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GRADUATE SCHOOL

MASTER THESIS

DESIGN AND IMPLEMENTATION OF ANALOG FILTER AND AMPLIFIER FOR SURFACE EMG SIGNALS

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ELECTRICAL AND ELECTRONICS ENGINEERING

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We certify that, as the jury, we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

DESIGN AND IMPLEMENTATION OF ANALOG FILTER AND AMPLIFIER FOR SURFACE EMG SIGNALS

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Msc, Electrical and Electronics Engineering

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JUNE 2020

In this study, it was aimed to design a wearable device that can take real-time measurement and activity monitoring of electromyography (EMG) from the forearm muscles with the help of surface electrodes of healthy individuals. The opening and closing movements of the hand were repeated and measurements were made. The voltage between 0-10 mV on the arm surface during the measurements is increased by the operational amplifier. In the designed amplifier circuit, raw surface EMG has been successfully measured. Filter circuits are designed to remove noise caused by electrical or other factors on the EMG signal. These filters are high pass and low pass filters. The filters have been observed to eliminate noises on the EMG signal. In order to analyze the amplified EMG signal more easily, the signals in the negative polarization were switched to positive polarization with the full wave rectifier. After this stage, the designed smoothing circuit greatly reduced the noise in the signals generated during the contraction, and it was observed that the data were more clear than other stages. At the end of these stages, the amplitude of the signal is greatly reduced. The gain circuit output voltage which was designed to increase the amplitude of the signal, was measured as 3 V maximum.

In order to analyze the EMG signal easily and practically, a microcontroller based control card with HMI module and SD card input is designed. In this way, real time tracking and recording initiation of the data can be done with the interface on the touch screen. The data were recorded in ".csv" format. The recorded data can be used as a dataset for classifying arm movements with neural networks.

Key Words: electromyography, operational amplifier, electronic filter, precision rectifier, smoothing, neural networks, HMI, SD card.

Öz

YÜZEY EMG SİNYALLERİ İÇİN ANALOG FİLTRE VE YÜKSELTEÇ TASARIMI VE UYGULAMASI

Hasan ÖZALP

Msc, Electrical and Electronics Engineering

Advisor: Asst.Prof.Dr. Nalan Özkurt

JUNE 2020

Bu çalışmada, sağlıklı bireylerin yüzey elektrotlar yardımıyla, ön kol kaslarından elektromyografi (EMG) ölçümünün, gerçek zamanlı alınması ve aktivite takibi yapabilen giyilebilir cihaz tasarımı hedeflenmiştir. Elin açma ve kapatma hareketleri tekrarlanarak ölçümler yapılmıştır. Ölçümler sırasında kol yüzeyi üzerinde oluşan, 0-10 mV arasındaki voltaj işlemsel yükselteç ile arttırılmıştır. Tasarlanan yükselteç devresinde, ham yüzey EMG başarılı şekilde ölçülmüştür. EMG sinyali üzerindeki elektriksel veya diğer etkenlerden kaynaklı gürültülerin çıkartılması için filtre devreleri tasarlanmıştır. Bu filtreler, yüksek geçiren ve alçak geçiren filtrelerdir. Filtrelerin, EMG sinyali üzerindeki gürültüleri yok ettikleri gözlemlenmiştir. Yükseltilmiş EMG sinyalinin daha kolay incelenebilmesi için, negatif polarmadaki sinyaller hassas doğrultucu ile pozitif polarmaya geçirilmiştir. Bu aşamadan sonra tasarlanan yumuşatma devresi, kasılma sırasında oluşan sinyallerdeki gürültüleri büyük oranda azaltmıştır diğer aşamalara göre verilerin daha net oldukları gözlemlenmiştir. Bu aşamalar sonunda, sinyalin genliği büyük oranda azalmıştır. Sinyalin genliğini arttırmak için tasarlanan kazanç devresi çıkış voltajı maksimum 3 V olarak ölçülmüştür.

EMG sinyalinin kolay ve pratik şekilde incelenebilmesi için, üzerinde HMI modülü ve SD kart girişi bulunan mikrodenetleyici tabanlı kontrol kartı tasarlanmıştır. Bu sayede, verilerin gerçek zamanlı takibi ve kayıt başlatılması dokunmatik ekran üzerinde bulunan ara yüz ile yapılabilmiştir. Veriler ".cvs" formatında kayıt edilmiştir. Kayıtlı veriler yapay sinir ağları ile kol hareketlerinin sınıflandırılmasında veri kümesi olarak kullanılabilecektir.

Anahtar Kelimeler: Elektromiyografi, işlemsel yükselteç, elektronik filtre, hassas doğrultucu, yumuşatma, yapay sinir ağları, HMI, SD kart.

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TEXT OF OATH

I declare and honestly confirm that my study, titled “Desing and Implementation of Analog Filter and Amplifier for Surface EMG Signals” and presented as a Master’s Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Full Name

Signature

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May 18, 2020

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CHAPTER 1 INTRODUCTION

Electromyography (EMG) signals are biopotential signals created by the contraction of the muscles. In the 17th and 18th centuries, scientists such as Jan Swammerdam, Francesco Redi, Luigi Galvani and Alessandro Volta worked to verify the biopotential signals caused by muscle contraction. Adrian and Bronk are the first scientists to detect EMG signal with needle electrode usage (Ertekin, 1995).

EMG signals are used in the treatment of muscle and nerve diseases, physical therapy and rehabilitation studies, and in the control of robotic prosthetic limbs developed for people with limb loss. Neural network studies in recent years have an important place in the development of these prostheses. EMG measurement studies have increased with surface electrodes since needle electrodes must be used by specialist healthcare professionals. One of the important problems in measurements with surface electrodes is the electrical noises. EMG signals on the surface of the body have very small amplitude, so electrical noise prevents its correct perception. In order to get better results in neural network studies, removing noise from EMG signals plays an important role.

As a result of the literature studies, it has been observed that many different methods are used to remove the noises affecting the EMG signals. In this study, Active filters were design and used to remove the noises of amplified EMG signals also Human machine inreface module is used to see real time signal from forearm and SD card port is used to record the EMG signal.

1.1 Aim of Thesis

The aim of this thesis is to design a wearable device that can measure EMG signal with surface electrodes for real-time tracking and recording data. The wearable device, which is aimed to be made, is purposed at accurately measuring daily movements by clearing electrical noise. Electronic filters will be used to remove these noises. These filters will gradually remove noises with different tasks. The effects of electronic filters to be designed at different cutting frequencies on the raw EMG signal will be monitored. EMG signals will be taken from the forearm muscles with the help of surface electrodes.

1.2 Organization of Thesis

The organization of the thesis is arranged as follows; in the first part, the history of the EMG signal, the general view of the thesis and the purpose of the thesis are specified. The methods that can be done to detect the surface EMG signal and clean it from the noises are mentioned. In the second chapter of the thesis, the structure of the muscles, how EMG signals are formed, noise affecting the EMG signal, amplifier and filter structures are explained. In the third chapter of the thesis, the designed electronic cards are explained together with their filtering stages and their effects on the raw EMG signal. For the wearable device to be designed, the electronic cards which are used and the modules which are used are mentioned.

CHAPTER 2

FEATURES OF THE EMG SIGNAL

2.1 Muscle Physiology

Muscle cells convert chemical energy into mechanical energy. Muscles play a role in revealing movement, producing heat and maintaining posture. Muscles have features; contractility, excitability, extensibility, elasticity. Muscle rate of body mass in babies is 25%, young is 40%, old is 30%. The muscular system in the human body consists of the heart muscle that forms the heart, the smooth muscles in the internal organs and the striped (skeletal) muscles that are connected to the skeleton with the help of tendons (Serbest, 2014).

2.1.1 Heart Muscle:

The heart muscle resembles a striated muscle in terms of structure, but its work is not performed like our striated muscle, these muscles are highly developed involuntary muscles. The muscle provides control with the nervous system. It is like a very dense web consisting of straight, thick and short fibbers. Nuclei are in the middle in the heart muscle. They can contract without nervous stimulation. Neural stimulation affects the time of contraction. Muscle tissue needs more oxygen and energy than other tissues (Webster, 1978). The structure of the heart muscle can be seen in Figure 2.1.

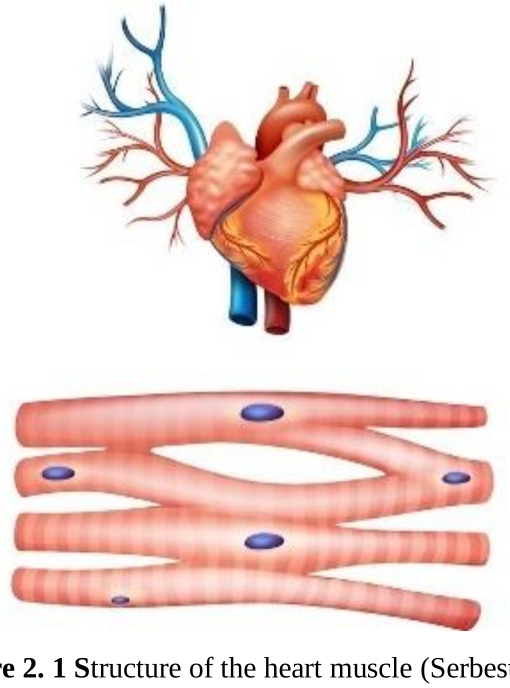


Figure 2. 1 Structure of the heart muscle (Serbest, 2014).

2.1.2 Smooth Muscle

They are muscles that show involuntary movement. The movement of these muscles is linked to the nervous system. Breathing, circulation, digestion, etc. systems consist of smooth muscles. The contraction processes of smooth muscles are quite long and they can maintain these contractions for a long time with minimum energy. The smooth structures of the smooth muscles are short, and the cell structures consist of an oval, single and pale colored, centred nucleus(Webster, 1978). The structure of the smooth muscle can be seen in Figure 2.2.

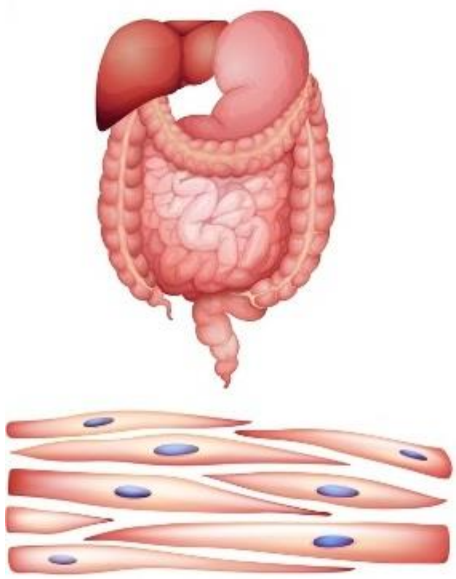


Figure 2. 2 Structure of the smooth muscle (Serbest, 2014).

2.1.3 Skeletal (Striped) Muscle:

Skeletal muscle within our request, skeletal muscles, working under the control of the cerebrospinal system, have more than one core and is the muscle group that forms our skeletal system. They consist of a large number of muscle fibbers. Muscle fibbers are thick and long. Skeletal muscles have a large number of cell nuclei. Skeletal muscles make up 40% of body weight. Approximately 75% of the muscles consist of water. Massive increase in muscle tissue as a result of regular work is called hypertrophy. If the muscle tissue remains immobile for a long time or if there is a damage to the muscle tissue, massive decrease and regression occur in the muscle tissue. This condition is called atrophy. In order for any muscle to create movement, it must be connected to at least two separate bones and cross a joint. The structure of the skeletal muscle can be seen in Figure 2.3.

Figure 2. 3 Structure of the skeletal muscle (Serbest, 2014).

The skeletal muscle has two ends and a body. The places that make the muscles attach to the bones are called Tendon or Beam. These structures transfer the force created by the muscles to the bones. Tendons are generally rounded. Bursae are slippery sacs between the tendons and bones, filled with fluid. Bursaeler facilitates its functions by providing easy gliding of muscles and tendons. The structure of the skeletal muscle can be seen in Figure 2.4.

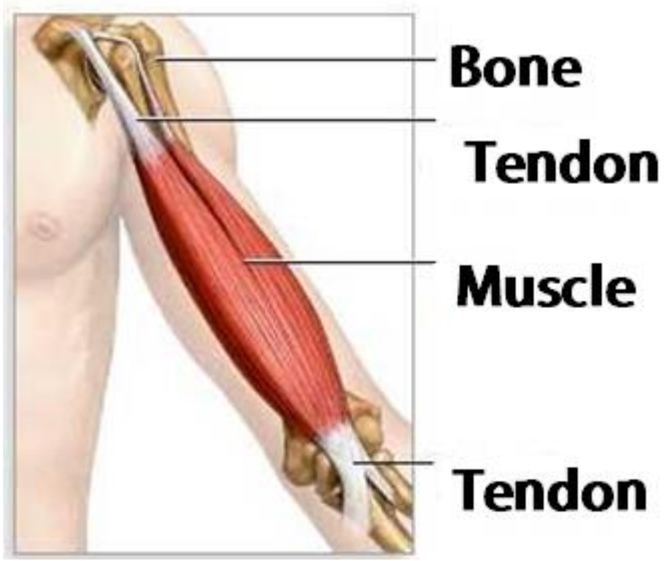


Figure 2. 4 Muscle and tendons (Serbest, 2014).

The beginning of the ends of the muscle adhering to the bones is called Origo, and the ending is called Insertio. Origo is usually the part that is close to the body, and the insertio is the part that remains far away from the body. Inertio describes the tip that moves when the muscle moves. The bulging part of the muscle fibber located between the tendons of the muscle is called the verter. Muscles are usually single-abdominal, but there are also two-verter muscles. The connective tissue that surrounds the outside of the muscular body is called epimysium. The place consisting of smaller bundles of fibber transverse from the muscle body, which is wrapped with the epimysium, is called fasciculus. It consists of a large number of muscles fibbers in each fasciculus. The connective tissue that surrounds each muscle fibber is called endomysium.

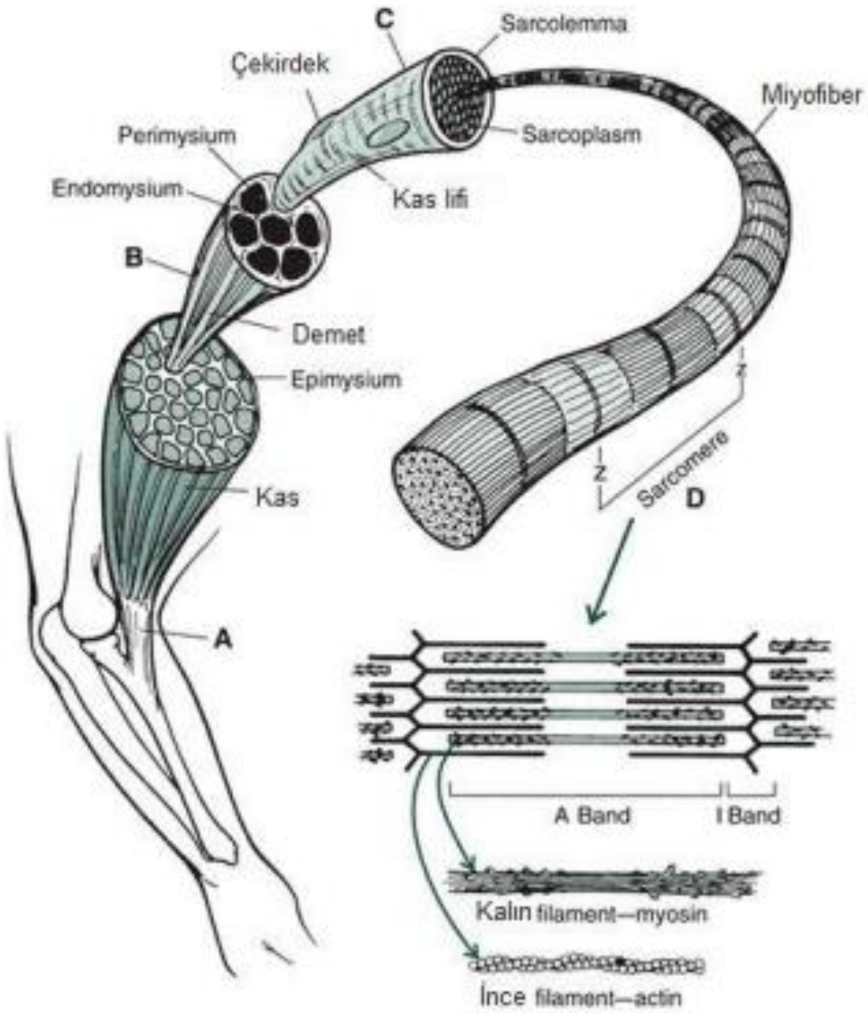


Figure 2. 5 Anatomical structure of the skeletal muscle (Serbest, 2014).

2.2. Muscle Contraction

Muscle fibers should be stimulated for the contraction of the muscles and the stimulation is carried through the motor nerves. The muscle also responds to a warning such as electric current. Muscle contracts dynamically and statically in two ways. Static contraction occurs only in the form of swelling of the muscle, the length of the muscle does not change. Dynamic contraction is in the form of both swelling and shortening of the muscle.

The chemical contraction that occurs in the muscles can be summarized as follows. When the muscle is active, first the glycogen stores in the muscle are emptied, carbon dioxide is released by consuming oxygen. The glycogen in the muscles breaks down to pyruvic acid, and energy stored through high-energy ATP (Adenozin triphosphate) molecules is released. Citric acid, CO_2, H_2O and new ATP molecules are also formed by the oxidation of pyruvic acid. In case of insufficient oxygen, lactic acid is formed by anaerobic reaction from pyruvic acid and energy is released. Excess oxygen taken by respiration, which continues by rising after the contractions, oxygen closes the gap in the muscles. 1/5 of the lactic acid accumulated in the muscles is oxidized, releasing energy with CO_2 and H_2O. The energy produced when the muscle is actively working turns into mechanical energy and heat energy. The energy efficiency of the muscles is around 25%. Most of the energy in the muscles is lost as heat energy. The place where the motor nerves reach the muscle fiber is called motor end plates. When information is received from the motor nerve to the motor end plates, acetylcholine is secreted, and the muscle is stimulated. Some smooth muscles use noradrenaline as a chemical news transmitter (Mandalidis & O'Brien, 2010).

2.2.1 Myoelectric Signal

Electric activation in muscle cells occurs in the cell membrane. Two main mechanisms that allow various substances to pass through the cell membrane are diffusion and active transport events. Diffusion is the movement of molecules from an area of high concentration of the molecules to an area with a lower concentration. The difference in the concentrations of the molecules in the two areas is called the concentration gradient. Active transport is the transition of small molecules from low-dense medium to very dense medium by spending ATP. If energy is not used in the diffusion event, energy is spent in the cell during active transport. In a muscle cell, the number of sodium (Na +) and chlorine (Cl) ions outside the cell is higher than in the cell. The number of potassium (Ka+) ions is higher in the cell and less outside the cell. When the cell membrane is stimulated with externally applied energy, the Na+ permeability of the membrane increases. Na+ ions flow into the cell and produce an ion current called depolarization. While Na + 10 ions flow into the cell, K + ions go out of the cell. This potential change is called action potential (about 30mV). Na + and K + ions in the cell are balanced. After a new steady state has been achieved and the transition of sodium ions through the membrane has stopped, there is not an ion current that will break the membrane resistance against sodium. The membrane returns to the selective conductive state and the cell returns to the resting state with the help of an active ion pump called Sodium Pump. This event is called repolarization (Figure 2.6). The potential difference due to the chemical reaction caused by sodium (Na +) and potassium (K +) ions as a result of neuro-electrical stimulation in the muscles is called myoelectric signal. Measuring, imaging and analysis of the myoelectric signal with the help of electrodes is called electromyography.

