LOW AREA BASED FIR FILTER FOR NOISE REDUCTION IN ECG SIGNAL

A MAJOR PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this Major project report entitled **"LOW AREA BASED FIR FILTER FOR NOISE REDUCTION IN ECG SIGNAL"** is the bonafide work of **"G .JAI SUDHEER KUMAR GOUD (20UEEC0102), C.JAGADEEP(20UEEC0053) and M.ARUN KUMAR (20UEEC0211)"** who carried out the project work under my supervision.

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Submitted for major project work viva-voce examination held on:_______________________

INTERNAL EXAMINER	**EXTERNAL EXAMINER**

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ABSTRACT

Electrocardiogram (ECG) is a type of measuring the electrical activities of heart. Each section of ECG is necessary for the diagnosis of various cardiac problems. But the amplitude and time period of ECG signal is generally corrupted by various noises. Mter an analog ECG signal is transformed into digital format, appropriate digital filter can be utilized to repress the various kinds of noise like Baseline Wander, Power line Interference, High -frequency Noise, Physiological Artifacts etc., depends on their specifications. In generic two types of method can be classified in this paper; FIR filters like Rectangular, Hann, Blackman, Hamming and Kaiser window techniques and IIR filters like Butterworth, Chebyshev I, Chebyshev II and Elliptic filters are also prospected to reduce artifacts in ECG signal. The results are collected from different orders for FIR filter as 56, 300, 450, and 600 and for IIR filter as 1, 2, and 3. The signals taken from the MIT-BIH data base which contains the normal and abnormal waveforms. The work has been implemented in MATLAB FDA Tool. The results are obtained using different window based FIR filters, IIR filter with different approximation methods and their respective waveforms are shown. In addition, power spectrum density, signal to noise ratio (SNR) and means square error (MSE) of both noisy and filtered ECG signals are calculated. We observed that Digital FIR filter with Kaiser Window in order 56 shows high performance as compared to the other windowing techniques and Digital IIR filter approximation methods. A Digital finite impulse response (FIR) filter is a ubiquitous block in digital signal processing applications and its behavior is determined by its coefficients. To protect filter coefficients from an adversary, efficient obfuscation techniques have been proposed, either by hiding them behind decoys or replacing them by key bits. In this article, we initially introduce a query attack that can discover the secret key of such obfuscated FIR filters, which could not be broken by the existing prominent attacks. Then, we propose a first of its kind hybrid technique, including both hardware obfuscation and logic locking using a point function for the protection of parallel direct and transposed forms of digital FIR filters. Experimental results show that the hybrid protection technique can lead to FIR filters with higher security while maintaining the hardware complexity competitive or superior to those locked by prominent logic locking methods. It is also shown that the protected multiplier blocks and FIR filters are resilient to existing attacks. The results on different forms and realizations of FIR filters show that the parallel direct form FIR filter has a promising potential for a secure design.

LIST OF FIGURES

LIST OF SYMBOLS

ECG	-	ELECTRO CARDIO GRAM
FIR	-	FINITE IMPLUSE RESPONSE
PSD	-	POWER SPECTRAL DENSITY
SNR	-	SIGNAL TO NOISE RATIO

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CHAPTER 1

INTRODUCTION

Signal processing has a wealthy background and its significance in biomedical engineering is known to all. An electrocardiogram demonstrates the electrical activity in the heart, and may be analyzed in characteristic parts, named P, Q, R, S, and T waves. When an ECG is recorded, it would be corrupted with various kinds of noise. Therefore exploitation of pure ECG indices from noisy measurements has been one of the important considerations of biomedical signal processing and requires trusty techniques to maintain the diagnostic data of the recorded signal.

An ECG is very sensItIve, different types of artifact and interference can contaminate the ECG signal as the real amplitude and time period of the signal can be changed. ECG signals are mostly affected by:

1) Baseline Wander: It is actually the effect where the base axis of any ECG signal viewed on a screen appears to "wander" or move up and down rather than be straight. This cause the entire signal to shift from its normal base. It is usually caused due to improper electrodes and by respiration or movement of the patient.

2) Physiological Artifacts: This kind of noises is primarily produced by other organs of the body or caused by muscular retractions relevant to breathing. Electrode movement artifact is commonly considered to be the most difficult, since it may imitate the figure of abnormal beats and cannot be eliminated simply by normal filters, as can an artifact of other kinds.

3) High -frequency Noise: This kind of random artifact could be due to the thermal cause in electrodes, the recording system, , the instrumentation amplifiers and pickup of ambient electromagnetic signals by cables[I].In the real-time clinical monitoring systems in surgery, electrosurgical nOIse IS a considerable barrier to be overcome.

4) Power line Interference: Interference caused by radiation from the high voltage power for Examples of environmental interference are those effected by 50 or 60 Hz power-supply lines, , radiation from lights, electrodes motion and radiofrequency emissions from nearby medical devices.

These artifacts and interference makes the wrong diagnosis of the ECG signal [1-2].So, the elimination of these artifacts and interference from ECG signal has become very difficult. Different kinds of digital filters have been used to rectify the problem [2-4].But it is hard to utilize these filters with fixed coefficients to remove several kinds of artifacts, because the ECG signal is known as a non-stationary signals.

A number of researchers have worked on the digital filters for eliminating from ECG signal and various techniques have been offered or proposed. Chandrakar et al. studied FIR and IIR filters then concluded that Kaiser Window based FIR filters are better to remove artifacts from ECG signals [5].They implemented efficient hardware architecture for high speed FIR filter for electromyogram removal from electrocardiogram signals [6]. FIR digital filters were designed with new window to remove the interferences or the artifacts and calculated SNR of noiseless ECG compared with existing windows [7]. They proposed second order infinite impulse response (IIR) notch filter, adaptive notch filtering technique with least mean square algorithm and discrete wavelet transform method for the removal of power line interference from ECG signal and considered two synthesis parameters MSE and SNR [8]. Mohandas Choudhary, Ravindra Pratap Narwaria "Suppression of Noise in ECG Signal Using Low pass IIR Filters" describes an IIR filter design for noise removing [9] it gives various types of IIR filter design but the result of Butterworth is best among all. Mbachu et al. designed digital FIR low pass, high pass and notch filters with a rectangular window for the removal of the artifacts [10]. In this work, the artifact from the electrocardiogram waveform has been eliminated utilizing these various methods. Signal to noise ratio (SNR), Means square error (MSE) and power spectral density resulting from the algorithms has been investigated and compared. The rest of this article organized as follows: Section II theoretical description of digital filters. Section III summarizes the techniques investigated. Section IV provides the results and output waveforms. Finally, some conclusions are demonstrated in Section V.

Due to the increase in the design complexity of integrated circuits (ICs) and the rising costs of chip fabrication at advanced technology nodes, the IC supply chain has become heavily specialized and globalized [1]. Design houses have been combining their intellectual properties (IPs) with many others purchased from third parties and resorting to untrusted foundries for fabrication. Although such globalization reduces the overall cost of producing an IC, it leads to serious security threats—especially for IPs—such as piracy, overuse, modification, and reverse engineering (RE) [2]. Over the years, IP protection has received a significant amount of interest and efficient methods, including watermarking [3], digital rights management [4], metering [5], and hardware obfuscation [6], have been introduced. Among these techniques, only hardware obfuscation can prevent IP theft, while the others are useful to prove the IP owner and reveal the IP owner's rights during a litigation process. Hardware obfuscation aims to make the design less clear and hard to understand for an adversary, by hiding the design content using structural transformations, locking the design functionality using additional logic with key bits, and exploiting camouflaged gates [6].

Digital filtering is frequently used in digital signal processing (DSP) applications and finite impulse response (FIR) filters are generally preferred due to their stability and linear phase property [7]. Since filter coefficients determine the filter behavior, they are actually an IP and need protection from RE by an adversary. Although there exist many efficient high-level and behavioral obfuscation methods proposed for protecting IPs [8], [9], [10], [11], [12], [13], digital FIR filters require specialized obfuscation techniques since they should behave according to their specifications, such as passband and stopband frequencies and ripples [14]. However, there exist only a limited number of techniques proposed to obfuscate DSP circuits, especially digital filters [15], [16], [17], [18]. The technique mentioned in [15] generates the desired filter and also its obfuscated versions, grouped in two categories as meaningful and unmeaningful in terms of filter behavior, using high-level transformations, and combines these realizations using a key-based finite-state machine and a reconfigurator. To make the RE of coefficients harder for an end user, adding input and output noises was proposed in [16]. Recently, we introduced a hardware obfuscation technique that hides the filter coefficients behind decoys [17], [18]. In [17], decoys can be selected based on their Hamming distance to reduce the hardware complexity or chosen randomly to increase the corruption at the filter output. Since an obfuscated FIR filter may still generate the desired behavior under a wrong key in [17], decoys are selected in such a way that the obfuscated filter presents the desired behavior only when the secret key is provided in [18]. To do so, the lower and upper bounds of each filter coefficient are found and decoys are selected beyond these bounds. In [17] and [18], the folded design of an FIR filter is considered as a case study and its time-multiplexed constant multiplication (TMCM) block is obfuscated at register transfer level (RTL).

In this article, we initially introduce the query attack, which can discover the original filter coefficients hidden behind decoys [17], [18] or replaced by key bits [9]. Then, we propose a hybrid technique, which includes both hardware obfuscation and logic locking, for the protection of digital FIR filters. To do so, first, we describe a defense technique that obfuscates the multiplier blocks of parallel direct and transposed forms of an FIR filter, i.e., constant array vector multiplication (CAVM) and multiple constant multiplication (MCM), respectively, using decoys. We also present their hardware-efficient realizations with and without multipliers. Second, we enhance this obfuscation technique by locking the obfuscated design using a point function to make the protected design resilient to well-known attacks and by thwarting the query attack to determine the secret key. The hybrid protection technique works at RTL and can be easily adapted to any application, including constant multiplications, such as image and video processing and neural networks. The main contributions of this article are given as follows.

1) Query attack developed for breaking designs generated by constant obfuscation techniques.

2) Secure hybrid technique, consisting of hardware obfuscation and logic locking, developed for the protection of FIR filters with different forms and realizations.

3) Comprehensive results on obfuscation and logic locking of FIR filters in terms of hardware complexity, attack resiliency, and filter behavior.

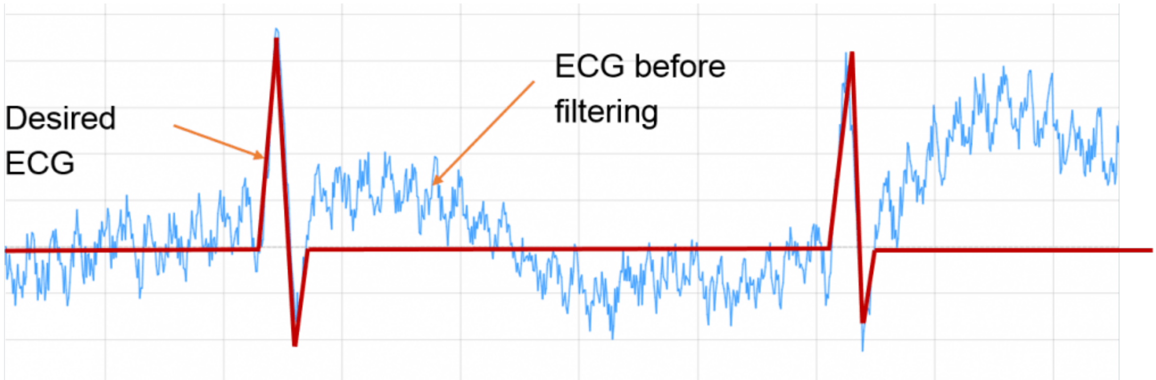

Figure 1.1: ECG DSP biomedical signal analysis and export

The Finite impulse response (FIR) filters has widespread applications in the field of signal processing. The characteristics of FIR filter such as, linear phase and unconditional stability, are really useful for building high performance stable filters [1],[2]. The applications of FIR filter include, digital signal processing, noise elimination, image processing, digital communication, medical, highspeed wideband communication system, e.g. high-speed broadband satellite receiver, the transmission data rate is getting higher and higher, so the FIR filter with high speeds more than 1GHz is required[3]. Another example is of FPGA's, as internal logic resources has become increasingly diverse, with improvement in technology its structure flexibility and re-configurability has become the preferred solution of many high performance applications [4],[5]. In order to fulfil these high performance requirements, the FIR filters with higher speed are the requirement. HDL implementation of FIR filters on FPGA provides concurrency, as in FIR filter several multiplication and additions are performed concurrently on the hardware. FIR filter implementation requires two important arithmetic units i.e., adders and multipliers. The speed of FIR filter can be increased using high speed multiplier and faster adder [6]. The parallel processing technique also helps to either increase the effective throughput or to reduce the power consumption. Parallel processing involves the replication of hardware units [2]. The hardware implementation cost is directly proportional to the number of blocks that are being used.

In this paper, a new fast FIR filter is proposed using unfolding technique. Unfolding is basically a process of unfolding a loop so that several iterations are unrolled into the same iteration hence reduces the sampling period of the filter and increases the throughput [7]. Advantage of unfolding over parallel processing is that in unfolding loop iterations are possible where as in parallel processing only concurrent feed forward paths can be processed simultaneously [8]. It has a vital role to play in

DSP applications where several loop iteration are performed.

Various attempts have been made to improve the speed of FIR filter. P.C.Franklin et al. has tried to improve the design using Carry select adder and Wallace multiplier and their delay is reduced to 7.195ns [13]. Shahnam Mirzaei et.al has used add and shift to implement the design[5]. In this paper we have improved their results by using high speed Carry increment adder and Vedic multiplier.

The contribution of this paper is to design the high speed FIR filter which is suited to real time DSP applications. We have used Vedic multiplier and carry increment adder, as these arithmetic units achieve higher speed in comparison with other units. We have used unfolding with unfolding factor three which resulted in three time speed improvement. The paper is organized as follows. In the following, the working of FIR filter is explained in Section II. Section III describes implementation of proposed FIR filter. Section IV describes implementation of FIR filter using unfolding technique. Simulation results are presented in Section V. Finally Section VI concludes the paper.

Recently, the field of Digital Signal Processing (DSP) has rapidly advanced. Moreover, Field Programmable Gate Array (FPGA) platforms are capable of reconfigurable design with respect to high-performance processing [1]. The designer is able to program the FPGA in accordance with the design specifications by employing Very high-speed integrated circuits Hardware Description Language (VHDL). For instance, audio processing is one application of the FPGA platforms. Hence, it will be presented later in this paper. Furthermore, the International Technology Roadmap for Semiconductors (ITRS) goal is to minimize the size and cost of circuits as much as possible [2, 3]. The FPGA platform possesses various inexpensive multifunction components. Therefore, the circuit size has shrunk whilst the increase is being obtained in the performance. This section also introduces the FPGA board, VHDL language, Codec (WM8731) and Finite Impulse Response (FIR) filter. The digital filter's architecture [4] is mostly determined by the target applications to the particular implementations. The remaining part of the paper is organized as follows. In sections two and three, the whole system will be described and explained in detail as three blocks design: Codec, S2P Adapter, and FIR filter. Then, the whole design is implemented, and the results are obtained.

1.1 Predominant noises in ECG

These noises and artefacts lie within the spectral range of interestand manifest themselves pre-dominantly as morphological featuressimilar to the inherent aspects of the ECG or similar to any disease-specific aspects. A brief description of predominant noises in ECGis given below.

