DEVELOPMENT OF ELECTRICAL RESISTANCE TOMOGRAPHY (ERT) DATA ACQUISITION PROTOCOLS FOR CONDUCTIVE MULTIPHASE PROCESSES

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Ir. Dr. Idris Bin Ismail
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
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December 2012

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.

Harold Usang Angai

ABSTRACT

This report describes a considerably low-cost improvement theory of existing data acquisition system for a 16-electrode Electrical Resistance Tomography (ERT). It comprises of electrical parts such as voltage measurement amplifier circuit and switching circuit. Quality of data acquired is crucial for future work of image processing which induced the importance of mentioned circuits. Experimentations are conducted on brine solution with different concentrations to classify lower and upper range of voltages for different applications as well as demonstrating the effect of different measurement protocols towards common mode voltages.

ACKNOWLEDGEMENTS

I would like to thank my respected supervisor, Ir. Dr. Idris Bin Ismail for his great guidance and supports throughout the project period. In addition, I would also like to express my utmost gratitude towards other lecturers that had indirectly assisted me in improving my research capability by giving constructive comments and recommendations.

Special thanks as well to my parents for their continuous supports morally and financially. Not to forget my beloved siblings for their assistance in various aspects that had brought me this far from the beginning of this project.

I would also like to thank Mr. Azhar for his kind assistance in the laboratory. His comments and suggestions had proved to be fruitful towards my project and personal knowledge throughout my research.

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LIST OF ABBREVIATIONS

ERT	– Electrical Resistance Tomography
EIT	– Electrical Impedance Tomography
ECT	– Electrical Capacitance Tomography
CMV	– Common mode voltage
CMRR	– Common mode rejection ratio
DAS	– Data Acquisition System
MPF	– Multiphase flow
LPF	– Low-pass filter
ADC	– Analogue to Digital converter
NR	– Newton Raphson
LBP	– Linear Back Projection
VCCS	– Voltage-Controlled Current Source
PGA	– Programmable Gain Amplifier
MOSFET	– Metal-Oxide Semiconductor Field Effect Transistor
DC	– Direct current
dB	– Decibel

Chapter 1
INTRODUCTION

1.1 Background

Electrical Resistance Tomography (ERT) had been developed solely for typical real-time monitoring of multi-phase flows in process engineering blocks [1]. The general idea of its process implementation is drawn from a continuous measurement technique which measure the differences in voltages between electrodes(sensors) around an outer cylindrical wall of monitoring premises *i.e.* pipelines, circular vessels *etc*. Coherent to that, it scans an entire 'slice' of the measurement area which will be used for image reconstruction in the latter process [1]. Nonetheless, the fundamental core of all the applications is its Data Acquisition System(DAS) which gather all the voltages measurements by using a well known specific measurement strategy namely the Normal Adjacent Strategy [1,2] in which for N number of electrodes, N(N-1)/2 measurements will be acquired. Other than that, there were also other measuring approaches that can be applied such as the Balanced method, Linear Array method and Conducting Boundary method respectively [1]. In addition, further explicit developments within several areas of this DAS are required to enhance the capability as well as extending its limitations by improving its flexibility in terms of the measured data acquisition processes. In fact, there are some known weaknesses of the existing ERT system such as its data acquisition speed, stability and reliability [3] that will eventually affect design basis of the overall system. All these issues will be discussed in detail in the latter sections.

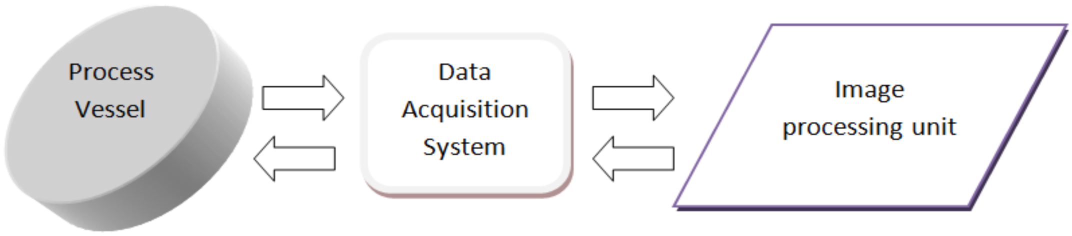


Figure 1: Typical process flow of ERT system

1.2 Problem Statement

ERT Data Acquisition System main predicament is commonly associated with data acquisition speed [3,5]. For a normal setup of sensors *i.e.* electrodes, 16 electrodes will be utilized and over hundreds of measurements will be taken and data interpretation period needs to be at its minimal bar in order to effectively process these data especially in real-time monitoring activities [4]. Other than that, decision on electrode material will as well coincide with the data acquisition design because production cost and efficiency will be the balancing entities which affect the stability of the whole system. Furthermore, common materials used for sensing electrodes are basically stainless steel, brass, and silver palladium alloy [1] which draw complications on purchasing them in appropriate scales. Moreover, overall stability of the system needs to be achieved as to produce high quality images of tested variables.

1.3 Objectives

The objective of this project is to improve the existing ERT system by focusing on the data acquisition system architecture. Nevertheless, the system can be enhanced by designing a better switching and signal conditioning circuit [6,7] inclusive of high-speed switching, filters, amplifiers, demodulators *etc.*, which will be the focal points of this study.

1.4 Project Relevancy

This project is very relevant especially in recent times where the applications cover a wide scope of technology. In fact, process monitoring is involved in every process industry especially Oil and Gas industry. Oil and Gas industry is starting to utilize

ERT system as a means to provide geophysical imaging for boreholes and sub-surface [8]. Other than that, there were also applications for multiphase flow measurements that are currently using the similar theory and implementation scheme as well. In addition, application of ERT is safer if it is to be compared to the typical multiphase measurement technology which uses radioactive materials to produce gamma (ɣ) ray [4] as a means of measurement. By perceiving on these fields, this project has the potential outbreak of technology which will bring about changes in the future technology of process industry globally.

1.5 Project Feasibility

Based on several studies on ERT Data Acquisition System, this project can be considered as a feasible one because any enhancement can be made in part-by-part basis. This means that every part plays a very important role in the DAS quality and modifications can be made focusing on several parts according to the time frame available. Furthermore, future improvements can be done as a continuity of the project in the future.

Chapter 2:
LITERATURE REVIEW

2.1 Electrical Tomography

There are various applications of tomography in numerous fields of industries. Its implementation is very much demanded due to the non-destructive nature of the system. Measurements distribution can be obtained from examining the electrical properties such as capacitance and conductivity in general.

2.1.1 Electrical Impedance Tomography (EIT)

EIT is basically a measurement technique that collects different conductivity distribution of a process vessel by examining the impedance between adjacent electrodes surrounding it. One of the advantages of EIT is that it is non-invasive in nature and does not require any ionizing radiation [17]. Secondly, the design of EIT can also be low in pricing as it is simpler to be designed. However, the drawbacks are significant because EIT produces low quality images due to reconstruction problems as an adverse effect of restricted number of electrodes used [18].

2.1.2 Electrical Capacitance Tomography (ECT)

ECT method however, injects current to one electrode and relative voltages values are taken with respect to the excitation electrode. By looking at the advantages, ECT has zero radiation, low cost, and the nature of non-invasive and non-intrusive properties [19]. On the other hand, ECT is often overwhelmed with stray capacitance that is emitted from the circuit which usually resulted in low measurement sensitivity [20].

2.1.3 Electrical Resistance Tomography (ERT)

ERT has the advantage of being having lesser number of independent measurements for image reconstruction which made it a simpler model for image processing [21]. Other than that, ERT has also been tested to be functional remotely by satellite implementation which reduces necessary site visits and eventually promotes significant survey-cost decrement [8]. However, huge drawback for ERT is related to its low spatial resolution [8].

Table 1: EIT, ECT, and ERT characteristics

System	Advantages	Disadvantages	References
EIT	Simple and low cost design. No ionizing radiation.	Poor imaging due to restricted number of electrodes.	[19,20]
ECT	Non-invasive and non-intrusive in nature	Significant noise due to stray capacitance	[19,20]
ERT	Simpler image reconstruction process.	Low spatial resolution	[8,21]

2.2 ERT in Conductive Processes

Focusing on conductive processes, such as extraction of water from oil due to different levels of conductivity, ERT has the highest significance since it “slices” through process vessels mediums by means of spatial conductivity distribution. In brief, ERT is most effective when applied to any processes where conductivity of main tested phase is lesser and the other phases have different conductivity [1]. Another example of conductive process is a multi-phase flow measurement. In a multi-phase flow (MPF) [19], there will be mixture of phases or components which content various degrees of conductivity and these levels are interpreted to give a real time visualization of effluent proportions in terms of water, bubbles, gas, *etc.* From the visualization obtained, it is possible to compute numerical distinction between different phases that are measured. For instance, an area of cross-sectional ‘a’ with ‘N’ number of components in a phase ‘x’ can be computed by

$$Q_x = a \sum_{i=1}^{N} f_{i(x)} v_i \tag{1}$$

2.3 Typical Data Acquisition System

An existing typical Data Acquisition System design usually comprise of several important parts such as measurement circuits, controlling unit, signal conditioning circuits, and sensors [14]. For ERT system, the data acquisition architecture would not be as much different from the typical requirements since every design is based on a general foundation. There are many ERT data acquisition designs proposed by different group of researchers and each design has its own balancing of advantages and disadvantages in terms of capability, data process speed, and stability of the system. Nonetheless, the system design especially on sensor can be altered to cater to any application requirements [12]. A typical Data Acquisition System can be observed below:

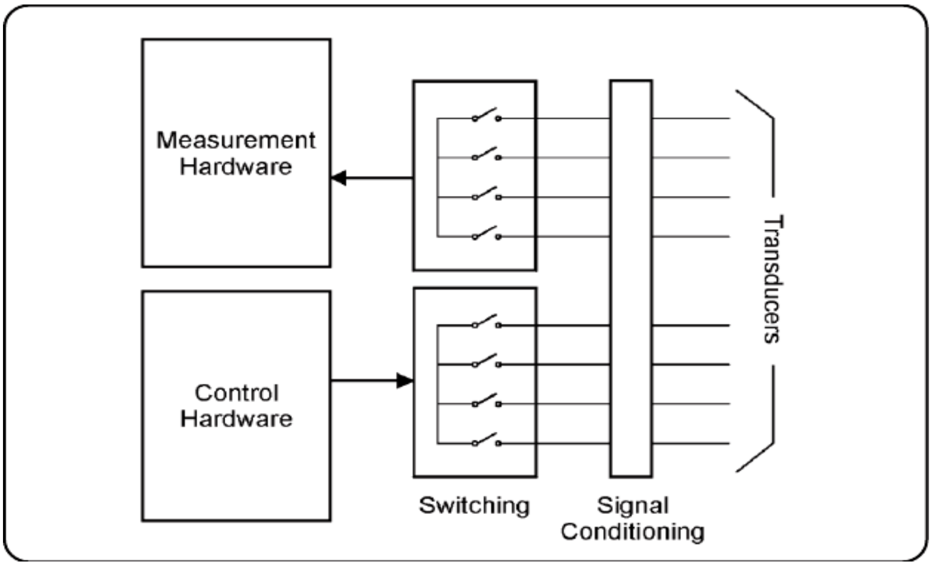


Figure 2: Typical Data Acquisition System[14]

Based on information mentioned previously, this Data Acquisition System can be divided into several parts of different roles in the process. In fact, each part has its own critical importance towards the whole system as to achieve system stability and a precise Data Acquisition System as a whole [10]. In terms of accuracy of the system, the main concerns are sensor design, noise filtering scheme and also the image reconstruction based on collected data [12]. However, there are also other affecting factors in the accuracy of the system such as multiplexing which is related to input current injections and output voltage measurements within a very short period of time in the range of nanoseconds (ns) [3].

Table 2: DAS properties comparison

Institute	Data Acquisition system properties	References
University Teknologi Petronas, Malaysia	a) Does not contain high frequency filtering components *i.e.* Low pass filter (LPF) due to usage of bi-directional current. b) Design has less complexity. c) Low resolution (LBP algorithm is used)	Baloch et al. [2]
Tianjin University (2004), China	a) Bypass LPF and demodulator function from the usage of bi-directional current. b) Shorter processing time.	Liu et al. [15]
Tianjin University (2007), China	a) Bi-directional current b) Usage of LPF and demodulator c) High cost I/O card and ADC used such as the PC7501 and PC7429\ d) Implementation of multi-switchers for fast switching(<250ns transition time)	Dong et al. [3]
Zhejiang University, China	a) DC used as excitation. b) Eliminates the effect of offset voltages and low frequency noise. c) Uses 14 injection electrodes instead of 16.	Zhu et al. [5]
Universiti Teknologi Malaysia	a) Uses Sample and Hold circuit for high speed data acquisition. b) High cost of DAS 1802HC for interfacing.	Rahim et al. [7]

2.4 Sensor/Electrode and Switch Design

Accordingly, most of Data Acquisition System design begins with sensor critical design because sensor plays a very crucial part in producing distinct potential difference that will be processed by the signal conditioning circuit. Sensing strategy can also be categorized into different known fashions which are Balanced method, Normal Adjacent, Linear, and Conducting Boundary strategy. There is also a current injection scheme used by most researchers such as the bi-directional current injection that will produce negative and positive pulse that eliminates the direct current (DC) properties when kept constant in every half cycle [3,11]. From numerous measurements of voltages subsequently after injection of current through adjacent electrode pairs, all data needs to be processed via signal conditioning circuit contained in the Data Acquisition System.

There are basically two types of sensors which are ‘hard-field’ and ‘soft-field’ sensors respectively. A ‘hard-field’ sensor is adequately sensitive to every portion of the cross section of measurement parameter while a ‘soft-field’ sensor’s sensitivity is very much dependent on the medium distribution inside a test vessel. A clear example of a ‘hard-field’ sensor is optical sensor. On the other hand, ‘soft-field’ sensor comprises of capacitance, conductivity, magnetic sensor *etc*. In fact, ERT is utilizing the ‘soft-field’ sensor since the sensor is heavily affected by distribution of tested medium.

For an initial excitation of current to the first pair of electrodes, a constant current source is utilized with considerable amount of switches as experimentation purposes. A Voltage Controlled Current Source(VCCS) will also be used as the constant current source and the general picture of the realization can be observed below in **Figure 3**.

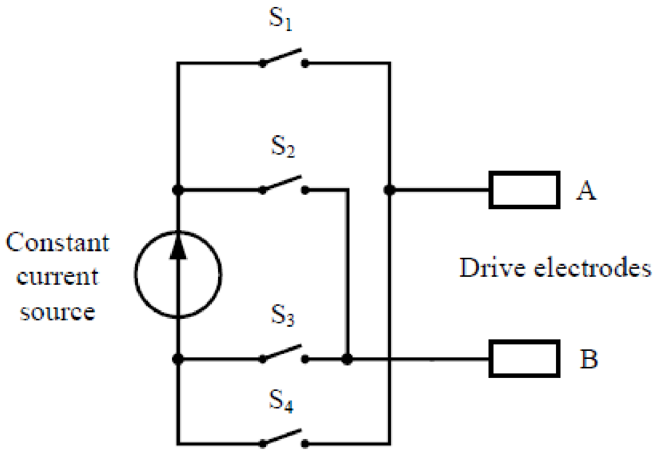


Figure 3: Bi-directional current generator[5]

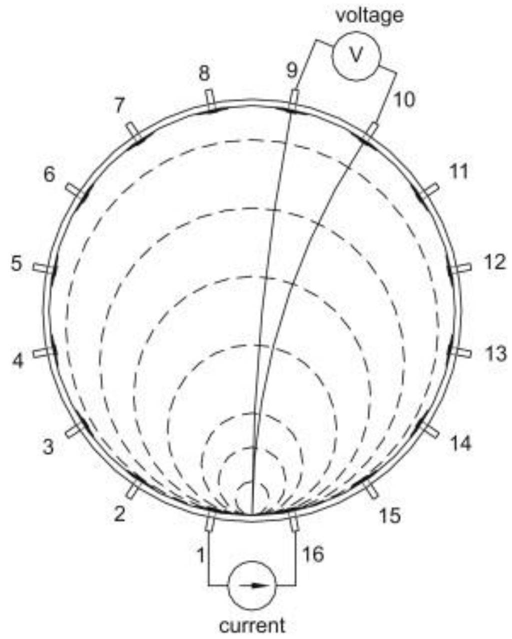


Figure 4: Electrode/Sensor arrangement for ERT (Normal Adjacent Strategy)

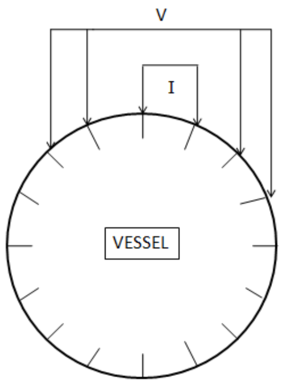


Figure 5: Electrode/Sensor arrangement for ERT (Balanced protocol)

Table 3: Switches comparison

Types of switch	Properties	Disadvantages
Relays	- Can operate high power application - Considerably cheap - Transition time: 5ms-20ms - Ease of use	Mechanical spring would wear out over time. (damping effect)
MOSFET gate switch	- Could be unstable - Transition: 20ps-200ps (max)	Difficulties in design and modelling.
Multi-Switcher	- Lesser space utilization - Transition speed: < 250ns	Expensive and huge in size
Bipolar Junction Transistor (BJT)	- Transition speed in the range of milliseconds - Easier to model compared to MOSFET	Specific design of biasing circuit needed

Based on the comparison, MOSFET gate switch is chosen due to its transition speed and size as compared to multi-switcher which is bulky. Despite the advantages of modelling difficulties, it can be simulated using certain software such as PSPICE and also Matlab.

2.5 Signal Conditioning

Signal conditioning circuit typically comprise of components such as amplifier, demodulator, filter etc., [3,14] which are meant to modify and enhance the gathered input signals before moving them to A/D converter to be converted into digital signal [3] . In addition, signal conditioning is crucial in making sure that the signal processed is reduced in noise via filtering which would eventually improve desired output at the end point before image reconstruction [12] is carried out. Other than that, signal amplification is also needed to increase the quality of information as the output signal measured might be too small to be processed. Nonetheless, there is also an alternative to combine these signal conditioning circuits into one set of programming function via microcontroller since this unit contains many functions that are required such as the 10 bits ADC *etc*.

