Small wireless ECG with Bluetooth™ communication to a PDA

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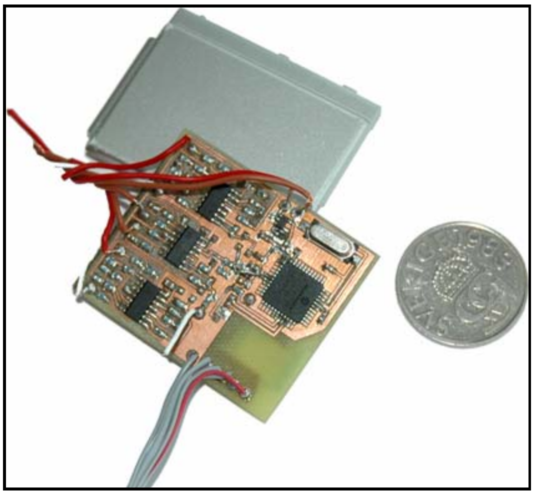

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Abstract

The Electrocardiogram (ECG) is en 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 the present is expensive and stationary. The aim of this project is to develop a small wireless sensor system to make the patient more mobile without losing the reliability of the ECG sensor.

Wireless patient monitoring has become a more established technology and a natural step in this progress is to develop a reliable ECG system that contributes to the cable reduction in medical and physiotherapy environments. The main focus of this thesis is to create a reliable small wireless ECG sensor system at low cost.

This thesis investigates the possibilities to create a small sized ECG sensor system that can be wirelessly connected to a handheld device that can graphically presents the ECG-signals.
A small embedded ECG sensor system prototype has been developed. Using Bluetooth™ technology the ECG sensor system can connect to a personal digital assistant (PDA).
Software for the PDA has been developed for presentation of the 2-channel ECG-sensor. With the use of a microprocessor the analogue signal is digitally converted at a specific sample rate that based on the resolution of the ECG-signals. The prototype is well suited for patient monitoring were a low noise and power efficient system has been created to be powered by a cellular phone battery.

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1 Background

Wireless ECG monitoring using Bluetooth™ has become a more and more established and acknowledged technology in the medical environment as in physical therapy. A natural step in the development is to make this technique more available and make it more user-friendly. One way to do this is to create a small wireless ECG that can be connected to a personal digital assistant (PDA) that will act as a data acquisition system (DAQ).

The development of this type of system has great advantages; the patient will be more mobile and the technique is relative low cost.

By creating an embedded sensor system with Bluetooth™ it can contribute to the cable reduction within the medical environment and therefore make the patient monitoring more efficient [15].

2 Aim

The first part of the project will be to create an electrocardiograph (ECG-sensor) with two channels that can be wirelessly connected using Bluetooth™ that will act as a data acquisition system (DAQ).

The ECG-sensor will be an embedded sensor system that contains a sensor, digital-to-analog processor and a Bluetooth™ module. This will be powered by a small battery which is normally used for cellular phones. The main focus of this development will be to create a reliable ECG- amplifier.

The second part will be to program the PDA so it will connect to the ECG-amplifier and work as a DAQ and present the ECG signals on its display. The system must be able to be connected continuously for supervision abilities.

3 List of definitions

ECG	**E**lectro**C**ardio**G**raph or ECG sensor, measure cardiac electrical potential waveforms. **E**lectro**C**ardio**G**ram presentation of an ECG sensor recording.
RLD	**R**ight **L**eg **D**rive
PDA	**P**ersonal **D**igital **A**ssistant or Pocket PC
SPP	Bluetooth protocol for **S**erial **P**ort **P**rofile
RFCOMM	Bluetooth protocol for **R**adio **F**requency **Comm**unication
Microcontroller	Computer-on-a-chip used to control electronic devices
ADC	**A**nalogue to **D**igital **C**onverter
LabView	**Lab**oratory **V**irtual **I**nstrumentation **E**ngineering **W**orkbench, a platform for visual language programming developed by National Instrument
NI	**N**ational **I**nstruments
UART	**U**niversal **A**synchronous **R**eceiver-**T**ransmitter
DAQ	**D**ata **Acq**uisition system.
Bluetooth™	A short range wireless communication technology developed for cable replacement.
SMD	**S**urface **M**ount **D**evices, electrical devices that are constructed with surface mount technology so the device can be mounted directly on printed surface board.

4 Electrocardiograph

An electrocardiograph records the electrical potential over the heart and produces an electrocardiogram (ECG or EKG). An ECG is a recording over the electrical activity of the heart which is presented as a continuous strip chart.

The ECG is the primary tool in cardiac electrophysiology for screening and diagnosis of cardiovascular diseases [1].

4.1 ECG signals

The electrocardiograph is constructed to measure the electrical potential between various points of the body. In a standard ECG recording there are five electrodes connected to the patient:

1. Right arm, RA
2. Left arm, LA
3. Left leg, LL
4. Right Leg, RL
5. Chest, C

Depending how the electrodes pairs are connected to the ECG sensor different waveforms and amplitudes can be obtained. Each pair contains unique information of the heart activity that can not be obtained from another pair of leads.

The different leads are dived into groups depending how they are connected to the ECG-amplifier [1].

- Bipolar limb leads, Einthoven tringle.
- Unipolar limb leads, augmented limb leads.
- Unipolar chest leads.

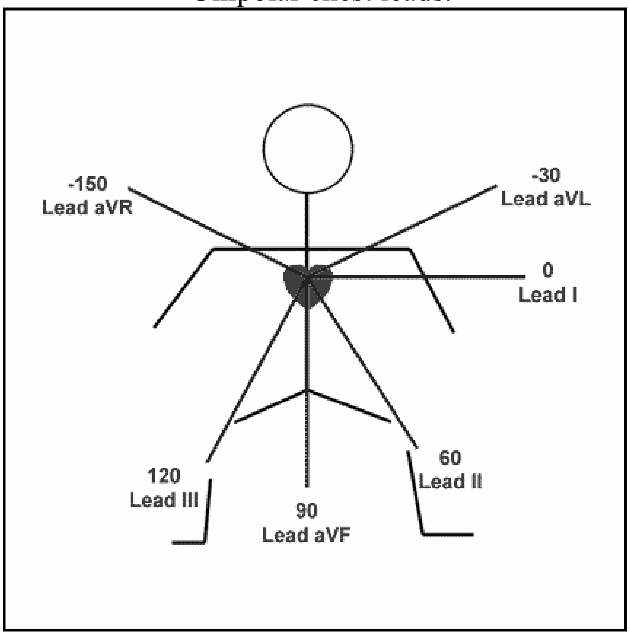

Figure 1 Cardiac Axis viewed by different leads [2]

4.1.1 Lead I

In this project the main signal measured is Lead I that is obtained by measuring the electrical potential between left arm and right arm. The left arm is the positive pole, an electrical wave moving towards the left arm will cause an upward deflection of the electrocardiograph. Lead has I angle that is 0º relative to the heart therefore it is most useful for detecting electrical activity in a horizontal direction [3].

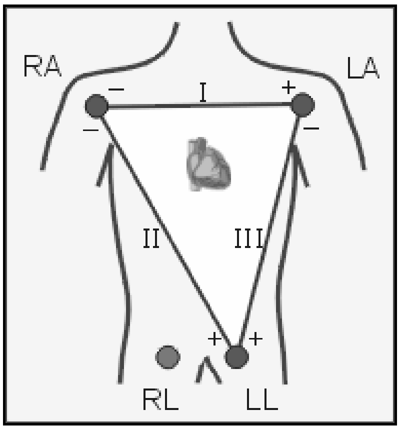

Figure 2 Standard limb led positions, bipolar. Einthoven triangle [4].

