Using Eye Movements To Control A Wheelchair

by

Nik Ammar bin Nik Hasbollah

Final Year Project report submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

MAY 2011

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CERTIFICATION OF APPROVAL

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Approved by,

(Dr. Mohd Zuki bin Yusoff)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

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

NIK AMMAR BIN NIK HASBOLLAH

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ABSTRACT

Some people in this world suffer from physical disabilities which limit their daily activities such as playing, walking, and communicating with other human beings. Many attempts have been made in order to reduce the limitations by using available resources such as the head movements, the brain activities, the eye movements and others. In this project, we will utilize the signals generated during the movements of the eyes to control a wheelchair. This attempt will help the people who suffer from the physical disability of both arms and legs thus help them to do daily activities without much supervision from other people. In the eye anatomy, two important parts are cornea and retina. Studies indicate that the metabolic rate of the cornea and the retina are different from each other, and this difference creates a very small voltage potential which is called as corneoretinal potential. The corneoretinal potential is aligned with the optical axis hence it changes with the direction of the gazes. Two pieces of electrodes will be attached on the patient's head to detect the voltage potential between these two points. An amplifier was designed to acquire the eye movement signals, and the signals patterns for each type of movements are observed. A programming code was developed based on the signals patterns to provide output controls for each type of the eye movements. The project results show that the amplifier is capable to detect the eye movements of left and right. However, some minor improvements need to be done in order to detect the upward and downward eye movements.

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Ag/Cl Electrodes – A Surface Type Electrode

CMRR – Common Mode Rejection Ratio

DRL - Driven Right Leg

EOG - Electro-Oculography

ESD – Electro-Static Discharge

INA126P – An Instrumentation Amplifier

OPA277- An Op-Amp Chip

PCB – Printed Circuit Board

RF – Radio Frequency

CHAPTER 1
INTRODUCTION

1.1 Background Of Project

In this project, we will design a device that will utilize the signals that is generated during the movement of the eyes. Three electrodes will be attached to the patient's face to acquire the signal. The method used for this project is called Electrooculography or simply EOG [1].

After the signal is obtained, it will go through amplification and filtering stage. Then, a programming code will be developed so that it can be used to move a wheelchair. The wheelchair movement will be dependent on the eyes movements. The signal generated during left gaze will be used to turn the wheelchair to the left, and right gaze will be used to turn the wheelchair to the right. Signals generated during looking upward can be used to move the wheelchair forward, and looking down for backward. Figure 1 represents the overall idea about this project.

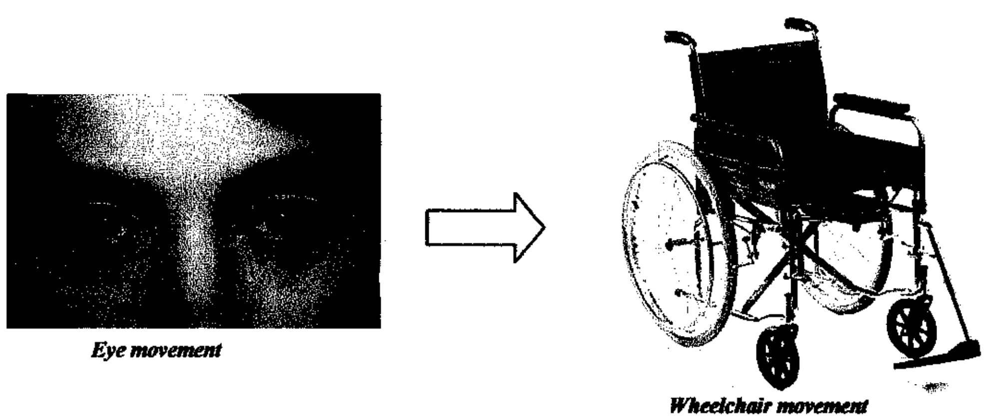

Figure 1: Eye movement is used to control a wheelchair

1.2 Problem Statement

Quadriplegia refers to paralysis of the body including legs and arms which is usually caused by damage at the spinal cord. People who suffer from quadriplegia face a lot of problems communicating with other human beings. Paraplegia is quite similar to quadriplegia, except that it does not affect arms. In other words, the sufferers of paraplegia may be able to communicate with others by utilizing their arms. For quadriplegia sufferers, they need different alternatives since their arms and legs malfunction. In order to impart these functionalities, attempts are being made to accommodate such patients by utilizing all of the available resources, such as head movements, brain activities, eyes movements, etc [2].

In this project, eye movements will be utilized as the alternative to control the movements of wheelchair in order to help quadriplegia sufferers.

1.3 Objectives

The main objective of this project is to design a prototype that can acquire EOG signal which is generated during the movement of eye. The prototype consists of two stages, which are amplification stage and filtering stage.

The second objective of this project is to analyze the EOG signal. An oscilloscope will be used and the signal pattern for each type of eye movement will be recorded.

After the signal is obtained, an analog to digital converter (ADC) will be used to convert the signal into digital form. Finally, a microcontroller will be used for output control purposes.

CHAPTER 2
LITERATURE REVIEW

2.1 Eye Ocular Muscle

Human ocular movements have been widely studied in neurophysiology and psychology. These studies indicate that there are four types of eye movements, called vestibular, optokinetic, saccadic, and pursuit [3].

The first two movements (i.e. vestibular and optpkinetic) have to do with the largely involuntary head motions. The saccadic movement is used to "jump" from one object of interest to another; this is the fastest type of eye movement. The pursuit movement is used to maintain fixation on a moving object [3].

Deliberate eye movement can convey useful information in basically two ways, which is through the six extra-ocular muscles (by absolute eye position, speed, and direction of eye movement), and second through the eyelid and other periorbital muscles (by unilateral or bilateral blinking or blink duration [3]. The eye ocular muscle is shown in Figure 2 below.

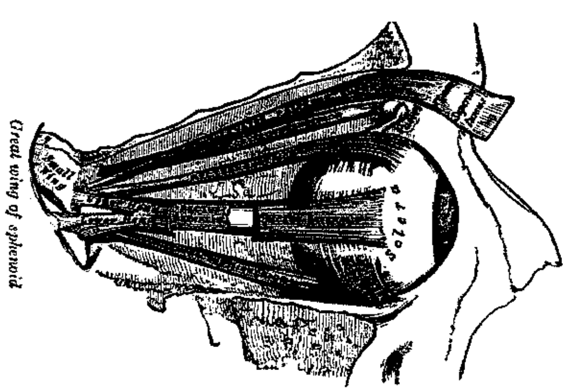

Figure 2 : The six-ocular muscles

2.2 Electro-Oculography(EOG)

Due to the higher metabolic rate at the retina compared to the cornea, the eye maintains a voltage of +0.4 ~ 1.0 mV with respect to the retina. This corneoretinal potential is roughly aligned with the optic axis. Hence it rotates with the direction of gaze [4]. It can be measured by surface electrodes placed on the skin around the eyes. These recorded signals are smaller (15 to 200 μV), so they are amplified before processing [5].

Electro-oculography has both important advantages and disadvantages over other eye tracking methods. On the positive side, the equipment is cheap, readily available, and can be used with glasses or contact lenses, unlike some reflection methods. The necessary fixtures do not obstruct the visual field, and are completely insensitive to head movements, although significant deviation from the last calibrated position would require the user to repeat a calibration sequence for accurate tracking [1].

On the other hand, the measured signals are subject to drift from several sources: changing skin resistance, electrode slippage or polarization, and even a variable corneoretinal potential due to light accommodation and level awareness. Noise pickup from other electrical devices can be minimized by careful shielding, but action potentials of the other facial muscles can mask the desired signal [1]. The most obvious shortcoming, uncorrectable by its very design, is the need for attachments directly on the user's face - six electrodes under the proposed scheme [6]. The proposed scheme is shown in Figure 3.

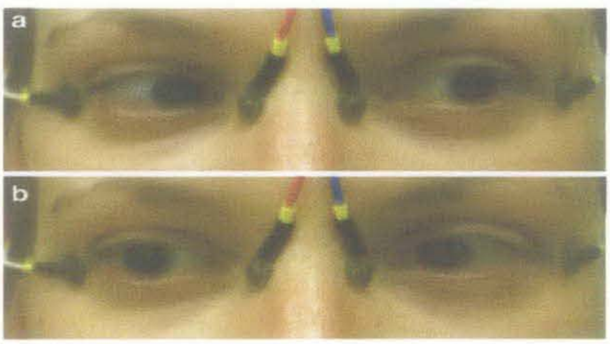

Figure 3 : Electrode placement for EOG

2.3 Signal Processing

Straightforward signal processing steps can be devised to condition the data so it can be reliably interpreted. Some of the noise patterns such as the 60 Hz line frequency can be easily removed, using a notch filter [6]. Other noise artifacts are mostly transients caused, for example, by the turning of an electrical switch on/off in the vicinity of the electrodes, contraction of the facial or neck muscles, slippage of the electrode due to sweat and eye blinking [6].

However, the signals produced by eye blinks are, in fact, quite regular. This makes it easy to recognize and eliminate them. On the other hand, because this type of signal is quite distinct from the usual data from pursuit or saccadic movements, they can be recognized and categorized as such. In other words, the EOG technique can potentially recognize eye "gestures" such as winking, blinking or a combination thereof [3].

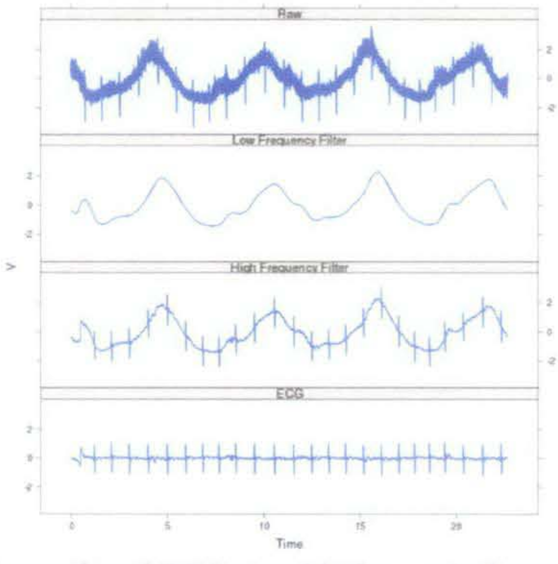

Figure 4 : The predicted EOG signal before and after noise removal

It is possible to obtain independent measurements from the two eyes. However, the two eyes move in conjunction in the vertical direction. Hence it is sufficient to measure the vertical motion of only one eye together with the horizontal motion of both eyes [6].

CHAPTER 3
METHODOLOGY

3.1 Methodology Overview

Initially, the signals generated during the movements of eyes will be sensed by using electrodes. For each channel, two electrodes were used so that the differential voltage between these two can be extracted and be used as the input signal.

When the signal is obtained, it undergoes the amplification stages. When the input signal is amplified, noise would also get amplified. Filter circuit is used to remove this unwanted noise. Radio frequency (RF) is the most common noise source. Other sources of noise that should be treated are power lines noise and substantial DC offset that may be caused by the skin humidity, the air humidity, etc.

After the signal was filtered and amplified, an analog to digital converter will be used to convert the signal into digital data. Once the signal is acquired, it will be analyzed and processed to differentiate between the eye movements.

Finally, a program will be designed to utilize the processed signal so that it can be used as the input signal to move a wheelchair. The methodology of this project is summarized in Figure 5 below.

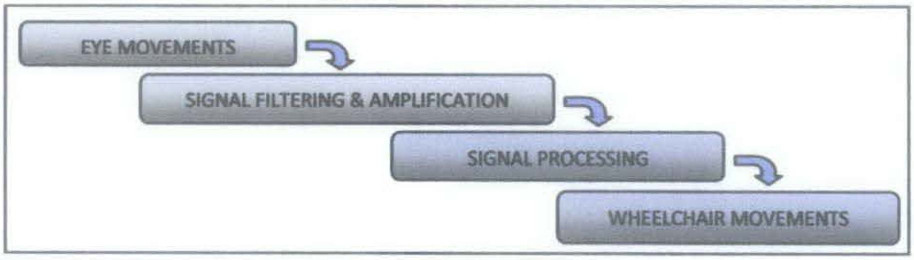

Figure 5 : The methodology of the project

3.2 EOG Amplifier Circuit Operation

This chapter will mainly discuss about the circuit operation of each of these stages. The circuit in Figure 6 shows the first part of the whole EOG amplifier circuit for a single channel. This circuit consists of five sub-stages which are radio-frequency interference rejection stage, overvoltage protection circuit, pre-amplifier, gain stage, and right driven leg (RDL) circuit.

The radio frequency rejection stage will provide rejection of signal which ranges from 47Hz and above. The overvoltage protection is used to ensure safety of test subject from static shock, since the device is directly connected to the test subject. The pre-amplifier and gain stage will provide suitable amplification of signal so that the measurement is readable and can be processed. For the driven leg circuitry, it is a common practice to use this circuit configuration on a bioelectric potential device to increase the common mode rejection ratio [5].

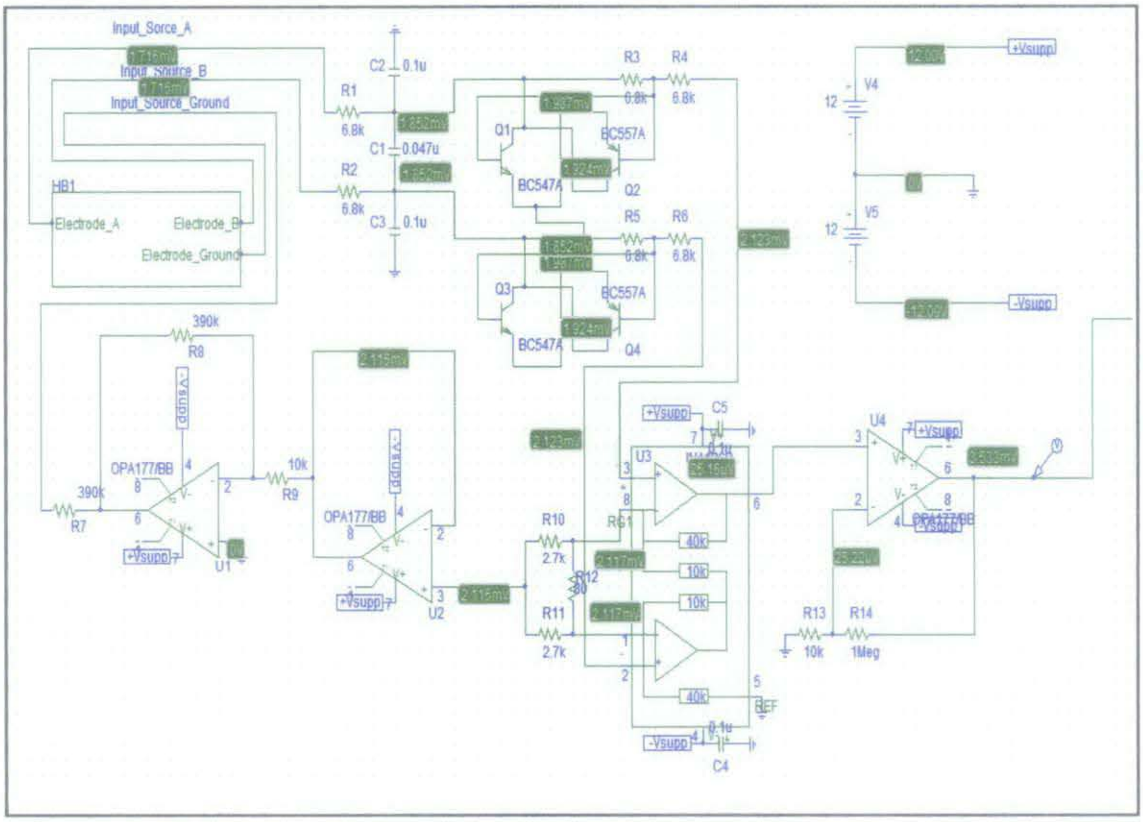

Figure 6 : First part of EOG amplifier

3.2.1 Radio frequency(RF) interference rejection circuit

The first stage of the biopotential amplifier circuit is the radio frequency(RF) noise rejection stage, and the input of this stage is connected with electrodes. The electrodes that have been used are Ag/Cl type.

