Design and implementation of Digital FIR Equiripple Notch Filter on ECG Signal for removal of Power line Interference

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Abstract: - Filtering of power line interference is very meaningful in the measurement of biomedical events recording, particularly in the case of recording signals as weak as the ECG. The available filters for power line interference either need a reference channel or regard the frequency as fixed 50/60Hz. Methods of noise reduction have decisive influence on performance of all electro-cardio-graphic (ECG) signal processing systems. This work deals with problems of power line interference reduction. In the literature of the last twenty years several solutions of removal of power line interference on electrocardiogram (ECG) signals can be found. Some analogue and digital approaches to this problem are presented and its properties, advantages and disadvantages are shown. Present paper deals with design and development of digital FIR equiripple filter. The basic ECG has the frequency range from .5Hz to 100Hz. Artifacts plays the vital role in the processing of the ECG signal. It becomes difficult for the Specialist to diagnose the diseases if the artifacts are present in the ECG signal. In the present work notch filter is designed and applied to the ECG signal containing power line noise. Complete design is performed with FDA tool in the Matlab. The equiripple notch filter designed is having higher order due to which increase in the computational complexity observed. For accessing real time ECG the related instrumentation has been developed in the laboratory. The result shows the ECG signal before filtering and after filtering with their frequency spectrums which clearly indicates the reduction of the power line interference in the ECG signal.

Keywords: Electrocardiogram, Simulation, Equiripple Filter, Real Time Filtering. Noise reduction.

1. Introduction

Signal processing, in general, has a rich history, and its importance is evident in such a diverse fields as biomedical engineering, acoustics, Sonar, radar, Seismology, speech communication, data communication, nuclear science, and many others. In many applications, as, for example, in EEG and ECG analysis or in systems foe speech transmission and speech recognition it can be used to extract some characteristic parameters. Alternatively, for to remove interference, such as noise, from the signal or to modify the signal to present it in a form which is more easily interpreted by an expert. Recent trends in the processing of the biomedical signals have been towards quantitative or the objective analysis of physiological systems and phenomena via signal analysis. The field of biomedical signal analysis or processing has advanced to the stage of practical application of signal processing and pattern analysis techniques foe efficient and improved noninvasive diagnosis, online monitoring of critical ill patients, and rehabilitation and sensory aids for the handicapped. Techniques developed by engineers are gaining wider acceptance by practicing clinicians, and the role of engineering in diagnosis and treatment is gaining much–observed respect. The major strength in the application of computers in biomedical signal analysis lies in the potential use of signal processing and modeling technique for the quantitative or the objective analysis. Analysis of signals by human observers is almost always accompanied by perceptual limitations, inter-personal variations, errors caused by fatigue, errors caused by the very low rate of incidence of certain sign of abnormality, environmental distortions, and so on. The establishment of the clinical electrocardiograph (ECG) by the Dutch physician willem Einthoven in 1903 marked the beginning of a new era in medical diagnostic techniques, including the entry of electronics in the health care. Since then, electronics, and subsequently computers, have become integral components of biomedical signal analysis system, performing variety of tasks from data acquisition and preprocessing for removal of artifacts to feature extraction and interpretation.

The electrocardiogram (ECG or EKG) is a diagnostic tool that measures and records the electrical activity of the heart in exquisite detail. Interpretation of these details allows diagnosis of a wide range of heart conditions. These conditions can vary from minor to life threatening. A typical ECG tracing of a normal heartbeat (or cardiac cycle) consists of a P wave, a QRS complex and a T wave. A small *U wave* is normally visible in 50 to 75% of ECGs. The baseline voltage of the electrocardiogram is known as the isoelectric line. Typically the isoelectric line is measured as the portion of the tracing following the T wave and preceding the next P wave. From the heart the SA node spontaneously depolarize to initiate an action impulse that is rapidly propagated through the atria (causing atrial contract), then slowly through the AV node and rapidly via the bundle branches and Purkinje system to the ventricles, causing ventricular contraction. The electrical activity of the heart can be recorded at the surface of the body using an electrocardiogram. Therefore the electro-cardio-gram (EKG) is simply a voltmeter that uses up to 12 different leads (electrodes) placed on designated areas of the body. Figure 1 shows the typical ECG trace.

