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Design Analysis of IIR Filter for Power Line Interference Reduction in ECG Signals

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Abstract
In this paper, interference due to 50Hz power line in the electrocardiogram (ECG) measurement is reduced with the help of IIR filters. Pick up of hum from power line is a very common phenomenon in the measurement of ECG signals. It is of prime need to reduce the variations coming due to power line so that one can analyze the most of the critical points in the measured signal. Power Line Interference (PLI) may seriously degrade the ECG signal, rendering the ECG analysis inaccurate. By employing digital filter approach the effect of PLI is drastically reduced, thus, avoiding the conditions like changing the recording sites or installing expensive shields. The developed IIR filter has been designed and simulated using MATLAB with Butterworth and Chebyshev techniques. Both filters have been analyzed and compared in terms of their performance. It is found in the results that Butterworth IIR filter gives a more satisfactory response.
***K*eywords-** ECG, IIR, notch filters, PLI.

I. Introduction

In the area of Electrocardiogram (ECG) analysis and filtration, the role of digital filters has a rich history. An electrocardiogram (ECG) is a graphical record of bioelectrical signal generated by the human body during cardiac cycle. ECG graphically gives useful information that relates to the heart functioning by means of a base line and waves representing the heart voltage changes during a period of time, usually a short period [1]-[3]. Putting leads on specific part of the human body, it is possible to get changes of the bioelectrical heart signal where one of the most basic forms of organizing them is known as Einthoven lead system. The ECG has a special value in the following clinical situations :

a. Auricular and ventricular hypertrophy.
b. Myocardial Infarction (heart attack).
c. Arrhythmias.
d. Generalized suffering affecting heart and blood pressure.
e. Electrolytic transformations.

In spite of the special value, the ECG is considered only a laboratory test. It is not an absolute truth concerning the cardiac pathologies diagnosis. There are examples of patients presenting string heart diseases which present a normal ECG, and also perfectly normal patients getting an abnormal ECG [4]. Therefore, an ECG must always be interpreted with the patient clinical information.

According to [5] a signal can be analyzed and processed in two domains, time and frequency. ECG signal is one of the human body signals which can be analyzed and worked in time domain or frequency domain. Figure 1 presents typical waves in an ECG signal. P, Q, R, S, T and U are specific wave forms identified in the time domain of an ECG signal. The QRS complex, formed by Q, R and S waves, represents a relevant wave form because the heart rate can be identified locating two successive QRS complex.

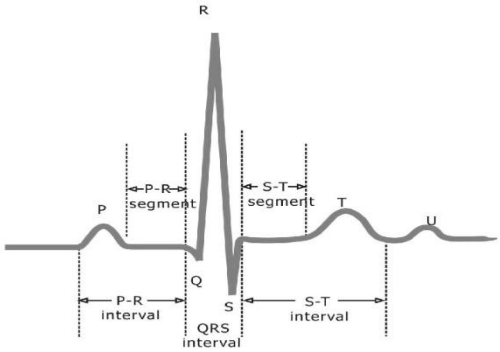

Figure 1 Typical waveform of ECG signal.

Frequency values of an ECG signal vary from 0 Hz to 100 Hz [3] whereas the associated amplitude values vary from 0.02 mV to 5 mV.ECG signals are very weak in amplitude and low in frequency. Hence they are susceptible to two major types of noises generated by biological and environmental resources. Biological sources of noise causes base line drift and amplitude modulation of ECG signal. Environmental sources of noise may cause PLI, instrumentation noise generated by electronic devices. For removing these unwanted noise added to the ECG signals, digital filtering is done. The computational requirement is a major factor which must be considered in practical applications. Digital filtering techniques are more flexible as they are built using software and can be changed at any design stage, which is not possible with their analog counterpart.

