School of Engineering Science ♦ Simon Fraser University
Burnaby ♦ British Columbia ♦ Canada
wireless-medicaldevices@sfu.ca

October 31, 2002

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Subject: Design Specification for a Wireless EMG System

Dear Dr. Rawicz:

The document enclosed with this letter, Design *Specifications of a Wireless EMG System*, lists the design specifications of our ENSC 340 Project. We are developing a wireless solution to solve many problems that are associated with standard EMG acquisition techniques.

Wireless Medical Devices was formed in June of 2002 by four highly skilled and motivated Engineering Science students: Eric Chow, Aaron Ridinger, David Press, and Andrew Pruszynski. We look forward to hearing your comments on our functional specification. Please feel free to contact me by phone @ (604) 782-7488 or email @ wireless-medicaldevices@sfu.ca.

Sincerely,

Jedrzej (Andrew) Pruszynski
Chief Executive Officer
Wireless Medical Devices

Enclosure: Design Specification for a Wireless EMG System

WIRELESS MEDICAL DEVICES

Design Specification for a Wireless EMG System

Project Team: Eric Chow
Dave Press
Andrew Pruszynski
Aaron Ridinger

Submitted To: Dr. Andrew Rawicz
Mr. Steve Whitmore

Revision Number: 1.0

Revision Date: October 31, 2002

Executive Summary

An Electromyograph is a recording of muscle activity used for rehabilitation, injury prevention and performance enhancement. Unfortunately, current systems rely on the use of restrictive wires and equipment that result in inaccurate and inconvenient diagnosis. Applying wireless communications principles to Electromyography (EMG) will lead directly to better diagnosis, research and rehabilitation. These advances have far-reaching implications for corporations, insurance agencies, athletes and patients.

Corporations will increase productivity as they reduce injuries occurring in the workplace. Insurance agencies will substantially cut their payment to the injured as the recovery time is minimized. Athletes will have completely unimpeded measurements of their muscle activity and thus increase performance and suffer fewer injuries. Lastly, and most importantly, the injured patient will get better analysis and diagnosis leading to faster rehabilitation.

The development of the Wireless EMG System (iEMG) will occur in two stages. By the end of the first stage WMD will present a prototype, called the iEMG, which will prove our concept of wirelessly acquiring muscle activity data. By December 2002, the iEMG will:

- Transmit wireless data from 8 EMG pads to a PC mounted receiver
- Record and display the data via a simple software package
- Demonstrate the miniaturization of the EMG pads and transmitter

After the second stage the iEMG will:

- Be reliable and user friendly
- Be capable of transmitting other biological signals such as ECG and EEG
- Have a more extensive software package

Table of Contents

EXECUTIVE SUMMARY **1**

LIST OF FIGURES AND TABLES **4**

ACRONYMS **5**

1 – INTRODUCTION **6**

1.1 – Scope 6
1.2 – Intended Audience 6

2 – SYSTEM OVERVIEW **7**

3 – EMG PADS **9**

3.1 – Signal Acquisition 10
3.2 – Noise Rejection 10
3.3 – Amplification 11
3.4 – Signal Filtering 12

4 – TGE MODULE REQUIREMENTS **13**

4.1 – Microcontroller 13
4.2 – Transmitter 16
4.3 – Antenna 17
4.4 – Ground Pad 17
4.5 – Power Supply 17
4.6 – Connections 19
4.7 – TGE Packaging 20

5 – RECEIVER STATION REQUIREMENTS **22**

5.1 Antennas 23
5.2 Receivers 24
5.3 Microcontrollers and Output Buffers 24
5.4 MUX and Sample Timing 26
5.5 Power Supply 28
5.6 Connections 29
5.7 Receiver Station Packaging 30

6 – SOFTWARE **31**

6.1 User Interface 31
6.2 Driver 35
6.3 Processing 35
6.4 Data Acquisition (DAQ) 37

7 – TEST PLAN **39**

7.1 – EMG Pad 39
7.2 – TGE and Receiver Station Hardware 39
7.3 – EMG Signal Transmission 39
7.4 – Software 40

8 – CONCLUSION 41
9 – REFERENCES... 42
APPENDIX A – SPECIFICATION FOR EMG PADS... 43

List of Figures and Tables

Figure 2.1 - System Block Diagram 7
Figure 2.2 - EMG Pads and TGE Module shown around the wrist and elbow 8
Figure 3.1 – Block Diagram of EMG Pad 9
Figure 3.2 – Schematic of EMG Pad 10
Figure 3.3 – Common noise rejection with respect to frequency 11
Figure 3.4 – The Relationship between R_1 (R_G) and AD620 Voltage Gain 11
Figure 4.1 – Overview of TGE module 13
Figure 4.2 – TGE microcontroller flowchart 15
Figure 4.3 – Ground Strap 17
Figure 4.4 – Power Supply 18
Figure 4.5 – Power supply output 18
Figure 4.6 – EMG pad connected to power supply 19
Figure 4.7 – Pin Connections between microcontroller and transceiver 20
Figure 4.8 - TGE package 21
Figure 5.1 – Receiver Station Block Diagram 22
Figure 5.2 – Antennas and Ground Plane 23
Figure 5.3 – Microcontroller Program Flow Chart 25
Figure 5.4 – 24 bit output word 26
Figure 5.5 – MUX master flowchart 27
Figure 5.6 – Over-sampling Timing Diagram 28
Figure 5.7 – Receiver Station Interconnections 29
Figure 6.1 – Wireless EMG system software components 31
Figure 6.2 – Layout of user interface 32
Figure 6.3 – Record button dialogue window 33
Figure 6.4 – Display button dialogue window 34
Figure 6.5 - Processing section block diagram 36
Figure 6.6 – Connector diagram for I/O card 38

Table 4.1 – TGE broadcast frequencies 16
Table 4.2 – Current Consumptions 19
Table 7.1 – Example of Different Test configurations 39

Acronyms

A/D	Analog to Digital
CMNR	Common Mode Noise Rejection
CMOS	Complementary Metal Oxide Semiconductor
DAQ	Data Acquisition
DCB	Data Conditioning Block
DRB	Data Recording Block
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyograph
ESD	Electrostatic Discharge
FSK	Frequency Shift Keying
GUI	Graphical User Interface
iEMG	Independent Electromyograph
ISM	Industrial, Scientific, and Medical
I/O	Input/Output
MUX	Multiplexer
PC	Personal Computer
PCB	Printed Circuit Board
PCI	Peripheral Card Interface
RAM	Random Access Memory
RF	Radio Frequency
ROM	Read Only Memory
RSSI	Received Signal Strength Indicator
SPI	Serial Peripheral Interface
TGE	Transmitter and Ground Electrode
TTL	Transistor-Transistor Logic
UI	User Interface
USART	Universal Synchronous Asynchronous Receiver Transmitter
WMD	Wireless Medical Devices

1 – Introduction

WMD will use proven EMG sensors and established wireless communications techniques to develop the iEMG. Our product will be more portable, easier to use, and more accurate than the current available systems. By eliminating all wires, iEMG can be quickly and easily setup in any environment. The lack of wires greatly reduces the restriction on the subject's movement, which in turn leads to more accurate diagnoses.

1.1 – Scope

This document describes the design specifications that must be met by the iEMG system. It explains how the product will be designed to meet all the functional requirements as described in the Functional Specification. Note that these design specifications only apply to the proof of concept device.

1.2 – Intended Audience

All members of the WMD team will use the design specifications. The engineers will use the document as a guide when making design decisions. Marketing personnel will use it to assess the product position in the market. Managers will gauge the project's progress based on these specifications. Lawyers will use this document to protect the intellectual property developed by WMD.

2 – System Overview

Figure 2.1 gives an overview of the Wireless EMG system. The EMG pads are placed on the subject's body to measure muscle activity. Each pad sends information to a TGE Module that is also placed on the subject. The TGE modules wirelessly transmit the EMG data to the Receiver Station. A PC installed with appropriate software collects the data from the Receiver and can display it to the screen in real-time and save the data for future use.

A reciever can simultaneoulsy receive data from up to four TGE Modules. Each TGE Module is connected to two EMG pads. In the final production module, one or more EMG pads may be replaced by an ECG or EEG pad.

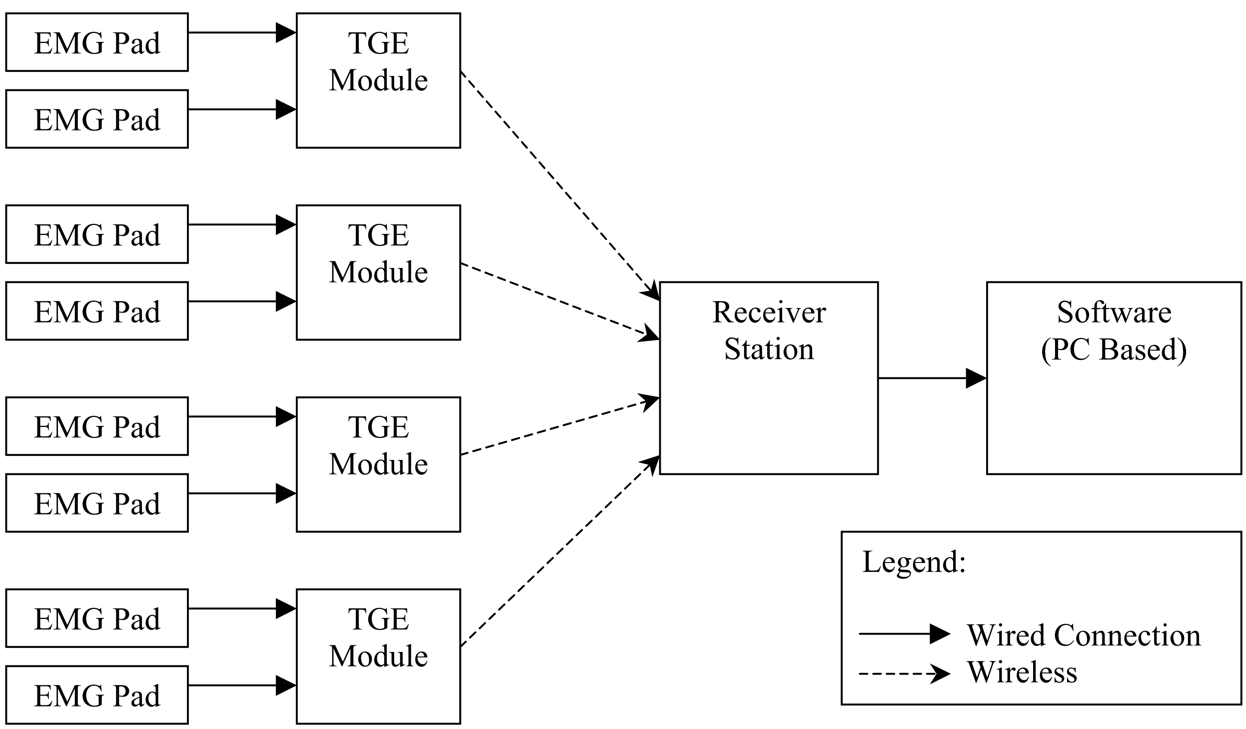


Figure 2.1 - System Block Diagram

The design specifications are organized according to the applicable system component (as described in Figure 2.1).

Figure 2.2 shows how the EMG pads and TGE Module can be placed on the subject's body to measure muscle activity.

