PHENOM 2005
Phase Three

ELE 589
University of Rhode Island
Department of Electrical, Computer and Biomedical Engineering
Kingston,RI 02881

Abstract: *Phase Three of the Personal HEart functioN Monitor (PHENOM) project for the ELE 589 Biomedical Imaging II course involved implementing the PIC processor into the design. The code was written and reworked, additional features were added to the design and the layout of the project box was completed.*

Team PIC-gemc

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Introduction

The PHENOM project had begun as a design project for the Biomedical Engineers with the purpose of creating a medical device. Each successive class contributes new features to an existing design. Over the years, the project has developed into a project that is composed of operational PPG and ECG circuits with microcontroller based input and output interfaces. The first PHENOM project utilized the Motorola 68HC11 microcontroller. The goal of our project was to create an operational circuit, using the previous design, that was able to interface with the PIC microcontroller and a new LCD display.

Circuit Design

To accelerate the design process and make it possible to finish the PHENOM project within a semester, a set of materials from previous semesters are given to each team along with a discussion of the concepts underlying the hardware and software in preparation. In this section, the circuits are dissected and the individual circuit sections are analyzed. First, a discussion of the electrocardiogram is given followed by the photoplethysmogram, the power supply for the circuit, and PIC processor circuit.

Electrocardiogram

The Electrocardiogram is divided into six sections. Sections 1 and 4 through 6 provide a gain to the circuit. Section 2 reduces common mode noise. Section 3 and 4 filter are high and low pass filters, respectively. The sections are broken-down and analyzed in the following ordered sections.

***Section One*:**

The first two op-amps operate as buffer amplifiers, they work in connection with a third op-amp, forming the instrumental amplifier. The first two op-amps remove the limitation of the differential amplifiers' performance due to the low input impedance. Any difference between the input voltages (the input from the left arm and the right arm) will drive a current through R1. The current goes through all three of the resisters and drives up the signal. The gain of the first two op-amps is A1, the gain of the third is A2, with the overall gain as A.

A1= -(R1 + 2R2)/R1 R1= 10K Ω R2= 22K Ω A1= -5.4

A2= (R4/R3) R3= 10K Ω R4= 47K Ω A2= 5

A= A1*A2 = -27

Section Two:

This stage is designed to reduce common mode noise by having a driven left leg. Half of the difference between the two arm potentials is passed back as a current to the left leg.

Section Three:

The high pass filter encountered at this stage eliminates the DC offset present in the incoming signal. The cutoff frequency is the following:

$$F_c = 1 / (2 * \pi * R * C) = 1 / (6.28 * 10^{-6} * 330{,}000) \approx 0.48 \text{ Hz}$$

Section Four:

The operational amplifier is wired as a low-pass filter, with an effective impedance of .5 micro farads in parallel with the 100K Ω. It has a frequency cut-off of the following:

$$F_c = 1 / (2 * \pi * R * C) = 1 / (2 * \pi * 0.5uF * (5k*100k)/(5k+100k)) \approx 66.85 \text{ Hz}$$

Section Five:

This is a simple inverting amplifier, with a gain of A= Ri + Rf/ Ri. In this case, as we want stages of 20 gain, and the 50 K Ω potentiometer is to compensate for the gain, we would like the potentiometer to measure 19 K Ω. Thus it is 20K Ω / 1K Ω.

Section Six:

By adjusting the 10k ohm potentiometer, the summer circuit will introduce a DC offset that varies between 3.4 and -3.4V.

DC Offset Max = 9V – 18V*(8.2K / 26.4K) = 3.4V
DC Offset Min = -9V + 18V*(8.2K / 26.4K) = -3.4V

Photoplethysmogram

Pre-Amp:

The Pre-amp stage amplifies the signal, which is a measure of the signal passing through the photodiodes of the PPG connector.

Bandpass filter:

The purpose of a bandpass filter is to allow frequencies within a certain range to pass while blocking out those higher and lower than the given parameters. In this case, it is a 1 K Hz bandpass filter.

