Wireless ECG Using Bluetooth

A Thesis report

submitted towards the partial fulfillment of the

requirements of the degree of

Master of Engineering

in

Electronic Instrumentation and Control Engineering

submitted by

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THAPAR UNIVERSITY, PATIALA – 147004

JULY 2010

Certificate

I hereby certify that the work which is being presented in the thesis entitled "**Wireless ECG using Bluetooth**", in partial fulfillment of the requirements for the award of degree of M.E. (EIC) at Electrical and Instrumentation Engineering Department, Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Ravinder Agarwal, Associate Professor and Head USIC and Sushil Chandra, Scientist 'E' and Head Biomedical Engineering, INMAS, DRDO.

The matter presented in this thesis has not been submitted in any other University/Institute for the award of any degree.

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Date: June 28, 2010

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Acknowledgement

The real spirit of achieving a goal is through the way of excellence and austere discipline. I would have never succeeded in completing my task without the cooperation, encouragement and help provided to me by various personalities.

With deep sense of gratitude I express my sincere thanks to my esteemed and worthy supervisor, **Dr. Ravinder Agarwal,** Associate Professor, Department of Electrical and Instrumentation Engineering and Head USIC**,** Thapar University, Patiala and **Mr. Sushil Chandra** Scientist ‘E’ and Head Biomedical Engineering, INMAS DRDO, Delhi and for their valuable guidance in carrying out this work under their effective supervision, encouragement, enlightenment and cooperation. Most of the novel ideas and solutions found in this thesis are the result of our numerous stimulating discussions. Their feedback and editorial comments were also invaluable for writing of this thesis.

I shall be failing in my duties if I do not express my deep sense of gratitude towards **Dr. Smarajit Ghosh,** Professor and Head of the Department of Electrical & Instrumentation Engineering, Thapar University, Patiala who has been a constant source of inspiration for me throughout this work.

I am also thankful to all the staff members of the Department for their full cooperation and help.

This acknowledgement would be incomplete if I do not mention the emotional support and blessings provided by my friends. I had a pleasant enjoyable and fruitful company with them.

My greatest thanks are to all who wished me success especially my parents, my brother and sisters whose support and care makes me stay on earth.

Place: TU, Patiala

Date: **(Ashish Kumar)**

Abstract

The Electrocardiogram (ECG) is an essential diagnostic tool that measure and record the electrical activity of the heart. A wide range of heart conditions can be detected when interpreting the recorded ECG signals. These qualities make the ECG a perfect instrument for patient monitoring and supervision. The commonly used ECG machine used for diagnosis and supervision at present is expensive and stationary. With the recent advance in technology, there are possibilities to create a small sized wireless ECG system capable of transmitting ECG signal via Bluetooth technology to a Laptop or PDA using LABVIEW at low cost and at low power dissipation powered by a cellular phone battery. In the present research work a small sized wireless ECG embedded system is developed to make the patient more mobile without losing the reliability of the ECG sensor. It consists of an amplifier, filtering, PIC microcontroller, Bluetooth Technology and LABVIEW as a platform for wireless transmission. With the use of a PIC microcontroller the analogue signal is digitally converted at a specific sample rate that based on the resolution of the ECG-signals. The digital data will be transmitted to Laptop on Bluetooth protocol where the digital signal can be processed in LABVIEW and graphically can be displayed.

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List of Abbreviations

ECG	-	Electrocardiogram
PDA	-	Personal digital assistance
LabVIEW	-	Laboratory Virtual Instruments Engineering Workbench
RISC	-	Reduced instruction set computer
CMRR	-	Common mode rejection ratio
IDFT	-	Inverse Discrete Fourier Transform
ADC	-	Analog Digital Converter
USART	-	Universal Synchronous and Asynchronous Receiver and Transceiver
UART	-	Universal Asynchronous Receiver and Transceiver

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1

1. Introduction

1.1 Project Background

With rapid advances in wireless communication network, the transmission of biomedical signal through wireless is not impossible anymore. There are many researches had been done in wireless biomedical sensor network (WBSN) to monitor physiological signal. Furthermore, telemedicine and remote monitoring of patients' physiological data are issues that have received increasing attention in recent years [1].
Some of the physiological signals are Electrocardiogram (ECG) which can be used to monitoring heart activity, an electromyogram (EMG) for monitoring muscle activity and an electroencephalogram (EEG) for monitoring brain electrical activity [2]. Among these physiological signal, ECG and heart rate are the most important to be measured. World Health Organization (WHO) estimated revealed that each year more than 16 million people around the world died of cardiovascular disease where this figure represent 30 percent of the global death toll [1].

Second chapter deals with the review of literature survey on similar projects like FM Based ECG, Micromedical, BlueNurse. The survey will be considered in this project and the previous research with different methodology.

Third chapter describe the theory ECG Background, Electrode Theory, Existing Wireless Technologies – Bluetooth and ZigBee Theory, PIC microcontroller – ADC and USART modules.

Fourth chapter described the methodology for Hardware and Software used in the work. Hardware Methodology covers block diagram / circuit diagram. Software Methodology, on the other hand covers all software used during the project development like ISIS proteus for simulation of Analog and Digital ECG data from the output of PIC microcontroller, Bluetooth – PC interfacing software, LabVIEW program for signal display.

Last chapter gives the results and discussion of the work done during the study, followed by future recommendation.

2

2. Literature Survey

2.1 Related Projects

A project of interest includes ’PicoRadio [3] (developed at the Berkley Wireless Research Centre) and is aimed at creating minimum energy networks of wireless nodes; however, the bit rates here are too low for ECG applications. Another project named. Smart Dust [4], being developed with similar aims, is running a very simple operating system named. TinyOS, which uses a scheduler for multithreading between tasks. This idea is to be incorporated into the design of the communications protocols.

There have been numerous attempts to develop a wireless ECG monitoring system where the patient being examined is to be free of wires. Till now this has not been available in the market. The first implementation encountered during research used a completely different idea for a wireless ECG monitor. The following methods use a slightly different implementation in that electrodes are physically connected together and then an ECG signal is calculated. This processed data is transmitted wirelessly from the patient to a mobile base station. The final implementation uses Bluetooth technology.

2.1.1 Heart Monitoring of clothed Person

The first implementation encountered uses a completely wireless system where a heartbeat sensor was devised that works without electrical connections to the patient (see Figure 2.1 for illustration).

Figure 2.1 Monitoring the Heart of a Fully Clothed Person

The patient is fully clothed and the sensor device scans from about one meter away. The device measures displacement current, which is a measure of the changing electric field in the air, generated by the shifting voltages on the skins surface.

2.1.2 Micromedical

Micromedical [6] has also attempted to implement a wireless ECG monitor where a three-node system (as a single device) takes the ECG reading and is capable of connecting to a mobile phone. The ECG wave is then transmitted to the treating Doctor. Although, the implementation is not ideal for hospital situations, it can be used as general checkups for patients in remote locations.

2.1.3 FM Based ECG system

Another ECG system [7] encountered where several nodes are connected as a system (placed on the patient's chest) to calculate the patients ECG and relays this through the tissue of the body (using FM modulation) to a transmitter located on the patients wrist and is transmitted to a base station as shown in Figure 2.2.

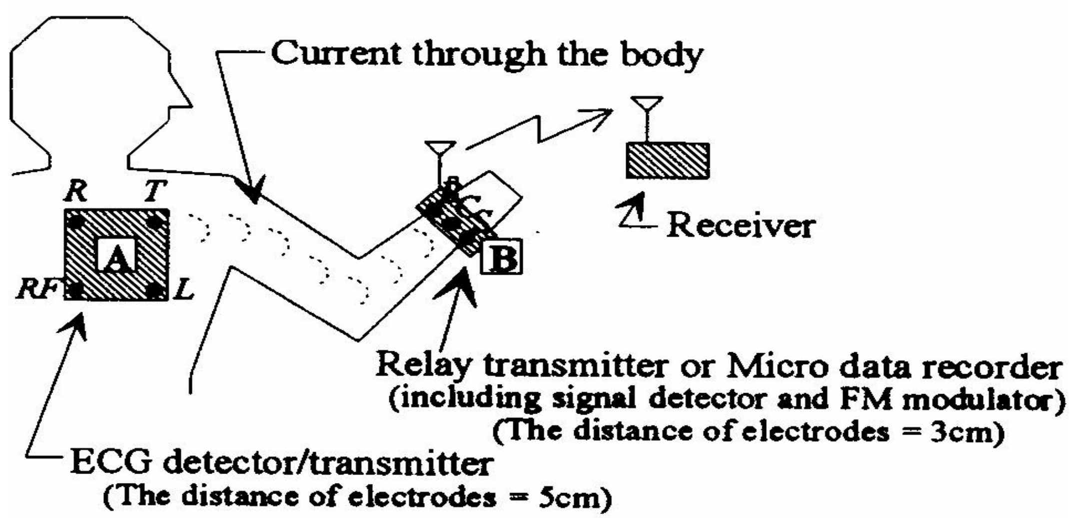

Figure 2.2 FM Based ECG

This implementation obtains extremely low power consumption due to the method used for signal transmission, however it suffers from the method of producing the ECG wave before transmission and where this is not the goal of this thesis project.

2.1.4 Bluetooth based Solution

This system expands on a previously developed internet based database which collects ECG data from patients. The Bluetooth communications protocol is used in the system to send the digitized ECG data to a WEB server via GSM phone modem [8].

2.1.5 BlueNurse

The solution aimed in the previous year used the Bluetooth wireless communications protocol to send an ECG signal from the patient to mobile station (laptop). The architecture used for this implementation involved using conventional ECG signal acquisition circuitry (ECG system which measures and filters an ECG signal with analogue circuitry before A/D converting). The node meant for transmitting the ECG signal consisted of three electrodes [9]. The system was unable to show an ECG reading of a patient wirelessly. That is, the Bluetooth wireless link was functional; however the ECG application was not interfaced to the communications link.

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3. Problem Statement

There are evidence that the number of people in the world that facing with the heart attack problem had increased. People suffering from this problem may have an attack at any time especially at home without any supervision. Sensor that enables ECG home monitoring to detect heartbeat can reduce this problem. By implementing wireless communication ECG monitoring can be done and transferred remotely. There are work previously on the sensor board specifically for ECG detecting, however the signal taken from simulator input.

The objective of the present work is to design and implement a prototype ECG system which replaces wired connections between sensor points and a central node with wireless links. Design goal of this system is to have the electrodes obtaining the signal also contain miniature circuitry required to process, digitize and wirelessly transmit the data over Bluetooth Protocol. Figures3.1 [1] below illustrate this future goal and the benefits it will offer

Figure 3.1 – Presented ECG System

Electrocardiograph is extracted and connected using Bluetooth, which acts as a data acquisition system (DAQ). The ECG-sensor is an embedded sensor system that contains a sensor, PIC microcontroller (ADC & USART) and a Bluetooth module. It is powered by a small battery which is normally used for cellular phones. The main focus of this development was to create a reliable ECG amplifier. The second part is to program the PDA/LAPTOP. It is connected to the ECG amplifier and works as a DAQ and presents the ECG signals on its display. The system is able to connect continuously for supervision abilities.

Successful implementation of the system would benefit to all involved in the use of electrocardiography as access to and movement of the patient would not be impeded by the physical constraints imposed by the cables. The work conducted, concentrates on designing and implementing a system architecture that is functional and reduces wired links to a minimum and attempts to prove the feasibility of completely wireless ECG.