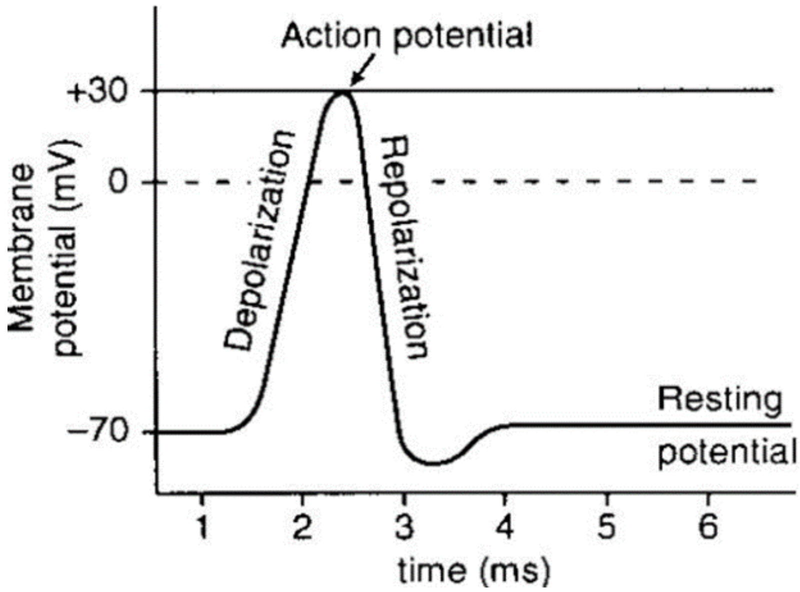


Figure 2. 6 Repolarization graph (Lodish et al., 2000).

2.3 Electromyography

Electromyography (EMG) are biopotential signals that result from muscle contraction. This is caused by various electrochemical events that occur in the body. When the stimuli from the brain are transmitted to the motor unit related to the nerves, the chemical changes that occur in the muscle cell start an action (movement) potential. Stimulated cells produce electrical difference by ionic current. EMG signals are detected from the body with the help of electrodes and electrodes have different names according to their types. Difference amplifiers are used to amplify these signals. The amplitude of the EMG signal varies from 0 to 10mV (between peaks) or from 0 to 1.5mV (RMS). The available signal is in the frequency range of 50 to 500 Hz and varies between 50 and 150Hz, which is the dominant one.

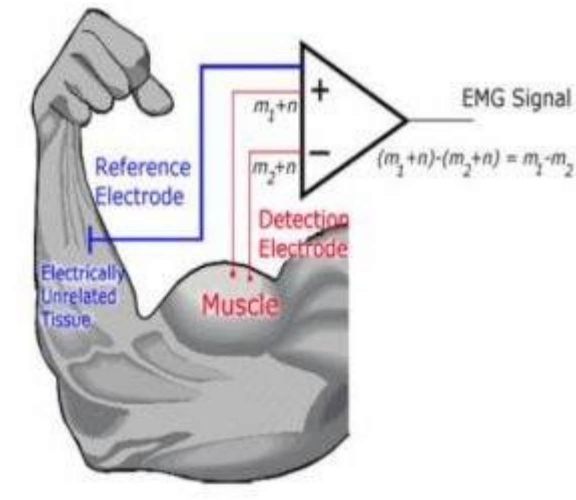


Figure 2. 7 Electromyography measurement procedure (Taşdemirci, 2017).

Electrodes placed on the skin will be detected by the sum of the marks formed by the muscle fibers active in that area. The resulting waveform is called the "interface pattern". The simplest schematic representation of EMG signal formation and EMG marks obtained with the help of a double surface electrode are shown in Figure 2.8. With the increase of activity, more motor units participate in the activity.

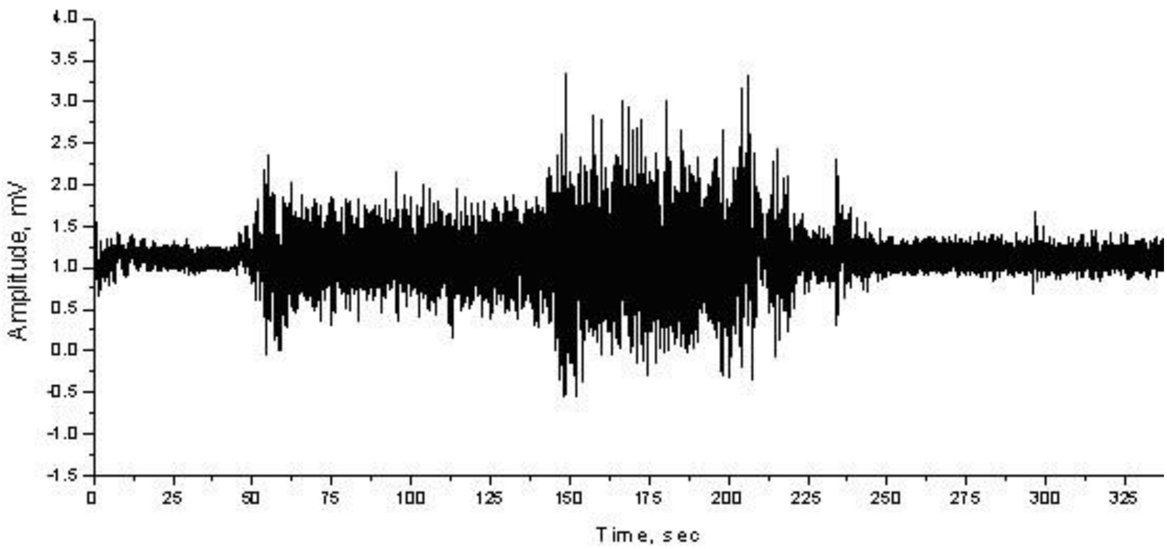


Figure 2. 8 Electromyography record (Taşdemirci, 2017).

The data obtained after the measurements are filtered. In this way, the disruptive effects of other organs, EMG device and external environment are reduced. If necessary, upgrading is applied to low amplitude data. Then, the obtained analog data is converted into digital structure. Electromyography method can be used in clinical applications, disease diagnosis, arm cut, etc. It is used as a resource to enable the replacement of the missing limb to move the prosthesis in case of limb loss (Taşdemirci, 2017).

2.3.1 Measurement and Application Reasons o f EMG

EMG and nerve conduction examinations are used to diagnose anterior horn cells, nerve roots, neural networks, end nerves, nerve muscle junction and muscle diseases, respectively. Because it is easy to apply, it is often used alone or sometimes in conjunction with other auxiliary methods such as imaging techniques, blood biochemistry to lead to the most accurate diagnosis possible. Sometimes it directs the physician to other methods for diagnosis, such as direct biopsy or surgical intervention. It is often used in painful situations caused by compression of the lower and neck hernias at certain points of the end nerves, sensation defects, diagnosis of diseases such as neuropathy and myopathy, in some cases where arm and leg weaknesses are seen, and how limited the damage to the nerves and muscles in limited or widespread muscle loss. In some cases, EMG marks are also used to guide and move the prosthetic organs. Although two types of electrodes are used for the removal of EMG signals, needle electrodes and surface electrodes, needle electrodes are preferred for the diagnosis of problems in the muscles. EMG measurement with needle electrodes is also called needle EMG. Concentric needles are generally used in these measurements (Figure 2.9). Needle EMG workings generally are not given any electrical impulses. It is used only for recording normal or abnormal electrical activity in the muscles. The needle electrode is immersed in the case directly for examination. MUP's generated by the stimuli sent from the brain are detected by electrodes and amplitudes are increased with sensitive amplifiers In this way, it can be viewed on the screen. In addition to visual inspection, the same signs are made audible thanks to the loudspeaker, and these sounds make an important contribution to the assessment of the physician performing the examination.

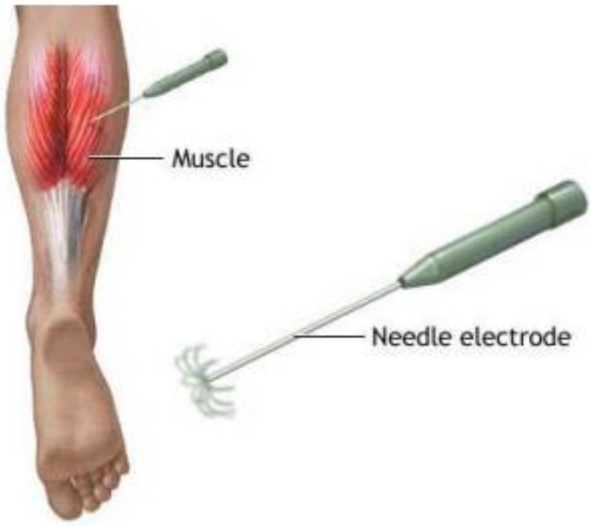


Figure 2. 9 Needle electrode muscle placement (MEGEP, 2008).

2.3.2 EMG Measurement Method

Biopotential signals obtained from the human body need to be strengthened to be processed, visualized and stored. The amplifiers used for this purpose are called biopotential amplifiers. Operational amplifiers are the main element of the amplifiers used for this purpose. Since the amplitudes of the signs to be amplified are very small (1 mV - 10 mV), it is very important that they are amplify without noise. EMG signals are obtained from the human body with the help of electrodes as shown in Figure 2.10.

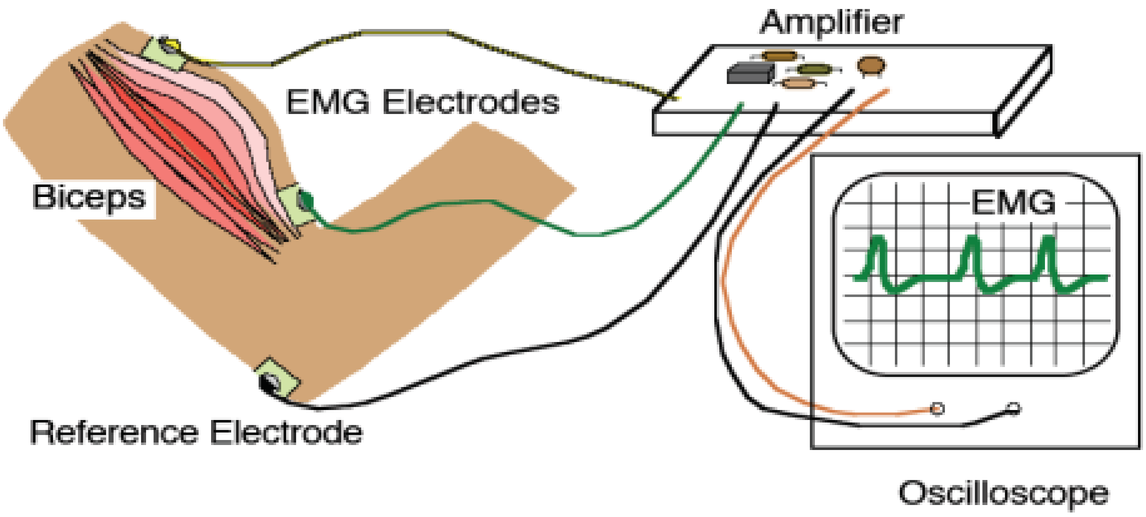


Figure 2. 10 Electromyography measurement method (MEGEP, 2008).

The surface electrodes have impedances of around 200–5000 Ω, so normal amplifiers can be used. However, when needle-type electrodes are used, their impedance increases up to 1 MΩ since their surfaces are smaller. However, when needle-type electrodes are used, their impedance increases up to 1 MΩ since their surfaces are smaller, in this case, FET types with high input impedance are preferred. The amplitude of the signal obtained when the needle-type electrode is used is large therefore not necessarily the gain of the amplifier to be large. Noises are generated due to the high gain of the amplifiers and the high impedance of the electrodes, so the amplifiers should have low noise characteristics. Since some biopotential signals (such as EMG signs) must be processed by taking their absolute values, they must also be straightened while the signs are amplifying (MEGEP, 2008).

2.3.3 Electrodes

Electrodes are used to measure the biopotential energy that occurs during the contraction of the muscles. Two electrodes are generally used to measure the EMG signal, the first one is the needle electrode and the other is the surface electrode. Electrodes are generally used as monopolar or bipolar (Baspinar et al., 2013).

2.3.3.1 Needle Electrodes

There are a lot of needle EMG measurement electrodes, but the most commonly used concentric needle electrodes (Figure 2.11). At the needle electrode, signal is measured by a wire passed through needle. Needle electrode most important advantages of needle electrodes are that they provide the opportunity to measure from the place closest to the point to be measured, thus allowing to measure even a single MUAP signal. The disadvantage of needle electrodes is that the person performing the measurement should be an expert, and the needle electrodes can hurt the person to be measured in case of excessive contraction.

Figure 2. 11 Needle Electrodes

Needle electrodes and their application should be described according to standard clinical protocol. The use of nonstandard needle electrodes should be fully described and include material, size , number and size of conductive contact points at the tip, depth of insertion and location in the muscle.

2.3.3.2 Surface Electrode

Surface EMG signals can be measured both with wet and dry electrodes. Commonly it is used wet electrodes require conductive electrolyte gel or sponge between the electrode and the skin, but it can provide high quality surface EMG signals. The wet electrodes often require skin preparation (e.g. shaving and skin abrasion), which can reduce skin–electrode impedance and motion artefacts (Tam & Webster, 1977). Modern dry electrodes do not require conductive gel and skin preparation, and still can reach signal quality comparable to wet electrodes (Laferrier & Gailey, 2010). For surface electrodes, silver/ silver chloride pre-gelled electrodes are the most often used electrodes and recommended for the general use (Hermens et al., 2000).
Besides easy and quick handling, hygienic aspects are not a problem when using this disposable electrode type. The electrode diameter (conductive area) should be sized to 1cm or smaller. Commercial disposable electrodes are manufactured as wet-gel electrodes or adhesive gel electrodes. Generally wet-gel electrodes have better conduction and impedance conditions than adhesive gel electrodes (Konrad, 2005).

Figure 2. 12 Surface electrode

Surface EMG is relatively easy to use as compared to other EMG electrodes. EMG signal is used to control the robotic mechanisms of prosthetic limbs. Surface EMG can also be used by engineers as it does not require medical certification or expertise in applications, latest EMG is widely used in research. Its use in rehabilitation prosthesis is suitable because it does not cause any discomfort to the patient it is applied to. Other EMG electrodes (needle and fine wire), when inserted into the skin of the person, can affect the feeling of twitching and cause it to move.

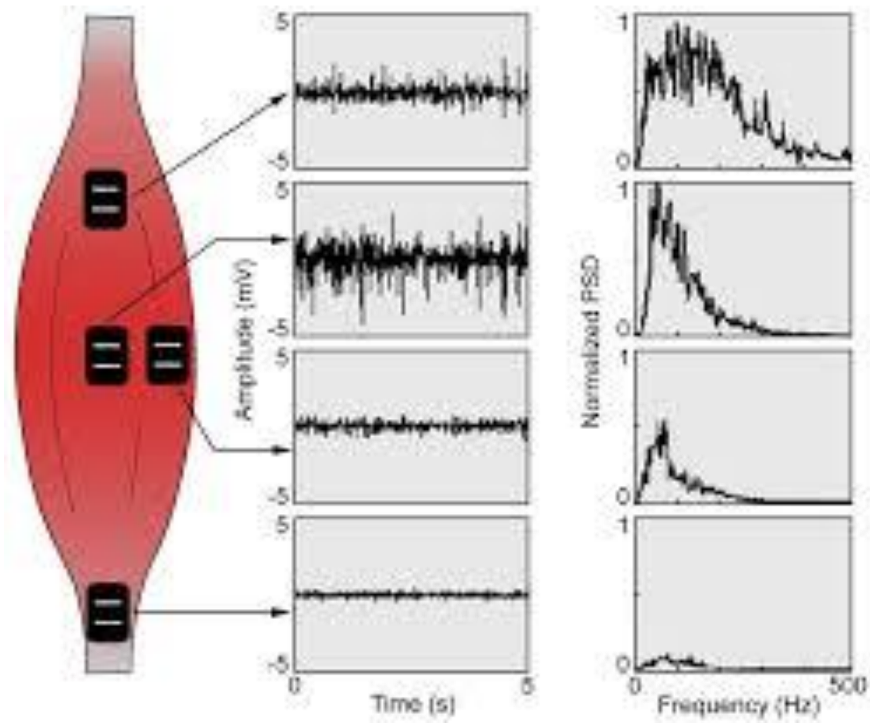


Figure 2. 13 Muscle EMG signal amplitudes of the different points of the graphic in the time domain and frequency domain.

In order to get the best results from surface EMG, it is important to have a proper understanding of the muscles from which the EMG signal is being extracted. The placement on skin also requires suitable study and requires skin preparation beforehand as well.

2.3.4 Pre Amplifier

Electronic circuits that amplify the electrical sign applied to its input are called amplifier. It uses active circuit elements to amplify the signal in the amplifier circuits. In doing so, they use the energy they receive from the power supply. A strong output signal is obtained. Amplifiers of current or voltage circuits a power gain. It is the symbol of the amplifier in Figure 1.15.

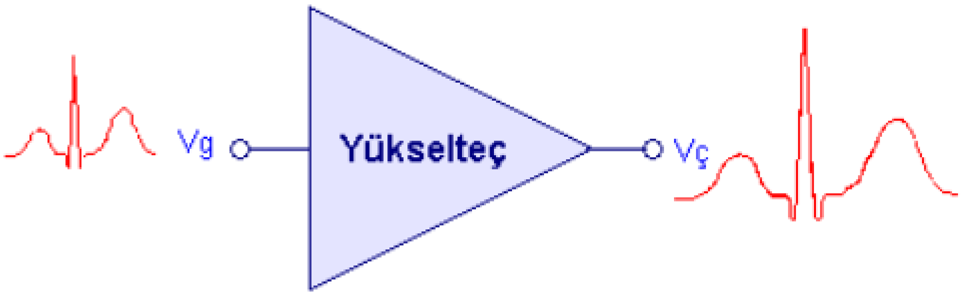


Figure 2. 14 Amplifier symbol

The human body produces electrical signals in µV amplitude during normal operation. In order to use ECG, EEG, EMG signals in devices such as bedside monitors, defibrillators, it must first be strengthened at the desired level. Amplifiers are important here. An amplifier is used to amplify the signal applied to its input at the desired level. The amplifier is an electronic device that provides current or voltage gain.

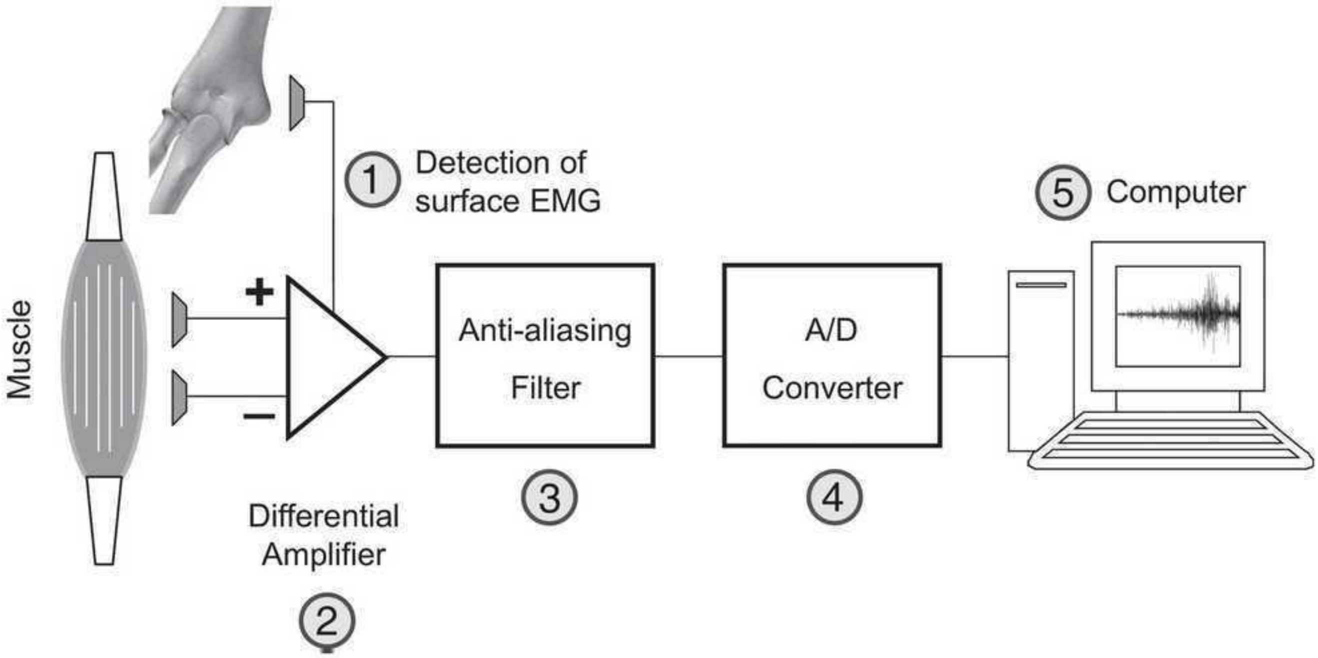


Figure 2. 15 EMG measurement diagram

2.3.5 The Sources Of The Noises and Noise Cancellation Techniques in Surface EMG Signals

The amplitude of the EMG signal is between 0-10 mV before amplification. EMG signals move by adding noise while moving in different tissues. Therefore, it is important to know the cause of the electrical noise. Electrical noises that will affect the EMG signal can be divided into the following types:

- Noise from electronic devices: All electronic devices generate noise. This noise cannot be eliminated but can be reduced by using high quality components.
- Ambient noise: Since our body is constantly under electromagnetic radiation, this radiation creates a source of noise in the body. Ambient noise can have an amplitude of 1-3 times the size of the EMG signal.
- Motion-induced artefact: Artefacts resulting from motion cause irregularity in the data. Movement artefact occurs due to electrode surface and electrode cable. This artefact can be reduced by the smooth design of the system.
- Structural instability of the signal: EMG amplitude occurs randomly. The EMG signal is affected by motor units operating in the 0-20 Hz frequency range. It is important to remove this type of noise from the signal (Reaz et al., 2006).

