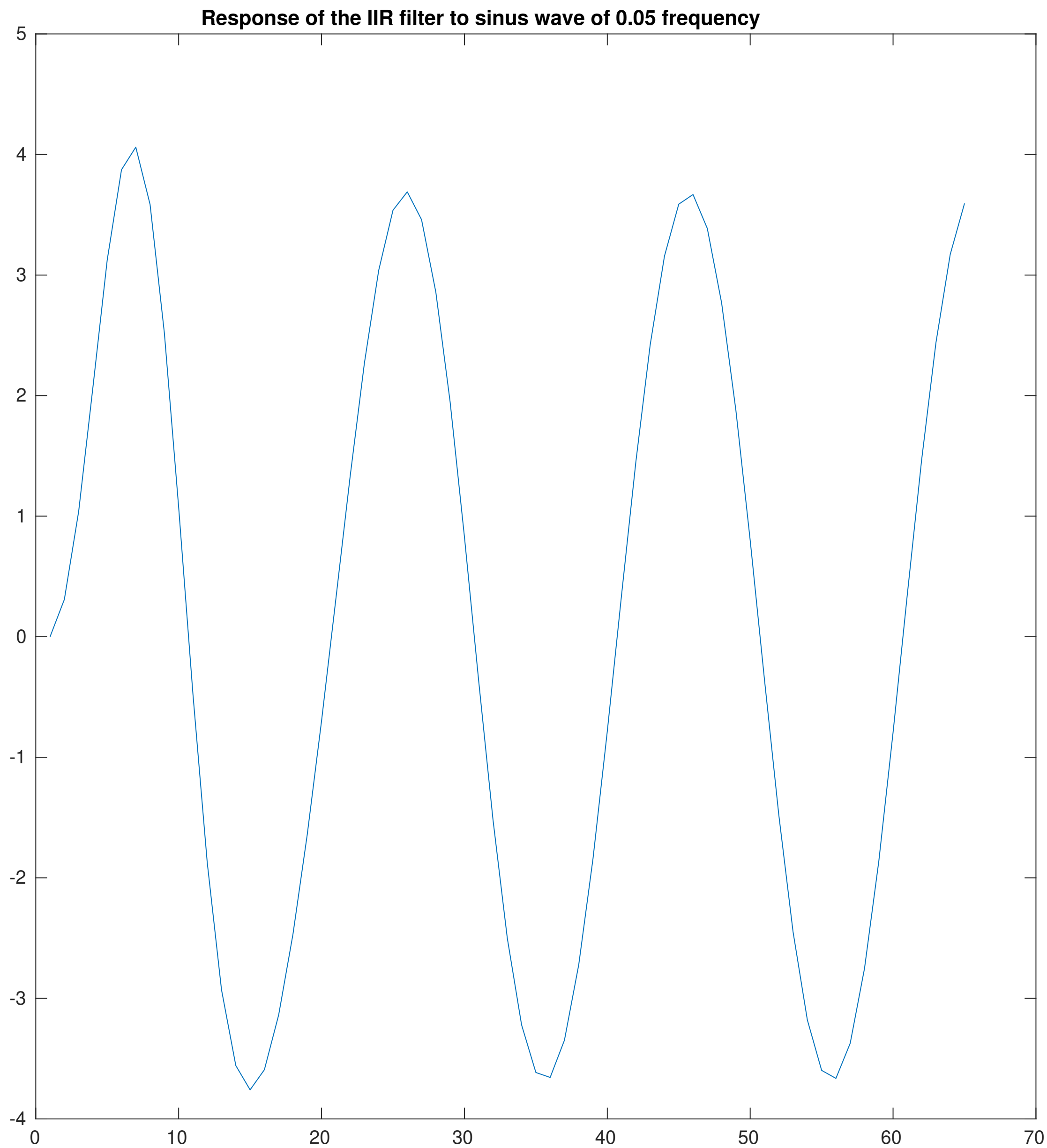
1.3 Group Delay



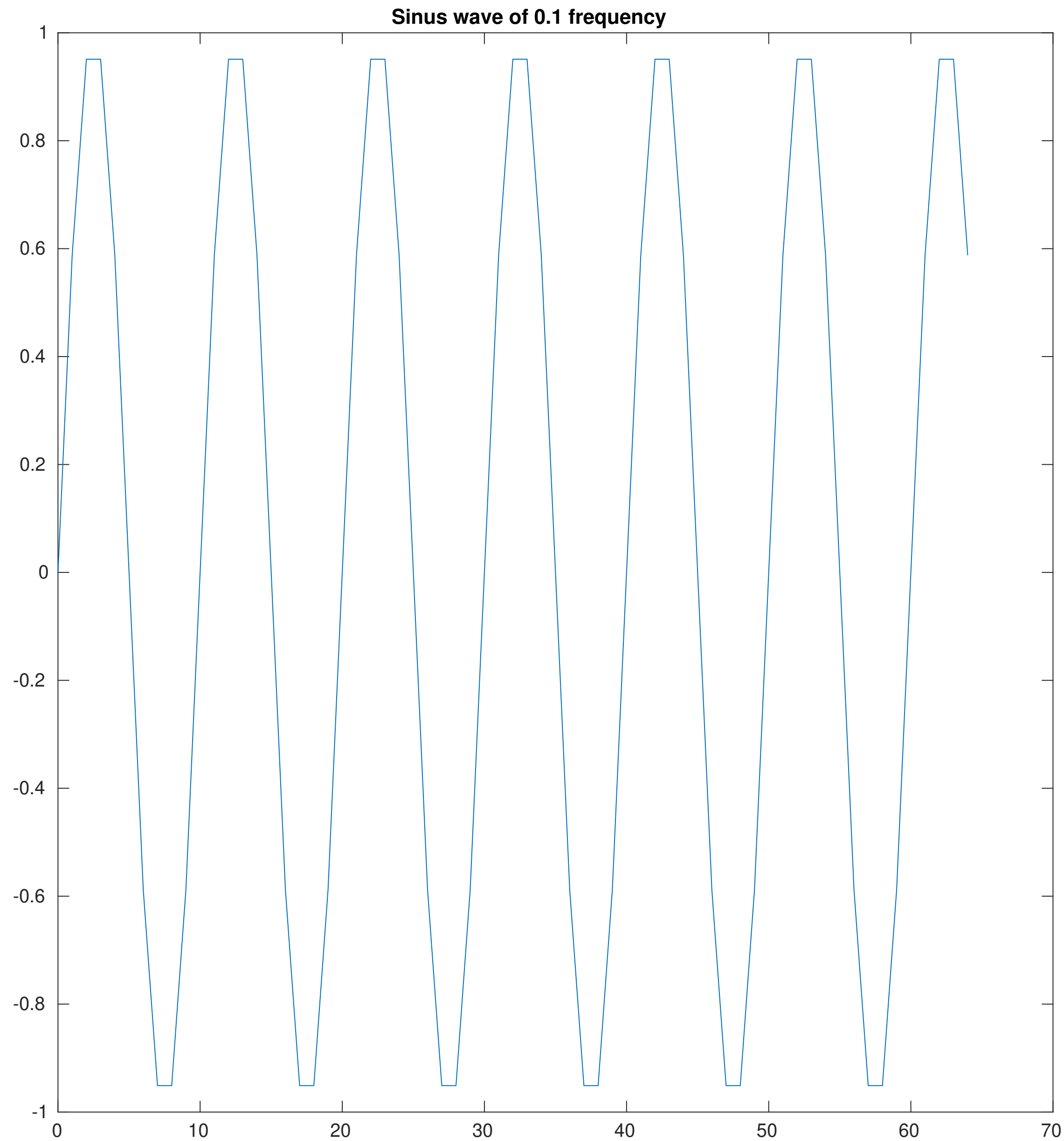
- Minimum value of group delay: -0.941828
- Maximum value of group delay: 8.57088
- Peak X coordinate: 0.199219

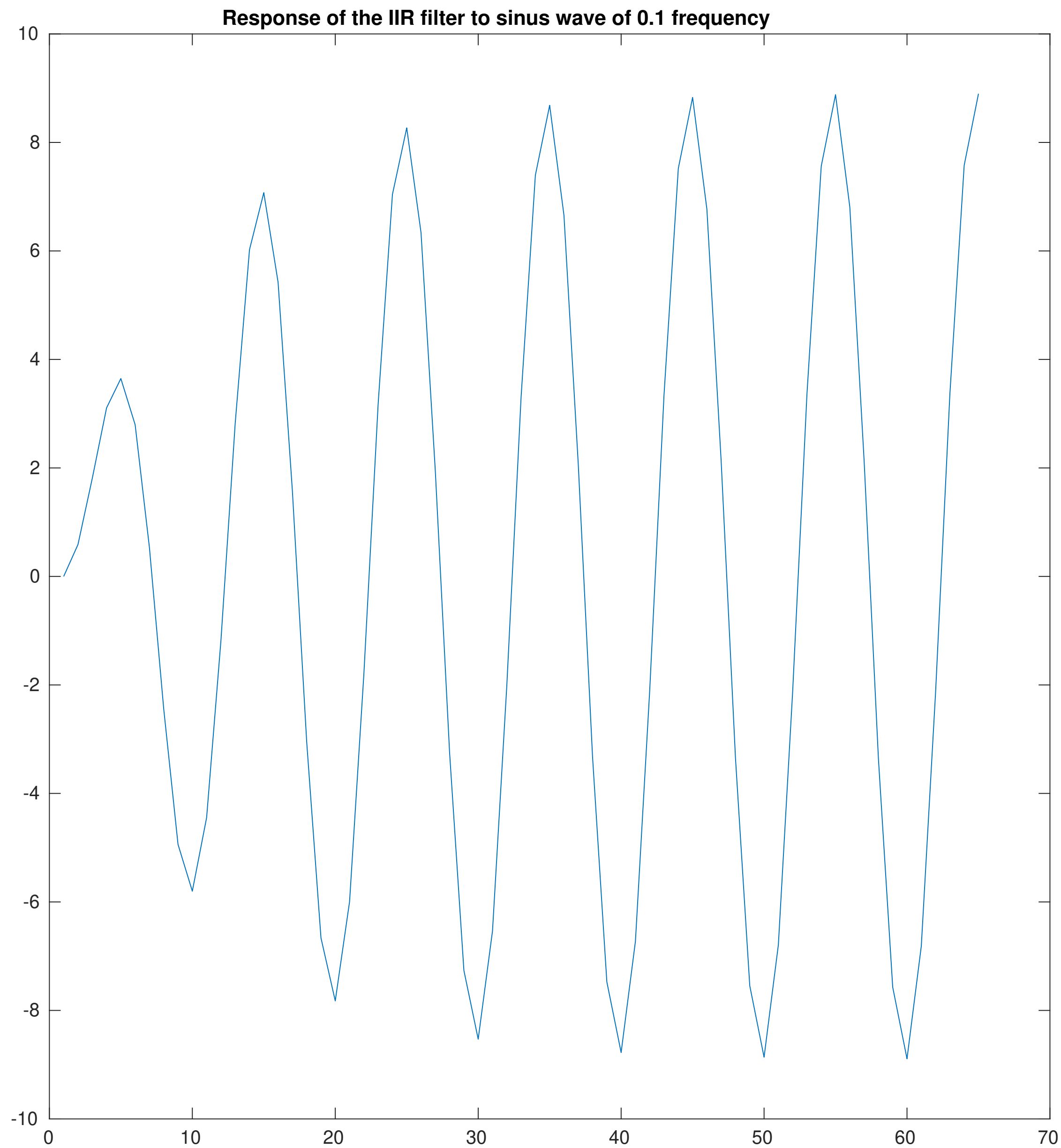
1.4 Responses for sine waves of different frequencies



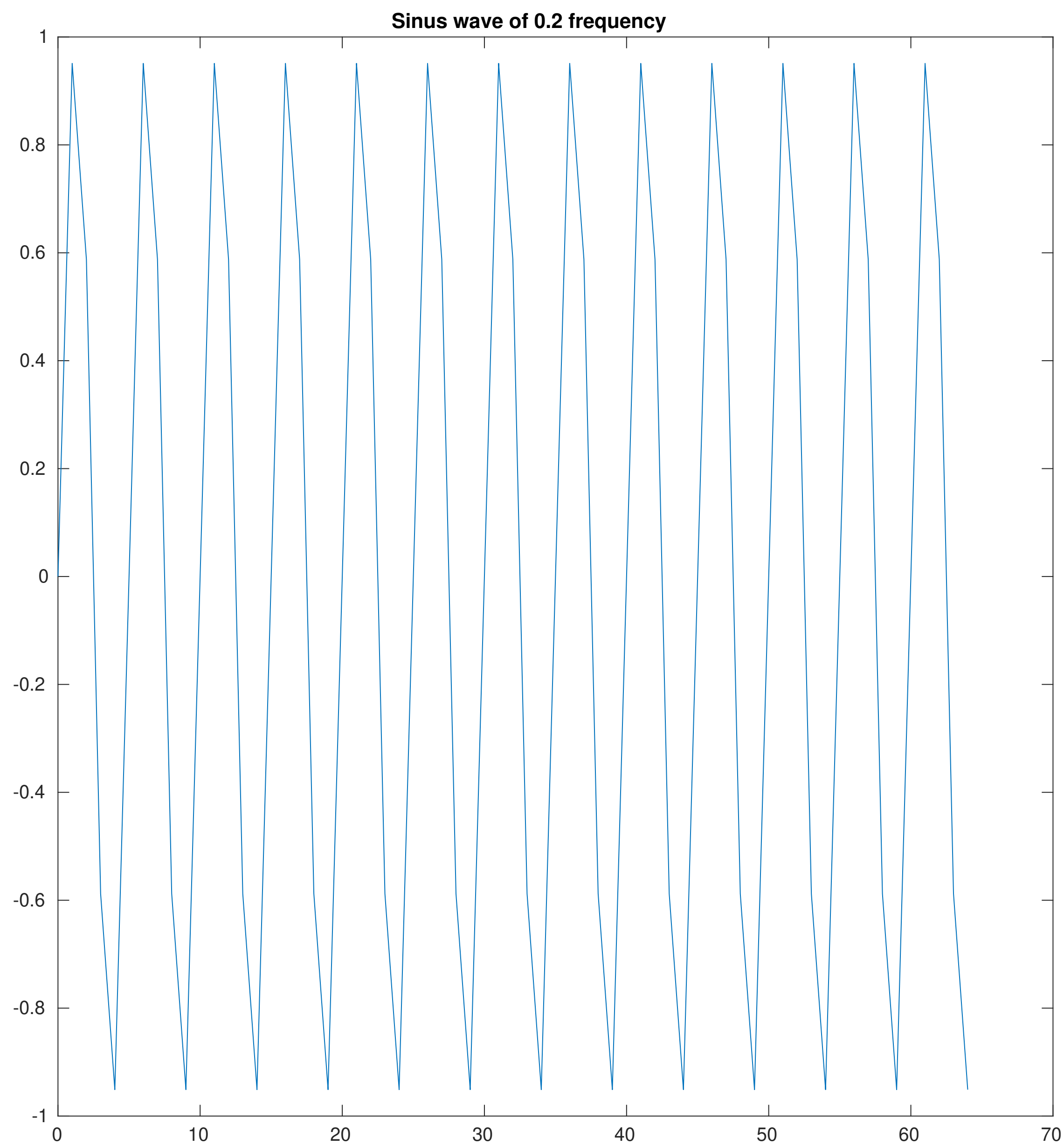

Response of the IIR filter to sinus wave of 0.05 frequency
5
4
3
2
1
0
-1
-2
-3
-4
0
10
20
30
40
50
60
70

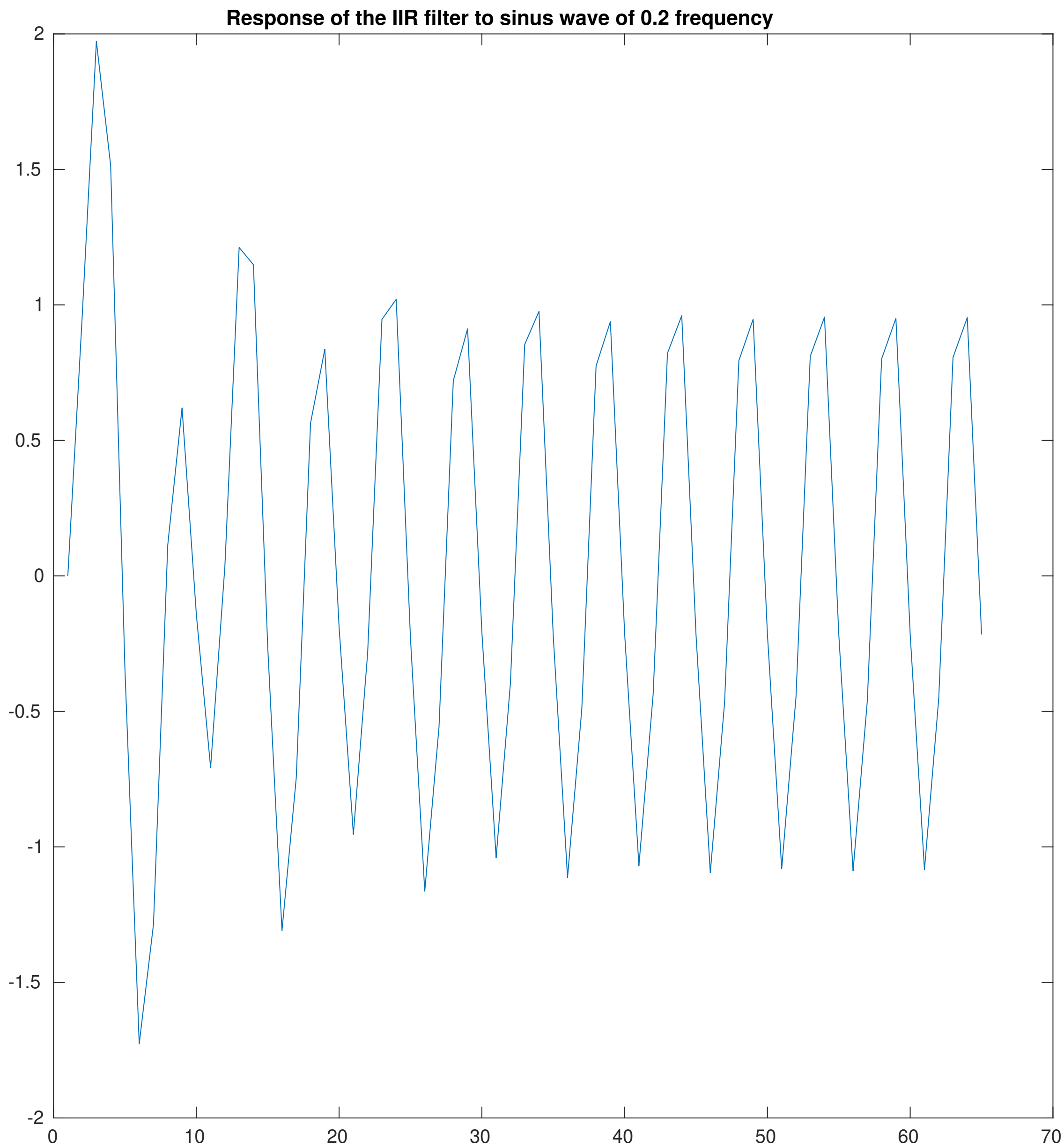
Response is similar though we have a little deformation at the start and the magnitude of the response is equal to around 4.


