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Date : 28 MAY 2014

DEVELOPMENT OF EMG AMPLIFICATION CIRCUIT

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

“ I declare that this report entitle “Development Of EMG Amplification Circuit” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree”

Signature :

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Date : 28 MAY 2014

ABSTRAK

Satu litar penguat signal electromyogram (EMG) direka dan diterjemahkan dalam kajian ini. Input litar penguat ini merupakan isyarat EMG yang diukur dari permukaan kulit menggunakan elektrod konfigurasi bipolar yang membolehkan pengukuran isyarat daripada otot yang terlibat dengan cara yang cekap. EMG boleh ditakrifkan sebagai potensi elektrik dihasilkan disebabkan oleh penguncupan otot. Walau bagaimanapun, amplitud isyarat EMG adalah lemah dan sangat kecil yang berada di antara 0 hingga 5mV. Objektif kajian ini adalah untuk mereka bentuk, membina dan mengesahkan litar penguatan EMG yang direka. Litar EMG tersebut terdiri daripada sensor, penghawa isyarat dan memaparkan data. Dalam kajian ini isyarat EMG akan diekstrak daripada otot tangan manusia untuk aktiviti cengkaman pelbagai tangan. Signal output yang dihasilkan menggunakan rekaan litar penguat EMG dijangka menunjukkan pelbagai corak EMG isyarat dihasilkan berdasarkan kuasa yang berbeza genggaman tangan digunakan.

ABSTRACT

An electromyogram (EMG) amplification device is designed and presented in this research. The designed amplifier circuit is fed with EMG signals measured from surface of the skin using bipolar electrodes configuration which enables the measurement of the signal from muscle interest in an efficient manner. EMG can be defined as the electrical po tential produced due to the contraction of muscle. It can be picked from the residual portion of muscles of an amputee. However, the amplitude of EMG signal is weak and very small which is between of 0 to 5mV. The objectives of this research are to design, construct and validate the designed EMG amplification circuit. The EMG measuring system consists of sensor, signal conditioning and display data. In this research the EMG signal will be extracted from human hand muscle for various hand grip activity. The designed EMG amplification is expected to show various pattern of EMG signal produced based on different hand grip force applied.

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CHAPTER 1

INTRODUCTION

1.0 BACKGROUND STUDY

Around the world, there are large number of persons with limb loss due to war, disease and accidents. For example, peoples who involved in tragic accidents will cause paralysis or an amputation which will make they face many difficulties in daily life. Therefore, the disabled individuals need to be assisted with modern technologies such as cybernetic prosthesis in order to improve their quality life. A cybernetic prosthesis is a type of robotic device which consist of a combination of joints, link, servo motors and control algorithm that are put together to resemble the gripping function of human hand [1]. The main objective of prosthetic device is to allow the amputee to grasp objects. By measuring and using the tiny voltage generated by the activity of muscle known as Electromyogram (EMG), the motion of cybernetic prosthesis can be controlled indirectly [1]. This voltage is amplified first and processed so that the actuators on the prosthesis move according to the desired motion when user flexes related muscle.

An approach used for recording, measuring and analysing the EMG signal were investigated by H. Piper for the first time using galvanometer in 1912 and followed by Gasser and Erlanger in 1924 with the assist of oscilloscope [2][3]. For the first time application of EMG signal for controlling powered upper limb prosthesis was applied during 1940s [4]. Then, the development of EMG field was increase rapidly throughout 1960s, 1970s and 1980s [5]. The study of EMG is related to the industry of Biomedical

Engineering and Biomechatronics field for prosthesis that apply EMG signal. In biomechanics field, EMG signal is use as an indicator for the beginning of muscle activation, its relationship towards the force produced by a muscle and use as index of the fatigue processes occurring within a muscle. In Biomedical application, EMG signal provide a way of sensing normal human being and classifying different movement of body effectively [6][7].

In this study, EMG signals are measured indirectly from muscle while the subject grips hand at fixed force but different wrist angle. The FDS (Flexor Digitorum Superficialis) muscle is selected because it is forearm muscle responsible for extension and flexion of hand. In daily life situation, most of human hand motion required both of hand force and joint wrist simultaneously such as to turn the knob to open a door. Data relating of hand grip strength at various wrist angle is very useful to be used as control algorithm to control hand motion of a cybernetic prosthetic hand. Currently, one of the regular methods to measure hand grip force and wrist angle is to use hand dynamometers. This device can provide accurate measurement of hand force applied at varying wrist angle [8].

Electromyogram is well known as EMG which is one of electrophysiological signal and it is extracted from skeletal muscle activity. Skeletal muscle produces electrical activity among muscle fibre caused by the nerve impulses that send from brain during contraction and relaxation of muscle. When muscle fibres contract, there is an exchange of ions in the muscle fibre membranes, this flow of ions generate an electrical current [8]. A pair of electrode made up from Silver Chloride (AgCl) is placed on surface of the skin in order to measure the flow of ions and convert into electron flow [9]. Typically, this signal is too tiny within the range (0-5mV) while the range of frequency is from (6-600Hz), which the dominant frequency range is from (20-150Hz) [10]. Therefore, it required a specifically design amplifier that will assist to amplify the signal. There are few amplification stage are required before the signal can be displayed since to eliminate the noises which interface the EMG signal.

1.1 PROBLEM STATEMENT AND MOTIVATION

Limb loss is not only growing problem in Malaysia but including the rest of the country due to the increasing number of accidents, diseases and serious crimes. After a tragic incident resulting in an amputation, the disabled individual needs to be assisted with all possible modern technological in order to improve his quality of life. A cybernetic prosthesis is a device which can greatly assist individuals with hand disabilities by enabling them to have some of the hand capabilities of an able bodied individual [11].

In war-torn countries such as Cambodia, Iraq, and Afghanistan, 80 to 85 percent of amputees are land mine survivors [12]. Due to the increasing rate of amputations, there is an ever-growing demand for cybernetic prosthesis. Thus, it is very costly for the amputees to afford it since not all the amputees have high rate income. Furthermore, importing components from industrialized countries is expensive. In order to reduce the price is by cutting the production cost to develop the device. One of the important parts of cybernetic prosthesis is EMG amplification device. Therefore, to develop a low cost EMG amplifier device is needed for reducing the price of cybernetic prosthesis.

EMG signal is useful to be used for cybernetic prosthesis. For example, EMG signal based on the hand grip force can be used as part of the control algorithm for cybernetic prosthesis in order to control the strength gripping [13]. Generally, the surface EMG signals are weak and too tiny within the range of 0-5mV. Thus, it is a necessary to boost up this signal with an amplifier which is specifically designed to measure the signal. With the assist of designed and simulation of amplification circuit by using Multisim software, EMG signal can be measure and record for further process.

EMG signals are commonly analysed in a few techniques, basically in terms of the signal's amplitude, frequency content and phase information that relatives to the reference signal. Interface instrumentation will be design which consists of required electronic circuitry to measure EMG signals from the human skin surface and the necessary software to record, display and process these raw EMG. It consists of instrumentation for EMG measurement, the surface electrodes that work as EMG sensor and the EMG signal conditioning circuits to amplify the signals, hand dynamometer that measures the hand grip, the data acquisition device (DAQ), digital oscilloscope and computer to display, record and process the EMG signals obtained experimentally.

1.2 OBJECTIVE OF STUDY

The objectives of this project are listed :

1. To design and simulate the EMG amplification circuit by using Multisim software.
2. To construct the designed EMG amplification circuit.
3. To validate the designed and constructed EMG amplification circuit through extraction of signal from human skin surface.

1.3 SCOPES OF STUDY

1. The experiment will perform with 5 healthy subject within the age range of 20-30 years on their dominant hand.
2. The surface EMG signal by using bipolar electrode configuration is extracted from Flexor Digitorum Superficialis (FDS) muscle.
3. The amplification device will be test by measuring EMG signal with 3 different level of hand grip strength (20N, 40N, 60N) and 3 different wrist angle position (90, 60, 120) degrees by using hand dynamometer.
4. The amplitude of EMG signal from 0-5mV will be amplified to transistor-transistor logic (TTL) ranges of 0-5 V.

CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter discusses projects and paper works related to this project. These related works have been reviewed carefully in order to improve the quality and reliability of this project. By reviewing the previous projects of other researchers, the gap analysis can be performed. The recommendation of their project can be taken into consideration as improvement of this project. Moreover, there are some useful ideas that can be implemented in this project from other similar projects. Therefore, literature review process extended right from the start until the end of the project. By reviewing the previous works, a proper plan on how this project can be conducted and the features that have to be added in order to make this project reliable and marketable are enlightened. Besides that, there are some findings sources added from internet and books which are very contributive to this project. Throughout the analysis at the beginning of the project the special feature in this project is determined and the components used in this project are decided. In addition, the function and the concept are well understood.

2.2 OVERVIEW OF EMG AMPLIFICATION SYSTEM

In order to develop an EMG amplification device, 5 research paper review to study the concept, methodology, and analysis technique and to make the best comparison and before implemented in this project research.

Sharul N.S. *et al* (2012) present measurement system for EMG signal extract from forearm muscle. The objective of this study is about to investigate the relationship between forearm EMG signal and hand wrist position at different hand grip strength. The system is divided into 4 parts. First part is EMG circuit that used to measure EMG signal from 3 forearm muscles. Second part is hand dynamometer which is required to measure the hand grip force and wrist angle and third part is a data acquisition (DAQ) hardware. The function of DAQ for this study is process data from EMG circuit and inputting data into a laptop for processing. Finally a laptop to record, process and display the EMG signal and force signal. Three muscles were selected which are Flexor Carpi Radialis (FCR), Flexor Digitorium Superficialis (FDS) and Extensor Digitorum Communis (FDC). All these muscle related to the hand and wrist motion. The EMG signal from these muscles is measure using 3 channel EMG circuit. The EMG circuit consists of instrumentation amplifier, high pass filter, low pass filter and galvanic isolation. At instrumentation stage, differential amplifier (Burr-Brown INA128P) is selected which has high common mode ratio (120dB) and gain is set as 20. To reduce unused frequency a high pass filter with 50Hz cut off frequency and a low pass filter with 500Hz cut off frequency were selected. A labVIEW 1V code was written to record both the EMG and hand grip force signals. In this study, left arm from one subject was chosen and asked to perform force level at 1N, 2N, 3N, 4N, 5N and 6N by gripping the hand dynamometer at 3 different angles (60^o, 90^o, and 120^o). Based on the result can be conclude that, the pattern EMG waveform produced from 3 muscle are similar even with different force apply and the 3 muscle can be differentiate by apply different angle of wrist.

Sharul N. S *et al* (2011), present development of EMG circuit in order to investigate the relationship between muscular efforts of the flexor muscle in forearm and hand grip strength. The FDS muscle was chosen since it is responsible for finger flexion during hand gripping. Basically, this experiment is about designing EMG circuit in order to measure EMG signal from the FDS muscle. By using bipolar electrode configuration, AgCl electrode is placed on the FDS muscle to detect the EMG signal. The input signal is amplified with gain 26 by using Burr-Brown INA128P which is one of instrumentation amplifier with high CMRR (120dB). Then the amplified signal is feed into band pass filter which is created by Sallen Key high pass filter with 20Hz cut off frequency and cascaded with Sallen Key low pass filter with 500Hz cut off frequency. When the input signal is filtered it is amplified again with inverting amplifier with gain 100. For safety of the user, galvanic isolation is applied using isolation amplifier. The TDS 1002B digital oscilloscope is used to record the amplified EMG signal. For the force measurement set up, the subject is required to grip the hand gripper with three different forces according to gripper coil deflection. 10% degree deflection represents minimum grip strength, 50% degree deflection represent for intermediate grip strength and 100% degree deflection for maximum grip strength. The result from the experiment showed that the EMG signal frequency is increasing as the hand grip strength increase.

Hao Lin, *et. al*. (2010) present a research and design on surface EMG amplifier. The objective of this study is to analyze the major noise and to design the parameter about surface EMG amplifier, then simulates by using Multisim2001. EMG circuit design consist of bipolar electrodes to pick up the EMG signal from surface body, a differential amplifier Burr-Brown's INA128 to pre-zoom the EMG signal and INA137 is used for reference level. In order to reduce the low frequency noise, a Sallen-Key high pass filter circuit with 10Hz cut off frequency is connected to the INA128. While, 50Hz frequency noise impact is overcome by using the 50Hz notch filter. Burr-Brown UAF42 was used to compose the T notch by using software CAD-FILTER42 from Burr-Brown. The parameters and Notch center frequency was set to be 49.8Hz and 50.2Hz. Next, the input signal is amplified for the second time by using the 100K resistance potentiometer as variable gain amplifier. The amplified signal is cascaded to Sallen-Key low pass filter with 100Hz cut-off frequency. The filter has simple structure, easily and fast adjusted. After that, the EMG signal is put into Analog-Device' AD536 in order to change the RMS to DC. The advantages are, it has excellent performance, can calculate any complex waveforms. The Canadian Interactive Image's Multisim2001 simulation software was used to simulate the hardware design. It is convenient, fast to simulate and easily to choose equipment and replace components.

Zahak Jamal *et al*.(2011). present a research relates to a method for detecting electromyography signals from the extension and relaxation of hand muscles. It is successfully demonstrated with simple DC motor for the two hand motion. In this study, two kinds of surface EMG electrodes were used for signal acquisition Delsys 2.1 single differential and Delsys 3.1 double differential active electrodes and simple disposable EMG electrodes. While, for the reference electrodes is 3M Red Dot Resting EKG Electrode. In addition, the EMG system used is the Delsys-Bagnoli portable EMG system which has two channels and also can amplify the signal up to 100, 1000, or 10000 times. The position of the electrodes is very importance as to distinguish all the five finger movements based on its reflective muscles. In order to drive the motor for a prosthetic hand, a differential amplification technique is used for signal acquisition. In this experiment, the IC INA121 was used as an instrumentation amplifier. It can give a gain up to 10000 times. After amplification, the analog signal needs to be converted to digital signal by using Analog-to-Digital Converter (ADC). A 10-bit ADC which came as peripheral with ATMEGA8 microcontroller was selected. The control for the motor is provided with help of thresholding method. When the digital output crosses this threshold, the microcontroller sets an output pin to '1' and forwarded to a motor drive circuitry in order to drive a motor. It was observed that the motion of fingers gave a set of pattern when their muscles were contracted.

Samir B, *et al.*(2007). The present invention related to develop a low cost grip transducer based on Hall Effect component to quantify the fingertip touch force. The aim of this research is to investigate how the fingertip force grasping affects the adductive motion of the thumb. The EMG amplifier design consists of three AgCl electrodes, a differential amplification of AD524 with gain 1000 to zoom the EMG signal. Then, the signal is feed to band pass filter which is made by 2nd order Butterworth high pass filter with cut off frequency 0.05Hz and cascaded with 4th order Butterworth low pass filter, 500Hz cut off frequency. Both outputs signal from EMG amplifier and from fingertip transducer are feed into commercial National Instrument (DaqBoard 1005) which has 20KHz sampling rate with 16bits resolution. A preliminary experimental test has been carried out for fingertip force grasping according to the AdP muscle for controlling the adductive motion of the thumb. The intensive activities can be observed during contact acting. The experimental results show that the changes of dynamic fingertip force affects the intensity of AdP EMG of the thumb and the acquired signals are satisfactory and present a high immunity to interferences particularly against the power source.

2.3 **SUMMARY OF LITERATURE REVIEW**

The summary of literature review are listed in the following Table 2.1

Table 2.1 : Summary of literature review for methodology and analysis of EMG amplification system

No	Authors Title Publication	Methodology			Analysis Techniques
		Design	Sample	Instrument	
1	Sharul nizam Sidek, Ahmad Jazlan Haja Mohideen (2012). **Measurement System to Study the Relationship between Forearm EMG Signal and Wrist Position at Varied hand Grip Force** *Paper presented at the International Conference on Biomedical Engineering 2012.* *IEEE conference Publication.*	Diff. amp ; INA128P CMRR=120dB Gain =20 High Pass Filter (OPA2604) CtF = 20Hz R = 32k C = 100nF Low Pass Filter (OPA2604) CtF = 500Hz R1 = 2k R2 = 330k C = 1nF Galvanic isolation ISO124	1 subject (left arm) Muscle used ; Extensor = EDC Flexor= FCR,FDS Force level : (1,2,3,4,5,6)N Duration : 10 s each level Wrist angle : 60,90,120	Hand dynamometer NI-6008 DAQ Surface AGCl electrode	Data display using LabVIEW Matlab Neural Network Toolbox used to establish the relationship between EMG signal and wrist angle. Performance of neural network validate by calculate MAE
2	Sharul nizam Sidek, Ahmad Jazlan Haja Mohideen (2012). **Development of EMG Circuit to study the relationship between Flexor Digitorum Superficialis Muscle Activity and Hand grip Strength.** *Paper presented at the 4th International Conference on mechatronics 2011.*	Diff. amp ; INA128P CMRR=120dB Gain =26 2nd order Sallen-Key High Pass Filter (OPA2604) CtF = 20Hz at -3dB C1=C2=100nF Sallen-Key Low Pass Filter (OPA2604) CtF = 500Hz at -3dB	1 subject (left arm) Muscle used ; Flexor= FDS Deflection level : Minimum=10% Intermediate=50% Maximum=100% Duration : 10 s each level	Hand gripper TDS 1002B digital oscilloscope Surface AGCl electrode	The frequency of the signal in Hz is observed at each hand grip strength level

	IEEE conference Publication.	C3 = 10nF Inverting amplifier (OPA2604) G = 100 R1 = 1k R2 = 100k Isolation amplifier ISO124			
3	Hao Li, Shan Xu, Peng Yung, Lingling Chen **A Research and Design on Surface EMG Amplifier** *Paper presented at the International Conference on Measuring Technology and Mechatronics Automation 2010.* *IEEE conference Publication.*	Diff. amp ; INA128 CMRR=120dB Gain =10 Sallen-Key High Pass Filter CtF = 10Hz Notch filter (UAF42) f = 50Hz Sallen-Key Low Pass Filter withvariable gain adjustment CtF = 200Hz R(max) (potentiometer)=100k Gain(max) = 213 RMS to DC (AD536)	Major noise frequency is 50Hz The parameter and the Notch center frequency is set up by using CAD-FILTER42 software from burr brown Multisim 2001 software is used to provide the input signal as low as the EMG signal of a Microvolt.	Multisim 2001 CAD-FILTER42 sotware	Use Canadian Interactive Image's Multisim2001and assist with virtual reality technology to simulate the design
4	Zahak Jamal et. al **Motor Drive Using Surface Electromyography For Flexion And Extension Of Finger And Hand Muscles** *Paper presented at the 4th International Conference on mechatronics on Biomedical and Informatics 2011.* *IEEE conference Publication*	Diff. amp ; INA121 CMRR =106dB Gain = 420 ADC Quantization = 10-bit Sampling rate = 125kSPS Range of conversion = 1 to +5V microC ATMEGA8	Muscle used ; Extensor = EDC Flexor = FDS Grasp and opening	Mechanical arm AgCl electrode	To classify motion of the flexing and extending of muscle of finger hand, the result is compared from two approaches 1) Self design amplification circuit 2) Delsys EMG system

		Motor drive IC L298			
5	Samir Boukhenous, Mohktar Attari **A Low Cost Grip Transducer Based Instrument To Quantity Fingertip Touch Force** *Paper presented at 29th Annual International Conference of IEE EMBS IEEE conference Publication*	Diff. amp ; AD524 CMRR=120dB Gain =1000 2nd order High Pass Filter CtF = 0.05Hz 4th order Low Pass Filter CtF = 500Hz DAQ Sampling rate = 20kHz Resolution = 16bits	Muscle used ; AdP Use Index finger and thumb Hall Effect component and permanent magnet placed on the grip device.	Fingertip transducer DAQ National instrument (DB1005)	The intensive activities are observed during fingertip contact. The intensity of EMG is affected by fingertip grasping.

As a sum up based on table 2.1, INA128P is selected as an instrumentation amplifier. INA128P gives very good accuracy and it is low power instrumentation amplifier. It also gives a high CMRR (120dB). Its gain may be set from 1 to 1000 V/V. The gain was set up to 26 at this stage. Output of the instrumentation amplifier is then passed through a band pass filter, which is designed for the frequency 20Hz to 500Hz. The first one is 2nd order Sallen-Key high pass filter having cut off frequency 20Hz, it helps to remove the small frequencies due to motion artifact. Then the signal pass through the second stage of band pass filter, it is 2nd order Sallen-Key low pass filter having limit of 500Hz frequency. Therefore, by maintain the frequency at 500Hz, optimum performance will be obtain as no signal content will be lost at the same time higher frequency will also filtered. Sallen-Key filter topology with Butterworth characteristics was chosen due to its capability to provide flat response in the pass band. After the band pass filter, the signal passes through an inverting amplifier. The gain is set 100 and the total gain of this EMG circuit is 26x100=2600. The resistor of inverting amplifier can be replaced with a potentiometer, enabling the EMG circuit to have variable gain. For the safety of the subject, galvanic isolation is implemented using an isolation amplifier (ISO124). For data display in this project research, the digital oscilloscope instrument is used to record the waveform. For the hand force measurement, hand dynamometer is better than hand gripper since it can provide accurate measurement and obtain simultaneous measurement. Another instrument called LABQUEST2 is used in this project research with the hand dynamometer in order to display the applied hand grip forces. It is easier to use, monitor, and record the value of forces compared to DAQ National Instruments which is more complex. Finally, the muscle that will be selected to extract the EMG signal in this project research is FDS muscle. As referring to research paper 1, it is stated that FDS muscle contribute towards in hand grip forces and it give higher EMG average power.

CHAPTER III

METHODOLOGY

3.0 INTRODUCTION

This chapter discussed about project methodology that are carried out in this research. It explained overall process taken throughout this project research starting from designing the amplifier circuit, constructing the circuit up to analysing the amplification data. This project methodology is crucial to ensure the project is developed systematically.

3.1 RESEARCH METHODOLOGY

The flow chart of development for EMG amplification device in this project research is shown in Figure 3.1. Based on the flowchart, the research started with the literature review after decided on problems statement and objectives of this project research in order to get more understanding about the conceptual circuit design and gain extra additional related information. Then, based on the acknowledgeable information the schematic diagram of EMG amplification circuit is designed and then simulated by using Multisim 12.0 software. Next, the EMG circuit is constructed according to the designed schematics diagram circuit and followed by analyzing the circuit to validate the performance of the designed EMG amplification device.

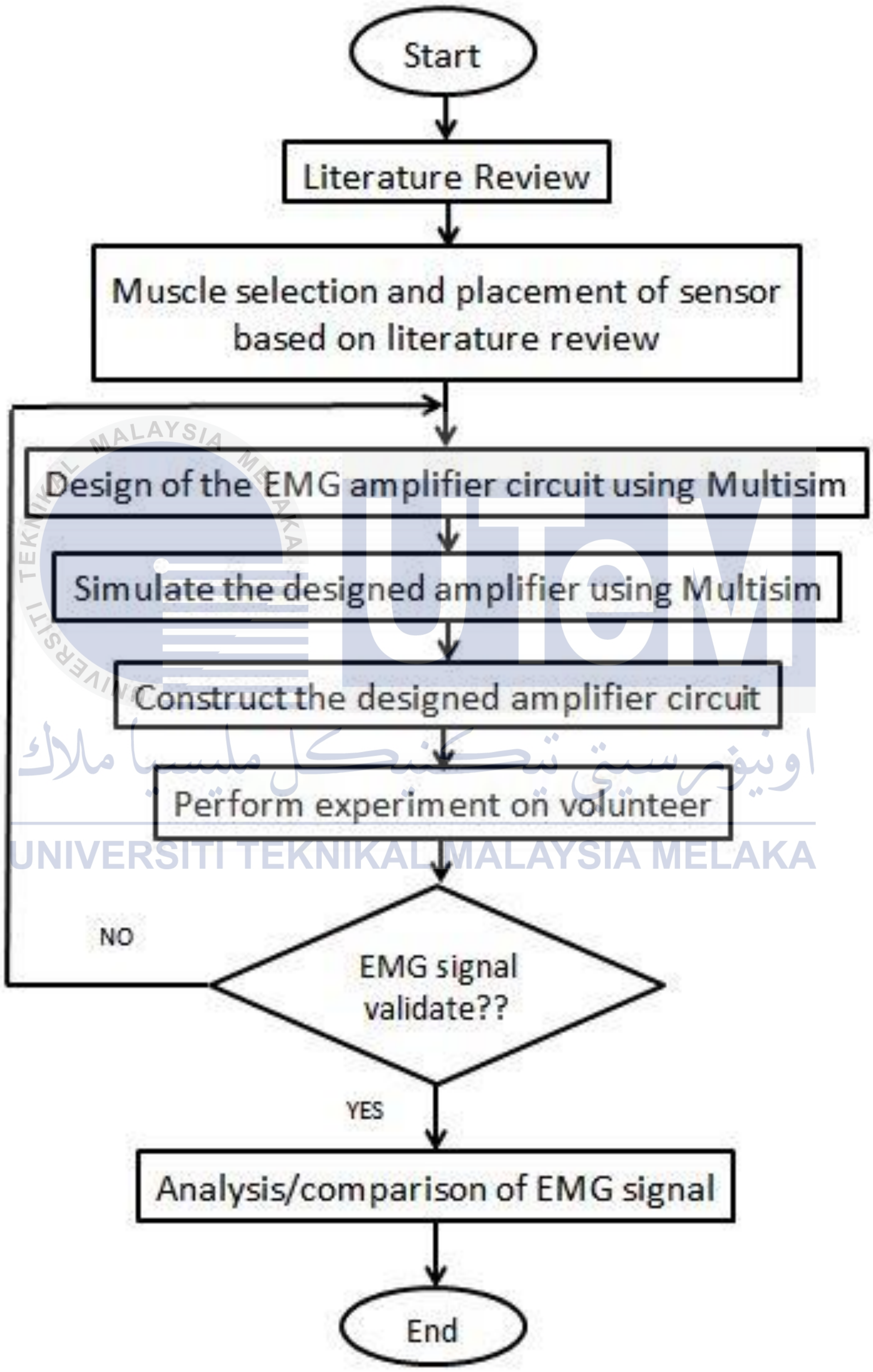

Figure 3.1 : The flow chart of research methodology

3.2 EMG AMPLIFICATION SYSTEM

EMG amplification device can be categorized as measuring system, therefore for the basic principle of measuring system it have sensor, signal conditioning and display [14]. The basic block diagram for the system is represented as Figure 3.2 and block diagram of EMG amplification device for this project is shown in Figure 3.3 :

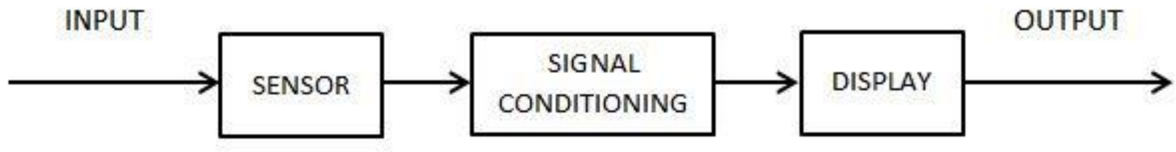

Figure 3.2 : Basic block diagram for measuring system model

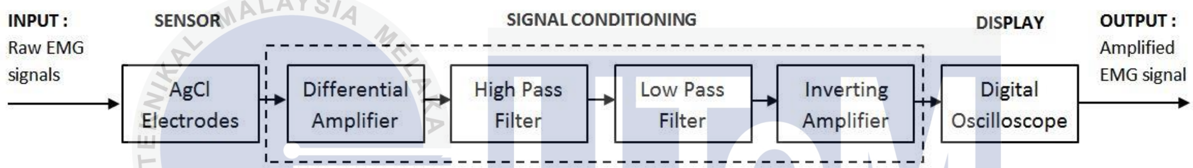

Figure 3.3 : EMG amplification system block diagram

Based on both figures, clear understanding can be obtained regarding the total operation of the system. It provides basic development for operational and probability of procedures, and aim areas where changes in operational procedures could simplify the overall system operation.

3.3 DESIGN OF EMG AMPLIFICATION SCHEMATIC CIRCUIT

For this project, EMG signals is measured using one input channel from FDS muscle and the designed EMG amplification circuit comprise of elements as below :

I. The Instrumentation Amplifier

Differential amplification can be achieved with the help of an instrumentation amplifier. In this project research, INA128 is used as it has broad application in medical instrumentation. Even though a differential amplifier has the ability to reduce unwanted noise signals that occur from both sides of the input wires, noises could still exist. Therefore it must be integrated with others element in order to minimize the noises. Figure 3.4 (a) shows the connection diagram for INA128 device and Figure 3.4 (b) showed the design of schematic diagram for INA128 via Multisim software.

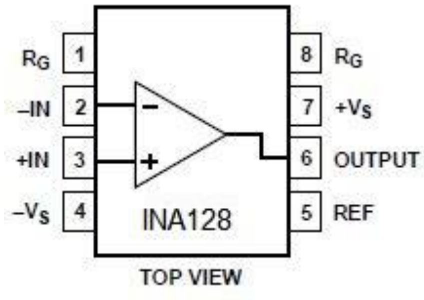

Figure 3.4 (a) : Connection diagram of INA128 device

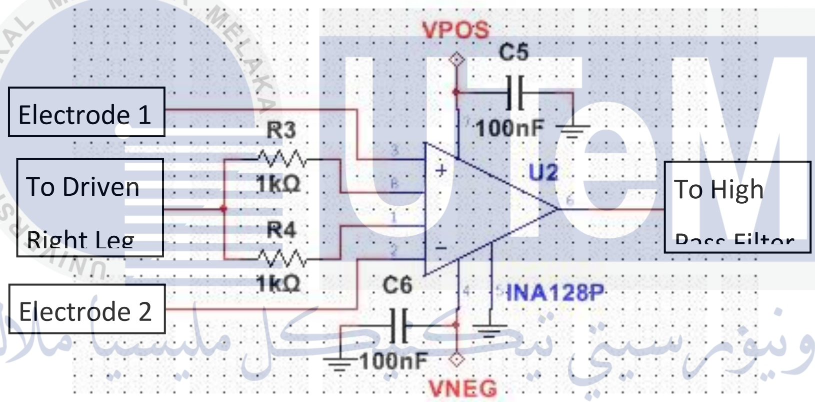

Figure 3.4 (b) : Design of schematic diagram circuit for INA128 device

At this preamplifier stage, selection of the circuit gain needs to consider the overpotentials factor of the AgCl electrodes. Overpotential is the difference between the half cell potential and the zero potential. It appears as DC offset on the oscilloscope [15]. The reason is to prevent from accidentally amplify the DC offsets which is not desirable instead of the EMG signal. The gain at this stage should be lower and further amplification should be done in other parts of the circuit. The gain of the instrumentation amplifier was set to 26 by placing a resistor between pin 1 and pin 8. Based on the datasheet, the gain is calculated as below [16] :

$$G = 1 + (50k\Omega / R_G)$$
$$= 1 + (50k\Omega / [R1 + R2])$$
$$= 1 + (50k / 2k)\Omega$$
$$= 26k\Omega$$

II. The Driven Right Leg (DRL) circuit

In order to reduce the impact of noise and increase the signal to noise ratio, there are a few noise reduction strategy and one of them are Driven Right Leg (DRL) concept which is applied in this project [17]. The DRL is widely used in the design of Electrocardiogram (ECG) circuits. Based on the DRL concept, the common mode noise signal is fed back to a 'bony' human part. In this project, elbow is selected to serves as the reference electrode due to its position near to the FDS muscle. Figure 3.5 showed the combination design of preamplifier (INA128) with DRL circuit.

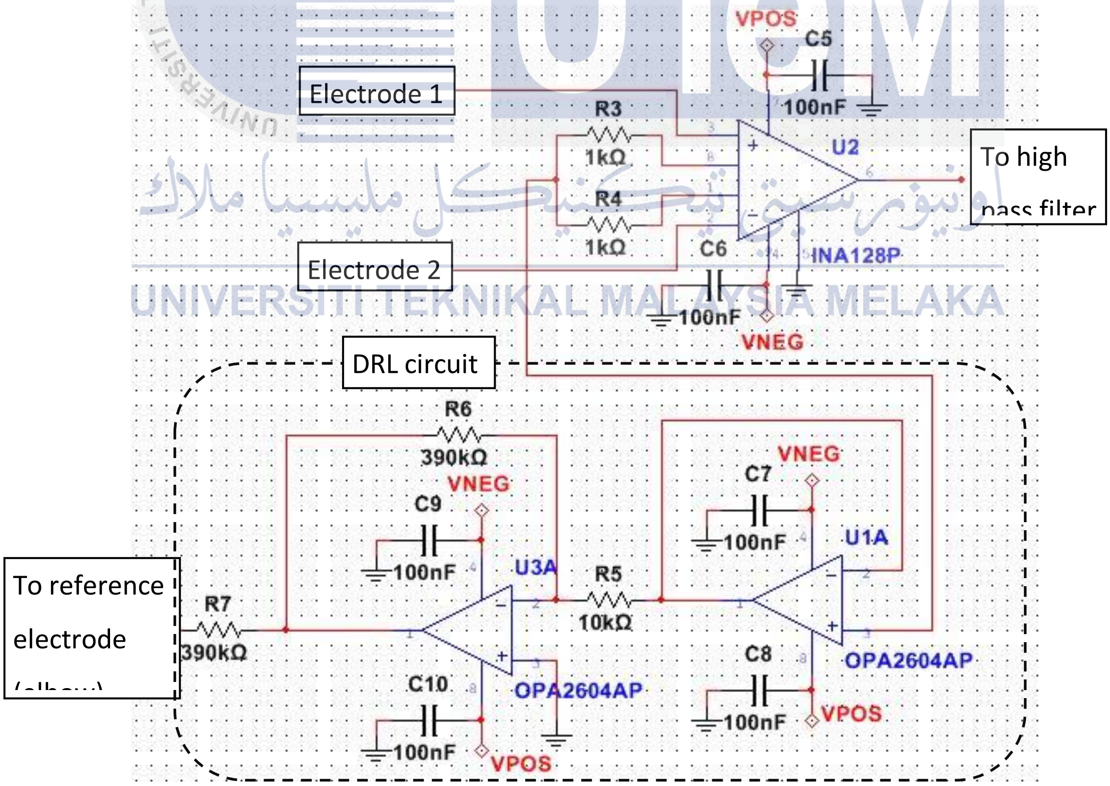

Figure 3.5 : Design of schematic diagram for INA128 with DRL circuit.

III. The High Pass Filter

Low frequency noise signals which have frequency below than 20Hz are introduced by the movement of electrodes in wires and it is known as motion artifact [18]. A high pass filter with cut off frequency at 20Hz at -3dB is cascaded at the output of preamplifier circuit (pin 6 of the 1NA128) as shown in figure 3.6. Therefore it can reduce noise introduced by motion artifact and DC offset [19]. A 2^{nd} order Sallen-Key filter topology with Butterworth characteristics is chosen due to its ability to give flat response in the pass band.

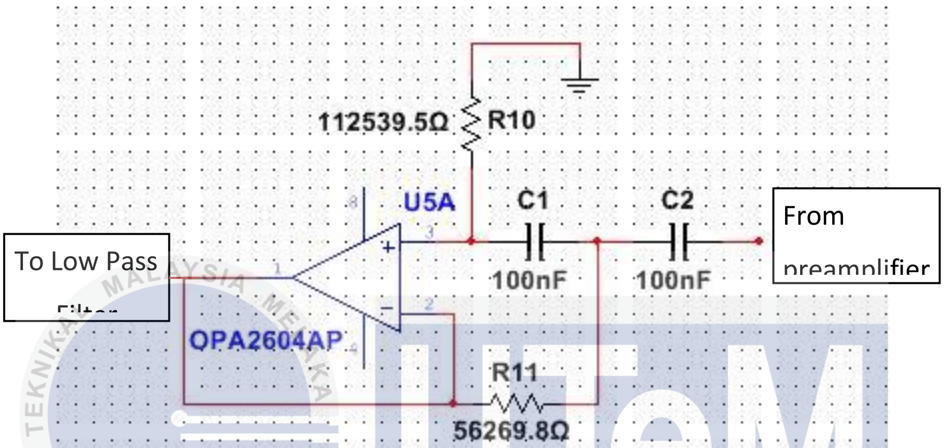

Figure 3.6 : Design of schematic diagram for Sallen Key High Pass Filter with 20Hz cut off frequency and unity gain

The method used to calculate the values of resistor and capacitor for the high pass filter as shown in Figure 3.6 are as follow :

a. <u>Initial value of capacitor selection, C1=C2 (Kindly refer to Figure 3.6)</u>

Based on [20], it is stated that the acceptable range for capacitor values for filter design is from 100nF for low frequencies to 100pF for high frequencies. Therefore, 20Hz is considered as a low frequency, thus C1=C2=100nF was selected.

b. <u>Finding values of R10 and R11 (Kindly refer to Figure 3.6)</u>

The online Sallen-Key high pass filter design calculator by Frank [21] was used. Key in C1=C2=100nF values and cut off frequency=20Hz gives R1=56269.8Ω and R2=112539.5Ω as shown in Figure 3.7 below.