2.6 Image Reconstruction Algorithm

Image reconstruction is another important part of the system where electrical conductivity are collected from the cross-sectional area inside a test vessel before they are processed and represented in a square grid depending on the pixels [1,2]. There are two types of main approaches which are the non-iterative *i.e.* Linear Back Projection and an iterative method *i.e.* Newton Raphson respectively. The usual algorithm used is the LBP algorithm which is believed to have a lesser complexity [2] compared to the other algorithm such as the NR algorithm [11]. Moreover, it is strongly supported that LBP algorithm is preferable for its simplicity because an existing Industrial Tomography System (ITS) such as the M3000 is also utilizing the LBP algorithm for its image reconstruction [16]. A simple concept of LBP algorithm can be visualized as measurement obtained at each sensor is projected backward through the same path towards the image space [23] producing data at each point. An acquisition for density distribution in LBP process can be described in *(2)*.

$$f(x,y) = \sum_{j=1}^{m} P_j (x \cos\theta_j + y \sin\theta_j) \Delta\theta \qquad (2)$$

Where,

F(x,y) = Reconstructed image function from LBP

θ_j = Projection angle

$\Delta\theta$ = Angular distance between adjacent projections

However, the main drawback of this method is the quality of image produced from the reconstructed process. In addition, in order to reduce the complexity of the algorithm to be applied in programming, the equation below can be used.

$$V_{ij} = \sum_{n=1}^{n=m} V_{s_n} S_n \qquad (3)$$

Where V_{sn} is the potential difference at each n number of sensors, S_n is the sensitivity maps of each of n number of sensor, and m is the total number of sensors.

2.7 Software(s)

Powerful software such as Matlab and LabVIEW are usually used especially for phase measurement such as a two-phase flow measurement [22]. Matlab is a powerful computational tool equipped with mathematical computations for modelling, design, control, test and measurement *etc.* LabVIEW is also a reliable simulation software however, Matlab is richer in toolboxes functions and also faster in simulation. Other software such as Multisim and PSPICE are also very useful in modelling circuits before realizing them. For the purpose of this project, LabVIEW will be used for overall system modelling by interfacing a multifunction Data Acquisition Card (DAQcard) M-series 6251 which are able to support multiple functions and up to 80 analogue inputs. This DAQcard will be connected directly to a PC via cable and block connector.

2.8 Hardware(s)

There are few circuits needed to be designed throughout this project. These include sensing electrodes which will be modelled first before connecting them to the other part of the circuitries such as Voltage Controlled Current Source(VCCS), multiplexers, Programmable Gain Amplifier(PGA), filters, demodulator, and A/D converter. An example of typical architecture of hardware can be observed below.

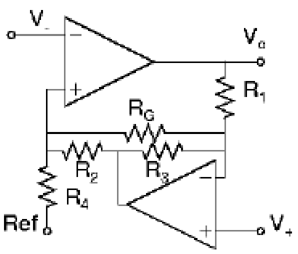


Figure 6: Typical 2 Op-amps VCCS

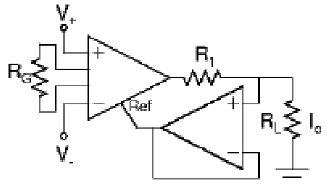


Figure 7: Typical constant current source

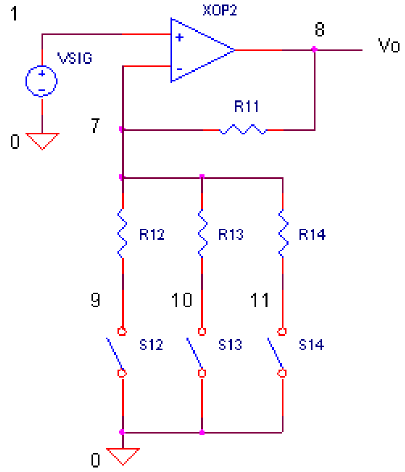


Figure 8: Typical Programmable Gain Amplifier(PGA)

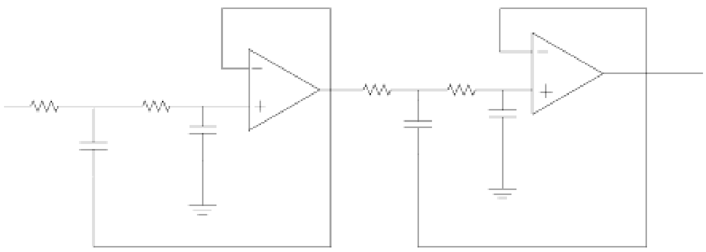


Figure 9: Typical 4th order Butterworth Filter

Chapter 3:
METHODOLOGY

3.1 General Research Methodology

Prior to achieving the goal of this research, a thorough study has been carried out through reviewing existing technology architecture and placing emphasis on areas that are in need of enhancement. After a detailed critical analysis had been done based on technologies comparison, a draft proposed design is induced through combinations of ideas and modification towards existing technology. Strategic steps towards completion of the proposed design are as follows:

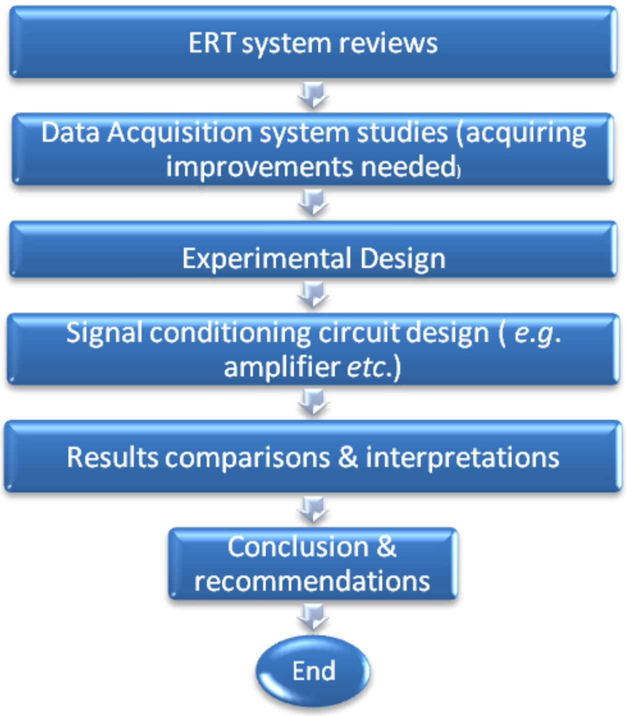


Figure 10: Project Flowchart

3.2 Functional Block Diagram

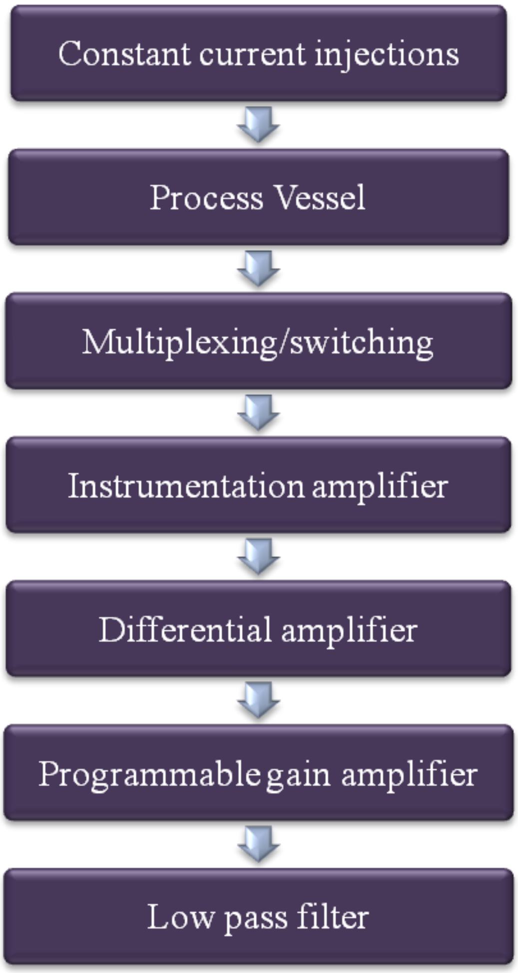


Figure 11: Functional flow diagram

From the chart, it can be observed that this paper is focusing more on hardware realization as compared to software interfacing. This is because hardware plays a more important role in acquiring quality data before data can be processed into a more significant signal before it can be utilized for image reconstruction which emphasize on strategic algorithm to enhance image quality. The purpose of this single loop measurement scheme is to ensure data process time and quality can be monitored before any improvement can be made.

3.3 Hardware Simulation

Simulation is done on a simple low pass filter since it is one of the most crucial parts of data acquisition. It is known that analogue data are very sensitive to noise and disturbance from surrounding and a filtering action is important to filter all the high frequency noise present in the circuit. In order to get a quality data for image reconstruction, a quality noise filtering is required. The draft stage schematic of the low pass filter is shown below in Figure 12 and Figure 13.