Sinus wave of 0.1 frequency
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
10
20
30
40
50
60
70


Response of the IIR filter to sinus wave of 0.1 frequency
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60
70

Response is again similar, we can observe bigger deformation at the start and the magnitude of the response decreases to around 2.


Sinus wave of 0.2 frequency
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
10
20
30
40
50
60
70


Response of the IIR filter to sinus wave of 0.2 frequency
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
10
20
30
40
50
60
70

Similar response, even bigger deformations at the start but we end up with the response with magnitude close to '1'.

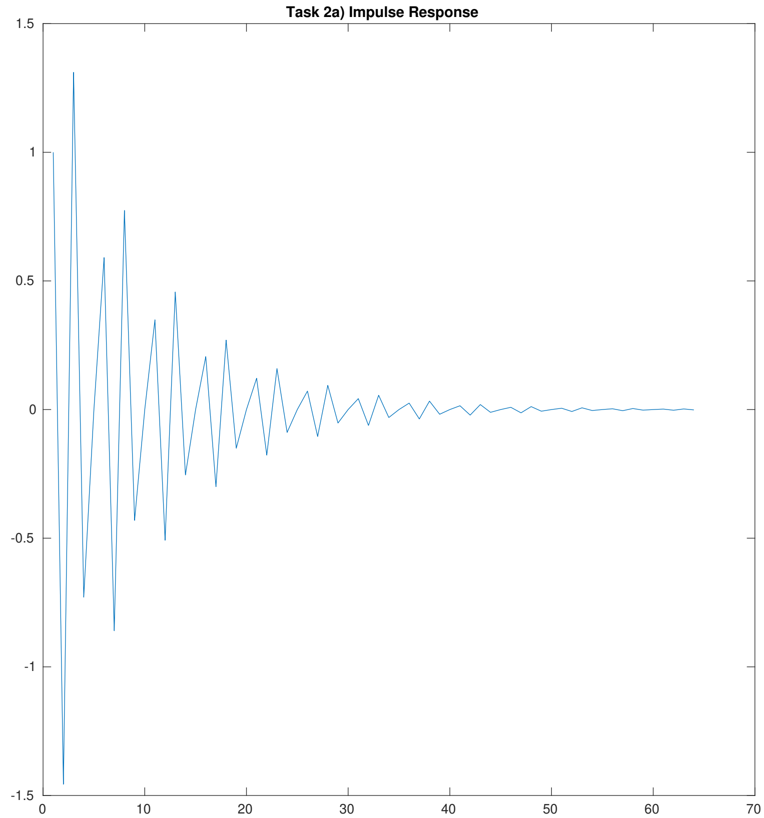
Chapter 2

Task 2

We use this code to generate filter coefficients:

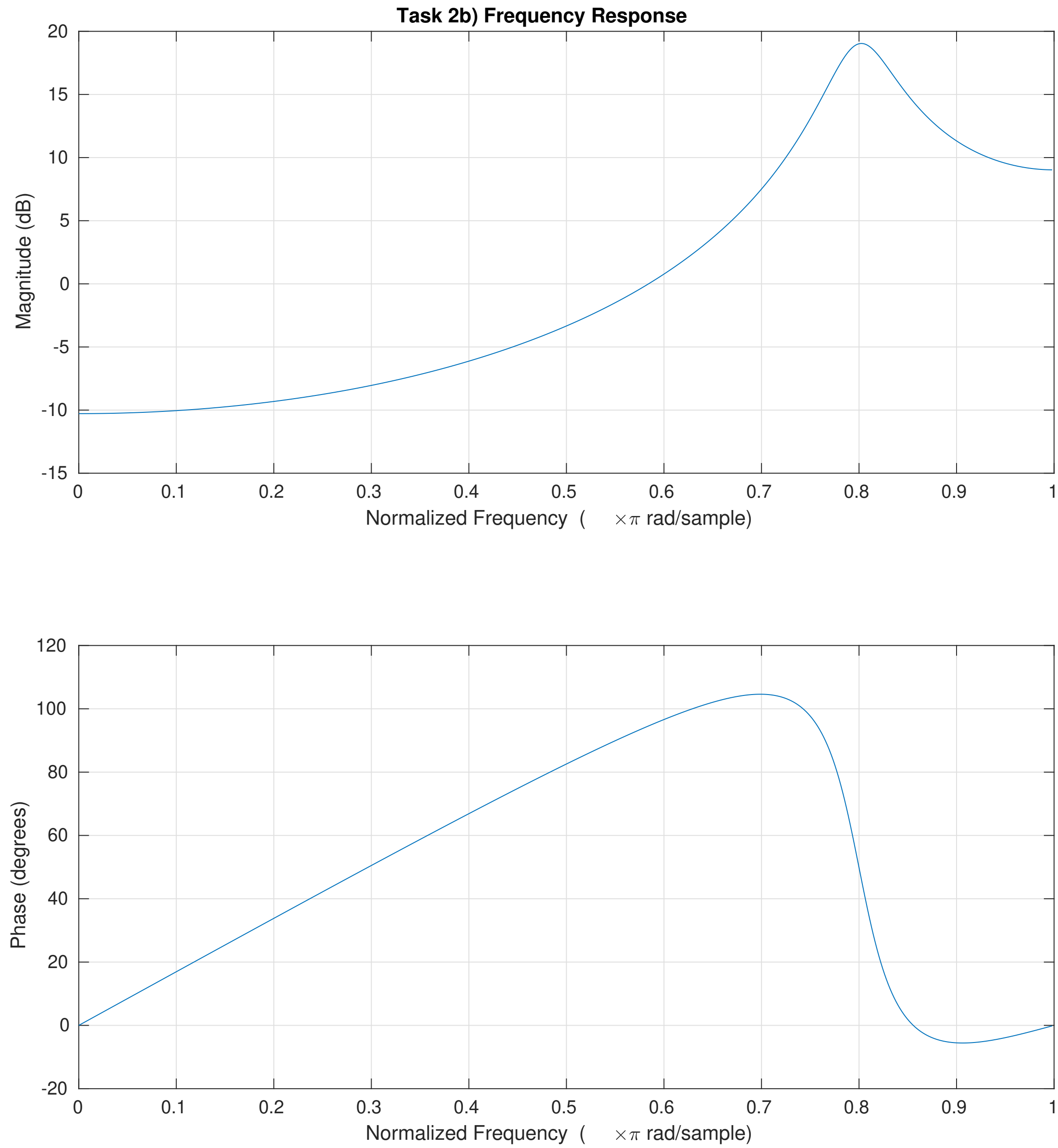
```
j = sqrt(-1);
poles = [0.9 * exp(j*0.8*pi), 0.9 * exp(-j*0.8*pi)];
A = poly(poles);
B = poly(0);
dlt = zeros(1, 64);
dlt(1) = 1;
Y = filter(B, A, dlt);9
```

2.1 Impulse Response

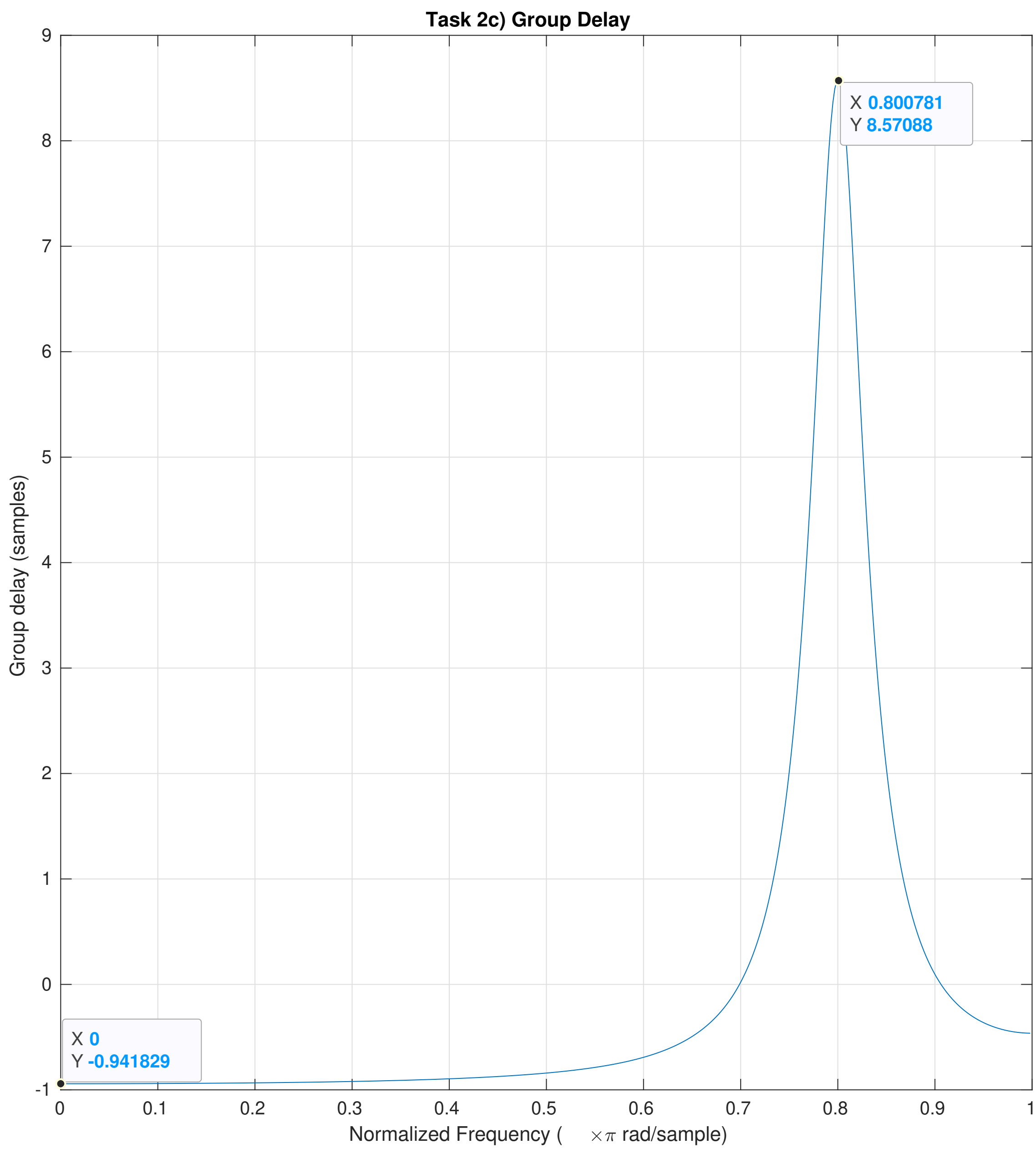


- Period of oscillation varies between 3 and 2
- Decay rate is equal to around 7 samples
- Signal is oscillating faster than in task 1 though it still will diminish.

