Dielectric Characterisation of Biological Tissues

by

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CERTIFICATION OF APPROVAL

DIELECTRIC CHARACTERISATION OF BIOLOGICAL TISSSUES

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Approval by:

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February 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.

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NUR ASMAH BINTI SERAKIM

ABSTRACT

Meat is a source of protein for our daily nutrition consumption. However, consumers still doubt if the meat product has been slaughtered properly to ensure that meat is hygienic. One significant different from these slaughtering techniques is the blood volume retained in meat after slaughtered. Using dielectric principle, the differences of the blood volume will affect it properties especially for molecular polarization process. Calculation of meat impedance will vary which indirectly characterize the meat properties. However, a suitable device for measuring purpose which is portable, cheap and user friendly is not produce yet. This project will link the concept of biological tissues and dielectric principle to characterize the properties of meat.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

1.1 Background of study

Nowadays, consumers believed that Halal meats produced are done with properly slaughtered technique. However, some still doubt about the slaughtering process from the very beginning to the end. Techniques created from day to day like applying electricity stunning to hasten the slaughtering process especially in mass production makes it more suspicious [4].

Blood volume retained in meat obtained from properly slaughtered (PS) animal is usually less than none properly slaughtered (NPS) animal. From religious point of view, the right technique of slaughtering is by slitting the throat of the animal with a sharp knife. Animal will be in unconscious state due to shortage of blood supply to the brain and large quantity of blood gushing out of the body. This process will produce more hygienic meat. [4] Molecular polarization inside the meat will be different based on the blood volumes retained. [6]

These biological tissues contain blood, water, fat etc where ions and electrolytes exist make it able for conducting electricity. Physical state of the tissues sample in term of size, shape and thickness will affect the sample properties. It can be characterized based on impedance values of the samples itself as a function of frequency.

The aim of this project is to determine whether it is possible to assemble a portable device for impedance measurement. This project will be divided in three parts, first the theoretical part, second is to determine the suitable designs to be used for assembling the device and the third part which is the critical part, to test the functionality of the device.

1.2 Problem statement

Research is done to classify the properties of properly slaughtered or non properly slaughtered animal using dielectric characterisation. Problems arise when the current equipment is expensive, and not portable. Therefore, an appropriate device is necessary to resolve the problem. Besides, there were also issue in selecting the suitable design to enable it being executed in UTP.

1.3 Objective

This study is aimed to achieve the intended objectives which are:

- To determine the possibility of assembling a portable device to facilitate the characterization process on meat samples.
- To obtain a result which is in line with previous study

1.4 Scope of the study

Analysis is made to identify a suitable design and will emphasize on the reliability of fabricated device to determine the impedance value. Testing is made with fixed frequency and fixed load resistance to narrow down the project scope and be more focus on the output result.

1.5 Relevancy, Feasibility & Time Frame

The project is related to electrical and electronics engineering. Thus the student can apply the engineering knowledge and relate it with the theory through practical work. The project cost lies between the amounts allocated for the FYP allowance. Besides, both equipment and software required are available. Project is divided in 2 semesters. The project tasks breakdowns are as follow:

Semester	Task
Semester 1	Familiarization of instrument Understanding on calibration set up Get the true value from experiment using basic measured material and compare with current data (contain error)
Semester 2	Start with choosing the suitable circuitry design Assemble all component according to simulation Test device operability

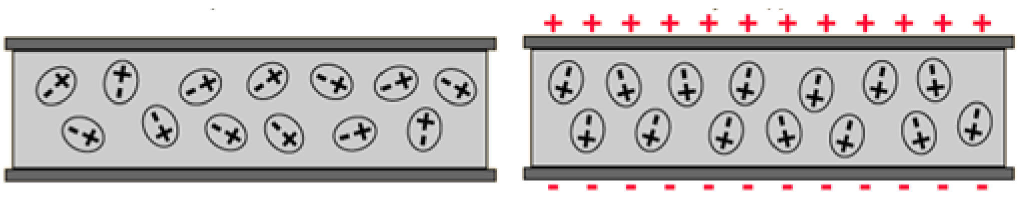
Table 1.1: Task breakdown

CHAPTER 2: LITERATURE REVIEW

Dielectrics characterisation is one of the methods to determine biological tissues properties. The molecular processes occurred in biological tissues actually can be measured according to resistance of the tissues. From the properties obtained, it will help in distinguish either meat produced is properly slaughtered (PS) or non properly slaughtered (NPS).

2.1 Dielectric

Dielectric is an electrical insulator that can polarize the medium measured by an applied external electric field. This is based on microscopic dipoles concept that occurred inside the material when external field applied. [7] Dielectric polarization occurred when charges inside the materials conducting electricity, causing displacement in electron distribution and later induced dipole moment. [2][7] The storage and dissipation of electric energy exist inside the measured medium will determine the dielectric properties. Solid, liquids or gaseous can be the materials for dielectric measurement because it can conduct electricity.



a) b)

Figure 2.1: Molecular polarization process. a) Unpolarized structure, b) structure that has been polarized by an applied external electric field.

Figure 2.1 shows the molecular polarization process. Dielectric function just like a capacitance where two plates of electrical insulator are put in parallel with the measured medium where molecular processes occurred. If the measured material completely fills the spaces between the plates, the capacitance will increase by some dielectric constant which also depends on the nature of the sample properties. [7]

Dielectric constant can be mathematically express as below [3] [7] [8]:

Complex relative, $\hat{\varepsilon}$ permittivity can be expressed as,

$$\hat{\varepsilon} = \varepsilon' - j\varepsilon''$$

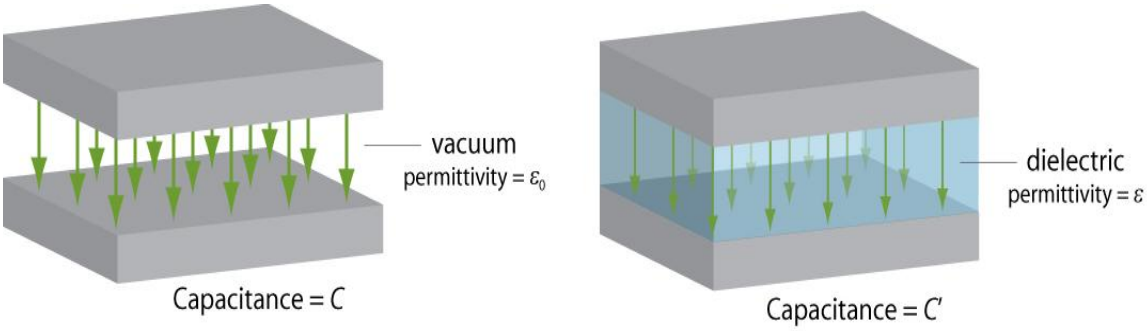
Where ε' is the relative real permittivity of the material and

ε'' The out-of phase loss factor associated with it such that

$$\varepsilon'' = \frac{\sigma}{\varepsilon_0 \omega}$$

σ Represent the conductivity of sample based on its molecular processes.

ε_0 Represent the permittivity of meat sample.



a) b)

Figure 2.2: Permittivity of dielectric constant for a) in vacuum and b) in measured medium. [14]

Figure 2.2 shows the permittivity of dielectric constant. Values of permittivity will be vary depend on the medium contact between two parallel plates. For vacuum condition, the permittivity value will be $\varepsilon_o = 8.8541878\, x\, 10^{-12}\ F.m^{-1}$.

2.2 Impedance Measurement

Impedance can be defined as an object conducting electrical current as the ratio of voltage and current in an object. It is measured in terms of resistance and reactance to determine its dissipated and store energy. [17] Other than that, it is also defined as voltage to current ration at a certain frequency in alternating current (AC) circuit. The impedance in a direct current (DC) is defined by the Ohm's low as:

$$Z = \frac{V}{I}$$

For AC circuit, impedance is consisting of real part and imaginary part. Real part will be representing as resistivity value and the imaginary part is representing by reactance and capacitance values.

$$Z = R + jX$$

Where R= real part and

jX= imaginary part.

Impedance for inductance:

$$Z = j\omega L$$

Impedance for capacitance:

$$Z_c = \frac{1}{j\omega C} \quad \text{Where, } j\omega = 2\pi F$$

It is an inexpensive method but very useful for studying the electrical properties of a sample. From this method, some analytical can be made to discuss in details about the sample properties and the sample compositions. Usually impedance is measure by injecting a known current and measuring the voltage or applying a voltage and measuring the current flow through sample.

Biological tissues impedance is analyzed based on the consisting of conducting medium that behaves like capacitor for its extracellular and intra cellular constituent. When the frequencies value is increase, impedance will decrease.

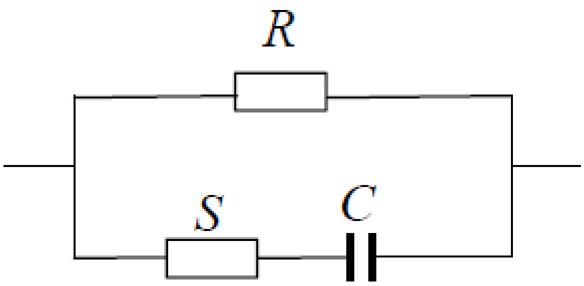


Figure 2.3: Equivalent impedance network using Cole model [18]

Figure 2.3 represent the example of biological tissues impedance using Cole model electrical network. [18] The impedance value can be calculated using equation below:

$$Z = R_{\omega} + \frac{R_O - R_{\omega}}{1 + \left(j\frac{\omega}{\omega_C}\right)^{1-\alpha}} \quad [18]$$

In this project, fix frequency is considered so that it will be easier for testing process purpose. Usually, impedance is the functions of frequency dependence which related to dielectric dispersion region that will be explain details in next sub topics.

2.3 Dispersion Region

Dispersion curve is corresponding to the real part of dielectric constant, ε' and the imaginary part, ε''. The frequency urged on the sample will determine its dielectric constant. However it is also influence by time factor due to molecular process inside the sample. If the post mortem time taken to measure the sample properties is longer, the polarization process inside the sample will increase due to electric field charged on it.