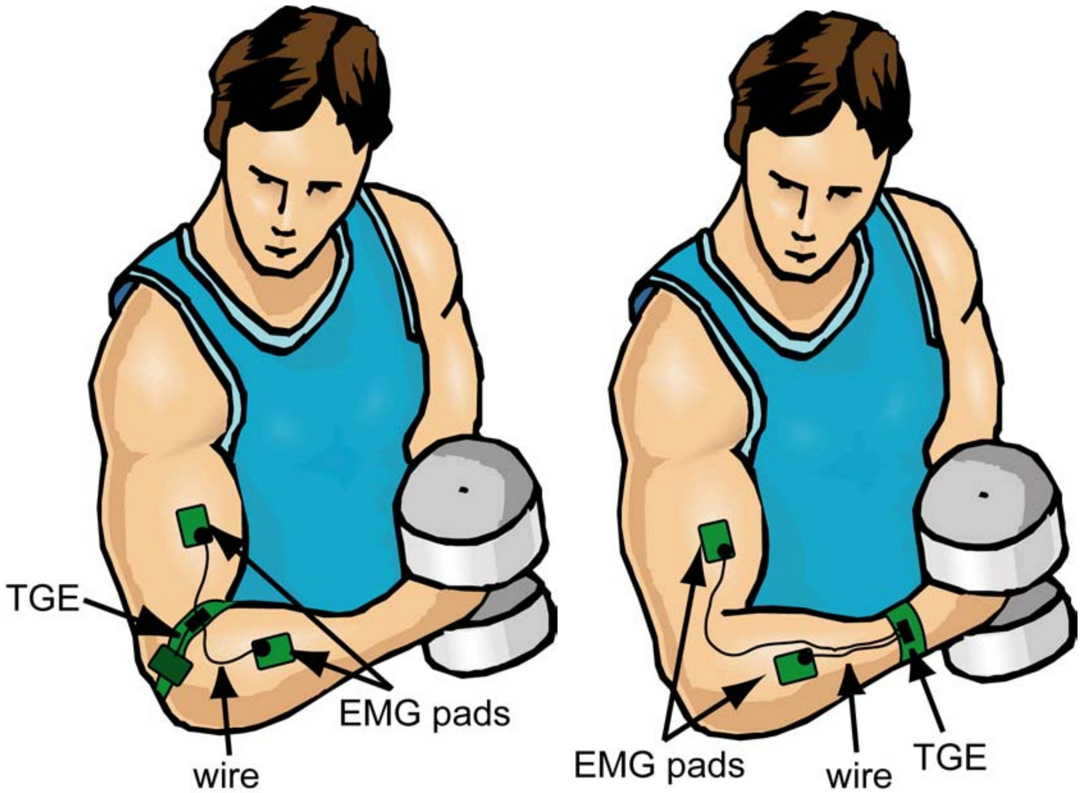
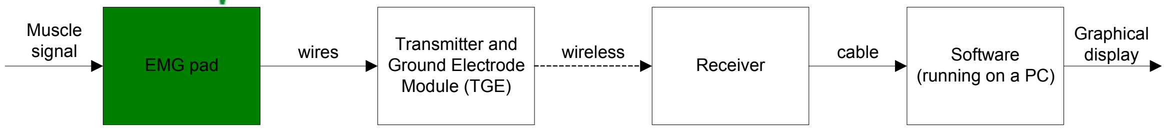


Figure 2.2 - EMG Pads and TGE Module shown around the wrist and elbow



3 – EMG Pads

The EMG pads are used to physically acquire and amplify the biological muscle activity signal. These devices are essentially high gain amplifiers with very good common mode noise rejection (CMNR) followed by a simple low-pass filtering circuit. In its task of delivering a useable data signal to other components of the system, the EMG pad essentially performs four major functions:

- Signal Acquisition
- Noise Rejection
- Amplification
- Signal (Low-Pass) Filtering

The EMG Pad receives its power from the TGE. It will operate on a voltage range of ±2.8V. The common ground electrode is located on a physical strap that is placed on a location not affected by the muscle activity signal that is being measured by that EMG. The EMG Data output is a signal that is tuned by the user to ensure a maximum output at the rails of operation. Appendix A shows detailed specifications for the EMG Pad.

A functional block diagram of the EMG Pad is shown in Figure 3.1. In addition, the full schematic of the final EMG pad used in the proof-of-concept device is shown in Figure 3.2.

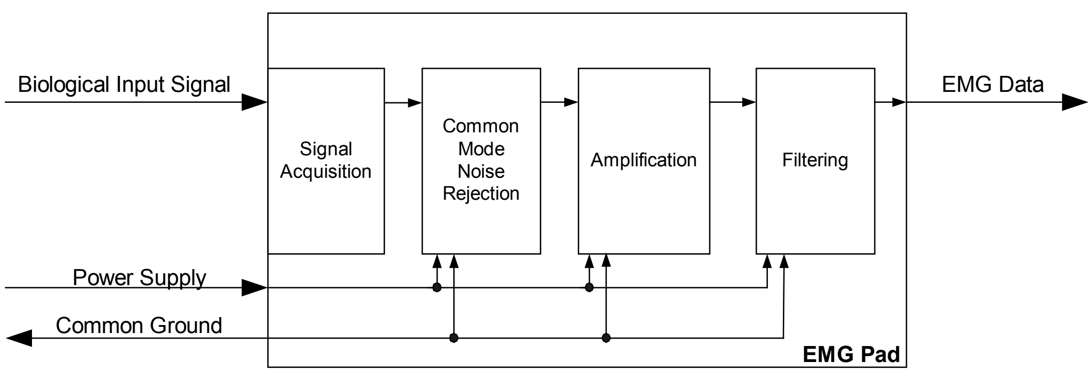
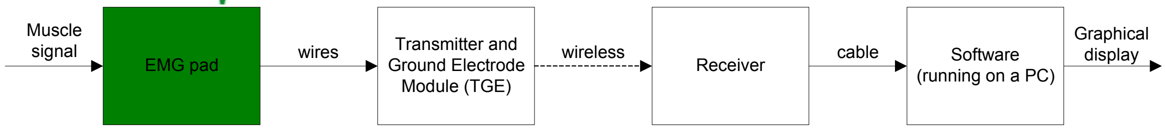


Figure 3.1 – Block Diagram of EMG Pad



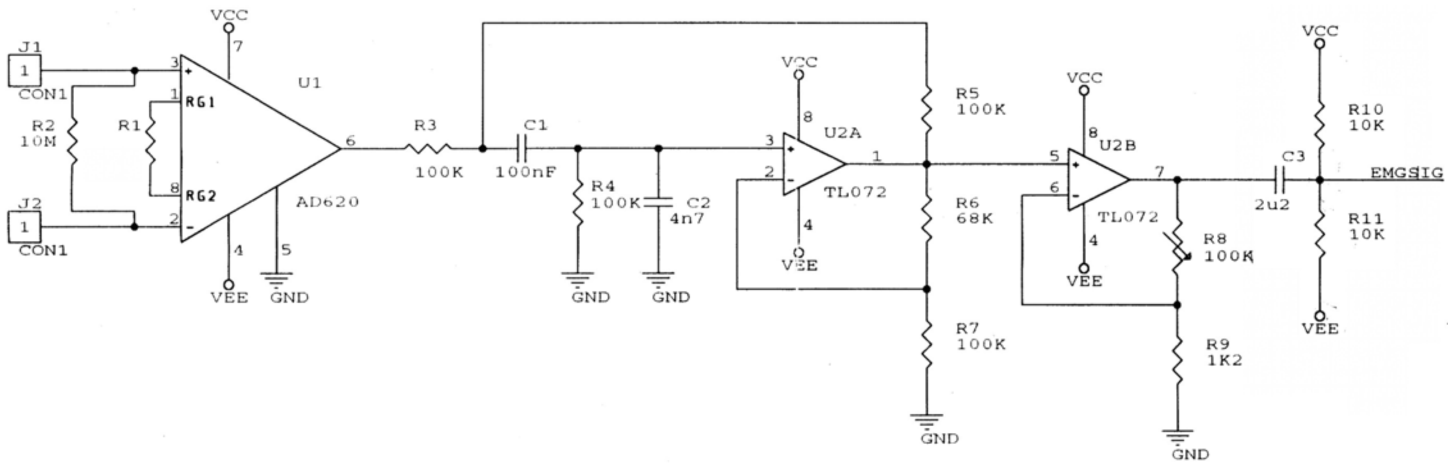


Figure 3.2 – Schematic of EMG Pad

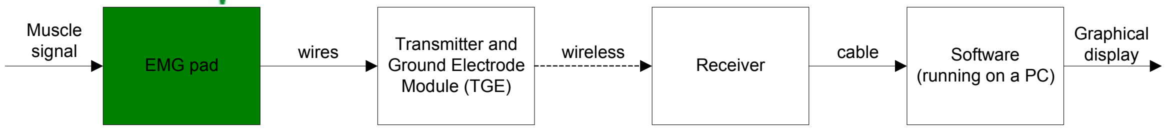
3.1 – Signal Acquisition

The signal is acquired by means of two stainless steel electrodes attached to the EMG Pad. The electrode must be made of a material that ensures low resistance to guarantee that the biological signal integrity is maintained. Stainless steel is used because it delivers high quality for a reasonable price. Using a higher quality product like silver or gold would result in a slight improvement by lowering resistance. However, the large cost differential for upgrading to this material is not worth the small improvement that would result.

3.2 – Noise Rejection

The signals that we are attempting to acquire are in the 20-500Hz frequency range. Unfortunately, electromagnetic interference is extremely high at 60Hz because of standard electrical background noise. In order to eliminate the effect of noise with minimum affect on the quality of the rest of the signal, the EMG pad employs the AD620, a low-cost, low-power instrumentation amplifier. This amplifier utilizes a common-mode noise rejection technique to eliminate external noise while allowing a maximum gain of 1000.

CMNR is a common technique to eliminate noise from a large system such as the human body. Since the biological signal is known to propagate down the length of the muscle fiber, any artifact in the signal that is common to both nodes (electrodes) with respect to time must be due to some external noise. The figure below shows the relationship between frequency, gain and CMNR for the AD620. From this figure it is clear that for



the frequencies of interest, the AD620 will be able to attenuate the noise by well above 100dB.

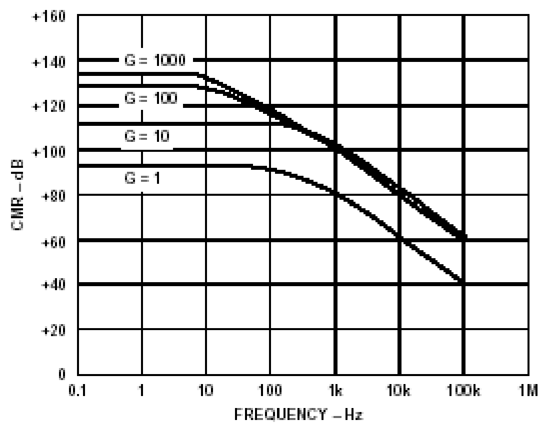


Figure 3.3 – Common noise rejection with respect to frequency

3.3 – Amplification

The amplification of the entire EMG electrode can range from 24 (27.6dB) to 2000 (66dB). In order to ensure the highest quality of amplified signal, this amplification is done in 3 stages. The first is an amplification of 20 done by the AD620. This initial amplification is selectable by changing the value of R1 in the circuit presented in Figure 3.2. The equation that relates AD620 voltage gain and R1 is shown in Figure 3.3.

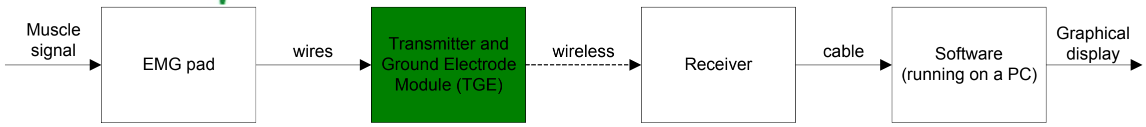
$$G = \frac{49.4\ k\Omega}{R_G} + 1$$

Figure 3.4 – The Relationship between R_1 (R_G) and AD620 Voltage Gain

The next two stages are both implemented on the standard TL072 Operational Amplifier. The first is essentially a voltage follower with gain or approximately 1 (0 dB). Finally, a simple non-inverting amplifier implements the last stage. In our EMG pad, R8 is a variable resistor that can be adjustable at the pad exterior by a standard trim-potentiometer. This variable gain combined with signal centering allows the user to adjust gain based on the strength of the input signal. Signal centering is done through C3, R10 and R11, which essentially places the signal halfway between the –2.8V and 2.8V (our rails). Combined, the amplification and centering ensure that maximum gain is achieved without clipping.

3.4 – Signal Filtering

The EMG pad provides some very basic filtering to reduce the unwanted components of the signal that lie outside the bandwidth of the muscle activity signal. The filtering is present before the second stage of amplification and yields an output signal that lies between 30 and 500Hz.



4 – TGE Module Requirements

Each TGE is responsible for acquiring the signals from two EMG pads, digitizing these signals, and sending the data wirelessly to the Receiver Station. It also provides the power and ground reference to the EMG pads. A block diagram of the TGE is shown below in Figure 4.1.

