CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF BIOMEDICAL ENGINEERING

Department of Biomedical Technology

Design and Implementation of EMG Amplifier for Myopotential Surface Measurements

Bachelor Thesis

Study program: Biomedical and Clinical Technology
Study branch: Biomedical Technician

Bachelor thesis supervisor: **Ing. Ladislav Bís**

Name Surname: Emmanuel.O. Irorobeje

Kladno: 2023

Thesis Assignment

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

BACHELOR'S THESIS ASSIGNMENT

I. PERSONAL AND STUDY DETAILS

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Department:	**Department of Biomedical Technology**		
Study program:	**Biomedical and Clinical Technology**		
Branch of study:	**Biomedical Technician**		

II. BACHELOR'S THESIS DETAILS

Bachelor's thesis title in English:

Design of EMG amplifier

Bachelor's thesis title in Czech:

Návrh EMG zesilovače

Guidelines:

Design and implement an EMG amplifier for surface myopotential measurements. For the design, choose an amplifier with high input impedance and CMMR min. 100dB. Design the amplifier as an additional shield for Arduino UNO type microcontroller. Test the implemented solution.

Bibliography / sources:

[1] Moon, Joon Ho et al., Moon, Joon Ho et al. "Validation of a wearable cuff-less wristwatch-type blood pressure monitoring device." Scientific reports vol. 10,1 19015. 4 Nov. 2020, doi:10.1038/s41598-020-75892-y, Scientific reports, ročník 10, číslo 1, 2020

[2] CHEN, W, Thermometry and interpretation of body temperatur, Biomed Eng Lett., ročník 1, 2019

[3] Metin Akay, Biomedical Signal Processing, ed. 1, Academic Press, 2012, 377 s., ISBN 0323140149

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DECLARATION

I hereby declare that I have completed this thesis with the topic "Design and implementation of EMG amplifier for myopotential surface measurements" independently and have attached an exhaustive list of citations of the sources used, which I listed in the list attached to the bachelor's thesis.

I do not have a compelling reason against using the thesis within the meaning of Section 60 of Act No.121 / 2000 Sb. on copyright, rights related to copyright and amending some laws (the Copyright Act).

In Kladno May15th 2023

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Emmanuel.O. Irorobeje

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First and foremost, I convey my gratitude to **Ing. Ladislav Bís**. my supervisor. Thank you for guiding me on this arduous and unusual path and for your patience with what I didn't comprehend and my mistakes. Your attitude and commitment to this thesis never made me feel powerless, and you were always willing to share your knowledge. Thank you once again for everything.

To my sponsors Thank-God Irorobeje, MSc, for encouraging me to look for all the marvellous things in the world and to my brother Francis Irorobeje, for teaching me not to be afraid to find them.

To Kladno, for being my home for four years. The city that has taught me the truth

behind this Kinyarwanda proverb, the bird that does not fly will never know where the good seeds are.

Thank you all.

ABSTRACT

Design and implementation of EMG amplifier for myopotential surface measurements

Electromyographic (EMG) signals are frequently used as a rehabilitation control signal and diagnostic tool in the medical field. It has so far been challenging to develop a better amplification and filtering circuit design that can perfectly capture the characteristics of surface EMG signals for the intended applications. This thesis focuses on designing and implementing an EMG amplifier for myopotential surface measurements.

The hardware and software components were integrated into a custom printed circuit board (PCB). It is a shield that collects the EMG signal from the human skeletal muscles, amplifies it, filters it and outputs it to the Arduino's analog pin. The input signals are amplified with a precision instrumentation amplifier INA122, with a CMRR of 100dB. The signal pre-processing uses the right leg drive and special low pass filters to reduce the acquisition system's common mode (CM) voltage and other noise sources. The analog EMG signal from the PCB output was digitised using a 10-bit ADC of the Arduino Uno. The digitised signal was transmitted by serial cable using the Arduino codes to a PC.

The result was a completely functional EMG device. These results were similar across tests and could be linked easily to muscle action and force. This EMG device may still have *50 Hz* common mode noise, which could have been caused by its wide bandwidth and poor low-frequency qualities.

Keywords

Surface electrode, EMG, bio-signal, Printed Circuit Board (PCB), Instrumentation Amplifier, Arduino-Uno.

Table of Contents

List of symbols and abbreviations

List of symbols

Symbol	Unit	Importance
V	Volt	the potential difference across terminal conducting wire
Ω	Ohm	resistance of a conductor of 1A,with a voltage of 1V
F	Farad	the capacity of a device to store electric charge
A	Amper	the flow of charged particles
Hz	Hertz	number of waves per second

List of abbreviations

Abbreviation	Importance
ADC	Analog-to-Digital converter
A0	AnalogOutput
AC	Alternating current
C	Capacitor
CMRR	Common mode rejection ratio
CMM	Common mode
CNS	Central nervous system
DC	Direct current
EMG	Electrocardiogram
EU	European Union
IA	Instrumentation amplifier
Ib	Input bias
IC	Integrated circuit
MCU	Microcontroller unit
Op Amp	Operational amplifier
PCB	Printed circuit board
PCBA	Printed circuit board Assembly
PC	Personal computer
R	Resistor
RMM	Root mean square
sEMG	Surface electromyography
SENIAN	EMG for non-invasive assessment Of muscles

1 Introduction

The growing prevalence of neuromuscular disorders like myasthenia gravies, myopathy, motor neuron diseases, and Parkinson's disease, among others, necessitated proper diagnostic device development. As per the Global Institute for Health Metrics and Evaluation, motor neuron disease claimed more than 237,053 lives in 2017[1]. Further, Parkinson's disease foundation reveals that more than 10 million individuals or suffering from Parkinson's disease across the globe [1]. The growing prevalence of such conditions is expected to propel the ongoing development of electromyography devices, and the rising demand for portable EMG devices is another major factor.

Biomedical signal analysis is one of the ways to monitor the parameters of the health conditions of the Human body. Some necessary biomedical signals include Electrocardiography (ECG), Electromyography (EMG), Electrooculography (EOG) etc. These signals are generated due to the bioelectric signal that produces across the cell membrane. EMG signal generates due to the bioelectric potential in the muscle's tissues. When a cell is at rest, sodium ions are more abundant outside than inside. This causes a slightly negative potential across the membrane. During some excited state, Sodium ions rush into the cells, and Potassium ions try to leave the cell. Sodium ions enter the cell rapidly, and Potassium ions cannot exit the cells at the same rate, causing a slightly positive charge across the membrane [2]. Thus, a potential difference can be seen during different excited states of muscle tissues.

EMG signal has two main applications. Firstly, it is used by clinicians for diagnostic purposes like evaluating voluntary movement and muscle functionality. On the other hand, engineers use it for prosthetic purposes. For example, assistive technologies like prosthetic hands and upper limb exoskeletons use the EMG signal for artificial physical manoeuvres.[3] [4]. These signals are of immense importance in the medical field. Different diseases can be detected, and proper signal analysis can yield a healthy individual's future health condition. EMG can detect diseases like Huntington's, Myopathies, Muscular dystrophies etc. EMG has its use in the sports world also. It is used to analyse a sportsperson's muscle strength and weakness. It can also suggest a running style to a sportsperson to produce more productive results during different sports. Modern research also showed that EMG could be used to analyse Gait, which can be used as a biometric tool Gait. It can also diagnose Parkinson's disease, Spondylosis [5]-[7] etc. These applications mentioned above require a noise-free EMG signal. It has so far been challenging to develop a better amplification and filtering circuit design that can perfectly capture the characteristics of surface EMG signals for the intended applications.

This thesis does not claim to invent new methods for measuring surface EMG but rather to examine the existing ones and the theory behind them and incorporate them into a single-channel acquisition system design. Creating a prototype based on this concept will also be the foundation for the first fully working EMG acquisition system prototype, customised for the Faculty of Biomedical Engineering laboratory needs at the Czech Technical University.

This thesis aims to design and implement an EMG amplifier for myopotential surface measurements. Electromyography (EMG) studies the detection, analysis, and application of electrical signals generated by skeletal muscles. The myoelectric signal, produced by weak electrical currents caused by the exchange of ions across muscle membranes and measured with electrodes, is produced during muscle activity. Surface electromyography(sEMG) is a non-invasive method of monitoring electrical muscle activity that can diagnose neuromuscular diseases, among other things. [8]. Motor neurons activate muscle fibres, and the electrical signals produced by the muscle fibres can be detected by electrodes placed on the skin's surface.

1.1 Skeletal muscle's electrical activity

To understand muscle activity, studying the EMG signals they produce is essential. The first step to comprehend this EMG signal is to measure it through a sensor. Also, to design a suitable sensor is necessary to know what has to be detected. Muscle definition should be presented before studying muscle's electrical activity and force-producing mechanisms. A muscle is a type of body tissue made up of long cells that, when activated, contract and cause motion. Skeletal muscle is in charge of controlling voluntary movements of the body and the preservation of posture. The one from which EMG signals are obtained is also one. Through the tendons, the skeletal muscle cells are connected to the bones. Each muscle comprises a group of fibres. These fibres are bordered by conjunctive and adipose tissue.

A motor unit connects a motor neuron and muscle fibre, enabling muscles to move by electrical impulses transmitted by the brain through the central nervous system (CNS) [9]. The bioelectric potential is a generic term for all the human body and other organisms electric potential. Motor units (MUs) are the functional units of the neuromuscular system. Each MU comprises a single motoneuron and the muscle fibres supplied by its axonal branches[10].

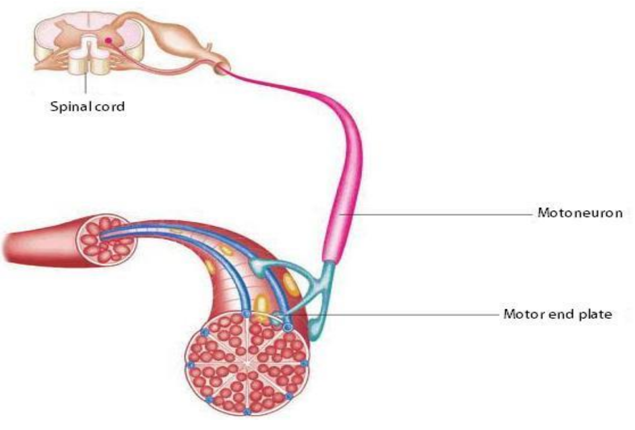


Figure 1.1 - The Motor Unit (MU) consists of an α-motoneuron and its innervating muscle fibres.

Once a motor neuron discharges, action potentials are generated at its neuromuscular junctions and propagate along all the muscle fibres toward the postsynaptic regions. The total of these potentials is called motor unit action potentials (MUAP) and is responsible for muscle contraction.

Electromyogram

Electromyography (EMG) studies the detection, analysis, and recording of the electrical activity of muscles throughout the body. The electromyograph is the device that records the EMG signal, and the electromyogram is the record that follows. The myoelectric signal, produced by weak electrical currents caused by the exchange of ions across muscle membranes and measured with electrodes, is produced during muscle activity.

Muscle force production depends on the number of active MUs and the rate with which the functional units discharge. Both mechanisms are known as temporal and spatial summation of MUAPs. The relative contribution of these mechanisms to regulating muscle force is debatable, as it varies between muscles, with the target force and the contraction type[11- 12]. MUs are generally recruited from the smallest to the largest (for instance, MUs with the fewest fibres are recruited first). This seems to be a result of muscle force production [13]. This systematic recruitment of MUs was termed the *size principle* [13]. Although such a principle has been verified extensively [10-17], the recruitment of Mus might be influenced by the mechanical muscle work [18], the length of muscle fibres[19] and the localisation of muscle fibres belonging to single Mus[20].

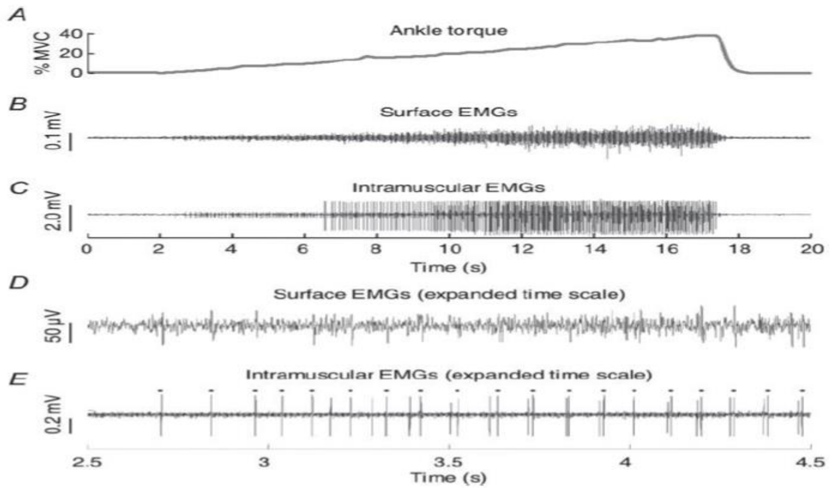


Fig. 1.2- *Electromyograms and motor unit action potentials). A) depict the plantar flexion torque from 0 to 40% MVC during an isometric ramp contraction. The medial gastrocnemius muscle's surface and intramuscular EMG recordings are displayed in B) and C), respectively. These signals' brief epochs are depicted in D) and E). Note how the surface action potentials of the initially recruited motor unit match the intramuscular action potentials (dots in E denote its discharge instant).*

The number of active MUs determines how much each particular MUAP may be seen in the surface EMG. Look at the force and EMG traces of a person whose plantar flexion force isometrically increased up to 40% of his (MVC) maximal voluntary contraction (MVC). Ankle torque increased (fig. 1.2A) with the amplitude of both surface and intramuscular EMGs (figs. 1.2B, C) after some milliseconds delay. Individual MUAPs are represented by EMG spikes in the intramuscular muscle. Therefore, it is evident that MUs were recruited at various points during the contraction, beginning with the smallest unit (small spikes in Fig. 1.2C).

Conversely, MUAPs are not equally evident in the surface EMG (fig. 1.2). The surface EMG transmits many action potentials from a population of MUs because surface electrodes are less selective than intramuscular electrodes[21]. The neurological system continuously modulates muscular force by leveraging effective relationships between MU recruitment and firing rate, exacerbating this summation of MUAPs.[23–25]. However, single MUAPs might be visible at low contraction levels in the interference surface EMG (figs. 1.2D, E . Consequently, different interpretations of MUAPs are obtained subject to whether EMGs are acquired with intramuscular or surface pairs of electrodes and on the strength of muscle contraction. The following section explains the EMG signals and noises associated with these signals.

EMG signal

An sEMG signal's amplitude can range from less than $50\mu V$ *to* $30\ mV$. depending on the muscle; operational amplifiers are needed to increase the strength of signals [5]. Since the signals are considerably weak, the amplification needs to be hundreds of times. The frequencies of the myoelectric signals lie between *0–500 Hz* but dominate around *50– 150* Hz. Analog filters are implemented to increase the quality of these signals. The function of filters is to block or attenuate specific frequencies, particularly *50 Hz* noise from AC power sources. [5] Furthermore, there is noise caused by other sources: from the interface between electrodes and the skin, from the movement of the electrode's cable connecting to the amplifier, from components, from PCB layout, amongst others. Proper design of the electronic circuitry can attenuate this noise. The myoelectric signal acquired by the electrodes needs to be processed in various steps before being used in a microcontroller unit (MCU). The signal needs to be detected, amplified, filtered, and integrated.