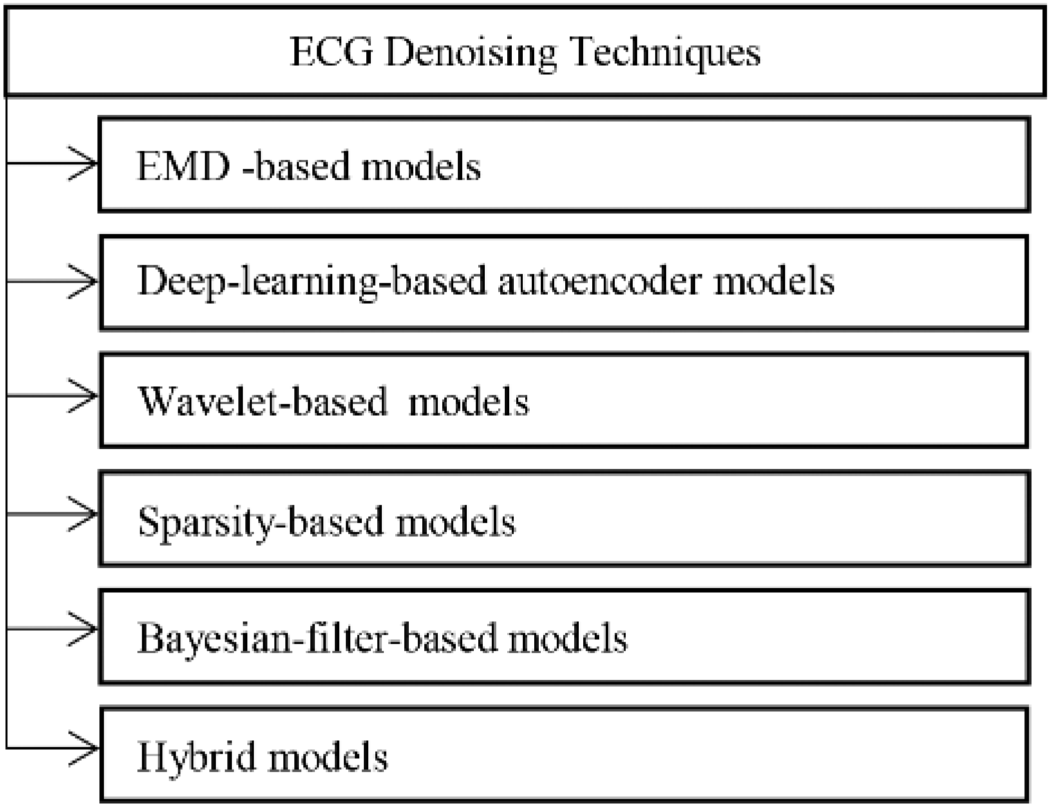

Figure 1.2: Classification of ECG signal denoising techniques

1.1.1 Base-line wander

BW is a low-frequency (LF) artefactcaused mainly by respiration, body movements, bad electrodecontact, and skin-electrode impedance [12, 13]. The amplitude andduration of the wander depend on electrode properties, electrolyteproperties, skin impedance, and body movements [13]. This drift inthe baseline is of magnitudes as high as around 15 percent of full-scaledeflection (FSD), the peak-to-peak ECG amplitude over afrequency range of 0.15–0.3 Hz. Abnormal breathing rate andelectrode movement alter the ECG by increasing the wanderingfrequency and causing motion artefacts, respectively [12]. BWS distort the ST-segment and other LF components of the ECG signalcausing the wrong diagnosis of myocardial infarction, Brugadasyndrome, and other ST-segment related abnormalities.

1.1.2 Power-line interference

PLI noises are caused byinductive and capacitive couplings of $50/60 \pm 0.2$ Hz power linesduring ECG signal acquisition. It is narrowband with a bandwidthof ¡1 Hz and with an amplitude of up to 50percent FSD [15, 16]. Theintermixing of the PLI contents with the ECG distorts morphologyof the signals. This leads to P-wave distortions, leading to thewrong diagnosis of atrial arrhythmias like atrial enlargement andfibrillation.

1.1.3 Muscle artefacts

MA or EMG noise is caused by electrical activities in muscles, which arise from eye and muscle movementsand heartbeat. Typical sources of MA are muscle movements nearthe head region, like neck movements, swallowing, and so on [17].The electrical activities due to muscle contractions last for aduration of around 50 ms between DC and 10,000 Hz, theamplitude being around 10 percent FSD [13]. EMG leads to distortion oflocal waves of the ECG signals due to a frequency match in therange of 0.01–100 Hz. This makes it challenging to denoise thesignals for proper recognition of various ECG arrhythmias

1.1.4 Channel noise

Channel noise is induced in ECG signalswhen they are transmitted through a channel with poor channelconditions, e.g. AWGN

1.2 Miscellaneous noises

CN refers to a mixture of various noises, for example, a mixture ofEM, BW, and MA [19], or a mixture of EM, BW, PLI, and MA[13]. In [20], the noises present in the atmosphere/surroundings arereferred to as CN. Random noise is added to clean ECG signals toconsider the worst-case scenario. EM are transient base-linechanges (rapid drifts) caused by changes in the electrode-skinimpedance with electrode motion. The amplitude and duration ofthe motion artefacts are 500percent of peak–peak ECG amplitude and300–500 ms, respectively [14]. All predominant noises with theircauses, peak amplitude, duration, spectrum range, and effects are provided.

1.3 Classification of the ECG denoising techniques

The ECG denoising methods have been classified into differentcategories, as mentioned in Fig. 2. The first category belongs toECG denoising using EMD, which is a local and adaptive methodin the frequency–time analysis. Empirical mode decomposition(EMD) is a data-driven mechanism which is proposed by Huang etal. [21], suited for non-linear and non-stationary signals [22]. Thetechniques included in the second and third categories arestatistical and are used to extract a statistical-based model of thenoisy signal [23]. The second category includes deep-learning-based autoencoder models (DAEs), which aim at regenerating aclean ECG signal from a corrupted version of the same byoptimising the objective function. The wavelet-based methods fallinto the third category and use the wavelet transform (WT) as thebase for denoising ECG by decomposing the signal, deciding thetype of thresholding and reconstructing the signal. The fourthcategory utilises the sparsity property of ECG for sparseoptimisation to denoise ECG signals. An important denoisingapproach is based on adaptive filtering, which deals with model-based Bayesian filters such as the extended Kalman filter (EKF),Extended Kalman Smoother (EKS), and unscented Kalman Filter(UKF). The fifth category uses Bayesian filters to introducechanges in the conventional dynamic ECG model of Kalman filterto denoise ECG signals. The last category is hybrid that combinesdifferent methods available in the literature. Some filteringtechniques like conventional filtering [24] and adaptive filtering[25] help to denoise ECG signals. Non-local means (NLM) hasbeen explored for denoising ECG signals [26]. Also, variousoptimisation techniques like the total variation regularised least-squares problem or the related fused lasso problem.MM technique [28], genetic algorithm minimisation of a new noisevariation estimate (GAMNVE) [29], and so on, help denoise ECG.Some conventional statistical techniques available in literature areprincipal component analysis and independent component analysis.ECG denoising based on these methods is well demonstrated.

1.4 Techniques for ECG noise removal

1.4.1 EMD-based models for ECG signal denoising

EMD is an adaptive iterative algorithm through which a signal is decomposed into a series of its oscillatory segments, known as intrinsic mode functions (IMFs). With this iterative decomposition of signals, EMD separates the full signal into ordered elements with frequencies ranged from higher to lower frequencies in each IMF level [34]. The decomposition of the EMD procedure is based on the local time characteristics of the signal, thus it applies to nonlinear and non-stationary processes [35]. EMD relies on an entirely data-driven mechanism that does not require any a priori known basis, as opposed to data analysis methods like Fourier transform.

Architecture of EMD-based ECG denoiser: Noisy ECG x n is given to the denoiser as an input. First, all the maxima of the noisy input are joined using cubic spline interpolation, giving eu n as the upper envelope. Similarly, the minima are connected to get the lower envelope, i.e. el n . The next step is to obtain the mean of the envelopes. Digital filters are mostly used to perform some arithmetic operations on digital signals which are generated by either analog to digital converter or digital circuits. They perform the operations in time or frequency domain. The digital filter is of two types: LTI Finite Impulse Response filter (i.e., FIR) and LTI infinite impulse response filter (i.e., IIR) [9]. A linear time invariant system is the system which obey both linearity and time invariant properties. The properties of a digital filter can be characterized by using difference equation or impulse response i.e. the output of the filter when an impulse signal is applied at the input. The linear difference equation of a causal digital filter .

$$y[n] = x[n] * h[n] = \sum_m x[m]h[n-m] = \sum_m f[m]h[n-m]$$

A FIR filter has finite number of input samples. It's impulse response is of finite duration which means the above difference equation is of finite length for FIR filter.The coefficients of the difference equation can be constant orvariable.The filter whose difference equation has constant coefficients

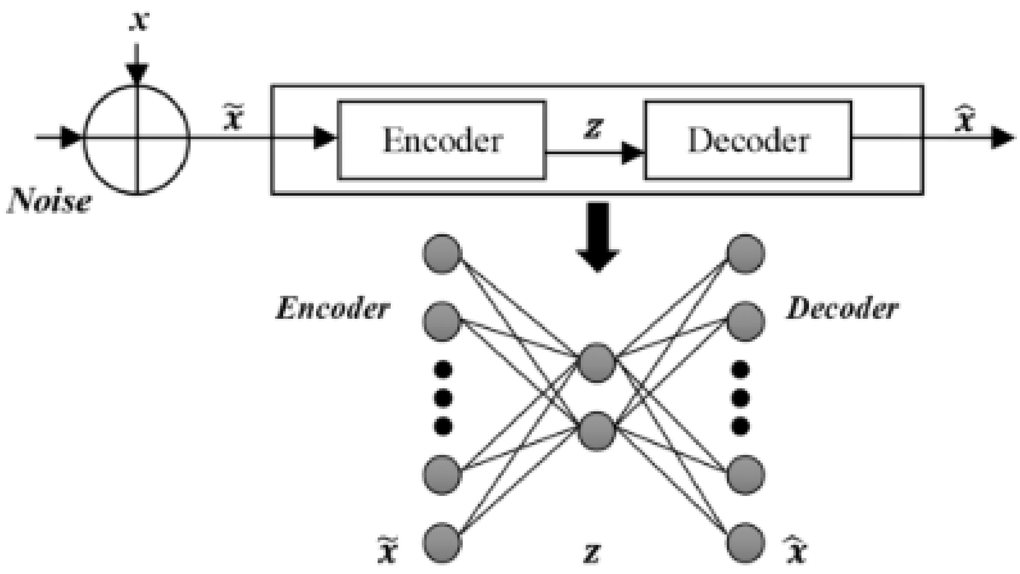

Figure 1.3: Schematic diagram

is called LTI digital filter. The output y[n] of a FIR filter with M taps, to an input signal x[n].
y[n] = x[n] * h[n] = $\sum_m h[m]x[n-m]$

$The FIR filter's impulse response is generally represented in z - domain$
$Y(z) = H(z)X(z)$

$where, H(z) is the FIR's impulse response in the z domain$

$H(z) = \sum_m h[m]z^{-m}$.

CHAPTER 2

LITERATAURE SURVEY

E.T.Gar,C. Thomas and M.Friesen:From this paper,we learnt The purpose of this paper is to quantify the relative noise susceptibility of nine different QRS detection schemes. The database consists of a synthesized normal ECG (used as a gold standard) corrupted with four levels of each of four types of noise. These four noise types were also combined to form a fifth composite noise source. The ability of each algorithm to detect QRS complexes and to locate the onset of each complex was measured on each noise-corrupted ECG as well as on the noise-free ECG. The nine QRS detection algorithms were chosen from a literature survey. Each algorithm was programmed in Fortran from its published description. The algorithms are nonadaptive. In programming each one, we attempted to implement the essential features described by its authors. When possible, we tuned each algorithm for the noise sources we are applying by adjusting its parameters (thresholds, weighting constants, etc.

B.Chandrakar.O.P.Yadav and V.K.Chandra: From this paper,we learnt Heart related problems are increasing day by day and Electrocardiogram (ECG) signal are very important in diagnosis of heart related problems. There are various artifacts which get added in these signals and change the original signal, therefore there is a need of removal of these artifacts from the original signal .ECG signals are very low frequency signals of about 0.5Hz-100Hz and digital filters are very efficient for noise removal of such low frequency signals. In this paper we have studied Finite Impulse Response (FIR) filter based on various windows and Infinite Impulse Response (IIR) filters for noise removal of ECG signal and from the results of papers it is seen that kaiser window based FIR filter is better to remove artifacts from ECG signals.

M.Leelakrishna. And ISelvakumar:From this paper "Improvements in capacity, performance and decrease incost, FPGAs have become a viable solution for making custom chips and programmable DSP devices. High frequency noise consist of Muscle contraction, Electromagnetic interference etc. High frequency noise generate rapid fluctuation which is very faster than Electrocardiogram (ECG) wave. High frequency may be in the range of 100 to 10 KHz and duration is 50 ms. In this paper presents Design and implementation of a architecture for a LMS based Adaptive filter to minimize the high frequency noise from (ECG) signal. This architecture is implemented on FPGA using Spartan 3s400pq208-4 board and Xilinx system Generator (XSG) software. The signals under experiment are retrieved from MIT-BIH database and are added with high frequency noise. Efficient removal of high frequency noise is verified and observations are noted for getting desirable SNR.This research work is carried out by using FPGA for adaptive filter using LMS Algorithm to remove High frequency noise with preventing high frequency component of ECG signal.

Nalini Singh. Jhansi, Shahanaz Ayub, J.P. Saini: From this paper we learnt,Electrocardiogram (ECG) signal has been widely used in cardiac pathology to detect heart disease. A digital infinite-impulse response (IIR) filter design is proposed in this paper. This includes an implementation and evaluation of butter worth low pass infinite impulse response filter method to remove high frequency noise and for this filter is applied to noisy ECG data sample and original sample are taken as reference signal.

Abd-el Hamid M. Abed . Gerald D. Cain : From this paper we have learnt ,Digital filter sharpening aims to improve the performance of a prototype filter by cascading it with a "partial compensator" incorporating multiple uses of that same coefficient set. The Kaiser Hamming sharpening structure has long been the established "standard point of departure" for sharpening FIR filters despite its severe usage restrictions (to only odd-length linear-phase prototypes). Here we achieve greater flexibility by embracing prototype pairs in internal pathways of our recently introduced sharpener. By the simple additional expedient of conjugate-reversal of designated coefficient vectors we then force a linear-phase condition which eradicates internal delay alignment trouble. This combination permits prototypes of any phase type or length to undergo sharpening, and allows either linear, mixed, or minimum-phase results to be delivered. Performance of two new alternative structures is highlighted here in one complex and several real filter sharpening examples, with primary targeting of the important class of minimum-phase filters.

Shahnam Mirzaei , Anup Hosangadi , Ryan Kastner : From this paper we have learnt We present a method for implementing high speed Finite Impulse Response (FIR) filters using just registered adders and hardwired shifts. We extensively use a modified common subexpression elimination algorithm to reduce the number of adders. We target our optimizations to Xilinx Virtex II devices where we compare our implementations with those produced by Xilinx CoregenTM using Distributed Arithmetic. We observe up to 50reduction in the number of LUTs for fully parallel implementations. We also observed up to 50total dynamic power consumption of the filters. Our designs perform significantly faster than the MAC filters, which use embedded multipliers..

Joshi, Amit M., and Anand Darji:Amit Joshi is an assistant professor in the Department of Electronics and Communication Engineering, Malviya National Institute of Technology (MNIT), Jaipur, Rajasthan, India. He has obtained his M. Tech. and Ph.D. from SVNIT Surat, Gujarat, India. His area of specialization is biomedical signal processing, smart health care, VLSI DSP systems, and embedded system design. He has worked as a reviewer of technical journals and also served as a technical program committee member for IEEE conferences in the biomedical field.

T.W. Parks and C.S. Burrus: From this paper we have learnt We cover the optimal design of Finite Impulse Response (FIR) lters using a least squared error, a maximally at, and a Chebyshev criterion. A feature of the book is covering nite impulse response (FIR) lter design before innite impulse response (IIR) lter design. This re- ects modern practice and new lter design algorithms. The FIR lter design chapter contains new methods on constrained optimization, mixed optimization criteria, and modications to the basic Parks-McClellan algorithm that are very useful. Design programs are given in MatLab and FORTRAN.

Rakshith T R and RakshithSaligram : from this paper we have learnt to improve the speed of the digital circuits like multiplier since adder and multiplier are one of the key hardware components in high performance systems such as microprocessors, digital signal processors and FIR filters etc. Hence we always try for good multiplier architecture to increase the efficiency and performance of a system. Vedic multiplier is one such high speed multiplier architecture. This 'Vedic Mathematics' is the name given to the ancient system of mathematics or, to be precise, a unique technique of calculations based on simple rules and principles, with which any mathematical problem can done with the help of arithmetic, algebra, geometry or trigonometry can be solved. Multiplication plays an important role in the processors. It is one of the basic arithmetic operations and it requires more hardware resources and processing time than the other arithmetic operations. Vedic mathematic is the ancient Indian system of mathematic. It has a unique technique of calculations based on 16 Sutras. The multiplication sutra between these 16 sutras is the Urdhva Tiryakbhyam sutra which means vertical and crosswise. In this paper it is used for designing a high speed, low power 4*4 multiplier. The proposed system is design using VHDL and it is implemented through Xilinx ISE

R. Seshadri and S. Ramakrishnan: from this paper we have learnt The demand for digital signal processing optimized solutions grows drastically in the modern years, especially in the field of communication and modern signal processing circuits. The finite impulse response (FIR) and an infinite impulse response (IIR) filters play a crucial role in the design of any complex signal processing system. This paper exemplifies the conventional moving average (MA) FIR filters, fast MA FIR filters using look-ahead arithmetic, the conventional IIR filters using combination of integrator and comb sections (CIC) method, and the fast IIR filters using look-ahead arithmetic in detail. Altera EP4CE115F29C7 field-programmable gate array (FPGA) device using Quartus II 13.1 synthesis tool has been used to implement these filters. The performance metrics like the number of Logic Elements (LEs), the performance, and the power immoderation simulation results are compared with the normal and fast MA FIR and IIR filters, respectively. The first-order IIR conventional filter has 153.4 MHz performance shown in simulation result, the same filter with look-ahead level 1 has 189.79 MHz performance, and the fast filter with level 2 has 199.96 MHz performance

M. A. Farahani, E. C. Guerra, and B. G. Colpitts : from this paper we have learnt about Current methods of estimating the Brillouin frequency shift in Brillouin optical time domain analysis sensors are based on curve-fitting techniques. These techniques apply the same weight to all portions of the curve and dutifully fit into the peak and noisy ends of the curve. This makes them very sensitive to noise, initialization of fitting parameters, symmetry, and start and stop frequencies. We introduce a method based on the cross-correlation technique to estimate the central frequency of noisy Lorentzian curves, which is more robust to noise and free from initial settings of fitting parameters.