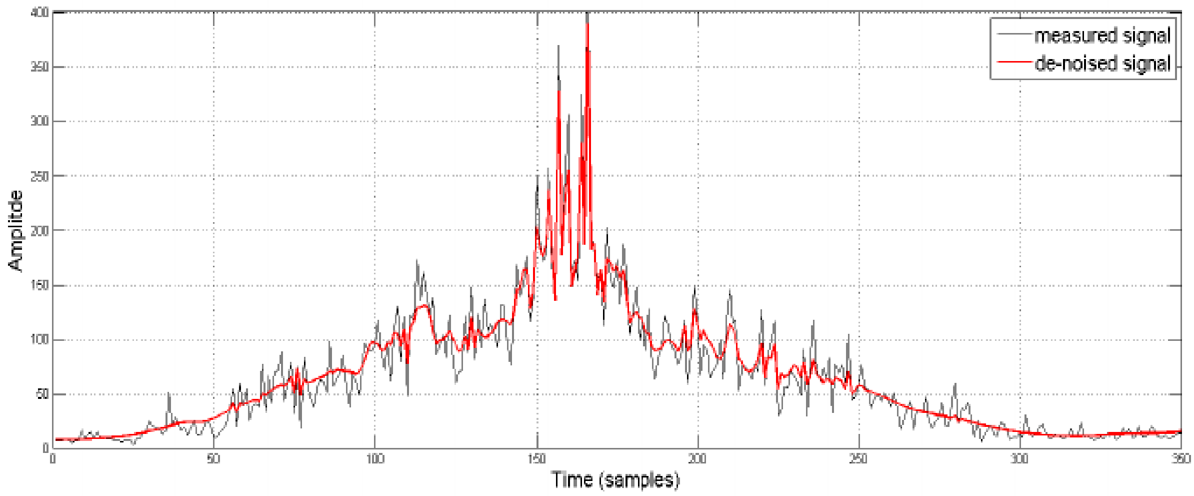


Figure 2. 16 Noisy and filtered graph of the surface EMG signal (Reaz et al., 2006).

Any signal may be represented with a summation of sinusoids of different frequencies. The surface EMGs are composed of sinusoids from 15 Hz to 400 Hz. When analog signals are sampled at rates smaller than twice of their highest frequency (for example less than 800 samples/s for the surface EMGs), sinusoids with frequencies above this threshold are superimposed on the low frequency sinusoids. 20 Hz high pass filter to EMG signal, 400 Hz flow pass filter and 50 Hz Notch filter are used to remove noise.

2.4 Filters

Electronic filters are electronic circuits that you can use to clean the electrical signs from harmonics and interference. Entry filters are divided into digital and analog filters. Filters are used to prevent noise on the EMG signal. Generally preferred filters are high pass filter, low pass filter and notch filter.

2.4.1Digital Filters

Digital filter is a method or algorithm that works on digitized analog signals and converts the input signal to the desired output signal. The main design purposes of filters with a wide range of applications can be counted as separating the interfering signals, reducing the noise in the signal, improving the signal quality, and recovering the distorted signal. The desired filter properties are defined in the frequency domain in terms of desired amplitude and phase response, in the design of frequency selective filters. Frequency conversions are examined in both analog and digital regions to convert low-pass model filter to other low-pass, band-pass, band-stop or high-pass filters related to digital filter design.

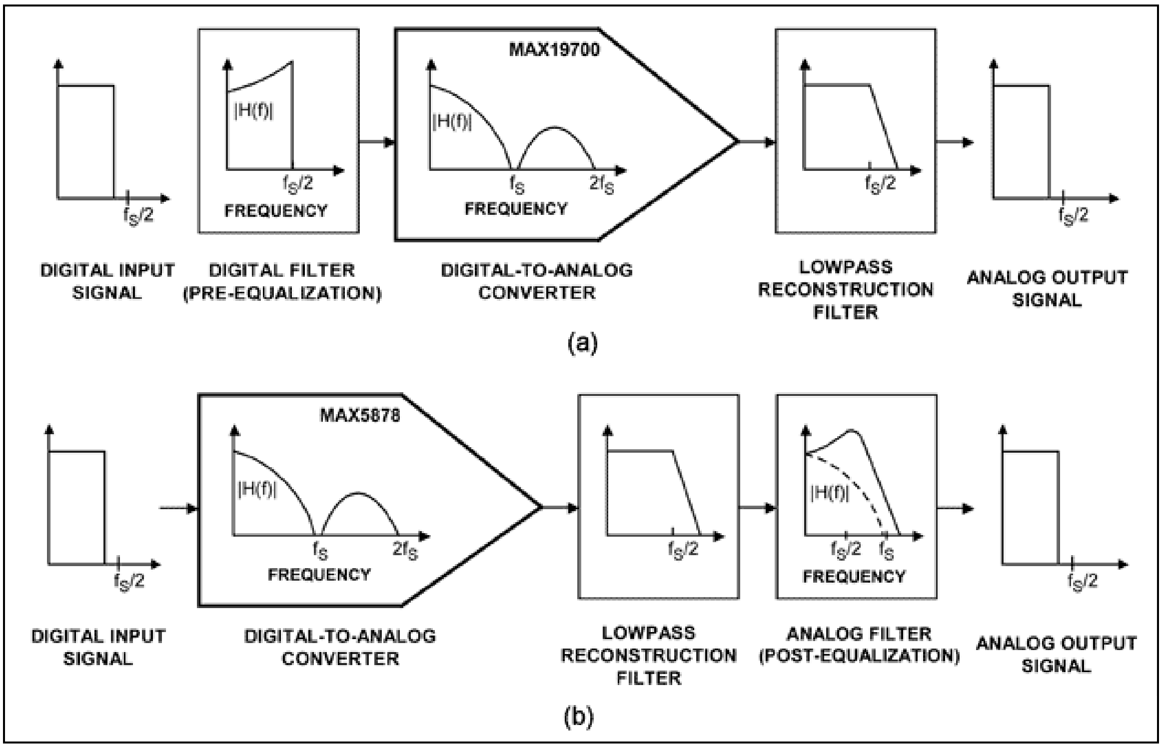


Figure 2. 17 Analog output of digital filtered signal is diagram (Proakis & Monolakis, 1996).

Digital filters can only work with digital signals. Therefore, the digital filter converts the analog signal to digital signal with the Analog to digital converter (ADC). After the conversion, the digitized signal is processed, and unnecessary frequency components are removed. Then, the obtained digital signal must be converted back to analog signal using a digital display Analogue-Digital Converter (DAC). Today, the design of FIR and IIR digital filters can be realized through computer software programs. After programming, programs in digital filters can be easily changed by rewriting their algorithms (Proakis & Monolakis, 1996).

2.4.1.1 Finite Impulse Response Filter (FIR)

Digital Finite-Pulse-Response (FIR) filters are mainly used in digital signal processing applications. It has many convenient features that are extremely popular in digital signal processing. FIR is used in a variety of applications such as speech recognition, speech synthesis, digital voice, telecommunications, noise cancellation and various other signal processing areas. The structure of the FIR filter is obtained by adding a series array. The basic building blocks of the FIR filter are collectors, multipliers and signal delay as shown in Figure 1.18. Multipliers must be fast enough for the filter's output to be close to ideal (Das et al., 2017).

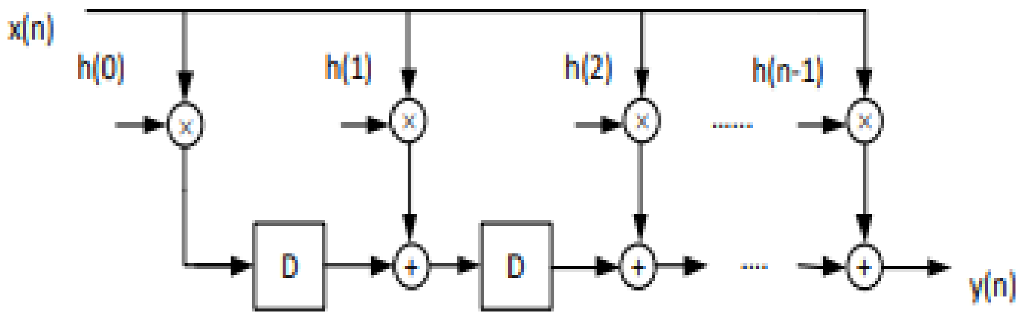


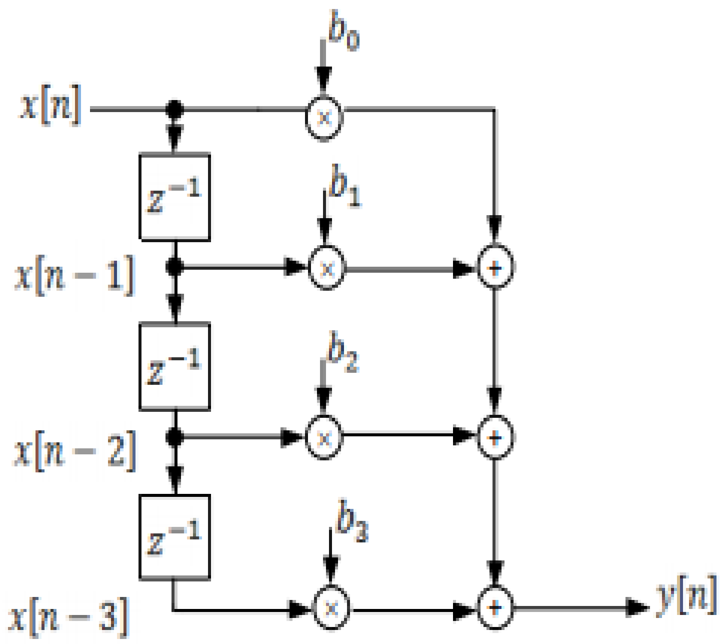
Figure 2. 18 Converted form of the FIR filter (Das et al., 2017).

FIR filters are the common names for filters without feedback. The filter output is completely connected to the input signal. The output does not feed its input. This means that the filter gives a finite response to a given impulse signal. The general equation of a digital FIR filter is as follows:

$$y[n] = \sum_{k=0}^{N} b_K x[n-k] \tag{1}$$

The output signal is obtained by multiplying the delayed values of the input signal by certain coefficients. This process is called “convolution.” So, by shifting the incoming signal so that the coefficients remain constant, we multiply these coefficients and add them to the output. The filter coefficient used determines the degree of the filter. As the filter degree increases, the quality of the filter also increases (Ustundag, 2020).

Direct form FIR filter block diagram and Direct Form FIR filter output equation are shown in figure 2.15;



$$y[n] = b_0 x[n] + b_1 x[n-1] + b_2 x[n-2] + 3x[n-3] \qquad (2)$$

Figure 2. 19 Direct Form FIR filter block diagram (Ustundag, 2020).

2.4.1.2 The Infinite Impulse Response Filter

The infinite impulse response (IIR) filter is an output generating filter using its current and previous inputs. The filter has fallback because the filter structure uses the previous output. Most systems that do not change in linear time have electronic and digital filters. The responses of the IIR and FIR filters are different from each other. Outputs of FIR filters are not based on feedback. The IIR filter uses fewer terms than the FIR filter of the same feature, so it is easier to calculate the IRR filter. The IIR filter is very fast, but sometimes problems can occur. FIR filter is very slow but works steadily (Mohamed N. Nounou, 2000).

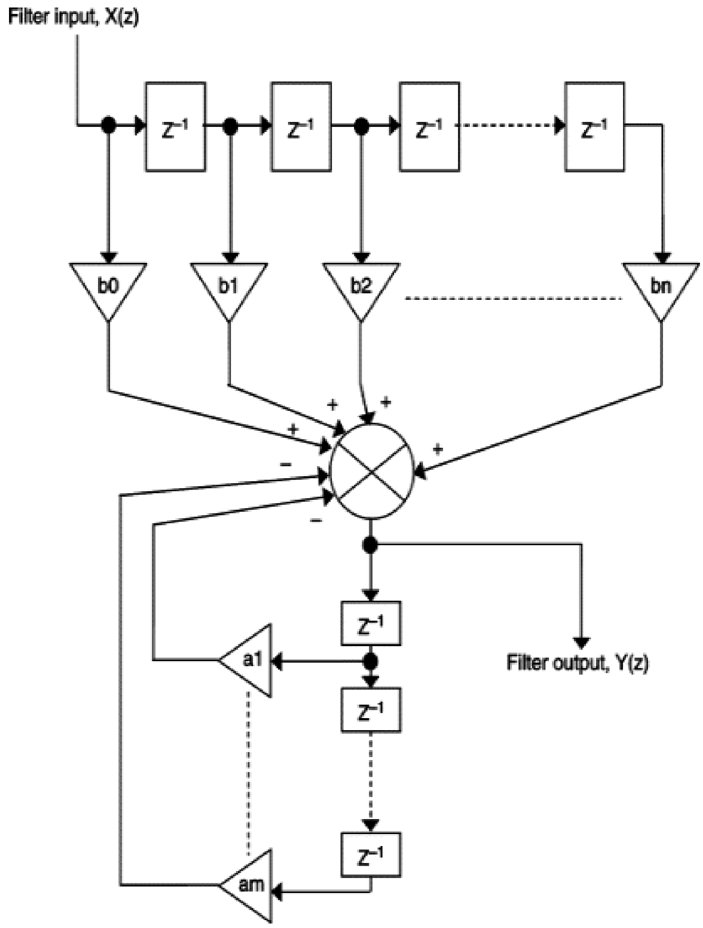


Figure 2. 20 Typical architecture of an IIR filter (Mohamed N. Nounou, 2000).

$$y_t = \sum_{i=0}^{M} b_j x_{t-i} - \sum_{j=1}^{L} a_j y_{t-j} \tag{3}$$

2.4.2 Analog Filters

Amplifiers, resistors, capacitors (capacitance), inductances etc. on analog electrical signals. Circuits consisting of circuit elements are called Analog Filter circuits. Analog filters are actively and passively examined in two parts. In passive filters, only inductors and capacitors are used. Active filters are a little more useful, but they are circuits using OPAMP.

2.4.2.1 Passive Filter.

The main task of an electronic filter is to suppress unwanted frequencies in the electrical signal, reshape the signal to pass the signals at the desired frequencies.They are unipolar filters made using a resistor and a reactive element. Especially RC filters are widely used as both low pass and high pass filters. Considering that the capacitor acts as an open circuit in low frequency, such as short circuit in high frequency, it is also seen that the capacitor is located in parallel or serial connection, revealing the characteristics of the filter (Active High Pass Filter - Op-Amp High Pass Filter, 2018).

2.4.2.1.1 Passive Low and High Filter

The RC Low Pass Filter is a simple filter circuit that passes the low frequency band consisting of a resistor and capacitor. The gain is constant between 0 Hz and the cut off frequency (f_C). The outputs of frequencies above the cut frequency are reduced by 3 dB. Frequencies between 0 Hz and cut off frequency (f_C) are band pass frequency, and frequencies greater than fc are band extinction frequency. The gain in the band quenching frequency is very low. Low pass filter is often used in audio, image processing and biomedical applications.

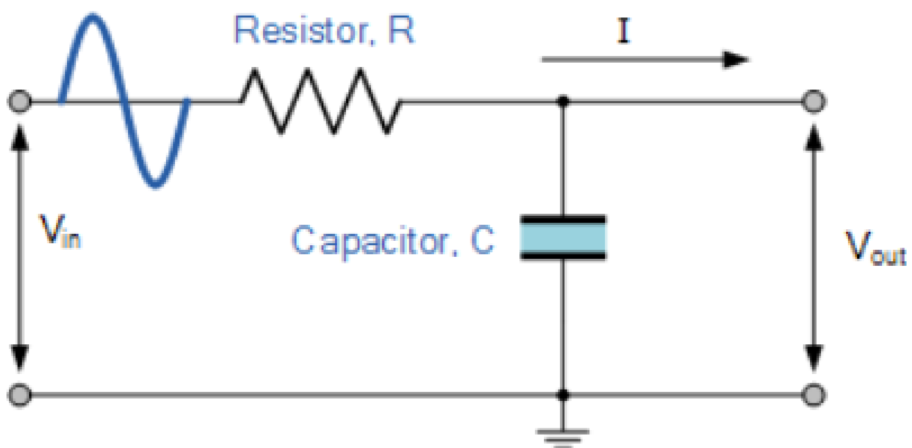


Figure 2. 21 RC low pass filter circuit

Low Pass Filter Transfer function:

$$H(w) = \frac{V_O}{V_\mathrm{i}} = \frac{V_1/jwC}{\mathrm{R} + 1/jwC} = \frac{V_1}{(1 + /jwRC)V_1} \quad (4)$$

$$H(w) = \frac{1}{1 + jwRC} \quad (5)$$

Filter cut off frequency is calculated by the formula:

$$f_C = \frac{1}{2\pi RC} \quad (6)$$

Frequency curve of the low pass filter circuit;

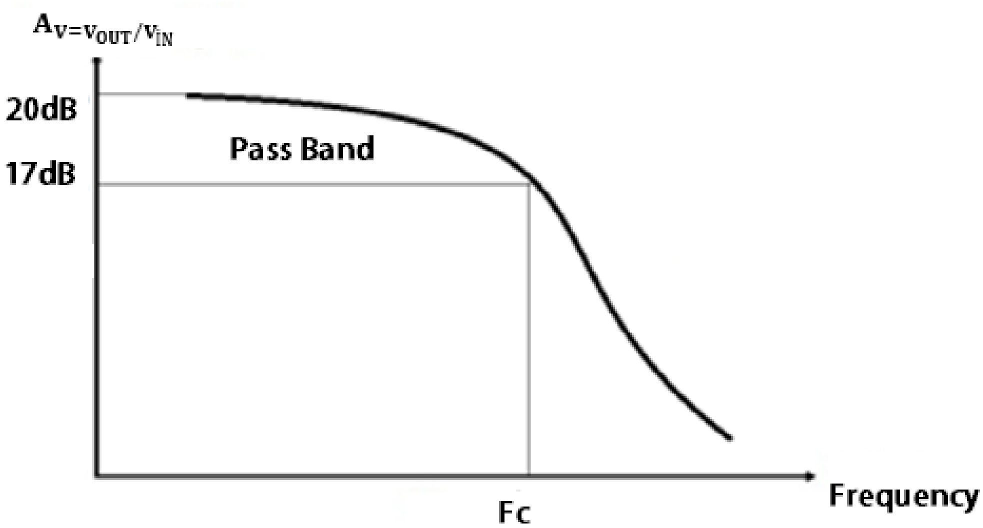


Figure 2. 22 RC low pass filter frequency curve

A passive high pass filter circuit consists of basic circuit elements such as a passive low pass filter circuit. The passive high pass filter is the opposite of the low pass filter. An RC high-pass filter circuit consists of a series connection of capacitor and resistor.

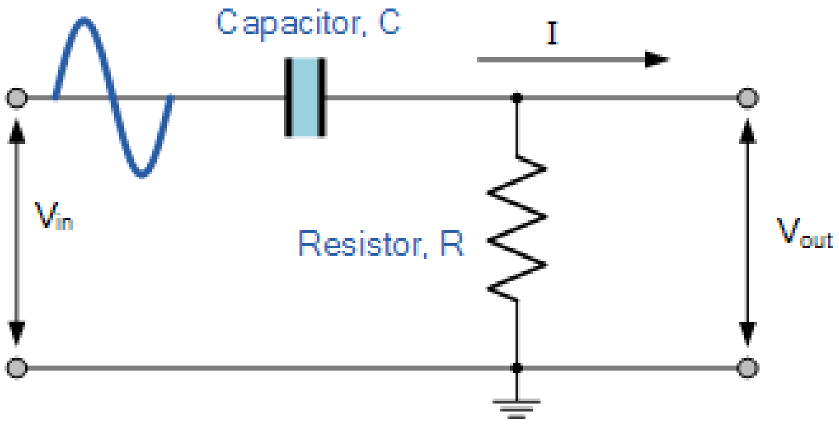


Figure 2. 23 RC high pass filter circuit

The RC high-pass filter circuit does not pass voltages at frequency values below a certain frequency. The circuit eliminates voltages below a certain frequency of f_C.$f_C$is the cut off frequency and determines the frequency to be processed. High pass filter is often used in audio, image processing and biomedical applications.

