WIRELESS ELECTROMYOGRAPH RECORDER

By

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical & Electronic Engineering Department
Universiti Teknologi PETRONAS
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Bachelor of Engineering (Hons)
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Approved by,

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Project Supervisor

Universiti Teknologi PETRONAS
Tronoh, Perak

September 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein has not been undertaken or performed by unspecified sources or persons.

WAN NUR SYAZWANI BT WAN ZIN

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Nevertheless, my great appreciation is dedicated to all my friends and those who are involved directly or indirectly with this project. Thank you.

ABSTRACT

Muscles generate low voltages which are around 100 mV when they contract. These voltages are weakened by internal tissues and the skin. Even though the voltages are weak but they can be measurable at the surface of the skin. Electromyography (EMG) recorder is used to measure a muscle electrical activity that occurs during muscle contraction and relaxation cycles. In medical applications, people mostly used a wired EMG recorder. However, the advanced technology had allowed wireless collection and recording of muscle electrical activities using an EMG recorder. Thus this report is going to discuss in depth about a wireless EMG recorder. This project background study will include problem statements to justify the need of this project, objectives, scope and limitation of the project as well as project feasibility. Literature reviews will also cover aspects like EMG signal, conventional EMG recorder, and types of wireless network that can be used. In the methodology part, the proposed design, tool and equipment will be discussed further. Result and discussion will explain about the output obtained from the project. This report will be wrapped up with a conclusion.

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CHAPTER 1: PROJECT BACKGROUND

1.1 Background Study

Since Emil du Bois-Reymond [1] discovered the nerve potential and electrical properties of biological cells and tissues, electromyography system has evolved rapidly for THE past hundreds of years. It started from analog EMG system, digital EMG system, microprocessor-controlled EMG system, PC-based EMG system and the most recent one are handheld and wireless EMG system such as the ZeroWire system [2] that was manufactured by Aurion shown in Figure 1.

Figure 1: ZeroWire system

Recent developments in all fields of electronic technologies have pushed EMG equipment into the present state. Wireless technologies such as Wi-Fi and Bluetooth have also been incorporated into today's existing EMG equipment to provide the user with extended mobility. Acquired EMG signals can now be picked up on the body and sent wirelessly to the personal computer (PC) where it is recorded, processed and analyzed. These features give many advantages to the users especially the patient, doctors, physician and others.

1.2 Problem Statement

Conventional electromyography equipment has few disadvantages which are:

1) The sensor electrodes are wired to the associated amplifier and display equipment which cause the users to suffer from the inconvenience of carrying many cabled electrodes [3].
2) Wire cables are subject to triboelectric phenomena whereby small electrode potentials are caused by physical movement of the signal carrying electrical cable [4]. Thus, the signal recorded could be not so accurate.
3) Besides, patient leakage current which is defined as the current flowing from a part applied to a patient to ground that originates from the accidental emergence of voltage from an external source on the patient may occur when using 240V DC equipment [5].

1.3 Objectives

The main objective of this project is to build a wireless EMG recorder. Other objectives are:

1) To apply the wireless module for signal transmission
2) To perform analysis on the EMG signals
3) To explore the function of MATLAB in recording and processing signals

1.4 Scope of Project

The scope of this project consists of research, prototype construction, testing, analysis and improvements. The research is important for better understanding on the theory and concept of a wireless electromyography recorder. After that, the concept will be applied to design and build the prototype. Then, testing must be done to the prototype in order to make sure it is working well. Furthermore, analysis of the result and improvements are included in the scope of this project.

CHAPTER 2: LITERATURE REVIEW

2.1 EMG Signals

EMG signals are basically made up of superimposed motor unit action potentials (MUAPs) from several motor units. For an in-depth analysis, the measured EMG signals can be decomposed into their constituent MUAPs. MUAPs from different motor units would show different characteristic shapes, while MUAPs recorded from the same motor unit are typically alike. The shapes of the MUAPs are important in conveying information about the characteristics and arrangement of the muscle fibers. Figure 2 shows three time domain signals namely the EMG signal which is made up of individual motor neuron action potentials, a rectified signal which looks similar to the EMG signal but all values are positive, and a signal representing the cumulative sum of the rectified signal reset to every 50 samples.

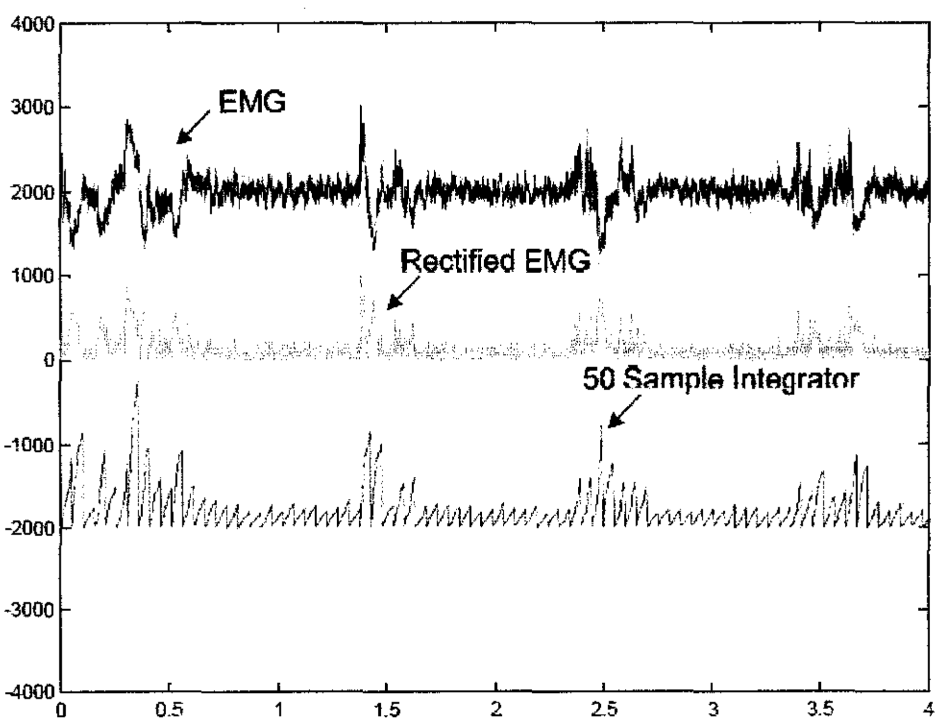


Figure 2: Three time domain EMG signals

2.2 Conventional EMG Recorder

Basic operation of a conventional EMG recorder starts when the EMG signal generated by the muscle fibers is captured by the electrodes, then amplified and filtered before being converted to a digital signal by the encoder. It is then sent to the computer to be processed, displayed and recorded by plotter software [7]. Figure 3 shows the operation flow of conventional EMG recorder.

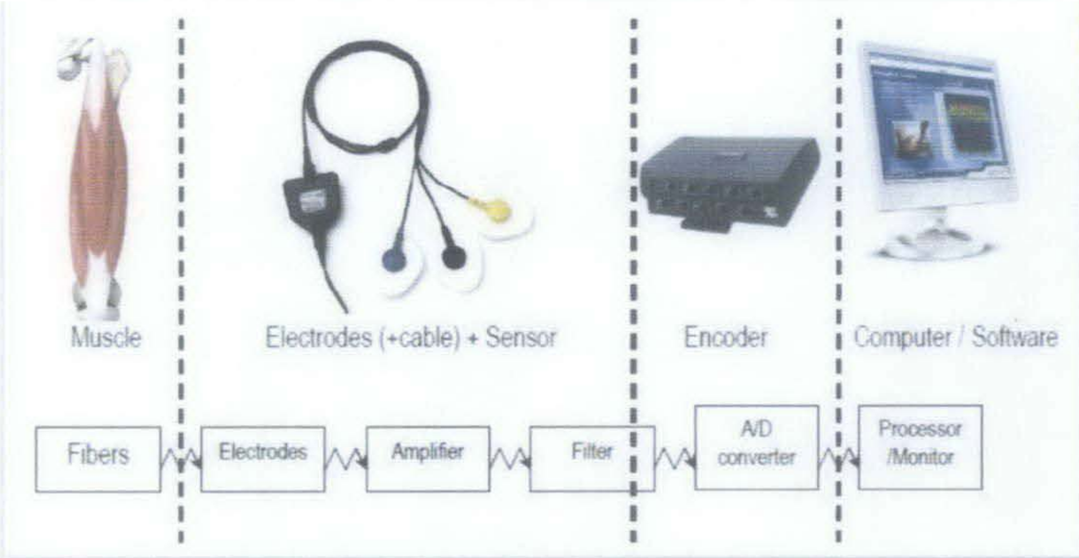


Figure 3: Operation flow of conventional EMG recorder

2.2.1 Electrodes

Usually, Ag-AgCl electrodes are used in over 80% of surface EMG applications. Figure 4 shows typical Ag/AgCl electrodes.