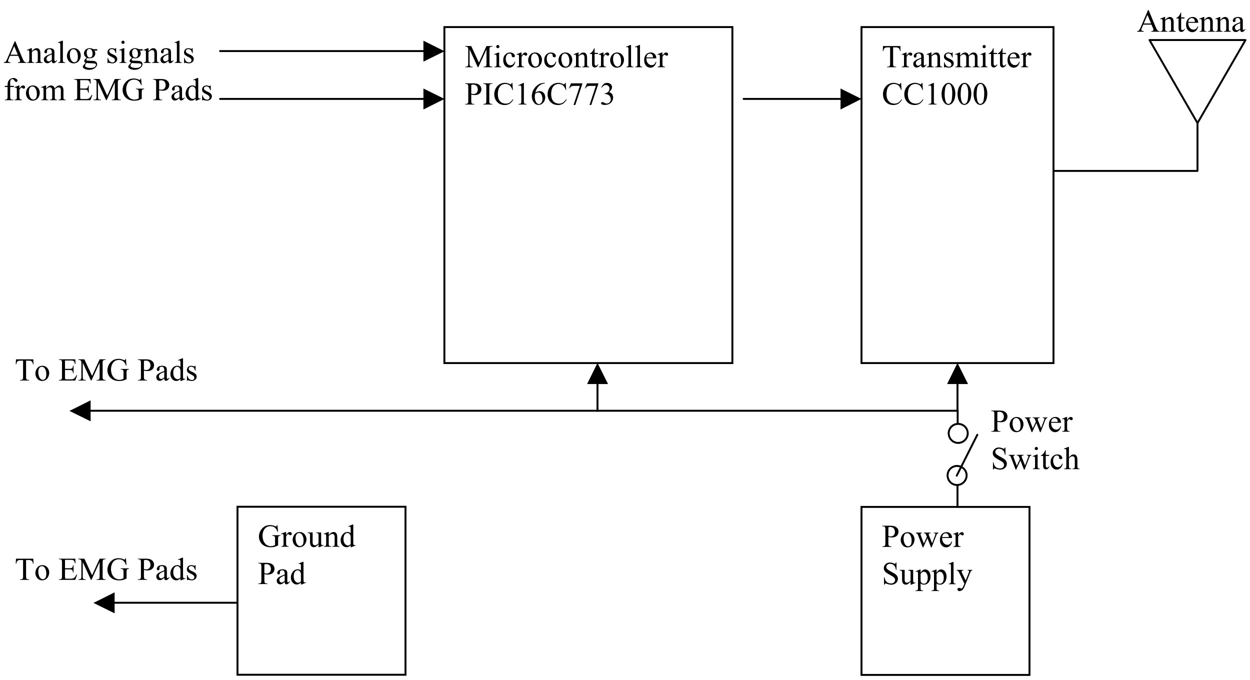


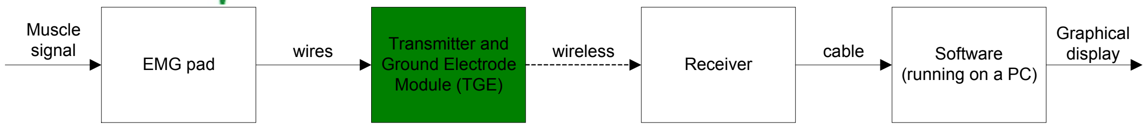
Figure 4.1 – Overview of TGE module

4.1 – Microcontroller

When selecting our microcontroller, we considered the following criteria to be essential:

- 2 A/D inputs to receive analog signals from two EMG pads, minimum 12 bit resolution
- SPI and USART ports to communicate with CC1000PP
- Erasable Programmable ROM
- Low Power consumption
- Flexible I/O design so that the same microcontroller can be used in the Receiver Module

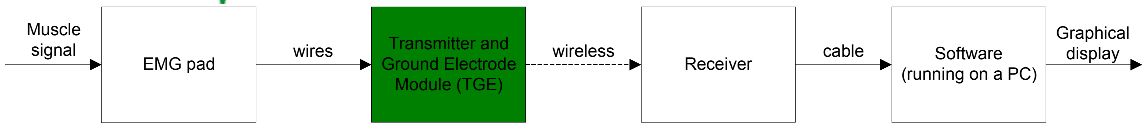
We chose to use the Microchip PIC16C773 Microcontroller to meet the above requirements. Microchip also makes a sister product, the PIC16C774, which uses the



same architecture but with more I/O pins, which we chose for the Receiver Module. The 16C773 comes in a 28-pin package, with six 12-bit A/D converters, and an SPI module. It has all the features we need without an excess of I/O pins that would only add to the cost and size of the TGE. It is available in small surface mount packages, which are desirable for a final product, although for the development and prototype stages we will be using a larger DIP package. PIC microcontrollers are also very commonly used, so resources are readily available to aid in programming and operating the devices.

The 16C773 can operate on supply voltages ranging from 2.5V to 5.5V, which leaves flexibility in our power supply design. In order to ensure compatibility with the CC1000 Transceiver, we will supply the microcontroller with a 2.8V power supply. It also allows the use of any external oscillator up to 20MHz as a clock, allowing us to find an optimum balance of processor speed and power consumption. We will use an 8MHz oscillator, causing the processor to draw only 4mA from a 2.8V supply, which is negligible compared with the power consumed by other TGE components.

Figure 4.2 shows the program flow of the microcontroller.



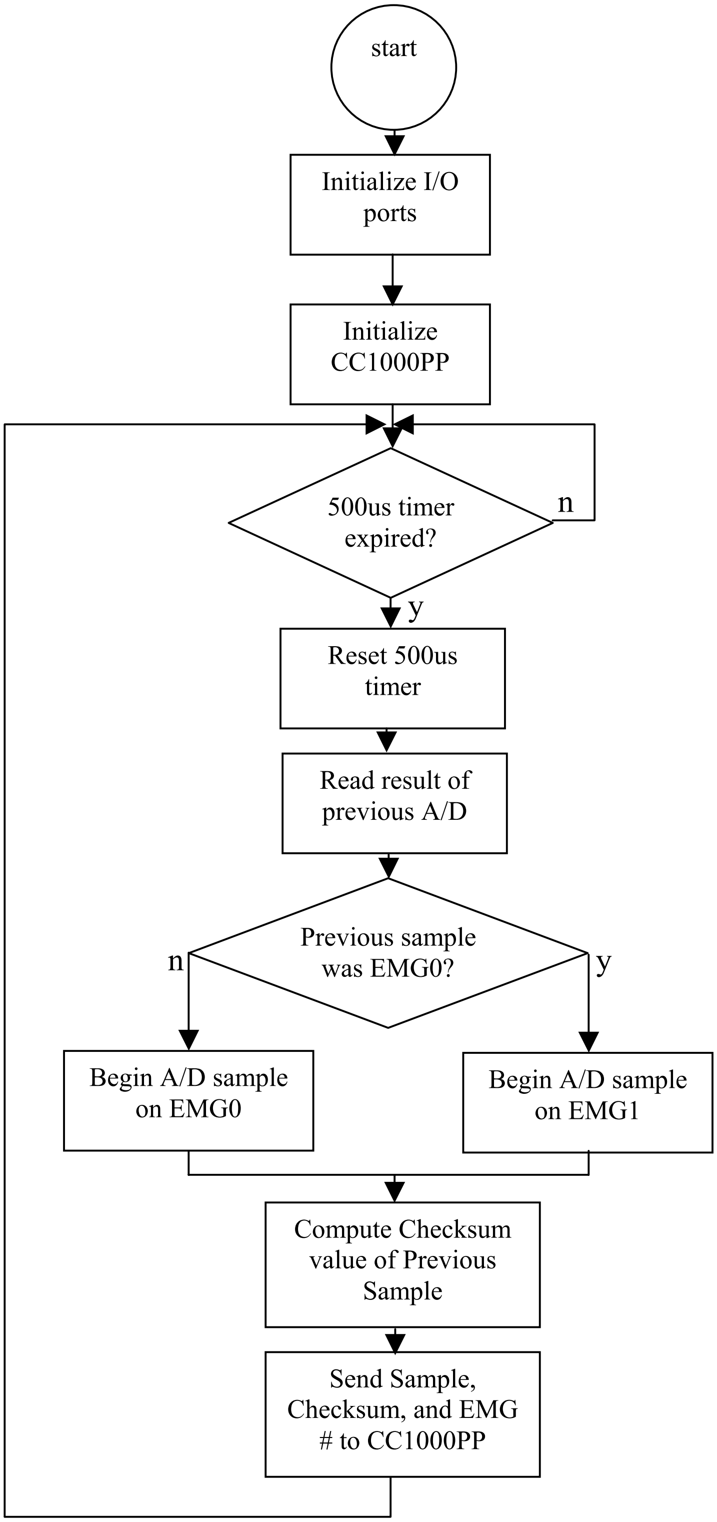
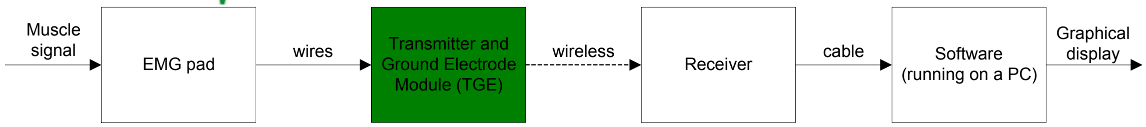


Figure 4.2 – TGE microcontroller flowchart



Each of the two EMG signals will be sampled at a rate of 1KHz. Since the signals are band-limited to 500 Hz, this rate ensures that no aliasing will be present. The end PC will use the checksum for error-checking purposes, but due to the timing constraints of the system, the TGE will be unable to rebroadcast a bad sample.

4.2 – Transmitter

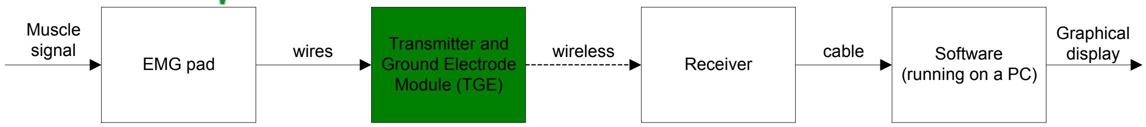
The transmitter modulates a base-band digital signal from the microcontroller onto an RF carrier and sends it to an antenna. The iEMG system must operate in the 902-928 MHz ISM band that is commonly used in hospital settings.

We will use the Chipcon CC1000 Plug and Play transceiver as the transmitter. The Plug and Play module contains all the external components, excluding the antenna, required to drive the CC1000 transceiver chip. The CC1000PP suits the needs of our system well because it is software tunable to broadcast carrier frequencies from 868-1000 MHz, which more than covers the necessary ISM band. There will be four TGE modules in a complete iEMG system, thus each of the four transmitting CC1000PPs will be programmed to operate on a different carrier frequency. These frequencies are evenly spaced throughout the ISM band to minimize interference between adjacent channels. Table 4.1 below summarizes the carrier frequencies that will be used.

EMG Pad number	TGE number	Broadcast Frequency
1 2	1	902 MHz
3 4	2	911 MHz
5 6	3	919 MHz
7 8	4	928 MHz

Table 4.1 – TGE broadcast frequencies

The CC1000PP uses FSK modulation, which is more interference-resistant than ASK. It consumes only 23 mA on a supply voltage of 2.8V, and can output 0.5 dBm of RF power to the antenna. It also supports high baud rates, as we will broadcast data at 76.8 Kbps.



4.3 – Antenna

It will be very difficult to produce an efficient broadcast antenna for the TGE module. An ideal antenna is the quarter-wave dipole antenna, which is a rigid 8.1 cm long wire perpendicular to a ground plane. Unfortunately, this design would prove very unwieldy on the subject's body.

We will simply use a 10 cm long flexible wire that is free to dangle from the TGE module. Although this will not provide optimum range for the iEMG system, detailed antenna optimization is beyond the scope of the prototype development. Despite the antenna restrictions, the device should still have a range of approximately 100 meters over open ground, or 50 meters indoors.

4.4 – Ground Pad

The reference ground pad for the EMG will be a conducting elasticized velcro strap. The strap will have sufficient contact area with the subject's skin to provide the EMG pad with a good ground reference for common mode noise rejection. Figure 4.3 below illustrates a ground electrode strap.

Figure 4.3 – Ground Strap

A small pocket on the strap will hold a package encasing the CC1000PP transceiver, PIC16C773, and power supply.

4.5 – Power Supply

The electronic components of the TGE are all designed to run off a supply voltage of 2.8V, while the EMG pads require voltages of ±2.8V. The power supply must also be compact and lightweight.

We have chosen to use a stack of four 1.4V zinc-air 675 Hearing Aid batteries. This will give a total of 5.6V and 675 mA hours. Figure 4.4 shows the battery stack.