Many of the researchers have worked on the methods to reduce the interferences. The use of digital filters in the analysis and filtration of ECG signals is being recommended [6]. The IIR filters were used for reducing the noise in the ECG signals.IIR filters presents a good solution to filtering the ECG for noise reduction. High pass, low pass and band stop filters were used to reduce all the noise below 0.5Hz, above 100Hz, and power line interference at 50Hz, respectively. An efficient FFT method to estimate PLI in ECG is also being recommended [7]. Power spectrum of ECG signals can also e calculated by other conventional methods also. It is important to measure the power spectrum of ECG signals in order to estimate the noise level being present at each and every spectral component.

Parabolic filters were also being tested to reduce the effects of 50Hz noise [8]. Parabolic filters presents a distinct advantage in band stop filtering. There are many factors which should be considered while justifying the role of any filter in noise removal, such as, stability in that particular region, phase linearity (specially in case of IIR filters) and the number of filter coefficients used. Digital filter structure such as window based FIR filter is proposed to maximally remove the noise from the ECG signal [9]. FIR filters presents an additional advantage of phase linearity in the region of interest, while, it presents the problem of increased number of filter coefficients, which in turn increases the hardware.

The use of ICA theory is employed to minimize the effect of PLI [10]. Power line interference occurs due to the presence of ac power lines near the measurement site. Due to these power lines, the 50Hz humming noise get added to the measured ECG signal. This causes the problem in measuring the information from the observed ECG. Experiments on accuracy of 50 Hz interference subtraction from an electrocardiogram were also being conducted [11].

A simple self tuned notch filters were considered for removing interference[12]. Notch filters presents a very high attenuation to a particular frequency of interest. Estimation of noise in the ECG by subtraction procedure is also being done [13].

II. IIR filters

A digital filter is a mathematical algorithm implemented in hardware/software that operates on a digital input signal to produce a digital output signal for the purpose of achieving a filtering objective. The term digital filter used in this paper refers to the software filter. Digital filters play a crucial role in digital signal processing, e.g., biomedical signal processing . The transfer function for IIR filter is:

$$H(z) = \frac{a_o + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3} \ldots + a_N z^{-N}}{1 + b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3} \ldots + b_M z^{-M}} \quad .(1)$$

Where a and b are the coefficients of the filter. Order of the filter is M.

The first step in ECG analysis is to record the electrical activity of the heart. This is done by putting electrodes on the surface of the body.ECG amplifiers are used for real time applications. The flow chart for the step by step by procedure involved in the proposed digital filtering is given below.