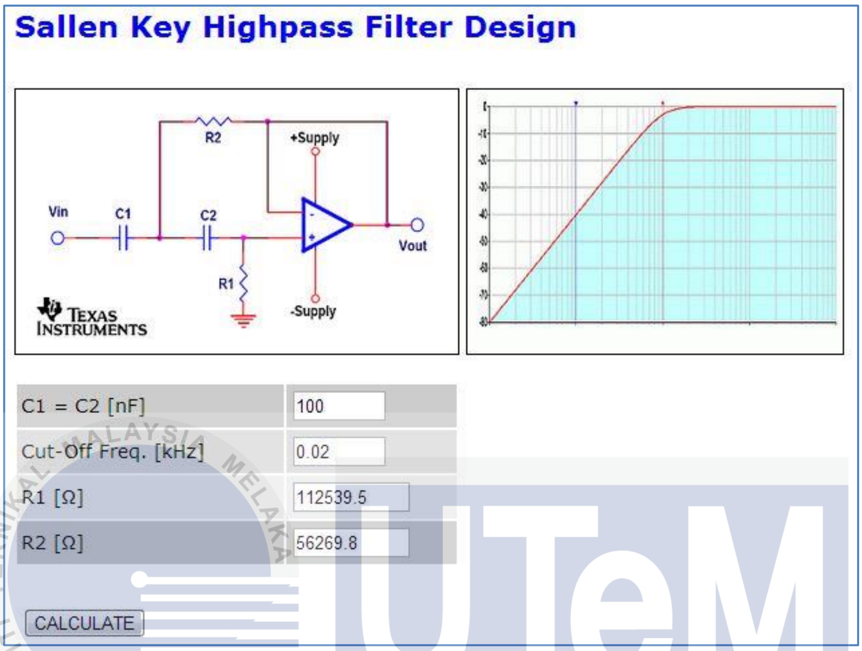

Figure 3.7 : Online calculator for High Pass Filter design [21]

IV. The Low Pass Filter

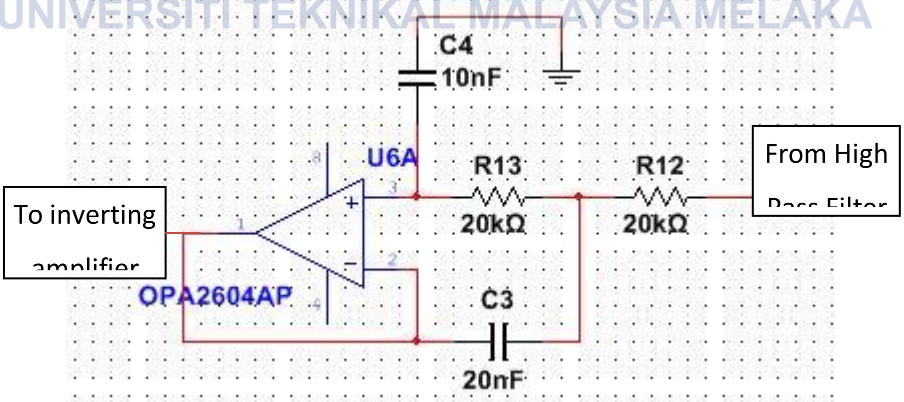

Figure 3.8 : Design of schematic diagram circuit for Sallen Key Low Pass Filter with 500Hz cut off frequency and unity gain

High frequency signals which have above 500Hz may come from surrounding electronic equipment [22]. In order to attenuate these high frequency signals caused by surrounding electronic equipment or radio waves a low pass filter with cut off frequency of 500Hz at -3db is cascaded at the output of the high pass filter. The low pass filter at this stage is also known as an anti-aliasing filter. The resistor and capacitor values in figure 3.8 are calculated using the following method :

A. <u>Finding C3, R12 and R13 (Kindly refer to figure 3.8)</u>

The online Sallen Key low pass filter design calculator by Frank [23] was used. Entering C4=10nF and cut off frequency 500Hz will gives R12=R13=20000Ω and C3=20nF approximately as shown figure 3.9 below.

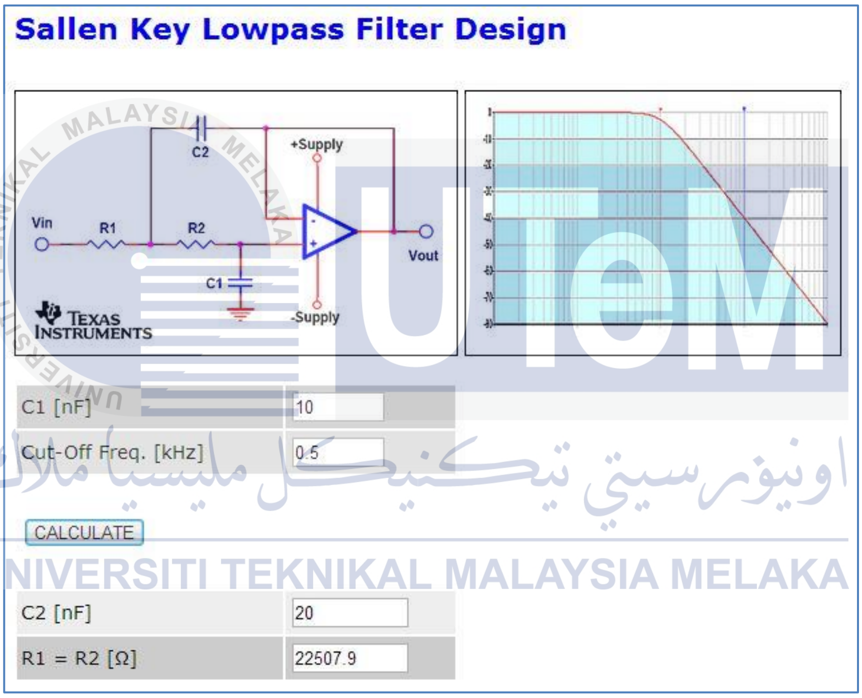

Figure 3.9 : Online calculator for Low Pass Filter [23]

V. The Inverting Amplifier

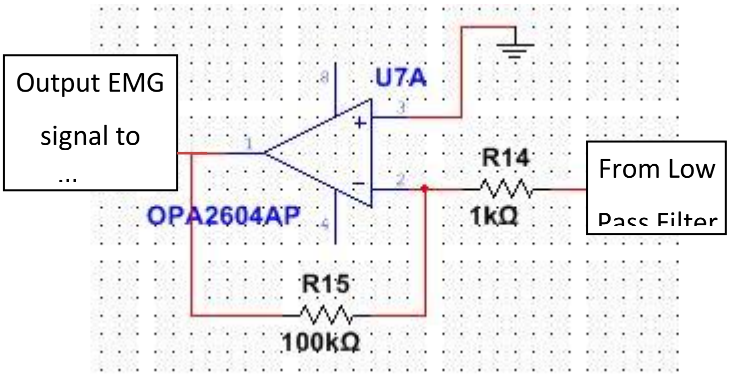

Figure 3.10 : Design of schematic diagram circuit for inverting amplifier with gain 100

Previously, the preamplifier has a gain 26 with both of the filters have unity gain. Further amplification of the EMG signal is needed for further processing. The inverting amplifier in figure 3.10 has a gain of R15/R14 = 100 and is cascaded to the output of the low pass filter. Therefore the total gain of this designed EMG circuit is 26x100 = 2600. Basically, different individuals have different EMG signal amplitudes measured from their FDS muscle. Therefore, to make this circuit more flexible to accommodate different people with different levels hand grip strength, R15 can be replaced with a potentiometer, enabling the EMG circuit to have variable gain instead of fixed gain.

VI. The Power Supply

Two 9V batteries are used to supply +9V and -9V power supplies to the INA128 instrumentation amplifier and the three operational amplifiers (OPA2604) used in the designed circuit.

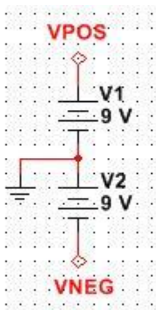

Figure 3.11 : Design of schematic diagram for 9volt batteries configuration

VII. Bypass capacitors

Each IC used has two 100nF bypass capacitors connected to it, one capacitor connected between the +9V power supply and ground while the other capacitor is connected between the -9V power supply and ground. Bypass capacitors are placed as close as possible to the power supply pins of each IC. The bypass capacitors prevent voltage drops on the power supply by storing electric charge to be released when a voltage spike occurs [24].

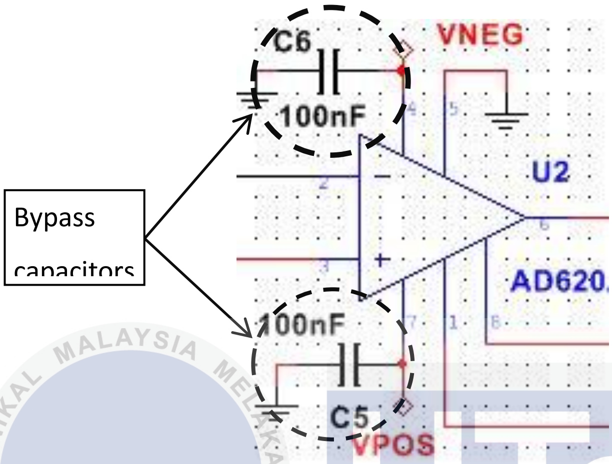

Figure 3.12 : Design of schematic diagram for bypass capacitors with Preamplifier, AD620

3.4 SIMULATION OF DESIGNED EMG CIRCUIT

After the completion of the design of EMG schematic diagram and it has been recommended as the optimized circuit for the processing of EMG. The Multisim 12.0 software is used to simulate the complete designed circuit. For the simulation part, the significant information is described as below :

I. The Input Signal

Function generator instrument is used as to represent raw EMG signals and the input signal configuration is set up according to the EMG signal characteristics. Suppose that input of surface EMG signal is a sine wave signal, typically the surface EMG signals are within the range of +/- 5000 microvolts, and the ranges of frequency content are from 6 Hz to 600 Hz, in which the dominant frequency range is from 20 Hz to 150 Hz [11]. Therefore, the frequency is set at 90Hz with amplitude 5mV peak. The function generator instrument is set up to serve as input signal as shown in Figure 3.13.

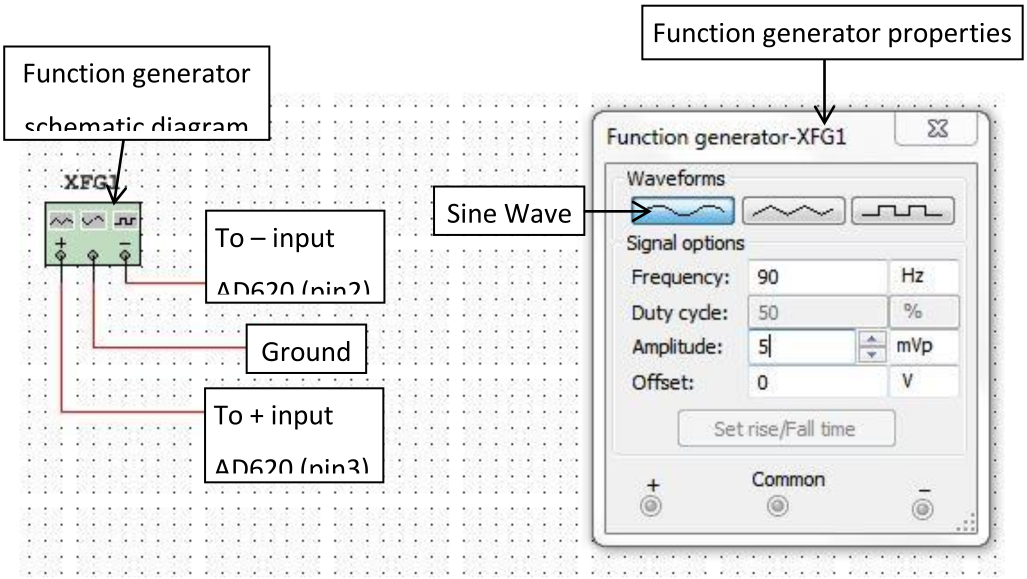

Figure 3.13 : Function generator instrument set up as input signal

II. The Measurement Tools

Four channel oscilloscope instrument and signal analyser instrument in software Multisim 12.0 are used to measure both input and output signal.

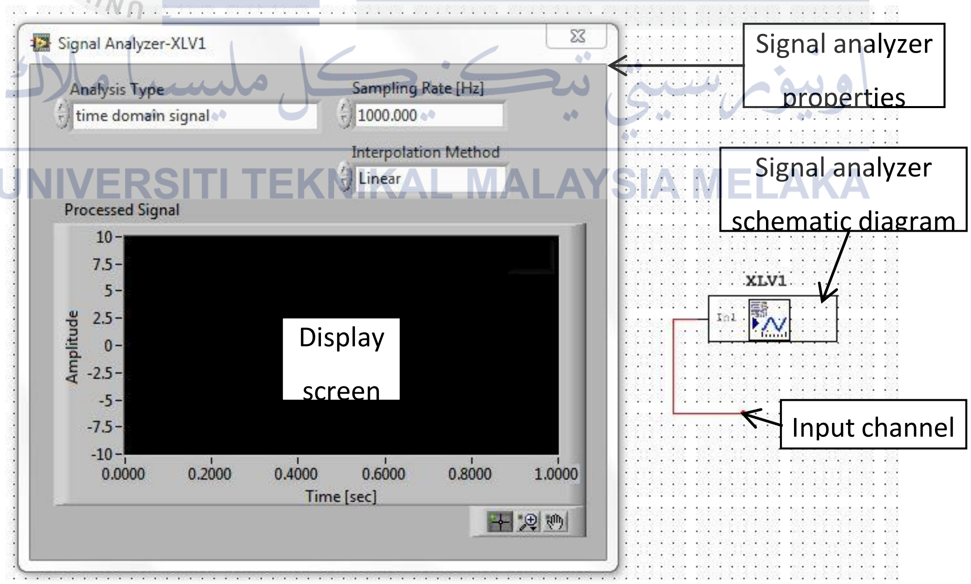

Figure 3.14 : Signal analyzer schematic diagram

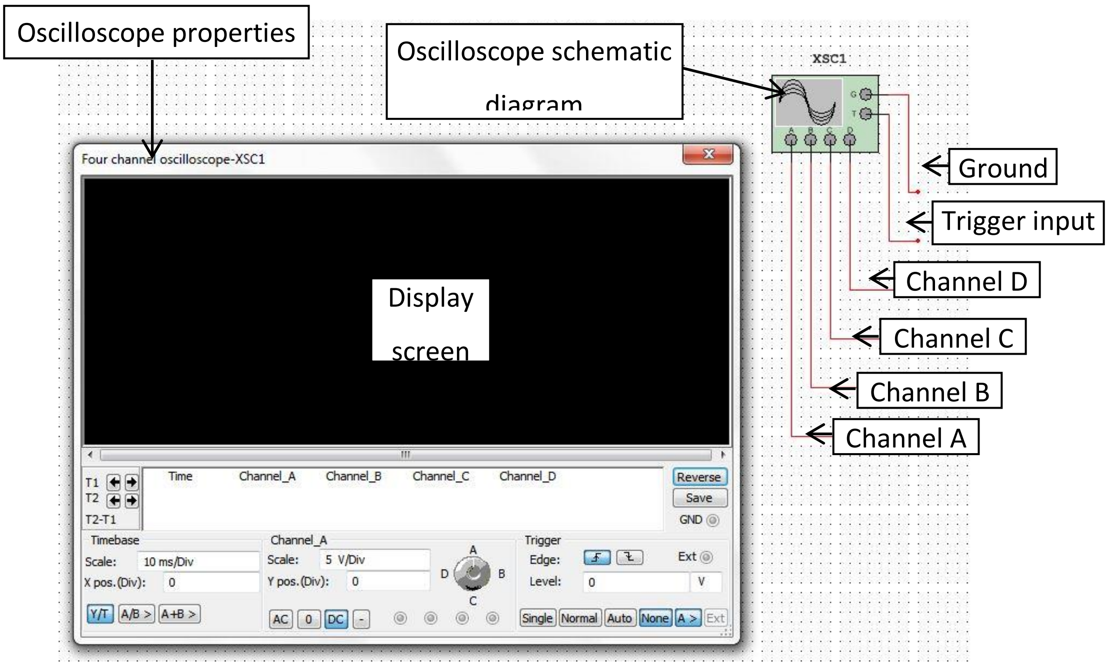

Figure 3.15 : Four channel oscilloscope instrument schematic diagram

III. The Simulation Procedure

Input signal from the function generator instruments and output signal from the designed EMG amplification circuit are measured and recorded using four channel oscilloscope and signal analyser instruments as shown in figure 3.16. Measurements are taken while the designed circuit is in simulation mode. The input and output signals is recorded and the captured of the waveform will be saved. During the simulation, the amplitude readings of the output signal in voltage is observed and analysed.

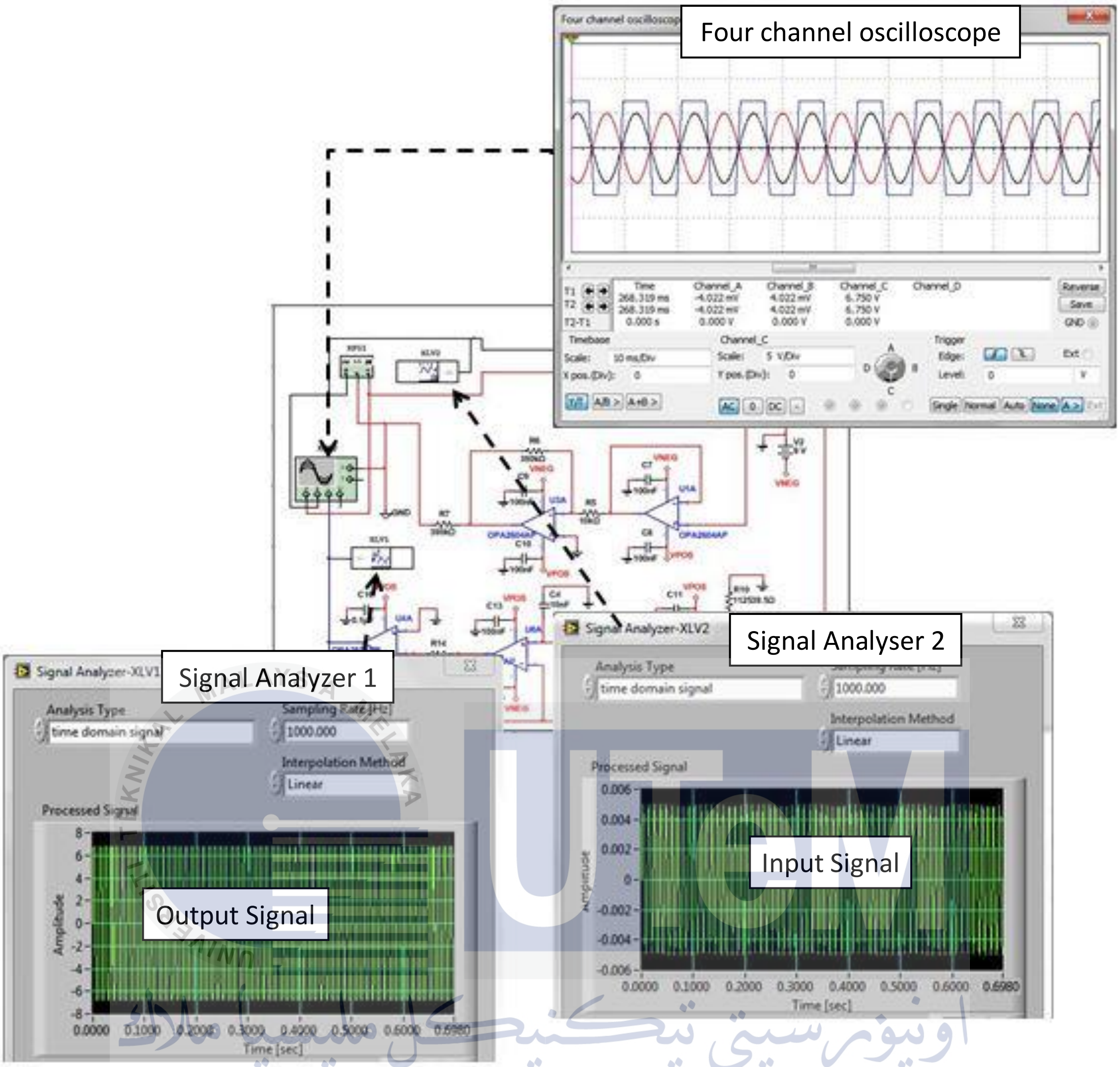

Figure 3.16 : Simulation experimental setup

The analyses of the output simulation are discussed for the next chapter 4 (Result and Analysis). The basic troubleshooting techniques are applied if there is failure when simulate the circuit. Such as, swapping identical components, having knowledge of the fun ction of the components, removing parallel components, dividing the system into sections and testing those sections, and simplifying and rebuilding or building small sections and testing them along the way. The likely failures in the system section discuss human error, bad wire connections, defective components, design error and power supply problems.

3.4 CONSTRUCTION OF DESIGNED EMG CIRCUIT

The next process is made up the hardware for the second objective requirement. The accepted result from the simulation of the designed schematic diagram by using Multisim software is used as the reference in building the circuit hardware. The construction of designed circuit are described below :

I. The Circuit Prototype

The solderless breadboard for electronics does not require soldering. Breadboard connections are held by friction, and the breadboard can be reused many times. Converting a circuit diagram to a breadboard layout is not straight forward because the arrangement of components on breadboard looks quite different from the schematic circuit diagram. When putting parts on breadboard, it must concentrate on their connections, not their positions on the circuit diagram. This makes it easy to use for creating temporary prototypes and experimenting with the designed circuit. It is shown in Figure 3.17 the complete design of EMG circuit on a breadboard for this project.

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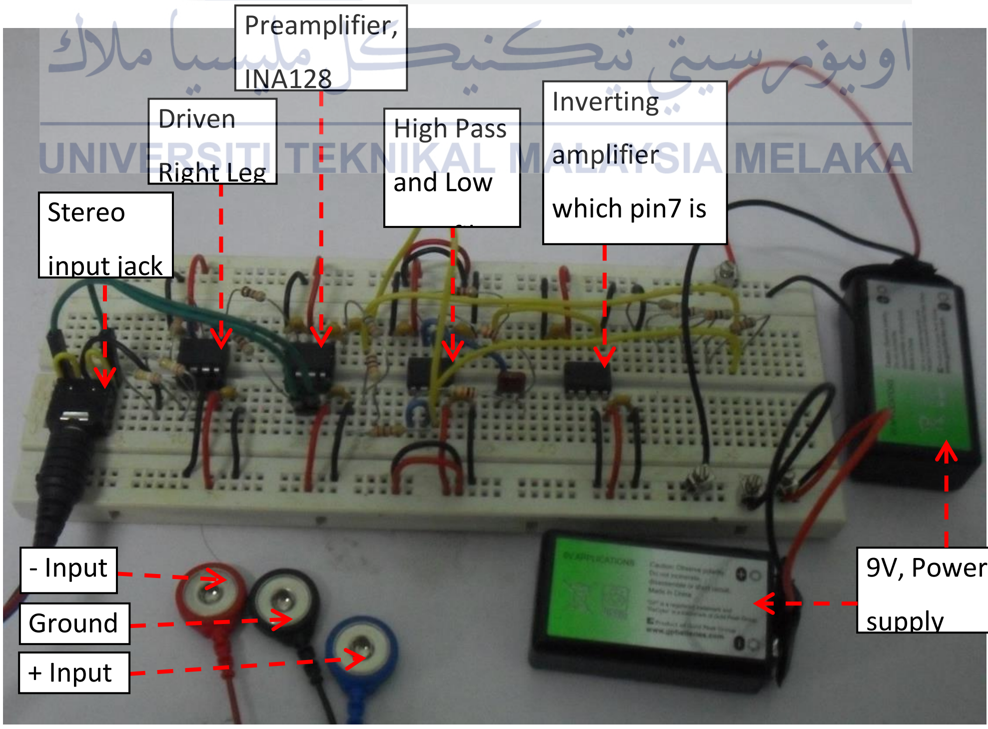


Figure 3.17 : EMG amplification circuit prototype

In order to validate the designed circuit prototype before it is confirmed to be translated into real Printed Circuit Board (PCB), the prototype circuit as shown in figure 3.17 above is tested same as the simulation part previously by using function generator and oscilloscope instruments. The experimental set up is shown in figure 3.18.

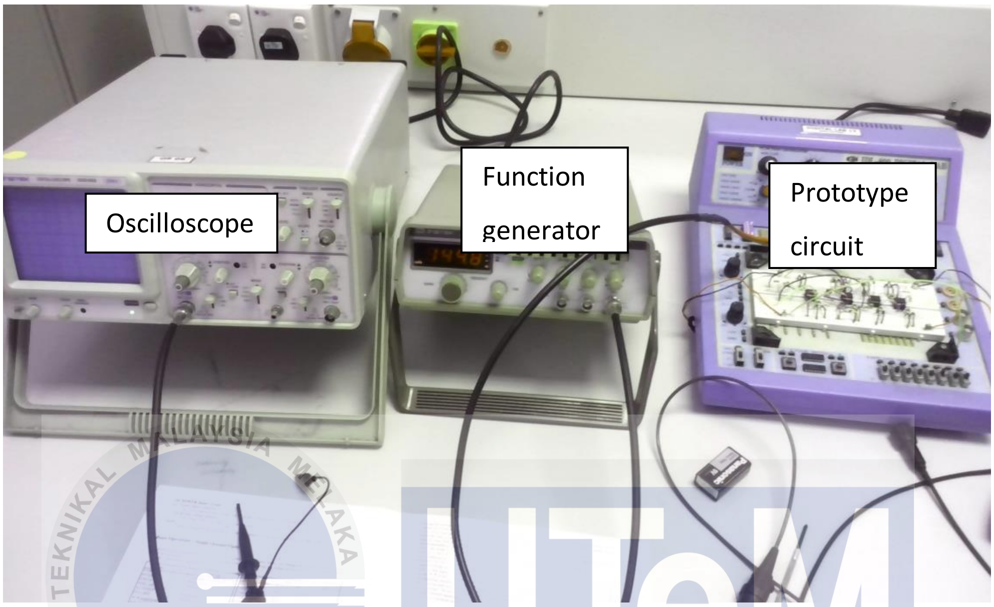


Figure 3.18 : Experimental set up to validate prototype circuit design

II. The Printed Circuit Board (PCB)

The two figures 3.19 and 3.20 below show the track side of a PCB layout normally the underneath side) and the component side (normally the top side) of the same EMG circuit that had been completely design previously. This PCB layout is designed by using Proteous ARES 7 PCB layout software.

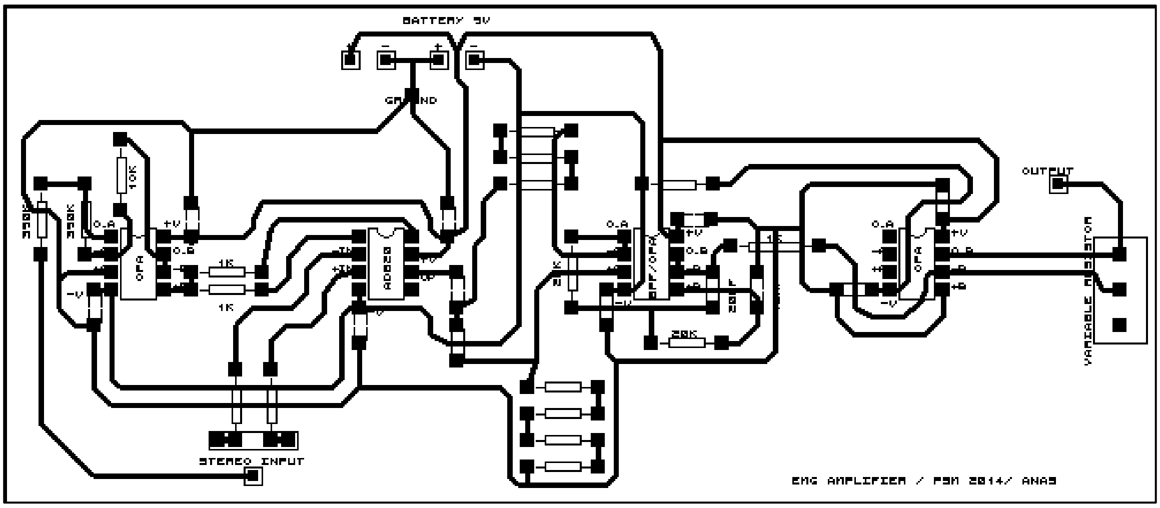


Figure 3.19 : PCB layout view from track side

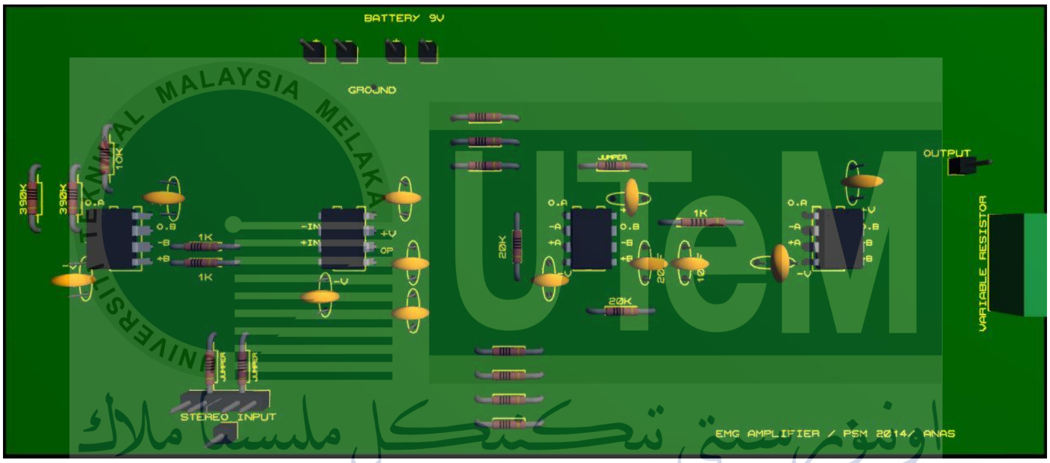


Figure 3.20 : 3D Visualization of the real life layout style shows the PCB with its components

Then the finished PCB layout is processed to become a real PCB as shown in figure 3.21 below. The integrated circuit and others electrical components related are ready to be placed in position and soldered.

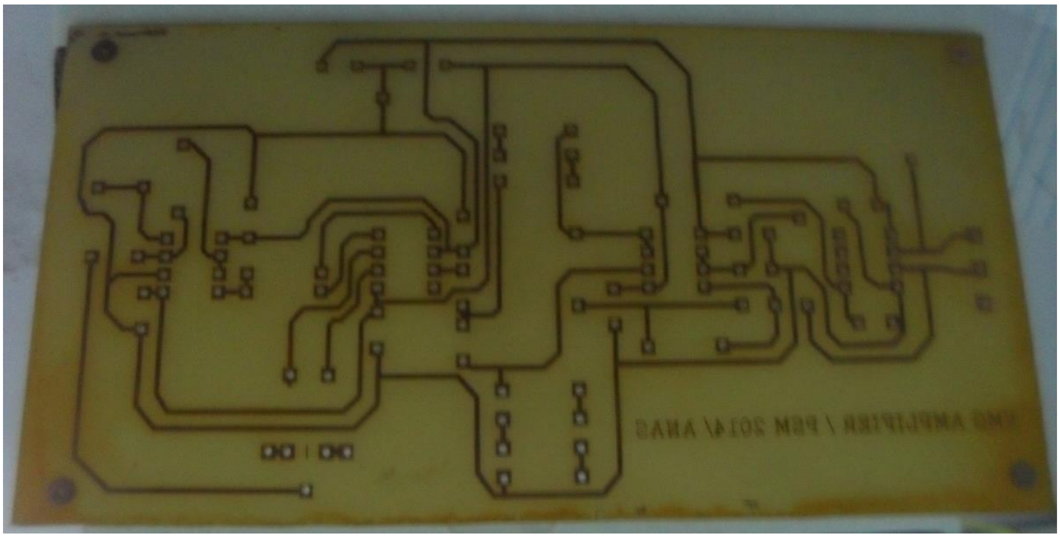


Figure 3.21 : The real Printed Circuit Board (PCB) of EMG amplification circuit for this project

3.6 EMG AMPLIFICATION PERFORMANCE

In order to test the designed EMG circuit and complete the final objective requirement, prior analyses need to be carried out to test performance of the design circuit in by conducting experiments. The experiments are conducted to measure the surface EMG signals from FDS muscle that consist of :

PART A : The measurement of EMG signals from FDS muscle based on 5 healthy subject by using developed EMG amplification circuit

PART B : The measurement for EMG signals from FDS muscle based on 1 subject by using Muscle Sensor V3

After that, the result are observed, recorded and compared to each other in order to validate the developed EMG amplifier circuit and confirm the EMG signal by a specific muscle function test for that particular muscle

A. Experiment Description

Amplifiers are used to increase the amplitude of a voltage or current, or to increase the amount of power available usually from an AC signal. Whatever the task, there are three categories of amplifier that relate to the properties of their output which are voltage amplifiers, current amplifiers and power amplifiers. So, in this project the voltage amplifier is being highlighted. The purpose of a voltage amplifier is to make the amplitude of the output voltage waveform greater than that of the input voltage waveform [13]. Although the amplitude of the output current may be greater or smaller than that of the input current, this change is less important for the amplifier´s designed purpose since the raw EMG signals obtained is recorded in voltage measurement. The measurements of EMG signals from FDS muscle are taken while the subject is gripping with minimum, intermediate and maximum strengths in 3 different wrist angles. The figure 3.19 showed the schematic diagram of the experimental set up.

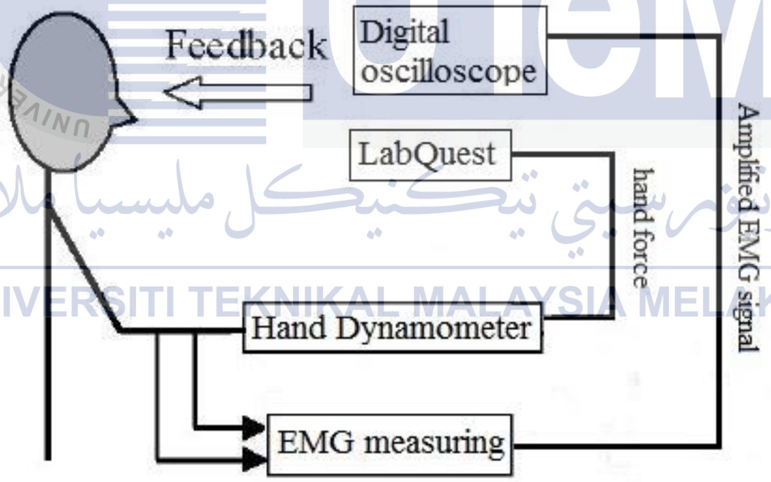
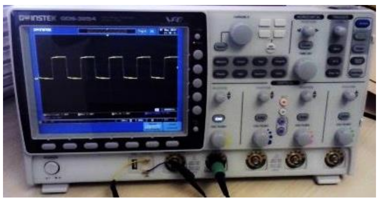


Figure 3.22 : Schematic diagram of experimental set up

B. The Equipment and Instruments

There are others additional equipment and instrument required in the experiments to obtained valid result. Table 3.1 shows summarized of

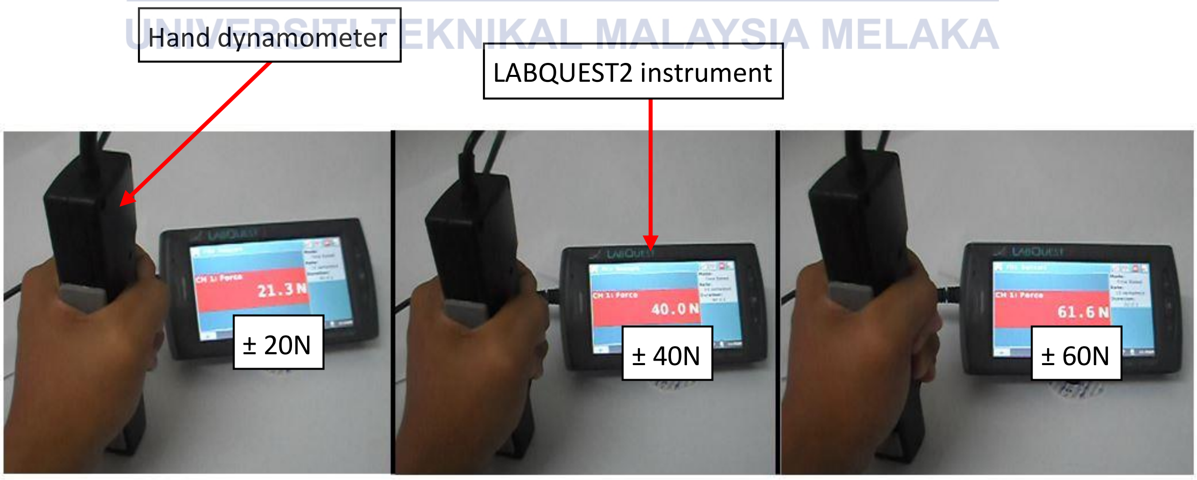
Table 3.1 : Components selection with specifications

NO	COMPONENTS	FUNCTION	FIGURE
1	Muscle Sensor (AgCl Electrodes)	To measure the EMG signal from the skin surface by detect the flow of ions and convert it into flow of electron.	
2	Muscle Sensor V3	To amplify, rectify, and smoothing the EMG signals	
3	Vernier Hand dynamometer	To measure the isometric grip strength of the hand and forearm muscles.	
4	LabQuest 2 interface	This tool is used with hand dynamometer to display the hand grip forces applied.	
5	GW INSTEK GDS-3254 digital oscilloscope	A graph displaying device that display the electrical signal based on the input to its probes.	

