

FPGA IMPLEMENTATION AND CAD SYSTEM OF ELECTROCARDIOGRAPHY FOR BIPOLAR LEADS USING HAAR WAVELET TRANSFORMATION

*Project Report submitted in partial fulfillment of the requirement for the
degree of*

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

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DECLARATION BY THE STUDENT

We hereby declare that the work reported in the B-Tech thesis entitled “**FPGA Implementation and CAD System of Electrocardiography for Bipolar Leads using Haar Wavelet Transformation**” submitted at **Jaypee University of Information Technology, Waknaghat India**, is an authentic record of my work carried out under the supervision of **Dr. Shruti Jain**. We have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the B. Tech project report entitled “**FPGA Implementation and CAD System of Electrocardiography for Bipolar Leads using Haar Wavelet Transformation**”, submitted by **Priya Verma** (131091), **Nikita Bansal** (131096) and **Kanika Thakur** (131099) in fulfillment for the award of Bachelor of Technology in Electronics and Communication Engineering by the Jaypee University of Information Technology, is the record of candidate’s own work carried out by him/her under my supervision. This work is original and has not been submitted partially or fully anywhere else for any other degree or diploma.

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विद्या तत्व ज्योतिसमः

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The project completion is an achievement to us, but it is would not be possible without the support and guidance of the people behind it.

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LIST OF ABBREVIATIONS & ACRONYMS

ECG	Electrocardiograph
FPGA	Field Programmable Gate Array
IA	Instrumentation Amplifier
RLD	Right Leg Driven
CMRR	Common Mode Rejection Ratio
DC	Direct current
HPF	High Pass Filter
LPF	Low Pass Filter
BPF	Band Pass Filter
LL	Left Leg
LA	Left Arm
RA	Right Arm
RL	Right Leg
CLB	Configurable Logic Blocks
aVR	Augmented Vector Right
aVL	Augmented Vector Left
aVF	Augmented Vector Foot
CAD	Computer Aided Design
VHDL	VHSIC Hardware Descriptive Language
RF	Radio Frequency
ADC	Analog to Digital converter
STFT	Short Term Fourier Transform
ROI	Region of Interest

ABSTRACT

Hardware Optimization

The main aim of our project is to optimize the hardware of ECG circuit by reducing the number of components in the circuitry of ECG to make the system less expensive. The components we have used in our optimized proposed ECG circuit are Instrumentation Amplifier, RLD circuit to reduce the common mode interference, reduced DC offset remover circuit, Notch filter to reduce RF interference, power line interference and muscle noise. We have used a bio-potential amplifier in such a manner that it reduces noise, RF interference; DC offset value, and common voltage from the existing circuit. In this project, we have shown how we can burn FPGA with the help of serial port communication.

Software Optimization

We have collected different ECG images from- http://www.beecardia.com/physiobank/database/ptbdb/s0530_re-patient278 upon which we have applied data preprocessing, feature extraction, data partitioning and data classification using SVM classifier. In this project we have use Haar wavelet as feature extraction technique and calculated several terminologies like overall accuracy, precision, misclassification rate etc which yields maximum accuracy of 95% if we consider all features (mean, standard deviation and energy) in one.

CHAPTER-1

INTRODUCTION TO ECG

Electrocardiography (ECG) is the procedure which records the electrical activity of the heart using electrodes placed on various parts of the body over a period of time. An electrocardiogram is a mechanism which detects the troubles associated with the heart's electrical activity. An ECG can be used to measure the BPM, heart chamber's size and location, and reveals the presence of any vandalism in the heart's muscle cells and the impact of cardiac drugs. An electrocardiograph is an instrument which is used to implement electrocardiography, and generates the electrocardiogram. The heart also known as a muscular pump consists of four chambers out of which upper two chambers are called atria and lower two chambers are called ventricles. Contraction of heart muscles occur due to natural electrical system which pumps blood via heart into the lungs and to the rest of the body. Heart is a muscular tissue in a way that it allows itself to pump blood throughout the body. The heart pumps blood due to which an action potential is generated when the heart wall consisting of muscle cells contracts. This action potential generates currents (electrical) that circulates throughout the body from the heart. The circulating currents generates minor differences in electrical potential between various locations in the body and these potentials can be detected and recorded through surface electrodes attached to the skin. These bio-potentials produces waveforms which are called electrocardiogram (ECG) waves which is a written graph of the electrical activities of the heart [1].

A semiconductor device, FPGA which is also an IC can be programmed again and again after manufacturing by the user to meet his requirements. It comprises of array of configurable logic blocks (CLB's) and switches (which forms connection between CLB's). Implementation of logic designs can be carried out on FPGA's by using either VHDL (VHSIC Hardware Description Language) or Verilog code on Xilinx Simulator [2].

An array of simple CLBs and switches which are used to identify the connections between CLBs are called FPGAs. Figure 1.1 shows the comprehensive structure of FPGA. Configuration of each CLB in FPGA is done individually first and then the configuration of switches is done to connect or disconnect CLBs to implement algorithm., The most commonly used technique is based on the usage of RAM/flash switches. Static RAM or flash bits manage the pass transistors for each interconnection in this technique. For example, the switch closes or opens by loading bit 1 or 0, respectively. Managing switches manually is impossible because the current FPGAs contain up to a large number of gates. Thus for configuring the switches, development software's are provided by the FPGA manufacturers that outputs a bit stream.

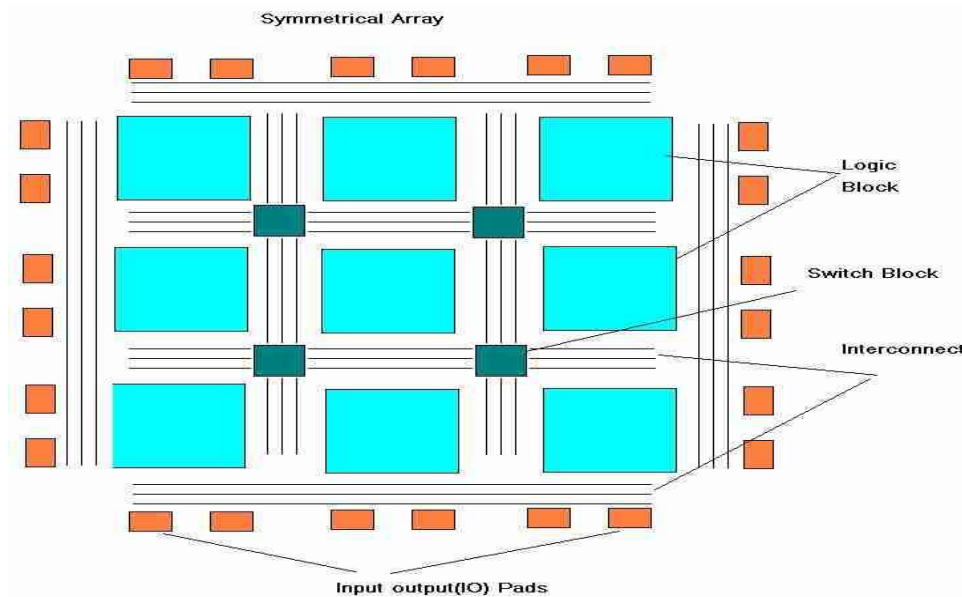


Figure 1.1: FPGAs structure [3]

FPGA gives good performance, high speed clock, high bandwidth, and facilitates simultaneously multiple operations. FPGA's has its applications in various fields like speech recognition, computer hardware emulation, metal detection etc.

1.1 Other ECG Signals

In addition to the conventional ECG signals, there are certain specific signals that are sometimes required. While the use of these is rare, the biomedical equipment technician or clinical engineer should be aware of them.

1.1.1 Interdigital ECG

This signal is taken between any two fingers. The inter digital ECG is used primarily in home monitoring of patients (especially those with implanted pace makers- reduced heart rate often precedes battery failure). One common technique is to use the index finger of each hand as signal source.

1.1.2 Esophageal ECG

In this type of ECG recording, an electrode is set placed in the esophagus close to the heart. A special ECG catheter containing a “pill electrode”, an external bipolar pacing electrode, or a special electrode equipped nasogastric tube is used to acquire the electrical signal. An principal application of esophageal ECG is to examine atrial activity of the heart. The relative amplitudes of the P and R waves are used to establish the position for atrial sensing.

1.1.3 Toilet Seat ECG

This type of recording uses twin electrodes placed on either side of toilet seat. The acquired signal is often connected to a computer in which arrhythmia detection software is running. The purpose is to detect cardiac arrhythmias that sometimes occur when patient is straining during defecation.

1.2 Twelve Lead ECG System

The standard twelve-lead ECG is a depiction of the electrical activity of heart measured from electrodes placed on various parts of body. Below described are the basic elements of the ECG and the lead system used to measure the ECG features.

1.2.1 Placement of the 12 Lead ECG:

The 12-lead ECG gives spatial details regarding the electrical activity of the heart approximately 3 directions perpendicular to each other:

- First: Right \Leftrightarrow Left
- Second: Superior \Leftrightarrow Inferior
- Third: Anterior \Leftrightarrow Posterior

A particular placement in space is represented by each of these 12 leads, as mentioned below :

Bipolar limb leads (frontal plane):

Lead I, lead II and lead III are known as the *limb leads*. The electrodes placed on the limbs (one on each arm and one on the left leg) form these signals. The Einthoven's triangle is formed by the limb leads placed on these points.

- **Lead I:** Lead I is the difference of the voltage between the LA electrode(+) and RA electrode(-).

$$I=LA-RA$$

- **Lead II:** Lead II is the difference of the voltage between the LL electrode (+) and the RA electrode(-).

$$II=LL-RA$$

- **Lead III:** Lead III is the difference of the voltage between the LL electrode(+) and the LA electrode(-).

$$III=LL-L$$

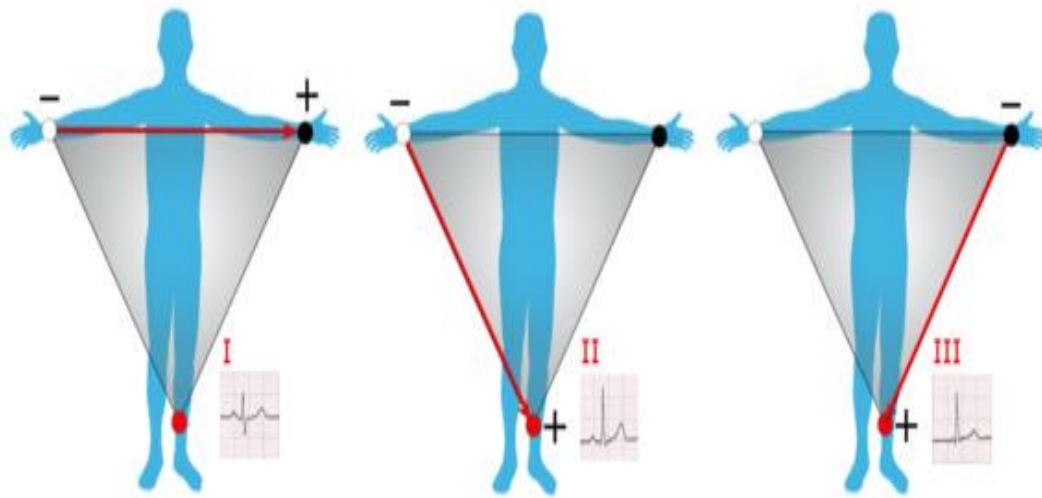


Figure 1.2: Bipolar Limb Leads [4]

Augmented unipolar limb leads (frontal plane):

There are three augmented limb leads- aVR, aVL, and aVF. They use the same three electrodes as the first three leads of ECG system. But their negative pole is the Goldberger's central terminal which is a combination of the inputs from the other two limb electrodes.