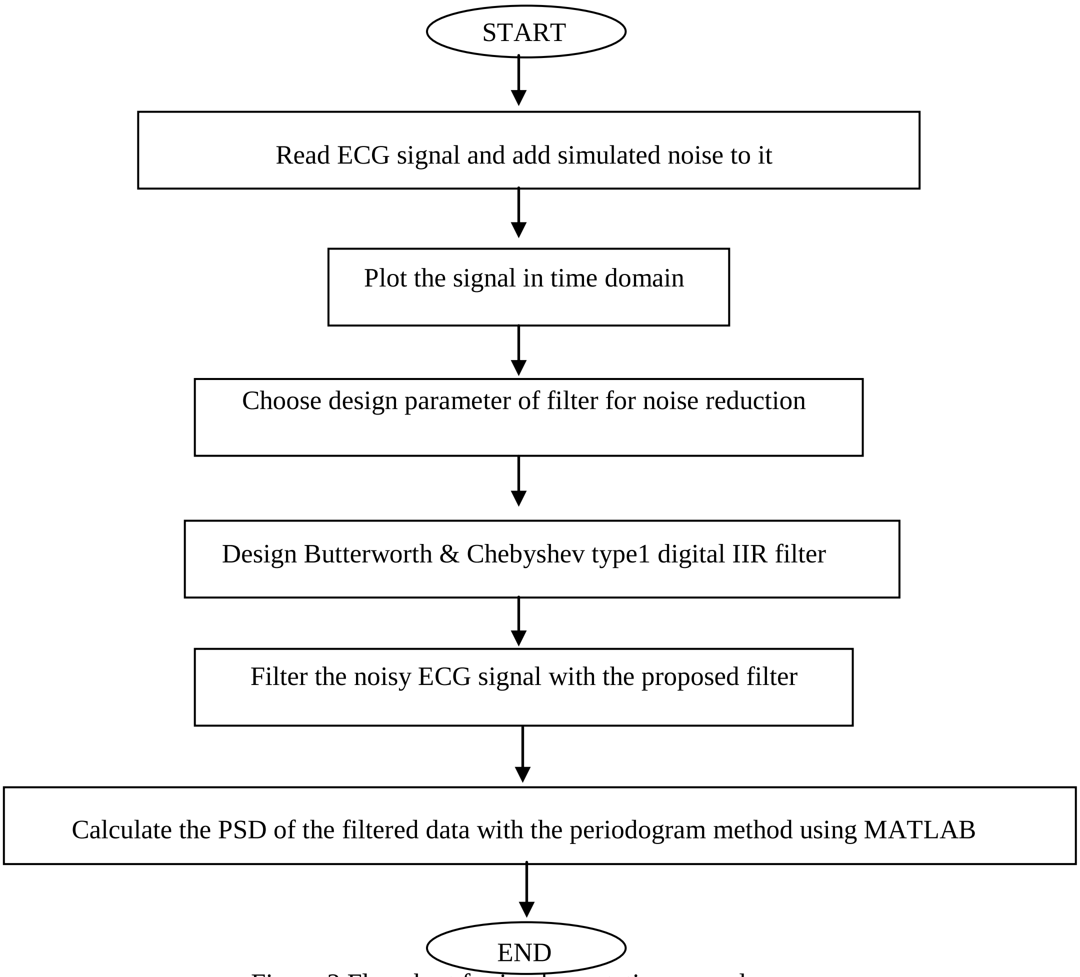

Figure 2 Flowchart for implementation procedures.

III. Proposed IIR Filter Design and Simulation

Digital IIR filters can be designed to be high pass, low pass, band pass or band stop. The band stop filter can be modified to work as a notch filter, which of our concern in this paper. Digital IIR filters are being designed from its analog counterpart by various methods like impulse invariant, matched z-transform or bilinear z-transform. Analog counterparts of digital IIR filters are butterworth, chebyshev1and chebyshev2. We will design the digital IIR filter with butterworth and chebyshev1 filters and present a comparative analysis of the both

A 50Hz butterworth notch filter is designed for power line interference reduction. Figure 3 shows that magnitude response is flat in the pass band. Figure 4 shows that phase response is linear in the pass band, thus making it suitable for the real time applications. Figure 5 shows the pole zero plot of the system. It is clear from the figure 5 that system is stable as no poles are outside the unit circle.

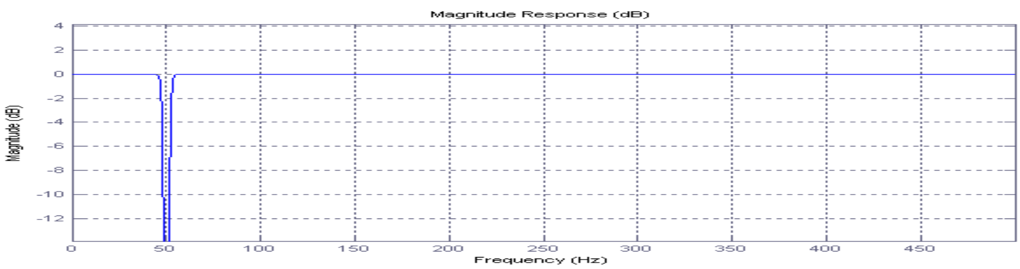

Figure 3 Magnitude response of butterworth notch filter.