The objectives of ECG wireless system are:

- To develop an ECG wireless sensors board to send ECG wirelessly to the PC/PDA using Bluetooth Technology during exercise or work or to physician for analysis through internet
- The system designed is aimed to minimize the noise (in hardware).
- Design of reliable and low power consumption system using Bluetooth Technology and PIC microcontroller

4

4. Theory

4.1 ECG Background and Theory

4.1.1 The Heart

The heart is the organ responsible for pumping blood through the circulatory system. The heart is made of a special kind of muscle, so that it can beat automatically without having to be told to do so by the brain. The left side of the heart drives oxygen rich blood out of the aortic semilunar outlet valve into circulation where it is delivered to all parts of the body. Blood returns to the right side of the heart low in oxygen and high in carbon-dioxide and is then pumped through the pulmonary semilunar pulmonic valve to the lungs to have its oxygen supply replenished before returning to the left side of the heart to begin the cycle again. Figure 4.1[10] shows the basic cardiopulmonary system

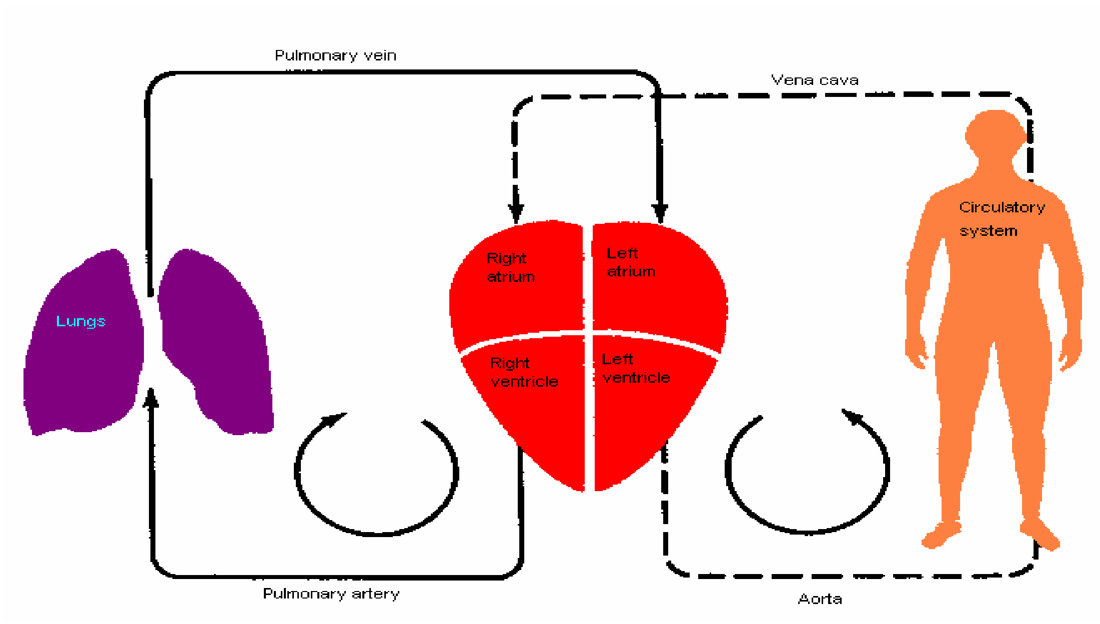

Figure 4.1 Basic cardiopulmonary system

For a 'typical' adult the heart beats at about 70-90 times a minute. If a typical individual lives for about 75 years, his or her heart will have cycled over 3.1536 billion times, pumping a total of 0.2107 billion liters of blood [10].

4.1.2 The ECG Waveform

An electrocardiogram is a measurement of the electrical activity of the heart (cardiac) muscle as obtained from the surface of the skin. As the heart performs its function of pumping blood through the circulatory system, a result of the action potentials responsible for the mechanical events within the heart is a certain sequence of electrical events [12]. In the resting state, cardiac muscle cells are 'polarized', with the inside of cell negatively charged with respect to its surroundings. The charge is created by different concentrations of ions such as potassium and sodium on either side of the cell membrane. In response to certain stimuli, movement of these ions occurs, particularly a rapid inward movement of sodium. In this process, known as 'depolarization', rapid loss of internal negative potential results in an electrical signal. The mechanism of cell depolarization and repolarization is used by used by nerve cells to carry impulses and by muscle cells for triggering mechanical contractions [11]. Figure 4.2 shows the electrical system of the heart.

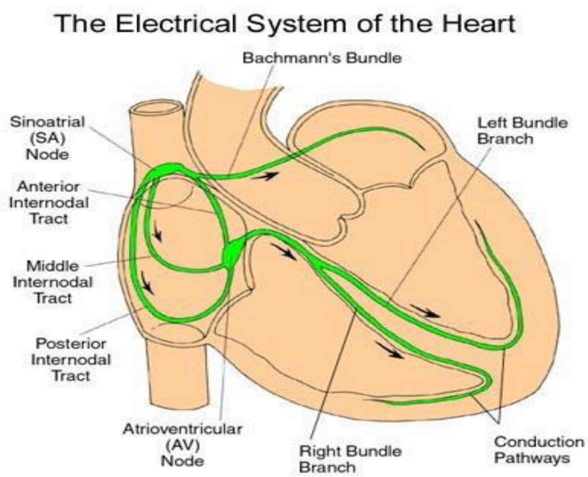

Figure 4.2 Electrical system of the heart

There are certain cells in the heart capable of spontaneous depolarization. These cells are important in the generation of heart rhythm and exist in the sinoatrial (SA) node of the heart. Cells in the sinoatrial node depolarize most rapidly and set the heart rate. Depolarization of the SA muscles causes them to contract and pump blood into the ventricles, before repolarising. The electrical signal then passes into the atrioventricular (AV) node causing the ventricles to contract and pump blood into the pulmonary and systematic circulation. The ventricle muscles then repolarise and the whole process repeats when the pacemaker cells in the SA node depolarize again. Figure 4.3 shows a typical ECG signal. P-wave is due to depolarization of the atria, QRS is due to depolarization of the ventricles and the T-wave is due to repolarisation of the ventricles.

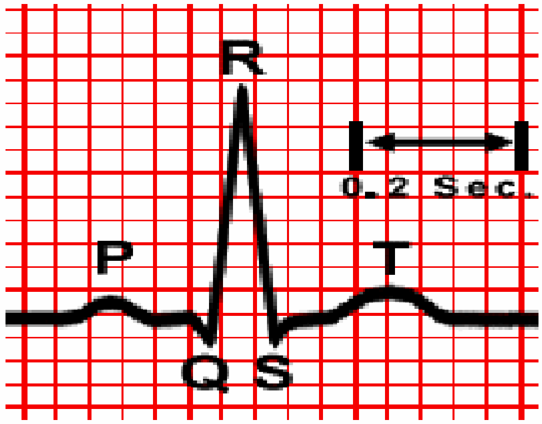

Figure 4.3 Typical Lead II Waveform

4.1.3 History of the Electrocardiogram

The electrical activity accompanying a heart-beat was first discovered by Kolliker and Mueller in 1856. After placing a nerve over a beating frog's heart, they noticed that the muscle associated with the nerve twitched once and sometimes twice. Stimulation of the nerve was obviously caused by depolarization and repolarisation of the ventricles. At that time there were no galvanometers∗ that could respond quick enough to measure the signal, so Donders (1872) recorded the twitches of the muscle to provide a graphic representation of the electrocardiographic signal.

In 1876, Marey made use of a capillary electrometer to describe a crude electrocardiogram of a tortoise using electrodes placed on the tortoise's exposed heart. The news of this led many investigators to create their own instruments and the ECG of mammals including humans was taken and different types of electrodes and their positioning was investigated. One such investigator was Waller, who recorded the ECG of a patient called Jimmy. Waller later revealed the identity of Jimmy to be his pet bulldog. Jimmy's ECG was recorded by having a forepaw and hindpaw in glass containers containing saline and metal electrodes as shown in Figure 4.4 [10].

Figure 4.4 Jimmy the Bulldog

The fidelity of ECG obtained using a capillary electrometer was poor and Einthoven (1903) wanted to create a better system using Ader's string telegraphic galvanometer. Einthoven's system proved to be a great success and soon string galvaonmeter based ECG systems were in clinical practice worldwide. Einthoven also came up with his theory regarding the Einthoven triangle and the lead positions based on this are still in use today and is responsible for the labelling of the various waves forming an ECG signal. Figure 4.5 [10] shows Einthoven's string galvanometer and a patient having his ECG recorded.

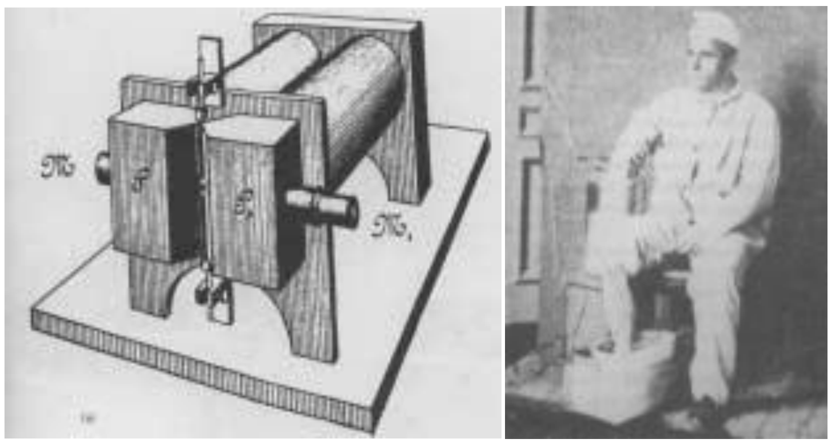

Figure 4.5 William Einthoven's ECG System

Since the early 1900s advances have come through the use of a greater number of leads such as in the augmented lead system or through body surface mapping (>64 recording sites used). As technology has advanced, so has the measuring system, making use of vacuum tubes, transistors, integrated chips and microprocessor technology as time has passed. The use of the electrocardiogram has also spread out from the hospital with ambulatory ECG, home electrocardiography and electrocardiograph telemetry systems in wide use.

4.1.4 Standard ECG Measurement

The electrical impulses within the heart act as a source of voltage, which generates a current flow in the torso and corresponding potentials on the skin. The potential distribution can be modeled as if the heart were a time-varying electric dipole. The dipole is located approximately as shown in Figure 4.6 by the vector M [13].

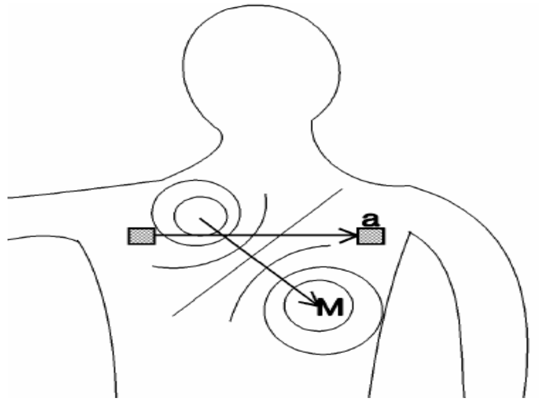

Figure 4.6 Vector Model of Heart and Electrode Interaction

If two leads are connected between two points on the body (forming a vector between them), electrical voltage observed between the two electrodes is given by the dot product of the two vectors [13].

Thus, to get a complete picture of the cardiac vector, multiple reference lead points and simultaneous measurements are required. An accurate indication of the frontal projection of the cardiac vector can be provided by three electrodes, one connected at each of the three vertices of the *Einthoven triangle* [10]. The 60 degree projection concept allows the connection points of the three electrodes to be the limbs

Modern standard ECG measurement makes use of further electrode connection points. The 12-lead ECG is made up of the three bipolar limb leads, the three augmented referenced limb leads and the six Wilson terminals (VW) referenced chest leads. The *augmented lead system* provides another look at the cardiac vector projected onto the frontal plane but rotated 30 degrees from that of the Einthoven triangle configuration. The connection of six electrodes put onto specific positions on the chest and the use of an indifferent electrode (V w) formed by summing the three limb leads allows for observation of the cardiac vector on the transverse plane [14].

Other subsets of the 12-lead ECG are used in situations which don't require as much data recording such as ambulatory ECG (usually 2 leads), intensive care at the bedside (usually 1 or 2 leads) or in telemetry systems (usually 1 lead).

The modern ECG machine has an analogue front-end leading to a 12- to 16 bit analog-to-digital (A/D) converter, a computational microprocessor, and dedicated input-output (I/O) processors.

4.2 Electrode Theory

4.2.1 ECG Sensor Requirement

The front end of an ECG sensor must be able to deal with the extremely weak nature of the signal it is measuring. Even the strongest ECG signal has a magnitude of less than 10mV, and furthermore the ECG signals have very low drive (very high output impedance). The requirements for a typical ECG sensor are as follows [13]:

- Capability to sense low amplitude signals in the range of 0.05 – 10mV
- Very high input impedance, > 5 M ohms
- Very low input leakage current, < 1 micro-Amp
- Flat frequency response of 0.05 – 100 Hz
- High Common Mode Rejection Ratio

4.2.2 Electrodes

Electrodes are used for sensing bio-electric potentials as caused by muscle and nerve cells. ECG electrodes are generally of the direct-contact type. They work as transducers converting ionic flow from the body through an electrolyte into electron current and consequentially an electric potential able to be measured by the front end of the ecg system. These transducers, known as bare-metal or recessed electrodes, generally consist of a metal such as silver or stainless steel, with a jelly electrolyte that contains chloride and other ions (Figure 4.7) [15].