Instead of sensing the EOG signal, the electrode also tends to act as an antenna that senses the radio frequency interference signals from the environment [4]. These interference signals may pollute the original signal and decrease the performance of the device.

To remove the unwanted interference signal, the RF interference rejection circuit is used, and the selected circuitry is shown in Figure 7 below.

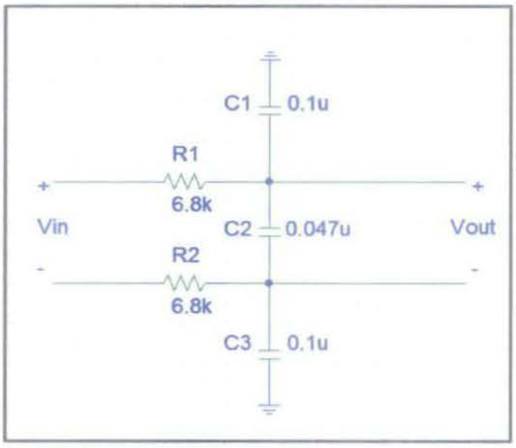

Figure 7 : RF Rejection Circuitry

The circuit will provide the cut-off point defined by Equation 1.

$$f_c = \frac{1}{2\pi(2R)(C_A+2C_B)} \tag{1}$$

where,

- $R=R_1=R_2= 6.8k\Omega$
- $C_A=C_2=0.047\mu F$
- $C_B=C_1=C3=0.1\mu F$

By using the component with the indicated values, the calculated 3dB cut off point for the radio frequency interference rejection stage is around 40Hz to 50Hz. Since the frequency range of interest is between dc to 10Hz, the above circuit will not cause troubles to the output signal. The circuit will help filtering and removing the higher frequencies signal that are coupled through the electrode's leads.

This circuit has been simulated by using PSpice Schematics. Refer to subsection 4.1.1 of chapter 4 for the simulation result.

3.2.2 Overvoltage protection

In order to acquire the EOG signal, electrodes will be attached to the skin of test subject. It is important that this device is safe for making direct connection with a person. Apart from that, it is also important to ensure that the device itself is protected from any static shocks that zap the person, and continue to operate properly. The chosen overvoltage protection circuitry can be seen in Figure 8.

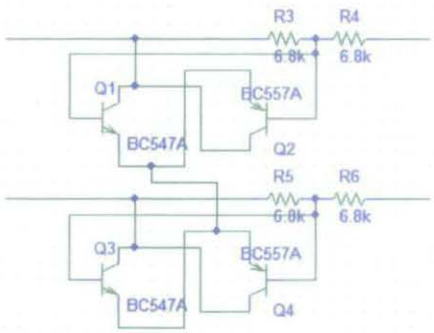

Figure 8 : Overvoltage protection circuit

This circuit works by providing protection in two directions. If one of the input terminals become too large, approximately 0.7V greater than GND then voltage drop across R3 will provide base current for Q1; this in turn causes current to be drawn from the collector of Q1, which will clamp down the voltage and make sure that it does not become too large. The corresponding Q2 is a PNP transistor, which protects against overvoltage in negative direction [1].

The circuitry also protects a person as well if either output terminal becomes too high. When the output terminal voltage is high, it provides base current for any of the transistor. Since voltage drop from base to emitter is constant, the voltage at input terminal will be pulled down.

3.2.3 Pre-amplifier circuit

The input signal of the device actually is the voltage difference taken from two points, which are electrode A and electrode B. However, it needs to be a single ended signal (referenced to one common point) for a useful analog to digital conversion. The required input impedance is greater than 100MΩ, and the Common Mode Rejection Ratio (CMRR) is greater than 110dB. This requirement can be easily achieved by using an integrated component known as an instrumentation amplifier. The selected instrumentation amplifier for this circuit is INA126P. This decision is made since the input impedance of this chip is 10GΩ, which greatly exceeds the expectation. The CMRR of INA126P is around 100 to 120dB, depending on the gain. So, the gain must be selected appropriately to ensure it meets the specified CMRR. The pre-amplifier stage is shown on Figure 9 below.

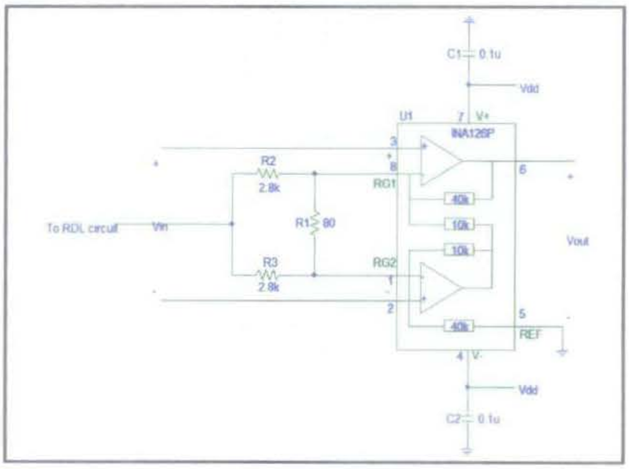

Figure 9 : Pre-Amplifier Circuit

For C1 and C2, they are placed there to provide ESD protection and noise reduction. It is common PCB practice to help noise reduction by placing these capacitors as physically close to the instrumentation amplifier chip as possible.

The selected value of C1 and C2 is 0.1μF. This is because 0.1μF is the common capacitance value for human ESD protection circuit. The capacitor will work as the capacitance bank if the circuit receives any electrostatic charges.

For the gain resistor, RG1 and RG2, instead of using one single resistor, they are selected separately because the center point between these resistors will be used later for the Right Driven Leg (RDL) circuit.

The gain of the 126P instrumentation amplifier can be defined in Equation 2. The data is obtained from the datasheet of INA126P chip.

$$G = 5 + \frac{80k}{R_G} \tag{2}$$

where,

- G = Gain of amplifier
- R_G = Gain resistor

By using the resistor values and configuration as in Figure 4, the total resistance is approximately 80Ω. Substituting this value into Equation 2, the gain achieved during this preamplifier stage is about 1000 times. It is possible to put a higher gain in this stage. However, in order to help reducing DC offset which might be affected due to skin temperature, air humidity and skin moisture, the implemented circuit is divided into two separate stages, which is pre-amplifier stage and main amplification stage. Moreover, the datasheet of INA126P also shows that CMRR of 120dB can be achieved by using a gain value of 1000.

3.2.4 Main amplification circuit

The purpose of this circuit is as the main amplification of the EOG signal. Even though the preamplifier stage provides a gain of 1000 times, it is insufficient for the signal to become readable. The circuitry of the stage is shown in Figure 10.

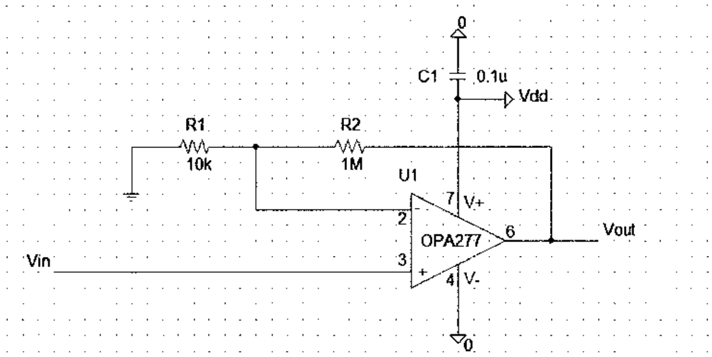

Figure 10 : Main amplification stage

This architecture is known as standard configuration of non-inverting amplifier. This configuration was chosen instead of inverting amplifier configuration because the purpose of this stage is only to amplify the signal, without inverting the output signal. The gain equation for this type of configuration is shown in Equation 3.

$$\frac{Vout}{Vin} = \frac{R_2}{R_1} + 1 \tag{3}$$

By using R1 = 10kΩ and R2 = 1MΩ, the gain of this stage will be 100 times. Multiplying with the gain at the preamplifier stage, the total gain that can be achieved is 100000. This gain value should be able to provide a readable EOG signal for further processing.

OPA277 was chosen as the Op-amp mainly because it provides an ultra low offset voltage, which is 10μV [7].

3.2.5 Driven right leg (DRL) circuit

Driven right leg or simply DRL circuit is a common circuit configuration which is used to reduce the Common Mode Interference. It is commonly used in a biological amplifier to improve the CMRR [3]. In this circuit, the configuration is used to improve the CMRR of the INA126P chip. The circuit configuration of the DRL circuit is shown in Figure 11.

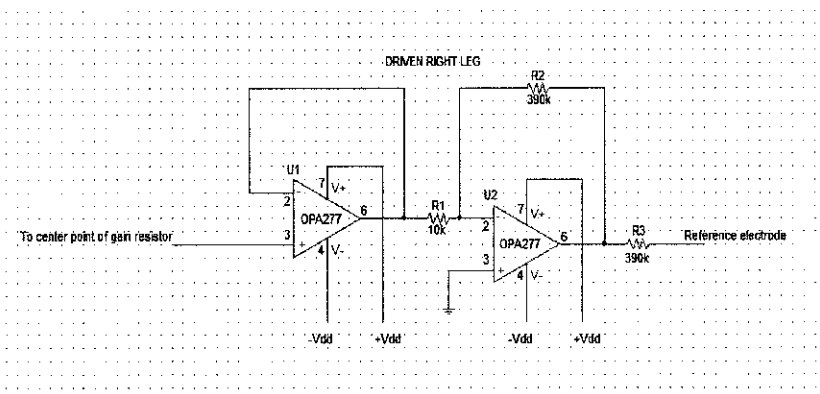

Figure 11 : Driven right leg circuit

The circuit reads what it believes to be noise, and transfers the signal back to the human body to remove the noise. The signal is transferred back to the body through a reference electrode.

3.3 EOG Filter Circuit Operation

This chapter will mainly discuss about the operation of each filter stage of the EOG amplifier. There are three filter stages that have been implemented in this circuit which are q-notch filter, fourth order high pass filter and fourth order low-pass filter.

The q-notch filter is used to remove power line noise. The fourth order high pass filter is used remove the substantial DC offset due to the test subject's skin, while the fourth order low-pass filter is used as anti-aliasing filter [2].

The circuit in Figure 12 shows the whole filter stage of the EOG amplifier circuit for a single channel.

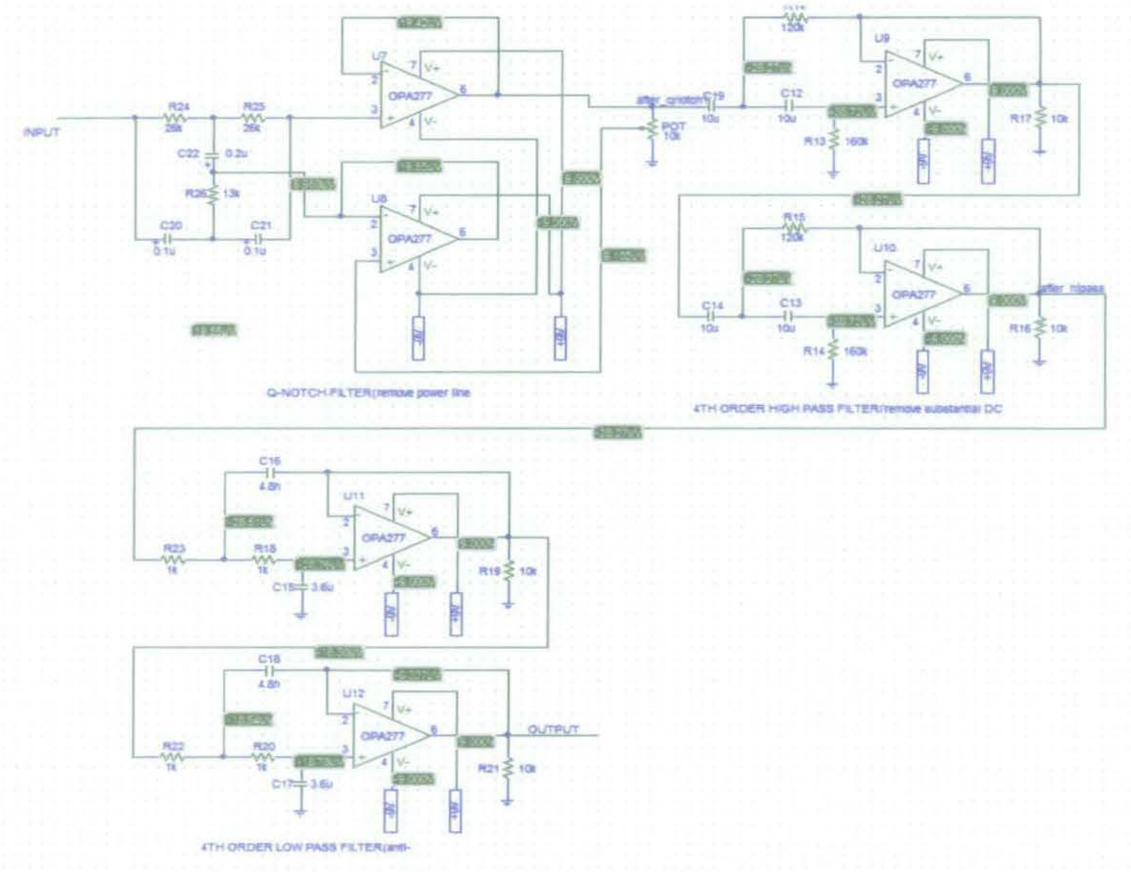

Figure 12 : Filter stage of EOG amplifier circuit

3.3.1 Q notch filter circuit

One of the noise sources that can effect the signal is the power line noise. This noise ranges from 50Hz to 60Hz. The head of the test's subject will behave as antenna, which allows a capacitance to be set up between overhead fluorescent lighting and the patient's head, with the air behaving as dielectric. Also, other electrical supply will induce power line noise.