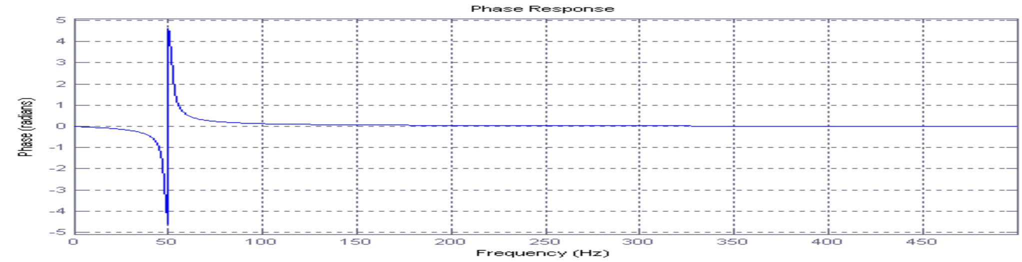

Figure 4 Phase response of butterworth notch filter.

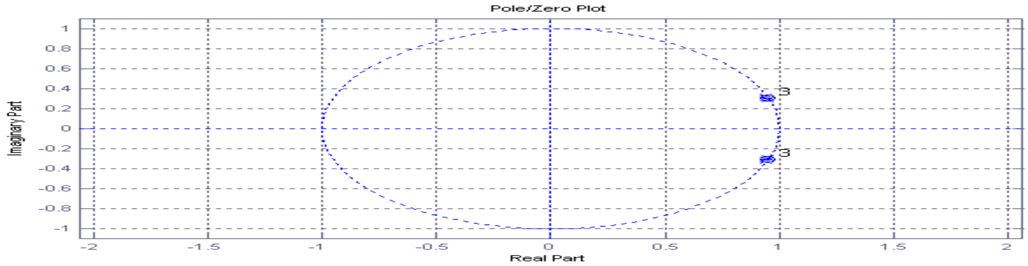

Figure 5 Pole zero plot of butterworth notch filter.

Next, a chebyshev type 1 bandstop filter is designed for power line interference removal. Figure 6 shows that magnitude response is flat in the pass band.

Figure 7 shows that phase response is linear in the pass band, thus making it suitable for the real time applications. Figure 8 shows the pole zero plot of the system. It is clear from the figure 5 that system is stable as no poles are outside the unit circle.

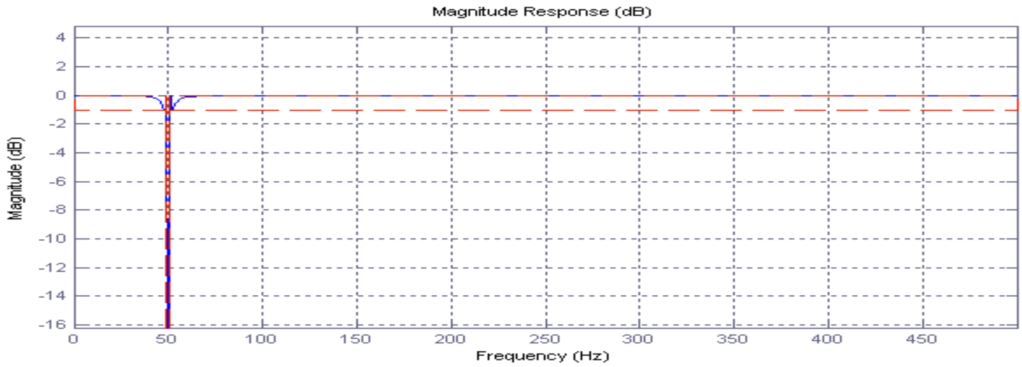

Figure 6 Magnitude response of chebyshev type 1 filter.