- **Lead aVR:** Lead aVR has the (+) electrode on the right arm. The combination of the LA electrode and the LL electrode becomes the (-) pole. This lead is from RA (+) to [LA & LL] (-) (Rightward)

$$aVR = RA - 1/2(LA + LL)$$

- **Lead aVL:** Lead aVL has the (+) electrode on the left arm. The combination of the RA electrode and the LL electrode becomes the (-) pole. This lead is from LA (+) to [RA & LL] (-) (Leftward)

$$aVL = LA - 1/2(RA + LL)$$

- **Lead aVF:** Lead aVF has the (+) electrode on the left leg. The combination of the RA electrode and the LA electrode. This lead is from LL (+) to [RA & LA] (-) (Inferior)

$$aVF = LL - 1/2(RA + LA)$$

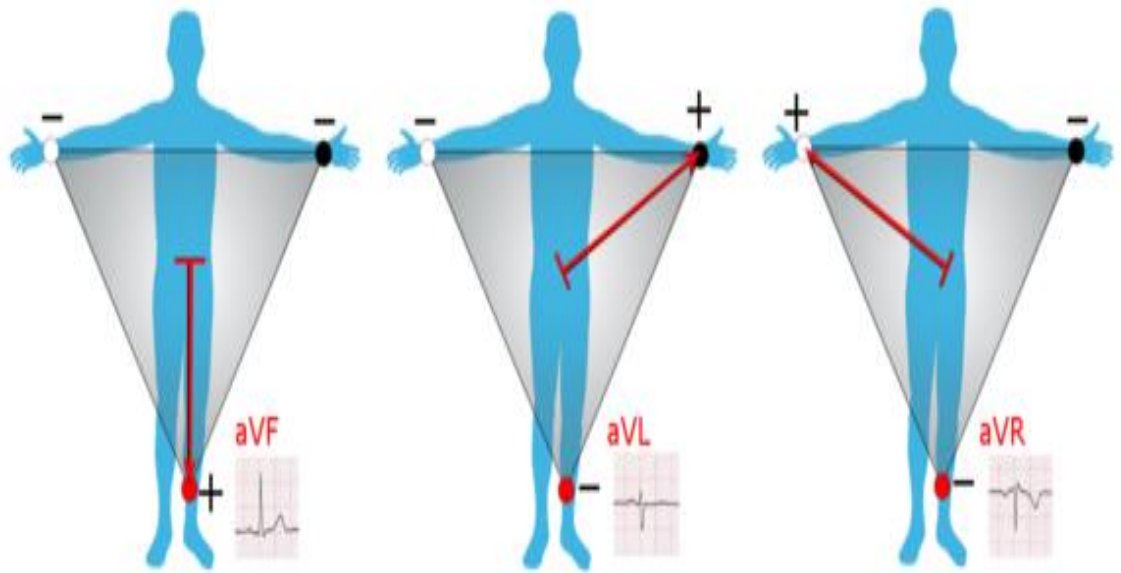


Figure 1.3: Augmented Limb Leads [4]

Unipolar (+) chest leads (horizontal plane):

- Leads V1, V2, V3: This lead lies in Posterior Anterior
- Leads V4, V5, V6: This lead lies in Right Left, or lateral.

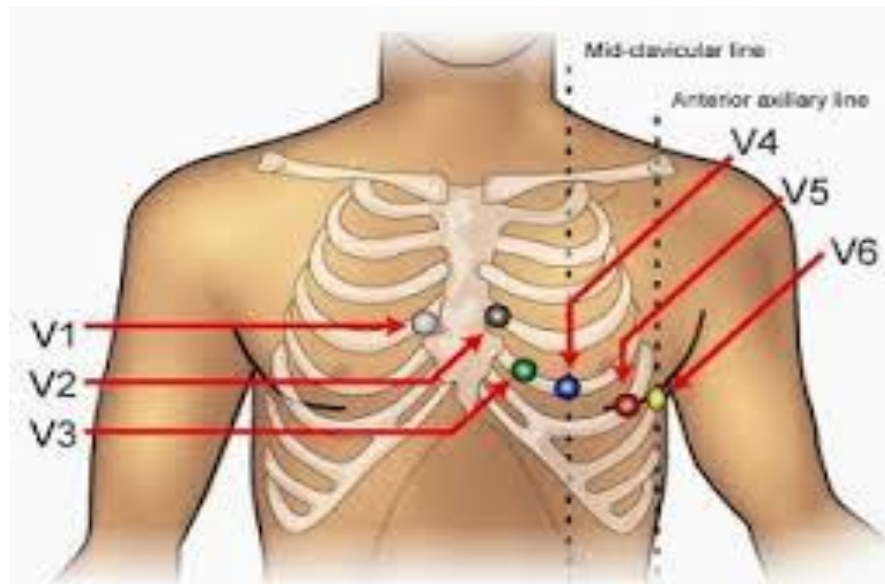


Figure 1.4: Unipolar Chest Leads [5]

1.3 Block Diagram of ECG

In the following section we are going to study the building blocks of existing ECG circuit as shown in figure 1.5.

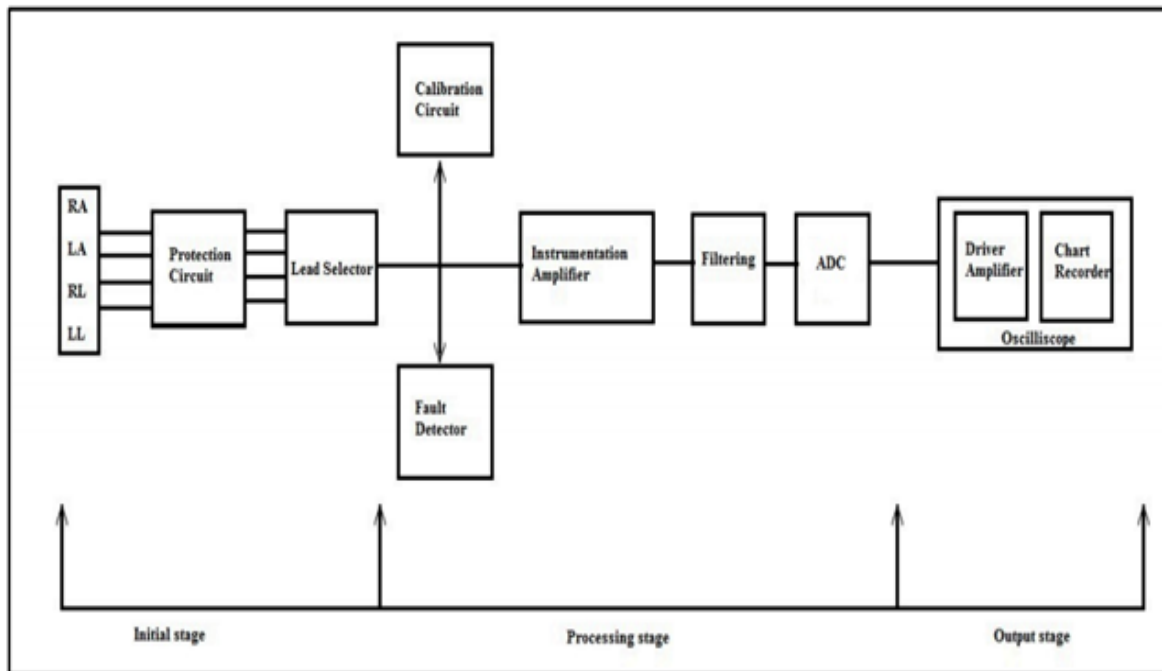


Figure 1.5: Instrumentation Diagram of ECG [7]

- a. **Protection Circuit:** This circuit protects the electrocardiograph which may damage under certain conditions due to high voltages or current spikes that may appear at the input.
- b. **Lead Selector:** The lead selector of the electrocardiograph is connected to each electrode placed on the human body. This block determines necessary electrodes for a particular lead and connects them to the remaining circuit. One or more leads to be recorded are selected by it.
- c. **Instrumentation amplifier:** Sometimes the amplification of the difference of two signals is desired..Due to its low input resistance, the difference amplifier may not satisfy criteria for circuit design. .In order to design an IA, a difference amplifier in combination with two non-inverting amplifiers is used as shown below in fig.1.6 which yields output voltage as:

$$V_{out} = \left(1 + \frac{2R_2}{R_1}\right) \left(\frac{R_4}{R_3}\right) (V_2 - V_1) \quad (1)$$

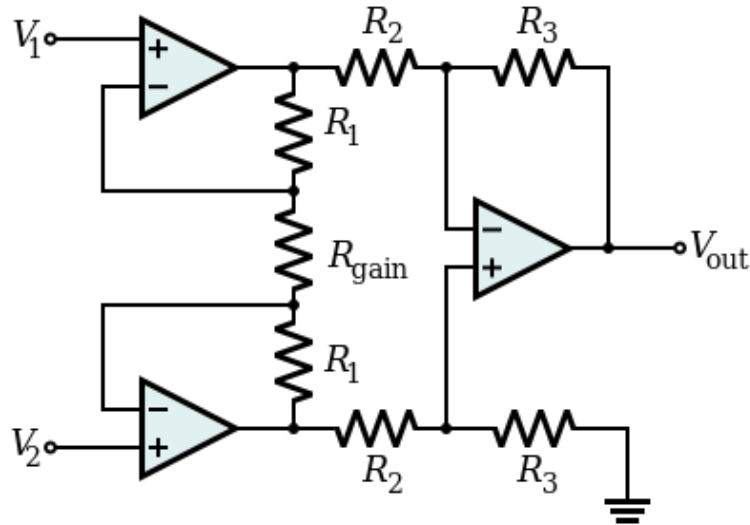


Figure 1.6: Instrumentation Amplifier [8]

- d. **Filters:** Unwanted noise is eradicated using filters. ECG generates very small signal levels of around 1mV, so filters are effectively used to remove a wide range of noise. Several reasons which are a cause of noise are mains hum (50/60Hz), unstable dc offset, interface of electrode and body , electrical noise from equipment in the environment, muscle noise and from internal dc/dc converters which are within the equipment itself.
- e. **ADC:** A process in which a continuously varying analog signal is converted into a multi-level digital signal is called ADC.