High Pass Filter Transfer function:

$$H(w) = \frac{V_O}{V_i} = \frac{jwRC}{1 + jwRC} = \frac{R}{(\mathrm{R} + \frac{1}{\mathrm{jwc}})} \quad (7)$$

Filter cutoff frequency is calculated by the formula:

$$f_C = \frac{1}{2\pi \mathrm{RC}} \quad (8)$$

Frequency curve of the high pass filter circuit;

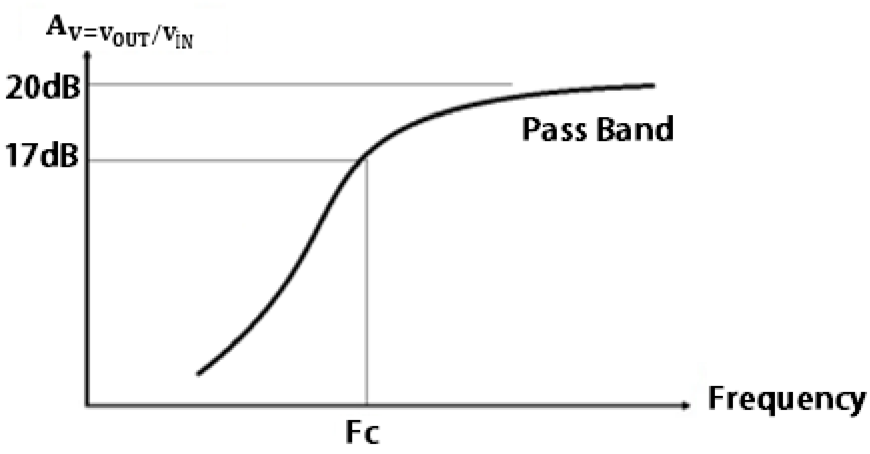


Figure 2. 24 RC low pass filter frequency curve

2.4.2.1.3 Notch Filter

Notch filters are a special type of band stop filter and they are produced by designing the bandwidth of the Band Stop Filter to be very narrow. Filter is generally used to suppress 50 Hz noise caused by mains voltage in biomedical engineering applications. Notch filters absorb a single frequency value or a very narrow frequency band according to their design. There are Low Pass Filter and High Pass Filters in the structure of notch filters.

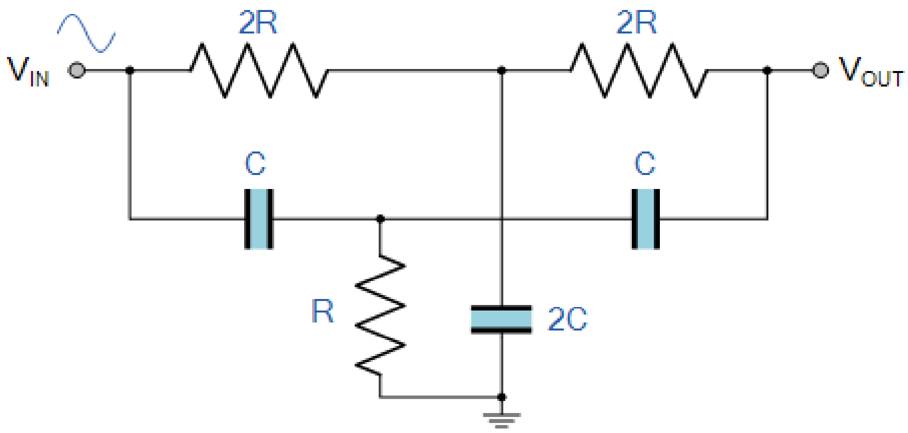


Figure 2. 25 T Notch filter circuit

Filter cutoff frequency is calculated by the formula:

$$f_C = \frac{1}{4\pi RC} \tag{9}$$

Disadvantage of notch filters are output power of the marks in the lower region of the cut frequency of the notch filter is lower than the output power in the upper region. Outputs of signals at a frequency lower than cut-off frequency of signals to be filtered are smaller than those of other signals. Therefore in filter design, while the resistance used in the low-pass filter has 2R value, the resistance in high-pass filter has the R value in filter design. The output of the low-pass filter layer will be weaker as more energy is spent on 2R.

2.4.2.2Active Filter

Electronic systems are arranged to operate with only one signal, although there are many signals or input information in the environment. This process of passing a single signal is called a filter process. Rectifier and filter circuits prevent unwanted signal and It only passes signals that are suitable for the operation of the system. These unwanted signals may be noise, noise and other system signals. Theoretically, the filter can clearly filter certain frequency ranges. But in practice, it cannot perfectly and completely filter frequencies. Rather, the filters weaken the input signal. Active filters are filters obtained using an active circuit element (such as Op Amp, transistor). The cut-off frequencies are easier to calculate, and the calculated values become more consistent. They draw their power from an external power source and use it to boost or amplify the output signal. Op-amp has a high input impedance, a low output impedance and a voltage gain determined by the resistor network within its feedback loop. Active filters are generally much easier to design than passive filters, they produce good performance characteristics, very good accuracy with a steep roll-off and low noise when used with a good circuit design.

2.4.2.2.1 Active Low and High Filter

Active low-pass filters are the most commonly used designs in filter design. The operating principle and frequency response of the active low pass filter are the same as passive filters. The only difference between active filter is used Op Amps. Output can be adjusted with OP Amps. The low pass filter allows frequencies below the cut off frequency to pass, not allowing frequencies above the cut-off frequency

The circuit diagram of an active low pass filter is shown in the following figure (Kaçmaz, 2013).

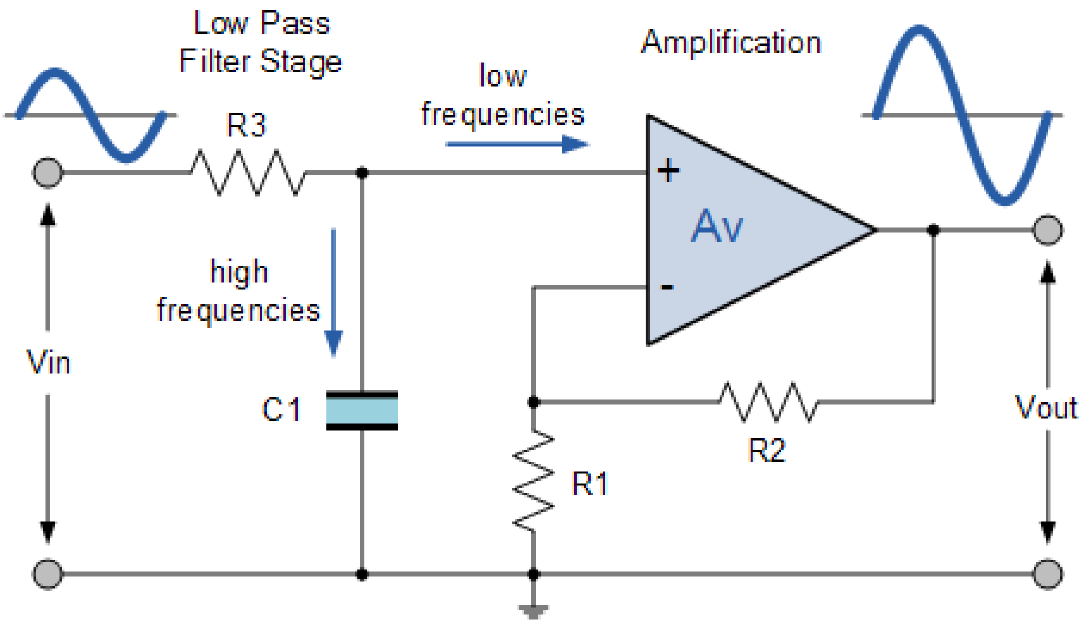


Figure 2. 26 Active low pass filter circuit

Low Pass Filter Formulas;

$$DC\ Gain = 1 + \frac{R_2}{R_1} \tag{10}$$

$$Voltage\ Gain(Av) = \frac{V_{out}}{V_{in}} = \frac{Af}{\sqrt{1 + \left(\frac{f}{fc}\right)^2}} \tag{11}$$

$$\mathrm{Av}(dB) = 20 \log 10 \left(\frac{V_{out}}{V_{in}}\right) \tag{12}$$

$$-3dB = 20 \log 10 \left(0.707 \frac{V_{out}}{V_{in}}\right) \tag{13}$$

$$fc = \frac{1}{2\pi \mathrm{RC}} \tag{14}$$

The active high pass circuit is obtained by adding an amplifier to a passive high pass circuit composed of passive filter circuit elements. The high pass filter is a filter system that suppresses signals at low frequencies, passes signals at high frequencies, and consists of an inverting operational amplifier that follows a passive filter. The frequency response of the circuit is the same as the frequency response of the passive filter. Active filters can be designed with OP AMPS, so they can generate gains at their output.

The circuit diagram of an active high pass filter is shown in the following figure;

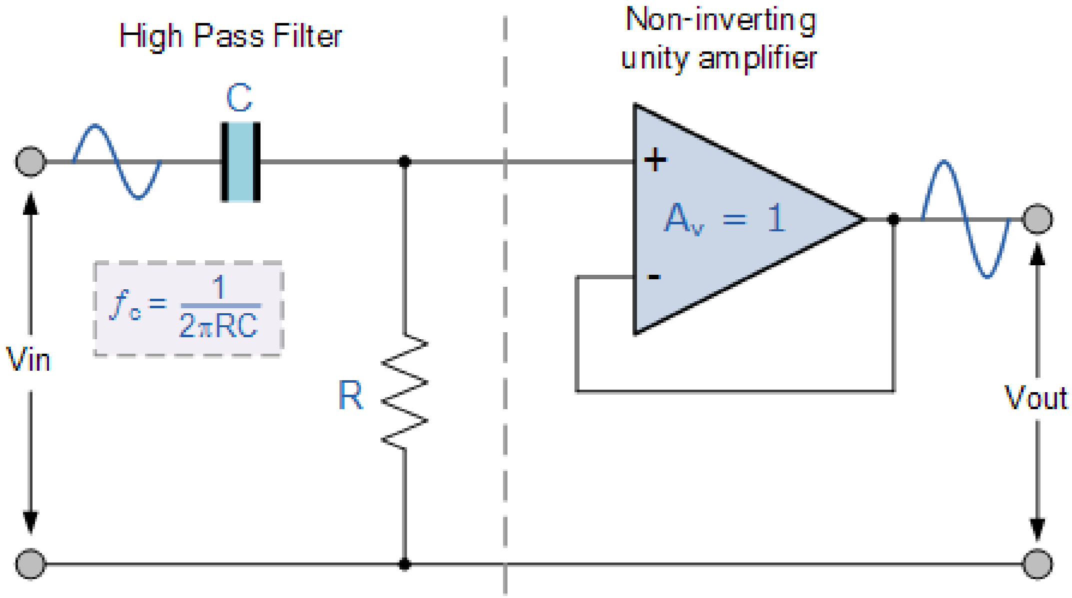


Figure 2. 27 Active high pass filter circuit

$$DC\ Gain = 1 + \frac{R2}{R1} \tag{15}$$

$$Voltage\ Gain(Av) = \frac{Vout}{Vin} = \frac{Af\left(\frac{f}{fc}\right)}{\sqrt{1 + \left(\frac{f}{fc}\right)^2}} \tag{16}$$

$$Av(dB) = 20\log 10\left(\frac{Vout}{Vin}\right) \tag{17}$$

$$-3dB = 20\log 10\left(0.707\frac{Vout}{Vin}\right) \tag{18}$$

$$fc = \frac{1}{2\pi RC} \quad (19)$$

2.4.2.2.2 Active Band Pass And Band Stop Filter

Bandpass filter are filters made to pass certain frequency ranges. For this, a high-pass filter and a low-pass filter art must be connected successively. The cut-off frequency of the low pass filter should be chosen higher than that of the high pass filter. $fc1$ is the low side of the frequency and $fc2$ is the high side of the frequency.

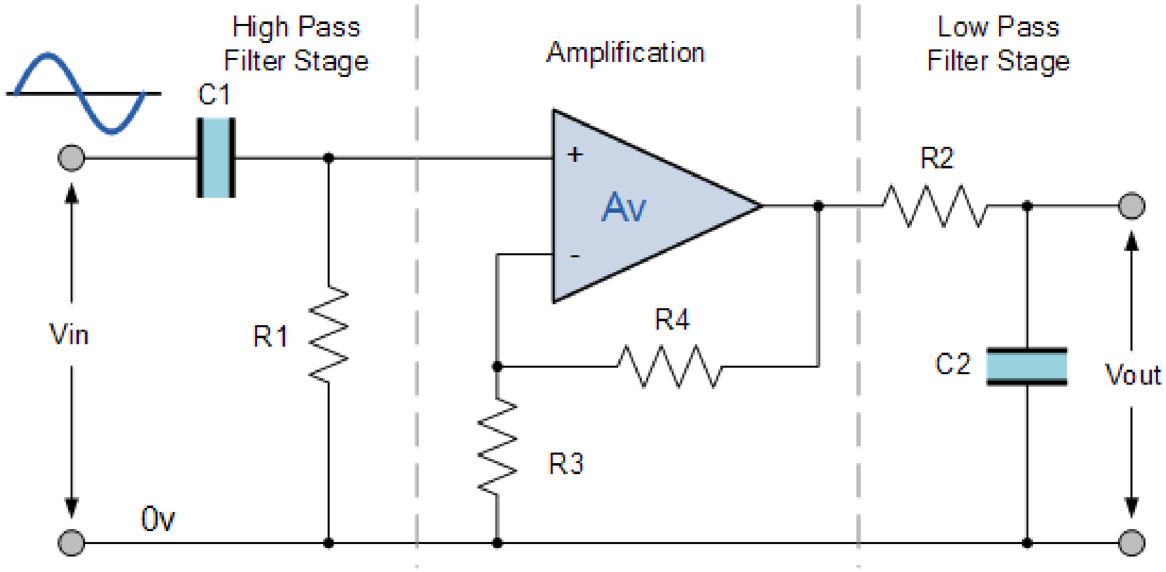


Figure 2. 28 Active band pass filter circuit

First, the high-pass filter prevents the low frequencies from passing up to the frequency $fc1$. After the resonance frequency, the low-pass filter comes into play and allows the passage of the signal up to $fc2$. It does not pass higher frequency signals.

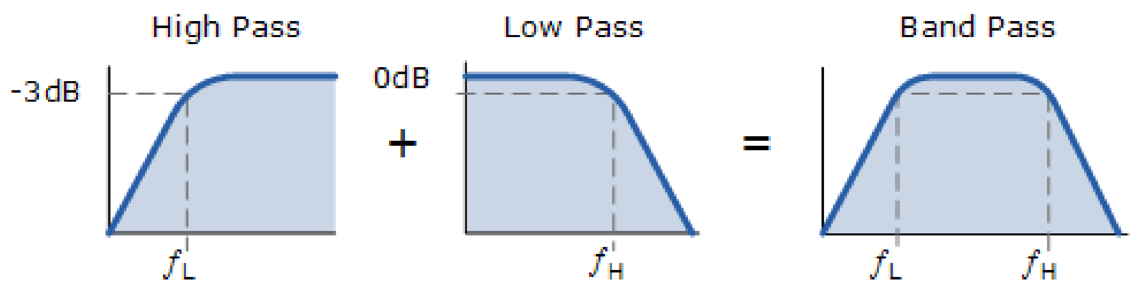


Figure 2. 29 Band pass filter curves

$$Voltage\ Gain = \frac{R2}{R1} \tag{20}$$

$$fc1 = \frac{1}{2\pi(R1)(C1)} \tag{21}$$

$$fc2 = \frac{1}{2\pi(R2)(C2)} \tag{22}$$

The task of the Band Stop filter can be understood from its name. Band stop filter does not pass the signal between two different frequencies and allows the signals in the other frequency to pass. Band stop filters have two cut off frequency and circuits work in two frequency ranges. f_L indicates the low side of the frequency and f_H indicates the high side of the frequency. As with Band Pass filters, these filters consist of both the High Pass Filter and the Low Pass Filter layer. Band-stopping circuits are frequently seen in biomedical devices.

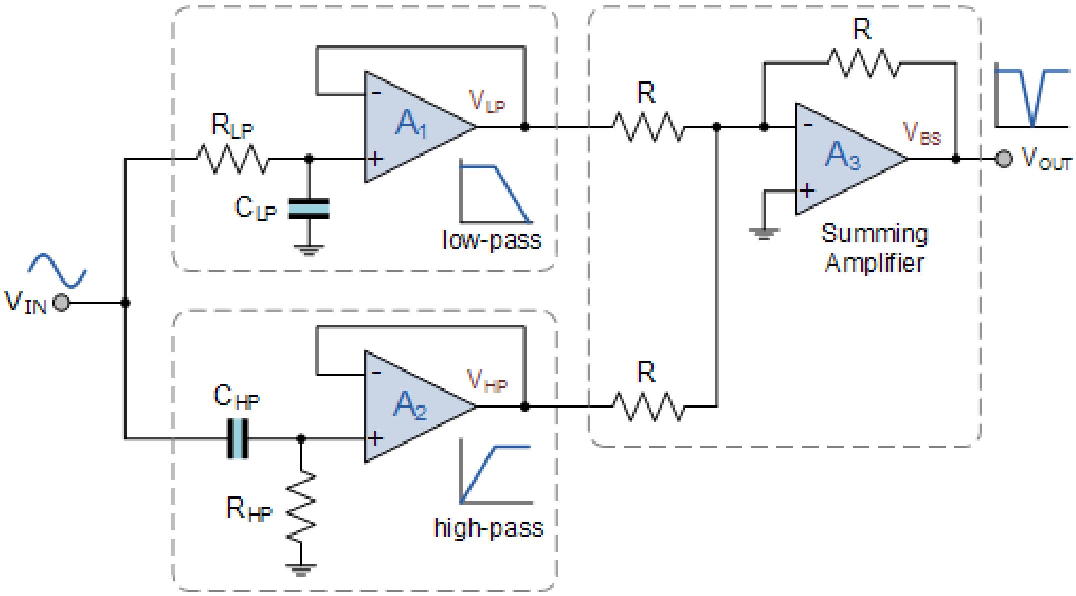


Figure 2. 30 Active band stop filter circuit

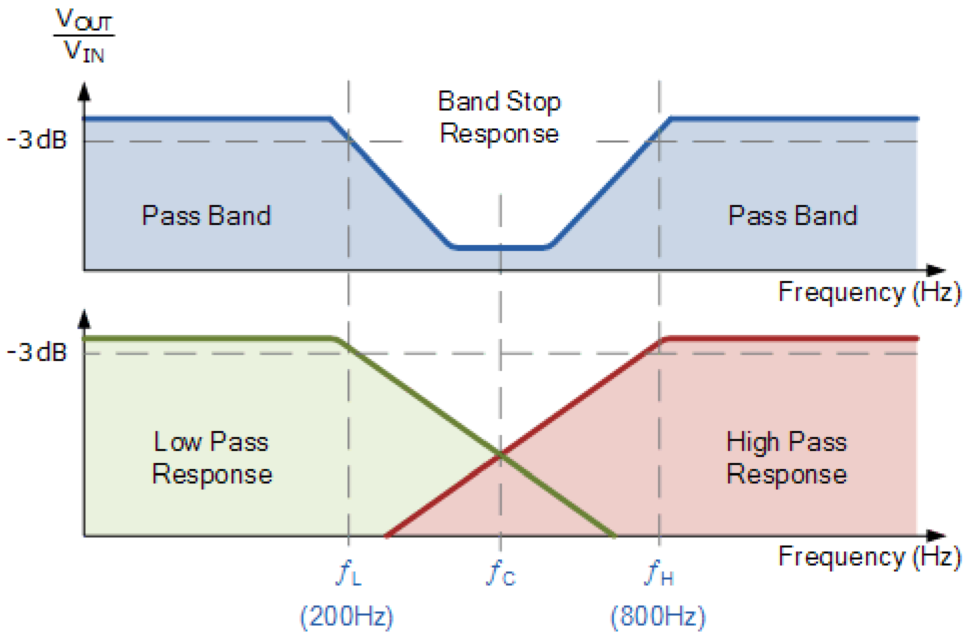


Figure 2. 31 Active band stop filter curves

$$fL = \frac{1}{2\pi RLC} \tag{23}$$

$$fH = \frac{1}{2\pi RHC} \tag{24}$$

2.5 EMG Rectification

The full wave rectifier is typically used to create a dc level from an ac input. This is often used to measure the amplitude of the ac signal. The full wave rectifier is an averaging detector. Generally, the EMG signal will be fluctuating in the range between positive and negative value during the muscle movement. Precision rectifier, known as super diode, is designed with an operational amplifier to act as an ideal diode and rectifier. It is very useful to process high precision signals with precision rectifier. The EMG signal has a very small amplitude, so it is necessary to rectifying the signal with a sensitive rectifier circuit. Precision full wave rectifier is important to rectify the signal for microcontroller processing purpose. The output of the full rectifier operation is the absolute value of the amplitude of the signal(Emanuel Singh et al., 2019).