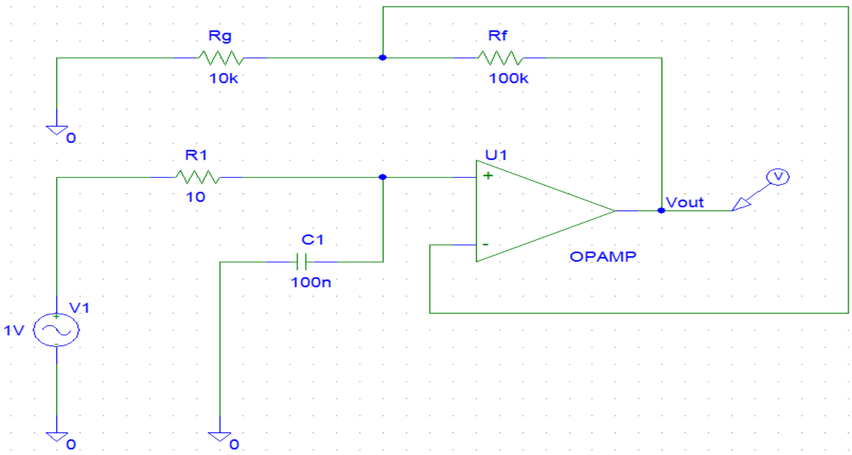


Figure 12: A simple low-pass filter (draft)

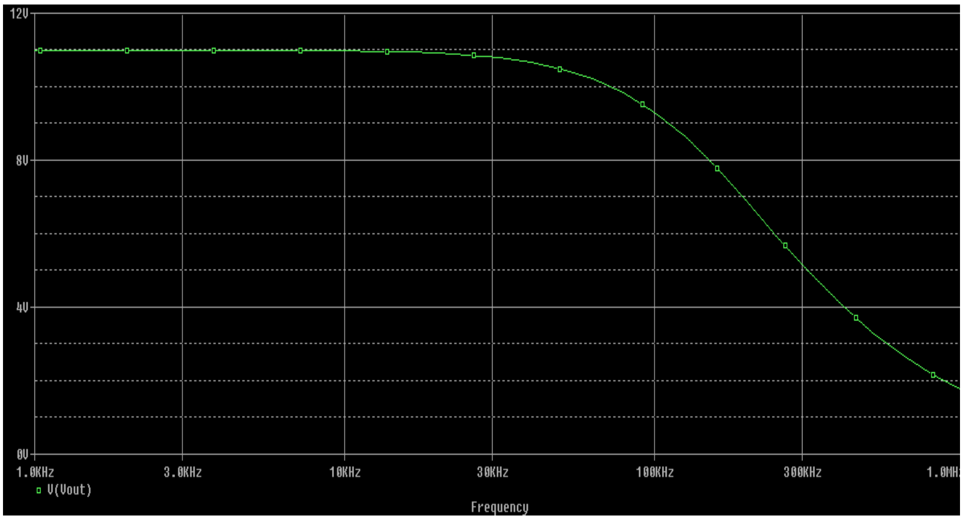


Figure 13: Output graph-160kHz cut-off

Based on previous configuration, a simple low pass filter can be designed by using the equation below:

$$f_c = \frac{1}{2\pi R_1 C} \qquad (4)$$

Where,

f_c = cut-off frequency

R_1 = input resistor

C = Capacitance

It can be observed that the cut-off frequency is around 160kHz. Although this circuit will not be utilized for the time being, it is very important to note that for a complete system to be made, the frequency range that is needed to be tolerated by the system is between 100kHz to 200kHz.

There is also a signal oscillator circuit design in order to produce a sinusoidal wave for the input current. However, this design is still under preliminary stage because the output of the signal needs to be adjusted to suit the requirement and some improvement needs to be implemented since this is an active-filter-tuned oscillator.

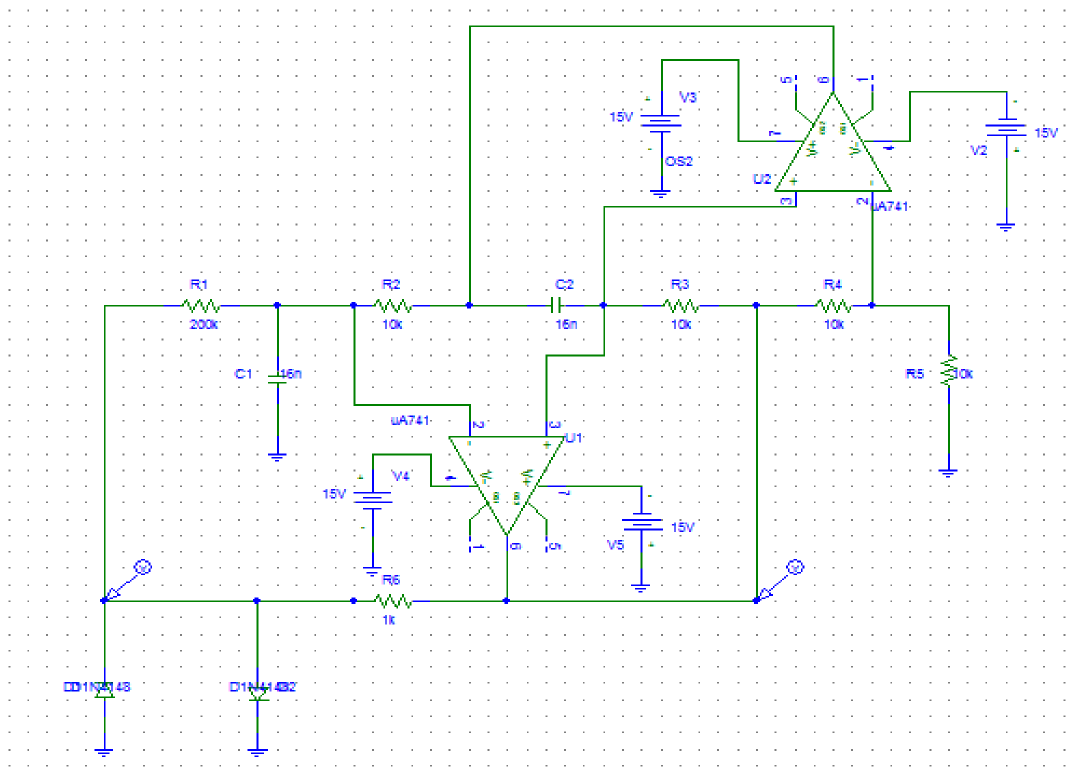


Figure 14: Signal oscillator circuit

However, this signal oscillator can be replaced with a CA100 calibrator as current injection and voltmeter. Another circuit that is crucial for this system is the differential amplifier which is used for measuring potential difference between two sense electrodes. The basic design of the differential circuit can be observed below.

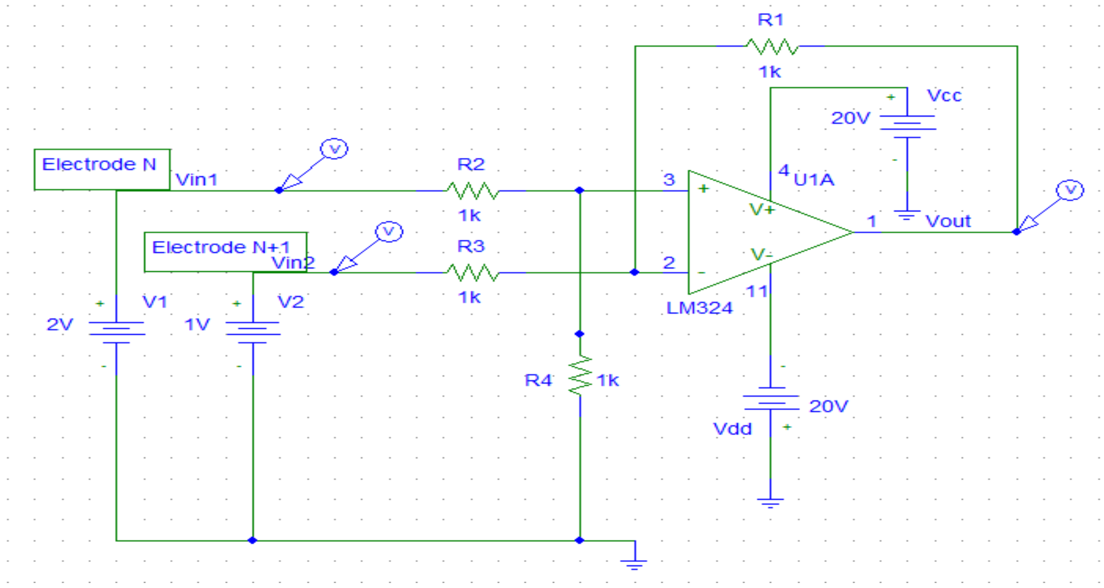


Figure 15: Differential Amplifier with unity gain (draft)

The output graph can be observed below with a DC sweep input to positive op-amp terminal ranging from 2V to 10V while the input to negative terminal of the op-amp is sustained for analysis purposes.