1.2 EMG System

EMG systems can be divided into three parts (see Figure 1.21) [9]: detection, amplification, and processing, which is how the EMG device in this thesis is structured.

Electrodes that conduct bioelectric signals are used in signal detection. Various electrode configurations and electrode types are used to measure biopotentials. This thesis requires three electrodes to detect myoelectric signals a positive, a negative, and a reference strategically placed along with the measured muscle. Because myoelectric signals are extremely weak, about *1–10mV* (peak-to-peak) depending on the muscle. Amplification is required to increase the detected signal's strength to process it. [9].

Amplification is achieved using operational amplifiers (Op-Amps), commonly used in various configurations to increase a signal's strength and stabilise it via negative feedback. This amplification must be processed around 10^3-10^4 times [9].

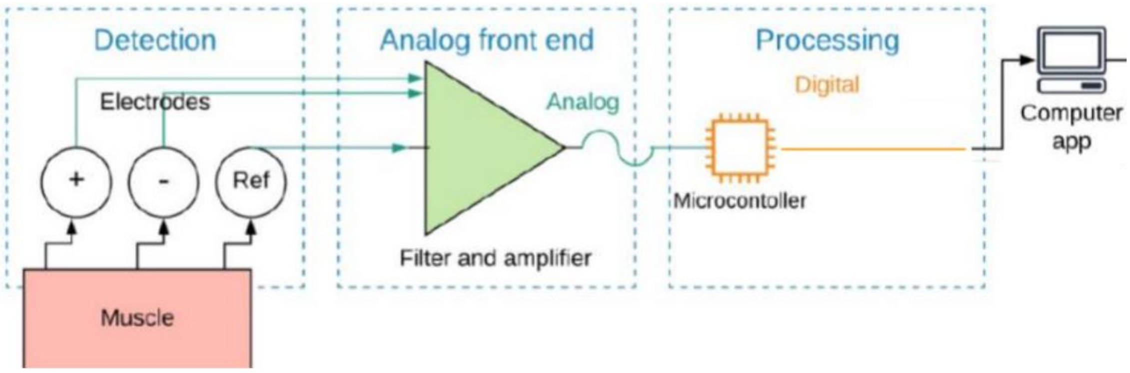


Figure 1.21 - Simplified overview of the EMG system.Adopted from [9]

Moreover, analog filters are required to improve the quality or resolution of these signals. Filters block or attenuate specific frequencies, particularly *50 Hz* common mode noise in EMG systems, and can significantly improve the quality of the measured signals.

After amplification, the signal is processed by a digital circuit, a microcontroller that converts analog data to digital data and transfers it to a computer. Other devices (computer). This report describes an EMG signal conditioning circuit with its Printed Circuit Board (PCB) to make a portable device which measures myopotential surface signal.

Contemporary concepts of EMG system design prefer the use of **EMG pre-amplifiers**. These miniaturised amplifiers are typically built-in cables or positioned on the electrodes (**Active electrodes**. The main idea of using small EMG pre-amplifiers near the detection site is early pick up of the signal, amplify it (e.g., 500 gain) and transmit it on a low.

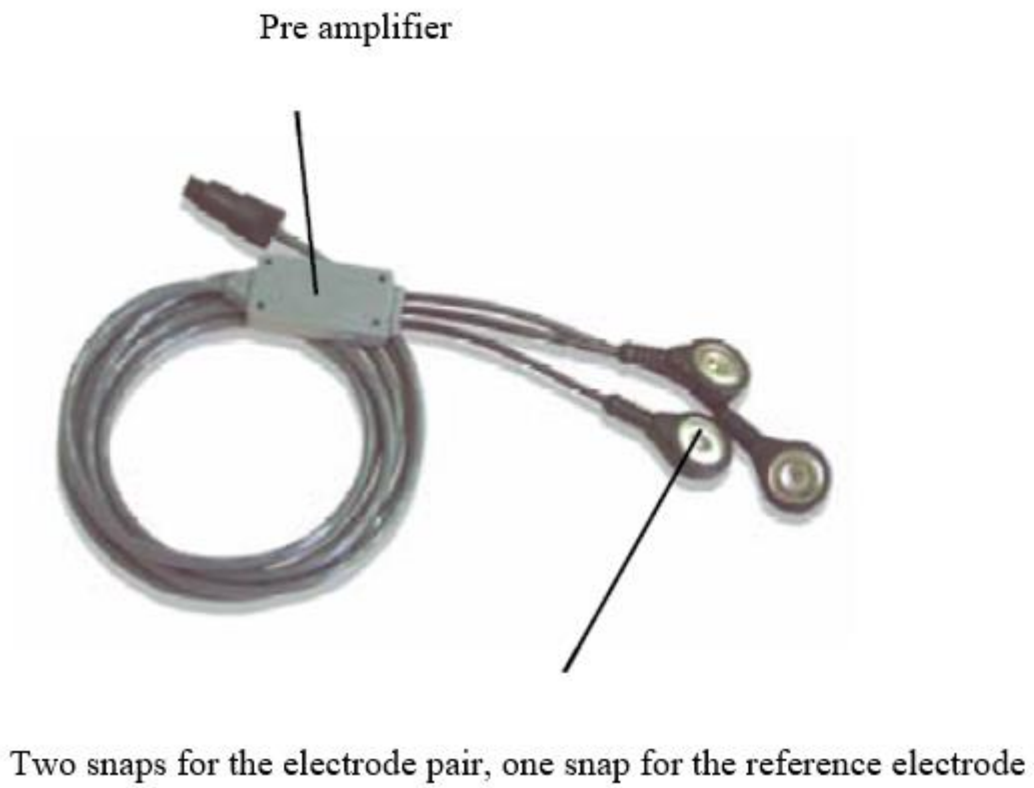


***Figure.1.21- Electrode leads with cable built-in pre-amplifiers System** NORAXON INC USA*

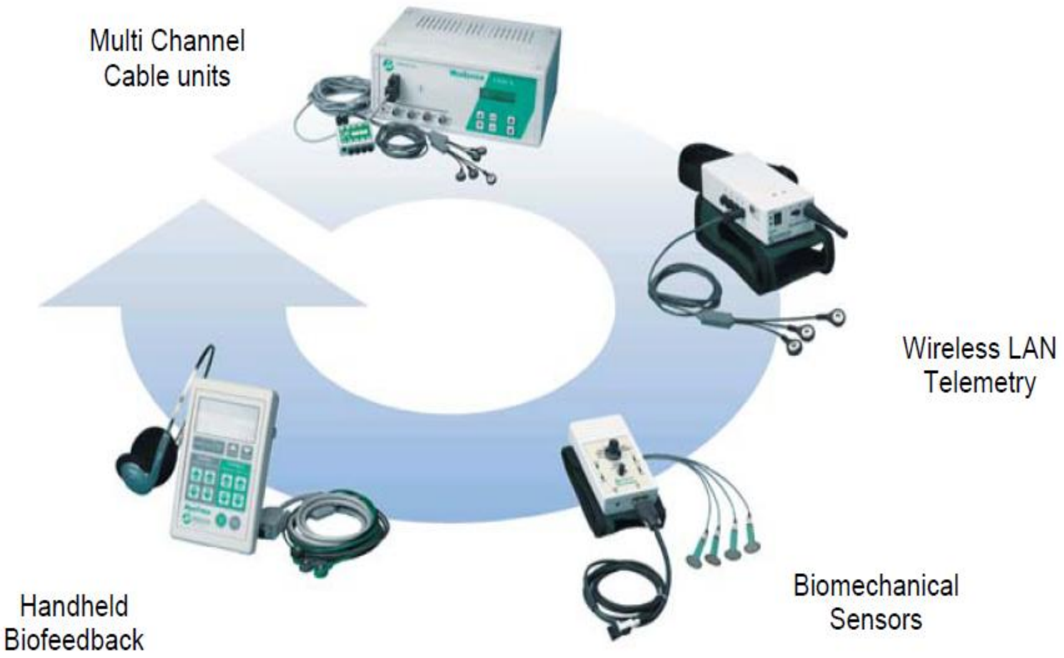


Figure1.22-Variety of EMG amplifiers ranging from 1 or 2-channel Biofeedback units to tethered and telemetric systems. Systems by NORAXON INC. USA

The un-amplified EMG signal on the skin has typical charges between a few microvolts and *2-3 millivolts*. The signal is generally amplified by a factor of at least 500 (e.g. when using pre-amplifiers) to 1000 (passive cable units). The most important part of the bioelectric voltage amplifier is a high-quality differential amplifier that receives very weak signals from the Human body in the presence of substantial interference without affecting the value and shape of the measured signal. It strengthens weak differential voltages in the presence of strong common voltages. The input amplifier converts the voltage difference between the two electrodes (differential input voltage) into a single amplified output voltage. Another crucial parameter of each amplifier is its input resistance. The resistance of contact ranges from several hundred to several kiloohms. The resistance of the electrodes creates a voltage divider with an input resistance of the amplifier, causing the measured bioelectric voltage to weaken. In addition, with the frequently occurring asymmetry of the electrode-to-body contact resistance at both inputs of the amplifier, an additional differential noise signal appears at its input. Therefore, the input resistance of each input of the amplifier should be equal to or much higher than the resistance of the electrodes. The amplifier's input impedance should have a value of at least 10x the given impedance of the electrode. Winter [26]suggests an input impedance of *1-10 Megaohm*. The frequency range of an EMG amplifier (bandpass settings) should start from *10 Hz* high-pass and go up to *500 Hz* low-pass, with Landmark's energy ranging from *50 to 150 Hz*. Any Notch filtering (to cancel, e.g. power line noise) must be avoided because it destroys too much signal information. [11]

2 Overview of the current state of the art

This chapter presents an overview of the current state and summarises it in detail as the current state of the thesis work and the initial conditions for its solution. It defines the problem to be resolved in this thesis work.

2.1 Available commercial solutions

The Digitimer D440 Isolated Amplifier is a low-noise solution for human EMG studies, specifically nerve excitability-related. A Driven Right Leg (DRL) circuit significantly enhances low-noise performance, reducing common-mode interference. The D440 features an amplification range of x100 to x20k. The gain, filter and mode settings for individual channels are adjusted using Digitimer's "virtual front panel" software or other software via a component object mode(COM) interface.

Figure.2.1- D440 EMG Amplifier

This amplifier has in each channel an Input impedance of 1 GΩ, a Common Mode Rejection *of 132dB @ 10Hz, -130dB @ 50Hz, -126dB @1kHz,* and a Driven Right Leg' system with adjustable gain for lower noise. Its *Low-cut filter is selectable between*

0 (DC), 0.159 Hz, 1Hz, 3Hz, 5Hz, 10Hz, 30 Hz, and 50Hz for -3dB and is first order. Also, its *High-cut filter* is Selectable between *1000Hz, 3000Hz, 5000Hz, and 10kHz* for -3dB and are second order, low phase shift Bessel style filters.

Despite these excellent qualities described in this section about this EMG amplifier, its market price is very high. Also, it uses a relatively large power supply and physical size. It's also made up of a lot of different parts.

The MyoWare 2.0 Muscle Sensor Development Kit includes MyoWare 2.0 ecosystem sensors and accessories used to measure and visualise muscle activity in the Human Body. Depending on the configuration, visualisation of the muscle parameters in action using the MyoWare 2.0 LED Shield overlay display or reading the raw values on the analog output using an Arduino -compatible microcontroller. The modules are equipped with **snap connectors**, thanks to which the MyoWare overlays can be stacked.

Figure 2.2-MyoWare 2.0 Muscle Sensor Development Kit - Medical Sensor Kit - SparkFun KIT-21269.

The drawback of these Myoware sensors is that one board has a fixed frequency of operation since there is no filter knob to adjust frequency to any desired range for a more effective EMG signal analysis. Future work should design a single board that can measure different biopotential signals.

2.2 Problems in the Measurement of biomedical signals

Problems in the Measurement of biosignals can be caused by the fact that EMG signals are very weak by their nature. Another factor which can cause the problem is a malfunction of the sensors. This section will discuss two issues: leakage currents and noises arising during the EMG signal measurement.

The stray resistance path between the measurement circuit and the nearby voltage source generates leakage currents. The permissible leakage current under normal conditions is *0.5mA and 1mA* under a single fault condition. The leakage current can be hazardous for patients and medical workers if it exceeds the permissible safe limit because only a small current can flow through the Human body.

Significant errors can be caused by noise sources such as magnetic fields, ground loops, and others. All real-world signals have noises. As mentioned above, noise can occur due to sensor defects or insufficient connection between sensors and the human body. The voltage errors arise because of the magnetic field in two conditions. The first condition is that the magnetic field changes with time. The second condition when the noise occurs is a relative motion between the field and the circuit. Voltages in conductors can be produced from local AC currents brought on by components in the test system or from the movement of a conductor in a magnetic field.

EMG signals artefact

Ambient noise. Ambient noise comes at various frequencies, but the most prevalent electrical noise in the EMG signal is *50 Hz or 60 Hz***,** which corresponds to power line noise. This noise can be minimised using a differential amplifier with a CMMR minimum value of *100 dB at 50/60 Hz*, Shielding electrode leads, and proper skin preparation. Common-mode interference is also reduced by incorporating a suitable leg drive circuit into the front-end of the device. Because the EMG signal's primary energy is in the

50– 150 Hz region, several experts advise against using a *50 or 60 Hz* notch filter because it partially removes frequency components next to the undesired ones.

Motion artefact. The movement at the contact between the electrode's detecting surface and the skin causes this form of noise. It has a *1–10 Hz* frequency and a voltage equivalent to the EMG's magnitude. This noise can be reduced by using high-pass filtering frequencies in the *1–10 Hz* range. As previously stated, skin preparation can help lower electrode-skin impedance while reducing motion artefacts. An electrode linked to an operational amplifier with high input and low output impedance is superior for motion artefact attenuation. This design will have a high impedance at the electrode and a low impedance at the cable as an impedance transformer. The noise is reduced by the displacement current flowing through low impedance to the ground. Furthermore, because the electrode-amplifier functions as an impedance transformer, there is less skin preparation needed

DC offset potential. Oil secretions and dead skin cells increase resistance on the skin's outermost layer, causing DC voltage potential production of up to *200–300 mV* during skin and electrode contact. All electrodes have a DC potential, which can be reduced with adequate skin preparation. With sufficient preparation, contact quality is often reduced. There are no standard processes; the degree of skin preparation is determined by the application and desired quality of the acquired data. Skin cleaning mainly entails removing dead skin with particular abrasive and conductive pastes or washing the skin with fine sandpaper and alcohol swabs. High electrode-skin impedance, if not addressed, can result in signal amplitude decrease and waveform distortion.

