Interference Reduction in ECG using Digital FIR Filters based on rectangular window

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Abstract:

Coronary heart disease (CHD) is the leading cause of death for both men and women in the all over the world and India too. CHD is caused by a narrowing of the coronary arteries that supply blood to the heart, and often results in a heart attack. Each year, about millions man kind suffers from heart attack. About maximum of those heart attacks are fatal. About half of those deaths occur within 1 hour of the start of symptoms and before the person reaches the hospital. A heart attack is a medical emergency. Hospitalization is required and possibly intensive care. ECG signal is very important signal in the cardiology. Different artifacts are the reason behind the corruption of the signal care should be taken to avoid the interferences in the ECG. The work is in that direction. Present paper deals with the design of the FIR filter using rectangular window. Basically three filters are designed namely low pass filter high pass filter and notch filter. All the filters are cascaded also. These filters are applied on the ECG signal in the real time manner. For the real time application the 711B add-on card has been used. Results clearly indicate that there is noise reduction in the ECG signal. A Comparative Results are Provided in the paper.

Key wards: - Rectangular window, real time ECG processing, mathlab Simulink.

1. Introduction

The electrocardiography deals with the electrical activity of the heart the state of the cardiac health is generally reflected in the shape of the ECG waveform and heart rate [1]. In many practical medical applications, filters are needed to obtain more relevant data from a signal, such as an ECG. Figure 1 shows the basic ECG waveform with clearly indicating time intervals.

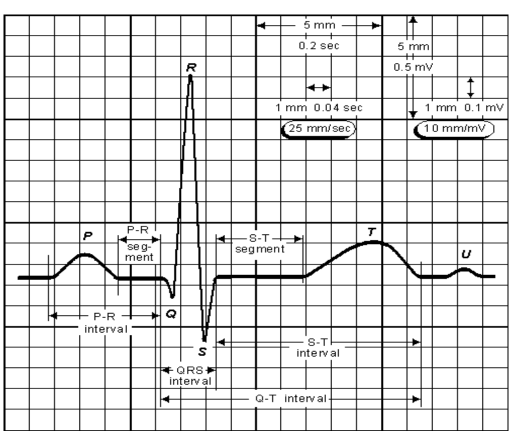

Figure 1: Basic ECG waveform.

Other problems, such as artifacts and power line frequencies often add unwanted data to these signals. Analog filters help deal with these problems. However, they may introduce non-linear phase shifts, skewing the signal also, the instrumentation depends on resistance, temperature, and design, which may also introduce more error. With more recent technology, digital filters are now capable of being implemented. Digital filters are much more precise due to a lack of instrumentation, thus offering a great advantage over analog filters. Digital filters can be placed into one of two categories: Finite Impulse Response (FIR), and Infinite Impulse Response (IIR). Filtering an ECG Signal is no easy task. One has to bear in mind that important ECG signals are at very low frequencies and are relatively distributed in the wide frequencies. Power line noise, low frequency noise and EMG are also the part of the sampled signals. Also filter coefficient must be few, to avoid to many computations, which is not acceptable for real time processing. Hence the challenge is to create an effective filter with minimum coefficients to isolate the signal from unwanted information.

Electrocardiographic signals (ECG) may be corrupted by various kinds of noise. Typical examples are:

1. Power line interference.
2. Electrode contact noise.
3. Motion artifacts.
4. Muscle contraction.
5. Base line drift.
6. Instrumentation noise generated by electronic devices.
7. Electro surgical noise.

Different researchers have worked on the removal of the interferences in the ECG signal. Cramer E, McManus CD, Neubert D. has suggested comparison in the digital approaches in power line interferences removal.[2] Mitov P. worked on the ECG interferences. Dotsinsky I, has also worked on the power line interferences cancellation [4]. Subtraction procedure has been suggested by Levkov C, Mihov G, Ivanov R, Daskalov I, Christov I, Dotsinsky I.[5], Signal averaging procedure is depicted in the literature of the Ider YZ, Saki MC, Gcer HA.[6], Nove method for the reduction of the base line wonder is suggested by the Sornmo L.[7]. The interference removal is the key problem related to the biomedical signal.[8-10]. Some solution for removal of the power line interference and base line wander and high frequency noise illustrated in the recent literature. Figure 2 shows ECG corrupted Due to Power line Interference and figure 3 shows ECG corrupted due to abrupt Base line Drift.

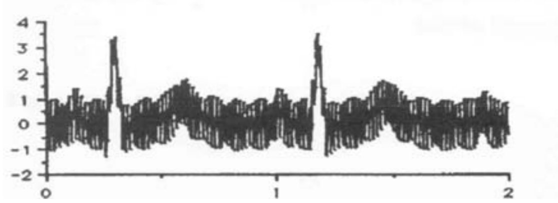

Figure 2: ECG corrupted Due to Power line Interference.