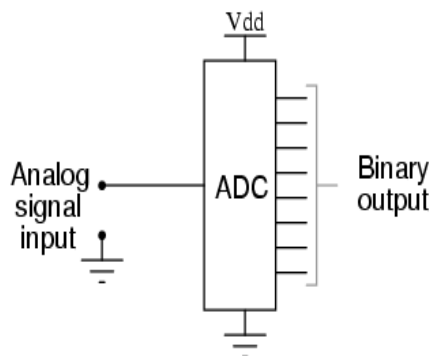


Figure 1.7: ADC [9]

- f. **Right leg driven circuit:** A reference ground potential point is provided by the right leg driven circuit on the patient's right leg as shown in Fig1.8. This circuit is used to lower down the noise levels on patient and reduces 60 Hz noise in a feedback configuration. Common mode voltage is as calculated by the formula below :

$$V_{cm} = \frac{R_{RL}i_D}{1 + \frac{2R_F}{R_a}} \quad (2)$$

where, R_{RL} stands for Right leg resistance, R_F stands for feedback resistance , i_D stands for Displacement current , R_a stands for Averaging resistance

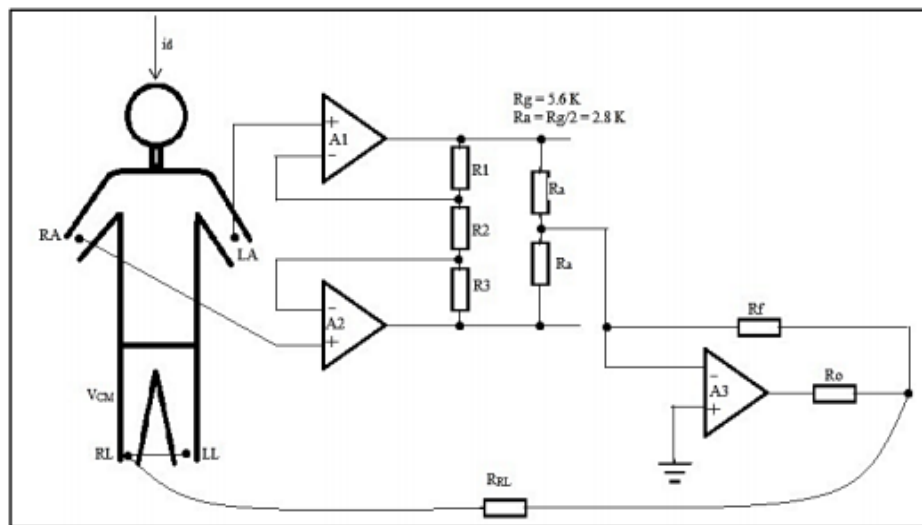


Figure 1.8: Right Leg Driven Circuit [7]

- g. **Oscilloscope:** Using driver amplifier and then chart recorder, the output of ECG system is displayed by this device.

CHAPTER-2

LITERATURE REVIEW

Author	Year	Method	Result
Pradhan UU <i>et al</i> [11]	2015	PCB, IC LM324 (preamplifier), IC LM386(ECG amplifier), 3 sensors, PSPICE analysis, software version 1.67	3 Lead ECG amplifier system used to avoid power line interference, noise free ECG signals with low cost are designed
Dhiman A <i>et al</i> [10]	2015	Instrumentation amplifier , high pass filter, right leg driven circuit	Hardware optimization of electronic circuit of ECG by using biopotential amplifier
Gupta R <i>et al</i> [7]	2014	Instrumentation amplifier , protection circuit, lead selector, filters, right leg driven circuit	Indigenous design of electronic circuit for ECG
Mesharam VP <i>et al</i> [12]	2014	FFT, Windowed FFT , multilayer perception(MLP) network to maximize accuracy	DSP based ECG abnormality classification using artificial neural networks
Mittal V <i>et al</i> [13]	2013	Principle component analysis of PCA, a mathematical procedure for orthogonal transformation, wavelet technique	Denoising and detection of ECG point wavelet and PCA
Vikesh V <i>et al</i> [20]	2013	MATLAB	Implemented ECG signal using MATLAB, served as computerized system
Muthuchudhar A <i>et al</i> [14]	2013	Four processes of ECG signal analysis are defined data compression, denoising, feature extraction, classification	Study of processes involved in ECG signal analysis is done
Jembula KK <i>et al</i> [19]	2013	Short term fourier transform, wavelet transformation , wavelet analysis using MATLAB	Designed ECG system on FPGA
Zhang Y <i>et al</i> [15]	2012	ADS1298, ADC, Integrated input multiplexers analog low pass filter, digital filter	Design ECG acquisition system based on ADS1298
Khandait PD <i>et al</i> [18]	2012	Wavelet transformation	Efficient ECG abnormalities

		techniques for feature extraction , beat detection	recognition using Neuro- Fuzzy approach
Shen T <i>et al</i> [16]	2010	Template matching method	Implemented 1 lead ECG, human identification system on normal population
Wavt Y <i>et al</i> [17]	2007	Preprocessing, Feature Extraction Classification	Analysed ECG for biometric recognition

CHAPTER-3

FPGA IMPLEMENTATION OF ECG CIRCUIT

We have optimized the existing ECG circuit by increasing its efficiency by the usage of Peak Detection Circuit and Notch Filter. Further we have also implemented our proposed ECG circuit on FPGA board.

3.1 Existing ECG Circuit 1

Circuit shown in Fig 3.1 is the existing ECG circuit having IA with preamplifiers and filters, Right leg driven circuit, DC offset remover circuit.

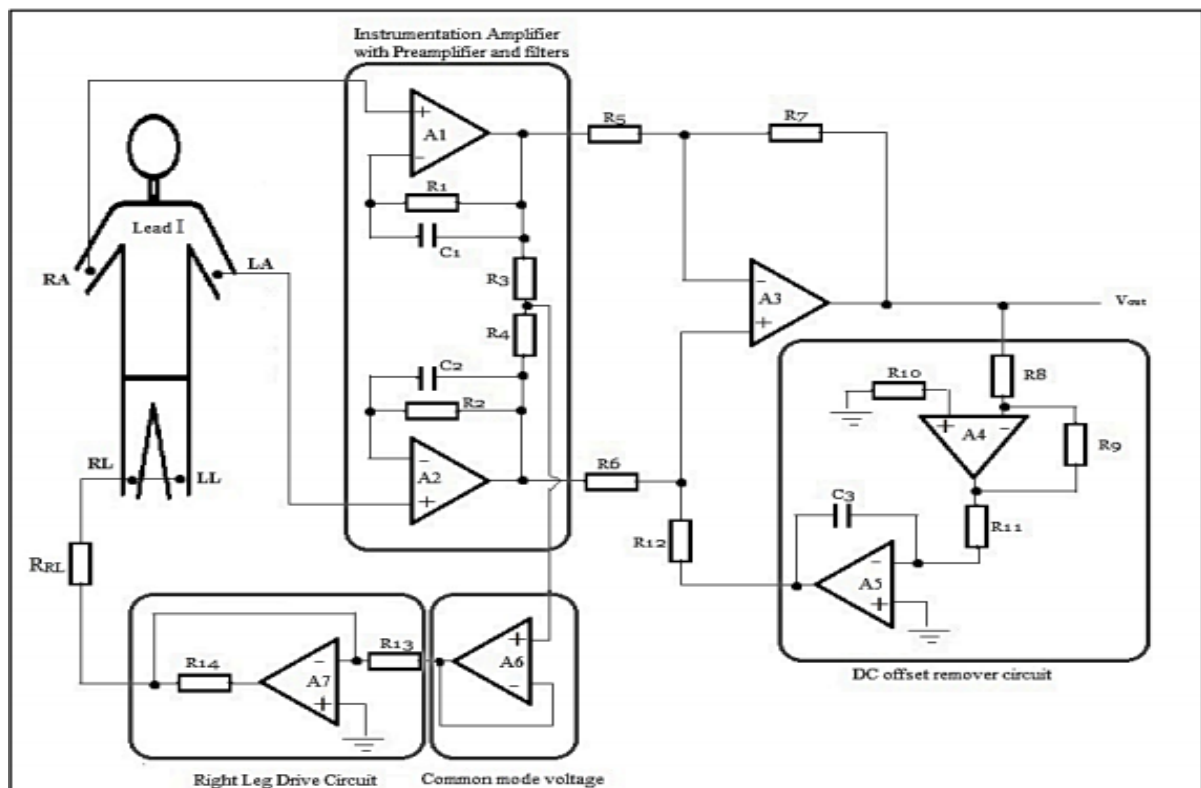


Figure 3.1: Existing ECG circuit 1[7]

1. **Inverter removal:** In spite of using inverter after RA this point has been kept at the (-) terminal of IA because for lead I, RA is at (-) terminal and LA is at (+) terminal.

2. **Common mode values and noise removal:** In order to increase CMRR, following methods are used to eradicate common mode values and noise from ECG

Right leg driven system: This is used to reduce noise when used in Feedback loop. A reference ground potential point is provided by the right leg driven circuit on the patient's right leg. This circuit is used to lower down the noise levels on patient and reduces 60 Hz noise in a feedback configuration.

3. **DC offset Removal and DC suppression:** The key parameters in bioelectric amplifiers are DC-suppression and DC-offset. A high gain level, a high CMRR [7], a equivalent input noise of low density, and a high input impedance are required by Bioelectric amplifiers. An IA is used as a front stage to obtain most of these features. But sometimes at the output of the IA, DC voltage levels appear which are generated by various things like electrode contact potentials, imbalance in impedances from electrodes placed at the input and input bias currents. Removal of these DC levels is important; else, output saturation phenomena will be generated when amplification is done in subsequent stages. Various techniques employed to remove the DC levels are described below:

4. **Filters:** The Instrumentation amplifier cascaded with the high pass filter with gain [10] is shown in figure 3.2. This circuit is used to eliminate DC level which comprises of feedback integrator which acts as an LPF. On the application of feedback, the DC component present in output voltage is eliminated and this whole stage therefore acts as a HPF having gain G. This circuit acts like an inverter circuit since input voltage is applied on inverting terminal as a result of which the input is amplified. Transfer function for the circuit shown in Figure 3.2 is given by the following equation:

$$H(\omega) = \frac{V_o}{V_i} = \frac{-G}{1 + \frac{(G+1)}{sR_3C}} \quad (3)$$

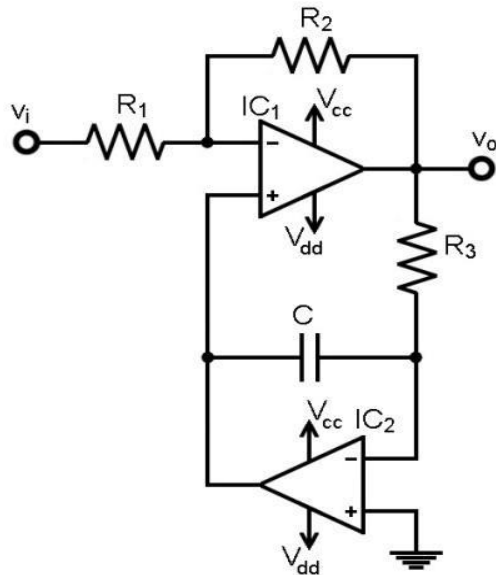


Figure 3.2: HPF with Differential amplifier part of IA [7]

LPF is used to reduce RF interference present in circuit [11]. At the front end of the IA, Filter should be used. Following figure 3.3 shows IA regulated with low pass filter as a result of which no filtering is required after IA.

