FACULTY OF ELECTRICAL ENGINEERING

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FINAL YEAR PROJECT REPORT

THE CHARACTERIZATION OF NEGATIVE CLOUD-TO-GROUND LIGHTNING FLASHES IN MALAYSIA UNDER THE INFLUENCE OF POLLUTION

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Bachelor of Electrical Engineering (Power Industrial)

June 2015

"I hereby declare that I have read this full report entitled "**The Characterization of Negative Cloud-To-Ground Lightning Flashes in Malaysia under the Influence of Pollution"** and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Industrial)"

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Date : 1 June 2015

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

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2015

I declared that this report entitled "**The Characterization of Negative Cloud-To-Ground Lightning Flashes in Malaysia under the Influence of Pollution"** is the result of my own research unless as cited in references. The report has not been accepted for any degree and not concurrently submitted in candidature of any other degree.

Signature : ____________________________

Name : Muhammad Ridwan Bin Muhamad

Date : 1 June 2015

To my beloved mother and father

Rodizah Binti Samsudin

Muhamad Bin Mohd. Yatim

“Thank you for your patience and support”

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ABSTRACT

Lightning is one of the unpredictable natural phenomenon. Study on lightning is very important because engineers must know lightning characteristics before designing lightning protection systems. This study is focused more on return stroke which occurs in negative cloud-to-ground lightning flash. The characteristics of the negative cloud-to-ground lightning flashes in Malaysia are studied by analyzing electric field generated by the whole flash in nanoseconds resolution. Six out of fifty successive negative cloud-to-ground lightning flashes were selected as sample and analyzed. The measurement was recorded in Universiti Teknikal Malaysia Melaka (UTeM) during southwest monsoon period which is from April to May 2015. It was found that, total number of interstroke intervals has an arithmetic mean value of 76.38ms, a geometric mean value of 4.32ms and does not depend on return stroke order. Of the six negative cloud-to-ground lightning flashes, 83.3% have multiple strokes. In addition, the minimum and maximum peak amplitude of first return stroke (RS) are 0.33 and 1.22V respectively. The mean and geometric mean of peak amplitude for first return stroke (RS) that have been recorded were 0.79 and 0.73V. The percentage of single-stroke flashes was 16.7%, while the mean numbers of strokes per flash and maximum number of stroke per flash were 3 and 5, respectively.

ABSTRAK

Kilat adalah satu fenomena yang tidak dapat diduga. Kajian terhadap kilat sangat penting kerana jurutera mesti mengetahui ciri-ciri kilat sebelum merekabentuk sistem perlindungan kilat. Kajian ini lebih fokus terhadap pulangan strok yang berlaku dalam kelip kilat negatif awan ke darat. Ciri-ciri kelip kilat negatif awan ke darat di Malaysia dikaji dengan menganalisa medan elektrik yang dihasilkan oleh keseluruhan kilat dalam resolusi nanosaat. Enam daripada lima puluh berturutan kelip kilat negatif awan ke darat dipilih sebagai sampel dan dianalisa. Pengukuran direkodkan di Universiti Teknikal Malaysia Melaka (UTeM) ketika monsun barat daya iaitu daripada April sehingga Mei 2015. Kajian ini telah mendapati bahawa, jumlah selang antara strok mempunyai nilai purata aritmetik sebanyak 76.38ms, nilai purata geometrik sebanyak 4.32ms dan tidak bergantung kepada susunan pulangan strok. Daripada enam kelip kilat negatif awan ke darat, 83.3% mempunyai berbilang strok. Di samping itu, nilai minimum dan maksimum amplitud puncak strok pulangan pertama masing-masing adalah 0.33 dan 1.22V. purata dan purat geometrik puncak amplitud untuk strok pulangan pertama yang telah dicatatkan adalah 0.79 dan 0.73V. Peratusan berkelip tunggal strok adalah 16.7%, manakala purata bilangan strok per kelip dan bilangan maksimum strok per kelip masing-masing adalah 3 dan 5.

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LIST OF ABBREVIATIONS

Al	-	Aluminium
ALDIS	-	Austrian Lightning Detection and Information System
Cd	-	Cadmium
Cu	-	Copper
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
Cr	-	Chromium
CG	-	Cloud-to-ground
CCN	-	Cloud condensation nuclei
EFM	-	Electric field mill
Fe	-	Ferum
HCL	-	Hydrogen chloride
H_2S	-	Hydrogen sulfide
NLDN	-	National Lightning Detection Network
NOx	-	Nitrogen oxide
O_3	-	Ozone
Pb	-	Plumbum
PCB	-	Printed circuit board
PM_{10}	-	Particulate Matter

RS	-	Return stroke
SO_2	-	Sulfur Dioxide
Zn	-	Zinc

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CHAPTER 1

INTRODUCTION

1.1 Background of Project (Motivation and Significance of Project)

The first study of the effect of urban area on the enhancement of the cloud-to-ground (CG) lightning activity over and downwind of cities has been initiated through literature published by [1]. Then, several studies have been conducted to study the effect of an urban area on the initiation and enhancement of CG lightning by researchers [2, 3, 4, 5, 6, 7, 8, and 9]. The study found that summer thunderstorms were locally enhanced in the city of St. Louis [10] and researchers reported that urban effects have caused convective precipitation anomalies in the city of Mexico [11]. Apparently, human activities have contributed to an increase of concentration of air pollution in urban area and also caused a thermodynamic effect due to differential heating of the city surface [7]. As a result, pollution over the cities can raise the concentration of cloud condensation nuclei (CCN) and this may affect the characteristics of the negative cloud-to ground lightning flashes such as the number of strokes per flash and interstroke intervals (time separation between strokes). For the reason, characteristics combined with the relationship between air pollution over cities in Malaysia are beginning to be of interest to researchers for the purpose of weather forecast and the designing of lightning protection systems. For example, a researcher [12] found that the failure mode of surge-protective devices deployed in power systems depends on the number of strokes per flash and interstroke intervals. This study contends that the number of strokes per flash and the interstroke intervals are every important parameter to consider in coordinating the circuit breakers in power distribution systems.

1.2 Problem Statement

In Malaysia, industrial activity that contributes high pollution appeared in Penang, Perak, Selangor and Johor [13]. Some studies in U.S.A, Spain and Brazil claim that pollution may enhance the lightning activity by providing highly negative charge at negative charge center [2]. The statement mention as above have no clear evidence to prove. Therefore, it is crucial to conduct lightning measurement in Malaysia in order to investigate the impact of air pollution against the enhancement of lightning activities.

1.3 Objectives

The objectives of conducting this project are as follow:

1.3.1 To develop a hardware for measuring electrostatic field (slow field changes) and radiation field (fast field changes) generated by lightning flash.

1.3.2 To analyze statistical information on electric field produced by negative cloud-to-ground lightning flashes.

1.3.3 To perform comparative study against cloud-to-ground lightning flashes in Malaysia and Spain under the influence of pollution.

1.4 Scope of the Project

This project will focus on identification of negative cloud-to-ground lightning flashes in Malaysia in which the lightning measurement is performed at Faculty of Electrical Engineering in Universiti Teknikal Malaysia, Melaka (UTeM). In this project, software named PROTEUS is used to design and simulate circuit for measuring lightning wave. Upon completing the circuit, it will be transferred to PCB board before combining it with complete hardware. The hardware consists of parallel plate antenna, fast field circuit, operational amplifier at interest frequency of 80MHz and oscilloscope which is used for the measurement of electrostatic field and radiation field. The important parameters concerned in this project include number of strokes per flash, interstroke intervals (time separation between strokes), peak amplitude of lightning wave captured and other statistical information of the lightning flash such as mean, geometric mean and standard deviation. Besides that, air pollutant data provided by Clean Air Innitiative-Asia Secretiarat and the study of Luis Rivas Soriano and Fernando de Pablo from University of Salamanca, Spain are used to compare the cloud-to-ground lightning flashes in Malaysia and Spain under the influence of pollution, respectively.

1.5 Report Outline

This report consists of five chapters.

Chapter 1:- In this chapter, there will be explanation about background of project (motivation and significant of project), problem statement, objectives and scope of the project.

Chapter 2:- The literature review will be given on important facts about lightning and will focus on the characteristic of ground flashes. Those facts are obtained from papers, journal, articles, reference book and others.

Chapter 3:- It will review about the methodology of project which encompasses the development of project devices, simulation of circuit for verification and flow chart of project.

Chapter 4:- For this chapter, there is description of analysis and discussion of result obtained from the lightning measurement activity.

Chapter 5:- Finally, this chapter provides conclusion and summary of the research. Last but not least, there will be recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Related Works

This chapter presents related work in this field.

2.1.1 Lightning Forming Process

The first process in the generation of lightning is charge separation [14]. There are two hypotheses describing the process: Polarization mechanism hypothesis and electrostatic induction hypothesis. For polarization mechanism hypothesis by which charge separation occur still be the subject for researchers and this hypothesis has two components. Firstly, falling droplets of ice and rain become electrically polarized as they fall through the atmosphere's natural electric field. Secondly, colliding ice particles become charged by electrostatic induction. Ice and super-cooled water are the keys to the process. Violent winds buffet tiny hailstones as they form, causing them to collide. When the hailstones hit ice crystals, some negative ions transfer from one particle to another. The smaller, lighter particles lose negative ions and become positive; the larger, more massive particles gain negative ions and become negative.

According to the electrostatic induction hypothesis charges are driven apart by as-yet uncertain processes. Charge separation appears to require strong updrafts which carry water droplets upward, super-cooling them to between -10 and -20 °C. The collision between water with ice crystals to form a soft ice-water mixture is called graupel. Then, the collisions result in a slight positive charge being transferred to ice crystals and a slight negative charge to the graupel. Updrafts drive lighter ice crystals upwards, causing the cloud top to accumulate increasing positive charge. The heavier negatively charged graupel falls towards the middle and lower portions of the cloud, building up an increasing negative charge. Charge separation and accumulation continue until the electrical potential becomes sufficient to initiate lightning discharges, which occurs when the gathering of positive and negative charges forms a sufficiently strong electric field. There are several additional hypotheses for the origin of charge separation. According to one such hypothesis, charge separation is initiated by the ionization of an air molecule by an incoming cosmic ray.

2.1.1.1 Leader Formation

After the induce charge separation happen, the upper part of cloud becomes positively charged and the lower part of the cloud become negatively charged. Thus, the negative charge at the base of cloud induces a positive charge on the ground. In the thundercloud, there are negatively charged mixed water and ice region that causes an initial bipolar discharge or path of ionized air. The discharge path of ionized are called leaders. Meanwhile, the negative charge leaders are called “stepped leaders”, travels towards the ground in forked pattern. The progression of stepped leader start to increase slowly which may continue for several tens to several hundreds of milliseconds to approach the ground. At this initial phase, there are relatively small electric current (tens or hundreds of amperes) and usually the leader is almost invisible compared to the subsequent lightning channel. When a stepped leader approaches the ground, the positive charges on the ground enhance the electric field. In Heinz Kasemir first theory [15], he states that the electric field is highest on trees and tall buildings. If electric field is strong enough, a conductive discharge called a positive streamer can develop from these points. As the field increases, the positive streamer is attracted to the stepped leader and a channel moves up to meet it. Once they connect, a strong current propagates upwards as a brightly visible return stroke. As a result, the surrounding air is superheated to $20{,}000^{0}$C and rapid expansion takes place, producing a shockwave which is heard as thunder. This form of lightning is called cloud-to-ground lightning.