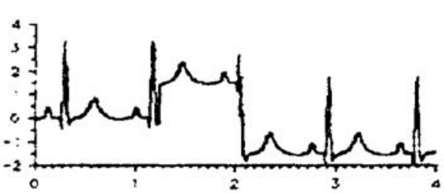

Figure 3: ECG corrupted due to abrupt Base line Drift.

1.1 Rectangular window

The weighting function for the rectangular window is given by

$$W_R(n) = 1 \quad \text{, For } |n| \le \frac{M-1}{2}$$

$$= 0\text{, otherwise}$$

The Spectrum of the $W_R(n)$ can be obtained by taking Fourier transform of the above equation 2.12, as

$$W_R(e^{j\varpi T}) = e \sum_{n=\frac{-(M-1)}{2}}^{\frac{(M-1)}{2}} e^{-j\varpi nT}$$

Substituting n=m-(M-1)/2 and replacing m by n,

$$W_R(e^{j\varpi T}) = e^{j\varpi\frac{(M-1)}{2}T} \sum_{n=0}^{(M-1)} e^{-j\varpi nt}$$

$$W_R(e^{j\varpi T}) = \frac{\sin(\varpi MT)}{\sin(\frac{\varpi T}{2})}$$

The transition width of main lobe for this is approximately $4\pi / M$. The first side lobe is of 13dB down the peak of the main lobe and the roll off is 20dB per decade. For the causal rectangular window the frequency response is given by the equation

$$W_R(e^{j\varpi T}) = \sum_{n=0}^{(M-1)} e^{-j\varpi nT}$$

$$= e^{j\varpi\frac{(M-1)}{2}T} \frac{\sin(\frac{\varpi MT}{2})}{\sin(\frac{\varpi T}{2})}$$

From the equation 2.13 and 2.14 it can be noted that the linear phase response of the causal filter is given by $\varpi(M-1)T/2$ and the non-causal impulse response has a zero phase shift. Figure 4 shows the typical Rectangular window in which the leakage factor is 9.2%, Relative side lobe attenuation is -13.0dB, main lobe width is (-3dB) 0.172.

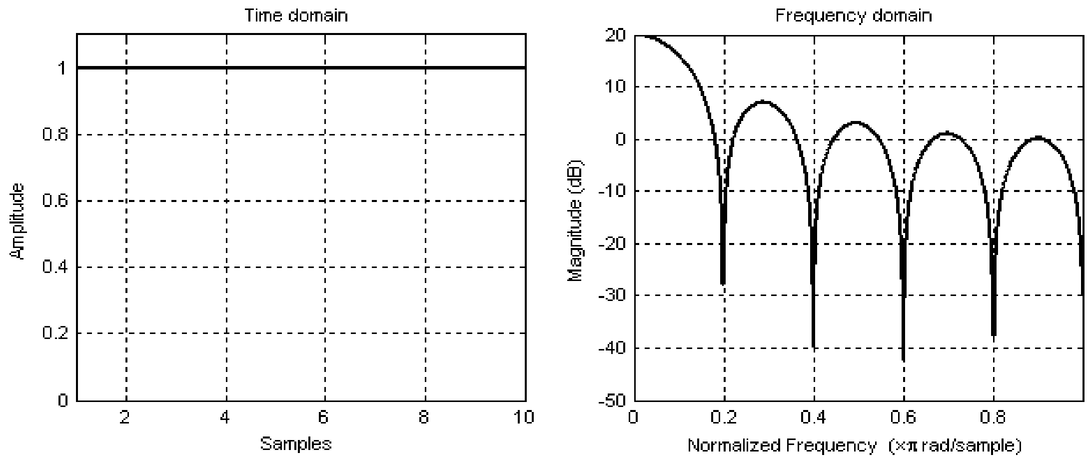

Figure 4 Typical Rectangular Window.

2. Design of Digital filters using Window

2.1.1 Removal of High Frequency Noise using low pass filter designed with windows.

The application of low pass filter for removal of high frequency signals from the ECG using digital FIR filters designed with window technique is described in the present section. Four different types of windows were used namely rectangular window, Hamming window, Hanning window and Kaiser Window [3-10].

2.1.2 Design of the low pass filter using windows:

The low pass filters were designed by using different windows. Order of the filter is 100 and sampling frequency is 1000Hz.