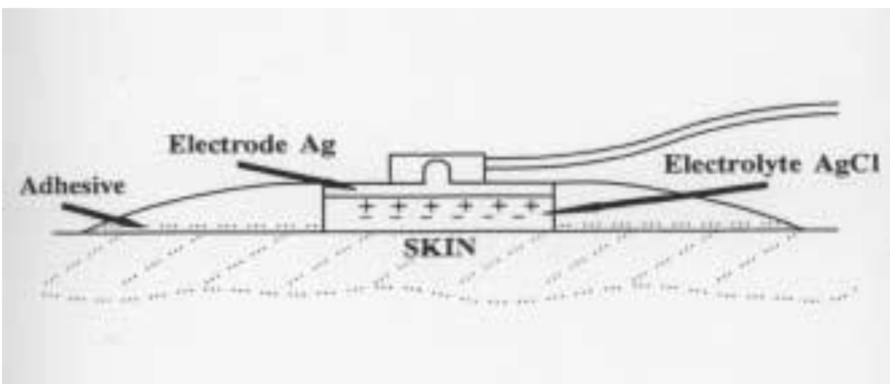

Figure 4.7 Recessed Electrode Structure

On the skin side of the electrode interface, conduction is from the drift of ions as the ECG waveform spreads throughout the body. On the metal side of the electrode, conduction results from metal ions dissolving or solidifying to maintain a chemical equilibrium using this or a similar chemical reaction:

$$Ag \leftrightarrow Ag^+ + e^-$$

The result is a voltage drop across the electrode-electrolyte interface that varies depending on the electrical activity on the skin. The voltage between two electrodes is then the difference in the two half-cell potentials. Figure 4.8 Dry Electrode Structure [10]

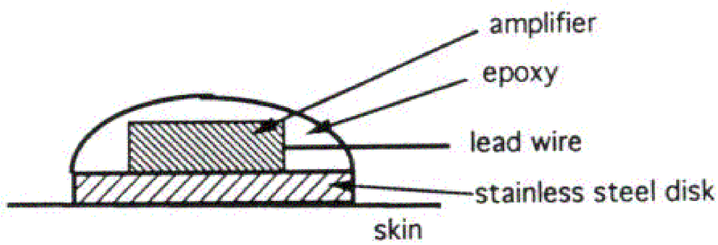

Figure 4.8 Dry Electrode Structure

Plain metal electrodes like stainless steel disks can be applied without a paste. The theory of operation is the same but the resistivity of the skin electrode interface is much greater. They are useable when proper electrostatic shielding against interference is applied and the electrode is connected to an amplifier with very high input impedance, but the voltage measured will be considerably less than that obtained with an electrode utilizing an electrolyte.

4.3 Existing Wireless Technologies

Communication protocols provide an integral backbone of any wireless systems. Sensors and instruments have long been using wireless technology, but extensive research into this field has only recently boomed due to advances in technology such as 802.11, Hiperlan, Bluetooth and ZigBee. Table 4.1 shows a comparison table of some of the different Wireless technologies available [16]**.**

Table 4.1 Wireless Technologies Comparison Table

	IEEE 802.11a	**IEEE 802.11b**	**Hiperlan1**	**Hiperlan2**	**Bluetooth Class 1**
Frequency band	5 GHz	2.4 GHz	5 GHz	5 GHz	2.4 GHz
Frequencies	5.47-5.725 GHz	2.4-2.483 GHz	5.15-5.30 GHz	5.15-5.30 GHz	2.4-2.483 GHz
Max Capacity	20 Mbps	11 Mbps	20 Mbps	54 Mbps	732.2 Mbps

Typical power	25mW	30mW	0.1-1 W	25mW	1mW
QoS	Low	Low	Medium	High	Medium
Interference	Satellite	Microwave, cordless, phones, Bluetooth	Satellite	Satellite	Microwave, cordless, phones, Bluetooth
Typical Radius	20-100 m	30-200 m	20-100 m	20-100 m	20 m
Cost	Medium	High	Low	Low	Medium

Most of the above technologies can be ignored. When deciding upon the wireless protocol, focus is put towards two protocol standards which not only provide a more than convenient replacement for cables, but with their capacity for autonomous interaction and rich functionality, will become increasingly popular in the search for hassle free wireless communication. These are: Bluetooth and ZigBee

4.3.1 Bluetooth

4.3.1.1 Bluetooth Theory

The Bluetooth wireless system [17] has its origins in the late 1990s, when Ericsson Mobile Communications launched an initiative to study wireless alternatives to the cables which linked the mobile phones with accessories such as headsets. It was names after Harald Bluetooth (Harald Gormsson) a 10^{th} century Danish King who united Denmark and Norway. This was appropriate as it symbolised the uniting of isolated devices and systems. The scope for Bluetooth is such, that currently over 2000 companies are participating in the special interest group (SIG) formed in 1998 by Ericsson, Nokia, IBM, Intel and Toshiba, while many more are developing Bluetooth products. Several Bluetooth consumer products are becoming available now, and soon it will be evident whether this technology is accepted by the general public and is able to provide an improved standard of life.

Bluetooth is a pure adhoc networking protocol used especially for short-range, low power wireless communication radio link between two devices operating in the unlicensed 2.4 GHz industrial scientific and medical (ISM) band. Bluetooth.s design incorporates a piconet network in which two or more Bluetooth devices form a communication channel to exchange data. The first device to initiates the channel is the master while the other devices on the piconet are the slave.

In addition, the Bluetooth technology is capable of engaging in several piconets present in the same vicinity in a Time Division Multiplexing fashion. This phenomena, known as scatternet (shown in Figure 4.9) gives Bluetooth a more versatile look [18].

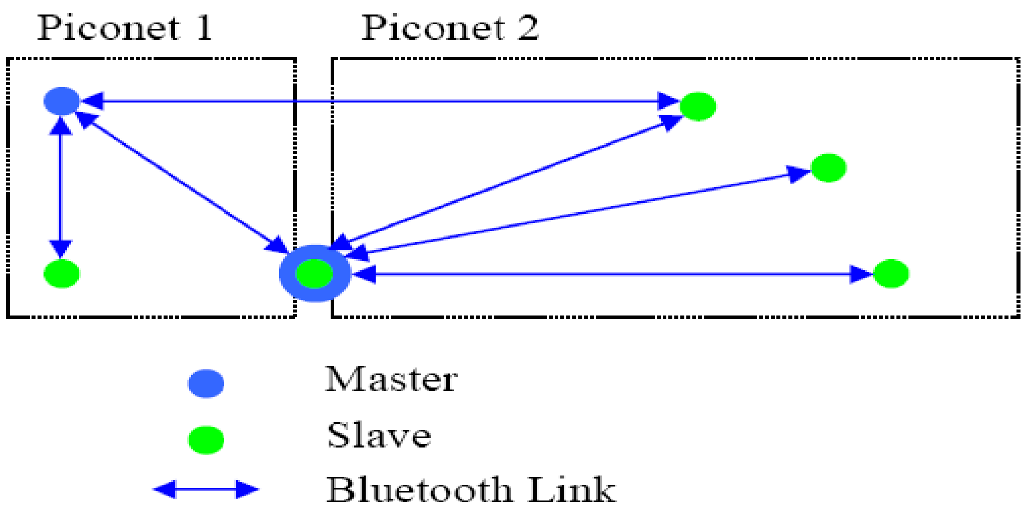

Figure 4.9 Bluetooth Scatternet

Hybrid direct-sequence spread spectrum and frequency hopping spread spectrum technology is used as the transmission scheme. The Bluetooth module transmits at 1mW (0 dBm) at a useful data speed of 721 kbps per piconet. It can accommodate up to eight devices per piconet, in which the expected coverage range is around 10 m.

4.3.1.2 Bluetooth Stack

To facilitate the data transmission in Bluetooth, they have designed a series of protocols within the system that processes data for suitable transmission and receipt. Its structure consists of a microprocessor to handle all baseband specification, and several software layers. [19] Each layer in the stack is responsible for structuring the data to allow accurate communication over the Bluetooth Link. Figure 4.10 provides a representation of the Bluetooth Stack [20].

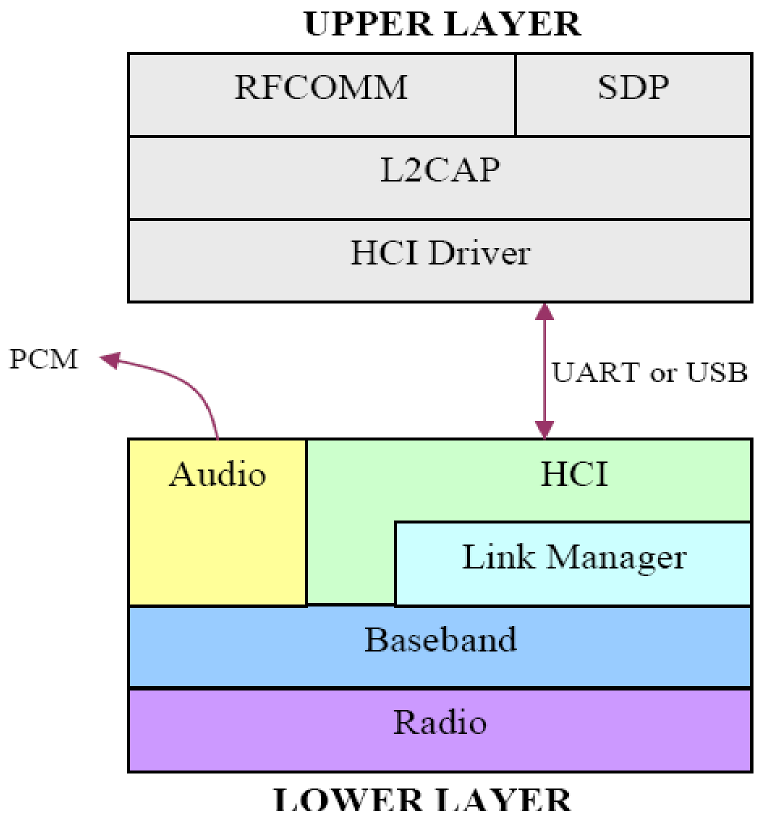

Figure 4.10 Bluetooth specification protocol stack

Radio Layer is the lowest defined layer of the protocol and it defines the requirements of the Bluetooth transceiver.

Baseband Layer is concerned with the link control at the bit and packet level as well as the coding and encryption for the packet assembly and frequency hopping operations.

Link Manager Layer configures the link, in that it is responsible for encryption, authentication, and state of stations in the piconet, power modes, and traffic scheduling and packet format.

Host controller interface (HCI) accommodates the transferring of data between the upper and lower layer (baseband controller) via a physical bus, allowing the user access Bluetooth baseband capabilities.

Audio communication is relatively simple as it involves opening an audio link in a pulse code modulated (PCM) format.

Logical link control and adaptation protocol (L2CAP) allows for protocol multiplexing and segmentation of outgoing packets.

Service Discovery Protocol (SDP) provides the means for application to discover which services are available and the characteristics of those services. *RFCOMM Layer* emulates the RS-232 control and data signaling over the Bluetooth baseband

4.3.2 Zigbee

4.3.2.1 ZigBee Stack and Theory

One of the emerging standards in the move toward a wireless world is an approach called ZigBee. [21] Pioneered by Phillips, it has since formed into an alliance of companies working together to create a wireless communication protocol. The ZigBee stack unlike Bluetooth is relatively straightforward, as can be seen in Figure 4.11 [22].

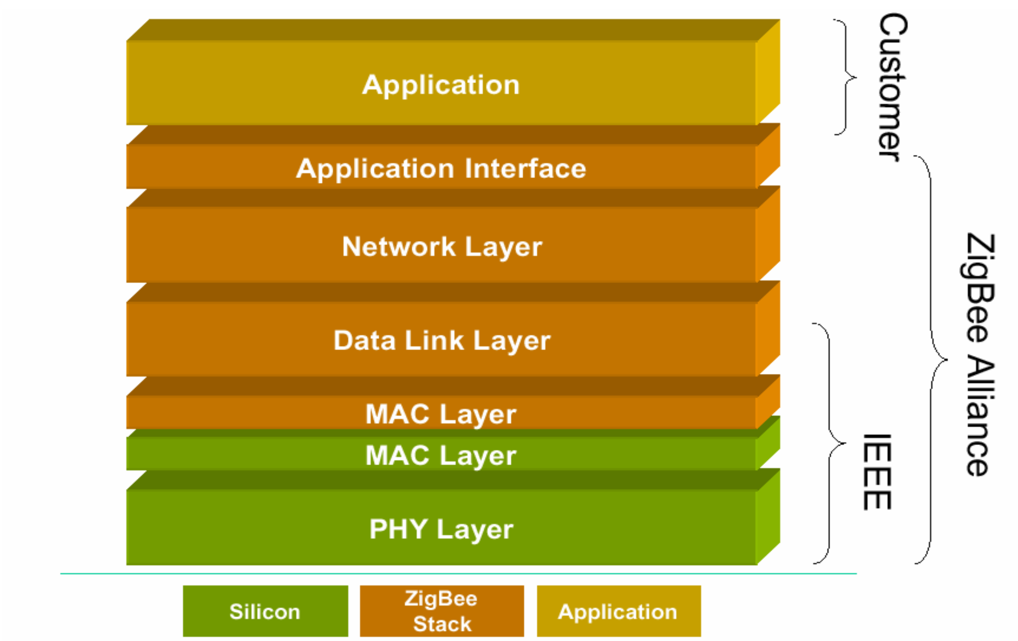

Figure 4.11 Zigbee Protocol Stack

The higher protocol layers are being developed by the Zigbee Alliance group while interests in the lower layers of the stack (MAC, PHY and LLC) are being developed by the IEEE 802.11 working group 4 (802.11.4) which is aimed at achieving data throughput of 220kbps in the 2.4GHz band. Protocol features include [23]:

- Service discovery
- Master / Slave topology
- Automatic network configuration
- Dynamic slave device addressing

- Up to 254 (+ master) network nodes
- TDMA slots can be allocated
- Full handshaking for packet transfers (reliable data transfer)
- CSMA/CA channel access mechanism
- 28kbps and 250kbps data throughput
- Power management features

The Zigbee protocol operates in the three different frequency bands (2.GHz, 915MHz. USA ISM band and 868MHz –Europe), which employs DSSS for transmission and reception of data. As seen above, different data throughputs can use however influencing the distance of transmission.