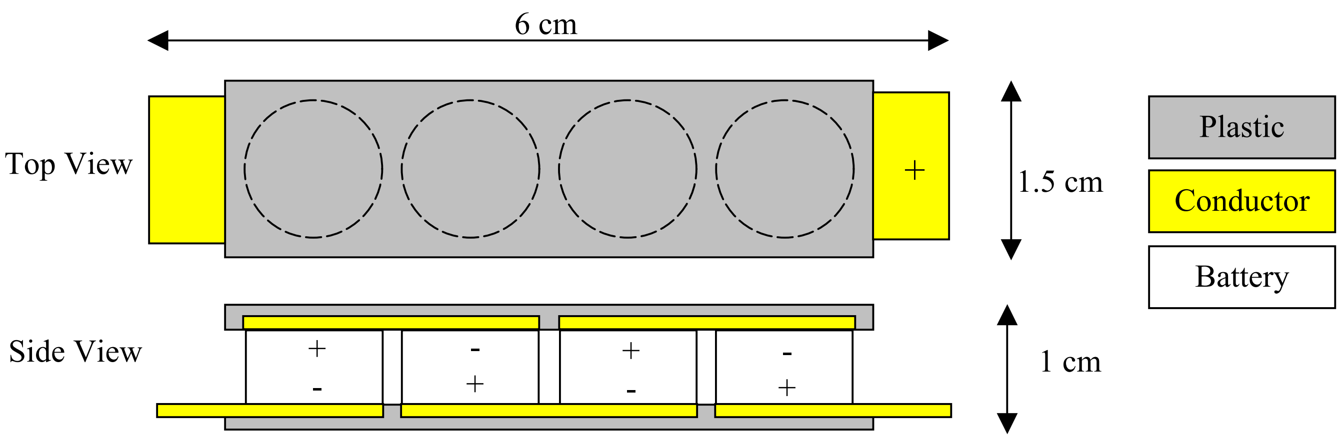


Figure 4.4 – Power Supply

The power supply will use two diode-connected transistors as a voltage divider to produce a 2.8V supply as shown in Figure 4.5. The power switch is also shown.

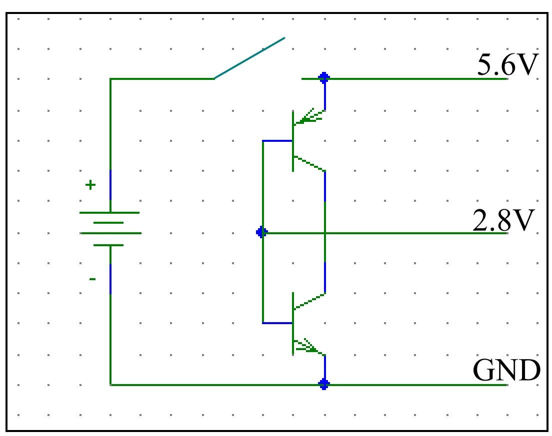


Figure 4.5 – Power supply output

The current consumption of each component powered by the power supply is shown in Table 4.2.

Component	Current Consumption (mA)
EMG Pad x2	10 x2
PIC16C773	4
CC1000PP	23
Total	**47**

Table 4.2 – Current Consumptions

Since the battery stack can supply up to 675 mA hours at 5.6V, the TGE and two EMG pads will run for over 10 hours.

4.6 – Connections

The TGE will be connected to two EMG pads by means of two wire bundles. Each wire bundle will contain four wires: an amplified EMG signal from the pad, positive and negative supply voltages, and a ground reference. The wire bundles will each be 1 meter long to facilitate placement of the EMG pads nearly anywhere on the subject's body.

The EMG pad requires supply voltages of ±2.8V and a ground reference. Figure 4.6 below illustrates these EMG pad inputs will be connected to the power supply and ground electrode strap.

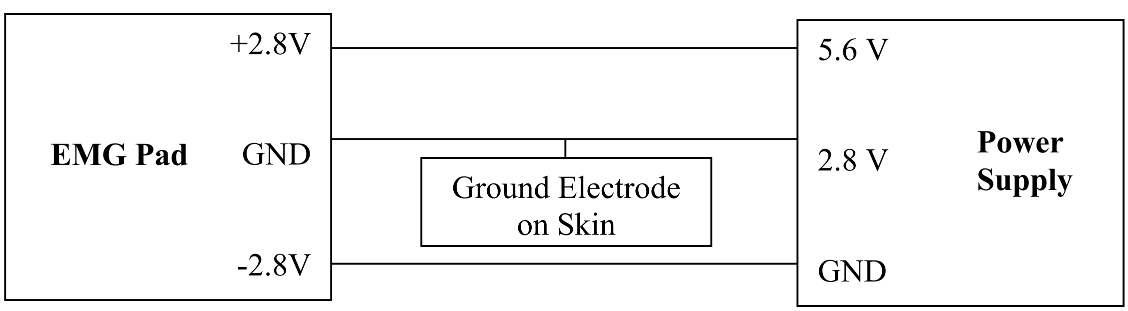
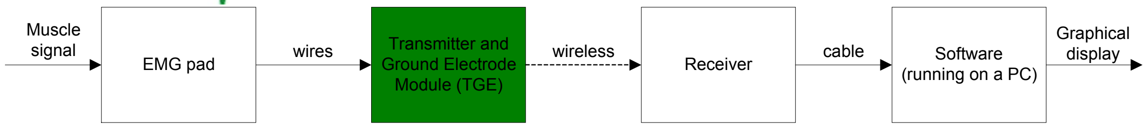


Figure 4.6 – EMG pad connected to power supply

The analog output signal from the each EMG pad varies between –2.8V and 2.8V relative to the EMG's ground. This signal will be interpreted by the A/D converter on the PIC16C773 as being between 0 and 5.6V, since it uses a different ground reference. This is shown in Figure 4.7, along with other relevant pin connections between the PIC16C773 and the CC1000PP.



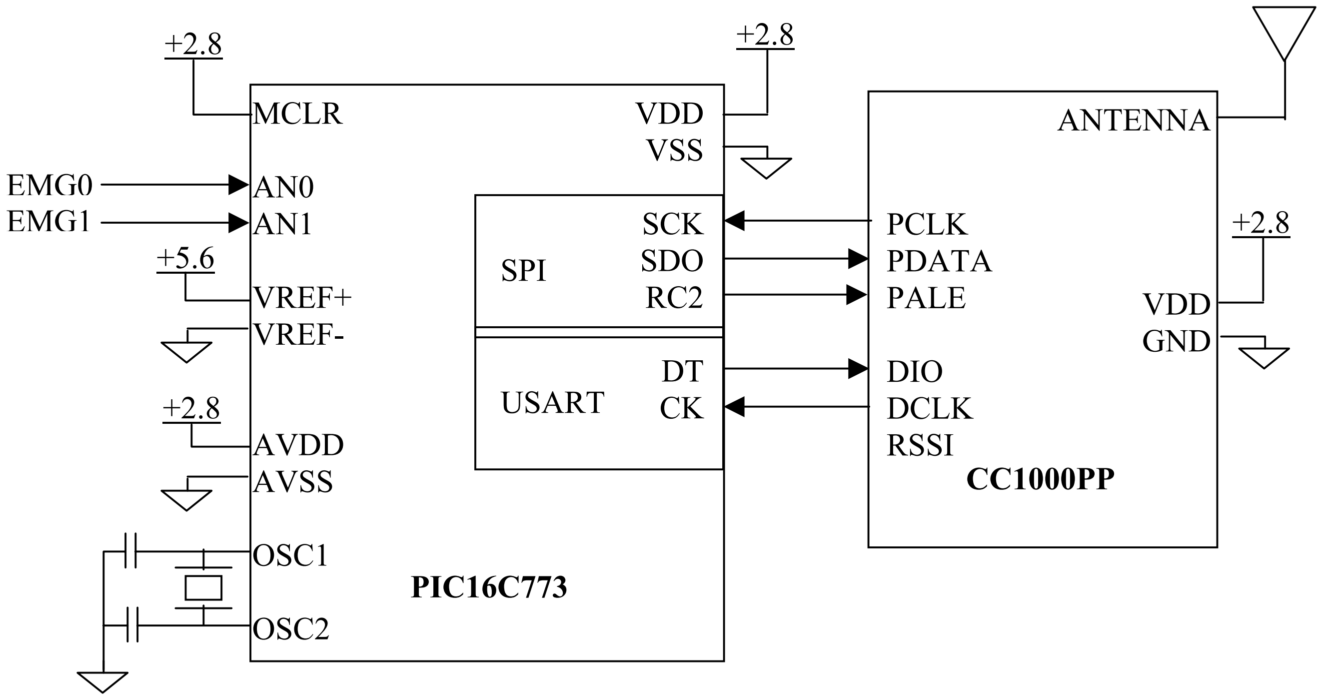
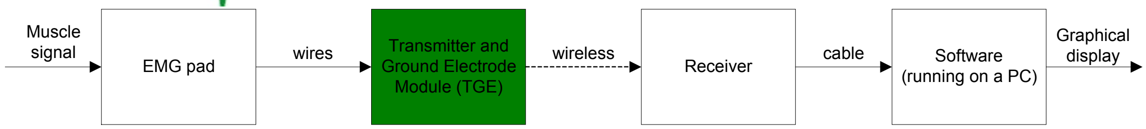


Figure 4.7 – Pin Connections between microcontroller and transceiver

4.7 – TGE Packaging

The power supply circuitry, PIC16C773 microprocessor and external oscillator, CC1000PP Transceiver will be mounted on a vector board for the prototype. It is simpler to mount components on a vector board than a PCB and the small number of components in the TGE make a vector board equally compact. Surrounding all electronic components other than the CC1000PP will be a grounded piece of aluminum foil to act as an RF shield preventing unwanted interactions between the RF and base-band components.

The vector board will be packaged in a plastic casing that will protect the components from damage and external sources. The casing will also hold the power supply. Small holes in the casing will allow the toggle switch, wire antenna, and two EMG wire bundles to connect to the TGE. Figure 4.8 presents a likeness of the casing.



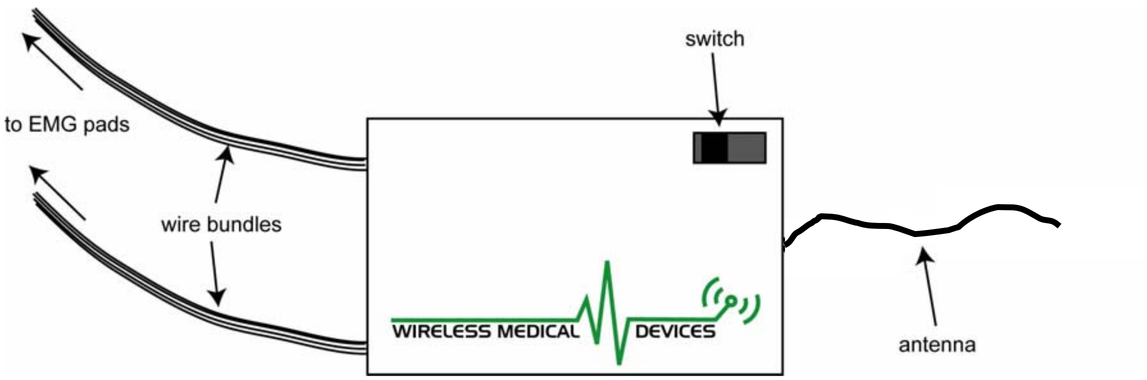
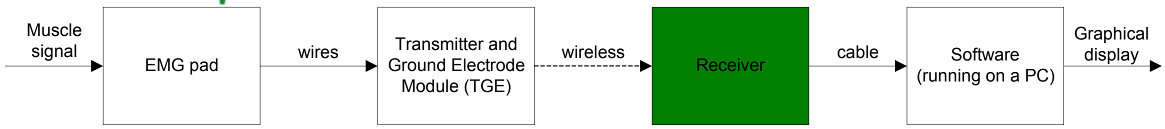


Figure 4.8 - TGE package



5 – Receiver Station Requirements

The Receiver Station is responsible for receiving the data simultaneously broadcast by four different TGE modules, and making this data available to the PC in a timely manner. A block diagram of the Receiver Station is shown in figure 5.1.