2.1.3 Design using rectangular window:

When FIR filter is designed using rectangular window of the order of 100, Figure 5 shows the Time and frequency domain description of Rectangular window for order 100. It is found that the main lobe width is (-3dB) 0.0157 and the relative side lobe attenuation of -13.3dB. Figure 6 shows the magnitude and figure 7 shows the phase response of the FIR low pass filter. From the response it is seen that the filter has sharp attenuation and pulsation present in the stop band. In the pass band it provides the linear phase. Impulse response confirms the stability of the filter.

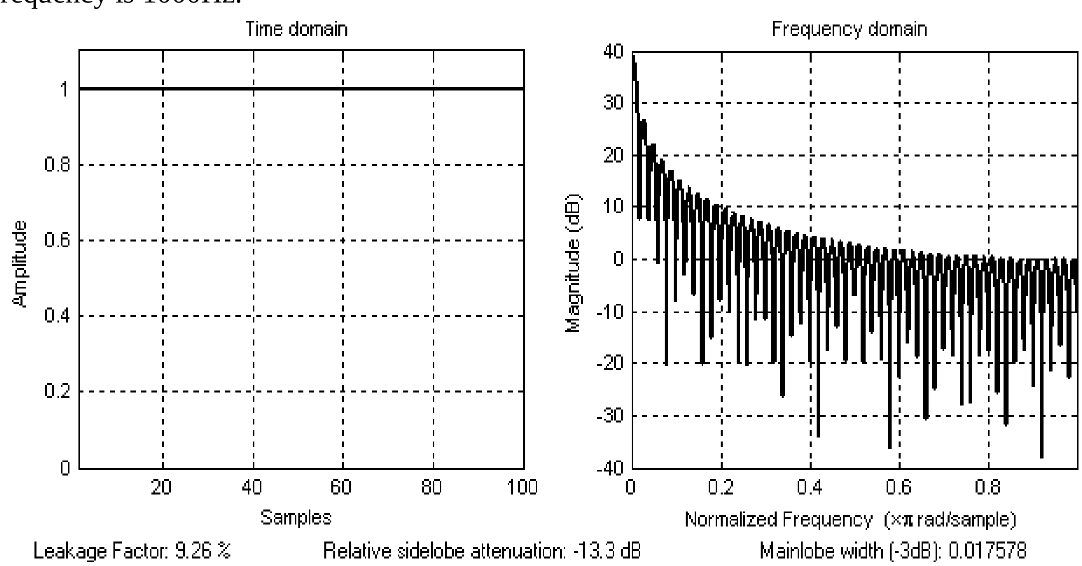

Figure 5: Time and frequency domain description of Rectangular window

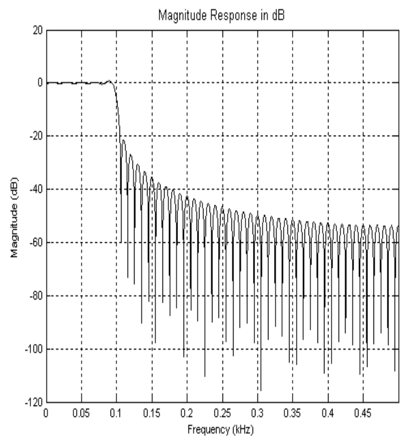

Figure 6: Magnitude response of the low pass filter using rectangular window.

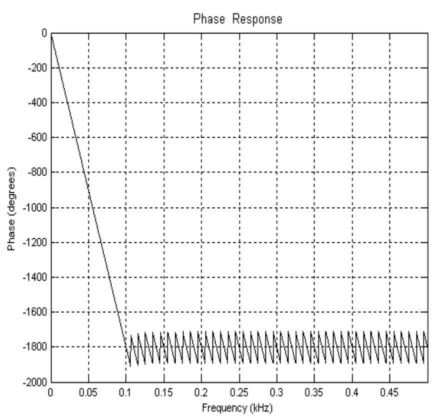

Figure 7: Phase response of the filter.

2.2 Removal of Low Frequency Noise: Using High pass filter designed using windows.

Design of high pass filter using windows methods to face the problem of base line wonder in the ECG signal is described in this section. Different windows namely rectangular window, hamming window, Hanning window and the Kaiser Window ware used to design the high pass filter.

2.2.1 Design of the High pass filter using windows:

The high pass filter was designed using window function. The order of filter was 100 and sampling frequency 1000Hz.

2.2.2 Using rectangular window:

The design of the FIR filter using rectangular window of the order of 100 is described in present section. Figure 8 shows magnitude and figure 9 shows the phase response of the FIR high pass filter. Figure 10 and figure 11 show the Impulse response and step response of the high pass filter. It is found that for the filter in the design the main lobe width is (-3dB) 0.0157 and the relative side lobe attenuation of -13.3dB. From the response it is observed that the filter is stable. In the pass band it provides the linear phase.