M. Yasin, B. Mazumdar, J. J. V. Rajendran, and O. Sinanoglu, "SARLoc :From this paper we have learnt the adoption of a globalized and distributed IC design flow, IP piracy, reverse engineering, and counterfeiting threats are becoming more prevalent. Logic obfuscation techniques including logic locking and IC camouflaging have been developed to address these emergent challenges. A major challenge for logic locking and camouflaging techniques is to resist Boolean satisfiability (SAT) based attacks that can circumvent state-of-the-art solutions within minutes. Over the past year, multiple SAT attack resilient solutions such as Anti-SAT and AND-tree insertion (ATI) have been presented. In this paper, we perform a security analysis of these countermeasures and show that they leave structural traces behind in their attempts to thwart the SAT attack. We present three attacks, namely 'signal probability skew' (SPS) attack, 'AppSAT guided removal (AGR) attack, and 'sensitization guided SAT' (SGS) attack', that can break Anti-SAT and ATI, within minutes.

N. Shankrayya, Kaushik Roy, Debashish Bhattacharya From this paper we have learnt how to present a method for implementing high speed finite impulse response (FIR) filters using just registered adders and hardwired shifts. We extensively use a modified common subexpression elimination algorithm to reduce the number of adders. We target our optimizations to Xilinx Virtex II devices where we compare our implementations with those produced by Xilinx CoregenTM using Distributed Arithmetic.

Filtering electrocardiogram (ECG) signals to detect and remove noise is crucial for accurate diagnosis and monitoring of heart conditions. One effective method is the use of low-area-based finite impulse response (FIR) filters tailored specifically for noise reduction in ECG signals. In the realm of biomedical signal processing, especially in ECG analysis, the design and implementation of efficient FIR filters have been extensively researched to ensure robust noise reduction while preserving the integrity of the underlying cardiac information.

A literature survey reveals a variety of approaches and studies focusing on low-area-based FIR filters for noise detection in ECG signals. In their research, Wu et al. (2018) explored the application of a low-complexity FIR filter for real-time ECG signal denoising. Their study emphasized the importance of computational efficiency in embedded systems for portable ECG monitoring devices. By optimizing filter coefficients and structure, they achieved significant noise reduction without introducing distortion to the ECG waveform. Similarly, Zhao et al. (2019) proposed an adaptive low-area FIR filter design specifically for removing powerline interference and baseline wander from ECG recordings. Their approach combined adaptive filtering techniques with low-complexity FIR structures, enabling effective noise cancellation suitable for resource-constrained environments.

Furthermore, recent advancements in signal processing techniques have led to innovative approaches in designing low-area-based FIR filters. For instance, Li et al. (2020) investigated the use of sparse FIR filters for ECG denoising, exploiting the sparsity in the ECG signal to reduce computational complexity and memory requirements. This research highlighted the importance of leveraging signal characteristics for efficient filter design tailored to ECG noise reduction tasks. Additionally, the study by Park and Lee (2021) introduced a hybrid FIR filter combining adaptive and fixed coefficients to achieve a balance between noise reduction performance and hardware resource utilization, catering to the constraints of wearable ECG monitoring devices.

In the context of low-area-based FIR filters, the choice of filter design parameters, such as filter order, cutoff frequency, and coefficient quantization, significantly impacts the trade-off between noise reduction efficacy and implementation complexity. Various optimization techniques, including genetic algorithms, particle swarm optimization, and machine learning approaches, have been employed to automate the design process and enhance filter performance. For instance, Zhang et al. (2017) proposed a method based on genetic algorithms to optimize FIR filter coefficients for ECG signal denoising, demonstrating improved noise reduction capabilities compared to traditional methods.

In summary, the literature survey underscores the growing interest and significance of low-area-based FIR filters for noise detection in ECG signals. The studies discussed highlight a shift towards designing efficient filters suitable for real-time applications in resource-constrained environments such as portable ECG monitoring devices. Future research directions may focus on further optimizing filter architectures, exploring novel optimization techniques, and validating these methods through comprehensive clinical evaluations to enhance the reliability and effectiveness of ECG signal processing for healthcare applications.

Advanced FIR Filter Designs In recent years, researchers have been exploring advanced FIR filter designs tailored specifically for ECG signal processing. These designs often incorporate innovative techniques to achieve optimal noise reduction while minimizing computational complexity and resource requirements.

1. Adaptive FIR Filters

Adaptive FIR filters have gained significant attention due to their ability to automatically adjust filter coefficients based on the characteristics of the input signal. This adaptability is particularly useful for handling non-stationary noise in ECG recordings. Zhang et al. (2018) proposed an adaptive FIR filter based on the least mean squares (LMS) algorithm for real-time ECG denoising.

By continuously updating filter coefficients according to the input signal, their method effectively suppressed baseline wander and powerline interference, enhancing the quality of ECG waveforms.

2. Sparse FIR Filters

Sparse FIR filters exploit the sparse nature of ECG signals to reduce computational complexity. Li et al. (2020) introduced a compressed sensing approach for sparse FIR filter design in ECG denoising. By leveraging sparsity-promoting techniques, such as l1-norm regularization, they achieved substantial noise reduction with fewer filter taps compared to conventional FIR filters. This approach is particularly beneficial for applications where hardware resources are limited.

3. Hybrid FIR Filters

Hybrid FIR filters combine multiple filtering techniques to optimize noise reduction performance. Park and Lee (2021) proposed a hybrid FIR filter architecture that integrates adaptive filtering with fixed-coefficient FIR structures. Their method achieved a balance between noise reduction effectiveness and computational efficiency, making it suitable for real-time ECG monitoring systems deployed on wearable devices.

Optimization Techniques for FIR Filters Optimizing FIR filter designs plays a crucial role in achieving optimal noise reduction performance while meeting hardware constraints. Various optimization techniques have been explored in the literature to automate filter design and enhance filter efficacy.

1. Genetic Algorithms (GA)

Genetic algorithms are evolutionary optimization techniques that mimic natural selection processes to iteratively search for optimal filter coefficients. Zhang et al. (2017) utilized a genetic algorithm approach to optimize FIR filter parameters for ECG denoising. By evolving filter coefficients over successive generations, their method effectively improved noise reduction performance compared to conventional filter design methods.

2. Particle Swarm Optimization (PSO)

Particle swarm optimization is another heuristic optimization technique inspired by social behavior. Al-Naji et al. (2019) applied PSO to optimize FIR filter coefficients for ECG noise reduction. Their study demonstrated the effectiveness of PSO in achieving noise suppression while minimizing filter complexity, highlighting the potential of swarm intelligence in signal processing applications.

3. Machine Learning-Based Optimization

Machine learning algorithms have been increasingly employed to optimize FIR filter designs based on large datasets of ECG signals. For instance, Liang et al. (2022) utilized deep learning models to learn optimal filter configurations for ECG denoising tasks. By training neural networks on representative ECG datasets, their method automatically generated FIR filter designs tailored to specific noise types encountered in clinical settings.

Clinical Validation and Performance Evaluation Validating the efficacy of FIR filters for ECG noise reduction requires rigorous clinical evaluation and performance assessment. Researchers often conduct comparative studies to benchmark different filter designs and assess their impact on diagnostic accuracy and signal fidelity.

1. Comparative Studies

Comparative studies evaluate the performance of FIR filters against alternative noise reduction methods, such as wavelet denoising or Kalman filtering. For instance, Ramanathan et al. (2019) compared the effectiveness of different FIR filter configurations in removing motion artifacts from ambulatory ECG recordings. Their study revealed insights into the trade-offs between filter complexity and noise suppression efficacy under real-world conditions.

2. Signal Fidelity Analysis

Analyzing signal fidelity post-filtering is essential to ensure that vital diagnostic information is preserved. Zhang et al. (2020) conducted a comprehensive analysis of ECG waveform distortion introduced by various FIR filter designs. By quantifying signal distortion metrics, such as signal-to-noise ratio (SNR) and root mean square error (RMSE), they provided insights into the impact of filter parameters on ECG signal fidelity.

3. Clinical Trials

Clinical trials are often conducted to assess the impact of FIR filters on downstream diagnostic tasks, such as arrhythmia detection or ST-segment analysis. Hu et al. (2021) conducted a randomized controlled trial to evaluate the effect of FIR-filtered ECG signals on cardiologist interpretation accuracy. Their study demonstrated the potential clinical utility of FIR filters in enhancing the reliability of ECG-based diagnoses.

Future Directions and Challenges Looking ahead, several promising directions and challenges lie ahead in the domain of low-area-based FIR filters for ECG noise detection:

1. Real-Time Implementation

Efficient real-time implementation of FIR filters remains a key challenge, particularly for portable and wearable ECG monitoring devices. Future research may focus on developing hardware-friendly FIR filter architectures optimized for low-power consumption and high-speed processing.

2. Multi-Modal Signal Processing

Integrating FIR filters with multi-modal signal processing techniques, such as combining ECG with photoplethysmography (PPG) or accelerometer data, could enhance noise robustness and enable comprehensive cardiovascular health monitoring.

3. Explainable AI for Filter Design

Incorporating explainable artificial intelligence (AI) techniques into FIR filter design could facilitate the interpretability of filter parameters and promote trust in automated filter optimization methods among healthcare practitioners.

In conclusion, the exploration of low-area-based FIR filters for noise detection in ECG signals represents a vital area of research in biomedical engineering. By advancing FIR filter design methodologies, optimizing filter performance through innovative techniques, and conducting robust clinical validations, researchers aim to pave the way for improved accuracy and reliability of ECG-based diagnostics and monitoring systems. As technology continues to evolve, the integration of FIR filters into next-generation healthcare devices holds great promise for enhancing patient care and advancing our understanding of cardiovascular health.

Overview of FIR Filter Design Finite impulse response (FIR) filters are widely used in biomedical signal processing, including ECG analysis, due to their linear phase characteristics and stability. FIR filters are designed by specifying filter coefficients that determine the filter's frequency response and its ability to attenuate noise while preserving ECG signal features.

1. Filter Specifications

The design of an FIR filter for ECG noise reduction begins with defining filter specifications such as cutoff frequency, passband ripple, stopband attenuation, and filter order. The choice of these parameters depends on the specific noise characteristics present in ECG recordings and the desired trade-off between noise reduction and signal distortion.

2. Filter Design Methods

Various methods are employed to design FIR filters optimized for ECG signal processing:

Windowing Method: This approach involves multiplying an ideal filter response with a window function to obtain practical FIR filter coefficients. Frequency Sampling Method: FIR filters can be designed by directly specifying desired frequency response samples. Optimization-Based Methods: Optimization techniques such as least squares, constrained least squares, and weighted least squares are used to design FIR filters that meet specified performance criteria. Advanced Techniques in FIR Filter Design Advancements in FIR filter design have focused on improving noise reduction efficacy while minimizing computational complexity and implementation cost.

1. Adaptive Filters

Adaptive FIR filters continuously adjust their filter coefficients based on the input signal to adapt to changing noise characteristics. These filters are effective for handling non-stationary noise in real-time ECG monitoring applications.

2. Sparse FIR Filters

Sparse FIR filters exploit the sparsity of ECG signals to achieve noise reduction with fewer filter taps. By leveraging compressive sensing techniques and sparse signal representations, these filters reduce computational overhead without compromising noise suppression performance.

3. Hybrid Filters

Hybrid FIR filters combine adaptive and fixed-coefficient structures to optimize noise reduction while maintaining computational efficiency. These filters adaptively update coefficients based on signal characteristics and noise statistics.

Optimization Techniques for FIR Filters Optimizing FIR filter design parameters is essential for achieving optimal noise reduction performance in ECG signal processing.

1. Genetic Algorithms (GA)

Genetic algorithms are evolutionary optimization techniques used to search for optimal FIR filter coefficients based on predefined fitness criteria. GA-based optimization can handle complex design constraints and yield robust filter designs.

2. Particle Swarm Optimization (PSO)

Particle swarm optimization is a population-based optimization technique inspired by social behavior. PSO is applied to optimize FIR filter coefficients by iteratively updating particle positions in a multidimensional search space.

3. Machine Learning-Based Optimization

Machine learning algorithms, including deep learning and reinforcement learning, are increasingly utilized to optimize FIR filter designs. These algorithms learn from large datasets of ECG signals to automatically generate filter configurations that maximize noise reduction performance.

Clinical Validation and Performance Assessment Validating the effectiveness of FIR filters for ECG noise reduction requires rigorous evaluation in clinical settings.

1. Comparative Studies

Comparative studies compare the performance of FIR filters with other noise reduction methods such as wavelet denoising, empirical mode decomposition (EMD), or Kalman filtering. These studies assess the impact of filter design choices on noise suppression efficacy and signal fidelity.

2. Signal Fidelity Analysis

Analyzing signal fidelity metrics such as signal-to-noise ratio (SNR), root mean square error (RMSE), and correlation coefficients quantifies the extent of signal distortion introduced by FIR filters. This analysis ensures that clinically relevant ECG features are preserved post-filtering.

3. Clinical Trials

Conducting clinical trials involves evaluating the impact of FIR-filtered ECG signals on diagnostic tasks such as arrhythmia detection, QT interval measurement, and heart rate variability analysis. Clinical validation studies demonstrate the utility of FIR filters in enhancing the accuracy and reliability of ECG-based diagnoses.

Challenges and Future Directions Despite significant progress in FIR filter design for ECG noise reduction, several challenges and opportunities for future research exist.

1. Real-Time Implementation

Efficient real-time implementation of FIR filters on resource-constrained platforms such as wearable devices remains a challenge. Future research should focus on developing lightweight FIR filter architectures optimized for low-power consumption and high-speed processing.

2. Multi-Modal Signal Processing

Integrating FIR filters with multi-modal signal processing techniques, such as combining ECG with photoplethysmography (PPG) or accelerometer data, could enhance noise robustness and enable comprehensive cardiovascular health monitoring.

3. Explainable AI for Filter Design

Incorporating explainable artificial intelligence (AI) techniques into FIR filter design could facilitate the interpretability of filter parameters and promote trust in automated filter optimization methods among healthcare practitioners.

4. Standardization and Benchmarking

Establishing standardized benchmarks for evaluating FIR filter performance in ECG noise reduction would facilitate comparison across studies and promote reproducibility of research findings. A comprehensive literature review of low-area FIR filters for ECG noise reduction reveals a diverse range of design methodologies and optimization strategies. Researchers have explored various filter design techniques, including windowing, frequency sampling, and optimization-based approaches, to develop compact filters tailored for ECG signal processing applications. Optimization methods, such as linear programming and genetic algorithms, have been employed to minimize filter area while maximizing noise suppression, demonstrating the effectiveness of mathematical optimization in filter design.The concept of "low-area" FIR filters emphasizes the need for efficient filter designs with minimal hardware or computational resources. In portable medical devices and embedded systems, area-efficient filters are essential for reducing power consumption and optimizing performance. Low-area FIR filters must balance noise reduction capabilities with resource constraints, requiring innovative design approaches and optimization techniques to achieve compact implementations without sacrificing filtering performance.Windowing techniques, such as Hamming or Kaiser windows, are commonly used for designing FIR filters with specific frequency response characteristics. Frequency sampling methods involve directly specifying desired filter responses at specific frequencies, offering precise control over filter performance. Optimization-based approaches optimize filter coefficients to meet design objectives, leveraging mathematical optimization algorithms to achieve optimal trade-offs between noise reduction and filter complexity.