Envelope Detector:

After the signal passes through the bandpass filter, it goes through the envelope detector. This cuts the signal down, eliminating noise, and following the top line of the signal. The signal still contains a DC offset. Ideally, the envelope detector wants to connect the peaks of the incoming signal to create a smooth output.

Final Section:

The final section of the PPG further reduces the signal range by way of a bandpass filter, and adds a DC bias.

PIC Processor Circuit Design

The main purpose of the PIC processor in our circuit is to gather input and control the output interfaces. In contrast to the previous Motorola 68HC11 design, the design process is simplified through programming in the C programming language and in-circuit programming. In the rest of this section, a discussion of the input and output tasks placed upon the microcontroller will be given.

Input:

The inputs are the following: ECG, PPG, and the soft-key push button. The ECG and PPG interface the PIC microcontroller through AD ports. It is assumed that the ECG and PPG signals are within a 0 to 5 volt range to be sampled properly. In addition, a push button is connected to allow for soft-key control of the PHENOM project to change display modes. The current options are: PPG, ECG, drawing test pattern, and character test pattern. With respect to the ECG and PPG signals, samples are gathered at a 10ms sampling rate. One of the main concerns when implementing the soft-key is the need for a software debounce to prevent registering multiple hits from one press of the button. Debouncing is handled by ignoring button press interrupts until a specified duration passes.

Output:

A function of the PIC microcontroller is to generate a 1 kHz square wave to drive the PPG emitter diode and control the LCD display. A timer is used to generate the square wave by using a timer overflow interrupt. When the timer is exhausted, the interrupt will be triggered allowing for multitasking in between toggling output states. The display utilizes a parallel interface requiring many input and output pins. But unlike the old display, no timing information needs to be generated. Commands and data are sent asynchronously to the display controller. The process of writing to the display requires a call of display functions. For example, two of the available features are to write a pixel to a specified XY coordinate and to draw a character from our custom designed character ROM. Using both of these functions, we are able to generate waveforms and text on the display for ease of use.