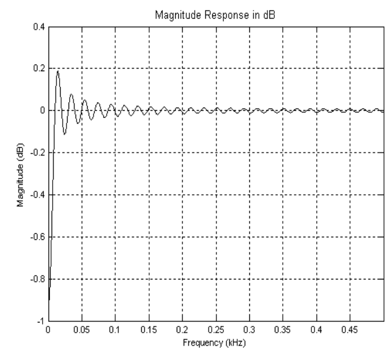

Figure 8: magnitude response of the High pass filter using rectangular window.

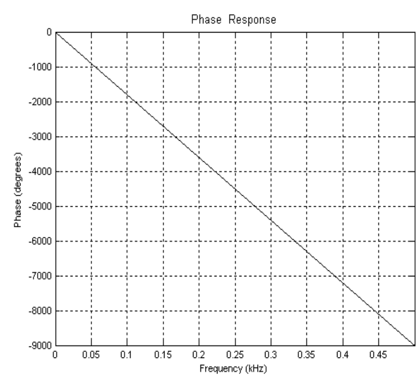

Figure 9: Phase response of the High pass filter using rectangular window.

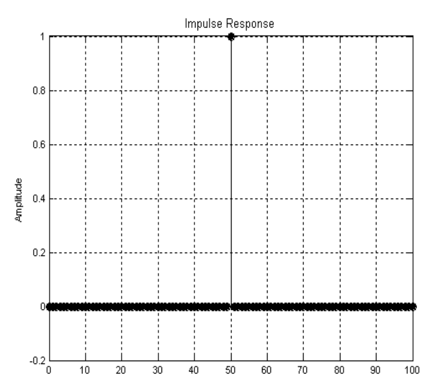

Figure 10: Impulse response of the High pass filter using rectangular window

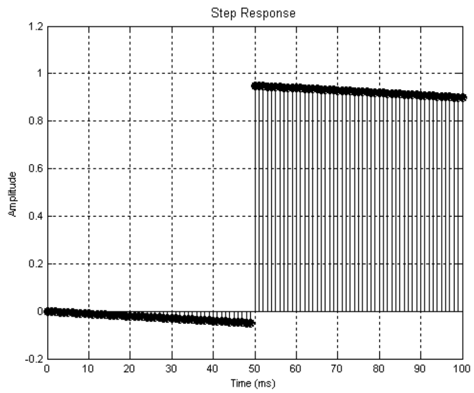

Figure 11: Step response of the High pass filter using rectangular window

2.3 Removal of Power line interference: Using notch filter designed using windows.

This section describes design of notch filter using windows to face the problem of power line in the ECG signal. Different power line interference removal techniques are reported in the literature. In the present section different filters design with different window function were used.

2.3.1 Design of the notch filter using windows:

Figure 12 shows that magnitude and figure 13 shows the phase response of the FIR notch filter using rectangular window. Figure 14 and figure 15 shows the Impulse response and step response of the notch filter. It is found that the main lobe width is (-3dB) 0.0175 and the relative side lobe attenuation of -13.6dB. Designed filter is stable and it is confirmed from the impulse response.

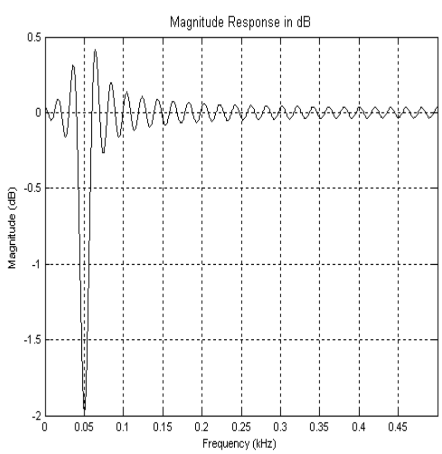

Figure 12: Magnitude response of the filter.

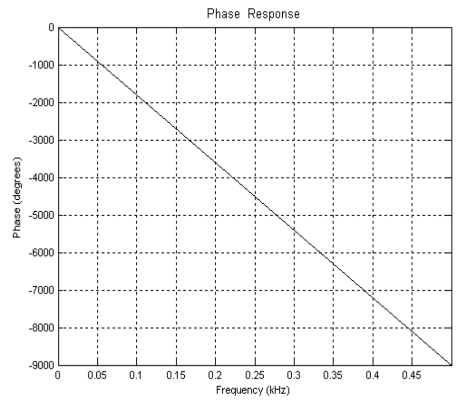

Figure 13: Phase response of the filter using rectangular window.