Muscle crosstalk. Muscle crosstalk occurs when another muscle generates a signal recorded over one muscle and sent to the recording electrodes. Crosstalk can be reduced by carefully selecting electrode size and inter-electrode distances and strategically placing electrodes. Crosstalk is less common when inter-electrode spaces are less. However, excessively short distances can result in electrode shorting (e.g., due to sweat). The suggested inter-electrode length or the electrode's radius is typically *1–2 cm*

Inherent noise.

The electronics instrumentation's inherent noise. Any electronic device will produce noise in the thousands of Hertz range. Modern electronics tend to have noise smaller than *1.5 mV RMS* (relative to the input) over the *20–500 Hz* band, although this noise cannot be eradicated.

After an extensive review of the state of the art of the EMG amplifier and upgrade to existing devices, particularly to [27]. This thesis aims to design and implement a cost-effective, portable, easy-to-use, low-power EMG amplifier to measure myopotential signals.

3 Aims

The primary aim of this thesis is to design a practical EMG device which can be used for myopotential surface measurements.

The objectives of the thesis are subdivided into

1. **Designing of the EMG amplifier circuitry**; After careful planning, the circuit schematic will be implemented using Eagle's software. This schematic will be converted to PCB.

2. **Implementation of the EMG amplifier circuitry**; The circuit implementation will be done by carefully assembling all relevant components on the PCB.

3. **Testing the implemented solution; After** assembling all components, each component on the PCB will be tested for functionality using a multimeter waveform generator and the oscilloscope. During the final testing, the EMG amplifier will be correctly connected to the Arduino board to digitise the analog signal received from the analog pin of the EMG amplifier. The Arduino board will be connected to a PC where the EMG signal will be displayed, confirming the functionality of the EMG amplifier.

4 Methods

This section focuses on the work structure used to implement this thesis. The thesis had a top-down approach (see Figure 4.0). An overview and architecture based on the requirements of this thesis EMG system were established and divided into functional blocks. These blocks were then implemented separately and eventually integrated.

The EMG system consisted of all these available blocks. The finished product will be experimentally tested and troubleshot until the requirements have been met.

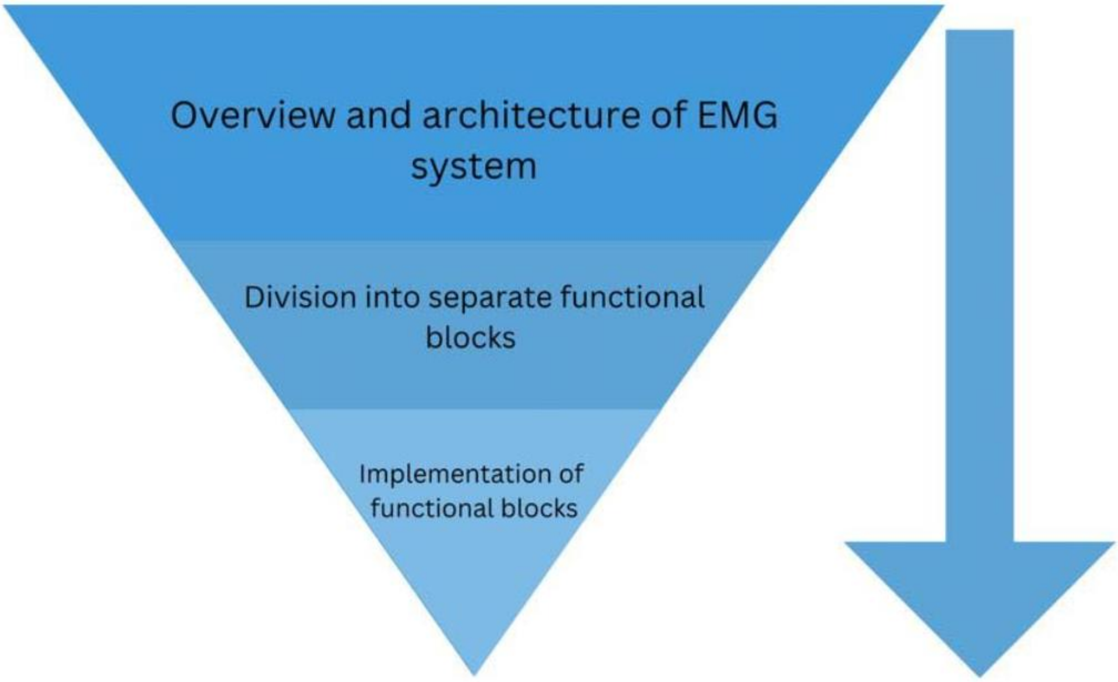


Figure 4.0 - Research process, top-down approach

4.1 Architecture of the EMG System

This section covers the electronic review of the EMG system consisting of a review of the EMG system block Schematic, EMG electrodes, signals amplification, different noise filtering circuitry types, Arduino Microcontroller and Arduino IDE.

The amplifier's block amplifies the signal, and the filter-block band pass the signal to get an EMG signal sensitive to muscle contractions and expansions. After the filter block, the signal is sent to the data acquisition block, in which the signals are stored in a computer using MCU.

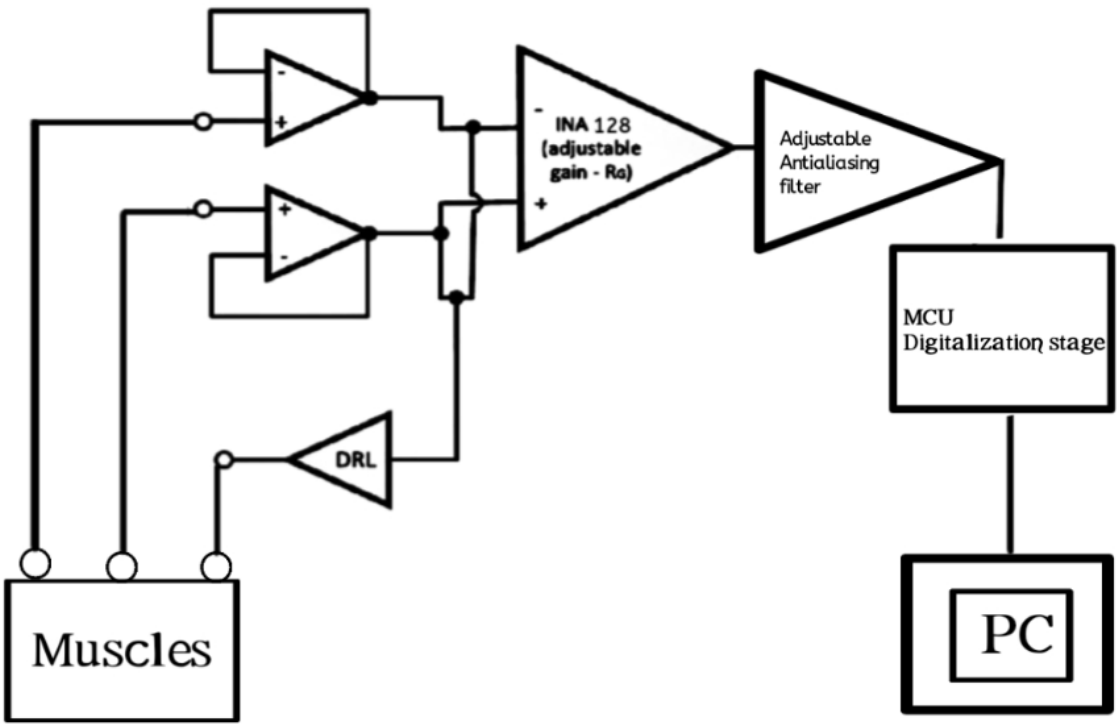


Figure 4.1 depicts the circuit's block diagram

The Electrodes

The electrode's quality and nature directly affect the quality of the EMG signals. There are mainly two types of electrodes in the market, non-invasive surface electrodes and invasive inserted electrodes (wire or needle) used for EMG signal detection. The surface electrode has two categories, passive and active.

Fig 4.2a- Active electrode with cables

Fig 4.2b- Passive electrode with cables

The passive electrode has a conductive detection surface touching the skin. In contrast, the active electrode has a differential amplifier with a passive electrode to reduce the effects of capacitance coupling and provide a very low output impedance rather than transmitting the signal to the amplifier through long lead wires. The advantage of an active electrode is the reduced capacitance coupling, and the very low output impedance will not introduce significant noises from the power line and cable movement artefact [2].

Instrumentation Amplifier

A closed-loop gain block with a differential input and a single-ended output is known as an instrumentation amplifier (In-amp). (with respect to a reference terminal). Usually, the impedances of the two input terminals are balanced and have high values. The input bias currents are generally low, typically *1nA* to *50nA*. As with op-amps, output impedance is very low, especially at low frequencies.[27] The gain of these devices is set by only one resistor if it is not present internally, which is isolated from the terminal inputs. Although Op-amps, differential amplifiers, and In-amps provide common mode rejection, Op-amps are not designed to prevent the common mode signal from appearing in the output. The In-Amps are the best choice when extracting weak signals because they only amplify the difference between the input terminals while rejecting common signals to both. The instrumentation amplifier performs differential amplification by subtracting the voltages *V1* and *V2*. This way, the noise signal common at *V1* and *V2* (electrode inputs), e.g. power line interference, etc., are eliminated. The tendency of a differential amplification to reject signals common to both inputs is determined by the common-mode rejection ratio (CMRR), i.e., the Common mode rejection ratio (CMRR) measures how well an operational amplifier can reject noise present on both inputs [4]. Currently, the best CMRR achievable with current technology is around *120 (dB/Octave @ 50Hz,* for example)[4].

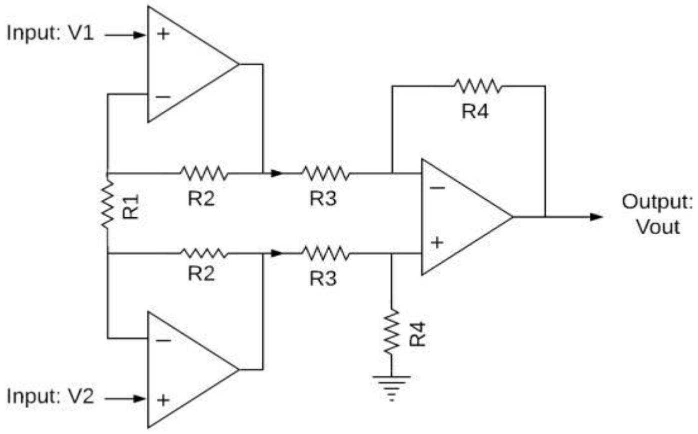


Figure 4.3 - Instrumentation Amplifier

The gain A and output voltage V_O of an instrumentation amplifier can be expressed

$$\mathbf{A = \left(1 + \frac{2R_2}{R_1}\right) \times \frac{R_4}{R_3}} \qquad (4.1)$$

$$\mathbf{V_o = (V_2 - V_1) \times A} \qquad (4.2)$$

The values of *R3 and R4* are usually set to be equal since a high gain in the second stage gain is likely to amplify noise.

Driven Right Leg

The driven right leg (DRL) circuit has initially designed for interference reduction in ECG recordings and later applied to other biopotential recordings [28]. The system is based on a feedback circuit that drives the common mode voltage back to the patient's body, amplified and phase reversed by *180* ^{o}. This feedback loop improves CMRR by an amount equal to (1 + A), where A is the closed loop gain of the feedback loop [29]. A DRL circuit implemented in the EMG system prototype is used to reduce the patient body's common mode and improve the Measurement but also provides the third electrode whereby the bias current of the amplifier had to flow due to the presence of the DC rejection filter. The DRL circuit comprises an operational amplifier, a *1nF* capacitance to reduce high- frequency gain and possible instability [28] in parallel with a *1k*Ω resistor, and a final resistor of *1M*Ω in between the DRL circuit output and the Human body. This resistor was chosen with a high value to protect the patient (in case of a fault condition where the patient's body is accidentally connected to the system ground [29] and although the IEC standard allows a lower resistor value, it was oversized for prototype construction purposes (in future prototypes and the final version of the EMG acquisition system, this value can be lowered down until *100k*Ω [29] to improve the CMRR of the entire system further).

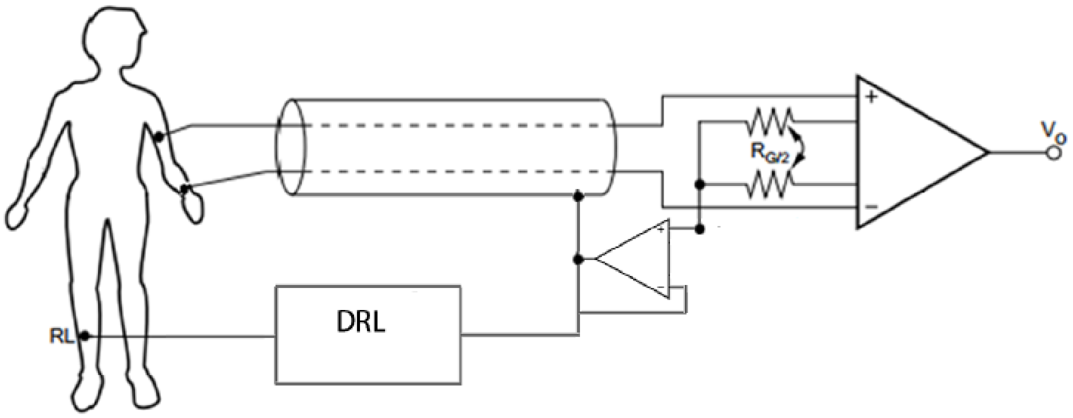


Figure 4.4- Representation of how to drive the shields in each Measurement Channel.[30].

One primary concern about the DRL circuit is the possible instability it can cause. In any closed loop, oscillations may appear if the *Barkhausen stability criterion* is not satisfied. However, if proper care is taken, the DRL may significantly reduce the power line interference.

Amplification

The next step is amplification. Myoelectric signals must be amplified to a suitable level for analysis and further processing. Figure 4.5 is an example of a non-inverting amplifier in contrast to an inverting op-amp, which produces a negative gain. The input signal is applied straight to the non-inverting (+) terminal, resulting in a positive gain, which means the input signal won't be inverted on the output. The gain A of a non-inverting op-amp is determined by equation 4.3. The feedback loop with the *Rf – R2* voltage divider network applies a small part of the output back to the inverting (-) terminal, stabilising the output considerably. Technically, an op-amp amplifies the difference in voltage between the two input terminals.

$$A = 1 + \frac{R_f}{R_2} \quad (4.3)$$

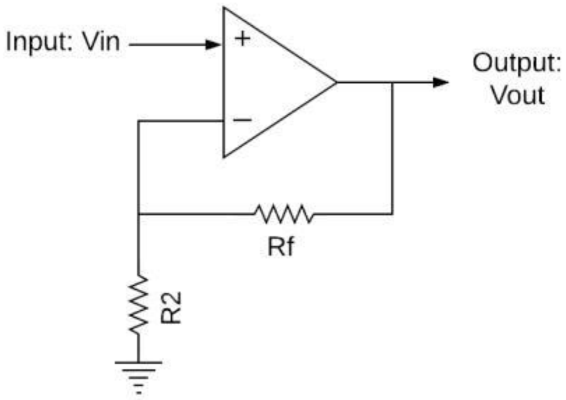


Figure 4.5 - Non-Inverting Operational Amplifier

Filtering

Filtering is a way to attenuate specific frequencies. In an EMG system, filters remove high and low-frequency components due to capacitive coupling, inductive coupling and electromagnetic interference (EMI). It's possible to implement filtering with Op-Amps, which gives better filtering quality and allows amplification. These filters are called Active filters or active Op-Amp filters. A filter can also have a specific order, a number that identifies to what degree a filter attenuates a signal and is measured in dB/decade. Three distinct filter types are widely used.