2.1.1.2 Discharge

When electric field becomes strong enough, the electrical discharge (the bolt of lightning) not only occur between thunderstorm cloud-to-ground. It may also occur within thunderstorm cloud (intra-cloud lightning) or between two different clouds (inter-cloud lightning). During the strike, successive portions of air become a conductive discharge channel as the electrons and positive ions of air molecules are pulled away from each other and forced to flow in opposite directions. As a result, the discharge channel is superheated rapidly by the lightning thus, causing the air to expand rapidly. Eventually, produces a shock wave heard as thunder.

Figure 2.1: Lightning discharge [16]

2.1.1.3 Re-strike

One of devices that can capture lightning strike is high-speed videos (examined frame by frame). It shows that most lightning strikes are made up of multiple individual strokes. Observation work of [17] in southern Brazil utilized this techniques reported that a typical strike is made of 3 to 4 strokes. There are possible to be more than that. Typically, each re-strike is separated by 40 to 50 milliseconds. Re-strikes can cause an extremely intense illumination (strobe light effect). However, each successive strike is preceded by intermediate dart leader strokes again to, but weaker than the initial stepped leader. The stroke usually re-uses the discharge channel taken by the previous strokes. The successive strokes causes the sound of thunder from the lightning strike can be heard in a long time.

2.1.2 Types of Lightning

There are various types of lightning that scientist and the public have named them. Some of them are cloud-to-cloud lightning, cloud-to-ground lightning, ground-to-cloud lightning, upper-atmospheric lightning, and many more. Most lightning bolts are within 5-6 miles (8-9.6 km) long [18]. Cloud-to-cloud lightning occurs between areas of clouds that have different potential without contacting the ground.

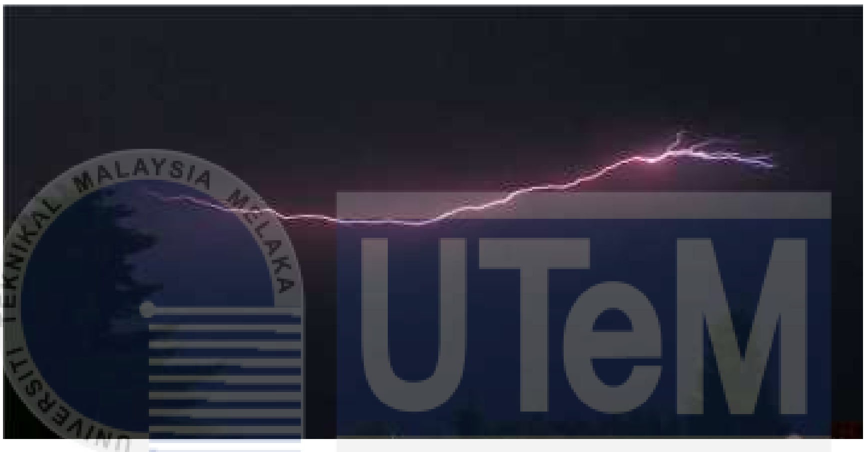

Figure 2.2: Cloud-to-cloud lightning [16]

Figure 2.3: Multiple path of cloud-to-cloud lightning [16]

Cloud-to-ground lightning is a great lightning discharge between a cumulonimbus cloud and the ground initiated by the downward moving leader stroke. This type of lightning is harm for living things and property of all known types.

Figure 2.4: Cloud-to- ground lightning [16]

Upper-atmospheric lightning is a strange lightning storm phenomenon above storm. It has been reported by scientists at least on the year of 1886. This type of lightning also called as mega-lightning.

Figure 2.5: Upper-atmospheric lightning and electrical discharge phenomena [16]

2.1.3 Lightning Triggering Ways

2.1.3.1 Rocket-Triggered

To induce a lightning strike, researchers fire a rocket dragging a wire into an approaching electrical storm. If they are lucky, current will flow from the cloud, through the wire, to the ground, and vaporize the wire. If scientists witness a second lightning strike, it typically follows the path of the vaporized wire, but not always.

2.1.3.2 Volcanically Triggered

Extremely large volcanic eruptions, which eject gases and material high into the atmosphere, can trigger lightning. This phenomenon was documented by [19] Pliny the Elder during the AD79 eruption of Vesuvius, in which he perished.

Figure 2.6: Lightning triggered by a volcanic materials thrust high into atmosphere [16].

2.1.3.3 Laser Triggered

Researchers have attempted to trigger lightning strike since 1970’s. Triggering lightning is crucial as it enables researchers to study the mechanisms underlying lightning strikes. Moreover, triggered lightning strikes will allow engineers to evaluate and test the lightning-sensitivity of airplanes and critical infrastructure such as power lines. A high pulse laser will ionize molecules in the air channels that act like conducting wires extending into the thundercloud. After discharging the laser pulse, researchers quantified the electrical activity in the clouds.

2.2 Relationship between Lightning and Air Pollution

Sources of air pollution in Malaysia can be grouped into several main categories as: Firstly, industrial - the substances discharged into the environment due to technological process like: organic and inorganic powders that contains metals (Pb, Zn, Al, Fe, Cu, Cr, Ni, Cd), gases and vapors (SO_2, NOx, NH_3, HCL, CO, CO_2, H_2S [13]. Secondly, automotive vehicles traffic - that produce inorganic gases: nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and particulate matter (PM_{10}) [13]. The areas with traffic arteries surrounded by tall and compact buildings that prevent dispersion of air causes the concentration of air pollution become higher. Next, thermal power station - represent major sources of air pollution in urban areas, by way of operating with liquid fuels having a high sulfur content, spilling into the atmosphere significant amounts of NOx , SO_2, CO, CO_2, smoke, and fly ash [13]. As a result, these negative charge molecules that contain in the polluted air can absorb into moisture in the air. Thus, it indirectly provides high negative charge at negative charge center. Lightning can be defined as a transient, high current electric discharge whose path length is generally measured in kilometers. Therefore, it can be studied via measurement of electrostatic field (slow field changes), radiation field (fast field changes) and magnetic fields associated with the charge motion. According to previous researchers such as [20], lightning strike level definition can be split into three categories; low (-60kA, +60kA), medium (-120kA, -60kA) and (+120kA, +60kA), high (-180kA, -120kA) and (+180kA, +120kA). Therefore it is important to have the best knowledge about lightning because lightning strikes can cause fatal to human being and harm other things such as electrical equipment, trees, vehicles and so on.

2.3 Further Review of Previous Related Works

Finding of study from a reliable sources such as [21] reported that the characteristic of negative cloud-to-ground lightning flashes can be obtained by using two types of measurement techniques; (1) measurements based on two the correlated electric field recording on the electric fields generated by the whole flash with high levels of temporal resolution which is performed by [22] in Sweden and [23] in Sri Lanka; (2) a high speed photographic records as performed by [24] in New Mexico, and [25][26] in Florida. Eventually, they achieved a consensus when their results almost the same about the characteristic of negative cloud-to-ground lightning flash such as number of stroke count (mean, percentage of single-stroke flashes), and their interstroke intervals. In addition, [21] used data from National Lightning Detection Network (NLDN) for Florida and New Mexico, Austrian Lightning Detection and Information System (ALDIS) to explain about the difference of negative cloud-to-ground lightning flash recorded. Researcher [21] reported that the percentage of single- stroke flashes reported by the NLDN is a factor of 2 to 3 times higher than the “accurate-stroke-count” studies in Florida and is a factor of 3 to 4 times higher in New Mexico.

In Malaysia, the measurement of electric fields generated by the negative CG lightning flashes were recorded by researchers [27] from April to June 2009 during the southwest monsoon period in the Johor state at the southern part of Peninsular Malaysia. They examined that 1299 negative CG lightning flashes and 533 cloud flashes were recorded. This showed that climate change also affect the types of lightning produced [4]. Result of finding of [27] the interstroke intervals usually occur between 50 and 100 ms. The arithmetic mean, geometric mean and median duration are 86, 67 and 70 ms, respectively. The minimum and maximum interstroke intervals in this study are 0.5 and 461 ms respectively. Furthermore, [27] also reported 10 out of 100 negative cloud-to-ground flashes were found to be less than 20ms of interstroke intervals, which mostly occur once in a flash. However, the characteristic of the interstroke intervals of less than 20ms was unexplainable with reference to the physical reason of the flash, thunder storm condition and geographical region.

Table 2.1: Statistics of interstroke intervals from the total number of strokes [27].

Researcher and location	n	Min. (ms)	Max.(ms)	Arithemetric mean (ms)	Geometric mean (ms)
Zikri (2010), Malaysia,1ºN	100	0.5	461	86	67
Saba et al.(2006) Brazil 23.2ºN	233	2	782	83	61
Qie et al. (2002), China, 36º36ºN.	50	4.8	3285	643	46.6
Cooray and Jayaratne (1994), Sri Lanka 59ºN	81	0.98	509	828	56.5
Cooray Perez (1994), 59.8ºN	271	2.5	376	65	48
Thottappilil et al. (1992), Florida, 29ºN	46	-	-	-	57
Thomson (1980), Pappua New Guinea, 9ºS	80	-	-	90	61

n: Total number of flashes

Table 2.2: Summary of strikes per flash and percentage of single stroke flashes [27].

Researcher and Location	Total number of flashes	Number and type of storms	Percentage of single-stroke flashes (%)	Maximum multiplicity	Mean multiplicity
Zikri, Malaysia (2010) 1ºN	100	7 convective thunderstorms in April to June (south west monsoon period)	16	14	4
Saba et. Al (2006), Brazil 23.2ºN	233	27 frontal convective and thunderstorms	20	16	3.8
Qie et al.,(2002), China,36º36´N.	83	9 summer thunderstorm	39.8	14	3.76
Cooray and Jayaratne (1994), SriLanka,6.91º North	81	3 convective thunderstorms in April (inter-monsoonal period)	21	12	4.5
Cooray and Pérez (1994), Sweden,59.81º North	137	2 frontal summer thunderstorms	18	10	3.4
Rakov etal.(1994), Florida,27.41º North	76	3 convective summer thunderstorms	17	18	4.6
Kitagawa et al. (1962), Socorro, New Mexico, 34ºN	193	3 summer night thunderstorms	14	26	6.4

2.4 Principles of the Methods in Measuring Electric Field

2.4.1 Electric Field Mill or Generating Voltmeter

The EFM's operation and theory is based on the basic laws of electromagnetism. When a conducting plate is exposed to an electric field, a charge will be induced proportional to the electric field and the plate area. The normal atmospheric resistivity is too high to permit easy measurement of the electric field. Hence, it would not normally induce detectable amounts of current into the EFM conductors. The EFM creates a high rate of change of alternating electric fields using a motor-driven rotor stator arrangement.