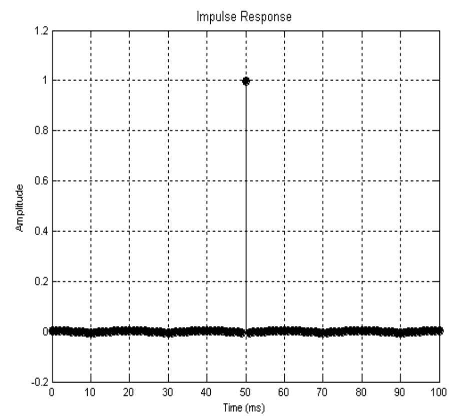

Figure 14: Impulse response of the filter using rectangular window

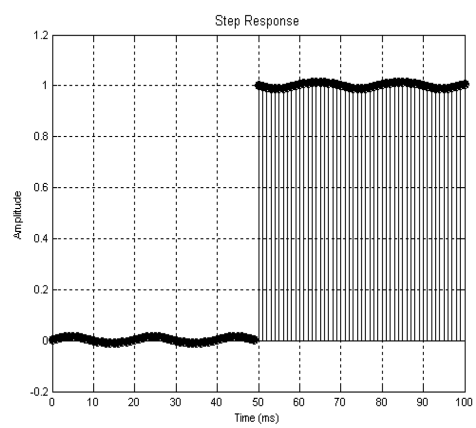

Figure 15: Step response of the filter using rectangular window.

3. Model used in the present work

In the model the digital input indicates the data from the711B add-on card all the filters are designed and cascaded to get the final results. Figure

16 shows model used for real time filtering of ECG signal using Window based filters.

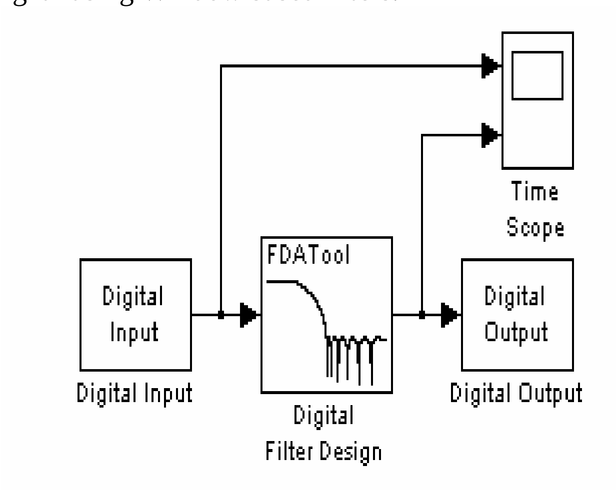

Figure 16: Model used in the system.

4. Results

Results for the filter implementation are divided into three groups like results of Low pass filter, High pass filter and notch filter.

4.1 Results of the implementation of the Low pass filter designed using windows:

Figure 17 shows the ECG signal before application of low pass filter using window function. The signal contains the high frequency, low frequency and power line interference. It is also confirmed from the figure 18 which shows the frequency spectrum of the ECG before filtration. It shows that the average power of the signal above the 100Hz is approximately -58dB.

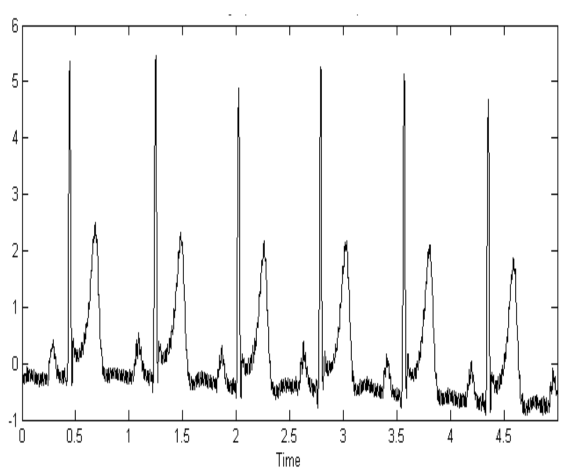

Figure 17: ECG signal before application of low pass filter using window function.

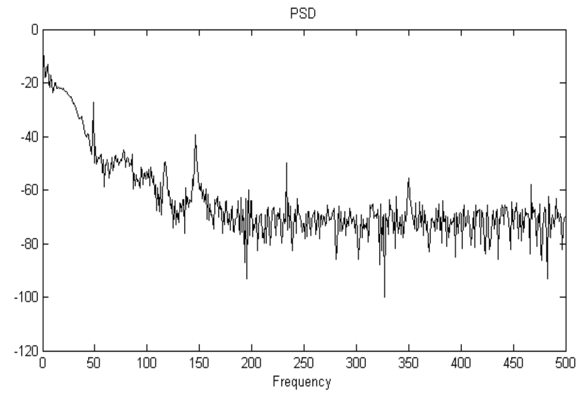

Figure 18: frequency spectrum of the ECG shown in figure 17

Figure 19 Shows ECG signal when the low pass filter is applied. Figure 20 also shows the frequency response corresponds to the filtered signal. It is seen that when the filter is applied the power of the signal above the 100 Hz reduced to -70dB. It clears that this filter removes the high frequency signal from the raw ECG.