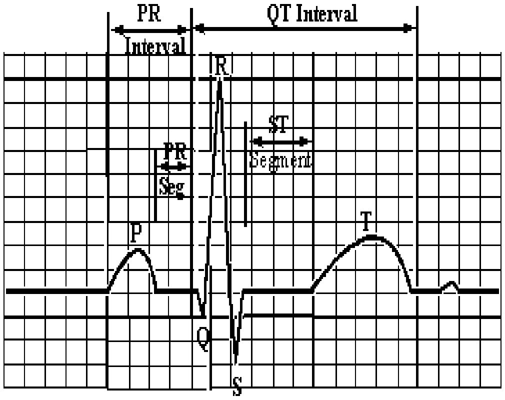

Figure 1: Typical ECG trace.

The electrical activity of the heart is generally sensed by monitoring electrodes placed on the skin surface. The electrical signal is very small (normally 0.0001 to 0.003 volt). These signals are within the frequency range of 0.05 to 100 Hertz (Hz.) or cycles per second. Unfortunately, other artifactual signals of similar frequency and often larger amplitude reach the skin surface and mix with the ECG signals. Artifactual signals arise from several internal and external sources. Means Electro-cardio-graphic 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. Electrosurgical noise.

From various artifacts contaminate electrocardiogram (ECG) recording, the most common are power line interference and baseline drift. Power line interference is easily recognizable since the interfering voltage in the ECG may have frequency 50 Hz. The interference may be due to stray effect of the alternating current fields due to loops in the patient’s cables. Other causes are loose contacts on the patient’s cable as well as dirty electrodes. When the machine or the patient is not properly grounded, power line interference may even completely obscure the ECG waveform. The most common cause of 50 Hz interference is the disconnected electrode resulting in a very strong disturbing signal, and therefore needs quick action. Electromagnetic interference from the power lines also results in poor quality tracings. Electrical equipments such as air conditioner, elevators and X-ray units draw heavy power line current, which induce 50 Hz signals in the input circuits of the ECG machine. Electrical power systems also induce extremely rapid pulse or the spike on the trace, as a result of switching action. Care should be taken to suppress these transients. Figure 2 shows the ECG signal with power line interference. The power-line interference, as obtained from the same electrodes as the ECG, is difficult to remove, due to the frequency of the time-varying power line signal that lies within the frequency range of the ECG signal. Therefore, how to eliminate or reduce the effect of 50/60Hz interference has been one of the most important problems in biomedical signal measurement. During the last twenty years, the literature has proposed several solutions to remove the power line interference from ECG signals. Most of these solutions are based on ECG signals. Digital filters for AC-noise removal falls into four common categories [1, 2]:

1) Low pass filters that also severely attenuate important frequency components of the ECG signal above a cut off frequency which lies below 50/60 Hz;
2) General notch-rejection filters which can be grouped into two categories: IIR and FIR filters.
3) Adaptive filters remove interference from ECG using reference input a pure power line noise. This filtering method leaves the source signal undistorted, but it cannot follow fast changes in the interference amplitude producing an undesired ringing effect.
4) Global filters have the main drawback of producing an inter-beat average difference and are not very suitable for real-time implementations.

For the meaningful and accurate detection, steps have to be taken to filter out or discard all these noise sources. Analog filters help in dealing with these problems; however, they may introduce nonlinear phase shifts, skewing the signal. Also, the instrumentation depends on resistance, temperature, and design, which also may introduce more error. With more recant technology, Digital filters are now capable of being implemented offering more advantages over the analog one. Digital filters are more precise due to a lack of instrumentation. The work on design and implementation of Digital filter on the ECG signal is in progress in the different part of the world.

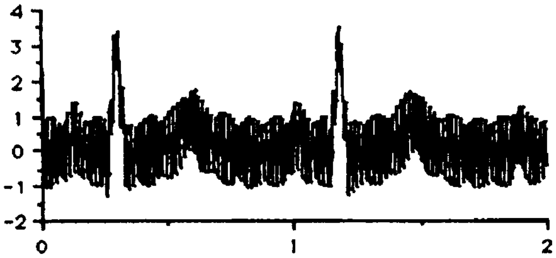

Figure 2: ECG corrupted Due to Power line Interference.