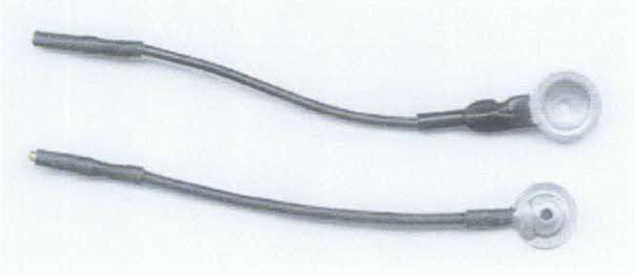


Figure 4: Typical Ag/AgCl Electrodes

Silver - silver-chloride (Ag- AgCl) is the most common composite for the metallic part of gelled electrodes. The AgCl layer allows current from the muscle to pass more freely across the junction between the electrolyte and the electrode. This introduces less electrical noise into the measurement, as compared with equivalent metallic electrodes. [8]. An EMG signal is collected by using a surface EMG electrode placed on the skin of the muscle of interest. Figure 4 shows the placement of two EMG electrodes on the biceps and one for the reference. Reference electrode is placed on the wrist, which is the bony area of hand. This wrist is chosen because fewer muscles contained at this area will not generate EMG signal. Before placing the electrode, the subject skin is cleaned to reduce the resistance of the outer layer of the skin and ensure a good electrical contact. The distance between the two electrodes is 2 to 5 cm apart and aligned with the long axis marked on the skin overlaying the belly of the biceps muscle [9].

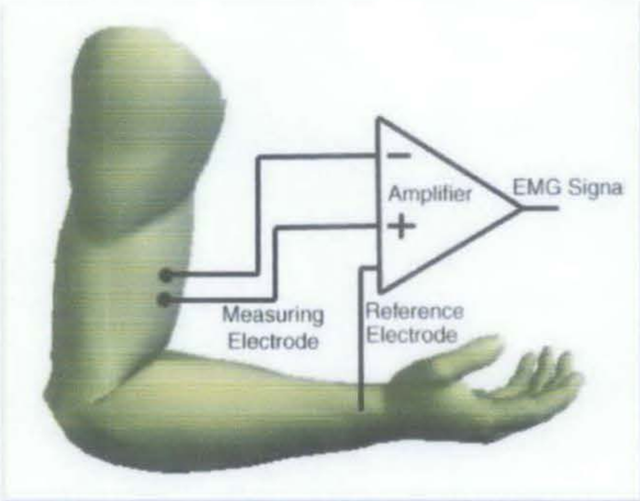


Figure 5: The placement of two EMG electrodes

2.2.2 ***Amplifier***

An amplifier is also necessary to optimize the resolution of the recording or digitizing equipment [10]. Amplifiers of high quality have adjustable gains of between, at least, 100 and 10 000 to maximize the signal to noise ratio of the EMG signal during each recording. This range of gains provides the sufficient range of amplifications for surface EMG signals which can range typically from 0 to 6mV peak to peak.

While there may be several stages of amplification, the most important stage is often described as pre-amplification. Pre-amplification implies the first stage of amplification, close to the signal source. There are several important properties to consider in a pre-amplifier:

- High common mode rejection ratio
- Very high input impedance
- Short distance to the signal source
- Strong DC signal suppression

2.2.3 *Filter*

Basically, there are three types of filters applied to EMG data: high-pass, low-pass, and notch filters [11]. A low-pass filter is used in order to allow signal frequencies below the low cut-off frequency to pass and stops frequencies above the cut-off frequency. This type of filter is commonly used to help reduce environmental noise and provide a smoother signal. For a high-pass filter, it allows frequencies higher than the cut-off frequency to pass and removes any steady direct current (DC) component or slow fluctuations from the signal [12]. A notch filter removes a particular frequency from a signal and has a frequency response that falls to zero over a narrow range of frequencies (i.e. a 50 Hz notch may block signals from 49.5 – 50.5 Hz).

2.2.4 *Analog-to-Digital converter*

The digitization process of an analog signal is performed by a device known as an Analog-to-Digital Converter (ADC) [13]. The following ADC characteristics should be considered:

- ADC Range Setting
- Gain Setting
- Minimum Resolution

2.2.5 Processor/monitor

At the processor of the computer, the EMG signal will be recorded by using certain software and the signal graph will be displayed on the monitor. After the recording, the signal characteristics will be processed for further analysis.

2.3 Wireless Network

Wireless networks based technologies has facilitated biomedical researches for several decades and has been applied to convey bioelectric potentials like electrocardiograms (ECG), electromyograms (EMG), or electroencephalograms (EEG) [14]. Some benefits of using wireless networks based technologies in include:

- Non-invasive monitoring
- Cost saving and efficient method of care
- Ease of communication between care givers and patients

2.3.1 Types of wireless network in medical applications

There are various types of wireless network that are being applied in medical applications such as in [15]:

1) WBAN (Wireless Body Area Network)

These Body Area Networks (BANS) have extremely low power requirements which make them fit for integrating them in day to day wearables. In the medical application field, these unobtrusive devices can be attached to patient's bodies to collect vital health information such as ECG, blood pressures, etc. When used inside hospitals, BANs can be used to monitor patients in critical conditions. Outside the hospital, i.e., homecare, patients' vital signs can be collected and transmitted over the Internet to their doctors and nurses in real time.

2) RFID (Radio Frequency Identification)

RFID tags are used in hospitals to keep track of equipment. They can also be planted on patients as well as doctors to know at time where they are. RFIDs are extremely low powered radio devices that do not need any battery power.

3) WPAN (Wireless Personal Area Network)

WPANS using 802.15.4 or Bluetooth have potential uses in the medical fields. These are short range networks that can be deployed for example, within a patient's room. Nurses are able to monitor patients in real time without having to visit them frequently. These saves them time and give them the opportunity to take care of more patients. Bluetooth is also a good technology for short range communication.

4) Sensor Networks

Sensor Networks technologies such as Zigbee are being combined with WBANs to form smaller scale networks that can be placed on human clothing (or other objects) and provide unobtrusive access to their health information. Due to lower power requirements, they can be deployed for a long period of time. Due to limited range and low price, sensor networks also are deployed in large numbers and thus form a distributed network covering a large portion of space.

5) GPRS/UMTS

GPRS and UMTS wireless technologies have also found their uses in the area of medical applications. An application called MobiHealth, had been designed by using BANs with GPRS/UMTS for Internet connectivity.

6) Wireless LAN (802.11)

Most hospitals, universities and corporate offices these days provide wireless LAN access. Some benefits include untethered access to the Internet. Hospitals can use the wireless LAN channels to transfer patient data around the hospital. Communication between medical devices is also made possible using this wireless channel.

2.3.2 Wireless network standards

Although the area of wireless networks for medical applications is largely without standards due to companies developing products based on their own standards, some standards do exist as listed below. Recently there are increasing demands for creating strict standards, especially for pacemakers, which are being used by a large number of heart patients across America [15].

- IEEE Standards Medical Device Communications/Health Informatics Standards Subscription
- ISO/IEEE Health informatics - Point-of-care medical device communication
- IEEE Standard for Medical Device Communications-Transport Profile
- Mobile Health Care Alliance
- Setting standards for mobile health information systems
- Medical Implant Communications Service in the 402-405 MHz band
- High-speed, ultra-low power, non-voice transmissions to and from implanted medical devices such as cardiac pacemakers and defibrillators.

2.3.3 Comparison of the ways to create wireless communication

There are plenty of other options to create wireless communication or even small networks of devices and applications [16]. Here is the comparison of some of the ways to create wireless communication between two or more devices:

i) XBee

Advantages: No collision of messages; very specific addressing of messages; can be extremely long range, fast.

Disadvantages: Slightly expensive; sometimes difficult to configure.

ii) Wireless Internet

Advantages: No collisions of messages; very specific addressing of messages; allows sending many different kinds of data; fast.
Disadvantages: Expensive; difficult to configure communication between another

computer and a wireless card; depending on the network and router; limited to range of wireless network.

iii) Cellphone

Advantages: Range unlimited; no collisions of messages; very specific addressing of messages.