2.2 Frequency Response



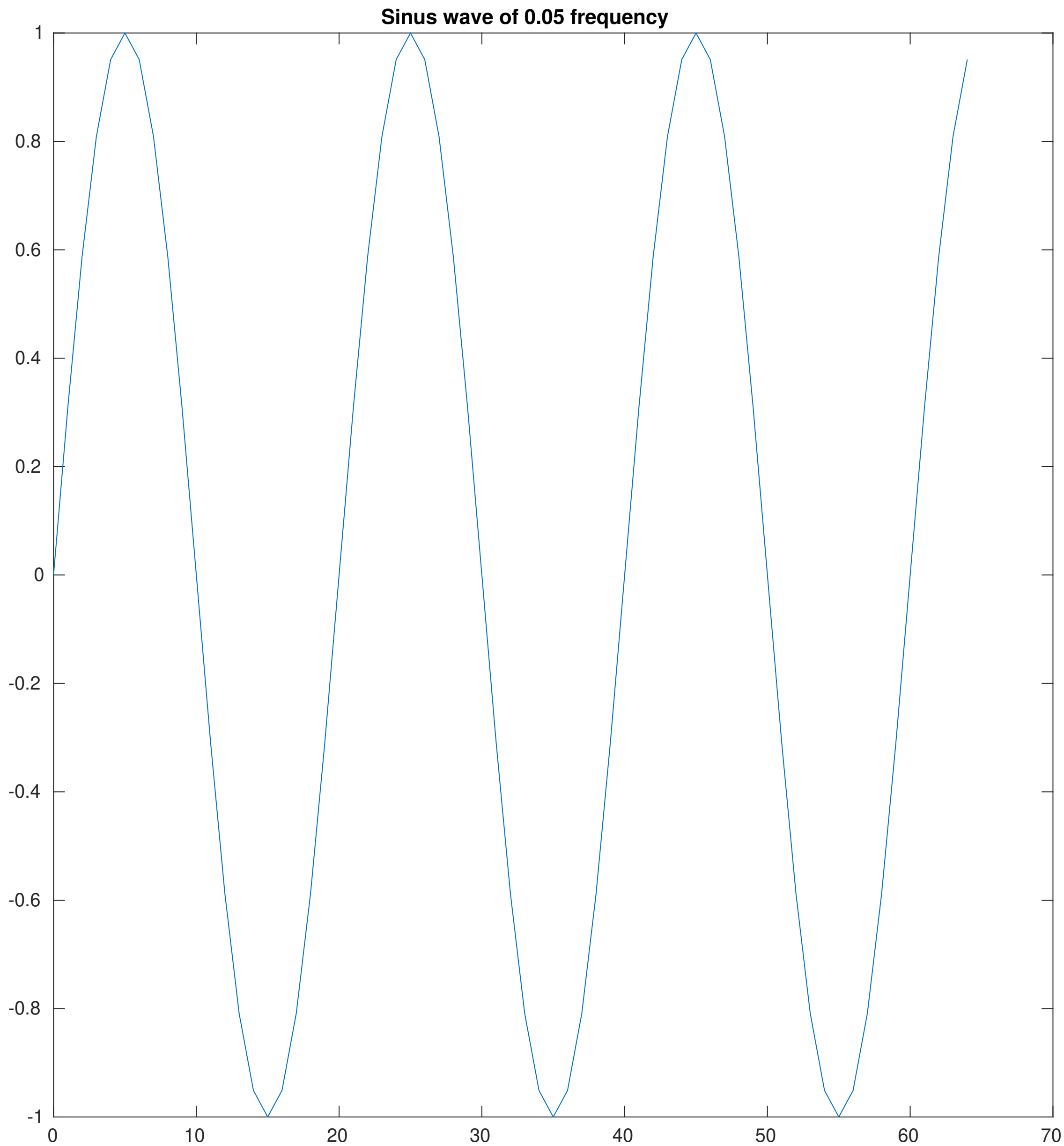
2.3 Group Delay

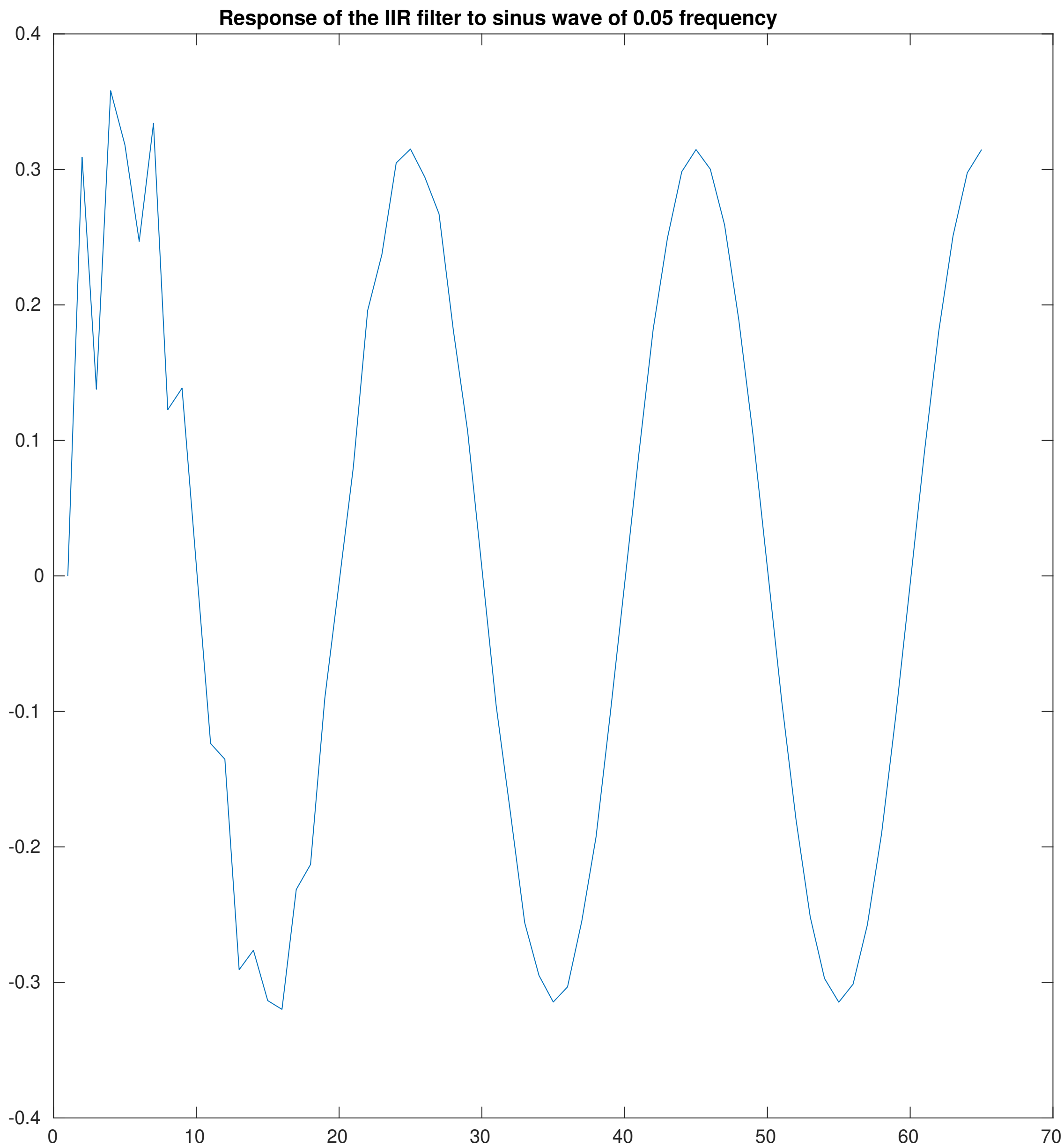


- Minimum value of group delay: -0.941828
- Maximum value of group delay: 8.57088
- Peak X coordinate: 0.800781

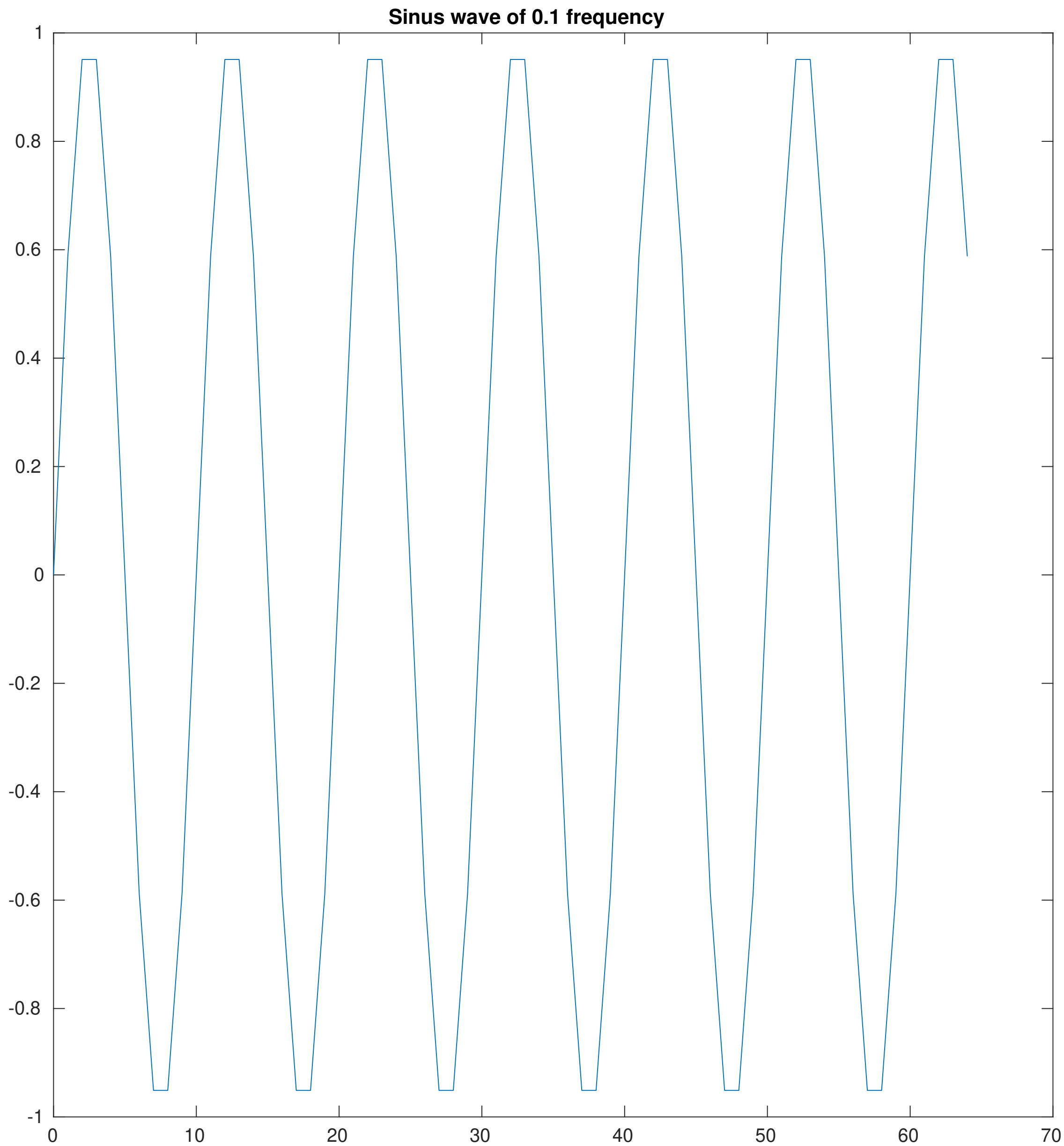
As we can see from graphs and from results frequency response and group delay are mirrored compared to task 1.

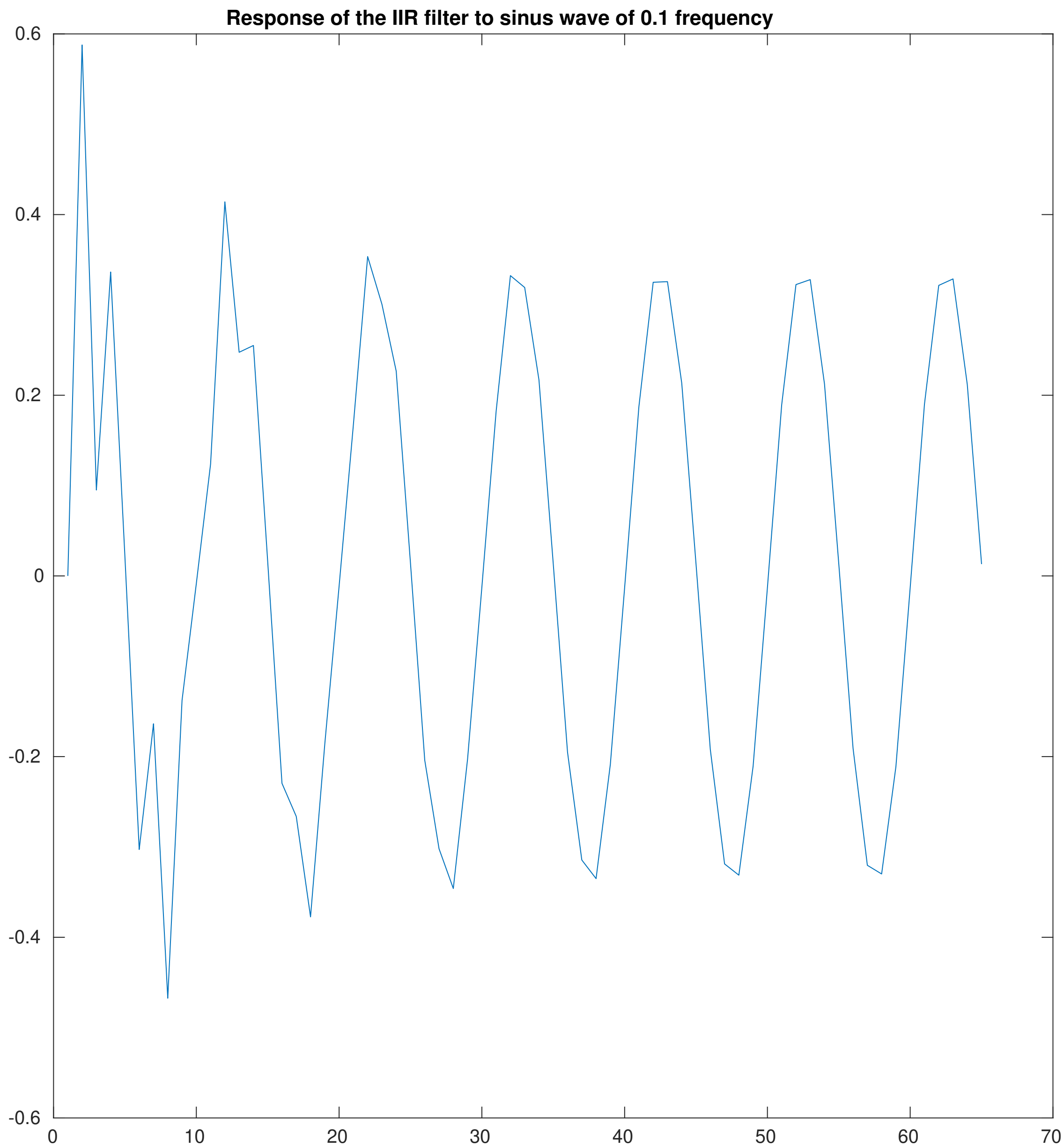
2.4 Responses for sine waves of different frequencies



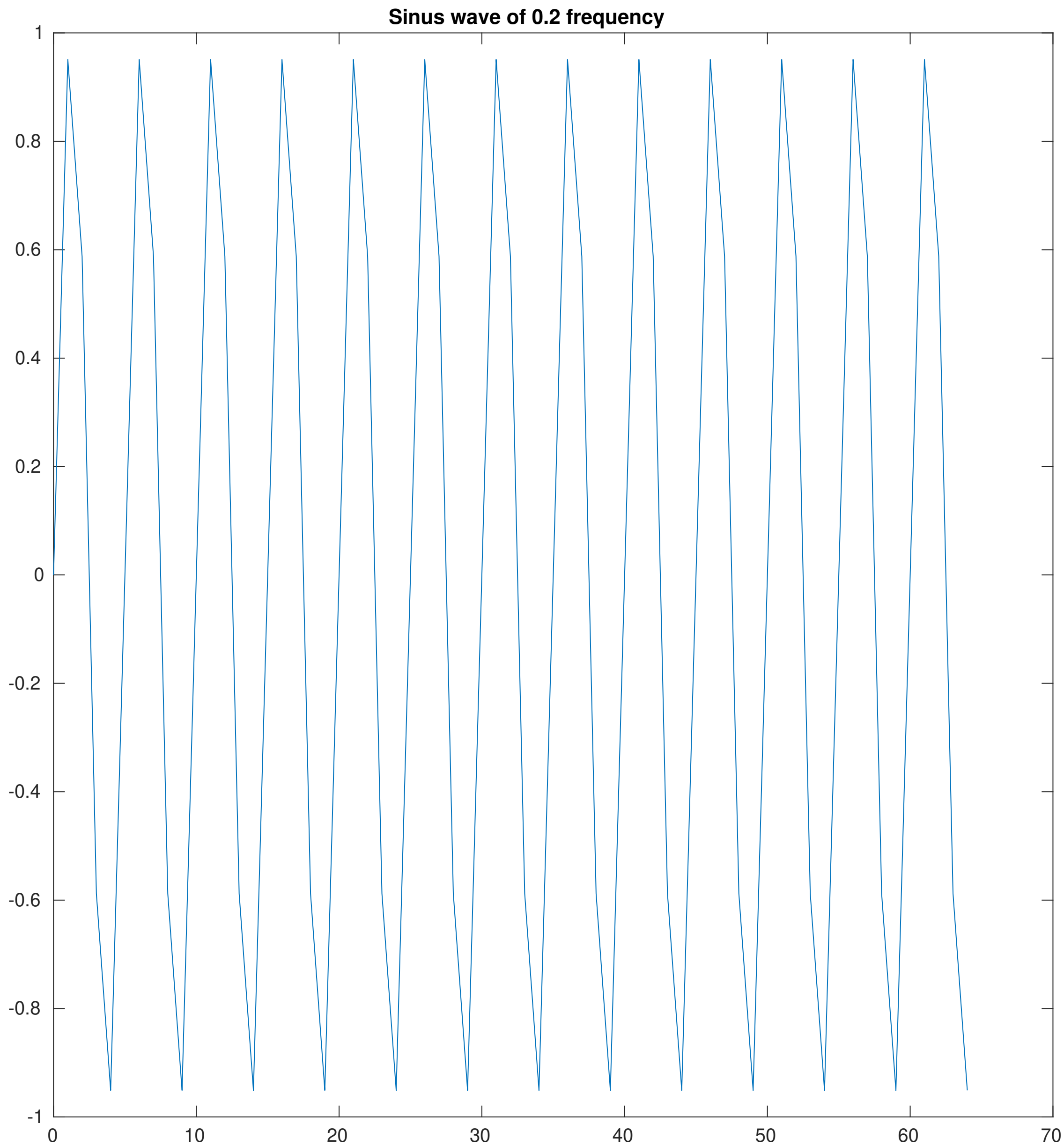

Response of the IIR filter to sinus wave of 0.05 frequency
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
60
70

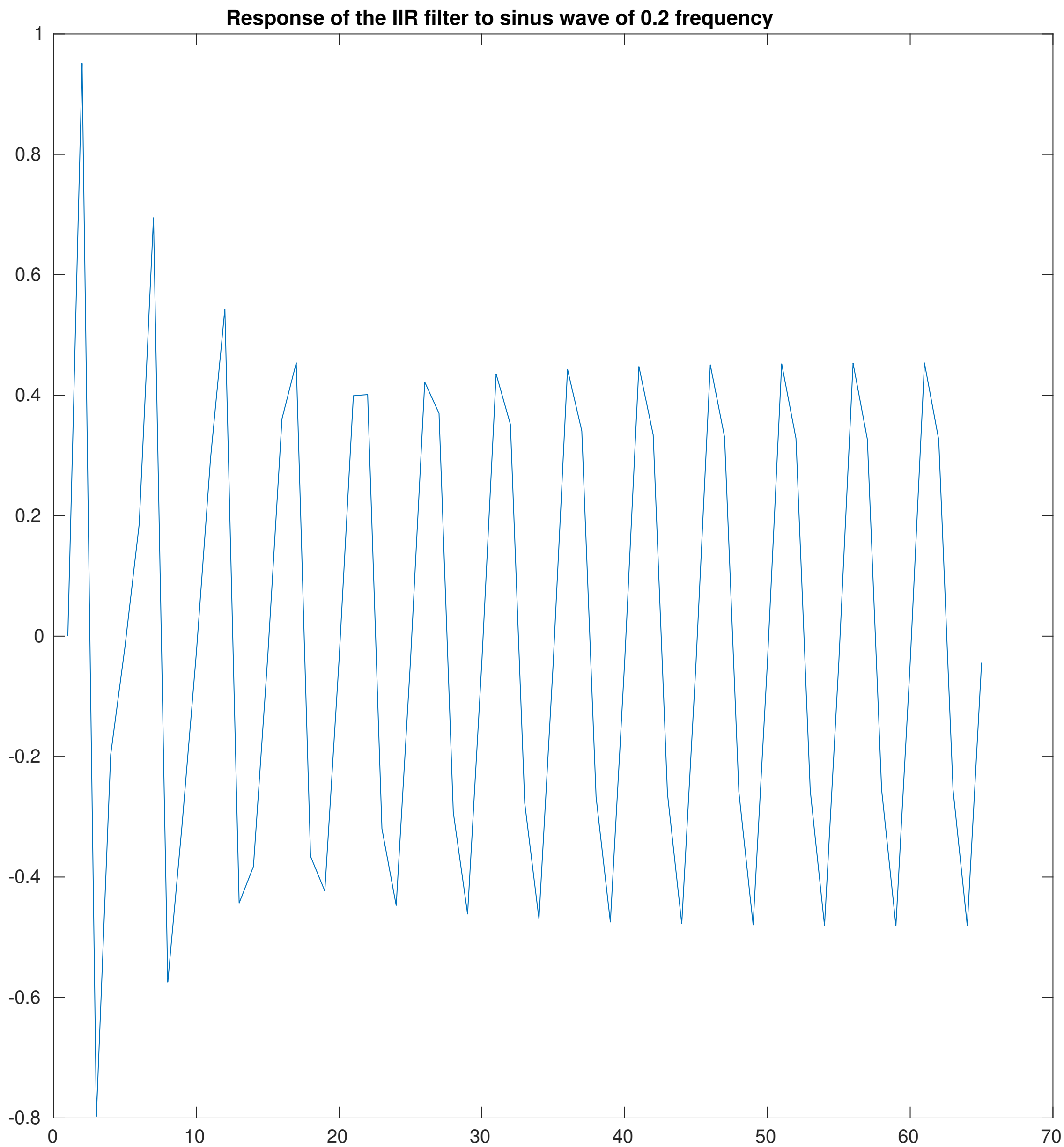
Magnitude of response equal to: 0.3


Sinus wave of 0.1 frequency
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
10
20
30
40
50
60
70