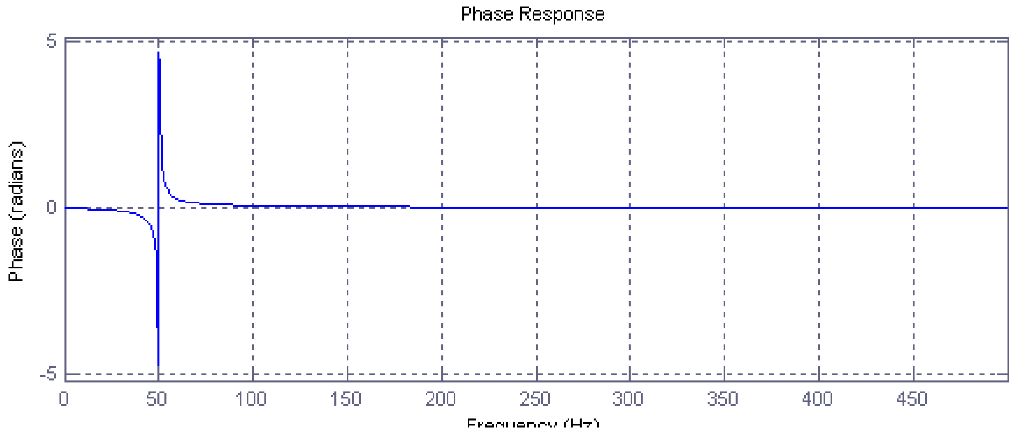

Figure 7 Phase response of chebyshev type 1 filter.

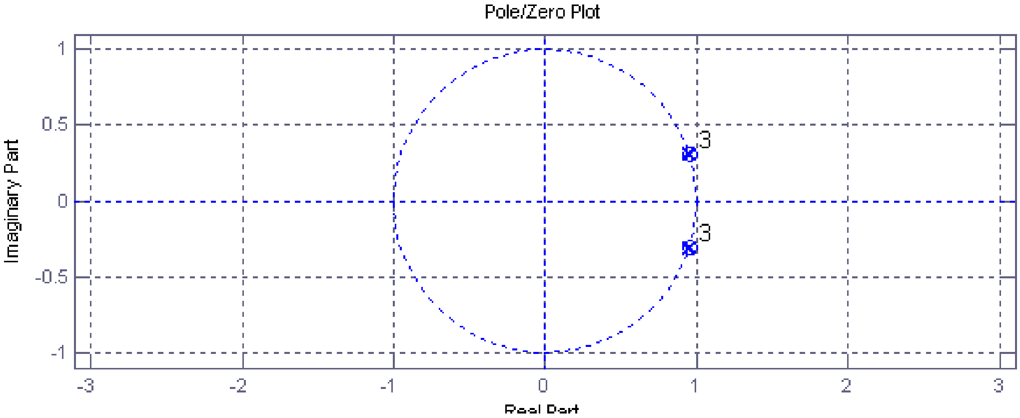

Figure 8 Pole zero plot of chebyshev type 1 filter.

The chebyshev filter is designed so as to stop the interference coming from the power line. Usually the noise from power line is not exactly concentrated at 50Hz. It is centered around 50 Hz. So, a bandstop filter presents additional advantage.

IV. Results & Discussions

ECG signal before filtration is shown by figure 9. This ECG signal is corrupted by noise. Figure 10 shows filtered ECG signal. The filtration is done using butterworth digital IIR filter for removing 50Hz noise.

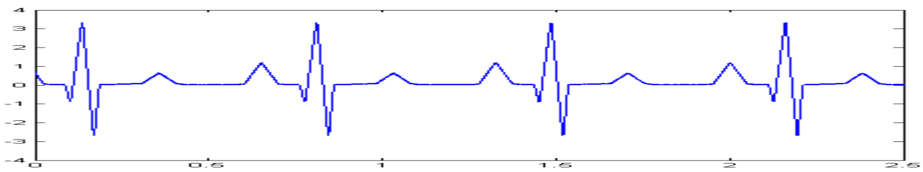

Figure 9 ECG signal before filtration.