Disadvantages: Requires either a SIM card with an account or prepaid credits; difficult to configure with the Arduino; can be relatively slow; expensive; high power requirements.

iv) Bluetooth

Advantages: Allows large amounts of data; comparatively fast; does not require much power.

Disadvantages: Difficult to configure; expensive.

v) Radio

Advantages: Cheap; easy to configure; requires little power.

Disadvantages: Cannot have more than one transmitter in an area; no addressing of messages; range limited; comparatively slow.

CHAPTER 3: METHODOLOGY

3.1 System overview

Two surface EMG electrodes which are placed on the muscle tissue on the body will send the signal to the amplifier circuit. After the signal is amplified, it will go through a filter circuit in order to remove noise. The signal is then digitized using an Analog-to-Digital Converter (ADC). A wireless transmitter then transmits the recorded EMG signal to a wireless receiver circuit over wireless medium. At final stage, the data are sent to a personal computer via a USB connection that processes the digitized signal. The structure of the wireless EMG system is shown in Figure 6.

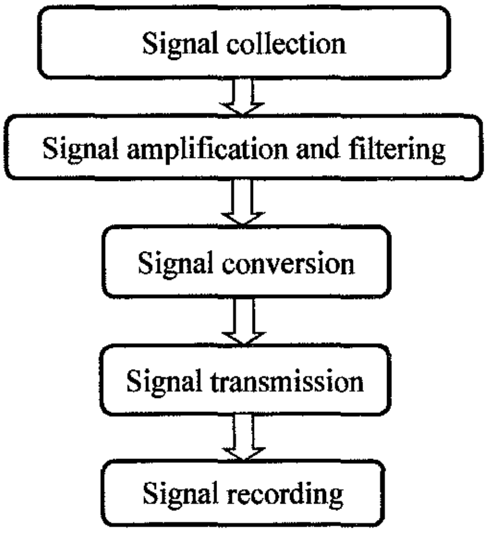


Figure 6: Wireless EMG system

3.2 Tools and Equipments

3.2.1 Hardware

1) Surface EMG electrodes

In this project, as shown in Figure 7, MEDI-TRACE™ Series Foam Electrodes will be used since it has a smaller, teardrop shape footprint for convenient lead placement on small or pediatric patients [17]. The low profile foam substrate is fluid and tear resistant. The patented conductive adhesive hydrogel maximizes adhesion and electrical contact.

Figure 7: MEDI -TRACE™ Series Foam Electrodes

2) Amplifier

The acquired EMG signal from the electrode is fed into an amplification stage. In the amplification stage, the acquired EMG signal is amplified by two different amplifiers. A differential amplifier is used with a gain of 110 as the first amplification and an inverting amplifier with a gain of -15 is used for the second amplification. The INA106 (shown in Figure 8) is a differential amplifier which will measure and amplify the very small voltage differences between the two electrodes placed on the muscle.

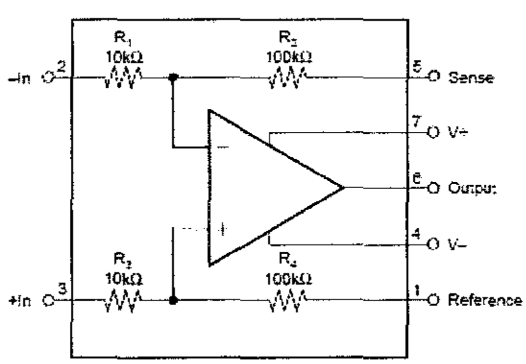
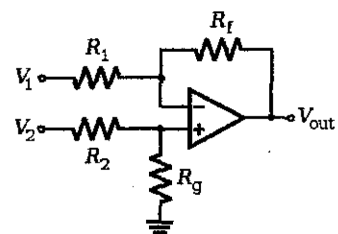


Figure 8: INA106 configuration

To produce gain of 110, a INA106 and 1MΩ resistor is used. The calculation for the gain of the differential amplifier is shown in Equation 1 as below:



$$\begin{aligned} A &= R_f/R_1 = R_g/R_2 \\ &= (100k + 1M)/10k \\ &= 110dB \end{aligned} \tag{1}$$

where $R_f = R_g = 100k + 1M = 1.1M\Omega$, $R_1 = R_2 = 10k\Omega$

The TL072 chip (as shown in Figure 9) is a low noise JFET-input operational amplifier which is be used to build an inverting amplifier, active high pass filter, full wave rectifier and active low pass filter in this system.

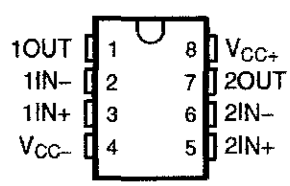
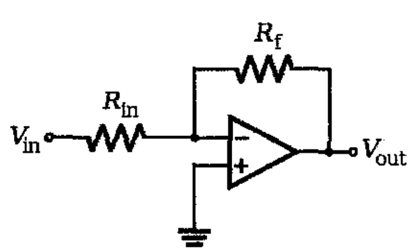


Figure 9: TL072 pin configuration

To produce gain of -15, 150kΩ and 10kΩ resistors are used. The calculation of gain of the inverting amplifier is shown in Equation 2 as below:



$$\begin{aligned} A &= - R_f / R_{in} \\ &= - 150k / 10k \\ &= - 15dB \end{aligned} \tag{2}$$

where $R_f = 150k\Omega$, $R_{in} = 150k\Omega$

3) **Filter and rectifier**

A filter is used to eliminate the noise contained in the signal after the signal is amplified. In this system, an operational amplifier that was included in the TL072 chip is used for building high pass filter, low pass filter and rectifier.

An active high pass filter (as shown in Figure 10) with 106Hz cut off frequency is used to get rid of any DC offset and low frequency noise.

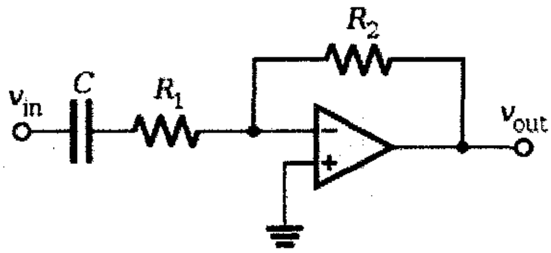


Figure 10: Active high pass filter

To produce 106Hz cut off frequency, two 150kΩ resistors and a 0.01μF capacitor are used. The calculation of the cut off frequency of active high pass filter is shown in Equation 3 as below:

$$f_c = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(150k)(0.01\mu)} = 106\text{Hz} \quad (3)$$

where $R_1 = R_2$ =150kΩ, C = 0.01μF

An active low-pass filter (as shown in Figure 11) is designed to filter out the humps of the signal in order to produce a smooth signal. The cut off frequency for this filter is 1.9Hz.

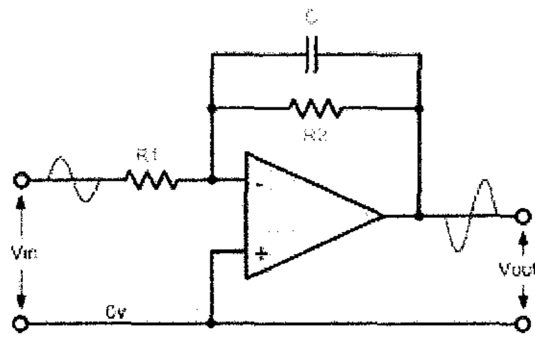


Figure 11: Active low-pass filter

The calculation of the cut off frequency for an active low-pass filter is shown in Equation 4 as below:

$$f_c = \frac{1}{2\pi R_2 C} = \frac{1}{2\pi(82k)(1.0\mu)} = 1.9 \text{ Hz} \quad (4)$$

where $R_1 = R_2 = 82k\Omega$, $C = 1.0\mu F$

The amplified and filtered signal will then be rectified using an active full-wave rectifier [19] as shown in Figure 12. The rectifier will take the negative portion of our signal and turn it positive so the entire signal falls within the positive voltage region.