To counter this problem, a simple Q notch filter is implemented after the amplification stage, with the Q set at 60Hz. Figure 13 shows the circuit of the Q notch filter.

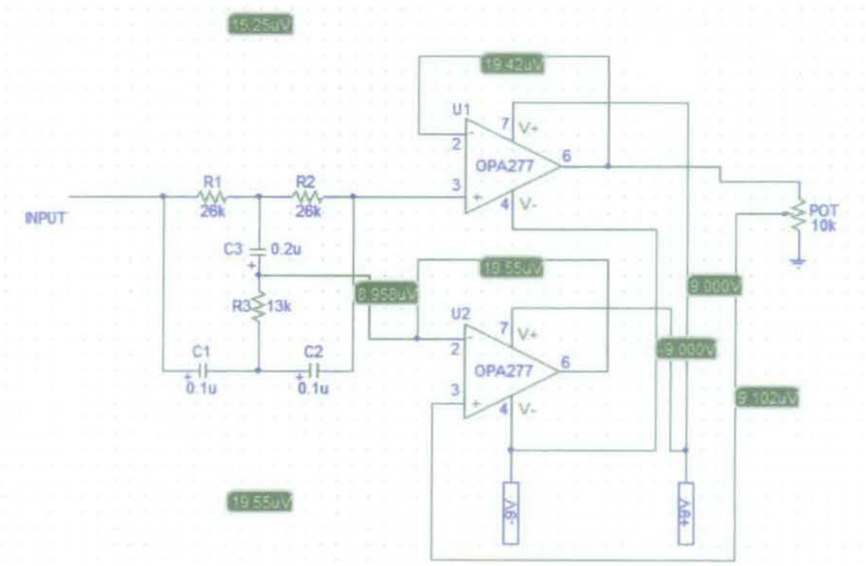

Figure 13 : Q notch filter

The cut off frequency of the Q notch filter is calculated based on Equation 4 below.

$$fc = \frac{1}{2\pi RC} \tag{4}$$

where,

- $R_1 = R_2 = 26k\Omega$
- $R_3 = 1/2\ R_1 = 13k\Omega$
- $C_3 = 0.2\mu F$
- $C_1 = C_2 = 1/2\ C_3 = 0.2\mu F$

3.3.2 Fourth rrder high pass filter circuit

Another problem that occurs when acquiring and amplifying EOG signal is the overcoming of substantial DC offset generated by the potential difference between the reference electrode and other electrodes [5]. This DC offset can be removed by using a high pass filter.

By using a fourth order high pass filter, it will have a sharp roll off rate, which is 80dB/decade. The cut off frequency is chosen at 0.14Hz to remove this DC. Figure 14 below shows the stage of the fourth order high pass filter.

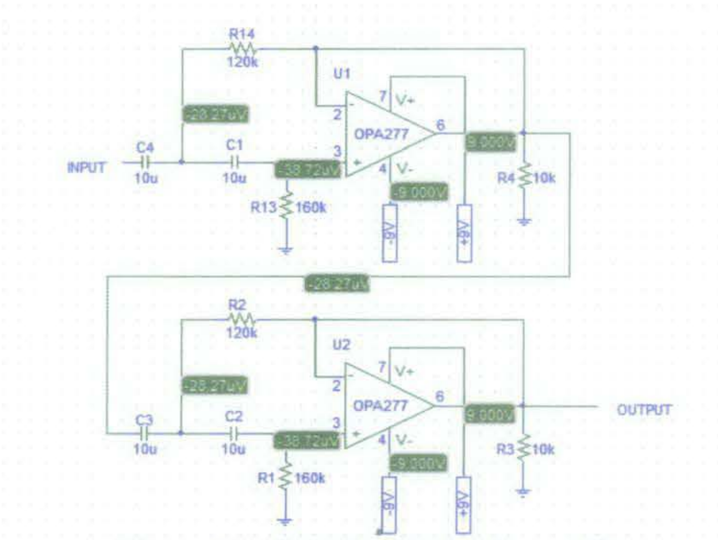

Figure 14 : Fourth order high pass filter

The cut off frequency of this circuit is calculated based on the equation 5 below.

$$fc = \frac{1.1017}{2\pi R_A C} = \frac{1.4688}{2\pi R_B C} \tag{5}$$

where,

- fc = Cut off frequency
- RA = R1 = R13 = 160kΩ
- RB = R2 = R14 = 120kΩ
- C = C1 = C2 = C3 = C4 = 0.2μF

3.3.3 Fourth order low pass filter circuit

The fourth order low pass filter is the final stage of EOG amplifier circuit. This stage is implemented due to aliasing. Aliasing may occur if the input signal has the frequency components that are greater than half of sampling frequency. The sampling frequency that is achieved through custom software, namely 'Processing' is 100Hz.

Since power line noises have frequency range between 50-60Hz which is greater than half of the sampling frequency, there is a need to implement an anti-aliasing filter. Figure 15 below shows the stage of the fourth order low pass filter.

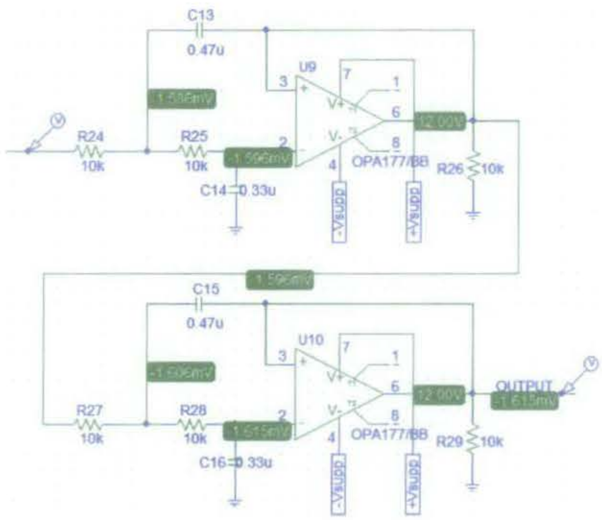

Figure 15 : Fourth order low pass filter

To ensure good performance, the cut off frequency of this filter should not exceed a quarter of the sampling rate [2]. The chosen cut off frequency is 30Hz. The component values are selected based on Equation 6 and 7.

$$C_A = \frac{0.9076}{2\Pi f_c R} \quad (6)$$

$$C_B = \frac{0.6809}{2\Pi f_c R} \quad (7)$$

where,

- $C_A = C_{13} = C_{15} = 0.47\mu F$
- $C_B = C_{14} = C_{16} = 0.33\mu F$
- $R = R_{24} = R_{25} = R_{27} = R_{28} = 120k\Omega$

3.4 Data Calibration

After the signal is amplified and filtered, an analog to digital converter (ADC) will be used to obtain the signal in digital form. However, most ADC was designed to operate within 0 to 5V signal range.

The amplifier and filter circuit was designed to operate within -2.5 to +2.5V. This means, another stage needs to be implemented to add an offset to the signal before it goes into ADC.

This problem can be solved by using a summer circuit. This circuit will add a DC offset to the original signal. A voltage divider using a potentiometer is implemented in this circuit so that the offset level can be controlled to suit the output reading.

The picture of the circuit is shown in Figure 16 below.

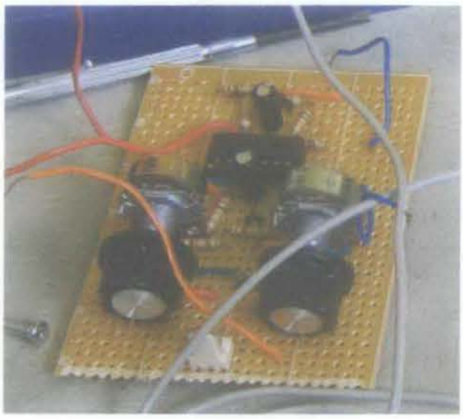

Figure 16 : Summer circuit

3.5 Data Acquisition

For data acquisition, it is obtained by using an analog to digital converter (ADC) which is connected to a computer. The ADC reads the analog signal and converts it to a digital signal. The ADC then sends the signal to custom software to display the result.

An Arduino Uno board is used as the ADC due to its ease of use, and user friendliness. Another alternative for ADC purpose is to use Microchip PIC16F, but it will need an external circuit to work as ADC thus increasing the complexity of the project.

Another alternative is by using a dedicated ADC chip, which will provide a more accurate reading; however these chips are likely to be very expensive. Some of the advantages of using this chip is that the ADC can read very high voltage ranges, and it gives a more accurate reading.

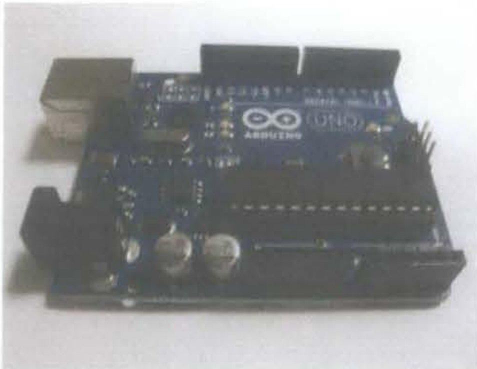

Figure 17 : Arduino Uno board

The coding for the Arduino Uno board for sketching waveform is shown in Figure 18. The full coding for processing output is attached in Appendix A.

```
#define ANALOG_IN 0

void setup() {
  Serial.begin(9600);
}

void loop() {
  int val = analogRead(ANALOG_IN);
  Serial.print( 0xff, BYTE);
  Serial.print( (val >> 8) & 0xff, BYTE);
  Serial.print( val & 0xff, BYTE);
}
```

Figure 18 : Arduino's code for sketching waveform

One of the disadvantages of using the Arduino Uno board is that it can only read signals ranging from 0 to 5V. The EOG board was designed to give an output voltage ranging from -10V to +10V voltage swings.

Due to this reason, the resistor value at gain stage is changed several times until the reading is readable.

For the computer interfacing, custom software namely 'Processing' is used. This software is used since it is developed specifically for the Arduino board.

The coding for 'Processing' software is shown in Figure 19.

```
import processing.serial.*;

Serial port;  // Create object from Serial class
int val;      // Data received from the serial port
int[] values;

void setup()
{
  size(640, 480);
  // Open the port that the board is connected to and use the same speed (9
  println(Serial.list());
  port = new Serial(this, Serial.list()[1], 9600);
  values = new int[width];
  smooth();
}

int getY(int val) {
  return (int)(val / 1023.0f * height) - 1;
}

void draw()
{
  while (port.available() >= 3) {
    if (port.read() == 0xff) {
      val = (port.read() << 8) | (port.read());
    }
  }
  for (int i=0; i<width-1; i++)
    values[i] = values[i+1];
  values[width-1] = val;
  background(0);
  stroke(255);
  for (int x=1; x<width; x++) {
    line(width-x,   height-1-getY(values[x-1]),
         width-1-x, height-1-getY(values[x]));
  }
}
```

Figure 19 : Processing code

CHAPTER 4
RESULTS AND DISCUSSION

4.1 PSpice Simulation Results

In this part, all the results are obtained from simulation. The results are taken from four points of the whole circuitry. The points are - after the amplification stage, after the q-notch filter stage, after the high-pass filter stage, and after the low-pass filter stage.

4.1.1 Amplification Stage

The simulation result after the amplification stage (amplitude vs frequency) is shown in Figure 20 below.

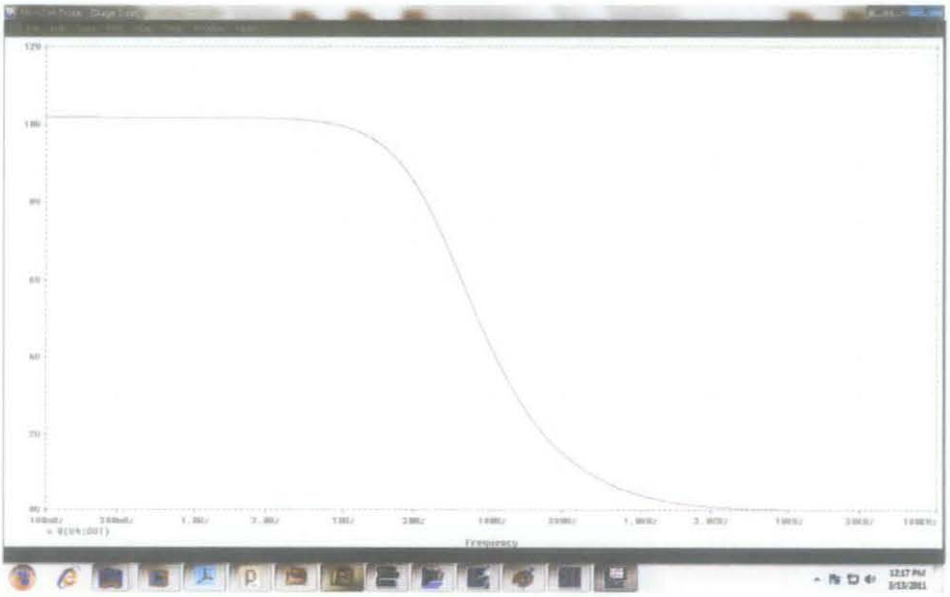

Figure 20 : PSpice simulation result of RF rejection circuit

As can be seen from the simulation results, the signal contains have frequency component higher than 1kHz will be filtered. The removal of the higher frequency signals is performed by the first stage of the circuitry, which is the radio frequency interference removal stage.

The useful data obtained from the simulation result is summarized are Table 1. For each of the output values, the simulated input value is set to 100μV.

Table 1 : Simulation Result of Amplification Stage

Frequency (Hz)	Output voltage (V)
0	9.978
1	9.973
10	8.898
30	7.270
100	3.688
1000	0.443

From the result, it also shows that when the input voltage is 100μV, the output voltage may be amplified up to approximately 10V, depending on the frequency's component. The amplification is done by through two stages which are pre-amplifier stage and gain stage.

Theoretically, the amplification of each individual stage can be summarized in Table 2 and Table 3 below.

Table 2 : Amplification at pre-amplifier stage (theoretical)

Before amplification	After Amplification
10μV	10mV
50μV	50mV
100μV	100mV

Table 3 : Total amplification of EOG amplifier (theoretical)

Before amplification	After Amplification
10mV	1V
50mV	5V
100mV	10V

The input of EOG signal is between 10μV to 100μV. It can be seen from Table 2 that after the pre-amplification stage, the voltage is not large enough for further processing. In order for the EOG signal to be readable, the gain stage is implemented as the second stage for amplification purpose.

After going through the gain stage, the signal would be amplified to a readable value, theoretically. The output voltage of the signal may rise up to 10V depending on the frequency component of the signal itself.

So, it can be seen from the simulation result that by using radio frequency interference rejection circuit, the high frequency signal which is considered as an unwanted signal that is coupled through the electrode and its lead can be filtered and removed. The total amplification done by the two stages is approximately 100,000 times.

4.1.2 Q-notch filter

The simulation result after q-notch filter (amplitude vs frequency) is shown in Figure 21 below.