Low pass filter

Low pass filters "pass" frequencies below cut-off frequency *fc* and attenuate frequencies above fc. Typical first-order low-pass filters consist of a resistor and a capacitor, known as *RC* circuits [27]. An RC filter is a first-order filter that attenuates *20dB/decade* and has a cut-off frequency of 3dB below the maximum gain. The gain A and the cut-off frequency *fc1* of the 1st order low pass filter can be determined by;

$$A = -\frac{R_2}{R_1} \quad (4.4)$$

$$fc_l = \frac{1}{2\pi R_2 C_1} \tag{4.5}$$

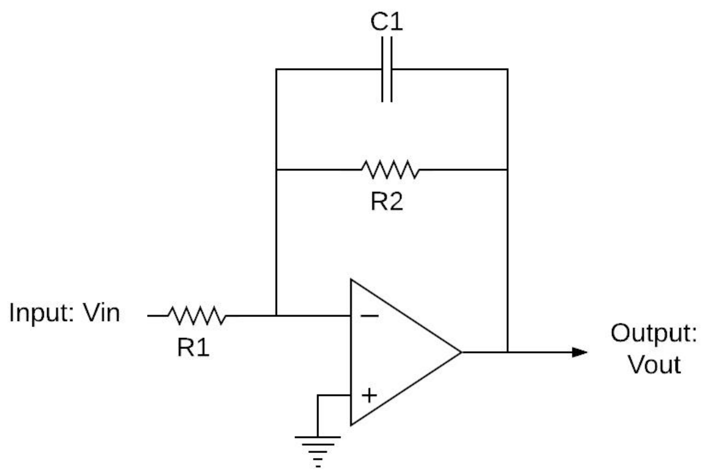


Figure 4.6-Active inverting RC first order low pass filter

Integrator

An integrator (figure 4.6) is a circuit that performs integration: The output is the integration of the input over a set amount of time. An integrator circuit consists of both passive and active components. The purpose of the integrator is to sum the infinitely small quantities in the waveform signal over some time. In this thesis, it is used in tandem with a full-wave rectifier to create a stable and legible DC signal [13]. An extra resistor, *R2,* added gain, as shown in Figure 4.6 above.

Bandpass filter

A bandpass filter (figure 4.7) combines a high pass filter and a low pass filter. The filter has two cut-off frequencies, one for lower and one for higher. The bandpass filter allows frequencies in the passband to have high gain and attenuate outside the passband. The width of the passband is referred to as the bandwidth; a high bandwidth passes a more range of frequencies, and a small bandwidth only allows a few frequencies to pass [29]. The *RC* pair determines the cut-off frequencies (see Equations 4.7 and 4.8). A first-order active inverting bandpass filter applied gain and attenuated frequencies below

15 Hz and above *723 Hz*. By choosing resistors *R1* and *R2* (see equation 4.6), the gain was set to 22 linear scales and cut-off set using the equation for *fc1* and *fc2*. Furthermore, the inverting bandpass in Figure 4.7 inverts the input signal resulting in a negative gain on the output, an essential factor in the EMG circuit.

$$A = -\frac{R_2}{R_1} \tag{4.6}$$

$$fc_1 = \frac{1}{2\pi R_1 C_1} \tag{4.7}$$

$$fc_2 = \frac{1}{2\pi R_2 C_2} \tag{4.8}$$

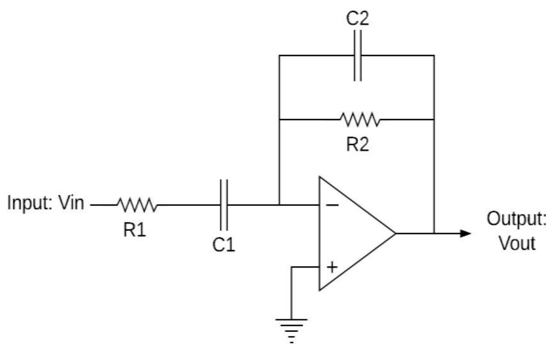


Figure 4.7 - Inverting Band Pass Filter

AC coupled instrumentation amplifier circuit

This circuit converts a DC-coupled input into an instrumentation amplifier's AC-coupled output. Its output is fed back through an integrator; the integrator's output is used to modulate the reference voltage of the amplifier. This creates a high-pass filter which effectively eliminates the output offset. This circuit avoids the need for large capacitors and resistors on the input, which can significantly degrade CMRR due to component mismatch.

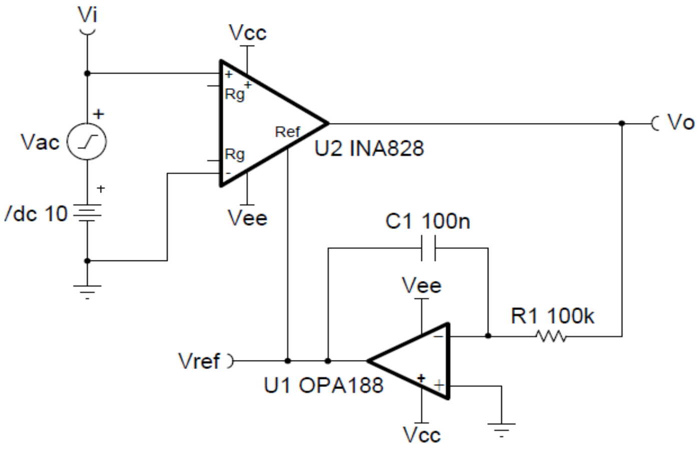


Figure 4.8-AC coupled instrumentation amplifier circuit [31]

Arduino Microcontroller

The main functional component of the device is the microcontroller, which ensures the program's running and data collection and communication between other functional blocks and the user. Arduino comprises a physical programmable circuit board (often called a microcontroller) and software, or Integrated Development Environment, that runs on the computer to write and upload code to the circuit board. The software development IC is implemented on the Arduino Uno board, which has an Atmel microcontroller; ATmega328P is selected as the microcontroller of this system mainly because of its high computing power, large memory, and several connectable peripherals. In addition, this microcontroller can fulfil the requirements of low-power consumption. ATmega328P has a small *5mm x 5mm* QFN32 package. In the active mode, the power consumption is *0. 2mA at 1MHz* and *1.8V,* while it consumes only *0.1 µA* in the power-down mode.[22]

The main functions performed by the microcontroller in the device are:

- data collection from frond-end analog measurement circuit,
- record the measured values on the SD card,
- communication with the user using buttons and a display,
- save the configuration files for displaying the web page with the results,

The connection of the microcontroller to the circuit is shown in Figure 4.9. The meaning of each output is described in this section. The output pin's names correspond to those in the electronic schemes presented in this section. Some selected characteristics of the microcontroller are;

Operating Voltage *+1.8V to +5.5V*

23 number programmable I/O Lines

CPU - 8-bit AVR

Communication Interfaces - Master/Slave SPI Serial Interface, Programmable Serial USART, Two-Wire Serial Interface

ADC Module - 6Channels, 10-bit resolution

Timer Module - Two 8-bit Counter, One 16-bit counter

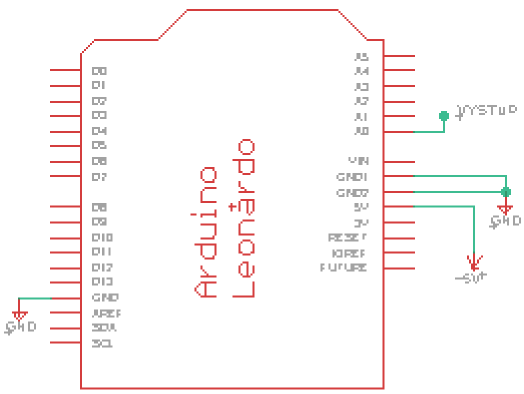
Program Memory Type - Flash(32Kbytes)

Internal Oscillator - 8MHz calibrated internal Oscillator

CPU Speed - 1MIPS for 1MHz

RAM - 2Kbytes internal SRAM and 1Kbyte EEPROM

For easier programming, the ESP-WROOM-32 development board was chosen for implementation with this microcontroller. It mainly contains a USB-UART converter (specifically CP2102), so it is possible to program the microcontroller directly from a PC connected to the USB micro board by a cable.



4.9- Figure wiring of microcontroller

Arduino Uno

The Arduino Uno is a great choice, and it has 14 digital output/input pins (6 of which can be utilised as Pulse width modulation PWM outputs), six analog inputs, a USB connector, a power jack, and a reset button. It can be connected to a computer with a USB cable.

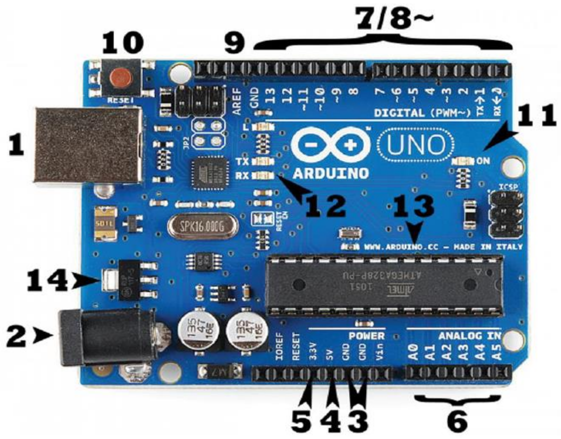


Figure- 10 Arduino Uno

Power (USB/Barrel jack)

Every Arduino board needs a means to be connected to a power source. The Arduino UNO can be powered by an USB cable from the computer or a wall power supply end in a barrel jack. In Figure 10b above, the USB connection is labelled **(1)** and the barrel jack is labelled **(2)**. The USB connection is also a means of loading code onto an Arduino board.

Pins (5V, 3.3V, GND, Analog, Digital pins)

The pins on the Arduino are where wires connections can be constructed to a circuit (probably to contact with a breadboard and some wire). Usually, they have black plastic 'headers' that allow plugging a wire into the board. The Arduino has different kinds of pins, each of which is labelled on the board and used for various functions.

Selected Arduino pins

- **GND (3)**: Short for 'Ground'. On the Arduino board, several GND pins can be utilised to ground a circuit

- **5V (4) & 3.3V (5)**: The 5V pin supplies 5 volts, and the 3.3V pin supplies 3.3 volts of power. Most simple components used with the Arduino run very well at 5 or 3.3 volts.
- **Analog (6)**: Analog In pins are located in the section of the UNO marked A0 through A5 with the label "Analog In.". These pins can read an analog signal from sensors and transform it into a readable digital value.
- **Digital (7)**: The digital pins are on opposite sides of the analog pins (0 through 13 on the UNO). These pins can be utilised for digital output and input, such as detecting button presses (like powering an LED).

Arduino Software

Arduino IDE is open-source software, where IDE stands for Integrated Development Environment. This official software introduced by Arduino is primarily used for writing, compiling and uploading code in almost all Arduino boards.

The Arduino Uno contains a programmed microcontroller on the board that accepts the information as code. The main code, often called a sketch, written on the IDE platform will generate a Hex File, which is then transmitted and uploaded to the controller on the board. The IDE environment mainly contains two essential parts: Editor and Compiler. The former is used for writing the required code and later for compiling and uploading the code into the designated Arduino board. This Arduino IDE environment supports both C and C++ languages.

4.2 Materials & Equpiment Used

This section presents the list of components, materials and Equipment used for the construction and testing of the EMG amplifier

Table 4.2- depicts a list of components used

Abbreviation	Value	Other Components
Resistors		3 – T. Block connector with two inputs
8	100 kΩ	3 – T. Block connector with two inputs
1	470 kΩ	8 – Socket for Op Amps
1	390 kΩ	8 – Sliding switches
1	39 kΩ	
1	200 kΩ	3 – INA122P
1	20 kΩ	
1	10 kΩ	
Capacitor		3 – MCP6022P
4	100nf	
1	10nF	Arduino Uno
1	3.3 nF	Microcontroller
1	680 nF	PC
1	33 nF	

Table 4.3 shows a list of Equipment used for testing the EMG amplifier

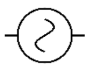
Device	model	Manufacture	Serial number / Inventory number	Symbol
Function waveform Generator	AFG3102	Rigol	DS01052B	
Oscilloscope	DSO1002A	Agilent Technologies	CN:54263892	

Figure 4.2.1-- Digital Storage Oscilloscope

Figure 4.2..2- functional waveform generator

4.3 Construction of the Circuit

After designing the circuit, the next step is the construction. The prototype's construction process began once the design was complete and reviewed by this thesis's supervisors. Instead of using breadboards for rapid circuit construction, the prototype was done directly in a custom-designed PCB. The construction processes started with the PCB layout design and finished with the manual soldering of each component in place for testing and validation. The steps followed for the PCB construction were:

At first, after careful planning, the conceptual ideal of the EMG system circuit was drawn on paper schematics and was followed by component optimisation, performed by considering accuracy, size, and market availability: Eagle's program was used for schematic entry of the designed circuit, allowing drawing and route of the actual PCB layout. However, many of the devices selected as parts of the EMG system (the blocking capacitors, for example) were unavailable in the Eagle's library and were created for the first time. A Gerber file was generated in the Eagle's program following simple steps. The Gerber file was sent to the JLC PCB manufacturer to produce this EMG amplifier PCB. Next was assembling the components onto the board. As the PCB was ready, Active and Passive Electronic Components were soldered into it before it could be used to measure myopotential. PCB assembly was implemented manually using two techniques. Through-Hole Mount, Component leads were inserted into PCB holes drilled in this installation style. This style was used to assemble all components except the blocking capacitors, which sit under each amplifier's socket. Surface Mount Technology (SMT) Surface Mount Technology or SMT is a PCB assembly process for SMD electronic components. SMD components don't have leads or legs. They were mounted on the surface of the circuit board. This technique was used to assemble the blocking capacitors.

The whole wave soldering PCB Assembly Process includes the following steps:

I. Inserting of electronic components: The component's leads were inserted through their respective holes on the PCB

II. Flux application: Flux was applied on the surface of the hole, this is to enhance the firm holding of components in place

III. Preheat: Heating the joint conducts the iron's heat to the PCB to prepare the board for soldering. With a small amount of solder on the iron's tip, there was touching of the tip to the component lead and board. Connecting the tip with both these pieces is critical to ensure the solder sticks them together and heats them properly. The iron held on the joint for a few seconds, as overheating the joint will cause bubbling, thus avoided.

IV. Hand Solder: The solder was applied directly to the heated joint. After it was heated thoroughly and correctly, the hot joint was enough to melt the solder and begin to flow freely. Continuous touching of the solder strand to the joint until a small mound had formed, usually in a cane shape.

