Filtration Of Artifacts In ECG Signal Using Rectangular Window-Based Digital Filters

Mbachu C.B [1], Idigo Victor [2], Ifeagwu Emmanuel [3],Nsionu I.I[4]

[1]Department of Electrical and Electronic Engineering, Anambra State University, Uli. Anambra State(234),Nigeria

[2]Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka. Anambra State(234),Nigeria

[3]Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka. Anambra State(234),Nigeria

Abstract

Increased cases of cardiac arrests resulting from coronary heart disease (CHD) underscores the need for accurate equipment for monitoring and diagnosis of the health conditions of hearts of human beings so that proper medical treatment and advice can be given to people who suffer from heart or heart-related diseases. An electrocardiograph is an instrument or equipment for checking heath condition of hearts by measurement of the quality of electrocardiographic (ECG) signal. The ECG signal is usually corrupt by artifacts and these must be removed before the real shape of the signal can be determined. Filters can be used to realize this. This paper therefore presents designs of digital FIR low pass, high pass and notch filters necessary for the removal of the artifacts. Each filter is designed with a rectangular window. Noisy ECG signal is passed through each filter and results are obtained and presented.

Keywords: rectangular window, corrupting noises. Matlab and Simulink, elecroardiogram.

Introduction

The most vital informative signals used in the diagnosis of patients are the ECG signal, which is generated from the electrical activity of the heart; electromyographic (EMG) signal, which is generated from the electrical activity of the muscles; and the electroencephalographic (EEG) signal, which is generated from the electrical activity of the brain. ECG signals in practice and their natural forms present very small amplitudes of 1mV and frequency components below 100HZ. Due to these characteristics, recording ECG signal tends to be very sensitive to various interferences such as 50/60HZ power line, baseline wander, electromyogram, and electroencephagram. Baseline wander is signal generated due to respiration and the freqency is below 1Hz.

Different researchers have worked on the filtration of ECG signal. Abdel-Rahman-Qawasmi and Khaled Daqrouq suggested using discrete wavelet transform (DWT) [1] in filtering high and low frequencies in ECG signal. Mikhled Alfaouri and Khaled Daqrouq also suggested using wavelet transform thresholding (WTT) to process non-stationary signals such as ECG signals [2]. This is possible by applying the multi-resolution decomposing into subsignals. FC Chang et al presented the use of adaptive filters in removing power line interference in ECG [3]. In [4] Mahesh S. Chavan et al worked on FIR digital fillers for the removal

of baseline wander, powerline interference and encephalogram in ECG signal. In [5] Mateo et al made use of the madeline structure algorithm to remove baseline wander in ECG. This structure is based on a grown artificial neutral network (ANN) allowing for optimization of both the hidden layer number of nodes and the coefficient matrixes, and the matrixes are optimized following the Widrow-Hoff delta algorithm. Mahesh S. Chavan, RA Agarwala and M.D Uplane suggested that Kaiser window can be used to design and implement digital FIR filters for low frequency, high frequency and powerline interferences removal in ECG signal [6]. Mahrokh G. Shayesteh and Mahdi Mottagi-Kashtiban in [7] developed a new window, which is based on optimizing the coefficients of Hamming window using extended Kalman filter, and for designing FIR filters. This new window can be applied to the design of FIR filter for ECG signal denoising. In [8] Mahesh S. Chavan et al provided the use of rectangular window to design a 50- order FIR filters comprising low pass, high pass and
notch filters for reduction of high frequency, low frequency and power line interferences in ECG. In the work the authors applied the filters on the ECG signal in a real time manner using 711B add-on card. J.A Van Alste' and T.S Schilder worked on how the number of taps of FIR filter can be reduced without affecting its efficiency in the removal of baselne wander and powerline interference from ECG [9]. Mahesh et al provided the design and application of digital FIR equiripple filter in reduction of powerline interference in ECG. Fig. 1 is a normal standard ECG signal waveform.