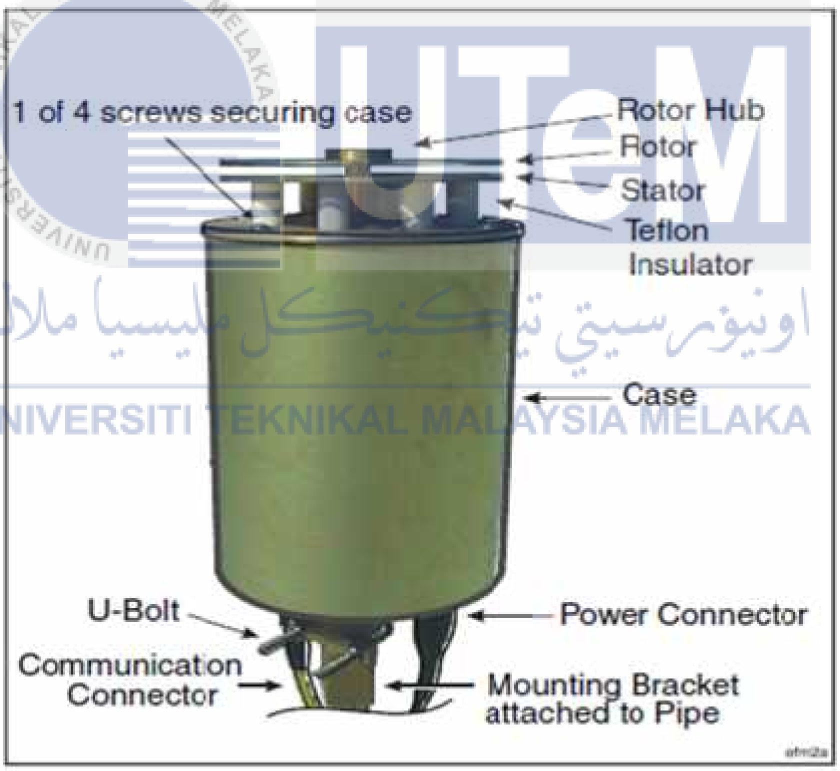

Figure 2.7: Extrerior part of Electric field mill [28].

As the rotor turns, it alternately exposes the stator to the electric field and shields it. Detectable charges are induced onto the stator plates as the rotor chops the electric field. This charge is sampled at the instant that the rotor provides maximum stator plate exposure giving a series of samples whose magnitude and polarity are proportional to the electrical field intensity. A charge amplifier converts these tiny charges to usable voltages. The frequency of the samples is approximately 100 Hz, the frequency of the chopping of the electric field. The sampling of the voltage is synchronized to the position of the rotor by a magnetic sensor that monitors the rotation of the motor shaft. By spanning the time gap between samples with a sample-and-hold amplifier, a quasi-DC voltage is obtained with a polarity that matches field polarity and a magnitude that is proportional to the field magnitude. This output can be measured by a DC voltmeter, computer analog to digital converter, chart recorder, or other display or recording device. The output can also be digitally transmitted to a computer.

2.4.2 Parallel Plate Antenna System

In principle, electric field intensity can be measured as function of time by measuring voltage between upper plate of antenna and the ground. In this system, typically wavelength of electric field is larger than dimension of antenna. The effective height of antenna buried in ground to obtain accurate result is an about 0.5 m and other end is about 1.5m above ground surface. When electronic circuit is connected to antenna, the output voltage will be depend on decay time constant, RC. If RC=∞, the output voltage has same physical development as the background electric field. The range for antenna capacitance, Cg was about 58pF to 60pF. The experimental set up and equivalent circuit is shown in Figure 2.8 and Figure 2.9.

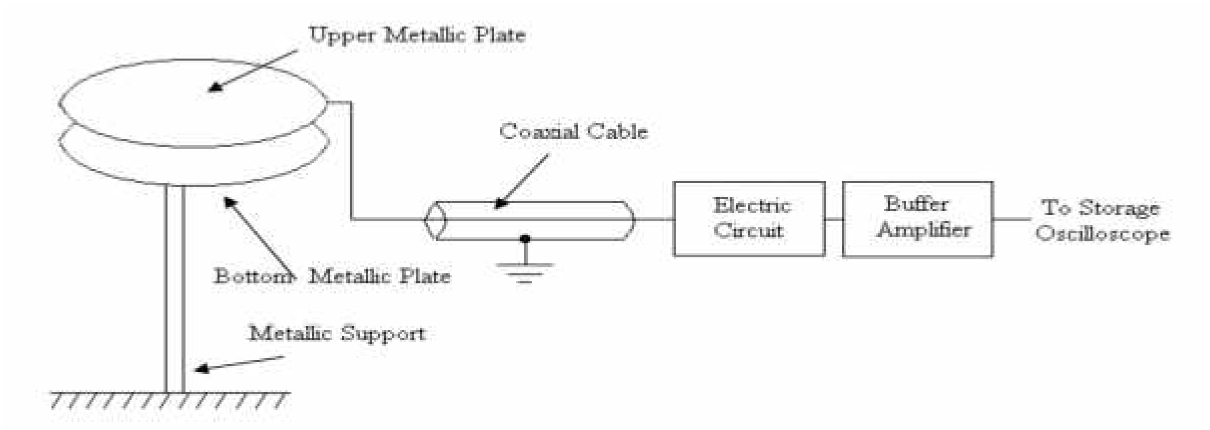

Figure 2.8: Experimental set up for lightning measurement [29].

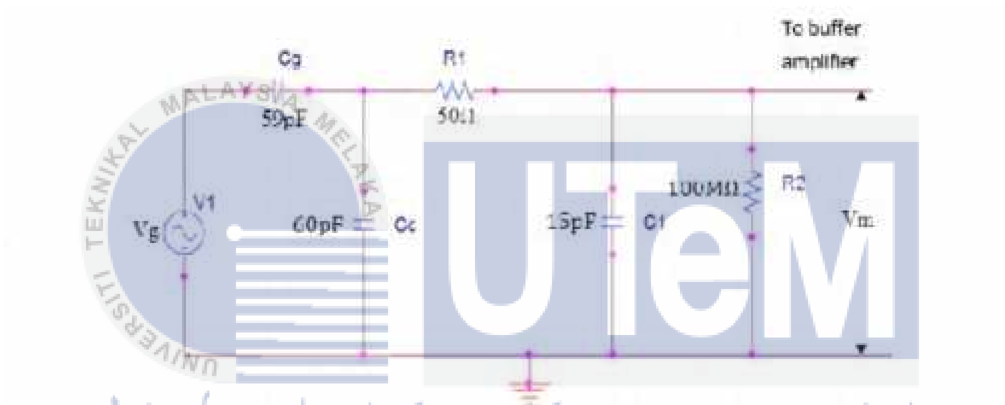

Figure 2.9 : The equivalent circuit of the system [29].

According to the Thevenins equivalent analysis,

$$V_m/Vg = [\ sC_gR_2/\{1+s(R_1+R_2)\ .\ (C_g + C_c) + sF_1\ ] \qquad (2.1)$$

Where $F_1 = R_2\ [C_1 + sR_1\ .\ C_1\ (C_g + C_c)]$ and $s = j2\pi f$.

The equation above is valid to calculate the frequency response of the circuit.

Therefore, the decay time constant of the circuit is,

$$T = (C_1 + C_g + C_c).\ R_2 = 13.4\text{ms} \qquad (2.2)$$

This value is large enough to record lightning generated electric field signals with a high accuracy.

2.5 Summary and Discussion of Review.

In short, scientists and researchers always study about the lightning under influence of pollution. Lightning is amazing phenomena to be subject of study because there are several types of lightning and each of them have their own characteristic. Lightning also can be harm to living things and other property. Thus, scientists, researchers, power engineer and others must know about lightning in order to protect human beings and equipment. There are some parameters that can be used to measure lightning. Some of them are, electrostatic field (slow fields changes), radiation field (fast field changes), and magnetic field associated with the charge motion.

There are several methods that can be used to measure electrostatic field such as electric field mill (EFM) and plate antenna system. Nevertheless, each of them has their own advantages and disadvantages. The advantages of EFM are it provides valuable information on when the local charge is no longer present in the near-course vicinity, thus enabling play to resume as soon as possible and it picked up lightning discharges that were not displayed by the lightning detection network, making it a better tool for real-time lightning detection [30]. Meanwhile, the disadvantage of EFM is difficult to calibrate for absolute measurement of static electric field, because of the influence of the surrounding structure and local enhancement or attenuation [30]. According to [31], parallel plate antenna system capable to record lightning generated electric field signals with a high accuracy and the cost to build up the antenna is cheaper than EFM. One disadvantage with using this plate antenna above 30MHz is that the radiation from the antenna will result in room resonances that change the electric field generated the lines of antenna [31]. As conclusion, parallel plate antenna system was chosen for this project due to its advantages mentioned as above.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

This chapter will describe about systematic process and procedure for completing this project. The flow chart has been constructed to show the course of conducting this project. Besides that, the details of construction of hardware such as antenna and electronic circuit used in measuring electric field will be discussed in this chapter. In addition, this section also will present a preliminary result from simulation of electronic circuit before conducting the experimental activity. In this project, there is an assumption where the lightning measurement location is greatly influenced by the southwest monsoon (April to May). This information is also important in reducing variations in results due to differing measurement methods and sampling techniques as used by different researchers.