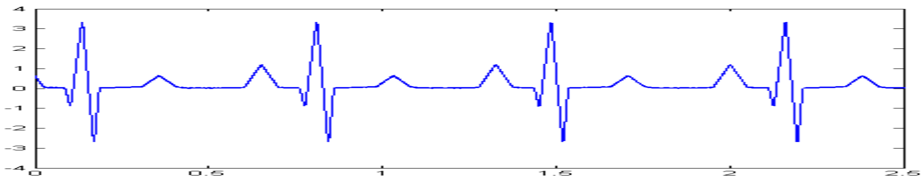

Figure 10 ECG signal after butterworth filtering.

The power spectral density of the noisy ECG signal is shown by figure 11. Figure 12 shows the power spectral density of filtered ECG signal. At the frequency of 50Hz, frequency spectrum before filtration shows a signal power of -80dB. After application of digital butterworth filtering, frequency spectrum shows a signal power of -108 dB. This result clearly exhibits the utility of the proposed butterworth filter in reducing PLI at 50Hz.

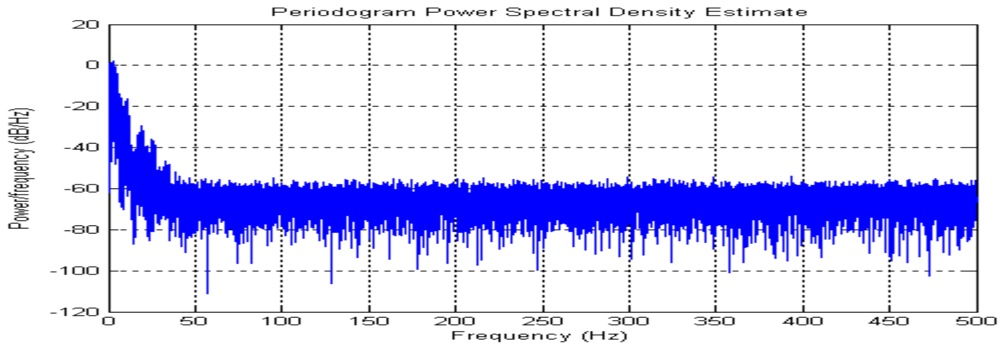

Figure 11 Power spectral density of noisy ECG signal.

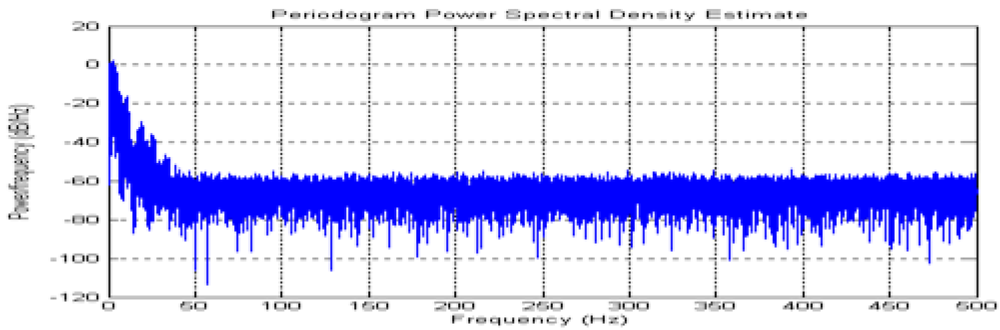

Figure 12 Power spectral density of butterworth filtered ECG signal.

ECG signal before filtration is show by figure 13. This ECG signal is corrupted by noise and contains noise at various spectral components. Figure 14 shows filtered ECG signal. The filtration is done using Chebyshev type 1 IIR filter for removing 50Hz noise. The filter is bandstop type so as to stop the noise centered around 50Hz.