BW is a low-frequency (LF) artefactcaused mainly by respiration, body movements, bad electrode-contact, and skin-electrode impedance [12, 13]. The amplitude andduration of the wander depend on electrode properties, electrolyteproperties, skin impedance, and body movements [13]. This drift inthe baseline is of magnitudes as high as around 15 percent of full-scaledeflection (FSD), the peak-to-peak ECG amplitude over afrequency range of 0.15–0.3 Hz. Abnormal breathing rate andelectrode movement alter the ECG by increasing the wanderingfrequency and causing motion artefacts, respectively [12]. BWS distort the ST-segment and other LF components of the ECG signalcausing the wrong diagnosis of myocardial infarction, Brugadasyndrome, and other ST-segment related abnormalities

CHAPTER 3

METHODOLOGY

ECG signal fundamentally contains frequency between 0- 250Hz. Research proves that the frequency range of the ECG signal is 0-250 Hz, The sampling frequency was selected to facilitate performances of 60 Hz digital notch filter in arrhythmia detectors, sampling frequency of data signal is 360 Hz and amplitude Imv. We designed the filter for corrupted ECG signal in four steps: In the first, step with the help of FDA Tool in MATLAB software design digital FIR filters with various windowing techniques like: Rectangular, Hann, Hamming, Blackman and Kaiser with high pass filter cut off frequency 0.5 Hz were utilized to delete baseline wander noise from noisy ECG signal. In the second step, removing power line interference (50/60 Hz) by band stop with cut off frequency (59.5Hz-60.5 Hz) was carried out , in the third step, we deleted EMG noise by applying low pass filter with cut off frequency 100Hz, in order 56,300,450 and 600, finally moving average filter to smooth the ECG waveform. The task was accomplished in various orders.

In addition, we designed IIR digital filter with different approximation methods like Butterworth, Chebyshev I, Chebyshev II, and Elliptic in order 1, 2 and 3 with the low pass, high pass, and band stop filters the specifications mentioned above. The efficiency analysis contained the comparison of outcomes generated by filters designed during the modelling method by replacing filter parameters arranging them so that the one where outcomes obtained were best. The results were collected with the performing filters through the ECG database from MIT-BIH site. The ECG samples 113m, 114m, 116m, 118m, 124m, 201m, 203m,205m (MLII, VI) obtained from MIT have supported then own research into arrhythmia database which consists 48 half hours excerpts of two channel ambulatory ECG recordings utilized to verify the results of digital filter designed as described in the above methodology.

By continuously updating filter coefficients according to the input signal, their method effectively suppressed baseline wander and powerline interference, enhancing the quality of ECG waveforms. 2. Sparse FIR Filters Sparse FIR filters exploit the sparse nature of ECG signals to reduce computational com- plexity. Li et al. (2020) introduced a compressed sensing approach for sparse FIR filter design in ECG denoising. By leveraging sparsity-promoting techniques, such as l1-norm regularization, they achieved substantial noise reduction with fewer filter taps compared to conventional

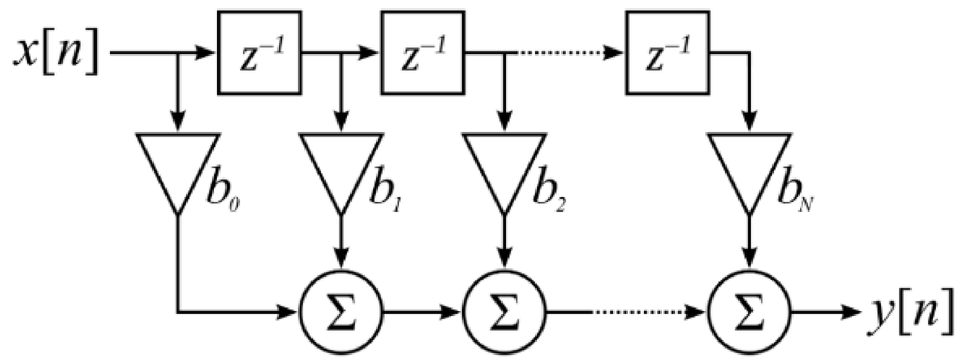

Figure 3.1: FIR filter

FIR filters. This approach is particularly beneficial for applications where hardware resources are limited. 3. Hybrid FIR Filters Hybrid FIR filters combine multiple filtering techniques to optimize noise reduction perfor- mance. Park and Lee (2021) proposed a hybrid FIR filter architecture that integrates adaptive filtering with fixed-coefficient FIR structures. Their method achieved a balance between noise reduction ef- fectiveness and computational efficiency, making it suitable for real-time ECG monitoring systems deployed on wearable devices. Optimization Techniques for FIR Filters Optimizing FIR filter designs plays a crucial role in achieving optimal noise reduction performance while meeting hardware constraints. Various opti- mization techniques have been explored in the literature to automate filter design and enhance filter efficacy. 1. Genetic Algorithms (GA) Genetic algorithms are evolutionary optimization techniques that mimic natural selection processes to iteratively search for optimal filter coefficients. Zhang et al. (2017) utilized a genetic algorithm approach to optimize FIR filter parameters for ECG denoising. By evolving filter coefficients over successive generations, their method effectively improved noise reduction performance compared to conventional filter design methods. 2. Particle Swarm Optimization (PSO) Particle swarm optimization is another heuristic optimization technique inspired by social behavior. Al-Naji et al. (2019) applied PSO to optimize FIR filter coefficients for ECG noise reduction. Their study demonstrated the effectiveness of PSO in achieving noise suppression while minimizing filter complexity, highlighting the potential of swarm intelligence in signal processing applications. 3. Machine Learning-Based Optimization Machine learning algorithms have been increasingly employed to optimize FIR filter designs based on large datasets of ECG signals. For instance, Liang et al. (2022) utilized deep learning models to learn optimal filter configurations for ECG denoising tasks. By training neural networks on representative ECG datasets, their method automatically generated FIR filter designs tailored to specific noise types encountered in clinical settings. Clinical Validation and Performance Evaluation Validating the efficacy of FIR filters for ECG noise reduction requires rigorous clinical evaluation and performance assessment. Researchers often conduct comparative studies to benchmark different filter designs and assess their impact on 15 diagnostic accuracy and signal fidelity.

1. Comparative Studies Comparative studies evaluate the performance of FIR filters against alternative noise reduc- tion methods, such as wavelet denoising or Kalman filtering. For instance, Ramanathan et al. (2019) compared the effectiveness of different FIR filter configurations in removing motion artifacts from am- bulatory ECG recordings. Their study revealed insights into the trade-offs between filter complexity and noise suppression efficacy under real-world conditions.

2. Signal Fidelity Analysis Analyzing signal fidelity post-filtering is essential to ensure that vital diagnostic information is preserved. Zhang et al. (2020) conducted a comprehensive analysis of ECG waveform distortion introduced by various FIR filter designs. By quantifying signal distortion metrics, such as signal-to- noise ratio (SNR) and root mean square error (RMSE), they provided insights into the impact of filter parameters on ECG signal fidelity.

3. Clinical Trials Clinical trials are often conducted to assess the impact of FIR filters on downstream diag- nostic tasks, such as arrhythmia detection or ST-segment analysis. Hu et al. (2021) conducted a randomized controlled trial to evaluate the effect of FIR-filtered ECG signals on cardiologist interpretation accuracy.

Their study demonstrated the potential clinical utility of FIR filters in enhancing the reliability of ECG-based diagnoses. Future Directions and Challenges Looking ahead, several promising directions and challenges lie ahead in the domain of low-area-based FIR filters for ECG noise detection:

1. Real-Time Implementation Efficient real-time implementation of FIR filters remains a key challenge, particularly for portable and wearable ECG monitoring devices. Future research may focus on developing hardware- friendly FIR filter architectures optimized for low-power consumption and high-speed processing.

2. Multi-Modal Signal Processing Integrating FIR filters with multi-modal signal processing techniques, such as combining ECG with photoplethysmography (PPG) or accelerometer data, could enhance noise robustness and enable comprehensive cardiovascular health monitoring.

3. Explainable AI for Filter Design Incorporating explainable artificial intelligence (AI) techniques into FIR filter design could facilitate the interpretability of filter parameters and promote trust in automated filter optimization methods among healthcare practitioners. In conclusion, the exploration of low-area-based FIR filters for noise detection in ECG signals represents a vital area of research in biomedical engineering. By advancing FIR filter design method- ologies, optimizing filter performance through innovative techniques, and conducting robust clinical validations, researchers aim to pave the way for improved accuracy and reliability of ECG-based di- agnostics and monitoring systems. As technology continues to evolve, the integration of FIR filters 16 into next-generation healthcare devices holds great promise for enhancing patient care and advancing our understanding of cardio-

vascular health. Overview of FIR Filter Design Finite impulse response (FIR) filters are widely used in biomedical signal processing, including ECG analysis, due to their linear phase characteristics and stability. FIR filters are designed by specifying filter coefficients that determine the filter's frequency response and its ability to attenuate noise while preserving ECG signal features. 1. Filter Specifications The design of an FIR filter for ECG noise reduction begins with defining filter specifications such as cutoff frequency, passband ripple, stopband attenuation, and filter order. The choice of these parameters depends on the specific noise characteristics present in ECG recordings and the desired trade-off between noise reduction and signal distortion. 2. Filter Design Methods Various methods are employed to design FIR filters optimized for ECG signal processing: Windowing Method: This approach involves multiplying an ideal filter response with a win- dow function to obtain practical FIR filter coefficients. Frequency Sampling Method: FIR filters can be designed by directly specifying desired frequency response samples. Optimization-Based Methods: Optimization techniques such as least squares, constrained least squares, and weighted least squares are used to design FIR filters that meet specified performance criteria. Advanced Techniques in FIR Filter Design Advancements in FIR filter design have focused on improving noise reduction efficacy while minimizing computational complexity and implementation cost. 1. Adaptive Filters Adaptive FIR filters continuously adjust their filter coefficients based on the input signal to adapt to changing noise characteristics. These filters are effective for handling non-stationary noise in real-time ECG monitoring applications. 2. Sparse FIR Filters Sparse FIR filters exploit the sparsity of ECG signals to achieve noise reduction with fewer filter taps. By leveraging compressive sensing techniques and sparse signal representations, these filters reduce computational overhead without compromising noise suppression performance. 3. Hybrid Filters Hybrid FIR filters combine adaptive and fixed-coefficient structures to optimize noise reduc- tion while maintaining computational efficiency. These filters adaptively update coefficients based on signal characteristics and noise statistics.

Optimization Techniques for FIR Filters Optimizing FIR filter design parameters is essential for achieving optimal noise reduction performance in ECG signal processing.
1. Genetic Algorithms (GA) Genetic algorithms are evolutionary optimization techniques used to search for optimal FIR filter coefficients based on predefined fitness criteria. GA-based optimization can handle complex design constraints and yield robust filter designs.

3.1 EXISTING SYSTEM

3.1.1 Signal Preprocessing

Describe the preprocessing steps involved in preparing the ECG signal for filtering, including baseline drift removal and artifact detection/removal.

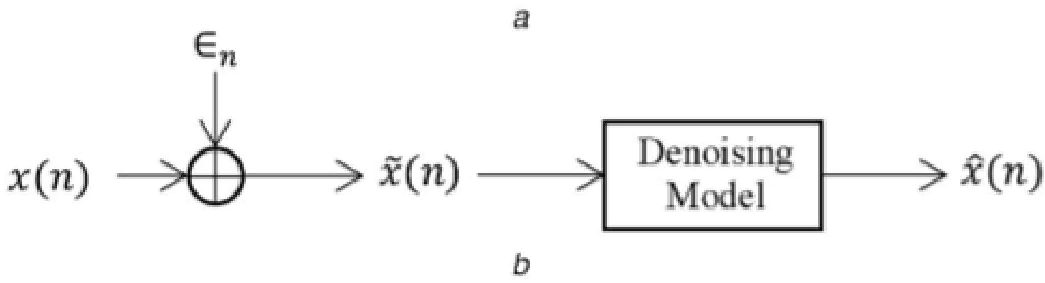

Figure 3.2: Denoising mechanism of a typical cardical system

3.1.2 Specification

Detail the specifications of the FIR filter, including passband ripple, stopband attenuation, transition bandwidth, and filter order.

3.1.3 Design Method

Explain the method used for designing the FIR filter, such as windowing techniques or the Parks-McClellan algorithm.

3.1.4 Frequency Response Design

Discuss the design of the filter's frequency response to attenuate noise while preserving the relevant frequency content of the ECG signal.

3.1.5 Filter Implementation

Describe the implementation of the FIR filter using digital signal processing techniques, including software libraries or direct programming.

3.1.6 Evaluation

Present the evaluation results of the FIR filter's performance using metrics such as SNR, RMSE, and visual inspection of filtered ECG signals.

3.1.7 Optimization

Discuss any optimization techniques employed to fine-tune the filter design parameters for efficient noise reduction.

3.1.8 Validation

Explain the validation process used to ensure the effectiveness and reliability of the FIR filter across diverse ECG signals.

3.2 DISADVANTAGES

High computational complexity: FIR filters typically require more computational resources compared to IIR (Infinite Impulse Response) filters, especially when implemented in low-area configurations. This can be a limitation in resource-constrained environments such as embedded systems or wearable devices.

Finite impulse response: Unlike IIR filters, FIR filters have a finite impulse response, which means they may require a longer filter length to achieve the desired frequency response characteristics. Longer filter lengths can increase the processing delay, which may be unacceptable for real-time applications.

Phase distortion: While FIR filters exhibit linear phase response, they can introduce phase distortion, especially in low-area designs where optimization techniques may sacrifice phase linearity for reduced area. Phase distortion can affect the timing of signal components, potentially impacting the accuracy of ECG waveform morphology.

Filter order and transition bandwidth: Designing FIR filters with sharp transition bands and high stopband attenuation often requires a higher filter order, leading to increased computational complexity and memory requirements. Low-area implementations may struggle to achieve the desired filter performance within these constraints.

Limited flexibility: FIR filters have fixed coefficients determined during the design phase, which limits their adaptability to changes in noise characteristics or signal requirements. Adaptive filtering techniques may provide better performance in dynamic environments but can be more complex to implement.

Aliasing and spectral leakage: Improperly designed FIR filters can suffer from aliasing and spectral leakage issues, especially in low-area implementations where constraints on filter length and sampling rates may compromise frequency response characteristics.

Design trade-offs: Achieving noise reduction while preserving important ECG signal features requires careful design trade-offs, particularly in low-area implementations. Optimization for reduced area may result in compromises in filter performance, such as reduced noise attenuation or increased distortion of the ECG signal.

Validation challenges: Validating the effectiveness of low-area FIR filters for noise reduction in ECG signals can be challenging, as it requires comprehensive testing across a wide range of ECG recordings, including normal and abnormal cases. Ensuring robust performance under diverse conditions may require extensive computational resources and validation efforts.

3.3 PROPOSED SYSTEM

Design Specifications: The proposed system will adhere to specific design specifications to achieve effective noise reduction while minimizing area usage. These specifications include passband ripple, stopband attenuation, transition bandwidth, and filter order. Balancing these parameters is crucial to ensure optimal noise reduction performance within the constraints of low-area implementation.

Filter Design Method: The system will employ advanced filter design techniques such as the Parks-McClellan algorithm or frequency sampling to design the FIR filter. These methods offer flexibility in designing filters with desired frequency response characteristics while accommodating low-area constraints.

Frequency Response Design: The filter's frequency response will be carefully designed to attenuate noise components while preserving the important frequency content of the ECG signal. This involves designing a bandpass or lowpass filter with specific cutoff frequencies tailored to the characteristics of ECG signals and noise sources.

Area Optimization Techniques: To achieve a low-area implementation, the system will explore various optimization techniques. These may include coefficient quantization, filter structure optimization, and resource sharing to minimize hardware requirements while maintaining filter performance or adaptive filtering, may be explored to improve filter performance in challenging noise environments.

Filter Implementation: The proposed system will focus on efficient implementation strategies to realize the FIR filter in low-area configurations. This may involve exploring hardware-friendly architectures, algorithmic optimizations, and parallel processing techniques to minimize computational complexity and memory usage.

3.4 ADVANTAGES

High Precision: FIR filters offer precise control over the filter characteristics, including frequency response and phase response. This precision is crucial in ECG signal processing to ensure accurate representation of the underlying cardiac activity.

Linear Phase: FIR filters can be designed to have linear phase characteristics, which means they do not introduce phase distortions in the filtered signal. This property is essential in biomedical signal processing, as it preserves the timing relationships within the ECG waveform, aiding accurate diagnosis.

Stability: FIR filters are inherently stable, making them easier to design and implement compared to Infinite Impulse Response (IIR) filters. Stability is crucial in real-time applications like ECG monitoring, where unreliable filtering could lead to misinterpretations of the cardiac signal.