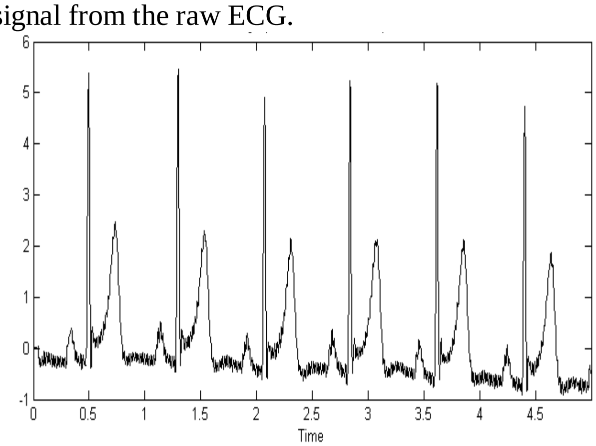

Figure 19: ECG signal after application of Low pass filter using Rectangular window

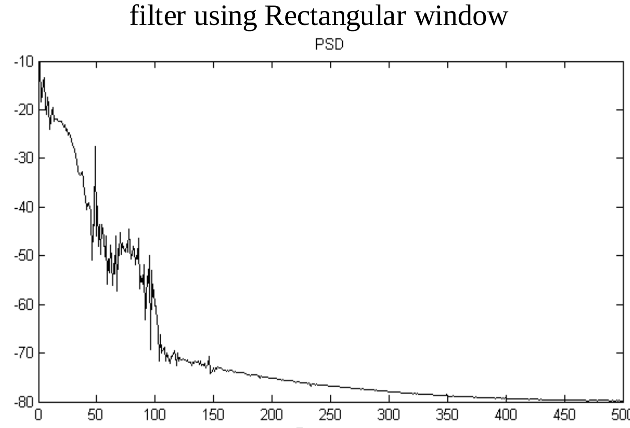

Figure 29: frequency spectrum of the ECG shown in figure 19 (Rectangular window).

4.2 Results of the implementation of the High pass filter designed using window:

Figure 30 shows the ECG signal before application of high pass filter. The signal contains the high frequency, low frequency and power line interference. It is also confirmed from the figure 31 which shows the frequency spectrum of the ECG before filtration. The average power of the signal below the 0.5Hz is approximately -12.5dB.

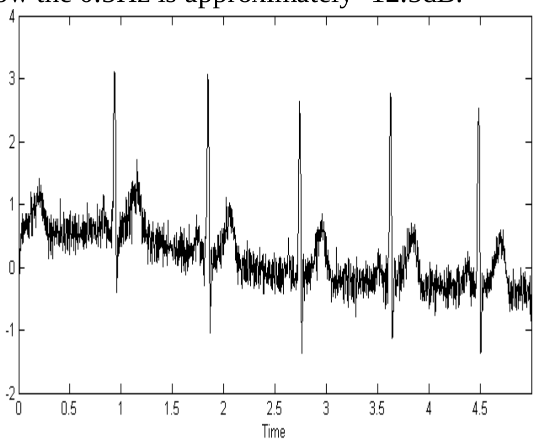

Figure 30: ECG signal before application of digital filter.

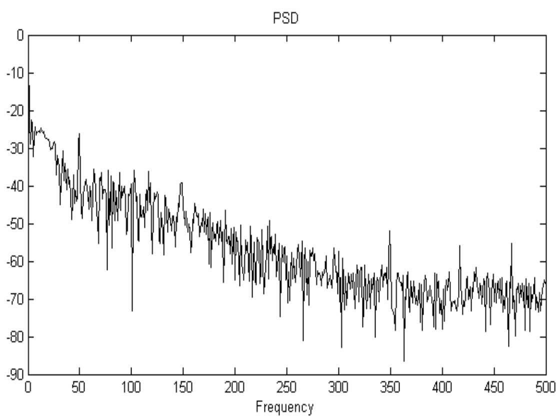

Figure 31: frequency spectrum of ECG signal before filtration.