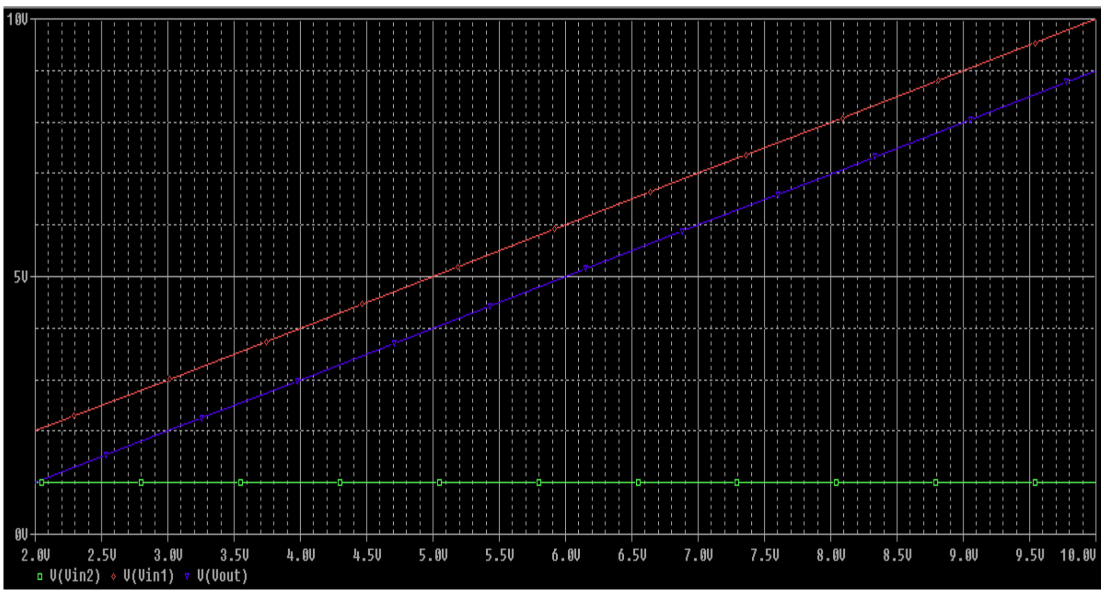


Figure 16: Output voltage graph

The differential circuit can be designed by the following equations:

Both I_{in} for inputs to the op-amp can be calculated from a basic kirchhoff's law:

$$I_{in1} = \frac{V_{in1} - V_3}{R_2} \tag{5}$$

$$I_{in2} = \frac{V_{in2} - V_2}{R_3} \tag{6}$$

Thus, the summing point would be:

$$V_3 = V_2 \tag{7}$$

and,

$$V_{in1} = V_3 \left(\frac{R_4}{R_4 + R_2}\right) \tag{8}$$

When $V_3=0$,

$$V_{out2} = -V_2 \left(\frac{R_1}{R_3}\right) \tag{9}$$

When $V_2=0$,

$$V_{out3} = V_3 \left(\frac{R_4}{R_4 + R_2}\right)\left(\frac{R_3 + R_1}{R_3}\right) \tag{10}$$

Hence, total output V_{out} from both input terminals:

$$V_{out} = V_{out2} + V_{out3} \tag{11}$$

Which equal to:

$$V_{out} = \left(\frac{R_1}{R_3}\right)(V_{in1} + V_{in2}) \tag{12}$$

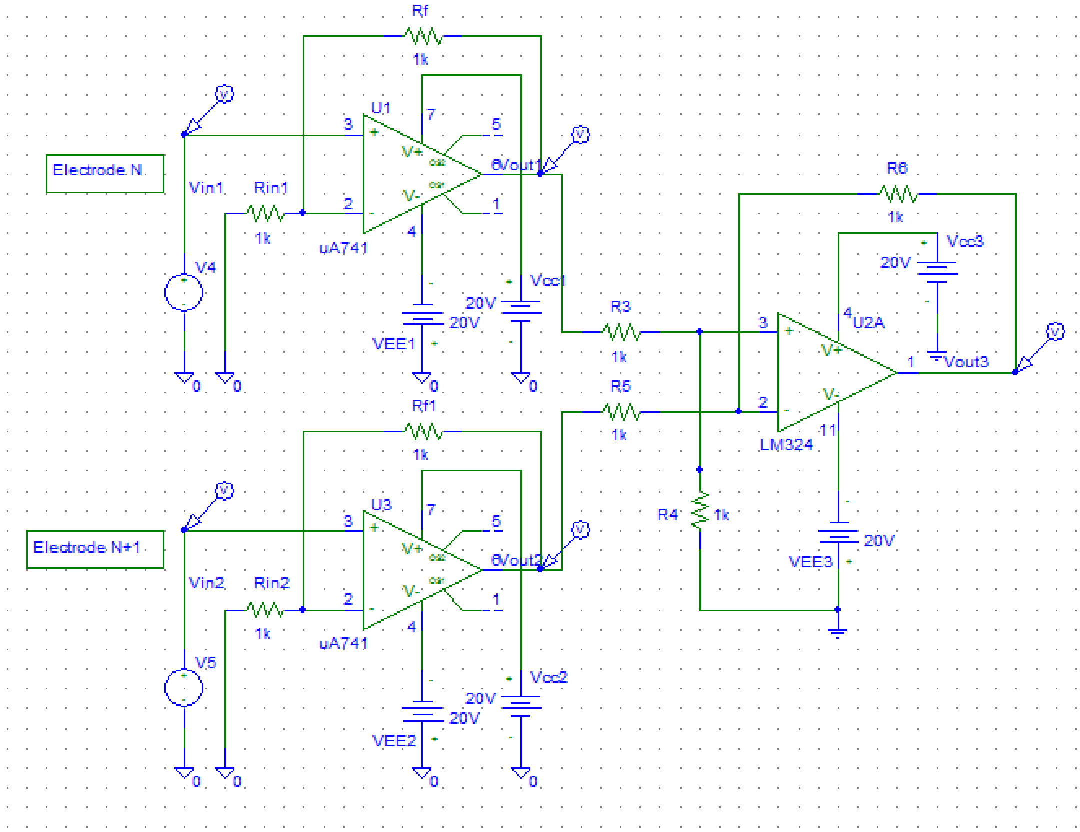


Figure 17: Finalized Instrumentation amplifier with voltage buffer

Figure above shows a finalized amplifier circuit with a gain 2. It is designed by using LM358 operational amplifier with typical 85dB of common mode rejection ratio. 2 pre-amplifier are connected to both inputs of the differential amplifier shown previously. The gain of the circuit can be calculated by using the formula below.

$$V_{out} = (V_2 - V_1)\left(1 + \frac{2R_1}{R_{gain}}\right)\left(\frac{R_3}{R_2}\right) \quad (13)$$

And the Common Mode Rejection Ratio (CMRR) can be formulated as follows:

$$CMRR\,(dB) = 20\,log_{10}\left(\frac{A_{Diff}}{A_{CM}}\right) \quad (14)$$

Where,
A_{Diff} = Differential gain
A_{CM} = Common mode gain

3.4 Project Activities

3.4.1 PSPICE Simulation

Basically, PSPICE is a software that is used to simulate analogue circuit and digital logic and can be used as well to design amplifiers, filters, buffers *etc.* For a start, several simulations had been done especially on low-pass filter circuit in order to determine which type of signal filter is more suitable to be applied in the signal conditioning circuit which will convert input signals into desirable forms of signals to be processed. Other than that, a Voltage Controlled Current Source (VCCS) design is also ongoing by using similar software to produce a continuous current source by means of voltage input from a sine wave generator [3]. Expected continuity from these simulations is circuit realization.

3.4.2 Labview Software Manual Study

Labview is a software which will be utilized for simulating the data acquisition process of the system by using virtual instruments. This manual would be very useful for a direct guidance in constructing block diagrams based on data acquisition processes. Furthermore, a basic understanding of Labview and data acquisition is very important to avoid problems during interfacing. Hence, a thorough study of the manual is crucial to assist in future progress.

3.4.3 Experiment Setup

Experiment is conducted by utilizing the designed amplifier to observe the effect towards measured voltage. Other than that, common mode voltages between both adjacent and balanced method are derived from a single-ended measurement to be compared and analyzed in different solution concentration. Calibrator CA100 is used for current excitation and voltage measurement. Setup of the experiment can be observed in the figure below.

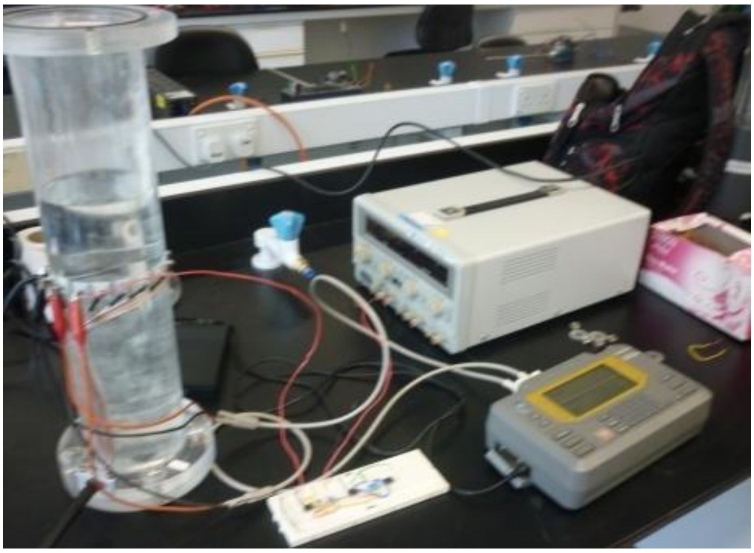


Figure 18: Experiment setup

3.5 Key Milestones

The aim of this project is to create a quality data acquisition system that will be able to contribute to the quality of images based on quality data. From the current progress, analogue input intake must be improved to be as accurate as possible to achieve desirable results. Not only that, image enhancement must also be done to further improve results obtained to construct a complete system. In fact, it would still be possible to produce a reliable device through the enhancements made since there is a potential breakthrough based on a thorough research made.

There are also several challenges to be solved especially when working with a project that require a high level of understanding and experience on subject concerned. Other than that, limited resources would be an issue as well especially when the project demanded extra specific information on a particular subject. Hence, in order to handle mentioned predicaments effectively, a head start of problem identification is indeed important to formulate appropriate solutions in the future.