$$yi = |\, xi| \tag{25}$$

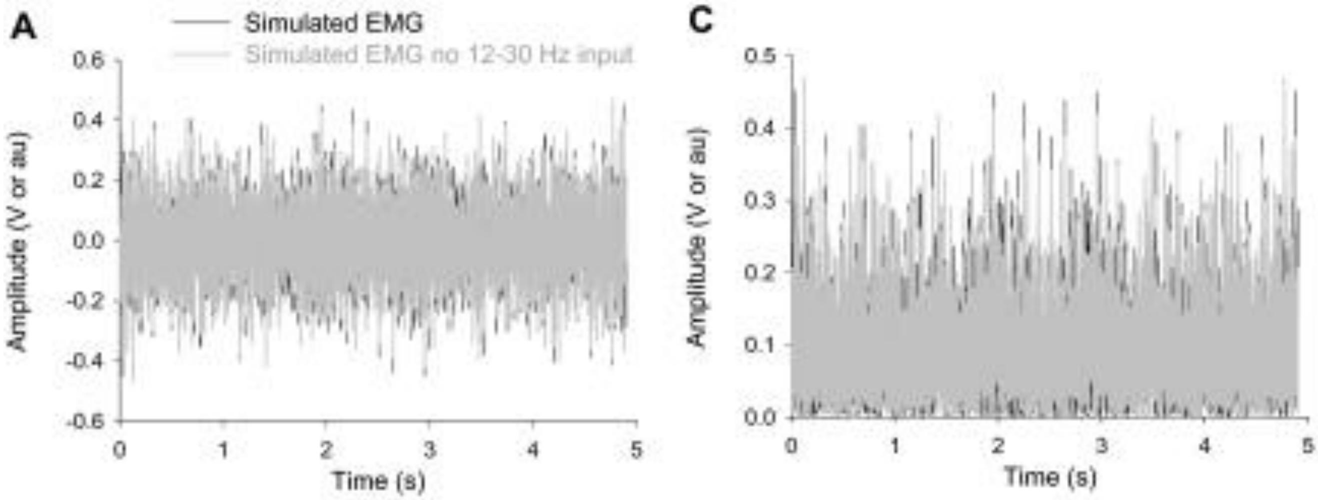


Figure 2. 32 Raw and Rectification EMG signals (Emanuel Singh et al., 2019).

The precision full wave rectification step must be performed before smoothing the EMG signals. There are many precision full wave rectifier circuit designs to achieve the absolute value of low amplitude signals such as EMG.

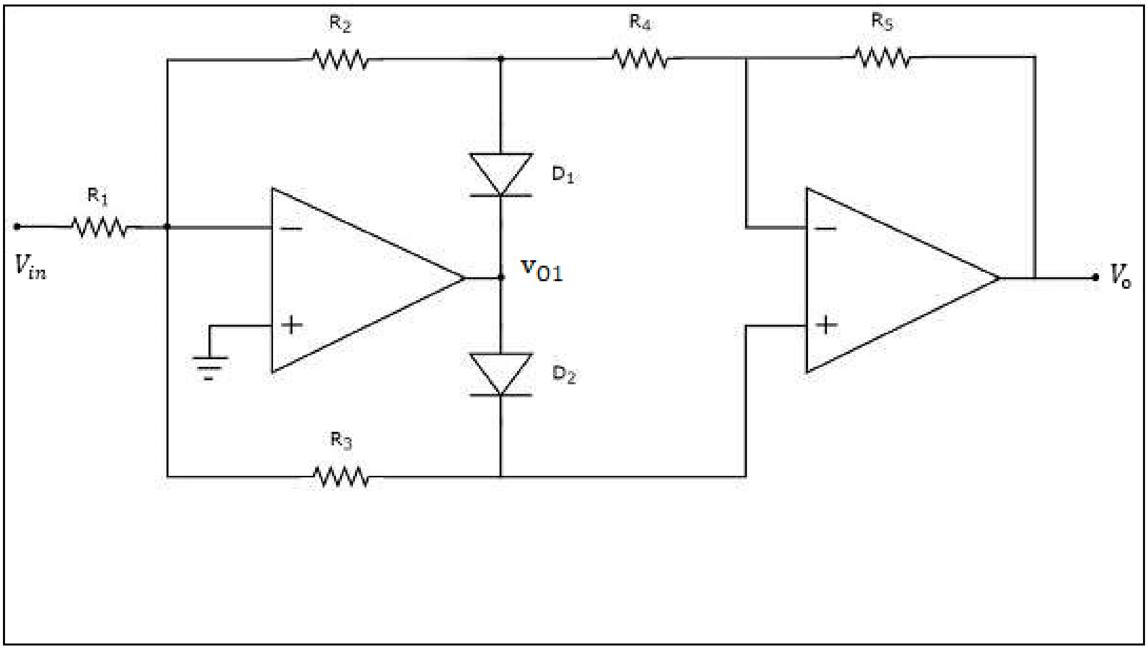


Figure 2. 33 Full wave rectification schematic

$$Vo = -\left(\frac{R5}{\mathrm{R4}}\right)\mathrm{Vo1} \tag{26}$$

Substituting the value of Vo1 in the above equation;

$$Vo = -\left(\frac{R5}{R4}\right)\left\{-\left(\frac{R2}{R1}\right)Vi\right\} \tag{27}$$

$$Vo=\left(\frac{R2R5}{R1R4}\right)Vi \tag{28}$$

$$Vo=-\left(\frac{R2}{R1}\right)Vi \tag{29}$$

2.6 EMG Smoothing

EMG signal is between 20-500 Hz. The EMG signal is on the positive and negative side, so it must be on the positive side to be able to analyse the signal. Full wave rectification must be done to pass the signal to the + side. After full-wave rectification, linear envelope is used to clear noise of the signal and detect only its upper points. Other name is smoothing. The rectification step is essential for getting the shape or “envelope” of the EMG signal. Filtering and smoothing process has close features and it aims to eliminate noises in two processes. Linear envelope is created by removing the middle part of the signal with smoothing. The combination of rectification and low-pass filtering is called finding the "linear envelope" of the signal.

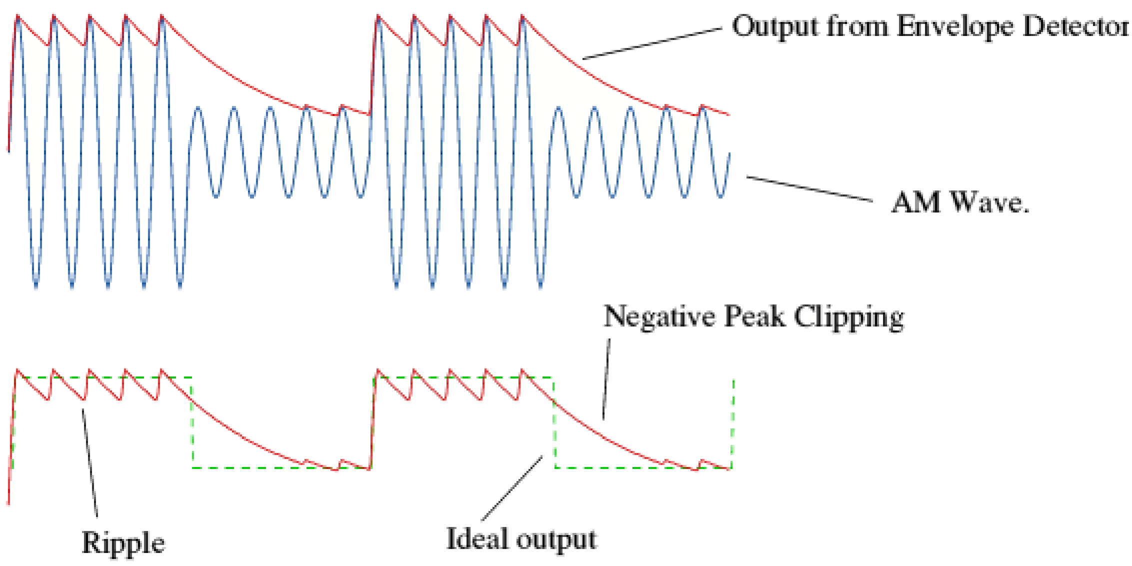


Figure 2. 34 Smoothing graph

The rectified signal is low pass filtered, with in the 5 – 100 Hz range, and the result looks like the "envelope" of the original signal. Low pass filter is generally preferred as active filter in EMG applications.

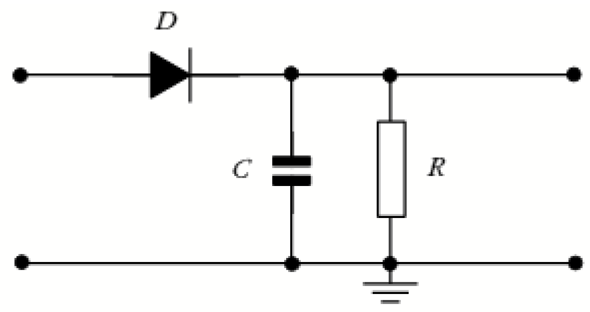


Figure 2. 35 Envelope circuit

CHAPTER 3

DESIGN OF EMG SENSOR AND CIRCUIT ANALYSIS

The surface EMG signal is measured by electrodes placed in the muscles. Needle electrodes are not used for measurement, so the amplitude of the signals is between 0-10 mV. In addition, when these electrodes contact the body, noises are generated due to the dirty or hairy body. Since the amplitudes of the surface EMG signals are very small, they must be amplified in order to understand the signals. Noises increase in the amplified signal, filter circuits should be designed to eliminate these noises. The filter circuit to be designed should pass through frequencies between 20-500 Hz. This chapter describes the measurement and conditioning of EMG signals. The applied block diagram is given in Figure 3.1
Each block will be explained in the following sections.

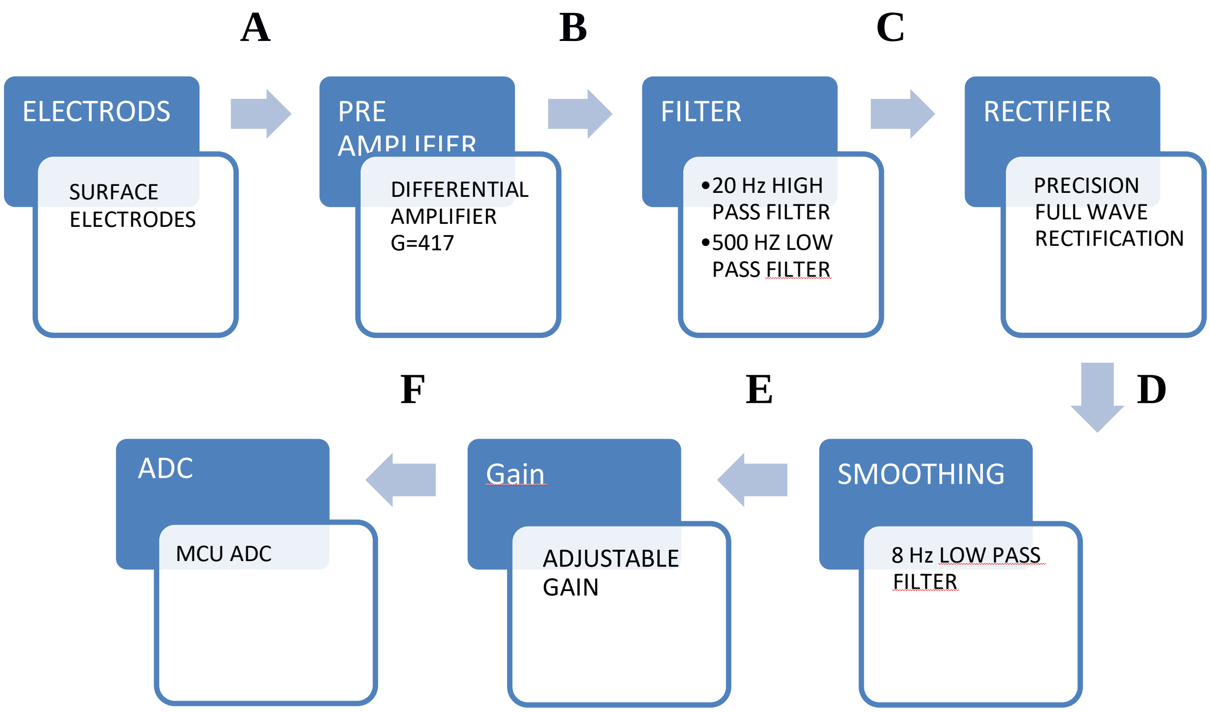


Figure 3. 1 EMG measurement block diagram

3.1 Surface Electrodes and Cable

Electrode type has a pre-gelled adhesive side with non-irritating gel, especially developed to prevent allergic reactions. The foam electrode is latex free and therefore suitable for every skin type. Beybi brand surface electrodes were used in surface EMG measurements. Electrode dimensions are 50 mm x 55 mm.

Figure 3. 2 Surface EMG electrode

EMG electrode cable connect to surface electrodes. Electrodes can be changed because the heads on the cable are button type. Electrode cable output has 3.5 mm audio jack. This connection is used to prevent electrical noise.

Figure 3. 3 EMG electrode cable

3.2 INA 128 Instrumentation Amplifier

The INA128 is low-power, general purpose instrumentation amplifiers offering excellent accuracy. A single external resistor sets any gain from 1 to 1000.Ina 128 has low offset voltage 50 uV. The amplifier was used for increasing the voltage on the electrodes.

Applications;

- Bridge amplifier
- Thermocouple amplifier
- RTD sensor amplifier
- Medical instrumentation
- Data acquisition

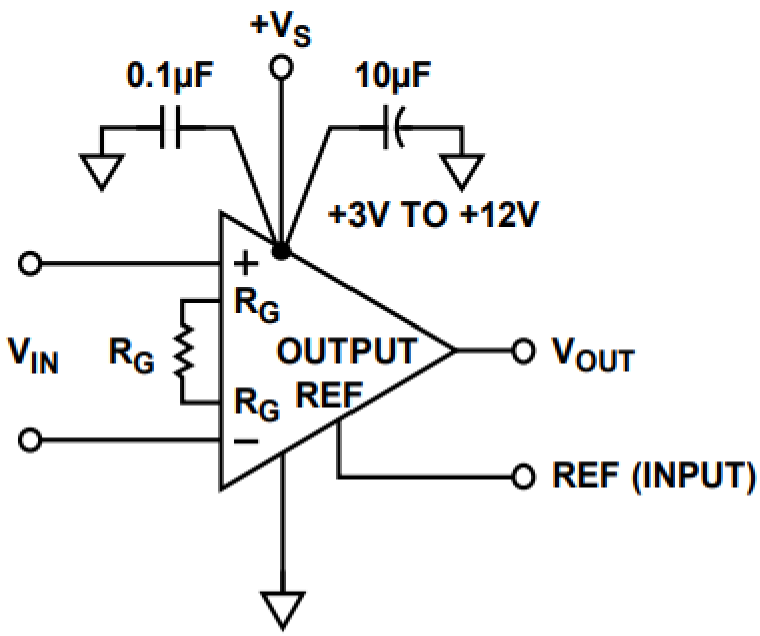


Figure 3. 4 INA 128 amplifier basic connection diagram

The signal level of surface EMG is nearly 3 mV.For investigation of this voltage, it should be minimum near 1V, so gain of surface EMG preamplifier circuit which is designed INA 128 amplifier, should be between 400 and 500.Output voltage is calculated by formulas below which is founded to INA 128 datasheet (TI, 2019).

$$Gain = 1 + \frac{50\ k\Omega}{\mathrm{RG}} \tag{30}$$

$$Vout = Gain\big((+Vin) - (-Vin)\big) + Vref \tag{31}$$

$$Gain = 1 + \frac{50\ k\Omega}{120\ \Omega} \cong 417 \tag{32}$$

$$Vout = 417\big((2{,}6mV) - (-2.6mV)\big) + 0V \tag{33}$$

$$Vout \cong 2{,}16\ V \tag{34}$$

Figure 3.4 shown that simulation of preamplifier circuit which was designed. Electrode 1 is connected to INA 128 amplifier +Vin pin and Electrode 2 is connected -Vin pin. In preliminary studies, it was observed that the EMG signal average +2.6 mV at Electrode 1 and -2.6 mV at Electrode 2. Because of this reason, Electrode 1 is selected 2.6 mV and Electrode 2 is selected -2.6 mV.Ref pin and Electrode 3 are connected to GND of power supply.
Measured of simulation output voltage shown in Figure 3.5 ;

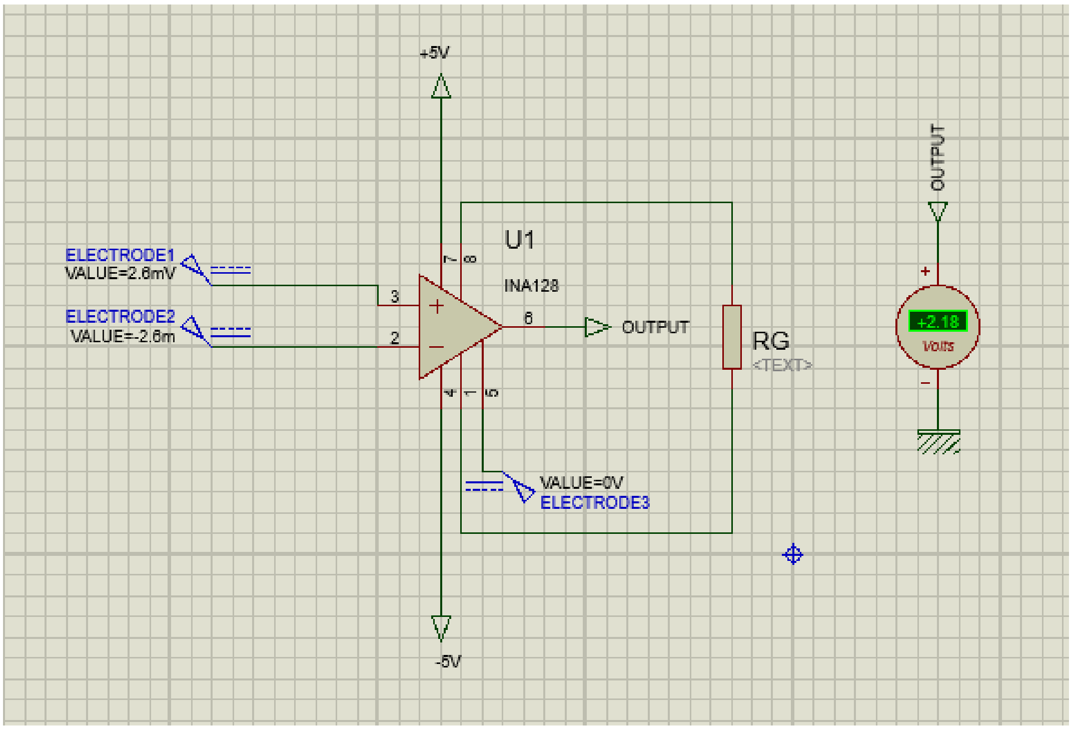


Figure 3. 5 Preamplifier simulated circuit with proteus

The measurement was made on the right arm. Electrode1 and Electrode 2 were placed to Extensor muscles. Electrode 3 was placed to reference point. Measurement of surface EMG was made according to open and close movement of arm. Figure 3.6 showns Oscilloscope records ,which is obtained to Contraction of the right arm.