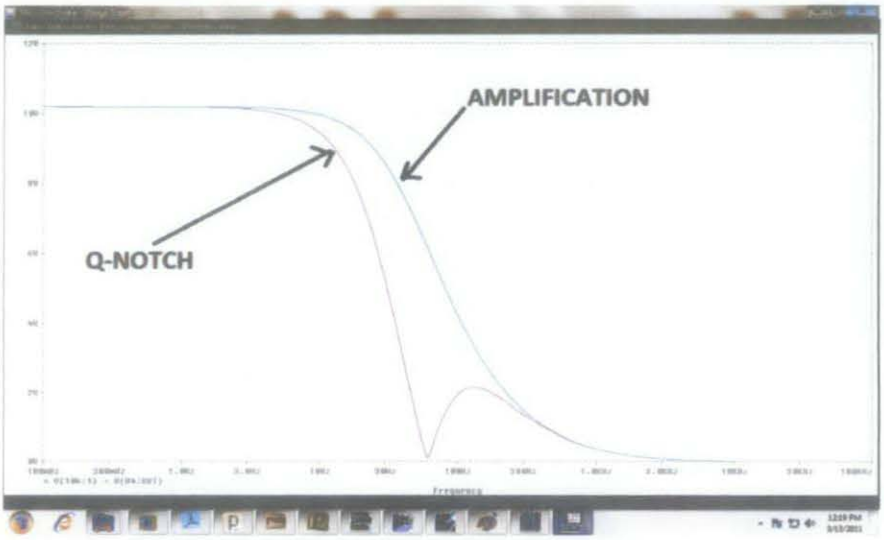

Figure 21 : Simulation result after q-notch filter

The graph indicated by 'amplification' show the result from the previous stage, which is the amplification stage, and the graph indicated by the 'q-notch' shows the simulation result after the q-notch filter stage.

As can be seen from the result, there is a sharp roll off at approximately 50-60Hz. This sharp roll off is provided by the q-notch filter. The terms 'Q' in the 'Q-notch filter' refers to the sharpness of the roll off.

The selected circuit configuration for the q-notch is chosen due to its ability to control the 'Q' by using a variable resistor.

At the time of simulation, the variable resistor is set to 0.5 position (50%). The data obtained from the graph is summarized in Table 4 below.

Table 4 : Simulation result of q-notch filter

Frequency (Hz)	Output voltage (V)
1	9.978
5	9.968
10	8.724
30	3.514
50	0.225
100	1.920
200	1.868
1000	0.337
2000	0.077

It is to be noted that the graph can be varied depending on the position of the variable resistor knob. At the time of simulation, the variable resistor is set to 0.5 position (50%).

The effect of using the variable value of Q can be seen in Figure 22. If the Q is too high, the roll off will be too sharp, and the removal may not cover the entire power line noise frequency ranges. If the Q is too low, the filter may remove the desired signal. By using the selected q-notch circuit configuration, it will provide more controllability over the performance.

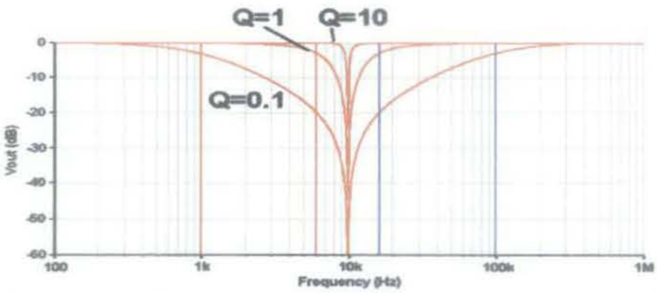

Figure 22: The effects of different q's of q-notch filter

4.1.3 Fourth order high pass filter

The simulation results after fourth order high pass filter (amplitude vs frequency) is shown in Figure 23 below.

Figure 23 : Simulation result after high pass filter

The graph indicated by 'q-notch' label shows the result from the previous stage, which is the q-notch filter stage, and the graph indicated by the 'high-pass' shows the simulation result after the fourth order high-pass filter stage.

The useful data obtained from the graph are summarized in Table 5 below.

Table 5 : Simulation result of high pass filter stage

Frequency (Hz)	Output voltage (V)
0.10	2.507
0.15	5.366
0.25	8.120
0.30	8.733
0.50	9.132
1.00	9.978

From the simulation result, it can be seen that at lower frequencies, the signal is filtered. The purpose of this filter stage is to remove substantial DC offsets that may be caused by many factors, such as the humidity of the air, the temperature of the skin, and sweating of the skin.

The fourth order circuit configuration is chosen in order to increase the roll off rate. This is to ensure that it will not remove the original EOG signal.

4.1.4 Fourth order low pass filter

The simulation result after the fourth order low pass filter is shown in Figure 24 below.

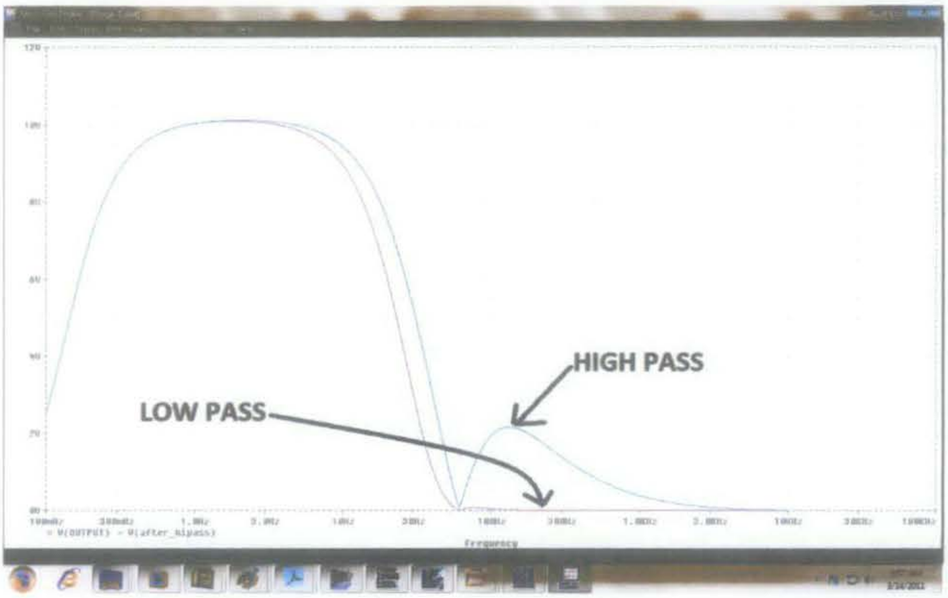

Figure 24 : Simulation result after low pass filter

The graph indicated by the 'high pass' shows the result from the previous stage, which is the fourth order high pass filter stage, and the graph indicated by the 'low pass' shows the simulation result after the fourth order low pass filter stage.

The useful data obtained from the graph is summarized in Table 6.

Table 6 : Simulation result of low pass filter

Frequency (Hz)	Output voltage (V)
0.10	2.507
0.25	8.120
0.50	9.132
1.00	9.978
10.00	8.452
30.00	3.138
50.00	0.165
100.00	0.046
1000.00	0.013

From the results, it shows that the graph after the fourth order low-pass filter is quite similar with the previous result, except for the frequency range of approximately 50Hz-1kHz which are filtered.

As the conclusion, at the final output terminal, the signal is amplified and unwanted noise will be removed.

The overall performance of the whole circuitry (amplitude vs frequency) is shown in Figure 25, and the simulation result at each stage (amplitude vs frequency) is summarized in Figure 26.

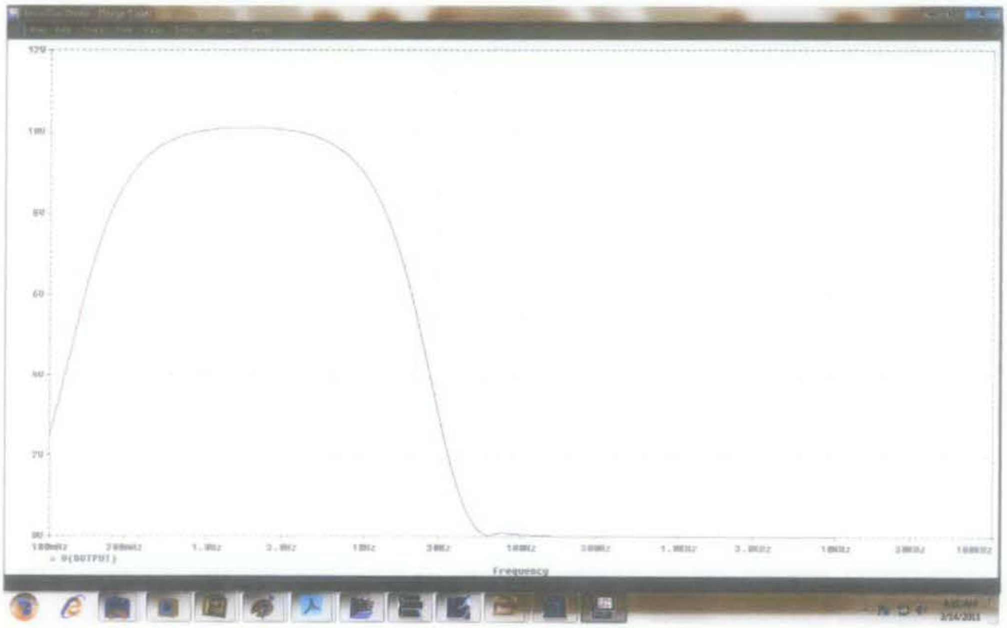

Figure 25 : Overall performance of EOG circuit

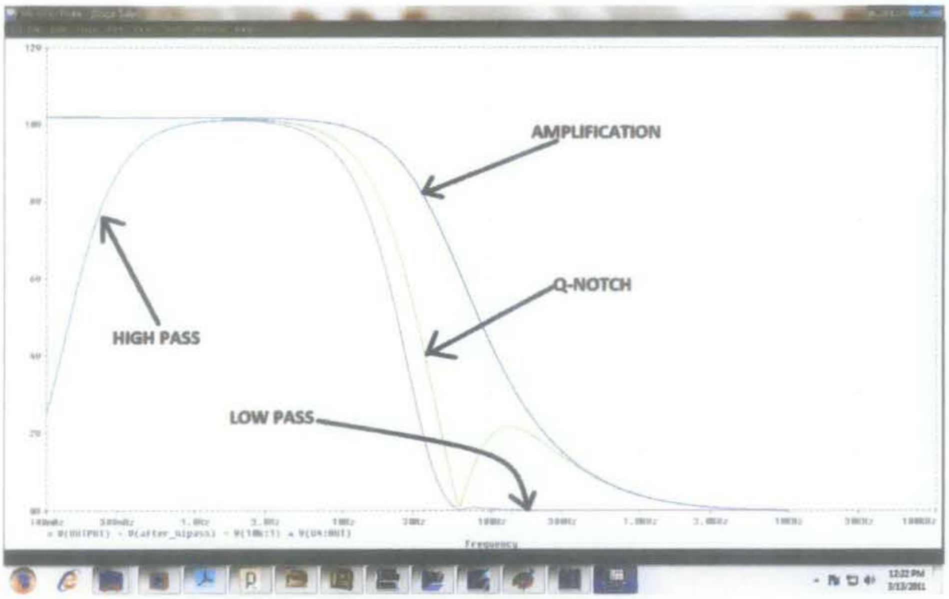

Figure 26 : Simulation result at each stage

The graph indicated by the 'amplification' shows the result after the amplification stage, the 'q-notch' shows the result after the q-notch filter stage, the 'high-pass' shows the result after the fourth order high pass filter stage, and the 'low-pass' shows the result after the fourth order low pass filter stage.

4.2 Actual Results

In this part, all the results are obtained by using a microcontroller. This microcontroller has a built-in analog to digital converter (ADC) module, which reads the analog signal and converts it to a digital signal. The digital signal is processed based on the programming code which is attached on the Appendix A.

From the results, it can be said that the amplifier is functional. However, the output control part is not 100% complete due to time constraint. The microcontroller is programmed to control the horizontal channel only.

4.2.1 Looking right and left

The results of the device for horizontal eye movements are very good. Using oscilloscope software that reads analog value from the microcontroller, the signal in real time can be observed.

The result of looking right is shown in Figure 27 and Figure 28.

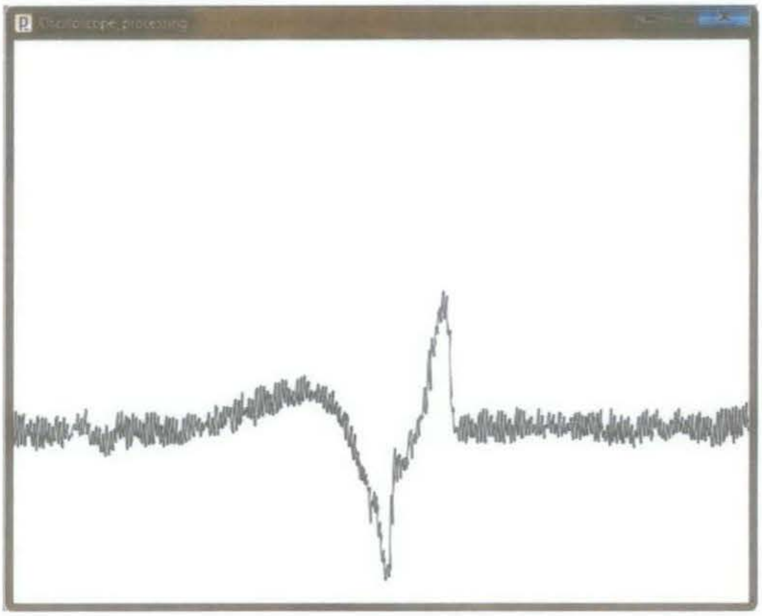

Figure 27 : Looking right instantly

From Figure 27, it shows the result when looking right at an instant. The eye is quickly moved to the right and back to center. When the eye is moving right, the right electrode will measure voltage from the cornea, and left electrode will measure voltage from the retina. As a result, the voltage will rise instantly as the eye is moved to the right.

The low voltage part represents the situation where the eye is moving back to the center. This situation can be observed clearly by doing the next experiment, where the eye is looking right for quite a moment, before it moved back to center position. The result of this experiment is shown in Figure 28.

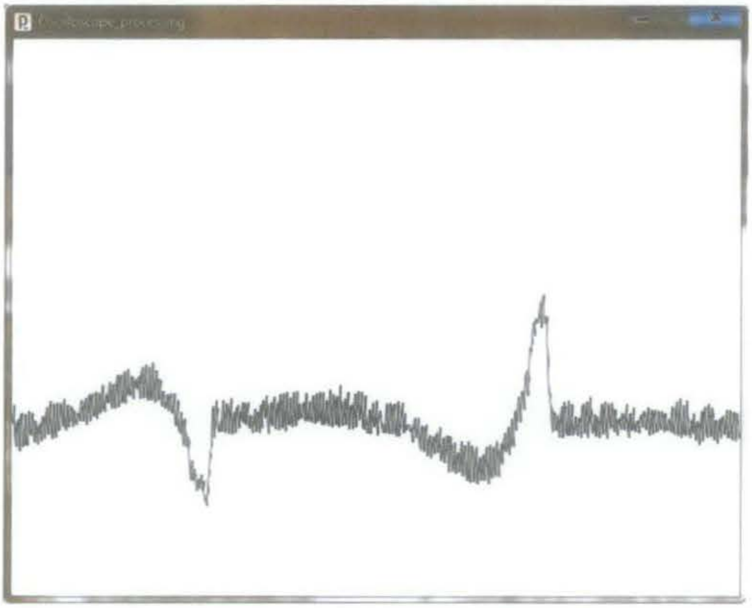

Figure 28 : Looking right for long time

For the left movement, the result is shown in Figure 29 and Figure 30.