3.6 Project Gantt Chart

Table 4: Project Gantt Chart (FYP-1)

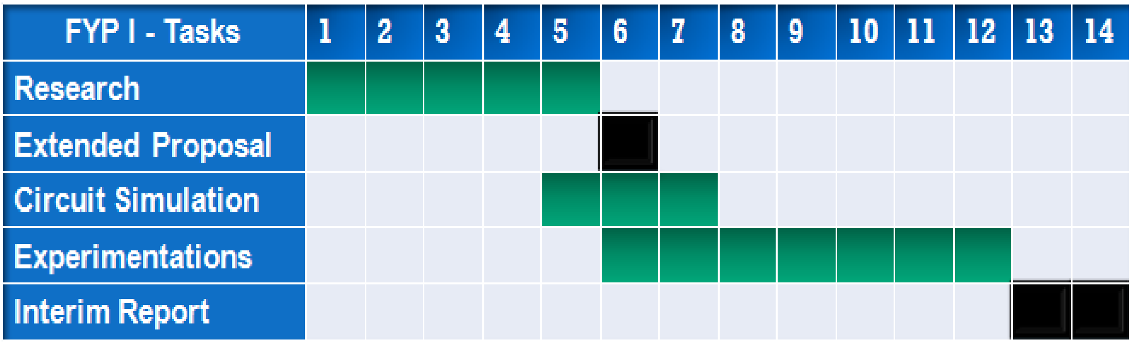
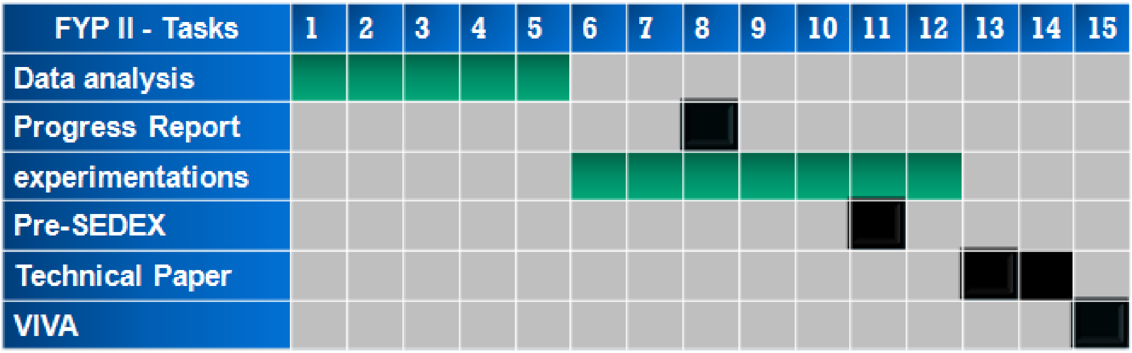


Table 5: Project Gantt Chart (FYP-2)



Chapter 4:
RESULTS AND DISCUSSIONS

An experiment is conducted in the laboratory by manually injecting constant current and measuring output voltage by using a calibration device called the CA100 Calibrator. This is done to create a margin of measurements which consist of a high range voltage and a low range voltage measurement.

The experiment setup consists of a phantom/vessel which is mounted with 16 sensing electrodes and pipe water is used as a testing medium since water has a fairly high conductivity which is in the range of 5-50 mS/m. However, brine will be the main medium of experiment in the final part since it has a wide scope of usage in the industry. For this preliminary experiment, pipe water is used with an additional PVC rod located inside the vessel to observe the effect towards voltage measured. The voltage readings taken can be observed below.

Table 6: Voltage measurement on the first two excitation current

Excitation electrodes (5mA)	Sensing electrodes pairs	Voltage measured (V)
1 and 2	3-4	1.547
	4-5	0.231
	5-6	0.117
	6-7	0.025
	7-8	0.064
	8-9	0.116
	9-10	0.159
	10-11	0.053
	11-12	0.011
	12-13	0.008
	13-14	0.043
	14-15	0.202

	15-16	1.444
2 and 3	4-5	1.572
	5-6	0.282
	6-7	0.035
	7-8	0.104
	8-9	0.123
	9-10	0.162
	10-11	0.101
	11-12	0.022
	12-13	0.017
	13-14	0.012
	14-15	0.036
	15-16	0.201
	16-1	1.533

From the tabulated result, it can be seen that the measured voltage near to the excitation current electrodes are much higher than those which are further away. This means that the sensitivity of measurements will reduce with increasing distance from the excitation point. However, when addition medium is added to the vessel such as a simple PVC rod, the voltage measured will be higher at the point of electrodes where the rod is located. The graph of voltage measurement is shown below.

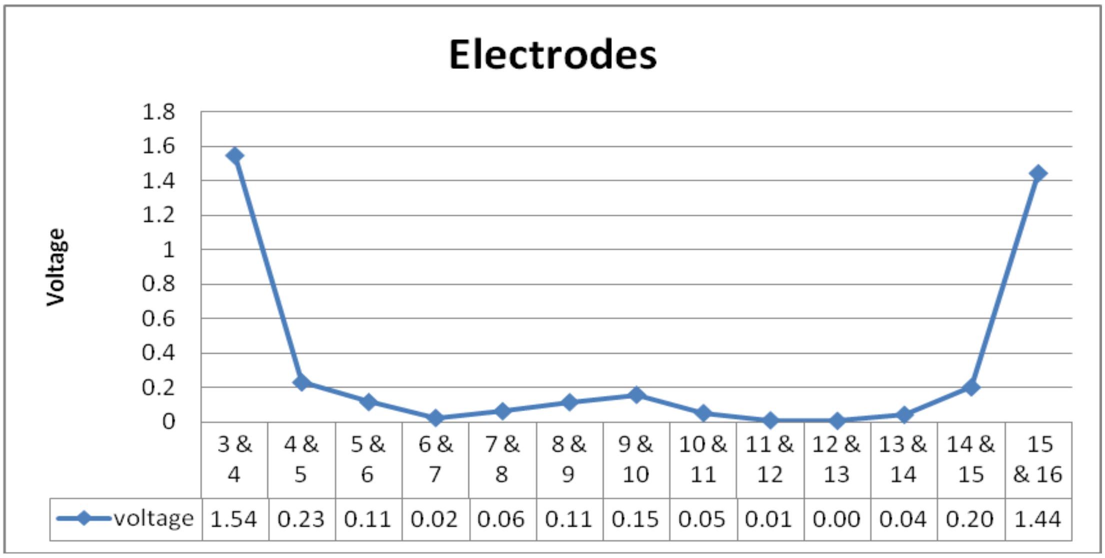


Figure 19: Voltage measurement (1-2 excitation electrode)

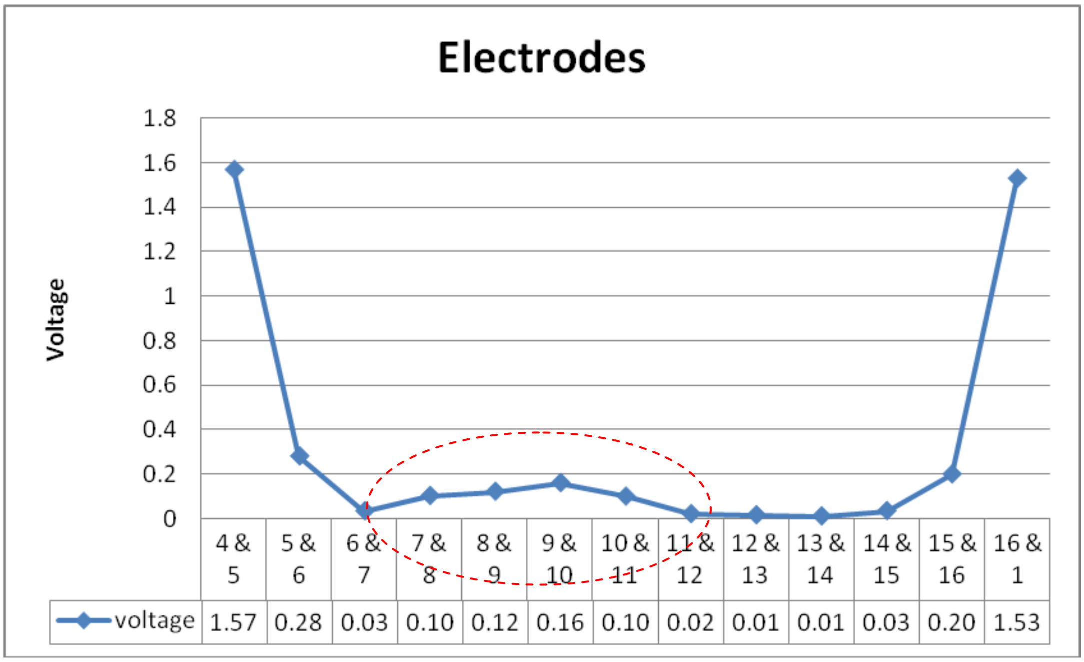


Figure 20: Voltage measurement (2-3 excitation electrode)

From the graph, it can be seen that the voltage between electrode n=7 to electrode n=11 is slightly higher than the other electrodes excluding the voltages near excitation electrodes. This shows that when a medium is present inside the vessel, the voltages surrounding that particular area will be higher than the other part.

Above depicted graphs are taken by using the adjacent protocol which will be compared to the other type of protocol named the balanced protocol in which opposite electrode readings are taken. For instance, if electrode 1 and 2 are used for current excitation electrodes, potential difference measured from electrodes 3-n, 4-(n-1), 5-(n-2) ... (n is the number of electrodes) will be taken. This protocol comprises of 112 measurements for a complete frame of data which is much lesser than adjacent protocol which is 208 measurements and a faster data acquisition period can be achieved. Other than that, balanced protocol will also result in a lower common mode voltage as compared to adjacent protocol. Common mode voltage for 1 round of measurement of data based on adjacent and balanced protocol which is derived from a single ended measurement protocol can be observed in the graphs below.