V. Cleaning: the PCB was cleaned using common cleaning pc materials

VI. Testing: The printed circuit board assembly PCBA is cleaned and checked when the wave soldering is complete. It was reworked, often done by hand, if any faults or solder joint defects, such as Pin Hole or blow hole wave soldering defects, were discovered.

After the PCB assembling, Interfacing the EGM Amplifier with Arduino was done. Both are stacked on top of each other to connect and to minimise space. The pin connections are shown in Table 4.3 below.

Table 4.3- shows the pins connections of Emg Amlifer with Arduino

EMG Amplifier	Pin Function	Arduino uno Connection
GND	Ground	GND
5.0V	5.0V power input	5V
OUTPUT	Amplifier Analog output	A0

Finally, the board was tested using three means. Firstly, each functional block tested its output and voltage supply to it. Secondly, The PCB was connected to the Arduino board, the input pins of the PCB were connected to the PC and the function generator, and the function generator sent a test signal via its coaxial cables to the input pins of the PCB. A written code, also known as a sketch, created on the IDE platform was uploaded to the controller on the board to digitise and display the test signal on the PC. Lastly, a human subject was used for this testing, and it started with wiping the skin with alcohol to remove dead skin and excess moisture. The 3-electrodes configuration was used in this thesis. The 3-electrodes format consists of one positive, negative, and reference electrode. The positive and negative electrodes are placed apart, resulting in a differential potential. This potential is what is measured in an EMG device. The reference electrode sets the common mode voltage for the differential Measurement. It typically carries a common-mode feedback component that attempts to attenuate or cancel low-frequency common-mode noise. The negative and positive electrodes were placed *4-5 cm* from each other along the length of the muscle fibres. The reference electrode was placed in a neutral zone. These electrodes are connected to the EMG amplifier connector pins. A written code was created on the IDE platform was uploaded in the controller on the board for digitisation and display on the EMG signal on the PC.

5 Results

This section presents the result of this thesis. It showcases the complete EMG system (analog and digital PCB), oscilloscope measurements, and digital circuits displayed in the PC. The measures provide a basis for this device's validity and reliability analysis.

5.1 Results of Each Functional Block

This section presents detailed results from implementing each EMG amplifier design stage functional block.

Surface Ag/AgCl electrodes

Surface Ag/AgCl electrodes were chosen over other standard electrodes due to their low half-cell potential (around *220 mV*), low and less drift of diffusion potential, temperature insensitivity, ease of use, economical, non-invasive, etc. ***Silver-Silver Chloride Electrodes*** have been used to detect the bio potential generated across two points due to muscle contraction. Usually, an electrolytic gel is applied to the electrode to improve its conductivity and low junction potential without causing skin irritation. Gelled electrodes contain a Silver-Silver chloride (Ag-AgCl) composite, an electrolytic substance that conducts electrons between electrodes and the skin. Disposable gelled EMG electrodes were used. Some skin preparations are required for measurements with gelled electrodes, as there must be good contact between the gel and the skin surface.

Protective resistors

The resistors *R9, R10* and *R11* are placed between the input pins (IN+, IN- and RLD) to electrodes to limit current injection to the subject. Also, the measured signal from the electrodes passes at the device's input through protective resistors, which protect the system from current spikes.

Buffer circuits

The voltage follower's primary goal is to provide the same amount of input voltage as the output voltage. The output impedance is made equal to the transmission line impedance. Thereby transmitting the same input signals to the output without depreciating the output signal. Its impedance-matching ability adjust the source or the load impedances to minimise the signal reflected from the load.

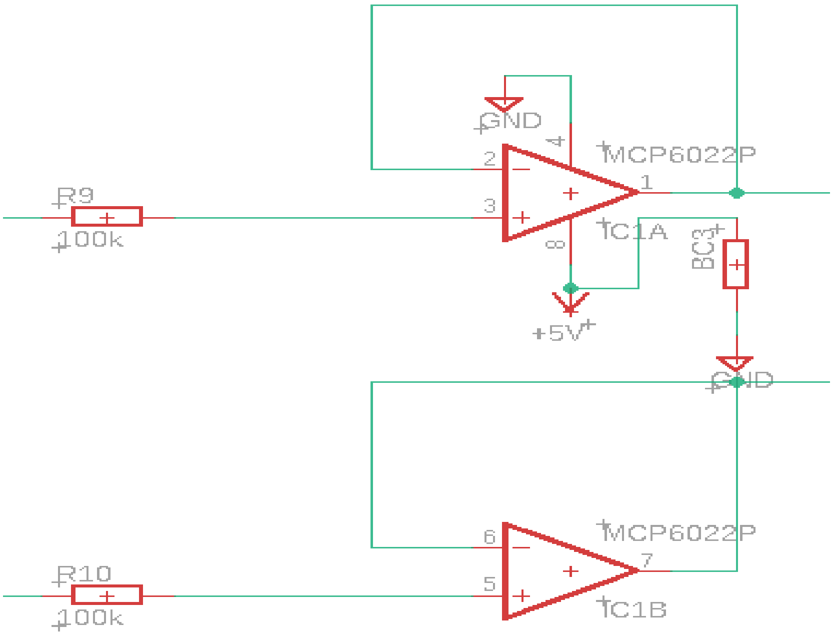


Figure 5.1- depicts the protective resistors connected to the buffer circuit.

The voltage follower aids in maintaining the voltage level from one circuit to the next. It saves the voltage source's signal. As the output resistance of a voltage follower is very low, its output load, INA122p, will receive a full-fledged signal (The voltage follower circuit's high input impedance allows it to accept even the weakest signal from the source without suffering any signal loss.

Driven right-leg circuitry

In this EMG amplifier recording system, the patient is not grounded. Rather, the right leg electrode is connected as shown in Figure 5.2. to the output of an additional op-amp. The common-mode voltage on the body is picked up by two averaging resistors, *R5* & *R6*, inverted and fed back through *R11* to the right leg. This circuit drives a minimal amount of current (less than *1 µA*) through the right leg to balance the displacement currents flowing in the body.

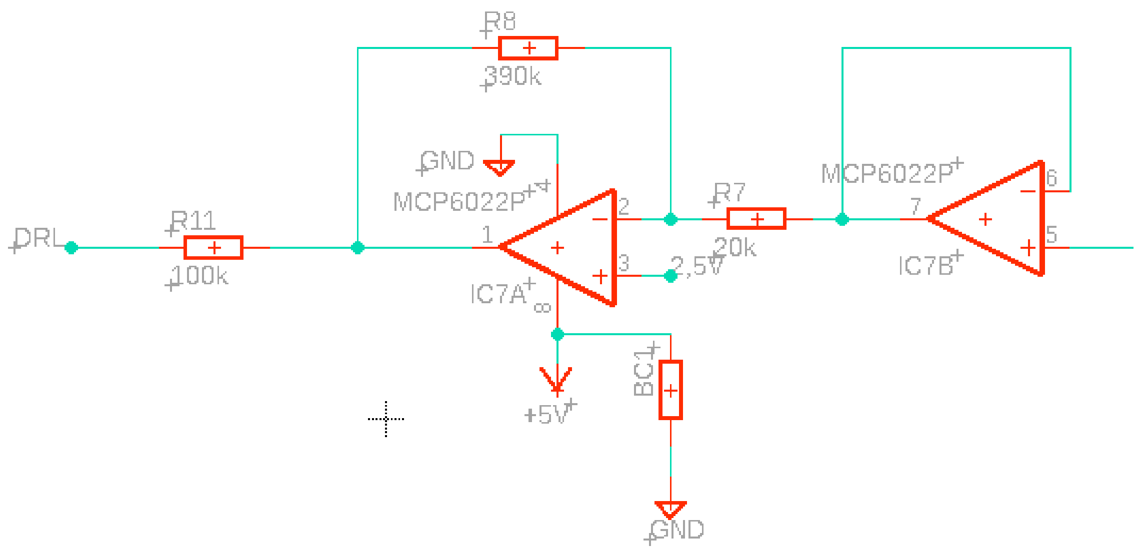


Figure 5.2- depicts the driven right-leg circuitry

The body, therefore, becomes a summing junction in a feedback loop, and the negative feedback from this circuit drives the common-mode voltage to a low value. The circuit additionally helps to increase the patient's safety. If an abnormally high voltage should appear between the patient and the ground due to electrical leakage or other means, the additional op-amp in the right leg circuit saturates. This ungrounds the patient since the amplifier can no longer drive the right leg. The resistance *R11* between the patient and the ground is usually several *K*Ω and is large enough to protect the patient. With a *100k*Ω resistor, for example, and a supply voltage of *10V*, the amplifier will saturate at a current of approximately *2 µA*.

INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA122 is exceptionally high, approximately 10^{10} Ω. However, the input bias current of both inputs must have a route. This input bias current is approximately *10nA* (current flows out of the input terminals). High input impedance means that there is an input bias current. However, the input bias current of both inputs must have a route. The input bias current measures roughly minimal with varying input voltage.

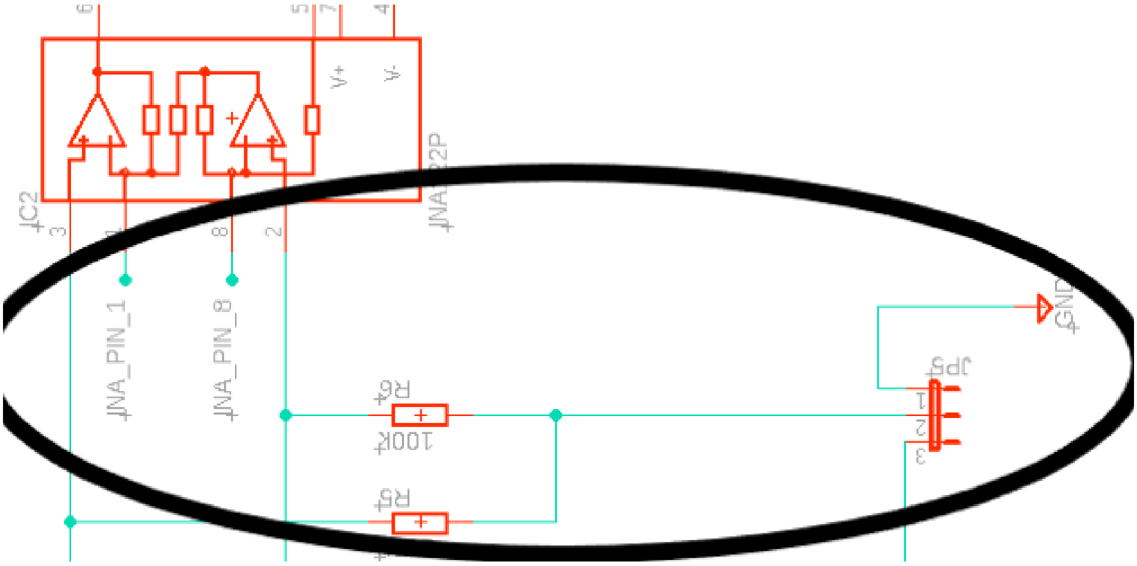


Figure 5.3 depicts the input bias current pathway

Input circuitry must provide a route for this input bias current for the proper operation of this device. Without a biased current path, the input amplifiers will get saturated when the inputs float to a potential higher than the INA122's common-mode range. With a higher source differential impedance of 1NA122, having a balanced input with two equal resistors gives the potential benefits of a reduced input offset voltage from bias current and better high-frequency common-mode rejection.

Pre-amplification

The INA122 from Texas Instruments was selected to implement the instrument amplifier. It is a precision instrumentation amplifier for precise, low-noise differential signal acquisition. This circuit is designed to amplify biomedical signals, and its gain (parameter G) can be precisely set by external resistance. This circuit excels in a low quiescent current (60μA).

The *RG* gain resistance has high accuracy, and the resistor signal is used for the active ground. The circuit's gain is given as,

$$G = 5 + \frac{200K}{R_G} \qquad (4.1)$$

The *RG* was implemented using three sliding switches to set the gain to any desired value of either *105,10* or 6.

High pass filter

A high pass filter was implemented via an AC-coupled instrumentation amplifier circuit. The output of the instrumentation amplifier is fed back through an integrator, and this integrator output is used to modify the reference voltage of the amplifier. This minimises any oscillations on the circuit, leading to overall circuit stability. Also, this creates a high-pass filter and effectively cancels the output offset. This circuit avoids the need for large capacitors and resistors on the input, which can significantly degrade CMRR due to component mismatch. The DC correction from output to reference is unity-gain. The integrator output can only correct for a signal within its input/output limitations; thus, the magnitude of DC voltage that can be corrected will degrade with increasing instrumentation amplifier gain. The lower cut-off frequency as fc using

$$fc_l = \frac{1}{2\pi R_1 C_1} \qquad (4.2)$$

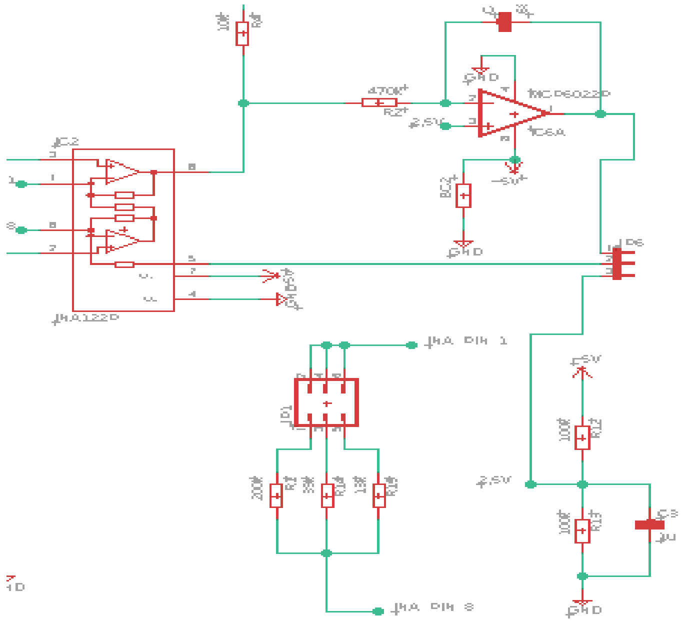


Figure 5.4- depicts the AC COUPLED INA122P amplifier

Low pass filter

A particular type of low-pass filter was implemented through an integrator circuit. This choice was influenced by the better linearity of its output waveform and the ease of obtaining selectable frequency circuitry.