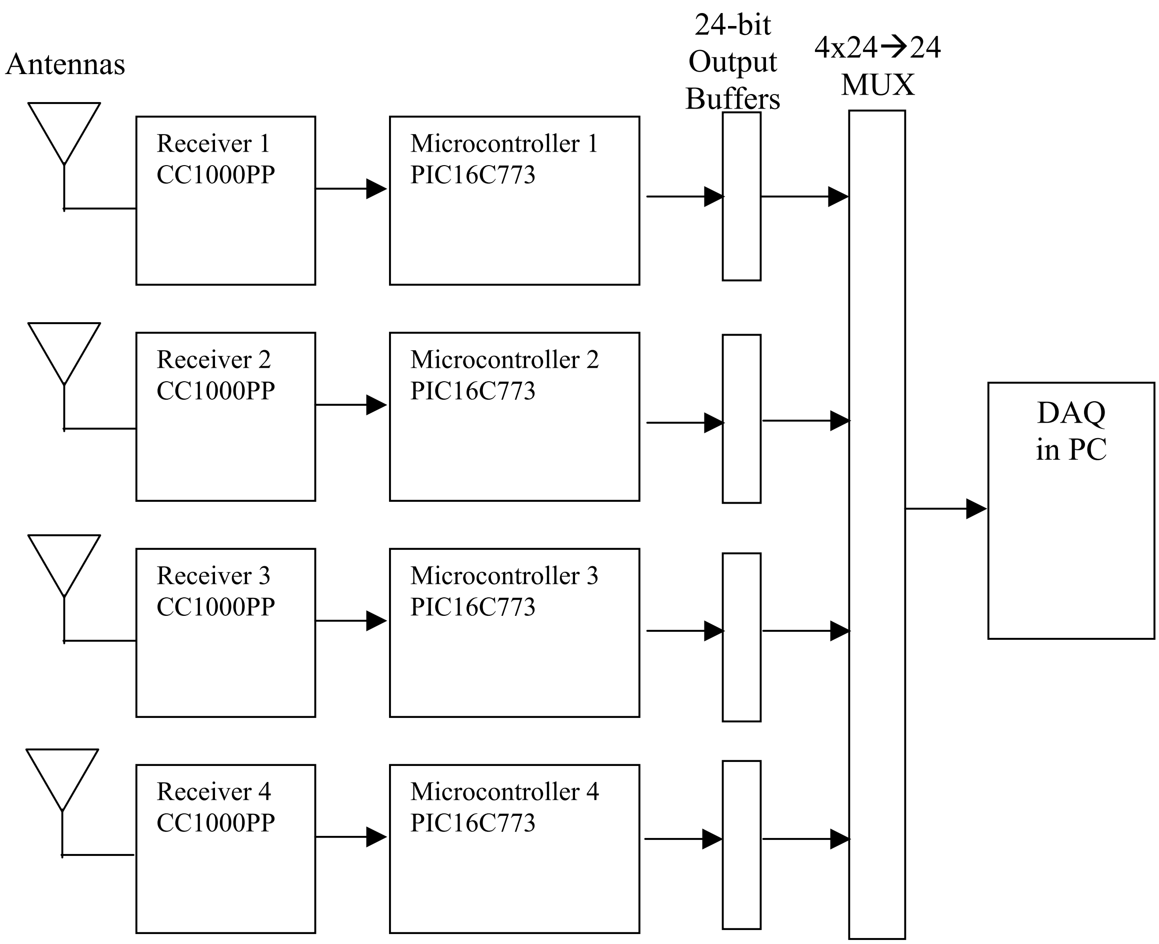
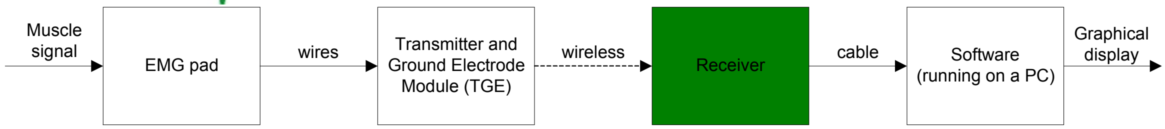


Figure 5.1 – Receiver Station Block Diagram



5.1 Antennas

As mentioned in section 4.4, the ideal antenna for our purposes is a quarter-wave dipole, perpendicular to a ground plane. For RF at 915 MHz, this dipole should be a rigid wire 8.1 cm in length. Because the size restrictions placed on the Receiver Station aren't as strict as on the TGE, we will use this ideal antenna.

Each CC1000PP receiver will be connected to its own antenna. It is possible for the four receivers to share one antenna, but the transmission line impedance matching that would require is beyond the scope of our prototype iEMG project. Each antenna will be a vertically mounted rigid wire, and the entire base of the Receiver Station will be made of aluminum to act as the ground plane. The CC1000PP receivers need to be close to their respective antennas, but the rest of the electronic components will be placed a distance of 20 cm away to reduce the effects of RF interference. A sketch of the antennas is shown in figure 5.2. The wires connecting the CC1000PP modules to the other electronic components have been left out of the figure for simplicity.

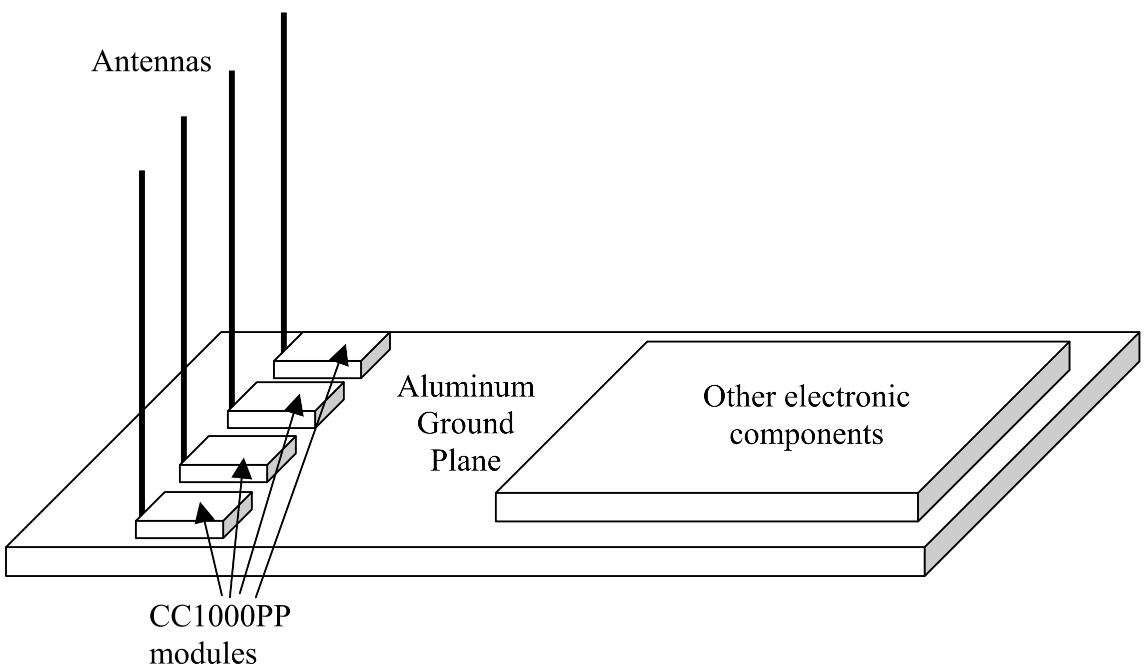
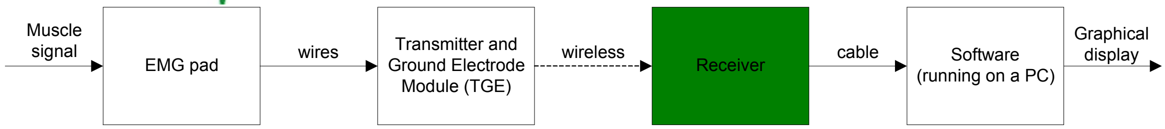


Figure 5.2 – Antennas and Ground Plane



5.2 Receivers

To ensure compatibility between the Receiver Station and the TGE's, CC1000PP transceiver modules will be used as receivers in the Receiver Station as well as transmitters in the TGE. The benefits of the CC1000PP, including high baud rate, ISM band compatibility, and a lack of external components, have already been discussed in section 4.2. The CC1000PP's are software programmable to switch between transmit and receive mode.

The CC1000PP also has an analog output called RSSI, which is the received signal strength indicator. These will be used by the PC software to warn the user when certain TGE modules are out of range.

5.3 Microcontrollers and Output Buffers

Each microcontroller in the Receiver Station needs an SPI and USART to communicate with its CC1000PP receiver, an A/D converter to monitor the received signal strength from the CC1000PP, and 25 other I/O pins to output the EMG sample in parallel. We chose to use Microchip PIC16C774 microcontrollers, which are identical to the PIC16C773's used in the TGE but in a 40-pin package rather than 28-pin. The extra 12 pins are all I/O's. These offer a major advantage in terms of programming, since any code written for the TGE microcontrollers can be easily adapted to run on the Receiver Station controllers.

Figure 5.3 is a flow chart of the microcontroller's program flow.

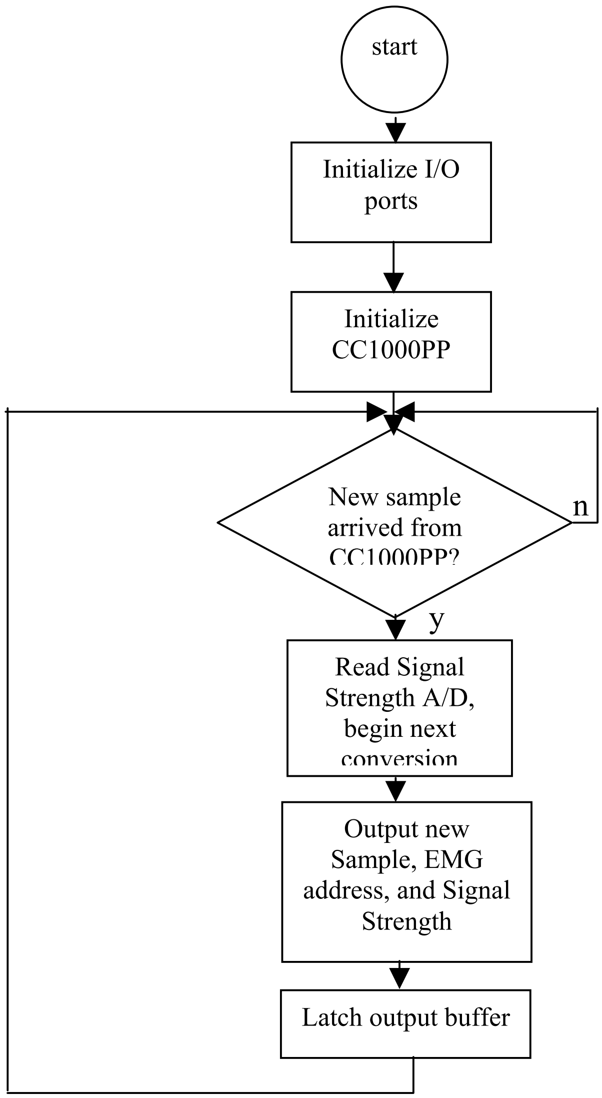
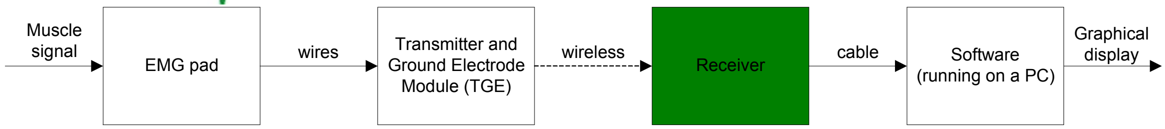


Figure 5.3 – Microcontroller Program Flow Chart

In addition to the flow chart shown above, one of the four microcontrollers plays the role of MUX master, which will be discussed in section 5.4.



The checksum will not be processed by microcontroller itself. Rather, the PC software will check data samples for errors as discussed in section 6.

Data samples from two EMG pads will arrive at each microcontroller in an alternating fashion. Each sample contains the address of the EMG pad from which the sample originated.

Figure 5.4 shows the format of the 24-bit word that is output by each PIC16C774.