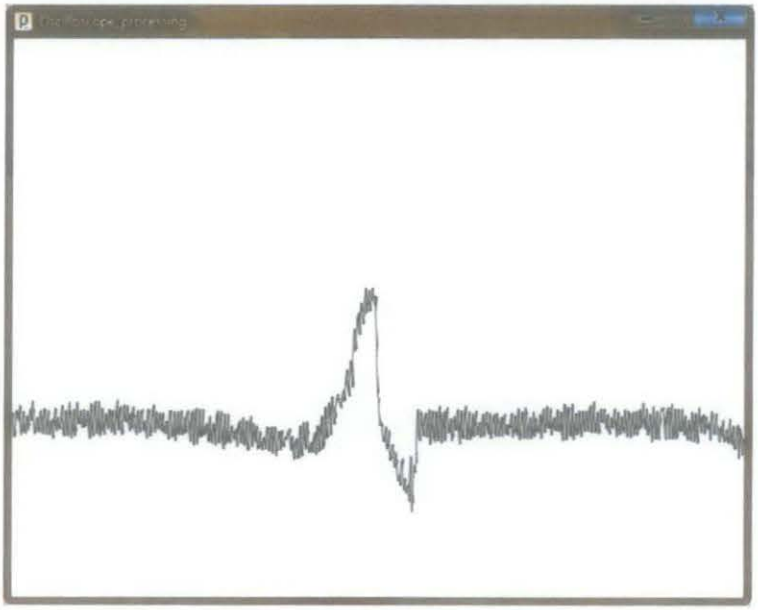

Figure 29 : Looking left instantly

Figure 29 shows the result when looking left at an instant. The eye is quickly moved to the left and back to center. When the eye is moving left, the left electrode will measure voltage from cornea, and right electrode will measure voltage from retina. As a result, the voltage will drop instantly as the eye is moved to the left.

The high voltage part represents the situation where the eye is moving back to the center. This situation can be observed clearly by doing the next experiment, where the eye is looking left for quite a moment, before it moved back to center position. The result of this experiment is shown in Figure 30.

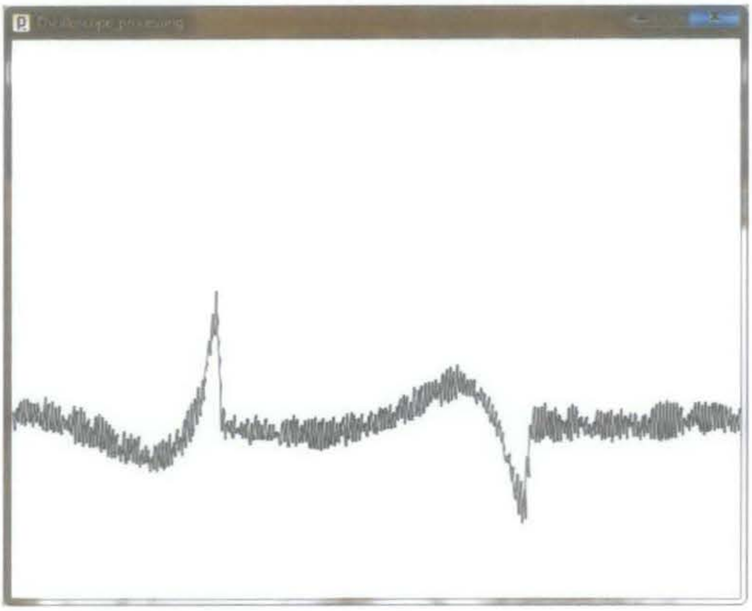

Figure 30 : Looking left for long time

For output control, three LEDs are used to represent left, right and center movements. Please refer to Appendix F for the results of the horizontal channel output control.

4.2.2 Looking up and down

The measurements of looking up and down are quite hard to be undertaken compared to looking right and left. Due to the size of electrodes, it is hard to attach them on right positions. The signal for up and down movements is not very reliable. The result for looking up and down is shown in Figure 31 and Figure 32.

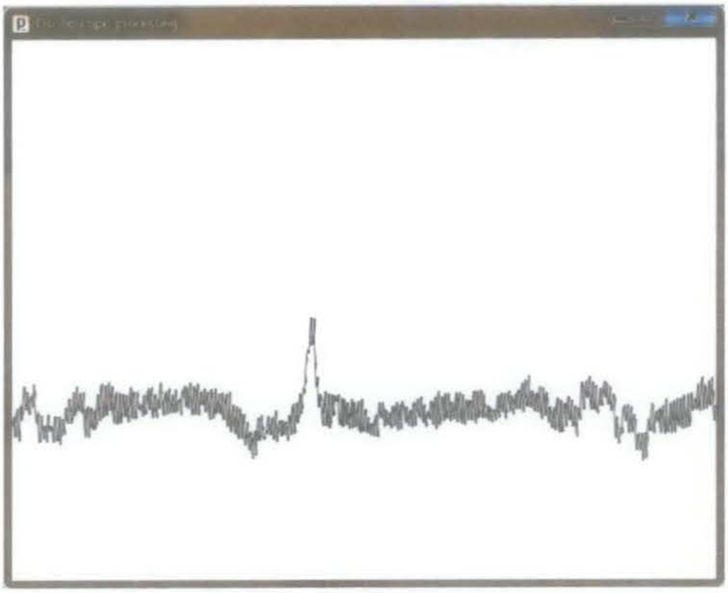

Figure 31 : Looking up

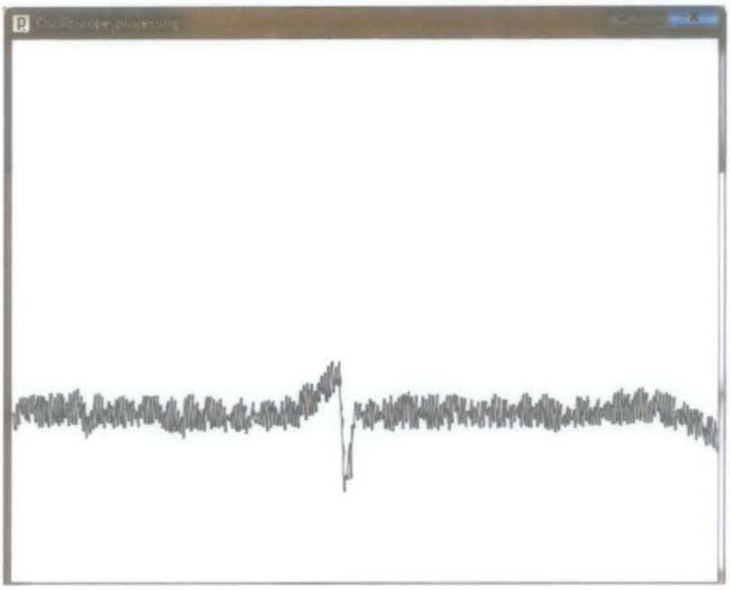

Figure 32 : Looking down

As can be seen from the results, the voltage will rise when looking up, and will drop when looking down. Compared to horizontal movements, the increment of voltage is not much. This has caused difficulties for output control, because it is hard for the eye to stay at a constant position. A little of unconscious movement may affect the output.

For other types of movement, the results are attached in Appendix E.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The prototype of this project is working properly. It consists of two amplification stages, which are pre-amplifier stage and main amplification stage. The pre-amplifier stage provides a gain of about 1000 times, and main amplification stage provides a gain of 100 times. The total amplification of both stages is approximately 100,000 times.

One of the biggest challenges in this project is to remove the unwanted noise. The original EOG signal has gone through several filtering stages in order for it to be readable and free from noise.

The result of the prototype is very good. The difference between right and left movement is very clear, and it is easy to distinguish between these two movements. Programming code for horizontal movements has been developed, and it is working well. However, a better programming code can be developed in order to give better output controls.

For vertical movements, the output reading is not very reliable, since the difference of high and low voltages are small. This may be due to the position of electrodes. The size of the electrodes are big, and it is hard to attach the electrodes to the right position. With smaller electrodes, the measurement for up and down movements might be better.

As conclusion, this project is not 100% complete yet. Programming code for vertical eye movements still needs to be developed. Even though the prototype works well, some minor improvements still can be incorporated to the amplifier and filter for better results.

5.2 Recommendations

The size of electrodes is quite big, and it is hard to attach them on the correct position. By using smaller sized electrodes, they can be attached on the right position easily, and the acquisition of EOG signal will be better.

Another recommendation related to electrodes is to avoid using disposable electrodes. It is hard to re-attach the electrodes if they are not positioned correctly. Plus, the gel between the electrodes and skin is very sticky, where dirt and dust are easily trapped.

Regarding the prototype, it can be improved further. Even though the signal is readable, some noise patterns still can be seen. By adding more filtering stages, the noise patterns can be eliminated, and better results will be obtained.

For programming part, the vertical channel is not completed yet. For horizontal motion, even though it is done, it still can be improved to give a better output control.

By doing further research on the signal patterns, more information can be extracted such as eye movement types and the position of the eyes.

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Appendix A : Programming Code

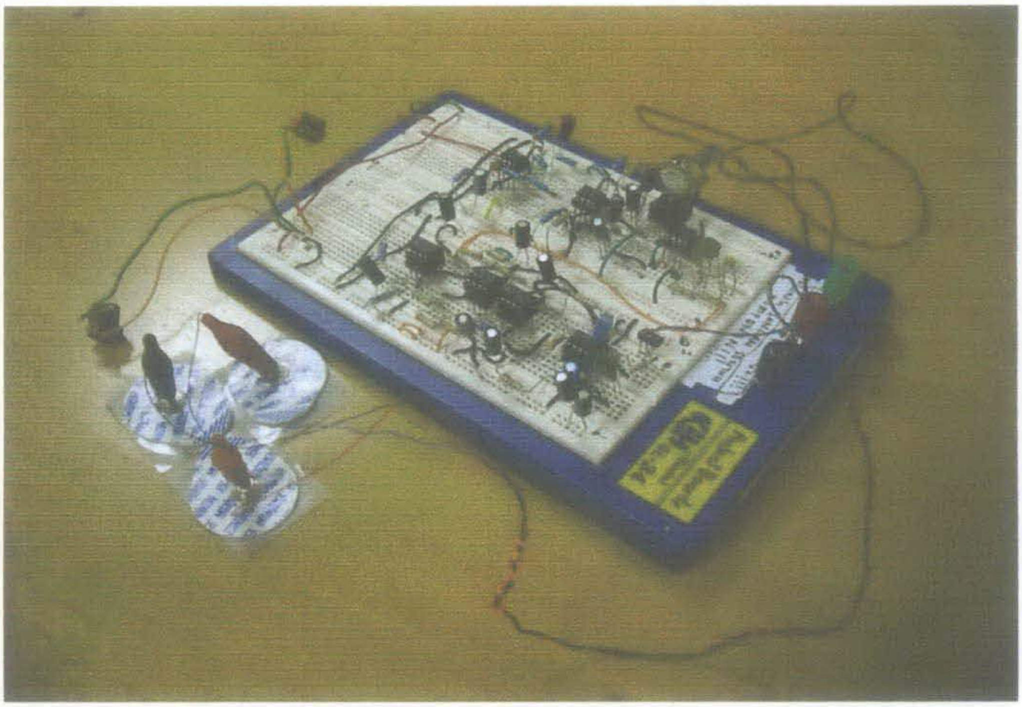
```
int  a = 0;
int  b = 0;
int  c = 0;
int  d = 0;

int  w = 0;
int  x = 0;
int  y = 0;
int  z = 0;

const int analogPin = A0;     // pin that the amp is attached to
const int ledPin1 = 11;        // pin that the LED is attached to
const int ledPin2 = 12;
const int ledPin3 = 13;

const int th_H = 614;
const int th_L = 410;
const int th_MH = 614;
const int th_ML = 410;

///////////////
/////setup/////
//////////////
void setup() {

  pinMode(ledPin1, OUTPUT);
  pinMode(ledPin2, OUTPUT);
  pinMode(ledPin3, OUTPUT);

  Serial.begin(9600);
}
////////////////start//////////////

void loop() {
  int Anal = analogRead(analogPin);

//////////////////////////////////////////////
  if (a==0 && b==0 && c==0 && d==0 && w==0 && x==0 && y==0 && z==0 && Anal<th_H && Anal>th_L)
    {
    digitalWrite(ledPin1,LOW);
    digitalWrite(ledPin2,HIGH);
    digitalWrite(ledPin3,LOW);

    Serial.print( 0xff, BYTE);
    Serial.print( (Anal >> 8) & 0xff, BYTE);
    Serial.print( Anal & 0xff, BYTE);
           }


/////////////////////////////////////////////trigger right start
  else if (a==0 && b==0 && c==0 && d==0 && w==0 && x==0 && y==0 && z==0 && Anal>th_H)
    {
     int a=1;
      while (a=1)
        {
         int Anal = analogRead(analogPin);
         if (Anal>th_H)
          { digitalWrite(ledPin1,HIGH);
            digitalWrite(ledPin2,LOW);
            digitalWrite(ledPin3,LOW);

            Serial.print( 0xff, BYTE);
            Serial.print( (Anal >> 8) & 0xff, BYTE);
            Serial.print( Anal & 0xff, BYTE);
          }
         else if (Anal<th_H && Anal>th_L)
          { int b=1;
            while (b=1)
              {
               int Anal = analogRead(analogPin);
               if (Anal>th_H)
                {
                 digitalWrite(ledPin1,HIGH);
                 digitalWrite(ledPin2,LOW);
                 digitalWrite(ledPin3,LOW);

                 Serial.print( 0xff, BYTE);
                 Serial.print( (Anal >> 8) & 0xff, BYTE);
                 Serial.print( Anal & 0xff, BYTE);

                 int a=1;
                 int b=0;
                }
               else if (Anal<th_H && Anal>th_L)
                {
                 digitalWrite(ledPin1,HIGH);
                 digitalWrite(ledPin2,LOW);
                 digitalWrite(ledPin3,LOW);

                 Serial.print( 0xff, BYTE);
```

```
Serial.print( (Anal >> 8) & 0xff, BYTE);
Serial.print( Anal & 0xff, BYTE);

int a=1;
int b=1;
}
else if (Anal<th_L)
{
  int c=1;
  while (c=1)
   {
    int Anal = analogRead(analogPin);
    if (Anal<th_L)
     {
      digitalWrite(ledPin1,HIGH);
      digitalWrite(ledPin2,LOW);
      digitalWrite(ledPin3,LOW);

      Serial.print( 0xff, BYTE);
      Serial.print( (Anal >> 8) & 0xff, BYTE);
      Serial.print( Anal & 0xff, BYTE);

      int a=1;
      int b=1;
      int c=1;
     }
    else if (Anal>th_L && Anal<th_ML)
     {
      int d=1;
      while (d=1)
       {
        int Anal = analogRead(analogPin);
        if (Anal<th_L)
         {
          digitalWrite(ledPin1,HIGH);
          digitalWrite(ledPin2,LOW);
          digitalWrite(ledPin3,LOW);

          Serial.print( 0xff, BYTE);
          Serial.print( (Anal >> 8) & 0xff, BYTE);
          Serial.print( Anal & 0xff, BYTE);

          int d=0;
         }
        else if (Anal>th_L && Anal<th_ML)
         {
          digitalWrite(ledPin1,HIGH);
          digitalWrite(ledPin2,LOW);
          digitalWrite(ledPin3,LOW);

          Serial.print( 0xff, BYTE);
          Serial.print( (Anal >> 8) & 0xff, BYTE);
          Serial.print( Anal & 0xff, BYTE);

          int d=1;
         }
        else if (Anal>th_ML && Anal<th_MH)
         {
          digitalWrite(ledPin1,HIGH);
          digitalWrite(ledPin2,LOW);
          digitalWrite(ledPin3,LOW);

          Serial.print( 0xff, BYTE);
          Serial.print( (Anal >> 8) & 0xff, BYTE);
          Serial.print( Anal & 0xff, BYTE);

          int a=0;
          int b=0;
          int c=0;
          int d=0;
         }
        else
{
 int a=0;
 int b=0;
 int c=0;
 int d=0;
 int w=0;
 int x=0;
 int y=0;
 int z=0;
}
       }
     }
    else
{
 int a=0;
 int b=0;
 int c=0;
 int d=0;
```