Response of the IIR filter to sinus wave of 0.1 frequency
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
10
20
30
40
50
60
70

Magnitude of response equal to around: 0.35


Sinus wave of 0.2 frequency
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
10
20
30
40
50
60
70


Response of the IIR filter to sinus wave of 0.2 frequency
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
10
20
30
40
50
60
70

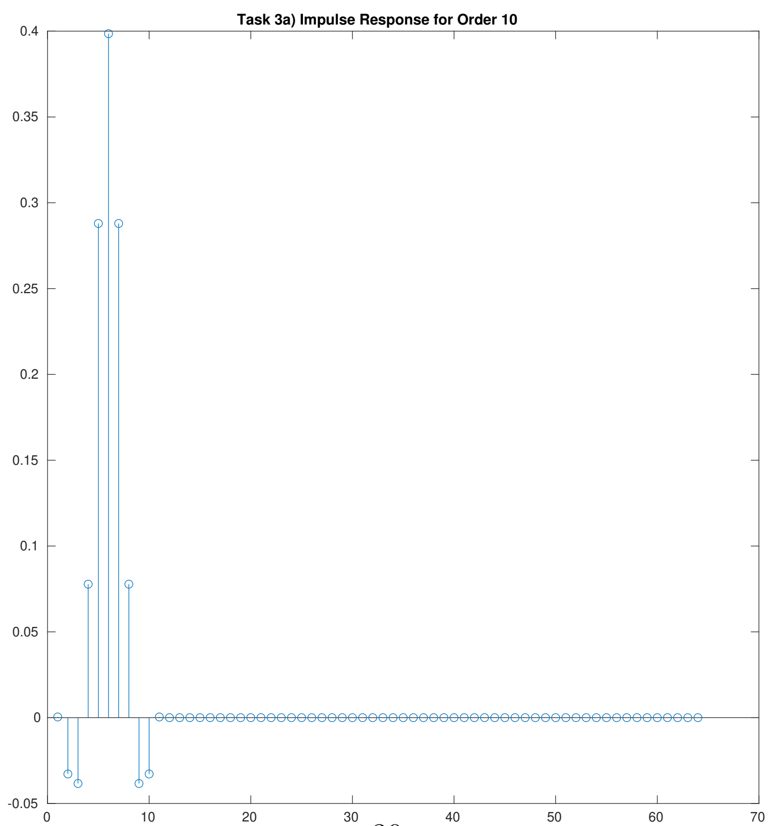
Magnitude of response equal to: 0.4

Chapter 3

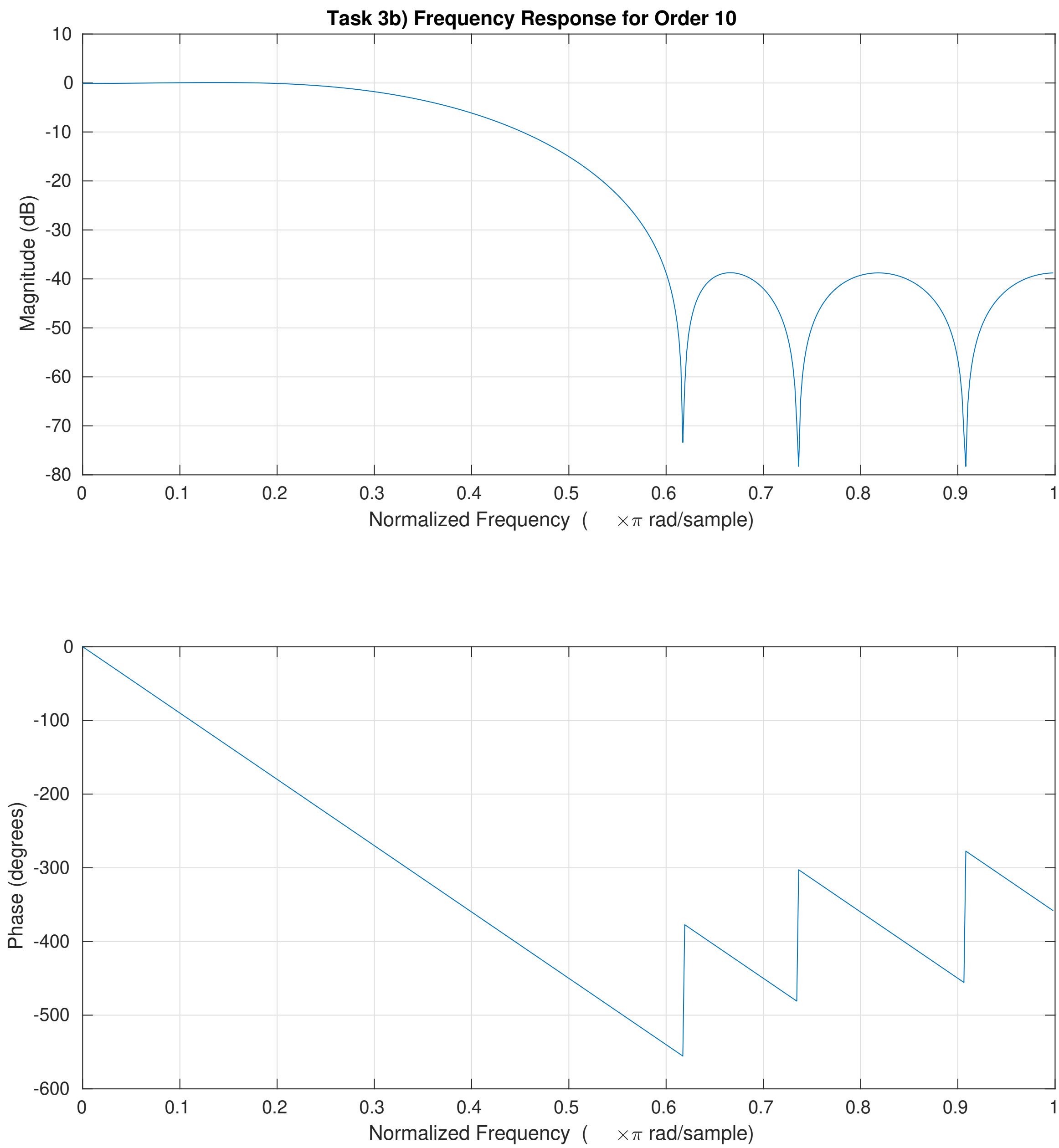
Task 3

3.1 Order 10, 0.2 π passband, 0.6 π stopband

3.1.1 Impulse Response



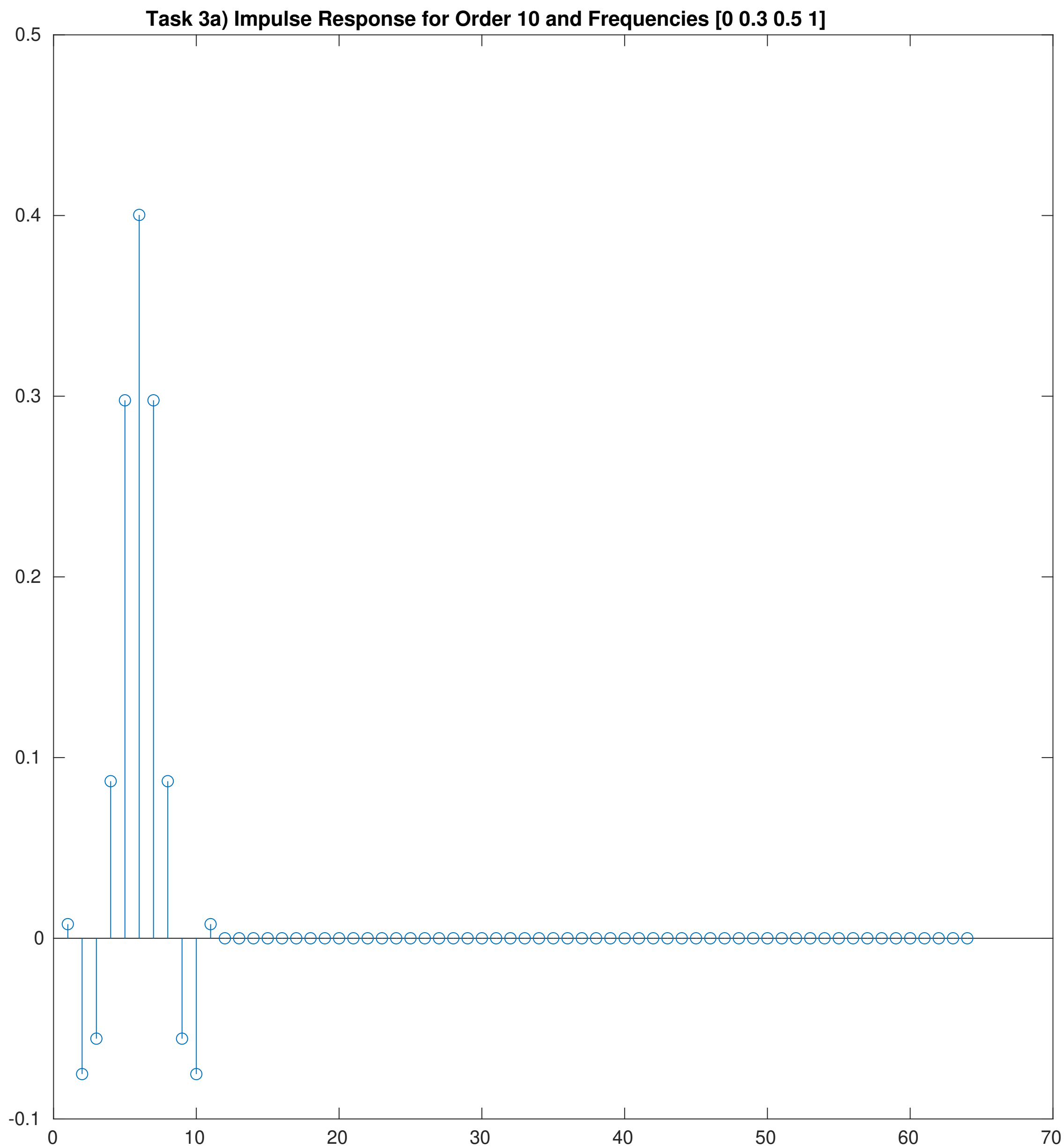
3.1.2 Frequency Response



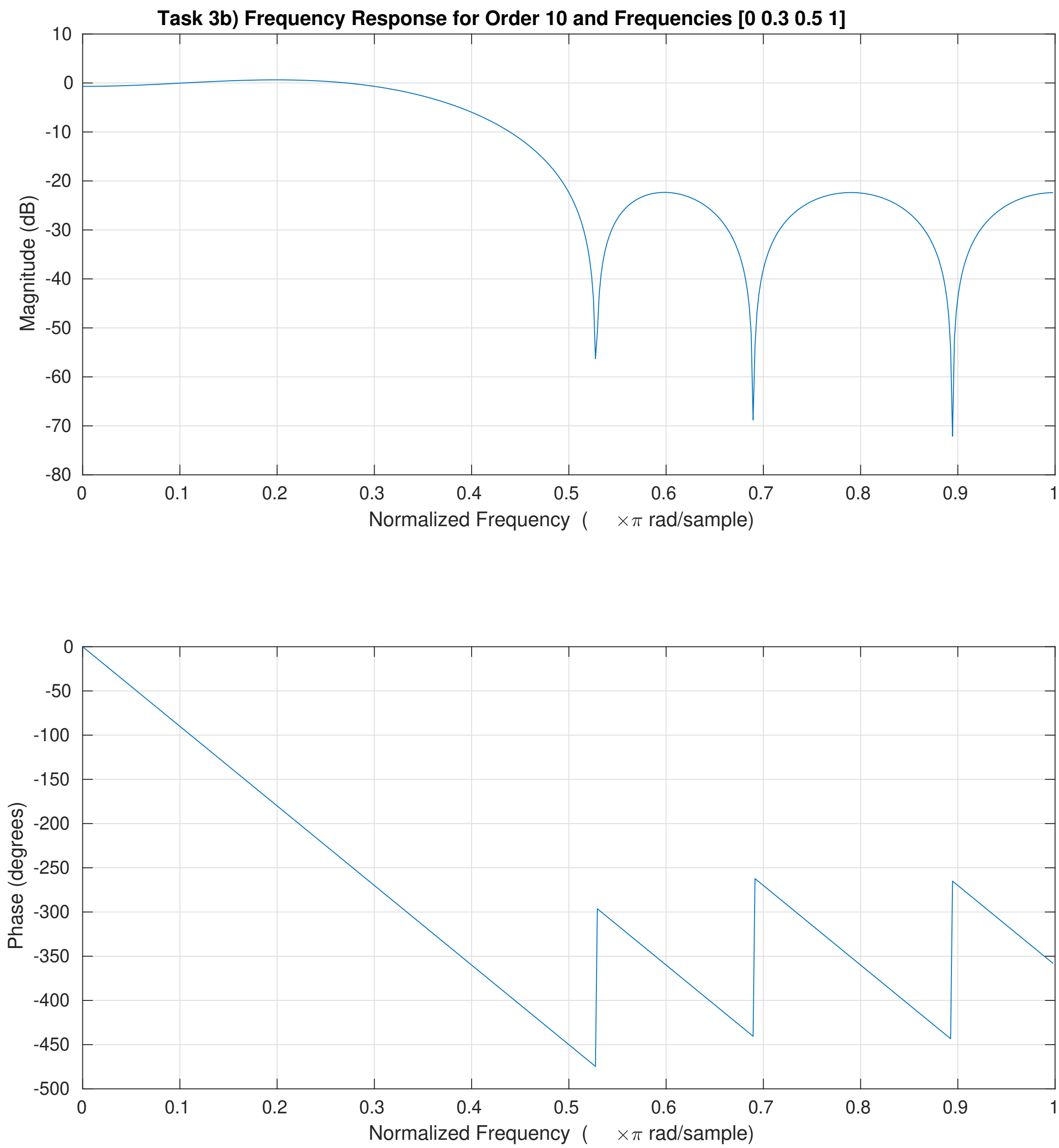
Starting at 0.2 π frequencies get more and more attenuated untill they reach 0.6 π when they become completely attenuated with peaks at around -40 dB