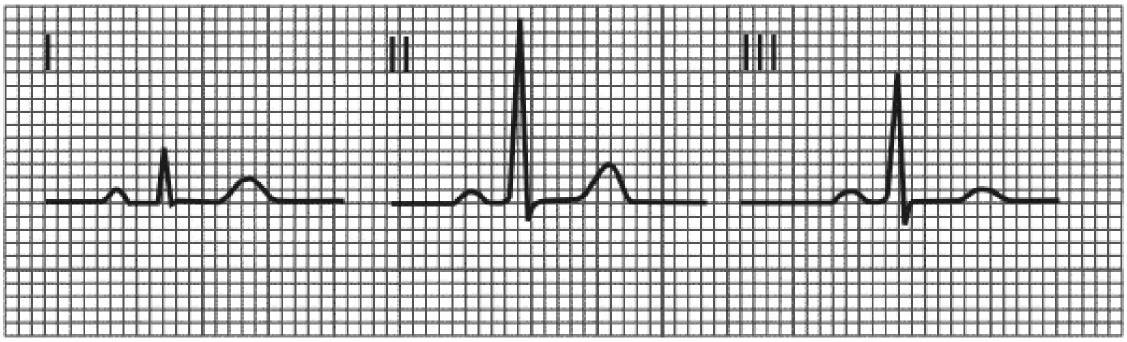

Figure 3 Signals acquired from standard ECG limb leads I, II and III [4].

4.1.2 Heart position signal

The second signal measures vertically over the heart to enable positioning of the heart for the portable ECG and can be used as a backup signal for patient monitoring if the first signal malfunctions during monitoring.

5 Bluetooth

5.1 Introduction

Bluetooth is a short-range wireless communication technology developed for cable replacement when connecting devices while maintaining a high level of security. The key features of Bluetooth technology are low power, low cost and durability.

5.1.1Piconets

The Bluetooth wireless technology allows either communication one-to-one or up to seven different Bluetooth devices to connect and interact with a 10 meter radius, this is called Piconet or PAN, personal area network. A requirement for the devices within a piconet is that they all have the same Bluetooth profile. A Bluetooth device can however be a member of endless numbers of Piconets. Each piconet has one master that initializes the connection the other Bluetooth devices are slaves. Bluetooth enabled devices can establish piconets dynamically and automatically as they enter and leave the masters radio proximity [12].

5.1.2 Spectrum

Bluetooth technology operates at 2.4 to 2.485 GHz ISM, industrial, scientific and medical band. The 2.4 GHz ISM band is available and unlicensed in most countries [5].

5.1.3 Core specification

The Bluetooth module used in this project conforms to the core specification version released in November 2003, Version 1.2 [13].

5.2 RFCOMM Protocol

The RFCOMM protocol is a simple transport protocol that provides an emulation of serial ports over the L2CAP protocol. The RFCOMM protocol can with additional requirements emulated the 9 circuits of RS-232 serial ports. Over 60 simultaneous connect are supported by the RFCOMM protocol between two Bluetooth devices; however the number of connection that can be used simultaneous is specific to the implementation [6].

5.3 Serial Port Profile

Serial port profile, SPP, defines the set-up of virtual serial ports between two Bluetooth™ devices. SPP is based on the RFCOMM protocol for emulating serial port communication and is used for cable replacement in application using RS-232 serial communication [7].

6. Limitations

Making the system wireless has its limitations, foremost it is the size and the weight of the ECG amplifier that has its limitations due mostly to the battery. The ECG will be placed on the chest on patient and should interfere as little as possible with the patient's mobility. The use of Bluetooth™ will limit the ECG-sensor system primary in the maximum data rate of 750 kbps and the 10 metre range.

The data rate will automatically limit the bandwidth of the ECG-sensor to 150Hz according to Nyquist sampling theorem that states that the sample frequency must be at least twice the bandwidth of the signal and the maximum sample frequency that can be used is 400Hz due to Bluetooth maximum data rate. This leads to that this system is more suited for patient monitoring than diagnostic purposes.
Other limitations are the battery time for the PDA as well as the ECG sensor system.

7 Electrical components

7.1 Operation amplifier

The operation amplifiers used in the application was chosen based on the electrical characteristics. The requirement that were essential for the operation amplifier that had to be fulfilled was;

- Single supply voltage at 3.3 V. The Mitsumi Bluetooth module is restricted to 3.3 V maximum; therefore the entire system will have the same supply voltage.
- Quad operation amplifier, due to the size requirement of the ECG sensor system size.
- High output current, the operation amplifier should be able to put out enough current so it can drive the Right Leg Drive function for an efficient reduction of 50Hz noise.
- Rail to Rail input and output, essential for high resolution output.

When deciding on operation amplifiers other characteristics were looked upon, not essential for the application, but important for functionality of the ECG amplifier. The most important characteristics here were;

- Low noise, eliminating disturbances in every step will make the ECG more reliable and make a high resolution possible.
- Low input offset, DC offset on the input will escalade and disturb the base line off ECG-signal.
- Low power consumption, the application will be power by battery and less power leads to longer battery life time.

7.1.1 TS924 Quad operation amplifier

The TS924 Quad Operation Amplifier that was chosen has the following characteristics [8];

- Rail to rail input an output
- Low input offset 900µV max, to avoid DC-level disturbances.
- Low noise.
- Single supply at 2.7 – 12 V,
- Low power consumption.
- Quad operation amplifier package SO14.
- High output current 80mA.

7.2 Voltage regulator

The positive voltage regulator XC6201P332MR was chosen for small size, package SOT25, and low power consumption TYP 2µA and max 5µA [9].

7.3 Microcontroller

The microcontroller Pic18LF452 was chosen due it has become more or less a standard device in low voltage application and is well suited for this application. The microcontroller is also compatible with available software and hardware, MikroC, MPLAB IDE 7.30 and PICSTART Plus.

The sample rate of 400 Hz enabled the use a 4 MHz crystal with out affecting the performance of the application. Using a 4 MHz crystal instead of the first intended 10 MHz will theoretically reduce the power consumption with out affecting the performance of the ADC due to the relatively slow sample rate of 400 Hz [14].

7.4 Bluetooth module

Parameters that led to the choice of the Mitsumi™ module:

- Version 1.2 Programmable with available hardware and software
- Low-cost
- The Department of Computer Science and Electronics has used it in prior projects. The supervisor has good knowledge of the module

7.4.1 Mitsumi Bluetooth™ Module

The Mitsumi Bluetooth® Module WML-C46 Class 2 includes the RFCOMM stack that supports the Serial Port Profile that is used in this project for the communication between the ECG amplifier and the handheld PDA [13].
BlueLab27 was used for programming the Mitsumi Bluetooth® Module with the serial port profile slave (spp_slave) to enable the PDA to locate and exchange link key with the ECG-amplifier. The Serial port profile master has the advantage that it consumes less power but is not detected by the PDA due too that the serial port profile on PDA also is master.

8 Electrical design

Trough out the electrical design of the analog part, the performance of the ECG-amplifier has been in focus to be able to provide a reliable and high resolution output signal.

When developing the digital part of the project it was firstly developed to work with a RS-232 cable for enabling testing of software, both LabView and the program developed for the microcontroller, before replacing the RS-232 cable with Bluetooth™ technology.

All schematics have been created in EAGLE 4.16 light.

8.1 ECG amplifier

The amplifier in this project is a standard single supply instrumental amplifier with an additional variable gain and a passive low pass filter of the first degree and a DC restoration loop for elimination of possible DC offset in the circuitry.
The input circuitry has no protection against high voltage discharges from defibrillators used on the patient. The ECG-sensor will have to be removed if use of defibrillator is necessary.

8.1.2 Instrumental amplifier

A standard single supply instrumental amplifier is used for the differential bioelectrical amplifier in the ECG-sensor. See figure 4.

Stage 1 Buffer

The first stage of the amplifier acts an input buffer amplifier with a low gain 3V/V see figure 5.

$$Gain = 1 + \frac{R6}{R7} + \frac{R6 + R7}{R13 + R14} = 1 + \frac{10k\Omega}{10k\Omega} + \frac{20k\Omega}{20k\Omega} = 3 V/V$$

$$Vout = (INA^{+} - INA^{-}) \cdot Gain$$

$Vout$ IC1A pin 1 and IC1B pin 7 is used as a reference in figure 5.

