University of Moratuwa

Department of Electronic and Telecommunication Engineering

BM4152

Bio-signal Processing

Assignment 1

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200664P

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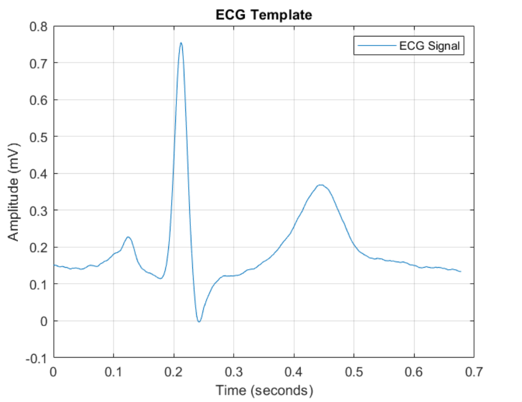
1. Smoothing Filters

1.1 Moving Average Filter

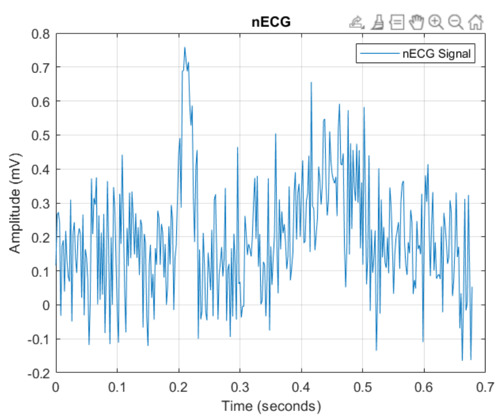
Preliminaries

ii)

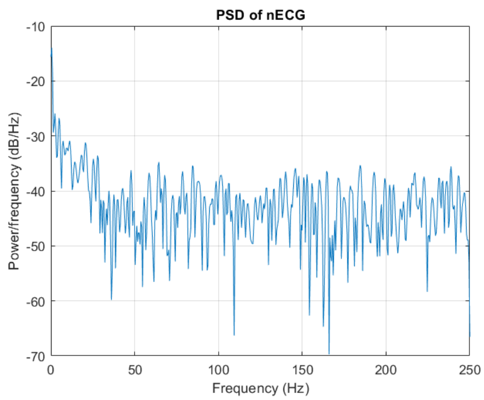


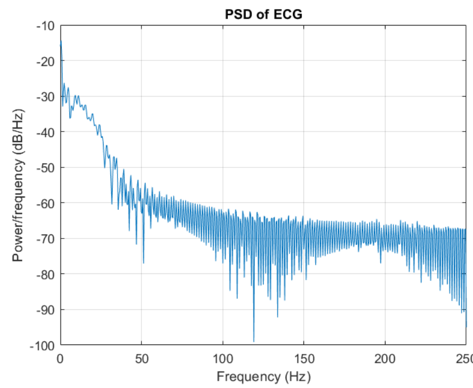
We can see the P wave, the QRS complex and also the T wave here.

iii)



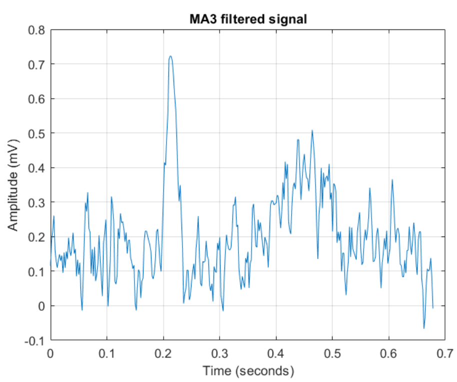
iv)





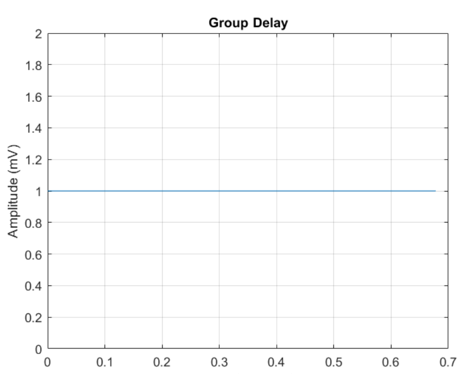
MA3 Filter Implementation with a customized script

i)



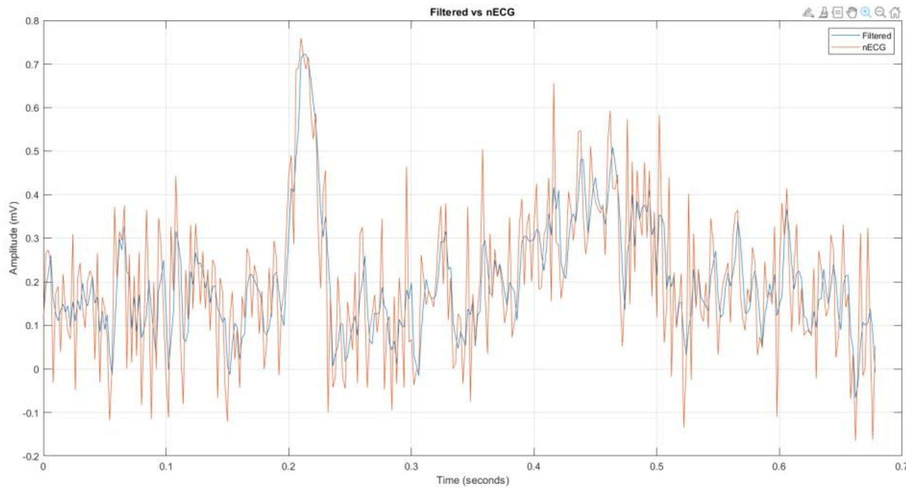
ii)

Group delay of the MA3 filter:

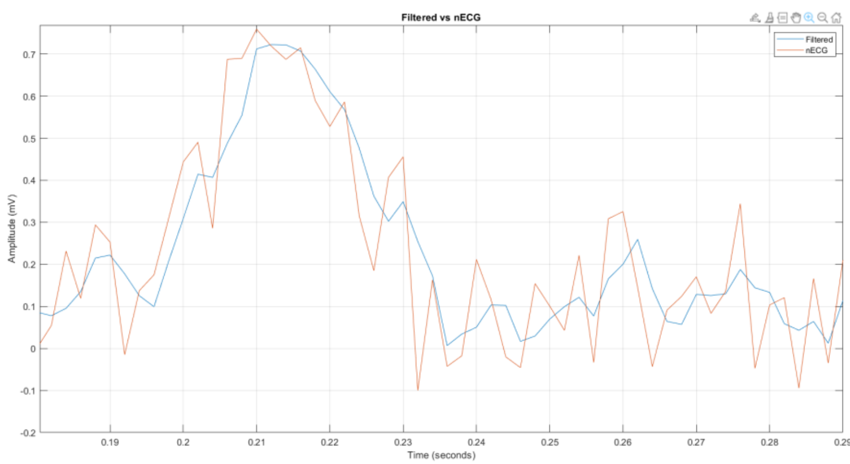


iii)

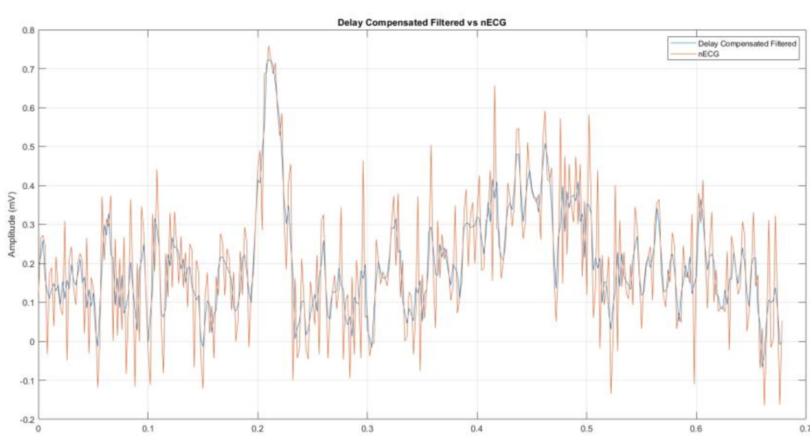
Group delay is 1; meaning there is a delay of a single sample.



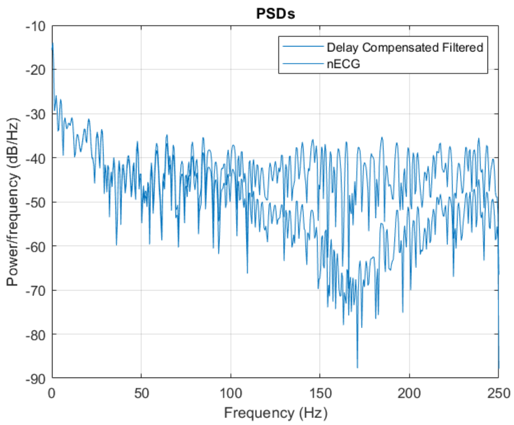
Zooming in to the peak:



Compensated the delay, by zero padding at the end and shifting the signal.



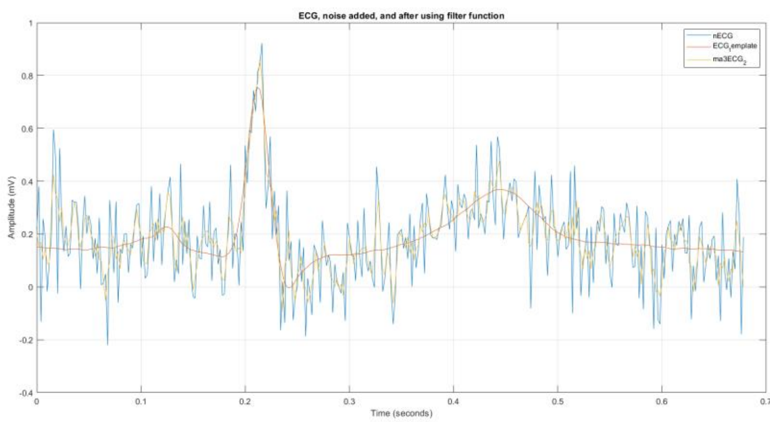
iv) The below one out of the two is the periodogram of the delay compensated signal.