3.2 Flow Chart

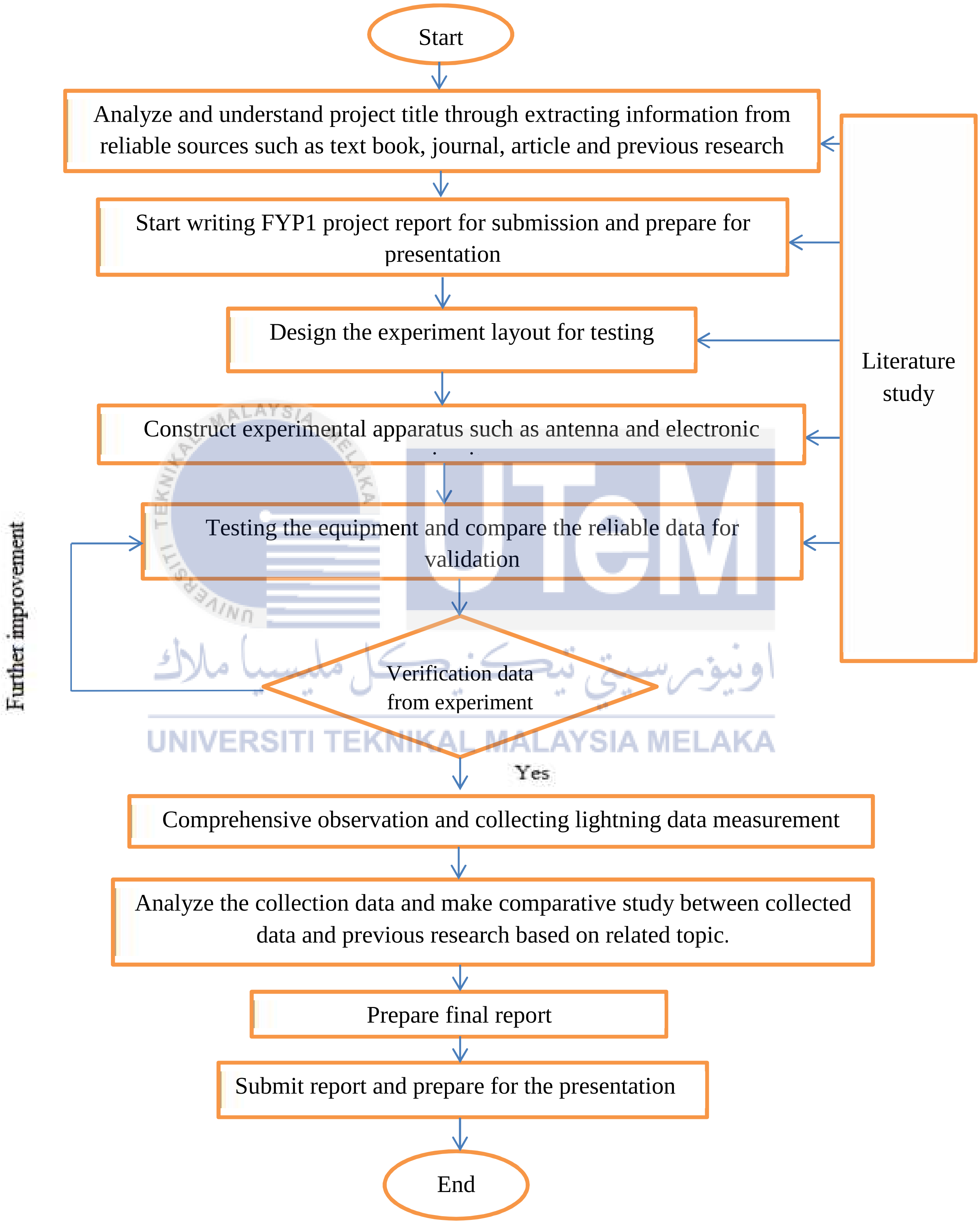

Figure 3.1: Flow Chart of research

3.3 Measurement Devices

3.3.1 Parallel Plate Antenna

The physical configuration of parallel plate antenna is shown in Figure 3.2. The antenna is build up of two identical metallic plates with diameter of 45cm. The upper and bottom metallic plate was separated by insulator (Teflon) about 4 cm thickness. By that combination, the two parallel plates will act as capacitor, Cg. The value of the antenna capacitance is in range of 58pF to 60pF. So, the value of 59 pF had been chosen as standard value for this project. The parallel plate will be supported by metallic rod with the length about two meters. The antenna will then connect with electronic circuit and oscilloscope by using coaxial cable. The antenna cannot be connected directly to the oscilloscope due to high frequency dependent output impedance compared to input impedance of oscilloscope. Otherwise, the antenna could not capture any signal if voltage drops over the oscilloscope because of high impedance of antenna. So, the antenna must associate with buffer amplifier circuit (broadband circuit). This antenna senses only the vertical field radiation. In order to avoid horizontal component of electric field, antenna is placed perpendicular to electric field vector or parallel to the ground.

Figure 3.2: Set up of antenna for measuring slow field radiation and fast field radiation at interest frequency of 3MHz and 30MHz.

3.3.1.1 The Equivalent Circuit of the System.

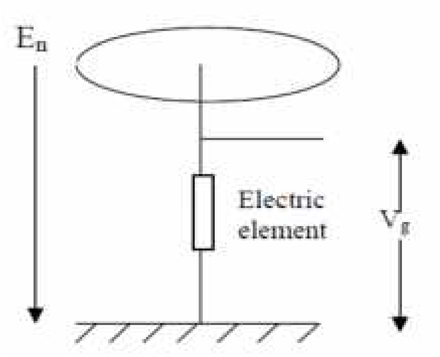

Figure 3.3: location of electric element [7]

Refer to figure 3.3, electric element can be a resistor or capacitor which will be used for measuring the current.

Case 1: Resistor as an electric element

$$I= dQ/dT \tag{3.1}$$

$$V_g = Ri \tag{3.2}$$

$$Vg = \varepsilon 0 \varepsilon rRS\ (dEn/dt) \tag{3.3}$$

Voltage V_g depends on the derivative of electric fields.

Case 2: Capacitor as an electric element

$$Q = V_g.C \tag{3.4}$$

$$Q = \int idt \tag{3.5}$$

$$Vg = (\varepsilon 0 \varepsilon rS\ /C).\ En \tag{3.6}$$

Voltage V_g is depends on the normal electric fields E_n.

To avoid difficulties in interpretation the records, a capacitor is used as an electric element. Thus, the electric field measured by this circuit is the actual electric field normal to the ground.

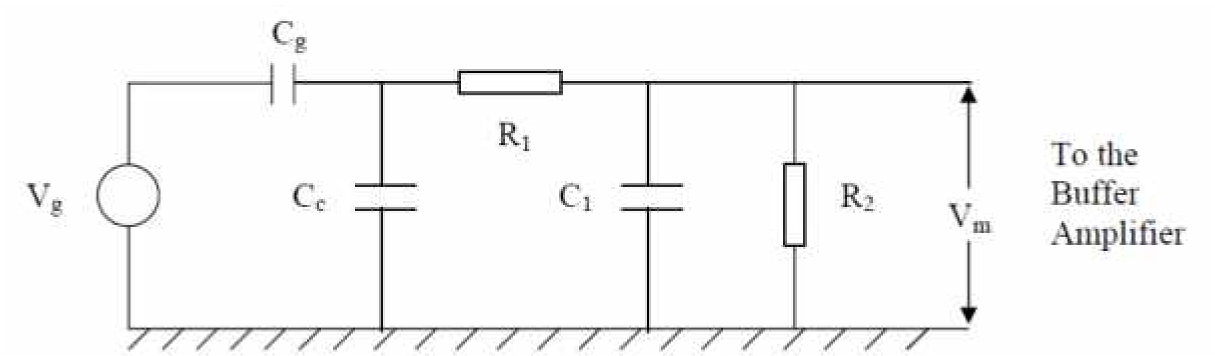

Figure 3.4: The equivalent circuit of the system [7]

Refer to figure 3.4, C_g is the capacitance of the parallel plate antenna. The value of capacitance for this antenna is 59pF. C_c is the capacitance of 60cm length coaxial cable which is used to link the antenna and the electric circuit. The value of the capacitance is 60pF. A 15pF capacitor, C_1 is used as the electric element. The electric field generated at C_1 is measured by measuring the changes in voltage V_g of the parallel plate. A high value of resistor R_2 is shunted with capacitance C_1. The purpose is to control the decay time constant $C_1.R_2$. Since the input impedance of buffer amplifier is usually high (in order of 10^3), a resistor of 100MΩ is used at R_2 in order to increase the decay time constant. Meanwhile, R_1 is a resistor used at the entrance of the electric circuit to eliminate the characteristic impedance of the coaxial cable that links the antenna and the electric circuit. The value of R_1 used is 50Ω. According to the Thevenins equivalent analysis,

$$V_m/Vg = [\ sC_gR_2/\{1+s(R_1+R_2)\ .\ (C_g + C_c) + sF_1\ ] \qquad (3.7)$$

Where $F_1 = R_2[C_1 + sR_1 \,.\, C_1(C_g + C_c)]$ and $s = j2\pi f$.

The equation above is valid to calculate the frequency response of the circuit.

The decay time constant of the circuit is,

$$T = (C_1 + C_g + C_c).\ R_2 = 13.4\text{ms} \qquad (3.8)$$

This value is large enough to record lightning generated electric field signals with a high accuracy.

3.3.2 Electronic Circuit Construction.

A high-speed buffer amplifier is used to measure lightning generated electric field in term of (amplitude and rise time). The use of this high- speed buffer amplifier may isolate the high impedance of the antenna and offer sufficient power to drive the signal from the antenna to the recording unit through the coaxial cable.

The buffer amplifier used is OPA637 because it is a monolithic unity gain high-speed buffer amplifier with a very wide bandwidth of 80MHz and high slow rate of 135 V/ µS. The output current of the amplifier can reach to 100mA, allows the OPA637 to drive 50Ω lines as shown in figure below.

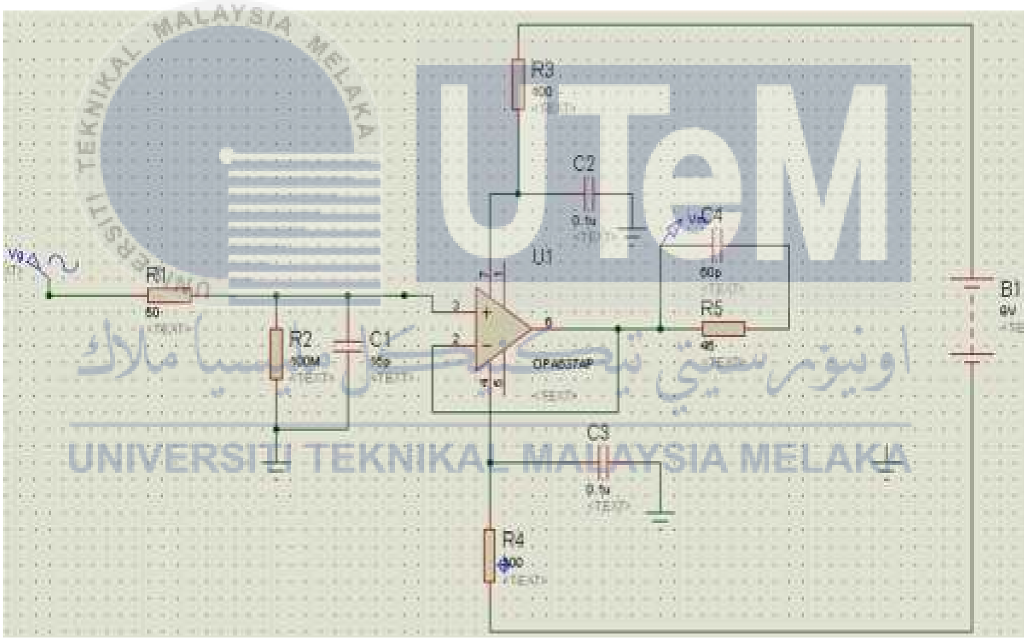

Figure 3.5: Buffer amplifier circuit diagram.

Refer to Figure 3.5, the both supplies of the circuit is bypassed with two high frequency ceramic capacitor (two 0.1µF at C_2 and C_3). They were placed very close to the buffer amplifier IC’s power supply pins for high frequency decoupling. Meanwhile, two resistors of 100Ω, R_3 and R_4 were placed in series with the power supply pins in order to protect the circuit from damages due to excessive currents flow. Since the frequency of this system is high, a resistor R_5 of 45Ω is used as the back termination resistor series with the Buffer Amplifier IC’s output line. The total of termination resistor is 50Ω because the output impedance of the OPA637 is 5Ω. Hence, it is easily to use 50Ω coaxial cable as the transmission line to send the signals to the recording unit. To optimize the circuit pulse response, a capacitor C_4(60pF/10% variable capacitor) is connected parallel with back termination resistor R_5. Figure 3.6 shows the observations of frequency domain for the circuit.