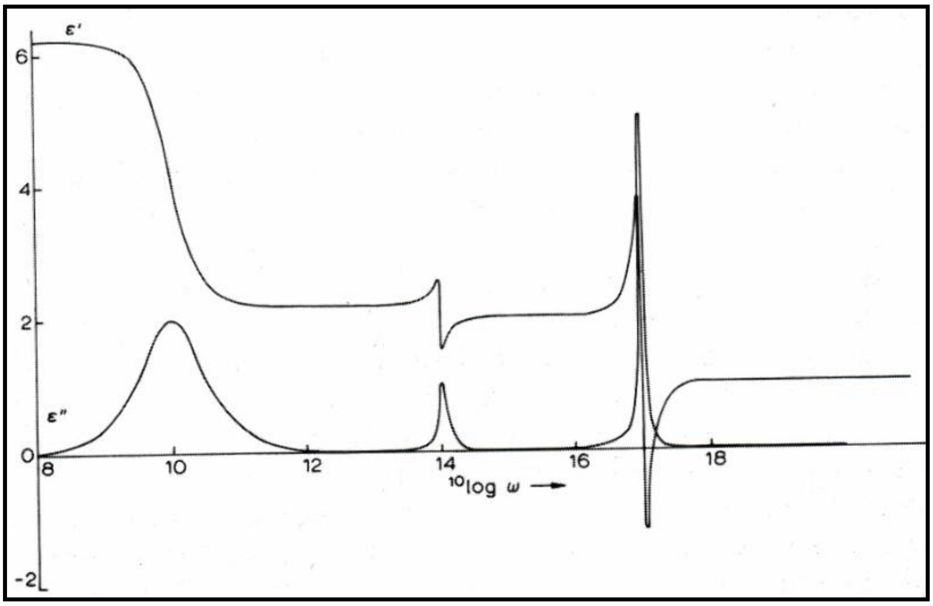


Figure 2.4: Dispersion region of frequency spectrum [7]

Here, relative permittivity and conductivity are frequency depends or commonly referred as 'dielectric dispersion'. [7][8] Their dielectric spectrum consists of three main regions known as α, β, and γ dispersions. The low-frequency, α dispersion usually in the hertz to kilohertz range while the β dispersion is up to few Megahertz range and γ dispersion is for higher range of frequency. [1]

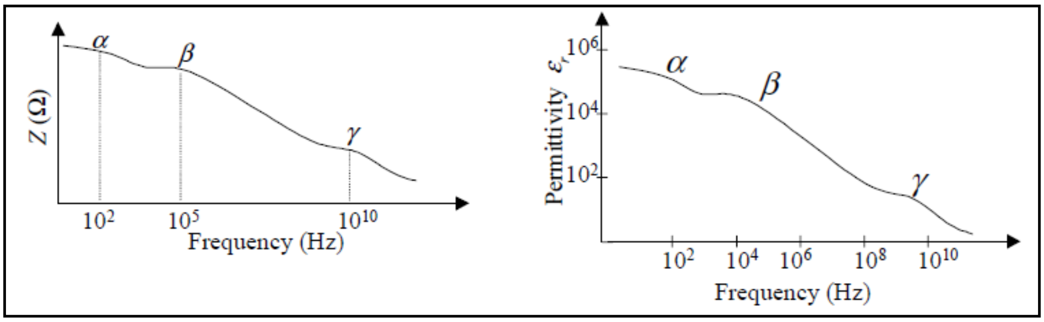


Figure 2.5: Plot of impedance and permittivity value as a function of frequency [19]

As shown in the Figure 2.5, the dispersions region of biological tissues exhibits anisotropy structure especially at alpha region frequencies. [19] So that only alpha region (low frequency) will be cover in this project for dispersions range. Frequencies chosen are within 50Hz to 1kHz. If the frequency is too high, there will be insufficient time for molecular process to be fully completed. Moreover, the device reliability is more accurate in low region dispersion compare to high region dispersion. Increasing in sample concentration will cause the value of conductivity increase but decrease in permittivity value. [7]

However some errors can occur when disturbances existed between conducting medium like parasitic capacitances and internal capacitances. So that, more cautions are needed to achieve the best condition when testing the circuit functionality.

2.4 Reviewed Design

2.4.1: Tetra Polar Electrodes

There are several configurations can be use for electrode such as single, bipolar, tetra polar, and orthogonal configuration. However in this project, it will focus on the usage of tetra polar configuration.

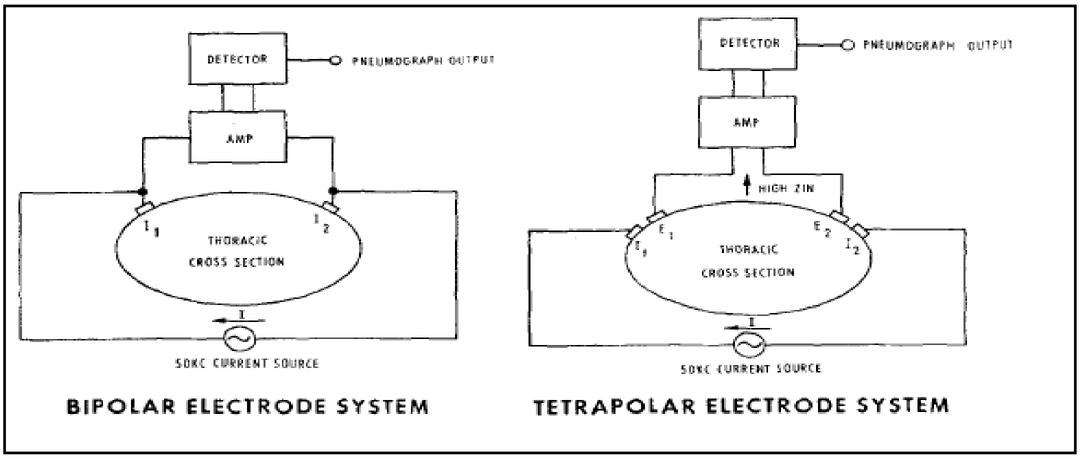


Figure 2.6: Differences between bipolar and tetra polar configuration [17]

Figure 2.6 shows the electrode configuration of a system. Tetra polar electrodes are simple to construct and it can overcome the weakness of bi-polar configuration with reducing the resistance between electrode and sample. There are two basic conditions to be fulfilled for ideal tetra polar electrode measurement. First, the output impedance of the current source must infinite and second the input impedance of voltage measurement circuit differential amplifier is infinite. It is important to avoid current drop and does not flow by the leads so the electrode will not affect the impedance voltage measurement.

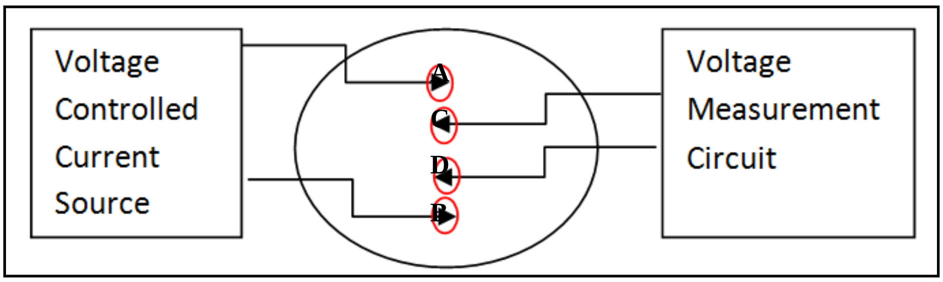


Figure 2.7: Tetra polar electrode used in this project

Figure 2.7 shows the electrodes configuration used in this system combining 4 pleating pins with 1 inch length.

2.4.2: Current Source Generator

Usually a simple current source circuit will convert a voltage supply into current source. The biggest weakness of the system is the loads implemented will affect the output current. Voltage drop across the load will reduce the excitation voltage and reducing output current value.

A) Current mirror current source circuit

Another suitable configuration for this system is current mirror current source using low pass filter DC-feedback. This structure is suitable to overcome gain accuracy issues produce by amplifier and saturation at the output by residual DC current. IC AD844 act as a current mirror while MAX436 operates as a voltage controlled current source [18].

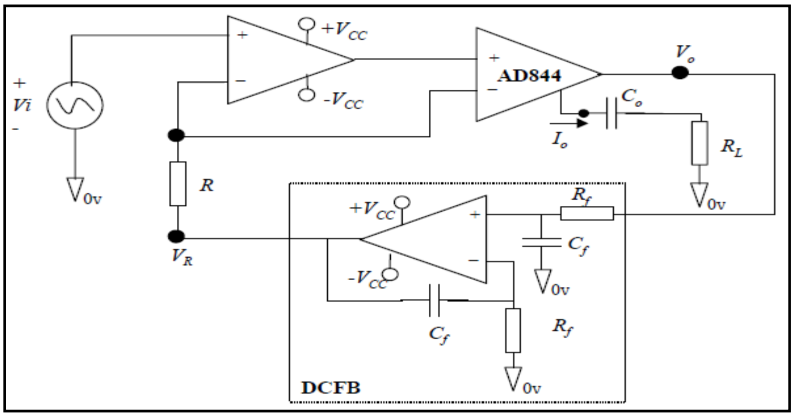


Figure 2.8 : Low pass filter of Direct Current Feedback [18]

From the Figure 2.8, when using this configuration, high DC gain is achieved and the DC feedback (DCFB) structure will remove the DC output voltage. Co is acting like blocking capacitor to prevent any direct current entering sample. However, it will demonstrate a large changes in output impedance if high current is injected and effect the output current. Mismatching between component will increase the drift capacitance.

Conclude that, current mirror current source configuration are more suitable for low frequency region because it produce more stable output but not suitable for high frequency region because it will exhibit increase in stray capacitance values. Unfortunately some component of this circuit are discontinued and this circuit is not suitable for new device developement.

B) Modified Howland Circuit

Studies show that Howland circuit is a good combination in generating constant current. [19]

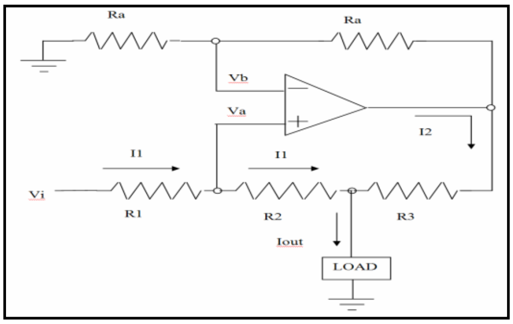
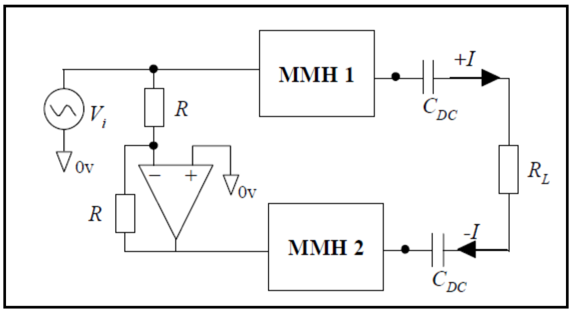
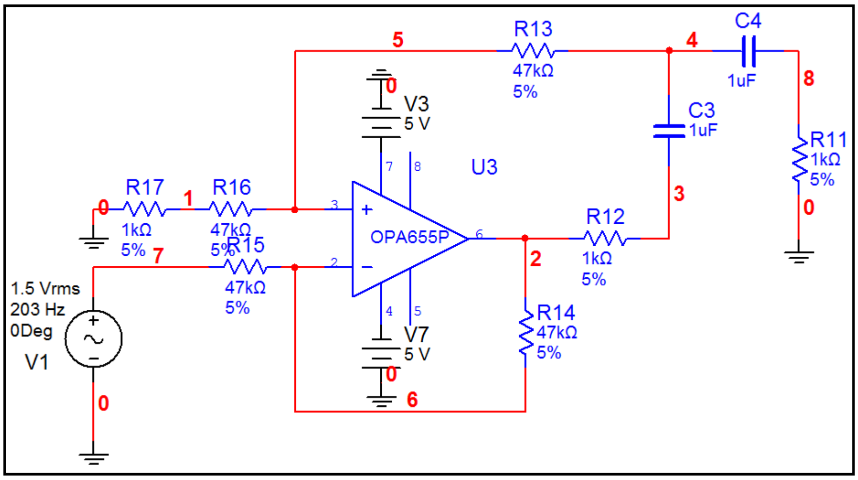


Figure 2.9: Basic structure of Modified Howland circuit [21]

Figure 2.9 show the basic structure of modified Howland circuit as current source. With additional R3 resistor, it can reduce the output voltage constraint of the circuit. Modified Howland circuit is a good current source application where as it does not affected by the load values. Other than that, this circuit producing more stable output current.