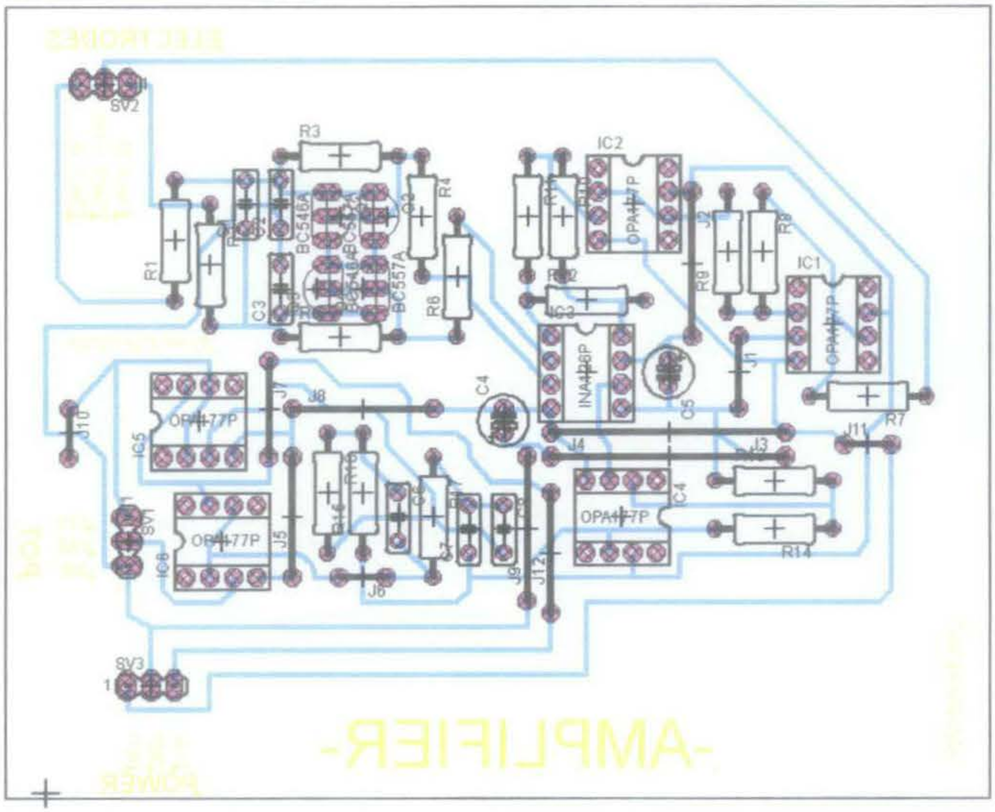
```
      int w=0;
      int x=0;
      int y=0;
      int z=0;
     }
                    }
                 }
                 else
     {
      int a=0;
      int b=0;
      int c=0;
      int d=0;
      int w=0;
      int x=0;
      int y=0;
      int z=0;
     }
              }
           }
           else
     {
      int a=0;
      int b=0;
      int c=0;
      int d=0;
      int w=0;
      int x=0;
      int y=0;
      int z=0;

     }
         }
     }

///////////////////////////////////////////trigger right done
///////////////////////////////////////////////////////
///////////////////////////////////////////trigger left start

  else if (a==0 && b==0 && c==0 && d==0 && w==0 && x==0 && y==0 && z==0 && Anal<th_L)
    {
     int w=1;
      while (w=1)
        {
         int Anal = analogRead(analogPin);
         if (Anal<th_L)
          { digitalWrite(ledPin1,LOW);
            digitalWrite(ledPin2,LOW);
            digitalWrite(ledPin3,HIGH);

            Serial.print( 0xff, BYTE);
            Serial.print( (Anal >> 8) & 0xff, BYTE);
            Serial.print( Anal & 0xff, BYTE);
          }
         else if (Anal<th_H && Anal>th_L)
          { int x=1;
            while (x=1)
              {
               int Anal = analogRead(analogPin);
               if (Anal<th_L)
                {
                 digitalWrite(ledPin1,LOW);
                 digitalWrite(ledPin2,LOW);
                 digitalWrite(ledPin3,HIGH);

                 Serial.print( 0xff, BYTE);
                 Serial.print( (Anal >> 8) & 0xff, BYTE);
                 Serial.print( Anal & 0xff, BYTE);

                 int w=1;
                 int x=0;
                }
               else if (Anal<th_H && Anal>th_L)
                {
                 digitalWrite(ledPin1,LOW);
                 digitalWrite(ledPin2,LOW);
                 digitalWrite(ledPin3,HIGH);

                 Serial.print( 0xff, BYTE);
                 Serial.print( (Anal >> 8) & 0xff, BYTE);
                 Serial.print( Anal & 0xff, BYTE);

                 int w=1;
                 int x=1;
                }
               else if (Anal>th_H)
                {
                  int y=1;
                  while (y=1)
                    {
                     int Anal = analogRead(analogPin);
```

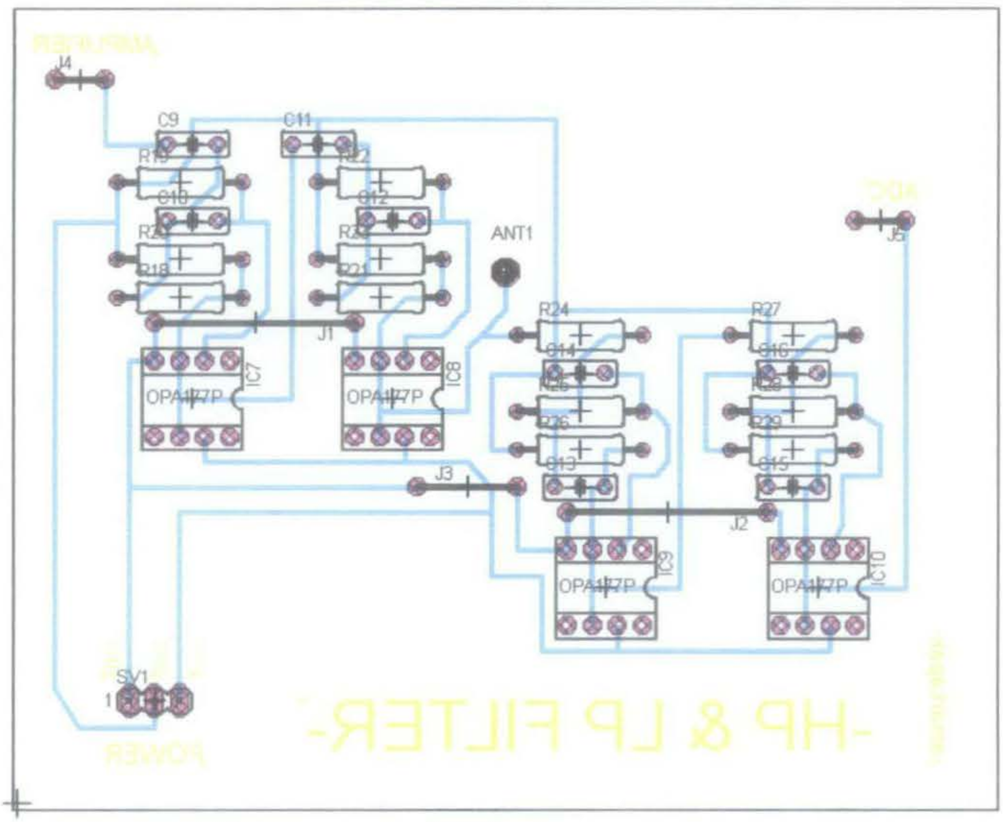
```
if (Anal>th_H)
 {
   digitalWrite(ledPin1,LOW);
   digitalWrite(ledPin2,LOW);
   digitalWrite(ledPin3,HIGH);

   Serial.print( 0xff, BYTE);
   Serial.print( (Anal >> 8) & 0xff, BYTE);
   Serial.print( Anal & 0xff, BYTE);

   int w=1;
   int x=1;
   int y=1;
 }
else if (Anal<th_H && Anal>th_MH)
 {
   int z=1;
   while (z=1)
     {
       int Anal = analogRead(analogPin);
       if (Anal>th_H)
         {
           digitalWrite(ledPin1,LOW);
           digitalWrite(ledPin2,LOW);
           digitalWrite(ledPin3,HIGH);

           Serial.print( 0xff, BYTE);
           Serial.print( (Anal >> 8) & 0xff, BYTE);
           Serial.print( Anal & 0xff, BYTE);
           int z=0;
         }
       else if (Anal<th_H && Anal>th_MH)
         {
           digitalWrite(ledPin1,LOW);
           digitalWrite(ledPin2,LOW);
           digitalWrite(ledPin3,HIGH);

           Serial.print( 0xff, BYTE);
           Serial.print( (Anal >> 8) & 0xff, BYTE);
           Serial.print( Anal & 0xff, BYTE);

           int z=1;
         }
       else if (Anal>th_ML && Anal<th_MH)
         {
           digitalWrite(ledPin1,LOW);
           digitalWrite(ledPin2,HIGH);
           digitalWrite(ledPin3,LOW);

           Serial.print( 0xff, BYTE);
           Serial.print( (Anal >> 8) & 0xff, BYTE);
           Serial.print( Anal & 0xff, BYTE);

           int w=0;
           int x=0;
           int y=0;
           int z=0;
         }
         else
{
 int a=0;
 int b=0;
 int c=0;
 int d=0;
 int w=0;
 int x=0;
 int y=0;
 int z=0;
}
     }
 }
else
{
 int a=0;
 int b=0;
 int c=0;
 int d=0;
 int w=0;
 int x=0;
 int y=0;
 int z=0;
}
      }
    }
    else
{
 int a=0;
 int b=0;
 int c=0;
```