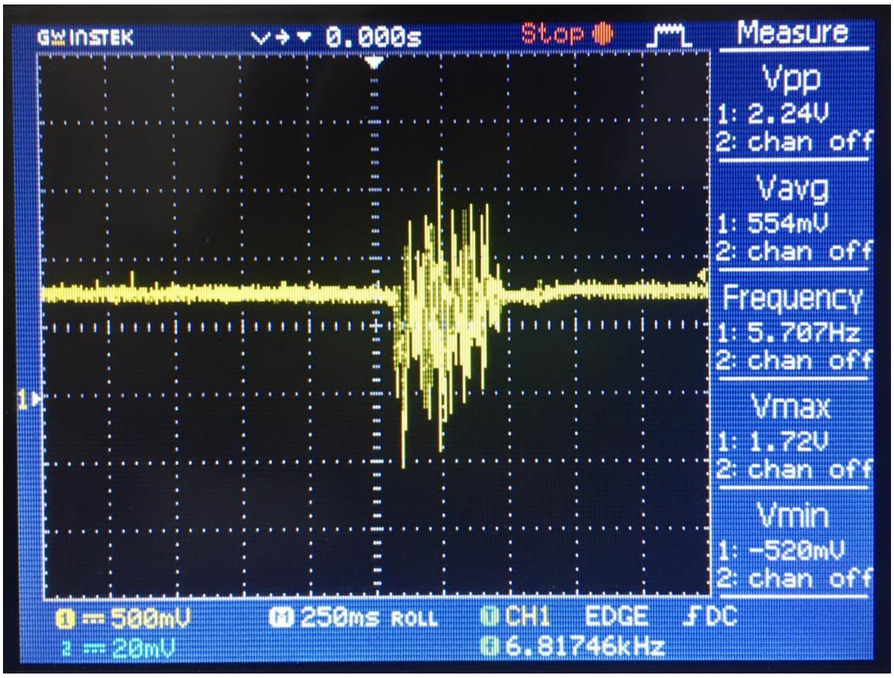


Figure 3. 6 Oscilloscope image of the raw EMG signal.

Measurement of preamplifier output, which is obtained to oscilloscope is shown in Figure. Frequency, Vmax and Vmin outputs were seen to using of oscilloscope measuring function shown that value which is calculation of Vout. According to the calculation and output of oscilloscope, circuit simulation is observed to give correct results.RAW EMG output amplitude can be change according to the placement of electrodes (Op & Applications, 2005). Electronic Filters are electronic circuits that exceed the desired values by preventing unwanted ones from the frequency components of electrical signals applied to their inputs and also by removing electrical signals from harmonics and interference. Electronic filters are designed to eliminate EMG signals from noise.

Passive or active electronic filters are used only in circuits where a signal amplitude is required in a limited frequency range. Sallen Key Filter is easy to use and understand. Sallen Key topology is an active filter design (Op & Applications, 2005). It is created with one operational amplifier and two resistors or capacitors thus creating a voltage-controlled voltage source design with high input impedance, low output impedance and good filter characteristics. and thus, enables separate Sallen-key filter sections to be cascaded together to produce much higher-grade filters.

OP07 is ultralow offset voltage operational amplifier. The amplifier can work between: ±3 V and ±18 V.OP07 has very ultra-low noise 0.6 µV p-p maximum. OP07 is used as an amplifier in filter, rectification and smoothing circuits (Analog Devices, 2011). Figure 2.4 shown as OP07 pin configuration;

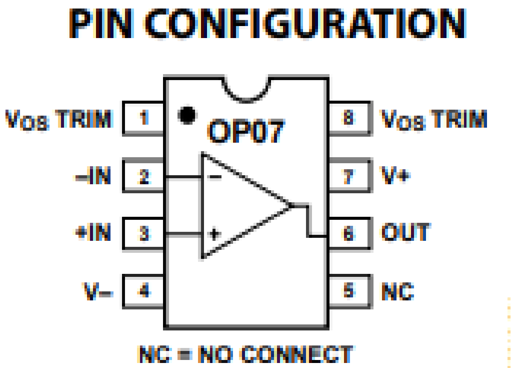


Figure 3. 7 OP07 Pinout diagram

EMG frequency is between 50 Hz and 150 Hz. Electrode and electrical noises create disturbances in the EMG signal. The EMG signal is affected by noise in the 0-20 Hz frequency range for this reason is designed 20 Hz High Pass Filter second order. Figure 3.7 shown that Sallen Key High Pass filter circuit.

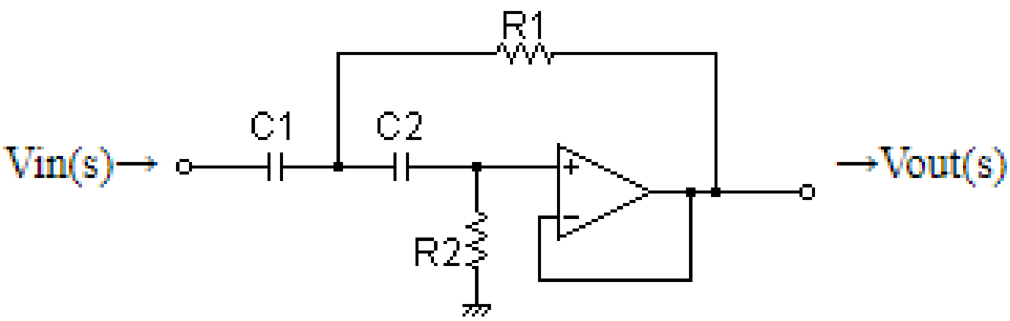


Figure 3. 8 Sallen Key low pass filter circuit

$$fc = \frac{1}{2\pi(\mathrm{R1} \times \mathrm{R2} \times \mathrm{C1} \times \mathrm{C2})} \quad (35)$$

$$C1=100\ nF \quad C2=100\ nF \quad R1=82\ K\Omega \quad R2=82\ k\Omega \tag{36}$$

$$fc = \frac{1}{2\pi(82k\Omega \times 82k\Omega \times 100nF \times 100nF)} \cong 18\ Hz \tag{37}$$

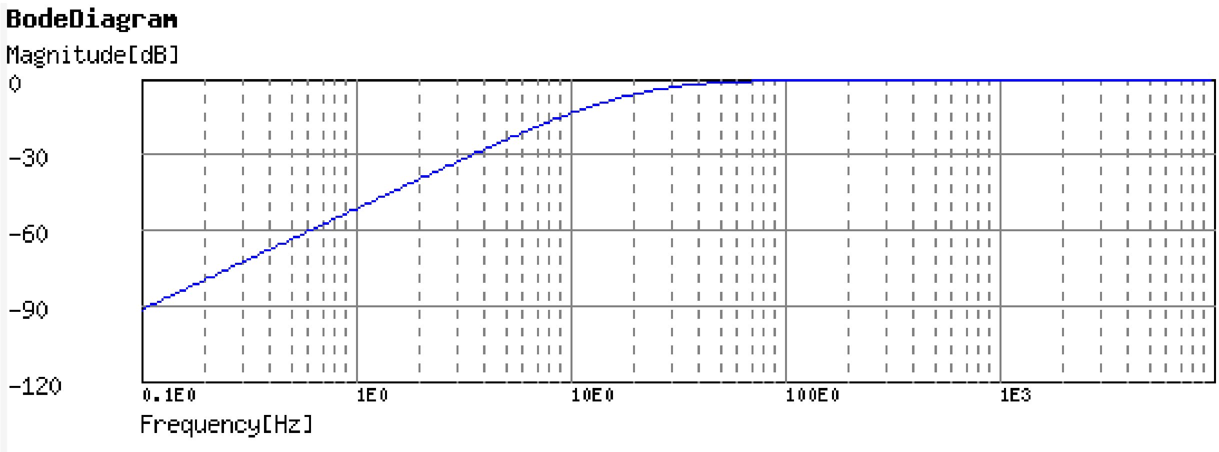


Figure 3. 9 Cut-off frequency curve of Sallen Key high pass filter

Filter of Magnitude/Frequency graph which is designed. Decrease of magnitude in 20 Hz frequency is shown to graph. Effect of 10 Hz sine signal is seen in simulation of oscilloscope.

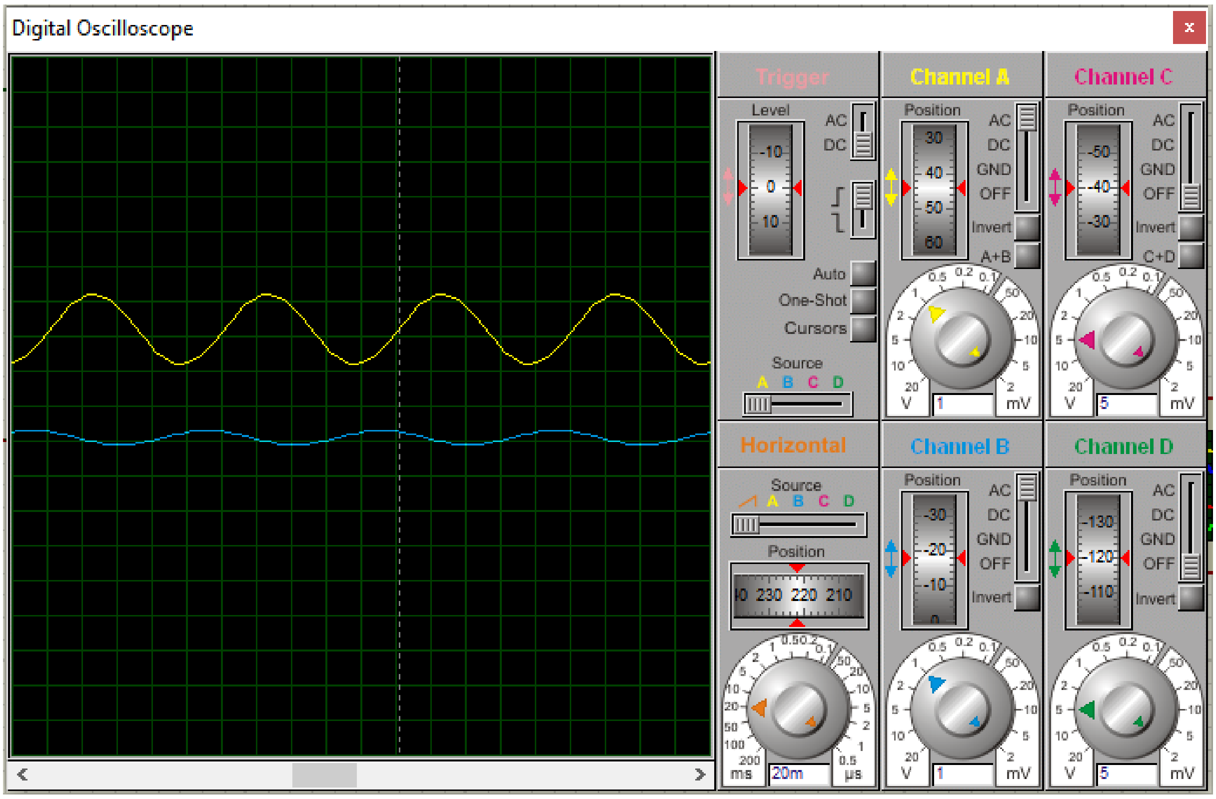


Figure 3. 10 Oscilloscope simulation image of the high pass filtered EMG signal.

Channel A is the yellow line and Channel B is the blue line. In the simulation, 10 Hz sine signal is applied and Channel A is also shown. Channel B is 18 Hz high pass filtered signal. The amplitude of the filtered signal has been shown to decrease by about 15 dB. When the frequency of the input signal was increased, it was observed that its amplitude increased in the filtered signal. When the frequency of the input signal is 50 Hz and above, it has no effect on the amplitude of the output signal.

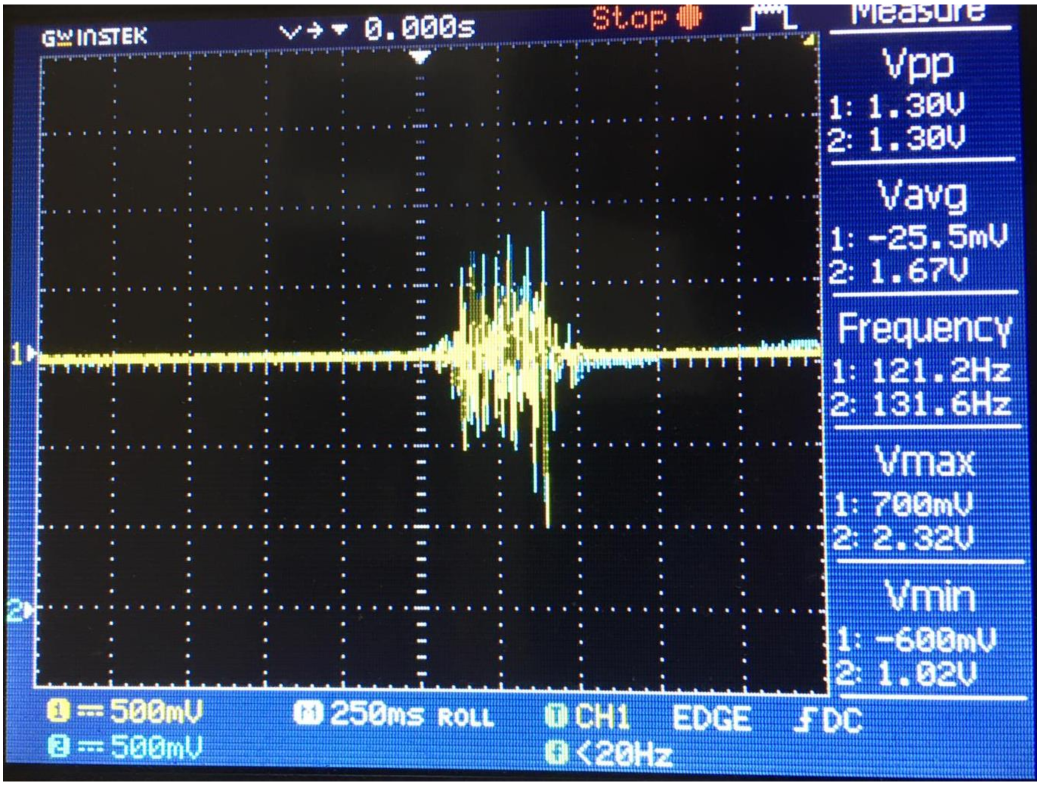


Figure 3. 11 Oscilloscope image of the high pass filtered and raw EMG signal.

Channel 1 is the yellow line and Channel 2 is the blue line. Figure 3.11 shown that filtered and raw EMG. Channel 1 is high pass filtered and Channel 2 is Raw EMG. The zero points of the RAW and filtered signal are superimposed to observe the difference between the signals Filtered signal noise appears to be reduced. The measurement page has the results of the signal. Vpp refers to the amplitude of the signal. The amplitudes of the RAW and filtered signals are the same and are 1.3 Volt, but their frequency slightly different. Frequency of RAW Signal is 131 Hz and filtered signal is 121 Hz.

3.3.1.Sallen Key Low Pass Filter

The EMG signal is affected by signals above 500 Hz, such as frequencies below 20 Hz so low pass filters are used to eliminate these effects. Second order 500 Hz low pass filter is designed to forestall noises. Figure 3.12 shows second order low pass filter schema. Bandpass filters are obtained by connecting low-pass and high-pass filter circuits in series. Lower and upper cut frequencies are calculated separately and the area in between gives the bandwidth of the system.

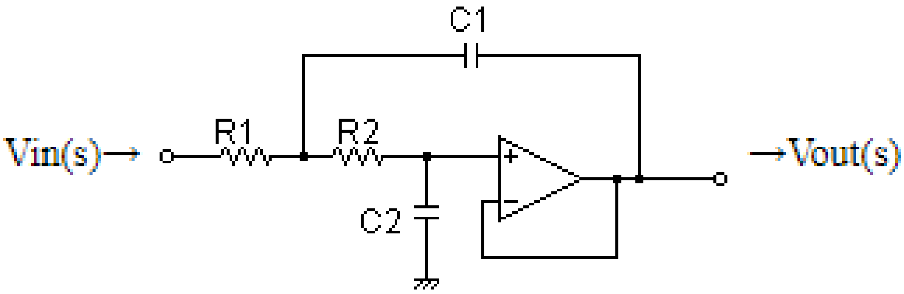


Figure 3. 12 Sallen Key low pass filter circuit

$$fc = \frac{1}{2\pi(\mathrm{R1} \times \mathrm{R2} \times \mathrm{C1} \times \mathrm{C2})} \tag{38}$$

C1=100 nF C2=100 nF R1=3.3 KΩ R2=3.3 kΩ (39)

$$fc = \frac{1}{2\pi(3.3\mathrm{k}\Omega \times 3.3\mathrm{k}\Omega \times 100\mathrm{nF} \times 100\mathrm{nF})} \cong 482\ Hz \tag{40}$$

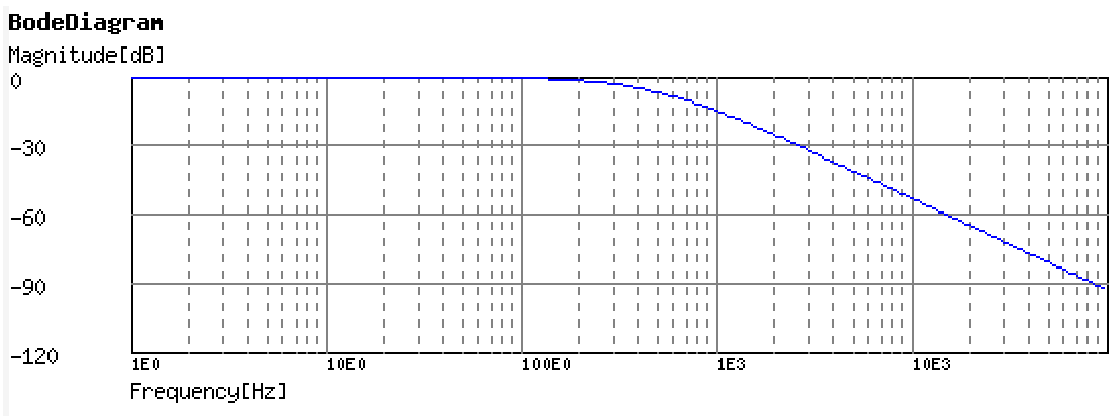


Figure 3. 13 Cut-off frequency curve of Sallen Key low pass filter

Figure 3.13 shown that Low Pass Filter of Magnitude/Frequency graph which is designed. Decrease of magnitude in 500 Hz frequency is shown to graph. Effect of 600 Hz sine signal is seen in simulation of oscilloscope.

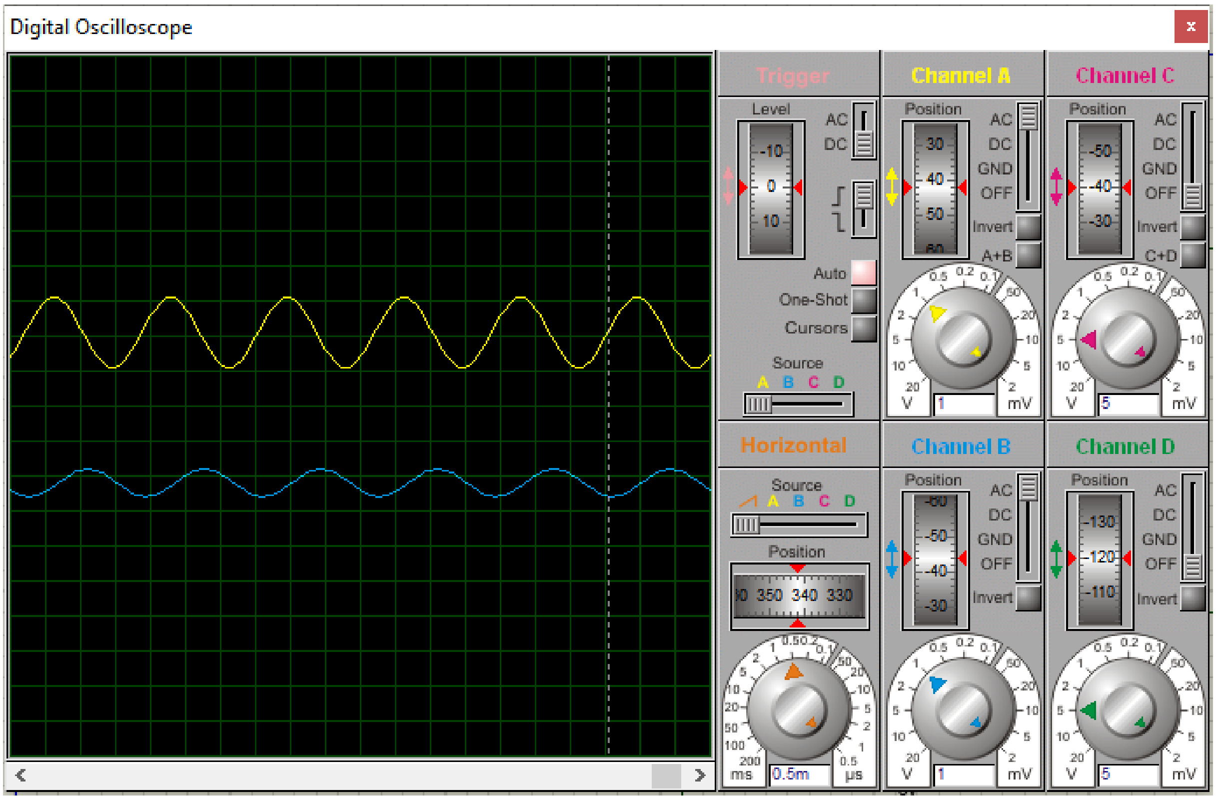


Figure 3. 14 Oscilloscope simulation image of the low pass filtered EMG signal.