The main purpose of this standard is to provide its customers with three main features:

- Low data rate
- Low power consumption
- Low cost

The design for ZigBee took into consideration the high power consumption of Bluetooth. For most application, the Zigbee module is capable of a battery life of 6 months to 2 years with AA batteries. This is achieved by using sleep mode functions to allow communication only when the application deems necessary. The Zigbee chip here draws a few milliamps in sleep mode against 100 micro amps or more for a comparable Bluetooth state. Furthermore this prevents the device from interference problems as it often won't be operating when other modules are using the 2.4 GHz band.

4.3.3 Protocol Selection

While both technologies have their advantages and disadvantages, they are in fact different solution optimized for different applications. Bluetooth provides an ideal ad hoc network between capable device for transferring audio, screen graphics, picture and file. On the other hand, the Zigbee device is ideally for a static network, which comprises of a multiple devices communicating with smaller packets. [24]. Here Bluetooth Protocol is used for transferring ECG data and graphics.

4.4 PIC Microcontroller

4.4.1 PIC16F877A

The PIC16F877A microcontroller [25] from Microchip is chosen since its easiness to use, high speed and its cost compare to other microcontrollers. PIC16F877A microcontroller has the following features:

- High performance RISC CPU
- Only 35 single word instructions to learn
- Operating speed: DC – 20 MHz clock input
- DC – 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
- Up to 368 x 8 bytes of Data Memory (RAM)
- Up to 256 x 8 bytes of EEPROM Data Memory
- Pin-out compatible to the PIC16C73B/74B/76/77
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable Operation
- Programmable code protection
- Low power, high speed CMOS FLASH/EEPROM technology
- Fully static design
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Low-power consumption
- Synchronous Serial Port (SSP) with SPI_ (Master mode) and I2C_ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) With 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)

Figure 4.12 shows the pin diagram of PIC16F877A

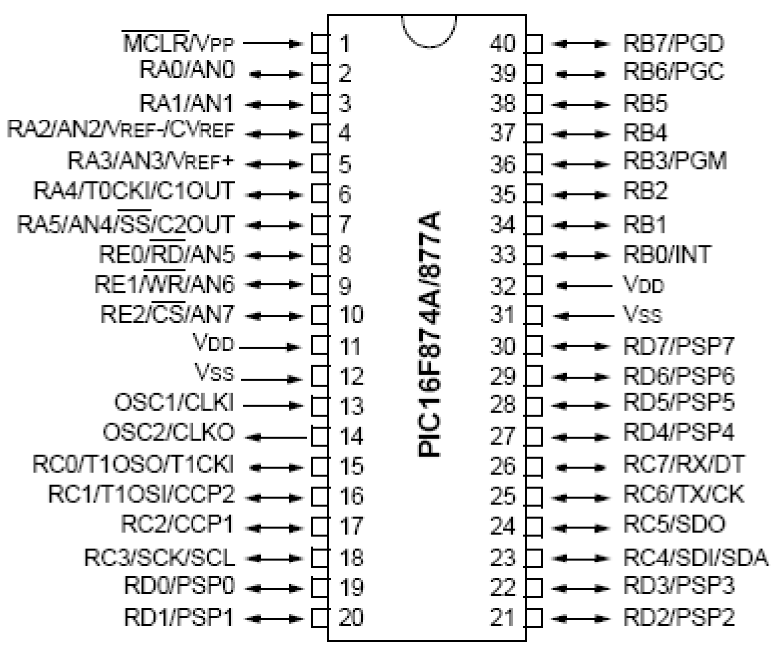

Figure 4.12 PICF877A pin diagrams

4.4.2 Analog to Digital Converter Module

The Analog-to-Digital (A/D) Converter module has five inputs for the 28-pin devices and eight for the 40/44-pin devices.

The conversion of an analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low-voltage reference input that is software selectable to some combination of VDD, VSS, RA2 or RA3.

The A/D converter has a unique feature of being able to operate while the device is in Sleep mode. To operate in Sleep, the A/D clock must be derived from the A/D's internal RC oscillator.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)

The ADRESH: ADRESL registers contain the 10-bit result of the A/D conversion. When the A/D conversion is complete, the result is loaded into this A/D Result register pair, the GO/DONE bit (ADCON0<2>) is cleared and the A/D interrupt flag bit ADIF is set. For an A/D Conversion, follow these steps are used:

1. Configure the A/D module:
   - Con figure analog pins/voltage reference and digital I/O (ADCON1)
   - Select A/D input channel (ADCON0)
   - Select A/D conversion clock (ADCON0)
   - Turn on A/D module (ADCON0)
2. Configure A/D interrupt (if desired):
   - Clear ADIF bit
   - Set ADIE bit
   - Set PEIE bit
   - Set GIE bit
3. Wait the required acquisition time.
4. Start conversion:
   - Set GO/DONE bit (ADCON0)

5 Wait for A/D conversion to complete by either:

- Polling for the GO/DONE bit to be cleared (interrupts disabled); OR waiting for the A/D Interrupt

6 Read A/D Result register pair (ADRESH:ADRESL), clear bit ADIF if required

7 For the next conversion, go to step 1 or step 2 as required. The A/D conversion time per bit is defined as TAD

4.4.3 USART Module

Transmitter (USART) module is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI) [17,21]. The USART can be configured as a full duplex asynchronous system that can communicate with peripheral devices such as CRT terminals and personal computers, or it can be configured as a half duplex synchronous system that can communicate with peripheral devices such as A/D or D/A integrated circuits, serial EEPROMs etc. The USART can be configured in the following modes:

- Asynchronous (full duplex)
- Synchronous – Master (half duplex)
- Synchronous – Slave (half duplex)

Bit SPEN (RCSTA<7>) and bits TRISC<7:6> have to be set in order to configure pins RC6/TX/CK and RC7/RX/DT as the Universal Synchronous Asynchronous Receiver Transmitter. The USART module also has a multi-processor communication capability using 9-bit address detection.

4.4.3.1 USART Baud Rate Generator

The BRG supports both the Asynchronous and Synchronous modes of the USART. It is a dedicated 8-bit baud rate generator. The SPBRG register controls the period of a free running 8-bit timer. In Asynchronous mode, bit BRGH (TXSTA<2>) also controls the baud rate. In Synchronous mode, bit BRGH is ignored.

Table 4.2 shows the formula for the computation of the baud rate for different USART modes which only apply in Master mode (internal clock). Given the desired baud rate and FOSC, the nearest integer value for the SPBRG register can be calculated using the formula in Table 3.2. From this, the error in baud rate can be determined. It may be advantageous to use the high baud rate (BRGH = 1), even for slower baud clocks. This is because the FOSC/(16(X + 1)) equation can reduce the baud rate error in some cases.

Writing a new value to the SPBRG register causes the BRG timer to be reset (or cleared). This ensures the BRG does not wait for a timer overflow before outputting the new baud rate.

Table 4.2 Baud Rate Formula Table

Sync	BRGH = 0 (Low Speed)	BRGH = 1 (High Speed)
0	(Asynchronous) Baud Rate = Fosc/(64(X+1))	Baud Rate = Fosc/(64(X+1))
1	(Synchronous) Baud Rate = Fosc/(4(X+1))	N/A

4.4.3.2 USART Asynchronous Mode

In this mode, the USART uses standard non-return-to-zero (NRZ) format (one START bit, eight or nine data bits, and one STOP bit). The most common data format is 8-bits. An on-chip, dedicated, 8-bit baud rate generator can be used to derive standard baud rate frequencies from the oscillator. The USART transmits and receives the LSB first. The transmitter and receiver are functionally independent, but use the same data format and baud rate. The baud rate generator produces a clock, either x16 or x64 of the bit shift rate, depending on bit BRGH (TXSTA<2>). Parity is not supported by the hardware, but can be implemented in software (and stored as the ninth data bit). Asynchronous mode is stopped during SLEEP. Asynchronous mode is selected by clearing bit SYNC (TXSTA<4>). The USART Asynchronous module consists of the following important elements:

- Baud Rate Generator
- Sampling Circuit
- Asynchronous Transmitter
- Asynchronous Receiver

5

5. Methodology

5.1 Hardware Methodology

This chapter deals with more than just how the final design was arrived at. It attempts to convey some lessons learnt throughout the course of the project. Initially circuitry able to obtain an ECG signal in a largely traditional manner was built and that is what is covered in this chapter. The circuitry was later used to try and obtain an ECG signal in the manner required for a completely wireless system. Appendix 2 shows actual hardware system.

5.1.1 Electrode Placement

The closer the electrodes are to the heart, the stronger the signal that will be obtained. Placing electrodes on the torso of a patient provides a stronger signal then on the wrists and legs. In keeping with the vector dipole model of the heart and the mathematical equation giving the differential voltage obtained as the dot product of the heart dipole vector and the vector between two electrodes, the closer these two vectors are to perpendicular, the greater the voltage obtained. This corresponds to electrode placing for Lead 3 of the Einthoven Triangle. Lead 2 obtains the weakest signal.

Figure 5.1 Electrodes used in the Project

Both commercial ECG electrodes and simple metal discs were trialed during the course of the project. The commercial electrodes provided the strongest signal for equivalent positioning and had the advantage of adhesive to hold them in place, Figure 5.1 shows the electrodes used in the Project. Coins and washers were used as dry electrodes. These provide acceptable results and the strength of the signal can be improved by applying an ionic solution (such as shampoo or toothpaste) to the skin for the metal to make contact with.

5.1.2 Instrumentation Amplifier

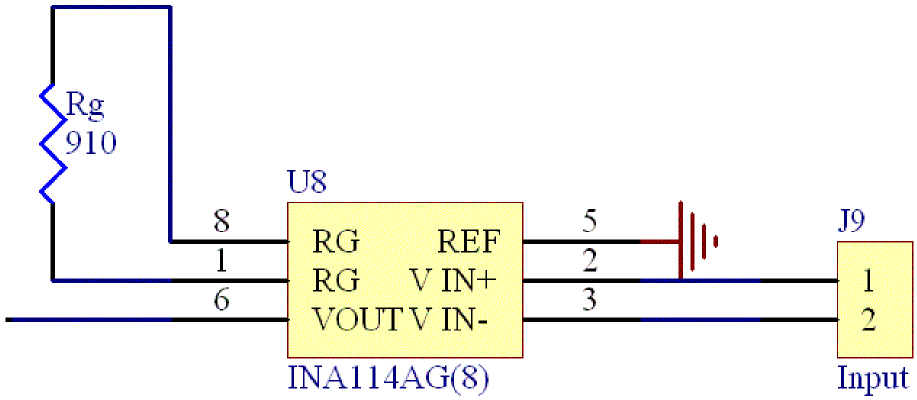

Figure 5.2 Instrumentation Amplifier Circuit

The instrumentation amplifier acts as the front-end for a signal acquisition system. Figure 5.2 shows the Circuit diagram The Burr-Brown INA114 was chosen for implementation in the system. It is a high precision amplifier commonly used in bio-electronics, featuring a measured CMRR of 115dB and a input impedance in the order of 1010Ω [26]. Gain is set by a single external resistor to be in the range of 1 to 10000 and is given by the equation [27]:

$$G = 1 + 50k\Omega / RG$$

Where, RG is the external resistor setting gain. The value of RG was chosen to be 910Ω making the gain close to 60.