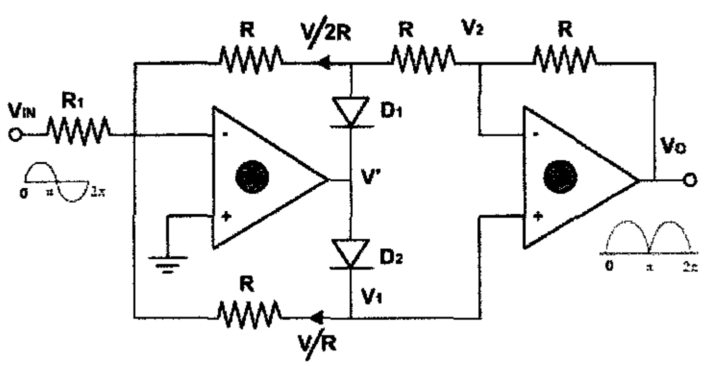


Figure 12: Active full-wave rectifier

When V_{in} is positive then V' = negative, D_1 is ON and D_2 is virtual ground at the input to (1). Because D_2 is non-conducting, and since there is no current in the R which is connected to the non-inverting input to (2), therefore, V_1 =0. Hence, the system consists of two operational amplifiers in cascade with the gain of A_1 equal to $(-R / R_1)$ and the gain of A_2 equal to $(-R / R) = -1$.

The resultant voltage output is $V_o = (R / R_1)\, v_{in} > 0$ (for $v_{in} > 0$ voltage output of (1)).

Consider now next half cycle when V_{in} is negative. The v' is positive D_1 is OFF and D_2 is ON because of the virtually ground at the input to (2) $V_2 = V_1 = V$. Since the input terminals of (2) are at the same (ground) potential, the current coming to the inverting terminal of (1) is as indicated in Figure 12.

The output voltage is $V_o = i\,R + v$ where $i = V / 2R$ (because input impedance of OPAMP is very high). Equation 5 shows the formula used in order to find V value.

$$V = -\frac{2}{3}\frac{R}{R_1}V_{in} \tag{5}$$

The sign of V_o in Equation 6 is again positive because V_{in} is negative in this half cycle. Therefore, outputs during two half cycles are the same; and full wave rectified output voltage is obtained as shown in Figure 12.

$$V_O = \frac{V}{2R} * R + V = \frac{3}{2}V = -\frac{R}{R_1}V_{in} \tag{6}$$

where $R = R_1 = 10k\Omega$, D1 = D2 = 1N4148

Another inverting amplifier circuit with a trimmer configured as a variable resistor is used in order to invert the signal one more time. By using a screw driver and turning the trimmer, gain of the signal can be adjusted to account for different signal strengths from different muscle groups.

4) Analog to Digital Converter (ADC)

The filtered signal is fed into an analog-to-digital converter (ADC) which reads the analog signal and converts it to digital signal. The ADC is used because RF wireless module cannot receive analog data straight away.

5) PIC18F452 controller

The digitized signal is processed by the PIC18F452 controller (shown in Figure 13) through suitable coding and then transmission using RF wireless module. The PIC18F452 Pinout I/O descriptions is shown in Appendix A.

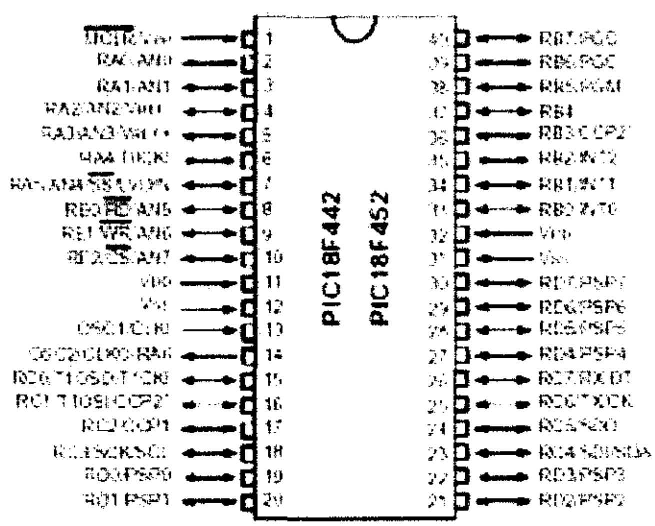


Figure 13: PIC18F452 controller

6) RF wireless module

The output of the PIC18F452 is given as the input to the RF transmitter. The FM-RTFQ2-433R transmitter and FM-RRFQ2-433 receiver circuits are used for transmission of EMG signal as shown in Figure 14 and Figure 15. The frequency range of the RF transmitter and the receiver is 433.92MHz. The transmitter and receiver pair enables the simple implementation of a data link at distances up to 75 metres in-building and 250 metres in open ground. The modulation technique used is frequency modulation (FM). The data rate of the modules could be up to 9.6kbps. The maximum supply voltage for the transmitter is 12V and for the receiver is 5V. The datasheet of these RF modules is shown in Appendix B.

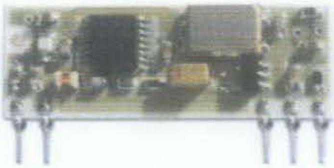


Figure 14: FM-RTFQ2-433R transmitter circuit

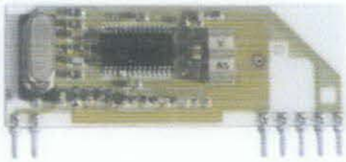


Figure 15: RF receiver circuit

The transmitter module has five pins as shown in Figure 16 below. Starting from left, Pin 1 and Pin 4 go to ground. Pin 5 is the data input from the microcontroller. Pin 3 is the supply voltage, which will commonly be 5 volts. Finally Pin 2 is the optional antenna.

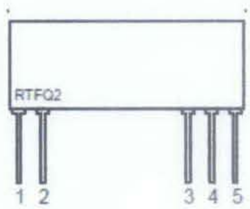


Figure 16: Transmitter pin configuration

The receiver module has 6 pins as shown in Figure 17 below. Pin 2 and Pin 15 go to ground. Pin 1 receives the incoming byte from the transmitter and Pin 18 sends the incoming byte out to the microcontroller. Pin 3 needs no connection, but can be taken to ground. Pin 14 represents Received Signal Strength Output which can be used as an indicator for the received signal strength. Pin 16 goes to supply voltage. Pin 17 goes to the AF output.

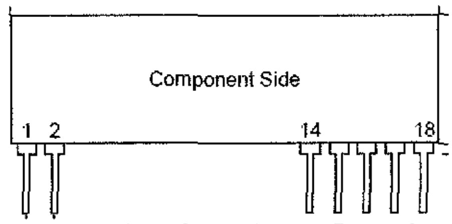


Figure 17: Receiver pin configuration

7) Computer

At the processor of the computer, the EMG signal will be recorded by using MATLAB software and the signal graph will be displayed on the monitor. After the recording, the signal characteristics will be processed for further application.

*3.2.2 **Software***

1) MATLAB Software

MATLAB® is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. MATLAB can be used in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology [20]. The collections of special-purpose MATLAB functions which are known as add-on toolboxes extend the MATLAB environment to solve particular classes of problems in these application areas.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Amplifier, Filter and Rectifier Circuit

The prototype for amplifier, filter and rectifier discussed in the Methodology chapter are built based on the schematics in Figure 18 and Figure 19.