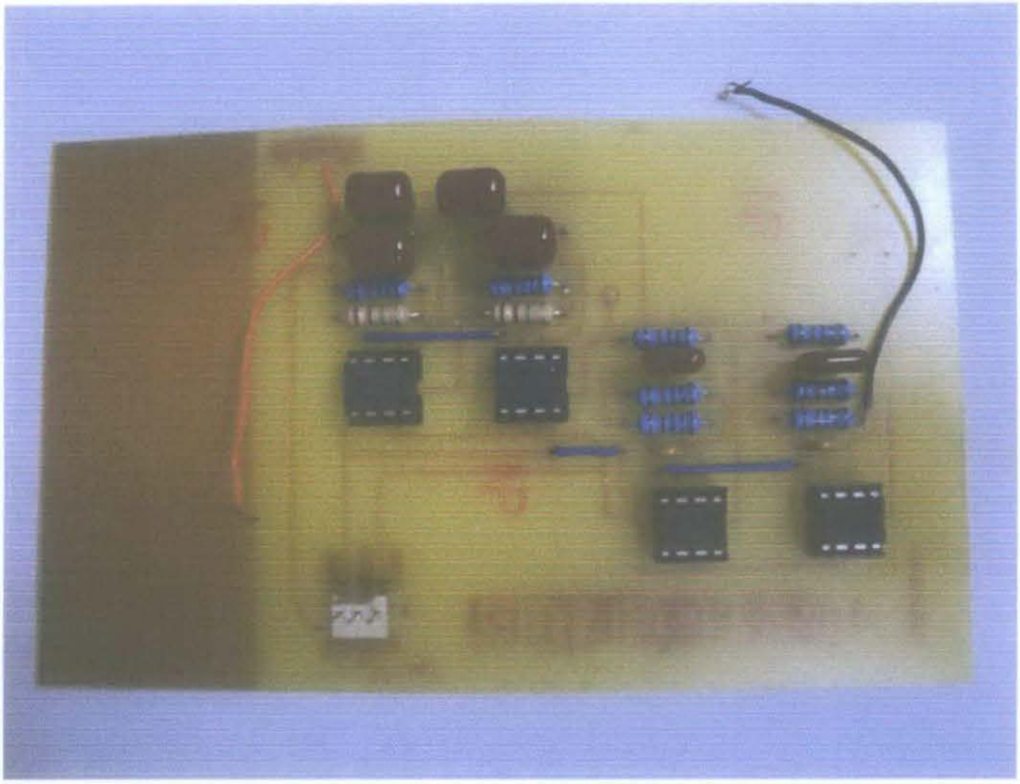
Appendix B : Prototypes

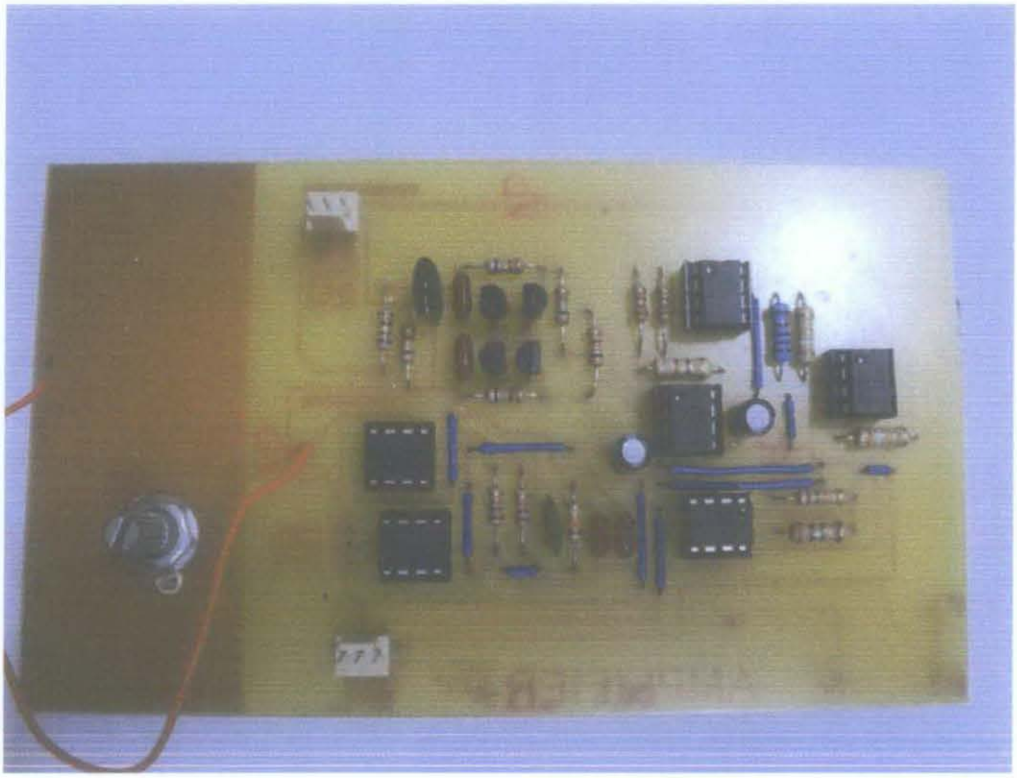


Appendix C : PCB Design

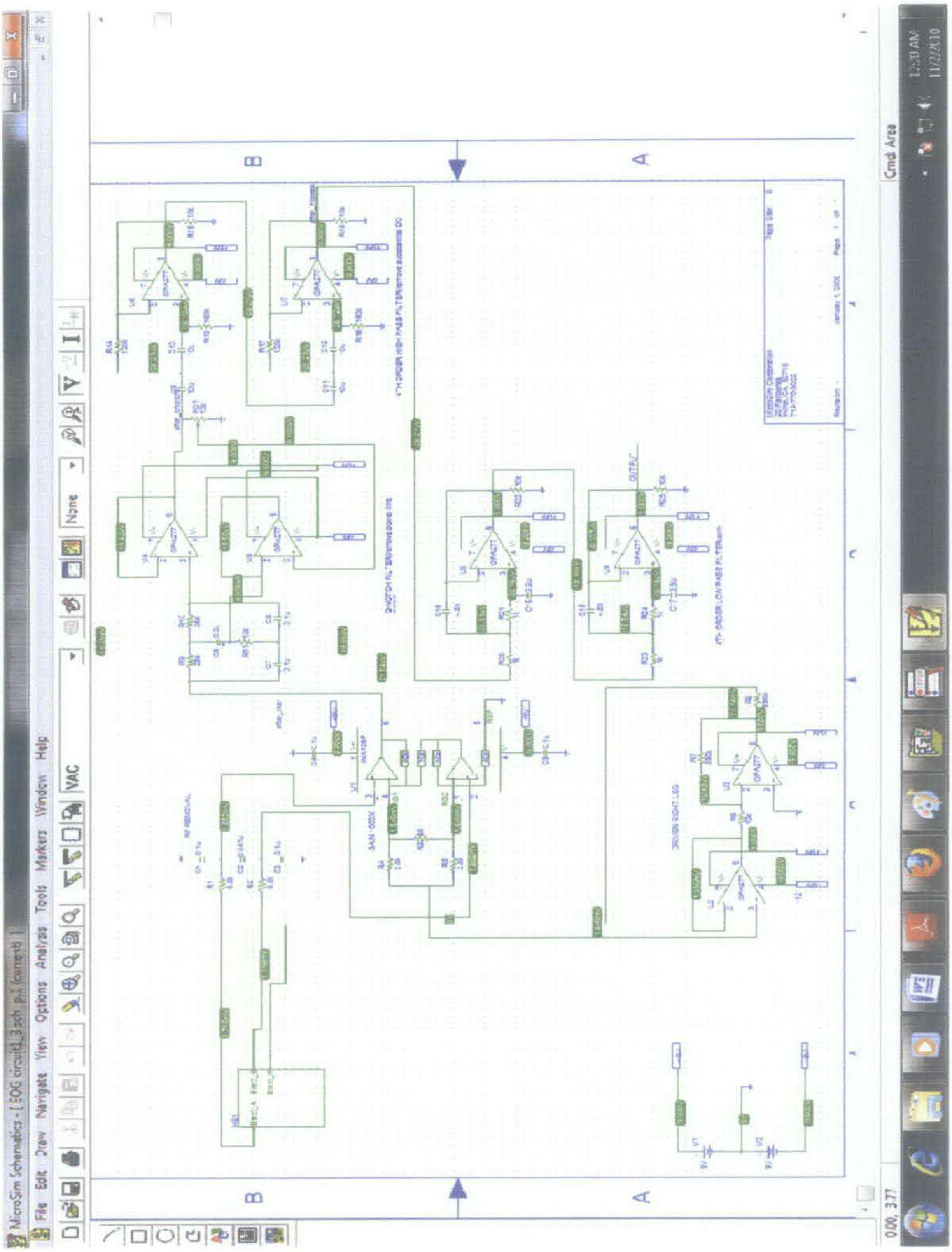




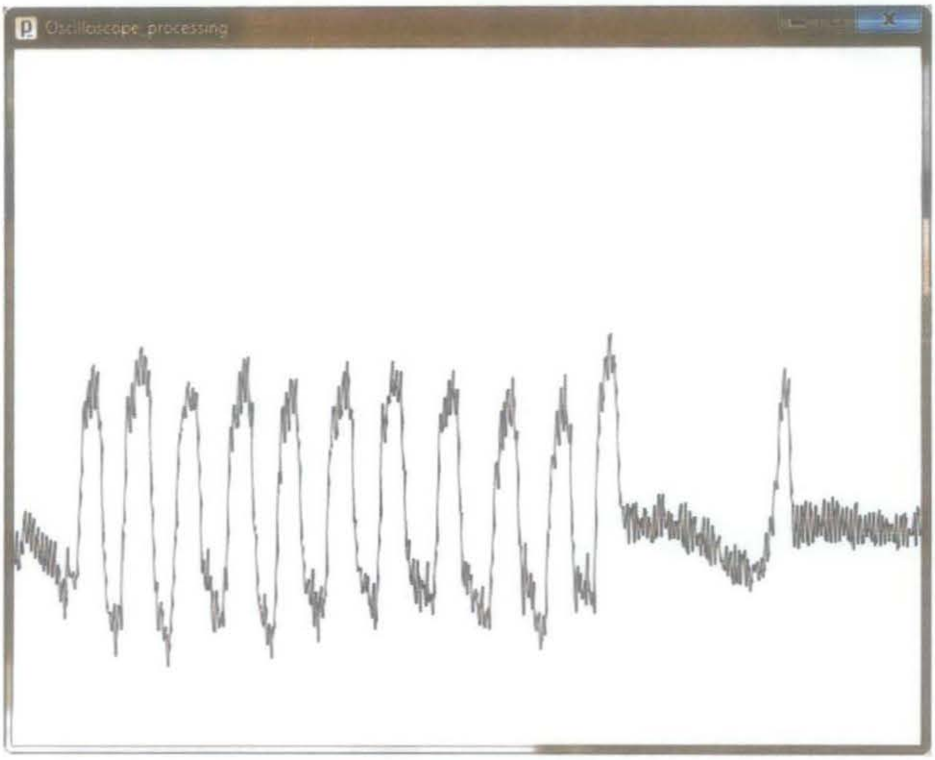




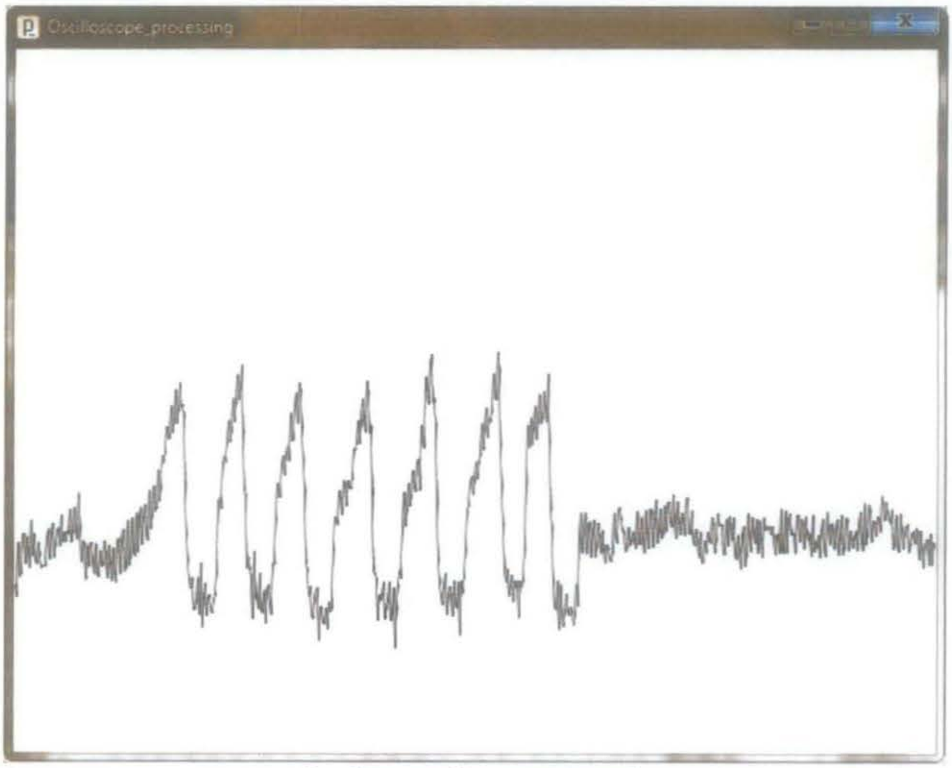
Appendix D : PSpice Circuit



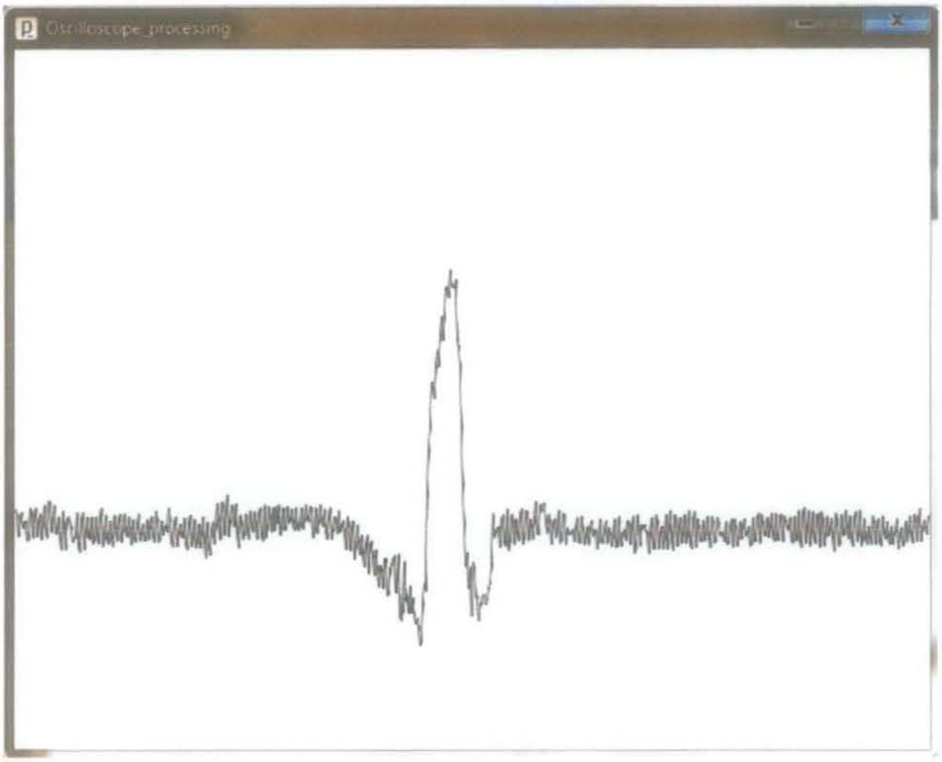
Appendix E : Output signals



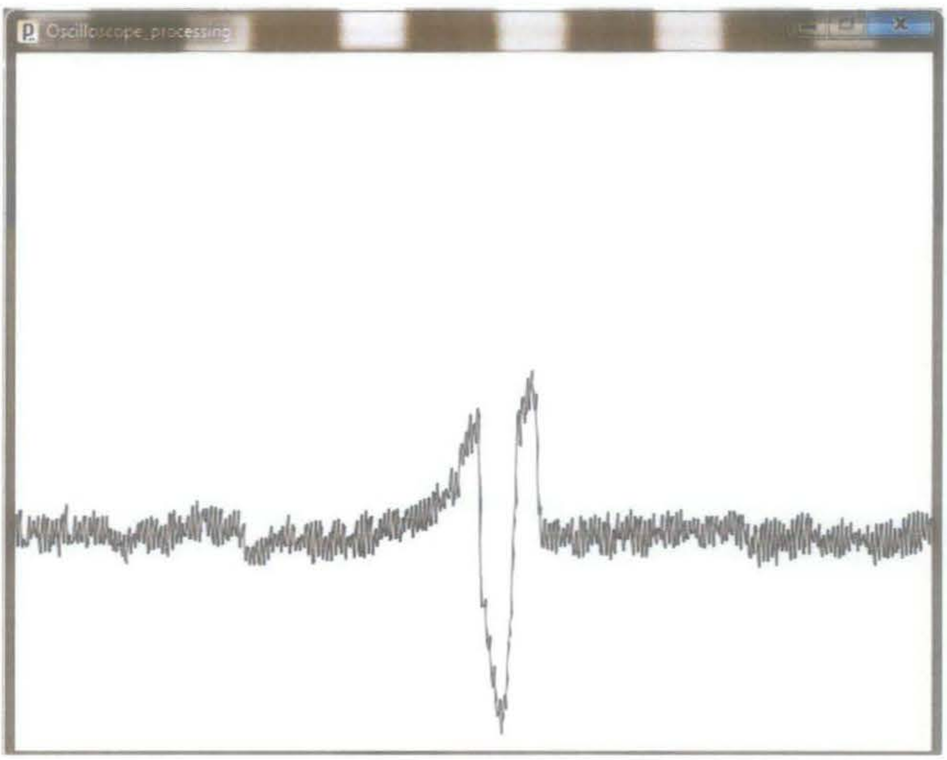
Looking right continuously



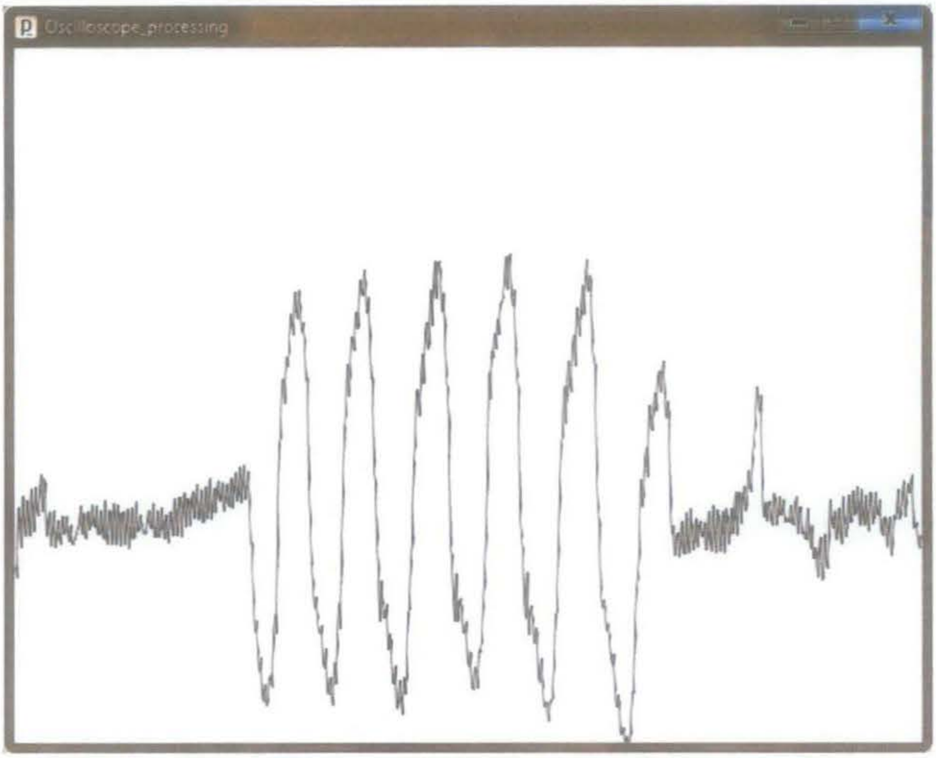
Looking right continuously



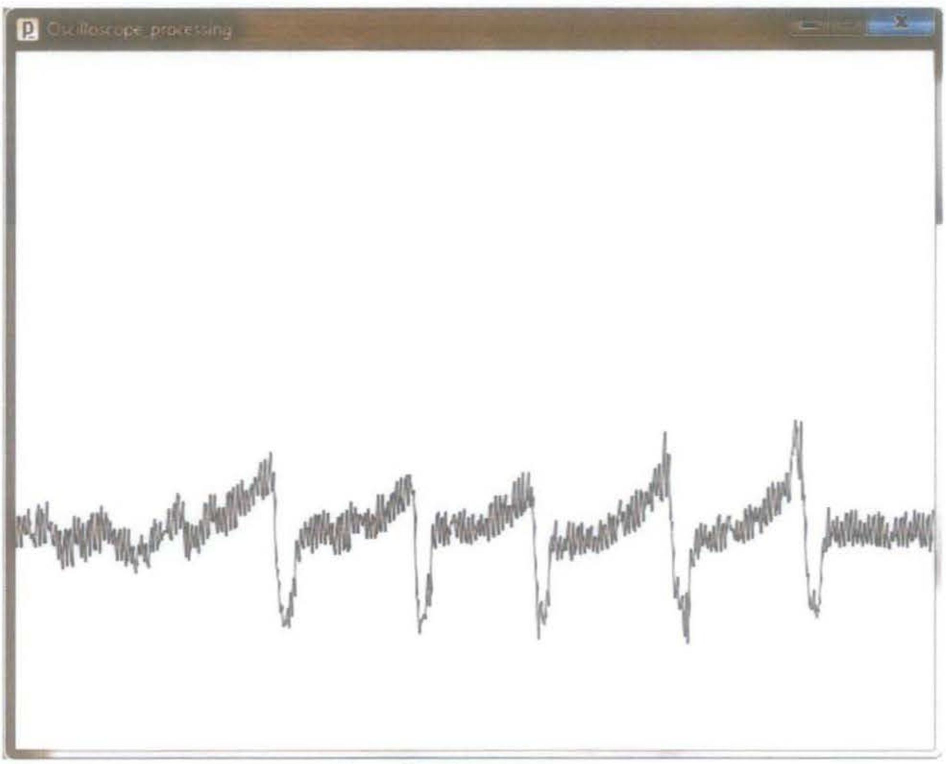
Looking left followed by right



Looking right followed by left

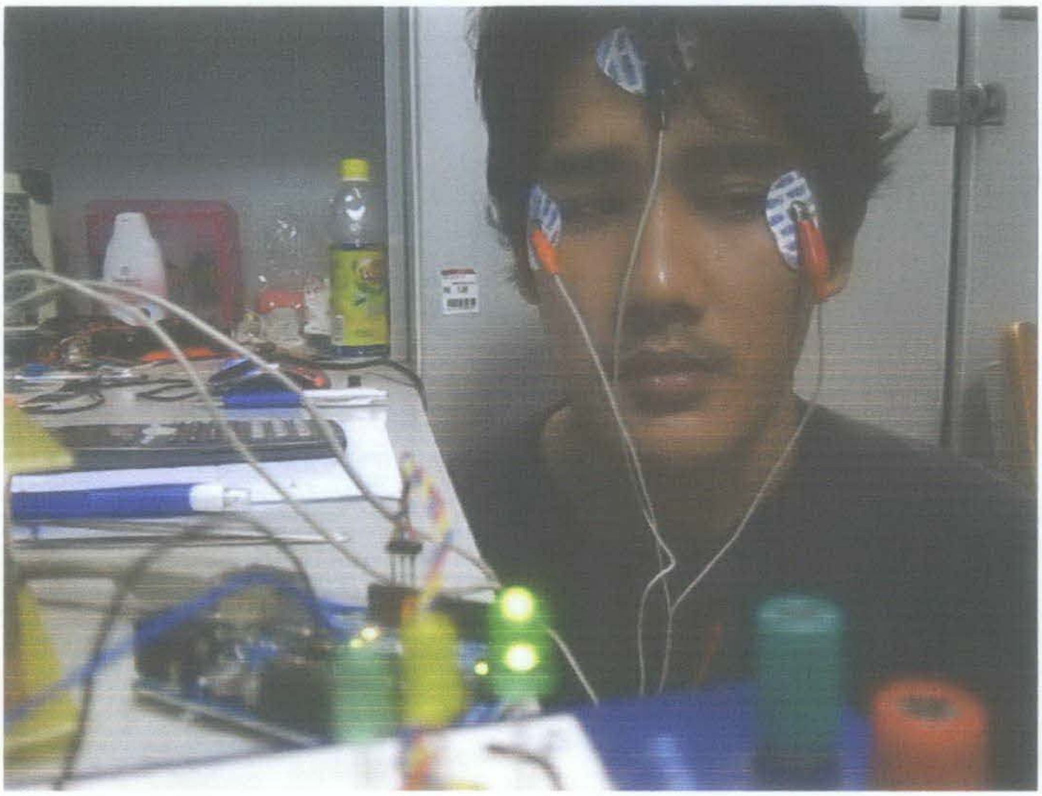


Continuously looking right and left



Eyes blinking pattern

Appendix F : Output results



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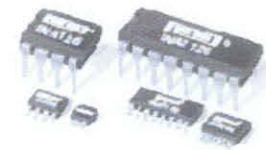


INA126
INA2126

*Micro*POWER INSTRUMENTATION AMPLIFIER
Single and Dual Versions

FEATURES

- LOW QUIESCENT CURRENT: 175µA/chan.
- WIDE SUPPLY RANGE: ±1.35V to ±18V
- LOW OFFSET VOLTAGE: 250µV max
- LOW OFFSET DRIFT: 3µV/°C max
- LOW NOISE: 35nV/$\sqrt{Hz}$
- LOW INPUT BIAS CURRENT: 25nA max
- 8-PIN DIP, SO-8, MSOP-8 SURFACE-MOUNT DUAL: 16-Pin DIP, SO-16, SSOP-16

APPLICATIONS

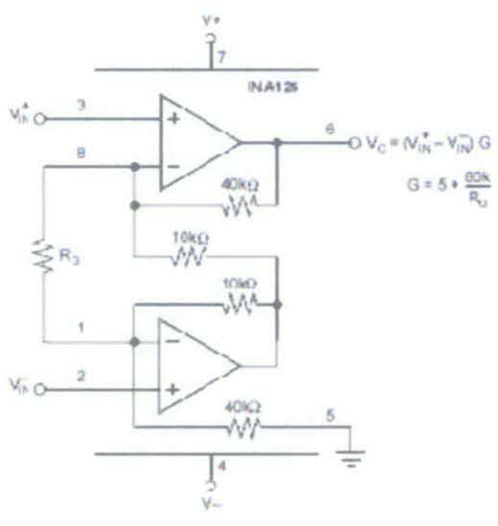
- INDUSTRIAL SENSOR AMPLIFIER: Bridge, RTD, Thermocouple
- PHYSIOLOGICAL AMPLIFIER: ECG, EEG, EMG
- MULTI-CHANNEL DATA ACQUISITION
- PORTABLE, BATTERY OPERATED SYSTEMS

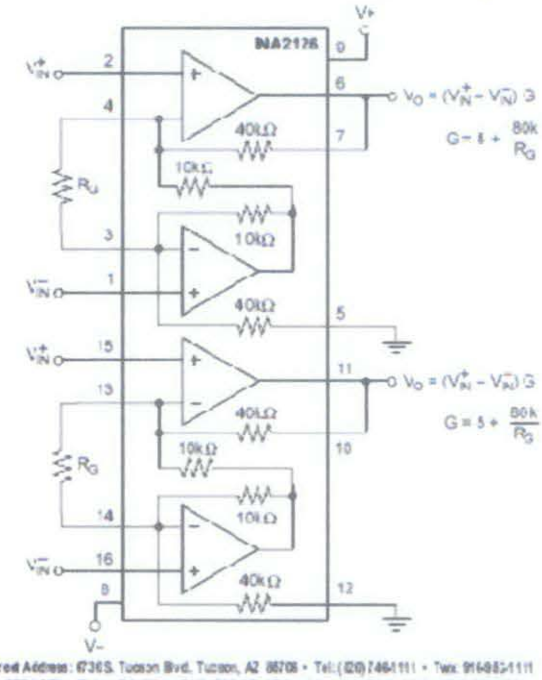
DESCRIPTION

The INA126 and INA2126 are precision instrumentation amplifiers for accurate, low noise differential signal acquisition. Their two-op-amp design provides excellent performance with very low quiescent current (175µA/chan.). This, combined with wide operating voltage range of ±1.35V to ±18V, makes them ideal for portable instrumentation and data acquisition systems.

Gain can be set from 5V/V to 10000V/V with a single external resistor. Laser trimmed input circuitry provides low offset voltage (250µV max), low offset voltage drift (3µV/°C max) and excellent common-mode rejection.

Single version package options include 8-pin plastic DIP, SO-8 surface mount, and fine-pitch MSOP-8 surface-mount. Dual version is available in the space-saving SSOP-16 fine-pitch surface mount, SO-16, and 16-pin DIP. All are specified for the –40°C to +85°C industrial temperature range.





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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

 PDS-1365C Printed in U.S.A. September, 1997

Appendix G: OPA 277 Datasheet