Many researchers have worked on development of method for reduction of noise in ECG signal. Choy TT, Leung P M. have used 50 Hz notch filters for the real time application on the ECG signal it is found that filter was capable of filtering noise by 40dB.with bandwidth of 4Hz and causes the attenuation in the QRS complex[3]. McManus CD, Neubert KD, Cramer E have surveyed different digital filter method like notch filters, adaptive filters and globally derived filters their performances are compared on artificial signals as well as actual ECGs and found that AC interference in these ECGs is shown to exhibit two qualities especially relevant to filter design: considerable deviations from a nominal 50 Hz frequency and substantial noise at higher harmonics. For this they suggested presented different digital filter methods to eliminate it [1]. Cramer E, McManus CD, Neubert D have introduced Global filtering of AC interference in the digitized ECG as a new concept. Two different filters embodying a global approach are developed. One is based on a least-squares error fit, the other uses a special summation method. Both methods are compared with a local predictive filter by applying each filter to artificial signals and to real ECGs [4]. Some researchers have used analog filters for removal of the power line interference. Hejjel L, used the analog digital notch filter for the reduction of the power line interference in the ECG signal for the heart rate variability analysis. The investigation addressed the analysis of the effects of AC interference and its filtering on the precision and accuracy of heart rate detection. Artificial ECG recordings with predefined parameters were simulated by a computer and a data acquisition card, consecutively filtered by an analog notch filter. It is found that the filtering of uncorrupted ECG signals does not result in heart rate period deviations. Power-line interference contamination proportionally alters the accuracy of representative point detection. Literature encouraged using the digital notch filter for the power line contamination removal [5]. Mihov G, Dotsinsky IV, Georgieva TS described the subtraction procedure for the power line interference removal in the ECG signal. In contrast to the well-known hardware and software filters, the procedure does not affect the signal frequency components around the rated power line frequency. Originally, the procedure was developed for multiplicity between the sampling rate and the interference frequency. The implementation of the subtraction procedure can be extended to almost all possible cases of sampling rate and interference frequency variation. The work was initially carried out in a MATLAB environment and latter on programmes have been written in C(+ +) language for digital signal processors and personal computers[6]. Hamilton PS hace worked on the application of the adaptive and non-adaptive digital filter on the ECG signal. He worked for the performance evaluation based on two implementations of the notch filters based on transient response time, signal distortion, and implementation complexity. Before filtration and after filtration results are given in the literature [7]. Sander A. et. al. designed and implemented a digital notch filter. A 50/60 Hz notch filter system was designed to eliminate power line interferences from the high-resolution ECG. This special filter causes only minimal distortions of the power spectra and thus permits us to filter high-resolution ECG's without any appreciable changes in the frequency distribution of the original signal. Since the filter is based on an integer coefficient filter technique, the calculation time is relatively short and the programming effort comparatively low [8]. Kumaravel N et.al. suggested the power line interference removal technique to enhance the signal characteristics for diagnosis. They suggested the performances of the linear FIR filter, Wave digital filter (WDF) and adaptive filter for the power-line frequency variations from 48.5 to 51.5 Hz in steps of 0.5 Hz. The performances of Rule-based FIR filter and Rule-based Wave digital filter are compared with the LMS adaptive filter. They found the adaptive filter more effective than the rule base filtering technique [9]. Wu Y, Yang Y, discussed the advantages and disadvantages of several conventional digital filter methods. Then, based on Levkov method, they proposed a new filter method.Using these methods to remove 50 Hz interference from more than 50 persons' ECG signals. Results shown that this new method is the best, and it can satisfy the real time requirement of digital ECG machine[10]. Van Alste JA et.al. suggested the application of an efficient FIR filter with reduced number of taps for the removal of the base line wonder and power line interference in the ECG [11]. Mitov IP described a method for reduction of power line interference (PLI) in electrocardiograms with sampling rate integer multiple of the nominal power line frequency and tested using simulated signals and records from the databases of the American Heart Association and the Massachusetts Institute of Technology. The method involves parabolic detrending of the ECG, estimation of the signal components with frequencies corresponding to PLI by discrete Fourier transform, and minimum-squared-error approximation of decimated series of averaged instantaneous values of PLI using appropriately defined weights. The main advantage of the developed method in comparison with other simpler and faster approaches is the accurate interference reduction in cases when the power line frequency deviates from the nominal 50 or 60 Hz. That means the track on the variation on the frequency has been kept. Due to computational burden, the method is more suitable for off-line application instead of the on line method [12]. Ziarani AK and Konrad A. suggested the adaptive digital filtering method for the power line interference reduction. This method employs, as its main building block, a recently developed signal processing algorithm capable of extracting a specified component of a signal and tracking its variations over time. Design considerations and performance of the method are with the aid of computer simulations. Superior performance is observed in terms of effective elimination of noise under conditions of varying power line interference frequency. This method is a simple and robust structure which complies with practical constraints involved in the problem such as low computational resource availability and low sampling frequency[13]. Dotsinsky I, Stoyanov T have assessed the efficiency of notch filters and a subtraction procedure for power-line interference cancellation in electrocardiogram (ECG) signals. In contrast with the subtraction procedure, widely used digital notch filters unacceptably affect QRS complexes [14]. Ider YZ, Saki MC, Gcer HA described a method for line interference reduction to be used in signal-averaged electrocardiography (SAECG) systems and its performance is analyzed. This new method is an adaptation of a different technique for removal of line interference from conventional electrocardiograms. It involves the recording of a line interference signal simultaneous with the lead signals, so that a shifted and scaled version of it can be used to subtract line interference from the leads. It is seen that this line interference subtraction method can reduce line interference effectively and without introducing any additional noise into the ECG signal [15]. Ider YZ, Koymen H. Suggested a theory that power line frequency must be accurately known if line interference is to be accurately subtracted from the output of a bi-potential amplifier[16]. Ferdjallah M.