5.1.3 Power Supply

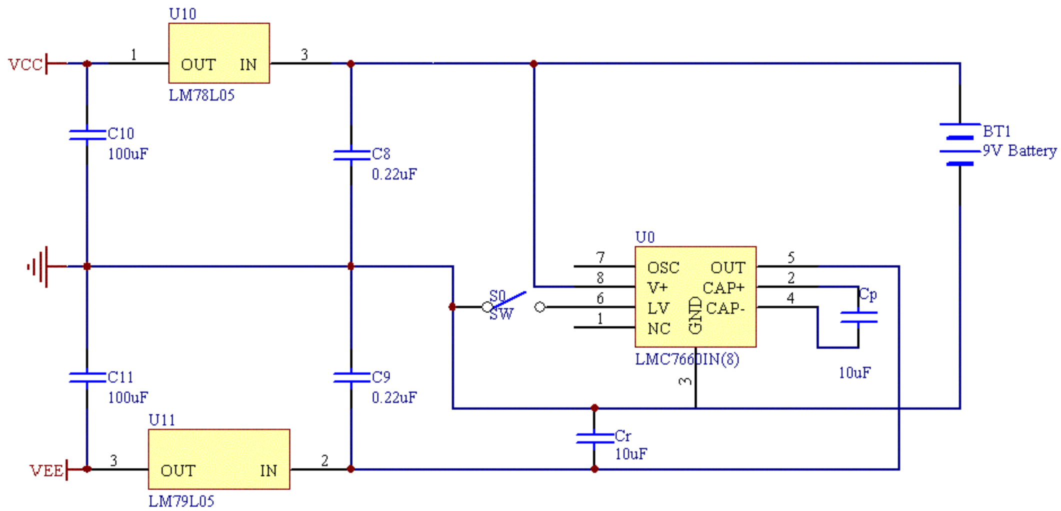

Figure 5.3 Power Supply Circuitry

The ECG signal being measured has components in both the negative and positive voltage domains. To cope with this, amplifiers in the system require positive and negative power supplies. For wireless philosophy, a battery is used to power the remote nodes.

To rectify the positive voltage supplied by the battery into an equivalent negative voltage, the LMC7660 switched capacitor voltage converter is used. This chip converts a supplied positive voltage into the equivalent negative voltage with 95% power efficiency [28]. The positive voltage from the battery and the negative voltage from the LMC7760 are then regulated to +5V and -5V respectively through LM78L05 and LM79LO5 voltage regulators. This gives a stable power supply that doesn't introduce noise and is suitable for the microprocessors.

5.1.4 Low Pass Filter

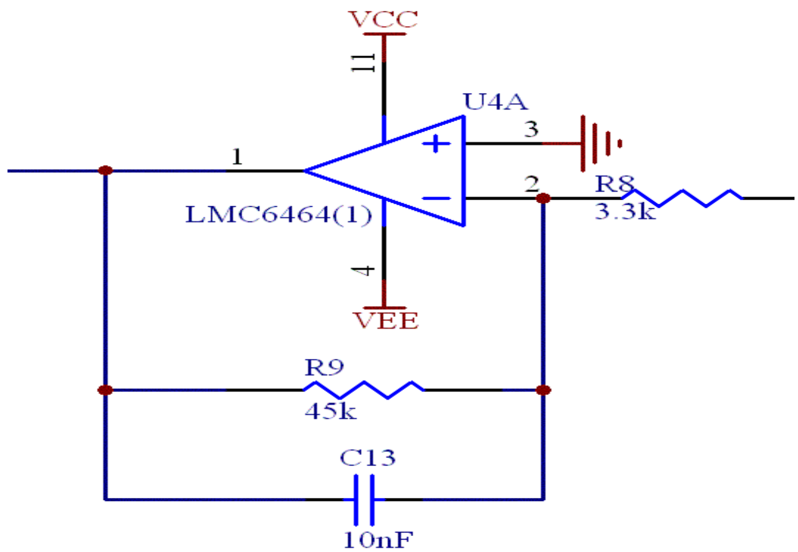

Figure 5.4 Implemented Low Pass Filter

Since the ECG signal is contained in the relatively narrow frequency spectrum below 100Hz, a low pass filter can remove a large amount of ambient noise. With microprocessors and an RF transmitter in close proximity to the analogue circuitry, the low pass filter is responsible for ensuring these do not detrimentally affect the ECG obtained.

The low pass filter implemented is shown in Figure 5.4. LMC6464 is implimented as first order active filter [27]. The corner frequency is calculated to be 105Hz. An active filter was used as it also provides gain. The gain of the filter is given by the ratio of R9 to R8; in this implementation it is 13.6. Figure 5.5 shows the frequency response of the filter as generated by PSPICE.

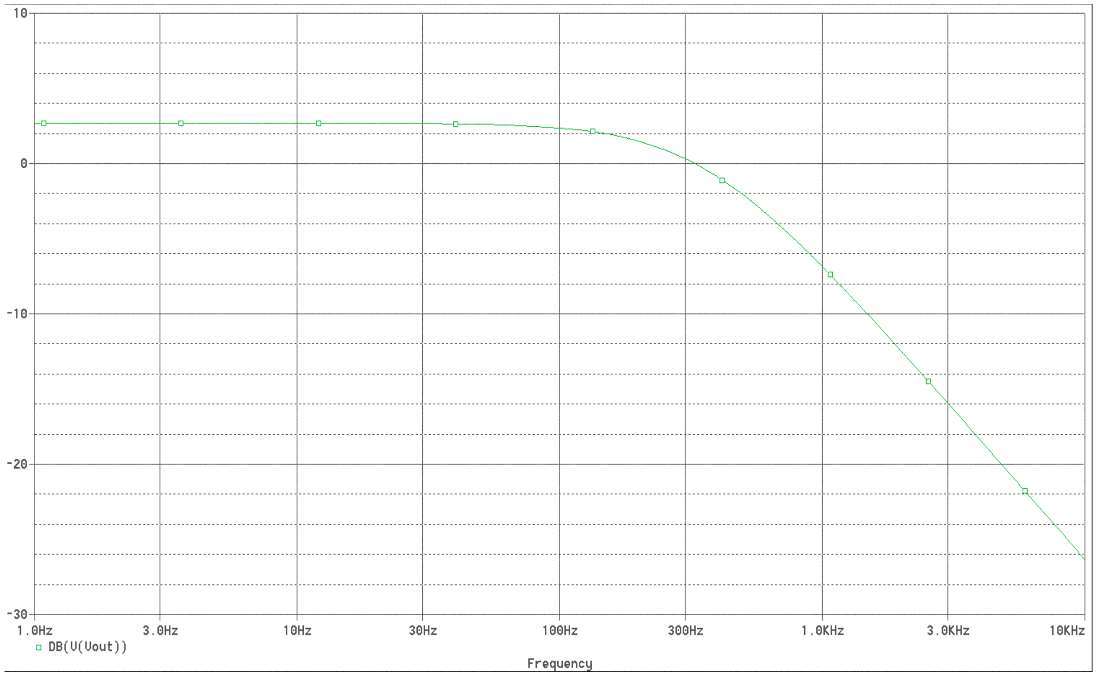

Figure 5.5 Frequency Response of Low Pass Filter

A first order filter was deemed to be adequate since little noise is contained in the frequency band immediately above 100Hz and the 20dB/decade attenuation roll-off is effective in removing the microprocessor and RF circuitry noise contained in the megahertz.

5.1.5 Notch Filter

Mains power noise is the biggest problem for normal ECG measurement, and especially so in this system due to the unsuitability of right leg driver circuitry. In order to combat this, a 50Hz Notch Filter UAF42 was used to eliminate 50Hz Ac main interference. The UAF42 is a monolithic, time continuous, 2nd order active filter building block for complex and simple filter design. An auxiliary high performance operational amplifier is also provided which can be used for buffering, gain, real pole circuits, or for summing the high pass and low pass output to create a band rejection (notch) filter [28]. Figure 5.6 shows the Notch Filter UAF42.

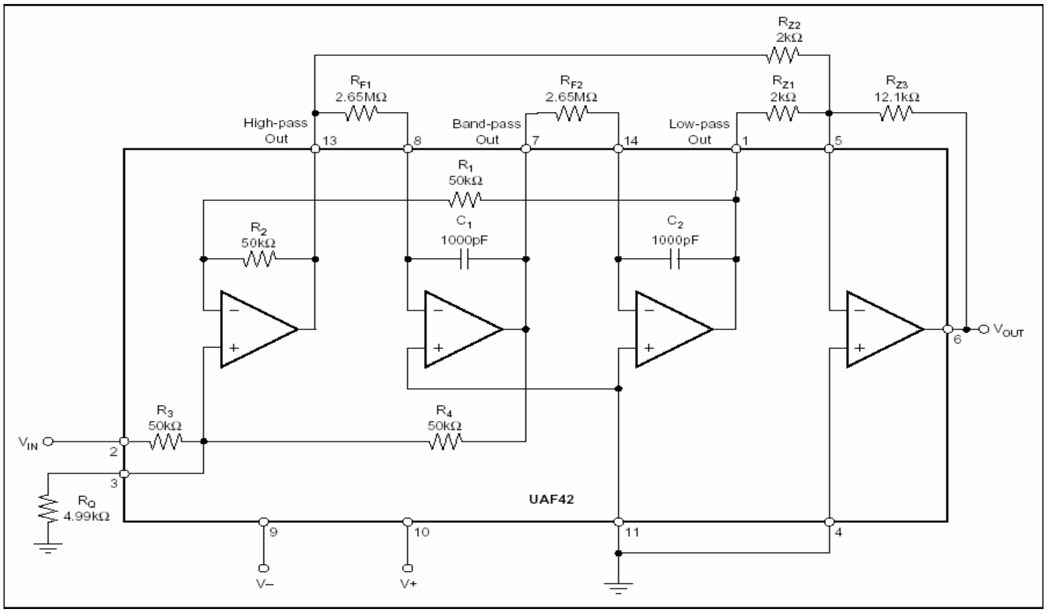

Figure 5.6 Connection of Notch filter UAF42

The experiment was done to see the performance of this notch filer using same approach as low pass filter. The result of this experiment as shown in table 5.1 below and figure 5.7 is a plotting graph at semi log paper.

Table 5.1 Results for UAF42 measurement

Frequency(Hz)	Output after LPF(dB)
25.45	-2.17
30.23	-2.17
47.77	-9.50
50	-14.74
54.30	-9.68
55.77	-7.35
56.68	-6.73
60	-3.12
61	-2.87
64	-2.39
72	-2.17
90	-2.17

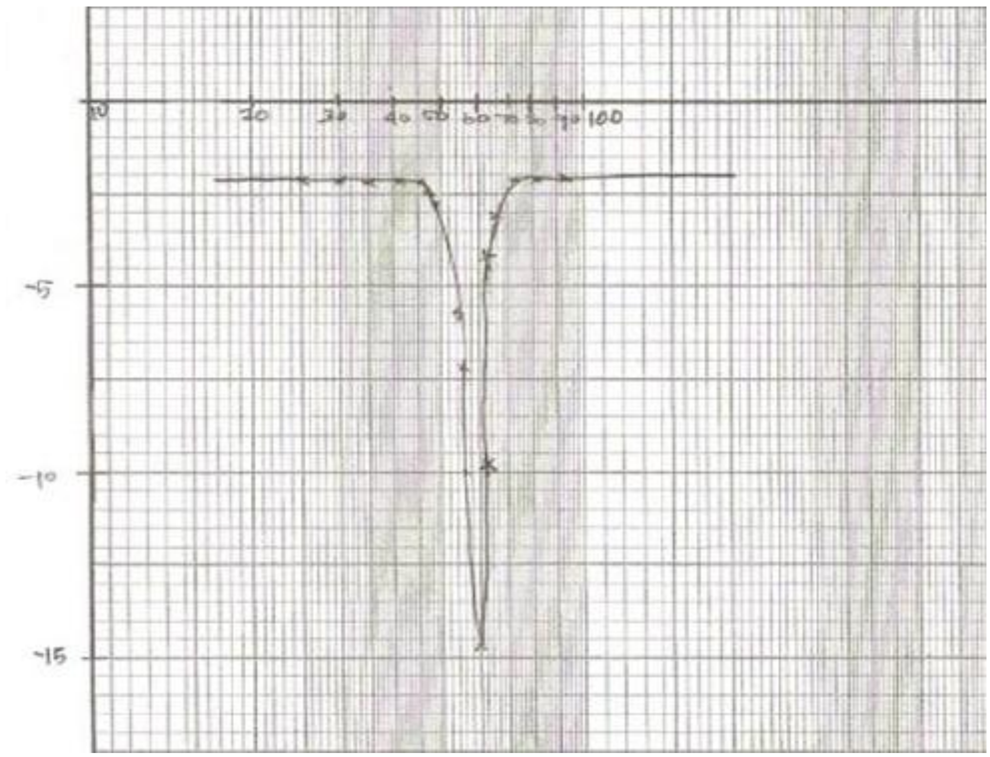

Figure 5.7 Graph of cutoff frequency for UAF42

5.1.6 Summing Amplifier

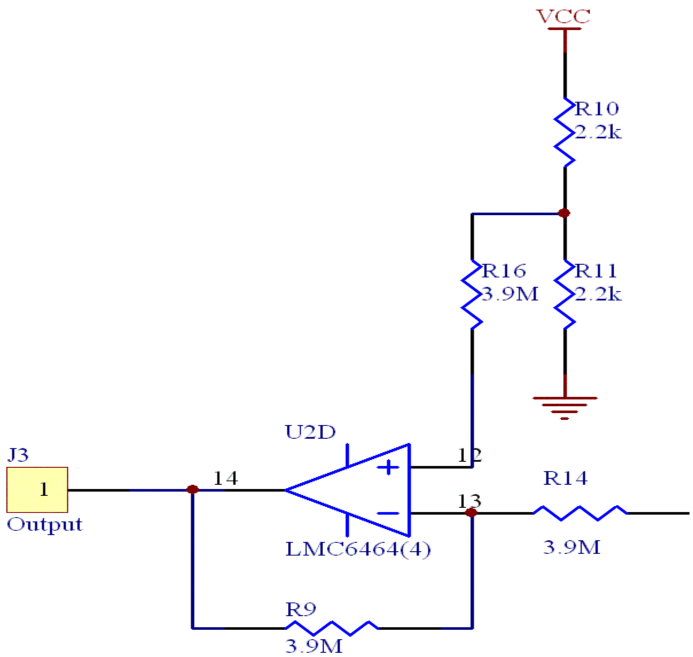

Figure 5.8 Implemented Summing Amplifier

After filtering and amplification, the data is ready to be digitized by the ADC. The ADC requires the signal it is sampling to be contained completely in the positive voltage domain. The summing amplifier is used to achieve this and its topology is shown in Figure 5.8. The DC voltage that the signal will be added to is supplied by the voltage divider formed with two 2.2kΩ resistors. The other resistors set the gain of the amplifier to be one, and are much larger than the resistors in the voltage divider so they don't influence the voltage division. In this way the output of the summing amplifier is the ECG signal transposed up by 2.5V.