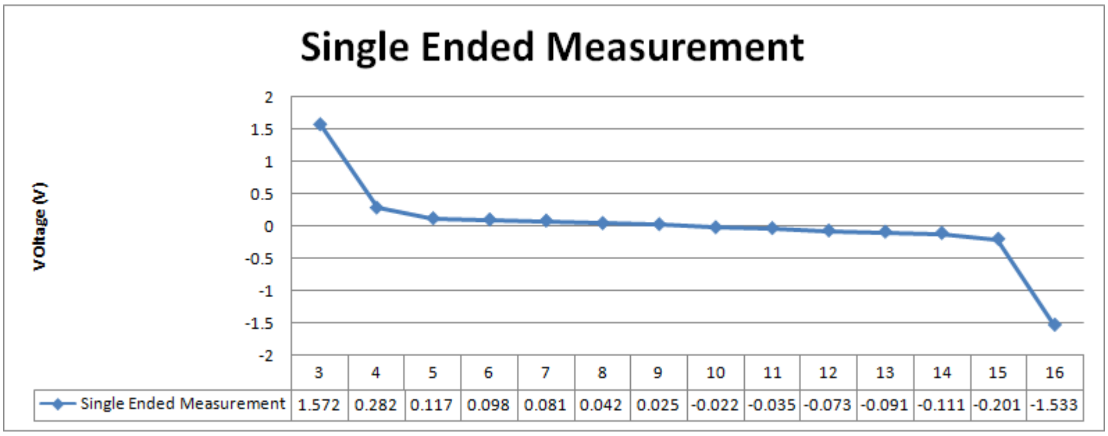


Figure 21: Single-ended measurement voltage

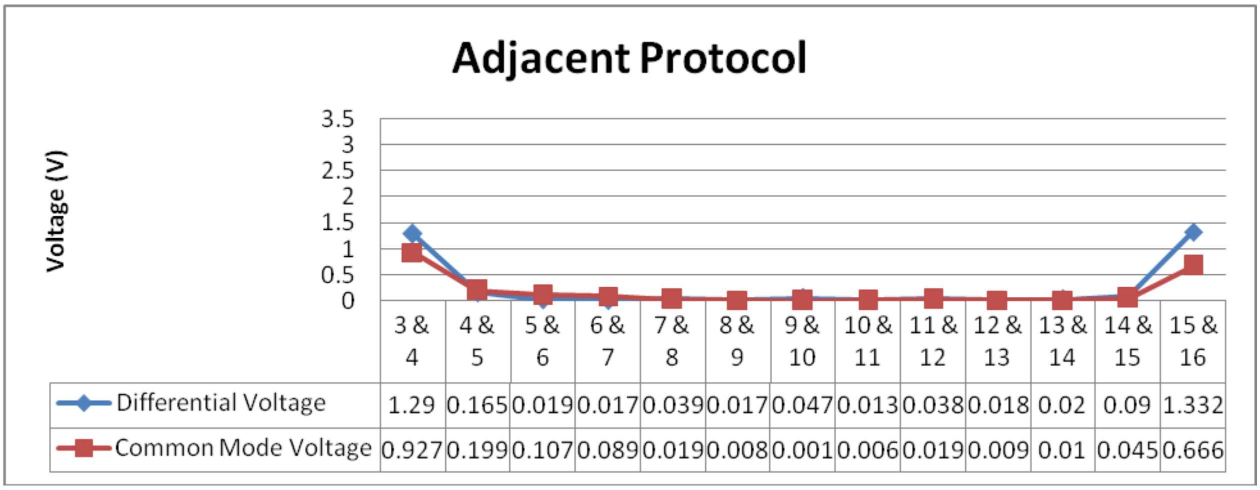


Figure 22: Adjacent Protocol common mode voltage

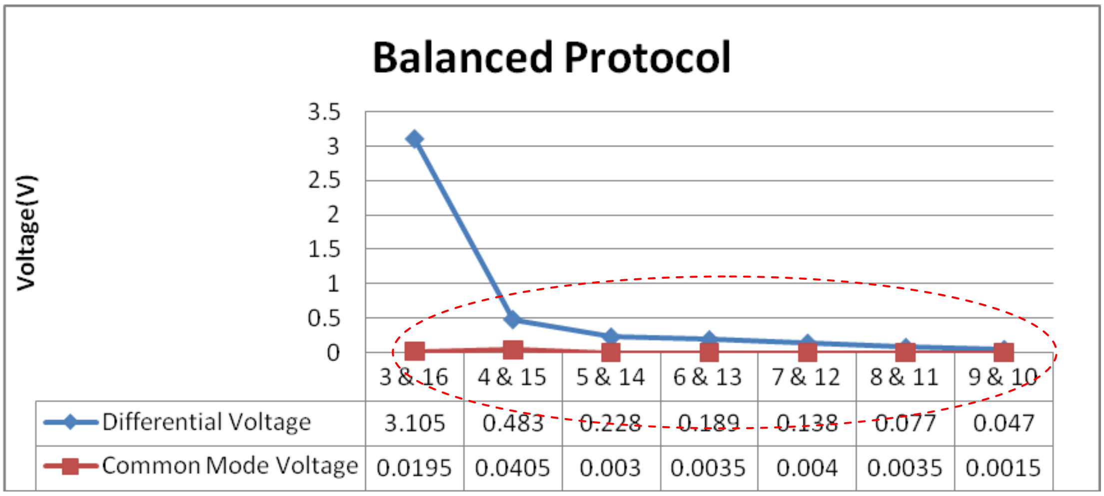


Figure 23: Balanced protocol common mode voltage

This subsequent experiment will be conducted by using different concentration of brine which is utilized in food processing, food preservation, drilling fluid, and street-snow clearing. The table for different concentration of brine is depicted below.

Table 7: Brine concentration

Typical Application	Brine concentration (%)
Common food processing (canned *etc*.)	0.1 – 3
Food preservation	3 – 9
Drilling fluid (vary accordingly)	10 – >20
Snow clearing/melting	20 – 23.3

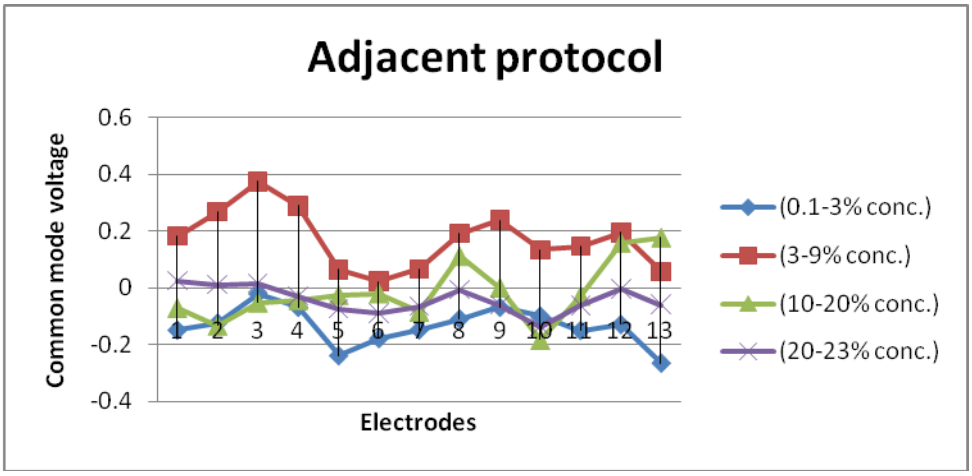


Figure 24: Common mode voltage (Adjacent protocol)

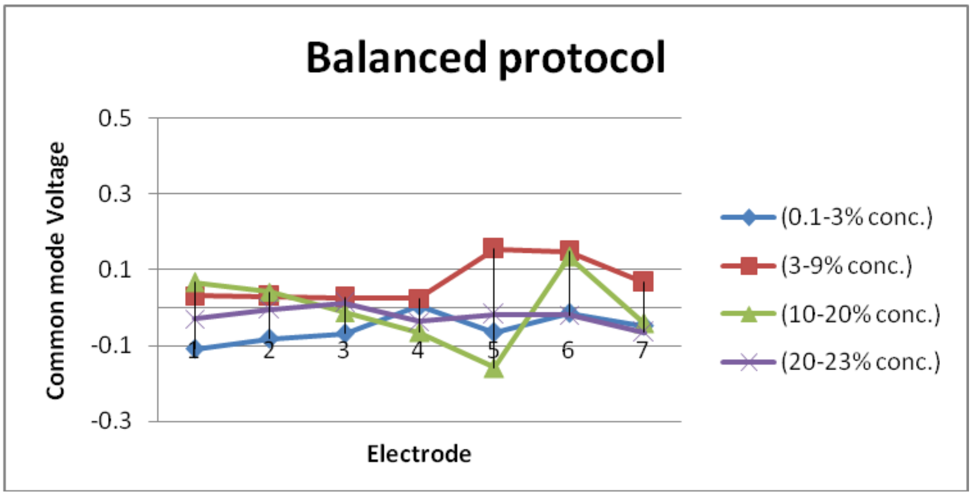


Figure 25: Common mode voltage (Balanced protocol)

From both graph, it can be seen that balanced protocol will always have lower common mode voltages compare to adjacent protocol. As for adjacent protocol, the maximum common mode obtained is approximately 0.4 volts. On a contrary, balanced protocol produced a maximum value of 0.15 volts in the same condition. In addition, differential voltage values for high and low range for every concentration respectively will be displayed in graphs below.