described two new local processing frequency-domain methods for the removal of powerline noise from electrophysiological signals. The first is based on an iterative division or a multiplication of a set of frequencies centered at 60 Hz. The second uses a basic property of the natural logarithm to smooth the 60-Hz noise. Both methods are intended to reduce power line noise without affecting the frequency spectrum of the signal in the regions surrounding 60 Hz [17]. Li BF et al suggested that the interference by 50-Hz noise arising from the power supply cables is common in PC-based application system, often considerably affecting the detection of useful signals. On the basis of self-adapting correlation method, the tried to address the problem of fast elimination of 50-Hz noise from the useful signals in PC-based application system such as digital ECG recording system [18]. For on line detection and averaging of the ECG waveforms Alperin N, Sadeh D. suggested a new correlation method which is a weighted correlation of differences proved to be most suitable for real-time signal averaging, and detection of waveforms' variations. Simulated ECG waveforms and real ECG recordings are also explained [19]. Pei SC, Tseng CC described that when a notch or comb filter is used to eliminate power line (AC) interference in the recording of electrocardiograms (ECG), the performance of the notch filter with transient suppression is better than that of the conventional notch filter with arbitrary initial condition[20]. Pottala EW et al suggested the Suppression of power line interference in the ECG signal using a bilinearly transformed null phase notch filter [21]. Lebedeva SV et al described the structure and algorithm of a digital suppression filter for circuit noise at 50 Hz. The filter slightly corrupts an electro-cardio-graphic signal [22].

There are different methods like window method and equiripple method also available. The simplest technique is known as "Windowed" filters. This technique is based on designing a filter using well-known frequency domain transition functions called "windows". The use of windows often involves a choice of the lesser of two evils. Some windows, such as the Rectangular, yield fast roll-off in the frequency domain, but have limited attenuation in the stop-band along with poor group delay characteristics. Other windows like the Blackman, have better stop-band attenuation and group delay, but have a wide transition-band (the band-width between the corner frequency and the frequency attenuation floor). Windowed filters are easy to use, are scalable.

An Equiripple or Remez Exchange (Parks-McClellan) design technique provides an alternative to windowing by allowing the designer to achieve the desired frequency response with the fewest number of coefficients. This is achieved by an iterative process of comparing a selected coefficient set to the actual frequency response specified until the solution is obtained that requires the fewest number of coefficients. Though the efficiency of this technique is obviously very desirable, there are some concerns.

- For equiripple algorithms some values may converge to a false result or not converge at all. Therefore, all coefficient sets must be pre-tested off-line for every corner frequency value.
- Application specific solutions (programs) that require signal tracking or dynamically changing performance parameters are typically better suited for windowing since convergence is not a concern with windowing.
- Equiripple designs are based on optimization theory and require an enormous amount of computation effort. With the availability of today's desktop computers, the computational intensity requirement is not a problem, but combined with the possibility of convergence failure.