Channel A is the yellow line and Channel B is the blue line. In the simulation, 600 Hz sine signal is applied and Channel A is also shown. Channel B is low pass filtered signal. The amplitude of the filtered signal has been shown to decrease by about 6 dB. When the frequency of the input signal was decreased, it was observed that its amplitude increased in the filtered signal. The filter has no effect on the amplitude when the input signal frequency is less than 200 Hz.

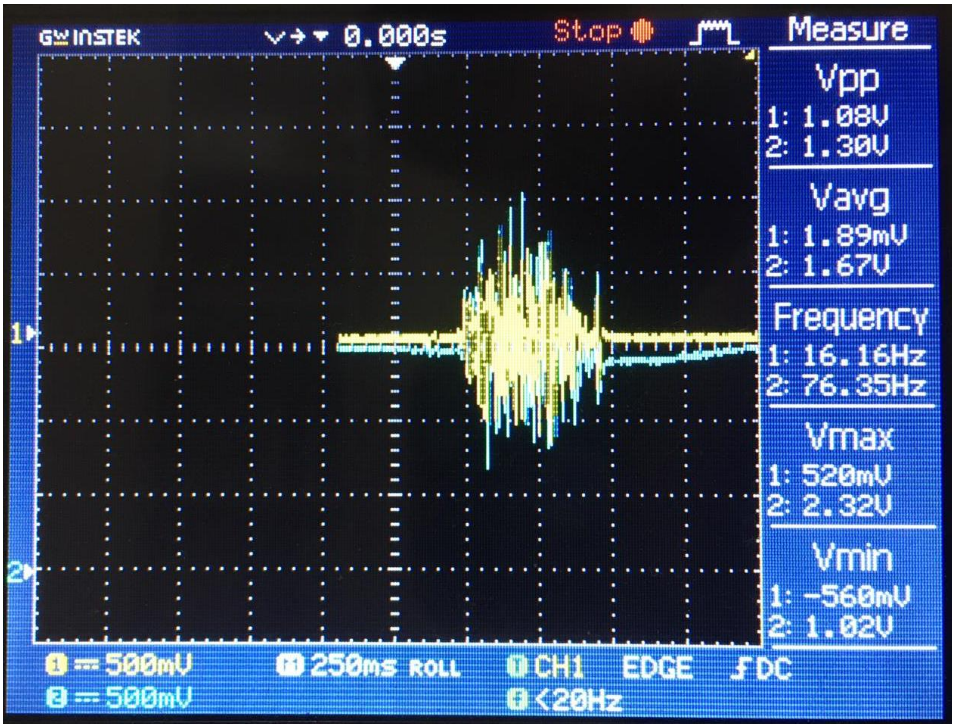


Figure 3. 15 Oscilloscope image of the band pass filtered and raw EMG signal.

Channel 1 is the yellow line and Channel 2 is the blue line. Figure 3.15 shown that filtered and raw EMG. Filtered signal is formed by connecting the high pass and low pass filter in series with each other. Thus, this bandpass filter is formed. The zero points of the RAW and filtered signal are superimposed to observe the difference between the signals Filtered signal noise and disturbance seem to be reduced. The amplitude of the filtered signal appears to change. Amplitude of the filtered signal is 1.08 Volt and frequency is 16 Hz. Amplitude of the RAW signal is 1.3 Volt and frequency is 76 Hz.After the band pass filter, noises were cleared and the frequency of the signal decreased.

3.4 Precision Rectification Circuit Design and Analysis

Simple rectifier circuits designed with diodes are not successful in rectifying small amplitude signals. Precision full-wave rectifier circuits are created with op-amps for designs that require a high degree of precision. The full wave rectifier is typically used to create a dc level from an ac input. This is often used to measure the amplitude of the ac signal. The full wave rectifier is an averaging detector. This is to be differentiated with a rms detector or a peak detector. The EMG signal creates oscillations to the positive and negative polarities at the zero point. This is equivalent to taking the absolute value of the signal. Rectification is mainly used as a pre-processing step before another process like averaging or computing the envelope of the signal.

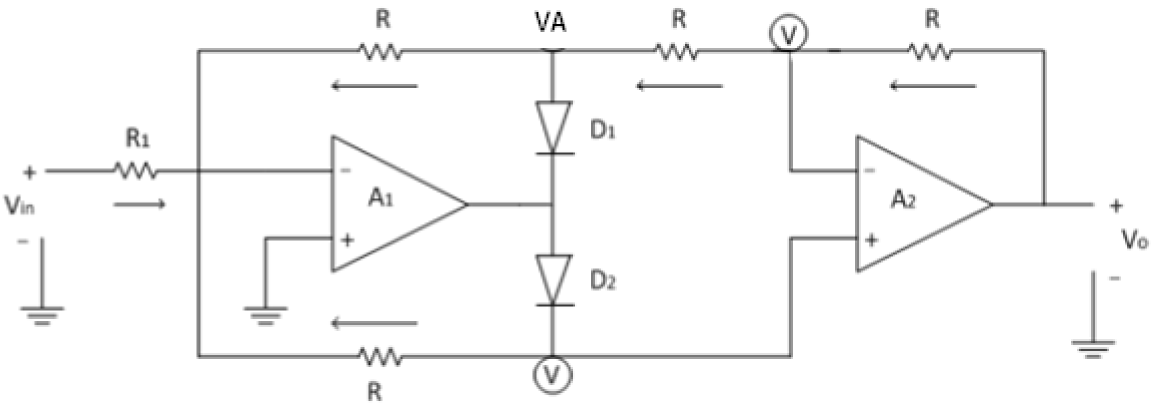


Figure 3. 16 Full wave rectifier circuit

$$Gain = \frac{R}{\mathrm{R1}} \tag{41}$$

$$VA = -\frac{R}{\mathrm{R1}} \times \mathrm{Vi} \qquad Vo = \frac{R}{\mathrm{R1}} \times \mathrm{Vin} \tag{42}$$

R1=150K ,R=150K ,D1=1n4148, D2=1n4148 (43)

$$Vo = |-\mathrm{Vin}\,| \tag{44}$$

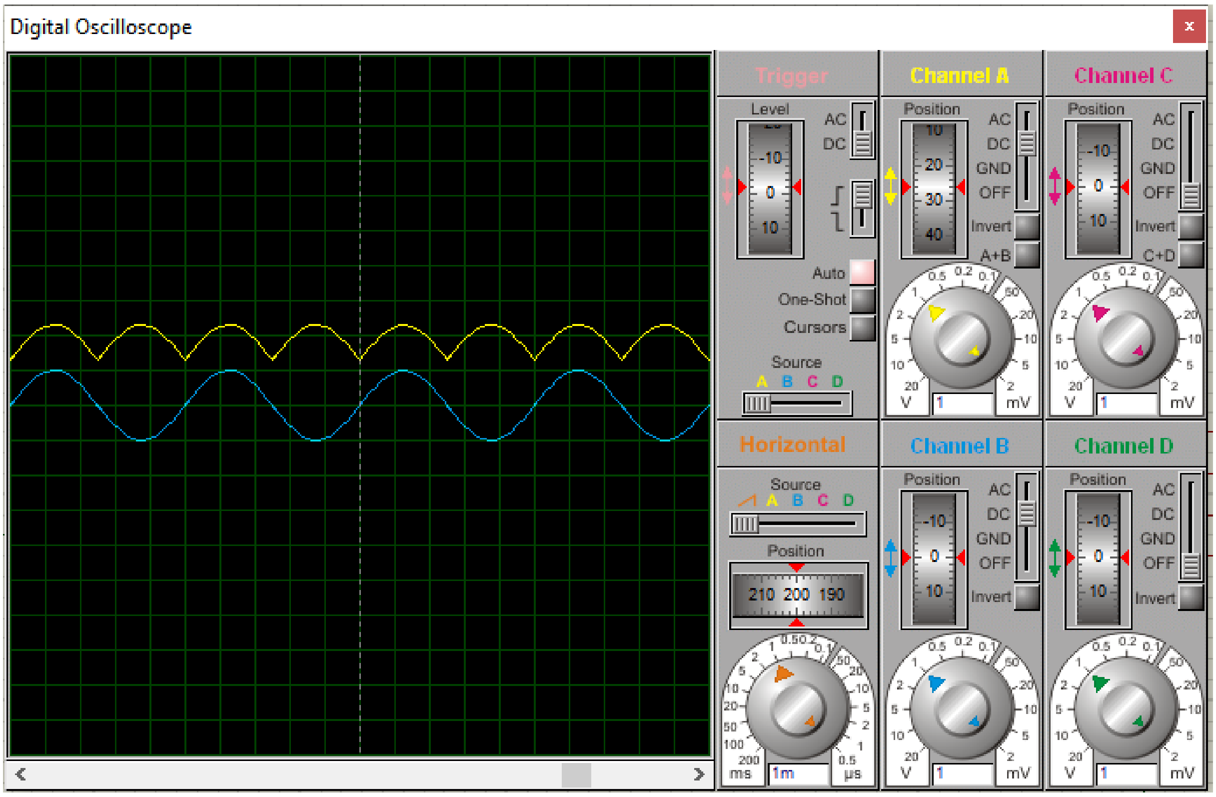


Figure 3. 17 Oscilloscope simulation image of the rectifying signal.

Channel A is the yellow line and Channel B is the blue line. In the simulation, 100 Hz sine signal is applied and Channel A is also shown. Channel B is full wave rectified filtered signal. As you can see in the above oscilloscope, the full wave rectifier circuit diagram that we considered will produce only positive half cycles for both positive and negative half cycles of a sinusoidal input.

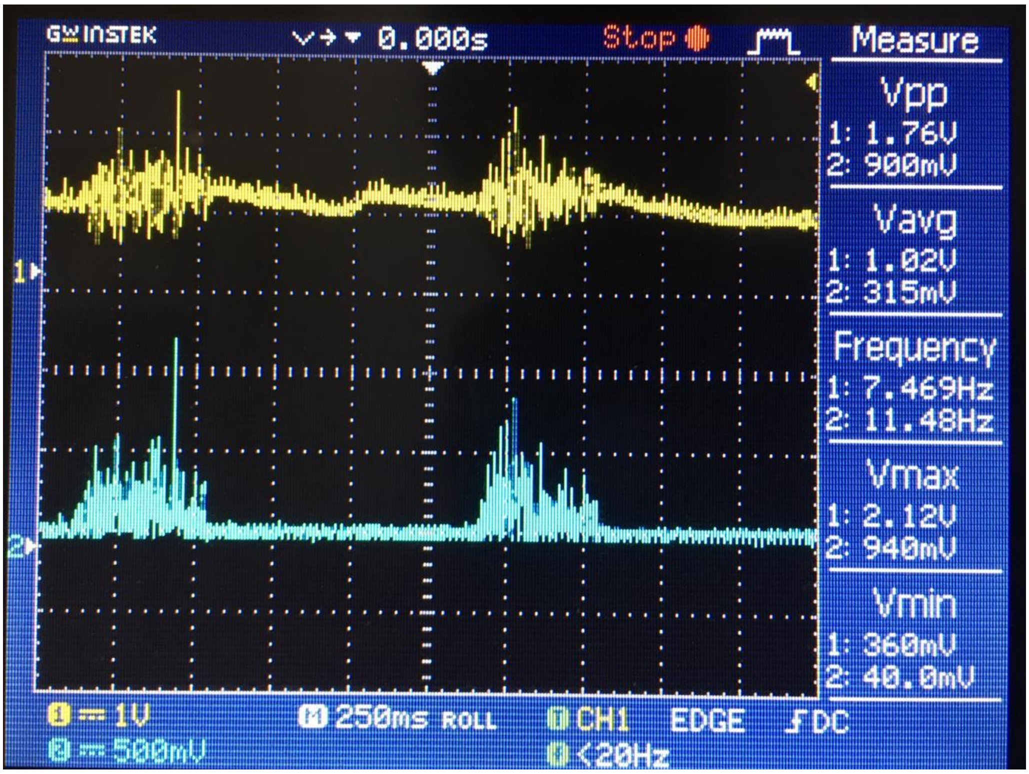


Figure 3. 18 Oscilloscope image of the rectifying and raw EMG signal.

Channel 1 is the yellow line and Channel 2 is the blue line. Figure 3.18 shown that rectified and raw EMG. Channel 1 is Rectified signal and Channel 2 is Raw EMG. The raw EMG signal is on the negative side, but the signal has passed to the positive side after rectifying. Vpp of the rectified signal 900 mV and its frequency is 11 Hz. Before rectifying, a bandpass filter designed for the raw EMG signal was applied.

3.5 Envelope Circuit Design and Analysis

Smoothing the rectified signal with a low pass filter of a given time constants often described as "smoothing with a low pass filter .The above process can be described as "linear envelope detection" by giving the time constant value and the cut-off frequency and the order of the low-pass filter used. A low pass filter between 1 - 5 Hz frequency should be applied, for the envelope detector.

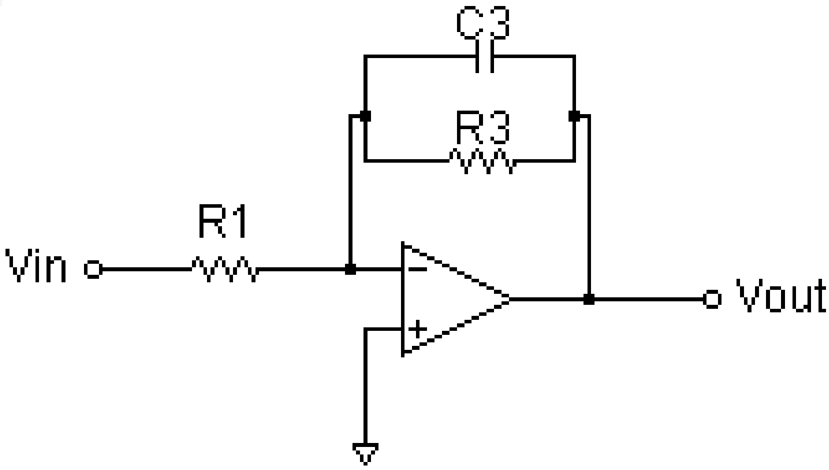


Figure 3. 19 Envelope circuit

$$fc = \frac{1}{2\pi(R3 \times C3)} \tag{45}$$

C3=1uF R3=52 kΩ (46)

$$fc = \frac{1}{2\pi(52k\Omega \times 1uF)} \cong 3\ Hz \tag{47}$$

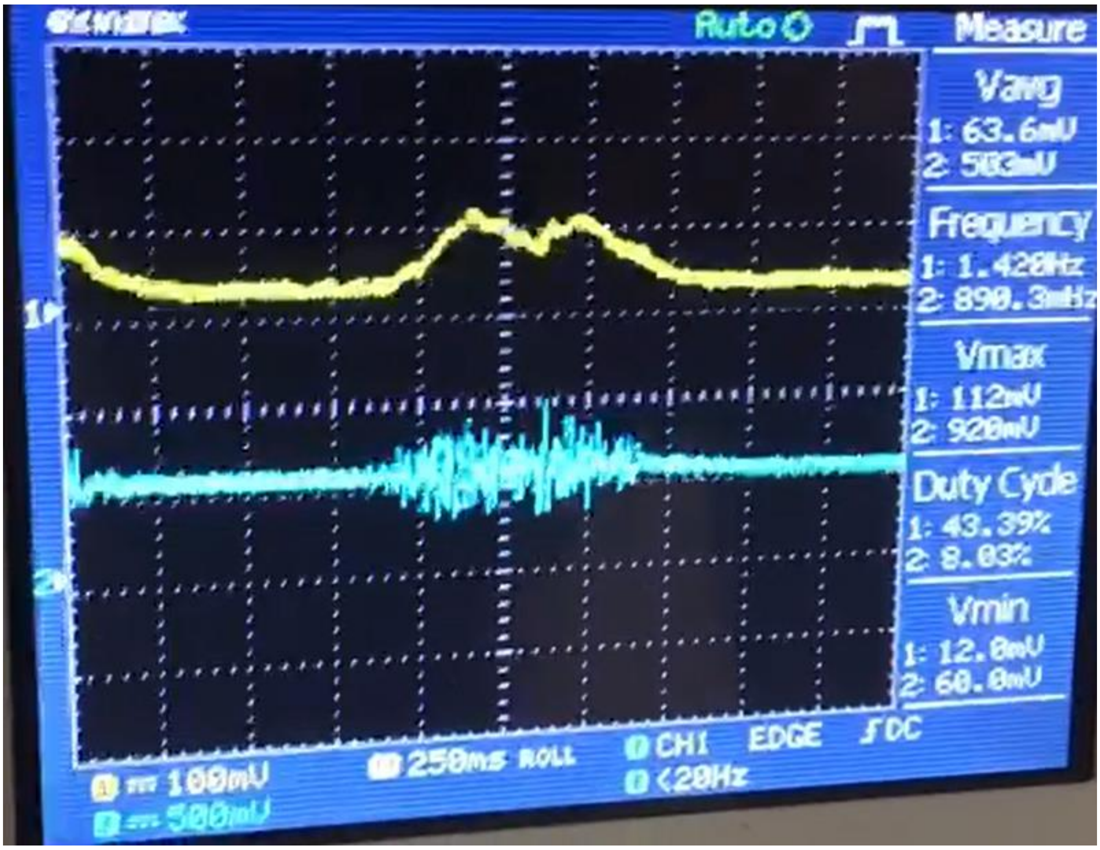


Figure 3. 20 Oscilloscope image of the smoothing and raw EMG signal.

Channel 1 is the yellow line and Channel 2 is the blue line. Figure 3.19 shown that smoothing and raw EMG. Smoothing signal is formed by connecting the band pass filter and rectifying in series with each other. The envelope of the EMG signal formed by the contraction of the arm is seen in Channel 1. The amplitude of the signal has decreased greatly. Vpp of the smoothing signal 176 mV and its frequency is 660 mHz. For this signal to be understood by microcontroller, a gain circuit should be designed at the output.

3.6 Gain Circuit Design and Analysis

OPAMP transmits weak electrical signals applied to its input magnified to its output with the help of active circuit elements in its circuit. In doing so, it uses the energy it receives from the power supply. OPAMP is a very high gain DC amplifiers. When applying the envelope of the signal in the previous stage, signal is inverted because the inverting low pass filter is designed. For this reason, the signal has passed to the negative side. In order to see the signal with a microcontroller, it is necessary to inverting and gain. Figure 3.20 shown that inverting amplifier circuit. After smoothing, the amplitude of the signal was measured at 176 mV. In order for the signal to be measured with the microcontroller, the amplitude of the signal must be higher than 1V. Therefore, it is preferred to increase the signal by 20 times.