5.2 Software Design Methodology

5.2.1 ISIS Proteus 7.6 VSM

ISIS provides the development environment for PROTEUS VSM, revolutionary interactive system level simulator. The product combines mixed mode circuit simulation, micro-processor models and interactive component models to allow the simulation of complete micro-controller based designs.

ISIS provides the means to enter the design in the first place, the architecture for real time interactive simulation and a system for managing the source and object code associated with each project. In addition, a number of graph objects can be placed on the schematic to enable conventional time, frequency and swept variable simulation to be performed.

Major features of PROTEUS VSM include:

- True Mixed Mode simulation based on Berkeley SPICE3F5 with extensions for digital simulation and true mixed mode operation.
- Support for both interactive and graph based simulation.
- CPU Models available for popular microcontrollers such as the PIC and 8051 series.
- Interactive peripheral models include LED and LCD displays, a universal matrix keypad, an RS232 terminal and a whole library of switches, pots, lamps, LEDs etc.
- Virtual Instruments include voltmeters, ammeters, a dual beam oscilloscope and a 24 channel logic analyzer.
- On-screen graphing - the graphs are placed directly on the schematic just like any other object. Graphs can be maximized to a full screen mode for cursor based measurement and so forth.
- Graph Based Analysis types include transient, frequency, noise, distortion, AC and DC sweeps and Fourier transform. An Audio graph allows playback of simulated waveforms.
- Direct support for analogue component models in SPICE format.
- Open architecture for ‘plug in’ component models coded in C++ or other languages. These can be electrical, Graphical or a combination of the two.
- Digital simulator includes a BASIC-like programming language for modeling and test vector generation.
- A design created for simulation can also be used to generate a netlist for creating a PCB - there is no need to enter the design a second time.

ECG sensor board consists of combination of the five different circuits which are instrumentation amplifier, amplifier, low pass filter, notch filter and summing amplifier. Figure 5.9 shows the schematic diagram for ECG sensor board that is designed using Proteus 7 Professional Software and simulated before transfer from breadboard to Printed Circuit Board (PCB).

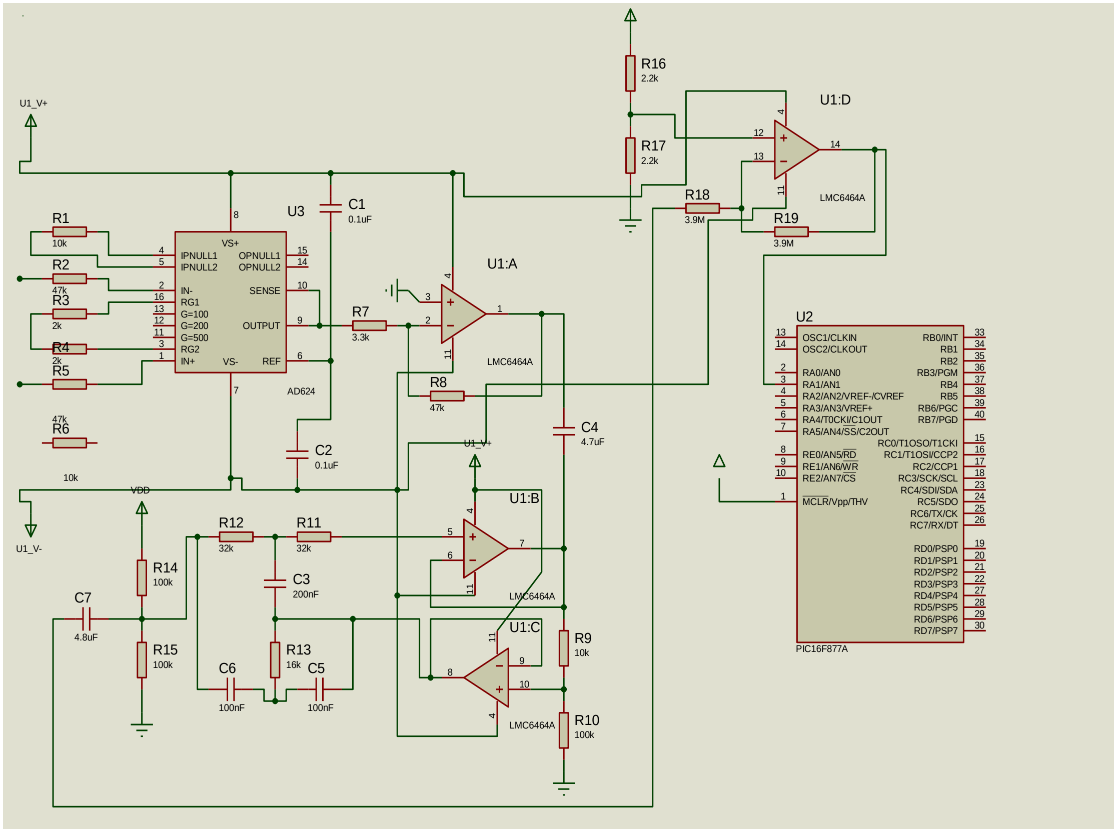

Figure 5.9 Schematic diagram for ECG sensor board

5.2.2 miKroC

mikroC is a powerful, feature rich development tool for PICmicros. It is designed to provide the programmer with the easiest possible solution for developing applications for embedded systems, without compromising performance or control.

PIC is the most popular 8-bit chip in the world, used in a wide variety of applications, and C, prized for its efficiency, is the natural choice for developing embedded systems. mikroC provides a successful match featuring highly advanced IDE, ANSI compliant compiler, broad set of hardware libraries, comprehensive documentation, and plenty of ready-to-run examples. Figure 5.10 shows the mikroC Integrated Drive Electronics (IDE).

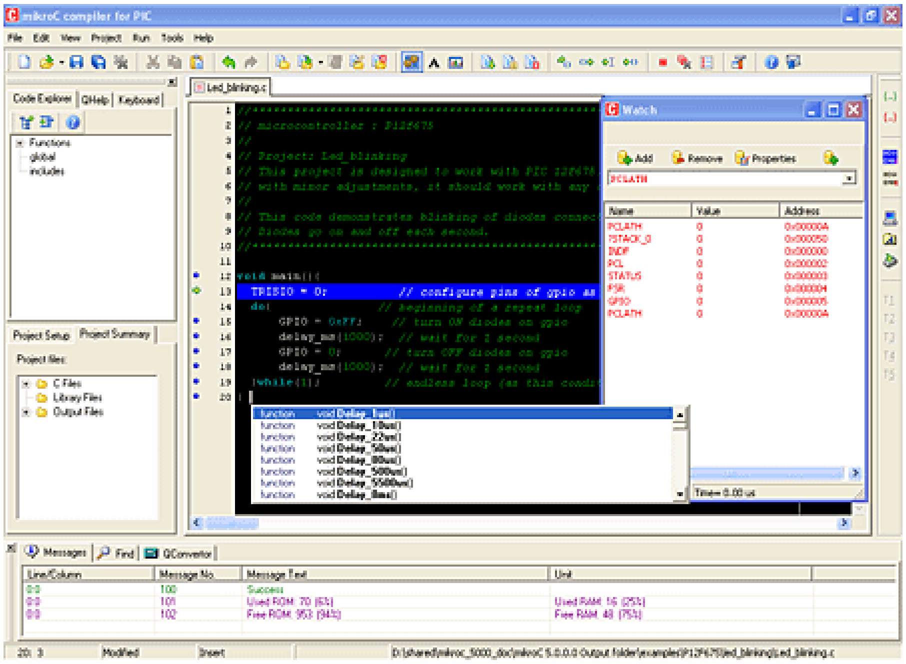

Figure 5.10 miKroC IDE

5.2.3 Bluetooth PC Interface Setup

From the Bluetooth module SKKCA-11, the data is sent to the USB dongle which is interfaced to the computer. Communication link between Bluetooth module and USB dongle is established by using Bluesoliel program. Finally, LABVIEW program displays the signal from the device connection. Figure 5.11 shows the proposed setup and operation for the wireless module.

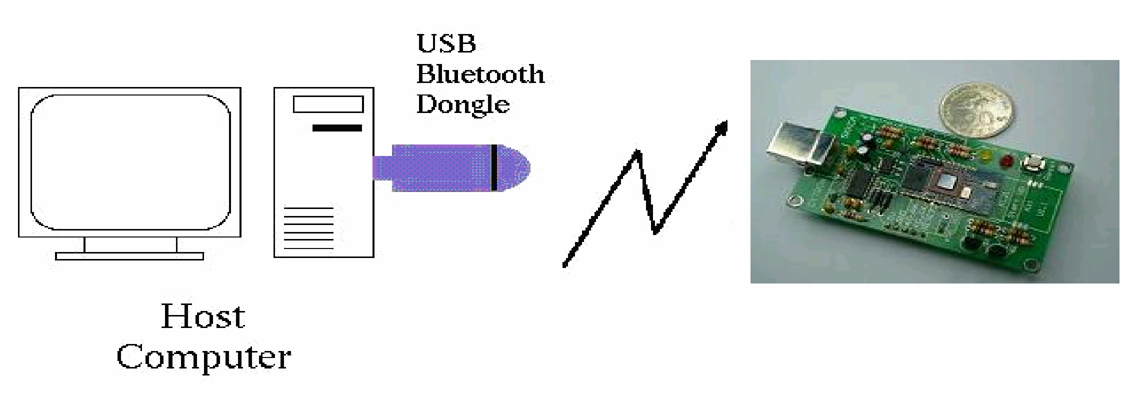

Figure 5.11 Bluetooth Interfacing Setup

5.2.4 IVT BlueSoleil software

Before the USB dongle is to be used, a communication link has to be established between the Bluetooth Module and Bluetooth Dongle using IVT BlueSoleil. Following are the steps of installing and establishing a link between the two

- Install the software IVT BlueSoleil using CD included with the USB dongle
- Once the software is successfully installed, plug in the USB dongle and run the software
- Switch on the power for the circuit with the SKKCA-21
- BlueSoleil window is available as shown in figure 5.12. Click the orange ball in the center of the window or press F5

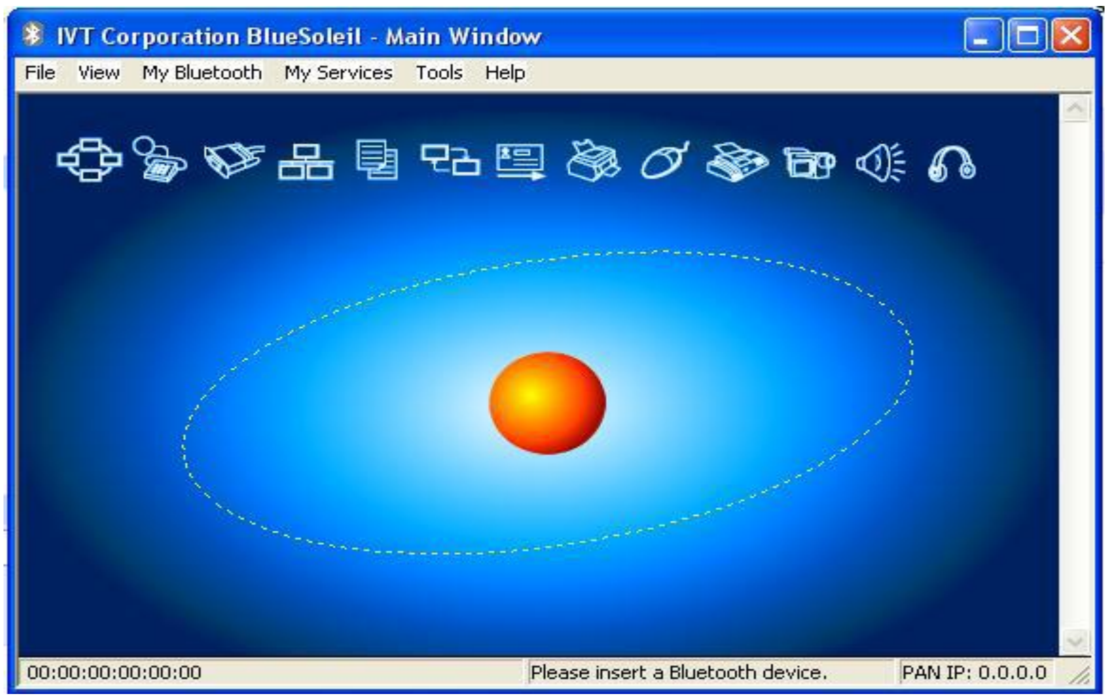

Figure 5.12 IVT BlueSoleil setup

- After searching, Bluetooth module is detected in the window and its Icon is available
- Next, double click on the symbol of the Bluetooth module. The software automatically selects the method to connect with the Bluetooth device.
- Right click on the symbol to select Connect->Bluetooth serial port service. Figure 5.13 shows the setup for Bluetooth port.