MA3 Filter Implementation with a customized script

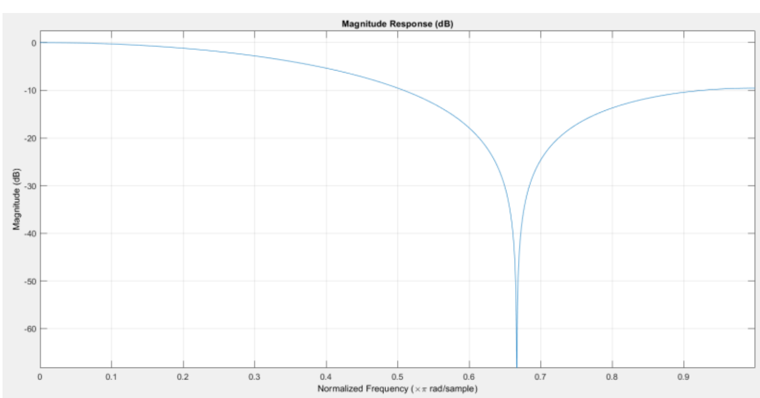
ii)

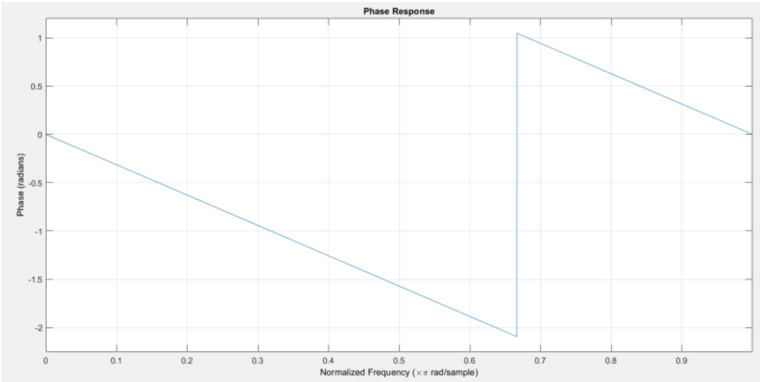
Here, the signal is delay compensated after filtering through shifting and zero padding.

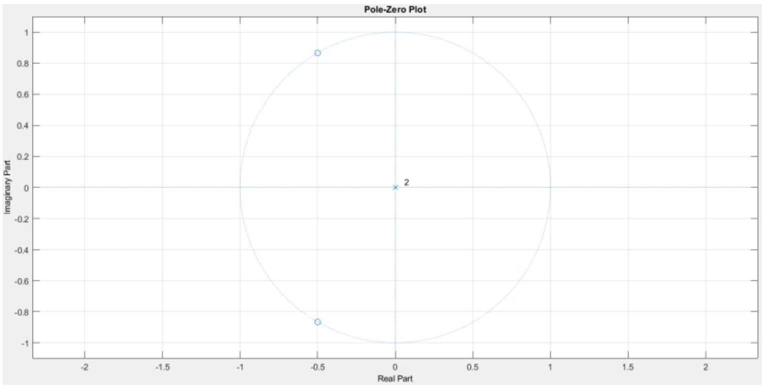


iii)

Inspecting the filter through fvtool:





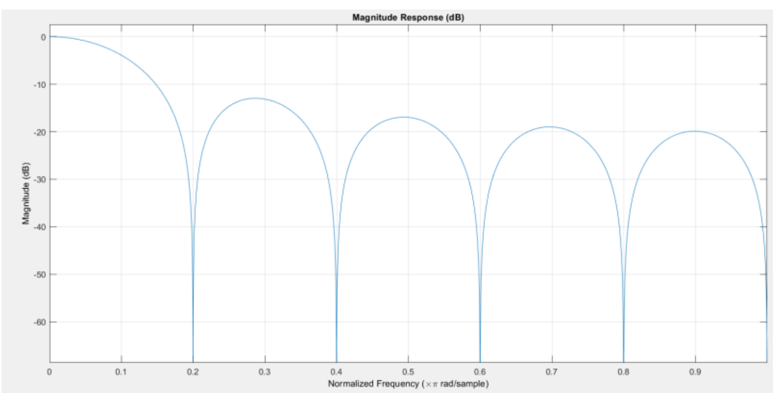


MA(10) filter implementation with the MATLAB built-in function

i)

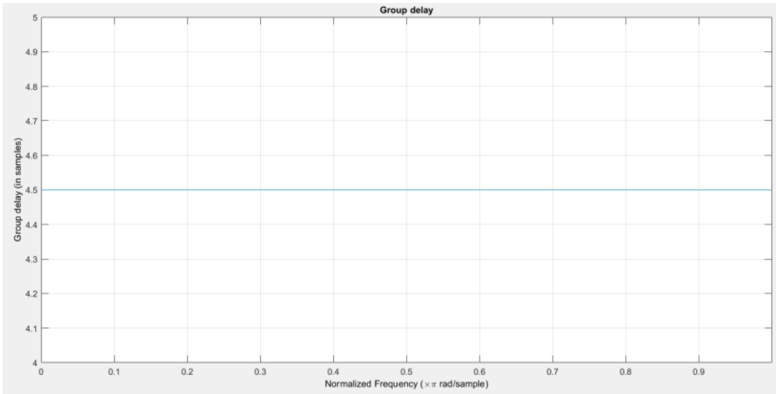
Here, more higher frequencies are cut off cut off compared to N = 3.

This is visible from the magnitude response plot.



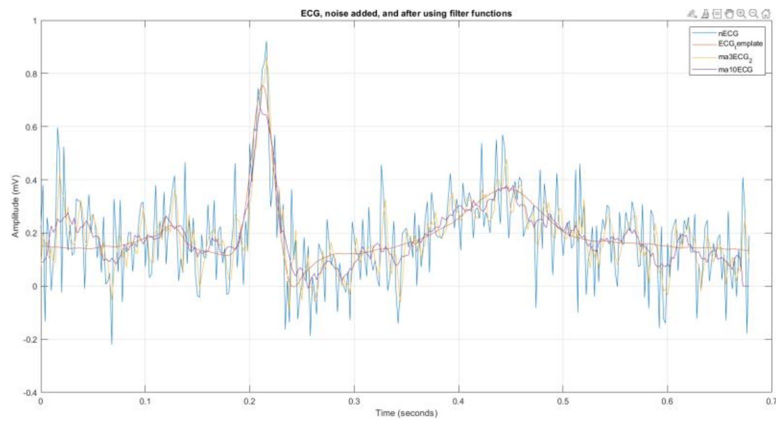
ii)

Identifying the group delay:

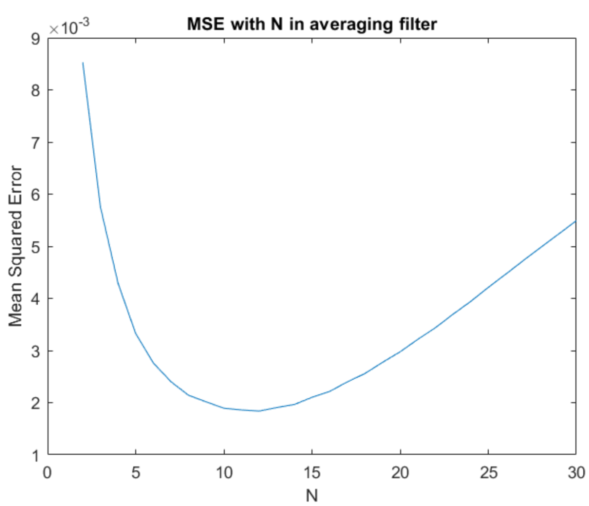


iv)

Here, the signal has smoothed more with the increase in order.



Optimum MA(N) filter order



Minimum is achieved at N = 13.

At low N values smoothing is not enough, high frequencies are not removed.

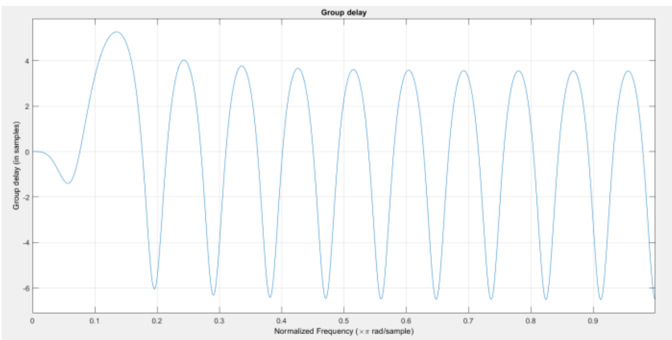
When the order is too high, as it was observed in the fvtool, more frequencies are attenuated, even in the mid ranges. Which is useful containing information about the ECG signal. Therefore, a moderate value must be selected.

1.2 Savitzky-Golay Filter

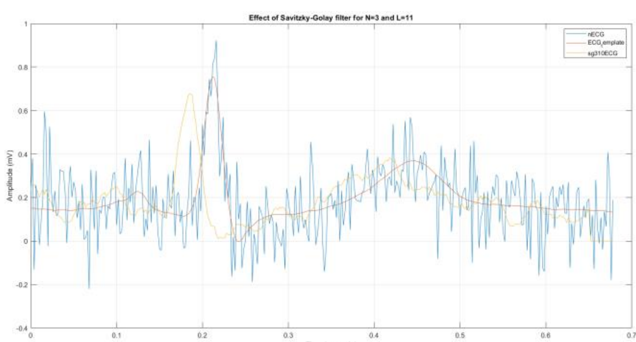
Application of SG(N,L)

i)

The group delay cannot be compensated as it is non linear.



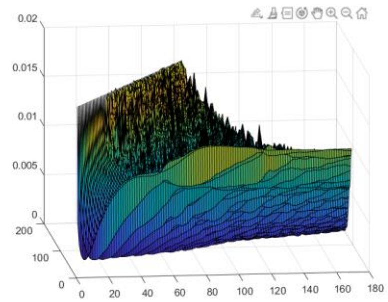
ii)



The signal is smoothed, however there are also distortions since the phase is non linear.