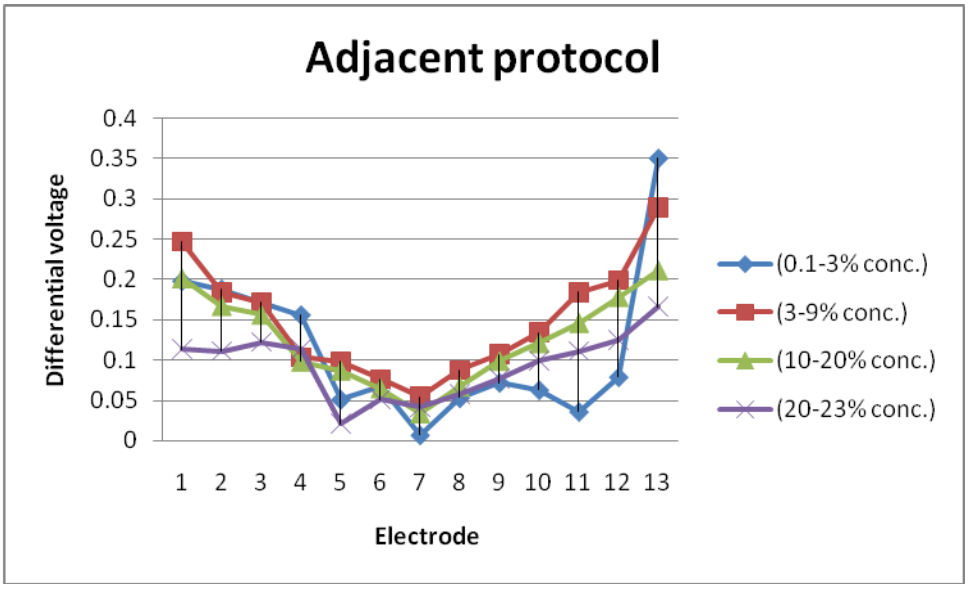


Figure 26: Differential voltage (Adjacent protocol)

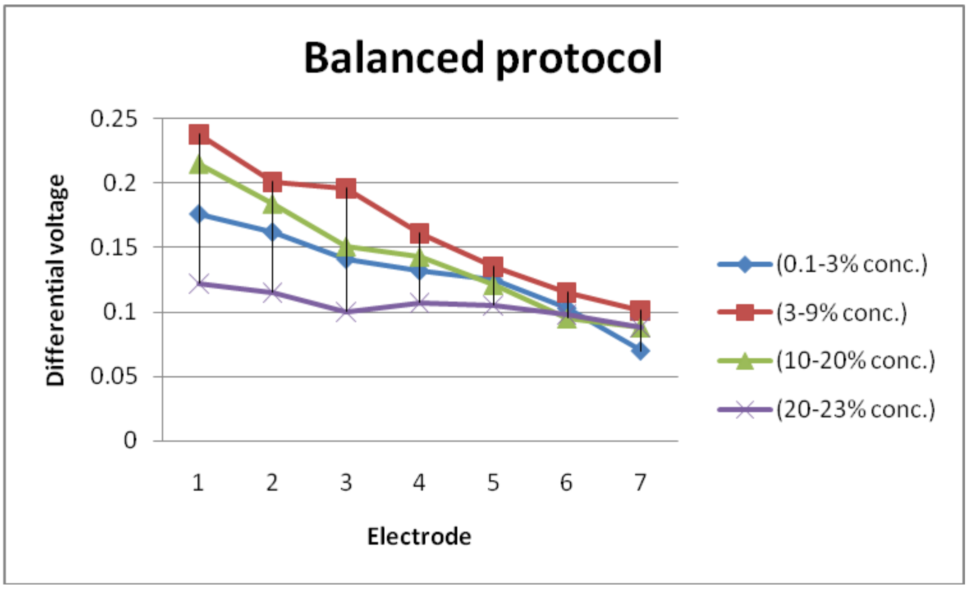


Figure 27: Differential voltage (Balanced protocol)

From the differential voltage measured, it can be deduced that a more uniform and stable values can be extracted by using the balanced method comparing to adjacent method. Figure 26 shows a non-uniform trend of measurements using adjacent method which results in a more complicated trending of data if it is to be applied in process industry. However, Figure 27 shows a more uniform and stable readings through balanced method which are easier to be interpreted.

Chapter 5 :

CONCLUSION AND RECOMMENDATIONS

As a conclusion, this project proven lower common mode voltages achieved by using balanced protocol. Other than that, uniform measurements can also be taken by using balanced protocol comparing to adjacent protocol. It can be observed that a fair progress has been done excluding the hardware-software interfacing area since more knowledge and experience are required to proceed further for the time being.

There are many aspects that need to be covered in the near future such as finalizing hardware, software programming implementation, interfacing data acquisition, and an image reconstruction process. All of these involved vast understanding and experience towards the subject. Nonetheless, a fair foundation has been made from the current stand of the project so far. Thus, with a greater effort and support from surrounding parties, it is greatly hoped that future progress will be smooth and encouraging and hence, resulting to further improvement of this project.

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APPENDICES

APPENDIX A

LM358N DATASHEET

LM158-LM258-LM358

Low power dual operational amplifiers

Features

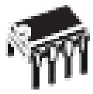
- Internally frequency compensated
- Large DC voltage gain: 100 dB
- Wide bandwidth (unity gain): 1.1 mHz (temperature compensated)
- Very low supply current per operator essentially independent of supply voltage
- Low input bias current: 20 nA (temperature compensated)
- Low input offset voltage: 2 mV
- Low input offset current: 2 nA
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing 0 V to (V_{CC} - 1.5 V)

Description

These circuits consist of two independent, high-gain, internally frequency-compensated op-amps which are designed specifically to operate from a single power supply over a wide range of voltages. The low power supply drain is independent of the magnitude of the power supply voltage.

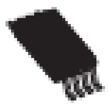
Application areas include transducer amplifiers, DC gain blocks and all the conventional op-amp circuits which now can be more easily implemented in single power supply systems. For example, these circuits can be directly supplied with the standard +5 V which is used in logic systems and will easily provide the required interface electronics without requiring any additional power supply.

In linear mode, the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.



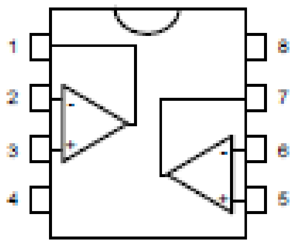
N
DIP-8
(Plastic package)

D & S
SO-8 & miniSO-8
(Plastic micropackage)



P
TSSOP8
(Thin shrink small outline package)

Pin connections
(Top view)



1 - Output 1
2 - Inverting input
3 - Non-inverting input
4 - V_{CC}^-
5 - Non-inverting input 2
6 - Inverting input 2
7 - Output 2
8 - V_{CC}^+

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4 Electrical characteristics

Table 3. Electrical characteristics for V_{CC^+} = +5V, V_{CC^-} = Ground, V_o = 1.4V, T_{amb} = +25°C (unless otherwise specified)

Symbol	Parameter	LM158A-LM258A LM358A			LM158-LM258 LM358			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input offset voltage [1] T_{amb} = +25° C LM158, LM258 LM158A		1	3 2		2	7 5	mV
	$T_{min} \leq T_{amb} \leq T_{max}$ LM158, LM258			4			9 7	
I_{io}	Input offset current T_{amb} = +25° C $T_{min} \leq T_{amb} \leq T_{max}$		2	10 30		2	30 40	nA
I_{ib}	Input bias current [2] T_{amb} = +25° C $T_{min} \leq T_{amb} \leq T_{max}$		20	50 100		20	150 200	nA
A_{vd}	Large signal voltage gain V_{CC} = +15 V, R_L = 2 kΩ, V_o = 1.4 V to 11.4 V T_{amb} = +25° C $T_{min} \leq T_{amb} \leq T_{max}$	50 25	100		50 25	100		V/mV
SVR	Supply voltage rejection ratio ($R_s \leq$ 10 kΩ) V_{CC}^+ = 5 V to 30 V T_{amb} = +25° C $T_{min} \leq T_{amb} \leq T_{max}$	65 65	100		65 65	100		dB
I_{CC}	Supply current, all amp, no load $T_{min} \leq T_{amb} \leq T_{max}$ V_{CC} = +5 V $T_{min} \leq T_{amb} \leq T_{max}$ V_{CC} = +30 V		0.7	1.2 2		0.7	1.2 2	mA
V_{icm}	Input common mode voltage range V_{CC} = +30 V [3] T_{amb} = +25° C $T_{min} \leq T_{amb} \leq T_{max}$	0 0		V_{CC}^+ -1.5 V_{CC}^+ -2	0 0		V_{CC}^+ -1.5 V_{CC}^+ -2	V
CMR	Common mode rejection ratio ($R_s \leq$ 10 kΩ) T_{amb} = +25° C $T_{min} \leq T_{amb} \leq T_{max}$	70 60	85		70 60	85		dB
I_{source}	Output current source V_{CC} = +15 V, V_o = +2 V, V_{id} = +1 V	20	40	60	20	40	60	mA
I_{sink}	Output sink current (V_{id} = -1V) V_{CC} = +15V, V_o = +2V V_{CC} = +15V, V_o = +0.2V	10 12	20 50		10 12	20 50		mA µA