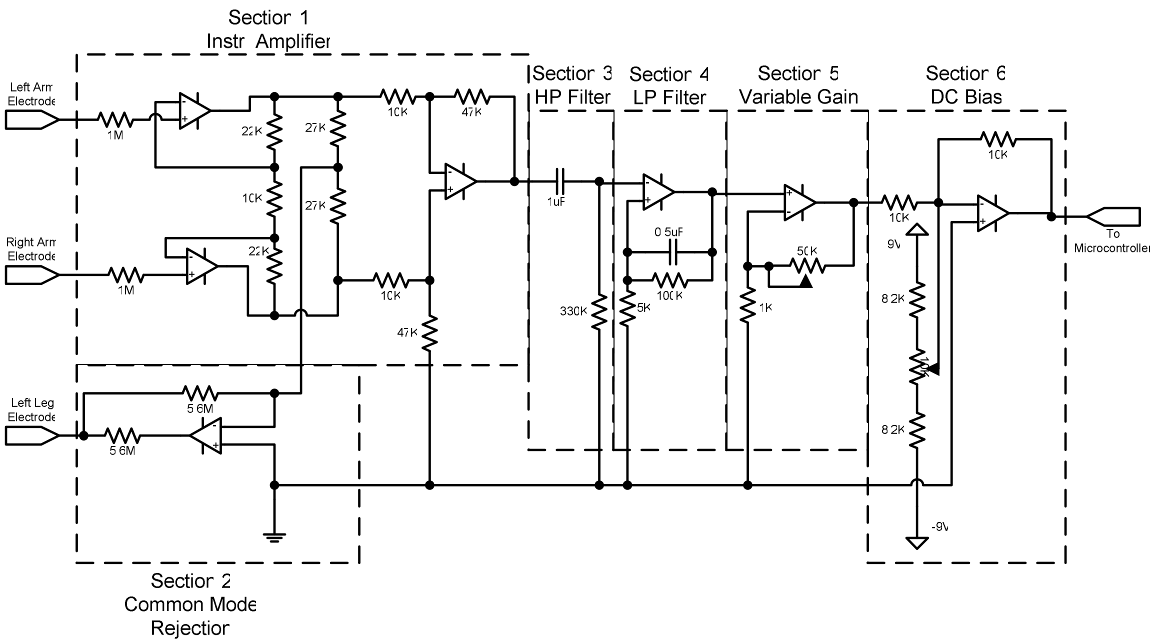
Discussion

The purpose of this design class was to take plans of the PHENOM. Project from the previous semesters, implement them and then develop addition features. The first stage of the project comprised of realizing the circuit for the ECG, PPG and power supply on the breadboard in a working state. The second stage built upon the accomplishments of the first stage by realizing the project on a circuit board as well as integrating the microcontroller and LCD display. The final stage of the PHENOM project consisted of adding new features to the design as well as creating a functional and aesthetically pleasing project box layout. The contributions that our team focused on were the soft-key interface as well as the character ROM.

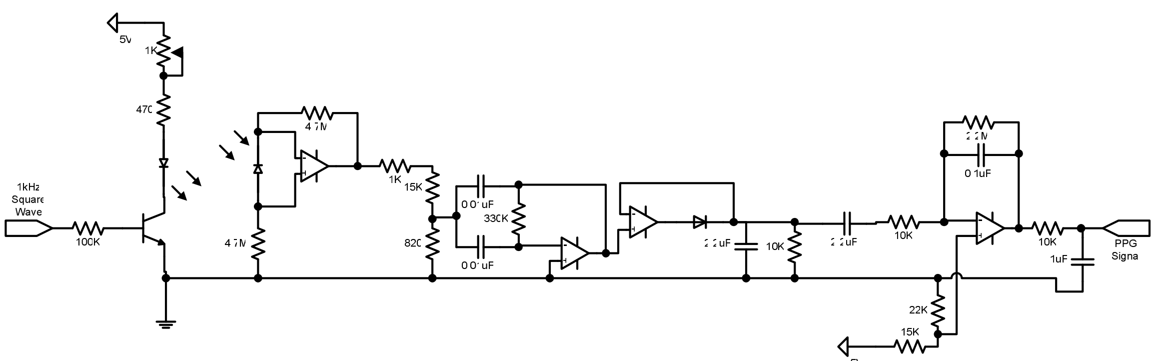
The current status of the project is that the ECG, PPG, PIC microcontroller, LCD display, and soft-key push button are connected and that the latter four are fully functional. The 18F452 model of the PIC processor was chosen because it had enough pins and resources for the project design. The majority of the resources were dedicated to the display. The rest were used for denoting the choice of mode and sampling A to D. There are four modes to that the PHENOM project can be in. In the PPG mode, a recognizable waveform is displayed with negligible noise present. In the ECG mode, invalid data is shown since the ECG circuit does not function properly. The circuit went from a noisy functioning state to a non-working state. In the test mode, a saw-tooth wave is drawn to verify functionality of the microcontroller. In the last mode, our character set is shown to demonstrate all of the characters available in the character ROM.