Figure 32 shows ECG signal, filtered by high pass filter using rectangular window. Figure 33 also shows the frequency response corresponds to the filtered signal. It is seen that when the filter is applied the power of the signal below 0.5Hz drops to -16dB. It shows that the filter removes the high frequency signal from the raw ECG.

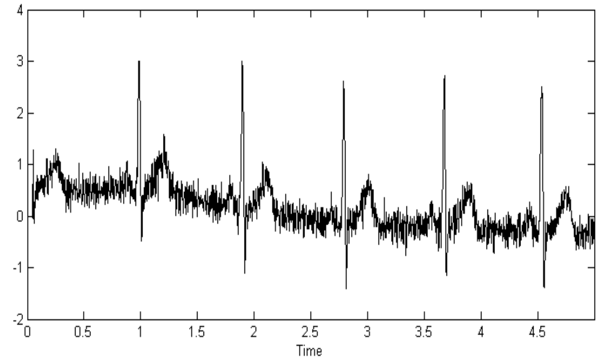

Figure 32: ECG signal after application of digital High filter using rectangular window.

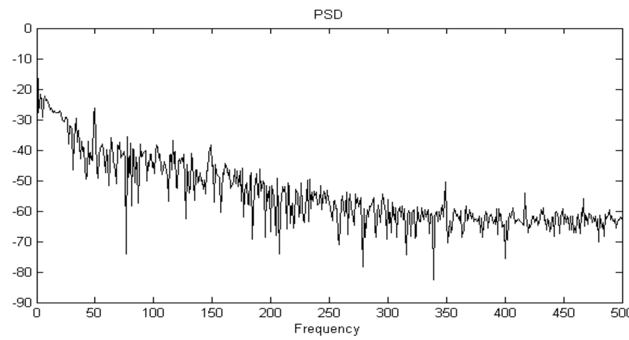

Figure 33: frequency spectrum of ECG after applying High pass filters using rectangular window.

4.3 Results of the implementation of the Notch filter designed using windows:

Figure 34 shows the ECG signal before application of notch filter using window function. The signal contains the high frequency, low frequency and power line interference. It is also confirmed from the figure 35 which shows the frequency spectrum of the ECG before filtration. It shows that the power of the signal at 50Hz is approximately -27.18dB.

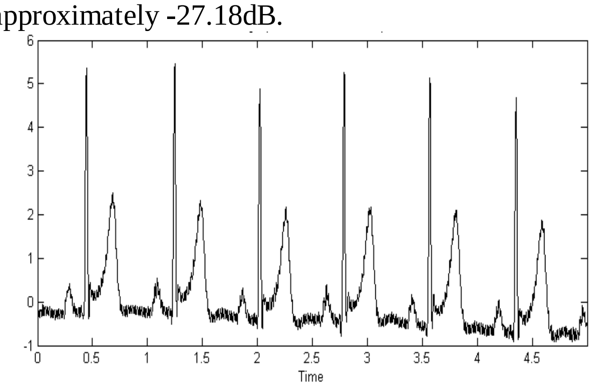

Figure 34: ECG signal before application of digital filter

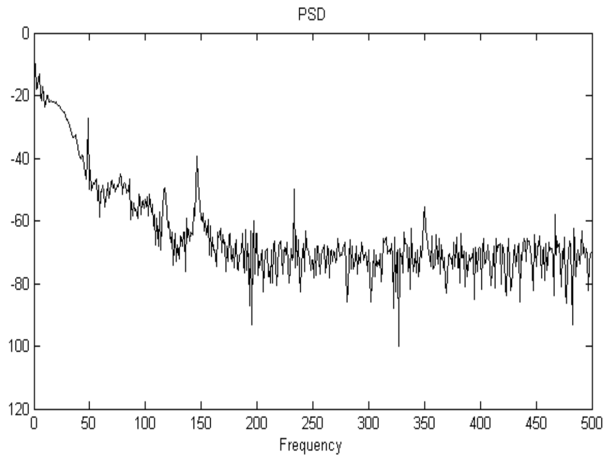

Figure 35: frequency spectrum of ECG signal before filtration

Figure 36 Shows ECG signal when the notch filter designed using rectangular window is applied. Figure 37 also shows the frequency response corresponds to the filtered signal using with rectangular window. It is seen that when the filter is applied the power of the signal at 50Hz drops to -29.58dB. It clears that this filter has reduced the interference.