C. The Hand Grip Force Measurement And Position Of Wrist Hand

In this project research requires EMG signals and hand grip force to be measured simultaneously. A hand dynamometer by Vernier (HD-BTA) is used to measure the hand grip force and it is connected with LABQUEST2 instrument to display the value of hand grip forces. The hand grip force is measured by holding the hand dynamometer in a vertical position, with lifted and hold perpendicular to the body and completely grasp the pressure pads as shown in Figure 3.23. It is hold for a sustained period (10 seconds) approximately. Minimum strength is defined as ±20N, intermediate strength is defined as ±40N and maximum strength is defined as ±60N of the hand dynamometer as shown in Figure 3.24 respectively. While, Figure 3.25 showed the three different position of wrist angle during hand grip force measurement experiment.

Figure 3.23 : Hand grip force posture



(a) (b) (c)

Figure 3.24 : Hand grip force measurement experiment setup,

a – Hand grip force at 20N, b –Hand grip force at 40N, c – Hand grip force at 60N

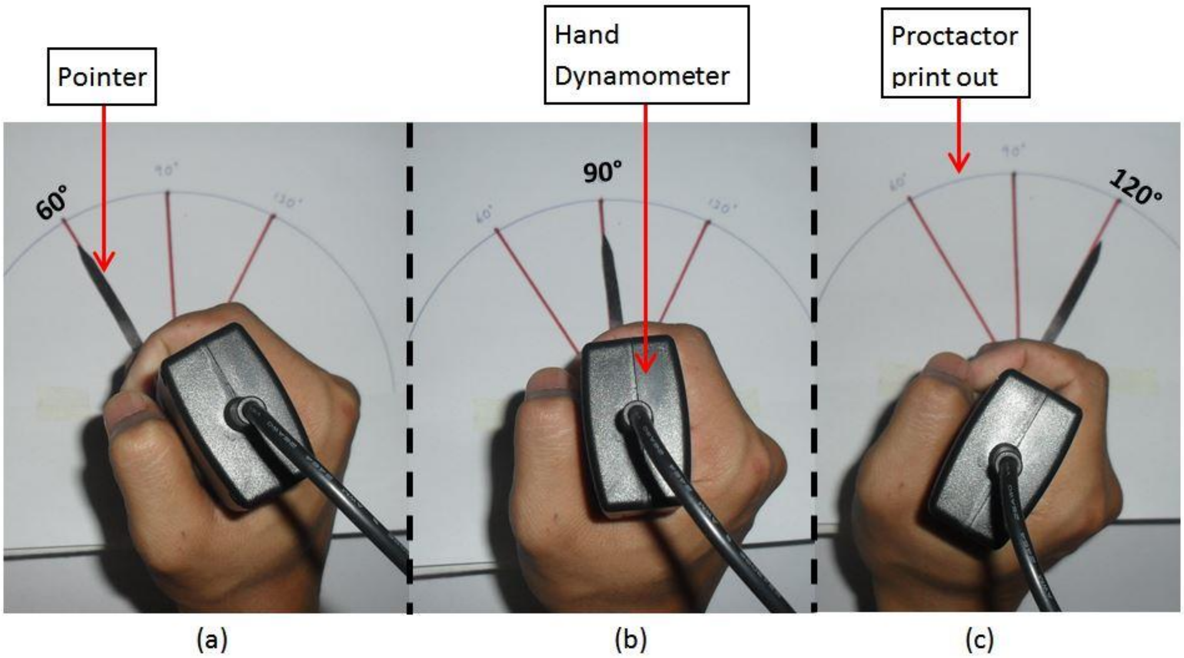


Figure 3.25 : Position wrist angle setup,
a – wrist angle at 90°, b – wrist angle 60°, c - wrist angle at 120°.

D. The Location of FDS muscle

The correct location of target muscle is important in EMG studies, because the muscle where the electrodes are placed have their own function. Basically, to detect the presence of the FDS muscle. The test involves allowing the fifth and the fourth digits to flex together as shown in figure 3.26. This indicates that the FDS is functionally dependent of the FDS to the fourth digit due to anatomical connections to the FDS of that digit [25].The method used to determine the location of FDS muscle is by place the hand palm on the medial epicondyle and extended thumb and fingers down the forearm as shown in figure 3.27. Then by referring each finger and thumb, all of them represent a particular muscle [25]:

- Thumb – Pronator Teres
- Index Finger – Flexor Carpi Radialis
- Middle Finger - Palmaris Longus
- **Ring Finger - Flexor Digitorum Superficialis**
- Little Finger - Flexor Carpi Ulnaris

Finally, the electrodes is placed on the skin surface below the ring finger as shown in figure 3.28. Then, let the electrodes rest with the skin surface before conducting experiments.

Figure 3.26 : Method of detecting the presence of FDS muscle

Figure 3.27 : Placement of the palm on medial epicondyle to determine location of FDS muscle

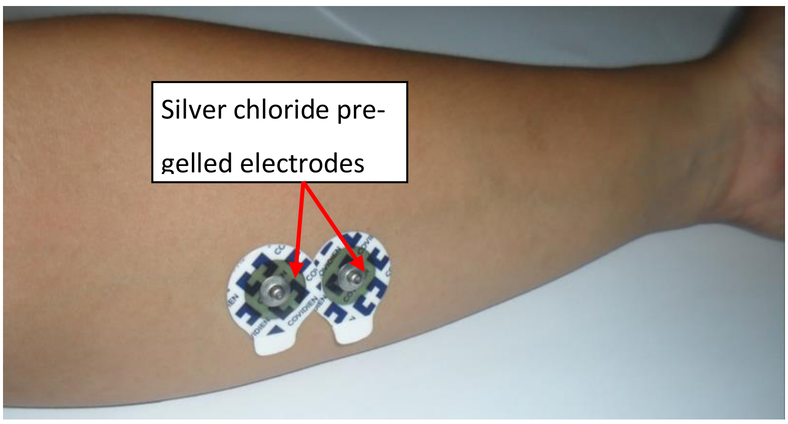


Figure 3.28 : Placement of AgCl Electrodes on the FDS muscle

E. The Skin Preparation Procedures

The following procedures may be considered as steps to prepare the electrode application:

I. Removing the hair

This is needed to improve the adhesion of the electrodes, especially under humid conditions or for sweaty skin types and/or dynamic movement conditions.

II. Cleaning of the skin

Table 3.3 : Cleaning skin methods [26]

METHOD	DESCRIPTION
Method A:	Special abrasive and conductive cleaning pastes are available which remove dead skin cells (they produce high impedance) and clean the skin from dirt and sweat.
Method B:	Alternatively, a very find sand paper can be used: A soft and controlled pressure in 3 or 4 sweeps usually is enough to get a good result. Avoid any harm to the skin from rubbing too hard. The use of sandpaper should be combined with an alcohol pad cleaning.
Method C:	The pure use of alcohol may be another alternative if used with a textile towel (that allows soft rubbing). This latter method may be sufficient for static muscle function tests in uncompromised conditions.

III. Impedance test

If the skin preparation was done properly, the skin typically gets a light red colour. This indicates a good skin impedance condition. To verify it, the resistance between the electrode pair can be measured. Usually the application area needs about 5 minutes to reach a stable electrical condition. Within the first minute one can observe a decrease of electrical resistance of over 50%, mainly due to chemical changes within the skin layers. Skin impedance ranges can be classified in:

Table 3.4 : Recommendations for electrode/skin impedance ranges [26]

Impedance range (KΩ)	**Descriptions**
1 - 5	- very good condition
5 - 10	- good and recommended if feasible
10 - 30	- acceptable for easy conditions
30 - 50	- less good, attention is needed
> 50	- should be avoided or requires a second cleaning run

The impedance test method to measure the resistance between the electrodes pins as shown in Figure 3.29.

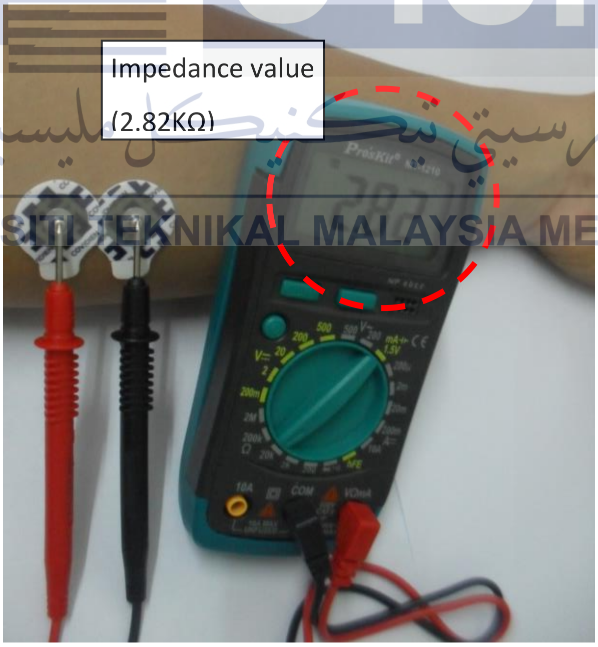


Figure 3.29 : Impedance test for skin preparation procedures

IV. General guidelines electrode application

For surface electrodes, silver/ silver chloride pre-gelled electrodes are the most often used electrodes and recommended for the general use. The electrode diameter (conductive area) should be sized to 1cm or smaller. The general guidelines of electrode application are :

- Wet-gel electrodes have the best skin impedance values
- Use small electrodes to increase the selectivity of measurement (avoid cross-talk)
- The smaller the electrode (active detection area) the higher the impedance values
- Select the closest possible inter-electrode distance to increase selectivity. The general recommendation for the inter-electrode distance is 2 cm (canter point to canter point)
  As shown in figure 3.30 below.

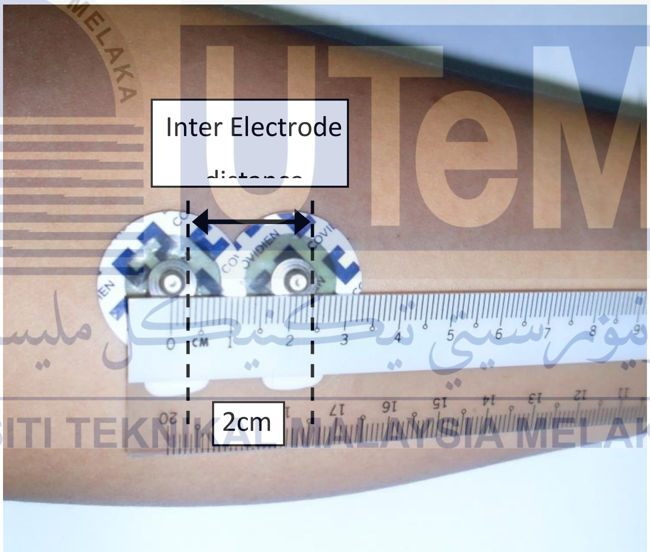


Figure 3.30 : Inter-electrode distance measurement

- Apply electrodes in parallel to the muscle fibre direction
- Use the dominant middle portion of the muscle belly for best selectivity
- Take care that the electrode site remains on the active muscle mass during muscle shortening.

V. Securing the Cables

Finally, securing an appropriate cable and pre-amplifier on the skin is necessary. This helps to avoid cable movement artifacts and minimizes the risk of separating the electrodes from the skin. Use regular tape, elastic straps or net bandages to secure each electrode lead, however, avoid too much tension. It is recommended not to directly tape over the electrodes to keep a constant application pressure for all electrodes.

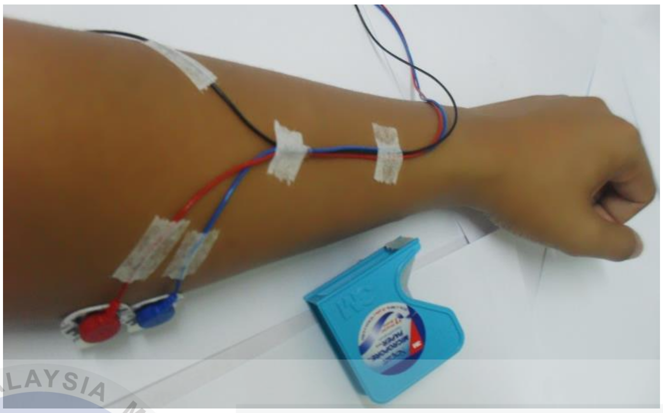


Figure 3.31 : Cable secured with tape

3.7 METHOD TO ANALYSE THE EXPERIMENTAL RESULT

As mention previously in sub chapter 3.4 the experiment described consist of part A and part B. Firstly for part A, the measurement of EMG signals from FDS muscle based on 5 healthy subjects. The result of amplified EMG signals from five subject are compared in term of its waveform pattern to differentiated into three parts which are 90 degrees, 60 degrees and 120 degrees in order verified it is tested for FDS muscle by using the developed EMG amplification circuit. Secondly for part B, the measurement for EMG signals from FDS muscle based on 1 subject by using muscle sensor V3 and developed EMG amplification circuit. The measurement results from these two devices are compared and analysed in term of its amplitude (V_{p-p}) to verify thus the developed EMG amplification successfully amplified the raw EMG signal. The general specification of both devices are tabulated in table below

Table 3.5 : Specification of muscle sensor V3 and developed EMG amplification device

Specifications	Muscle sensor V3	Developed EMG amplification device
Power supply voltage	±3V	±9V
Gain	10 350	2600
Input voltage	2-5mV	2-5mV
Rectifier with capacitor filter	YES	NO
Sensor	AgCl Electrodes	AgCl Electrodes

CHAPTER IV

RESULT AND ANALYSIS

4.0 INTRODUCTION

This chapter discussed on the results obtained in this research. It covers the complete schematic diagram of designed circuit and simulation result of the circuit throughout the Multisim 12.0 software. The complete construction of circuit hardware on Printed Circuit Board and finally the results from the experiment based on two sources first come from the developed circuit in this project and second from muscle sensor V3 kit. The result from the simulation and from the available circuit in market will be analyzed and compared with the designed circuit in this research in order to validate the performance of the designed circuit.

4.1 RESULT FOR THE DESIGNED EMG CIRCUIT AND ITS SIMULATION OF AMPLIFICATION.

The design schematic circuit and simulation carried out as described in previous chapter and the captured of input and output EMG signals were shown in this chapter. The developed circuit is initially simulated on Multisim software to achieve the desired end functionality of the design. The designed circuit has been recommended as the optimized circuit for the processing of EMG signals as shown in figure 4.1 below. The value of input and output signal in term of its amplitude is measured by using oscilloscope probe and signal analyzer. The results of the waveforms are captured and showed below.

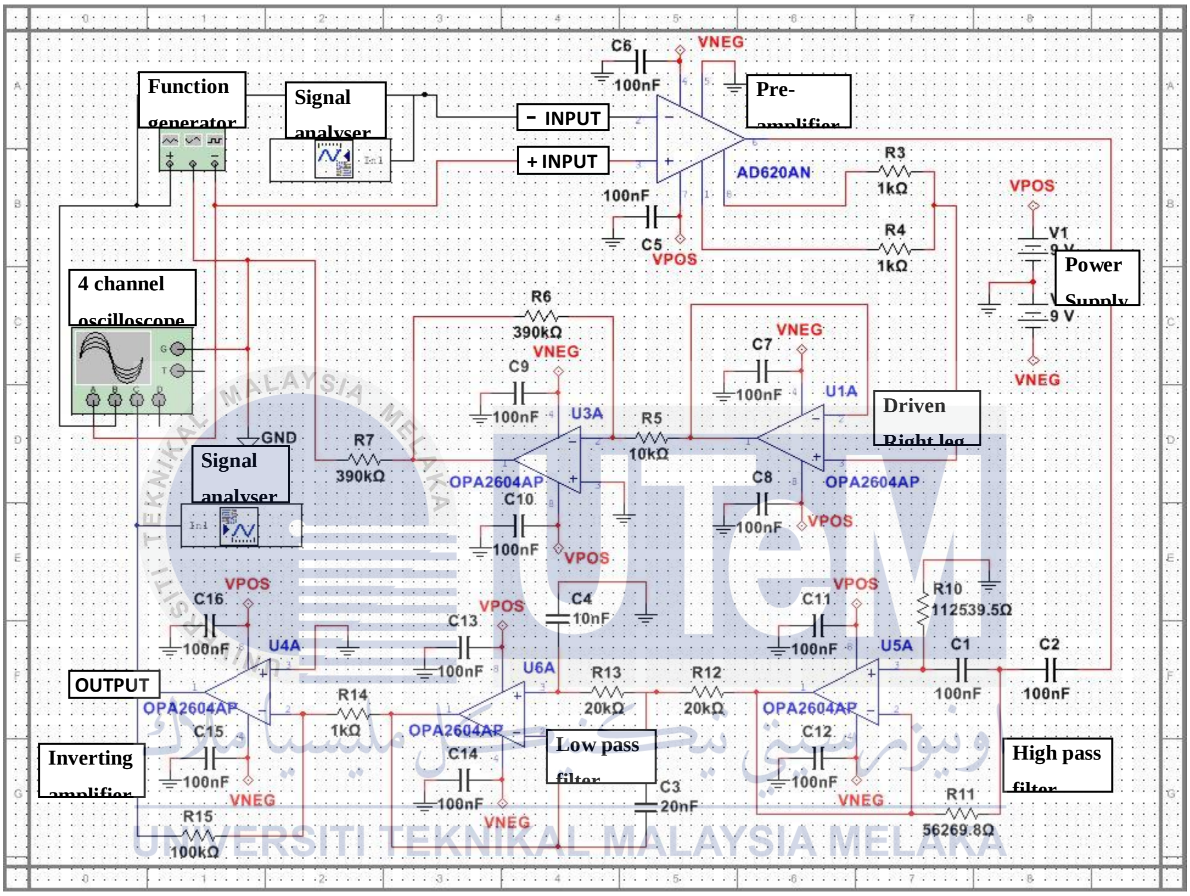


Figure 4.1 : Complete schematic diagram of the designed EMG amplification circuit

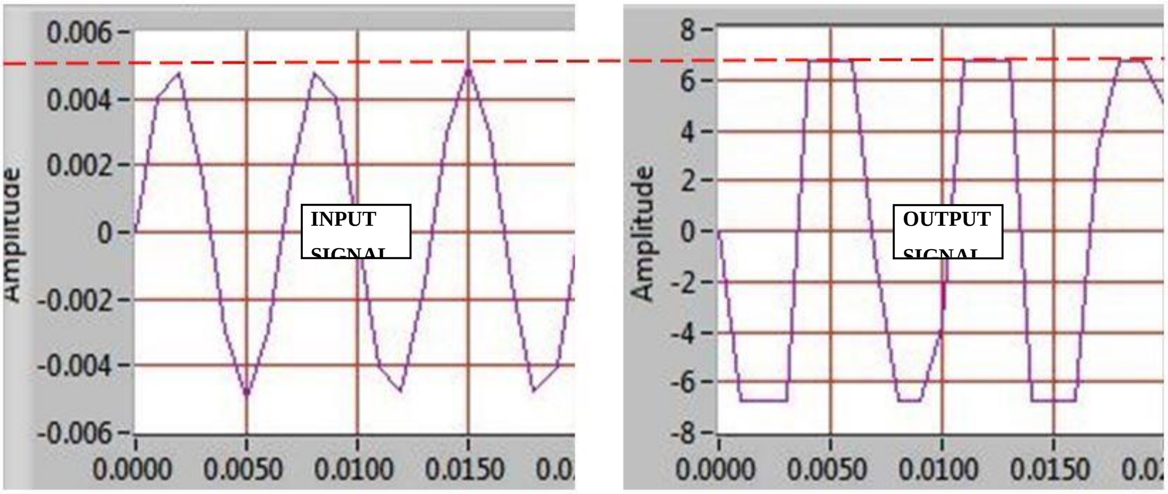


Figure 4.2 : The comparison of waveform between input signal and output signal

The figure 4.2 above represent the signals before (left) and after(right) amplified by using signal analyzer tools. Based on the observation of both graphs, the comparison in terms of theirs amplitude value can be seen clearly. The input signal was amplified from 0.005V to become 6.5V approximately.

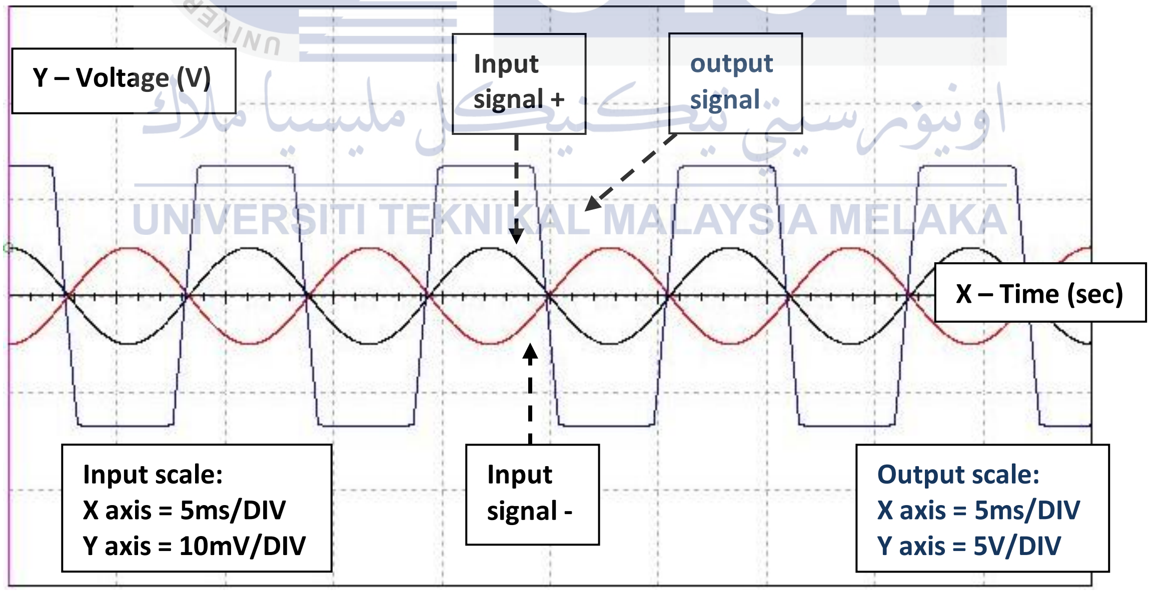


Figure 4.3 : Output signal from the designed EMG circuit

Another display tools that had been used instead of signal analyser was four channel oscilloscopes. Based on the figure 4.3 above, the oscilloscope display three signals instantaneously which represented by waveform with blue line colour for output signal, the black line for negative input signal, and the red line colour as positive input signal. The input and output values given by the circuit during simulation are listed below :

Positive input signal (red) = +0.005 V

Negative input signal (black) = - 0.005 V

Output signal (blue) = 6.747V

As the result of this part, based on the simulation the input signal is completely amplified from 0.005V to ±6V by using the designed EMG circuit. Thus, the designed circuit is valid for amplification signals.

4.2 RESULTS FOR THE DESIGNED EMG CIRCUIT CONSTRUCTION

The complete construction of designed EMG amplification circuit on Printed Circuit Board (PCB) as shown in Figure 4.4 and all the electrical components used on the circuit are listed in Table 4.1.

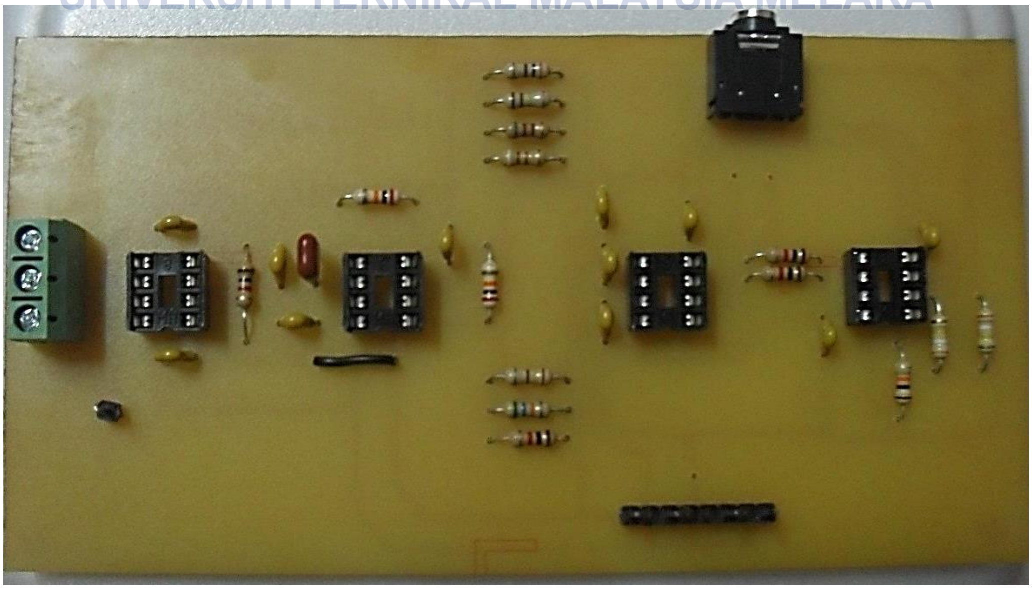


Figure 4.4 : The construction of the designed circuit on PCB.

Table 4.1 : Bills of materials

No	COMPONENTS	QUANTITY
1	AD620	1
2	OPA2604	3
3	Stereo Input jack	1
4	Capacitor (100nF)	8
5	Capacitor (10nF)	1
6	Capacitor (20nF)	1
7	Resistor (1K)	3
8	Resistor (390K)	2
9	Resistor (20K)	2
10	Resistor (100K)	2
11	Potentiometer	1

4.3 EXPERIMENTAL RESULT

The experiment are carried out as described in the previous section and the value of output signal in term of its amplitude is measured by using GW INSTEK GDS-3254 digital oscilloscope instrument. The results of the waveforms are captured and showed below.

4.3.1 The measurement of raw EMG signals and measurement of EMG signal when subject at rest mode

I. <u>The measurement results of raw EMG signals</u>

The raw EMG signal having average peak-peak value of about 50mV due to the varying amplitude as shown in figure 4.5. The varying amplitude distinctly shows the places where the muscle is contracted and where it relaxes. In the positive peak the muscle contracts and the later occurs at the negative peak.

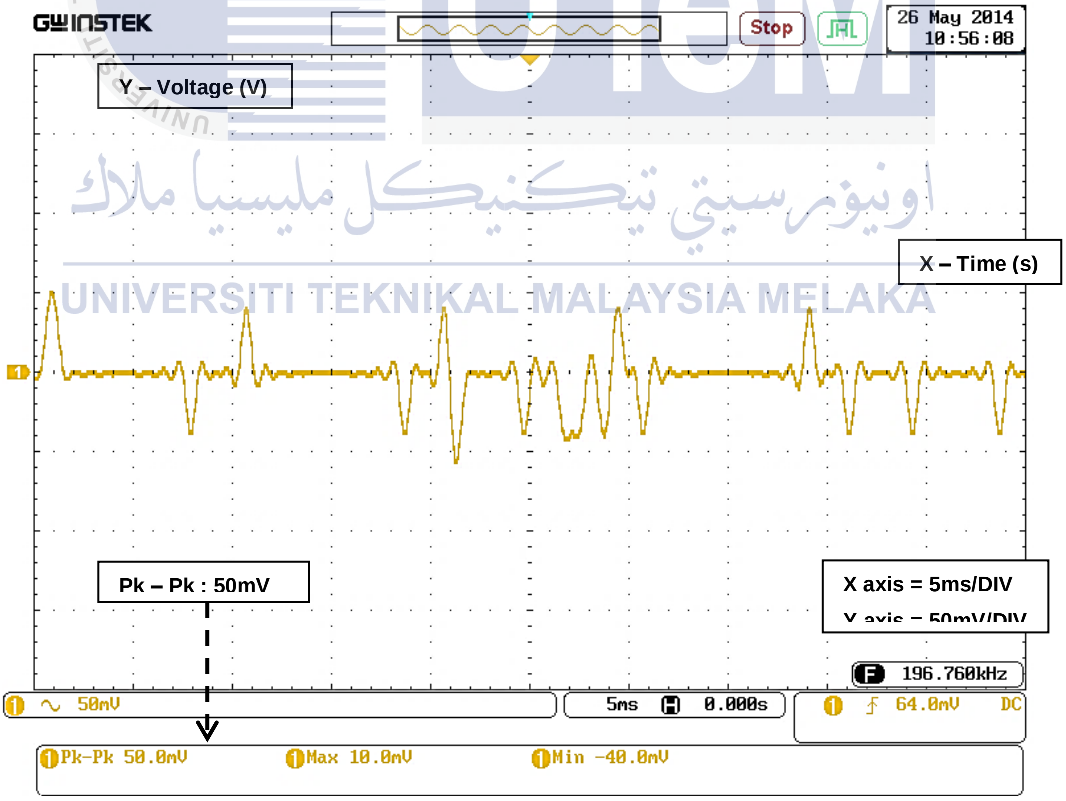


Figure 4.5 : The waveform of raw EMG signal

II. <u>The measurement of EMG signal at rest mode</u>

The EMG signal having average peak-peak value of about 360mV at rest mode where the hand of the subject is free from any force or movement as shown in figure 4.5.

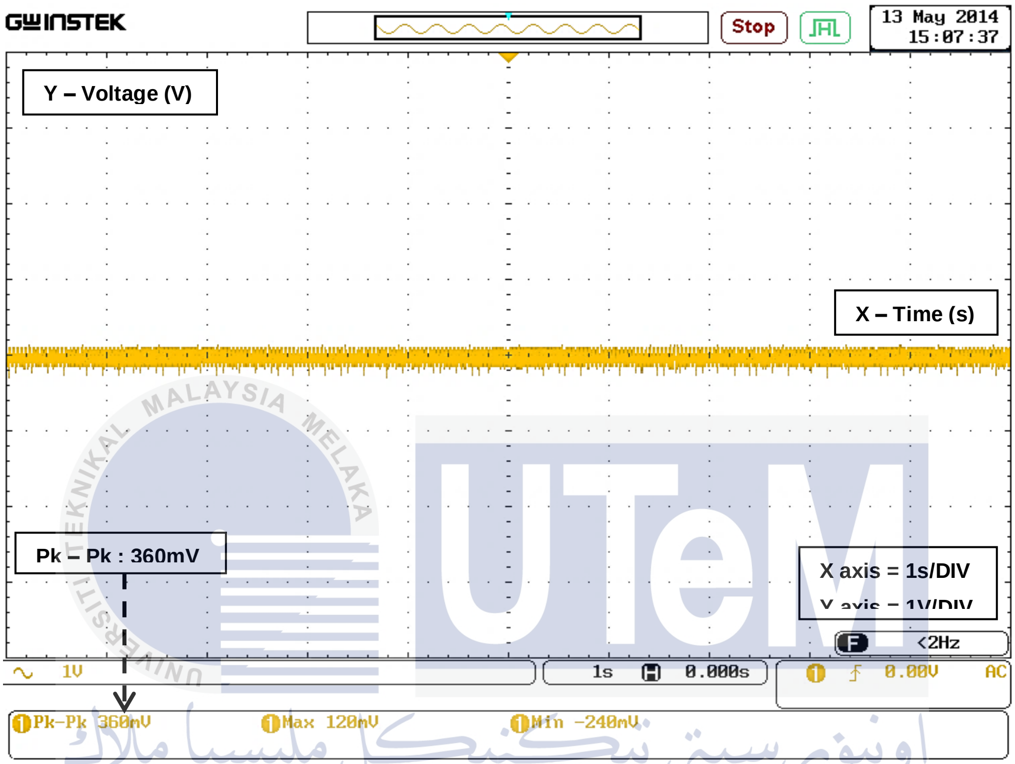


Figure 4.6 : The waveform of EMG signals when subject at rest mode

4.3.2 The Measurement Result of EMG Signals Using Developed EMG amplification circuit

The captured of amplified EMG signals for different wrist angle with 3 level hand forces(20N, 40Nand 60N) by using the developed EMG amplification circuit are showed below :