APPENDIX – A

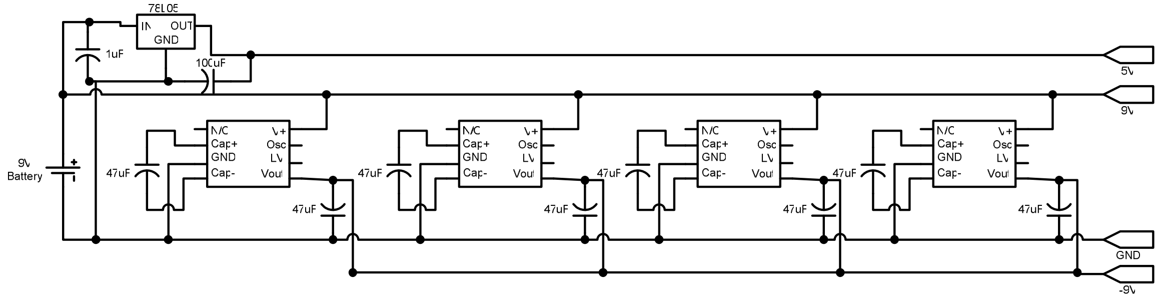
Circuit Diagrams



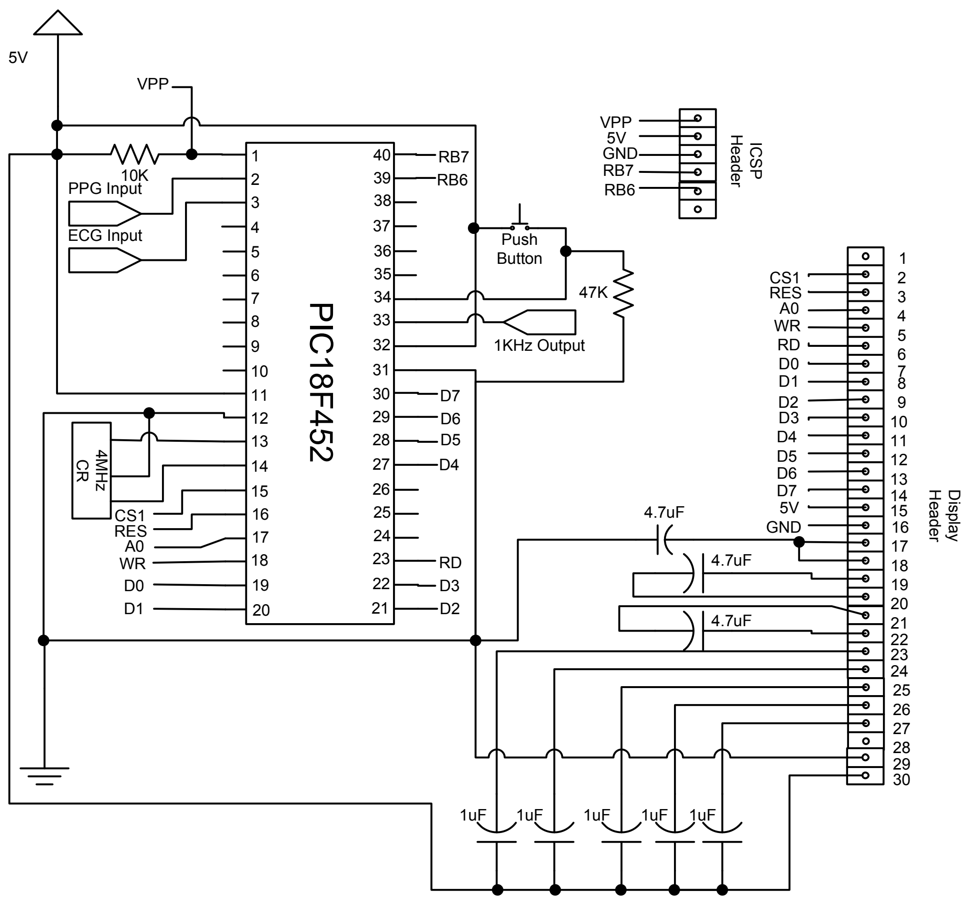
ECG Circuit Diagram



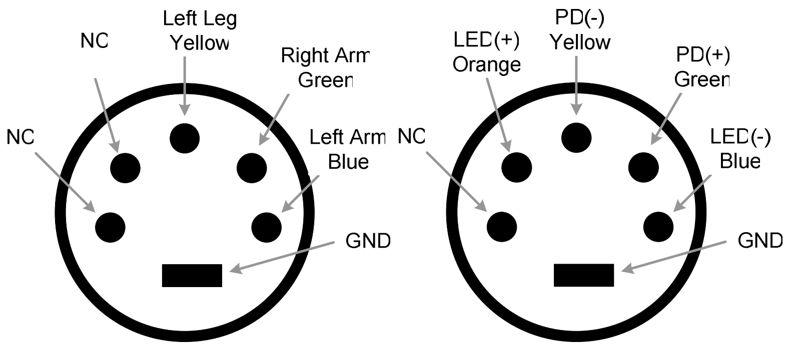
PPG Circuit Diagram



Power Supply Circuit Diagram