3.2 Order 10, 0.3 π passband, 0.5 π stopband

3.2.1 Impulse Response



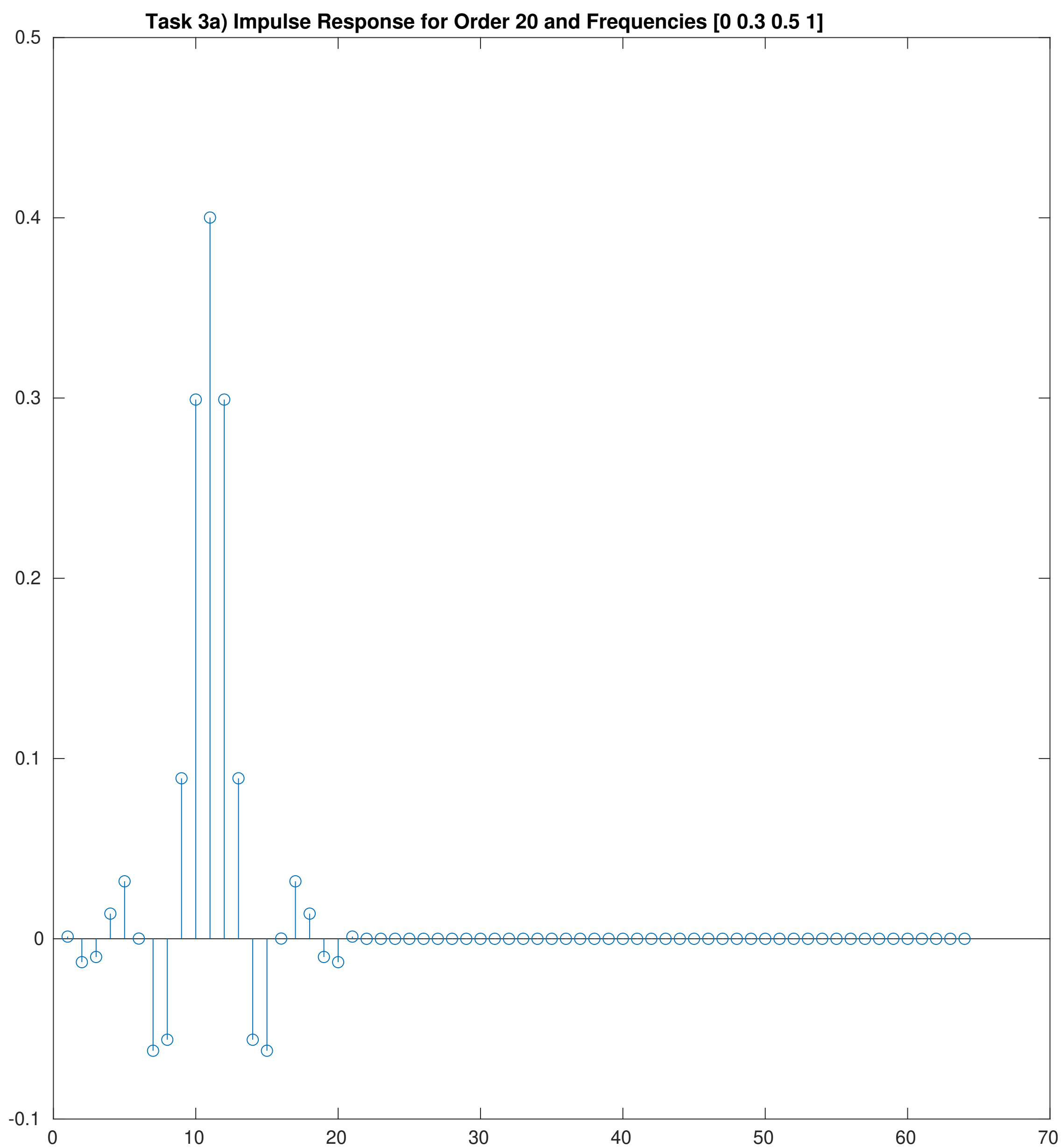
3.2.2 Frequency Response



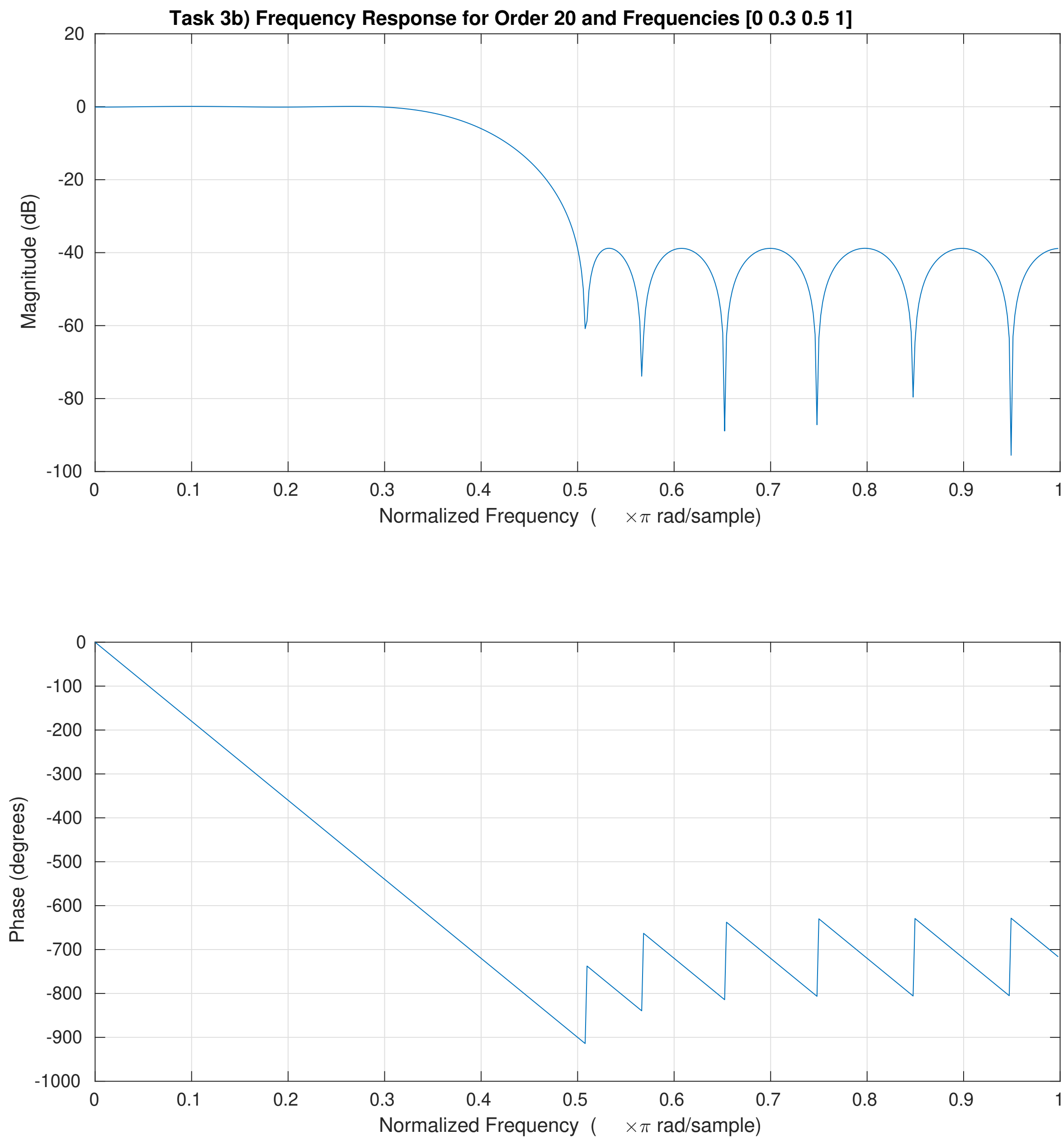
Starting at 0.3 π frequencies get more and more attenuated untill they reach 0.5 π when they become completely attenuated with peaks at around -20 dB

3.3 Order 20, 0.3 π passband, 0.5 π stopband

3.3.1 Impulse Response



3.3.2 Frequency Response



Starting at 0.3 π frequencies get more and more attenuated untill they reach 0.5 π when they become completely attenuated with peaks at around -40 dB. But this time we can see that the graph is much more dense, difference in frequency between one peak and another are much smaller.