I. <u>The results of EMG signals for wrist angle 90 degrees</u>

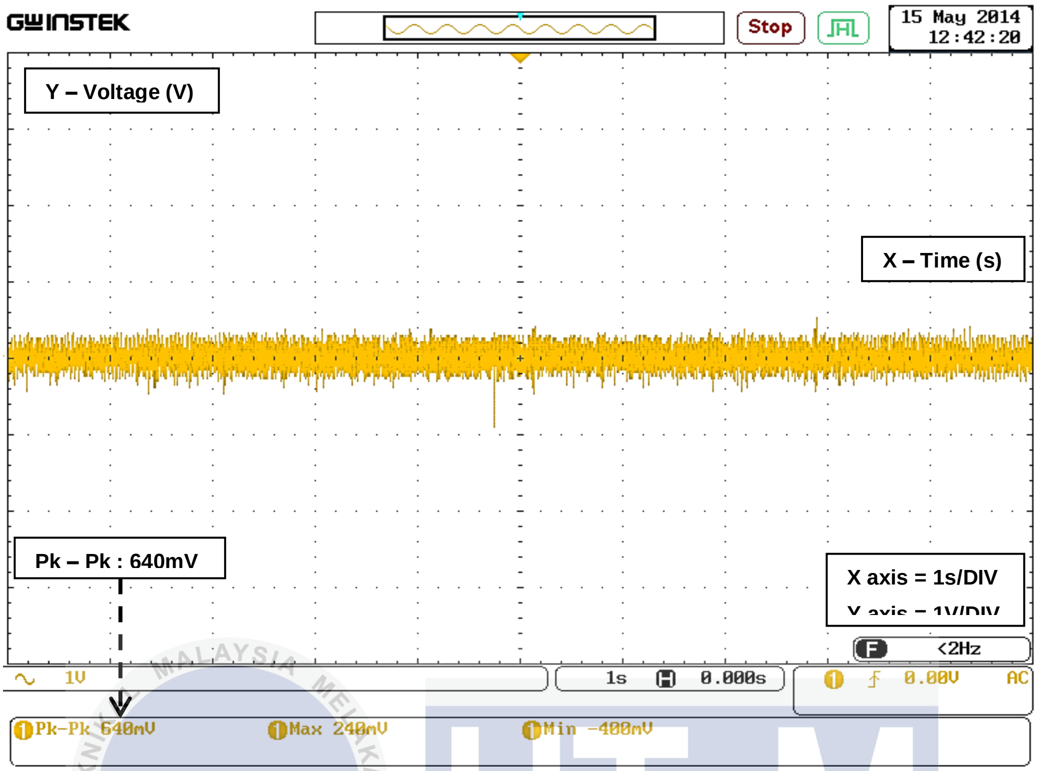


Figure 4.7 : The amplified of EMG signals for 20N hand grip force

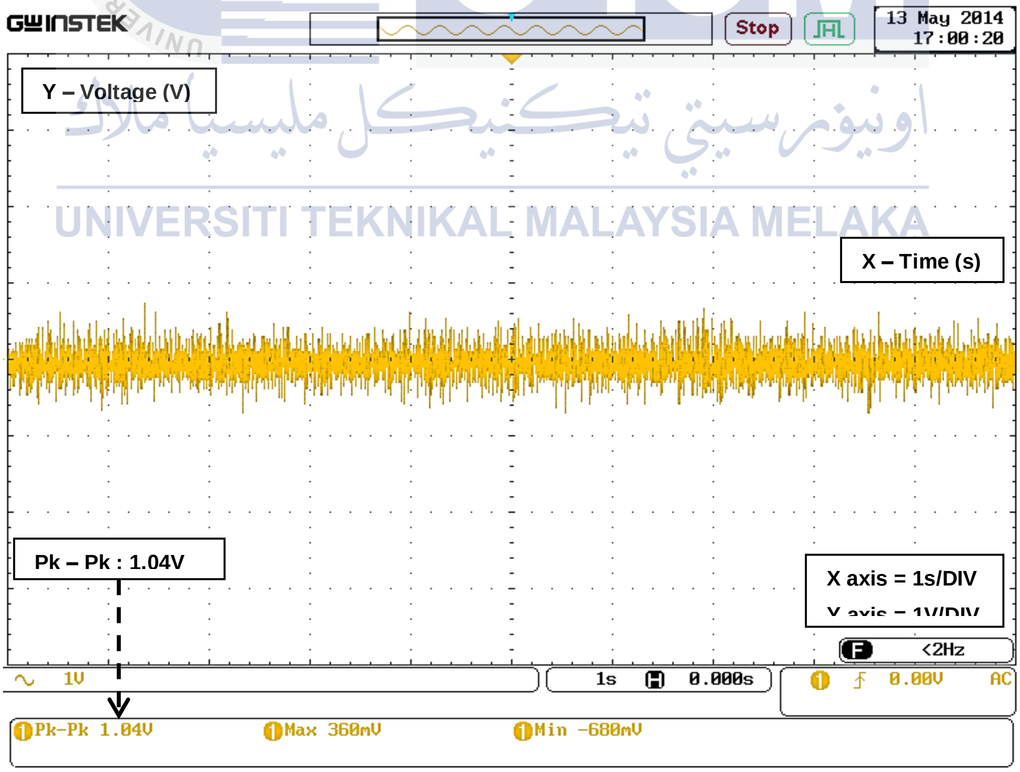


Figure 4.8 : The amplified of EMG signals for 40N hand grip force

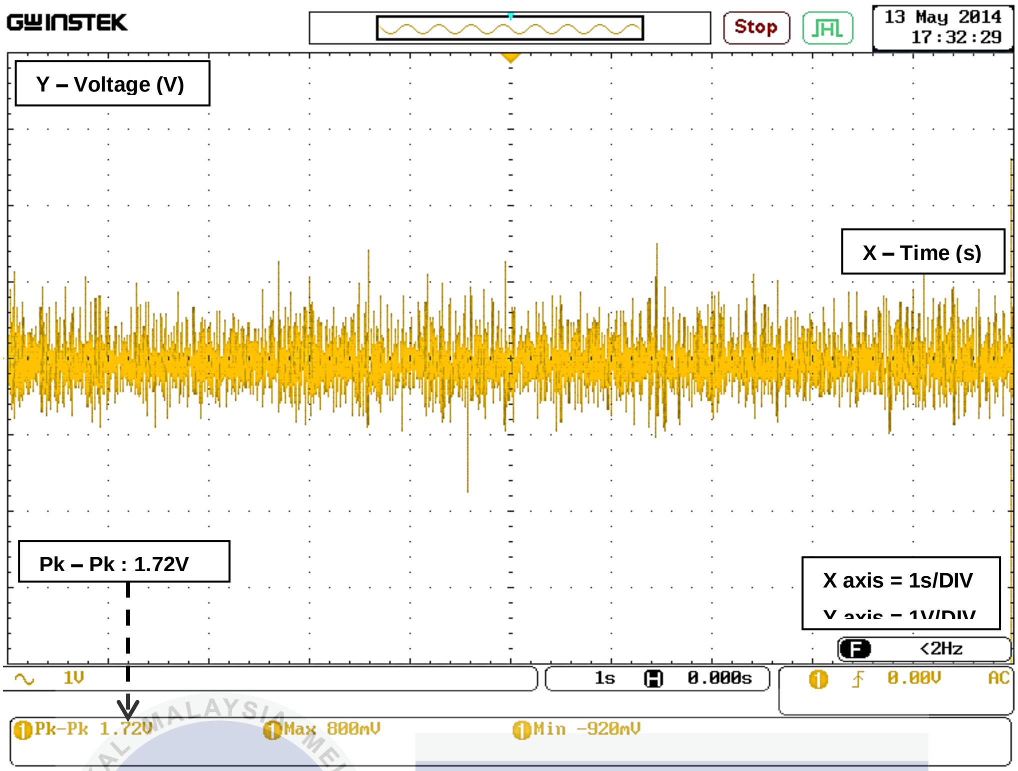


Figure 4.9 : The amplified of EMG signals for 60N hand grip force

II. The results of EMG signals for wrist angle 120 degrees

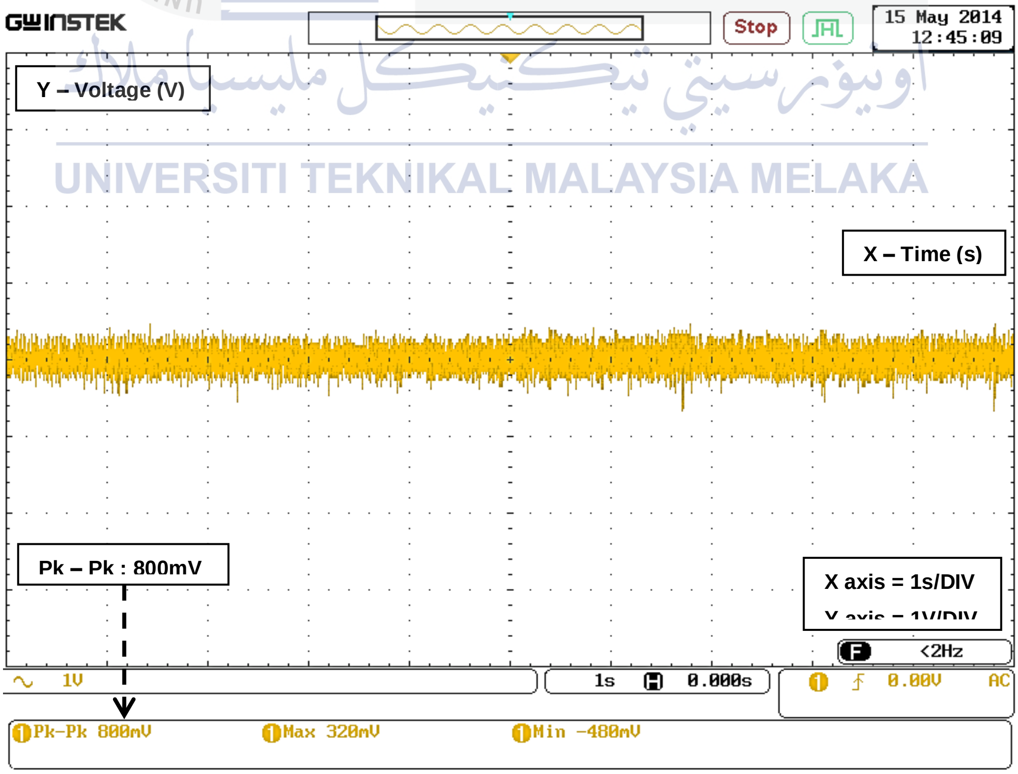


Figure 4.10 : The amplified of EMG signals for 20N hand grip force

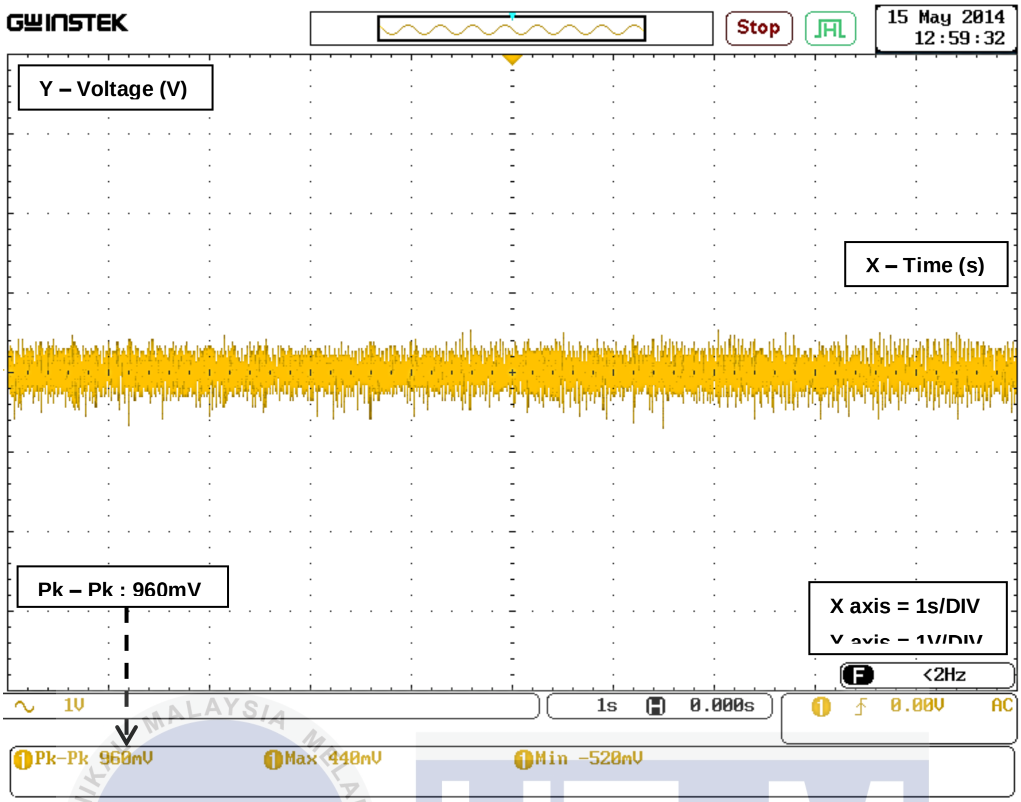


Figure 4.11 : The amplified of EMG signals for 40N hand grip force

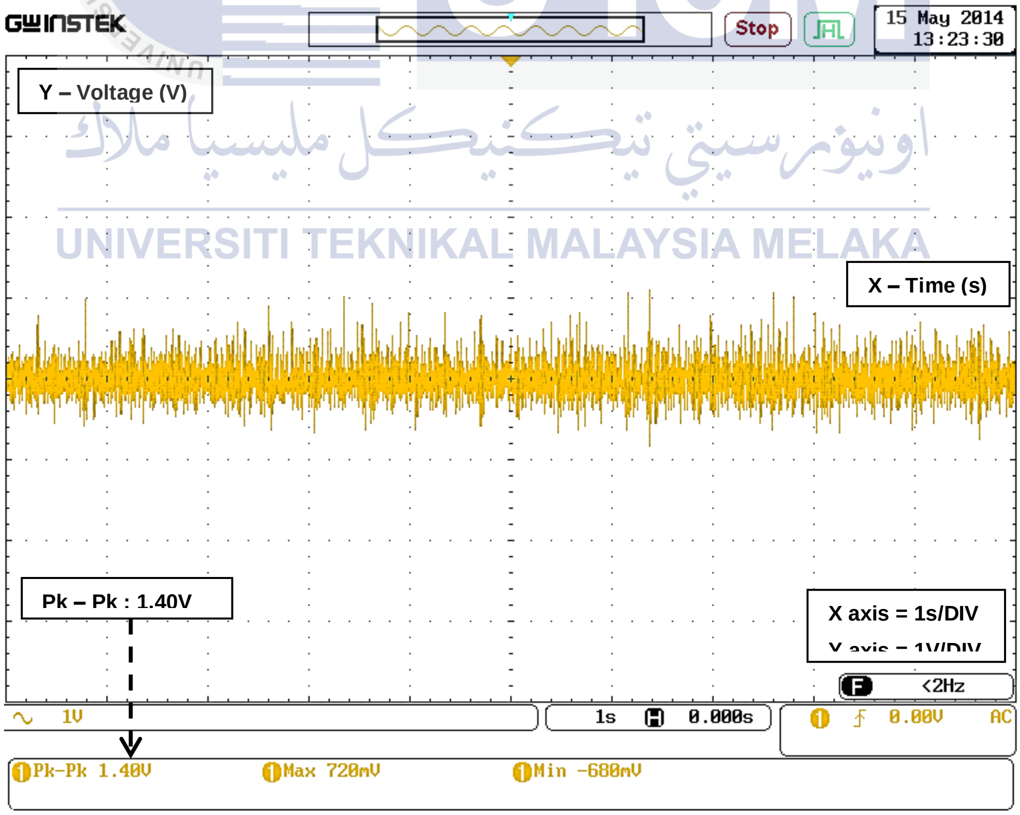


Figure 4.12 : The amplified of EMG signals for 60N hand grip force

III. <u>The results of EMG signals for wrist angle 60 degrees</u>

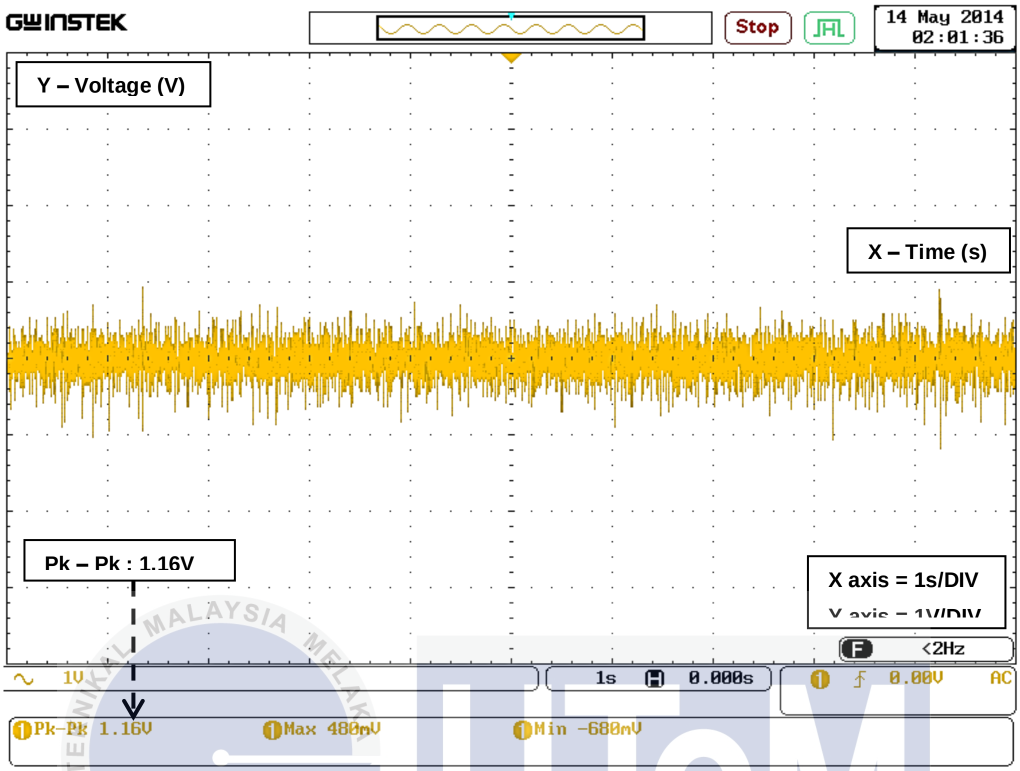


Figure 4.13 : The amplified of EMG signals for 20N hand grip force

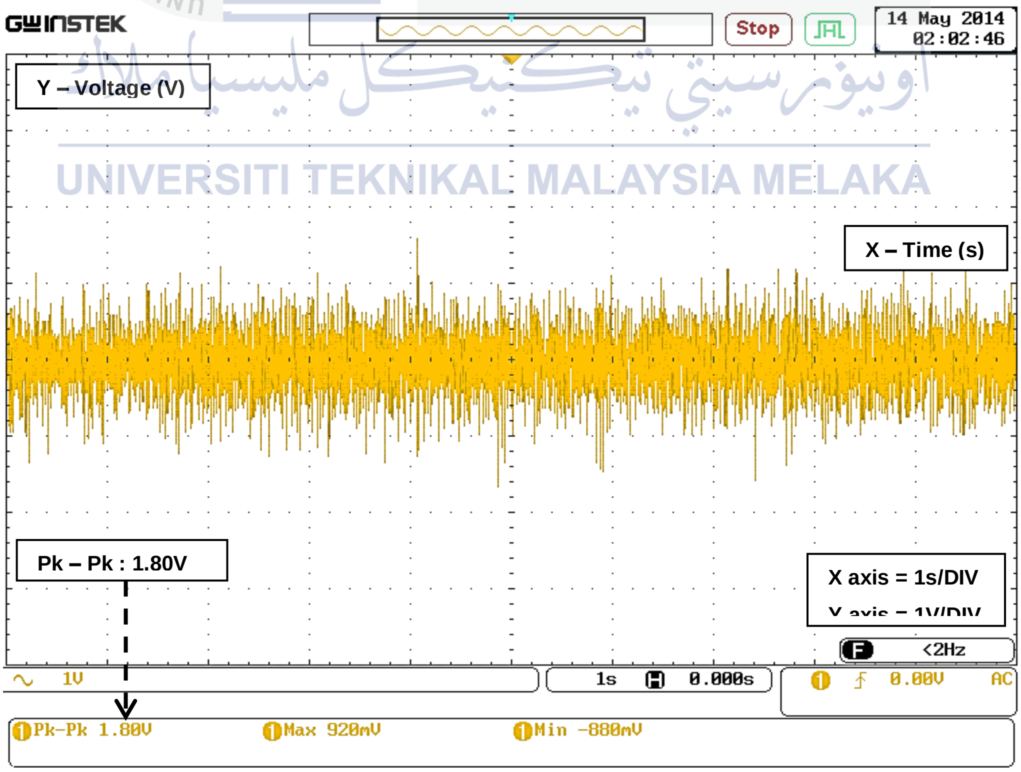


Figure 4.14 : The amplified of EMG signals for 40N hand grip force

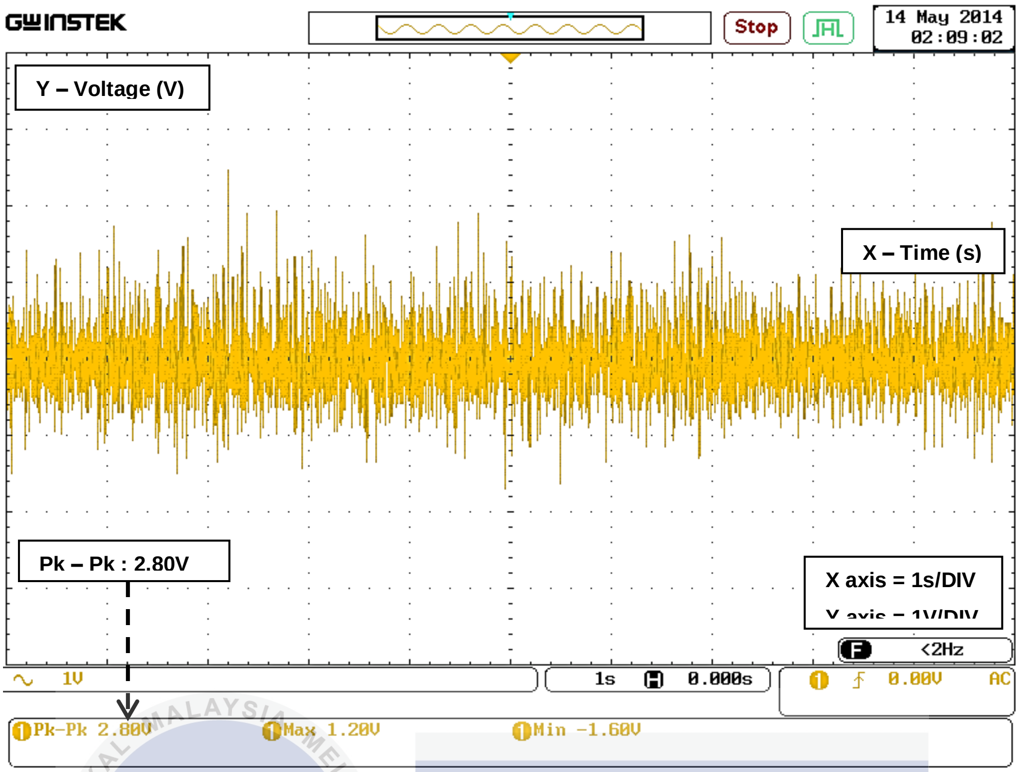


Figure 4.15 : The amplified of EMG signals for 60N hand grip force

4.3.3 The Measurement of EMG Signals Using Muscle Sensor V3

The captured of amplified EMG signals for different wrist angle with 3 level hand forces by using the muscle sensor V3 are showed below :