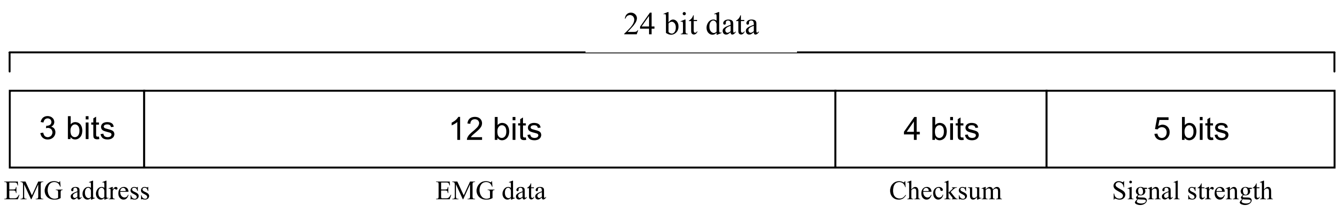
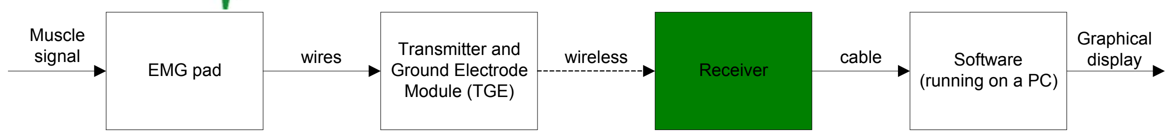


Figure 5.4 – 24 bit output word

Because each output word is 24 bits wide, three of the microcontroller's ports are required to output the word. A 24 bit wide output buffer is connected to these ports, and is latched by the microcontroller after it has written to all three ports. This ensures that the PC will never read an output word that has only been partially written.

5.4 MUX and Sample Timing

The DAQ card has only 24 input pins. Thus, the four 24-bit words coming from the four microcontrollers must be multiplexed onto a single 24-bit bus. This function is performed by a 24x4→24 MUX. The MUX is controlled by one of the four microcontrollers, called the MUX master. In addition to the program described in section 5.3, the MUX master will run a second process, which is shown in figure 5.5. This MUX master process will be interrupt driven and very short so that it will not interfere with the microcontroller's other duties.



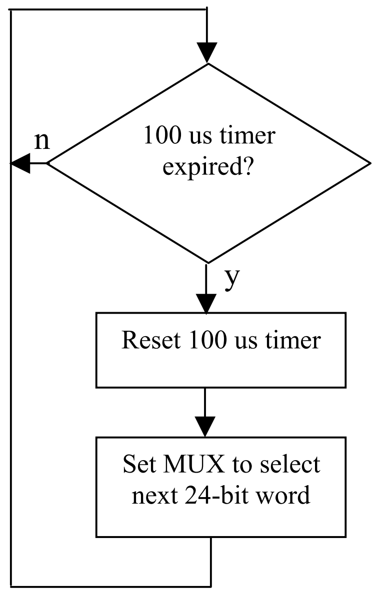


Figure 5.5 – MUX master flowchart

Each microcontroller is outputting a new 24-bit word at a rate of 2 KHz. The MUX is switching at a rate of 10 KHz, to ensure that it will select every sample to be output at least once. The PC software will read the output of the MUX at a rate of 12 KHz, ensuring that the PC will record every sample at least once. This over-sampling scheme means that frequently the PC will read a given sample twice. It will be up to the PC software to detect when this has happened and throw out those duplicate samples. An example timing diagram of the over-sampling is shown below in figure 5.6.

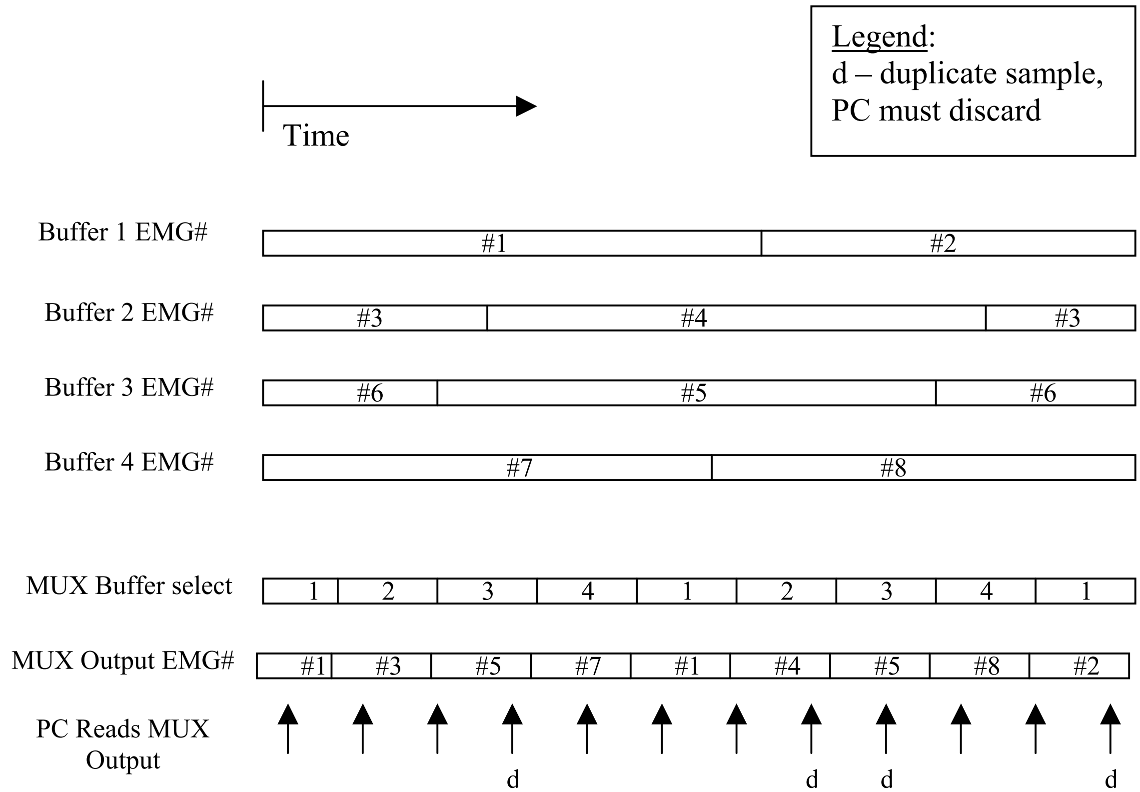


Figure 5.6 – Over-sampling Timing Diagram

5.5 Power Supply

The CC1000PP must be operated with a supply voltage between 2.5 and 3.3 Volts. We have chosen to run it at an intermediate supply voltage of 3V. In order that the digital logic in the microcontrollers and other electronic components is compatible, all the electronics in the Receiver Station will be run from a 3V supply.

The DAQ card supplies a 5V power pin directly from the PC. This will be reduced by means of a voltage divider to 3V. Because the power restrictions on the Receiver Station are much less strict than on the TGE, we will use a simple two-resistor voltage divider.

The total current consumption by all components on the Receiver Station will be approximately 100 mA. Even with the power wasted by the voltage divider, the total power consumed by the Receiver Station will be negligible compared with the power consumed by a desktop or even laptop PC.

5.6 Connections

The interconnections between the PIC16C774's and the CC1000PP's will be identical to those described in Section 4.6, except that the received signal strength indicator pin (RSSI) on the CC1000PP will be connected to an analog input pin (AN0) on the PIC16C774. Figure 5.7 illustrates how the microcontrollers will be connected to the output buffers and MUX.

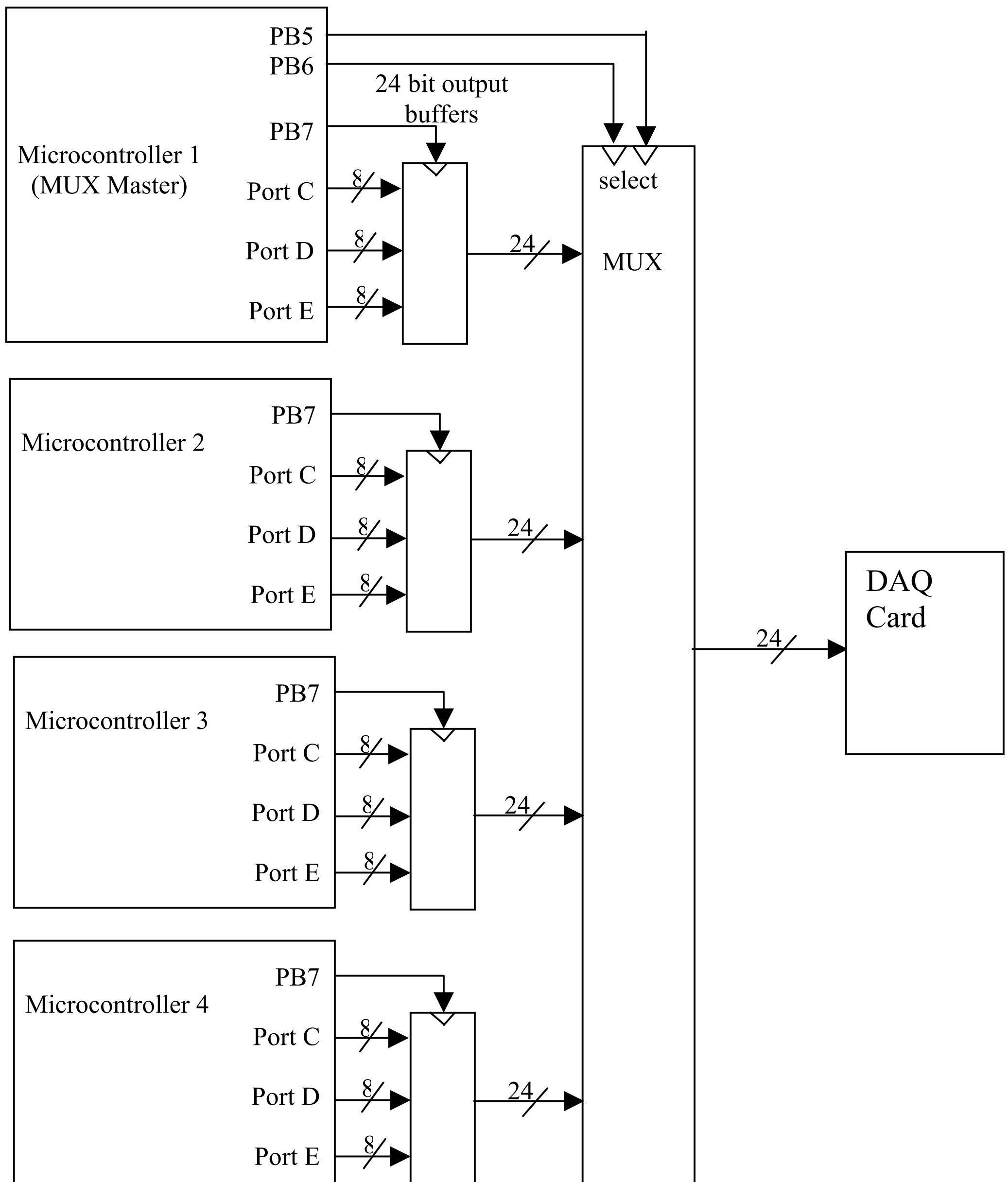
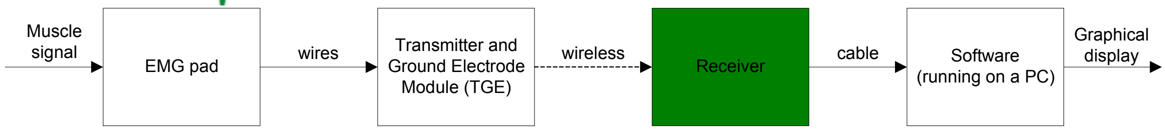


Figure 5.7 – Receiver Station Interconnections



5.7 Receiver Station Packaging

All components on the Receiver Station will be mounted on vector boards for ease of prototyping. As mentioned in section 5.1, an aluminum ground plate that is required by the antennas will be placed below these vector boards. All the electronic components, other than the CC1000PP modules, will be surrounded by grounded aluminum foil to act as an RF shield. This will prevent the RF signal from interfering with the base-band electronics.

The entire Receiver Station, including antennas, will be placed in a plastic box to prevent damage from the outside world. The box will be approximately 10 cm high by 20 cm wide by 30 cm long. The only opening to the box will allow a ribbon to connect the MUX output to the DAQ card in the PC, and to provide power to the Receiver Station.

6 – Software

The main goal of the software will be to save and display the muscle activity data transmitted from the EMG electrodes.

The software section of the wireless EMG system can be divided into four major components.

- Data acquisition (DAQ)
- Processing
- Driver
- User interface.

A simplified block diagram of the software component of the iEMG system is presented in Figure 6.1.