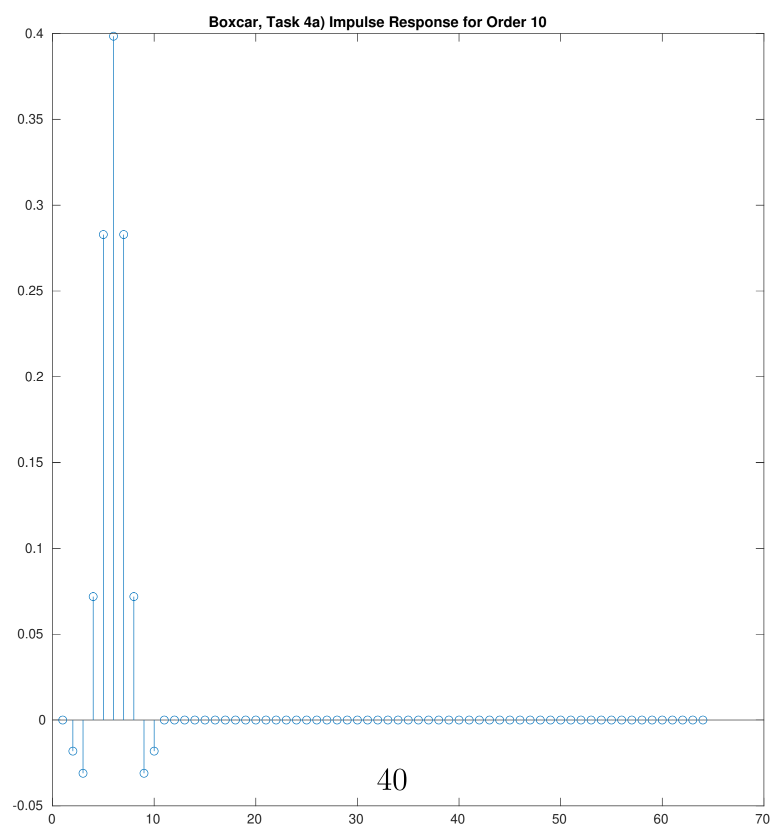
Chapter 4

Task 4

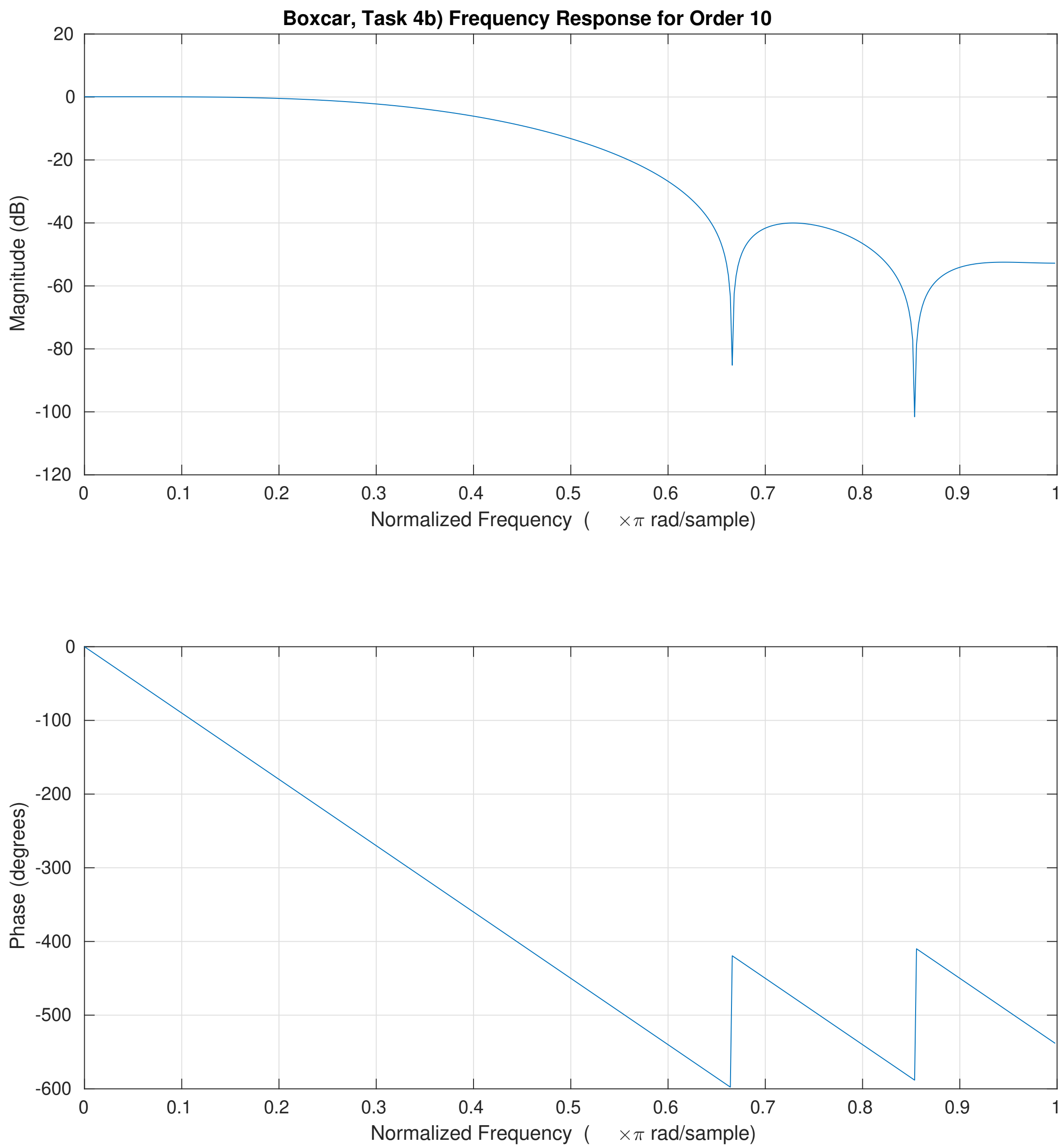
4.1 Boxcar Window

4.1.1 Order 10, 0.2 π passband, 0.6 π stopband

Impulse Response

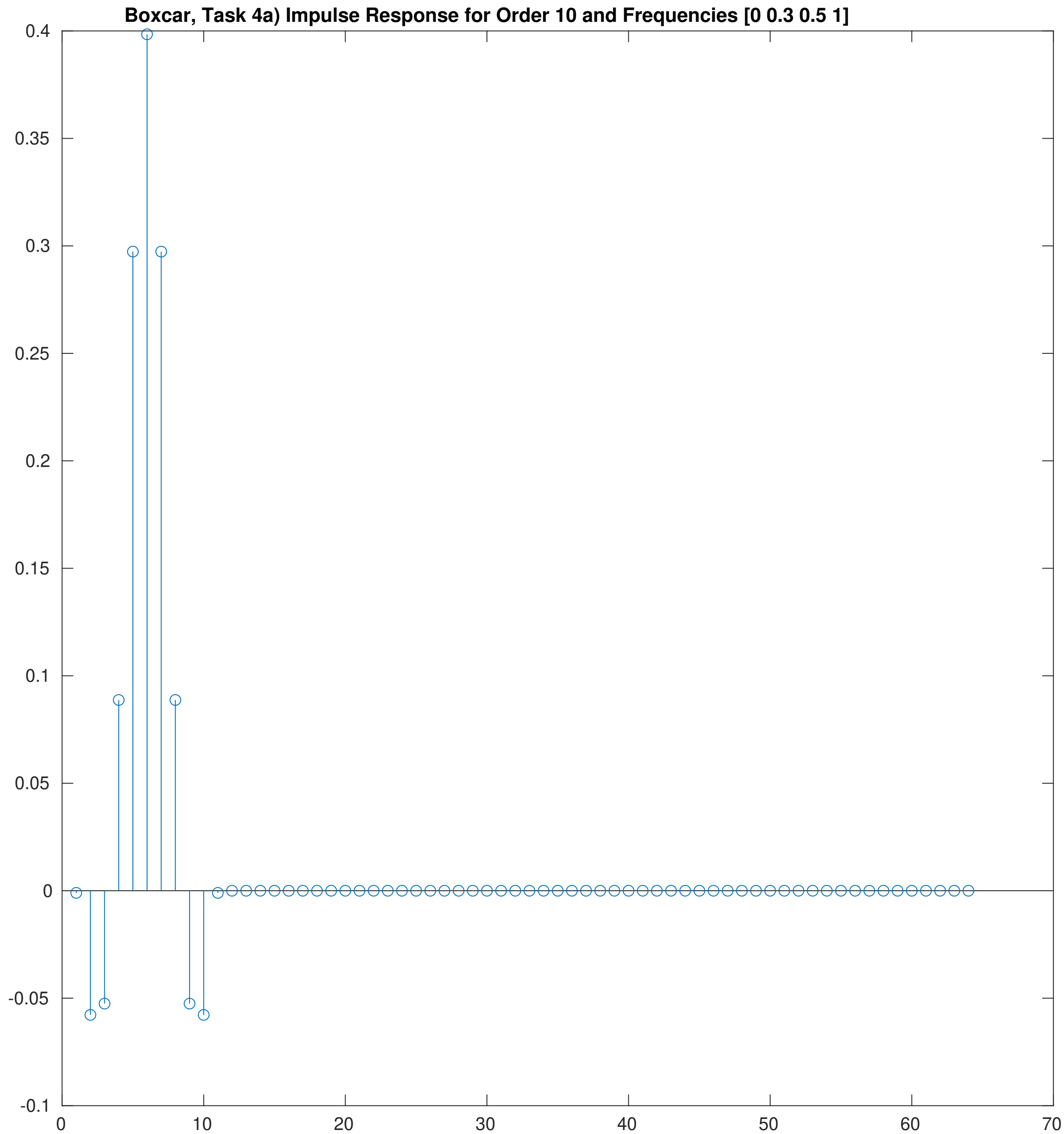


Frequency Response

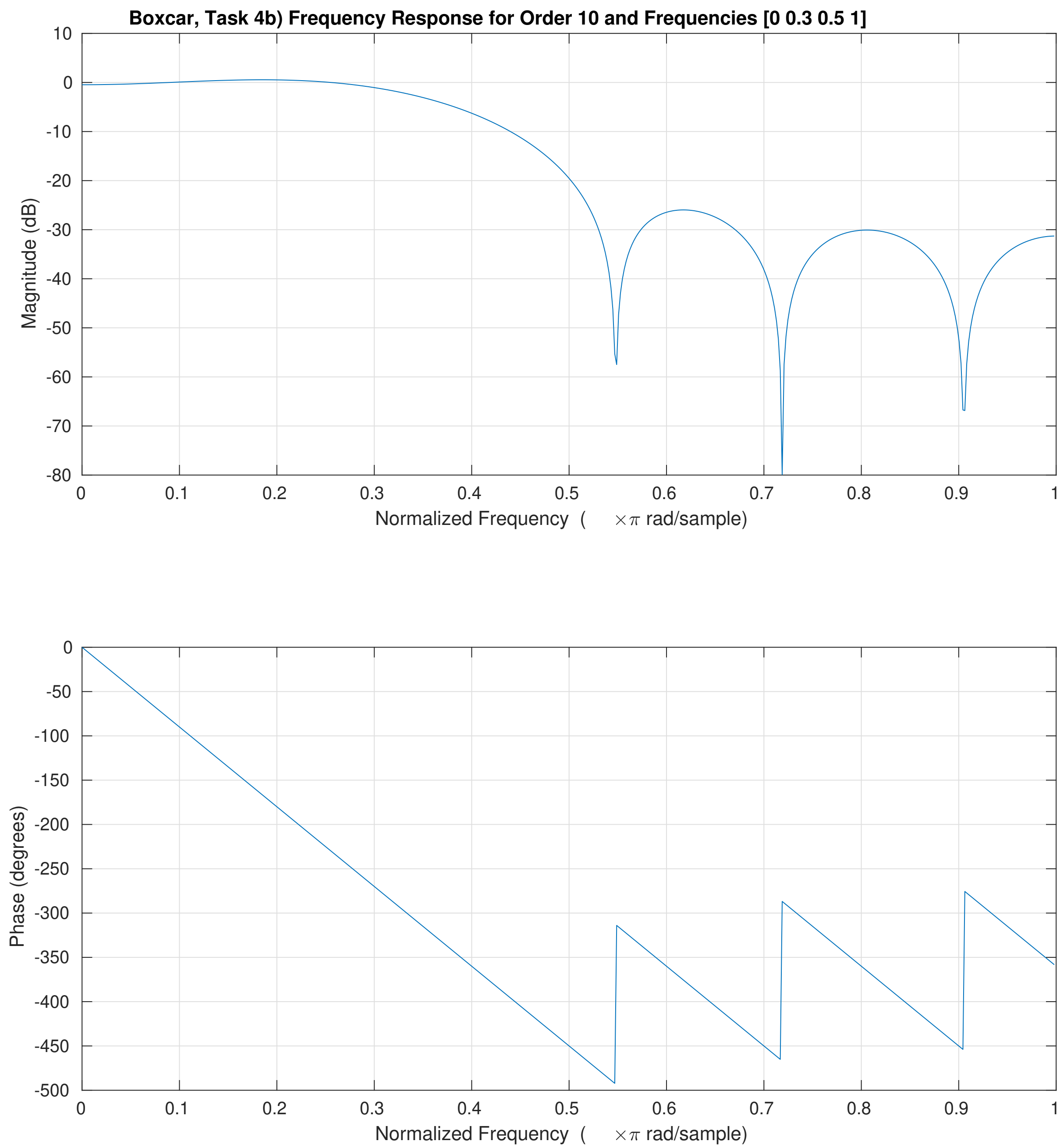


4.1.2 Order 10, 0.3 π passband, 0.5 π stopband

Impulse Response

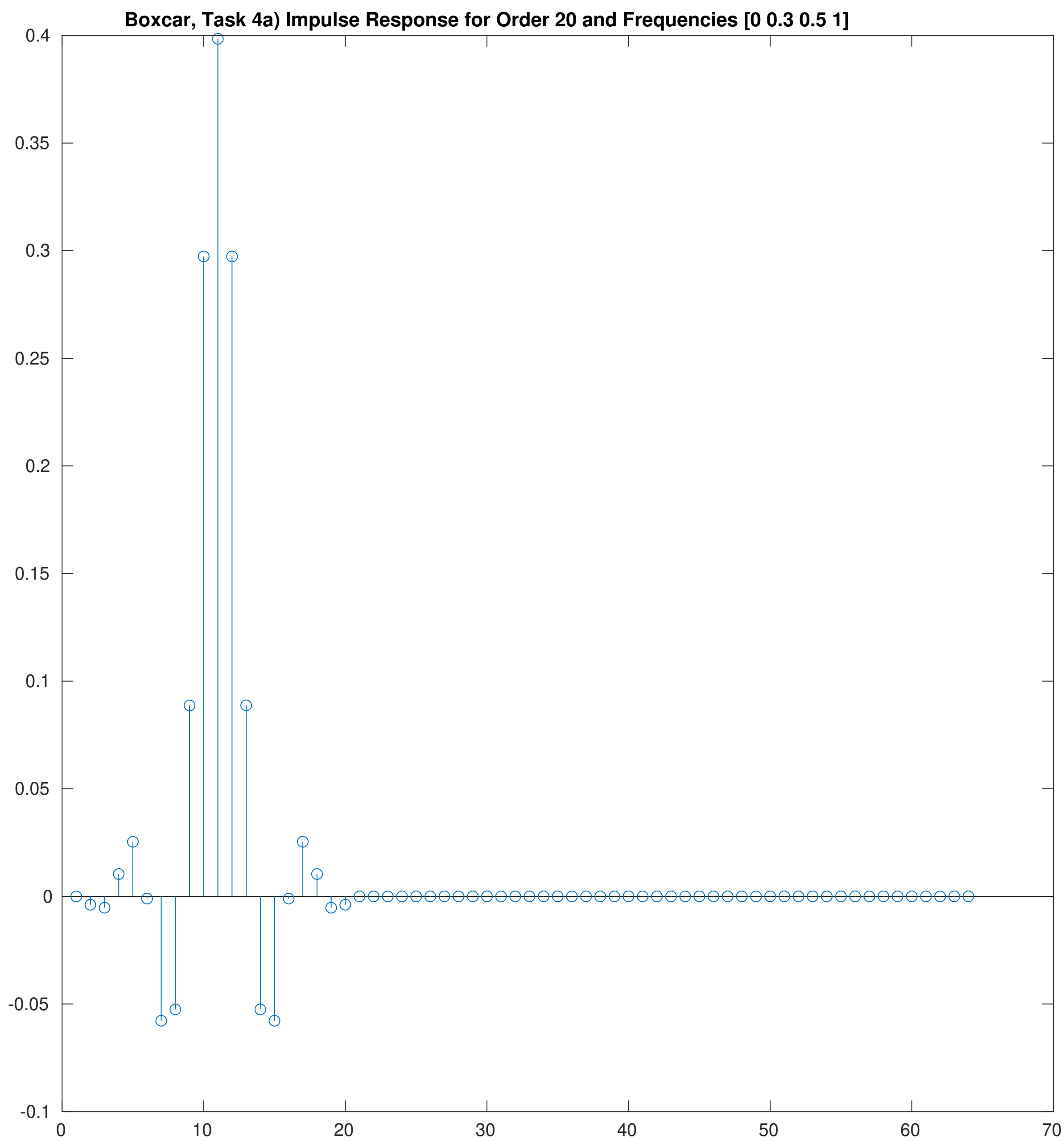


Frequency Response

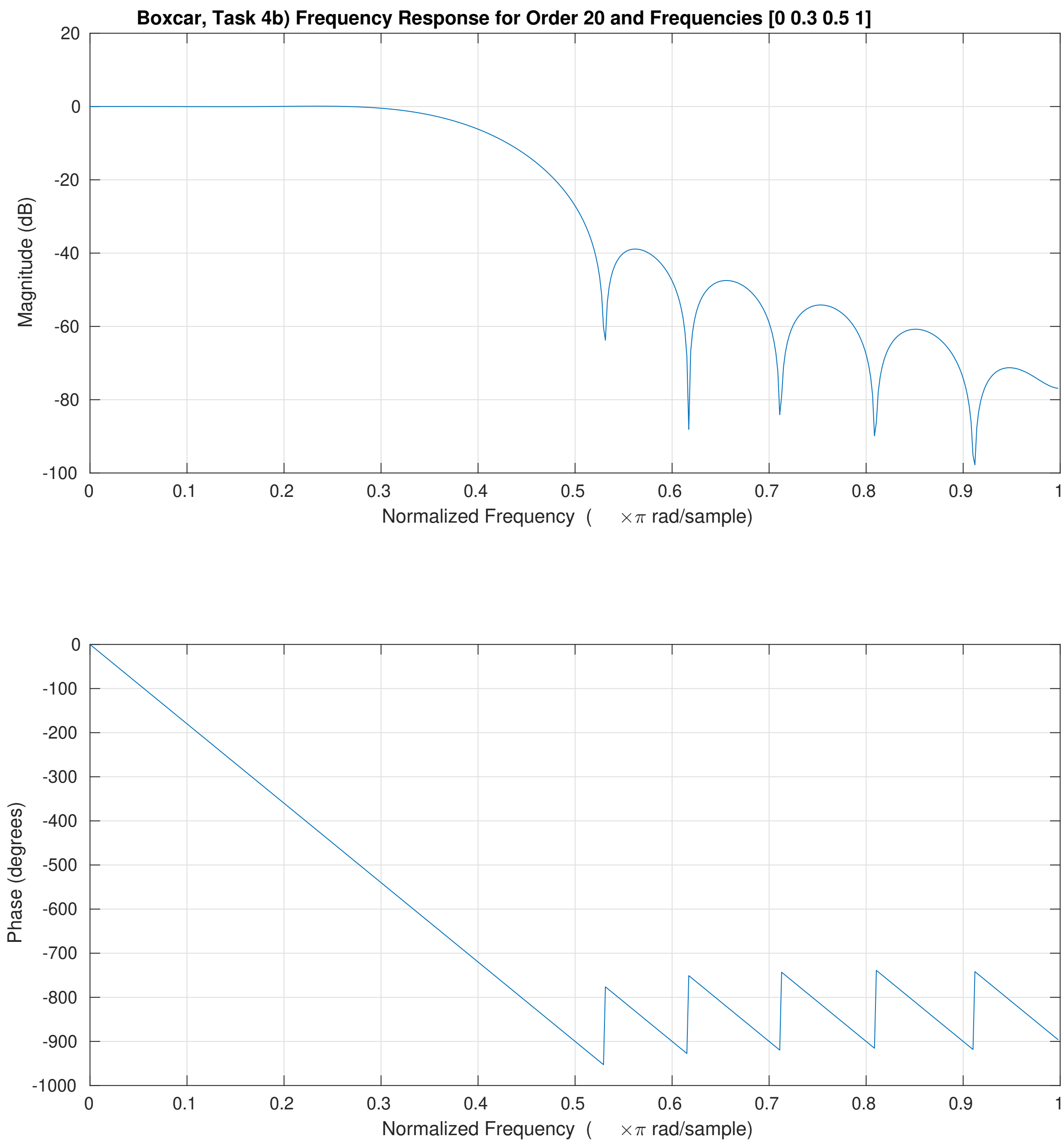


4.1.3 Order 20, 0.3 π passband, 0.5 π stopband

Impulse Response



Frequency Response



We can see following differences when compared to task 3: Frequencies between 0.2 π and 0.6 π and 0.3 π to 0.5 π are attenuated much faster, (as frequency increases attenuation is faster). Desired transition band and transition band that we actually reach is slightly of for both cases (For first case we reach around 0.65 but we wanted 0.6, for second case we reach around 0.55 but we wanted 0.5) We can also see that with increasing frequencies sidelobes peaks get smaller for both cases. This means that the filter is slightly worse. For passband at 0.2 π and stopband at 0.6 π and order 10 we reach magnitude: around -40 dB and it decreseas from this point

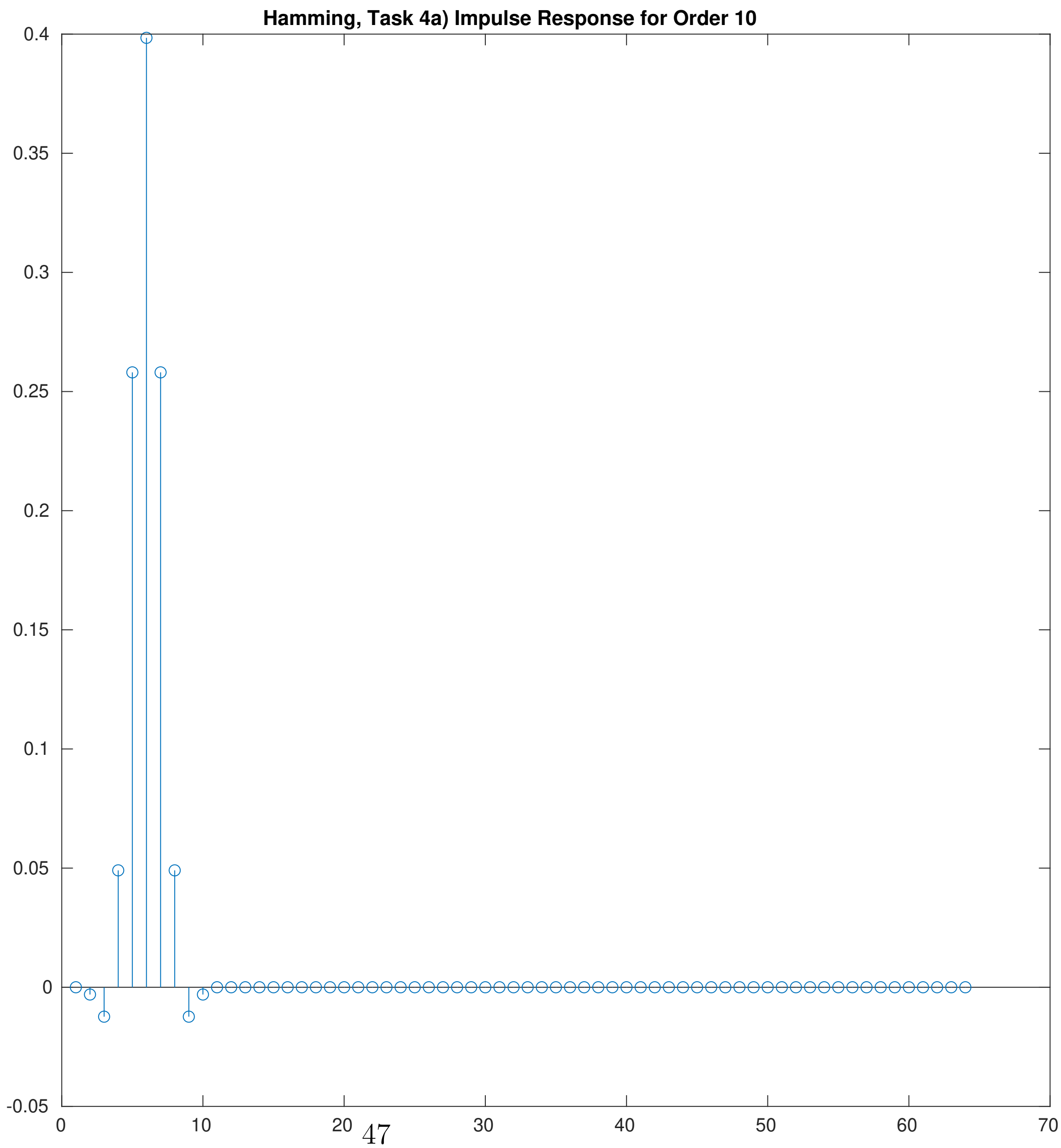
For passband at 0.3 π and stopband at 0.5 π and order 10 we reach magnitude: around -35 dB and it decreseas from this point

For passband at 0.3 π and stopband at 0.5 π and order 20 we reach magnitude: around -40 dB and it decreases from this point