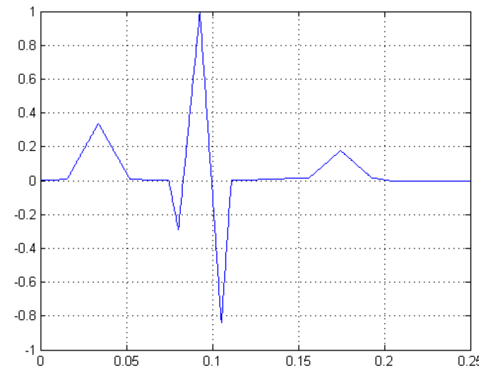

Fig. 1: Normal ECG waveform

2 Design of low pass filter

A rectangular window is used for the design. Fig. 2a shows the time domain amplitude response of a rectangular window function while Fig. 2b depicts the response in frequency domain [4, 11]. Low pass filter is used to remove the high frequency signals constituting noise in ECG. The cut- off frequency is 100Hz and sampling frequency is 1000Hz, while the order of the filter is 100. FDAtool of Matlab is used to carry out the design.

The impulse response, magnitude and phase responses of the filter are shown in fig. 3, fig. 4 and fig. 5 respectively

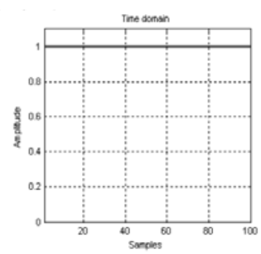

Fig. 2a: Time domain response of a rectangular window

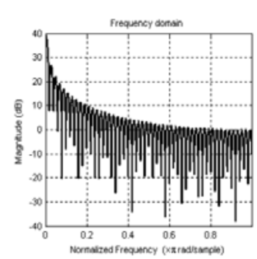

Fig. 2b: Frequency domain response of a rectangular window

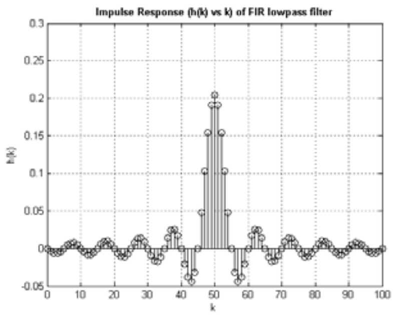

Fig. 3: Impulse response of the low pass filter.

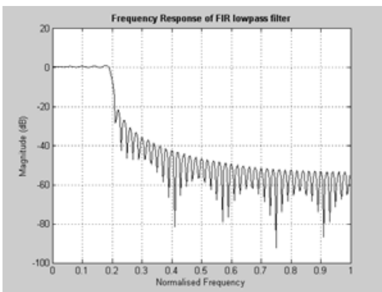

Fig. 4: Magnitude response of the low pass filter

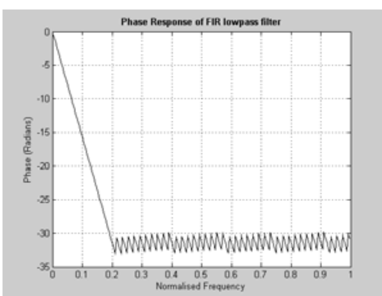

Fig. 5: Phase response of the low pass filter

3. Design of high pass filter.

The high pass filter is used for the removal of low frequency signals that constitute noise in ECG. The cut off frequency is 0.5Hz. The sampling frequency is 1000Hz and the order of the filter is 100. Rectangular window is applied as the weighting window. Fig. 6 depicts the impulse response of the filter while fig 7 and fig 8 provide the magnitude and phase response respectively.

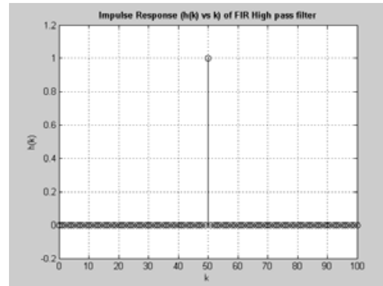

Fig. 6: Impulse response of the high pass filter.

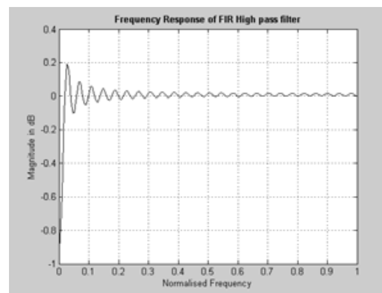

Fig. 7: Magnitude response of the high pass filter

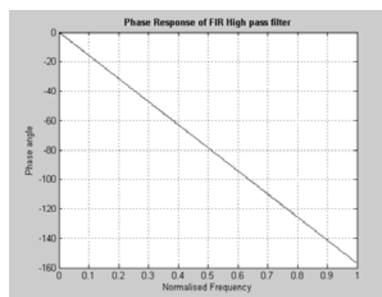

Fig. 8: Phase response of the high pass filter

4 Design of Notch Filter

The ECG signal is applied to the notch filter to remove the powerline interference in ECG. The powerline frequency here is 50Hz and the sampling frequency is 1000Hz. The order of the filter is 100 and rectangular window is the weighting window. The impulse response of the filter is shown in fig. 9 and the magnitude response, shown in Fig. 10. Fig. 11 shows the phase response of the filter