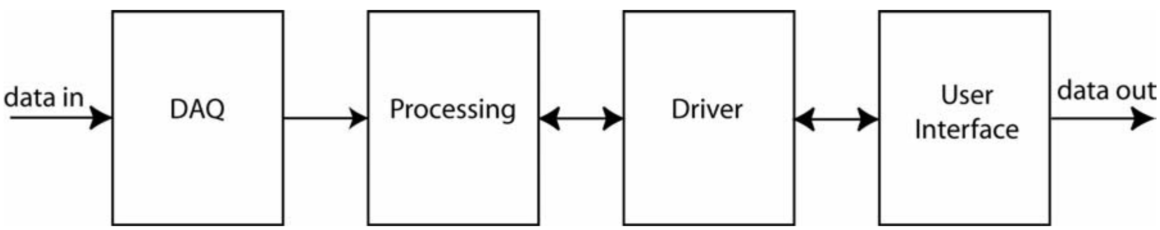


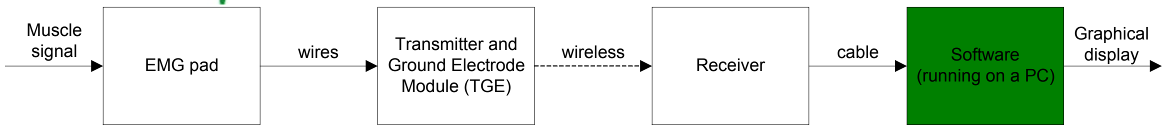
Figure 6.1 – Wireless EMG system software components

The data acquisition block links the software to the external data coming in from the receiver station. The processing block takes the incoming data and conditions it so that the data is suitable for saving or displaying in the user interface. The driver controls communications between the processing block and the user interface. Lastly, the user interface provides the user with a graphical method for recording and displaying data.

The following sections describe the detailed operation of each block in the iEMG system software.

6.1 User Interface

The user interface will allow the user to graphically control the recording and displaying of data received from the EMG electrodes. Figure 6.2 shows a possible layout of the user interface. The actual layout may not be identical to the one presented.



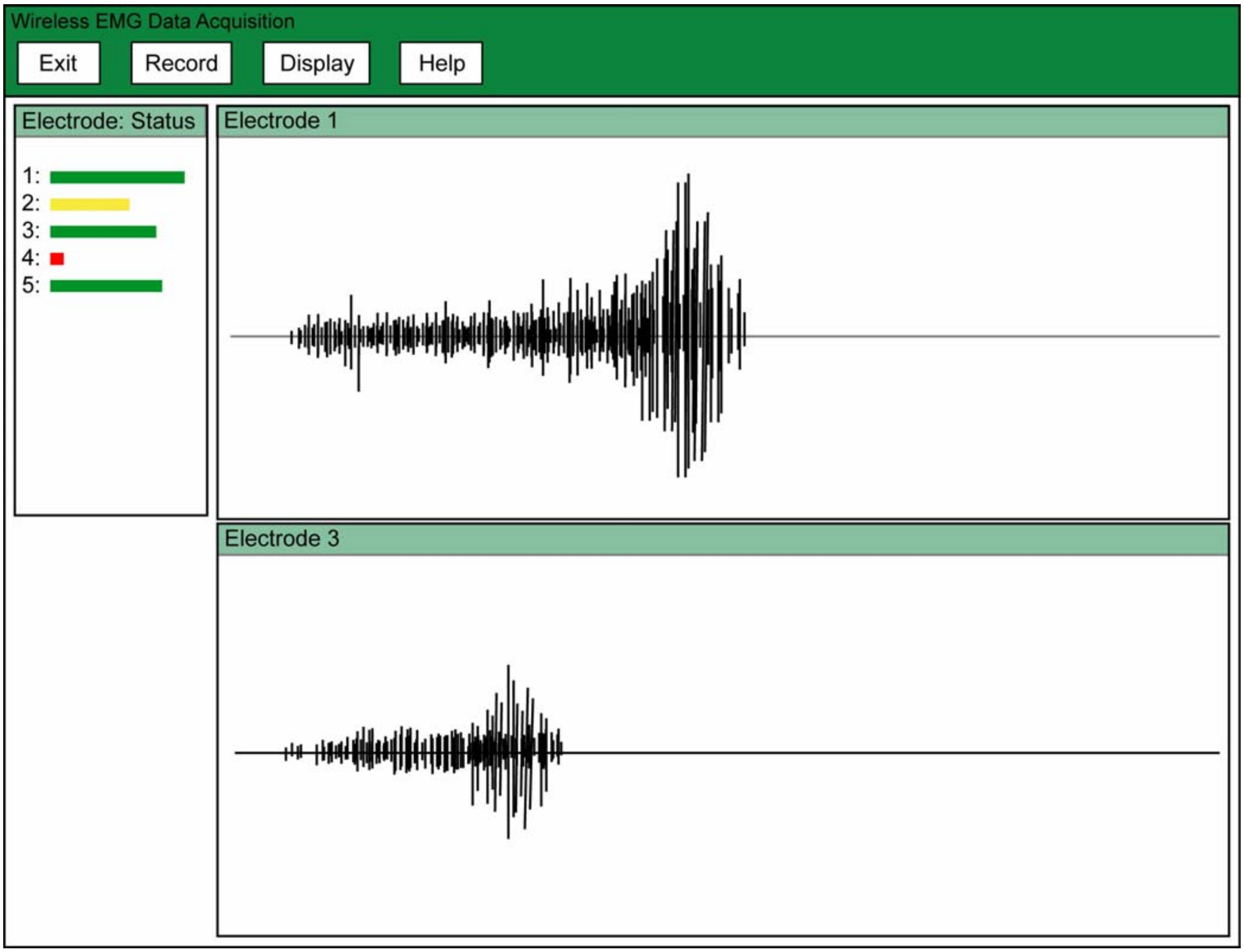


Figure 6.2 – Layout of user interface

The interface will consist of four buttons (exit, record, display and help), one window to display the status of the EMG electrodes, and multiple windows displaying the EMG data.

6.1.1 Exit Button

When the *Exit* button is clicked, the wireless EMG software will close. Any data that is currently being recorded will be stopped, and all future data that is transmitted will be lost. Data that was recorded before the *Exit* button was clicked will still be saved in the appropriate file.

6.1.2 Record Button

The record button will bring up a window that prompts the user to input necessary parameters for recording data. The window will be similar to the one shown in Figure 6.3.

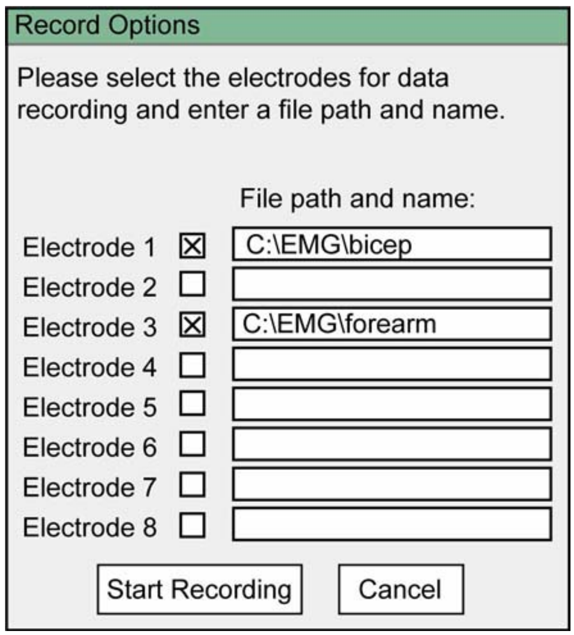


Figure 6.3 – Record button dialogue window

As seen in Figure 6.3, the user will be able to select which electrodes they wish to record data from by checking the appropriate check box. The user will be required to type in the file name and path for where they wish to save the data. The user must specify a different file name for each electrode they are recording data from. At the bottom of this window there will be two buttons labeled *Start Recording* and *Cancel.* When the *Start Recording* button is clicked, data will be written to the appropriate file. Also, the label of the *Record* button will be changed to "Stop." The *Cancel* button will close the window without recording and discarding all changes made within the dialogue window.

6.1.3 Display Button

The display button will open a window presenting options for displaying EMG signals on the screen in real time. The window will be similar to the one shown in Figure 6.4.

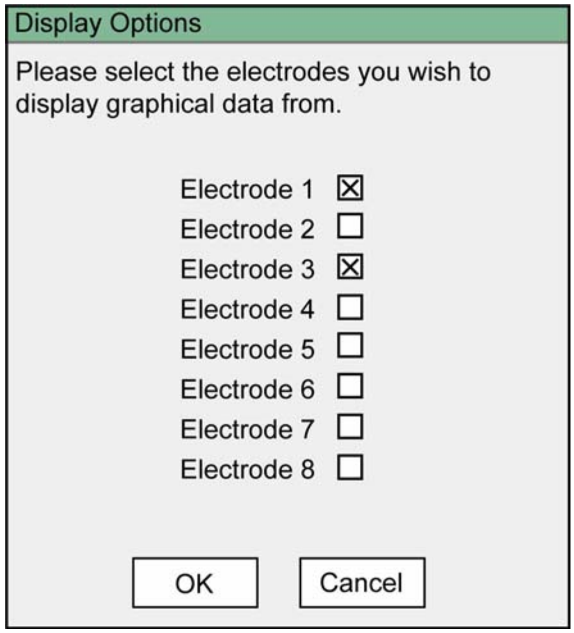


Figure 6.4 – Display button dialogue window

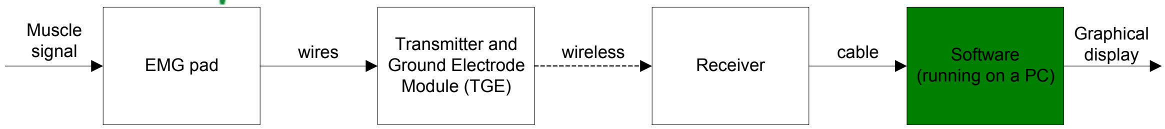
The user will be able to select which EMG electrodes they wish to view on screen by checking the appropriate box. At the bottom of this window, there will be two buttons labeled *OK* and *Cancel.* When the *OK* button is clicked the window will be closed and the software will update the screen with the changes that the user specified. The *Cancel* button will close the window without applying the changes.

With time permitting, an option will be added that will allow the user to re-label the windows displayed on screen from the default labels of “Electrode 1,” “Electrode 2,” etc. to a user defined label.

6.1.4 Help Button

Due to time constraints for the “proof of concept” device, the help menu may not be implemented. However, the design will still be outlined here.

When the help button is clicked a window will be opened that will offer the user two options: system tour, and troubleshooting. The system tour option will give the user an overview of what the system is capable of, the functions of the various components of the user interface and how to operate the software. The troubleshooting option will display a chart outlining problems that may occur, their possible causes, and the possible fixes.



6.1.5 Electrode Status Window

The electrode status window will list the electrodes detected by the system. A graphical meter representing signal strength will indicate the status of each electrode in real time. This will make it much easier for the user to determine the quality of the incoming data.

6.1.6 EMG Electrode Graphical Display Windows

These windows will display the graphical representation of the incoming muscle activity data from each EMG electrode. The number of windows displayed on the screen is determined by the user (see section *6.1.3 Display Button*).

It should be pointed out that a lack of PC processing power might limit the ability of the GUI to display all 8 channels at 1000 samples per second in real time. Limiting the number of windows or reducing the displayed sample rate may solve this problem. Also, data displayed to the screen will not utilize the checksum provided to find data errors. Note that such changes would apply only to the display and not the recorded data.

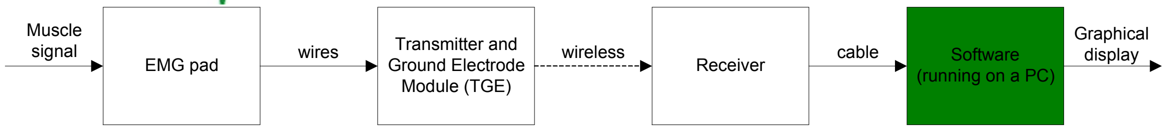
6.2 Driver

The driver is the link between the graphical user interface and the processing block. It interprets the user input and implements the appropriate actions in the processing block. Each button click is linked to a function call within the driver software. We decided to implement the driver to free the UI so that it can continue interaction with the user.

The driver also limits the graphical processing load on the UI by controlling the plotting of the incoming data. It must determine which data point is next to plot, form a line (via linear interpolation) between this point and the previous data point and pass this line to the UI when it is requested.

6.3 Processing

The processing block reads the incoming data from the DAQ and sorts it according to which EMG electrode the data was received from. The processing block can be broken down into two sub-sections: data conditioning and data recording. Figure 6.5 presents a block diagram of the processing block.