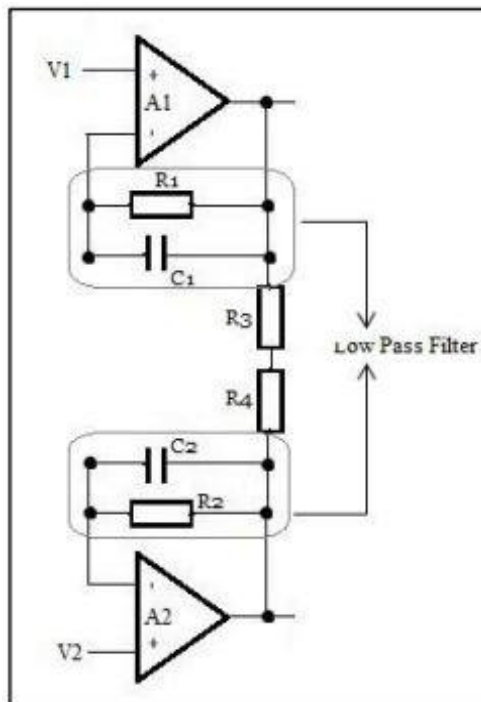


Figure 3.3: Low pass filter with IA [7]

3.2 Existing ECG Circuit 2:

Fig 3.4 shows the hardware optimized version of ECG circuit 1 for lead II using IA with preamplifiers and filters, Right leg driven circuit and DC offset remover circuit.

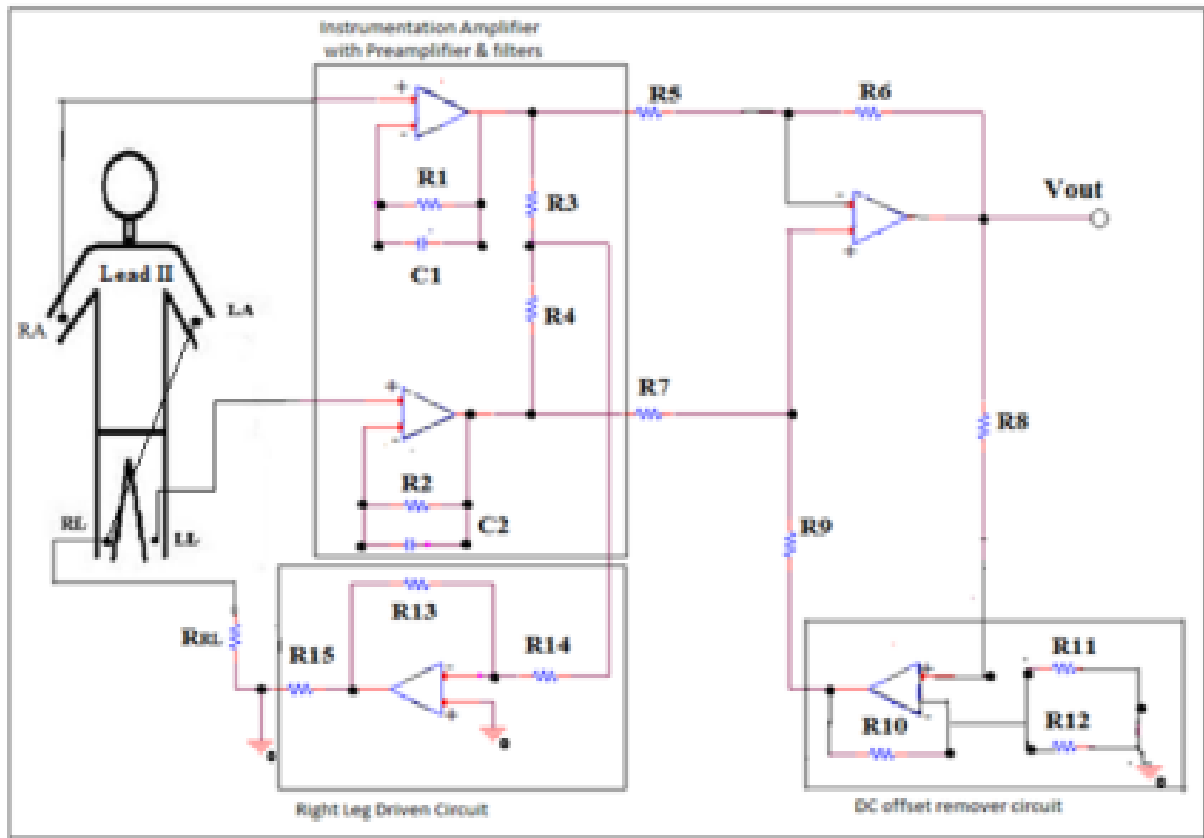


Figure 3.4 : Existing ECG circuit 2[10]

3.3 Limitations of Existing Circuits :

1. 50-60 Hz magnitude power line interference is required to be removed from the circuit
2. To carry out accurate ECG diagnosis, the detection of failure between electrode connection and the skin is required.

So, the effectiveness and capability of existing circuits discussed above can be enhanced by making various alterations .Below discussed are these changes:

1. As an alternate of low pass filter, application of Notch filter.

2. Peak detector circuit.

3.4 Proposed Circuit:

Fig 3.5 shows the proposed ECG circuit which includes Peak Detection Circuit, IA with notch filter, DC offset circuit, RLD and is a optimized modification of above two existing ECG circuits

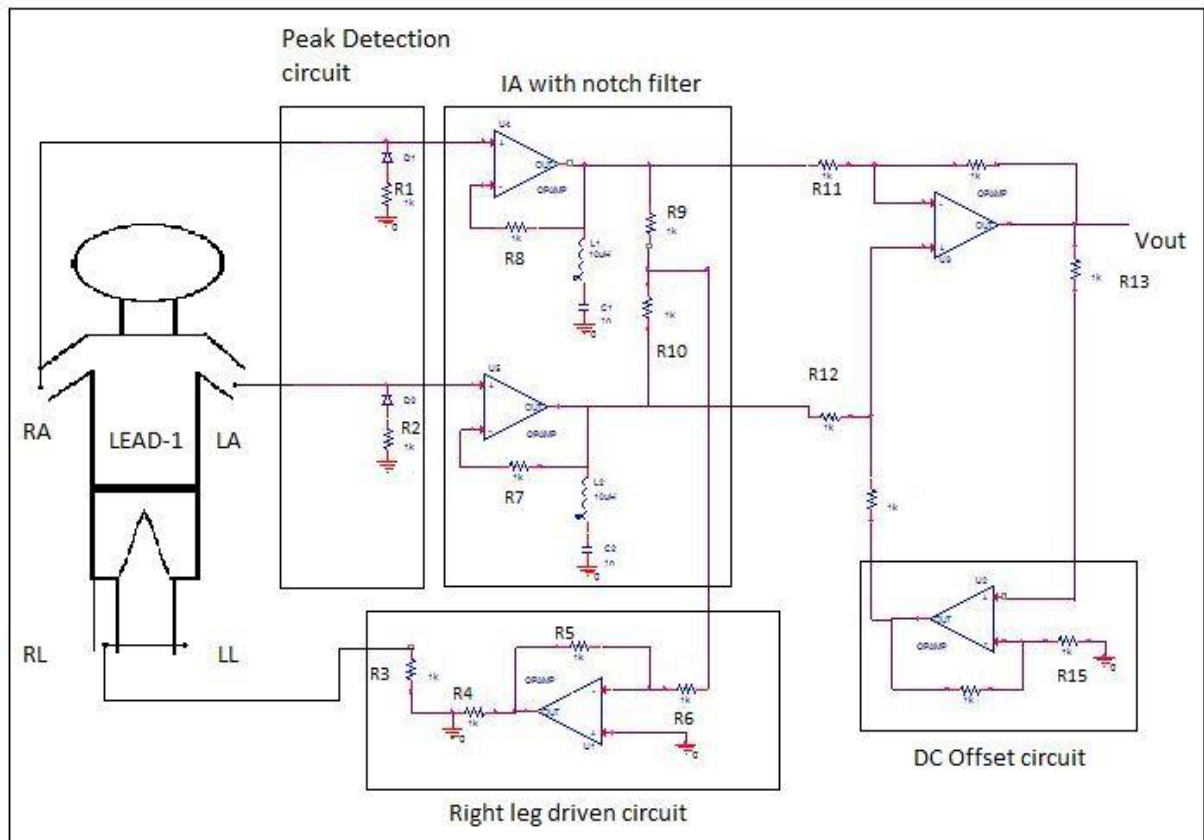


Figure 3.5: Proposed circuit of ECG

1) Notch filter

A band-rejection or a band-stop filter is used to pass most frequencies unchanged and to lessen those which lie in a certain range to extreme low levels. It is the converse of BPF. A notch filter is a band-rejection filter consisting of a narrow stop band .It has a high Q

factor. A particular frequency having a notch where signals are rejected is removed using a notch filter most of which are fixed frequency, but some of these are able to attune the notch frequency.

A notch filter is actually a band rejection filter which lets go all the frequencies except for a particular range of frequencies. It is a parallel combination of LPF and HPF [18].

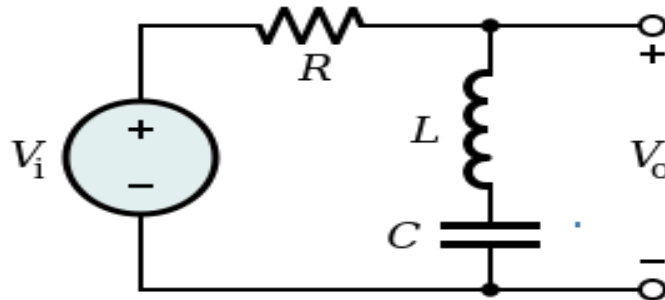


Figure 3.6: Design of simple notch filter using L and C [18]

Notch Filter in the audio domain

Anti-hum filter

Countries where 60 Hz power lines are used:

- Low Frequency \rightarrow 59 Hz
- Middle Frequency \rightarrow 60 Hz
- High Frequency \rightarrow 61 Hz

It depicts that all frequencies are passed through this filter, instead of those in the range of 59–61 Hz. Though its higher harmonics can still be there, mains hum from the 60 Hz power line is filtered out using notch filter. The filter has a 49–51 Hz range for countries having power transmission at 50 Hz. To reduce the hardware circuitry and to minimize the noise and RF interference, low pass filter is adapted with the IA in the current existing circuits of ECG. The RF interference and the muscle interference noise are removed using low pass filter. But to carryout accurate diagnosis and to get waveform free from noise,

power line interference of magnitude 50-60Hz also needs to be eradicated. A notch filter/band rejection filter is employed to remove this interference.

Notch filter's resonance frequency is given by the formula-

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad (4)$$

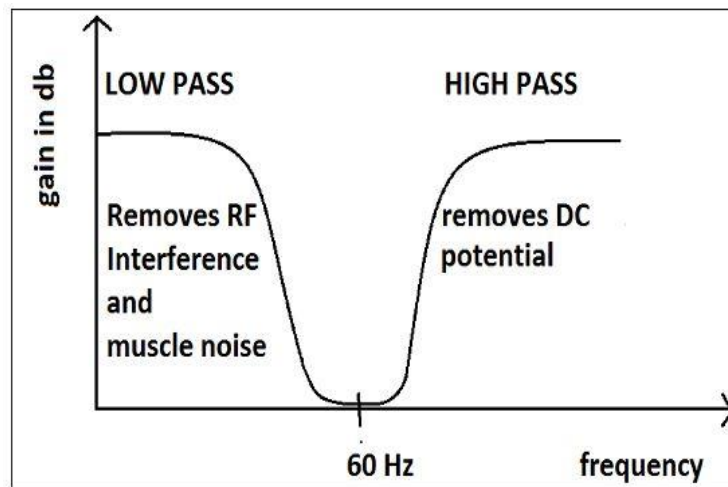


Figure 3.7: Notch Filter's Frequency Response [10]

High pass filter is used to remove DC potentials and low pass filter is used to remove RF interference. Power line interference is removed by the combination of both. In this project, 60 Hz power interference removal is done using notch filter designing.