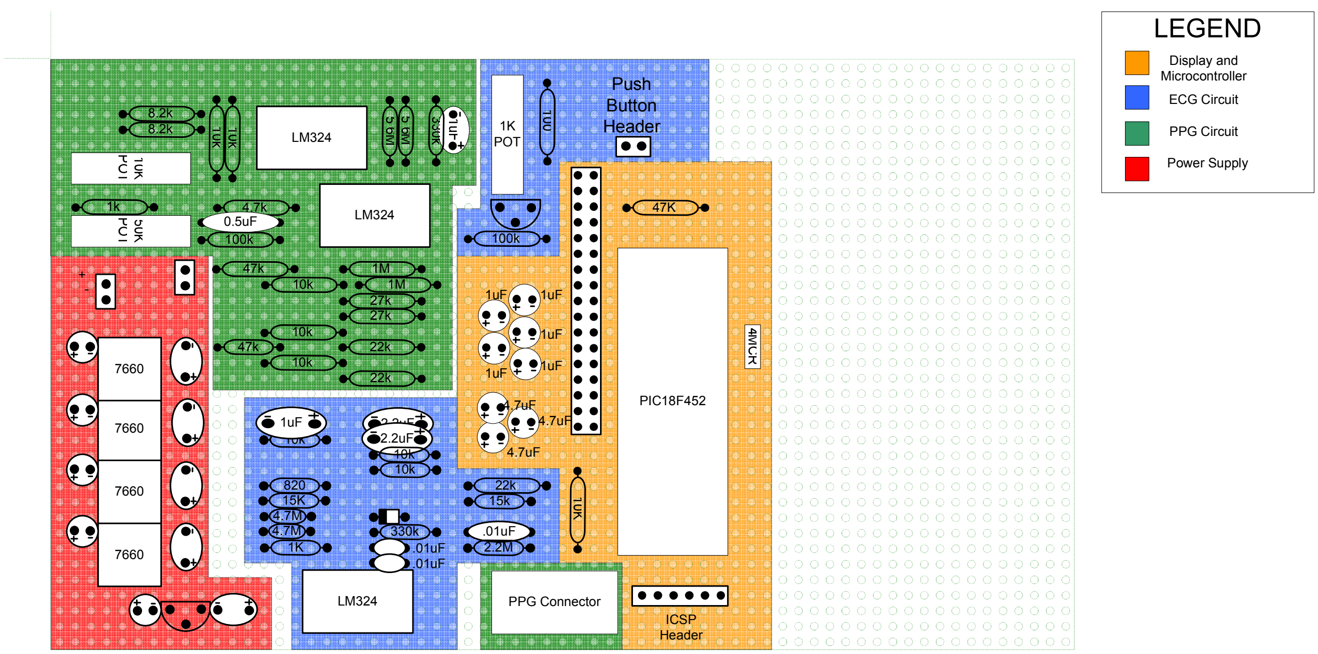
PIC Processor Circuit Diagram



Looking into the connector Looking into the connector

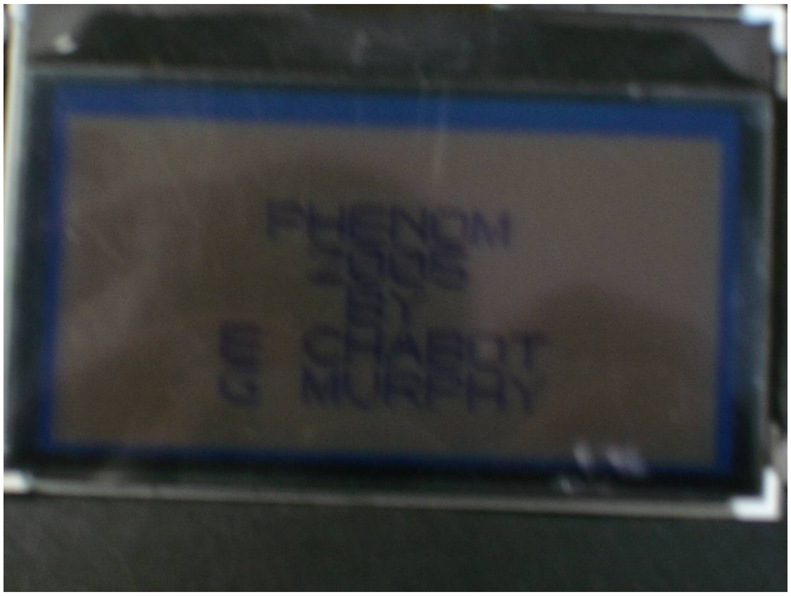
The ECG and PPG female connector pin-outs are given above on the left and right, respectively.