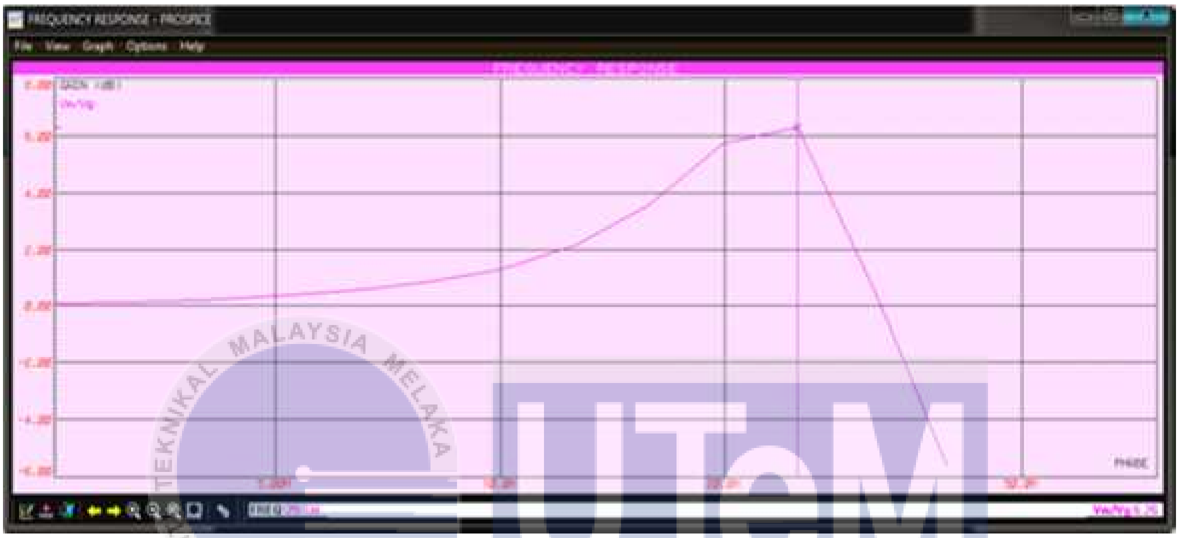

Figure 3.6: Simulation graph of frequency response at 30MHz.

Figure 3.7 : Hardware circuit of 3MHz and 30MHz for measurement

3.3.3 Oscilloscope

In order to illustrate the signal generated by the flash, oscilloscope will be used in detecting interference signal of the antenna when lightning flash is induced. The type of oscilloscope used in this experiment is Teledyne LeCroy HDO4024 High Definition Oscilloscopes. The special feature of this oscilloscope is it can capture the signal up to 1GHz with high sample rate and 16 times more resolution compared to other oscilloscope. So, the captured signal is clear and smooth. Further information on this oscilloscope can be obtain on datasheet provide by the manufacturer. In this experiment, the sampling rate was set to 20MS/s with the total length recorded of 1 s. The oscilloscope was set to 300ms in pre-trigger mode so that the signals of both polarities could be captured.

Figure 3.8: Teledyne LeCroy HDO4024 High Definition Oscilloscope.

3.4 Data Measurement

This process involves is to obtain the data from the measurement that detected by the parallel plate antenna and captured by oscilloscope. The induced voltage detected by the antenna was displayed at oscilloscope's screen and interpretations of data were taken place to observe characteristic of waveform such as peak voltage, duration and so forth. In this experiment, the sampling rate was set to 20MS/s with the total length recorded being 1s. The oscilloscope was set to 300ms in pre-trigger mode so that the signals of both polarities could be captured. The recorded data by oscilloscope was presented using viewer-software (Wave Studio) provided by oscilloscope's manufacturer. The viewer-software like Wave Studio was used to view and analyses the waveform based on peak and duration of pulses. Figure 3.9 shows the oscilloscope setting for data measurement.

Figure 3.9: Oscilloscope used for measurement

3.5 Data Analysis and Result

After data is collected from the measurement, all the will sort out based on related study. Then, the chosen data will be tabulated in order to ease the analysis process. The statistical information such as max, min, arithmetic mean, geometric mean and standard deviation were provided for data interpretation. The comparative study between this and previous research was required for verification of data measurement. After the data were analyzed, the result was discussed more detail and compare to each other.

3.6 Data Verification

Based on the data analysis and the result that have been recorded, the verification of data is essential to ensure that the recorded data is satisfying and valid to the project. The previous comprehensive data from other researcher can be a guideline for determination of data validation. If the data or result is not valid, the measurement must be executed again to fulfill the specification as well as requirement of the project.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Measurement and Analysis

In this study, there were fifty successive negative cloud-to-ground flashes which were recorded between April and May 2015, during the southwest monsoon period in the state of Malacca. This is the best period for taking lightning measurement because lightning activities tend to occur within this period instead of the other months. Note that, six out of fifty successive negative cloud-to-ground flashes were selected as sample. Universiti Teknikal Malaysia, Melaka (UTeM) is located at the southern part of Peninsular Malaysia, in close proximity to the latitude of (2º 18'59.04''N) and longitude of (102º 16' 52.8636''E). The measuring station was located on land at a location which is 71m above sea level.

In this project, three parallel plate antennas were used to detect fast field at interest frequency of 3MHz and 30MHz signal. A vertical rod antenna was used to detect slow field signal. Firstly, the peak amplitude and period of signal were determined by taking into account the slow field signal as a reference for the fast field signal. Both of signals were observed and compared to ensure that the signals are located in the same coordinates. The upper waveform shows the fast field measurement and the bottom waveform shows the slow field measurement. This study focused more on return stroke occurs in negative cloud-to-ground lightning flash. There are four main parameters considered on characterization of the negative cloud-to-ground lightning flashes which are number of strokes per flash, interstroke intervals (time separation between strokes), peak amplitude and statistical information of the lightning flash (mean, geometric mean, standard deviation).

4.2 Measurement Data Using 3MHz Fast Field Circuit

Flash 1

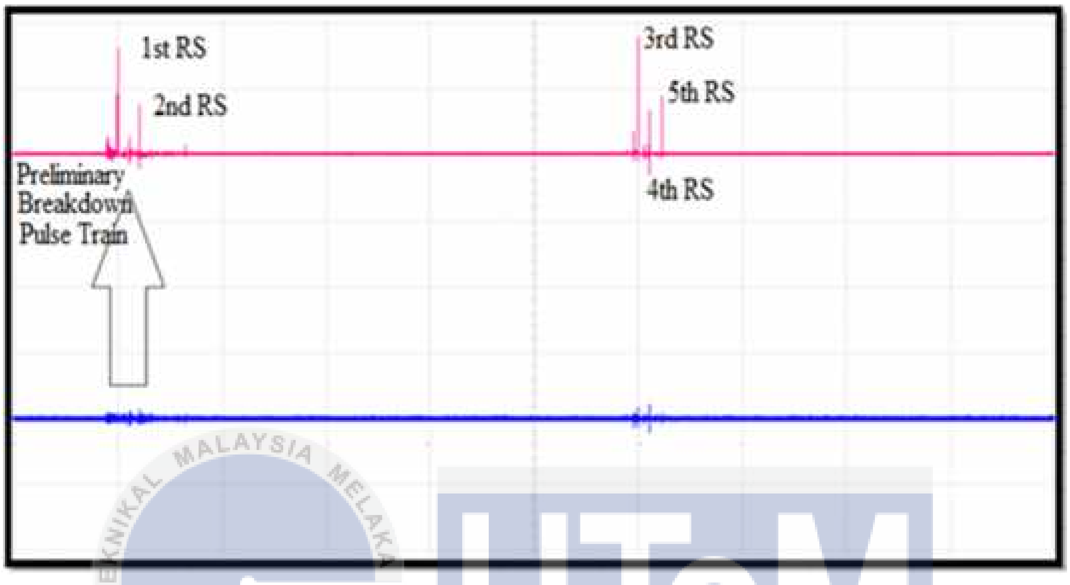

Figure 4.1: First signal detected by antenna.

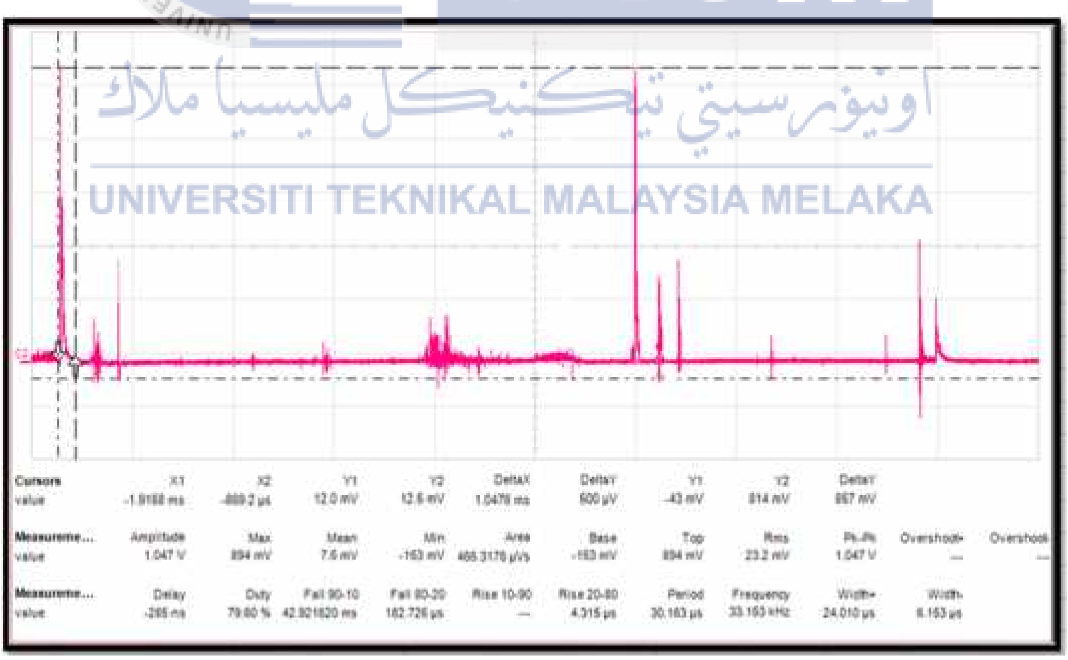

Figure 4.2: Close view of first signal.

Figure 4.1 and 4.2 shows first signal detected by the antenna and the signal was zoomed to get clear picture. Flash 1 contains total of 5 return strokes (RS). The maximum peak of RS and total interstroke interval of RS are 0.86V and 271.96ms respectively.