Optimum SG(N,L) filter parameters

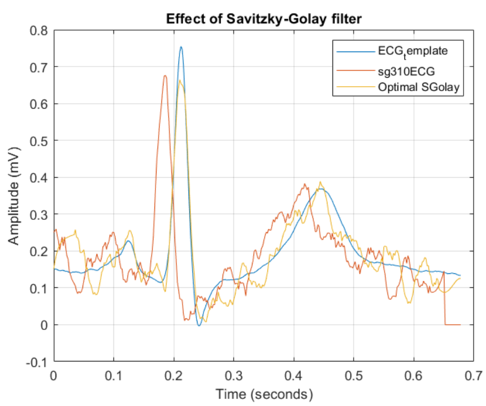
i)



Max_L was selected such that the length of the signal is considered the maximum total length that can be taken. The N values ranged such that always it was lesser or equalt to L'-1.

Optimal Values are L = 17 and N = 4.

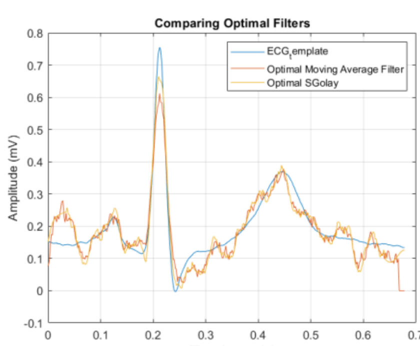
ii) The optimal one has a lesser phase distortion.



iii)

Sgolay Optimal: Elapsed time is 0.005500 seconds.

Optimal moving average: Elapsed time is 0.004374 seconds.



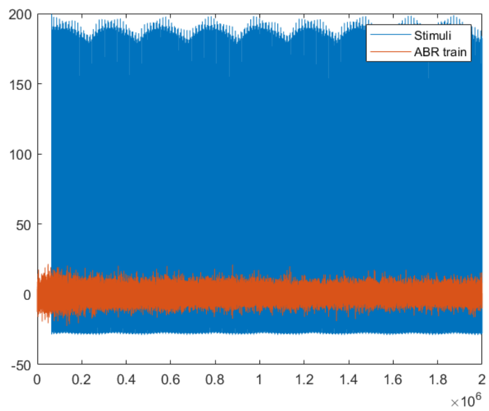
Impact is more or less same but sgolay has a higher computational complexity comparatively.

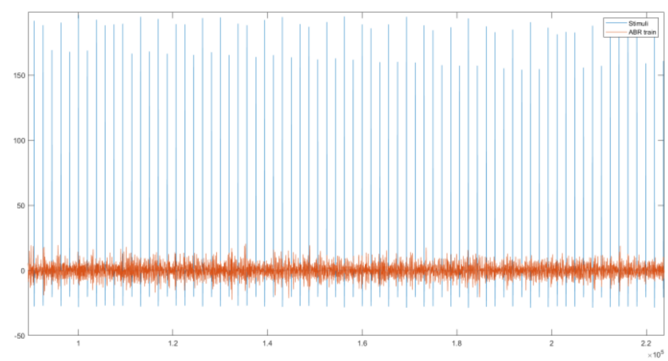
2. Ensemble Averaging

2.1. Signal with multiple measurements

Preliminaries

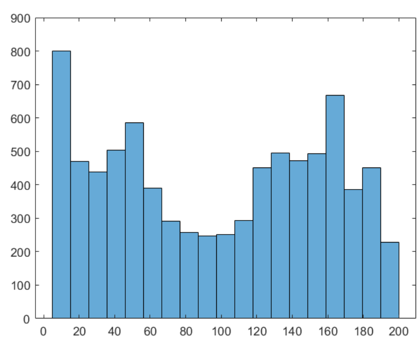
iii)



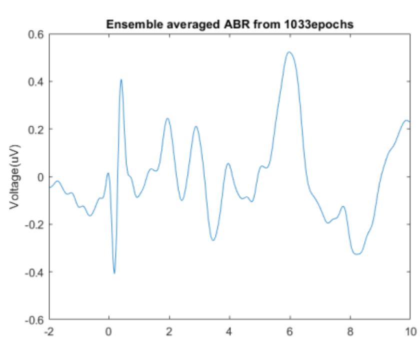


iv)

Histogram of magnitudes of auditory pulses.The selected threshold was 100.

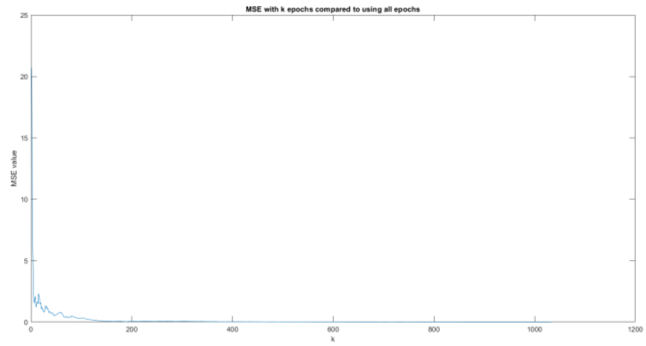


viii)



Improvement of the SNR

ii)

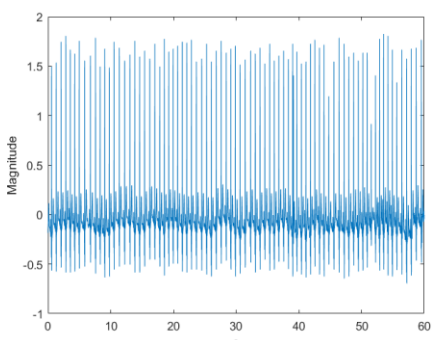


As the number of epochs increase by a factor of N, the compared to the initial signal, the variance of noise affecting the signal reduces by a factor of N. Therefore, we can see with the number of epochs, variance has lowered, causing a lesser MSE. Here, we consider the ABR response a deterministic signal.

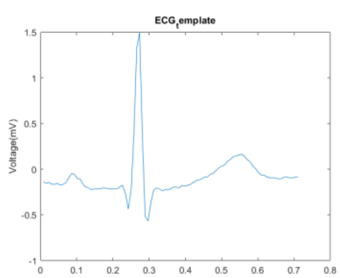
2.2. Signal with repetitive patterns

Viewing the signal and addition of Gaussian white noise

ii)



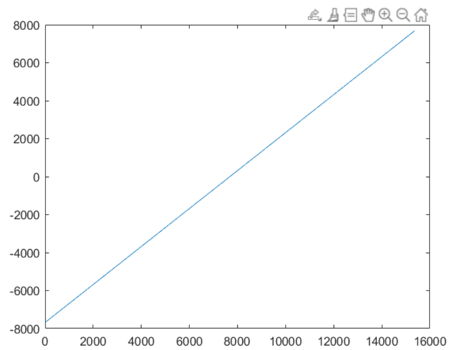
iii)

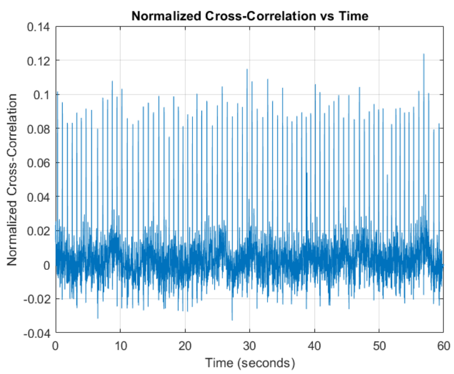


Segmenting ECG into separate epochs and ensemble averaging

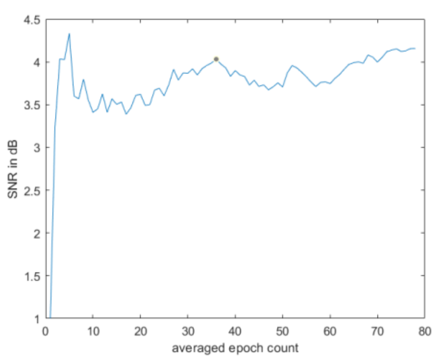
ii)

By observing the lags array, we can see that the ECG_template correlation with the nECG, is calculated by placing the ECG_template at the last point of nECG. Therefore, to see adjusted time axis, we have to take the required part of the signal and flip it.

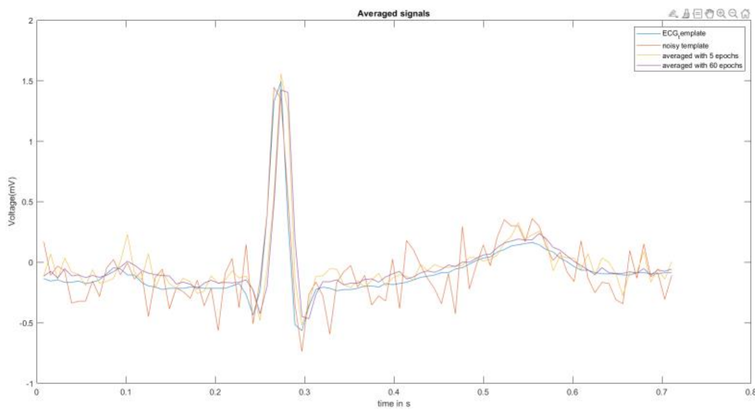




iv)



v)



vi)

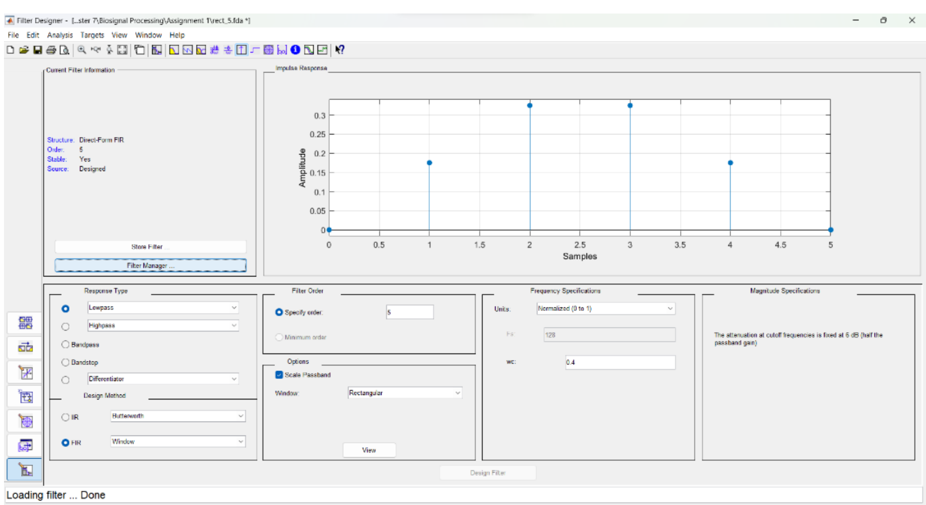
Here, we can see at the identification of peaks through thresholding, around 5 samples get thresholded near the peak. therefore, the last of that peak set, and the first of the next peak set is chosen in this algorithm, which are however not the correct representatives of the actual correlation peak. Therefore, if we use findpeaks or some other peak detection algorithm after the correlation calculation, that issue will be solved.