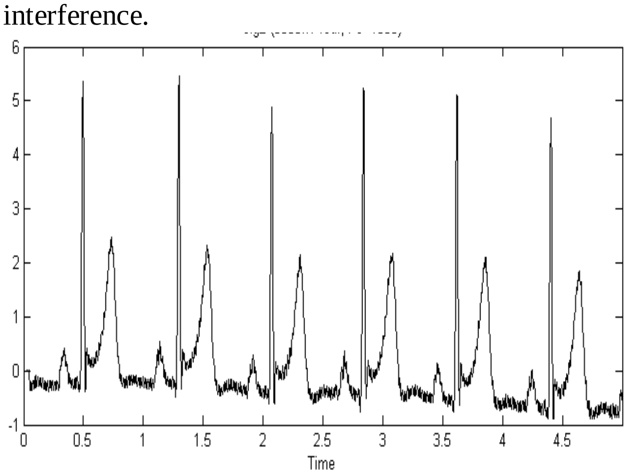

Figure 36: ECG signal after application of digital filter using rectangular window

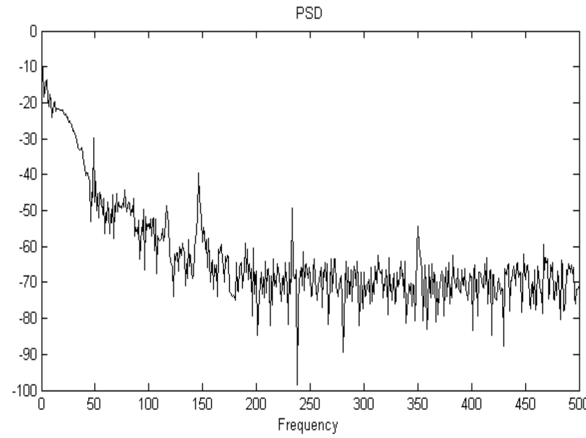

Figure 37: frequency spectrum of ECG signal after application filter using rectangular window.

5. Conclusions

Design of the filters using Rectangular window is simple in comparison with other types of the window. It is found that in the designs of the filter there is ripple present in the pass band of all filters but they give stable responses. All the filters are providing the linear phase. By the visualizing frequency spectrum it is seen that there is reduction in the 50 Hz noise present in the ECG signal. Among the different window technique Windows like rectangular, Hamming, Hanning and Kaiser were compared to design and implement low pass, high pass and Notch filter. The filters were designed using different window techniques by using filter order 100 and sampling frequency 1000Hz. The signal power was measured before application of the filter and after filtration of the signal. The same experiment was carried out for all filters. The results of different high pass filters using windows are depicted in table 1. From the table it is seen that on an average signal power reduces by 3 to 5dB after application of the filter. The noise reduction was more in Kaiser Window. It is further observed that when ECG signal is filtered PQRST complex is modified.

Table 1: Results of reduction of baseline wander using window

Type of Filter	Filter Order	Signal power before Filtration in dB	Signal Power After Filtration in dB	Effect on PQRST waveform
Rectangular Window	100	-12.5	-16	Modified
Hanning Window	100	-12.5	-15	Modified
Hamming Window	100	-12.5	-15	Modified
Kaiser Window	100	-12.5	-17	Modified

To filter the powerline interference notch filters were designed using different window technique. The order of filter was 100 and sampling frequency 1000Hz. Results of notch filter are shown in table 2. It is seen that the power of the filtered signal reduced by –1 to 2.5dB. The 2.4dB reduction was observed in rectangular window filter and Kaiser window filter. Which indicates the removal of power line interference. It is further seen that the PQRST segment of ECG modified when it is filtered through rectangular, Hamming and Hanning window. However, slightly modified by Kaiser Window. Table 2 shows Comparison of these filters using window techniques with other filters for noise reduction. Table 3 shows results of reduction of Power line Interference using windows and its effect on QRS complex.

Table 2 Comparison of these filters using window techniques with others.

Filter Design Method	Multipliers	Adders	Delays	Power at 50Hz Before filtration	Power at 50 Hz after filtration
Minimax	1149	2296	2296	-	-
Multiplier free RSS filter	0	37	2248	10dB	-40dB
Rectangular window	100	101	101	-27.18 dB	-29.58dB
Hanning window	100	101	101	-27.18 dB	-28.77dB
Hamming window	100	101	101	-27.18 dB	-29.18dB
Kaiser Window	100	101	101	-27.18 dB	-29.59dB
Equiripple Method	580	579	579	-26.29dB	-35.75dB
L. S. Method	101	1010	100	-36.00dB	-42.00dB

Table 3: results of reduction of Power line Interference using windows

Type of Filter	Filter Order	Signal power before Filtration in dB	Signal Power After Filtration in dB	Effect on PQRST waveform
Rectangular Window	100	-27.18	-29.58	More distortion
Hanning Window	100	-27.18	-28.77	Less Variation
Hamming Window	100	-27.18	-29.18	Less Variation
Kaiser Window	100	-27.18	-29.59	Less Variation

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