(a)



(b)

Figure 2.10: (a) Block function of Modified Howland circuit and (b) Component for each of MMH circuit. [18]

From the Figure 2.10, bipolar modified Howland circuit are constructed to produce dual-balanced output current. [18] Two modified Howland circuit are combined as a current sinking (MMH2) and current sourcing (MMH1). Unity gain concept is applied to the system to ensure both electrodes will have the same output current.

By using bipolar modified Howland circuit, the undesirable common mode volatge could be minimised because it contains two-phase of current sources controller which are current source, +I and current sink -I. From that, the output current will remain constant when both current sinking and current sourcing are in balanced condition. As result, more stable output current is produced. However, extra precuation are needed because if the mismatch component occur, it will generating the common mode voltage that will lead to instable output surrent.

As conclusion, bipolar moodified howland circuit is used in this project because it is more reliable in term of frequency range and component availability.

CHAPTER 3: METHODOLOGY AND PROJECT WORK

3.1: Project Progress Flow Chart

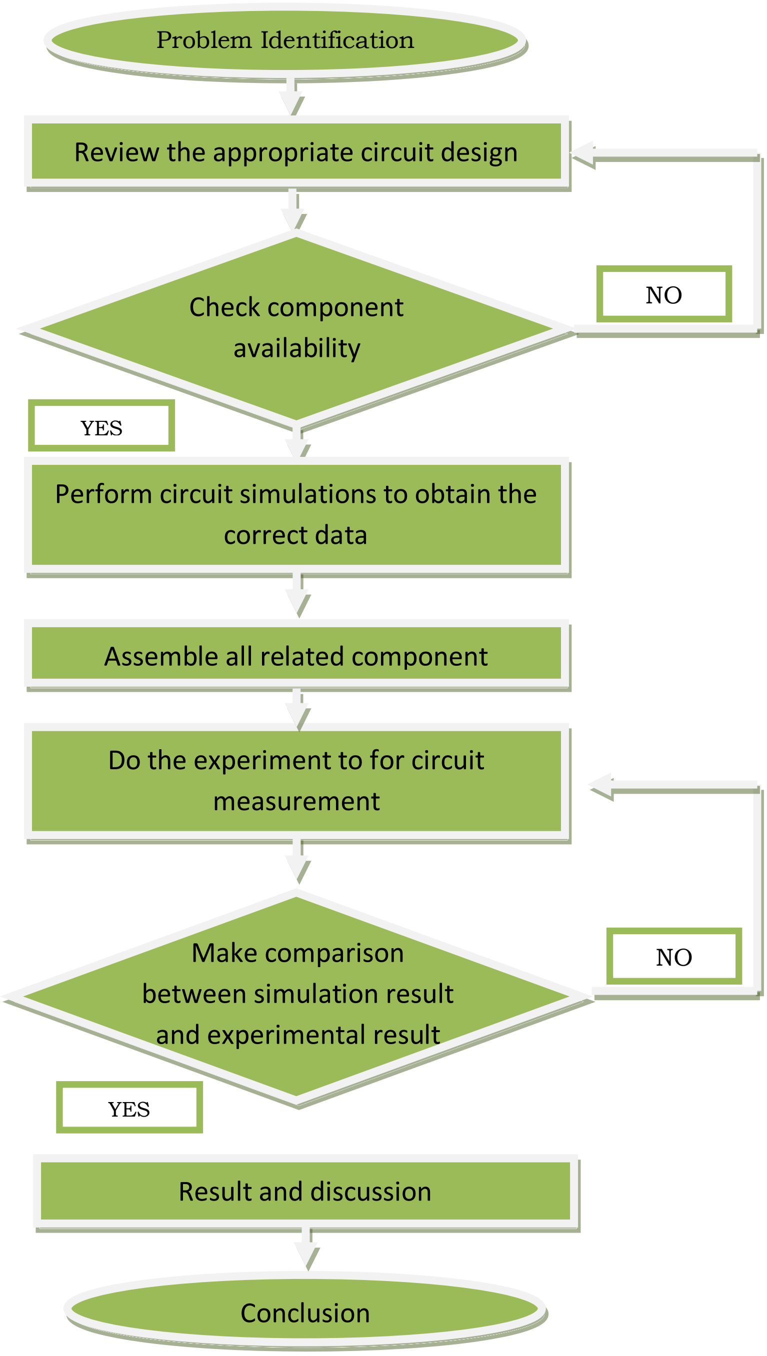


Figure 3.1: Project progress flow chart.

Figure 3.1 explain the progress and the process required in this study. The problem identification process involves preliminary analysis on existing circuit design.

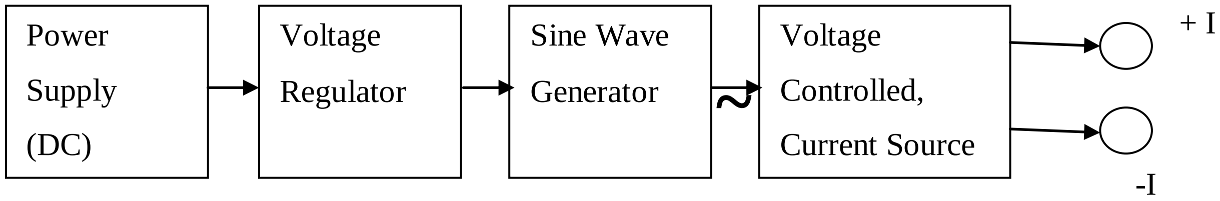
All the circuit design reviewed is based on the previous researched study. Then it is followed by gathering the required information available such as component availability, technical specification or datasheet of each component used, and circuit design criteria. Some of the components are discontinued and the design must be reviewed again until the suitable design is chosen.

Later it is followed with extracting and interprets all the data available with simulate the design using Multisim Pspice software. From here, simulation result is obtained to predict the output from circuit design.

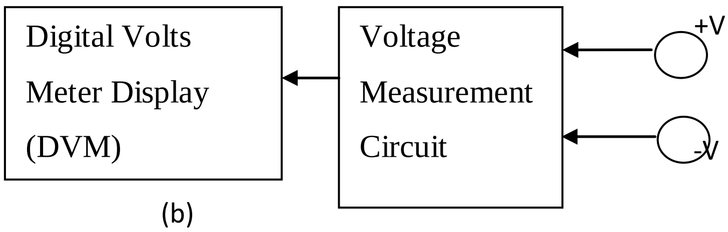
After finished with simulation result of each device part, assembling process is start with all existing components. Breadboard is chosen as assemble medium because it will be easier as testing circuit is construct.

The circuit is tested to obtained experimental data. Next, both simulation data and experimental data are compared to determine system feasibility. Next, analysis or discussion is done from the results obtained. Lastly, conclusion is made from the project progress.

3.2 Instrumentation Operation



(a)



(b)

Figure 3.2: Block function of tissue impedance measurement system.(a) A current source and (b) A voltage measurement circuit

Usually transfer impedance system is operating by injecting a known current and measuring the output voltage. The most crucial part is to obtain the accurate current generator over a wide range frequencies and variability of loads value.

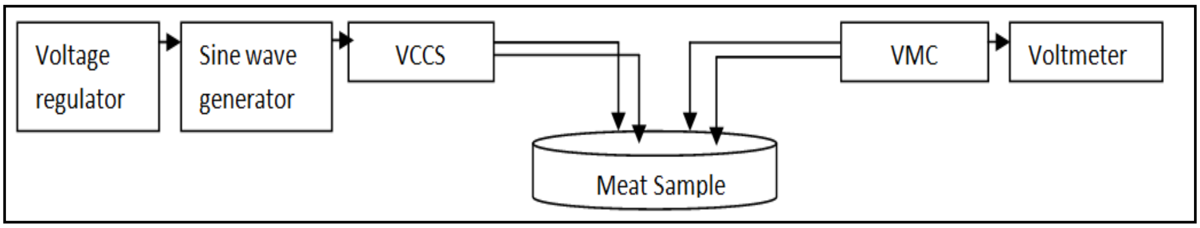


Figure 3.3: Device operation overview

In designing this portable device, DC power supply is used to generate voltage. Firstly, voltage regulator is used to keep the regulated voltage in the system is at desired value and to prevent the power supply from producing unstable current that will damage the internal component of the circuit. 12V battery is used with voltage regulator to generate a constant 5V voltage supply to the system.

The second part of this system is a sine wave generator. It will acts as function generator in generating pulse or sine wave. Fixed frequency at 203 Hertz is used to narrow down the project scope and focus more on device reliability. As mention above, low frequency region is more suitable because the effects can be seen clearly. If high frequency is applied, the device will be less accurate.

Next, a voltage controlled, current source (VCCS) system is constructed. Purpose of this part is to generate a constant current source at 1mA.

Then, a tetra polar electrode configuration is constructed and acts as a contact medium between meat sample and the system. Two electrodes will inject current, and the others two will be use to measure the voltage.

Finally, a voltage measurement circuit is designed to measure the output voltage from the meat sample. It is function like an amplifier circuit to amplify the output voltage so that it will be easier for measuring. A digital voltmeter is then use as a display device.

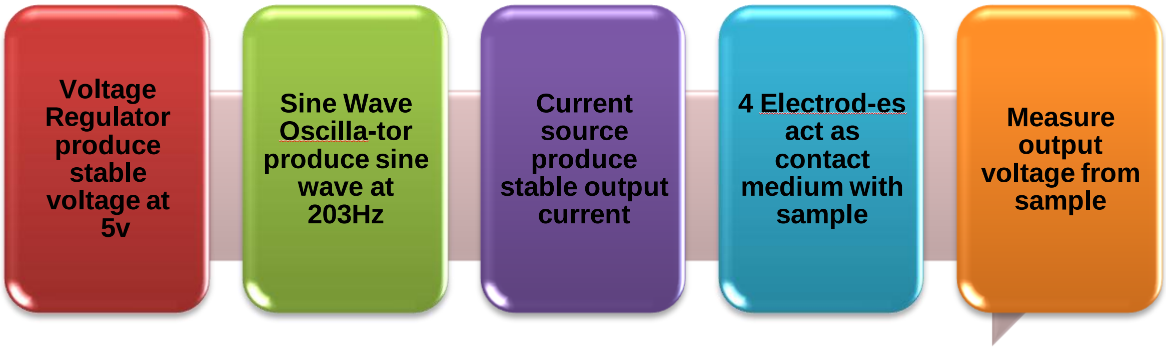


Figure 3.4: Summarization of instrument mechanism

3.3 Material and Equipment

Here are the list of component use for current source circuit and voltage measurement circuit. Both circuits are using OPA656U from Texas Instrument with certain characteristics that already mention before.