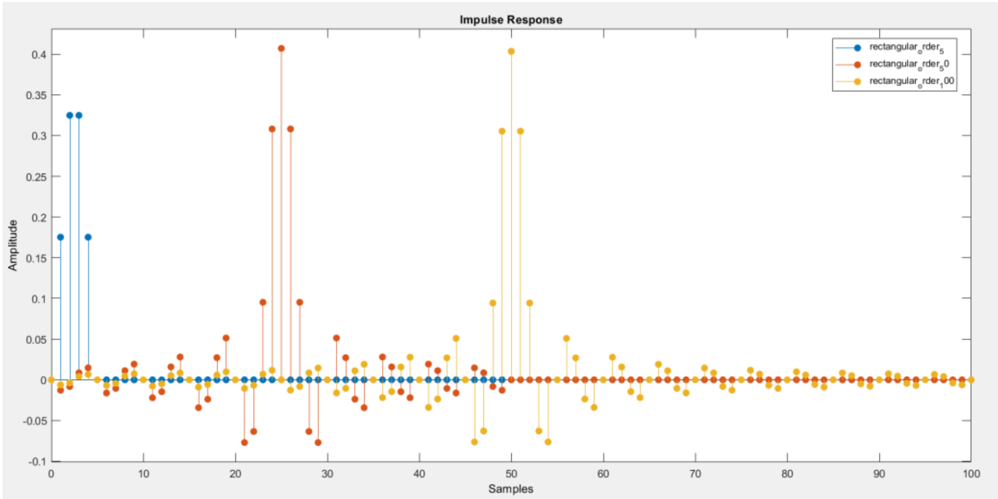
3. Designing FIR filters using windows

3.1. Characteristics of window functions (use the fdatool)

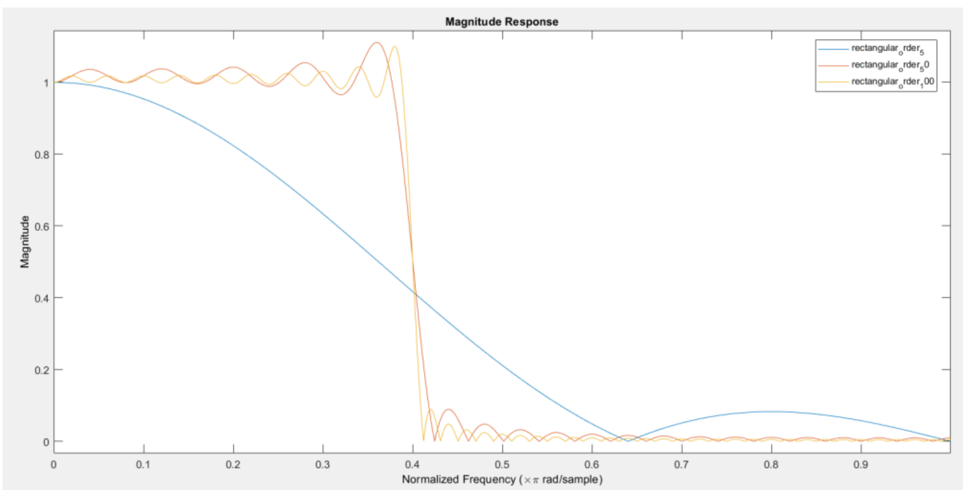
i)

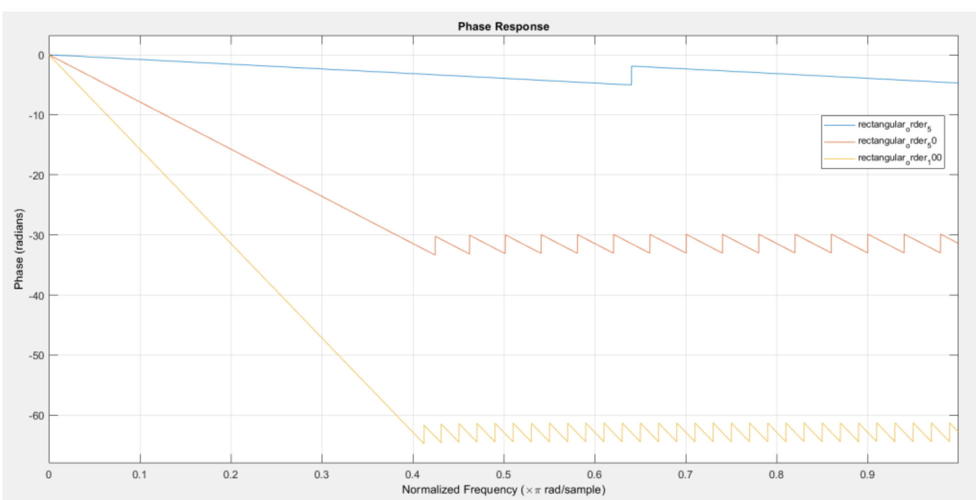
Using fdatool:




Impulse Response
Amplitude
Samples
rectangular_order_5
rectangular_order_50
rectangular_order_100

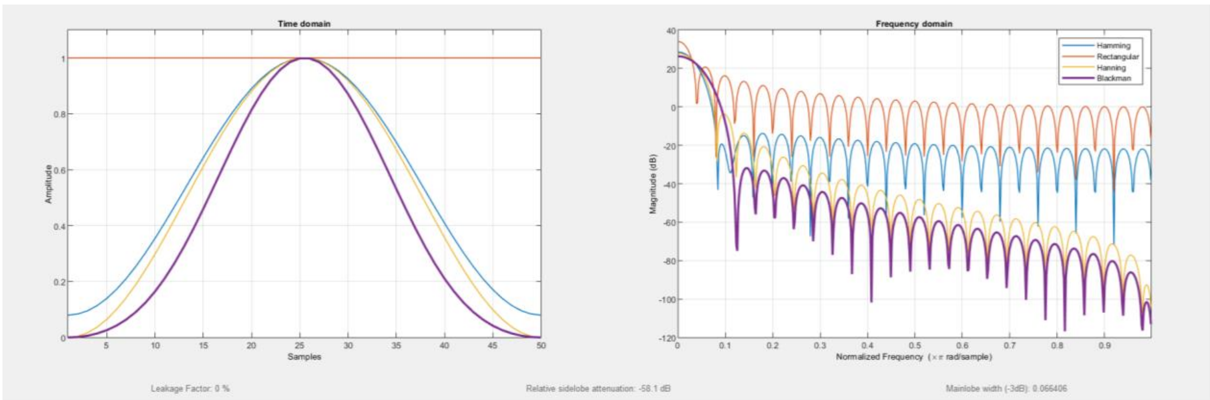
ii)


Magnitude Response
Magnitude
Normalized Frequency (×π rad/sample)
rectangular_order_5
rectangular_order_50
rectangular_order_100


Phase Response
Phase (radians)
Normalized Frequency (×π rad/sample)
rectangular_order_5
rectangular_order_50
rectangular_order_100

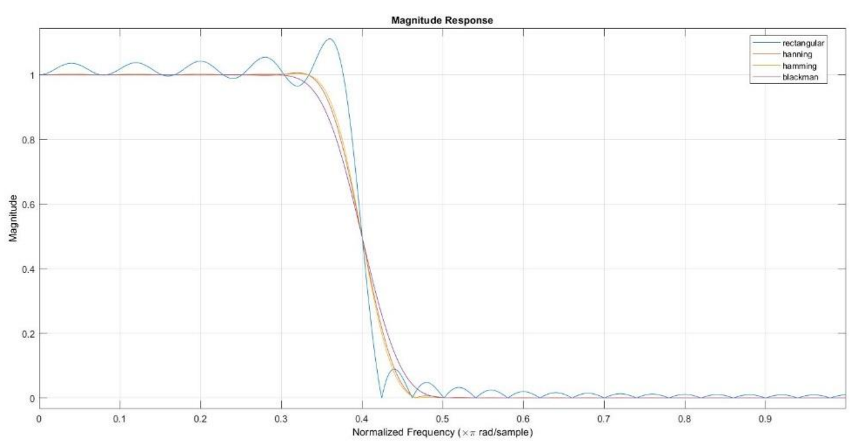
iii)

Morphology of windows:



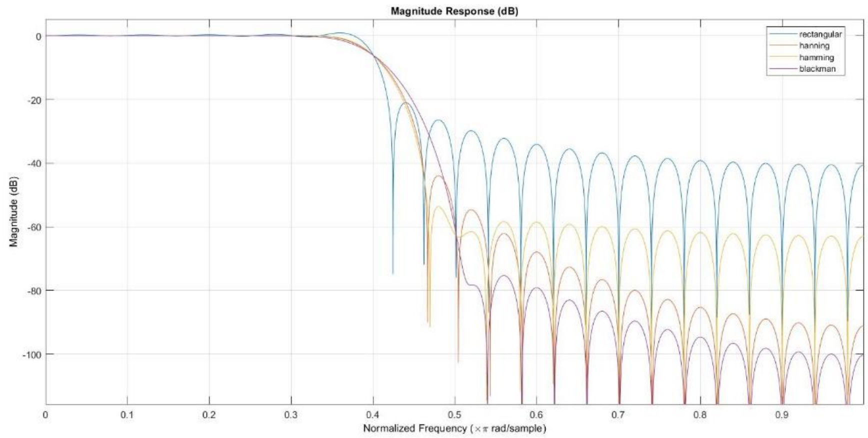
- The rectangular window is constant across its length, with no tapering. While others have bell shapes. Hanning, and Blackamn starts and ends with zero magnitude. Thus reducing discontinuities and spectral leakage in frequency domain.