With this survey of methods used for removal of power line interference from the ECG signal it was seen that no any method based on FIR notch equiripple filters have been suggested. Present work deals with design and development of FIR equiripple notch filter for reduction of power line interference in the ECG signal.

2. Design of Equiripple Notch Filter

Power line interference is one of the reasons of corruption of the ECG signal. Mostly it causes the 50Hz interference and there higher order harmonics gets added to the ECG. This section deals with the design and implementation of the equiripple digital notch filter to the ECG signal. The results are presented using the frequency spectrum of the ECG signal before and after filtration.

2.1 Design of notch filter:

In this design the minimum order of the filter selected is 580 and the sampling frequency of 1000Hz which the response shown below. Figure 3 shows the Magnitude response of the equiripple notch filter. Figure 4 shows phase response of the equiripple notch filter. Figure 5 shows Group delay of the equiripple notch filter. Figure 6 shows impulse response of the equiripple notch filter. Figure 7 shows step response of the equiripple notch filter. Figure 8 shows the Pole Zero diagram of the equiripple notch Filter.

From the design and the following responses some observations are as follows:

- It requires higher order to get the desired magnitude response.
- It gives linear phase.
- It provides the stable filter.

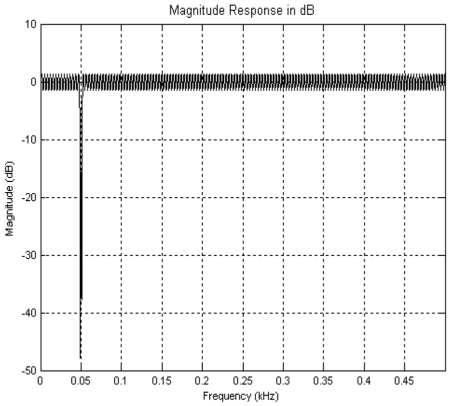

Figure 3: Magnitude response of the Equiripple notch filter

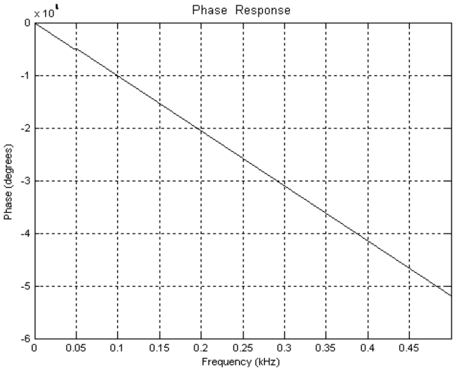

Figure 4: Phase response of the Equiripple notch filter.

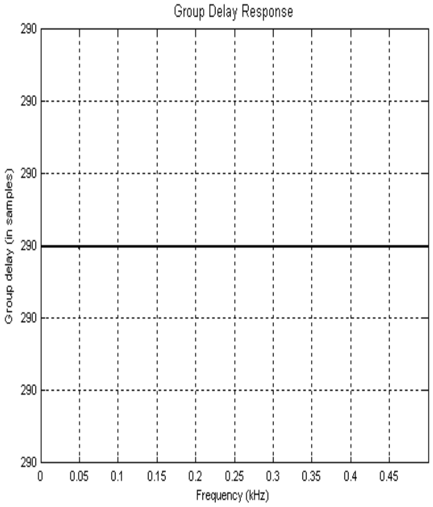

Figure 5: Group delay response of the Equiripple notch filter.

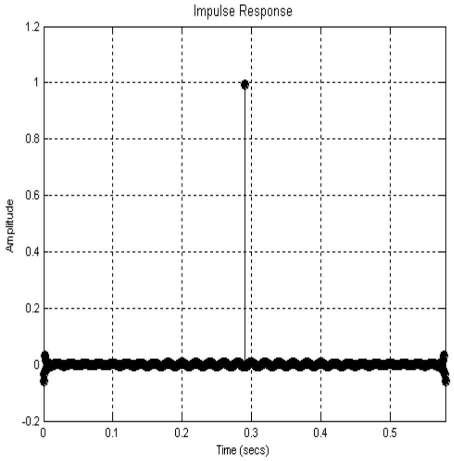

Figure 6: Impulse response of the Equiripple notch filter.