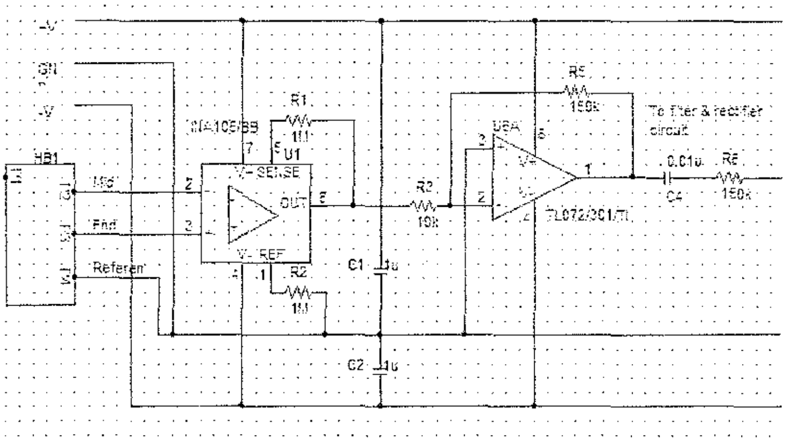


Figure 18: Schematic for amplifier

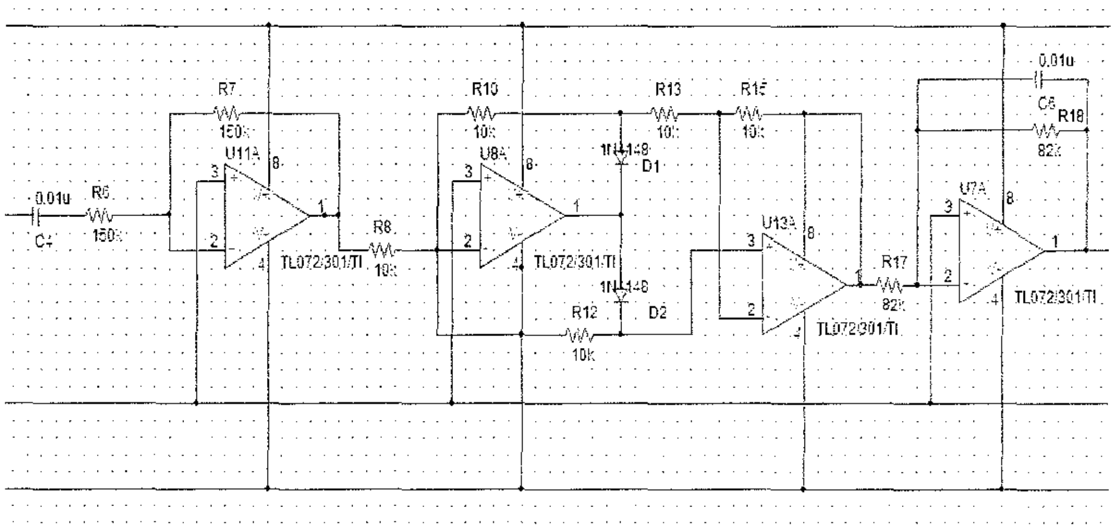


Figure 19: Schematic for filter and rectifier

The circuits in Figure 18 and 19 are built on the breadboard as shown in Figure 20. The circuit uses positive and negative power supply by connecting two 9V batteries in series.

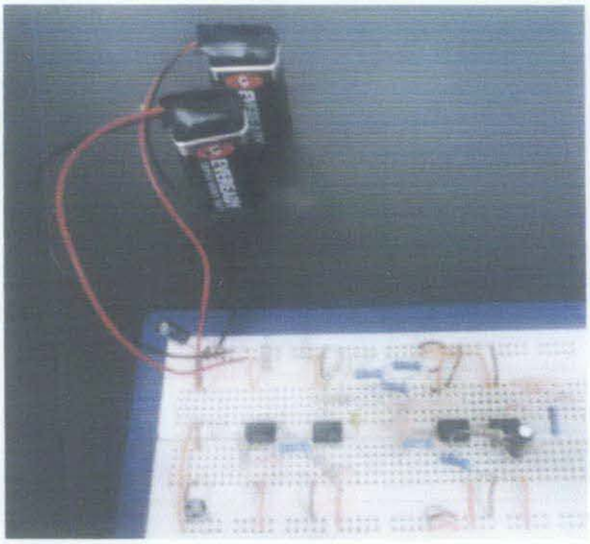


Figure 20: Circuit for amplifier, filter and rectifier

This circuit was tested with analog oscilloscope but the output signal produces some noise. This problem may be solved by inserting a higher value of a variable resistor to adjust the noise.

4.2 Wireless Transmission Circuit

4.2.1 **Components**

Few important components that are used in wireless transmission circuit are:

i. Two PICs 18F452

   These two microcontrollers will be doing the processing of the data being transmitted and received. One sends information to the RF Module transmitter and the other PIC understands and executes the information sent to it by the RF Module receiver.

ii. RF 434MHz transmitter module

This 5 pin module is small enough to fit into this project and add wireless communication.

iii. RF 434MHz receiver module

The RF interface receiver module is larger for demodulation and amplification circuitry. It also has a simple array of power, ground and data pins to connect up with the PIC's USART.

iv. Two LM7805 +5v Regulators

Two of these +5V regulators are used to control the battery input down to +5 volts. This is the power needed to run the PIC microcontrollers and can also be used for the RF transmitter and receiver modules. The LM7805 takes battery input and regulates it down to +5V.

4.2.2 **Testing**

To confirm that the proper information is being received, two testing circuits are built on the breadboards as shown in Figure 21 and 22 by using two buttons for input which will be present on the transmitter part and two LEDs for output on the receiver part. Suppose that one button is pressed, a specific command will light up one LED; when the other button is pressed, the other LED will be turned on. To produce this action, the two PIC18F452s are being programmed with two firmware files (see Appendix C) by using PIC Kit 2 software.

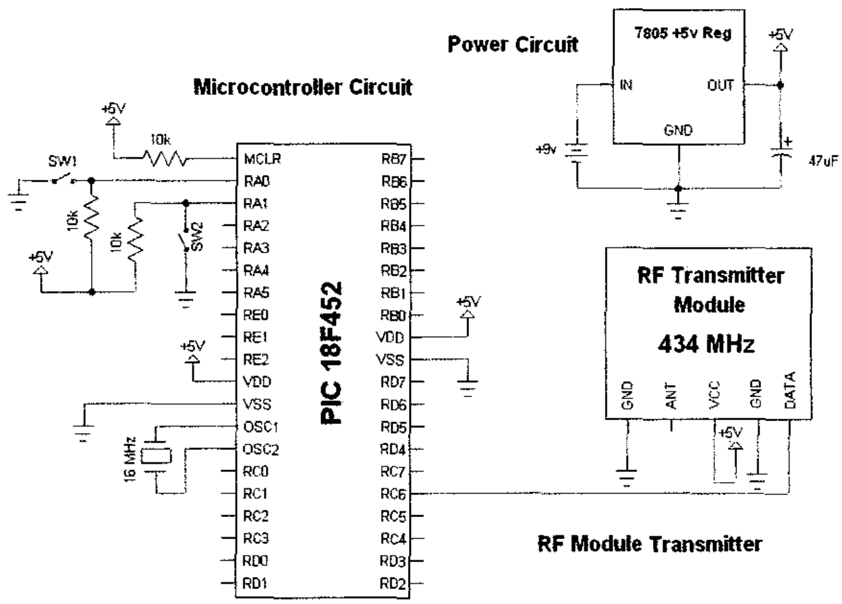


Figure 21: Schematic of Transmitter part

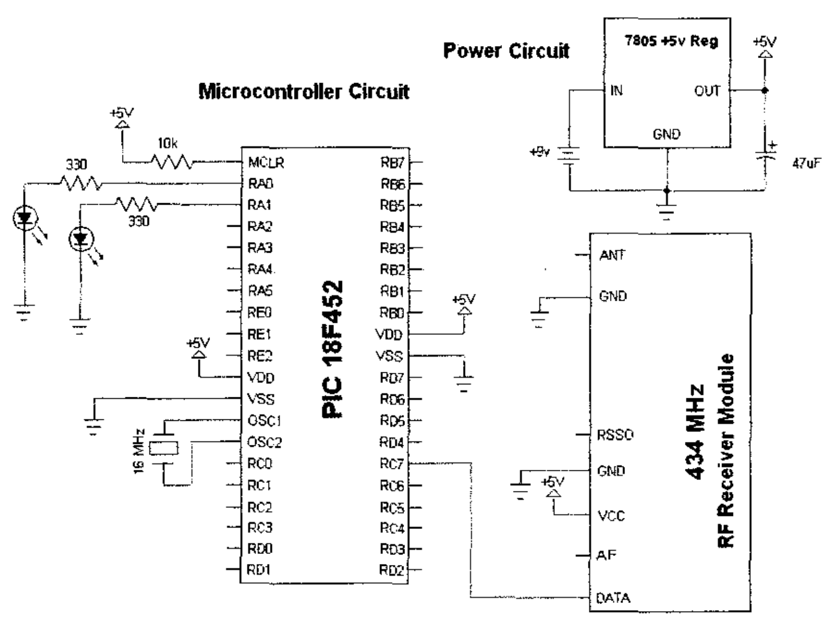


Figure 22: Schematic of Receiver part

The circuit was then tested using an analog oscilloscope. The output signal produced by the RF transmitter is shown in Figure 23.

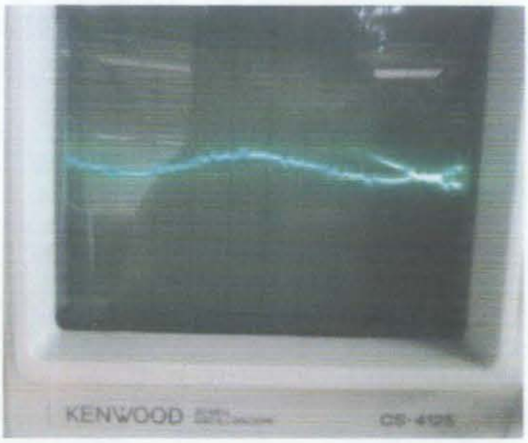


Figure 23: Output signal of RF transmitter

The output signal produced by the RF transmitter is in sinusoidal waveform. The output is not accurate as it should be in triangular waveform since the transmission is in digital form. On the other hand, the output signal produced by the RF receiver is a 5V peak-to-peak triangular waveform as shown in Figure 24. The output is not accurate too since the signal that was transmitted by the receiver should be same with the signal received at the receiver. The configuration on wireless transmission circuit must be checked properly to avoid unwanted signal.