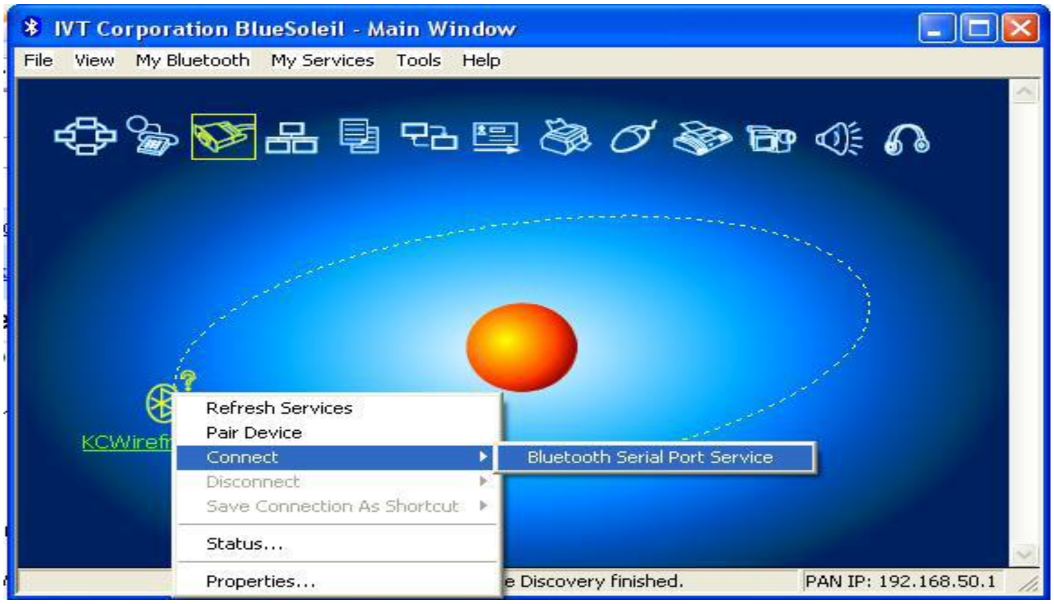

Figure 5.13 Bluetooth COM PORT setup

- Finally, window appears with the designated serial port. Click yes to proceed. Figure 5.14 shows the Bluetooth connection that has been established.

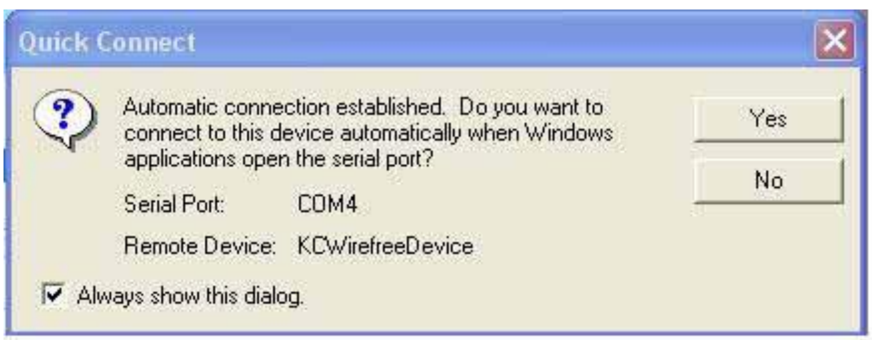

Figure 5.14 Bluetooth Connection Dialog

5.2.5 USART setting

The most important configuration is USART. USART depends on timing or the baud rate, therefore the most important task is to configure the baud rate of microcontroller, Bluetooth module, and LabVIEW VISA

The USART is configured making it ready to communicate with Bluetooth module. The settings are.

i. Baud rate = 57600 bps
ii. Data bits = 8
iii. Parity = none
iv. Stop bit = 1

The settings are done using programming language of the PIC microcontroller. Figure 5.15 shows a flow chart of general concept for microcontroller to communicate and process data from KC Wirefree Bluetooth transceiver.

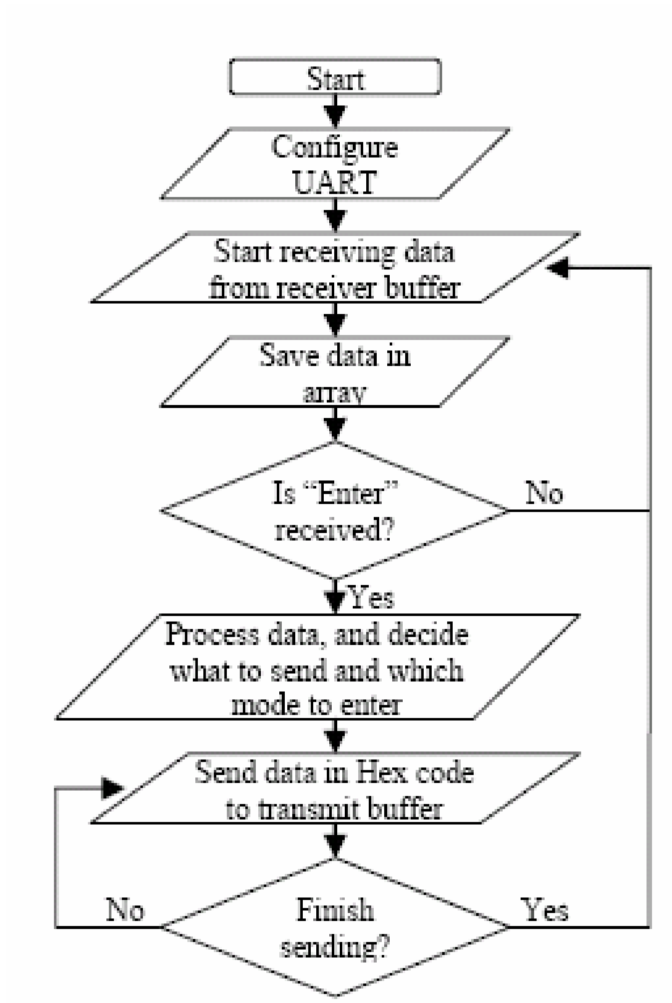

Figure5.15 Flow chart for microcontroller to communicate with Bluetooth transceiver

After configuring UART engine of microcontroller, program waits for data from UART's receiver buffer. Store the received data array and checks whether the "Enter" is received. If "Enter" is not yet received, continue to wait and keep receiving data. If "Enter" is received, process the data array stored and decides which mode to enter or which AT command to be sent? For example, when the received array of data is "ATZV BDAdress

00043E008137”, microcontroller sends “AT+ZV SPPConnect 000000E41213” to Bluetooth transceiver. This data array is to be send to transmitter buffer. If “AT-ZV –BypassMode–” is received, the microcontroller has entered bypass mode and AT commands are NOT to be send to Bluetooth transceiver. This is the programming concept, a better algorithm can be written for microcontroller. AT command is a language originally used by modem, now it has been applied in Bluetooth SPP, Every AT command start with AT and end with “enter” or <CR><LF> (i.e. “<CR>\n” in C, or in Hex value is 0x0D 0x0A).

Some common description of AT command in KC Serial

- “AT+*parameter*” is command send from host to module or serial adaptor.
- “AT–*parameter*” is command send from module to host.
- Every AT command must start with “AT” or 0x41 0x54 in Hex value.
- Every AT command must be ended with “Enter” or 0x0D 0x0A in Hex value.

There are 2 modes in Bluetooth configuration. First mode is Command mode, this mode indicate that all data send from host is a command for Bluetooth transceiver, and data send from Bluetooth transceiver to host is event reporting status of Bluetooth transceiver. Second mode is Bypass mode; this mode can only appear when connection between 2 Bluetooth transceivers is established. In Bypass mode, every single byte of data from host will be sent over Bluetooth wireless link to the other Bluetooth node.

4.2.6 LabVIEW2009

LabVIEW is a graphical programming environment used by millions of engineers and scientists to develop sophisticated measurement, test, and control systems using intuitive graphical icons and wires that resemble a flowchart. LabVIEW offers unrivaled integration with thousands of hardware devices and provides hundreds of built-in libraries for advanced analysis and data visualization. The LabVIEW platform is scalable across multiple targets and operating systems, and since its introduction in 1986 has become an industry leader. LabVIEW program for wireless ECG is presented below.

Front Panel and Block Diagram is shown in Figure 5.16 and 5.17 respectively.