Flash2

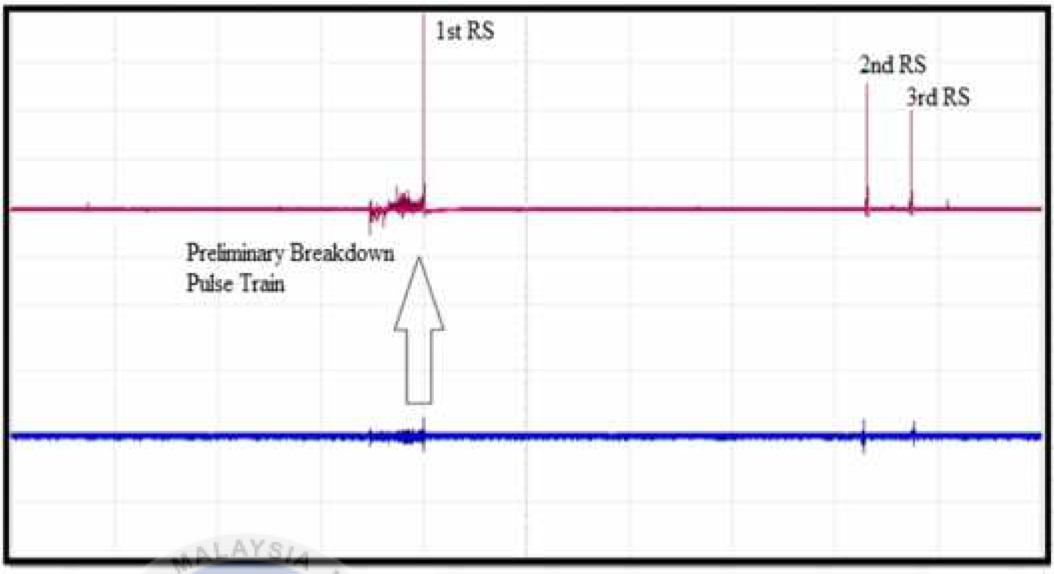

Figure 4.3: Second signal detected by antenna.

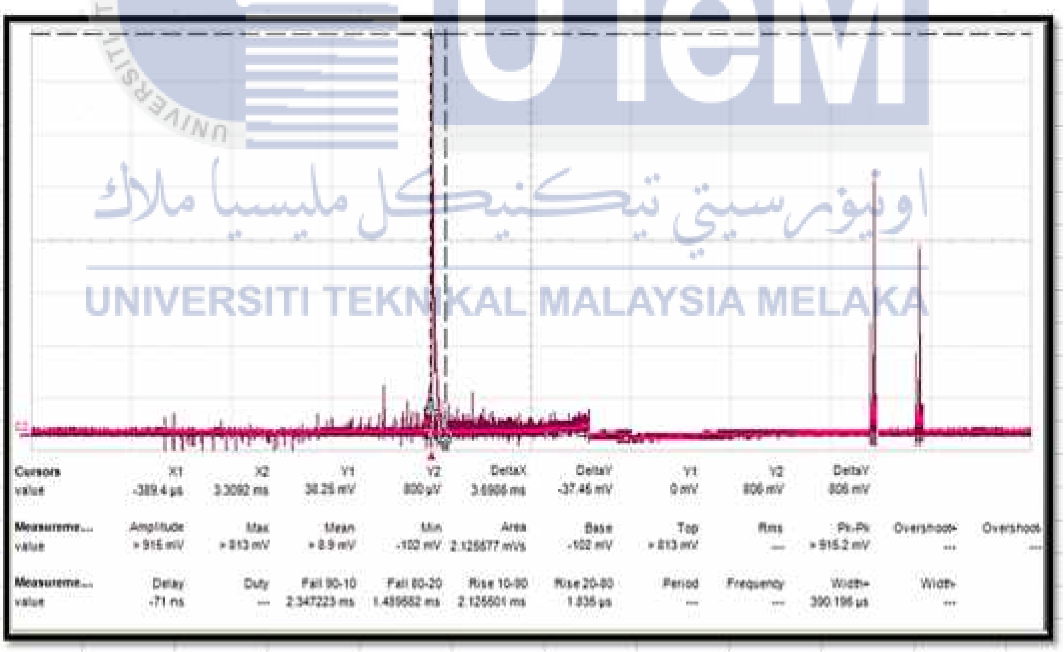

Figure 4.4: Close view of second signal.

Figure 4.3 and 4.4 shows second signal detected by the antenna with close view. The total number of RS, total interstroke interval of RS and maximum peak of the signal, are 2, 183.49ms and 0.81V respectively.

4.3 Measurement Data Using 30MHz Fast Field Circuit

Flash 3

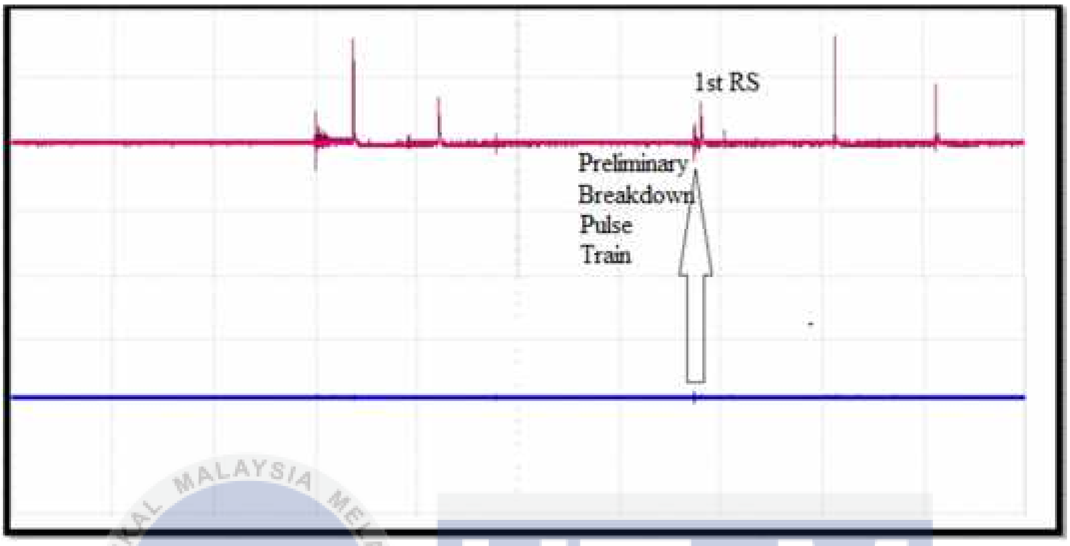

Figure 4.5: Third signal detected by antenna.

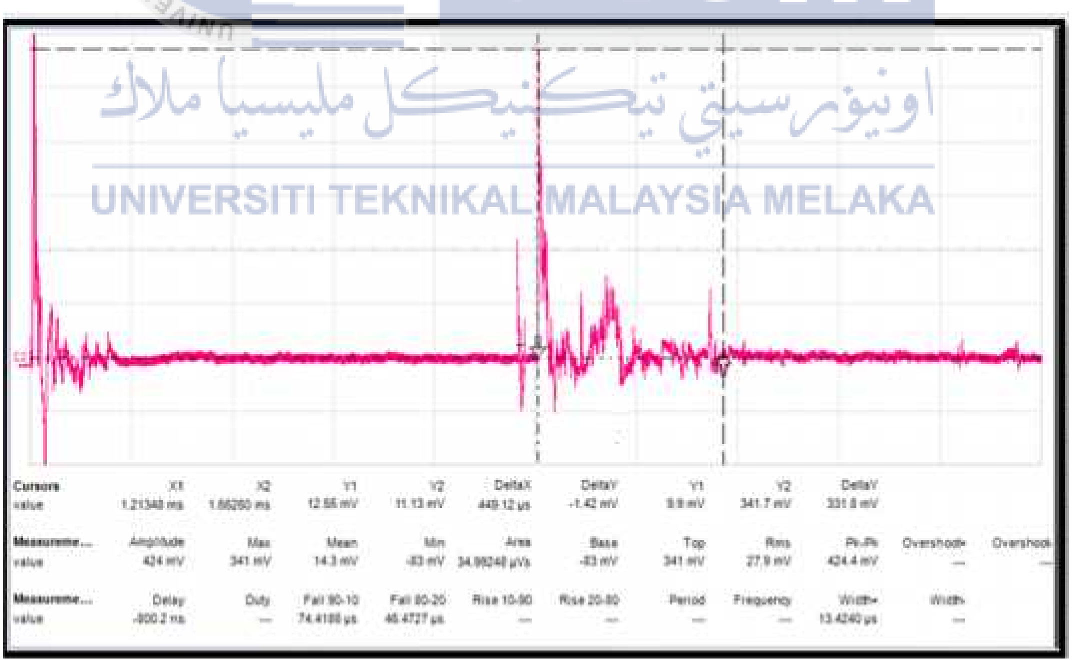

Figure 4.6: Close view of third signal.

Next, the signal of Flash 3 was shown in figure 4.5 and 4.6. The signals contain total number of 1RS, total interstroke interval of 1.49ms and maximum peak of 1.22V.

Flash 4

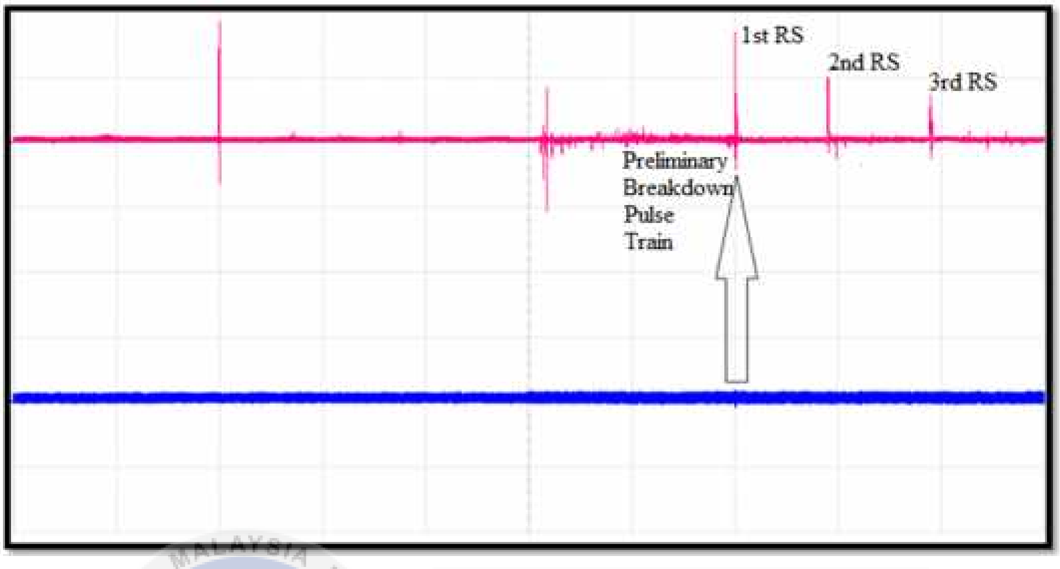

Figure 4.7: Fourth signal detected by antenna.