Applications of notch filter :

1. In RF domain:

- a) *Avoidance of the carrier frequency:* In order to avoid the carrier frequency, a very narrow notch filter can be employed while computing the non-linearity of power amplifiers.
- b) *Wave trap:* A simple LC circuit which is also a notch filter is used for the removal of particular interfering frequency. Radio receivers that are in the vicinity of a transmitter are used in this technique to swamp all the other

signals. The signal is greatly reduced, from the local transmitter by the use of wave trap.

2. **In optical domain** : In optical domain, notch filters depend upon destructive interference.
3. **Use in amplifiers** : Notch filters are mainly used in the electric guitar amplifiers. Actually, a 'hum' at 60 Hz frequency is generated by this electric guitar. In order to make the best equipment and to amplify the signal generated by the electric guitar amplifier, this filter is used to minimize the hum. Various other application of notch filter includes its use in base instrument amplifiers and mandolin.
4. **Use in removal of unwanted harmonics** : In electronics and communication, the original signal interferes as a result of which the signal is distorted due to some noise (harmonics) which generates error in the output. Hence, unwanted harmonics are eliminated by these filters.

2) Peak Detection Circuit

These are used for quickly transforming input signals which are AC in nature. During the connection of electrodes with the body of the patient depending upon the selection of leads, sometimes there is a failure in the connection of electrode and the body of the patient[7]. This can result in no waveform or distortion in the ECG waveform which can lead to inaccurate analysis.

In to protect our ECG system from such kind of failures, we can include a peak detection circuit which is simply a connection of diode and a capacitor in series. In this circuit, capacitor charging and discharging will depend upon time constant $\tau = RC$.

3.5 Implementation in MATLAB

Implementation of proposed ECG circuit is done on pspice; some output values are recorded which are written in a text file and saved in MATLAB directory. To obtain the

desired ECG waveform as shown in Figure 3.8, the text file is loaded in MATLAB which is saved in the MATLAB directory.

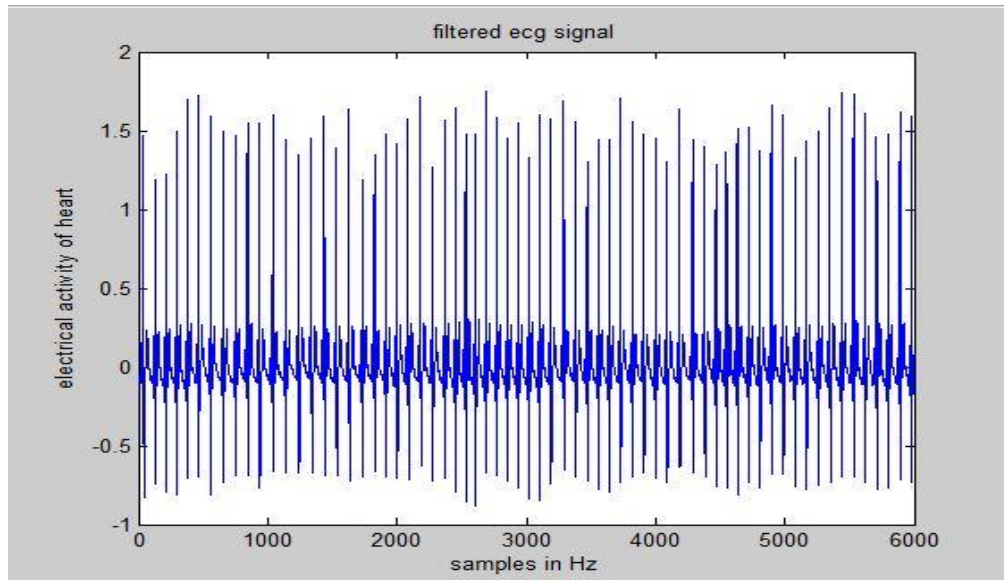


Figure 3.8: Waveform from our proposed ECG circuit

P, Q, R, S, T peaks of ECG waveform are shown in magnified view of our output in Figure 3.9. Using this we calculated BPM which comes out to be 67.

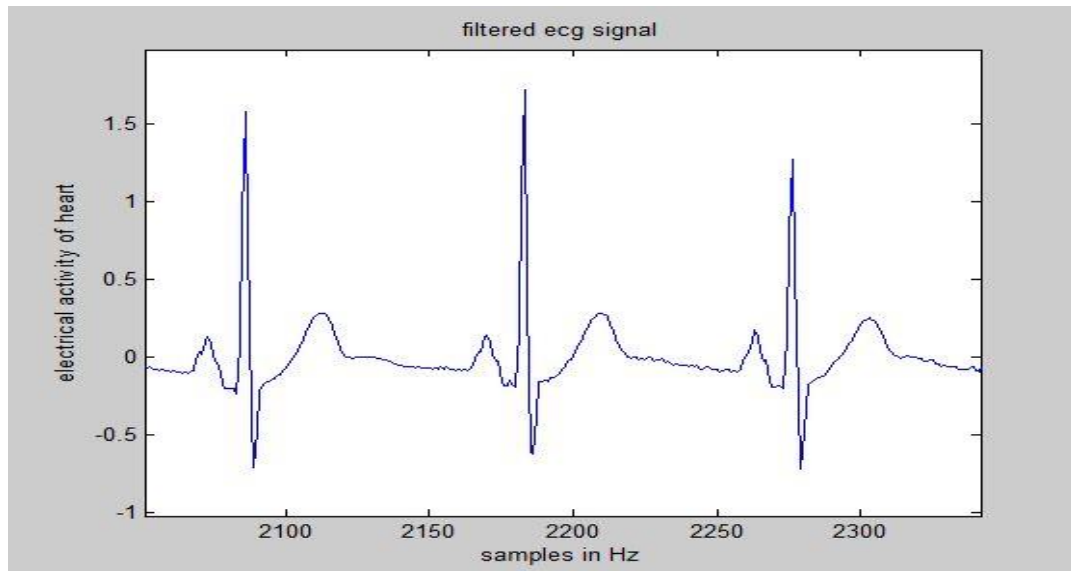


Figure 3.9: Magnified view of ECG waveform

3.6 Implementation in PSPICE

Here we have shown the output of IA part of ECG circuitry using two different waveforms where simulation settings were shown in Fig 3.10. Firstly we have given two sine waves of different amplitudes to IA whose result is shown in Fig 3.11. Secondly we have given two triangular waves of different amplitudes to IA whose result is shown in Fig 3.12, and then we have recorded the output waveform for the two cases.

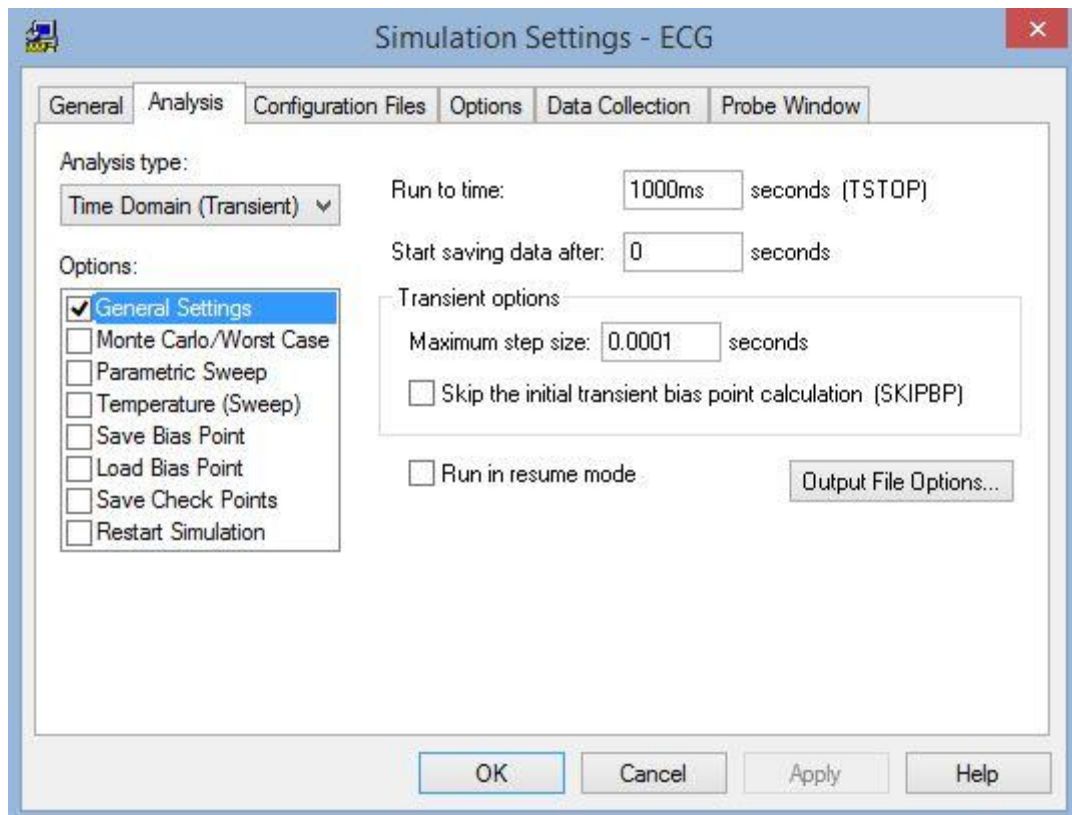


Figure 3.10: Simulation settings

3.6.1 Output using sin wave

A) Giving sine wave as input1

$V_{OFF} \rightarrow 0$

$V_{AMPL} \rightarrow 2$

$FREQ \rightarrow 50$

$AC \rightarrow 0$

B) Giving sine wave as input2

$V_{OFF} \rightarrow 0$

$V_{AMPL} \rightarrow 5$

$FREQ \rightarrow 50$

$AC \rightarrow 0$

Taking all resistor values to be 1k ohm, output is as shown below:

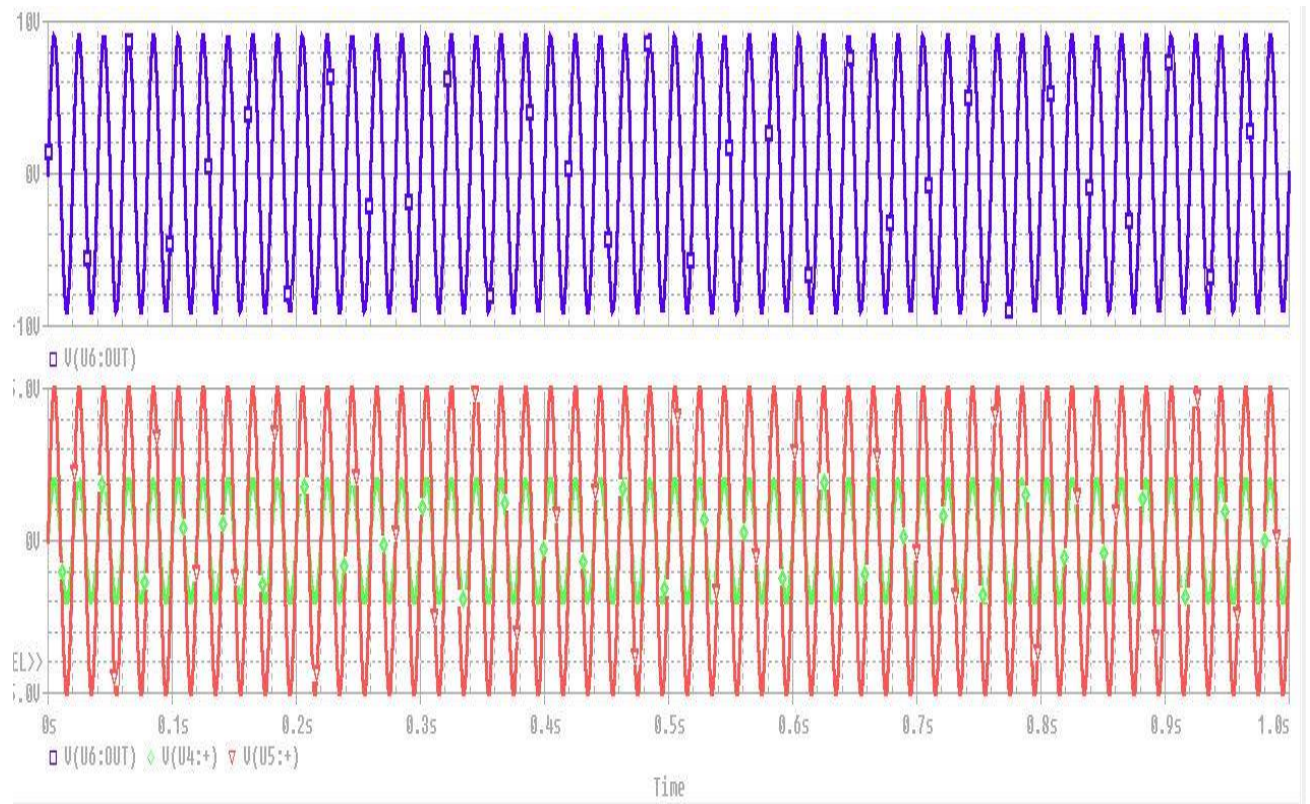


Figure 3.11: Output on PSPICE using sinusoidal wave

3.6.2 Output using triangular wave

A) Giving triangular wave as input1:

$V_1 \rightarrow 0$

$V_2 \rightarrow 2$

TD→0.02
TR→0.02
PW→0
PER→0.04

B) Giving triangular wave as input2

$V_1 \rightarrow 0$
 $V_2 \rightarrow 5$
TD→0.02
TR→0.02
PW→0
PER→0.04

Taking all resistor values to be 1k ohm, output is as shown below:

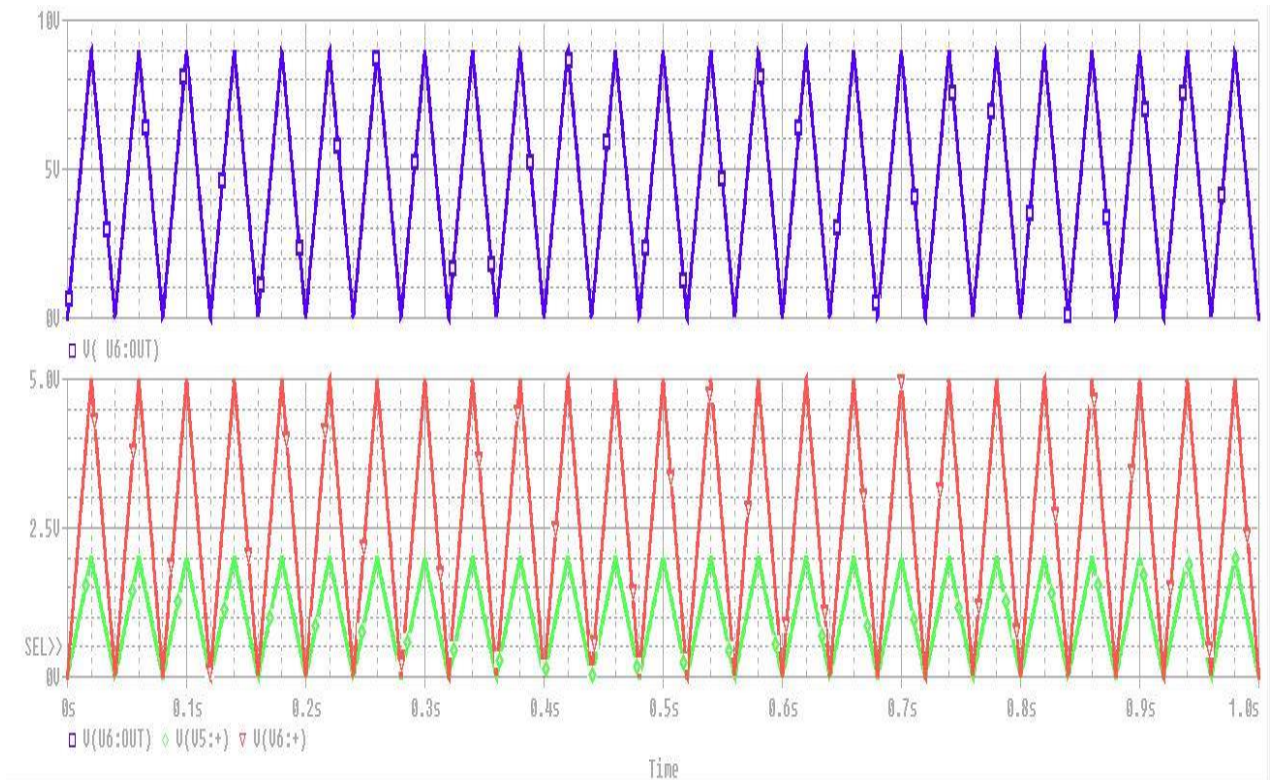


Figure 3.12: Output on PSPICE using triangular wave

3.7 Implementation on FPGA Board:

- The data is sent serially to the FPGA by MATLAB which is a set of database in binary format.
- FPGA is used to implement serial protocol using techniques involving Serial Communication.
- RAM stores the received serial data.
- Extracting features from RAM and then saved in new RAM.
- The data sent by MATLAB is retransmitted back to MATLAB by FPGA XC6SLX45
- The peak values are computed in new RAM after successful transmission.
- The heart rate value will be sent in PC after detecting the peaks of waveforms.

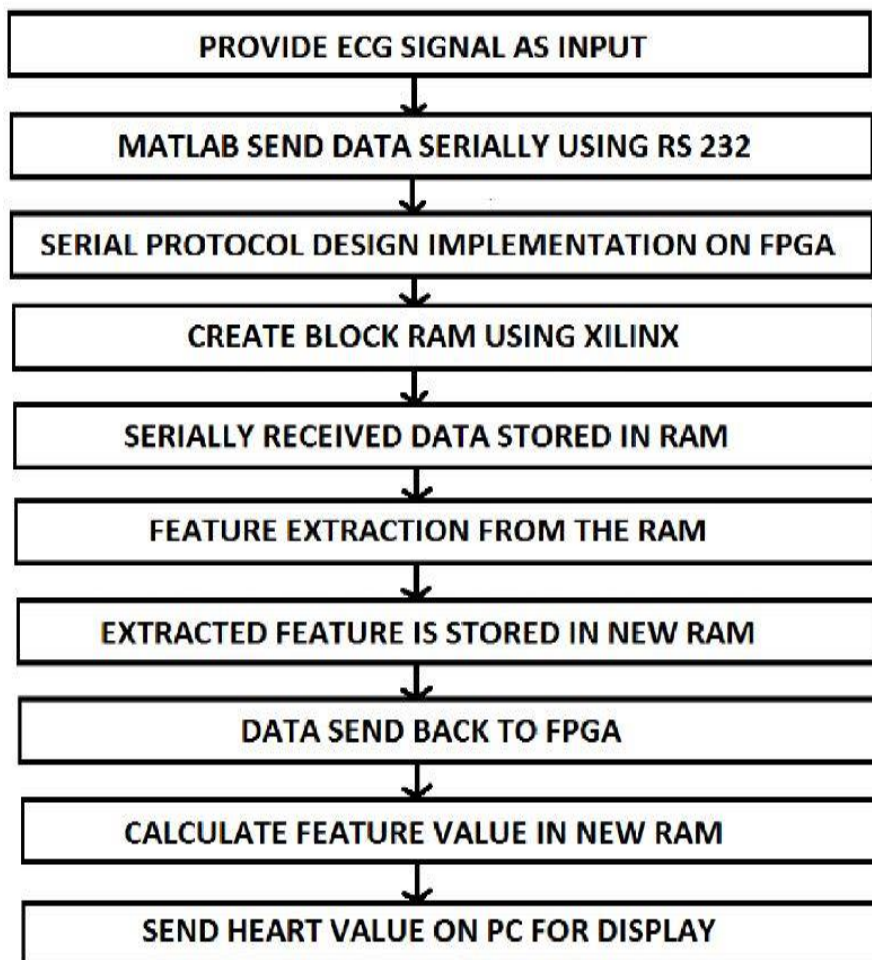


Figure 3.13: FPGA work flow for ECG implementation[20]

Explanation of board:

- The name of the FPGA board used here is XILINX Spartan -6 XC6SLX45
- It has two input and output HDMI ports.
- It has trimode Ethernet interface.
- On board USB based FPGA configuration circuitry.
- It has real time power supply monitors.



Figure 3.14: FPGA Implementation

CHAPTER - 4

CAD SYSTEM OF ECG FOR BIPOLAR LEADS USING HAAR WAVELET TRANSFORMATION

In this chapter, we have compared various transforms with wavelet transforms. We have collected 80 ECG images from database upon which we have applied data preprocessing, feature extraction, data partitioning and data classification using SVM classifier. Haar wavelet is used as feature extraction technique from we have calculated overall accuracy, precision, misclassification rate etc-

4.1 Dataset Description

- In order to perform any transformation technique, benchmarked database is taken online from http://www.beecardia.com/physiobank/database/ptbdb/s0530_re-patient278

4.2 Regions of Interest Selection (ROIs)

The ROI size is chosen such that it should produce a fair amount of pixels. To determine textural features, sensible ROI size is taken.

4.3 Feature Extraction Module

It is a method used to convert the visually extractable and non-extractable features into mathematical descriptors. These descriptors are shape-based which are known as morphological features and the intensity distribution based which are known as textural features. The intensity distribution methods consist of:

(a) Statistical Methods

(b) Signal Processing Based Methods

(c) Transform domain methods.

4.3.1 Morphological Features

Morphological methods include the shape based properties which includes Area, Perimeter, Convexity, Eccentricity, Extent, Euler No., Hole Area Ratio (HAR) and Solidity [17].

4.3.2 Textural Features

Textural Features are classified into three parts namely- Statistical Features, Signal Processing based methods and Transform Domain :

4.3.2.1 Statistical Features: Depending upon the gray level intensities of the pixels of a particular image, this technique is used for fetching the textural features from an image.

- a) **First Order Statistics:** The first order statistics are derived from the gray level intensity histograms of the image for each ROI.
- b) **Second Order Statistics-GLCM Features:** Second order statistics includes the computations with the GLCM which explains the frequent combinations of pixels pairs in an image.
- c) **Higher Order Statistics-GLRLM Features:** GLRLM evaluates the higher order statistics. Texture features are evaluated using the different combinations of intensities at relative position of each other.
- d) **Other Statistical Features**
 - **Edge Features (Absolute Gradient):** The spatial differences in a particular image are evaluated by determining the value of absolute gradient. If sudden differences are present in the image, then gradient will be high else it will be low.