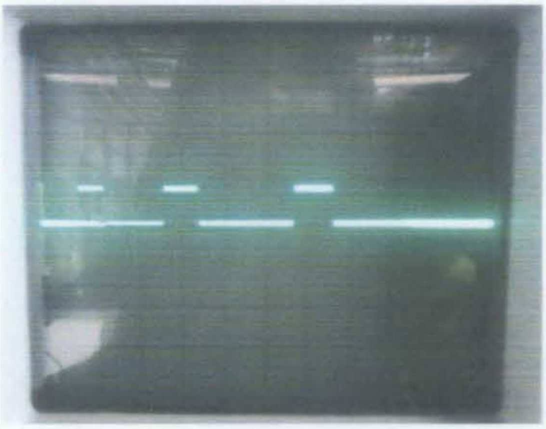


Figure 24: Output signal of RF receiver

Then, another testing was performed by applying frequency as the input to the PIC18F452 at the transmitter part. The frequency applied was 5Hz. The output signal for both RF transmitter and receiver were measured using digital storage oscilloscope as shown in Figure 25.

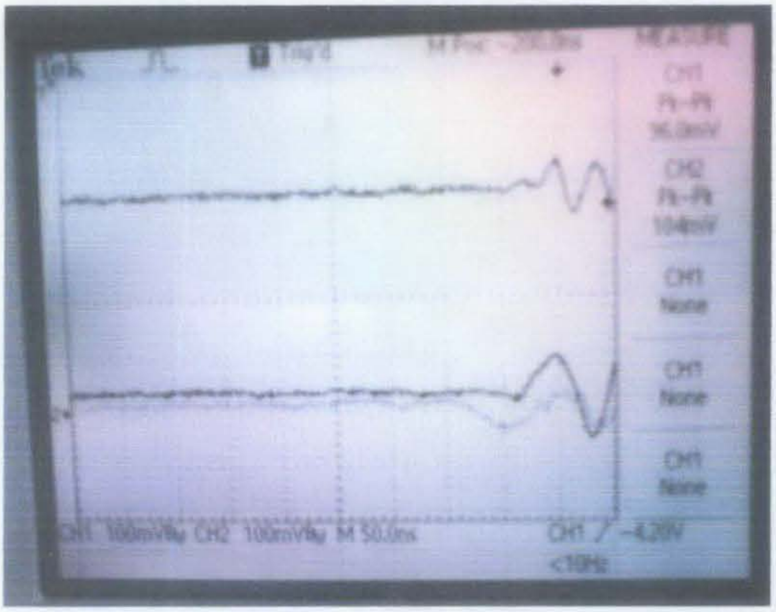


Figure 25: Output signal of RF receiver and transmitter

The upper signal shows the output for the RF transmitter and the lower signal shows the output for the RF receiver. The measurement shows that both output signals are quite similar despite the differences on the peak-to-peak voltages. For the transmitter output, the peak-to-peak voltage is 96.0mV and the receiver output produces a bigger peak-to-peak voltage which is 104mV.

The next step that should be furthered is to make sure that the EMG signal can be transmitted wirelessly using the RF transmitter and receiver. The main concern is to find a suitable sampling frequency so that the signal can be recorded in the plotter software.

CHAPTER 5: CONCLUSION

As mentioned earlier in the objective, the main purpose is to design and build a wireless electromyography recorder which allows for wireless collection and recording of EMG signals. In the mean time, the objective of this project has not been fully achieved yet. The biggest challenge in this project is to make sure that the signal is sent successfully through the wireless medium and record it. In order to get an accurate signal, extra attention should be put on the wireless transmission.

As conclusion, this project is not complete 100% yet. If this project can be implemented successfully, it will bring many benefits to the user, especially the one with muscle diseases, and it can be applied in other advanced applications such as moving a wheelchair.

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TABLE 1-3: PIC18F4X2 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	DIP	PLCC	TQFP			
$\overline{MCLR}$/VPP	1	2	18			Master Clear (input) or high voltage ICSP programming enable pin.
$\overline{MCLR}$				I	ST	Master Clear (Reset) input. This pin is an active low RESET to the device.
VPP				I	ST	High voltage ICSP programming enable pin.
NC	—			—	—	These pins should be left unconnected.
OSC1/CLKI	13	14	30			Oscillator crystal or external clock input.
OSC1				I	ST	Oscillator crystal input or external clock source input. ST buffer when configured in RC mode. CMOS otherwise.
CLKI				I	CMOS	External clock source input. Always associated with pin function OSC1. (See related OSC1/CLKI, OSC2/CLKO pins.)
OSC2/CLKO/RA6	14	15	31			Oscillator crystal or clock output.
OSC2				O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO				O	—	In RC mode, OSC2 pin outputs CLKO, which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6				I/O	TTL	General Purpose I/O pin.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19			
RA0				I/O	TTL	Digital I/O.
AN0				I	Analog	Analog input 0.
RA1/AN1	3	4	20			
RA1				I/O	TTL	Digital I/O.
AN1				I	Analog	Analog input 1.
RA2/AN2/VREF-	4	5	21			
RA2				I/O	TTL	Digital I/O.
AN2				I	Analog	Analog input 2.
VREF-				I	Analog	A/D Reference Voltage (Low) input.
RA3/AN3/VREF+	5	6	22			
RA3				I/O	TTL	Digital I/O.
AN3				I	Analog	Analog input 3.
VREF+				I	Analog	A/D Reference Voltage (High) input.
RA4/T0CKI	6	7	23			
RA4				I/O	ST/OD	Digital I/O. Open drain when configured as output.
T0CKI				I	ST	Timer0 external clock input.
RA5/AN4/$\overline{SS}$/LVDIN	7	8	24			
RA5				I/O	TTL	Digital I/O.
AN4				I	Analog	Analog input 4.
$\overline{SS}$				I	ST	SPI Slave Select input.
LVDIN				I	Analog	Low Voltage Detect Input.
RA6						(See the OSC2/CLKO/RA6 pin.)

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power; OD = Open Drain (no P diode to VDD)

TABLE 1-3: PIC18F4X2 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	DIP	PLCC	TQFP			
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/INT0	33	36	8			
RB0				I/O	TTL	Digital I/O.
INT0				I	ST	External Interrupt 0.
RB1/INT1	34	37	9			
RB1				I/O	TTL	
INT1				I	ST	External Interrupt 1.
RB2/INT2	35	38	10			
RB2				I/O	TTL	Digital I/O.
INT2				I	ST	External Interrupt 2.
RB3/CCP2	36	39	11			
RB3				I/O	TTL	Digital I/O.
CCP2				I/O	ST	Capture2 input, Compare2 output, PWM2 output.
RB4	37	41	14	I/O	TTL	Digital I/O. Interrupt-on-change pin.
RB5/PGM	38	42	15			
RB5				I/O	TTL	Digital I/O. Interrupt-on-change pin.
PGM				I/O	ST	Low Voltage ICSP programming enable pin.
RB6/PGC	39	43	16			
RB6				I/O	TTL	Digital I/O. Interrupt-on-change pin.
PGC				I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/PGD	40	44	17			
RB7				I/O	TTL	Digital I/O. Interrupt-on-change pin.
PGD				I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend: TTL = TTL compatible input — CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels — I = Input
O = Output — P = Power
OD = Open Drain (no P diode to V_{DD})

TABLE 1-3: PIC18F4X2 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number DIP	PLCC	TQFP	Pin Type	Buffer Type	Description
						PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	15	16	32			
RC0				I/O	ST	Digital I/O.
T1OSO				O	—	Timer1 oscillator output.
T1CKI				I	ST	Timer1/Timer3 external clock input.
RC1/T1OSI/CCP2	16	18	35			
RC1				I/O	ST	Digital I/O.
T1OSI				I	CMOS	Timer1 oscillator input.
CCP2				I/O	ST	Capture2 input, Compare2 output, PWM2 output.
RC2/CCP1	17	19	36			
RC2				I/O	ST	Digital I/O.
CCP1				I/O	ST	Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	18	20	37			
RC3				I/O	ST	Digital I/O.
SCK				I/O	ST	Synchronous serial clock input/output for SPI mode.
SCL				I/O	ST	Synchronous serial clock input/output for I^2C mode.
RC4/SDI/SDA	23	25	42			
RC4				I/O	ST	Digital I/O.
SDI				I	ST	SPI Data In.
SDA				I/O	ST	I^2C Data I/O.
RC5/SDO	24	26	43			
RC5				I/O	ST	Digital I/O.
SDO				O	—	SPI Data Out.
RC6/TX/CK	25	27	44			
RC6				I/O	ST	Digital I/O.
TX				O	—	USART Asynchronous Transmit.
CK				I/O	ST	USART Synchronous Clock (see related RX/DT).
RC7/RX/DT	26	29	1			
RC7				I/O	ST	Digital I/O.
RX				I	ST	USART Asynchronous Receive.
DT				I/O	ST	USART Synchronous Data (see related TX/CK).