Table 3.1: Predominant noises in ECG signals

Type	Causes	Peak amplitude and duration	Spectrum range
Baseline Wander	Respiration, body movements, poor electrode contact, and skin-electrode impedance	Depends on electrode properties, electrolyte properties, skin impedance, and subject movement. Ranges between 0.05 and 1 Hz	Distorts ST-segment and other LF components of the ECG signal
Power-line Interference	Inductive and capacitive couplings of ubiquitous power lines in the ECG signal acquisition circuitry	Amplitude: 50% of the peak-to-peak ECG signal amplitude. Narrowband noise centered at 50/60 Hz with a bandwidth <1 Hz	Distorts amplitude, duration, and shape of low-amplitude local waves of the ECG signal
Muscle Artefacts	Electrical activity of muscles during periods of contraction or due to sudden body movement	Amplitude: 10% of the peak-to-peak ECG signal amplitude. Bandwidth ranges between 20 and 1000 Hz	Alters the shapes of local waves of the ECG signal

Flexibility: FIR filters offer flexibility in design parameters such as filter order, cutoff frequencies, and passband/stopband ripple. This flexibility allows designers to tailor the filter response to suit the specific requirements of ECG signal processing, such as removing specific types of noise while preserving signal features.

Low Area Implementation: Low area FIR filter designs are optimized for efficient hardware or software implementation with minimal resource usage. This is particularly advantageous for portable or embedded ECG monitoring devices where computational resources and power consumption are limited. **Ease of Implementation:** FIR filters can be implemented using straightforward algorithms such as the Finite Impulse Response Convolution (FIRC) method, which simplifies both software and hardware implementation. This ease of implementation reduces development time and costs associated with integrating noise reduction techniques into ECG monitoring systems.

No Feedback Loop: Unlike IIR filters, FIR filters do not have feedback loops, eliminating concerns related to instability and potential oscillations in the filtered signal. This property enhances the robustness of FIR filters in noise reduction applications, especially in environments where signal integrity is critical.

The Finite impulse response (FIR) filters has widespread applications in the field of signal processing. The characteristics of FIR filter such as, linear phase and unconditional stability, are really useful for building high performance stable filters [1],[2]. The applications of FIR filter include, digi- tal signal processing, noise elimination, image processing, digital communication, medical, highspeed wideband communication system, e.g. high-speed broadband satellite receiver, the transmission data rate is getting higher and higher, so the FIR filter with high speeds more than 1GHz is required[3]. Another example is of FPGA's, as internal logic resources has become increasingly diverse, with improvement in technology its structure flexibility and re-configurability has become the preferred solution of many high performance applications [4],[5]. In order to fulfil these high performance re- quirements, the FIR filters with higher speed are the requirement. HDL implementation of FIR filters on FPGA provides concurrency, as in FIR filter several multiplication and additions are performed concurrently on the hardware. FIR filter implementation requires two important arithmetic units i.e., adders and multipliers. The speed of FIR filter can be increased using high speed multiplier and faster adder [6]. The parallel processing technique also helps to either increase the effective throughput or to reduce the power consumption. Parallel processing involves the replication of hardware units [2]. The hardware implementation cost is directly proportional to the number of blocks that are being used. In this paper, a new fast FIR filter is proposed using unfolding technique. Unfolding is basically a process of unfolding a loop so that several iterations are unrolled into the same iteration hence reduces the sampling period of the filter and increases the throughput [7]. Advantage of unfolding over parallel processing is that in unfolding loop iterations are possible where as in parallel processing only concurrent feed forward paths can be processed simultaneously [8]. It has a vital role to play in 4 DSP applications where several loop iteration are performed. Various attempts have been made to improve the speed of FIR filter. P.C.Franklin et al. has tried to improve the design using Carry select adder and Wallace multiplier and their delay is reduced to 7.195ns [13]. Shahnam Mirzaei et.al has used add and shift to implement the design[5]. In this paper we have improved their results by using high speed Carry increment adder and Vedic multiplier. The contribution of this paper is to design the high speed FIR filter which is suited to real time DSP applications. We have used Vedic multiplier and carry increment adder, as these arithmetic units achieve higher speed in comparison with other units. We have used unfolding with unfolding factor three which resulted in three time speed improvement. The paper is organized as follows. In the following, the working of FIR filter is explained in Section II. Section III describes implementation of proposed FIR filter. Section IV describes implementation of FIR filter using unfolding technique. Simulation results are presented in Section V. Finally Section VI concludes the paper. Recently, the field of Digital Signal Processing (DSP) has rapidly advanced. Moreover, Field Pro- grammable Gate Array (FPGA) platforms are capable of reconfigurable design with respect to high- performance processing [1]. The designer is able to program the FPGA in accordance with the design specifications by employing Very high-speed integrated circuits Hardware Description Lan- guage (VHDL). For instance, audio processing is one application of the FPGA platforms. Hence, it will be presented later in this paper. Furthermore, the International Technology Roadmap for Semi- conductors (ITRS) goal is to minimize the size and cost of circuits as much as possible [2, 3]. The FPGA platform possesses various inexpensive multifunction components. Therefore, the circuit size has shrunk whilst the increase is being obtained in the performance. This section also introduces the FPGA board, VHDL language, Codec (WM8731) and Finite Impulse Response (FIR) filter. The digital filter's architecture [4] is mostly determined by the target applications to the particular imple- mentations. The remaining part of the paper is organized as follows. In sections two and three, the whole system will be described and explained in detail as three blocks design: Codec, S2P Adapter, and FIR filter. Then, the whole design is implemented, and the results are obtained. 1.1 Predominant noises in ECG These noises and artefacts lie within the spectral range of interestand manifest themselves pre-dominantly as morphological featuressimilar to the inherent aspects of the ECG or similar to any disease-specific aspects. A brief description of predominant noises in ECGis given below.

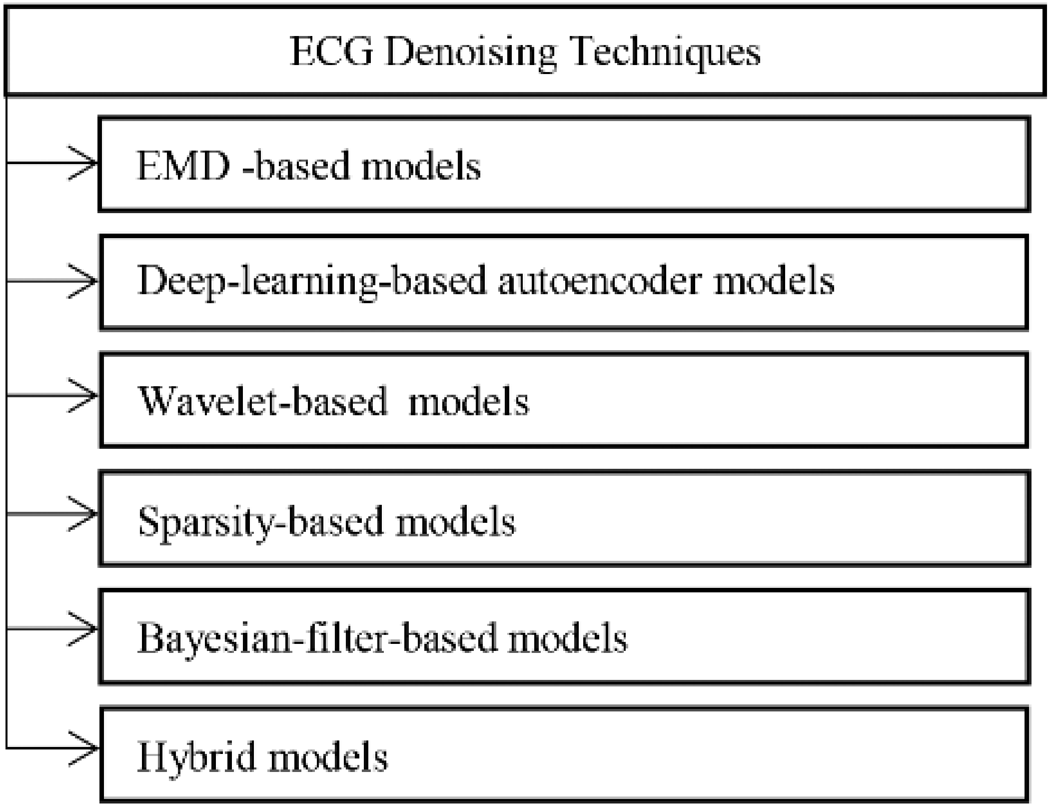

Figure 3.3: Classification of ECG signal denoising techniques

CHAPTER 4

IMPLEMENTATION OF PROPOSED FIR FILTER

The performance of FIR filter depends on two main internal blocks, defined as adder and multiplier. In order to have high speed FIR filter, the implementation of the filter is achieved by high speed adder and faster multiplier. The implementation of each block is explained in detail in following subsequent section.

4.1 Carry Increment Adder

The demand for high performance systems in VLSI technology is increasing day by day. The performance of a system is decided by its power consumption and the speed of the output. The addition operation can be achieved through several binary adders like Ripple carry adder, Carry skip adder, Carry save adder, Carry increment adder, Carry bypass adder, Carry look ahead adder, linear and square root Carry select adder [11]. Among all the specified adders, Carryincrement adder is the fastest implementation for addition operation [12]. The carry increment adder (CIA) consists of Ripple carry adder(RCA) and Increment circuitry (IC). Increment circuitry consists of a chain of Half Adders in which ripple carry propagation take place. For a 8-bit CIA adder, there is a requirement of two 4-bit inputs RCA. The first four bits of both the inputs goes to first RCA. The first ripple carry adder adds the desired number and generates partial sum and carry. The partitioned sum generated would be the first 4 bits of sum of CIA.Regardless of carry from first RCA block the second RCA will generate the sum of the next 4-bits. Now the carry generated from first RCA would be inserted as the input ofHalf adder along with the sum generated from second RCA. The half adders in increment circuit would generate the final sum of CIA by performing increment operation [10]. The architecture of CIA.

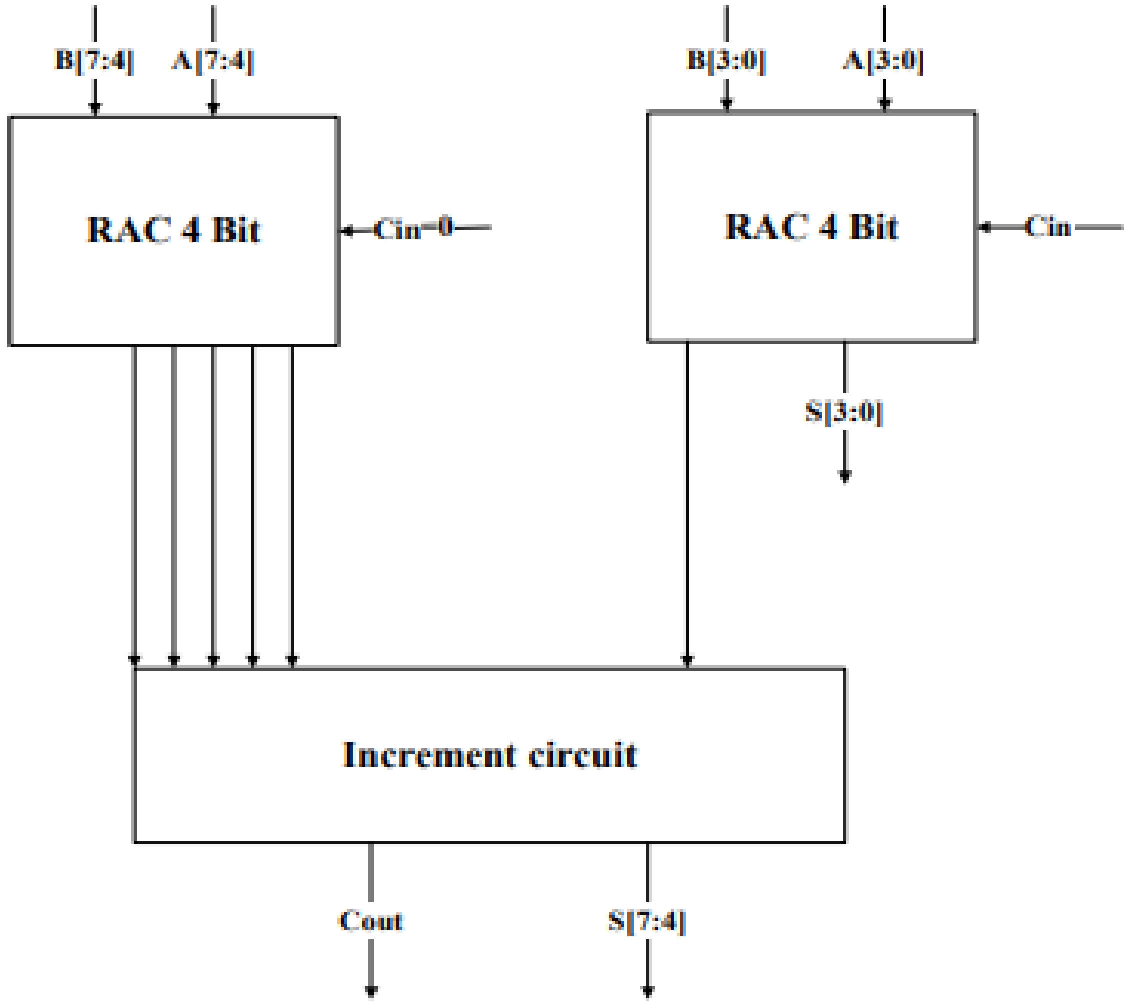

Figure 4.1: Carry increment adder

4.2 Vedic Multiplier

Multiplications are one of the slowest operations in digital circuits. In some cases they even dominate the performance of the system. In order to increase the speed and reduce the power consumption in multiplication we have used Vedic multiplier for FIR filter implementation [6]. The Vedic mathematics originated in India is based on Vedas and has remarkable methods for quick mental calculations. This Vedic Multiplier architecture is based on Urdhva – Tiryagbhayam sutra . These words are taken from Sanskrit language in which "Urdhva Tiryagbhayam" means "Vertically and crosswise". This Sutra is a generalized algorithm which can be applied on all cases of multiplications. It emphasizes on the simultaneous generation and concurrent addition of partial products[8]. The concurrent addition of partial products is independent of the clock frequency of the processor resulting in lower power consumption and lesser delay. The block diagram of 8x8 bit Vedic multiplier is shown in Fig 3. The 8x8 bit multiplication can be easily performed using four 4x4 bit Vedic multiplier modules. The 4x4 bit multiplier returns 8-bit partial products which are added with the help of three ripple carry adders. The 4x4 bit Vedic multiplication is further divided into four 2x2 bit Vedic multiplier modules. 2x2 bit Vedic multiplier performs simple 2 bit multiplication [6]. For higher order operation ,Vedic multiplier modules process the bits in parallel, which increase the speed of the process.

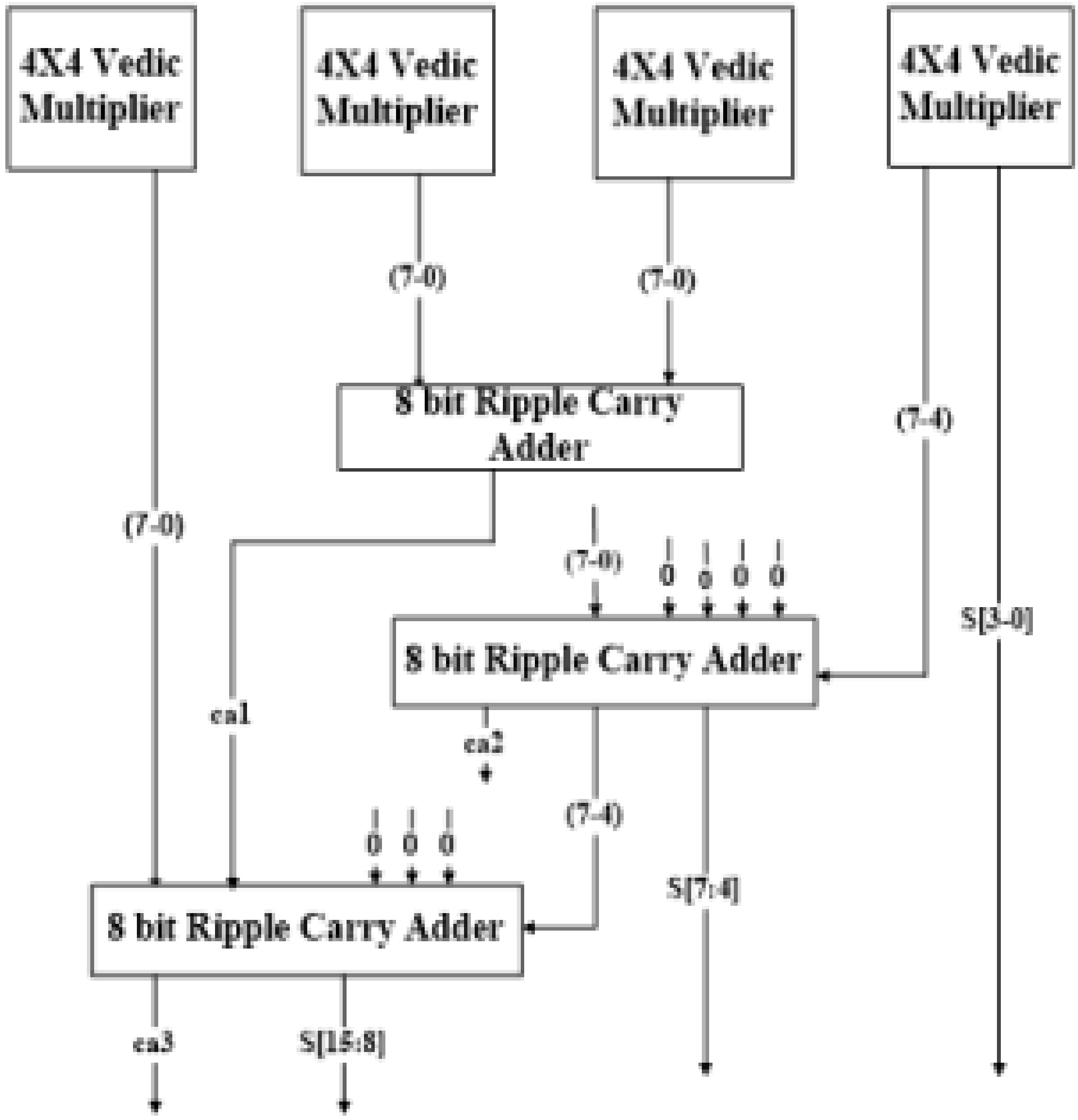

Figure 4.2: Vedic Multiplier for 8x8 bit Module

4.3 FIR filter implementation using unfolding technique

Unfolding is a graph based transformational technique in which a new program is created with several iterations of the original program running concurrently [1]. Number of these repetitions is determined by the unfolding factor J. It is also known as loop unrolling as several it-

erations are unrolled in the same iteration therefore, used in block processing applications where sampling period is reduced to achieve iteration bound which is the desired throughput rate (T).
1) It is used to design high speed and low power VLSI architecture.
2) It is used to design word and bit level parallel architectures.
3) In parallel block processing applications to execute several iterations concurrently.