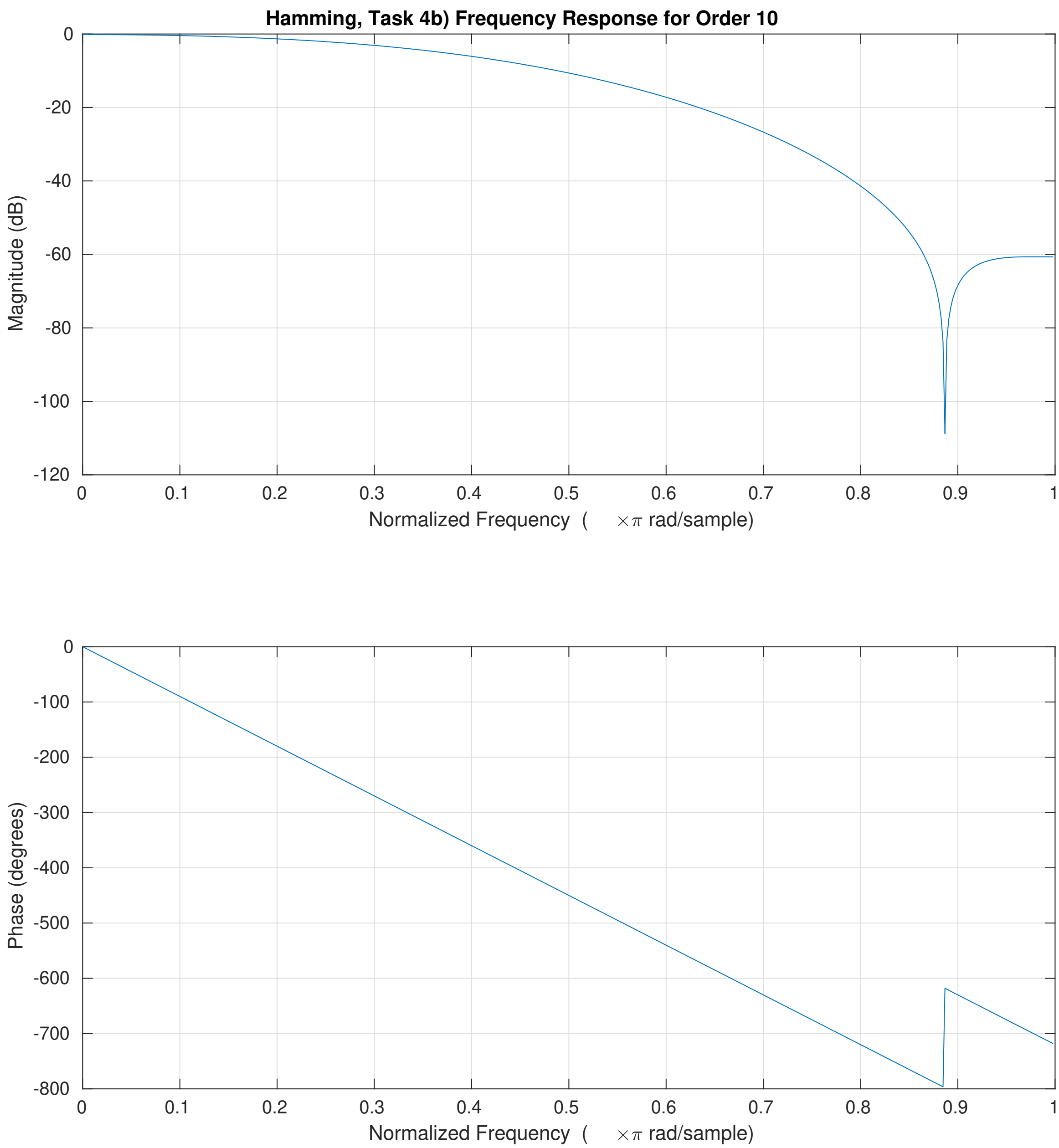
4.2 Hamming Window

4.2.1 Order 10, 0.2 π passband, 0.6 π stopband

Impulse Response

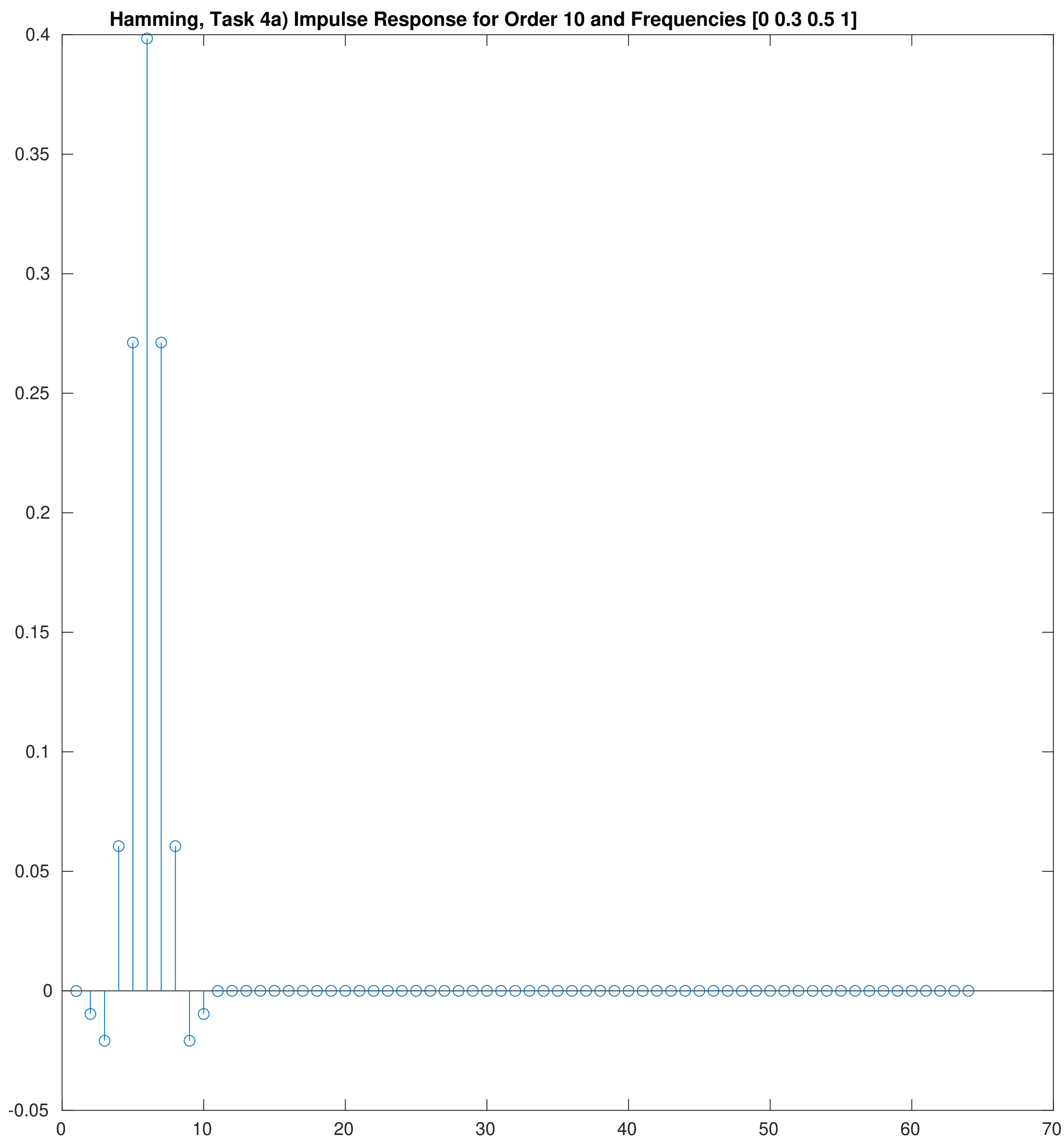


Frequency Response

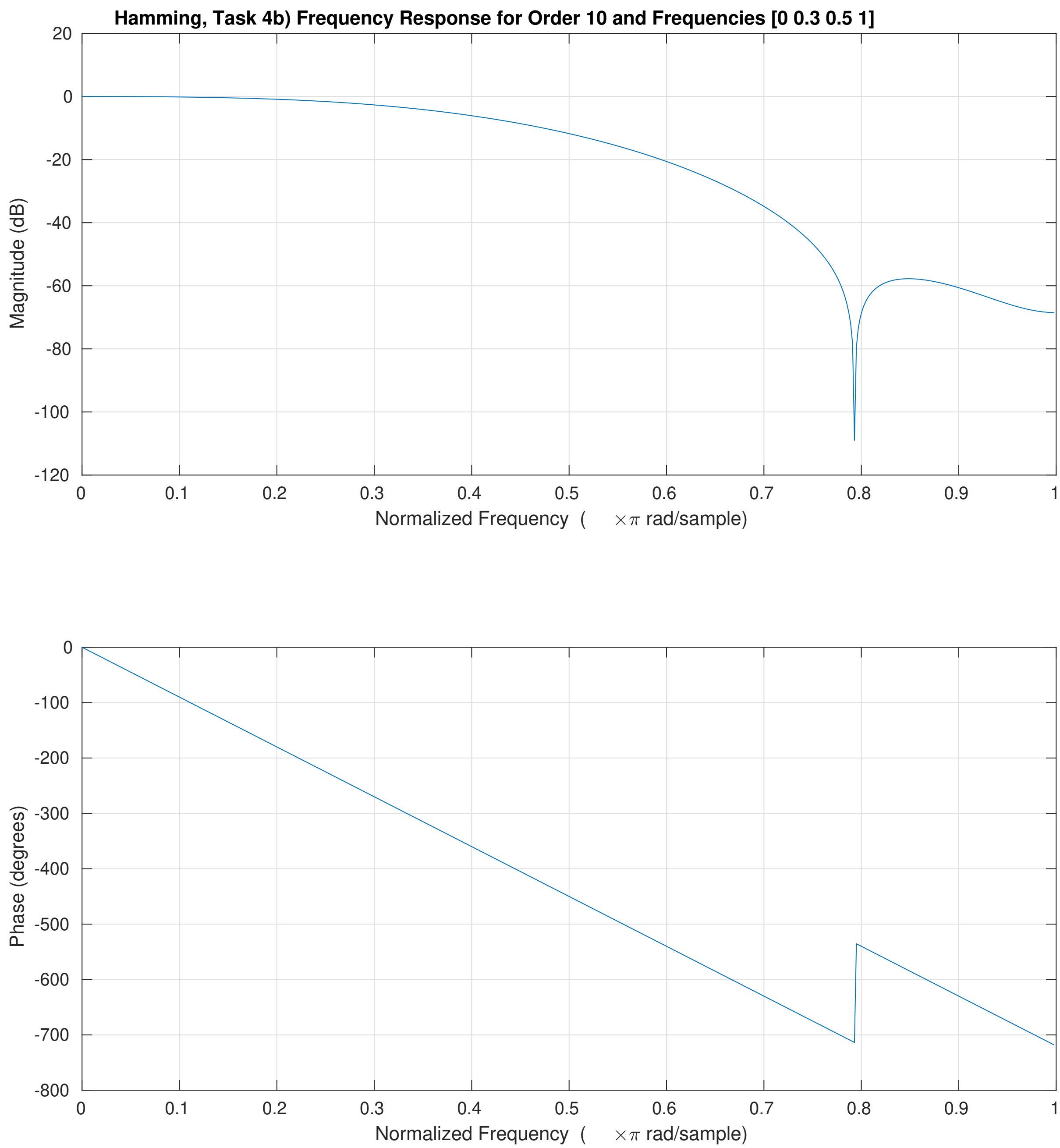


4.2.2 Order 10, 0.3 π passband, 0.5 π stopband

Impulse Response

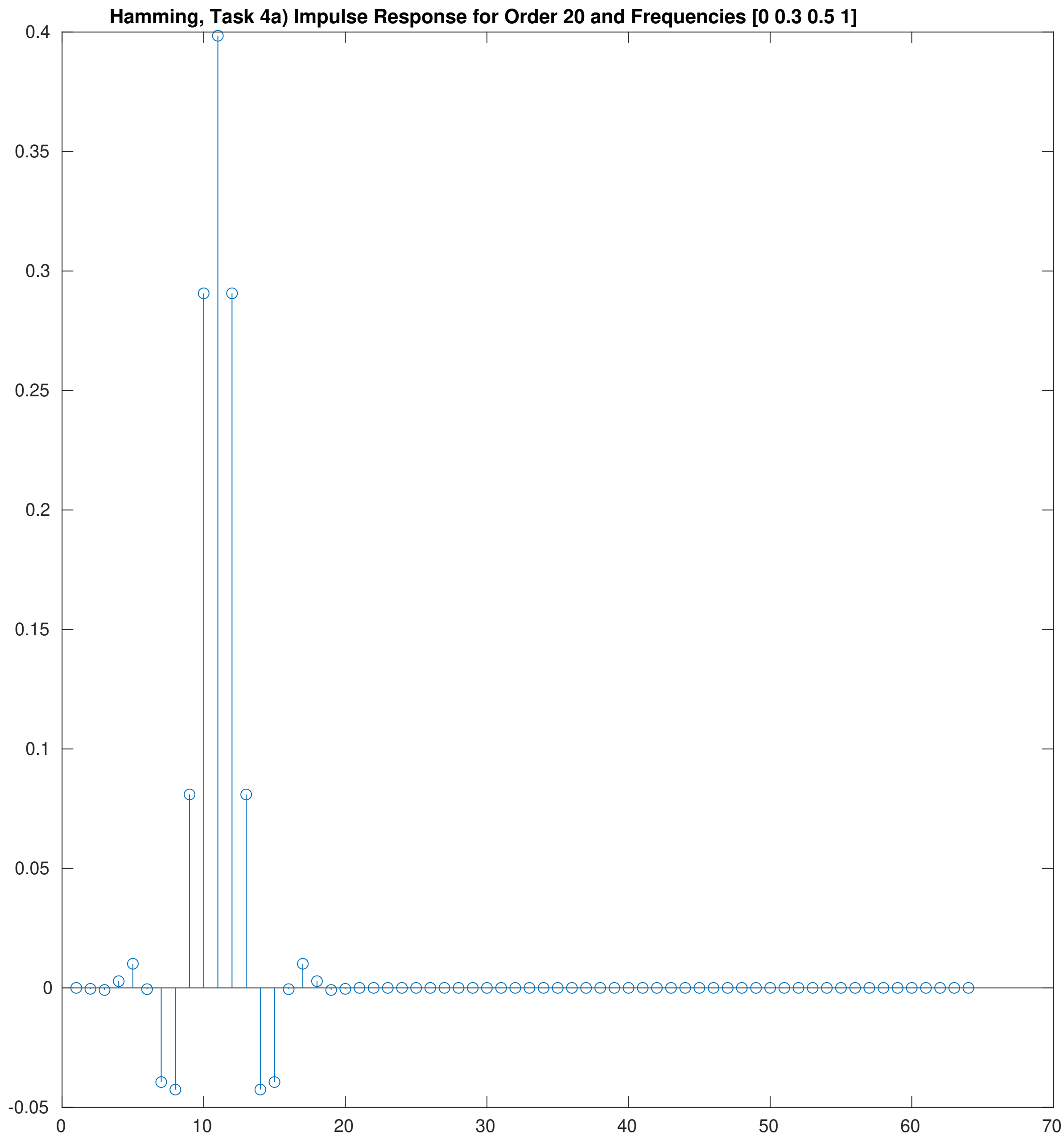


Frequency Response

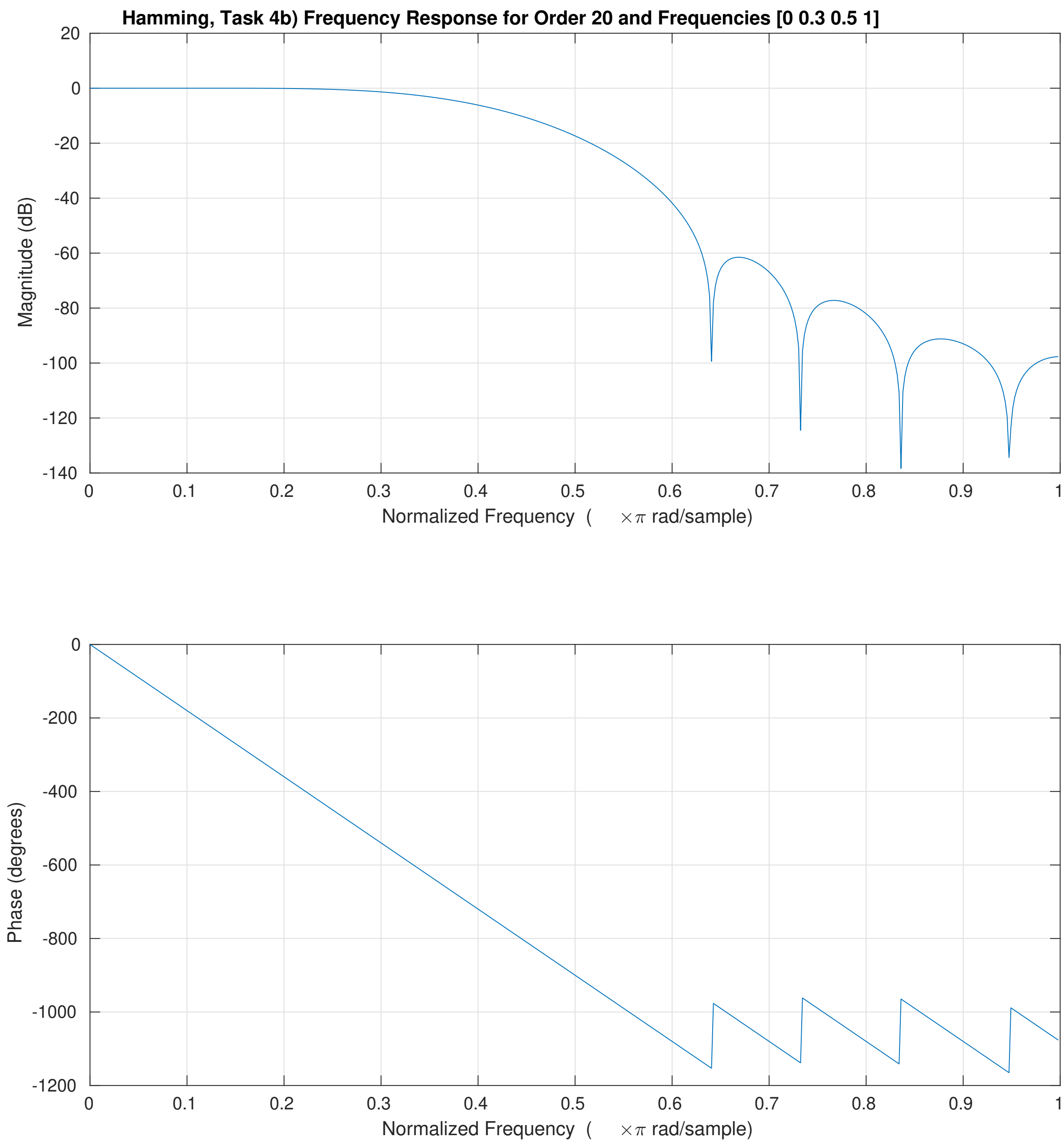


4.2.3 Order 20, 0.3 π passband, 0.5 π stopband

Impulse Response



Frequency Response



We can see following differences when compared to task 3: Frequencies between 0.2 π and 0.6 π and 0.3 π to 0.5 π are attenuated much faster, (as frequency increases attenuation is faster). Desired transition band and transition band that we actually reach are off for both cases (For first case we reach around 0.85 but we wanted 0.6, for second case we reach around 0.79 but we wanted 0.5) but if we increase order to 20 we get much closer to the desired transition band (to around 0.65 for the second case) We can also see that with increasing frequencies sidelobes peaks get smaller for both cases. This means that the filter is slightly worse.