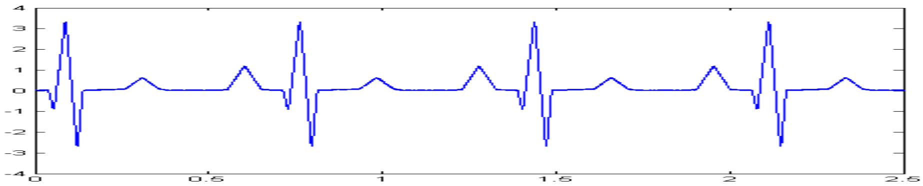

Figure 13 Noisy ECG signal.

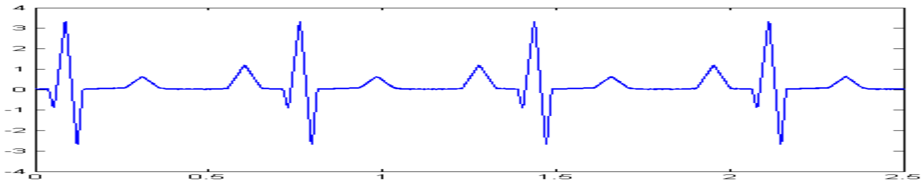

Figure 14 ECG signal after Chebyshev type 1 filtering.

The power spectral density of the noisy ECG signal is shown in figure 15. Figure 16 shows the power spectral density of filtered ECG signal. At the frequency of 50Hz , frequency spectrum before filtration shows a signal power of -82dB. After application of digital Chebyshev type 1 filtering, frequency spectrum shows a signal power of -100 dB. This result clearly exhibits the utility of the proposed filter in reducing PLI at 50Hz.

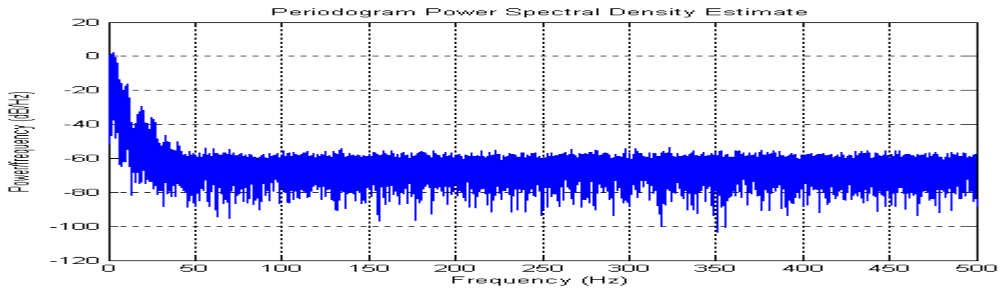

Figure 15 Power spectral density of noisy ECG signal.

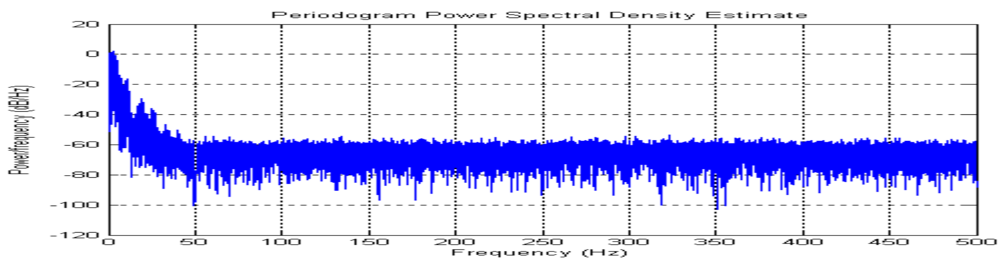

Figure 16 Power spectral density of ECG signal after Chebyshev type 1 filtering.

The comparative analysis of the proposed digital IIR filtering methods for PLI removal in ECG signals is shown in table 1. It is clear from the table that digital Butterworth filter presents a larger attenuation to the interference signals at 50Hz. Thus, it finds more suitability for removing 50Hz power line interference.

Table 1 Comparative analysis of the two proposed IIR filters.