Burr-Brown Products
from Texas Instruments

OPA277
OPA2277
OPA4277

SBOS079A – MARCH 1999 – REVISED APRIL 2005

High Precision OPERATIONAL AMPLIFIERS

FEATURES

- ULTRA LOW OFFSET VOLTAGE: 10μV
- ULTRA LOW DRIFT: ±0.1μV/°C
- HIGH OPEN-LOOP GAIN: 134dB
- HIGH COMMON-MODE REJECTION: 140dB
- HIGH POWER SUPPLY REJECTION: 130dB
- LOW BIAS CURRENT: 1nA max
- WIDE SUPPLY RANGE: ±2V to ±18V
- LOW QUIESCENT CURRENT: 800μA/amplifier
- SINGLE, DUAL, AND QUAD VERSIONS
- REPLACES OP-07, OP-77, OP-177

APPLICATIONS

- TRANSDUCER AMPLIFIER
- BRIDGE AMPLIFIER
- TEMPERATURE MEASUREMENTS
- STRAIN GAGE AMPLIFIER
- PRECISION INTEGRATOR
- BATTERY POWERED INSTRUMENTS
- TEST EQUIPMENT

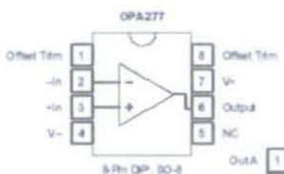
DESCRIPTION

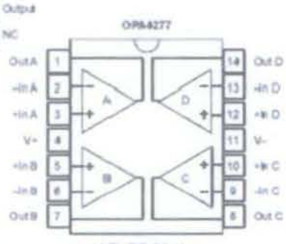
The OPA277 series precision op amps replace the industry standard OP-177. They offer improved noise, wider output voltage swing, and are twice as fast with half the quiescent current. Features include ultra low offset voltage and drift, low bias current, high common-mode rejection, and high power supply rejection. Single, dual, and quad versions have identical specifications for maximum design flexibility.

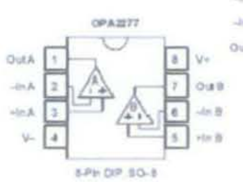
OPA277 series op amps operate from ±2V to ±18V supplies with excellent performance. Unlike most op amps which are specified at only one supply voltage, the OPA277 series is specified for real-world applications; a single limit applies over the ±5V to ±15V supply range. High performance is maintained as the amplifiers swing to their specified limits. Because the initial offset voltage (±20μV max) is so low, user adjustment is usually not required. However, the single version (OPA277) provides external trim pins for special applications.

OPA277 op amps are easy to use and free from phase inversion and overload problems found in some other op amps. They are stable in unity gain and provide excellent dynamic behavior over a wide range of load conditions. Dual and quad versions feature completely independent circuitry for lowest crosstalk and freedom from interaction, even when overdriven or overloaded.

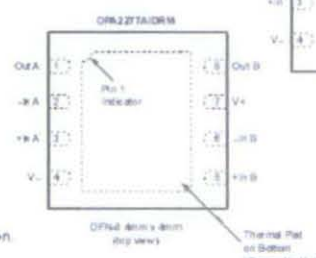
Single (OPA277) and dual (OPA2277) versions are available in DIP-8, SO-8, and DFN-8 (4mm x 4mm) packages. The quad (OPA4277) comes in DIP-14 and SO-14 surface-mount packages. All are fully specified from –40°C to +85°C and operate from –55°C to +125°C.

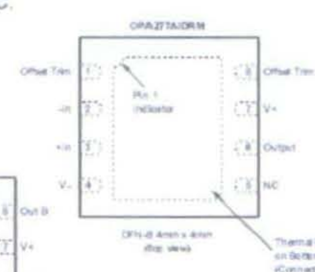






NC = No connection.





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