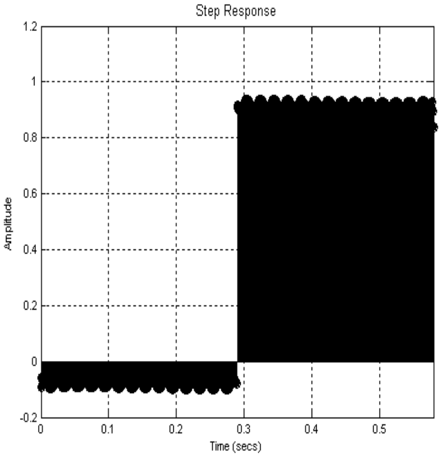

Figure 7: Step response of the Equiripple notch filter.

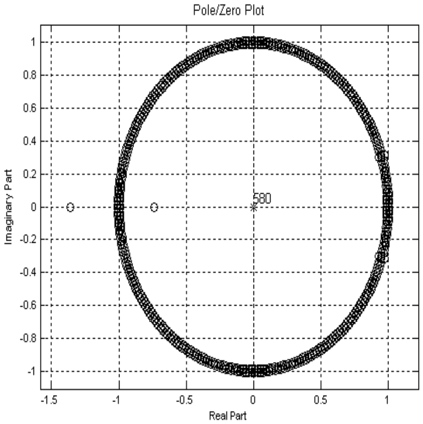

Figure 8: Pole Zero diagram of the Equiripple Notch filter

2.2 Realization of the Equiripple notch filter:

For the realization it requires large number of multiplier element, delay elements and adder elements approximately 580 multipliers, 579 delay and 579 adder elements. It clears that as the order of the filter is high the computational complexity is more. There for it adds the delay in the response.

2.3 Implementation of Equiripple notch filter:

To get the real time filtration the model in matlab is built. The parameters of the model are set to get real time filtration of the ECG signal. Figure shows 9 model used for the real time notch filtration. Time scope presents ECG signal before filtration and also stores 5000 samples of the signal. Time scope 1 presents ECG signal after filtration and stores 5000 sample points of the ECG signal. The sampling frequency used in the present work is 1000Hz.

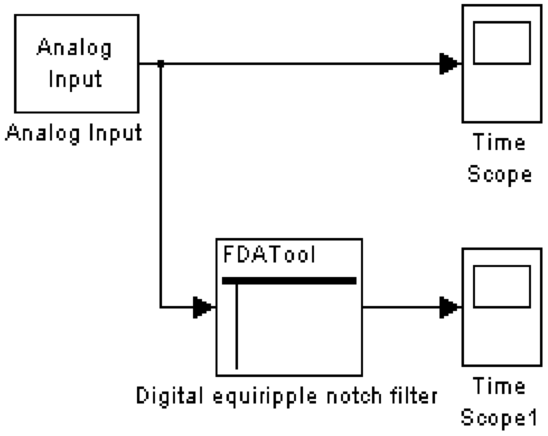

Figure 9: Real time filtration model for the ECG using equiripple notch filter.

3. Results of implementation of the Equiripple notch filter:

Figure 10 shows ECG signal before application of equiripple notch filter. Figure 11 shows ECG signal after application of equiripple notch filter. Corresponding frequency spectrum of the before application of filter and after application of the filter are shown in figure 12and figure 13 respectively. From the frequency spectrum for the before filtration ECG it is seen that power corresponding to the 50 Hz is -26.29dB. When the notch filter is applied the power corresponds to the 50 Hz signal is reduced to -35.75dB. It clears that filter reduces the power line interference in the ECG signal. The limitation of this filter is it requires higher order so that computational complexity is more and very difficult to realize the filter. Figure 11 of the ECG trace after filtration clears that due to computational overhead the original ECG trace is shifted towards to right.

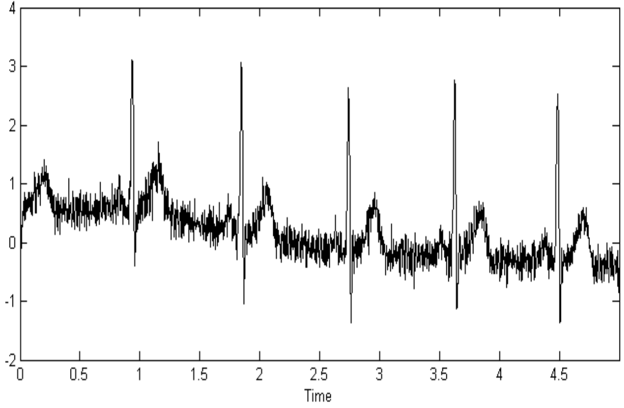

Figure 10: ECG signal before application of notch filter.