3.3.1 Current source circuit component

Operational amplifier

1. OPA656U by Texas Instrument Production

Resistor

1. 10k Ohm
2. 2k Ohm
3. 1k Ohm
4. 1M Ohm
5. 8k Ohm

Capacitor:

1. 1u F

3.3.2 Voltage measurement circuit component

Operational amplifier

1. OPA656U by Texas instrument production

Resistor:

1. 470 Ohm
2. 276 Ohm
3. 13.8k Ohm
4. 10k Ohm
5. 10M Ohm

Capacitor:

1. 33n F
2. 2u F
3. 1u F
4. 100p

3.4: Activities/Gantt Chart and Milestone

Gant chart for semester one:

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Selection of Project Topic: Dielectric Characterisation of Biological Tissues	■	■	■				**Mid Semester Break (7/02-11/02/2012)**								
2	Preliminary Research Work: Research on literatures related to the topic		■	■	■											
3	Submission of Extended Proposal					■	■									
4	**Project Work:** • Familiarization with related measurement instrument						■									
	• Operating procedures to measure solid and liquid samples.						■									
	• Load composition								■	■						
	• Frequency limitation								■	■						
5	Proposal Defence								■	■	■					
6	**Project work continues:** • Received meat samples from VRI, Ipoh										■	■	■	■		
	• Preliminary measurement of the samples										■	■	■	■		
	• Collecting data from measurement										■	■	■	■		
7	Submission of draft for interim report														■	
8	Submission of Interim Report Final Draft															■

Table 3.1: Gantt chart and Key Milestone for semester first

Gant chart for semester two:

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Continue research on literatures that related to the topic	■	■					Mid Semester Break (04/07/2012-08/07/2012)								
2	Reviewing several suitable design before assembling device			■	■	■										
3	Obtaining simulation result from selected design					■	■		■							
4	Purchasing all required component								■	■	■					
5	Assembling circuit as decided • Voltage regulator										■					
	• Sine wave oscillator											■				
	• 4 electrodes											■				
	• Voltage measurement circuit												■	■		
	• Current source												■	■	■	
6	Make comparison between experimental data and experimental data										■	■	■	■	■	
7	Submission of final report															■

Table 3.2: Gantt chart and Key Milestone for semester two

CHAPTER 4: RESULT AND DISCUSSION

In this chapter, the result will be discussed part by part starting from voltage regulator, sine wave generator, current source generator, tetra polar electrode and voltage measurement circuit.

4.1: Voltage regulator

Purpose of this voltage regulator is to ensure that voltage supply to the system does not axceed ±5V DC to prevent the other components from damage by excessive voltage. When 12V input voltage applied to the circuit, the output from circuit will produce constant voltage at ±5V DC.

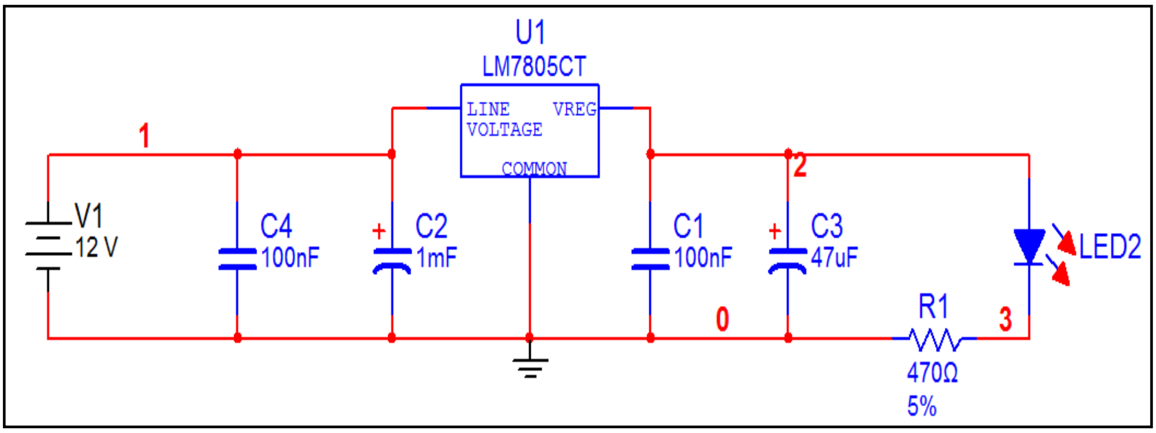
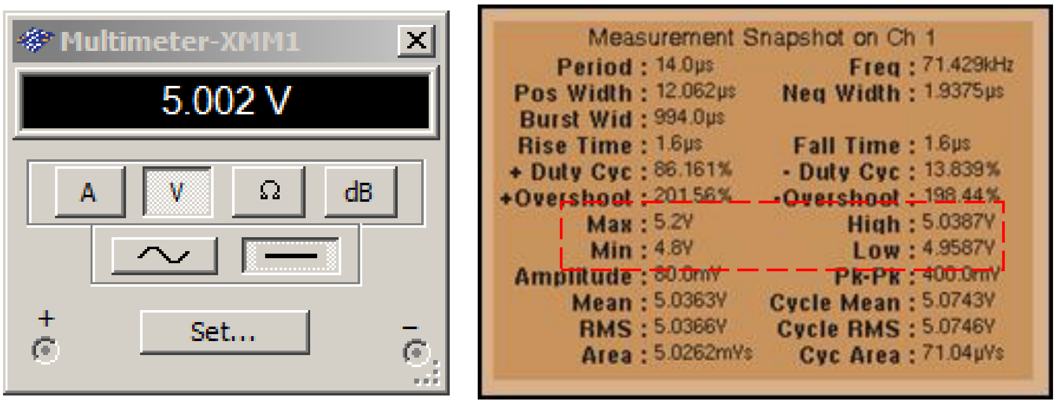


Figure 4.1: Voltage regulator schematic

Figure 4.1 above shows the schematic for voltage regulator circuit. Voltage regulator is usually used to produce a stable voltage sourcing. In this project, ±5V direct current (DC) is use as voltage supply to the main circuit using 7805 regulator integrated circuit (IC) with 470Ohm resistor, 1000uF, 0.1F, and 47uF capacitor.



(a) (b)

Figure 4.2: (a) Simulation result and (b) Experimental result for output voltage.

Referring to Figure 4.2 above, it shows that the simulation result for output voltage from this circuit is constant at +5.002V direct current (DC) while experimental result shows the output voltage is at +5.0363V(mean value). The maximum voltage is 5.2V and minimum value is 4.8V.

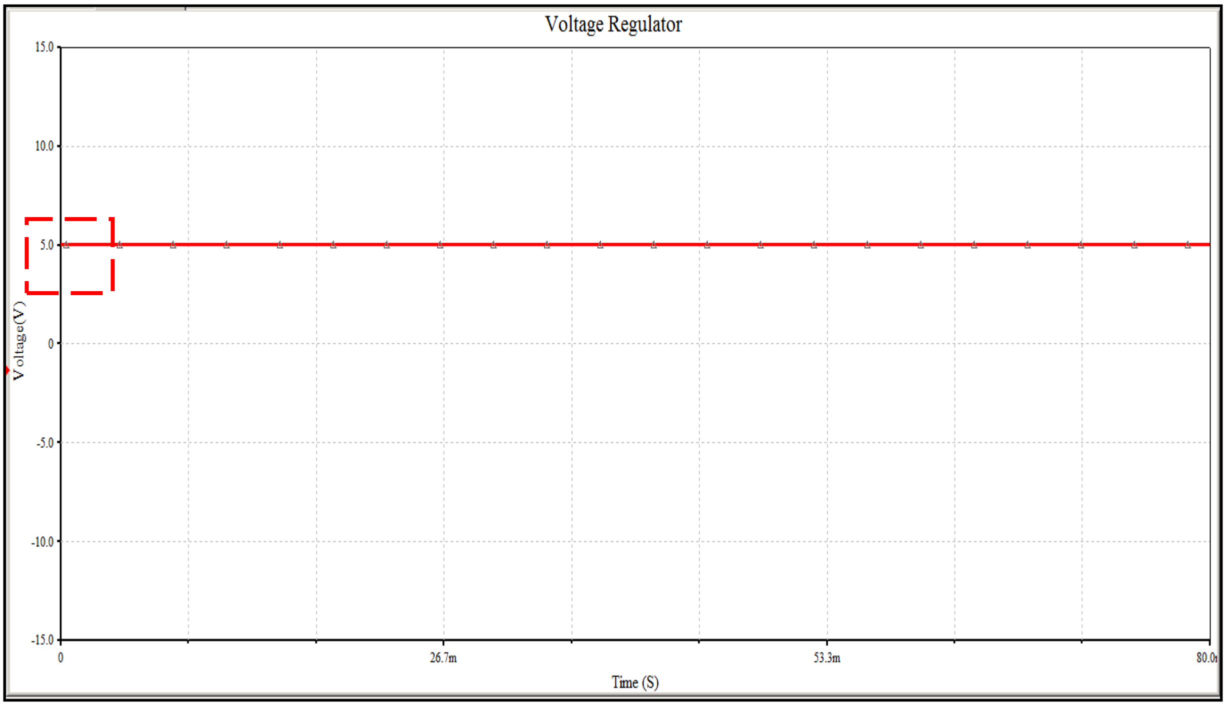


Figure 4.3: Simulation result for voltage regulator.

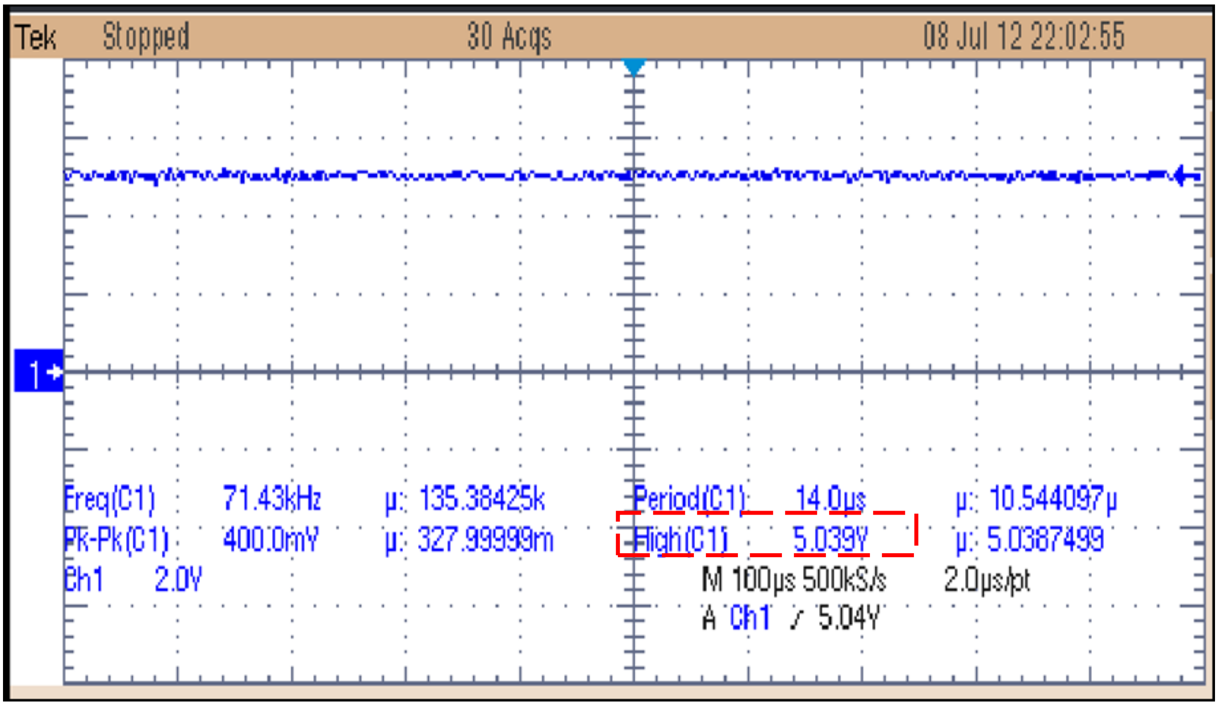


Figure 4.4: Experimental result for voltage regulator.