Stage 2 Differential amplifier

The second stage of the ECG-sensor is the differential amplifier with a gain of approximate -2V/V see figure 5.

$$Vout = -Vin \cdot \frac{R39}{R19} = Vin \cdot \frac{10k\Omega}{4.7k\Omega} \approx 2.13 V/V$$

Total amplification of the instrumental amplifier is approximate

$$3 V/V \cdot -2.13 V/V \approx -6.4 V/V$$

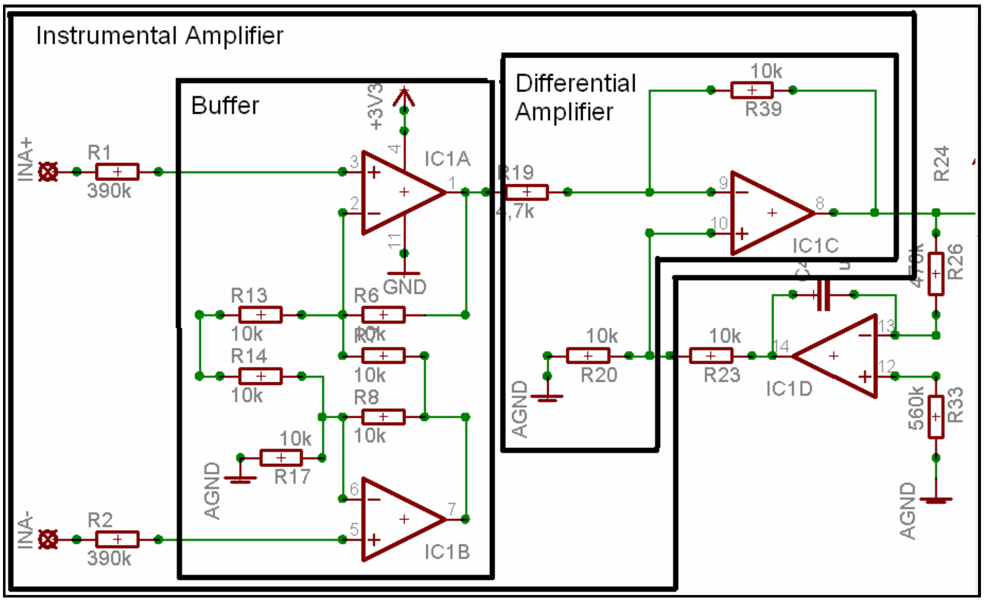

Figure 4: Single supply instrumental amplifier.

8.1.3 DC restoration

Third stage in the amplification is the DC restoration amplifier that uses a feedback arrangement to eliminate the DC offset in the bioelectrical amplifier.

The speed of the DC restoration is determined with the time constant, RC, in the high-pass filter, R26 and C4 in figure 5. It will take up to 10 RC times constant for a full reduction of the DC offset in the circuitry [1].

RC is set to approximate 0.5Hz for monitoring mode [1].

RC is calculated to $R26 \cdot C4 = 1\mu F \cdot 470k\Omega = 0.47Hz$

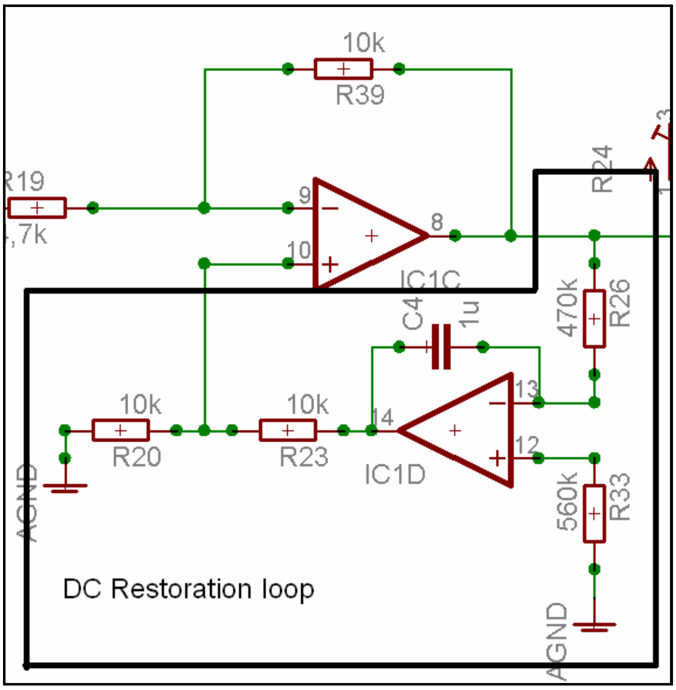

Figure 5: DC restoration loop, monitoring mode.

8.1.4 Variable gain and filter

Variable gain has been implemented in to the last step in the ECG-amplifier so that the output can be adjusted for the individual differences in signal strength obtained from the leads approximate 0,5mV – 3mV, see figure 6.

This makes it possible to make a more reliable alarm function and to improve the resolution. And a low pass filter with a calculated cut-off frequency of 159 Hz.

$$\text{Cut-off frequency} = \frac{1}{2\pi \cdot C \cdot R} = \frac{1}{2\pi \cdot 1nF \cdot 1M\Omega} \approx 159Hz$$

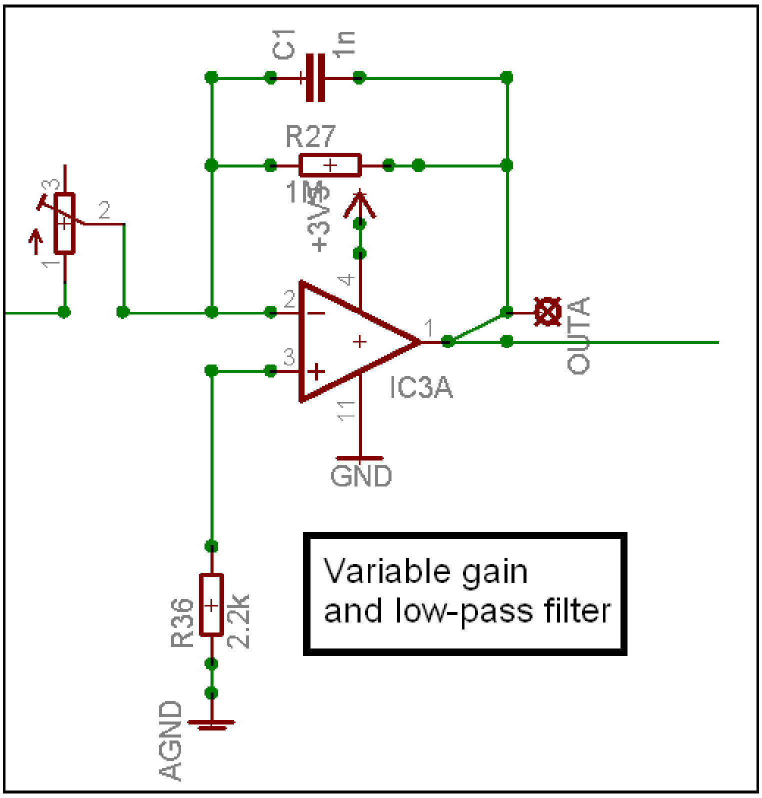

Figure 6: Variable gain and 150 Hz low-pass filter.

8.1.5 Right Leg drive

The function of the Right Leg Drive (RLD) is to eliminate the common mode noise generate from the body. The two signals that are entering the differential amplifier from the leads placed on the right and left arm according to Einthovens triangle are summed, inverted and amplified back into the body though the right leg by a common-mode amplifier. This signal is fed back to the other leads and eliminates the noise signal drowning the wanted ECG-signals, see figure 7 [1].