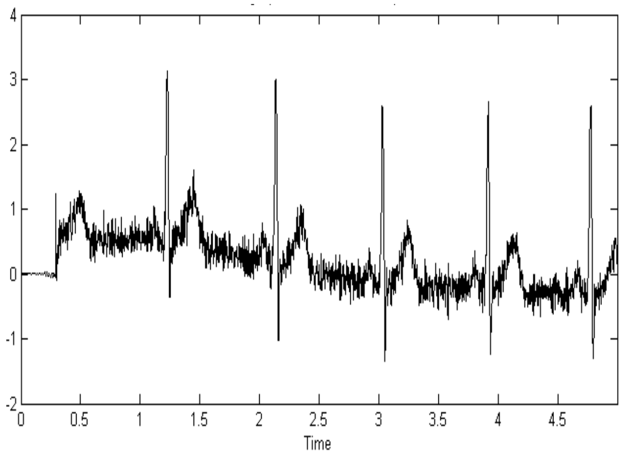

Figure 11: ECG signal after application of equiripple notch filter.

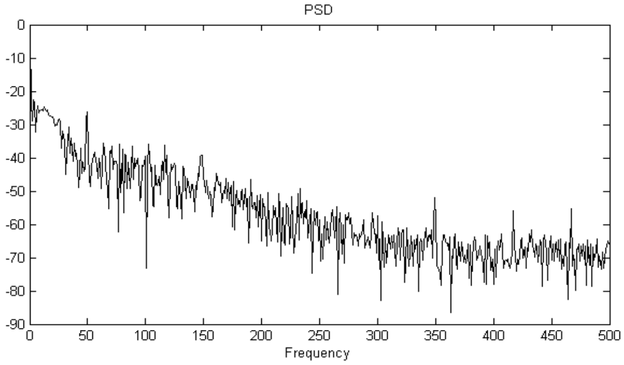

Figure 12: Frequency spectrum of the ECG before Filtration.

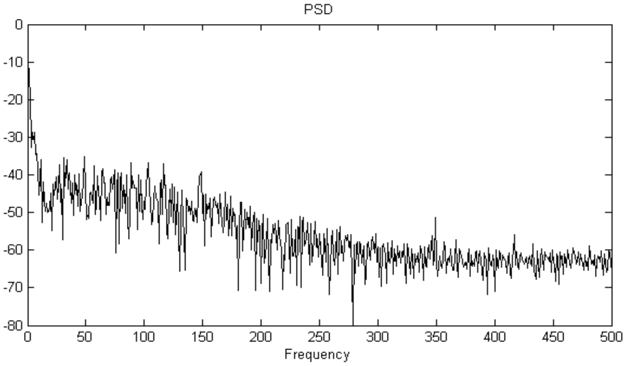

Figure 13: Frequency spectrum of the ECG after application of the notch filter.

4. Conclusion:

The Finite Impulse Response [FIR], filter produces the impulse response which has a limited number of terms. These types of filters are generally realized nonrecursively, which means that there is no feedback involved in computation of the output data. The output of the filter depends only on the present and past inputs. FIR filters based on equiripple design have been designed and implemented. Table 1 shows the comparison of the present work with other known methods and table 2 shows the effect of filtration of QRS complex with equiripple and L.S. Method. It is observed that due to application of the notch filter the QRS complex of the ECG waveform has been modified. In comparison with the window method reduction in signal power of 50 Hz is more in the Equiripple and Least squares methods. In the window method the number of elements required are less while in equiripple method more computational elements are required there fore computational time is the major difficulty of the equiripple type digital filter implemented on the noisy ECG signal. Method is cost effective and flexible. The effect of variation in the line frequency is not considered in the present work.

Table 1: Comparison of different FIR structures For PLI Reduction.

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

Table 2: Effect of filtration on QRS complex using Equiripple and least squares method.

Type of Filter	Filter Order	Effect on QRS complex
Equiripple Filter	580	Affects QRS Complex
L.S. Method	100	Affects QRS Complex

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