I. The results of EMG signals for wrist angle 90 degrees

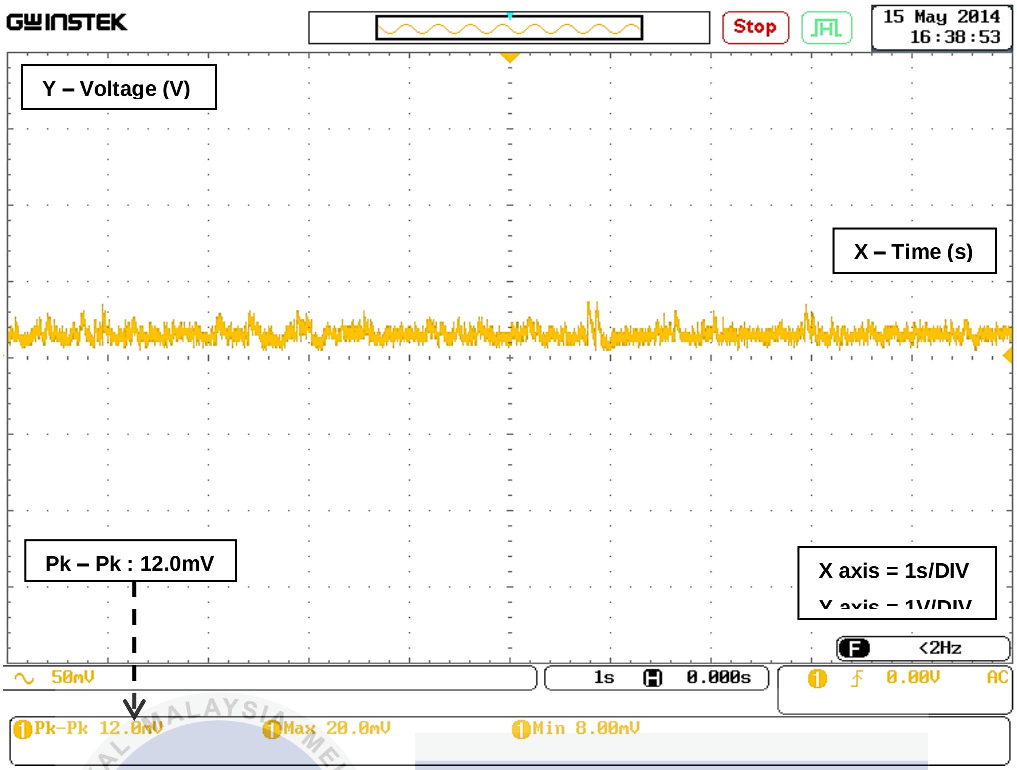


Figure 4.16 : The amplified of EMG signals for 20N hand grip force

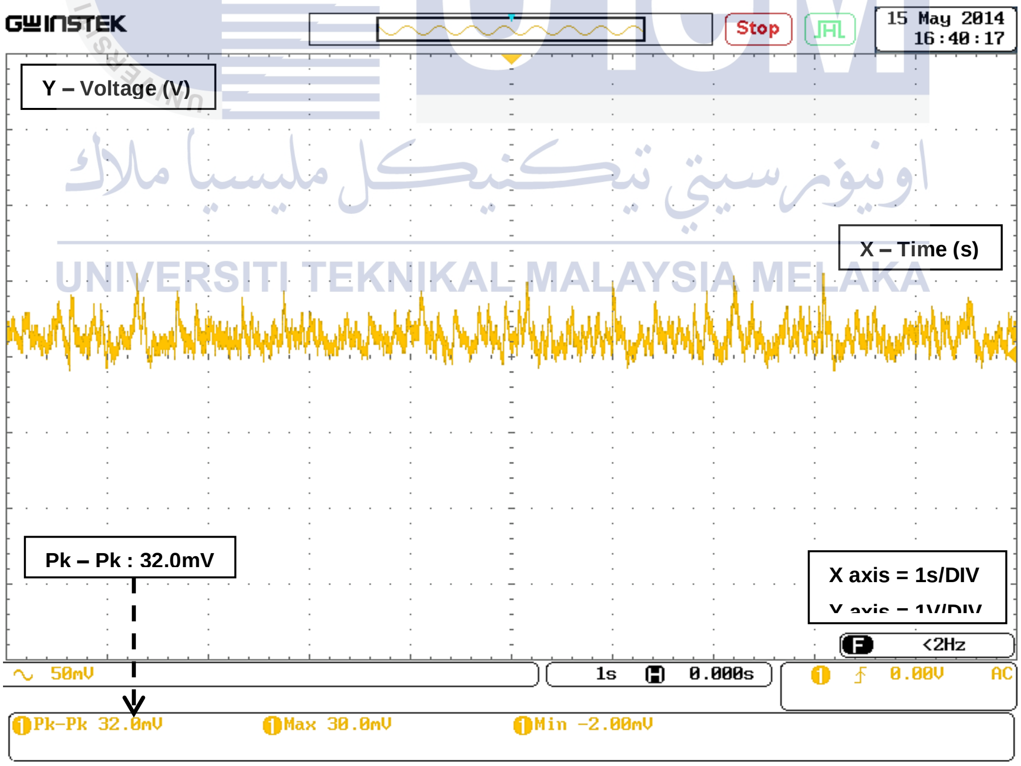


Figure 4.17 : The amplified of EMG signals for 40N hand grip force

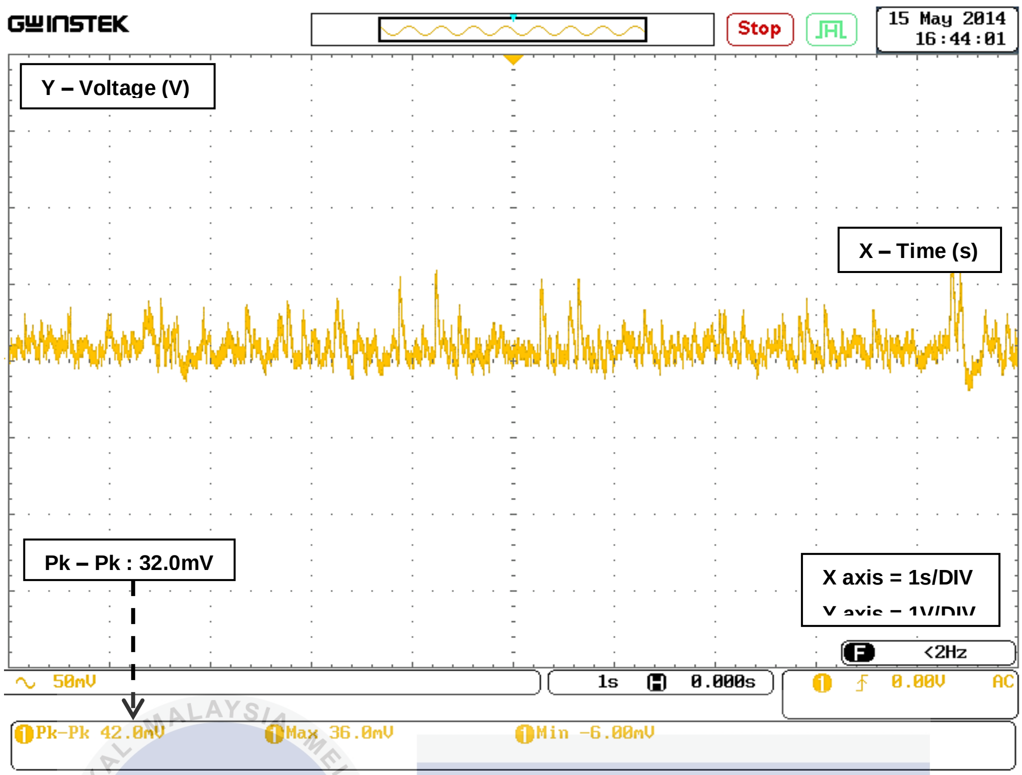


Figure 4.18 : The amplified of EMG signals for 60N hand grip force

II. <u>The results of EMG signals for wrist angle 120 degrees</u>

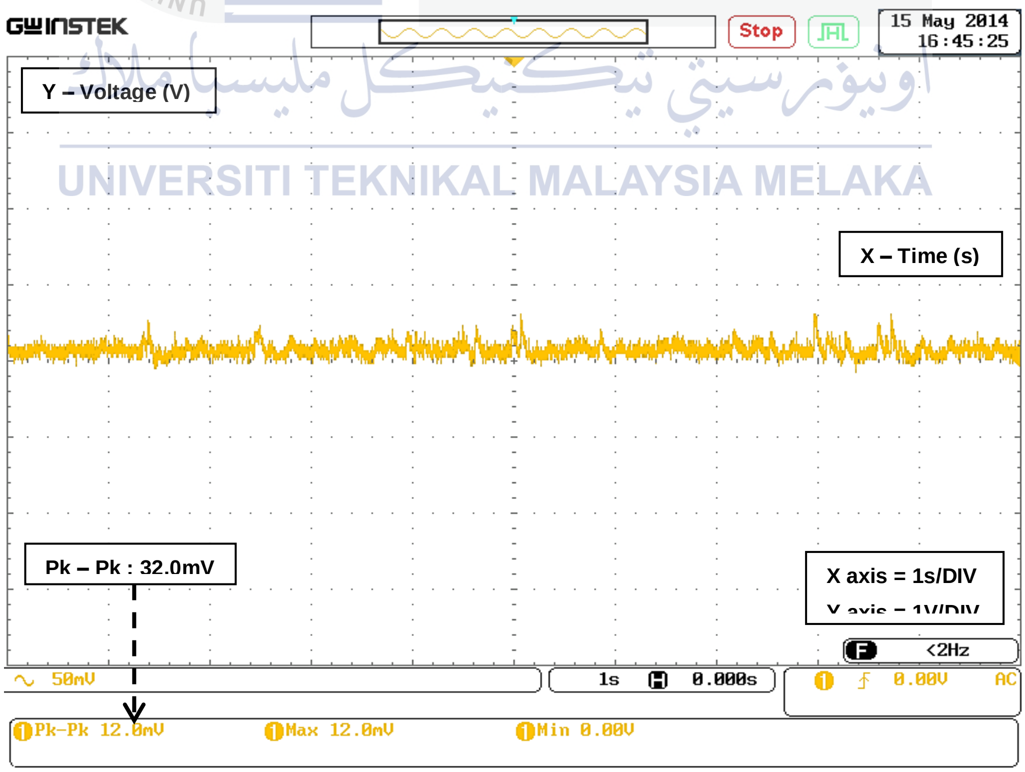


Figure 4.19 : The amplified of EMG signals for 20N hand grip force

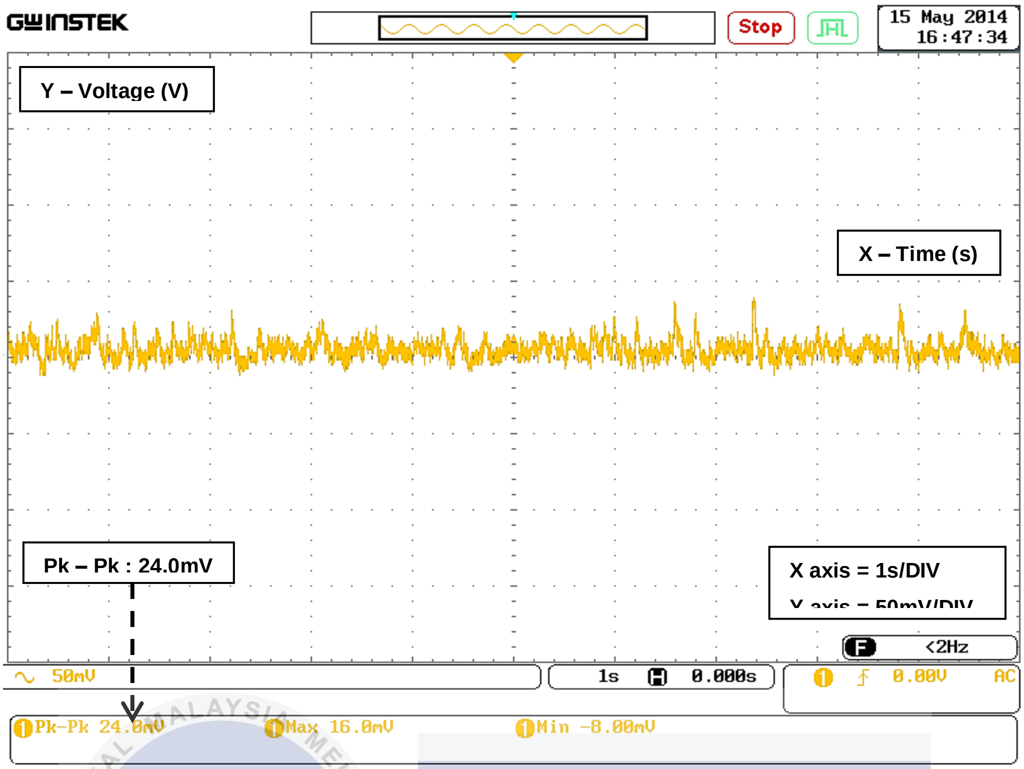


Figure 4.20 : The amplified of EMG signals for 20N hand grip force

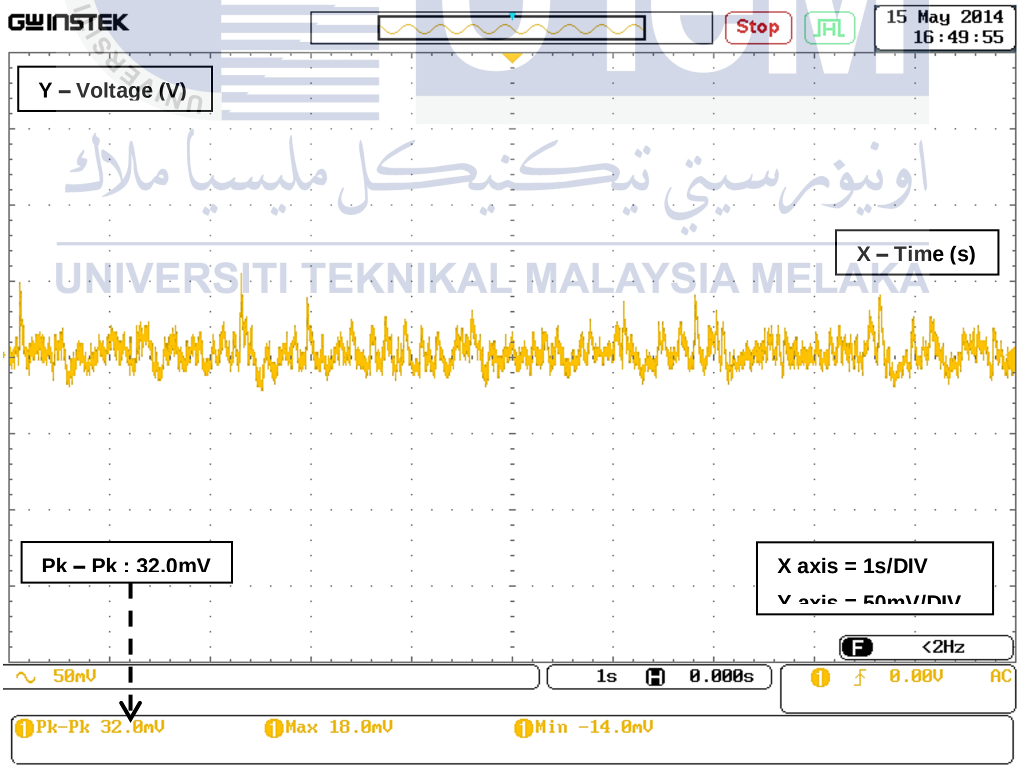


Figure 4.21 : The amplified of EMG signals for 120 degree at 60N

III. The results of EMG signals for wrist angle 120 degrees

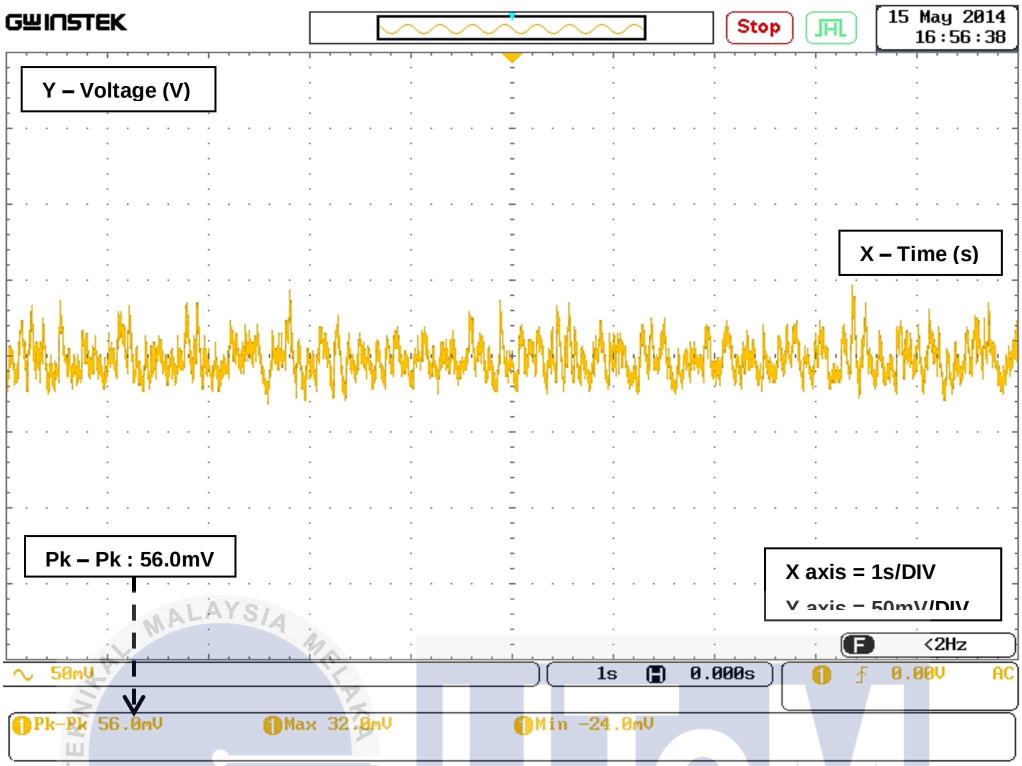


Figure 4.22 : The amplified of EMG signals for 60 degree at 20N

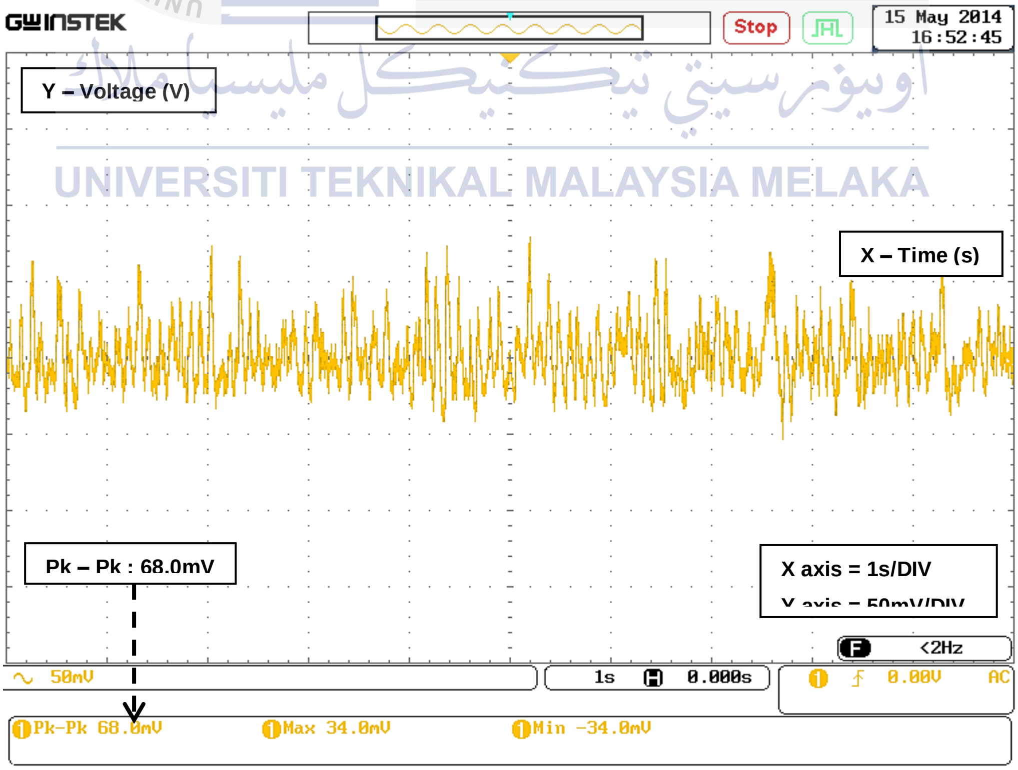


Figure 4.23 : The amplified of EMG signals for 60 degree at 40N

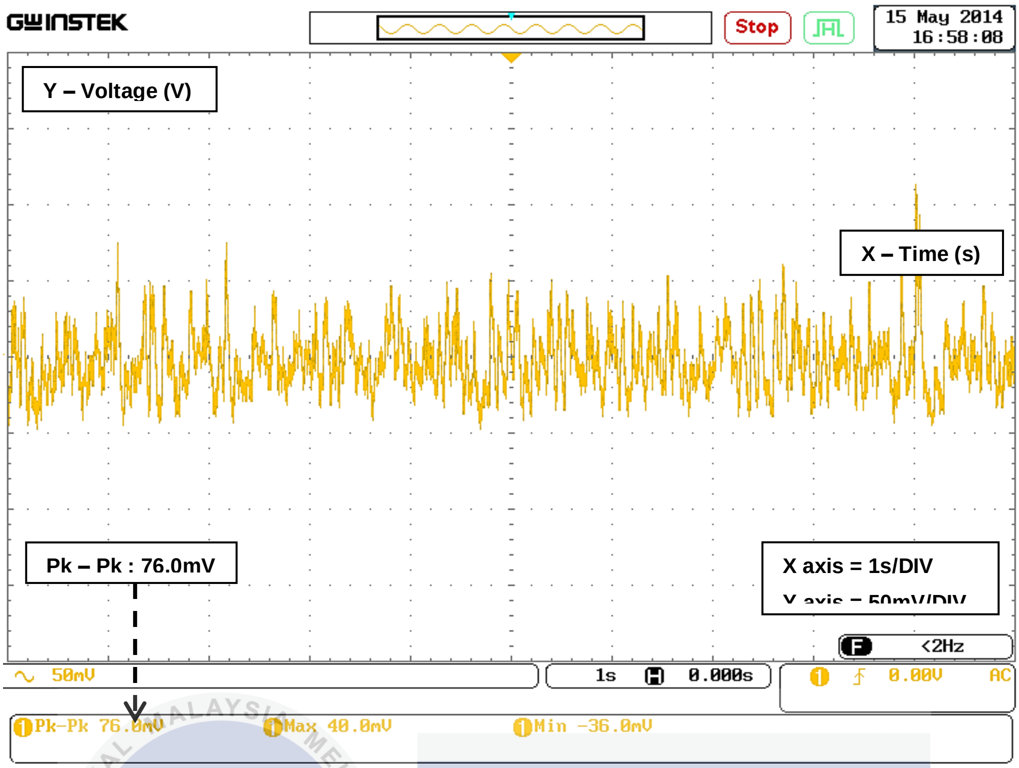


Figure 4.24 : The amplified of EMG signals for 60 degree at 60N

Other figures of measurement results are put in Appendices B.

4.4 ANALYSIS OF EXPERIMENTAL RESULTS

PART A : The measurement of EMG signals from FDS muscle based on 5 subject

The measurement result of impedance test for each subject is listed in Table 4.2 and the measurement result of EMG signal obtained from each subject is tabulated in Table 4.3. After that a graph of amplitude against force with different angle is plotted in Figure 4.25.

Table 4.2 : Measurement result of impedance test

SUBJECT	IMPEDANCE VALUE (KΩ)
#1	2.87
#2	6.32
#3	2.35
#4	20.55
#5	13.20

Table 4.3 : The measurement data of EMG signal from 5 subject

Wrist angle (º)	Hand grip force (N)	Amplitude, V_{P-P}				
		Subject #1	Subject #2	Subject #3	Subject #4	Subject #5
90	20	0.653	1.120	0.986	0.543	0.813
	40	1.000	1.232	1.400	0.675	0.973
	60	1.693	1.530	1.632	0.894	1.453
60	20	1.520	1.400	1.683	1.000	1.563
	40	1.920	2.012	2.217	1.363	1.786
	60	2.707	2.278	3.000	1.543	1.934
120	20	0.813	1.110	1.071	0.413	0.653
	40	0.973	1.240	1.150	0.487	1.000
	60	1.453	1.320	1.430	0.526	1.038

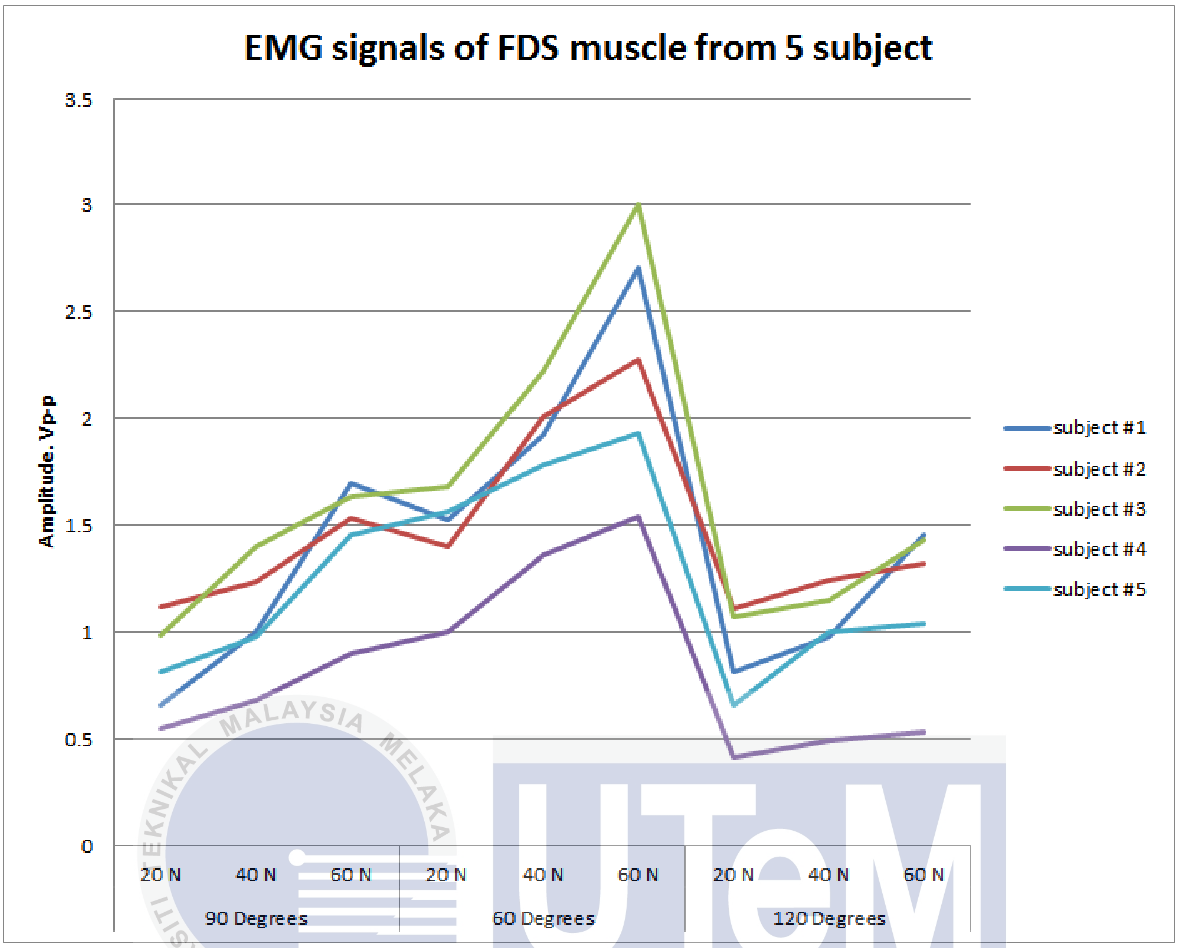


Figure 4.25 : comparison graph of EMG signal between 5 subject

According to graph above, these results suggest that the amplitude of the EMG signal for every wrist angle position (90, 60 and 120) measured from the FDS using both devices increases with increasing hand grip force beginning with 20N until 40N. It can be observed that when the position of the subject's hand wrist angle is changed from 90 degrees to 60 degrees, the subject's EMG from FDS muscles increase in amplitude. This shows that the FDS muscles are working to flex the wrist and maintain the position of the wrist at 60 degrees. When the position of the subject's hand is changed to 120 degrees, the amplitude of the EMG of FDS muscles is reduced. This shows that the FDS muscle is at rest during 120 degrees.

During the measurement of EMG from the muscle membrane up to the electrodes, the EMG signal can be influenced by several external factors altering its shape and characteristics. They can basically be grouped in:

1) Tissue characteristics

Basically, human body is a good electrical conductor, however the electrical conductivity is influenced by several factors and one of them is tissue type as shown in figure 4.26. Given the same amount of muscle electricity, normal condition produces more EMG magnitude due to smaller distance between muscle and electrodes. These conditions can greatly vary from subject to subject even within subject and prevent a direct comparison of EMG amplitude on the unprocessed EMG signal.

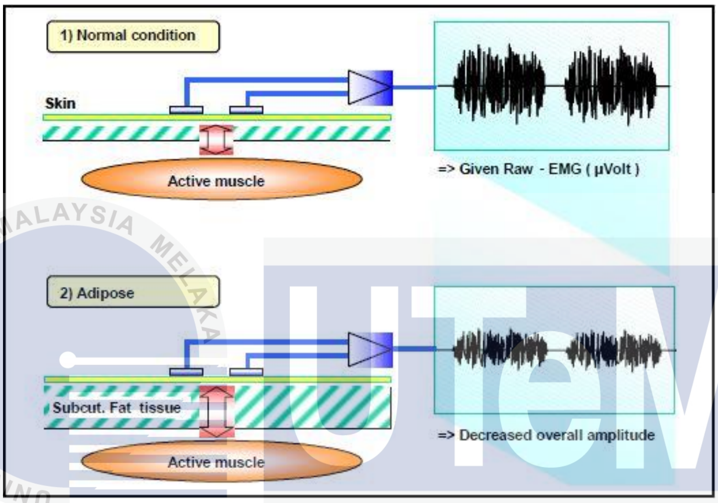


Figure 4.26 : The influence of varying thickness of tissue layers below the electrodes

2) Changes in the geometry between muscle belly and electrode site

Any change of distance between signal origin and detection site will alter the EMG reading. It is very important to locate the electrode pair in a central position over the muscle belly keeping in mind the possible muscle migration below the electrode site during joint movement. The reason is to avoid dislocation of the electrodes away from the active muscle mass. Another aspect is the shortening and lengthening of the skin itself. If single electrodes are used, enough inter-electrode distance (typically 1-2 cm) has to be selected to avoid the situation that the electrodes push themselves off.

3) External noise

Special care must be taken in very noisy electrical environments. An EMG amplifier can "catch" ground noise from the power net which results in increased baseline noise (50 to 60 Hz). The most demanding is the direct interference of power hum, typically produced by incorrect grounding of other external devices. Also try to change the power plug and always try to avoid multiple plug connectors and cable drums for the EMG amplifier.

As a conclusion from this analysis, the processed signal represented by graph in figure 4.25, it can be observed that the amplitude of EMG signals from the FDS muscles can be differentiated into three parts which are 90 degrees, 60 degrees and 120 degrees. This waveform pattern is similar for all the learning and verifying data collected at 20N, 40N and 60N of hand dynamometer. It is confirmed that it is tested for FDS muscle by a specific muscle function.

PART B : The comparison of measurement for EMG signals from FDS muscle based on 1 subject by using :

I. Muscle Sensor V3

II. Developed EMG amplification circuit

i. <u>Measurement results for muscle sensor V3</u>

The measurement result of amplified EMG signals obtained using muscle sensor V3 is shown in Table 4.4

Table 4.4 : The result of EMG signals obtained using muscle sensor V3

Wrist angle (^{o})	Hand grip force (N)	Amplitude (V_{P-P})	Average reading (V_{P-P})
90	20	0.011	0.012
		0.012	
		0.010	
	40	0.030	0.032
		0.034	
		0.032	
	60	0.042	0.042
		0.042	
		0.041	
120	20	0.011	0.012
		0.012	
		0.010	
	40	0.022	0.024
		0.020	
		0.021	
	60	0.030	0.032
		0.035	

		0.033	
60	**20**	**0.055**	**0.040**
		0.057	
		0.056	
	40	**0.066**	**0.056**
		0.067	
		0.069	
	60	**0.077**	**0.076**
		0.078	
		0.077	

ii. <u>Measurement results for developed EMG amplification circuit</u>

The measurement result of amplified EMG signals obtained using developed EMG amplification circuit is shown in Table 4.5

Table 4.5 : The result of EMG signals using the developed EMG amplification device

Wrist angle (^{o})	**Hand grip force (N)**	**Amplitude (V_{P-P})**	**Average reading (V_{P-P})**
90	**20**	**0.680**	**0.653**
		0.640	
		0.640	
	40	**1.000**	**1.000**
		0.960	
		1.040	
	60	**1.720**	**1.693**
		1.640	
		1.720	

120	20	0.800	0.813
		0.840	
		0.800	
	40	1.040	0.973
		0.960	
		0.920	
	60	1.600	1.453
		1.400	
		1.360	
60	20	1.120	1.187
		1.160	
		1.280	
	40	1.920	1.773
		1.600	
		1.800	
	60	2.560	2.707
		2.800	
		2.760	

iii. <u>Comparison of measurement result from both devices</u>

The comparison of the amplitude readings obtained using both devices are tabulated in Table 4.6. Then, a graph is constructed based on Table 4.6 to compare the result from both devices as shown in Figure 4.77

Table 4.6 : Comparison of the amplitude readings obtained using both devices.

Wrist angle (^{o})	**Hand grip force (N)**	**Muscle sensor V3**	**Designed EMG device**
90	**20**	**0.012**	**0.653**
	40	**0.032**	**1.000**
	60	**0.043**	**1.693**
120	**20**	**0.040**	**1.520**
	40	**0.056**	**1.920**
	60	**0.076**	**2.707**
60	**20**	**0.012**	**0.813**
	40	**0.024**	**0.973**
	60	**0.032**	**1.453**

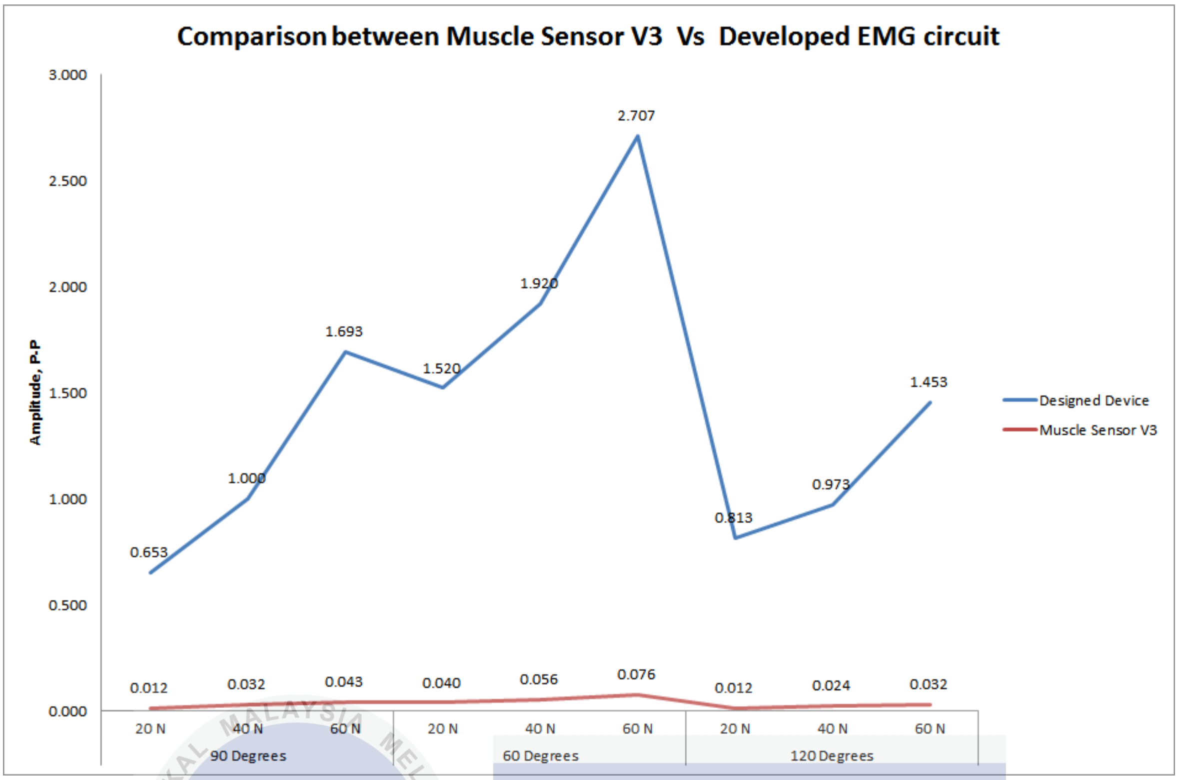


Figure 4.27 : Comparison of processed EMG signal obtained from muscle sensor v3 with developed EMG amplification circuit

Both of graphs in figure 4.27 showed that EMG signal for every wrist angle position (90, 60 and 120) measured from the FDS using both devices increases with increasing hand grip force beginning with 20N until 40N, but there are quite different in amplitude values. Among these two circuits, the developed EMG circuit board gave the higher output readings in term of its amplitude (peak to peak) compared to muscle sensor V3. This is because, the muscle sensor V3 amplified, rectified, and smoothed signal that will work well with a microcontroller’s analog-to-digital converter (ADC). Whereas, the developed EMG device doesn’t has the rectifier element. This difference can be explained by using a simple sine wave as an example, illustrated below.

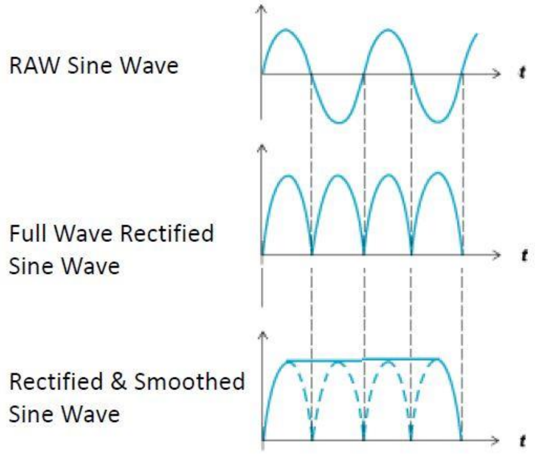


Figure 4.28 : Difference between 3 different waves

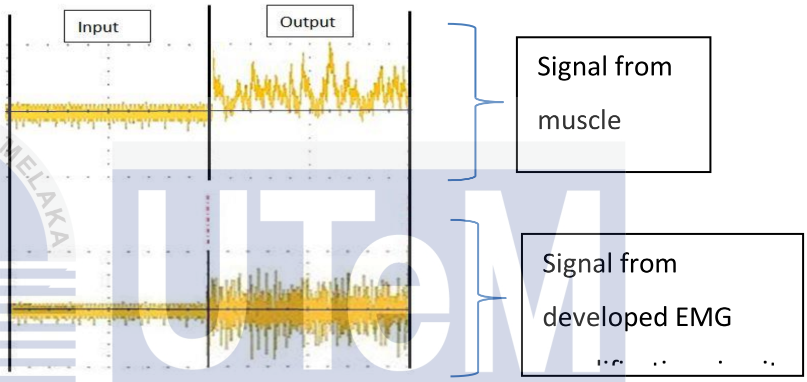


Figure 4.29 : Comparison of output signal obtained from both of devices

Therefore when the oscilloscope measured the peak to peak voltage of the rectified and smoothed sine wave, it will consider the summation of maximum point with the minimum point of signal as shown in figure. As the result, the voltage readings become lower compared to the signal that not been rectified as the output signals obtained from the developed EMG circuit board. The figure 4.29 showed clear captured the comparison of output signal processed by both devices. Another factor that is, the output ranges for both devices in between 0-Vs, Vs signifies the voltage of the power source which is ±5V. The voltages depending on the amount of activity in the selected muscle, where for muscle sensor V3 and ±9V for developed EMG device. Even with the correct biasing voltage level set, it is still possible for the output waveform to become distorted due to a large input signal being amplified by the circuits gain. The output voltage signal becomes clipped in both the positive and negative parts of the waveform and no longer resembles a sine wave. This type of amplitude distortion is called clipping and is the result of “over-driving” the input of the amplifier.

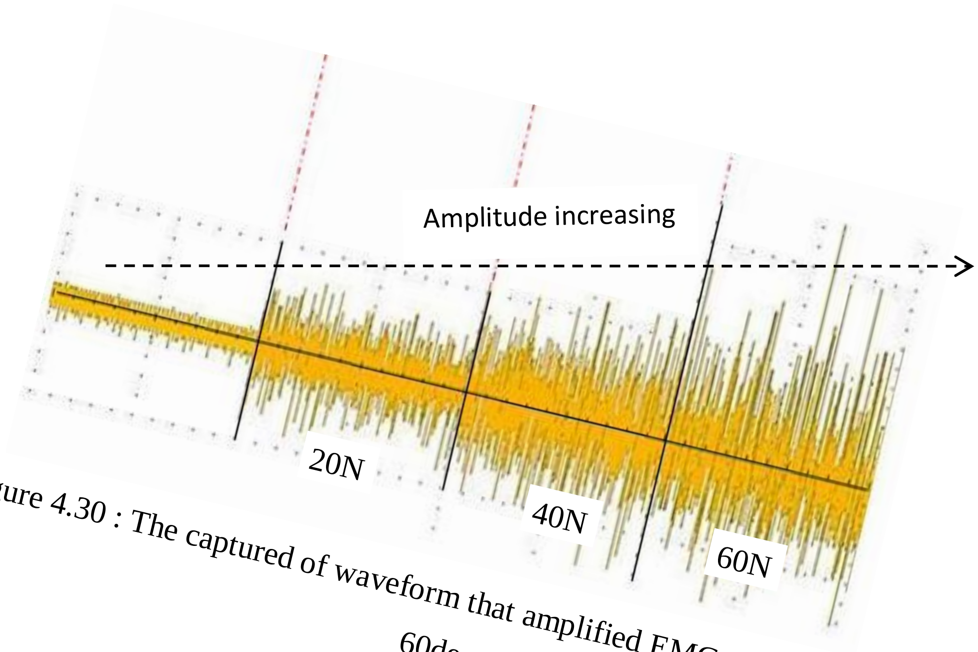


Figure 4.30 : The captured of waveform that amplified EMG signals at wrist angle 60degrees

As a conclusion from this analysis, even though the amplitude readings are different for both devices yet it still successfully amplified the EMG signals and it is confirmed that the EMG recording is revealed when the subject is activated the FDS muscle as illustrated in figure above. The amplitude of EMG signals from the FDS muscles is amplified completely into three hand grip forces which are 20N, 40N and 60N of hand dynamometer with wrist angle position, 90 degrees, 60 degrees and 120 degrees.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.0 INTRODUCTION

This chapter presented the conclusion throughout this project research in order to integrate the various issues covered in the research and to make comments upon the meaning of all of it. Besides, some recommendations are suggested for future work and improvement of this project research.

5.1 CONCLUSION

Overall, this research consists of 3 objectives that must be fulfilled. The first objective covers the design and simulation of the EMG amplification circuit. The circuit design consist of instrumentation amplifier, high pass filter, low pass filter, and inverting amplifier. The design of schematic diagram and simulation is develop by using Multisim 12.0 software. The second objective relates about the construction of EMG circuit designed. Starting with building of the prototype for designed circuit using breadboard and eventually translate into Printed Circuit Board (PCB). Finally, the third objective is to validate the designed and constructed EMG amplification circuit through extraction of

EMG signal from FDS muscle. The EMG signals from the FDS muscle was measured during hand grip strength at various forces with different wrist angles. These signals are taken from silver chloride pre-gelled electrodes. Increasing hand grip force resulted in increase in amplitude of the recorded EMG signal.

As a conclusion the entire objectives of this research are successfully achieved. The EMG amplification circuit is designed completely and its input signal that represent as virtual EMG signal is amplified well through simulation in Multisim. The INA128 performs well as a preamplifier as well as the inverting amplifier and Sallen Key pass filter gives optimum performance. This information can be useful for further development to establish the relationship between EMG from FDS and hand grip strength.

5.2 RECOMENDATION

Even though our system design has been completed and tested with a one input channel prototype module, there are some things that still needed to be completed with the existing system:

- Obtain more than one input channel to measure more types of muscle in same time
- Passing the output of this EMG circuit through a rectifier and smoothing low pass filter circuit creates an envelope of the signal.
- Provide galvanic isolation along the signal path so that the ground of the EMG circuit and the ground of the oscilloscope are separated.

With these recommendations completed, and research testing underway, a new wave of recommendations and system improvements would become known.

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APPENDIX A

GANTT CHART FYP 1

Project Plan															
Activity / **Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Meeting with Supervisor to Determine Project Title															
Appointment with supervisor for proposal of PSM project title															
Writing personal data in the Log Book															
Looking sources related to the title and do the literature review															
Discussion project progress with the supervisor															
Study about the software will be use and find the suitable hardware															
Discussion and writing for chapter 2															
Discussion and writing for chapter 3															
Proposal for PSM 1 seminar paper															
Preparation for Seminar 1															
Presentation of PSM 1 (PSM 1 Seminar)															
Seminar feedback, log book update and improvement and PSM 1 final report															
Log book submission and PSM 1 final report															

APPENDIX A

GANTT CHART FYP 2

Project Plan

Activity \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
imulate electronic circuit	■	■	■												
ssamble electronic circuit	■	■	■	■	■	■	■	■							
esign machanical prototype		■	■	■	■	■	■	■	■						
evelope machanical prototype		■	■	■	■	■	■	■	■						
rite program for pic					■	■	■	■	■	■	■				
iscussion project progress with the supervisor		■	■	■	■	■	■	■	■	■	■	■	■	■	■
ompile the programming section						■	■	■	■						
nsert programming into hardware						■	■	■	■						
esting and troubleshooting the programming and ardware				■	■	■	■	■	■						
iscussion and writing for chapter 4								■	■						
iscussion and writing for chapter 5									■	■					
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riting the Project Proceeding Paper										■	■	■	■		
reparation for Seminar 2											■	■	■		
resentation of PSM 2 (PSM 2 Seminar)														■	
eminar feedback, log book update and mprovement and PSM 2 final report															■
og book submission and PSM 2 final report															■

APPENDIX B

BURR-BROWN®

OPA2604

www.burr-brown.com/databook/OPA2604.html

Dual FET-Input, Low Distortion OPERATIONAL AMPLIFIER

FEATURES

- LOW DISTORTION: 0.0003% at 1kHz
- LOW NOISE: $10nV/\sqrt{Hz}$
- HIGH SLEW RATE: 25V/μs
- WIDE GAIN-BANDWIDTH: 20MHz
- UNITY-GAIN STABLE
- WIDE SUPPLY RANGE: $V_S = \pm4.5$ to $\pm24V$
- DRIVES 600Ω LOADS

APPLICATIONS

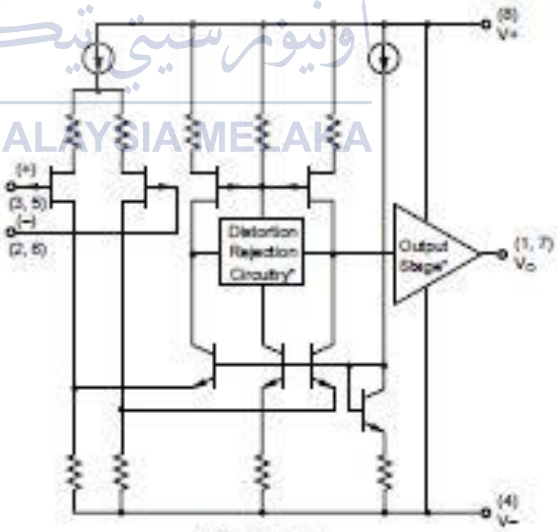
- PROFESSIONAL AUDIO EQUIPMENT
- PCM DAC I/V CONVERTER
- SPECTRAL ANALYSIS EQUIPMENT
- ACTIVE FILTERS
- TRANSDUCER AMPLIFIER
- DATA ACQUISITION

DESCRIPTION

The OPA2604 is a dual, FET-input operational amplifier designed for enhanced AC performance. Very low distortion, low noise and wide bandwidth provide superior performance in high quality audio and other applications requiring excellent dynamic performance.

New circuit techniques and special laser trimming of dynamic circuit performance yield very low harmonic distortion. The result is an op amp with exceptional sound quality. The low-noise FET input of the OPA2604 provides wide dynamic range, even with high source impedance. Offset voltage is laser-trimmed to minimize the need for interstage coupling capacitors.

The OPA2604 is available in 8-pin plastic mini-DIP and SO-8 surface-mount packages, specified for the –25°C to +85°C temperature range.



* Patents Granted:
#5053718, 5019789

International Airport Industrial Park • Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111 • Twx: 910-952-1111
Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

APPENDIX B

ANALOG DEVICES

Low Cost Low Power Instrumentation Amplifier

AD620

FEATURES

Easy to use
- Gain set with one external resistor
  - (Gain range 1 to 10,000)
- Wide power supply range (±2.3 V to ±18 V)
- Higher performance than 3 op amp IA designs
- Available in 8-lead DIP and SOIC packaging
- Low power, 1.3 mA max supply current

Excellent dc performance (B grade)
- 50 μV max, input offset voltage
- 0.6 μV/°C max, input offset drift
- 1.0 nA max, input bias current
- 100 dB min common-mode rejection ratio (G = 10)

Low noise
- 9 nV/√Hz @ 1 kHz, input voltage noise
- 0.28 μV p-p noise (0.1 Hz to 10 Hz)

Excellent ac specifications
- 120 kHz bandwidth (G = 100)
- 15 μs settling time to 0.01%

APPLICATIONS

Weigh scales
ECG and medical instrumentation
Transducer interface
Data acquisition systems
Industrial process controls
Battery-powered and portable equipment

Table 1. Next Generation Upgrades for AD620

Part	Comment
AD8221	Better specs at lower price
AD8222	Dual channel or differential out
AD8226	Low power, wide input range
AD8220	JFET input
AD8228	Best gain accuracy
AD8295	+2 precision op amps or differential out
AD8429	Ultra low noise

CONNECTION DIAGRAM

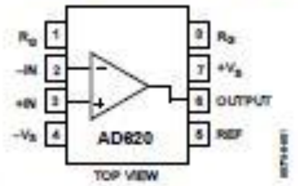


Figure 1. 8-Lead PDIP (N), CERDIP (Q), and SOIC (R) Packages

PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 10,000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs and offers lower power (only 1.3 mA max supply current), making it a good fit for battery-powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 μV max, and offset drift of 0.6 μV/°C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications, such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Superбeta processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/√Hz at 1 kHz, 0.28 μV p-p in the 0.1 Hz to 10 Hz band, and 0.1 pA/√Hz input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 μs to 0.01%, and its cost is low enough to enable designs with one in-amp per channel.