- **Neighborhood Gray Tone Difference Matrix Features:** Neighborhood Gray Tone Difference Matrix computes busyness, coarseness, complexity, contrast, and strength and considers a difference between the gray level between pixels.
 - **Statistical Feature Matrix (SFM):** SFM computes coarseness, contrast, periodicity and roughness of pixels at different distances within an image.
- e) **Gray Level Difference Statistics (GLDS):** GLDS computes contrast, energy, entropy, homogeneity, and mean on the basis of the co-occurrence of a pixel pair that have difference in gray levels separated by a particular distance.

4.3.2.2 Signal Processing based Methods

Laws' Mask Texture Analysis: In this technique small convolution masks acting as filters are convolved with ROIs so that the texture features are improved.

4.3.3 Transform Domain based Methods

Feature extraction can also be done in the transform domain over various scales by using different multi resolution schemes like wavelet packet transform (WPT) and Gabor Wavelet transform (GWT).

4.3.3.1 Fourier Transform:

The representation of signal in frequency domain is called Fourier Transform. The term Fourier transform involves mathematical operations that relates the frequency domain representation of the signal to a function of time. The Fourier transform is

not confined to functions of time, but to have a unified language, the domain of the original function of signal is commonly termed as time domain.

It comprises of two types:

a) Continuous Fourier Transform

It breaks signals into the series of complex exponentials $\exp(-j 2 \pi f t)$. At angular frequency $\omega = 2 \pi f$ and time t , FT is given by:

$$X(j\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t} dt \quad (5)$$

where $X(\omega)$ is the Fourier transform of $x(t)$ Condition of convergence of $x(t)$ is as follows:

$$\int_T |x(t)|^2 dt < \infty \quad (6)$$

b) Discrete Fourier Transform

Using discrete Fourier transform (DFT), an equivalent-length sequence of equally-spaced samples of the discrete-time Fourier transform (DTFT) is converted from a finite sequence of equally-spaced samples of a function. The obtained sequence is a complex-valued function of frequency and is given by:

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-2\pi i kn/N}, \quad k \in Z \quad (7)$$

c) Short Term Fourier Transform

The short-time Fourier transform (STFT), is related to Fourier Transform used to find the phase content and sinusoidal frequency of local parts of a signal which varies with time. Practically, methods for determining STFTs include dividing a longer time signal into shorter fragments of equal length and computing the FT separately on each shorter fragment. This is how the Fourier spectrum on each shorter fragment is revealed. This enables one to plot the changing spectra of the signal as a function of time.

Continuous STFT is given by:

$$STFT\{x(t)\}(\tau, \omega) = X(\tau, \omega) = \int_{-\infty}^{\infty} x(t)\omega(t - \tau)e^{-i\omega t} dt \quad (8)$$

Discrete STFT is given by:

$$STFT\{x[n]\}(m, \omega) = X(m, \omega) = \sum_{n=-\infty}^{\infty} x[n]\omega[n - m]e^{-j\omega n} \quad (9)$$

- The time and frequency content of a signal $x[n]$ at specific point in TF plane cannot be determined. It cannot be known that at any given time instant, what spectral components are present. We can only investigate the spectral components which are present at any given time interval. This gives rise to an issue of resolution, and becomes the main reason why WT is preferred over STFT by researchers. STFT provides a fixed resolution, while WT provides a variable resolution at all times.

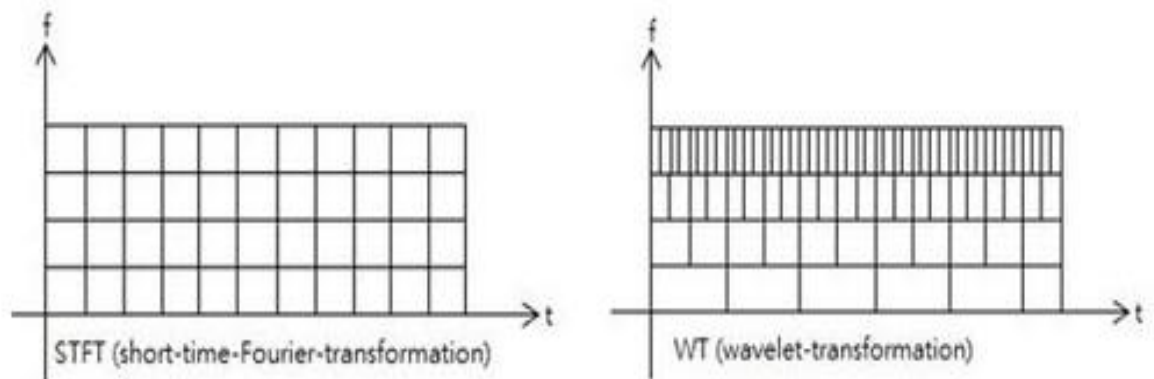


Figure 4.1: Time frequency representation of STFT and WT

- Functions that have discontinuities and sharp peaks are well represented by WT as compared to FT. It also precisely deconstructs and reconstructs finite, non-stationary and/or non-periodic signals.
- Various drifts, trends, and sudden changes are not detected by FT.
- The information about at what time, the spectral components appear is not given by FT.

4.3.3.2 Laplace Transform

For a function $f(t)$ where $t > 0$, the Laplace Transform is given as below defined over the interval 0 to ∞ :

$$L\{f(t)\} = \int_0^{\infty} e^{-st} f(t) dt \quad (10)$$

The obtained expression is expressed as $F(s)$ which is a function of s . To study continuous signal and to realize analog circuit equivalents, Laplace Transforms are particularly used.

4.3.3.3 Z Transform

For a signal of finite length, the z-transform is expressed by the expression:

$$X(z) = \sum_{k=0}^N x[k]z^{-k} \quad (11)$$

where interval that supports sequence is 0 to N , and z is any arbitrary complex number. Discrete time signals and LTI systems are analyzed using Z-Transform. It also realizes discrete circuit equivalents.

4.3.3.4 Wavelet Transformation :

Mathematically, a wavelet series represents a real- or complex-valued square integrable function according to a particular orthonormal series generated using a wavelet. As of now, of all the transformations present, WT is the most popular time-frequency-transformations.

In wavelet transformation, changes are allowed only in time domain, but not in shape. An appropriate mother wavelet functions is chosen for this transformation. Variation in the time domain is anticipated to match to the analogous frequency of the mother wavelet function. According to the uncertainty principle of signal processing,

$$\Delta t \Delta \omega \geq \frac{1}{2} \quad (12)$$

where time is represented by t and angular frequency is represented by ω ($\omega = 2\pi f$, where f is frequency).

When value of Δt is large,

1. Time resolution is bad.
2. Frequency resolution is good
3. Frequency is low, scaling factor is large

When value of Δt is small,

1. Time resolution is good
2. Frequency resolution is bad.
3. Frequency is high, scaling factor is small.

For the required resolution in time to be higher, the resolution in frequency has to be lower. The value of Δt depends upon the length of extension of the analysis window.

a) Two Dimensional Gabor Wavelet Transform

The application of 2D-GWT results in a set of frequency and orientation selective filters that capture energy at a specific frequency and orientation. The 2D-GWT, considering three scales (0,1 and 2) and seven angles (22.5° , 45° , 67.5° , 90° , 112.5° , 135° and 157.5°) result in a group of 21 wavelets (7×3).

b) 2-D Discrete Wavelet Transform

A two-dimensional DWT when applied to images can be seen as two one-dimensional transform functions applied to rows and columns of the image separately [49]. When this operation is applied to an ROI image, a decomposition is done up to second level.

• Haar Wavelet Transform

The Haar wavelet is a series of "square-shaped" functions which are rescaled and collectively form a basis or family of wavelet. The representation of a target

function in terms of an orthonormal basis over an interval is allowed by wavelet transform which is familiar with Fourier Transform. It is primarily used as a teaching example and also identified as the first known wavelet basis.

It is the simplest wavelet known.

The mother wavelet function of a Haar's wavelet can be expressed as:

$$\varphi(t) = \begin{cases} 1 & 0 \leq t < \frac{1}{2} \\ -1 & \frac{1}{2} \leq t < 1 \\ 0 & \text{otherwise} \end{cases} \quad (13)$$

Its scaling function can be expressed as given below:

$$\phi(t) = \begin{cases} 1 & 0 \leq t < 1, \\ 0 & \text{otherwise} \end{cases} \quad (14)$$

The Haar wavelet has many noticeable properties as given below:

1. Approximation of a function which is real and continuous with compact support can be done uniformly by linear combinations of $\phi(t), \phi(2t), \phi(4t), \dots, \phi(2^n t) \dots$ and their shifted functions.
2. Approximation of a function which is real and continuous over the interval $[0, 1]$ can be done uniformly over the interval $[0,1]$ by linear combinations of constant functions $\phi(t), \phi(2t), \phi(4t), \dots, \phi(2^n t) \dots$ and their shifted functions.

❖ **Image Compression Example Using Haar Wavelet** Lossless image compression is performed effectively by Haar wavelet compression. It depends upon differencing and averaging values of an image matrix to produce a sparse matrix which is a matrix whose most of the entries are 0. A sparse matrix can be stored efficiently giving rise to file sizes which are smaller. We are using a gray scale image as given in figure 5.2 which can be represented by a $p \times q$ matrix whose values lie between 0 to 255 which are unsigned 8-bit integer values. This image is subdivided into blocks

of 8×8 , padding as necessary and these are the blocks on which we work. Given below is a 512×512 pixel grayscale image:



Figure 4.2: Grayscale image

The 8×8 upper left section of our image is shown below:

$$A = \begin{pmatrix} 88 & 88 & 89 & 90 & 92 & 94 & 96 & 97 \\ 90 & 90 & 91 & 92 & 93 & 95 & 97 & 97 \\ 92 & 92 & 93 & 94 & 95 & 96 & 97 & 97 \\ 93 & 93 & 94 & 95 & 96 & 96 & 96 & 96 \\ 92 & 93 & 95 & 96 & 96 & 96 & 96 & 95 \\ 92 & 94 & 96 & 98 & 99 & 99 & 98 & 97 \\ 94 & 96 & 99 & 101 & 103 & 103 & 102 & 101 \\ 95 & 97 & 101 & 104 & 106 & 106 & 105 & 105 \end{pmatrix}$$