Figure 4.3 show graphical result for simulation while Figure 4.4 shows the graphical result for experimental. However, slightly ripple exist in experimental result. This is due to low filter action of the circuit. It can be reduced by increasing the value of capacitor so that the capacitors will efficiently filter more voltage input from main power supply.

Conclude that both simulation result and experimental result shows the same behaviour. The experimental result may slightly vary due some effect such as internal resistance of components inside the circuit.

4.2 : Sine Wave Generator

Next the sine wave generator circuit. A constructed sine wave oscillator is used to substitute function generator function. Purpose of this circuit is to ensure that the generated sine wave is stable at a constant frequency.

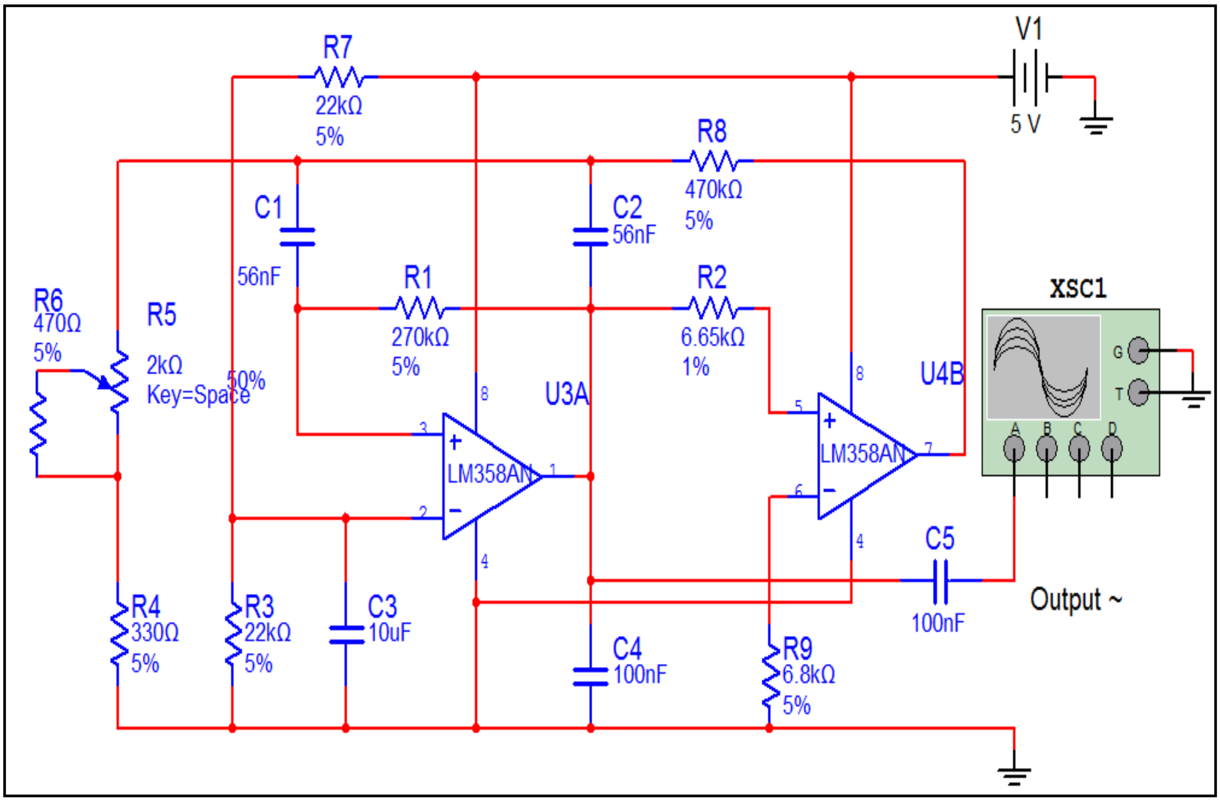
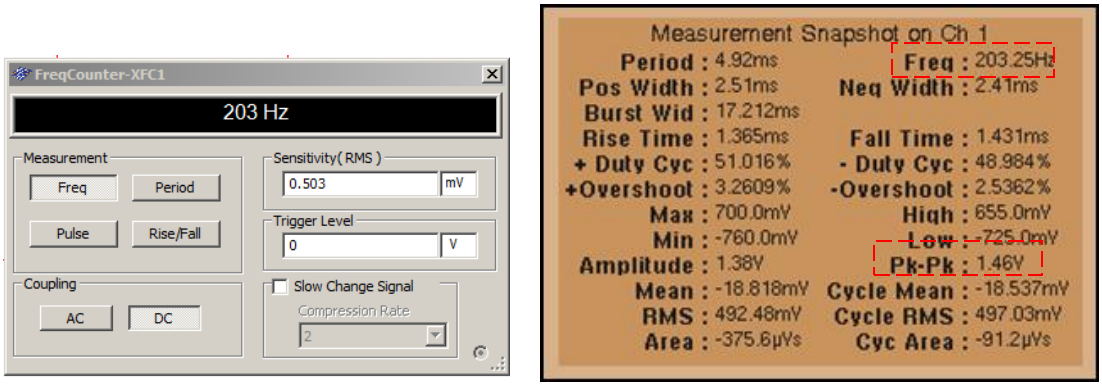


Figure 4.5: Sine wave generator circuit schematic

Figure 4.5 above shows the schematic for sine wave generator circuit. In this project, ±5V direct current (DC) is use as voltage supply. Dual operational amplifier, LM358 IC is used with high gain and internal frequency compensated. 2.2k preset potentiometer is used to limit the output frequency.



(a) (b)

Figure 4.6: (a) Simulation result and (b) Experimental result for sine wave generator.

Referring to Figure 4.6 above, it shows that the simulation result for frequency generated from this circuit is constant at 203Hertz with 1.5Vpp (equivalent with 0.5303 rms) while experimental result shows the frequency generated is at 203.25 Hertz with 1.46Vpp.

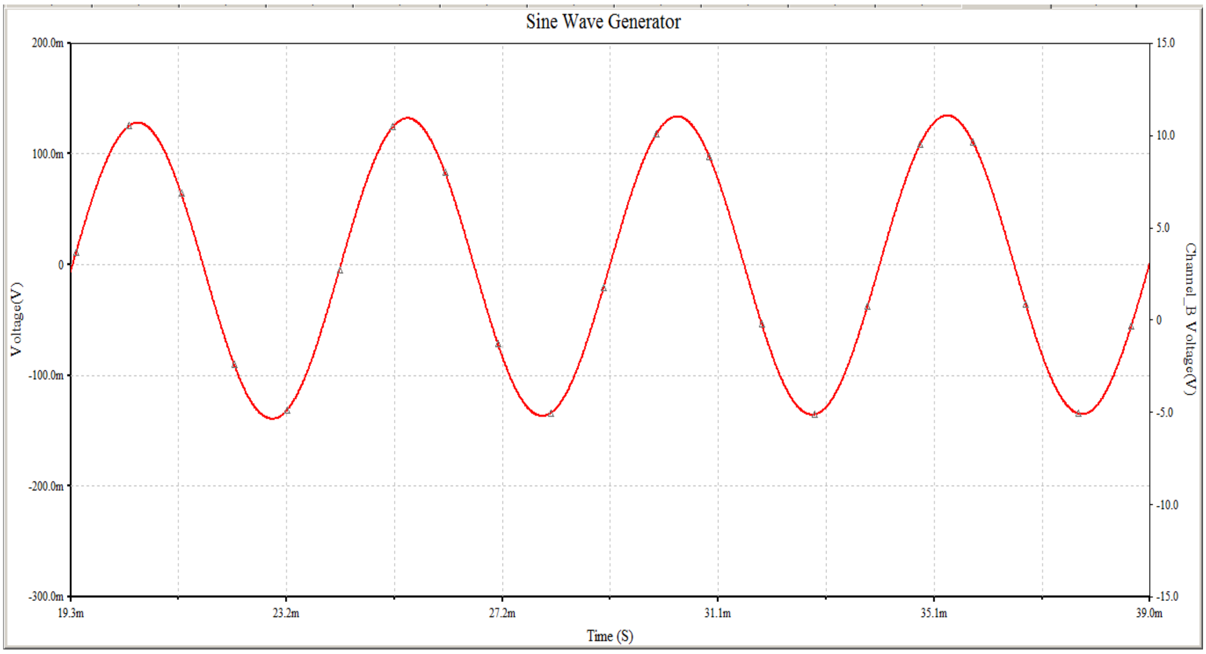


Figure 4.7: Simulation result for sine wave generator.

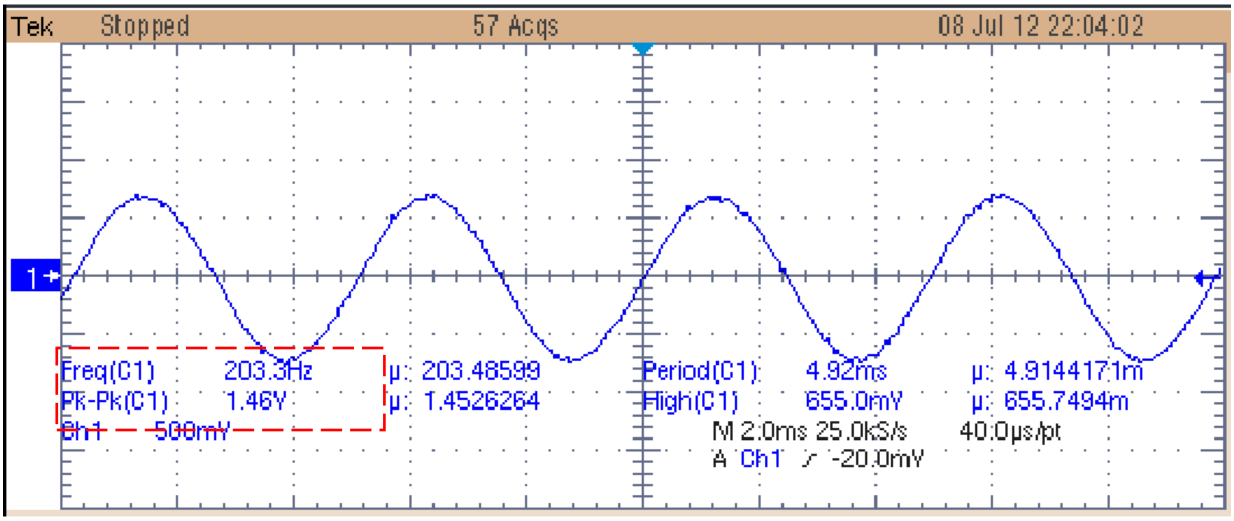


Figure 4.8: Experimental result for sine wave generator.