Legend: TTL = TTL compatible input
ST = Schmitt Trigger input with CMOS levels
O = Output
OD = Open Drain (no P diode to VDD)
CMOS = CMOS compatible input or output
I = Input
P = Power

TABLE 1-3: PIC18F4X2 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	DIP	PLCC	TQFP			
						PORTD is a bi-directional I/O port, or a Parallel Slave Port (PSP) for interfacing to a microprocessor port. These pins have TTL input buffers when PSP module is enabled.
RD0/PSP0	19	21	38	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
RD1/PSP1	20	22	39	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
RD2/PSP2	21	23	40	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
RD3/PSP3	22	24	41	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
RD4/PSP4	27	30	2	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
RD5/PSP5	28	31	3	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
RD6/PSP6	29	32	4	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
RD7/PSP7	30	33	5	I/O	ST	Digital I/O.
					TTL	Parallel Slave Port Data.
						PORTE is a bi-directional I/O port.
RE0/$\overline{RD}$/AN5	8	9	25	I/O		
RE0					ST	Digital I/O.
$\overline{RD}$					TTL	Read control for parallel slave port (see also $\overline{WR}$ and $\overline{CS}$ pins).
AN5					Analog	Analog input 5.
RE1/$\overline{WR}$/AN6	9	10	26	I/O		
RE1					ST	Digital I/O.
$\overline{WR}$					TTL	Write control for parallel slave port (see $\overline{CS}$ and $\overline{RD}$ pins).
AN6					Analog	Analog input 6.
RE2/$\overline{CS}$/AN7	10	11	27	I/O		
RE2					ST	Digital I/O.
$\overline{CS}$					TTL	Chip Select control for parallel slave port (see related $\overline{RD}$ and $\overline{WR}$).
AN7					Analog	Analog input 7.
V_{SS}	12, 31	13, 34	6, 29	P	—	Ground reference for logic and I/O pins.
V_{DD}	11, 32	12, 35	7, 28	P	—	Positive supply for logic and I/O pins.

Legend: TTL = TTL compatible input
ST = Schmitt Trigger input with CMOS levels
O = Output
OD = Open Drain (no P diode to V_{DD})
CMOS = CMOS compatible input or output
I = Input
P = Power

FM TRANSMITTER & RECEIVER HYBRID MODULES.

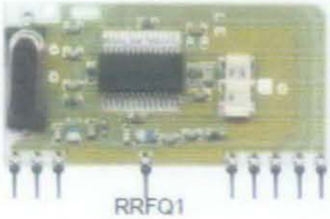
FM-RTFQ SERIES
FM-RRFQ SERIES

- FM Radio Transmitter & Receivers
- Available As 315 or 433 or 868MHz
- Transmit Range Up To 250m
- Miniature Packages
- Data Rate upto 9.6Kbps
- No Adjustable Components
- Very Stable Operating Frequency
- Operates from –20 to +85^{0}C

RTFQ1

Transmitter

- 3-12 Supply Voltage
- SIL or DIL Package



RRFQ1

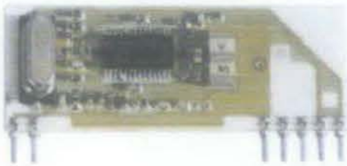
Receiver

- PLL XTAL Design
- CMOS/TTL Output
- RSSI Output
- **Standby Mode (max 100nA)**
- 5V Supply Voltage

RTFQ2

Applications

- Wireless Security Systems
- Car Alarms
- Remote Gate Controls
- Remote Sensing
- Data Capture
- Sensor Reporting



RRFQ2

Description

These miniature RF modules provide a cost effective high performance FM Radio data link, at either 315, 433.92 or 868MHz. Manufactured using laser trimmed Thick Film ceramic Hybrid the modules exhibits extremely stable electronic characteristics over an Industrial Temperature range. The hybrid technology uses no adjustable components and ensures very reliable operation.
This transmitter and receiver pair enables the simple implementation of a data link at distances upto 75 metres in-building and 250 metres open ground.

These modules will suit one-to-one and multi-node wireless links in applications including car and building security, EPOS and inventory tracking, remote industrial process monitoring and computer networking. Because of their small size and low power requirements, both modules are ideal for use in portable, battery-powered applications such as hand-held terminals.

FM TRANSMITTER & RECEIVER HYBRID MODULES.

FM-RTFQ SERIES
FM-RRFQ SERIES

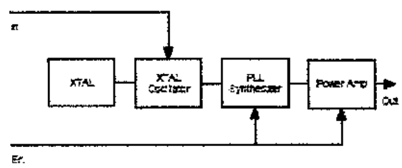
Transmitters

There are two versions of transmitter:

RTFQ1; A Dual in Line Package operating at 3.3V. This provides the most rugged mechanical fixing to the host PCB. Power Down mode is also available.

RTFQ2; A Single in Line Package incorporating a voltage regulator for 3-12V operation. (Compatible with many other RF transmitter modules available)

Transmitter Block Diagram



Part Numbering

Part Number	Description
FM-RTFQ1-315	DIL FM Transmitter Module 315 MHz
FM-RTFQ1-433	DIL FM Transmitter Module 433.92 MHz
FM-RTFQ1-868	DIL FM Transmitter Module 868.35 MHz
FM-RTFQ2-433R	SIL FM Transmitter Module 433.92 MHz 3-12V I/P
FM-RTFQ2-868R	SIL FM Transmitter Module 868.35 MHz 3-12V I/P

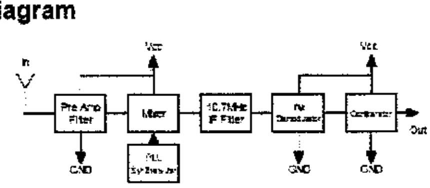
Receivers

There are two versions of receiver:

RRFQ1: A Single in Line Package with sleep / Power down mode.

RRFQ2: A Single in Line Package, pin compatible with many other receivers

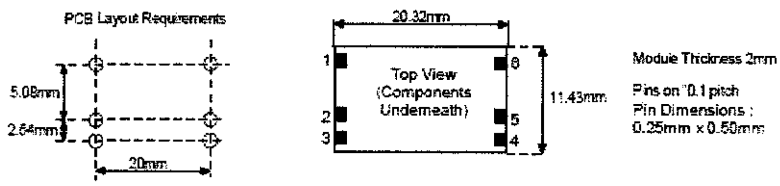
Receiver Block Diagram



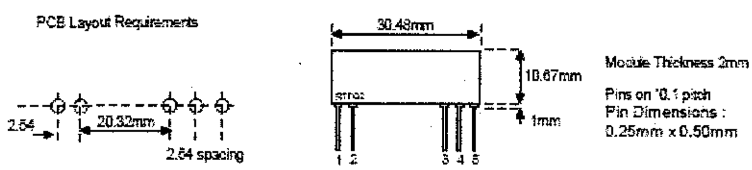
Part Numbering

Part Number	Description
FM-RRFQ1-315	SIL FM Receiver Module 315 MHz
FM-RRFQ1-433	SIL FM Receiver Module 433.92 MHz
FM-RRFQ1-868	SIL FM Receiver Module 868.35 MHz
FM-RRFQ2-433	SIL FM Receiver Module 433.92 MHz
FM-RRFQ2-868	SIL FM Receiver Module 868.35 MHz