Common-mode volt output from the $RLD = \dfrac{INB^{+} + INB^{-}}{2}$ [1]

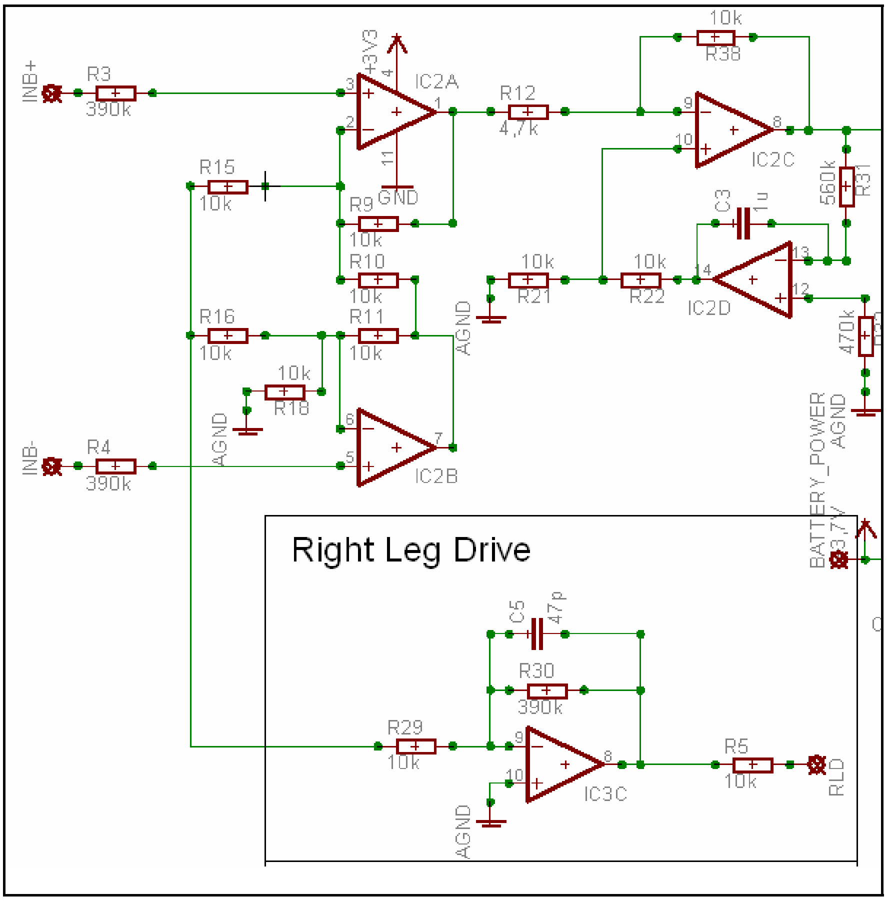

Figure 7: Right Leg Drive.

8.2 Microcontroller

The microcontroller pic18f452 is used as analog to digital converter (ADC) as well as universal asynchronous receiver-transmitter, UART, for a serial connection to the Mitsumi Bluetooth™ Module. The microcontroller also controls the sample frequency which is set to 400Hz for both signals.

The PGM, PGC, PGD, MCLR, VDD and GND pins are connected to a pin header for onboard programming using PICSTART Plus and MPLAB IDE 7.30, see figure 8.

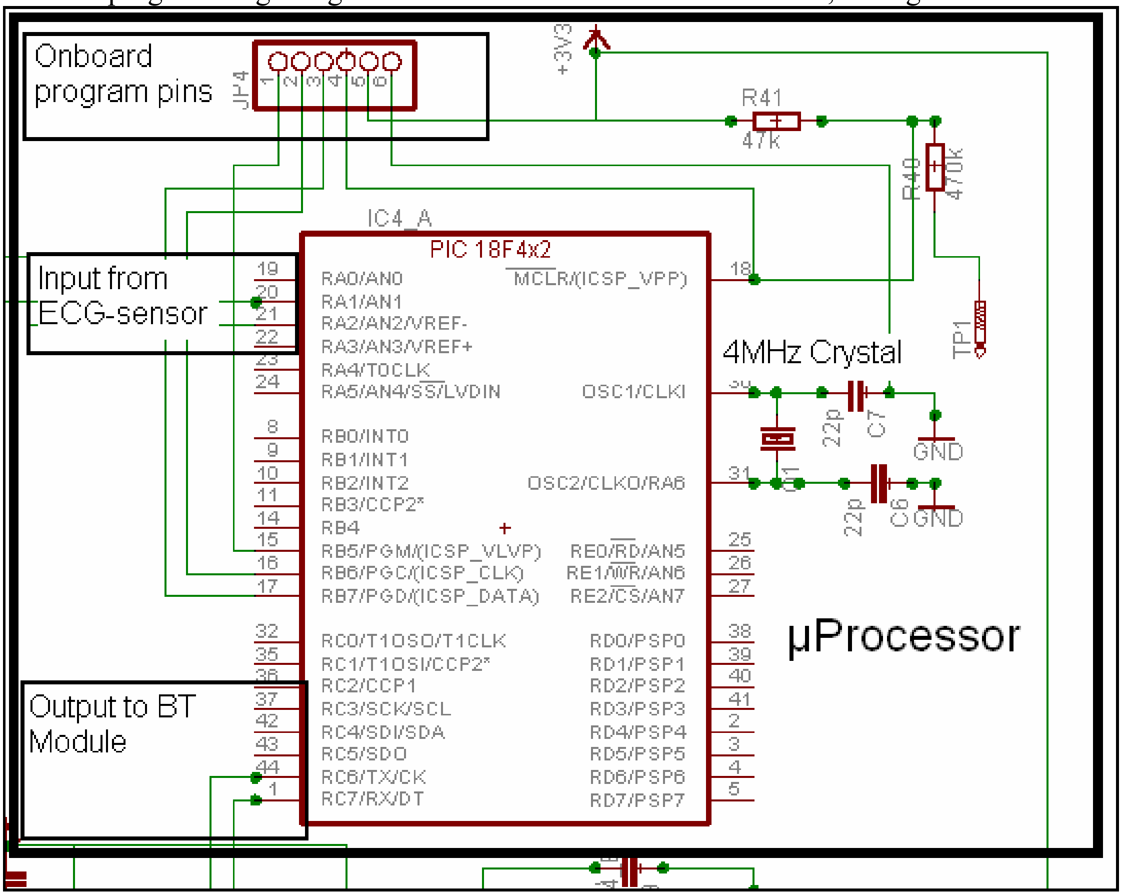

Figure 8: Schematics microcontroller PIC18LF452.

8.3 Bluetooth Module

The SPI_MOSI, SPI_CLK, SPI_CSB, SPI_MISO, RST, VDD, GND pins are connected to a pin header for onboard programming using Bluelab 27 and a LPT printer port programmer, see figure 9.

PIO7 is connected to a Blue LED for indication of connection to master. The LED will blink while searching for a host and shine continuously when connected.

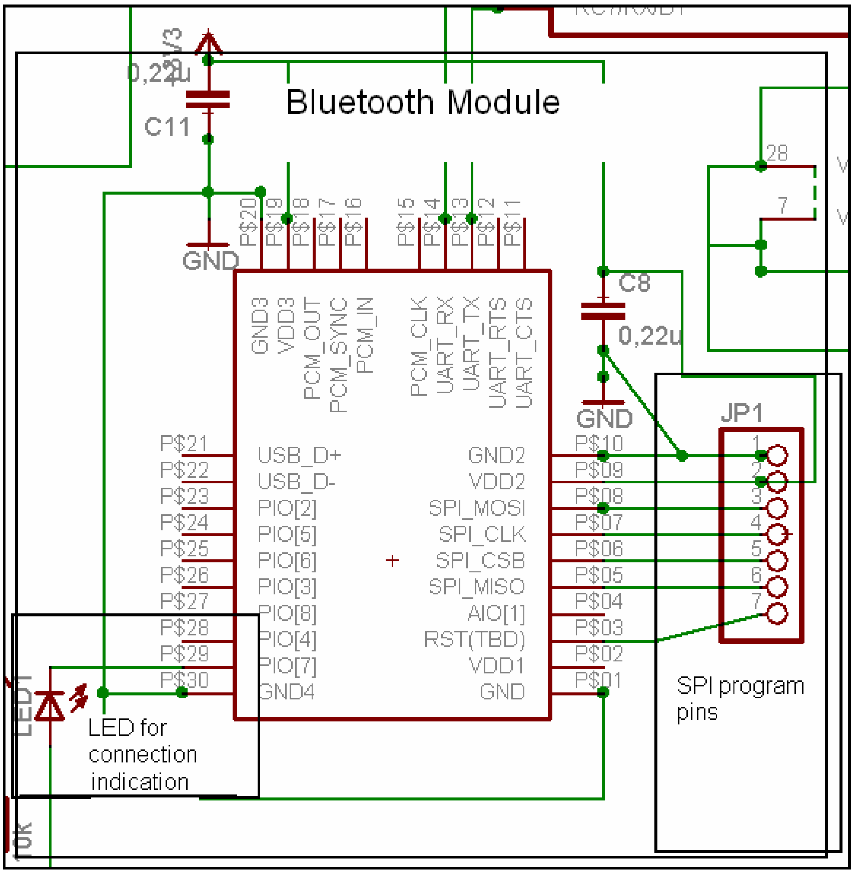

Figure 9 Bluetooth Module.