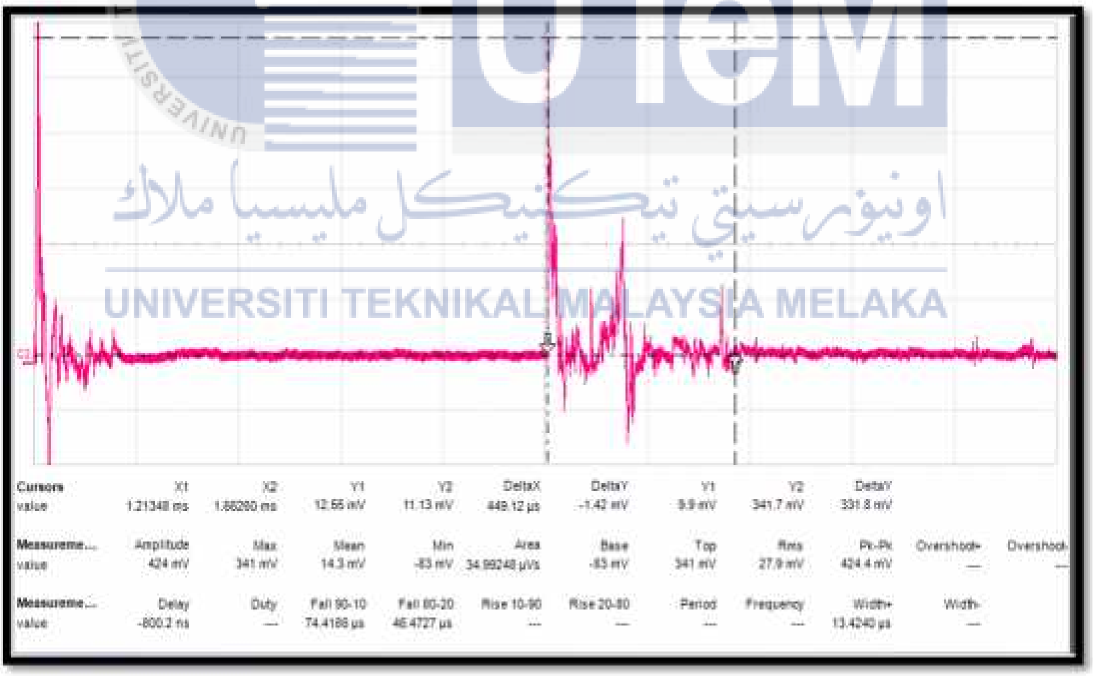

Figure 4.8: Close view of fourth signal.

Figure 4.7 and 4.8 shows signal generated by Flash 4. The signal contain total of 3 RS with total interstroke interval of 0.45ms. In addition, the maximum peak value for the signal is 0.33V.

Flash 5

Figure 4.9: Fifth signal detected by antenna.

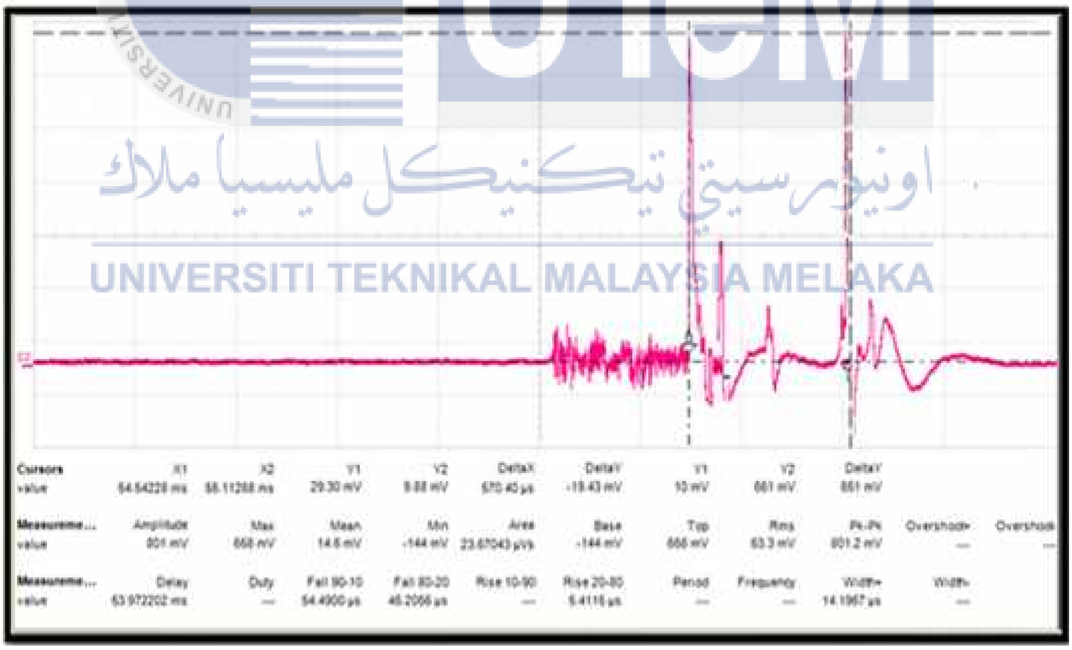

Figure 4.10: Close view of fifth signal.

Signal of Flash 5 was depicted in Figure 4.9 and 4.10. From the measurement, 3 RS was displayed by the signal within 0.57ms and the maximum recorded peak was 0.65V.

Flash 6

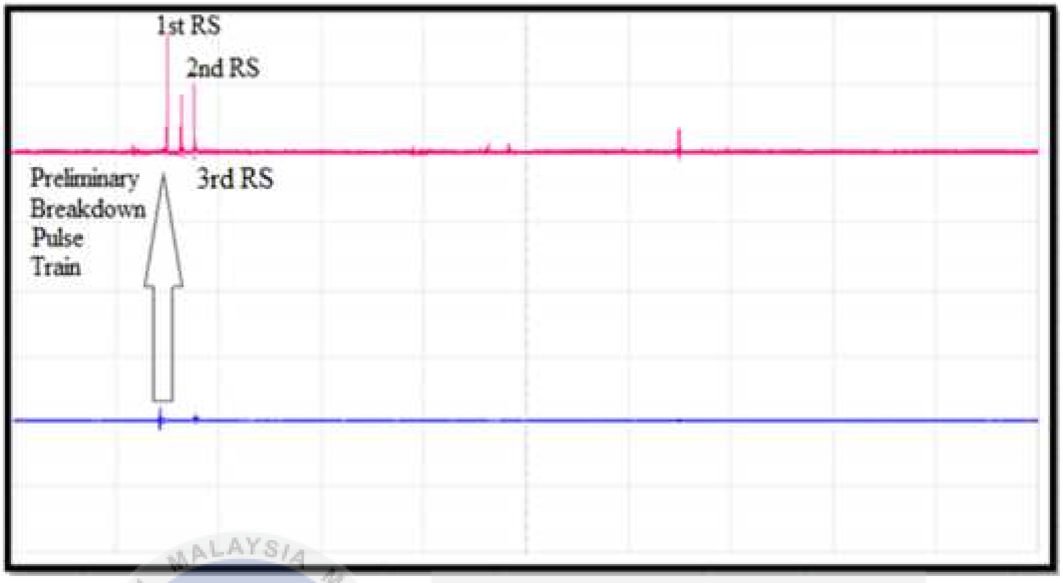

Figure 4.11: Sixth signal detected by antenna.

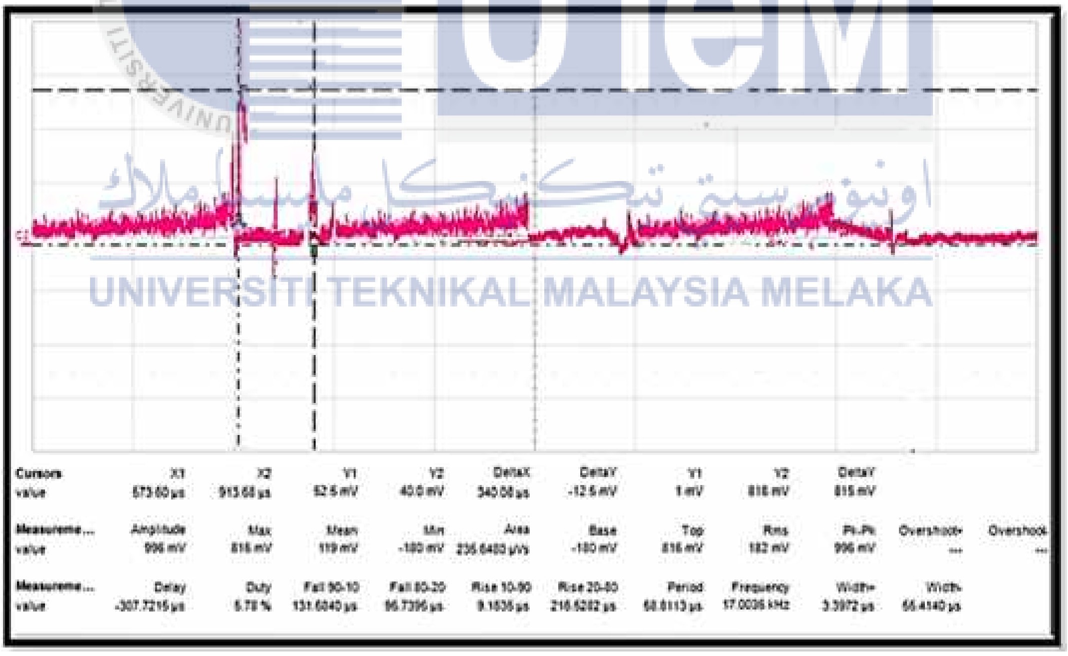

Figure 4.12: Close view of sixth signal.

Figure 4.11 and 4.12 shows signal of Flash 6 detected by the antenna. The total number of RS displayed by the signal is 3 and the total interstroke interval of RS is 0.34ms. Besides that, the maximum recorded peak value for the signal is 0.85V.

4.4 Data Analysis

Summarization of negative cloud-to-ground lightning characteristics was tabulated in table 4.1. From the observation of this study, the first negative return stroke was always preceded by the preliminary breakdown pulse and each of flash does not show systematic return stroke order. In this study, six out of fifty successive negative cloud-to-ground lightning flashes were selected as sample where they contain total of 18 return strokes (RS).

Table 4.1: Summary of negative cloud-to-ground lightning characteristics.

Flash No.	Number of RS	Interstorke Interval of RS(ms)	Vpeak for Return Stroke (V)
1	5	271.96	0.86
2	3	183.49	0.81
3	1	1.49	1.22
4	3	0.45	0.33
5	3	0.57	0.65
6	3	0.34	0.85
Total	18	458.30	4.71
Min	1	0.34	0.33
Max	5	271.96	1.22
Mean	3	76.38	0.79
Geometric Mean	3	4.32	0.73
Standard Deviation	1	120.52	0.29
Number of Strokes per Flash	3		

Result of this study is summarized in Table 4.1. Figure 4.13 shows the graph of minimum and maximum value of all measured data. The minimum and maximum of RS are 1 and 5 RS respectively. The range for RS to occur in negative cloud-to-ground lightning flash is from 0.34 to 271.96ms. In addition, the minimum and maximum values of RS amplitude are 0.33 and 1.22V.

Meanwhile, figure 4.14 shows the graph of mean and geometric mean for all measured data. From this study, it was found that average number of strokes per flash is 3. The value of mean and geometric mean of total interstroke interval are 76.38 and 4.32ms respectively. In the other hand, the mean and geometric mean for peak amplitude of RS are 0.79 and 0.73V.