RTFQ1 Mechanical Dimensions



RTFQ2 Mechanical Dimensions



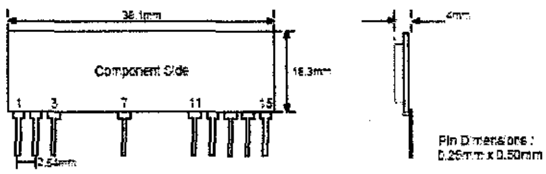
Pin Description

RTFQ1	RTFQ2	Name	Description
1	N/A	En	Enable (active high)
2	5	IN	Data input
3	1	GND	Ground. Connect to RF earth return path
4	3	Vcc	Supply Voltage
5	4	GND	Ground. Connect to RF earth return path
6	2	EA	External Antenna

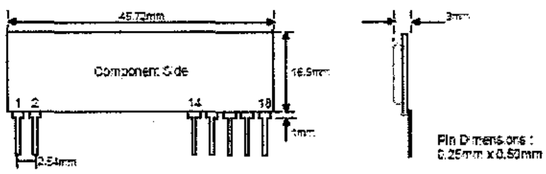
Technical Specifications

Electrical Characteristics	MIN	TYPICAL	MAX	DIMENSION
Supply Voltage RTFQ1	2.1	3.3	4.00	V
Supply Voltage RTFQ2	2.5		12.00	V
Supply Current		7	8	mA
Standby Current (IN = EN = Low)			100	nA
Frequency		315.0 433.92 868.35		MHz
RF Output into 50Ω (Vcc=3.3V)		+5 / +5 / +1		dBm
Initial Frequency Accuracy	-35	0	+35	KHz
FM Deviation	25	30	35	KHz
Harmonic Spurious Emissions		-50		dBc
Input High Voltage RTFQ1	1.5		Vcc	V
Input High Voltage RTFQ2	1.5		5.5	V
Power up Time (En to full RF)			1	mS
Power up Time (Power on to full RF)			5	mS
Max Data Rate			9.6	KHz
Operating Temperature	-25		+80	°C

RRFQ1 Mechanical Details



RRFQ2 Mechanical Details



Pin Description

RRFQ1	RRFQ2	Pin Description
1	16	+Vcc
2, 7, 11	2, 15	GND
3	1	Data In (Antenna)
12		NC
13	14	Received Signal Strength Output
N/A	17	AF Output
14	18	Data Out
15	N/A	Power Down 0V = Standby 5V = Operating

RSSI Output*

RF In (dBm)	RSSI (V)
-120	1.20
-110	1.32
-100	1.50
-90	1.78
-80	2.06
-70	2.35
-60	2.62
-50	2.72
-40	2.75

RSSI Output

The RSSI provides a DC Voltage proportional to the peak value of the receive data signal. This output can be used as an indicator for the received signal strength to use in wake-up circuits etc.

An RC circuit is normally used to provide the timing for the RSSI signal. The modules have a 10nF capacitor internally connected to GND, therefore a pull down resistor (to GND) connected to the RSSI pin may be used to generate a simple RC network time constant for the RSSI signal output.

Please note that the maximum output current is typically 950µA, the discharge current is lower than 2µA

Technical Specifications

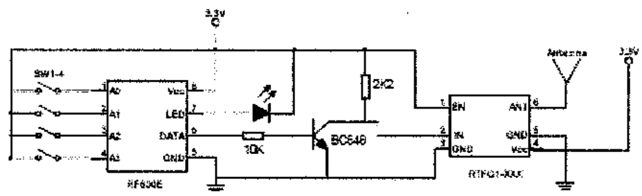
Electrical Characteristics	Min	Typical	Max	Dimension	Notes
Supply Voltage (Vcc)	4.5	5	5.5	V	
Supply Current (Operating)		5.7	6.8	mA	
Supply Current (Standby)			100	nA	
Receiver Frequency		315.00 433.92 868.35		MHz	
R.F Sensitivity (100% AM) 315 ,433MHZ versions 868MHz versions		-103 -100		dBm	
3dB Bandwidth		+/-150		KHz	
Data Rate	300		9,600	Hz	
Turn on Time			5	mSecs	1
Turn on Time		8		mSecs	2
Level of Emitted Spectrum			-70	dBm	
Low Level Output Voltage			0.8	V	I = 200uA
High Level Output Voltage	Vcc-1			V	I = 200uA
RSSI Output		0.95		mA	
Operating Temperature Range	-25		+80	°C	

Notes
1. Time from PD pin going high to stable data. (RRFQ1 only)
2. Time from Power ON to stable data.

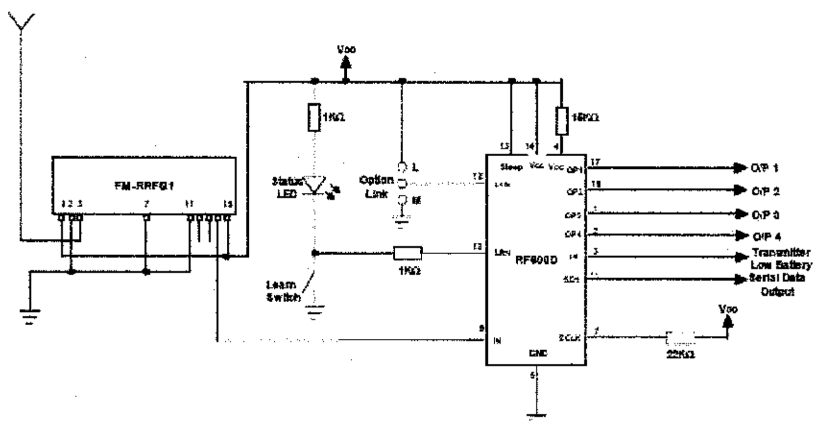
Typical Application

The following circuits show a remote control system with 'self learning feature' for more information please see Datasheet DS600

Transmitter Circuit



Receiver Circuit



Prototyping Hints:

It is essential when building any Low Power Radio System that you have a 'clean' DC power source. Typically the ripple voltage should be less than 10mV Peak to Peak. Normally a 470uF decoupling capacitor is sufficient de-coupling for an AC derived DC power source.

Never place a Transmitter or Receiver directly into Vero-Board or any similar prototyping board. This will severely restrict the range. Rather, use small lengths of wire from the prototyping board to the pins of the Transmitter or Receiver.

A useful antenna, for testing purposes, for both the Transmitter and Receiver on 433MHz is to use a piece of wire 17.3cm long (23.8cm at 315MHz) soldered directly to the antenna pin.

For more information or general enquiries, please contact;

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RF Solutions is a member of the Low Power Radio Association

Appendix C: RF Transmitter and Receiver Firmware Files

RF Transmitter Firmware

------------« Begin Code »------------

```
//********Button/Command Output Control************
//**********************************************
//If No Button Pressed, Send Command L0
if(PORTDbits.RD0 == 1 &&
PORTDbits.RD1 == 1){
  //Turn LED ON
  putcUSART( '0' ); //write value of PORTD
  Delay10KTCYx(10);
  putcUSART( 'L' ); //write value of PORTD
  Delay10KTCYx(10);
}
//If Button #1 Is Pressed, Send Command L1
else if(PORTDbits.RD0 == 0 &&
PORTDbits.RD1 == 1){
  //Turn LED OFF
  putcUSART( '1' ); //write value of PORTD
  Delay10KTCYx(10);
  putcUSART( 'L' ); //write value of PORTD
  Delay10KTCYx(10);
}
//If Button #2 Is Pressed, Send Command L2
else if(PORTDbits.RD0 == 1 &&
PORTDbits.RD1 == 0){
  //Turn LED OFF
  putcUSART( '2' ); //write value of PORTD
  Delay10KTCYx(10);
  putcUSART( 'L' ); //write value of PORTD
  Delay10KTCYx(10);
}
//**********************************************
```

-----------« End Code »------------

RF Receiver Firmware

-----------« Begin Code »-----------

```
//******** Button/LED Control *********
if(data_array[1] == 'L' &&
  data_array[2] == '0')
  PORTA= 0x00;
//**** Button 1 Pressed - LED #1 On ****
else if(data_array[1] == 'L' &&
  data_array[2] == '1')
  PORTA= 0x01;
//**** Button 2 Pressed - LED #2 On ****
else if(data_array[1] == 'L' &&
  data_array[2] == '2')
  PORTA= 0x02;
//***************************************
...
....
...
//Interrupt Evaluation Routine
if(PIR1bits.RCIF){
  buf = ReadUSART();
  data_array[7] = data_array[6];
  data_array[6] = data_array[5];
  data_array[5] = data_array[4];
  data_array[4] = data_array[3];
  data_array[3] = data_array[2];
  data_array[2] = data_array[1];
  data_array[1] = data_array[0];
  data_array[0] = buf;
  PIR1bits.RCIF = 0; //Clear RCIF Flag
}
```

-----------« End Code »-----------