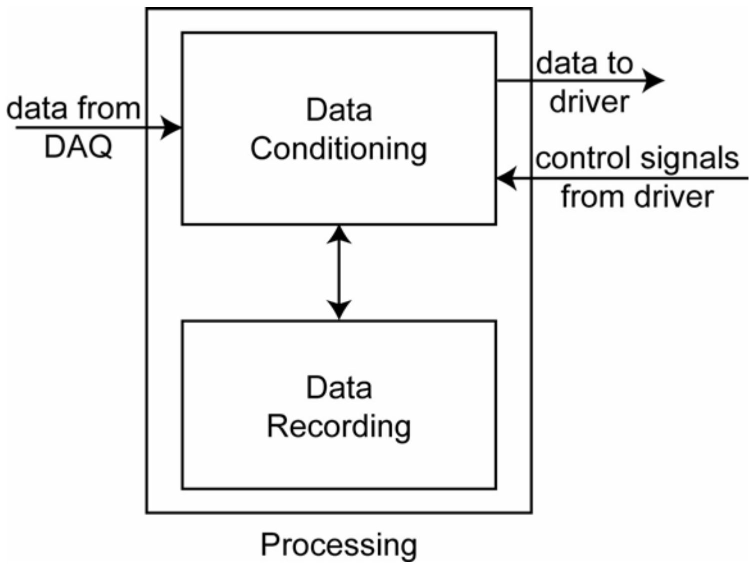


Figure 6.5 - Processing section block diagram

6.3.1 Data Conditioning

The data-conditioning block (DCB) performs several critical functions. First, it collects data from the DAQ block without losing any samples. It then stores the data according to its originating electrode. Next, the data is checked to ensure that no repeated samples were collected. Lastly, when the recording is completed, the data conditioning must check for errors and correct any erroneous samples. The following sections details the functions performed by the DCB.

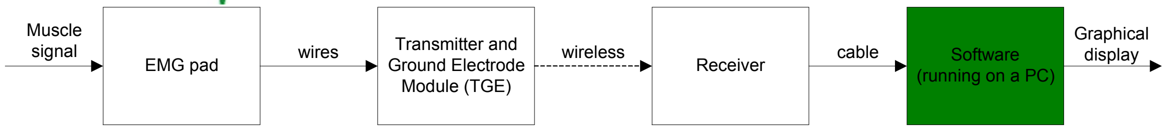
6.3.1.1 Reading Input Data

The DCB will read the 24 bit data stored in the registers associated with Port A, B and C of the DAQ and store this value in RAM. Since, the Receiver Station passes the data to the DAQ at a rate of 10kHz, the DCB will sample the registers at 12kHz to ensure that no samples are lost. The raw sampled data will then be stored as an array.

6.3.1.2 Sorting Data

As shown in figure 5.4, the upper 3 bits represent the originating electrode and the following 12 bits correspond to the muscle activity data. For graphical display and recording purposes, the data must be sorted according to originating electrode. The DCB will examine the first three bits of the data to determine the originating electrode. Then the DCB will store the 12 bit in the memory location associated with that electrode.

Since the data is sampled at 12kHz, we will be over-sampling the incoming data. The DCB will compare the latest data value for each electrode with the previous data value. If the values are the same then the DCB will discard that sample. Since there are 8



electrodes that are all multiplexed onto the single 24bit input, we can guarantee that two subsequent values must be different to be valid. This is because it is impossible for two subsequent samples to come from the same electrode. Therefore, there must be a change in the upper 3 bits of the 24bit data for any two subsequent samples.

6.3.1.3 Error Checking

To ensure that no erroneous samples are stored, a checksum is implemented in the transmitted data. Because of limited processing power, we will not be performing any error checking in real-time. Therefore, data displayed to the screen may contain errors. However, since the error rate will be small, they will not be noticed when displayed in real-time. When the *Stop* button is pressed, the DCB will access the saved data for each channel and process the checksum. Any sample that is not correct will be replaced by the average of its surrounding samples. We could utilize more complex interpolation methods but the accuracy gained is not worth the added processing time.

6.3.2 Data Recording

The data-recording block (DRB) is responsible for saving user selected muscle activity data. When the record button is clicked in the user interface, the parameters are sent through the driver to the DRB, which then creates the specified files. The DRB copies the data from the memory location that corresponds with the right electrode and saves it in a text file. Each new data sample will be saved on a new line in the text file.

6.4 Data Acquisition (DAQ)

The data acquisition block is a PCI digital I/O card (PCI-DIO24) purchased from Omega. This card consists of a 82C55 digital I/O chip which controls 24 bi-directional CMOS digital TTL lines. The 24 digital I/O lines are divided into three eight-bit ports. The I/O card supports interrupt handling.

The card allows us to acquire digital data and store these values to internal PC registers. The rest of the subsequent blocks can then access the data as described in this section.

The I/O card will connect to the receiver station via a 37-pin D type connector. The connector diagram is shown in Figure 6.6.

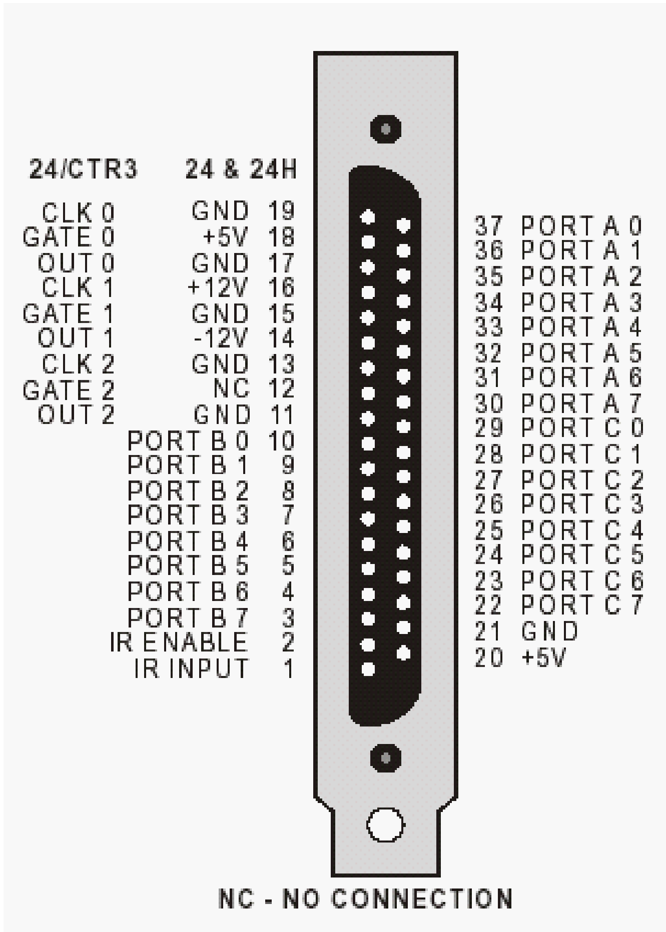


Figure 6.6 – Connector diagram for I/O card

7 – Test Plan

7.1 – EMG Pad

The EMG Pad will be tested by attaching it to a proven EMG system located in the Biomechanics Laboratory at Simon Fraser University. The output of the EMG will then be observed in several practical situations to see if it is reasonable.

7.2 – TGE and Receiver Station Hardware

Components and connections will be checked before any power is supplied. IC pin connections will be verified and component values and connections will be verified to match schematics.

Power supply will be ensured to provide the required DC voltage at each designated node.

7.3 – EMG Signal Transmission

The main concern with transmitting EMG data wirelessly is interference between different channels. Tests will be implemented to determine range and signal fidelity in various situations and environments.

A known signal, such as a sine wave, will be inputted to the TGE module for signal transmission. The Receiver Station output will be monitored by viewing the results on the PC GUI to verify successful signal transmission.

7.2.1 Signal Range and Fidelity

Different configurations, which include single TGE and multiple TGE use, will be tested in several environments. Table 7.1 gives an example of tests to be implemented. In the following table, the maximum range is determined to be the maximum distance the TGE can be from the Receiver Station before there is a rate of .001errors/sample.

# of TGEs in use	Input Signal	Location	Maximum Range (meters)
1	Sine wave	ENSC Lab	
		Academic Quadrangle	
		Football Field	
2	Sine wave	ENSC Lab	
		Academic Quadrangle	
		Football Field	
4	Sine wave	ENSC Lab	
		Academic Quadrangle	
		Football Field	

Table 7.1 – Example of Different Test configurations

7.2.2 Component Stage Verification

The TGE and Receiver Station prototypes will be built so that critical stages in the TGE Module and Receiver Station can be easily probed to verify proper functionality. Critical stages could include the I/O pins of the PIC16C773 and CC1000PP. The RSSI pin on the CC1000PP will be monitored to test the range of the TGE modules. The RSSI(Received Signal Strength Indication) pin outputs a voltage relative to the electromagnetic field strength of the received signal.

7.4 – Software

There are several major cases that must be tested to ensure that the software is operating correctly.

7.4.1 DAQ

The DAQ comes with test software. The *Internal Test* command will test if the card is installed correctly and the *External Test* command will test the input/output pins.

7.4.2 Processing Block

To test the sorting function, we will setup a PIC microcontroller to output a known bit pattern. This pattern will assign a set value of data, signal strength and checksum to each electrode address. We will then look at the generated files to see if they are correct.

To test the error correction, we repeat the test above and ensure the checksum field in incorrect based on the test data. We expect to see all the files be an empty set.

7.4.3 Driver and User Interface

Since the driver and user interface are essentially the same system, they will be tested together. At this point it is assumed that all the other software components are functioning correctly.

We will test the real-time display by using a PIC to simulate a sinusoidal function with the appropriate address and checksum values. We will then view this output in real-time. The frequency of the sinusoid will be changed to test the bound of correct operation. We will also simulate different signal strengths by changing this field in the 24-bit field and observing the effect on the screen.

Each button will be tested qualitatively to ensure correct action in a wide variety of expected and unexpected situations. We will ask people not associated with the project to use the software to find bugs associated with unexpected usage.

8 – Conclusion

This document contains the design specifications for the prototype version of a complete wireless EMG system, called the iEMG. The prototype is specified to prove the concept of wirelessly acquiring muscle activity data in an efficient and convenient way without jeopardizing the quality of data. The prototype will meet these requirements by December 2002.

9 – References

[1] Dr. Andrew Rawicz, School of Engineering Science, Simon Fraser University

[2] AD620 Product Specification (www.analog.com/products/ad620)

[3] PCI-DIO24 Product Specification (www.omega.com)

[4] PIC16C733 Product Specification (www.microchip.com)

[5] CC1000PP Product Specification (www.chipcon.com)

[6] DelSys Inc. Electromyography (www.delsys.com)

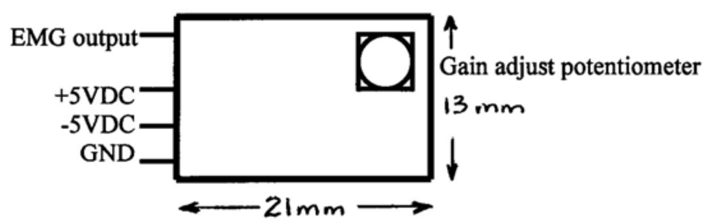
[7] KinMyo Electromyography (www.kine.is)

Appendix A – Specification for EMG Pads

Electrode Notes and Specifications

Specifications	Units	Min	Nom	Max
Maximum Gain (CCW to increase gain)	V/V	1800	2000	2200
Minimum Gain (CW to decrease gain)	V/V	22	24	26
Upper cutoff frequency	Hz	450	500	550
Lower cutoff frequency	Hz	25	30	35
Maximum output before clipping (peak-peak)	V	5.0	5.5	6.0
Noise at maximum gain (peak-peak)	mV	n/a	10	20
Operating temperature	°C	0	25	50
Storage temperature	°C	-25	25	75
Operating current	mA	5	10	20
Supply voltage (bipolar)	V	4.9	5.0	5.1
Supply voltage noise (peak-peak)	mV	n/a	1	5
Impedance from subject to supply ground	ohm	0	n/a	100
Mechanical shock (6 axis)	g	n/a	n/a	30
Input impedance	ohm	-10%	10^{10}	+10%

Pinout



Cable color code

white = EMG output
red = +5VDC
black = -5VDC
green = ground

Usage Notes

- Don't forget to ground subject!!
- Use electrolyte gel sparingly -- high input impedance and stainless contacts reduce effect of skin impedance
- Cable connector is physically polarized and will only engage in correct orientation -- do not force if insertion is difficult
- Clean using only mild detergent or mild solvents (eg: propanol or methanol) -- do not immerse, wipe with a soaked swab or cloth
- Avoid getting liquids or particulate contaminants on top surface (particularly gain adjustment potentiometer), rinse with alcohol and allow to dry in upside-down position
- Use adhesive tape to affix electrode to skin -- do not mechanically clamp