Figure 4.7 show graphical result for simulation while Figure 4.8 shows the graphical result for experimental. Both graphical results are plotted based on time domain(S) versus voltage (V). Conclude that sine wave signal produce is constant and stable at 203 Hertz with 1.5Vpp.

4.4: Voltage Measurement Circuit

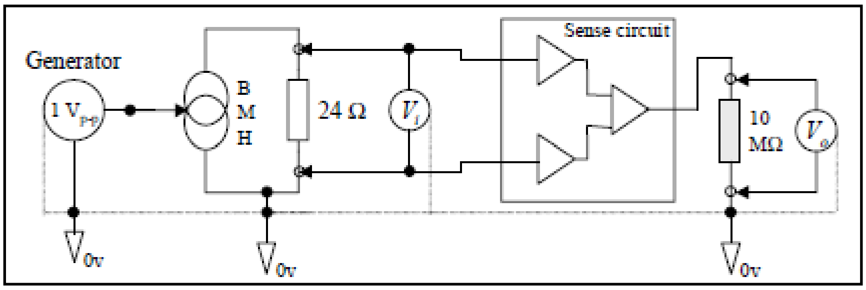


Figure 4.9: Block function of voltage measurement circuit. [18]

Figure 4.9 shows the block function of voltage measurement circuit connected to a current source circuit. It is also labelled as 'sense circuit' which consist of operational amplifier. This circuit will measure the output voltage from the sample.

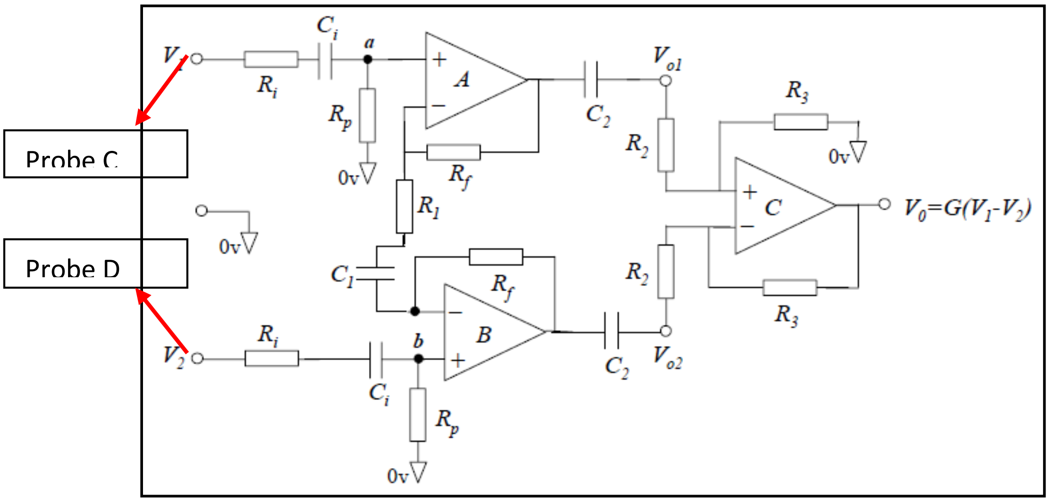


Figure 4.10: Voltage measurement circuit with a differential output. [18]

Figure 4.10, shows that the input V1 and V2 are from the sample which are connected to system using probe C and probe D. Capacitor Ci functioned to block any DC potential voltage from entering system by acting as high-pass filter combine with resistor Rp. It is also function to block any DC current from flowing in.

Advantages from this system are, with using resistor Rp, bias current can be set up to flow into non-inverting input of operational amplifier A and B. It is also can maximize the input impedance of the amplifier.

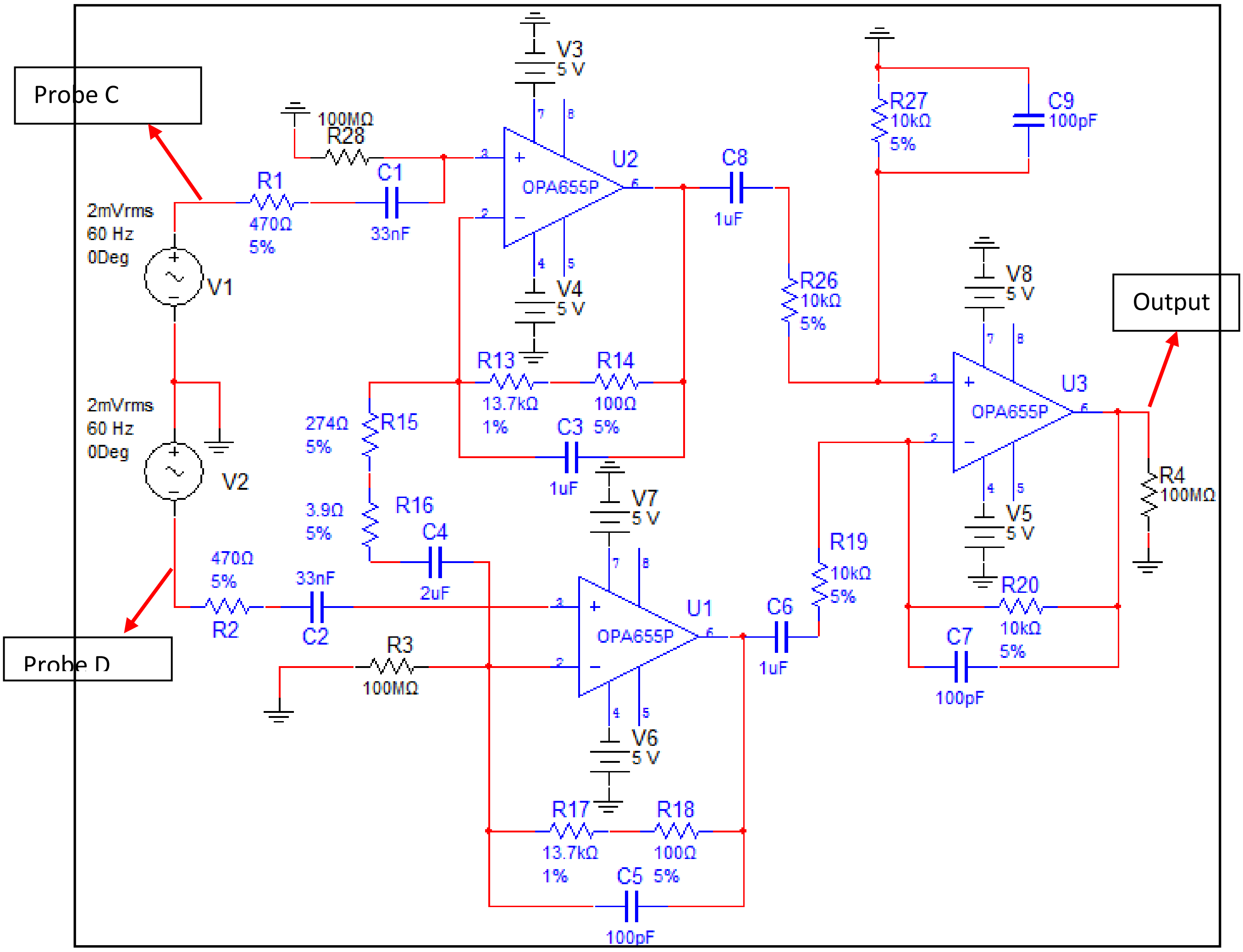


Figure 4.11: Voltage measurement circuit schematic.

Figure 4.11 shows the schematic of a Voltage Measurement Circuit. Output voltage from the load measured is assumed to be 0.002Vrms (5.65mVpp). Probe C and Probe D is connected to the load as labelled in Figure 4.11.

Output from this circuit is connected to digital voltmeter (DVM) for measuring purpose. In this project, DVM is function as display device. This circuit will function as amplifier to amplify the output voltage measured from sample. However, in real application, this values may be vary depend on the load resistance values.

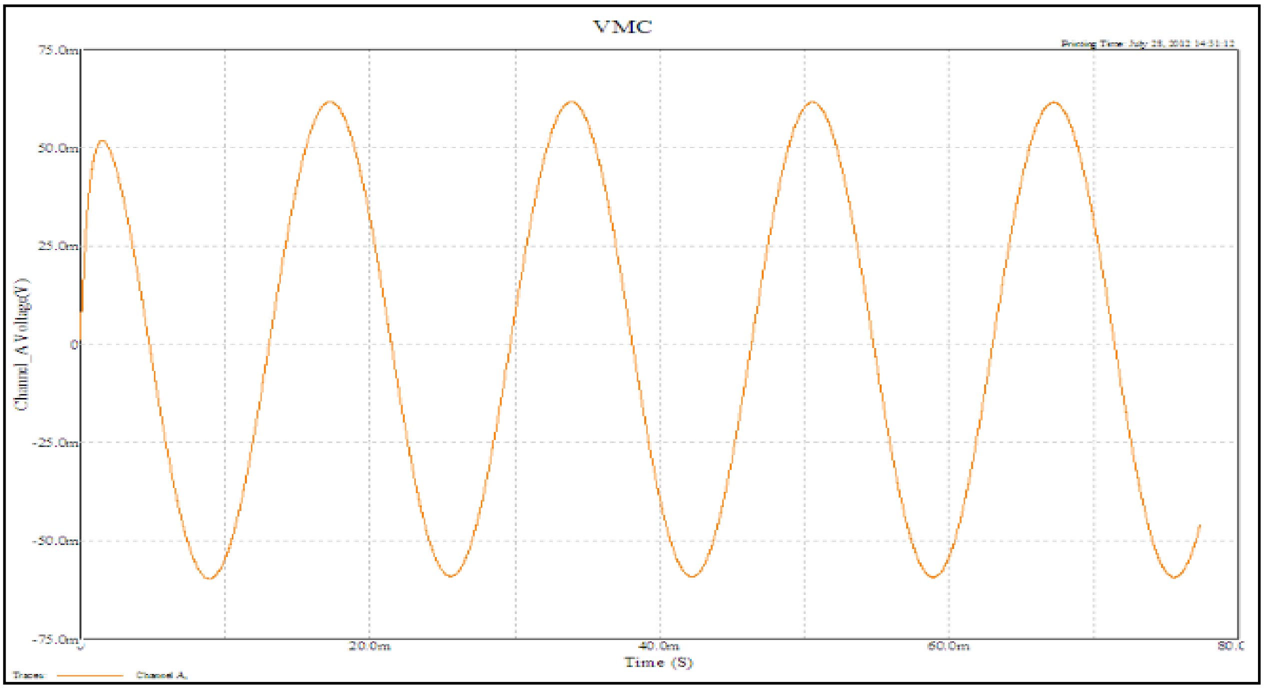


Figure 4.12: Simulation result for sine wave generator.