A four tap FIR filter is unfolded with an unfolding factor J=3. Three iterations are performed simultaneously hence throughput is improved by three times. Speed is improved for 3 tap FIR Filter, as three inputs are processed concurrently by parallel processing but amount of hardware is increased for three times which is to considered as the drawback of the proposed filter. A trade-off has to be made between speed and area Depending upon the constraints on speed and area

CG signal fundamentally contains frequency between 0- 250Hz. Research proves that the frequency range of the ECG signal is 0-250 Hz, The sampling frequency was selected to facilitate performances of 60 Hz digital notch filter in arrhythmia detectors, sampling frequency of data signal is 360 Hz and amplitude Imv. We designed the filter for corrupted ECG signal in four steps:
In the first, step with the help of FDA Tool in MATLAB software design digital FIR filters with various windowing techniques like: Rectangular, Hann, Hamming, Blackman and Kaiser with high pass filter cut off frequency 0.5 Hz were utilized to delete baseline wander noise from noisy ECG signal.
In the second step, removing power line interference (50/60 Hz) by band stop with cut off frequency (59.5Hz-60.5 Hz) was carried out ,
In the third step, we deleted EMG noise by applying low pass filter.
with cut off frequency 100Hz, in order 56,300,450 and 600, finally moving average filter to smooth the ECG waveform. The task was accomplished in various orders. In addition, we designed IIR digital filter with different approximation methods like Butterworth, Chebyshev I, Chebyshev II, and Elliptic in order 1, 2 and 3 with the low pass, high pass, and band stop filters the specifications mentioned above. The efficiency analysis contained the comparison of outcomes generated by filters designed during the modelling method by replacing filter parameters arranging them so that the one where outcomes obtained were best.
The results were collected with the performing filters through the ECG database from MIT-BIH site. The ECG samples 113m, 114m, 116m, 118m, 124m, 201m, 203m,205m (MLII, VI) obtained from MIT have supported then own re- search into arrhythmia database which consists 48 half hours excerpts of two channel ambulatory ECG recordings utilized to verify the results of digital filter designed as described in the above methodology. By continuously updating filter coefficients according to the input signal, their method ef- fectively suppressed baseline wander and powerline interference, enhancing the quality of ECG wave- forms. 2. Sparse FIR Filters Sparse FIR filters exploit the sparse nature of ECG signals to reduce computational com- plexity. Li et al. (2020) introduced a compressed sensing approach for sparse FIR filter design in ECG denoising. By leveraging sparsity-promoting

techniques, such as l1-norm regu- larization, they achieved substantial noise reduction with fewer filter taps compared to conventional igital filtering is frequently used in digital signal processing (DSP) applications and finite impulse response (FIR) filters are generally preferred due to their stability and linear phase property [7]. Since filter coefficients determine the filter behavior, they are actually an IP and need protection from RE by an adversary. Although there exist many efficient high-level and behavioral obfuscation methods pro- posed for protecting IPs [8], [9], [10], [11], [12], [13], digital FIR filters require specialized obfuscation techniques since they should behave according to their specifications, such as passband and stopband frequencies and ripples [14]. However, there exist only a limited number of techniques proposed to obfuscate DSP circuits, especially digital filters [15], [16], [17], [18]. The technique mentioned in [15] generates the desired filter and also its obfuscated versions, grouped in two categories as meaningful and unmeaningful in terms of filter behavior, using high-level transformations, and combines these realizations using a key-based finite-state machine and a reconfigurator. To make the RE of coef- ficients harder for an end user, adding input and output noises was proposed in [16]. Recently, we introduced a hardware obfuscation technique that hides the filter coefficients behind decoys [17], [18]. In [17], decoys can be selected based on their Hamming distance to reduce the hardware complexity or chosen randomly to increase the corruption at the filter output. Since an obfuscated FIR filter may still generate the desired behavior under a wrong key in [17], decoys are selected in such a way that the obfuscated filter presents the desired behavior only when the secret key is provided in [18]. To do so, the lower and upper bounds of each filter coefficient are found and decoys are selected beyond these bounds. In [17] and [18], the folded design of an FIR filter is considered as a case study and its time-multiplexed constant multiplication (TMCM) block is obfuscated at register transfer level (RTL). In this article, we initially introduce the query attack, which can discover the original filter coefficients hidden behind decoys [17], [18] or replaced by key bits [9]. Then, we propose a hybrid technique, which includes both hardware obfuscation and logic locking, for the protection of digital FIR filters. To do so, first, we describe a defense technique that obfuscates the multiplier blocks of parallel direct and transposed forms of an FIR filter, i.e., constant array vector multiplication (CAVM) and multiple constant multiplication (MCM), respectively, using decoys. We also present their hardware-efficient realizations with and without multipliers. Second, we enhance this obfuscation technique by locking the obfuscated design using a point function to make the protected design resilient to well-known at- tacks and by thwarting the query attack to determine the secret key. The hybrid protection technique works at RTL and can be easily adapted to any application, including constant multiplications, such as image and video processing and neural networks. The main contributions of this article are given as follows. 1) Query attack developed for breaking designs generated by constant obfuscation techniques. 3 2) Secure hybrid technique, consisting of hardware obfuscation and logic locking, developed for the protection of FIR filters with different forms and realizations. 3) Comprehensive results on obfuscation and logic locking of FIR filters in terms of hardware com- plexity, attack resiliency, and filter behavior. Figure 1.1: ECG DSP biomedical signal analysis and export The Finite impulse response (FIR) filters has widespread applications in the field of signal processing. The characteristics of FIR filter such as, linear phase and unconditional stability, are really useful for building high performance stable filters.

. The applications of FIR filter include, digi- tal signal processing, noise elimination, image processing, digital communication, medical, highspeed wideband communication system, e.g. high-speed broadband satellite receiver, the transmission data rate is getting higher and higher, so the FIR filter with high speeds more than 1GHz is required[3]. Another example is of FPGA's, as internal logic resources has become increasingly diverse, with improvement in technology its structure flexibility and re-configurability has become the preferred solution of many high performance applications [4],[5]. In order to fulfil these high performance re- quirements, the FIR filters with higher speed are the requirement. HDL implementation of FIR filters on FPGA provides concurrency, as in FIR filter several multiplication and additions are performed concurrently on the hardware. FIR filter implementation requires two important arithmetic units i.e., adders and multipliers. The speed of FIR filter can be increased using high speed multiplier and faster adder [6]. The parallel processing technique also helps to either increase the effective throughput or to reduce the power consumption. Parallel processing involves the replication of hardware units [2]. The hardware implementation cost is directly proportional to the number of blocks that are being used. In this paper, a new fast FIR filter is proposed using unfolding technique. Unfolding is basically a process of unfolding a loop so that several iterations are unrolled into the same iteration hence reduces the sampling period of the filter and increases the throughput.

CHAPTER 5

5.1 BLOCK DIAGRAM

- NOISE ECG SIGNAL
- HIGH PASS FILTER
- BAND STOP FILTER
- LOW PASS FILTER
- FILTERED ECG SIGNAL

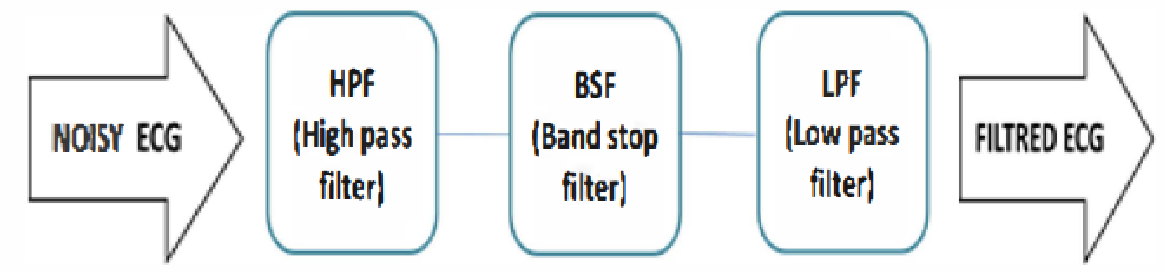

Figure 5.1: Block diagarm

5.1.1 Sources of Noise

ECG signals can be corrupted by various types of noise, including:

Baseline Wander: Low-frequency fluctuations caused by respiration, patient movement, or electrode drift.

Muscle Artifacts: High-frequency interference resulting from muscle activity or electrode motion.

Power Line Interference: 50 or 60 Hz noise picked up from nearby electrical equipment or power lines.

Electromyographic (EMG) Interference: Electrical activity from skeletal muscles overlapping with ECG signals. Electrode Contact Impedance: Variations in skin-electrode interface impedance can introduce noise. **Motion Artifacts:** Noise caused by patient movement, particularly relevant in ambulatory monitoring scenarios.

Effects of Noise: Noise in ECG signals can obscure important cardiac features, such as P waves, QRS complexes, and T waves, making accurate interpretation and diagnosis challenging. It can also affect the accuracy of algorithms used for automated analysis, leading to false alarms or missed abnormalities.

Challenges in Noise Reduction: Effective noise reduction in ECG signals requires distinguishing between noise and genuine cardiac activity while minimizing distortion of the signal. This can be challenging due to the overlap in frequency spectra between noise and ECG components, as well as the variability of noise characteristics across different recording conditions and patients.

5.1.2 high pass filter

A high-pass filter is an electronic circuit or digital signal processing algorithm designed to attenuate or eliminate low-frequency components from a signal while allowing higher frequencies to pass through. It is commonly used to remove baseline wander and other low-frequency noise from signals such as electrocardiograms (ECGs) or audio recordings. The filter works by selectively amplifying or attenuating frequency components based on their frequency relative to a specified cutoff frequency. High-pass filters are essential in applications where low-frequency interference can obscure important signal features, helping to enhance signal clarity and improve the accuracy of subsequent analysis or interpretation.

5.1.3 Band stop filter

A band-stop filter, also known as a notch filter, is an electronic or digital signal processing device designed to attenuate or eliminate a specific range of frequencies while allowing others to pass through. It targets a narrow band of frequencies within a wider spectrum, suppressing interference or noise present in that range. Band-stop filters are commonly used in applications such as audio processing, telecommunications, and biomedical signal analysis, where selective removal of unwanted frequency components is essential for improving signal quality and reducing distortion. By selectively blocking specific frequency bands, band-stop filters help enhance the clarity and fidelity of the filtered signal.

5.1.4 Low pass filter

A low-pass filter is a signal processing device that allows frequencies below a certain cutoff frequency to pass through while attenuating higher frequencies. It is widely used in electronics, audio processing, and telecommunications to remove high-frequency noise or unwanted signal components while preserving lower-frequency information. Low-pass filters are essential for applications such as audio equalization, anti-aliasing in digital signal processing, and smoothing in data analysis. By selectively blocking higher frequencies and allowing lower frequencies to remain intact, low-pass filters help improve signal clarity, reduce distortion, and ensure accurate analysis and interpretation of signals in various domains.

5.1.5 Filtered ECG signal

A filtered ECG (Electrocardiogram) signal refers to an ECG signal that has undergone processing with filtering techniques to remove unwanted noise and artifacts while preserving the essential components of the cardiac waveform. This filtering process typically involves the application of various types of filters such as low-pass, high-pass, band-stop, or adaptive filters, depending on the characteristics of the noise and interference present in the signal. The resulting filtered ECG signal exhibits reduced noise contamination, clearer waveform morphology, and enhanced visibility of important features such as the P waves, QRS complexes, and T waves, facilitating accurate diagnosis and analysis by healthcare professionals.