8.4 Complete Schematic

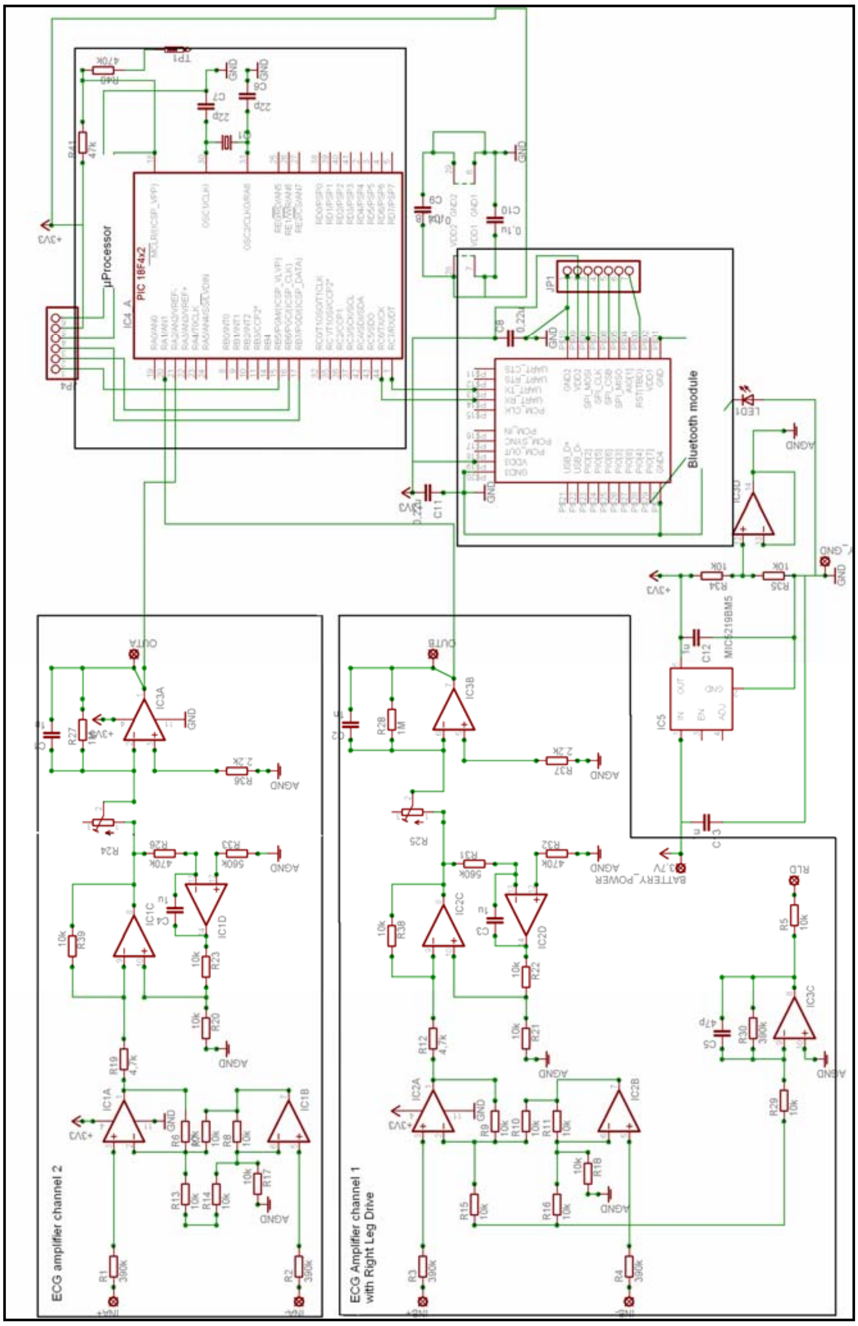

Figure 10: Schematic ECG-amplifier with microcontroller and Mitsumi Bluetooth Module.

8.5 Power consumption

ECG-amplifier including microcontroller 12.3 mA. The Microcontroller has a power consumption of 2.3 mA that is approximate 0.5 mA lower than when using 10 MHz crystal. When the Bluetooth™ module is programmed as spp_Slave the complete circuitry has a power consumption of 60 mA when connected in a piconet.

9 Design

The design requirement for the electrical CAD of ECG sensor system:

- Maximum dimensions 45*50 mm, the same as the battery.
- Dual layer card ECG amplifier and signal processing on layer 1.
  Bluetooth™ module on layer 2 no signals or GND on either side off the antenna.

The electrical design has been developed in EAGLE 4.16 light.

9.1 Top side

The top side of the electrical design consist of the 2-channel ECG sensor and microcontroller, see figure 11.

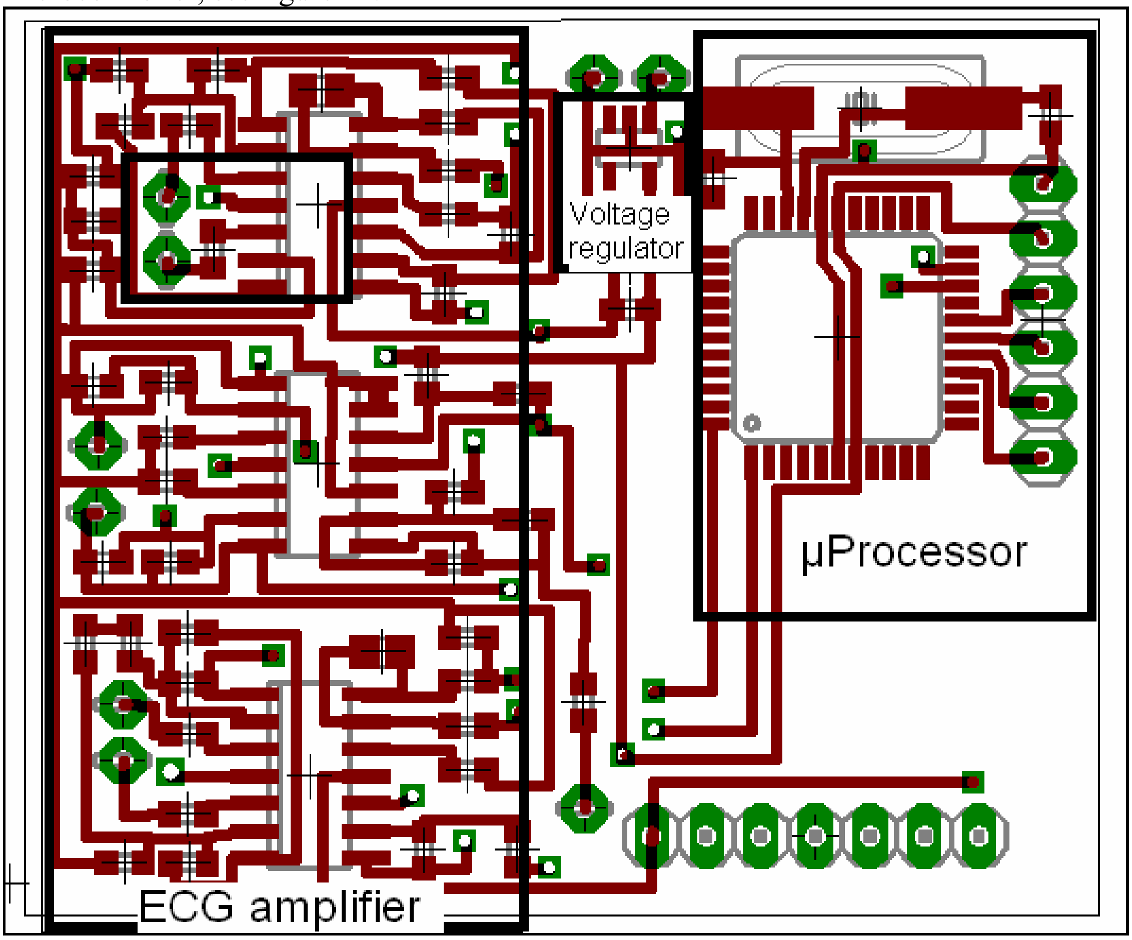

Figure 11: Top side ECG eagle cad.