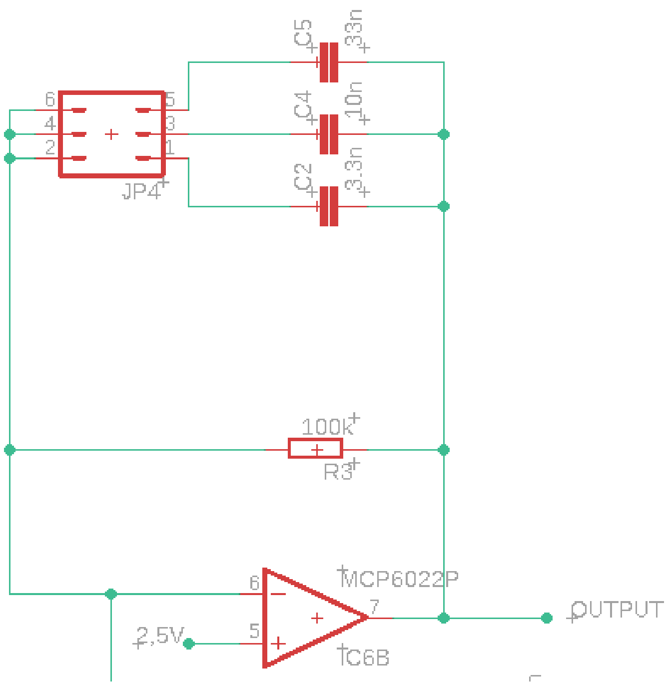


Figure 5.5- depicts the low-pass filter circuit

Switching between capacitors C1, C2, and C3, changing the frequency band of interest is possible. The gain (4.3) of the circuit is about 10, and The cut of frequency(equ 4.4) fc is calculated using calculated using the formula

$$A = 1+ \left(\frac{R_3}{R_4}\right) \tag{4.3}$$

$$\mathrm{f}c_l = \frac{1}{2\pi R_3 C} \tag{4.4}$$

Where *C could be* $C_{1.}$, C_2 *or* C_3

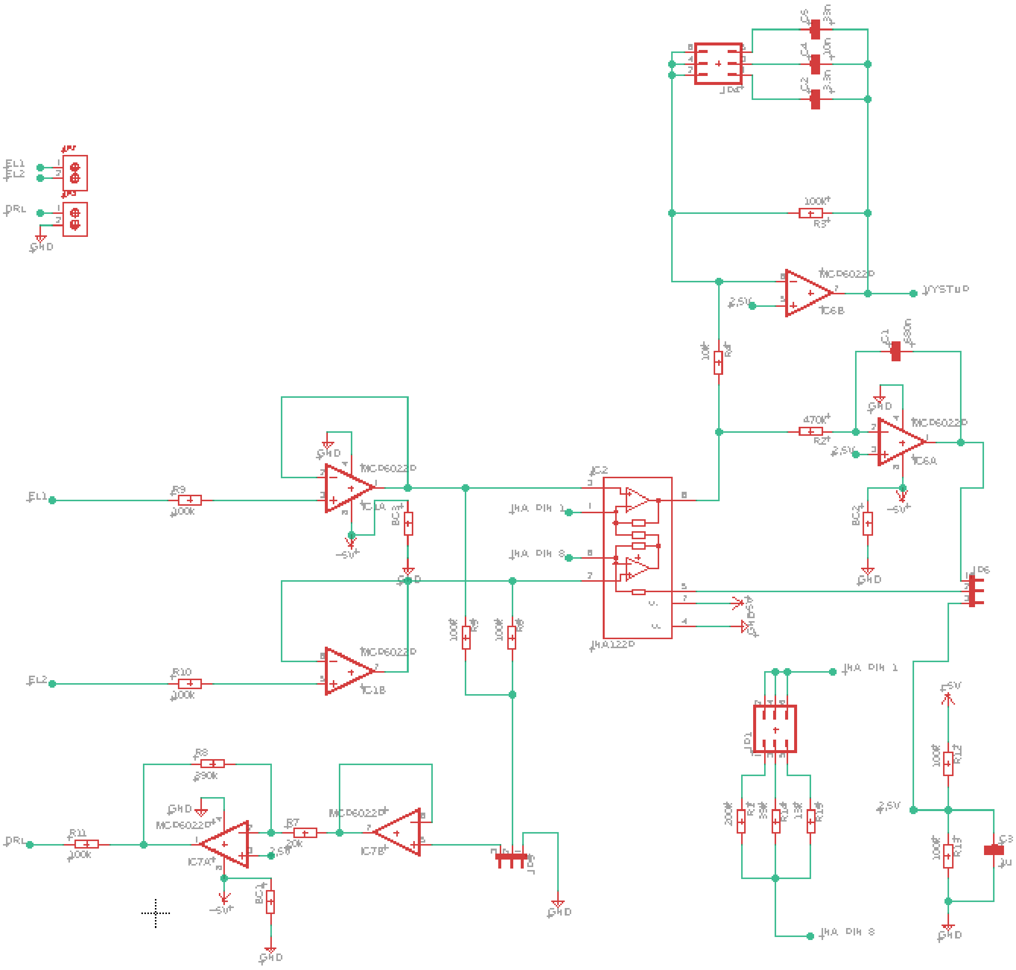


Figure 5.6- EMG acquisition system circuit

The PCB on which the circuit components are mounted must be considered carefully for good results in prototype construction. The practical considerations that most affected the final result in developing the EMG prototype are listed below in this section.

Tracks: The tracks between connections are as direct as possible without forming 90^0 curves or peaks. Two main characteristics were set: the width and the space between tracks and other PCB elements. In this prototype, the track width was fixed at 0.3mm by default). When drawing the tracks for the power supply, wider tracks were needed because of the higher current transport. Tracks are as short as possible to avoid parasitic effects, noise and interference pick-up.

Number of layers: The EMG prototype was constructed in a double-layer PCB. Two layers were used. These double-sided PCBs include top and bottom layers and traces/layers of conductive copper on both sides. The conductive copper and components are mounted on both sides of this double-sided PCB, leading to the trace's intersection or overlap. This double-sided PCB is best for realising high-density circuits and does not require point-to-point soldering.

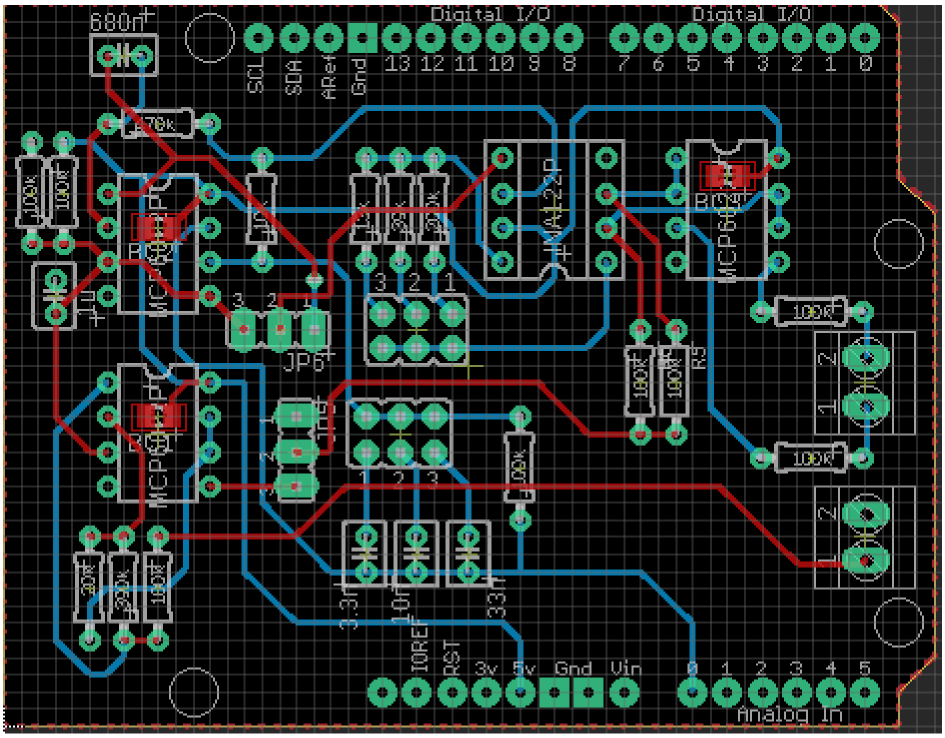


Figure 5.7a-depicts the top layer of the PCB schematic

This double-sided PCB gets traces on both sides by adding vias. The vias connect the components between the bottom and top layers.

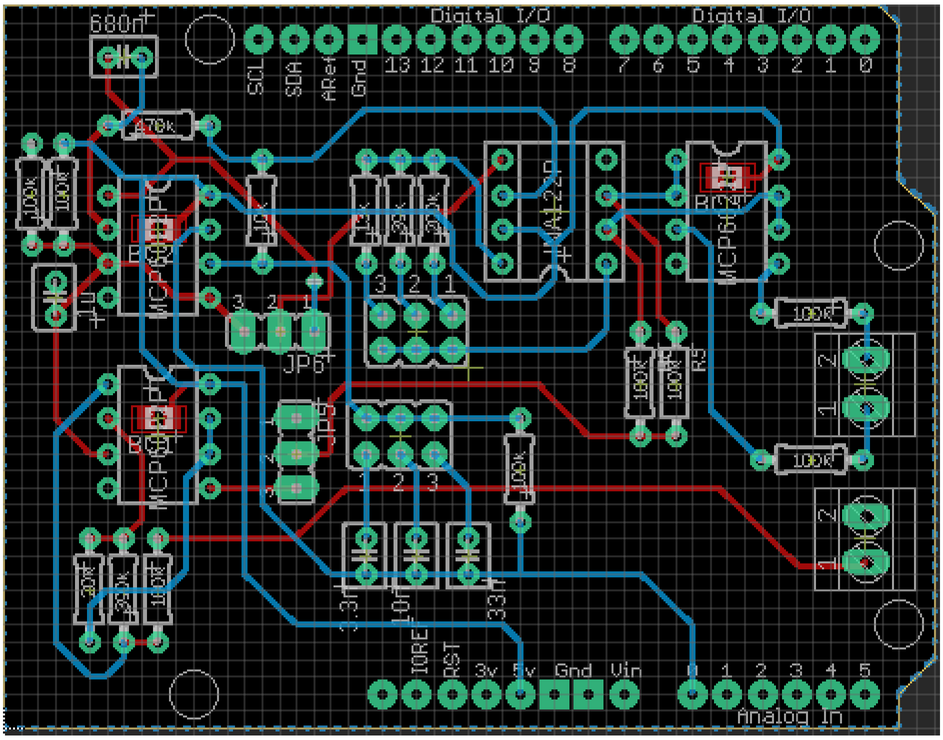


Figure 5.7b- depicts the Bottom layer of the PCB schematic

***Board structure*:** Some structural arrangements were followed to place the components in the PCB. The most convenient is by functional groups; in other words, all the components used for some specific purpose are placed together and not far away from each other. The blocks diagram presented in section 5.1, Figure 5.6 served as a guide to the component's placement; in that way, there was no unnecessary crossing between signals or back turns in the signal flow, helping to minimise track length and, therefore, noise and interference pick-up.

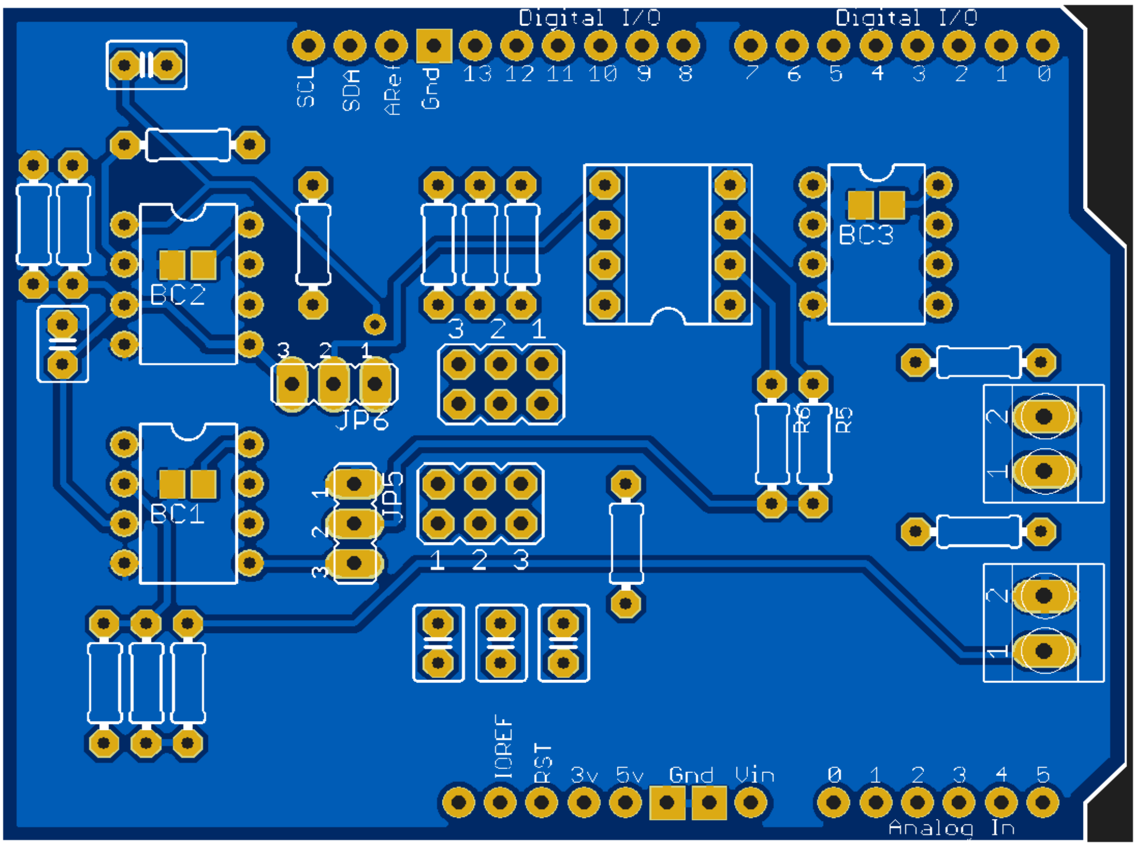


Figure 5.7c-depicts the top layer of the PCB

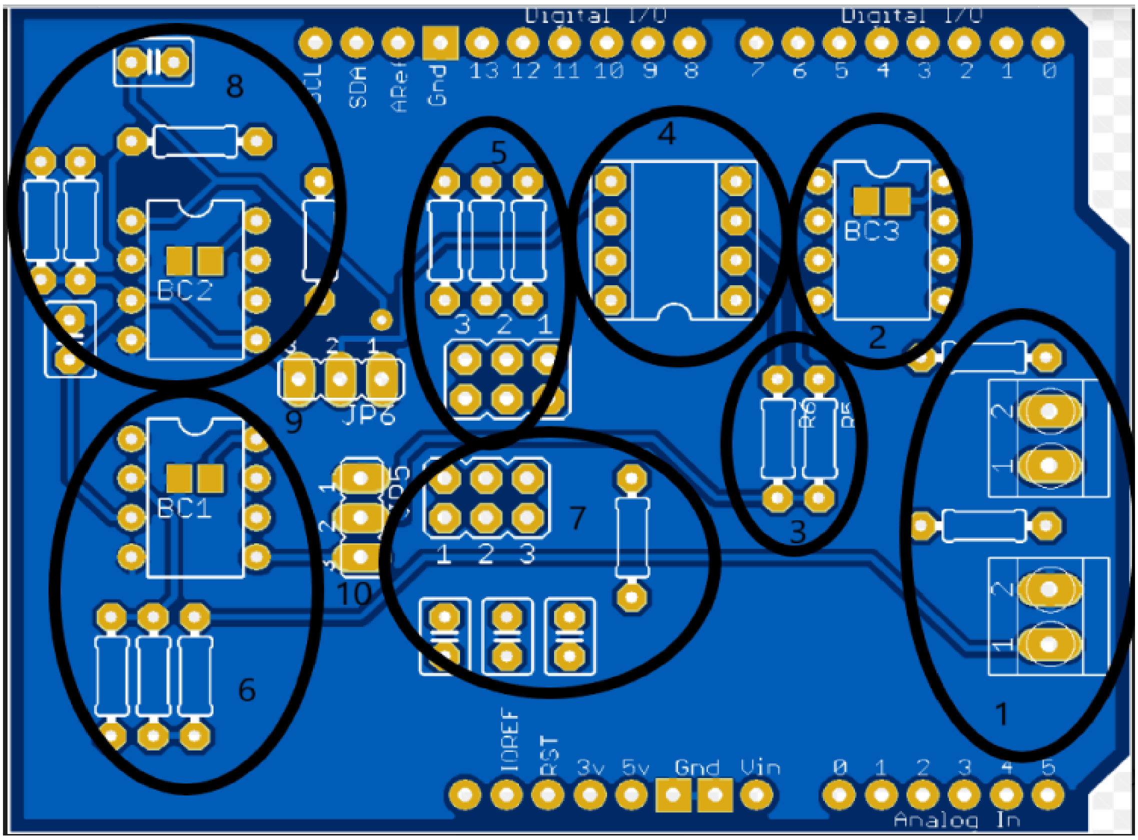


Figure 5.8d-depicts the top layer of the PCB with a detailed description

It can be seen how the signal flow determined the component placement: (1) input connector & protective resistors. (2) input buffer. (3) input bias current pathway. (4) instrumentation amplifier. (5) gain adjustment resistors & switches. (6) DRL stage (7) Filtering stage (8) Ac coupled instrumentation amplifier (9) switch for AC coupled instrumentation and ground pin (10)) switch for DR Land ground pin.