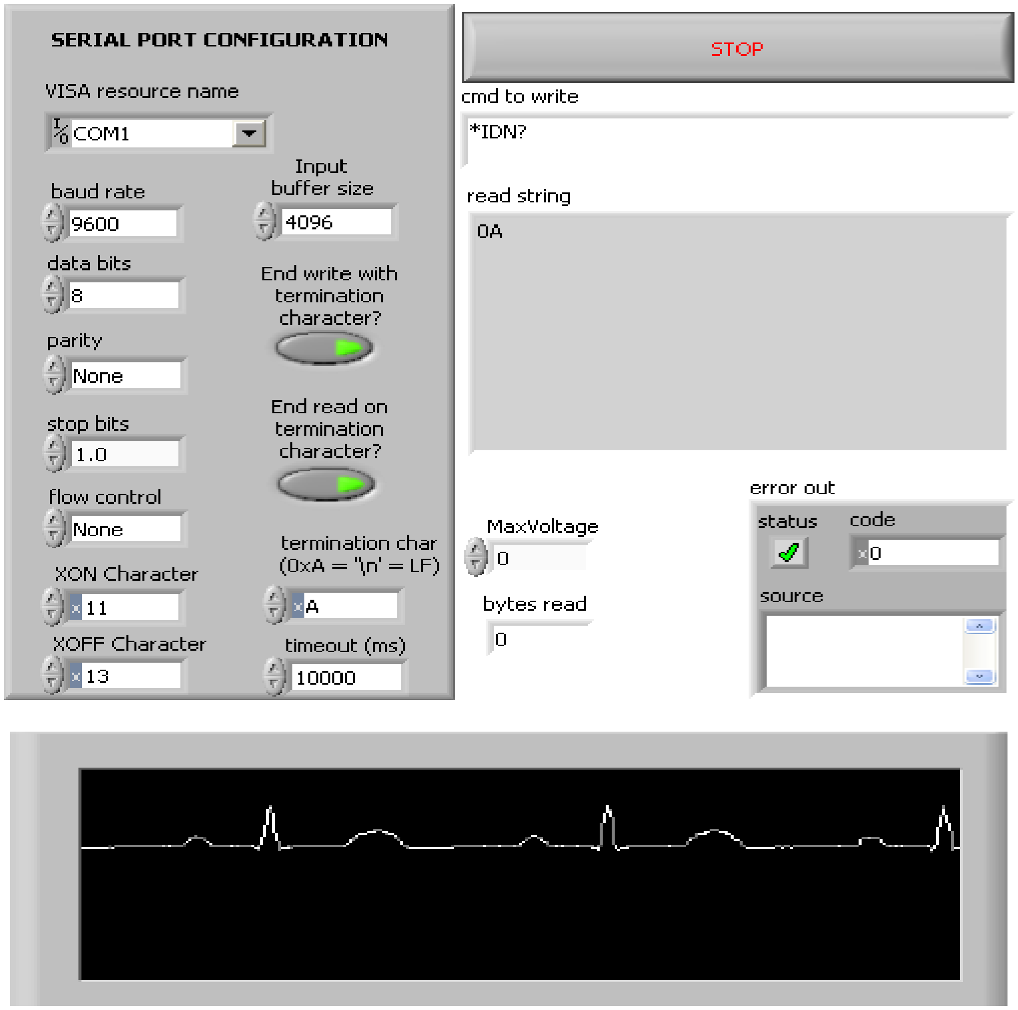

Fig 5.16 LabVIEW Front panel

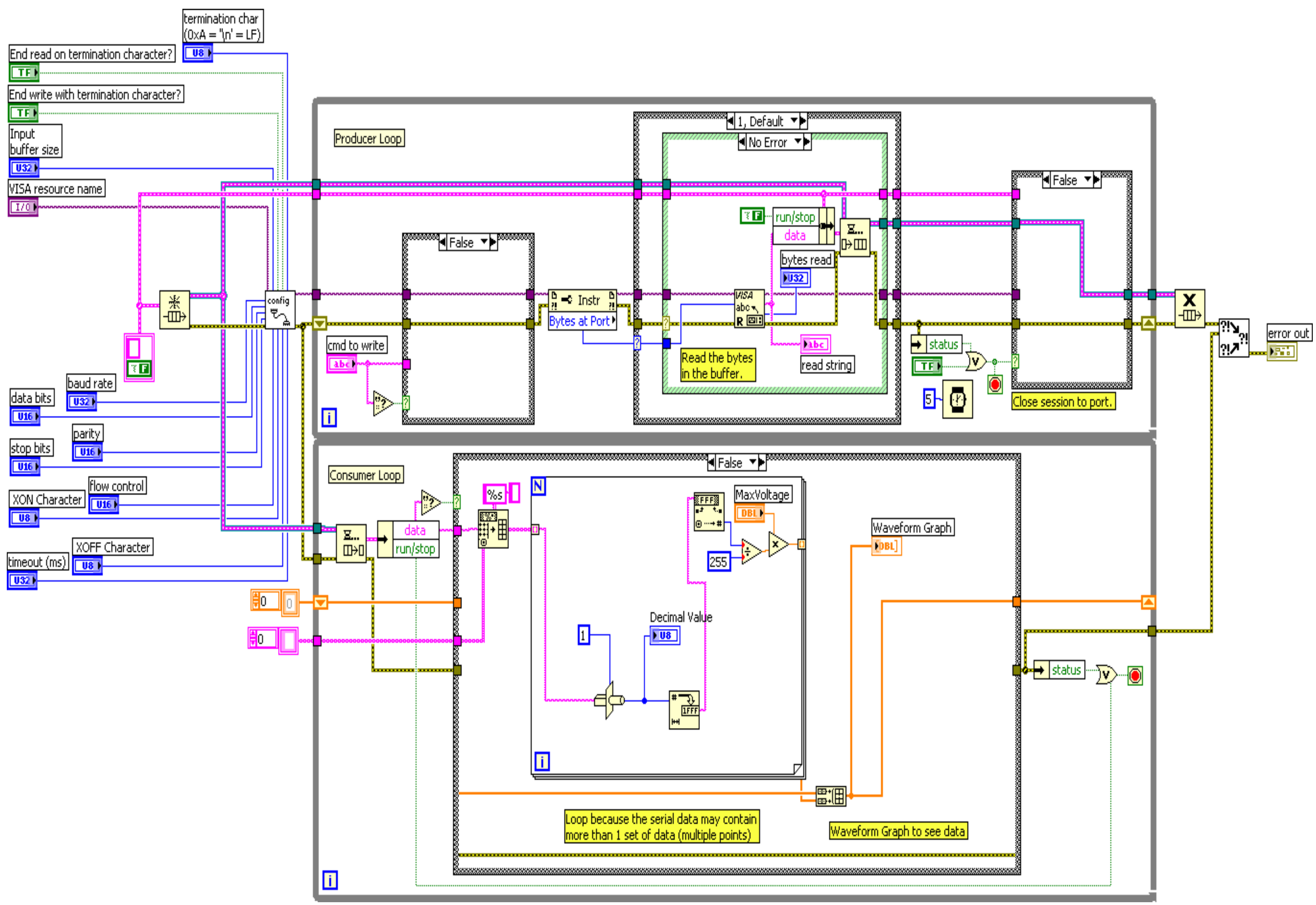
termination char
(0xA = '\n' = LF)
End read on termination character?
End write with termination character?
Input
buffer size
VISA resource name
data bits
baud rate
stop bits
parity
XON Character
flow control
timeout (ms)
XOFF Character
Producer Loop
1, Default
No Error
False
run/stop
data
bytes read
Instr
Bytes at Port
cmd to write
Read the bytes
in the buffer.
read string
status
5
Close session to port.
error out
Consumer Loop
%s
MaxVoltage
255
Waveform Graph
Decimal Value
1
Loop because the serial data may contain
more than 1 set of data (multiple points)
Waveform Graph to see data

Fig 5.17 LabVIEW Block Diagram

6

6. Result and Discussion

6.1 Results

Wireless ECG sensor system with 0-110 Hz resolution has been developed. Snapshot of the completed Wireless ECG is shown in Figure 6.1. All signals presented in this report are recorded in LabView2009. The ECG signal obtained from Lead 1 is shown in Figure 6.2

The digital to analogue conversion and sample rate is controlled by the Microcontroller; the sample rate of 400 Hz conforms to Nyquist theorem that states that the sample rate must be at least twice the resolution of the signal. With the Philips PM5136 function generator the real cut-off frequency of the ECG amplifier was established at 105 Hz..

The BlueSoliol software handled the connection to the ECG sensor system via a Bluetooth virtual serial port. The LabView2009 application for the PC manages the graphical display of the signals.

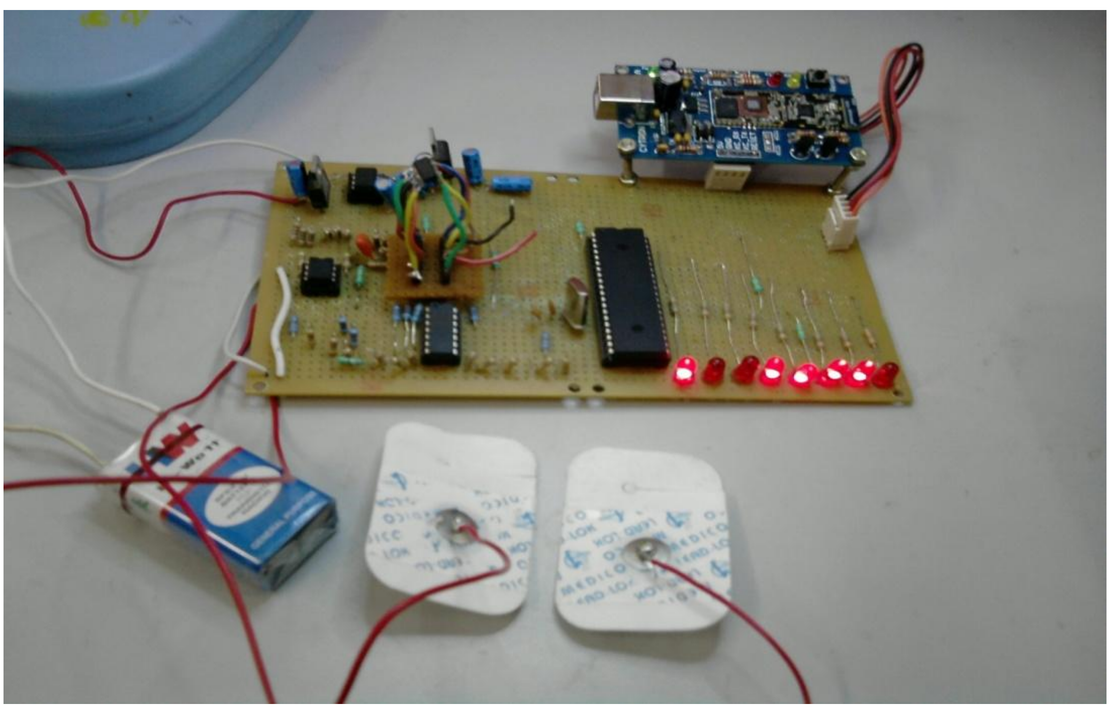

Figure 6.1 Snapshot of wireless ECG

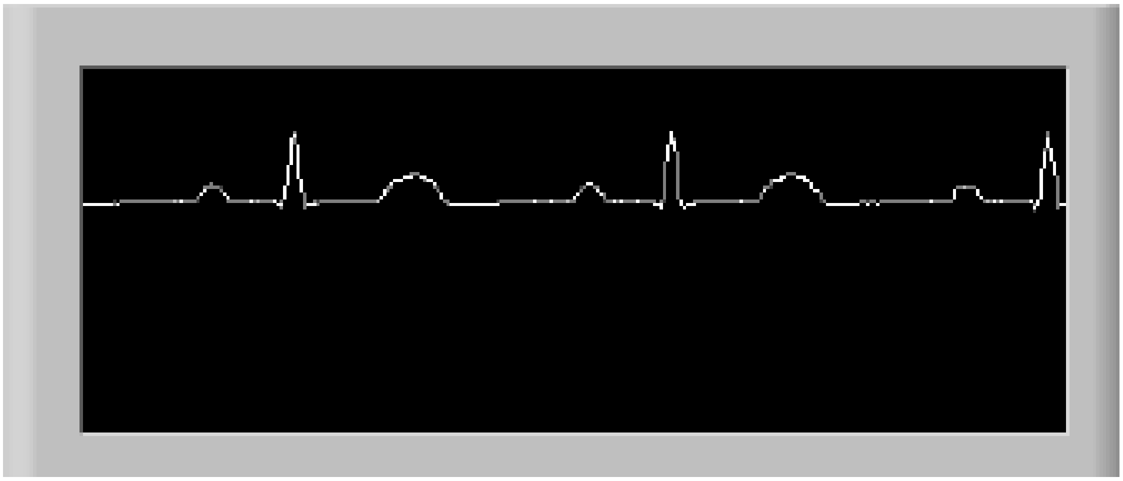

Figure 6.2 ECG signal from Lead I

6.2 Discussion

This project has been more of a research project than a conventional master thesis, where a lot of the time has been research for what is possible and finding a solution that will fit the application more than just constructing and testing. The initial ideas of connecting the ECG sensor system to a cellular phone and making a Java application for the graphical presentation were found to be almost impossible to make a standard solution if even possible. What seemed to be great advantages of using a regular cellular phone at the first stage of the project, later proved to be an obstacle. There is no real standard of the systems used in cellular phones as in PDA using windows mobile. This means that it requires more than one program developed if it should be used in larger quantities than just one system being able to connect to a specific cellular phone.

With the use of LabView2009, this is solved the only requirement is just that it is a Bluetooth enabled PC with NI VISA installed in it, no requirement of a specific brand or even a specific model of a brand as it would be with an application for cellular phones/PC. When discussing cellular phones and medical application there is an obvious disadvantage that it is not allowed having the cellular phone turned on in medical environments. No such rules apply to PDAs/PC.

The cable replacement took more time than expected which left no time for further development such as heart rate presentation or alarm function.

6.3 Conclusion and Future Recommendation

The project has resulted in a prototype of very small, wireless ECG usable in monitoring an exercising subject without being overloaded by inference from movement and surrounding electronics despite not deploying any filtering.

The work became more centered on the development, rather than analyzing the possible uses and results, of the device than expected. Much time was spent on building and testing the hardware since the use of SMD components not always suitable for manual attachment.

Even though the result and work during the project didn't exactly accord to the expectations it has been an interesting project giving insight into the process of developing an electronic measuring system.

Future Work can be done to implement advanced and reliable alarm function, connection to GPRS, SMS or perhaps to GPS depending to the handheld PDA inbuilt functions. Other advanced function such as digital noise rejection filter or FFT analysis can be implemented in the LabView2009 application depending on hardware of the PDA/PC.

It could even be considered to work with ZigBee radio instead of the Bluetooth™, as it may resolve the problems with serial port communications.

6.4 Summary

A small ECG sensor system with high resolution and effective noise reduction has been developed to measure and present ECG signal [both 50 Hz noise and DC offset has been successfully implemented in the ECG sensor system].

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Appendix – A

PIC microcontroller C Program Code

The C code program that is downloaded on to the microcontroller is presented below with comments to explain the function is marked with //.

```
void main()
{
    Unsigned int temp_res = 0;
    Usart_Init(57600);          //Initialize USART at 57600 Baud rate
    ADCON1 = 0x80;              //Loading ADC controlling register
    TRISA = 0xFF;               //PORTA as Input PORT
    TRISB = 0;                  //PORTB as Output PORT
Do {
     temp_res = ADC_Read(1)<<2;     // Reading ADC higher 8-bit
     Usart_Write(temp_res); //Sending 8-bit data via USART to Bluetooth
     PORTB = temp_res;          //Display on PORTB
     Delay_ms(22);
  } while(1);
}
```