Filter type	Before filtration	After filtration	Attenuation at 50Hz
	Power at 50Hz (dB)	Power at 50Hz (dB)	
Butterworth	-80	-108	28dB
Chebyshev type 1	-82	-100	18dB

The combined power spectrum density of ECG signal is shown by figure 17, before and filtration. The filter used is Butterworth IIR filter. It is clear from the figure that noise is removed up to a satisfactory extent. Figure 18 shows the combined power spectrum density of signals, before and filtration using digital Chebyshev type 1 filter.

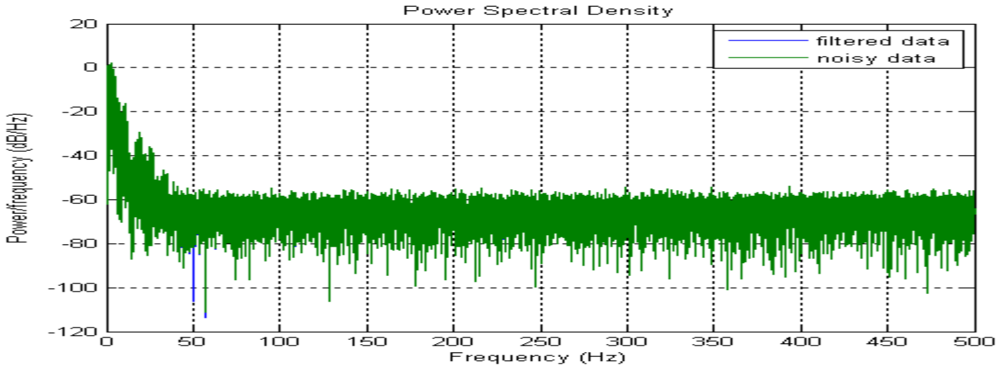

Figure 17 PSD after and before butterworth filtering.

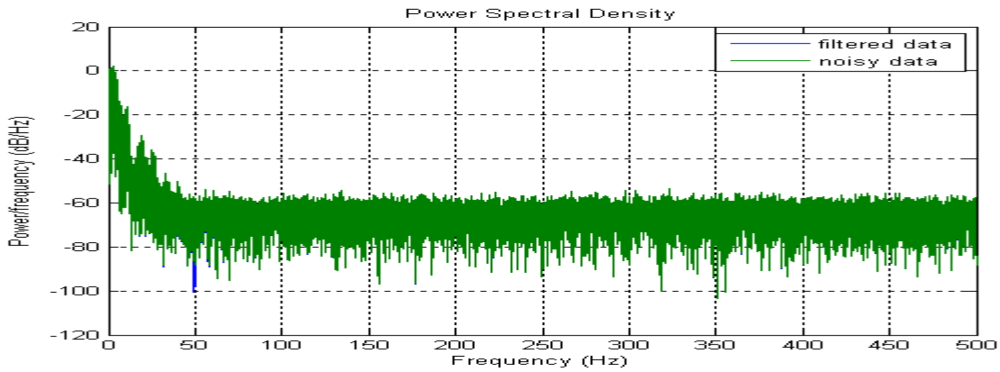

Figure 18 PSD after and before chebyshev type 1 filtering.

V. Conclusion

The proposed method provides an easy and less complex tool for reducing 50Hz PLI removal. The ECG is the most commonly studied potential interface, mainly due to its fine temporal resolution, ease of use, portability and low set-up cost. IIR filters provides a simple way to reduce the interference due to power line without losing any relevant data. The comparative analysis clearly shows the utility of Butterworth filter in PLI removal. Attenuation of 28 dB is offered at 50Hz by filtering with IIR Butterworth filter, which is fairly a large value and is suitable to stop noise at 50Hz. Chebyshev type 1 bandstop filter offers 18dB of attenuation at 50Hz. But this filter finds more suitability when the noise due to power line is present not only at 50Hz but it is centered around it. In the latter case, it is clearly visible from figure 18, Chebyshev type 1 bandstop filter is offering large attenuation to frequencies around 50Hz,

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