9.2 Bottom side

Bluetooth™ module no signals or GND are on either side off the Bluetooth antenna to avoid disturbances and loss of transmission radius, see figure 12.

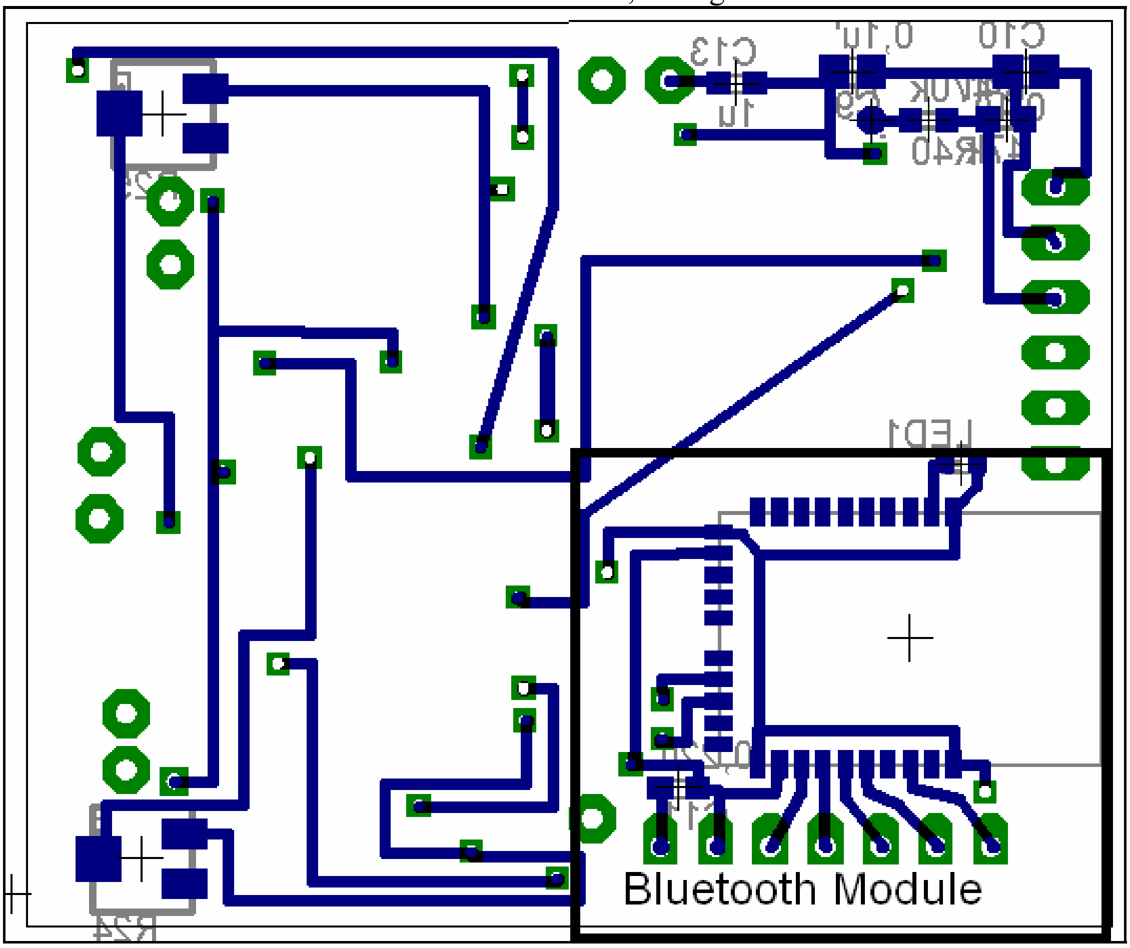

Figure 12: Bottom side eagle cad.

10 Programming

The programming part of this project is divided into to separate part, the microcontroller and LabView 8.0 for pocket PC.

The microcontroller, that will handle the output signal from the ECG amplifier, tasks consist of:

- Analog to digital conversion.
- Serial port configuration.
- Controlled sample rate.
- Sending data via serial UART to Bluetooth™ Module.

LabView on the PDA is required to handle the output signal from the ECG sensor system. The main tasks for the PDA will be:

- Connect to the ECG sensor system.
- Send start signal.
- Read output from ECG sensor system.
- Graphical display of the two separate signals.
- Send stop signal before exiting program.

10.1 Microcontroller

A C complier, MikroC has been used to create the program for the microcontroller, Pic18f452. MikroC creates a .HEX-file that can be downloaded into the microcontroller using MPLAB IDE 7.30 and PICSTART Plus.

Requirements for the microcontroller program:

Sample rate:	400 Hz
Crystal:	4 MHz
Number of channels:	2
Bits per Byte:	8
Baud rate:	19200 baud/s
Stop bit:	1

The inbuilt Analog to Digital Converter ADC returns a 10 bit value, by shifting the two least significant an 8 bit value that is left can be sent as one byte via the virtual serial port that is emulated by the Bluetooth™ Module Spp_slave profile.

10.1.1 Flow chart microcontroller

Function description of the program downloaded on the microcontroller is presented as a flow chart see figure 13.