Circuit Board Layout

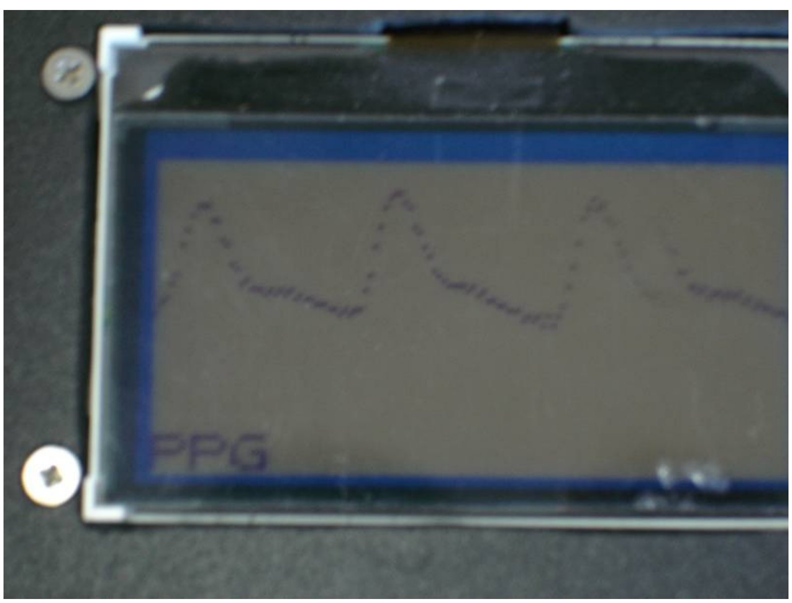


APPENDIX – B

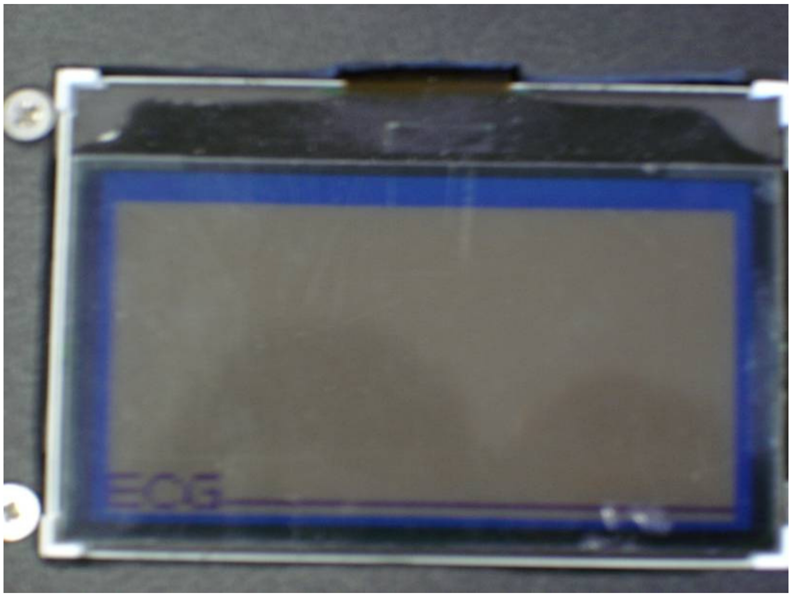
Device Images



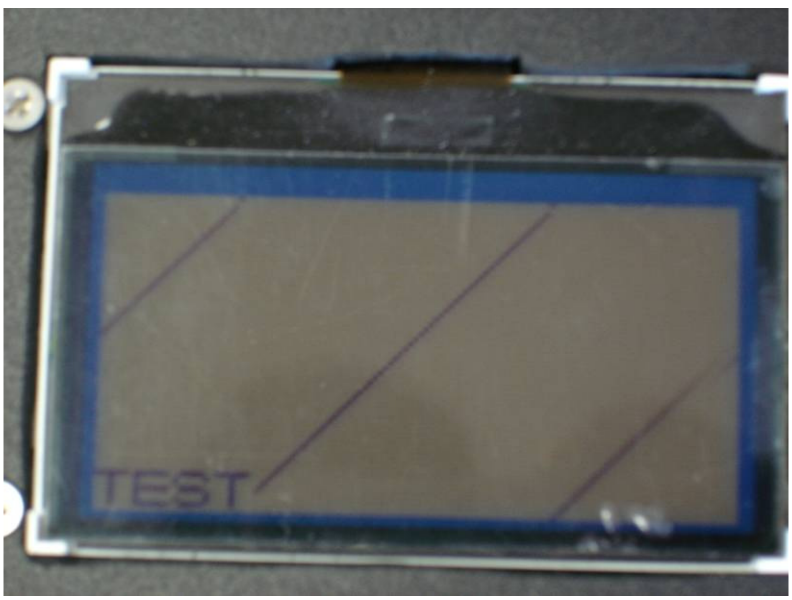
Introduction Screen



Mode 0 – PPG Waveform



Mode 1 – ECG Waveform



Mode 2 – Test Waveform

Mode 3 – Character Test Display

APPENDIX – C

Meeting Minutes for PHENOM Project

January 27, 2005 11:30-1:00

The members, Gabrielle and Eugene, gathered the components and began bread-boarding the power supply. The 9 volt input was checked and measured to be +/- 9 volts and the voltage after passing through the 5 volt regulator was measured to be 5.04 volts. The power supply has been found to be working correctly. For ease of use, the 9 volt battery was wired in connection with a push button for on/off power.

February 1, 2005 11:30-1:00

Both members worked on the photoplethysmogram. It was bread boarded, and ready for testing. The problem of the day was that the PPG connectors were not found for have a diagram denoting the connections. The meeting continued with trial and error of the PPG connector.

February 3, 2005 12:45-1:00

The two members discussed the plans for the following week. They received the pin diagram/layout of the PPG connector from Ron (the TA). We learned up on photodiodes and discussed the PPG schematic.

February 8, 2005 11:45-2:00

Both members worked on bread boarding the electrocardiogram. The gains of each section were first calculated and then tested. The results were that there were discrepancies between the theoretical and the measurements made.

February 15, 2005 1:30-2:00

Gabrielle finished bread boarding the last two sections of the ECG circuit.

February 17, 2005

Eugene and Gabrielle worked out the gains and tested the PPG. There were errors found. The result of the day was that it is necessary to trim the wires in case of a shortage and retest the circuit.

February 22, 2005 2:00-8:00

Team members worked on debugging the PPG and ECG circuits. The PPG circuit was fully operational but a sensitivity to the frequency of the input modulation around 1kHz. The ECG was reconstructed multiple times but still experienced problems.

February 23, 2005
The ECG was rewired on another bread-board but only the first two stages. It was found that a significant radio signal disturbance around 90MHz was being picked up with a magnitude equal to our ECG signal range. Section one was tested with a DC input varying in the ECG signal range to verify the proper gain. The gain was as expected of approximately 20.