Now we will take the first row:

$$r_1 = (88 \ 88 \ 89 \ 90 \ 92 \ 94 \ 96 \ 97)$$

The transformation process comprises of three steps of which the first step is grouping of all of the columns in pairs:

$$[88 \ 88], [89 \ 90], [92 \ 94], [96 \ 97]$$

The first 4 columns of r_1 are replaced with half of the sum of above pairs and the remaining 4 columns are replaced with $1/2$ of the difference of these pairs. This new row is given by $r_1 h_1$:

$$r_1 h_1 = (88 \ 89.5 \ 93 \ 96.5 \ 0 \ -0.5 \ -1 \ -0.5)$$

The first 4 entries i.e. 88, 89.5, 93, 96.5 are known as the approximation coefficients and the last 4 i.e. 0, -0.5, -1, 0.5 are known as detail coefficients. Now the pairing of the first 4 columns of $r_1 h_1$ is done:

$$[88 \ 89.5], [93 \ 96.5]$$

And replacement of the first 2 columns of $r_1 h_1$ is done with the $\frac{1}{2}$ of the sum of the values of pairs and the next 2 columns of $r_1 h_1$ with $\frac{1}{2}$ of the difference of these pairs. The last 4 rows of $r_1 h_1$ are left unaltered. This second new row is denoted by $r_1 h_1 h_2$:

$$r_1 h_1 h_2 = (88.75 \ 94.75 \ -0.75 \ -1.75 \ 0 \ -0.5 \ -1 \ -0.5)$$

Ultimately, the pairing of the first 2 entries of $r_1 h_1 h_2$ is done:

$$[88.75 \ 94.75]$$

And the replacement of the first column of $r_1 h_1 h_2$ is done with the $\frac{1}{2}$ of the sum of these pairs and the second column of $r_1 h_1 h_2$ with $\frac{1}{2}$ of the difference of these pairs. The last 6 rows of $r_1 h_1 h_2$ are left unaltered which is denoted as $r_1 h_1 h_2 h_3$:

$$r_1 h_1 h_2 h_3 = (91.75 \ -3 \ -0.75 \ -1.75 \ 0 \ -0.5 \ -1 \ -0.5)$$

This process is then repeated for all the rows of A. Following this, the same process is repeated for the columns of A in the same way as is done for the rows. The resultant matrix is given below:

$$\begin{pmatrix} 96 & -2.0312 & -1.5312 & -0.2188 & -0.4375 & -0.75 & -0.3125 & 0.125 \\ -2.4375 & -0.0312 & 0.7812 & -0.7812 & 0.4375 & 0.25 & -0.3125 & -0.25 \\ -1.125 & -0.625 & 0 & -0.625 & 0 & 0 & -0.375 & -0.125 \\ -2.6875 & 0.75 & 0.5625 & -0.0625 & 0.125 & 0.25 & 0 & 0.125 \\ -0.6875 & -0.3125 & 0 & -0.125 & 0 & 0 & 0 & -0.25 \\ -0.1875 & -0.3125 & 0 & -0.375 & 0 & 0 & -0.25 & 0 \\ -0.875 & 0.375 & 0.25 & -0.25 & 0.25 & 0.25 & 0 & 0 \\ -1.25 & 0.375 & 0.375 & 0.125 & 0 & 0.25 & 0 & 0.25 \end{pmatrix}$$

We observe that the resultant matrix obtained is a sparse matrix having several 0 entries and many entries close to 0 because the consecutive pixels in an image don't differ much which is a result of the differencing and averaging.

4.4 Data Partitioning

Partition of different ECG images is done by using Hold out Approach according to which splitting of the original dataset into two-parts (training and testing) is done and the testing score is used as a generalization measure.

Out of 80 ECG images, 40 are for training and 40 are for testing.

4.5 Classification Module

The process of making groups of the testing samples into its corresponding classes is called Classification. There are two types of classification : unsupervised classification and the supervised classification. Different classifiers are used in this module which are:

- PNN
- k-NN
- SSVM
- SVM

In order to classify the testing instances which are unknown, different ultrasound classes based on the training instances, the above mentioned classifiers are used.

4.5.1 k-Nearest Neighbour (k-NN) Classifier

In order to estimate the class of an unknown instance from its neighbors, the k -NN classifier is used. It works on the assumption that the feature vector which are close to one other belongs to the same class. Hence it tries for the grouping of the feature vector's instances into same classes which are nearby to each other.

4.5.2 Probabilistic Neural Network (PNN) Classifier

In order to estimate the class of unknown instances , PNN classifier is used which is supervised Bayesian based feed-forward neural network. There are four layers in PNN classifier which are pattern layer, input layer, output layer and summation layer

4.5.3 Support Vector Machine (SVM) Classifier

The class of SVM comes under supervised learning machine and the basis of its working is statistical theory. Using training data SVM's creates a hyperplane between the classes.

4.5.4 Smooth Support Vector Machine (SSVM) Classifier

SVM is related with the traditional quadratic program. In order to unconstrained smoothing unconstrained optimization reformulation SSVM classifier is employed. For the classification of pattern, SSVM work on the concept of smoothing the unconstrained optimization reformulation of the problems related to SVM.

4.6 Confusin Matrix : A confusion matrix is a table which is used to describe the behavior of a classifier or a classification model on a test data set whose true values are known is called a confusion matrix.

We have used Haar wavelet and SVM classifier and determine the confusion matrix of Bipolar leads.

Table 1: Confusion Matrix for features 6 and 7

		Predicted: NO	Predicted: YES	
n= 40				
Actual: NO		TN = 20	FP = 0	20
Actual: YES		FN = 2	TP = 18	20
		22	18	

- Two possible classes used to determine whether a disease is present or not are: "yes" and "no". "Yes" would mean the presence of a disease, and "no" would mean the absence of the disease.
- In our case, a total of 40 predictions were made i.e. 40 patients were tested to see if the disease is present.
- "Yes" was predicted 18 times, and "no" was predicted 22 times out of 40 cases by the classifier.
- As a result, 20 patients in the sample actually have the disease, and 20 patients do not.

As mentioned in the above table, the terms of the confusion matrix are defined below:

- **True positives (TP):** According to the confusion matrix, in these cases we predicted the presence of a disease (“predicted yes”) and patients actually do have the disease.

- **True negatives (TN):** According to the confusion matrix, in these cases we predicted the absence of a disease (“predicted no”) and patients actually don’t have the disease.
- **False positives (FP):** According to the confusion matrix, in these cases we predicted the presence of a disease (“predicted yes”) and patients actually don’t have the disease also known as Type 1 error.
- **False negatives (FN):** According to the confusion matrix, in these cases we predicted the absence of a disease (“predicted no”) and patients actually do have the disease.

Some basic terminologies computed from Confusion Matrix:

- **Accuracy:** This measures the correctness of a classifier.
 - $(TP+TN)/total$
- **Misclassification Rate:** This measures how imprecise a classifier is.
 - $(FP+FN)/total$
- **True Positive Rate:** This measures how often it predict yes, when it's actually yes.
 - $TP/actual\ yes$
 - also known as "Recall" or "Sensitivity"
- **False Positive Rate:** This measures how often it predict yes, when it's actually no.
 - $FP/actual\ no$
- **Specificity:** This measures how often it predict no, when it's actually no.
 - $TN/actual\ no$
- **Precision:** It measures how often it is correct when it predicts yes.
 - $TP/predicted\ yes$
- **Prevalence:** It measures the actual occurrence of yes condition sample?
 - $actual\ yes/total$

4.6.2 Observation Table

This table shows the confusion matrix for 7 features (mean, standard deviation(SD), energy, mean + SD, SD + energy, energy + mean, mean + SD + energy) of Haar Wavelet and shows the calculation of terms like accuracy, true positive value, specificity, precision etc.

$$\text{Mean, } \mu = \frac{1}{n} \sum_{i=1}^n x_i \quad (15)$$

$$\text{Standard deviation, } \sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \mu)^2} \quad (16)$$

$$\text{Energy, } E = \int_{-\infty}^{\infty} |x(t)|^2 dt \quad (17)$$

where x_i is the observed value, n is the sample size

Table 2: Observation table for Haar wavelet features for Bipolar Leads

	For feature 1, 3, 4, 5	For feature 2	For feature 6, 7												
Confusion Matrix	<table border="1"> <tr> <td>TN = 18</td> <td>FP = 2</td> </tr> <tr> <td>FN = 10</td> <td>TP = 10</td> </tr> </table>	TN = 18	FP = 2	FN = 10	TP = 10	<table border="1"> <tr> <td>TN = 18</td> <td>FP = 2</td> </tr> <tr> <td>FN = 5</td> <td>TP = 15</td> </tr> </table>	TN = 18	FP = 2	FN = 5	TP = 15	<table border="1"> <tr> <td>TN = 20</td> <td>FP = 0</td> </tr> <tr> <td>FN = 2</td> <td>TP = 18</td> </tr> </table>	TN = 20	FP = 0	FN = 2	TP = 18
TN = 18	FP = 2														
FN = 10	TP = 10														
TN = 18	FP = 2														
FN = 5	TP = 15														
TN = 20	FP = 0														
FN = 2	TP = 18														
Accuracy (%)	70	82.5	95												
Misclassification rate	0.3	0.175	0.05												
True positive rate	0.5	0.75	0.9												
False positive rate	0.1	0.1	0												
Specificity(%)	90	90	100												
Precision (%)	80	88	100												
Prevalence	0.5	0.5	0.5												

where, Features 1, 3, 4, 5 shows the Mean , Energy, Mean + SD, SD + Energy respectively.

Feature 2 shows SD

Feature 6, 7 shows Energy +Mean , Mean + SD + Energy respectively.

Out of all the features, features 6 and 7 shows the maximum accuracy of 95%, precision as well as specificity of 100% , maximum true positive rate of 0.9 and minimum false positive rate as 0. Misclassification rate is maximum for features 1, 3, 4, 5 i.e. 0.3, whereas, all the features have the same prevalence of 0.5.

CHAPTER-5

CONCLUSION AND FUTURE WORK

In our project, the performance and capability of ECG circuit is improved by using notch filter at the front end of IA. It is done to remove the power line interference which is of magnitude 60Hz together with RF interference and muscle noise to carryout precise diagnosis and to obtain noise redundant waveforms. Since the notch filter can act as both high pass filter and low pass filter, so it is used to optimize the hardware circuitry of ECG. So no separate filters are required. DC offset is removed with the help of DC offset removal circuit. To detect any faulty operations between electrodes and human body contacts, a Peak Detection Circuit is used. A bio-potential amplifier is used in such a way that it reduces common voltage, noise, DC offset value and RF interference from the existing ECG circuit. RLD circuit is used to increase CMRR. Moreover we have introduced serial communication usage between Xilinx and MATLAB which is used to burn XILINX Spartan-6 XC6SLX45 FPGA.

We have used Haar wavelet and SVM classifier to obtain the confusion matrix for bipolar leads. Then, we have computed various terminologies like overall accuracy, misclassification rate, precision, prevalence etc. for different Haar features.

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List of Publications:

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Hardware Optimization and Implementation of ECG circuit on FPGA

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Abstract –The main aim of our paper is to optimize the hardware of ECG circuit by reducing the number of components in the circuitry of ECG to make the system less expensive. The components we have used in our optimized proposed ECG circuit are Instrumentation Amplifier, RLD circuit to reduce the common mode interference, reduced DC offset remover circuit, Notch filter to reduce RF interference, power line interference and muscle noise. This paper presents how we can burn FPGA using MATLAB and Serial Port Communication.

Keywords –Peak detection circuit, Notch filter, Instrumentation amplifier, Field Programmable Gate Array, Right leg driven circuit, DC offset remover circuit.

electrodes that are attached on the surface of our skin. these potentials can be recognized and recorded. The final output is displayed on the oscilloscope screen. 12-lead ECG gives information regarding electrical motion of heart in 3 directions which are orthogonal to each other that is posterior-anterior, right-left and superior-inferior. There are 3 bipolar limb leads which are on the frontal plane i.e. lead I which are from right arm (-) to left arm (+), lead II which are from right arm (-) to left leg (+), lead III which are from left arm (-) to left leg (+). Also, we have augmented unipolar limb leads i.e. lead aVR which are from right arm (+) to left arm & left leg (-), lead aVL which are from left arm (+) to right arm & left leg (-), and lead aVF which are from left leg (+) to right arm & left leg (-).