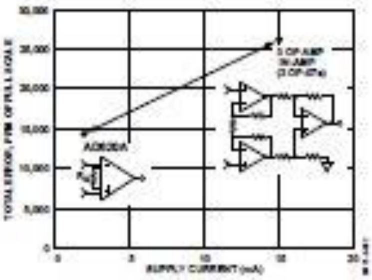


Figure 2. Three Op Amp IA Designs vs. AD620

Rev. H

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.326.8703

APPENDIX B

Muscle Sensor v3 **Advancer Technologies** Advancing the Future

Three-lead Differential Muscle/Electromyography Sensor for Microcontroller Applications

FEATURES

- Small Form Factor (1inch X 1inch)
- Specially Designed For Microcontrollers
- Adjustable Gain – Improved Ruggedness
- New On-board 3.5mm Cable Port
- Pins Fit Easily on Standard Breadboards

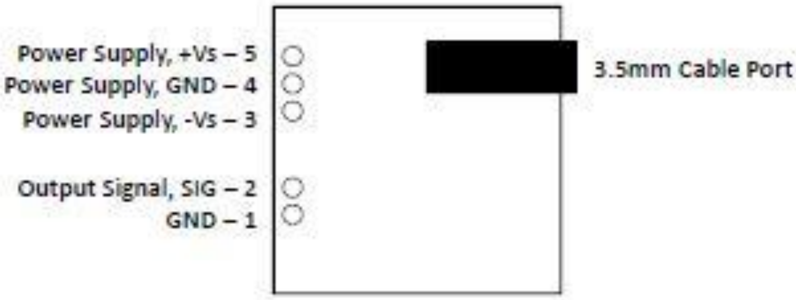
APPLICATIONS

- Video games
- Robots
- Medical Devices
- Wearable/Mobile Electronics
- Powered Exoskeleton suits

What is electromyography?

Measuring muscle activation via electric potential, referred to as electromyography (EMG), has traditionally been used for medical research and diagnosis of neuromuscular disorders. However, with the advent of ever shrinking yet more powerful microcontrollers and integrated circuits, EMG circuits and sensors have found their way into prosthetics, robotics and other control systems.

PIN LAYOUT



APPENDIX B

II. LABQUEST 2 HARDWARE

Once LabQuest is connected to AC power or the battery has been charged, press the power button located on the top of the unit, near the left edge. LabQuest will complete its booting procedure and automatically launch the LabQuest App by default, as shown above. If the screen does not light after a moment when used on battery power, connect the power adapter to LabQuest and to an AC power source, then try the power button again.

Power Button

- **Power on** – If the screen is off for any reason (LabQuest is off, asleep, or the screen has turned off to conserve battery power), press and release the power button to turn LabQuest back on. If LabQuest was off, LabQuest will also complete its booting procedure that takes about a minute and then display LabQuest App.

- **Sleep/wake** – When LabQuest is on, press and release the power button once to put LabQuest into a sleep mode. Note that the sleep mode does not start until you release the power button. In this mode, LabQuest uses less power but the battery can still drain. This mode is useful if you are going to return to data collection again soon, in which case waking LabQuest from sleep is quicker than restarting after shutdown. To wake LabQuest from sleep, press and release the power button.

- **Shut down** – To shut down LabQuest, hold the power button down for about five seconds. LabQuest displays a message indicating it is shutting down. Release the power button, and allow LabQuest to shut down. To cancel the shutdown procedure at this point, tap Cancel. You can also shut down LabQuest from the Home screen. To do this, tap System and then tap Shut Down.

- **Emergency shutdown** – If you hold the power button down for about eight seconds, LabQuest powers off uncleanly. This is the same as pulling the battery out of the unit while it is running. This is not recommended unless LabQuest is frozen, as you may lose your data and potentially cause file system corruption.

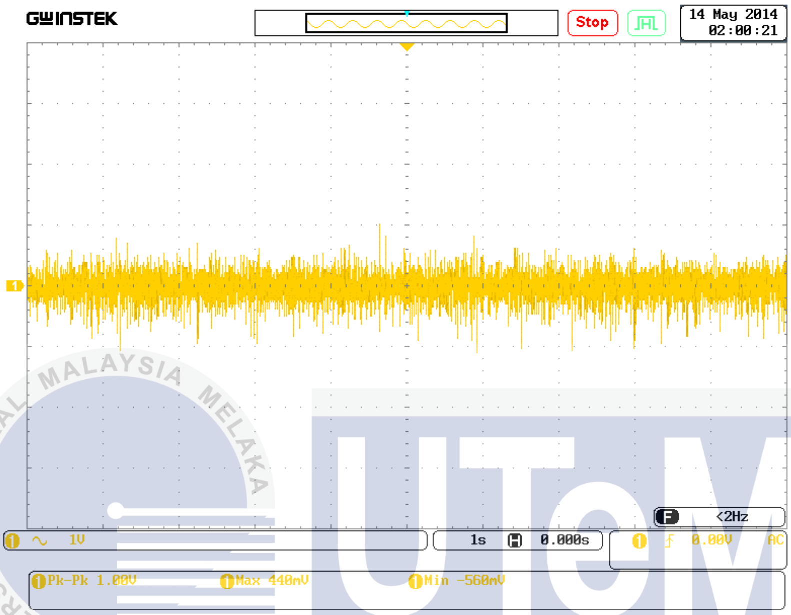
APPENDIX C

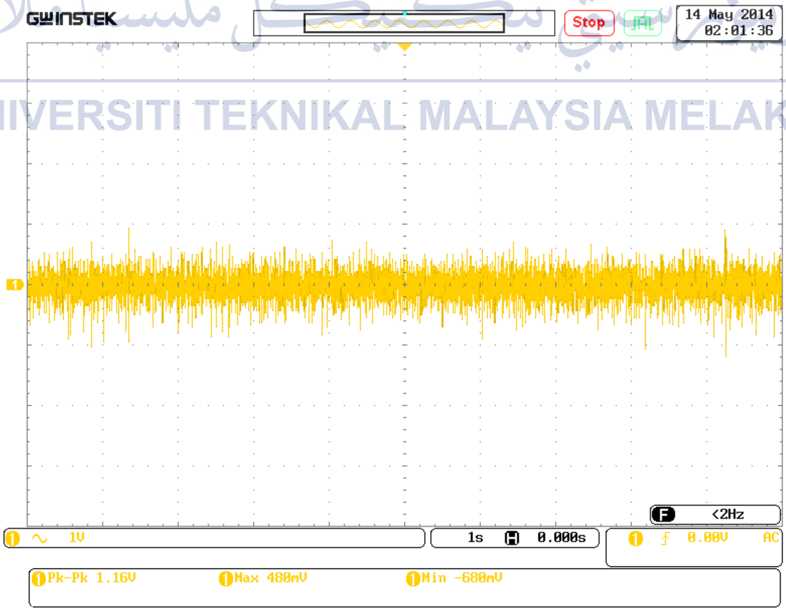
Figures of captured waveform using digital osilloscope

SUBJECT : 2

Wrist anlgle : 60 degrees

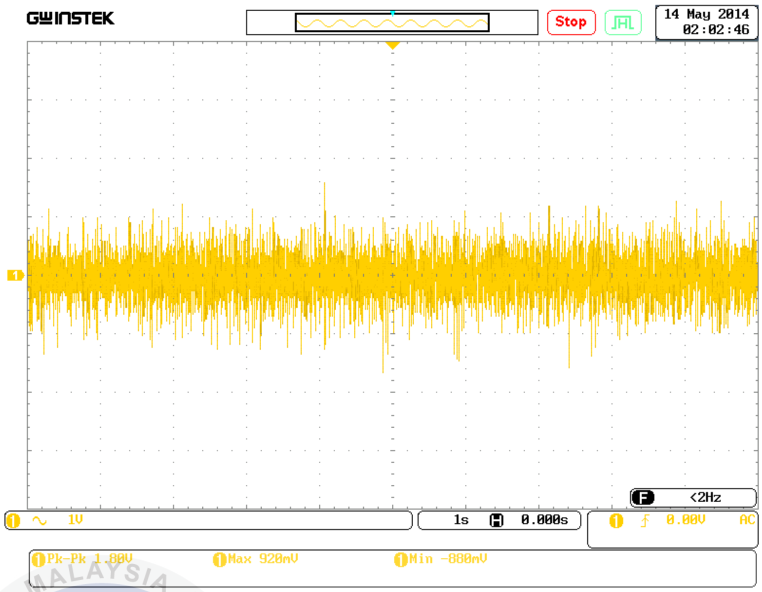
Hand grip force ; 20N

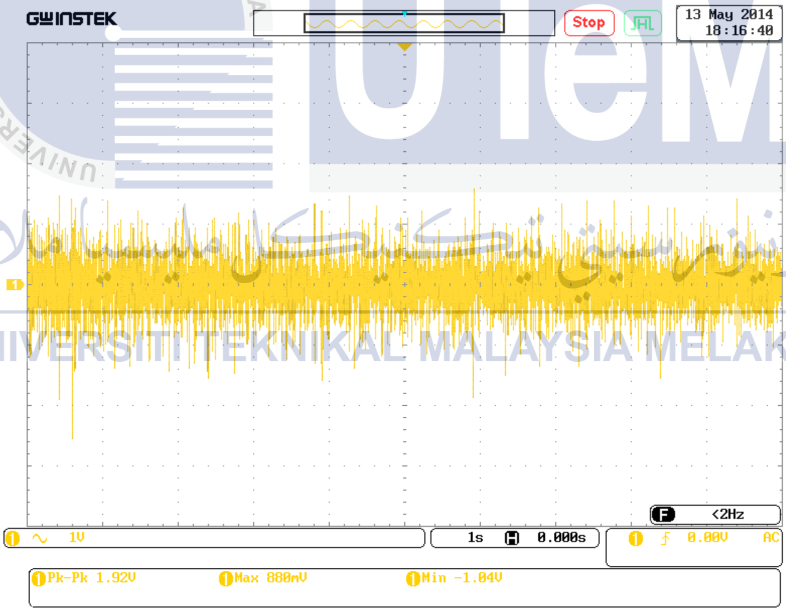




Wrist anlgle : 60 degrees

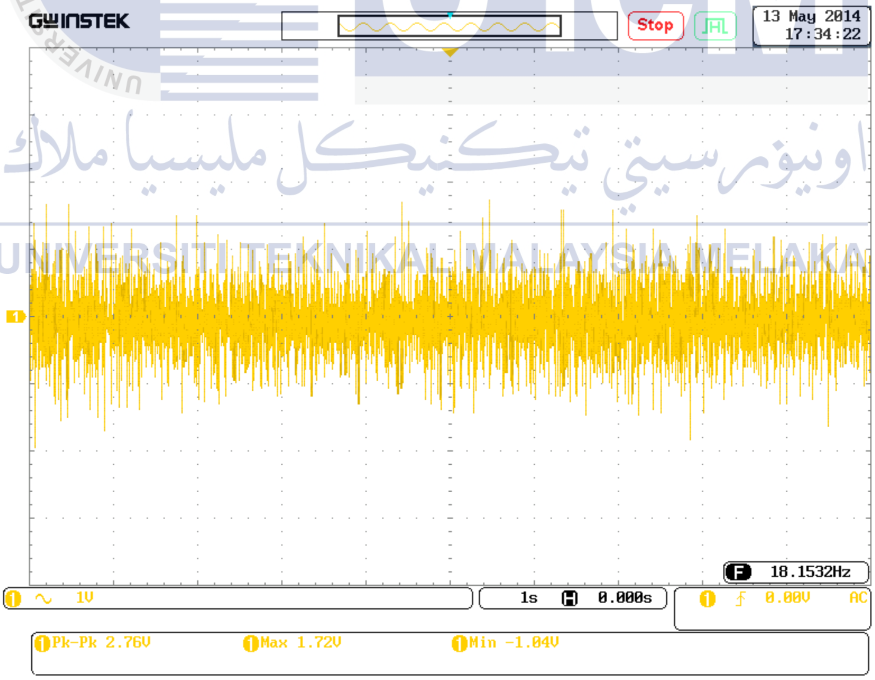
Hand grip force ; 40N





Wrist anlgle : 60 degrees

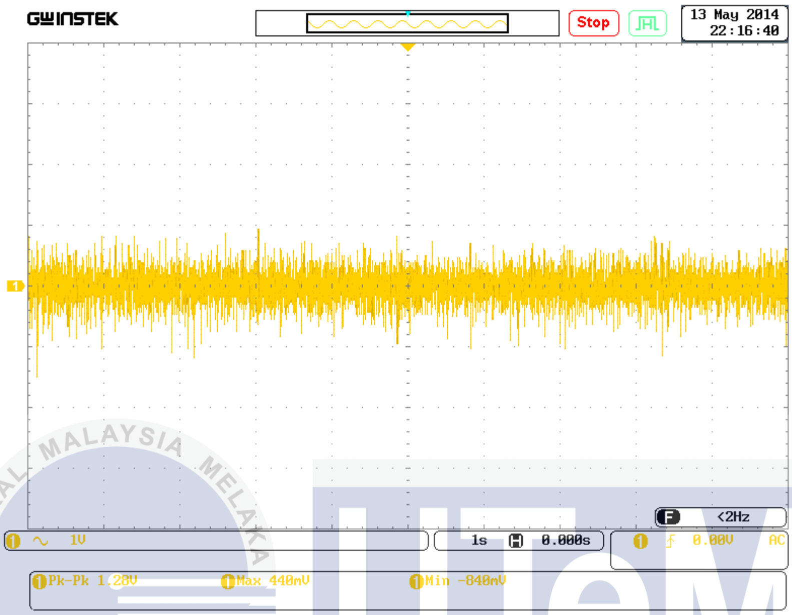
Hand grip force ; 60N

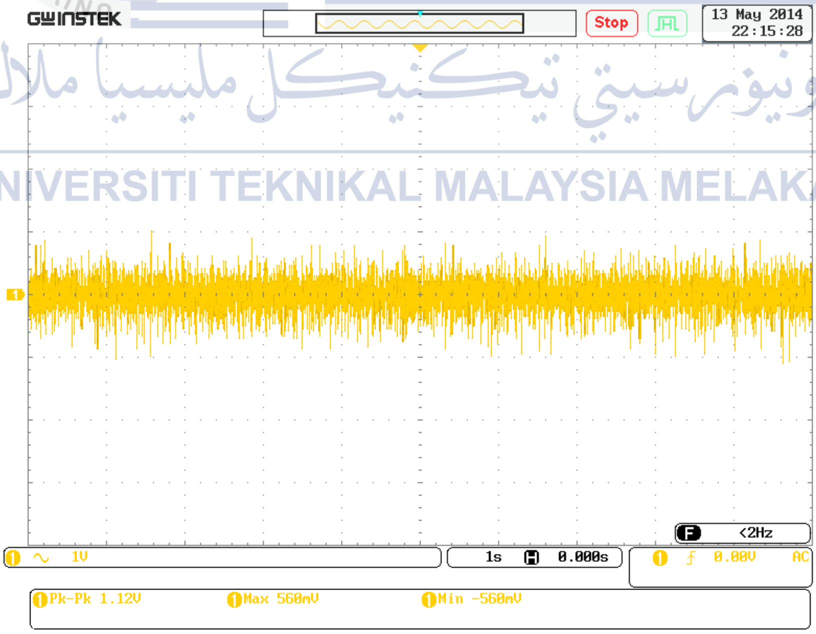


Subject : 3

Wrist anlgle : 60 degrees

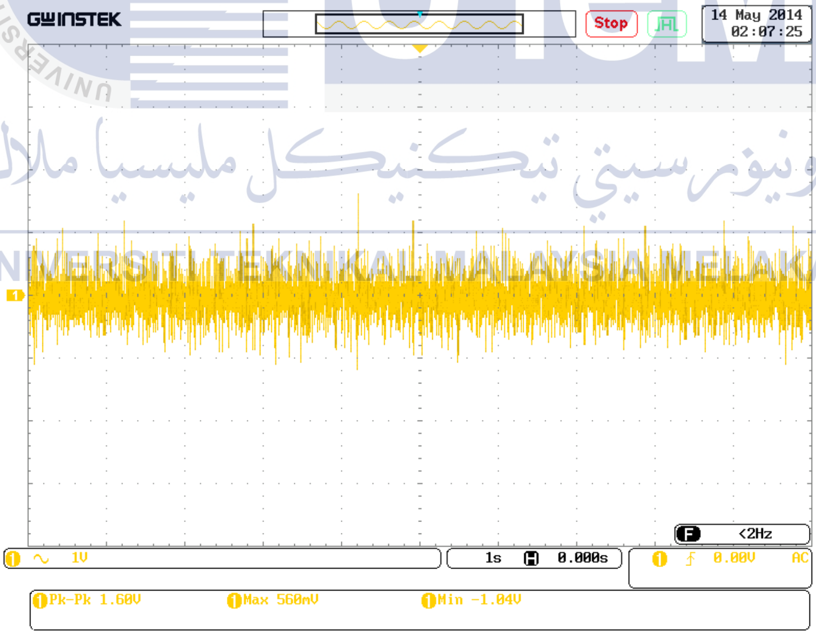
Hand grip force ; 20N





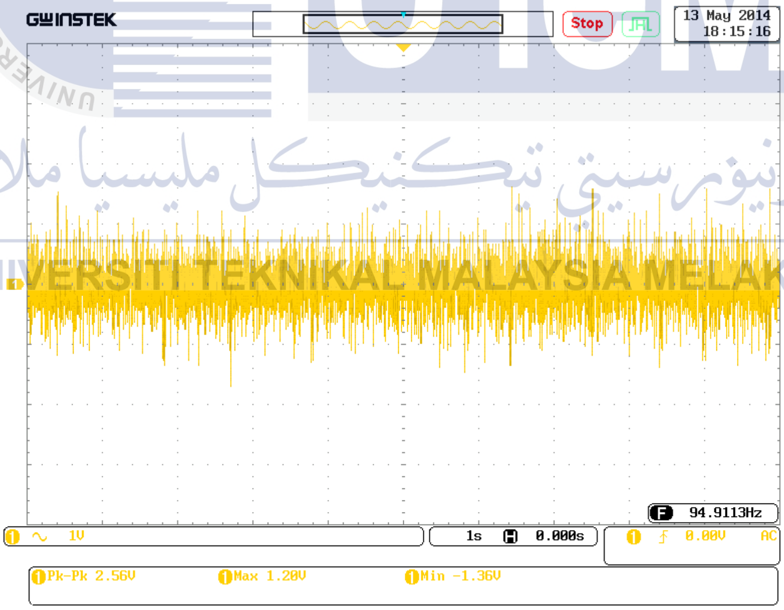
Wrist anlgle : 60 degrees

Hand grip force ; 40N



Wrist anlgle : 60 degrees

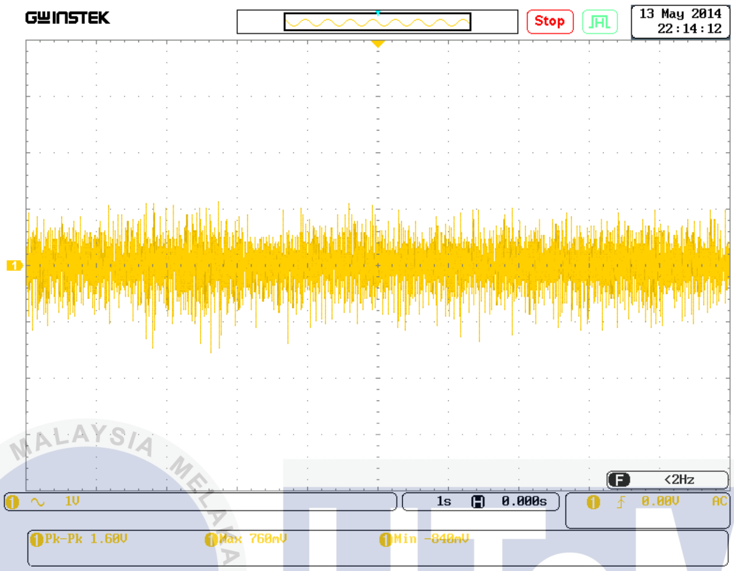
Hand grip force ; 60N

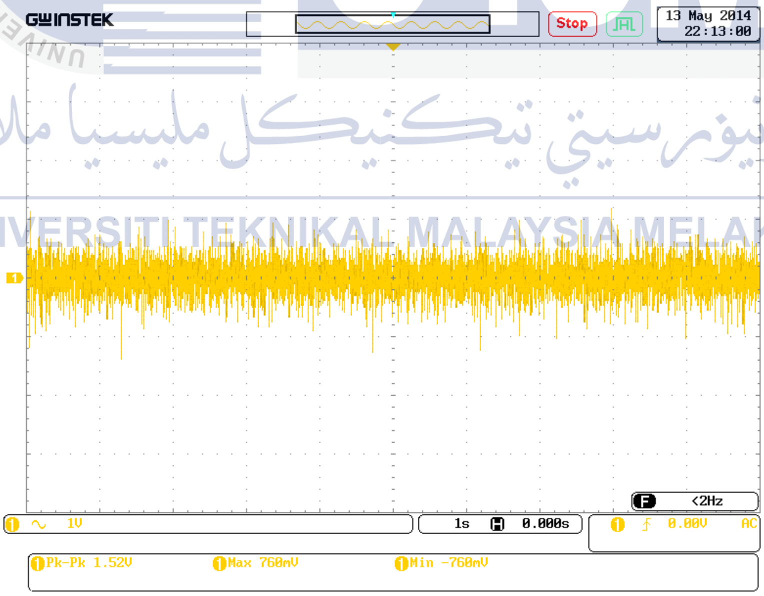


Subject : 4

Wrist anlgle : 60 degrees

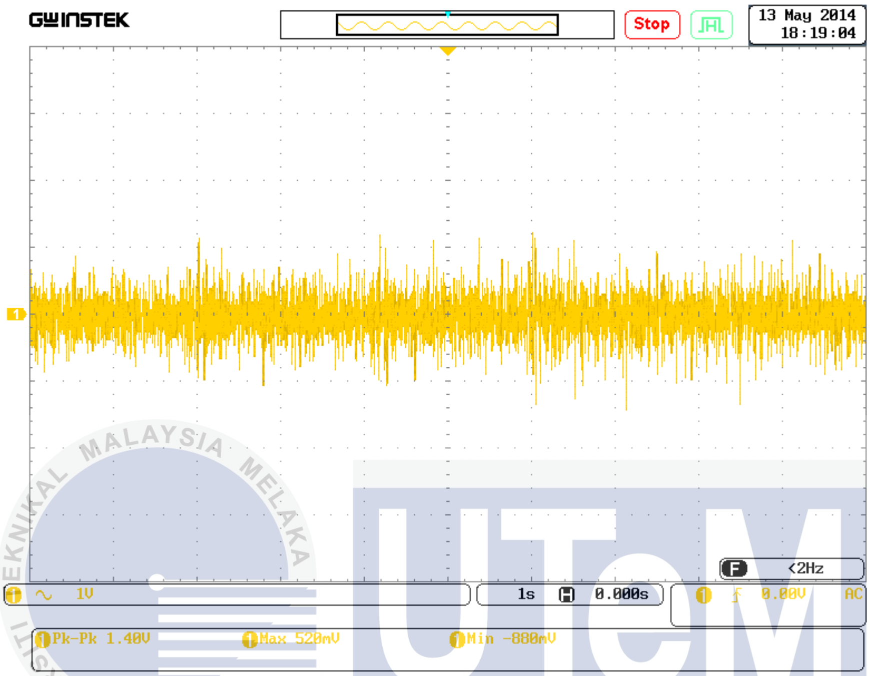
Hand grip force ; 20N

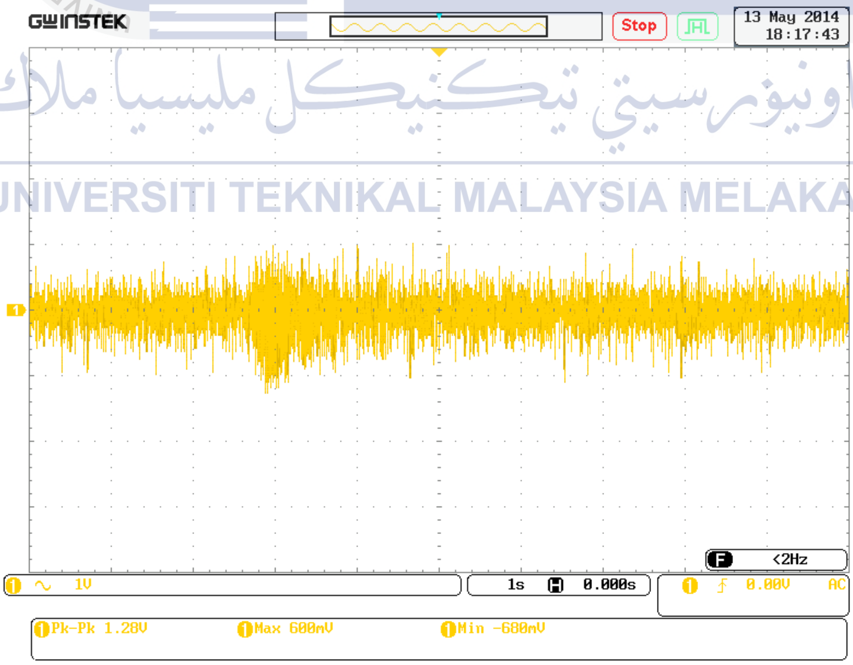




Wrist anlgle : 60 degrees

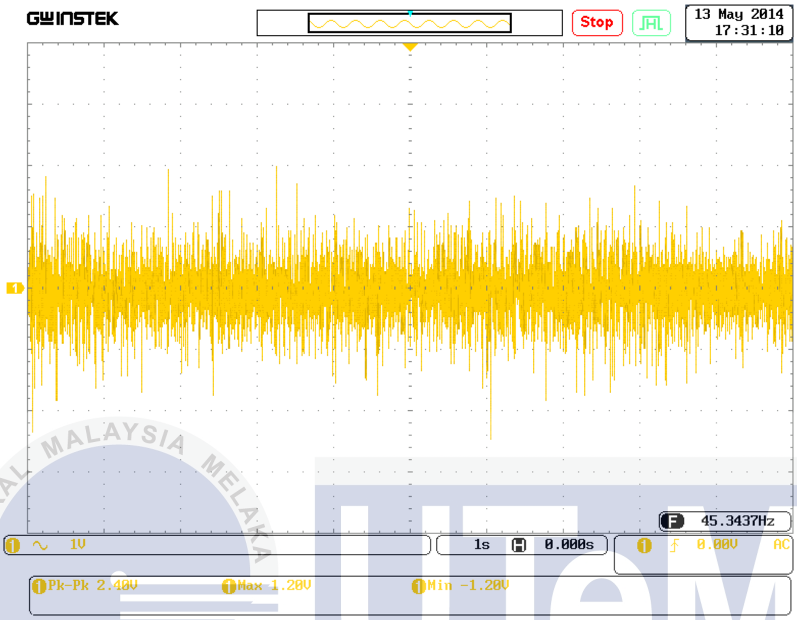
Hand grip force ; 40N

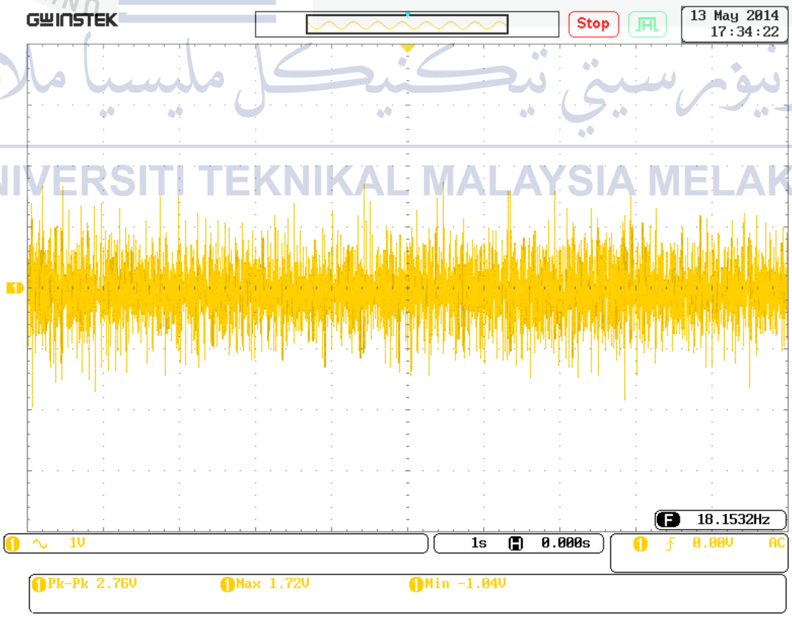




Wrist anlgle : 60 degrees

Hand grip force ; 60N

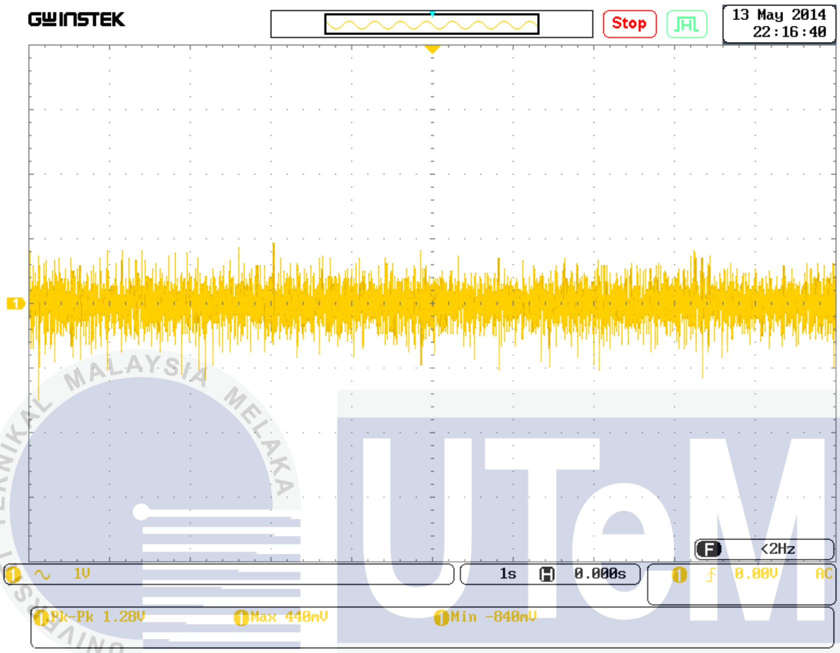


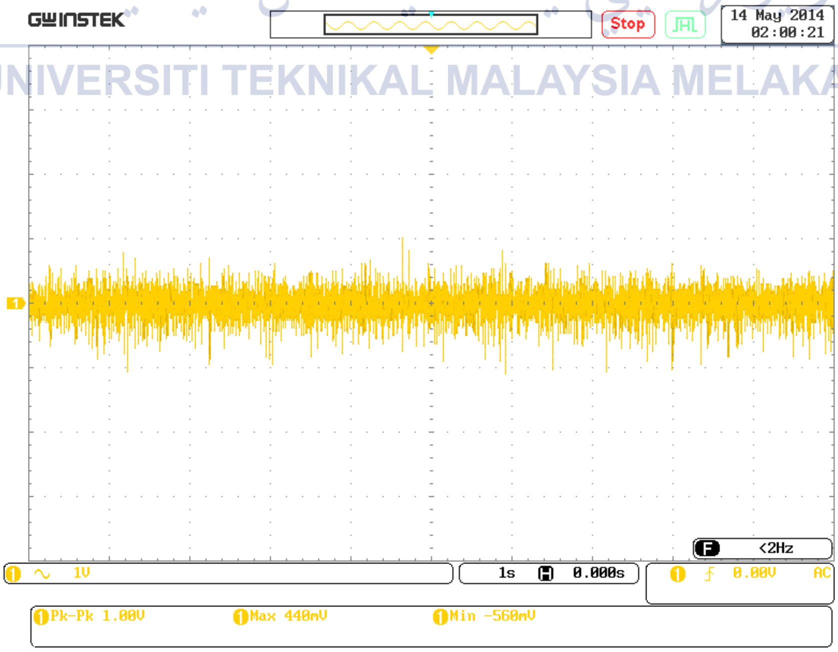


Subject : 5

Wrist anlgle : 60 degrees

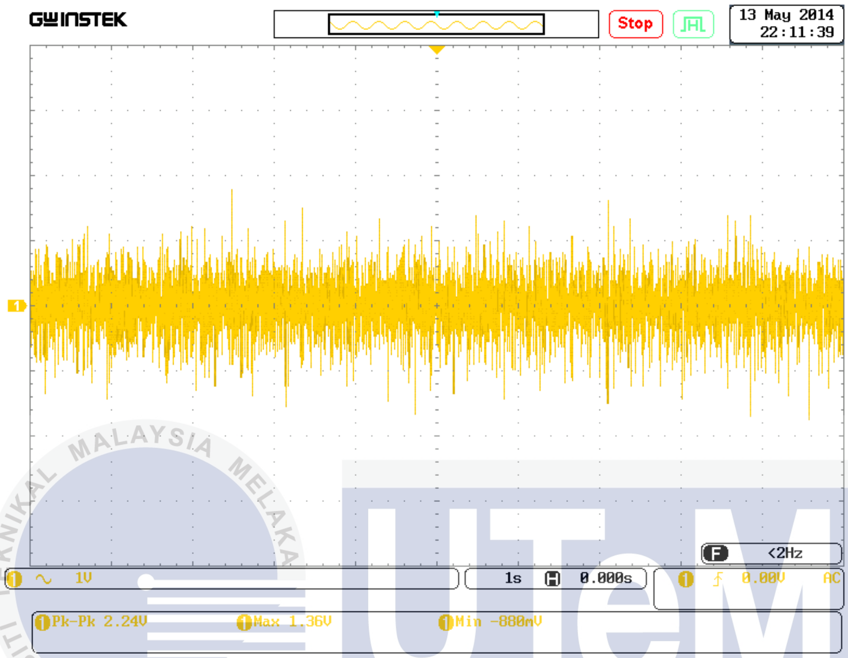
Hand grip force ; 20N

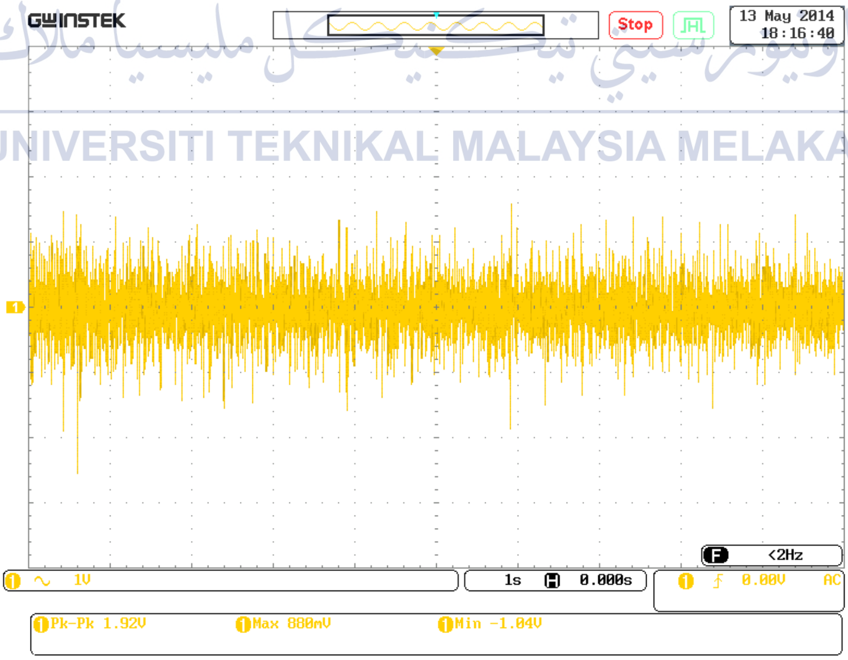




Wrist anlgle : 60 degrees

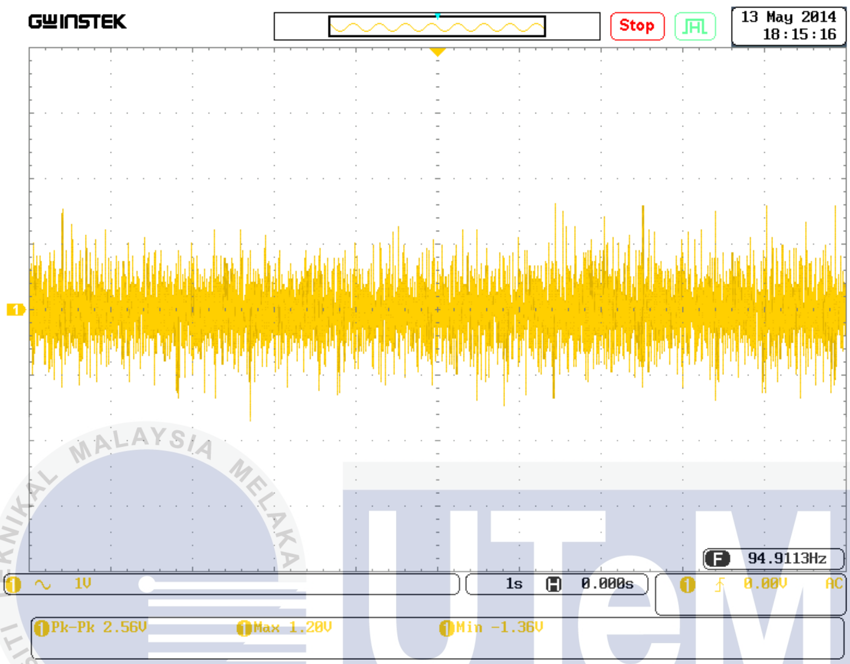
Hand grip force ; 40N

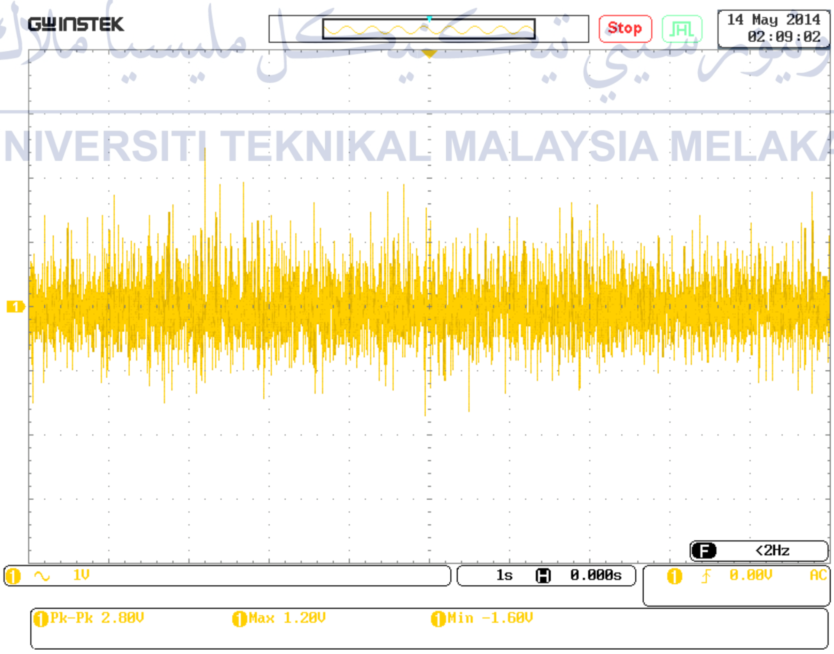




Wrist anlgle : 60 degrees

Hand grip force ; 60N





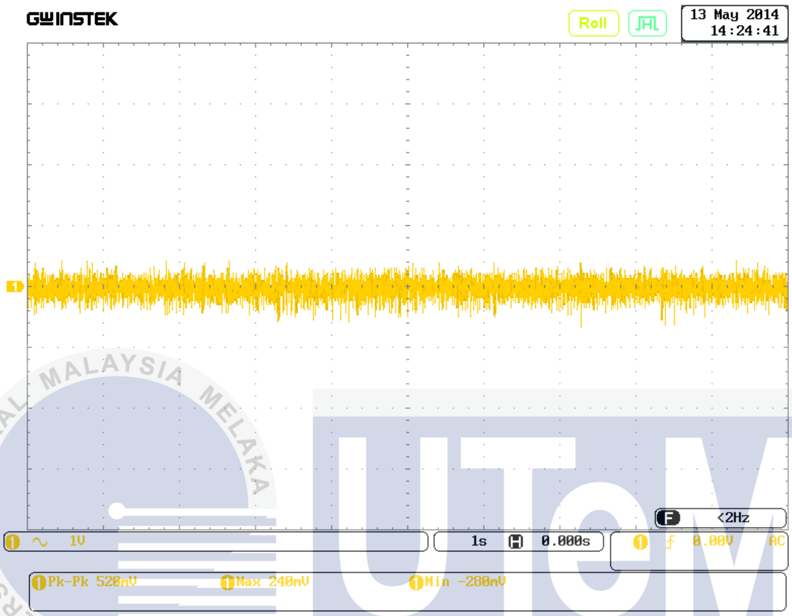
APPENDIX C

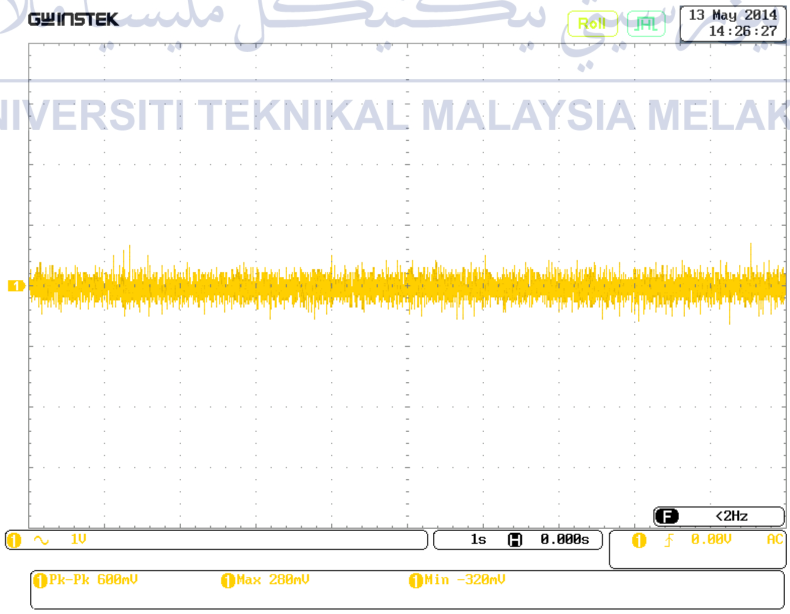
Figures of captured waveform using digital osilloscope