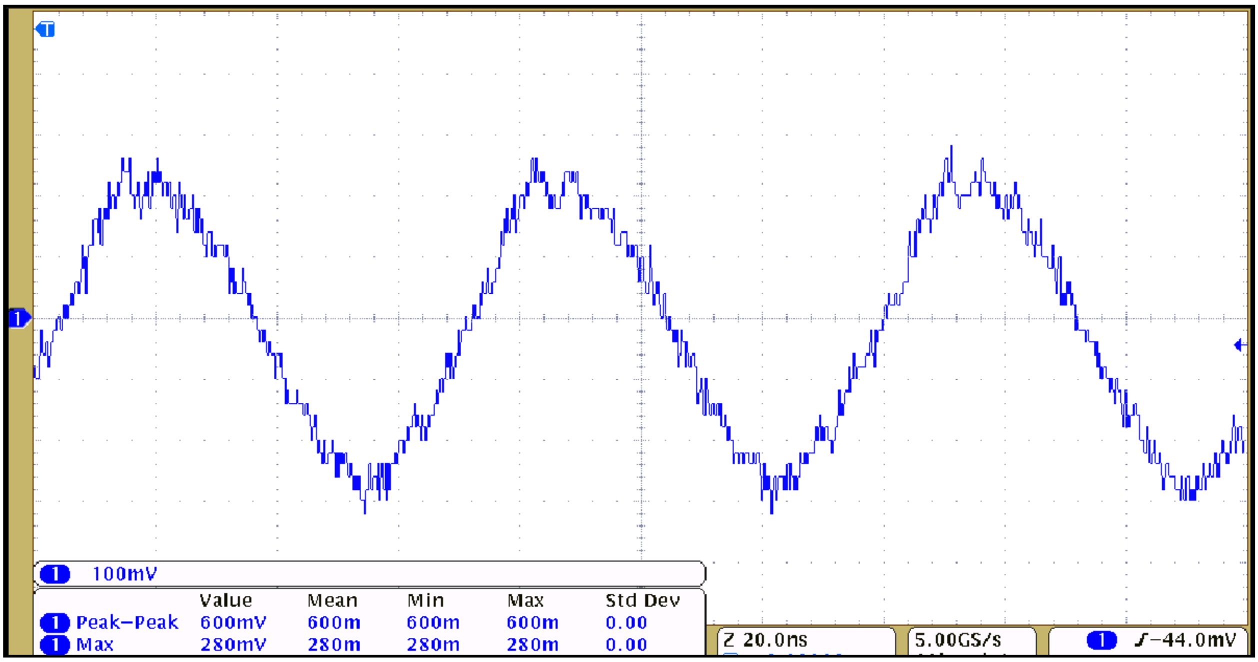


Figure 4.13: Experimental result for sine wave generator.

The same results are shown by the graphs above. Figure 4.12 show graphical result for simulation while Figure 4.13 shows the graphical result for experimental. Both graphical results are plotted based on time domain(S) versus voltage (V). Conclude that voltage measurement circuit is works well. The same result is obtained for simulation and experimental.

4.5: Current Source Generator

A) Modified Howland circuit

Operational amplifier OPA655 is already discontinued and been replaced by OPA656 with same specification from the same manufacturer.

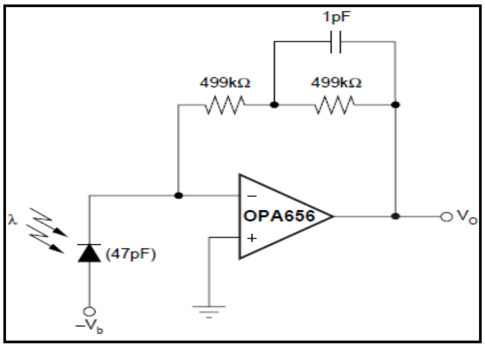


Figure 4.14: OPA656 wideband photodiode trans impedance amplifier [19]

Figure 4.14 show an example of OPA656 applications of wideband photodiode trans impedance. [19] OPA656 is manufactured by Texas Instrument and came with unity gain stable bandwidth where the output produces same just like input injected. It is wide frequency range up to 500 MHz and using FET-input to ensure high speed performance for analogue to digital converter with low noise integrators. [19]

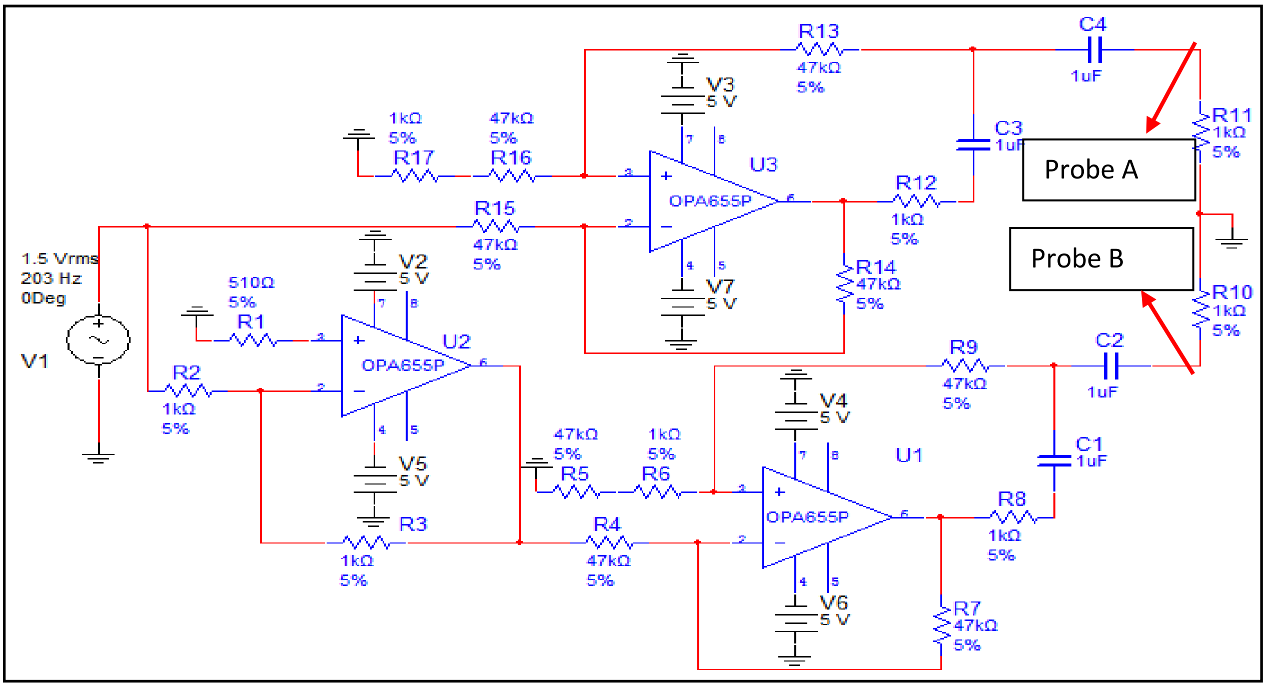
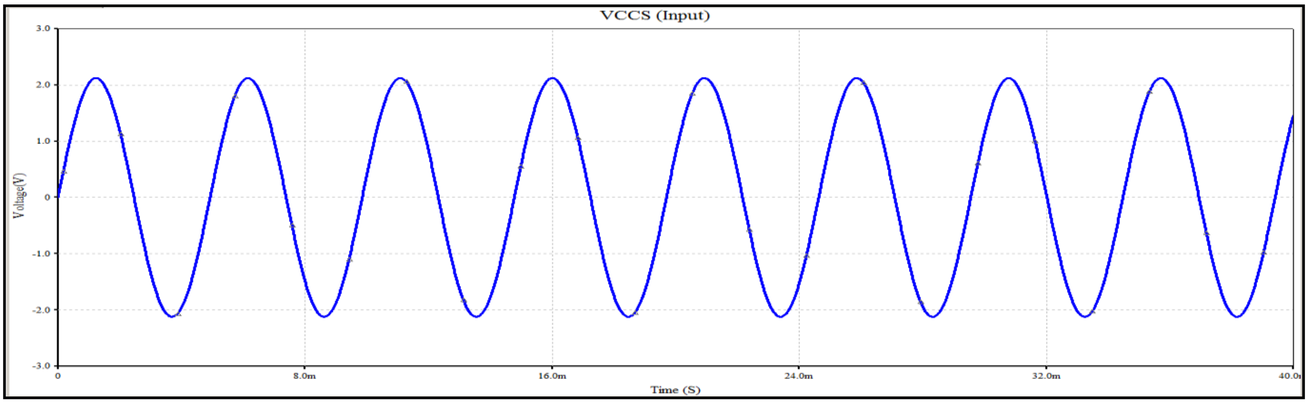


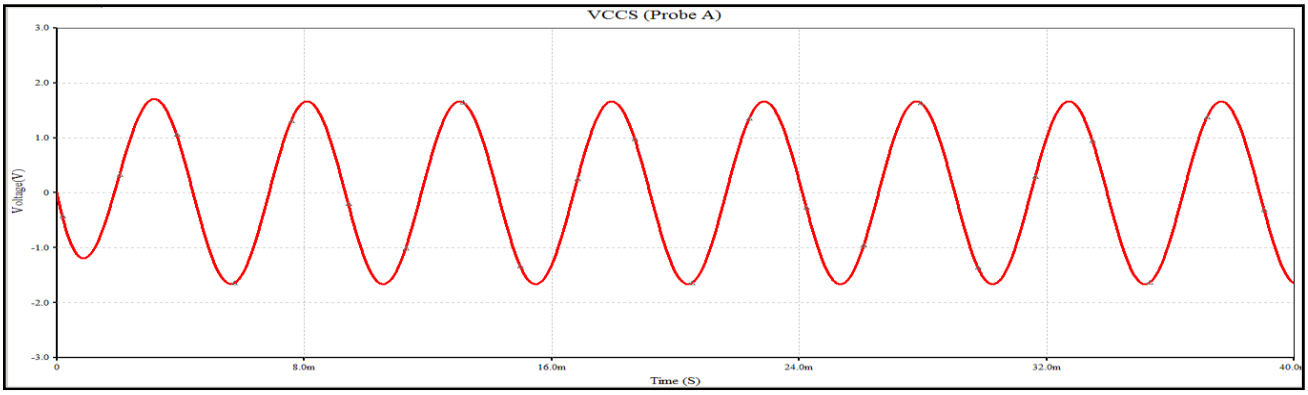
Figure 4.15: Current Source Circuit schematic Using Bipolar Modified Howland (BMH) structure

Figure 4.15 shows the schematic structure for BMH configuration. Load resistance is assumed to be 1kΩ. [18] Probe A and Probe B are connected as labelled.