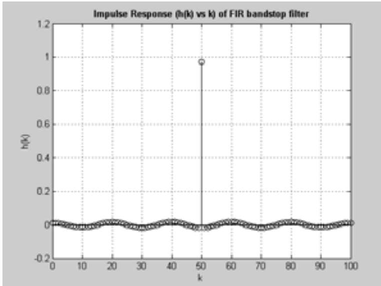

Fig. 9: Impulse response of the notch filter.

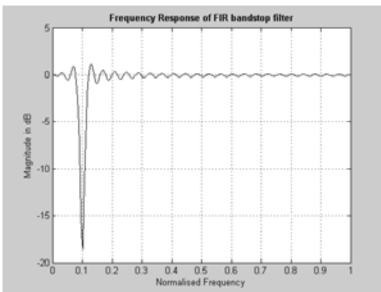

Fig. 10: Magnitude response of the notch filter

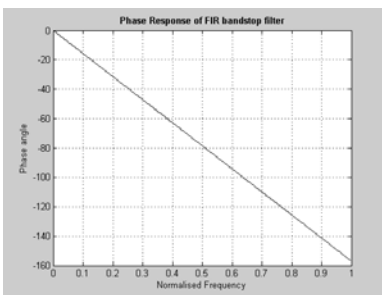

Fig. 11: Phase response of the notch filter

5 Results

The results of the implementation are divided into four groups: the result of the low pass filter, high pass filter, notch filter and the cascade of the three filters.

5.1 Results of the Implementation of the Low Pass Filter.

A raw noisy ECG signals contaminated with high frequency, low frequency and 50Hz powerline interference is shown in fig12. The frequency response of the raw ECG is shown in fig. 13. From fig. 13 the average power of ECG signal above 100Hz is (-52dB).

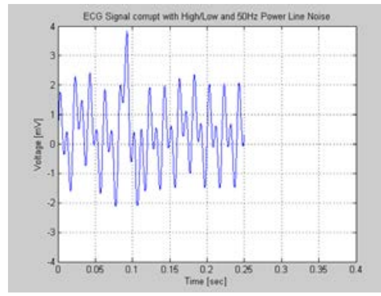

Fig. 12: ECG signal before application of low pass filter

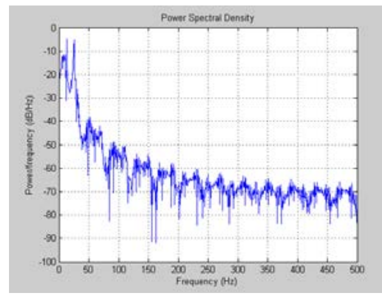

Fig. 13: Frequency response of ECG signal before application of low pass filter

Fig 14 shows the ECG signal after application of the low pass filter while fig 15 depicts the frequency response. From fig 15 it can be confirmed that the power of the signal above 100 Hz is reduced to (-60dB) which implies that the filter removes the high frequency noise from the raw ECG signal.

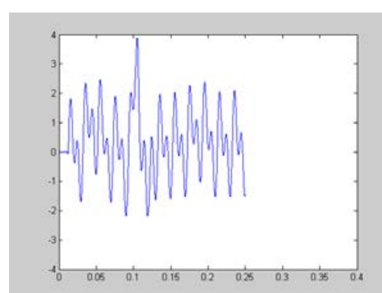

Fig. 14: ECG signal after application of low pass filter

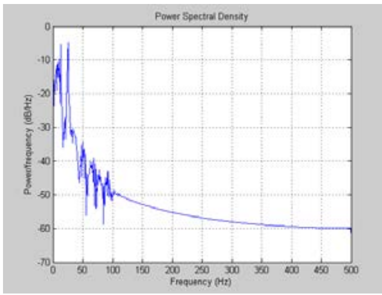

Fig. 15: Frequency response of ECG signal after application of low pass filter

5.2 Results of the implementation of the high pass filter.

From fig. 13, the average power of the raw ECG signal below 0.5Hz is approximately (-15.12dB). Fig 16 presents the ECG signal after application of the high pass filter, while fig 17 represents the frequency response. From fig 17 it can be seen that when the filter is used the power of the signals below 0.5Hz reduces to (-20.03dB). The power reduction implies that the high pass filter filters out the low frequency signal from the raw ECG signal.