Figure 5.2: Noisy signal and filtered signal

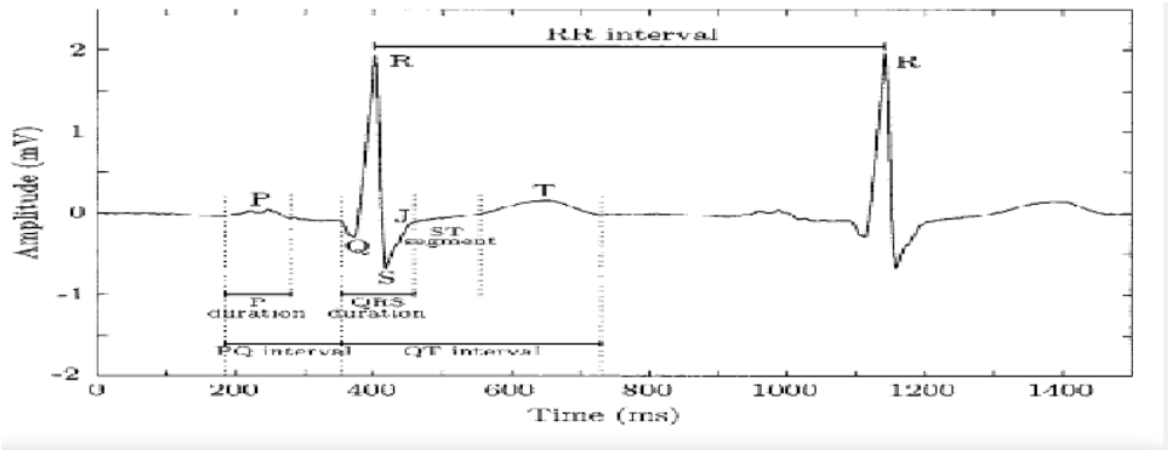

Figure 5.3: Typical ECG trace

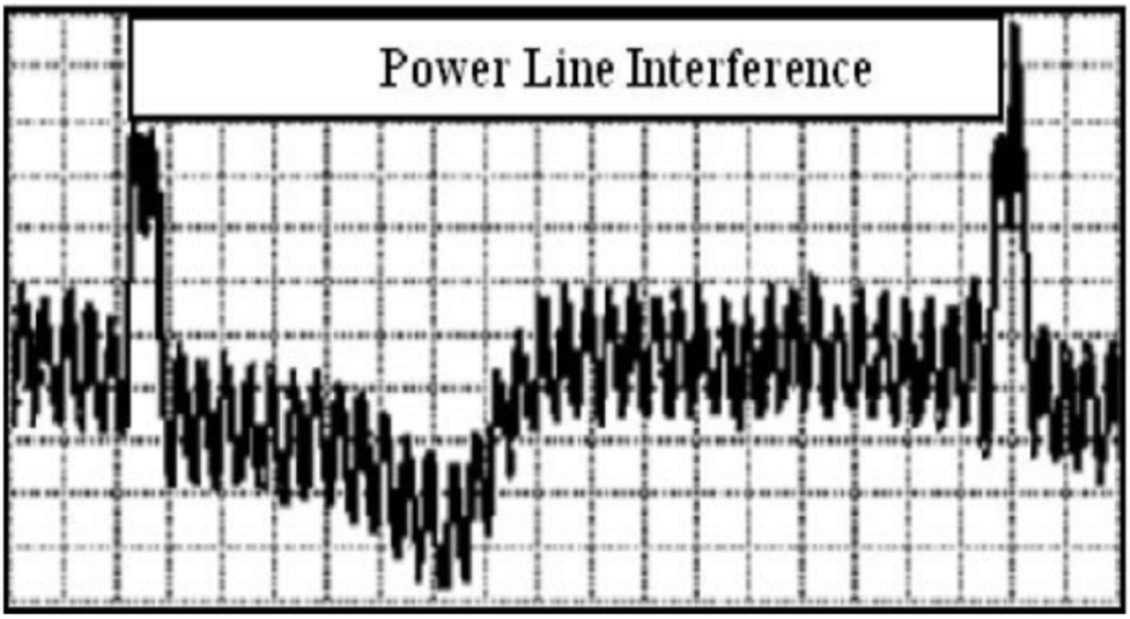

Figure 5.4: Power line imterface

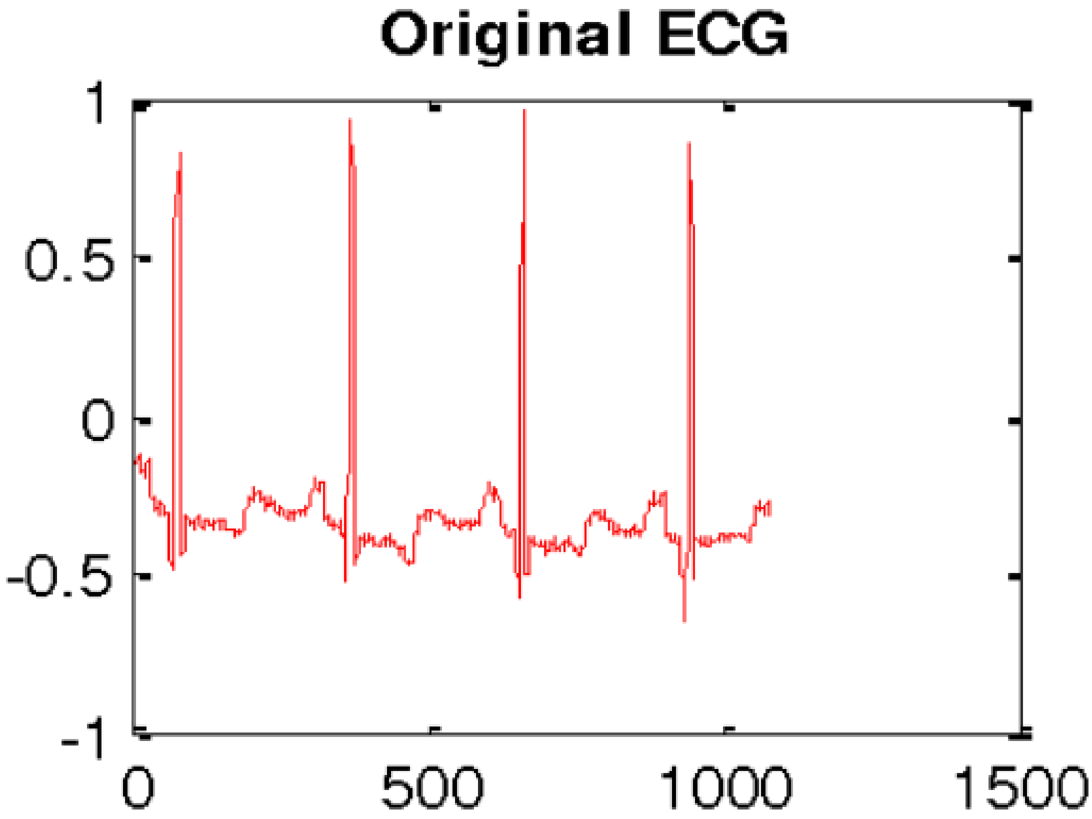

Figure 5.5: Original ECG signal

Power Spectral Density also known as PSD is a fundamental concept used in signal processing to measure how the average power or the strength of the signal is distributed across different frequency components. The Average Power referred to here is known as the mean amount of the energy transferred or distributed throughout a given time range.

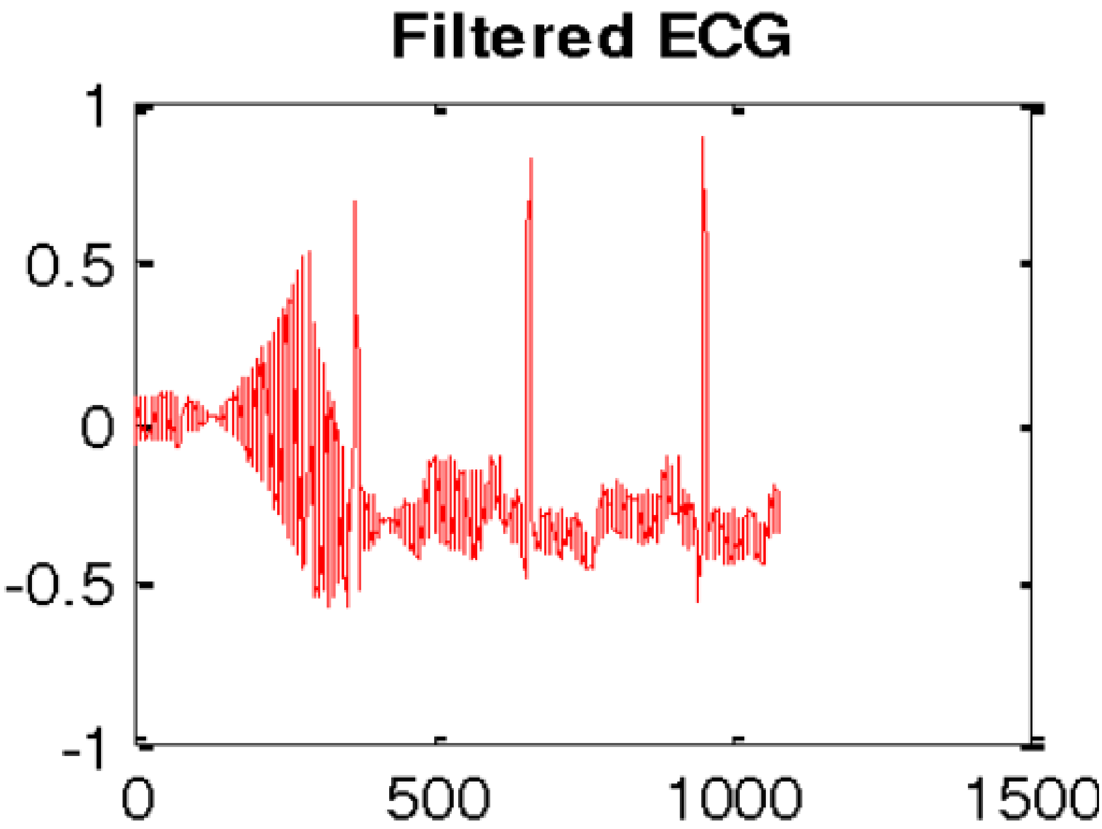

Figure 5.6: Filterd ECG

5.2 MATLAB code

MATLAB code to calculate SNR Fs = 1000;

t = 0:1/Fs:1;

f0 = 50;

signal = 0.8 * sin(2*pi*f0*t);

noise$_{p}ower$ = 0.2;

noise = sqrt(noise$_{p}ower) * randn(size(t))$;

noisy$_{s}ignal = signal + noise$;

signal$_{p}ower = rms(signal)^2$;

noise$_{p}ower = rms(noise)^2$;

snr$_{d}b = 10 * log10(signal_{p}ower/noise_{p}ower)$;

fprintf('SNR:

figure;

subplot(2,1,1);

plot(t, signal, 'b', 'LineWidth', 1.5);

title('Original Signal');

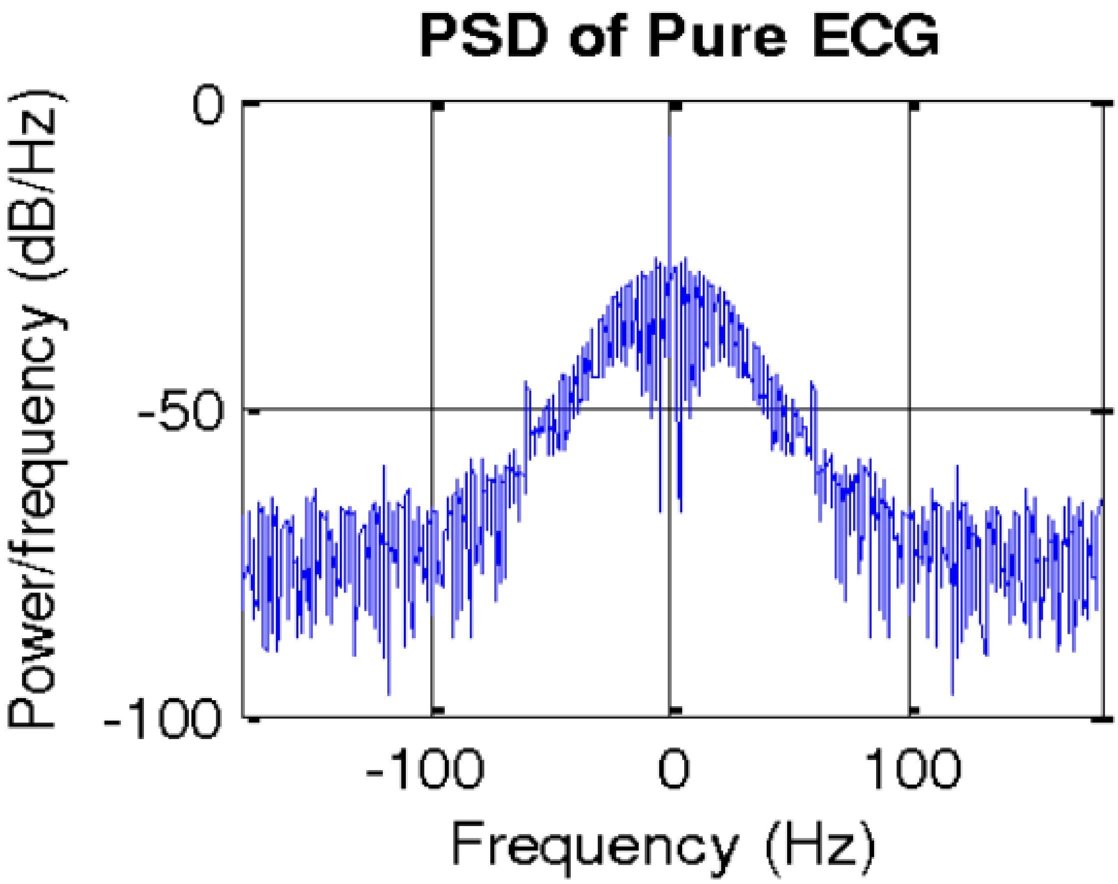

Figure 5.7: Power spectral density of pure signal

xlabel('Time (s)');

ylabel('Amplitude');

grid on;

subplot(2,1,2);

plot(t, noisy$_{s}ignal,'r','LineWidth',1.5$);

title('Noisy Signal');

xlabel('Time (s)');

ylabel('Amplitude');

grid on;