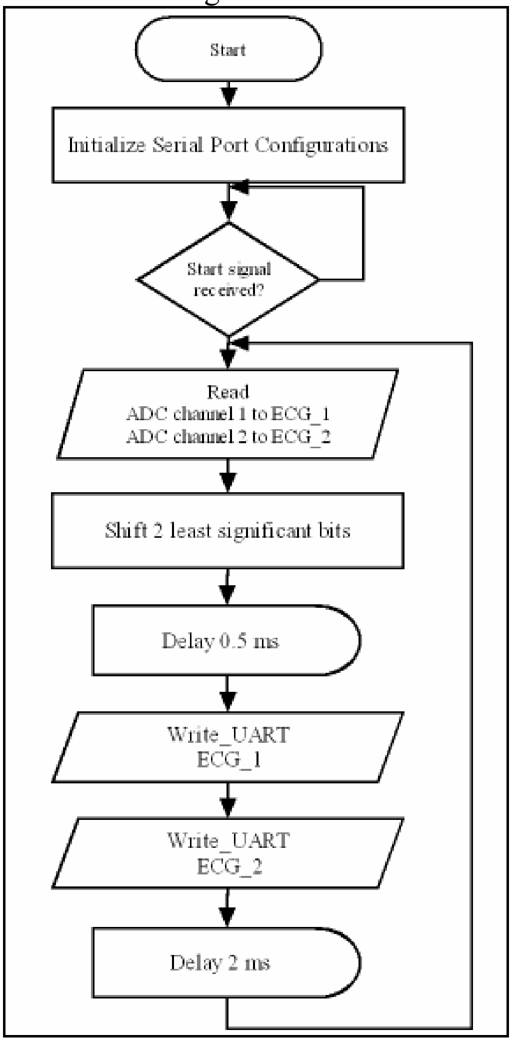

Figure 13 Flow chart program Microcontroller

10.1.2 Program

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

```
int temp_res1, temp_res2;
int i, start=0;
int EKG_1,EKG_2;

void main()
{
  ADCON1 = 0x80;                        // Configure analog inputs and Vref
  TRISA = 0xFF;                         //FF all AN is input // F1 an1-an3 output an0&an7 analog
input
  TRISB  = 0x00;                        // Pins RB1, RB0 are outputs
  Usart_Init(19200);              //Serial port configuration with 19200 baud rate
 do{
    if (Usart_Data_Ready())
      {
      start = Usart_Read();                 //get start signal from PDA

            do{
              for (i=0;i<100;i++)              // send 200 bytes at the time
              {
              temp_res1 = ADC_Read(1);            // Get results of AD conversion input AN1 EKG
              EKG_1=temp_res1/4;                  //Shift the 2 LSB
              temp_res2 = ADC_Read(0);            //  Get  results  of  AD  conversion  input  AN0
EKG_bu
              EKG_2=temp_res2/4;                  // shift the 2 LSB
              Delay_us(500);                      //wait 0.5 ms
              USART_Write(EKG_1);                 // send channel 1 8 bit result via  serial UART
              USART_Write(EKG_2);                 // send channel 2 8 bit result via  serial UART
              Delay_us(2500);             //wait 2.5 ms
              }
              start = Usart_Read();               //check start signal

              }while (start == '1');

      }
   } while(1);
} //~!                    //end of program
```

10.2 LabView

LabView 8.0 is a platform developed by National Instrument for graphical programming for instrument communication.
The Pocket PC module that is available for LabView 8.0 is well suited for this project, it supports both for serial communication and Windows Mobile 5.0 in the PDA has the required virtual serial port driver Widcomm that enable standard serial port communication between the PDA and ECG sensor system.
Requirement on the PDA [10]:

- Windows mobile 5.0, to be able to run LabView 8.0 for pocket PC.
- Bluetooth support.
- Virtual Serial Port Support, WIDCOMM Bluetooth driver (BTW-CE 1.4).

10.2.2 Flow chart

In figure 14 the flow chart for the LabView application for PDA is presented.

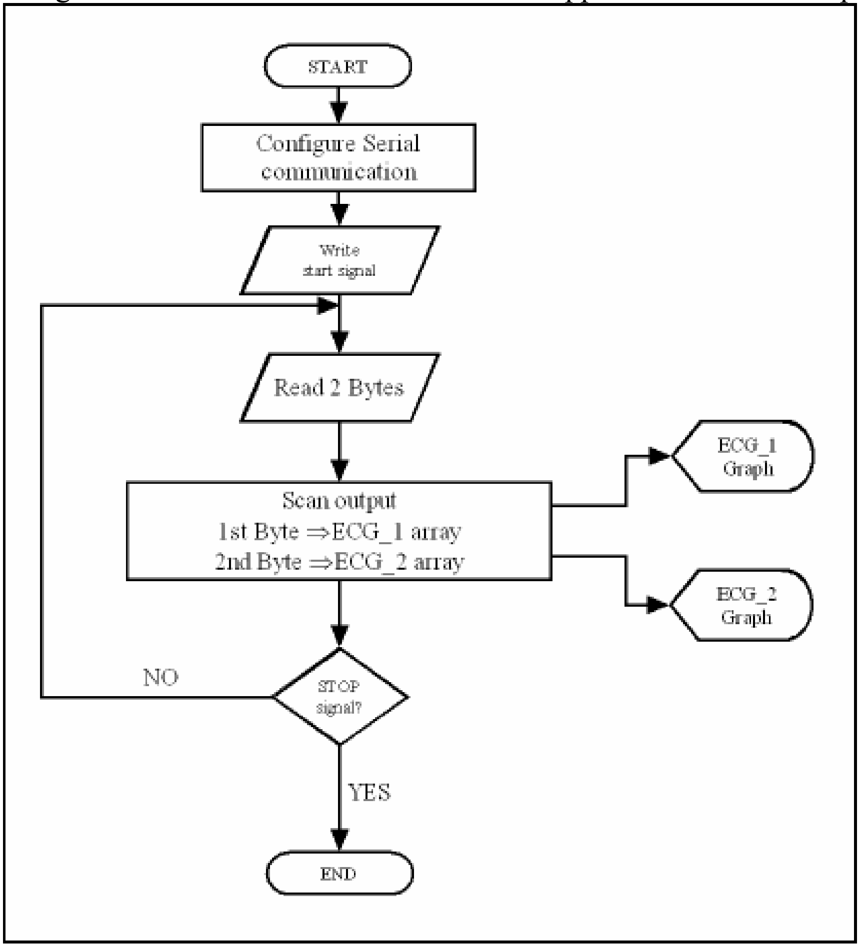

Figure 14 Flow chart LabView program.

10.2.3 Program

The LabView 8.0 for pocket PC application program that has been developed for the PDA is presented in figure 15.

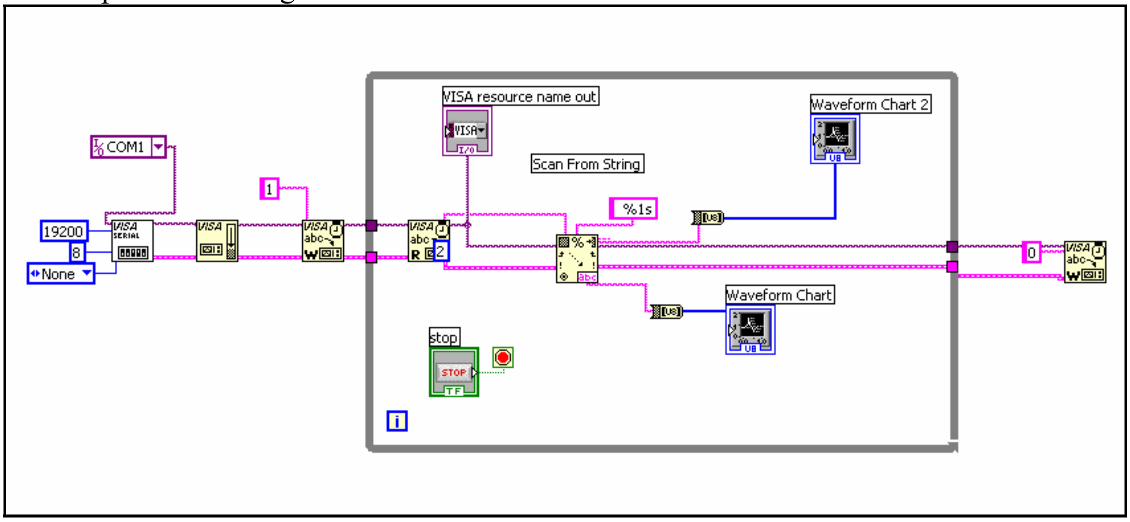

Figure 15 LabView 8.0 for pocket PC program.

11 Problem description

During the development progress several problems has occurred most of them easy to handle and what could be described as expected problems. In this chapter of the report some of the more challenging problems will be described and how they were solved.

11.1 Power consumption

The greatest challenge of developing this wireless electrocardiograph is the power consumption. When constructing a reliable ECG-sensor that will be powered by a battery usually used for cellular phones the power consumption must be as low as possible without interfering with the performance. For example there are operation amplifiers that have a lower consumption than the TS924, but it will not be able to supply the right leg drive function with the acquired output current and the noise reduction will not be efficient enough.

The Mitsumi Bluetooth module consumes about 45 mA when connected and programmed as spp_slave as required in this project, the spp_master configuration consumes less than half with 20 mA.

11.2 Noise reduction

The wanted electric potential that the ECG sensor is measuring is relative small in comparison to the noise that both the body and electrical wires absorbs form the surroundings. Mostly 50 Hz noise is absorbed from the power cables and all electrical equipment that is power by them. The ECG signals are specified to have a resolution 0-150 Hz therefore a low-pass filter that eliminates the 50Hz noise cannot be used.
The DC-offset is an additional problem in developing bioelectrical amplifiers.