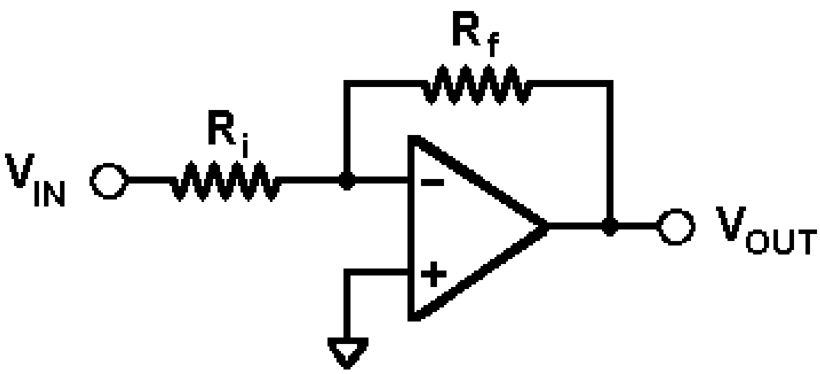


Figure 3. 21 Adjustable amplifier circuit

$$Gain = -\frac{Rf}{Ri} \tag{48}$$

Rf is a variable resistor so the gain can be adjusted.

$$Max\ Gain = -\frac{2K}{100} = 20 \tag{49}$$

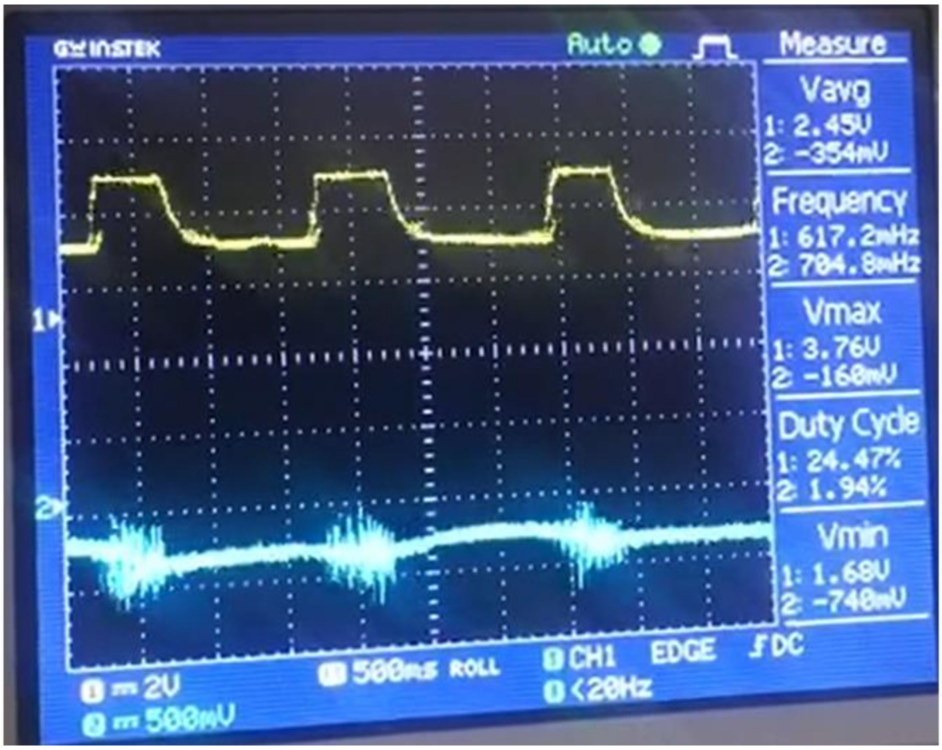


Figure 3. 22 Oscilloscope image of the EMG kit output and raw EMG signal.

Channel 1 is the yellow line and Channel 2 is the blue line. Figure 3.20 shown that gain and raw EMG. Channel 1 is gain signal and Channel 2 is Raw EMG. The envelope signal has increased its amplitude to the positive side with the designed gain circuit. Rf resistor is set nearly 2 KΩ. Vpp of the gain signal is 3 V.

3.7 EMG Measurement and Analysis Kit

An oscilloscope must be used to view all stages of the EMG signal. However, only real-time data are displayed with the oscilloscope and this method is very difficult. For this reason, it has designed a microcontroller-based measurement kit to make it easier to analyse the data in real time. Raw EMG, filtered EMG, rectified EMG and envelope EMG signals can be displayed separately using the analog inputs of the processor Signals are displayed on the touch screen. In addition, the data will be recorded with the SD card input in the kit. In this way, dataset can be created. The data set can be examined with programs such as MATLAB, Python and can be used in deep learning applications. The Figure below is picture of the EMG kit.

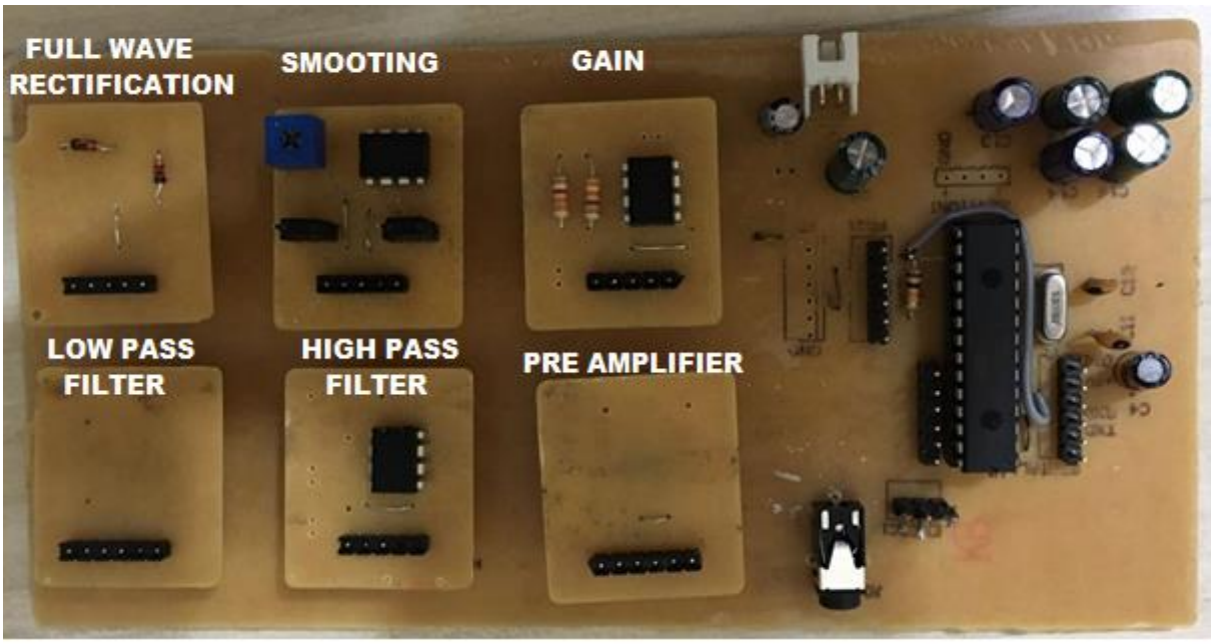


Figure 3. 23 EMG measurement and analysis kit

The EMG kit is designed like a shield. In this way, the amplifier circuits and filter circuits on it can be changed without affecting the design architecture.

3.7.1 Microcontroller

Microprocessors are the programmable microcomputer or I / O elements of the Input-Output units, Memory units and counter units in a single package. Microcontrollers are generally used in automatically controlled products and devices such as automatic control systems, medical devices, remote controls, office machines, home appliances, electrical appliances, toys and other embedded systems. In this thesis, microcontroller was used to convert analog data to digital data and these data are used to display in real time and to create a dataset. The microcontroller used is Atmega328p, a product of Atmel Firm(Atmel, 2015). Figure 3.22 shows Atmega 328p microprocessor;

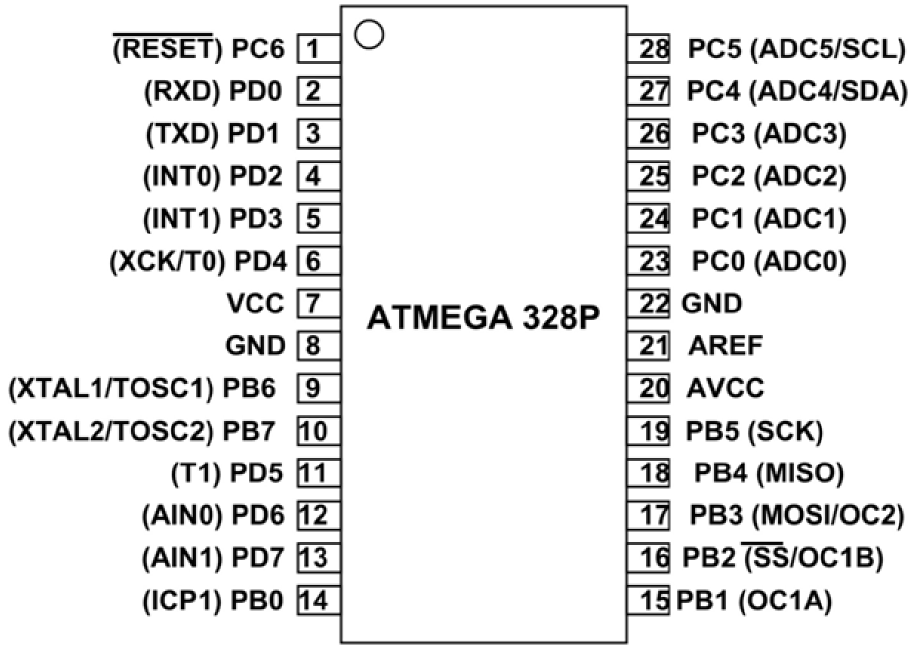


Figure 3. 24 Atmega 328p microprocessor pinout diagram

Atmega 328p has six Analog to Digital Convertor. These inputs are ADC0, ADC1, ADC2, ADC3, ADC4, ADC5. All analog inputs are used to measure all stages of the EMG sensor kit.

3.7.2 Nextion HMI

Nextion is a Human Machine Interface (HMI) solution combining an onboard processor and memory touch display with Nextion Editor software for HMI GUI project development. Nextion editor is software developed to design the interface. In this way, buttons, graphics, text, sliders and more can be created for the user (Nextion, 2020).

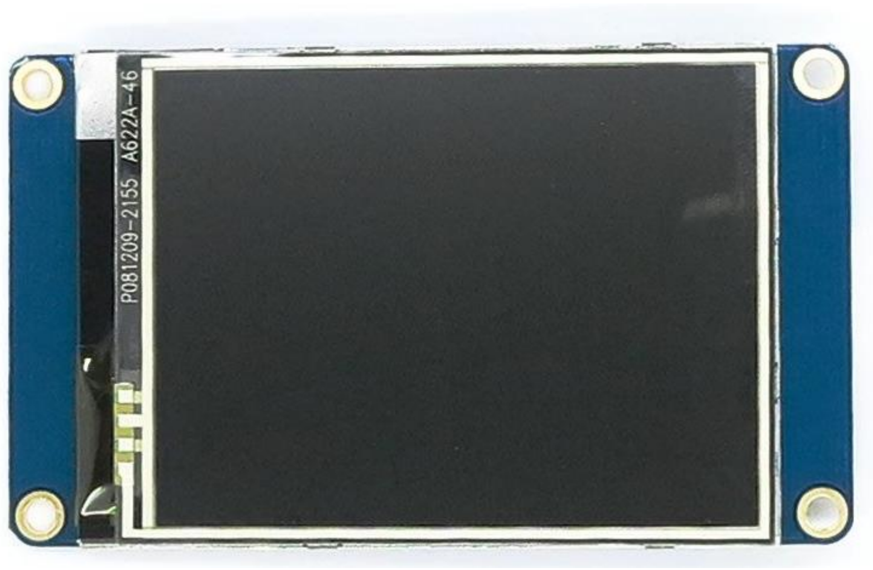


Figure 3. 25 2.8-inch Nextion HMI

2.8 inch Nextion HMI is used in the EMG sensor kit. EMG measurements can be monitored in real time with HMI. In addition, a data set of EMG data can be created during real-time monitoring. The created data set is saved in csv format. In this way, these datasets can be used in programs such as MATLAB, Python.

3.7.3 SD Card Record

An SD Card (Secure Digital Card) is an ultra-small flash memory card designed to provide high-capacity memory in a small size. SD cards are used in many small portable devices such as digital video camcorders, digital cameras, handheld computers, audio players and mobile phones. Sd card is used to record data in EMG sensor kit. The Sd card communicates with SPI. PI communication become using the MOSI, MISO, SCK, CS pins of ATmega328p and Sd card.

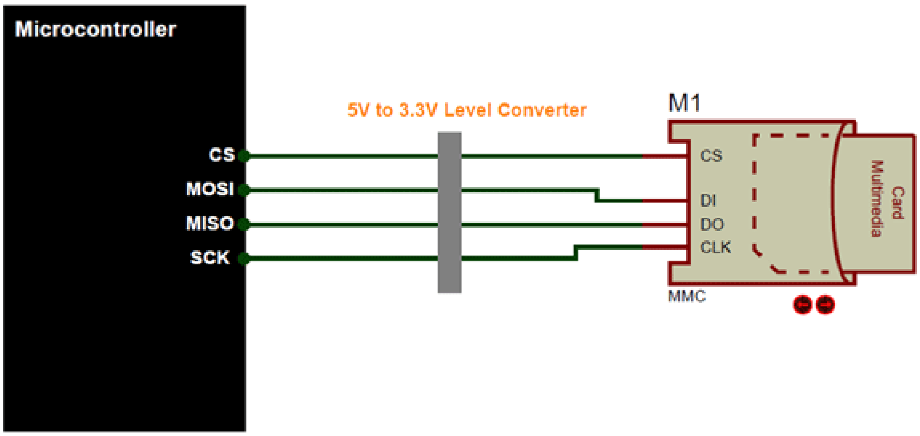


Figure 3. 26 SD card SPI communication diagram

Data recording is started by pressing the Sd record button on the HMI panel and to finish the recording, the same button must be pressed again.

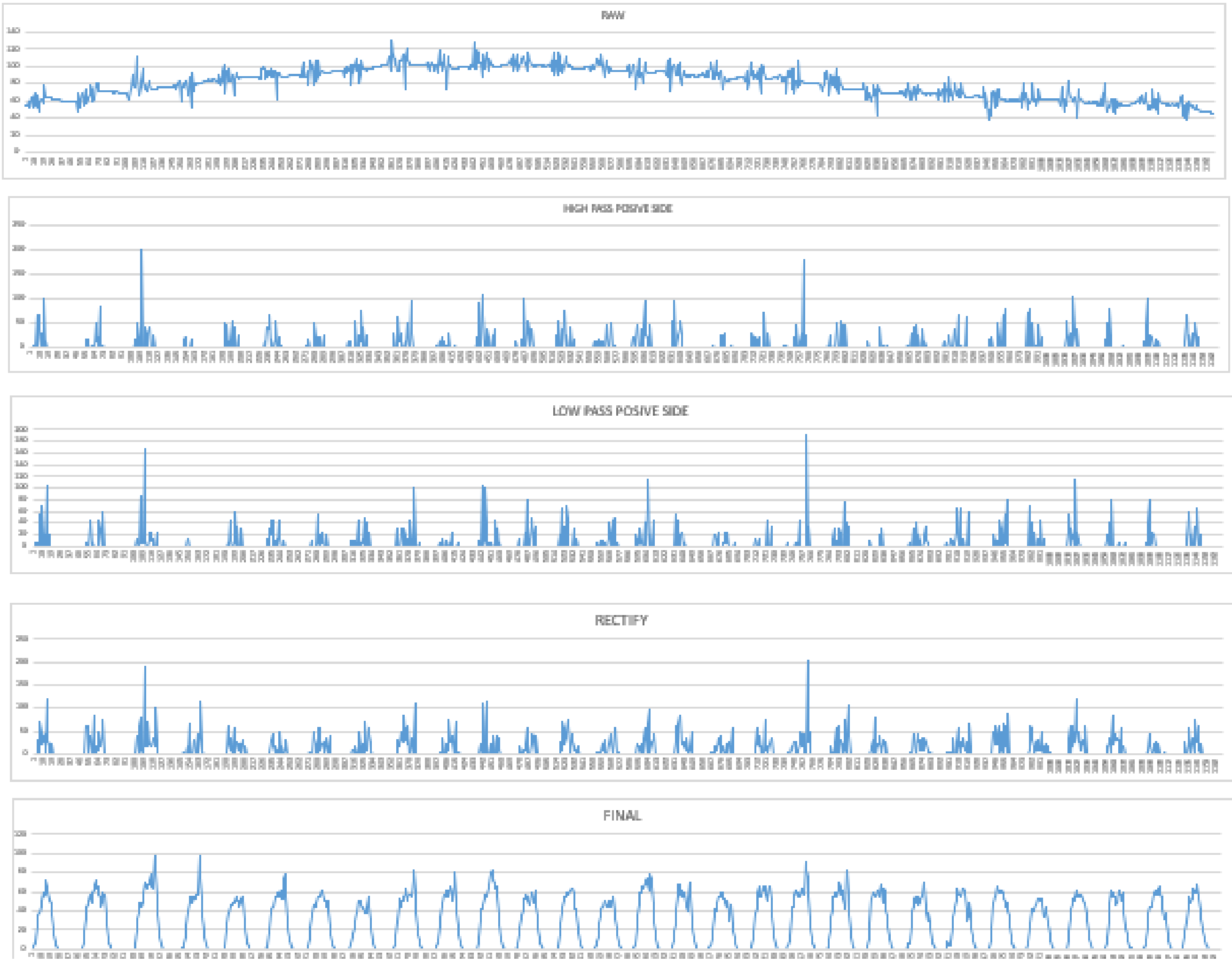


Figure 3. 27 EMG sensor recording all phase datas

Figure 3.27 shows real-time recordings of the EMG sensor in all phases. It is also observed in the records that the Raw EMG signal is affected by the noise. After low pass and High pass filters, these noises are cleared and the signal is at the center zero point. In the filter records, the negative side signals cannot be displayed, because the micro controllers do not detect to signals on the negative side. After the signal rectify process, the negative part passed to the positive side in its signals. In the final phase, the expected output from our sensor was recorded.

CHAPTER 5

CONCLUSIONS

Measurement and analysis of EMG signals are challenging issues of signal processing. EMG signals are used in the controls of robotic prosthetic limbs in individuals with limb loss as well as clinical treatments. Electrical noises are one of the important factors affecting the measurement quality of EMG signals. The correct realization of these measurements is important for the health operations of the prosthetic arms also its important to improve the classification rate of neural networks

In this study, a wearable device was designed to measure the EMG signals in the forearm muscles with the help of surface electrodes, to monitor and record the activity with HMI. During the movements of healthy individuals, the average voltage value between 1-10 mV in the forearm muscles was raised approximately 400 times with the operational amplifier to reach 1.5 levels. The signals are provided to be at a level to be examined. Surface electrodes were used for these measurements. The surface electrode has 3 inputs. These inputs are connected to the input +, input- and reference pins of the operational amplifier. Thus, a differential amplifier circuit is designed with operational amplifier. EMG signals are affected by electrical noises because they have very small amplitudes. These noises may have originated from the power supply, electrode, or other electronic device. Noises increase with operational amplifier. Active electronic filters are used to eliminate noise in the EMG signal. 20 Hz high pass filter and 500 Hz low pass filter circuits are designed and band pass filter is obtained by connecting each other in series. The outputs of the filter circuits were measured with the help of an oscilloscope and it was observed that the electrical noise in the output signal was eliminated. EMG signals are present in both positive polarity and negative polarity. Signals with negative polarity cannot be detected by microcontrollers. Therefore, full wave precision rectifier circuit is designed. As a result, the absolute values of the input signals are taken and converted into signals with only positive polarity. As a result of this stage, the amplitudes of EMG signals decreased and measured at 900mV levels. It has designed a softening circuit as the last step to eliminate the noises. Thanks to this design, a linear result is obtained by removing the noises in the mid-points of the rectified signals. It was observed that the output signals were smooth and cleans during the contraction of the muscles. As a result of this process, the amplitude of the signal was greatly reduced and measured at 150 mV levels.

Adjustable gain circuit is designed to increase the amplitude of the signal. Thanks to this, the output signal has been increased to 3.5 V with the trimpot on the circuit.

Microcontroller based control card is designed. This card is designed to be mounted on operational amplifier, high pass filter, low pass filter, full wave precision rectifier, smoothing circuit and gain circuits. In this way, it provided the opportunity to follow every stage of the EMG signals with the oscilloscope and microcontroller.

There are HMI panel input and SD card input on the control card. Real time tracking of the system was recorded with Nextion brand HMI and interface software written on it.

This study will allow practical and accurate measurement of EMG signals in the forearm muscles. The recorded data can be used as a dataset in neural network studies. If the power supply to be used for the operation of the system has high electrical noise, the EMG signals suffer from a level that cannot be filtered. For this reason, it is necessary to use an isolated power supply or battery.

In future, CNN based classification can be try on real time classification applications or accuracy can be increased with other deep learning architectures, also arrangements can be made for clinical diagnoses, and it can be used to control bionic arms.

In future, usage of EMG sensor kit, studies about classification of EMG data, it can benefit effects of raw EMG signal and filtered EMG signal in classification also it can be used to control bionic arms.

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