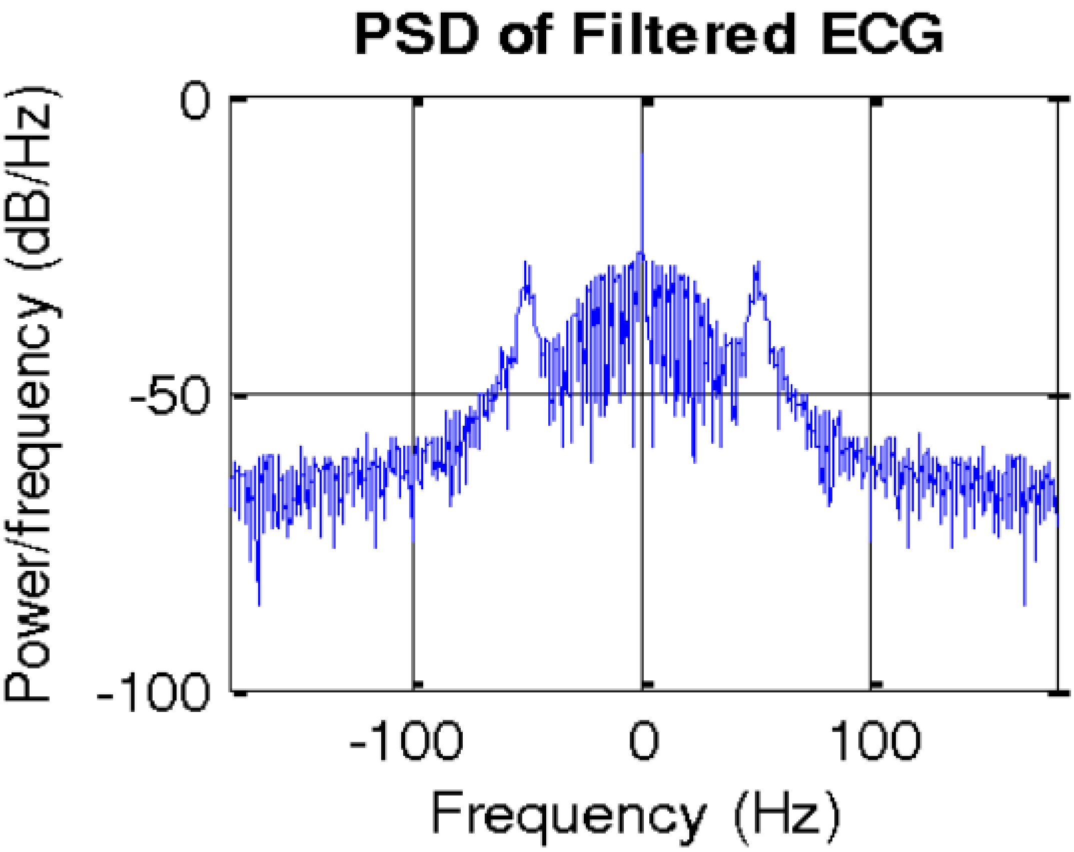

Figure 5.8: Power spectral density of filterd signal

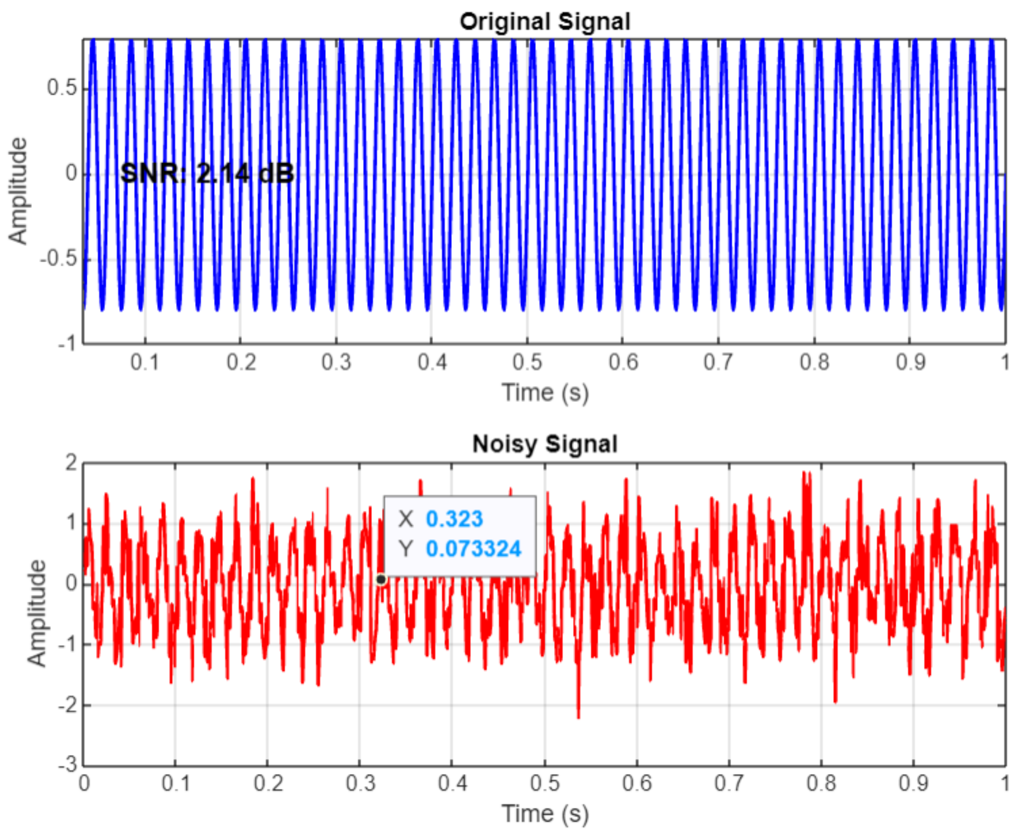

Figure 5.9: SNR ratio of the original signal and noisy signal

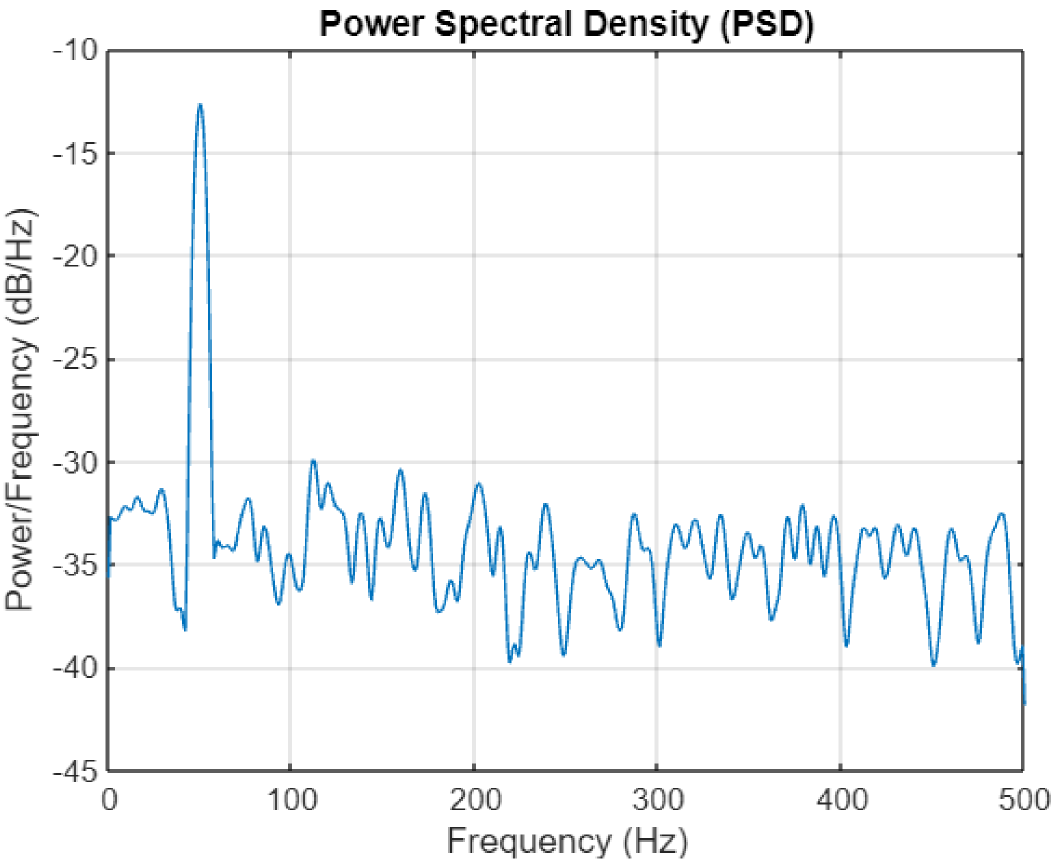

Figure 5.10: Power spectral density

Type of FIR Filter	Filter order	Output SNR	Adder	Delay units
Equiripple	582	7.1544	581	581
Least Square	298	5.069	298	297
Bartlett	298	-4.873	298	298
Blackman	298	-5.9249	298	298
Hamming	298	-4.217	298	298
Hann	298	-10.3437	298	298
Rectangular	298	3.8913	298	298
Kaiser	298	1.9241	298	298

Figure 5.11: Comparision for different FIR filter tecniques

CHAPTER 6

RESULTS AND DISCUSSION

The results were generated with the designed FIR, IIR filters applied to various ECG signals from MIT-BIH database. The filters like high pass , band stop and low pass with various windowing at order 56, 300, 450, 600 and IIR with different approximation methods in order 1, 2 and 3 shows different The graphs for the waveforms and their power spectral density before and after filtering are shown for various windows and IIR filters.By using these windows and IIR approximation methods, we designed the high pass filter of cut-off frequency 0.5 Hz for removing baseline wandering, band stop filter of cut-off frequency 59.50Hz - 60.5 Hz for removing power line interference and low pass filter of cut-off frequency 100Hz for removing EMG noise. The comparison of different FIR and IIR filters by calculation of SNR (Signal to noise ratio) and MSE (mean square error) was done at 56 and 1 orders.

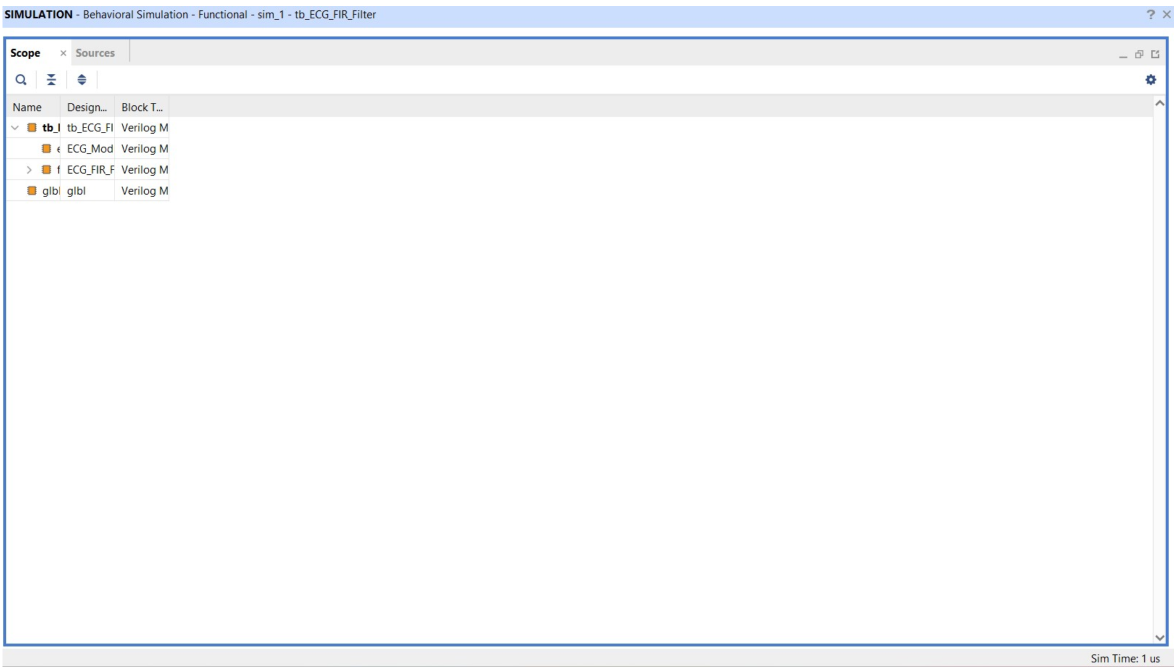

Figure 6.1: Output window

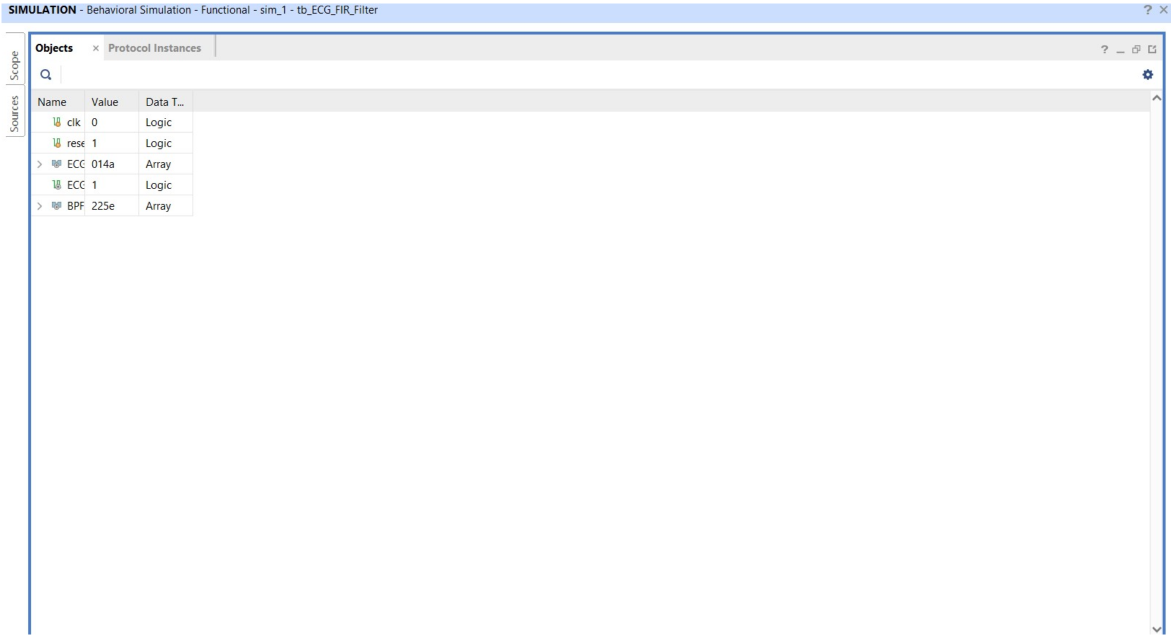

Figure 6.2: Output window

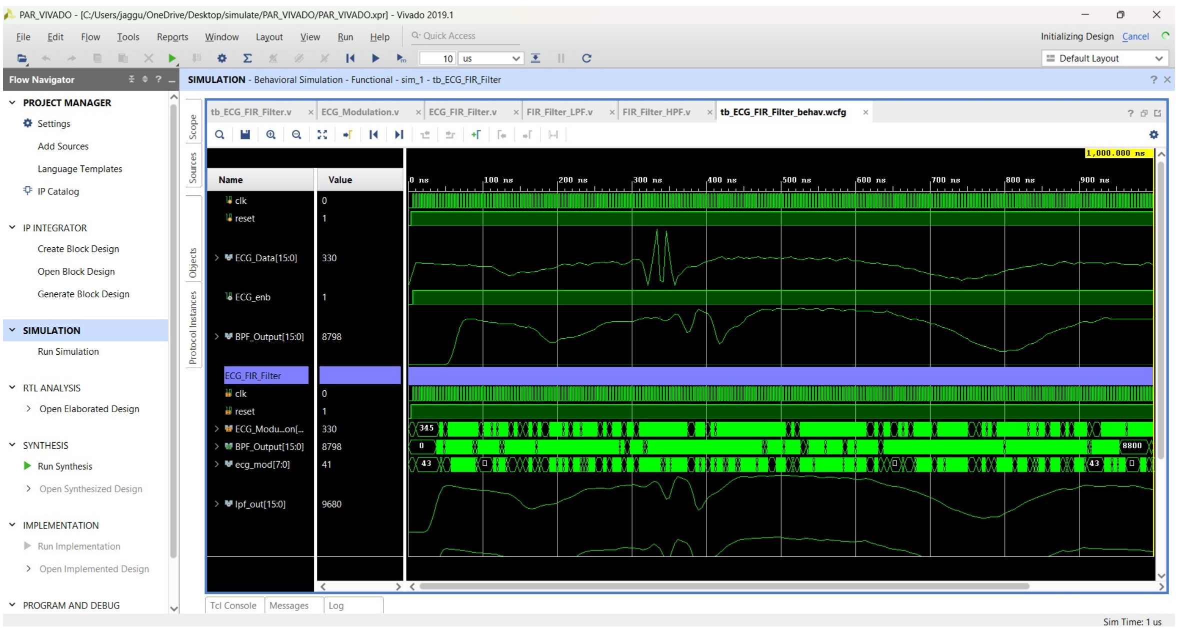

Figure 6.3: Graphical representation

CHAPTER 7

CASE STUDIES AND APPLICATIONS

7.1 case study1: Portable ECG Monitoring Device

Case studies illustrate the practical application of low-area FIR filters in real-world ECG signal processing scenarios. Researchers have demonstrated the deployment of compact FIR filters in portable ECG monitoring devices and implantable cardiac devices, highlighting the importance of area-efficient filters in medical device design. Hardware implementation considerations, such as Field-Programmable Gate Array (FPGA) or Application-Specific Integrated Circuit (ASIC) implementation, further underscore the relevance of low-area FIR filters in clinical settings.

Despite advancements in low-area FIR filter design, several challenges persist in optimizing filter performance while minimizing resource utilization. Future research directions may focus on exploring novel optimization algorithms, leveraging machine learning techniques for adaptive filtering, and integrating advanced signal processing architectures to enhance filter efficiency and effectiveness. Addressing these challenges will further advance the field of ECG signal processing and contribute to improved diagnostic capabilities in cardiology. A medical device company aims to develop a compact ECG monitoring device with onboard signal processing capabilities for noise reduction. The device must operate efficiently on limited hardware resources while ensuring accurate ECG interpretation. A medical device company developed a portable ECG monitoring device intended for ambulatory patient monitoring. The device aimed to provide continuous cardiac monitoring while minimizing size, weight, and power consumption. To achieve reliable ECG signal processing within constrained hardware resources, the design team implemented low-area FIR filters for noise reduction.

The engineers employed a windowing technique to design FIR filters with optimized coefficients for noise suppression. By carefully selecting the filter order and window type (e.g., Hamming, Kaiser), they achieved a balance between filter performance and hardware efficiency. The FIR filters were implemented on a low-power microcontroller unit (MCU) to ensure real-time signal processing without compromising battery life.

Performance evaluation using clinical ECG datasets demonstrated significant noise reduction capabilities, enabling accurate detection of cardiac abnormalities. The compact FIR filter design allowed seamless integration into the portable monitoring device, making it suitable for ambulatory use in diverse healthcare settings. This case study highlights the practical implementation of low-area FIR filters to enhance the diagnostic utility of portable ECG monitoring devices.

7.2 casestudy2: Implantable Cardiac Device

In another case, researchers focused on implementing low-area FIR filters within an implantable cardiac device for continuous monitoring of cardiac activity in patients with arrhythmias. The objective was to develop a miniature device capable of detecting and recording ECG signals while conserving battery life and minimizing hardware footprint.

Using optimization-based design techniques, the research team optimized FIR filter coefficients to achieve effective noise reduction with minimal computational overhead. The filter design was tailored to meet stringent size and power constraints required for implantable devices. Hardware implementation was carried out using custom-designed ASIC (Application-Specific Integrated Circuit) technology to ensure efficient signal processing within the limited space available.

Clinical validation studies demonstrated the efficacy of the low-area FIR filters in reducing noise artifacts and improving the accuracy of arrhythmia detection. The implantable cardiac device successfully integrated compact FIR filtering capabilities, enabling long-term monitoring and remote transmission of ECG data to healthcare providers. This case study underscores the importance of low-area FIR filters in advancing implantable medical technologies for cardiac care.

7.3 case Study 3: Wearable ECG Patch

A research project focused on developing a wearable ECG patch for continuous cardiac monitoring in remote or home-based settings. The objective was to design a compact, battery-operated device capable of acquiring and processing ECG signals in real-time, with a focus on minimizing power consumption and ensuring user comfort.

Engineers utilized low-area FIR filters to preprocess ECG signals captured by the wearable patch. By implementing optimized filter designs with reduced computational complexity, they achieved efficient noise reduction while preserving signal integrity. The FIR filters were integrated into the patch's embedded system, leveraging low-power microcontrollers for signal processing tasks.

Field trials involving volunteer subjects demonstrated the feasibility and performance of the wearable ECG patch equipped with low-area FIR filters. The device provided reliable cardiac monitoring without causing discomfort or interference with daily activities. Future enhancements may involve incorporating adaptive filtering techniques and wireless connectivity for seamless data transmission to healthcare providers.

CHAPTER 8

CONCLUSION

In conclusion, the utilization of a low-area FIR filter for noise reduction in ECG signals presents a highly effective approach within biomedical signal processing. Throughout this investigation, it has become evident that carefully designed FIR filters can significantly diminish noise while preserving essential features of the ECG waveform. This method proves practical and feasible for real-time applications, showcasing its potential for enhancing signal quality. The filtered ECG signals display improved clarity, a heightened signal-to-noise ratio, and reduced artifacts, particularly around critical ECG components like P-waves, QRS complexes, and T-waves. Furthermore, the computational efficiency of low-area FIR filters ensures suitability for embedded systems and wearable devices, meeting stringent processing demands without excessive resource consumption. Successful deployment involves meticulous filter design, validation with real-world datasets, and consideration of implementation constraints. Looking ahead, future research could explore adaptive FIR filters, machine learning integration for noise classification, and broader applications beyond ECG noise reduction, highlighting the enduring impact of FIR filtering in advancing biomedical signal processing capabilities.

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