5.2 EMG Amplifier

The result was a fully functioning EMG device that could measure the

the activity of myoelectric signals transmits this data via cables to a display device. There were two PCBs: one for digital processing and transmission (digital PCB), also known as Arduino uno microcontroller and one for the EMG circuit (analog PCB) was constructed. They stack on top of one another for connection and to save space. The result of the EMG device can be seen in figures 5.2.1 - 5.2.3 below, including the EMG measurement sent from the EMG device to PC.

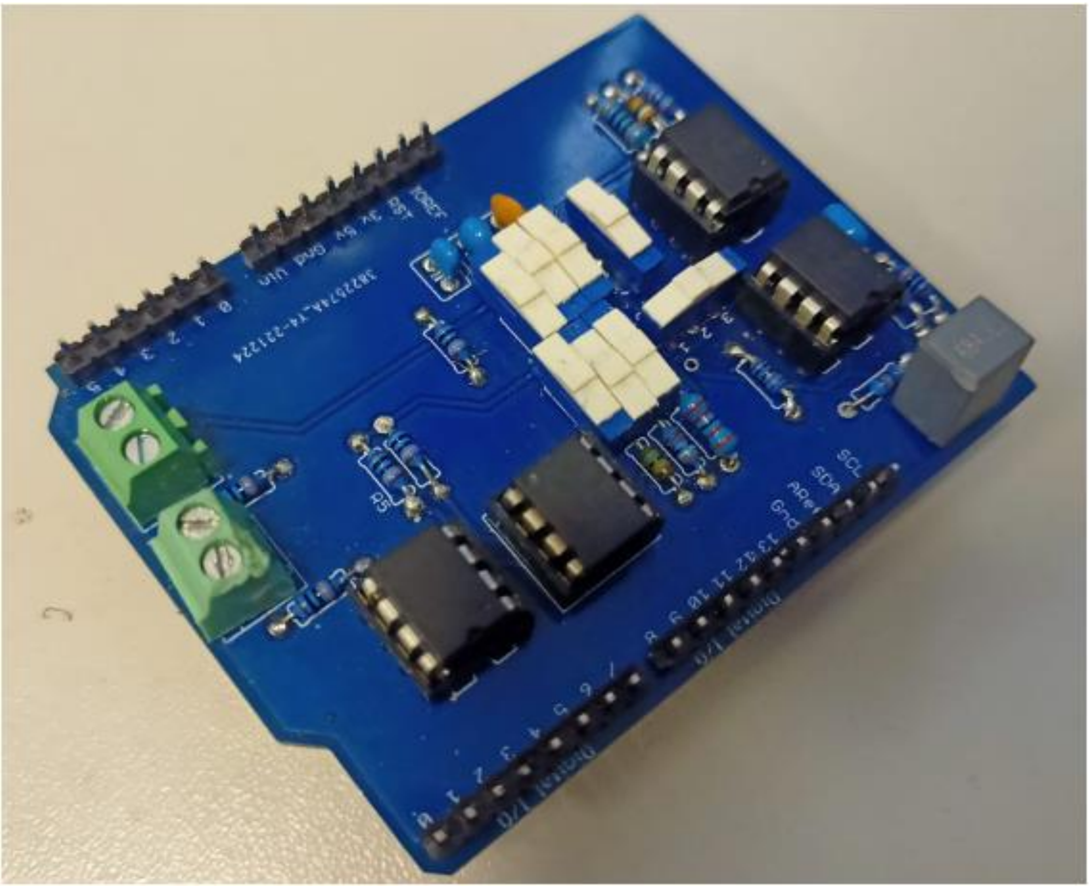


Figure 5.2.1 -Top view of Analog EMG amplifier

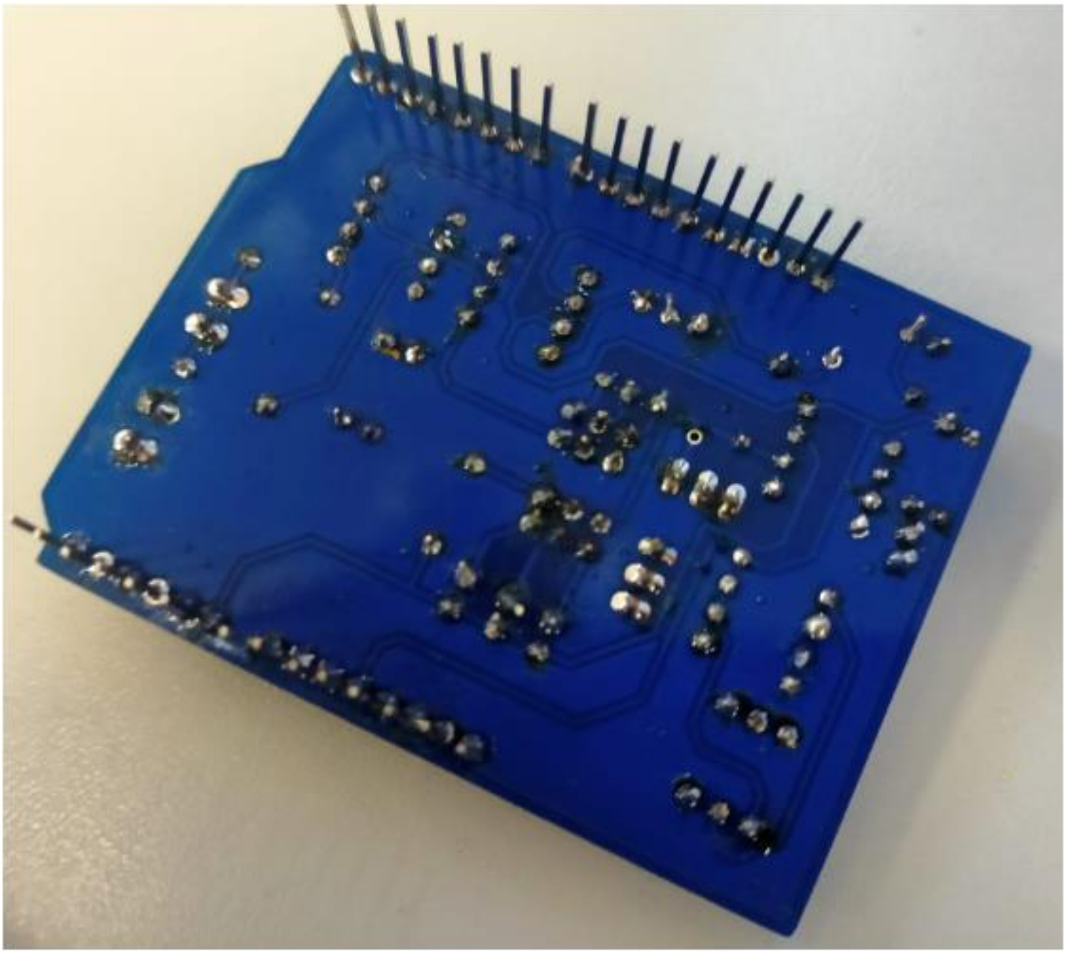


Figure5.2.2 -Bottom view of Analog EMG amplifier

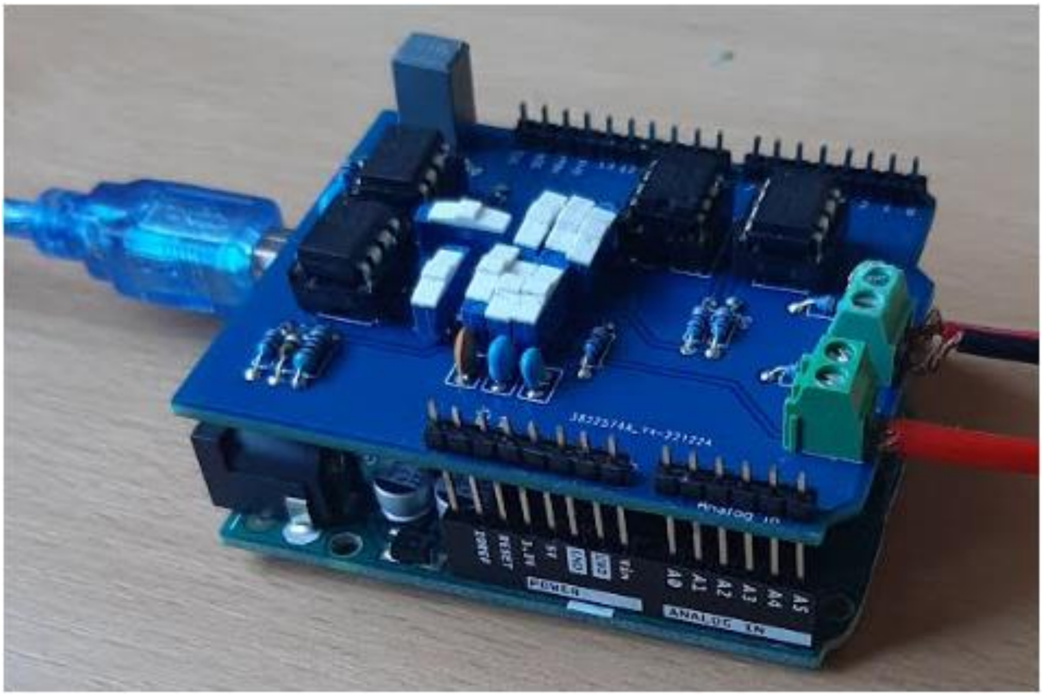


Figure 5.2.3 - Stacked EMG system

5.3 Procedures of Measurement of the EMG Signal

This section describes the procedure used for testing and validating the functionality of this thesis EMG amplifier system. The methods used for this testing are Signal Acquisition from a function waveform generator and Acquiring signals from human subjects.

The measurement method for texting of the EMG amplifier is described by the block scheme shown in Figure 5.3a.

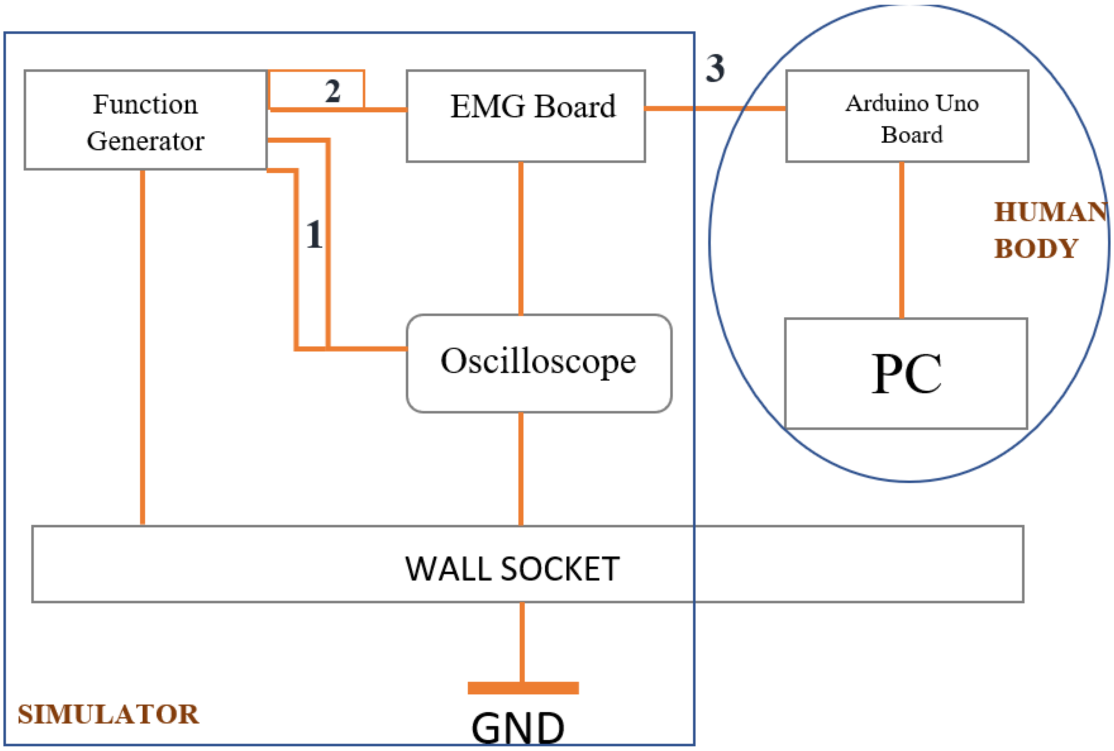


Figure 5.3a- Measuring method Block schematic.

Method of measuring signal from function Generator

The function generator that emulated the muscle EMG signal generation to simulate the human body, the output of the circuit was measured with the oscilloscope. The function generator and the oscilloscope are connected to the ground through their connection to the wall socket. At first, the function generator is connected to the oscilloscope using a coaxial cable. Two different sine waveforms of $1\ Hz$ frequency,$30\ \ mV$ of amplitude and $2\ kHz$ frequency,$70\ mV$ amplitude, were modulated and sent to the oscilloscope through the coaxial cable to display the signal.