Magnitude response in linear scale:



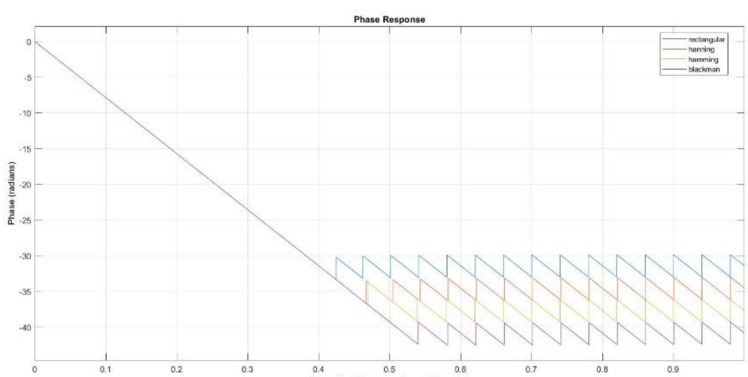
- In alternative windows reduced ripples are observed in the passband at expense of a wider transition band. Compared to Hanning and Hamming, Blackamn has a slightly wider transition band at the the same M. The half power cut off frequency is the same.

Magnitude response in dB:



- Blackmann has the lowest sidelobe magnitudes, while rectangular has the highest in the cut off range. The sidelobe magnitude has reduced at the expense of a wider main lobe. As we can see, the rectangular window has the main lobe in the required range, and it has increased with the lowered side lobe magnitudes in other methods. Thus, the rectangular window has the highest sidelobe magnitudes as well. Therefore, it is not suitable for applications where speactral leakage should be minimized. When comparing Hanning and Hamming, sidelobe magnitudes are lesser in Hanning, even though other features are slightly similar.

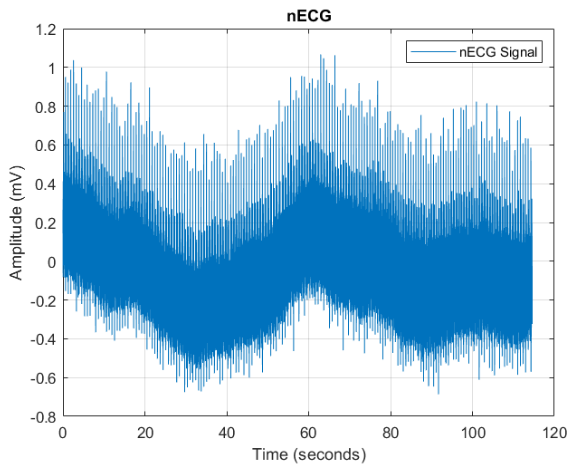
Phase response:

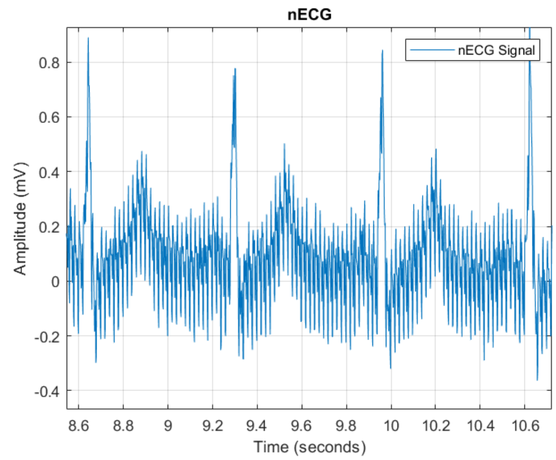


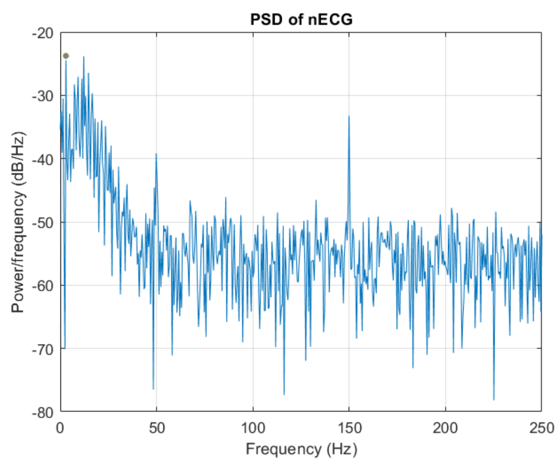
- Since all these windows are symmetric, their phase response is linear in the passband region.

3.2. FIR Filter design and application using the Kaiser window

i)







ii)

	High Pass	Low Pass
f_{pass}	90 Hz	0.5Hz
f_{stop}	70 Hz	1.5Hz
δ	0.01dB	0.01dB

	Stop Band
f_{stop} 1	50Hz
f_{stop} 2	100Hz
f_{stop} 3	150Hz

The industry standard was around 0.5- 100 Hz. However to minimize M, used 0.5 to 1.5 Hz in lowpass, and also, in high pass reduced the range to a lower range until the visible high frequency noise was removed. The high pass filter order was very high since the frequency range that should have the cutoff is low.

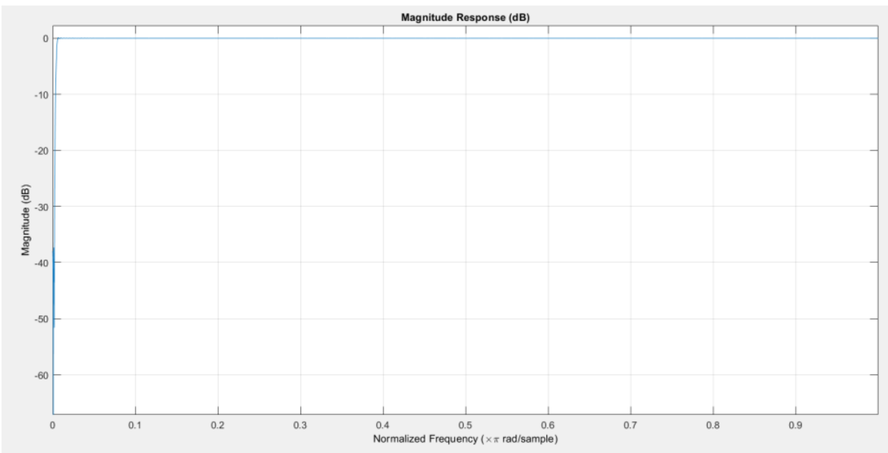
iii)

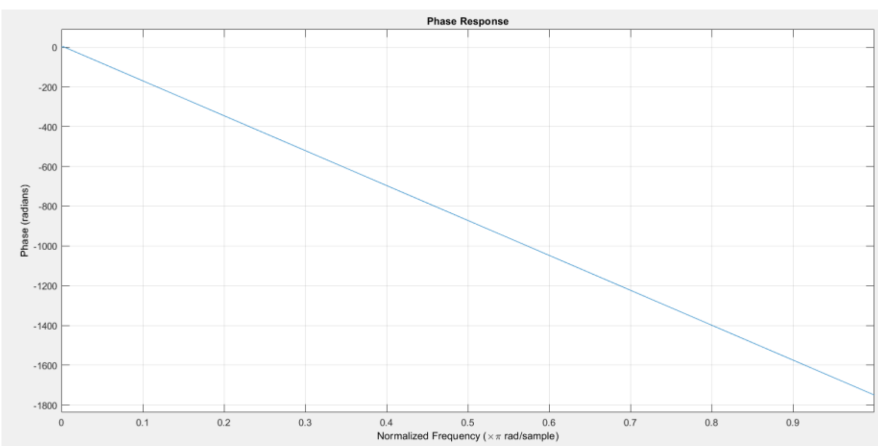
For High pass filter M = 1118, Beta = 3.395321e+00

For Low pass filter M = 56 and Beta = 3.395321e+00

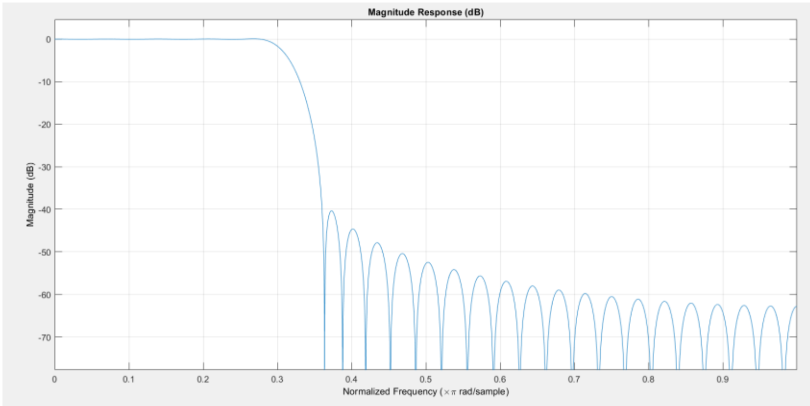
iv)

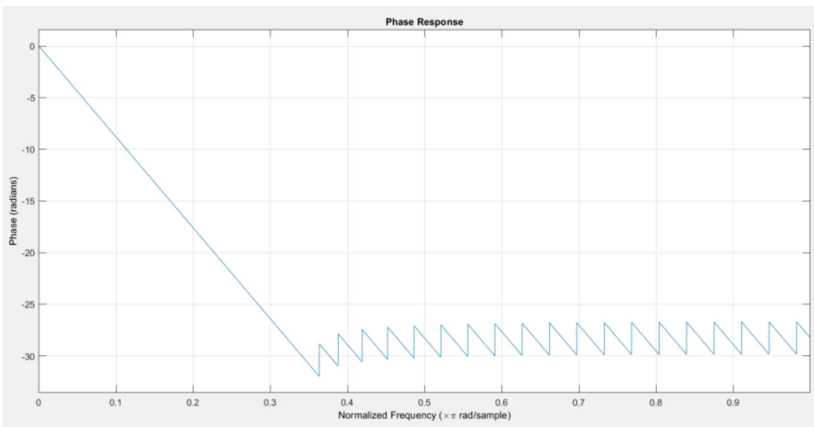
Highpass filter:



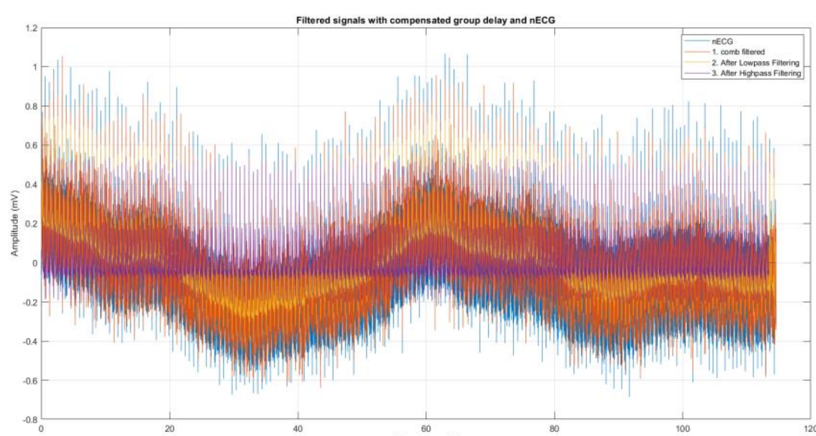


Lowpass Filter:



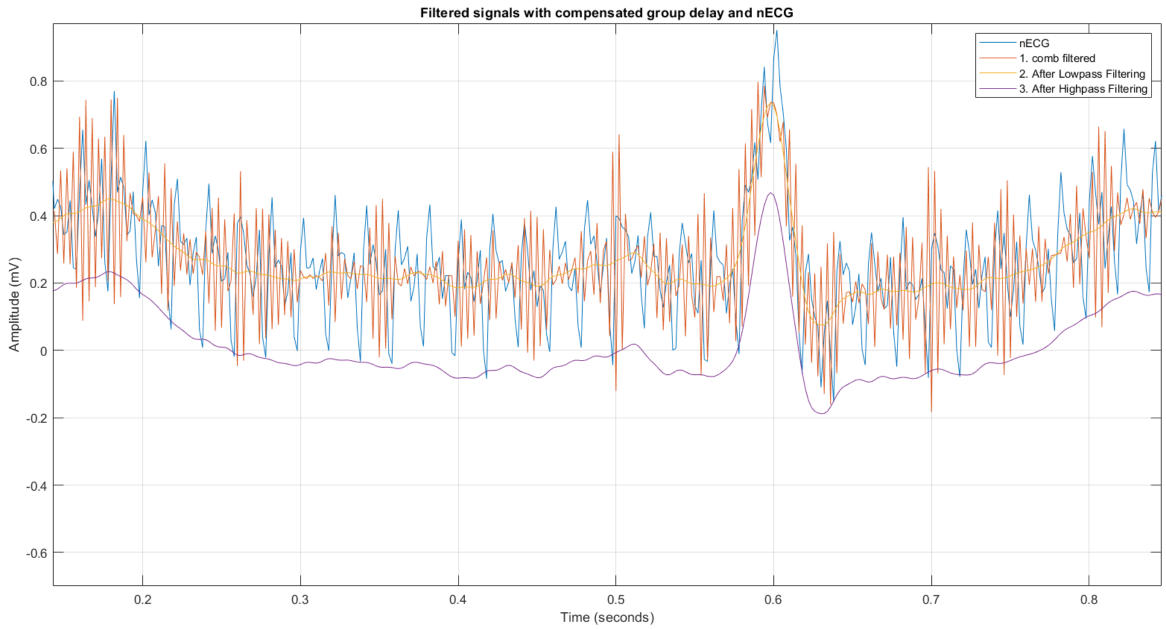


v)

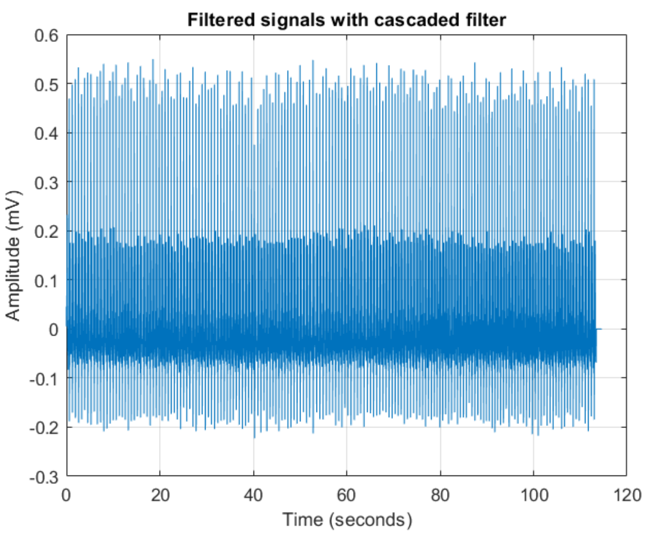


Each step is done after the other.

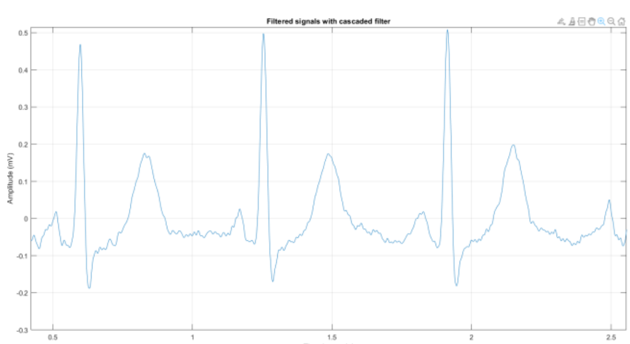
Zoomed in:


Filtered signals with compensated group delay and nECG
nECG
1. comb filtered
2. After Lowpass Filtering
3. After Highpass Filtering
Amplitude (mV)
Time (seconds)

vi)

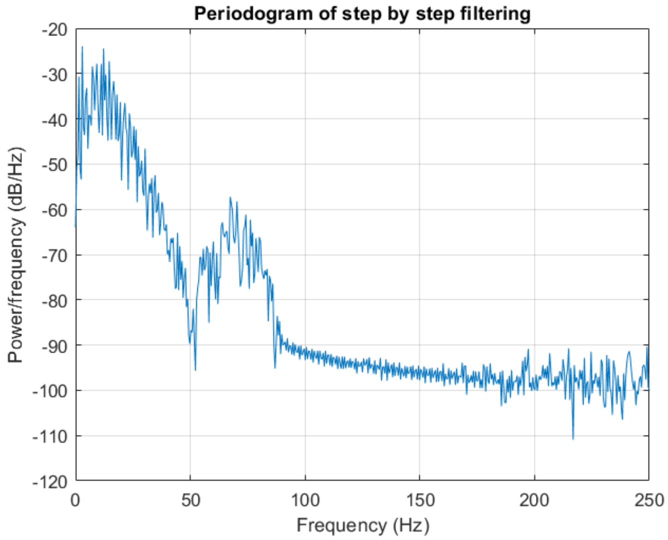

Filtered signals with cascaded filter
Amplitude (mV)
Time (seconds)

Zoomed:

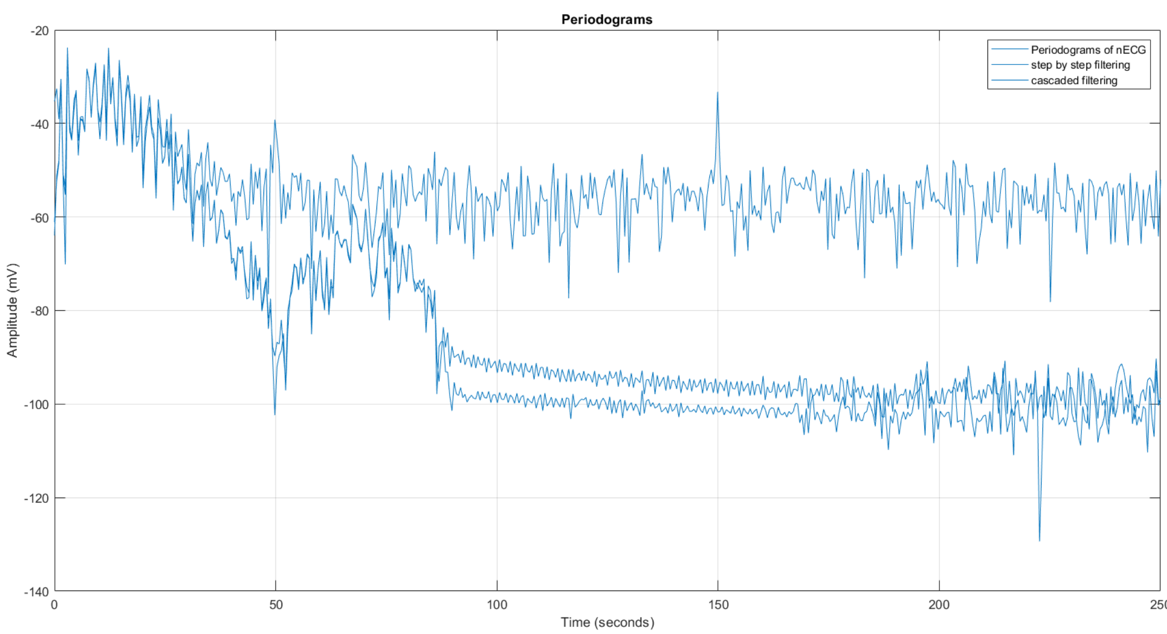

Filtered signals with cascaded filter
Amplitude (mV)
Time (seconds)

vi)