SUBJECT : 2

Wrist anlgle : 90 degrees

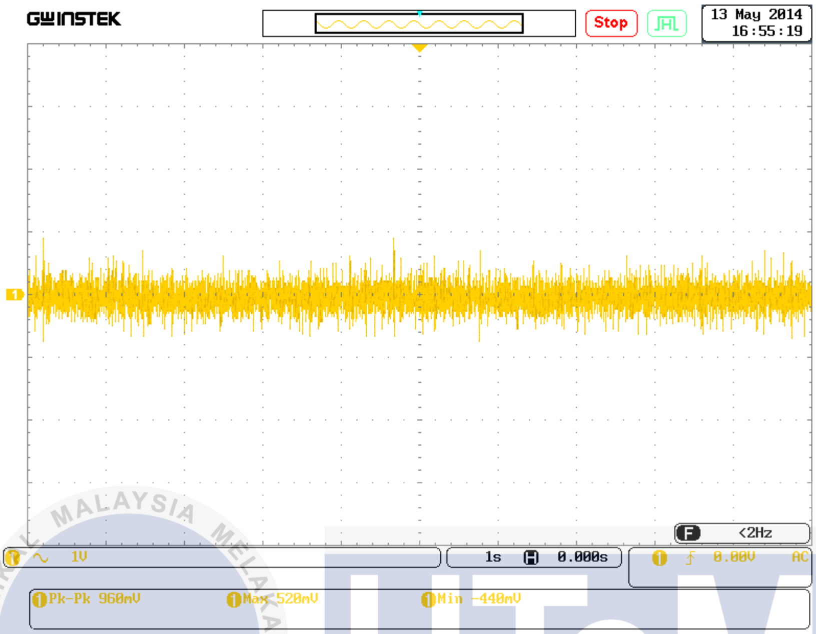
Hand grip force ; 20N

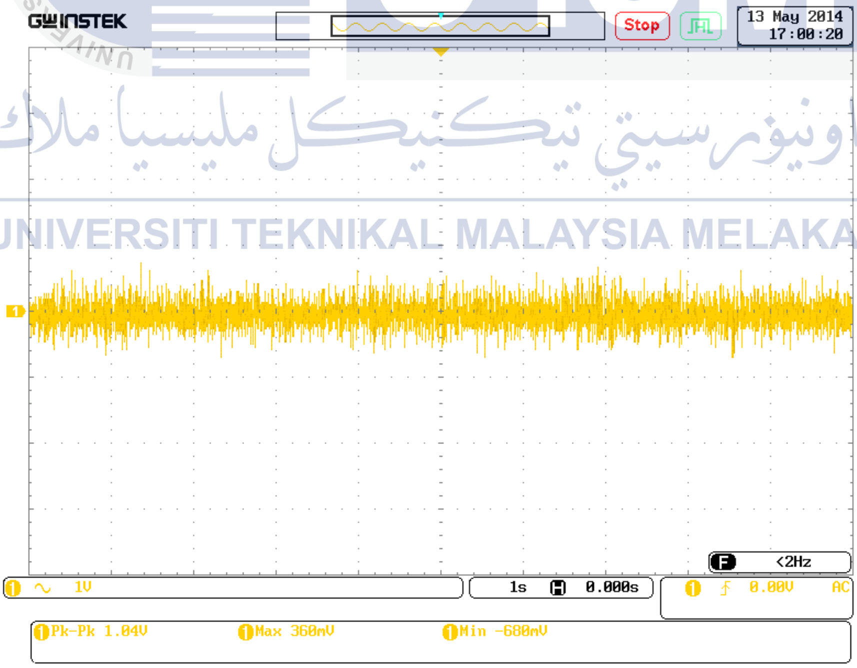




Wrist anlgle : 90 degrees

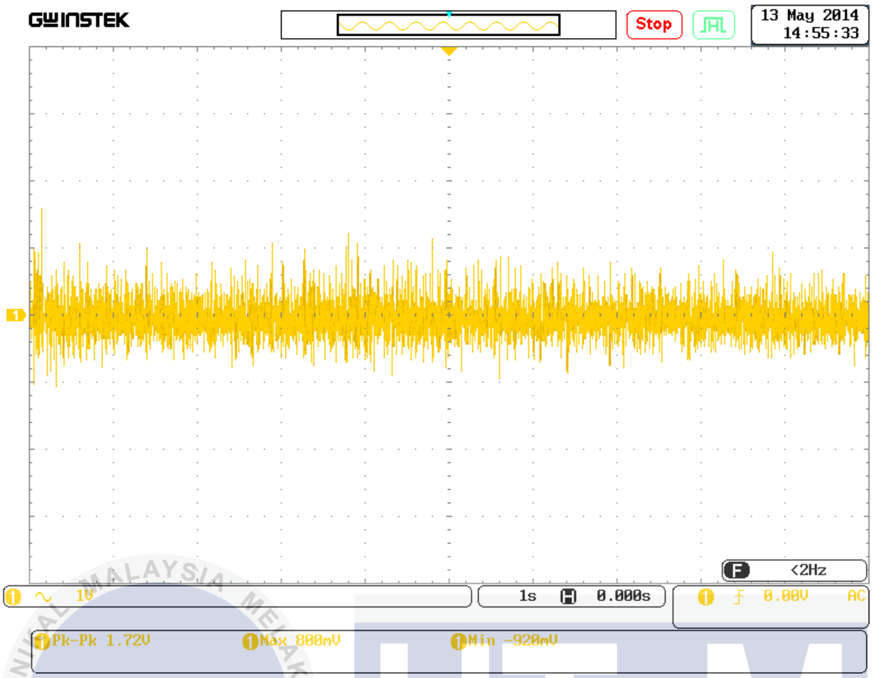
Hand grip force ; 40N

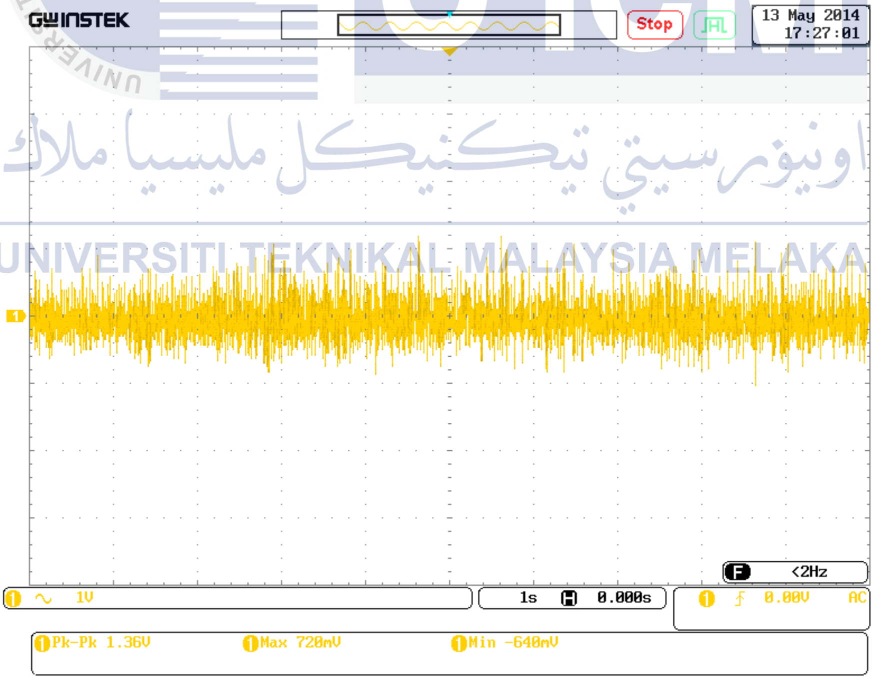




Wrist anlgle : 90 degrees

Hand grip force ; 60N

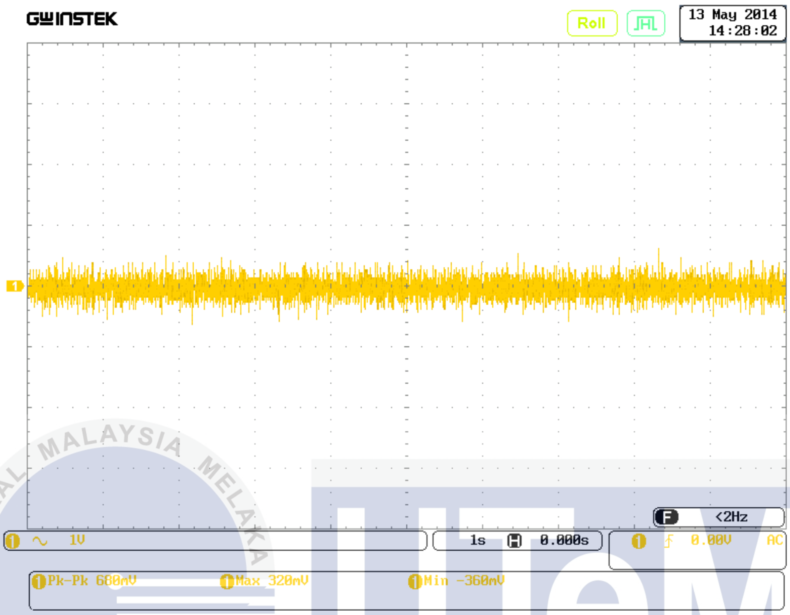


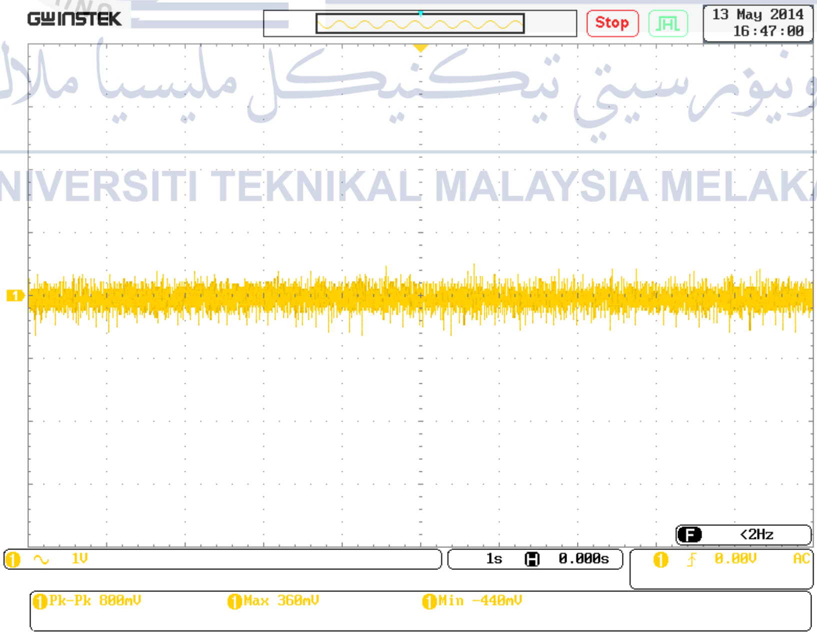


Subject : 3

Wrist anlgle : 90 degrees

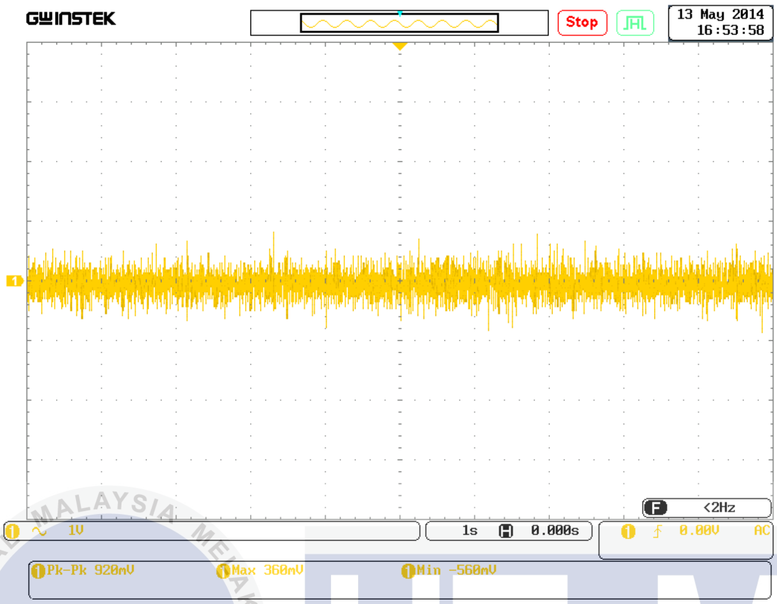
Hand grip force ; 20N





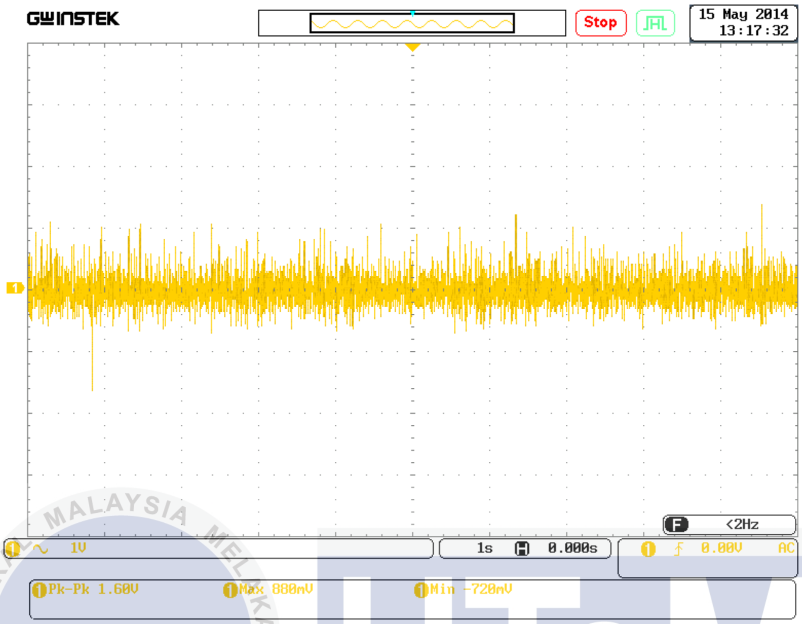
Wrist anlgle : 90 degrees

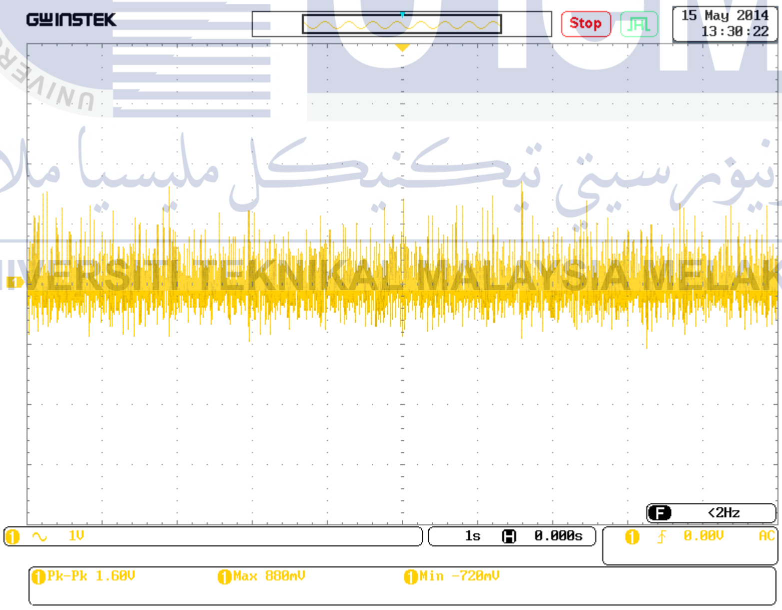
Hand grip force ; 40N



Wrist anlgle : 90 degrees

Hand grip force ; 60N

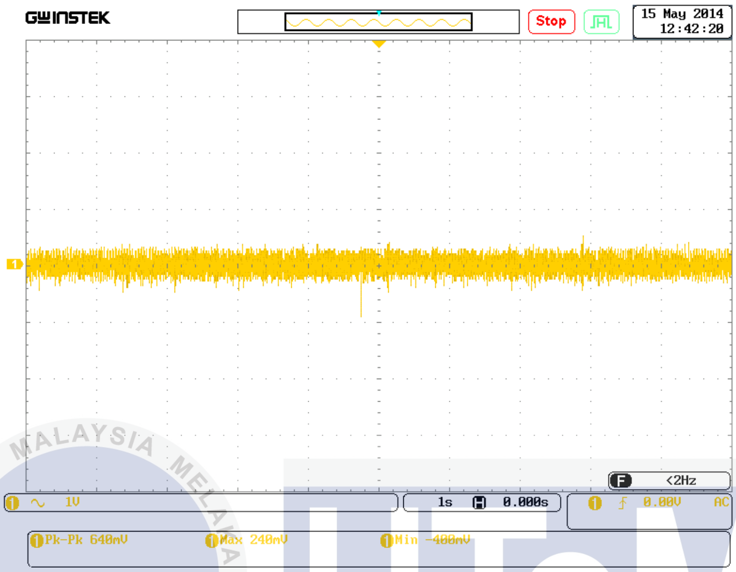


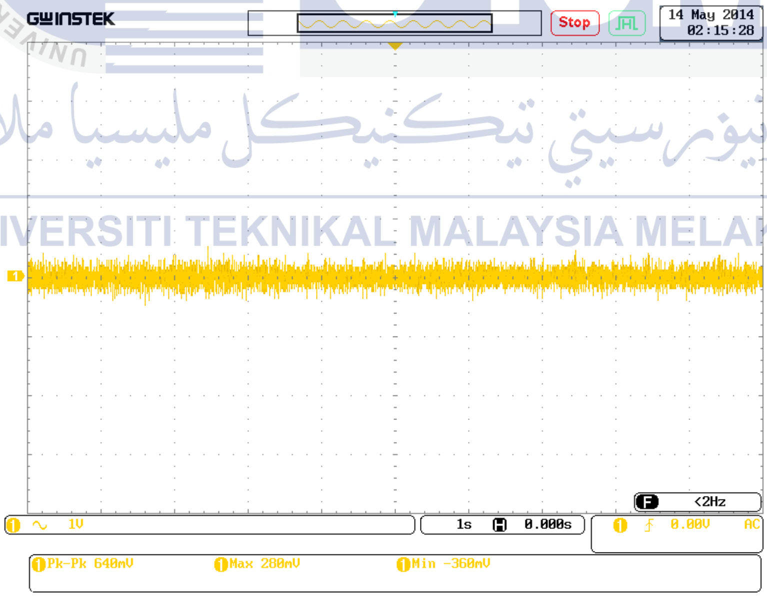


Subject : 4

Wrist anlgle : 90 degrees

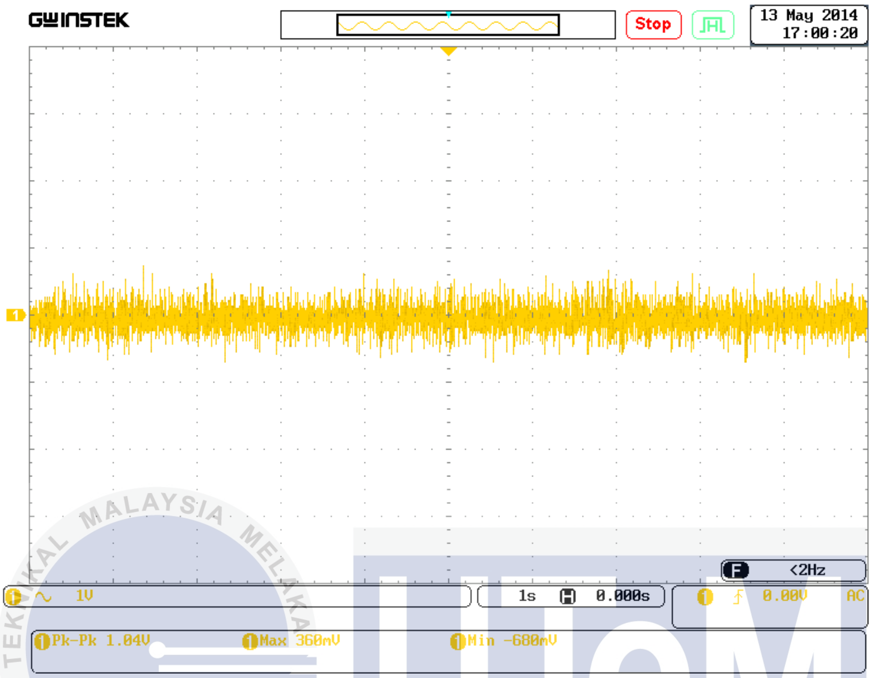
Hand grip force ; 20N

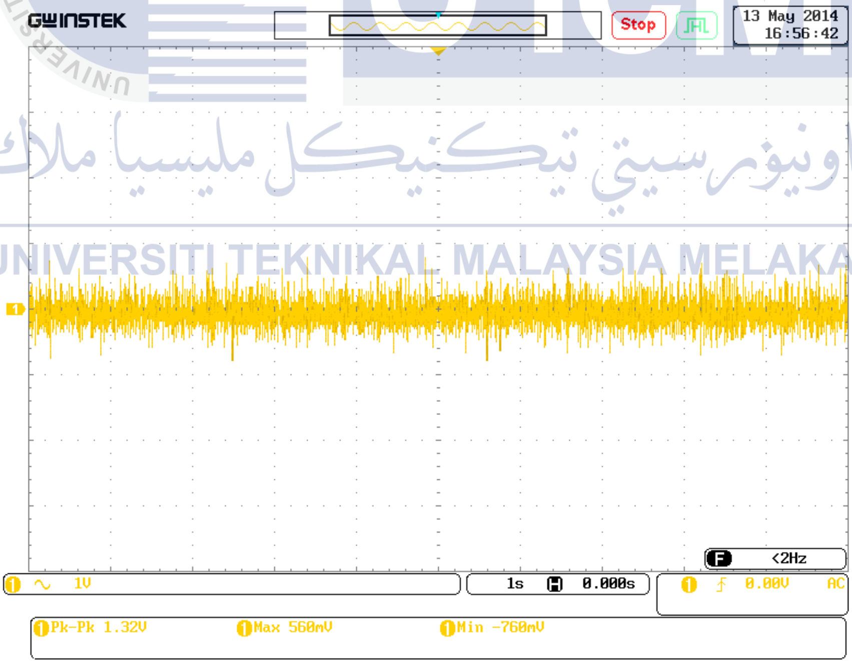




Wrist anlgle : 90 degrees

Hand grip force ; 40N





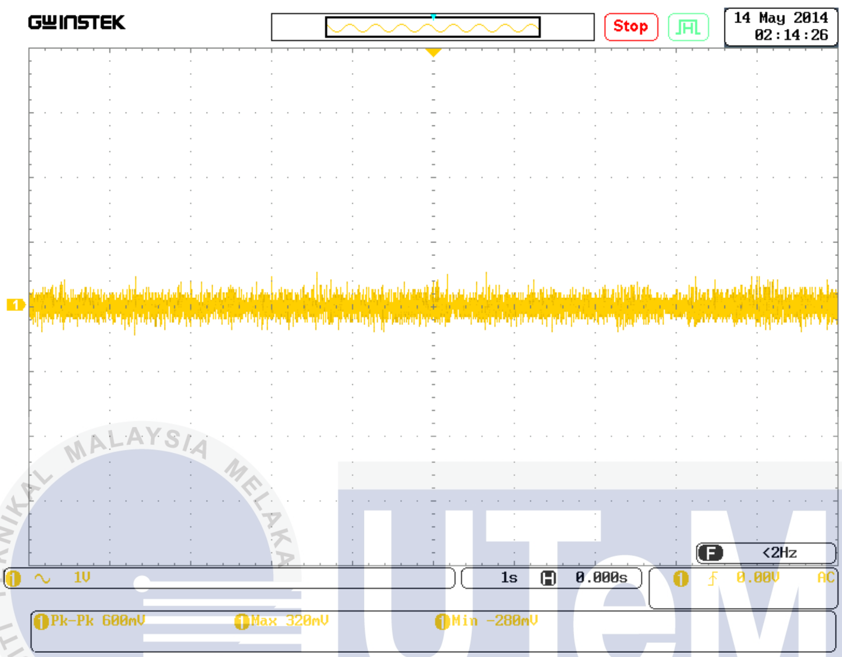
Wrist anlgle : 90 degrees

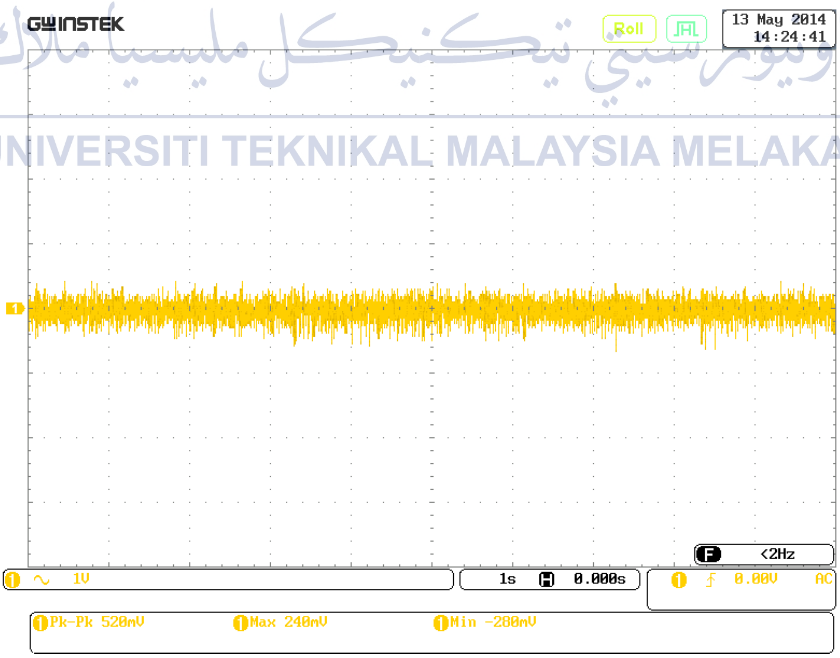
Hand grip force ; 60N

Subject : 5

Wrist anlgle : 90 degrees

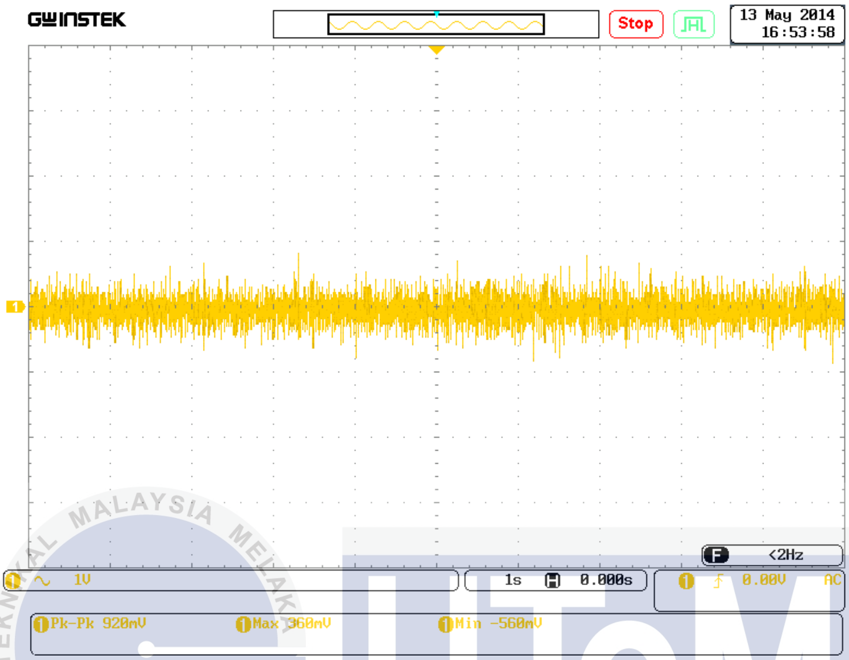
Hand grip force ; 20N

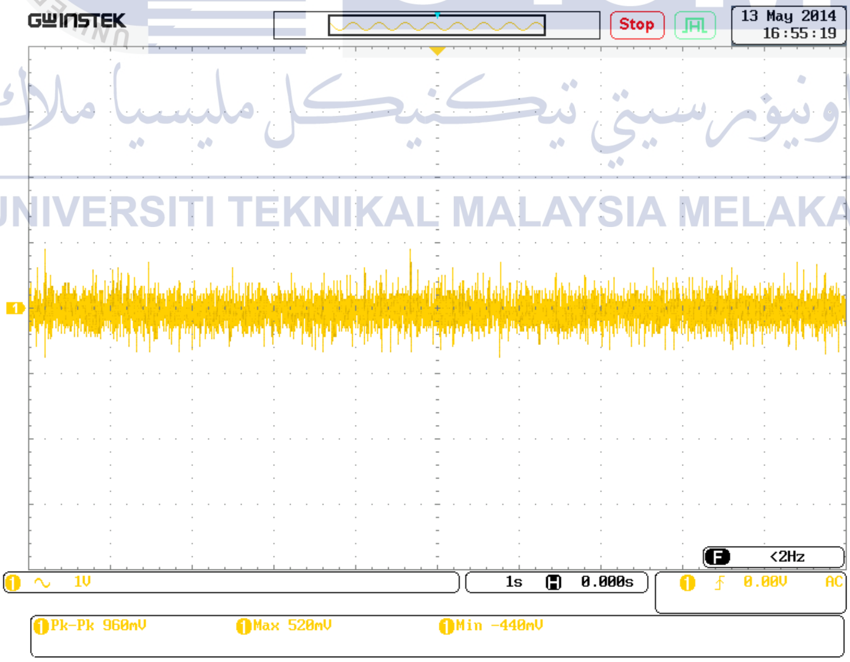




Wrist anlgle : 90 degrees

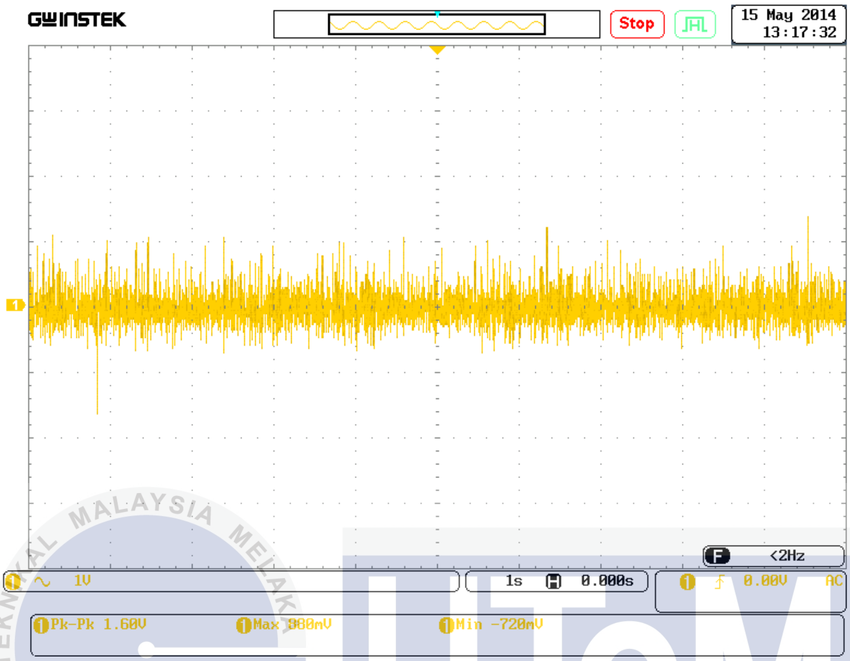
Hand grip force ; 40N

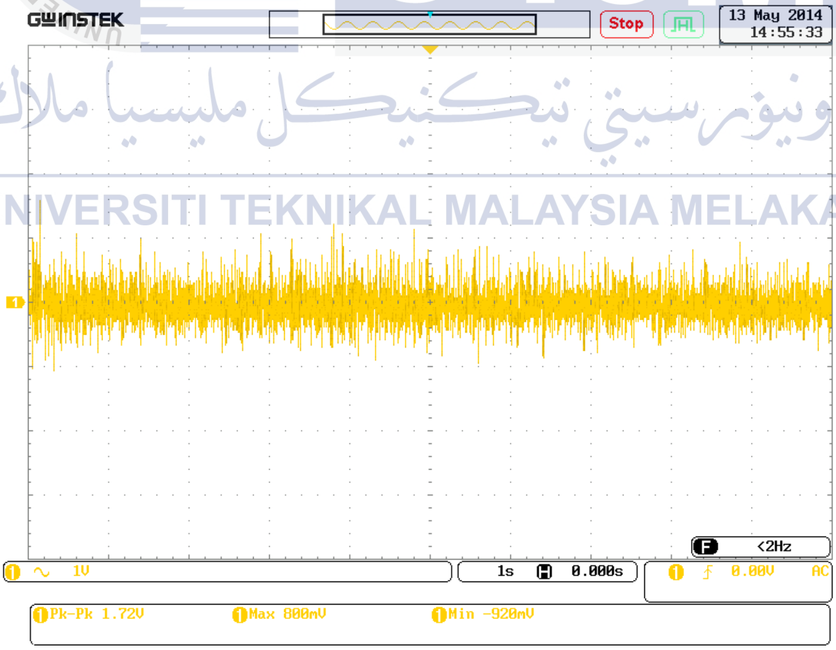




Wrist anlgle : 90 degrees

Hand grip force ; 60N





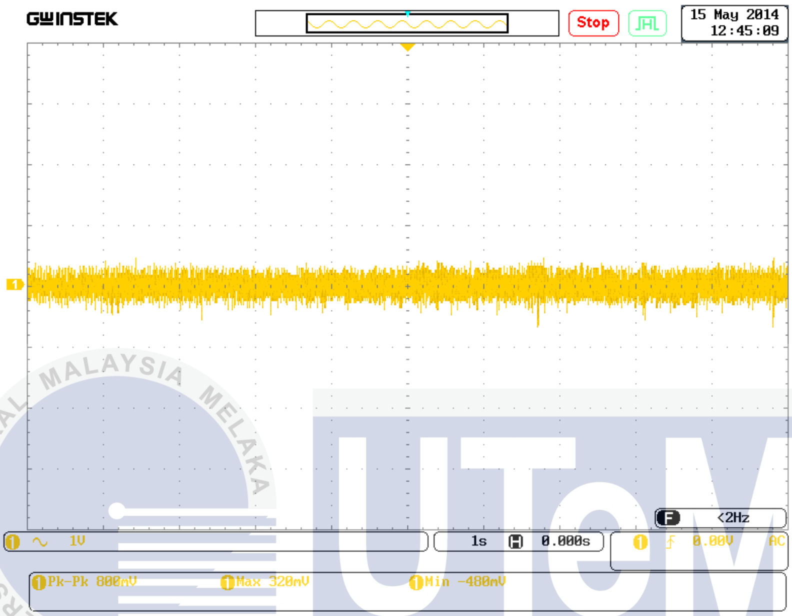
APPENDIX C

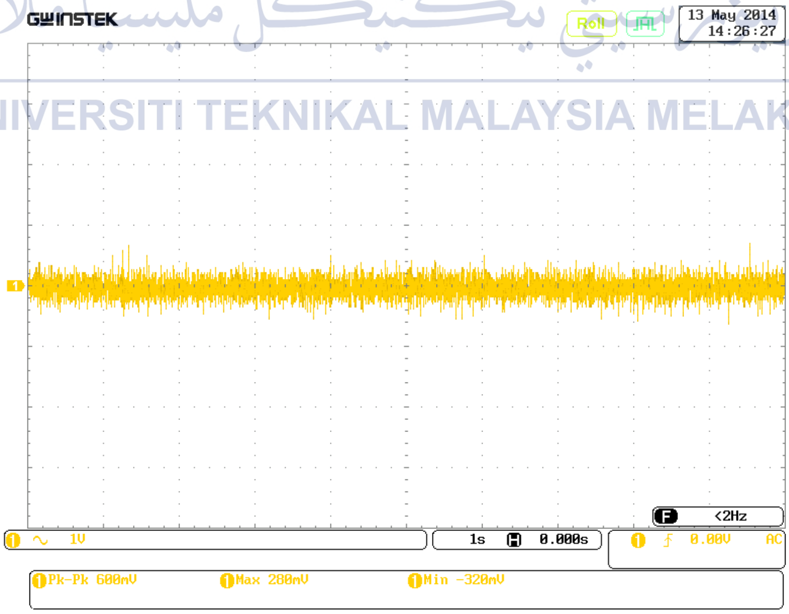
Figures of captured waveform using digital osilloscope