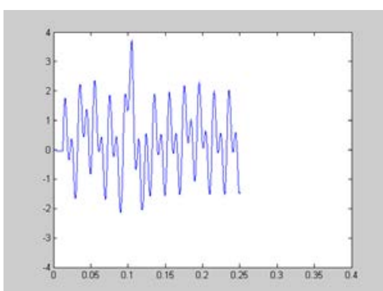

Fig. 16: ECG signal after application of high pass filter

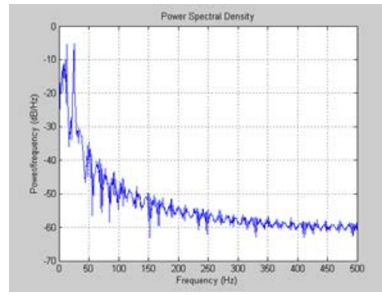

Fig. 17: Frequency response of ECG signal after application of high pass filter

5.3 Results of the Implementation of the Notch Filter.

From fig 13, the power of the raw ECG signal before filtration at 50Hz is (-38.25dB). Fig 18 shows the raw ECG signal after passing through the notch filter and fig 19 depicts the frequency response. From fig19 it can be seen that the power of the ECG signals after filtration with the notch filter drops to (-43dB), which is a confirmation that notch filter reduces power line interference.

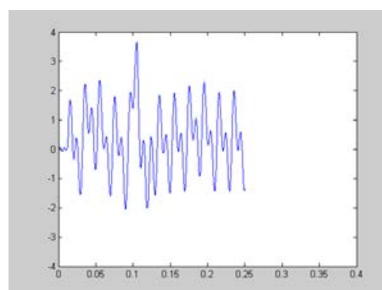

Fig. 18: ECG signal after application of notch filter

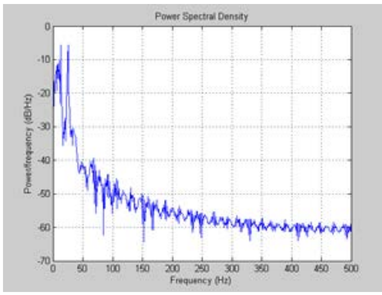

Fig. 19: Frequency response of ECG signal after application of notch filter

5.4 Result of Application of the Low pass, High Pass and Notch filters in Cascade

When the raw ECG signal of fig. 12 is passed through the three filters in cascade the signal appears as shown in fig.20. Comparing the result of fig.20, which is the result of the cascade filtering, with those of fig14, fig16 and fig18, which are outputs of the separate filtering, shows that fig. 20 represents an ECG signal filtered of its noises. The visible distortion appearing on it is because of Gibbs phenomenon associated with rectangular window. The summary of the results of the filtration is shown in table 1.

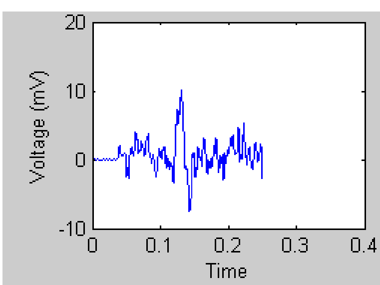

Fig. 20: ECG signal after filtration with the three filters in cascade.

Table 1: Filtration of ECG signal using Digital Filter Designed with Rectangular Window.

Type	**Signal power before filtration in dB**	**Signal power after filtration in dB**
Low pass filter, above 100 Hz	-52	-60
High pass filter, below 0.5 Hz	-15.12	-20
Notch filter, at 50 Hz	-3825	-43

Conclusion

The design of the filter shows that there are ripples in each of the filters but they have stable responses. The results show that each filter is able to remove the unwanted signals specifically designed for it to filter out. That is, the low pass filter is able to remove high frequency signals, the high pass filter is able to remove low frequency signals and the notch filter is also able to reduce power line interference. The distortions appearing in the cascade filtering output signal is because of the ripples associated with designs using rectangular windows. These distortions can be eliminated or reduced drastically by using other windows such as Kaiser Window, Hanning window or Hamming window instead.

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