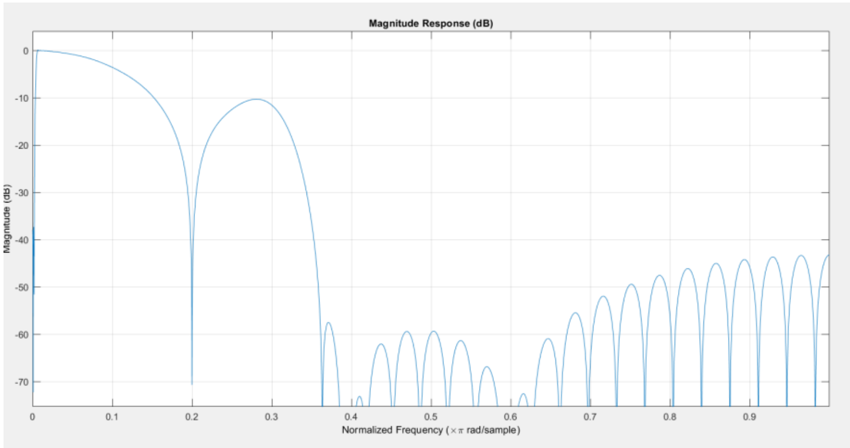
Periodogram of previously filtered signal:

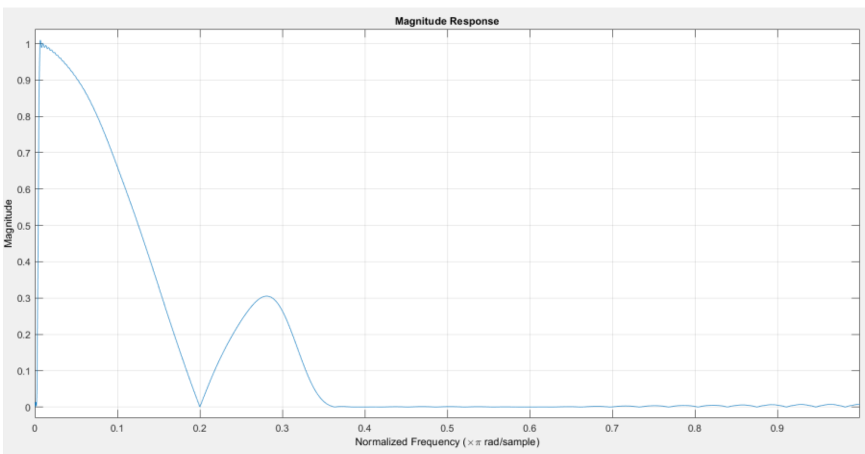


The at the bottom is when all filters are cascaded and applied at once. The difference is in the step by step filtering, I have compensated for the delay after each step. But at the cascaded filter, only at last the delay was compensated.



Magnitude response of cascaded filter:





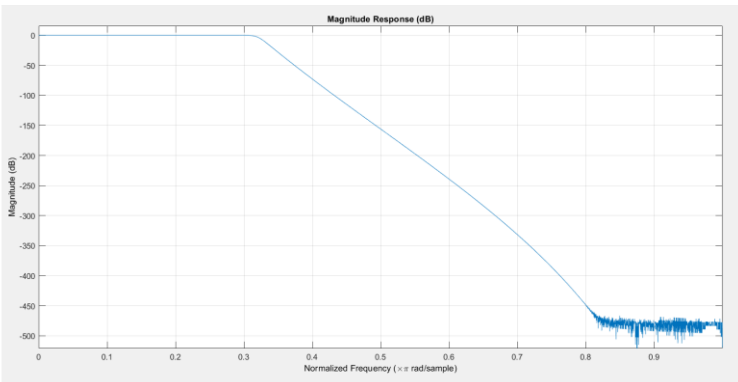
4. IIR Filters

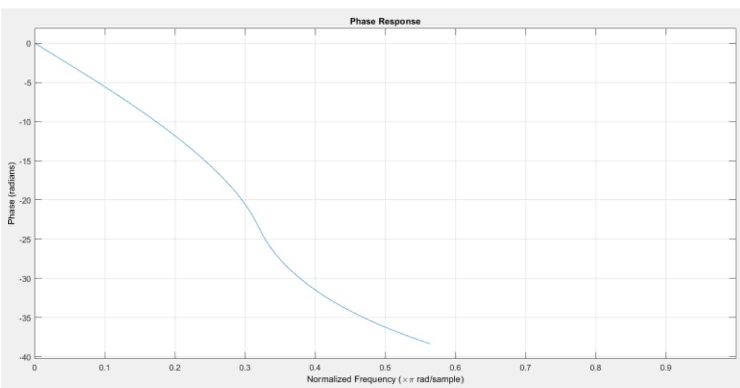
4.1. Realising IIR filters

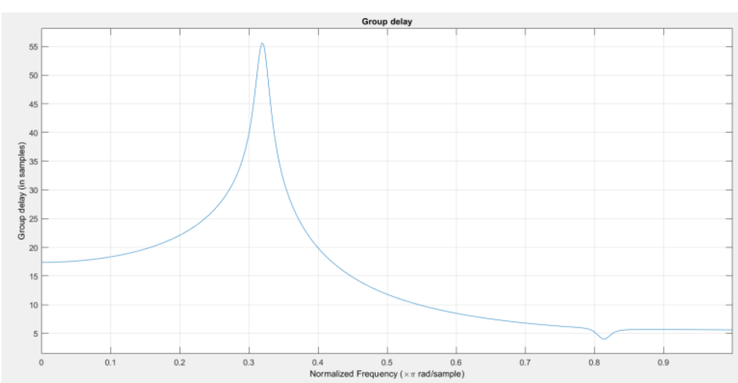
ii)

Filter orders were reduced since very high orders are unstable in IIR filters.

Order = 30;

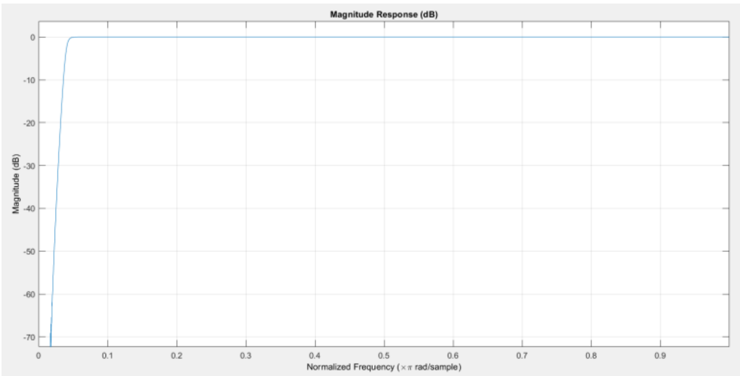


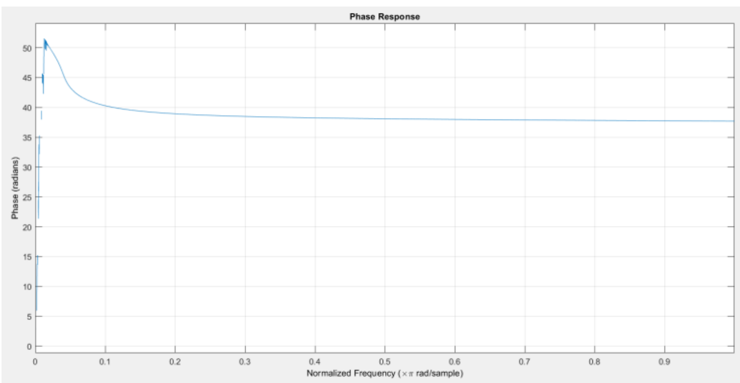


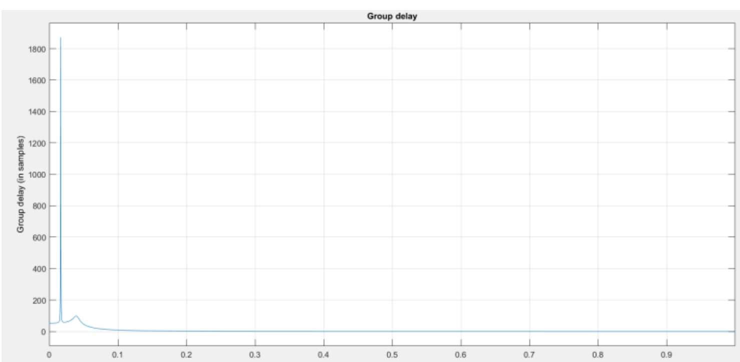


iii)

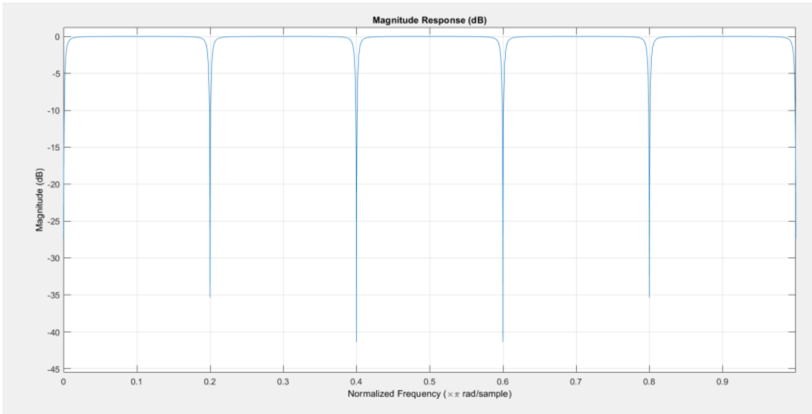
Highpass Filter:

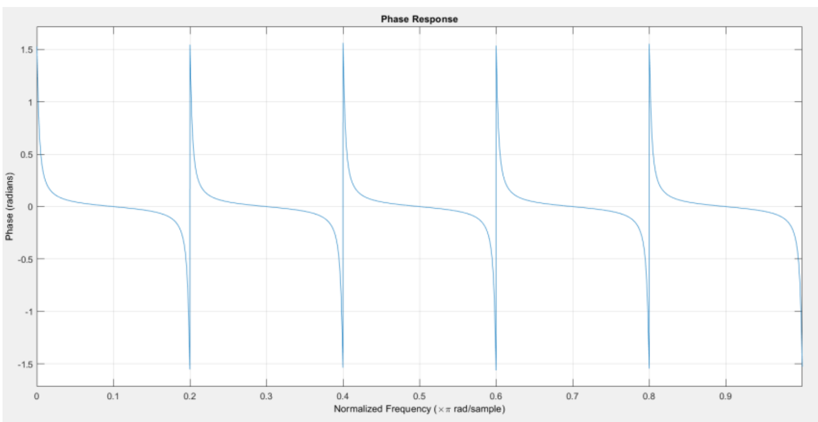


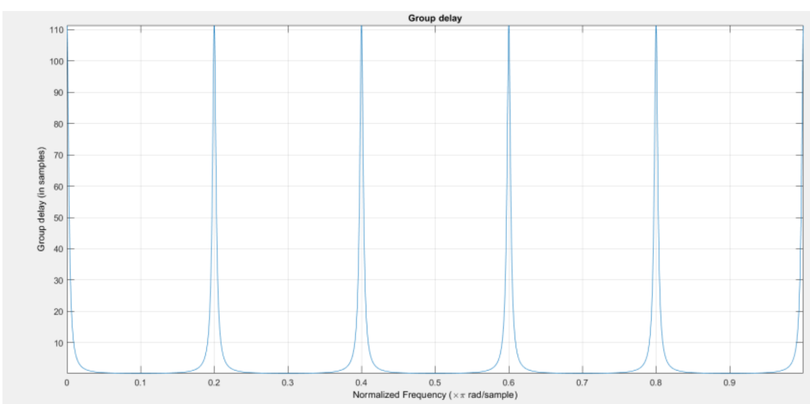




Comb Filter:

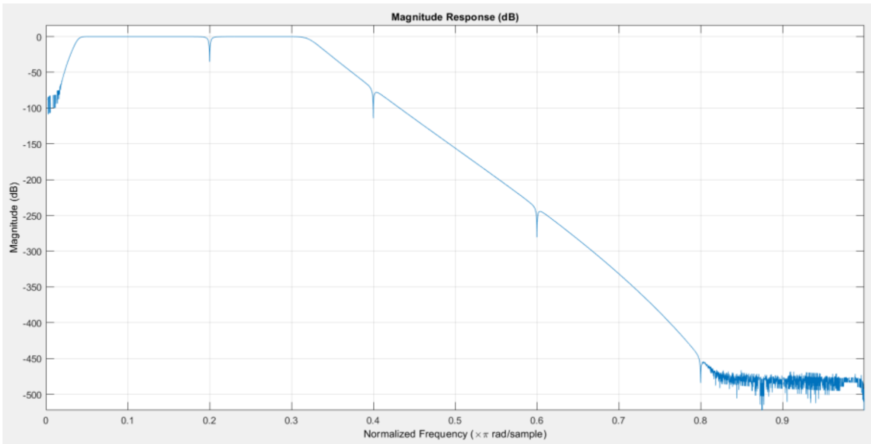

Magnitude Response (dB)
Magnitude (dB)
Normalized Frequency (×π rad/sample)


Phase Response
Phase (radians)
Normalized Frequency (×π rad/sample)

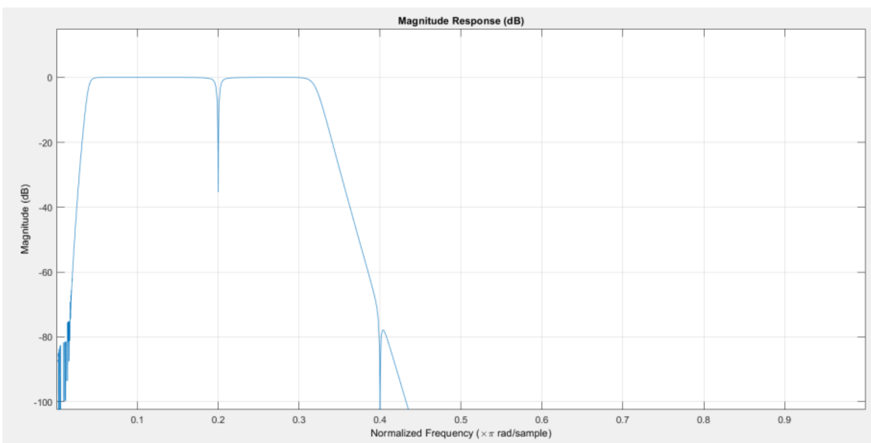

Group delay
Group delay (in samples)
Normalized Frequency (×π rad/sample)

iv)

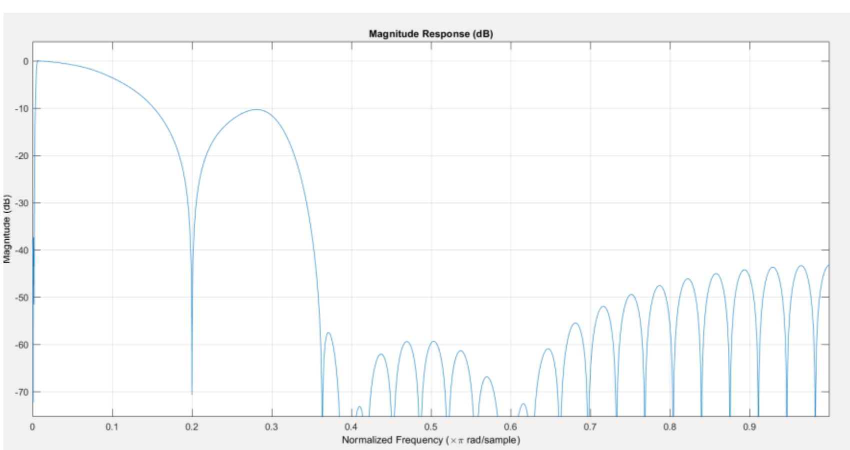
Combined IIR Filter:



Zoomed in:



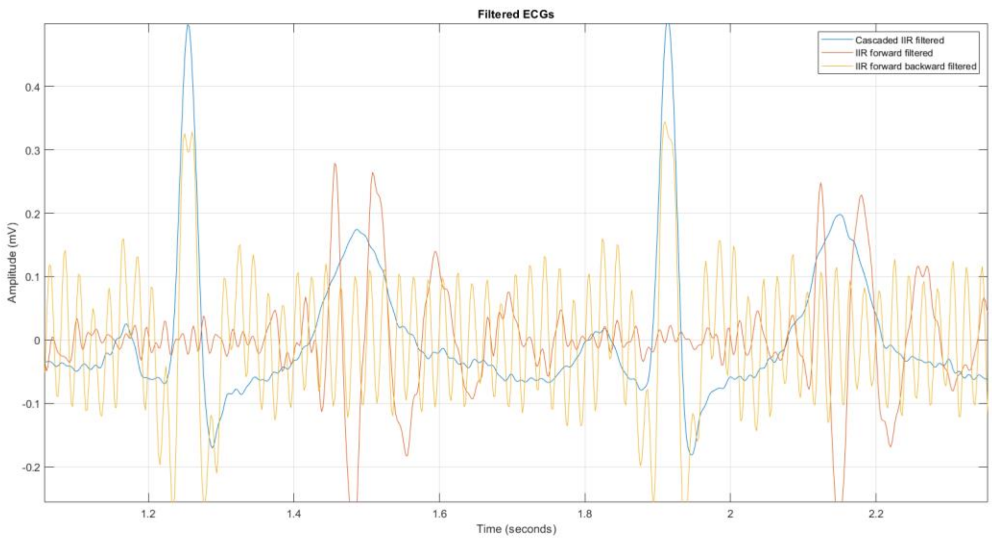
Of FIR filter:



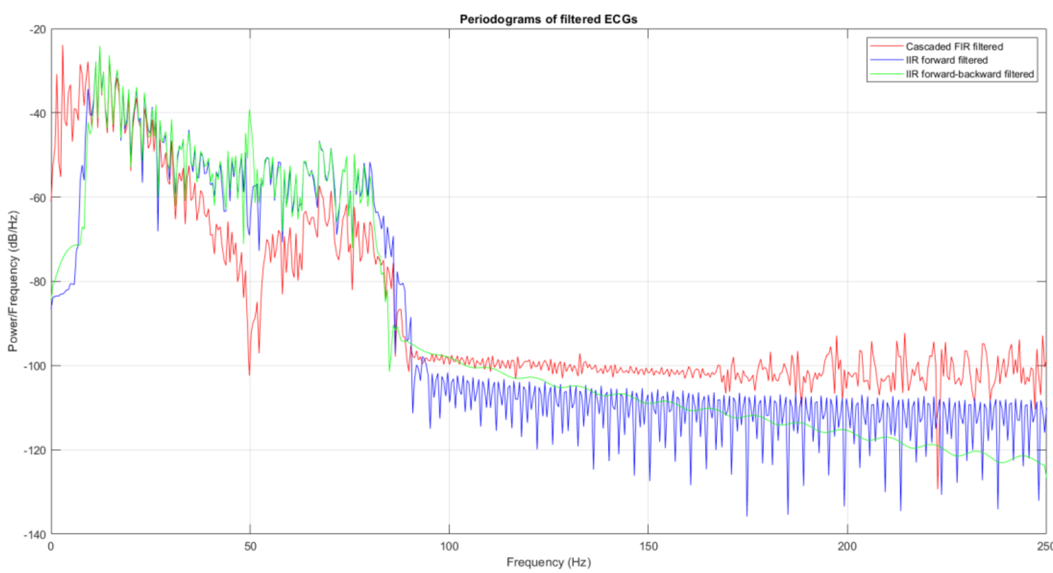
The highpass cutoff is not strong in the IIR filter, but the passbands and notch are perfect. The FIR provides a lower cutoff at notch. In the stop band the cutoff is slower in the IIR, and much sharper in the FIR. However, a big impact is made due to the differences in the order.

4.2. Filtering methods using IIR filters

iii)



iv)



Not clearly visible due to the difference in orders.