To avoid 50 Hz noise as thin and short wires as possible will be used for connecting the leads to the ECG sensor system, the electrical components will be surface mount devices (SMD) and the embedded system will be powered with a cellular phone battery.
But the most efficient way to reduce all unwanted noise is to use a Right Leg Drive loop to eliminate the noise absorbed by the wires and body by inverting the noise and feeding it back to the body via the right leg.

Implementing a DC restoration loop in the circuitry the DC level will be eliminated within a RC time constant that is determined according to the requirements for the ECG patient monitoring mode.

11.3 Bluetooth

The greatest obstacle in the project was the virtual serial port configuration as the first PDA with Palm OS did not support the Virtual serial port profile that was needed for serial communication between the PDA and ECG sensor system. The biggest problem was, and still is, the link key problem that follows when using the BlueLab27 firmware on the Mitsumi module; before connecting to a new host in a piconet the Mitsumi firmware spp_slave must be reset.

12 Result

The prototype has been tested to confirm test calculated parameters in the electrical design. Parameters such as the cut-off frequency of the low pass filter, variable gain, power consumption and noise reduction feed back loops has been thoroughly examined. The results of these measurements are presented below.

The size of the electrical design met the requirements of 40 x 55 mm with a final size of 40 x 50 mm.

All signals presented in this report are recorded in LabView 8.0.

12.1 ECG sensor system

A 2-channel ECG sensor system with 0-150 Hz resolution has been developed. The DC restoration loop in the system conforms to the restriction of an ECG monitoring system [1].

The digital to analogue conversion and sample rate is controlled by the Microcontroller; the sample rate of 400 Hz conforms to Nyqvist 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. The first signal, figure 16, has the original sinus signal amplitude of 4mV and the frequency of 5Hz. The second signal, figure 17, recorded has the same sinus amplitude of 4mV but the frequency of 150Hz. The second signal has a signal loss of -3dB at 150 Hz and hence the cut-off frequency is determined to 150Hz.

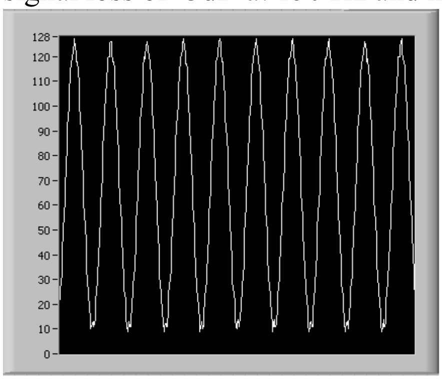

Figure 16 5Hz 2mV sinus wave

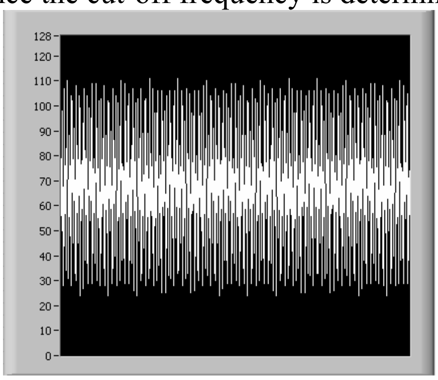

Figure 17 150Hz 2mV Sinus Wave

12.2 Pocket PC

The PDA handles the connection to the ECG sensor system via a Bluetooth virtual serial port. The LabView application for the PDA manage the graphical display of the two different signals, Lead I and Heart position signal that was required.
With the patient simulator Metron PS-140 various ECG signal can be simulated. Simulation of different signal strength, heart rates and imitation of different heart diseases is a great help for testing and calibrating the ECG-sensor. In figure 18 the ECG signal Lead I is simulated and recorded with LabView 8.0, the Heart Position Signal or Back-up signal is presented in figure 19. Both signals have an origin signal of 2 mV and 60 heart beats per minute.

Figure 18 Lead I

Figure 19 Heart Position Signal

12.3 Power consumption

A total current consumption of the prototype when connected in piconet and transmitting data at 400Hz via a virtual serial port is approximate 52 mA. The ECG-sensor including ECG amplifier and microprocessor consumes 12.3 mA of the total power consumption the rest is the Bluetooth™ module.

Consequently the total power consumption of the system is according to Ohms law:

$$P = U \cdot I$$

$$3.3V \cdot 52mA \approx 170mW$$

12.4 Noise reduction

In figure 20 a simulated signal using patient simulator Metron PS-140 the first signal is using the right leg drive (RLD) compared to the signal in figure 21 when the RLD is disconnected.

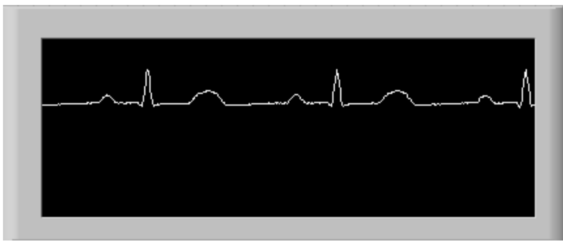

Figure 20 Lead I with RLD

Figure 21 Lead I without RLD

13 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 seamed 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 LabView this is solved the only requirement is just that it is a Bluetooth equipped pocket PC with Windows mobile 5.0, no requirement of a specific brand or even a specific model of a brand as it would be with an application for cellular phones. 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.

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

14 Future work

What had been nice to implement would be an 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 LabView application depending on hardware of the PDA.

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

15 Summary

A small ECG sensor system has been developed that is able to measure and present two different ECG-signals. High resolution and effective noise reduction, both 50 Hz noise and DC offset has been successfully implemented in the ECG sensor system.

When initializing this project what seamed to be the easy part off cable replacement with a Bluetooth™ has proven to be far more complicated to resolve than expected. Problems with both firmware and hardware when programming the Mitsumi module has taken great effort and has been time consuming. Much off the time that was meant to develop extra function for the PDA had to be categorized as future work. On the other hand great experience and an even greater knowledge for wireless sensor systems has been accomplished.

16 Software

Application	Developer	Description
LabView 8.0 för PDA	National Instrument	Graphical programming environment for pocket PC Windows Mobile 5.0
EAGLE 4.16 Light	CadSoft	Electrical CAD development program
MikroC v.5.0.1.2	MikroElektronika	C complier for microcontroller.
MPLAB IDE 7.30	MicroChip	Microcontroller program development environment.

17 Hardware

LPKF Protomat 120	LPKF Laser and electronics	Circuit board plotter
PicStartPlus	Microchip	Microprocessor programmer.
PC windows XP service pack 2		
Dlink BT120	DLink	USB Bluetooth adapter.

18 Part list

The list of components used and price at purchase is listed below. All components are bought a Micro-Kit [11], except the Bluetooth module Mitsumi WML-C10.

Name	Value/name	Package	Price (SEK)	Quantity
Capacitor	1nF	C0603	1.25	2
Capacitor	1μF	C0805	2.07	4
Capacitor	47pF	C0603	1.19	1
Capacitor	22pF	C0603	1.29	2
Capacitor	0.1μF	C0603	2.07	2
Capacitor	0.22μF	C0603	5.46	2
Operation amplifier	TS924	SO14	32.60	3
Microcontroller	18LF452	TQFP44	86.50	1
Pin header	7pin	1X07	-	1
Pin header	6pin	1X06	-	1
LED	EL19-21	LED0603	9.90	1
Crystal	4MHz	HC49UP	11.60	1
Resistor	10 kΩ	R0603	1.62	21
Resistor	390 kΩ	R0603	1.62	5
Resistor	4.7 kΩ	R0603	1.62	2
Resistor	470 kΩ	R0603	1.62	1
Resistor	1 MΩ	R0603	1.62	2
Resistor	560 kΩ	R0603	1.62	2
Resistor	470 kΩ	R0603	1.62	2
Resistor	2.2 kΩ	R0603	1.62	2
Resistor	47 kΩ	R0603	1.62	1
Potentiometer	10 kΩ	44J	35.50	2
Bluetooth module	WML-C10		100	1

Total cost: 457.20 SEK

19 List of reference

19.1 Book and scientific publications reference

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