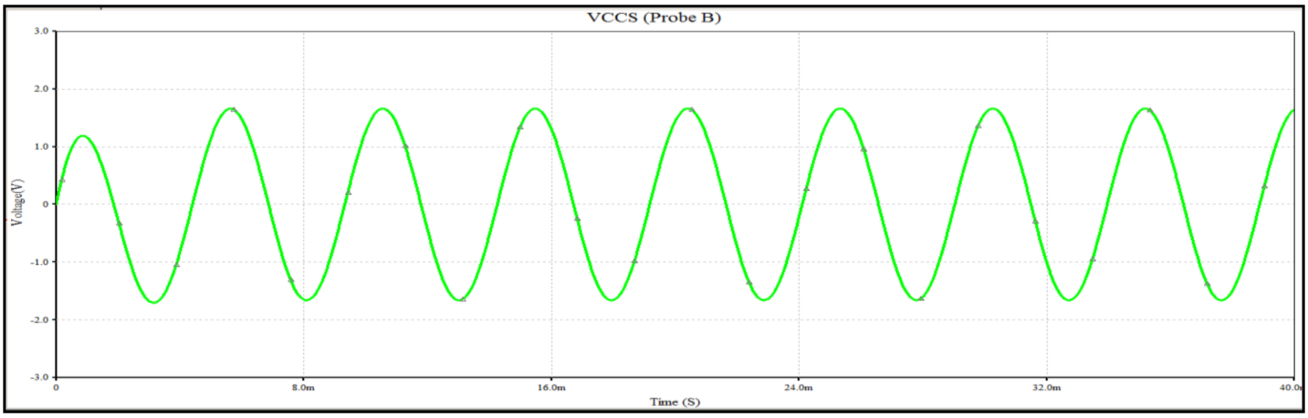
1mA output current is generated from this circuit. Next, current produced is injecting to the sample using Probe A and Probe B. Probe A and Probe B is use as contact medium between circuit and sample measured.



(a)



(b)



(c)

Figure 4.16: Simulation result for current source generator, (a) Input signal, (b) output signal at Probe A and (c) output signal at Probe B

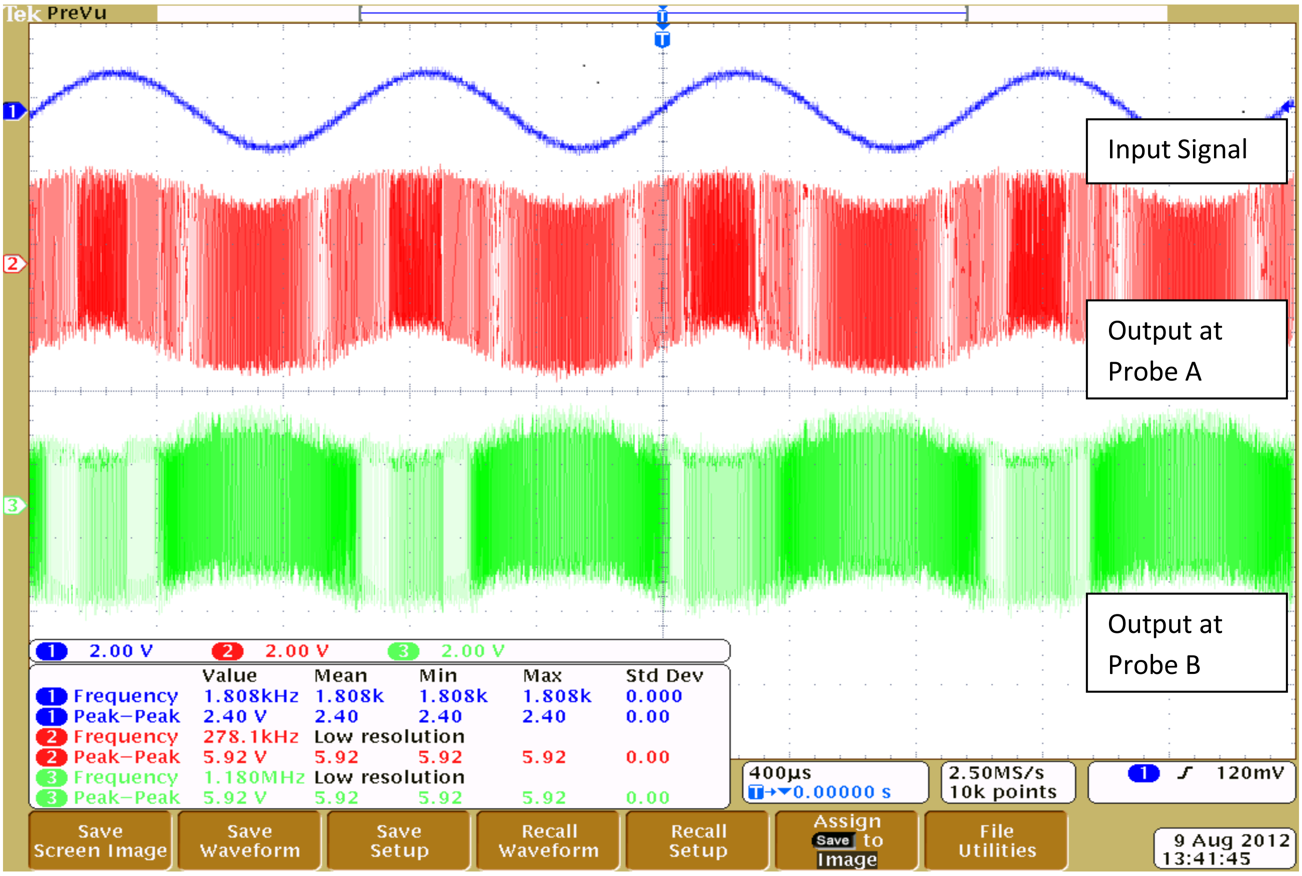


Figure 4.17: Experimental result for current source generator for Input signal, output signal at Probe A and output signal at Probe B

From Figure 4.16, output signal produced at Probe A is 180º out of phase in comparison with the input signal generated shown by figure 4.16 (a). Output signal produced at probe B is zero out of phase in comparison with input signal. Output signal at Probe A and Probe B produced the same amplitude and but 180º out of phase. This is because Probe A is designed as current sourcing while Probe B is designed as current sinking. Both probes will produce the same output current at 1mA.

However, experimental results obtained by Figure 4.17 are not same as simulated result. The output signal produced by Probe A and Probe B have the same phase but vary in term of frequency. As showed above, the signal is enveloped by high frequency noise.

The major reason that may cause this problem is the output current is feedback to the input current. Other than that, it may cause by the mismatching of resistances in the circuit constructed and parasitic capacitance produced by the breadboard itself.

B) Suggested modification

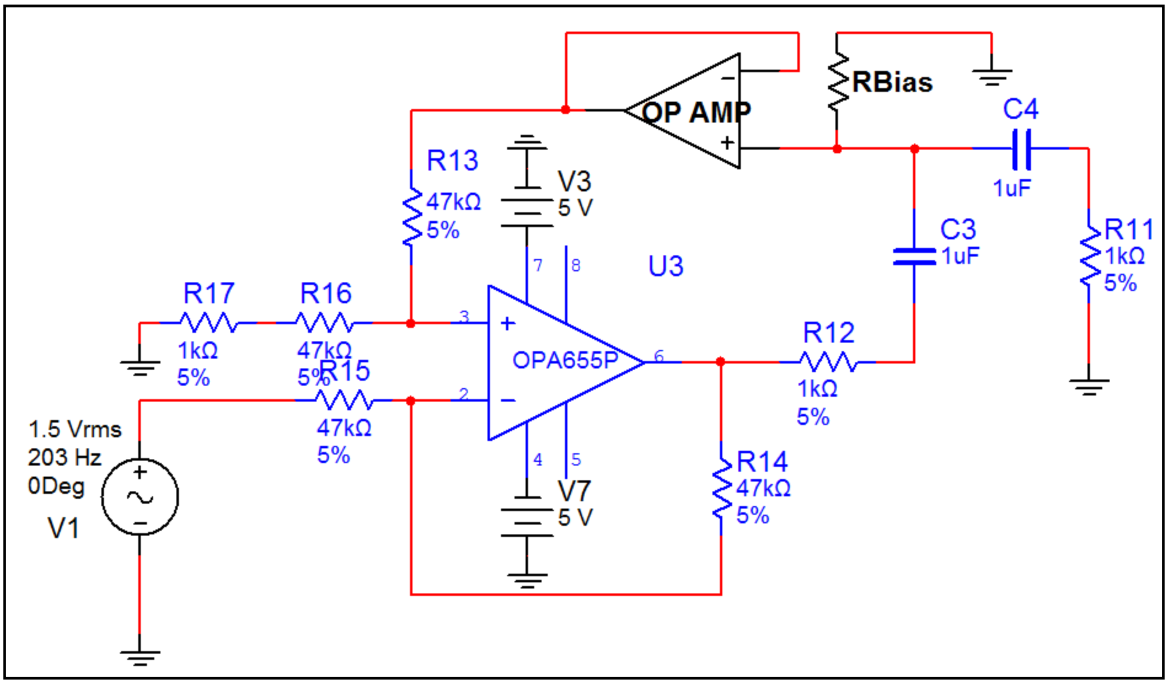


Figure 4.18: Suggested circuit modification

From Figure 4.18, suggested solution is adding an operational amplifier at buffer side. This operational amplifier will function as a bias circuit to the current system. It will block the current output from feedback to the input path. So that, no high frequencies will envelope the output current. However, the reliability of this modification is not determined yet. Further studies need to be done to ensure that the solution is accepted.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project was done in two ways; simulations and assembled hardware. Recall that the objective of this study is to determine the possibility of assembling a portable device to facilitate the characterization process on meat samples. By studying the designs of previous research, the suitable circuit design is chosen and constructed. The last objective for this project is to obtain a result which in line with previous study. Thus some adjustments are made to ensure accuracy of the result.

From the works that have been carried out it can be said that most of the objective are met. Most of the outcomes of the experimental result meet the theoretical result as shown in results and discussion parts. However, some error occurred in determining the accuracy of current source generator. The resulting output current produced is not uniform and not stable. Error from this part will cause significant impact on the overall system.

There are two assumptions made, the load resistance for current source generator is 1k Ohm and the output voltage measured from sample is 2m Vpp. All internal components are assumed to be in ideal condition while constructing the testing circuit.

Each of the measurement parts gives significant impact in the accuracy of the project. Some parameters are set at fixed values to narrow down the project scope. This minimizes the disturbance of the data itself.

5.2 Recommendation

In this project, the testing circuit is done using breadboard. Further analysis can be done using Printed Circuit Board (PCB) to reduce the external effects such as parasitic capacitance and the external resistance from the surrounding in order to achieve better accuracy. When using PCB, less wire are needed and the components are neatly connected

Else more in depth study could be done with the suggested modification in the system as mentioned above to obtain an accurate result and to test it's the functionality.

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APPENDICES