Secondly, The function generator is connected to the input connector of the EMG Amplifier board. A probe is used to connect the Analog A0 pin of the EMG amplifier board to the oscilloscope for digitisation and display of the signals. Also, Two different sine waveforms of *1 Hz* frequency,*30 mV* of amplitude and *2 kHz* frequency,*70 mV* amplitude, were modulated and sent to a single input pin of the EMG amplifier board through the coaxial cable. A coaxial probe carries the signal from the Analog A0 pin of the EMG amplifier board to the oscilloscope for digitisation and display of the signals

Method of measuring signal from the Human body

The Measurement of EMG signals is performed on the prototype using Ag/AgCl electrodes. The two-input electrode is placed on the ulnar carpal flexor muscle about 2 to 3 cm apart, while the third electrode is placed on the dorsal side of the hand. The three electrodes' applied parts are connected to the EMG board input connector pins. The EMG amplifier board is connected to the Arduino board. Both are stacked on each other to connect and minimise space. The pin connections are shown in Table 4.3 in Section 4.0. The ground pin of the EMG amplifier is connected to the ground pin of the Arduino board, the 5 V pin of the Arduino ins is connected to the 5 V pin of the EMG amplifier board and the output pin of the EMG amplifier is connected to the A0 pin of the Arduino. The Arduino board is connected to the PC using a USB cable. A written code on Arduino IDE is then uploaded on the Arduino board, which is digitised and displayed on the PC.

The placement of the two input electrodes on the left hand is shown in Figure 5.3b below. The riven right leg electrode is placed on the right hand.

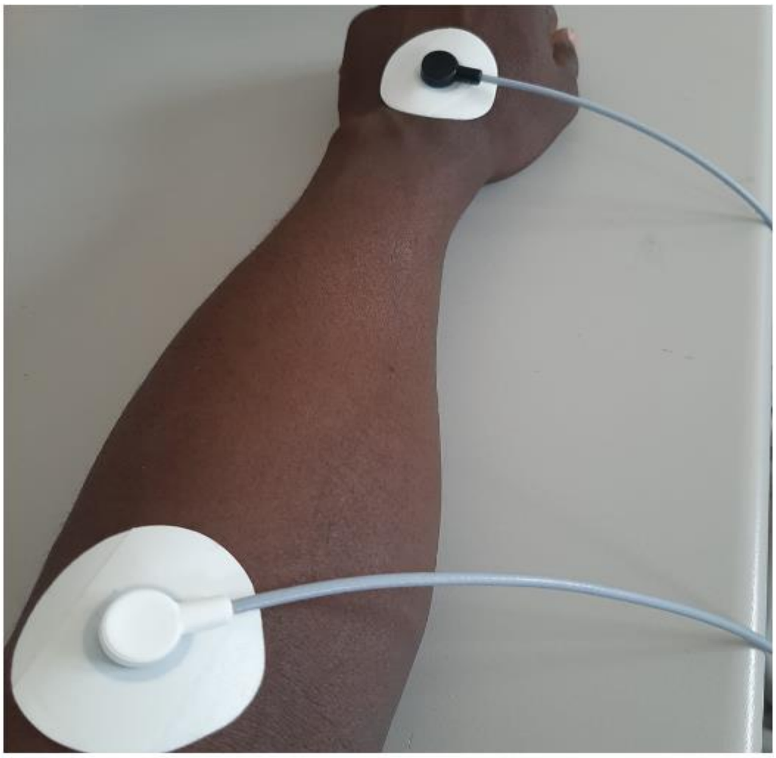


Figure 5.3b- Electrode placement in the human body.

5.4 EMG measurement results

This section presents the results obtained from the measure procedures described in section 5.3 above.

The result obtained from Step 1

Figure 5.5 shows the result display of the oscilloscope from step 1 in section 5.3.

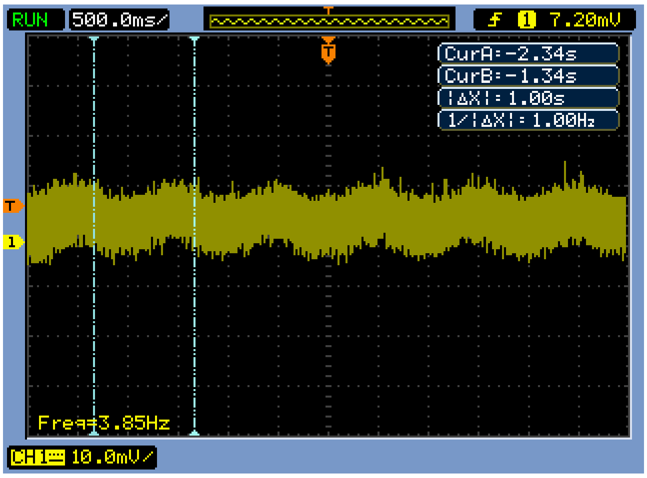


Figure 5.4- shows modulated 1 Hz sinewave signal

The result obtained from Step 2

Figure 5.5 shows the result display of the oscilloscope from step 2 in section 5.3.

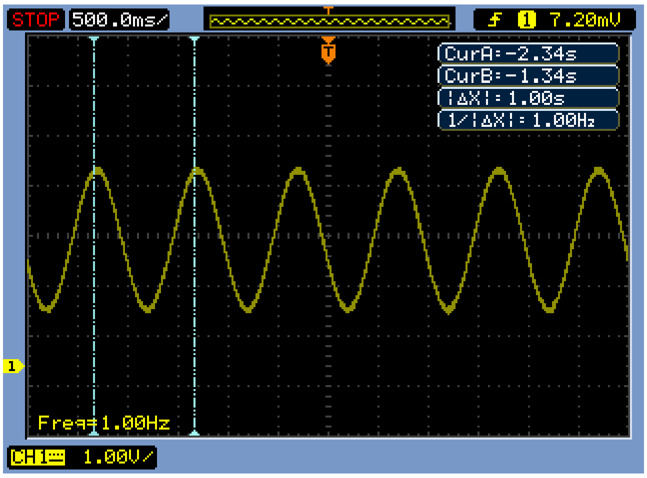


Figure 5.5- shows a filtered 1 Hz sinewave signal

The result obtained from Step 3

Figure 5.5 shows the result display of the oscilloscope from step 3 in section 5.3.

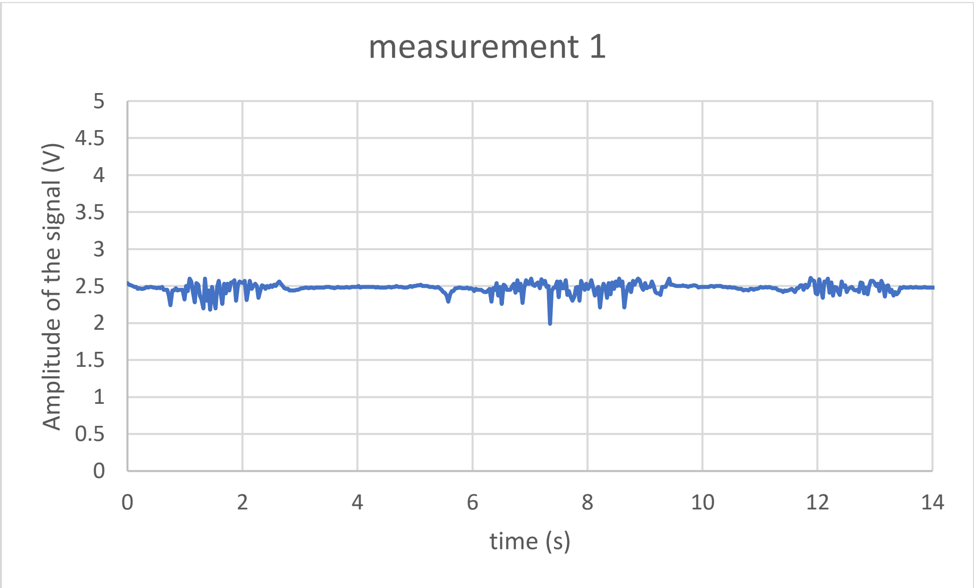


Figure 5.6- shows the raw EMG signal from the forearm

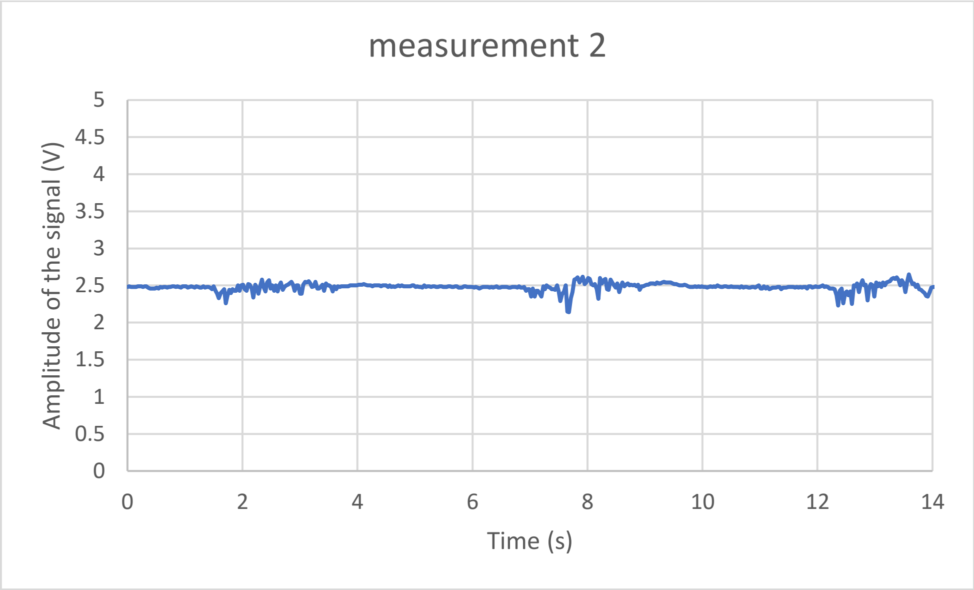


Figure 5.7- shows the raw EMG signal from the forearm

6 Discussion

The measured EMG signal from the electrodes passes at the device's input through protective resistors that protect the system from current spikes. The protection resistors are connected to the input of a voltage follower that serves as impedance matching. The signals from the voltage follower are fed to the inputs of an instrumentation amplifier, designated INA122. Also, an averaged signal from the voltage monitors at the input is fed from both inputs to the DRL circuit. The DRL circuit is used to suppress the consonant component of the interference. The most significant part of the interference is the prominent noise. When the switch between the DRL and the ground was turned on, the circuit produced output, whereas when the switch was turned off, the circuit gave no result.

The instrumentation amplifier allows adjustable gain depending on the resistance value of the resistor, designated RG. Sliding switches are used to control the gain. The gain factor could be 105,10 or 6. The instrumentation amplifier has an integrator signal applied to the reference input. The integrator and the instrumentation amplifier serve as a high-pass filter to suppress artefacts caused by breathing. The cut-off frequency of the high pass filter is around *0.5 Hz*. The output of the instrumentation amplifier is fed to the anti-aliasing filter, which acts as a low-pass filter. Although using sliding switches to control the gain of the instrumentation amplifier could give three sets of gain resistor settings, a potentiometer could have offered a much more comprehensive range of gain resistor adjustment. Too much of a high gain causes the amplifier to saturate, to little gain cause the signals to be significantly suppressed by noise. A potentiometer is an ideal solution to obtain a suitable amplification factor.

This filter is reconfigurable according to the user's needs. By switching between capacitors C1, C2, and C3, it is possible to change the frequency band of this myoamplifier. This selectable frequency range can be *48 Hz, 159 Hz, or 480 Hz*. These filters were able to filter high-frequency noise higher than 1 kHz.In further work,2nd order RC filter should be implemented. The 2nd order active filtering has two main advantages: high impedance input, low impedance output, and more excellent attenuation at a high range (- 40dB/decade as opposed to -20dB/decade for *RC* filter).

The amplification of the final stage is always the same, with a value of 10. A factor of 50,100 or 1050 can be used as the total amplification of the circuit. The system is supplied with an asymmetrical voltage of *5 V*. Due to the asymmetry of the supply voltage, it was necessary to use a DC level rise of the measured EMG signal equal to the reference voltage to avoid clipping the negative parts of the sensed signal. In the case of the implemented myo-amplifier, the reference voltage was half of the supply voltage.

The system schematic was implemented in the Eagle programming environment, creating a PCB. The final version of the device can be seen in Fig4.1. The myoamplifier is implemented as an Arduino Shield. Thus, attached to the Arduino UNO development board, which powers the designed myoamplifier, digitises the sensed biological signal, and then sends it to the computer for further processing. The signal is digitised using a 10-bit A/D converter, part of the microcontroller labelled ATmega328P. The reference voltage level of the A/D converter is identical to the supply voltage, which is 5v.

The result obtained from Step 1 of section 5.4 in Figure 5.4 shows a noisy 1 Hz sine wave. In step 2, this noisy signal was sent into the input of the EMG amplifier to verify the functionality and effectiveness of the low-pass filter of this EMG amplifier. The result in Figure 5.5 clearly shows how the EMG amplifier filter removed the 2k Hz noise, sending only the 1 Hz signal to the oscilloscope. This result validates the functionality of the EMG amplifier filter and its capacity to filter off unwanted frequencies.

The result from Step 3 of section 5.4 in Figure 5.6 - 57 shows the raw EMG signal obtained from the Human body. These results were obtained through a data streamer add-on for Excel, which assists in obtaining data from a microcontroller straight to the PC. When a fist was made, Action potentials were generated, and the EMG amplifier captured this action potential in the form of a voltage of around 2.5V. The up and downward deflection seen in Figure 5.6 and Figure 5.7 represents the depolarisation and repolarisation phase of the muscles during the first. The flat part of the signal of 2.5 V shows the action potential when there is no fist of the hand. This result, compared to section 1.2 (skeletal muscle activities), fig 1.2 shows a significant correlation with standard EMG signals. This further validates the functionality of this EMG amplifier.

Analysis of the voltage noise due to the amplifiers showed that nearly all noise is attributed to the electrode-amplifier circuit. Using active coaxial cables with pre-amplification could have been a much better solution as it helps tpo reduce noise picked up from the environment compared to passive electrodes. The subsequent electronics (high–pass filter, selectable gain filter, low–pass filter) contributed negligible noise to the signal chain. Additional noise reduction might be achieved by increasing the electrode-amplifier circuit's gain and using coaxial cable electrodes. Further noise reduction within the signal processing circuitry has little influence on the total noise.

7 Conclusion

The set goal was reached, a fully functional EMG Amplifier system with a CMRR of about 100dB capabilities. In this thesis, a portable device for collecting EMG signals on the human surface is designed. The system was used to test the flexor carpi ulnaris. The spectrum characteristics of the sampled surface EMG signal are analysed, and the practicability and validity of the EMG signal acquisition system are verified. The EMG recording principles are nothing new, but some unique solutions to fulfil specific requirements were found. For example, this thesis EMG amplifier uses adjustable switches to select a desired frequency for the EMG signal of interest.

Further research can be done in signal processing by implementing a second-order low-pass filter. The study may go toward setting wireless interfacing between the PCB and the computer. Furthermore, while sitting the gain of the INA122 amplifier, using a potentiometer to fine-tune the amplifier gain will be more efficient.

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