For passband at 0.2 π and stopband at 0.6 π and order 10 we reach magnitude: around -60 dB and it decreseas from this point

For passband at 0.3 π and stopband at 0.5 π and order 10 we reach magnitude: around -60 dB and it decreseas from this point

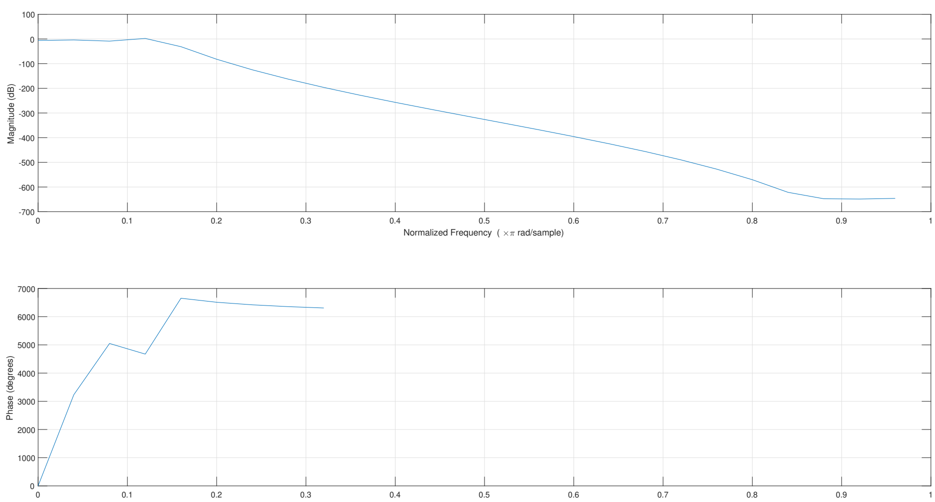
For passband at 0.3 π and stopband at 0.5 π and order 20 we reach magnitude: around -60 dB and it decreases from this point

Chapter 5

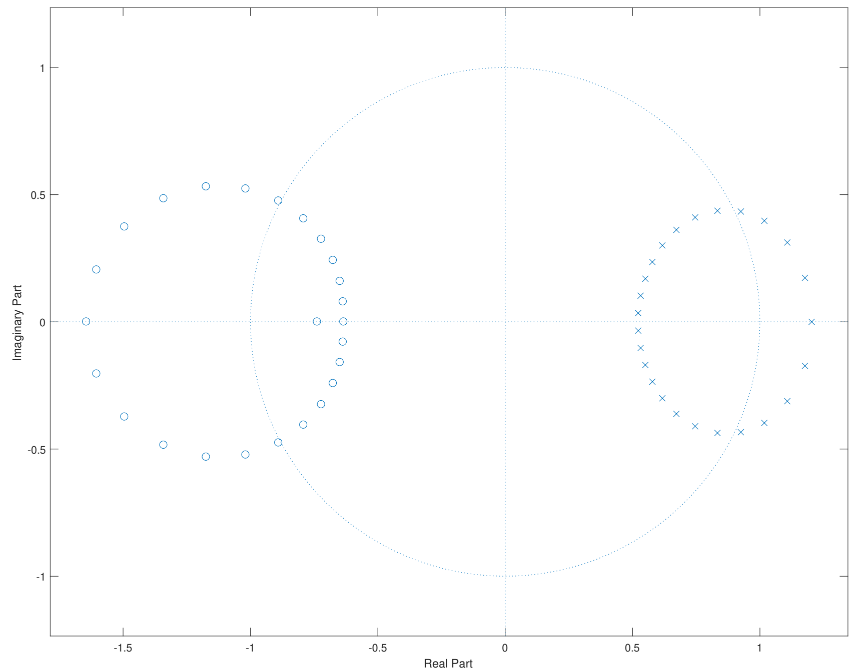
Task 5

5.1 Butterworth

5.1.1 Magnitude and Phase graphs

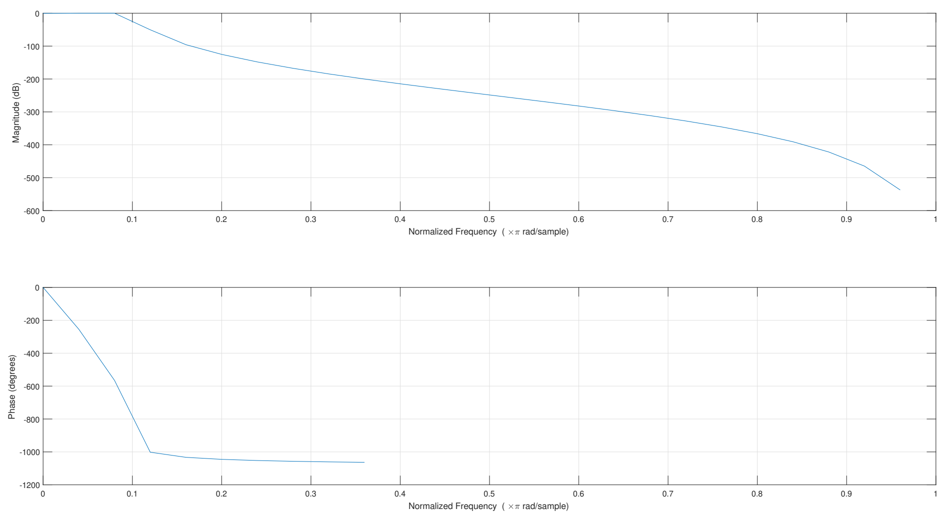


5.1.2 Zeros poles layout

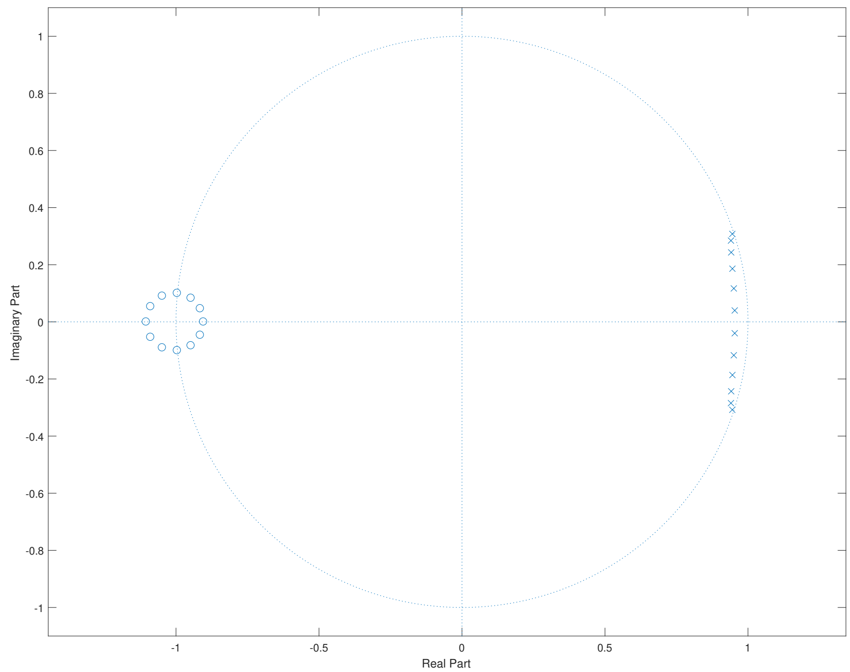


5.2 Chebbyshew Type 1

5.2.1 Magnitude and Phase graphs

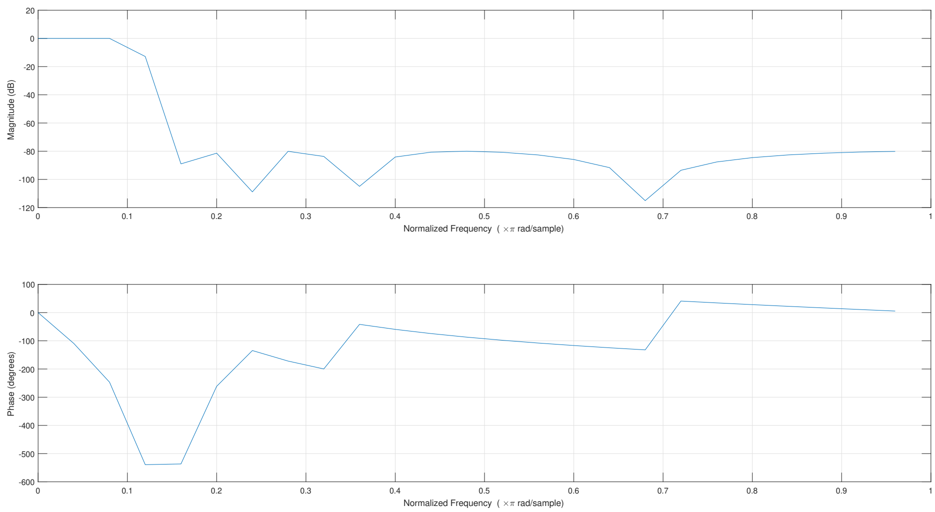


5.2.2 Zeros poles layout

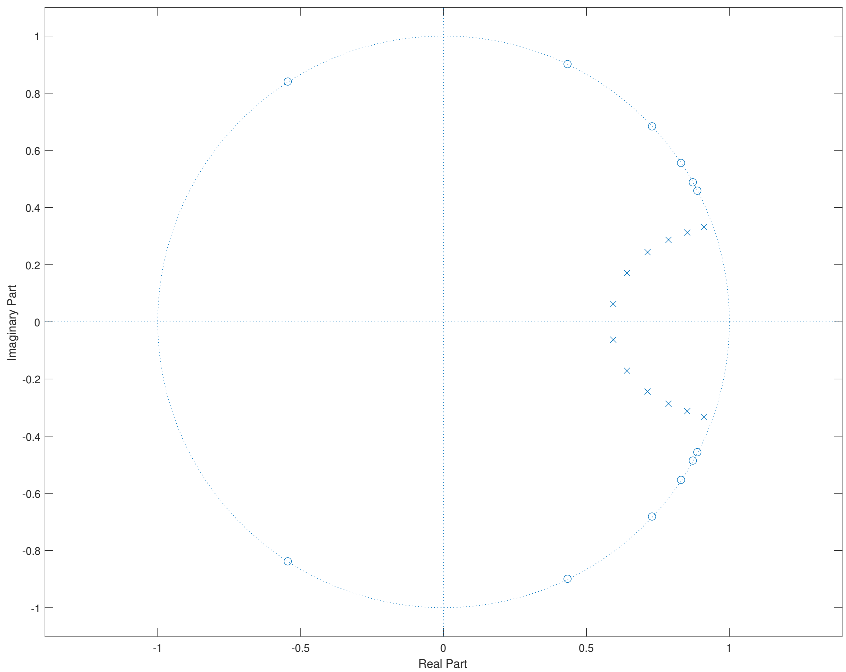


5.3 Chebbyshew Type 2

5.3.1 Magnitude and Phase graphs

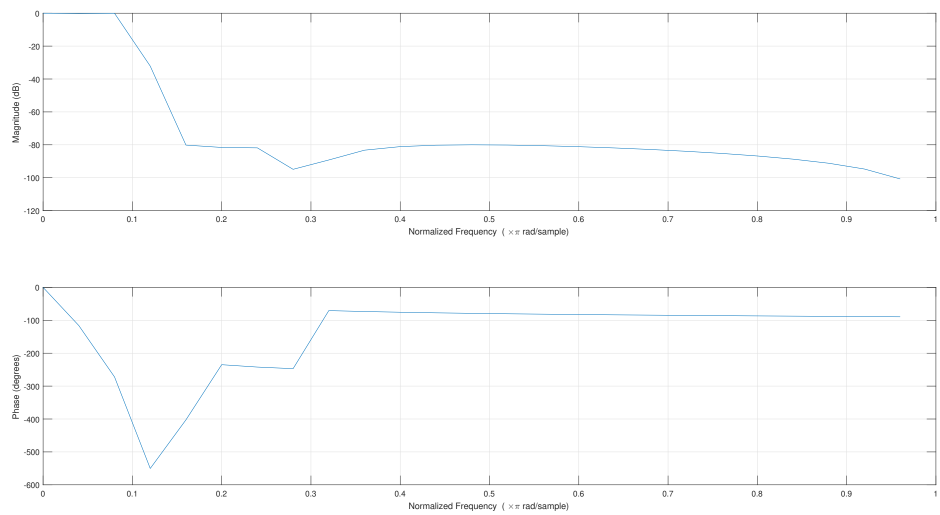


5.3.2 Zeros poles layout

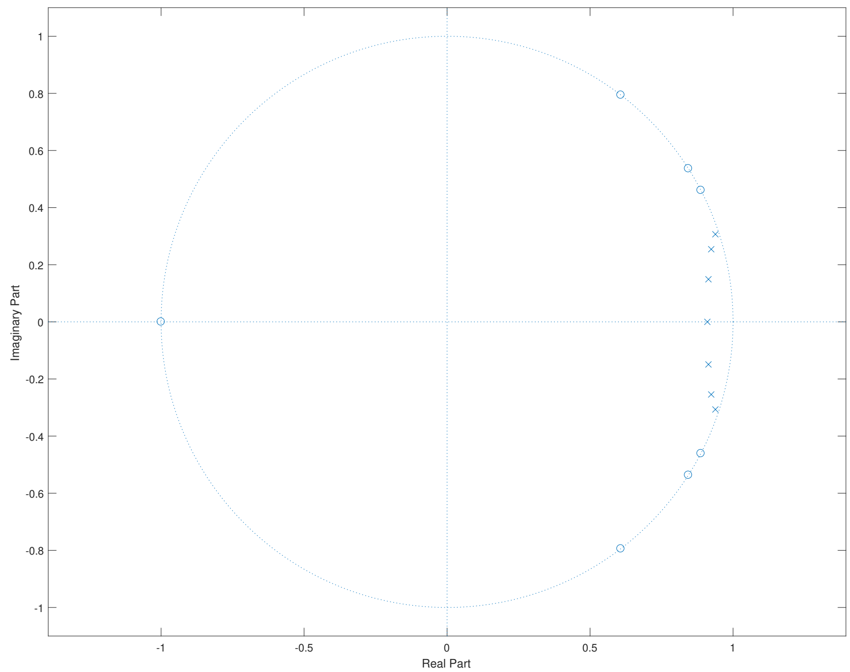


5.4 Cauer Eliptical

5.4.1 Magnitude and Phase graphs



5.4.2 Zeros poles layout



It took:

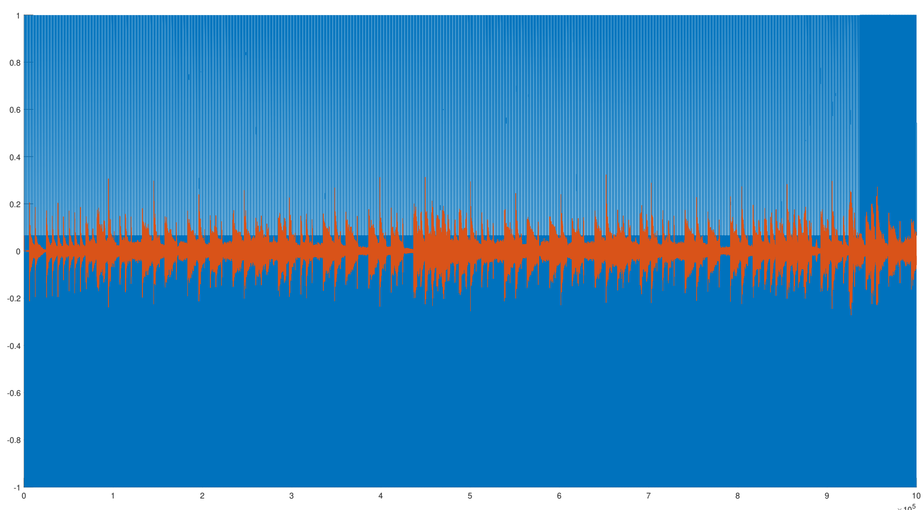
- 25 orders for Butterworth method
- 12 orders for Chebbyshew first method
- 12 orders for Chebbyshew second method
- 7 orders for Cauer/Eliptical method

As we can see we wanted to get Low Pass filter and we succeded in doing so, (Take a look at how magnitude goes down), we also managed to get linearization or phase in all cases which is also a success.

Chapter 6

Task 6

This is the graph of audio after adding sinusoidal signal to distort the original audio (Blue color) and after removing it using bandstop filter (orange color)



As we can see the distortion was successfuly removed and the signal now resembles of what it looked like before the distortion