March 3, 2005 11:30-2:00
We continue to work on the breadboard version of the project, getting further and cleaner outputs of the ECG. We took the plot from the oscilloscope and uploaded it into a Butterworth Matlab program. The parameters were changed to give a larger view of the waveform, the result a clean ECG signal.

March 8, 2005 11:30-2:00
Eugene worked on the LCD display and Gabrielle worked on soldering the power supply. The box was laid out, with each section of the project was allotted a space, with extra room for the microprocessor circuitry.

March 10 11:30-2:00
Gabrielle finished soldering the power supply. Both team members tested the power supply, with positive results. The circuit supplied 8.3 and negative 8.3 volts, with about 4.8 volts coming out of the 5-volt regulator.

March 22 11:30-2:00
The components of the PPG circuit were collected and holes were drilled in the circuit board so that it can be attached to the box later. The components were placed on the board and soldered.

March 24 11:30-2:00
Gabrielle worked on wiring up the PPG circuit, drawing up a schematic so that it can be easily followed. Each section of the PPG circuit was given a different color so that it could be more easily traced out in the testing process. Eugene began working on the schematic of the circuits on a Visio program.

March 25 7:45-8:30
Gabrielle worked on the PPG circuit. Eugene worked on wiring up the microcontroller and the display.

March 28 7:30-8:30
Gabrielle finished the wiring of the PPG circuit. Eugene demonstrated the display worked, but still needed to be interfaced to the circuit.

March 29 11:30-2:00
Gabrielle worked on gathering the components of the ECG circuit and then laying out and soldering them to the board. She then began wiring up the ECG circuit.

March 30 11:00-1:00
Gabrielle finished wiring up the ECG circuit. Eugene continued to work on the documentation of the schematic layout and diagrams.

March 31 11:30-2:00
Eugene and Gabrielle began testing the PPG circuit. The power and ground lines were tested, with positive results. The stages were tested, with a function generator as the input, a 1 K sine wave. The results were that it responded the way that it should, with an accurate band pass filter and the gains on the circuit.

April 1 10:30-1:00
Gabrielle worked on soldering the PPG and the ECG connecters to the circuit-board.

April 4, 2005 12:30-8:00
Eugene worked on the software to supply a 1 kHz signal to the PPG so that it could be more easily tested; the PPG was tested and tweaked until the output was an appropriate waveform. The ECG circuit was tested as well, although there are issues, the output wave form was run through a Butterworth Matlab program with the result of a very noisy, but correct frequency waveform. The box was also tested and working, the PPG aspect, with the circuit enclosed.

April 5, 2005 11:00-2:00
Both team members collaborated on the composition of the phase two report.

April 7, 2005 11:30-12:30
Both team members decided to try to build a new PPG connector. It was found through testing that the photodiodes available were not very sensitive, they were on the scale of a 10mV change whereas the Norelco was on the scale of 2V.

April 12, 2005 11:30- 2:00
The team decides to solder the LL directly to ground to try and achieve a less noisy ECG signal, no luck even with the coaxial cable connector.

April 14, 2005 11:00- 1:00
The coaxial cable was made to attach directly to the circuit board, and the 50 K potentiometer was varied, the signal seen was decent although still very noisy.

April 17, 2005 11:30- 1:30

The team decides to attempt to build a new ECG connector as the ones that we were using, the shielding was not connected to ground. The idea of building a second order filter was tossed around.

April 21, 2005 11:30- 2:00
The team plans out the next two weeks and implements the soft-key interface. The numeric and alphabet display was mapped out as well. The team went over the programming of the PIC and the layout for the alphabet characters in the character ROM.

April 28 2005 11:00- 2:00
The aesthetics of the project box were ameliorated, Letters in the alphabet were redone and the team discussed the current non-operational state of the ECG with Dr. Sun.

May 2, 2005 11:00- 1:00
The team created the cover for the box and began writing the final report.

May 3, 2005 11:00- 2:00
The team captured images of the project for the 5-minute presentation. The presentation was developed and the final report was finished.