SUBJECT **:** 2

Wrist anlgle : 120 degrees

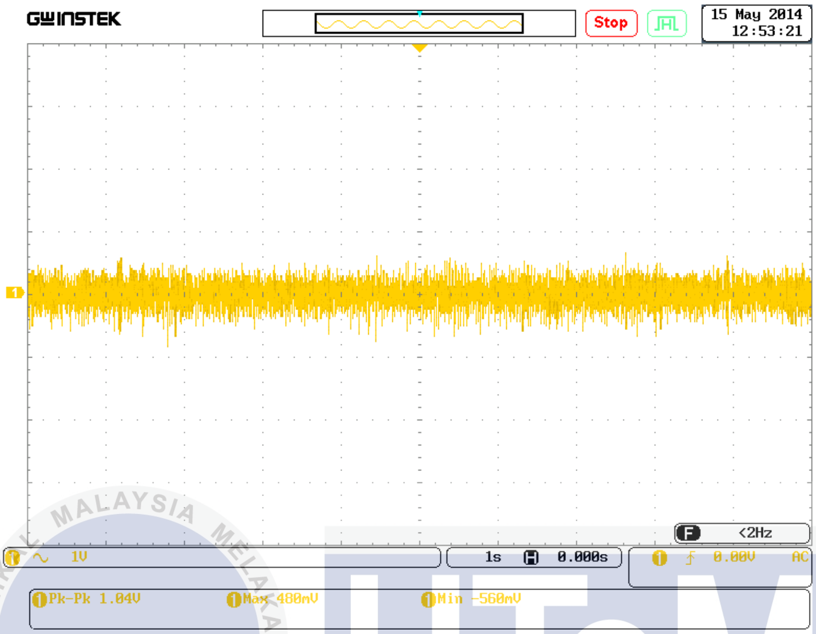
Hand grip force ; 20N

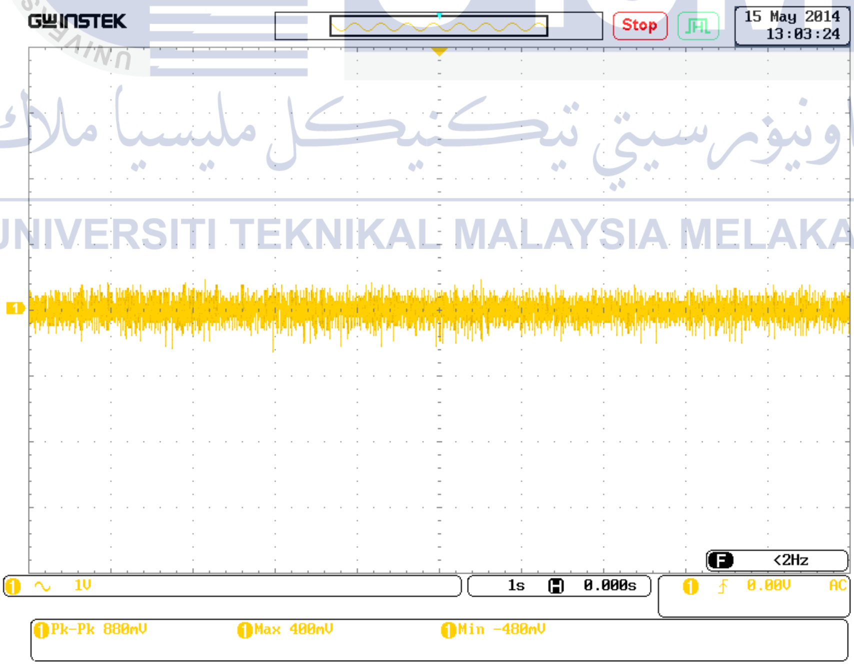




Wrist anlgle : 120 degrees

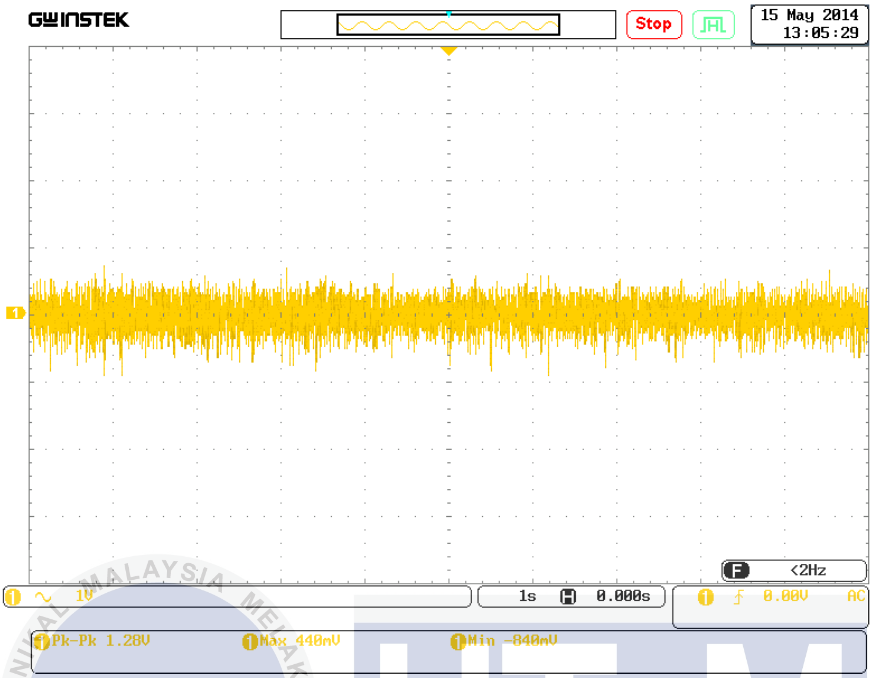
Hand grip force ; 40N

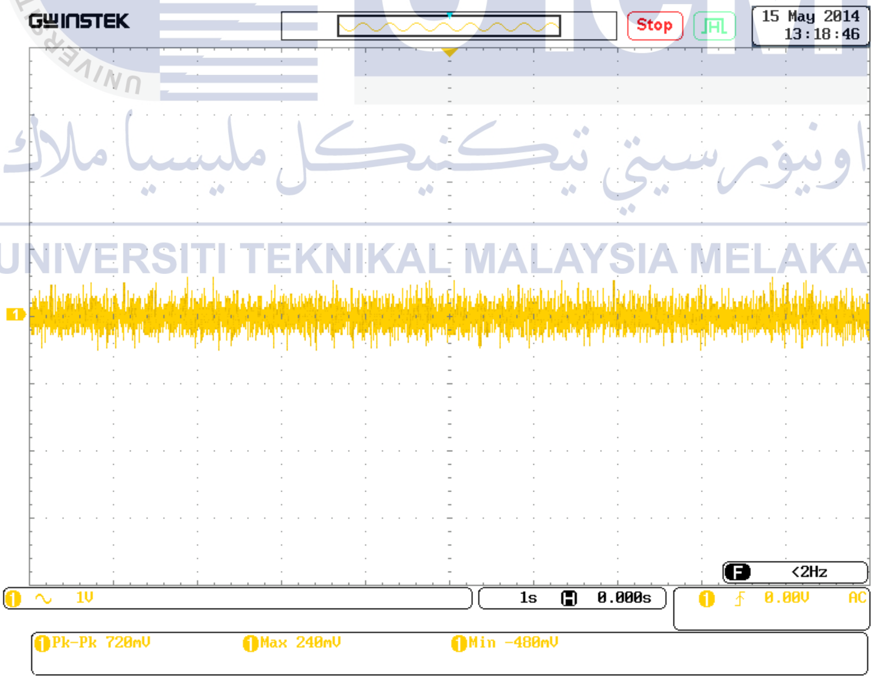




Wrist anlgle : 120 degrees

Hand grip force ; 60N

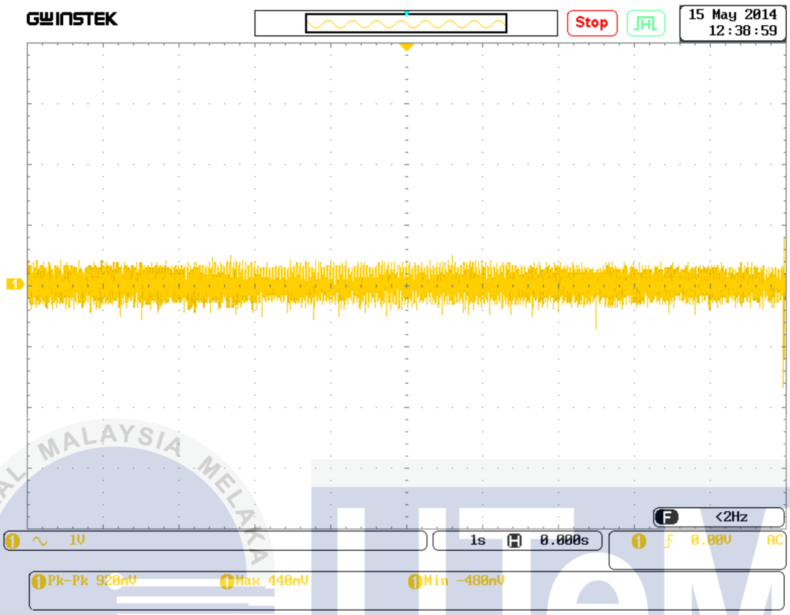


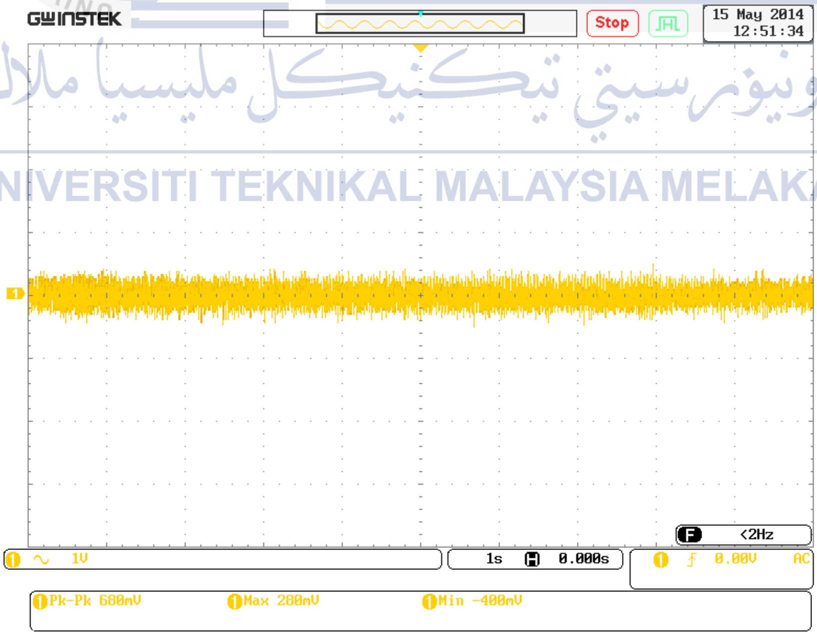


Subject : 3

Wrist anlgle : 90 degrees

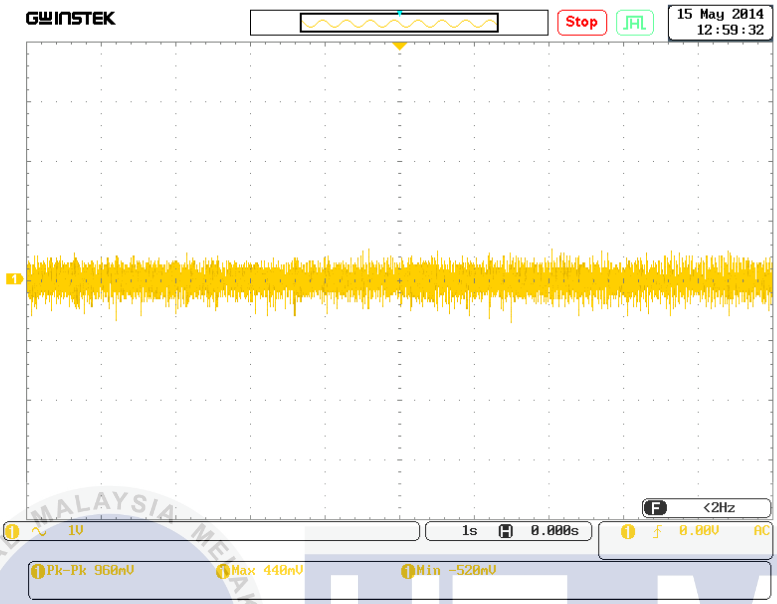
Hand grip force ; 20N





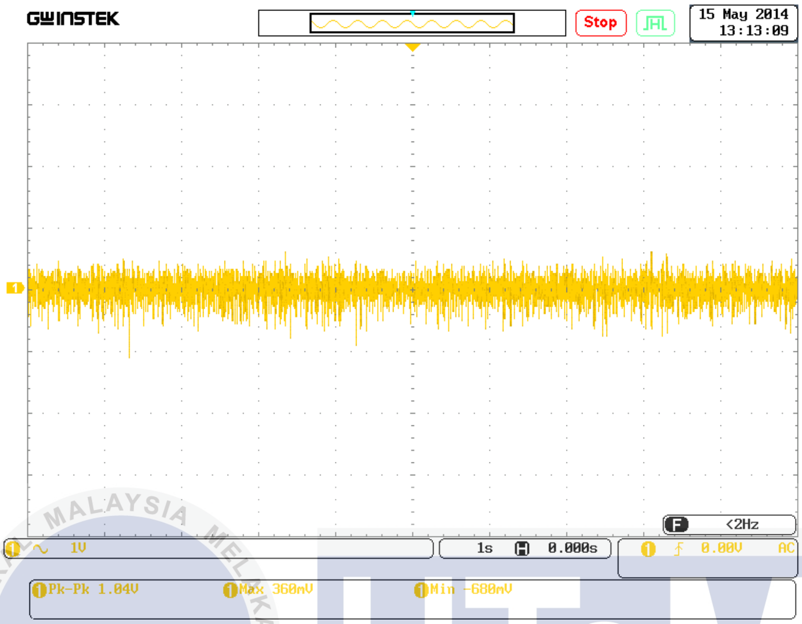
Wrist anlgle : 90 degrees

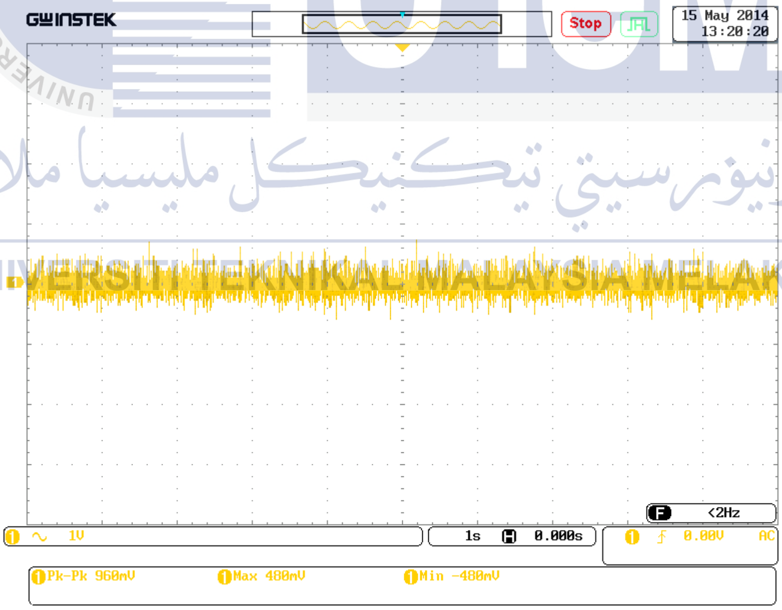
Hand grip force ; 40N



Wrist anlgle : 90 degrees

Hand grip force ; 60N

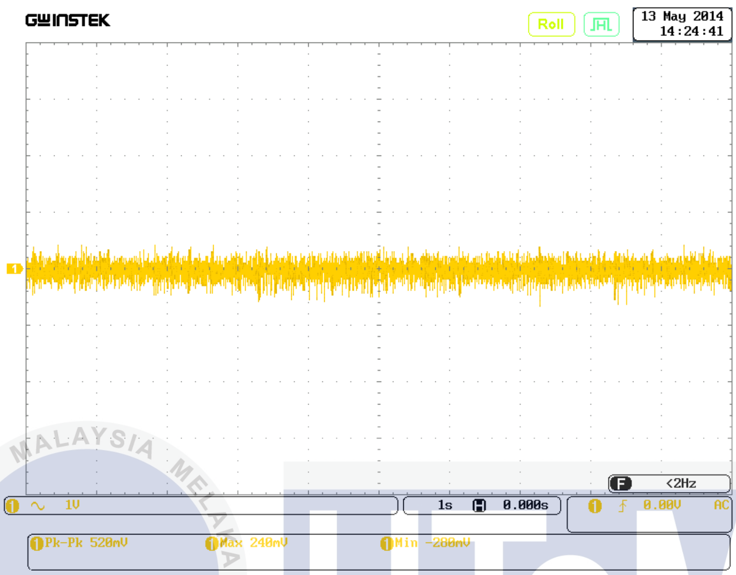


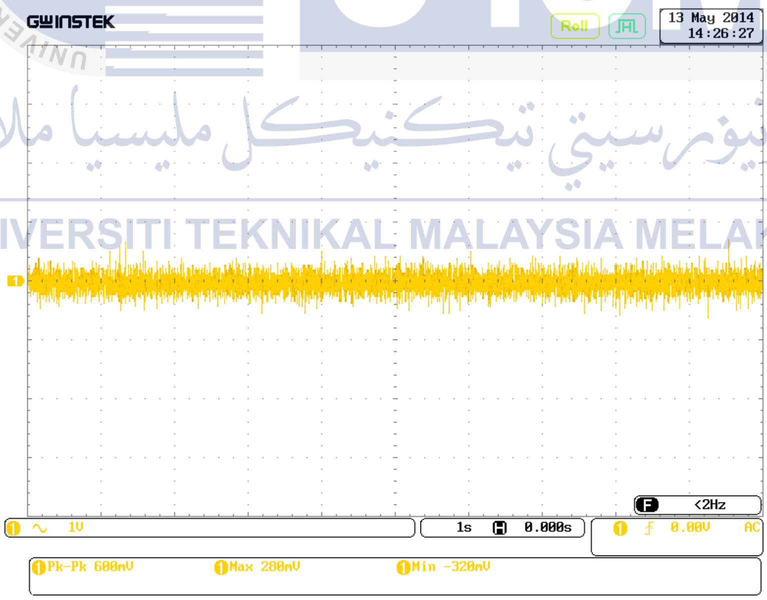


Subject : 4

Wrist anlgle : 120 degrees

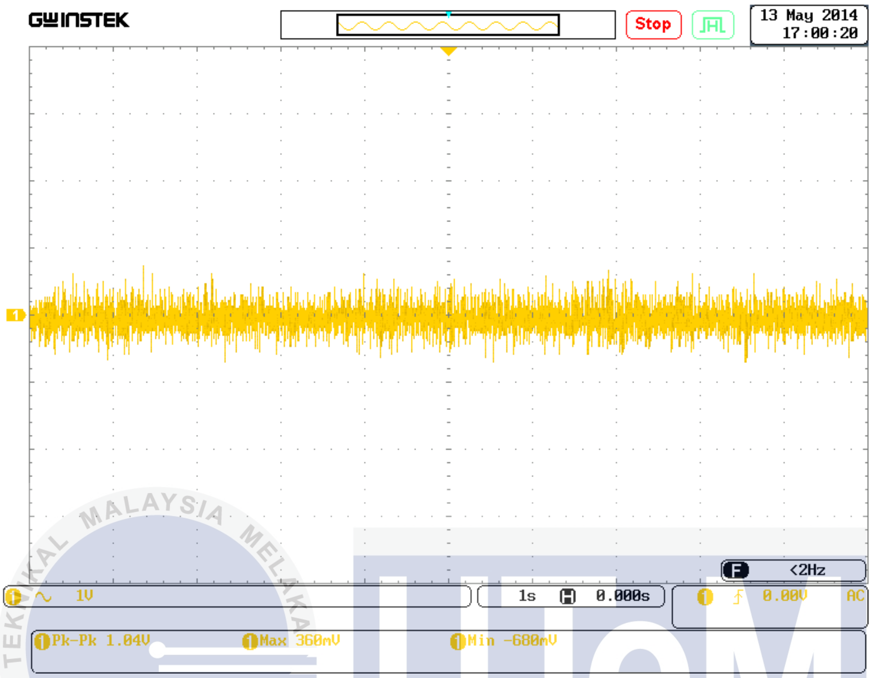
Hand grip force ; 20N

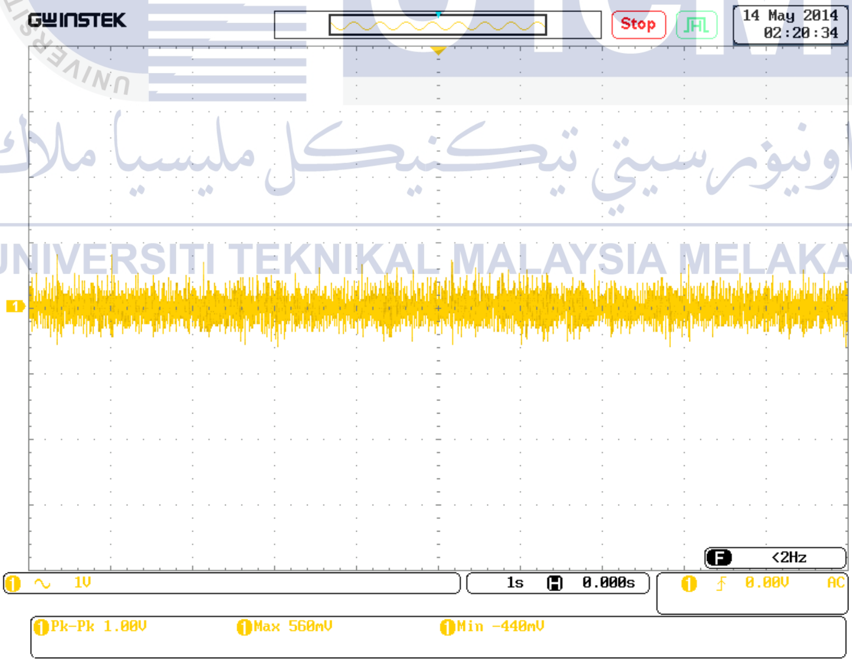




Wrist anlgle : 90 degrees

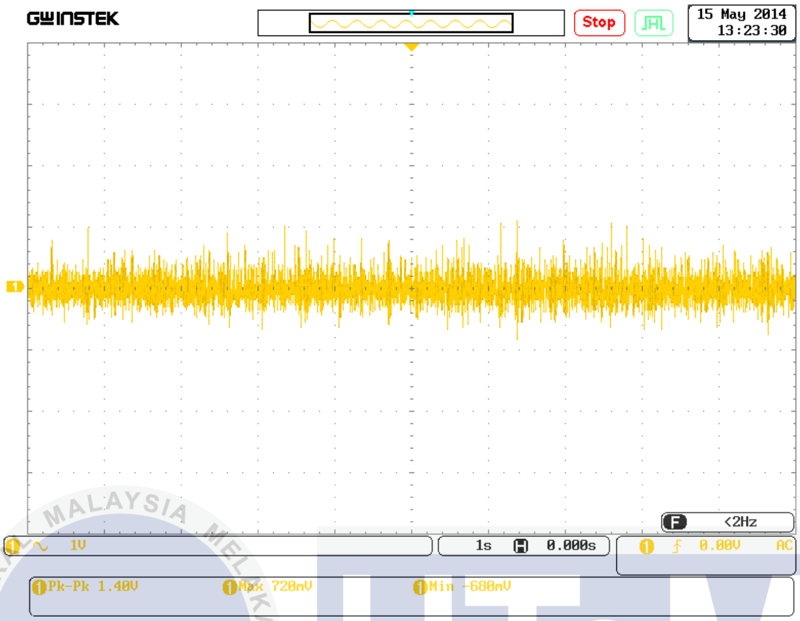
Hand grip force ; 40N





Wrist anlgle : 90 degrees

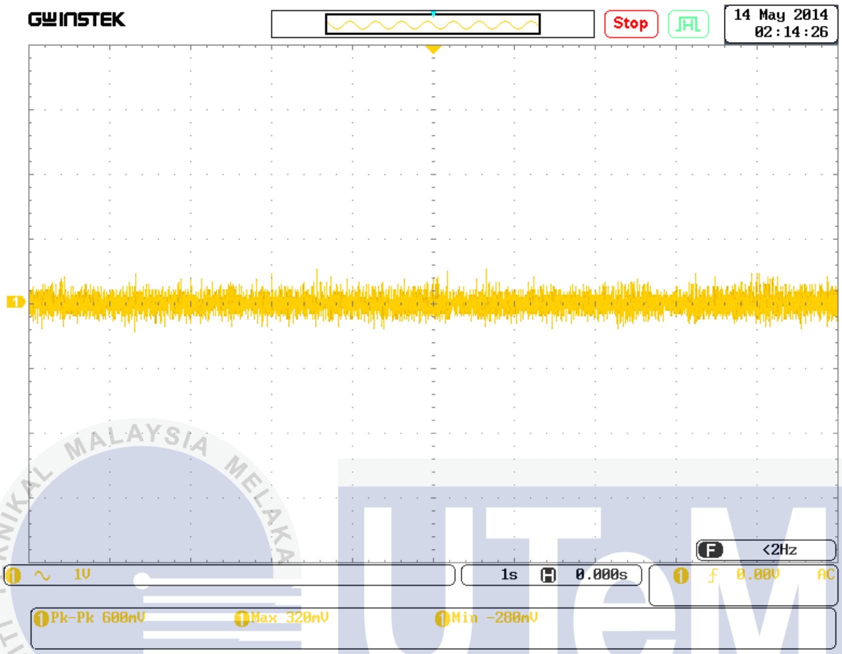
Hand grip force ; 60N

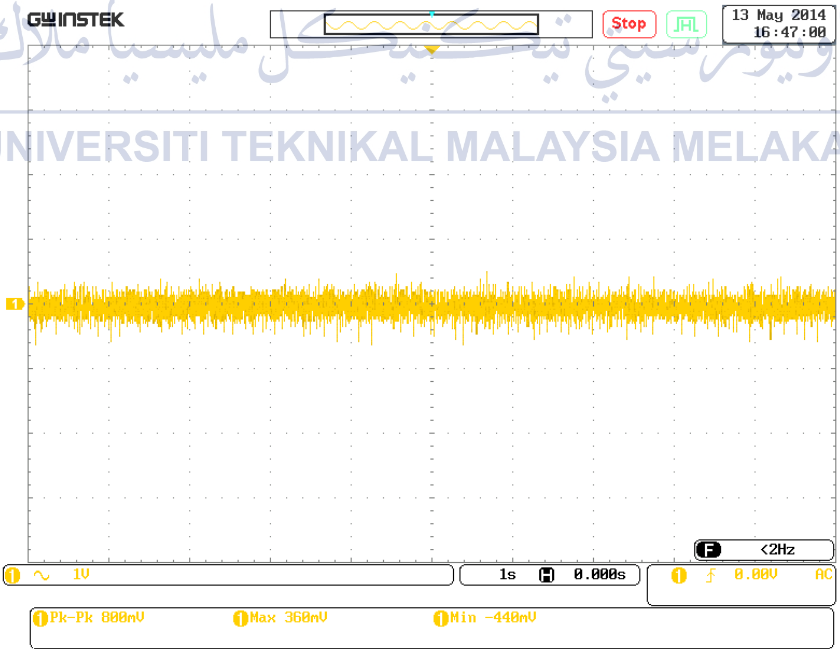


Subject : 5

Wrist anlgle : 120 degrees

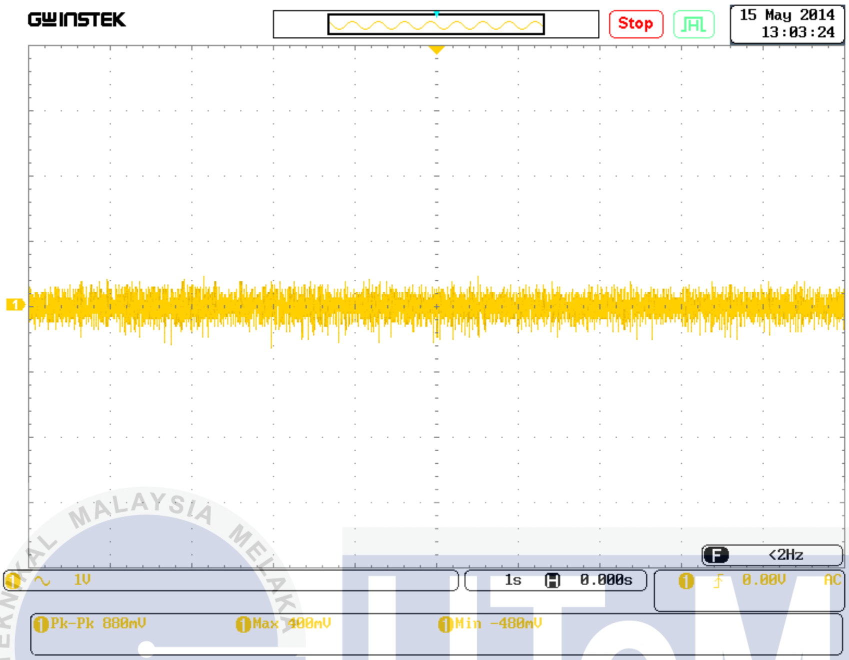
Hand grip force ; 20N

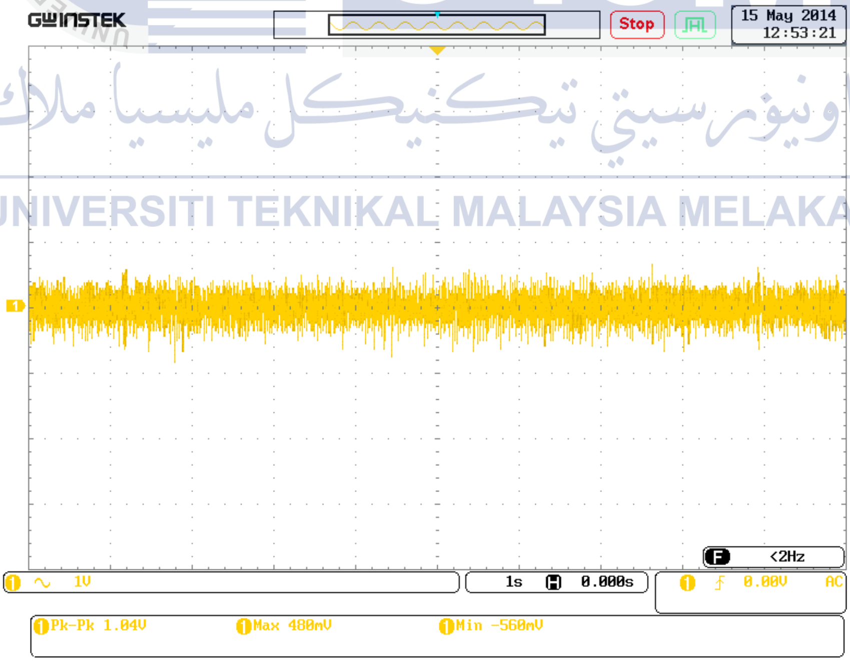




Wrist anlgle : 90 degrees

Hand grip force ; 40N





Wrist anlgle : 90 degrees

Hand grip force ; 60N