Figure 4.15 shows the graph of mean and standard deviation for all measured data. The high value of standard deviation indicates the data tend to spread out of mean and the small value of standard deviation indicates that the data is close to the mean. The value of mean and standard deviation for number of RS are 3 and 1 respectively. Notice that, the difference between them is small, thus it can be concluded that the result is as expected. Same goes to the mean and standard deviation value of peak amplitude of RS (0.29 and 0.79V) where they indicate small differences between them. Nevertheless, the mean and standard deviation value for interstroke interval (76.38 and 120.52ms) shows high differences between them. This indicates some of the data is far deviate of the mean. For example sample flash no. 3, 4, 5 and 6 with measurement reading of 1.49, 0.45, 0.57 and 0.34ms respectively.

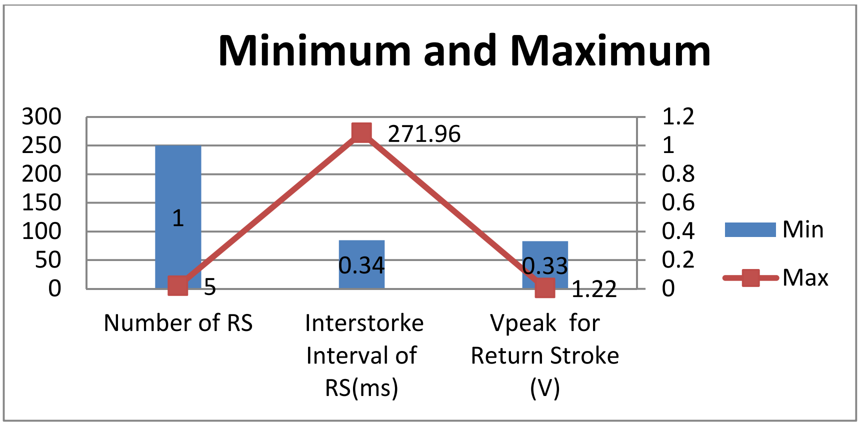

Figure 4.13: Graph of minimum and maximum value of all measured data.

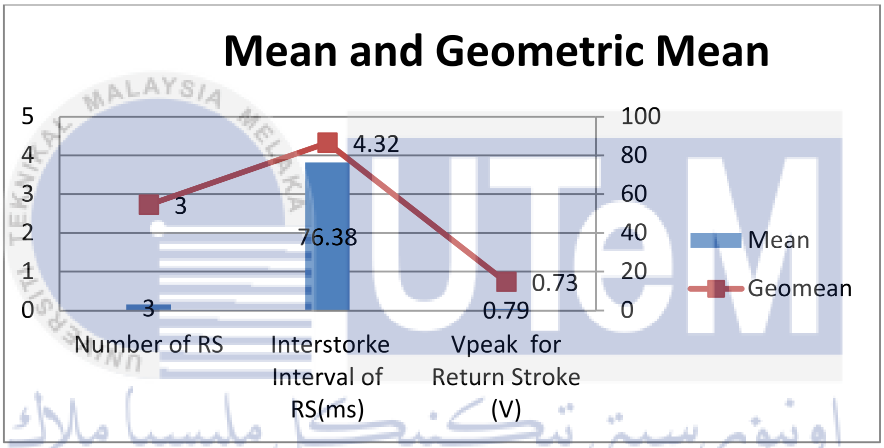

Figure 4.14: Graph of mean and geometric mean value of all measured data.

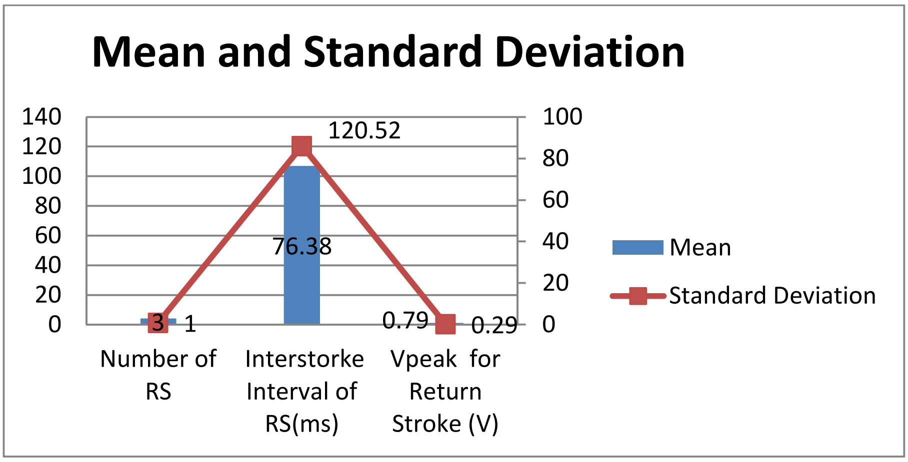

Figure 4.15: Graph of mean and standard deviation value of all measured data.

The result of all of these analyses is summarized in table 4.2 and 4.3 which also includes other results obtained in Malaysia, Brazil, China, Sri Lanka and Sweden. Then, the result of this study is compared to each other in order to verify the result.

Table 4.2: Statistics of interstroke intervals from the total number of strokes.

Researcher and location	n	Min. (ms)	Max.(ms)	Arithemetric mean (ms)	Geometric mean (ms)
This Study, 2015 (UTeM,Malaysia) 2˚N, 102˚E	6	0.34	271.96	76.38	4.32
Zikri (2010), Malaysia,1ºN	100	0.5	461	86	67
Saba et al.(2006), Brazil 23.2ºN	233	2	782	83	61
Qie et al. (2002), China, 36º36ºN.	50	4.8	3285	643	46.6
Cooray and Jayaratne (1994), Sri Lanka 59ºN	81	0.98	509	828	56.5
Cooray and Perez (1994), Sweden,59.81º North	271	2.5	376	65	48

n = Total number of flashes

The minimum, maximum and mean of interstroke intervals from this study are 0.34, 271.96 and 76.38ms respectively. According to table 4.2, these results are fairly the same to the result obtained by Zikri (2010), Malaysia, Saba et al. (2006), Brazil, Qie et al. (2002), China, Cooray and Jayaratne (1994), Sri Lanka and Cooray and Perez (1994), Sweden who did not found any systematic variation of the interstroke intervals with the stroke order.

Next, the results of geometric mean of the interstrokes interval in this study is compared to those results obtained in Malaysia, Brazil, China, Sri Lanka and Sweden as summarized in table 4.2. Notice that, the geometric mean in Malaysia (1ºN), Brazil (23.2ºN), China (36º36ºN), Sri Lanka (59ºN) and Sweden (59.81º N) are found to be 67, 61, 46.6, 56.5 and 48ms, respectively. For this study, the difference between interstrokes interval is the smallest (4.32ms) among the rest. It is because there are few cases (Flash 3, 4, 5 and 6) where the process of RS occurs fastest, 1.49, 0.72, 0.57 and 0.34ms. However, the characteristic of the interstrokes interval of less than 5ms was unexplainable due to the physical reason of the flash and geographical region.

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Table 4.3: Summary of strikes per flash and percentage of single stroke flashes.

Researcher and Location	Total number of flashes	Percentage of single-stroke flashes (%)	Maximum multiplicity	Mean multiplicity
This Study, 2015 (UTeM,Malaysia) 2˚N, 102˚E	6	16.7	5	3
Zikri, Malaysia (2010) 1ºN	100	16	14	4
Saba et. Al (2006), Brazil 23.2ºN	233	20	16	3.8
Qie et al.,(2002), China,36º36´N.	83	39.8	14	3.76
Cooray and Jayaratne (1994), SriLanka,6.91º North	81	21	12	4.5
Cooray and Pérez (1994), Sweden,59.81º North	137	18	10	3.4

Out of 6 flashes, 83.3% were found to contain more than one stroke with the maximum multiplicity of 5. The percentage of single-stroke flashes (16.7%) in this study is fairly similar to the percentage of single stroke flashes observed in Malaysia, 1ºN (16%), Brazil, 23.2 ºN (20%), China, 36 º36´N (39.8%), Sri Lanka, 6.91 ºN (21%), Sweden, 59.81 ºN (18%). The maximum multiplicity in Malaysia, 1ºN, Brazil, 23.2 ºN, China, 36 º36´N, Sri Lanka, 6.91 ºN, Sweden, 59.81 ºN, are 14, 16, 14, 12 and 10 respectively. The mean multiplicity in Malaysia, 1ºN, Brazil, 23.2 ºN, China, 36 º36´N, Sri Lanka, 6.91 ºN, Sweden, 59.81 ºN were 4, 3.8, 3.76, 4.5 and 3.4. It can conclude that there is similarity in lightning properties measured in this study since the difference is small among each other.

CHAPTER 5

CONCLUSION AND RECCOMENDATION

5.1 Conclusion

In this study, of 50 negative cloud-to-ground lightning flashes in Malaysia, only six flashes were selected as sample. The measurement based on the recording of electric fields generated by the whole flash in 1s using 50ns resolution is high enough to capture return stroke. It was found that, the average number of strokes per flash was 3 and 16.7% of the total flashes were single stroke flash. Furthermore, the arithmetic mean and geometric mean of interstroke intervals from 18 total numbers of strokes are 76.38 and 4.32ms respectively. From the observation of this study, the maximum peak amplitude of first RS for the whole flash was 1.22V, whereas the minimum peak amplitude of first RS was 0.33V.

Next, this comparative study with observations made in Malaysia, Brazil, China, Sri Lanka and Sweden are summarized as follows: The geometric mean of the time interstroke intervals range from 4.32 to 67ms. For this study, geometric mean of time interstroke interval deviates 10 times far from the geometric mean obtained in Malaysia, Brazil, China, Sri Lanka and Sweden. This was due to process of RS occurring in negative cloud-to-ground flashes within a short period. For example, flash number 3, 4, 5 and 6 with period of 1.49, 0.45, 0.57 and 0.34ms respectively. The percentage of a single stroke per flash, maximum multiplicity and mean multiplicity ranges from 16 to 39.8%, 5 to 16 and 3 to 4.5 respectively. Overall, the result of this study is fairly similar to the result obtained in Malaysia, Brazil, China, Sri Lanka and Sweden.

5.2 Recommendation

After completing this project, there are several recommendations which should be forwarded to ensure that the result obtained is more accurate. Firstly, it is suggested to conduct lightning measurement at an open space. It is because the radiation from the surrounding structure change the electric field generated on the lines of antenna, thus it affect against oscilloscope reading.

Lightning is dangerous natural phenomenon as it produces high-current electric discharge. It may be harmful for human or other life. Therefore, personal safety and equipment safety should be taken to avoid any injuries. For the measuring circuit, it must be able to withstand side effect of lightning strike and must be properly set up because the circuit becomes hot during measurement.

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APPENDIX A

TEXAS INSTRUMENTS OPA637AP. OP AMP, 80MHZ, 135V/uS, DIP-8

Click to zoom

Image is for illustrative purposes only. Please refer to product description.

Manufacturer: TEXAS INSTRUMENTS
Order Code: 1263170
Manufacturer Part No OPA637AP.

Product Information

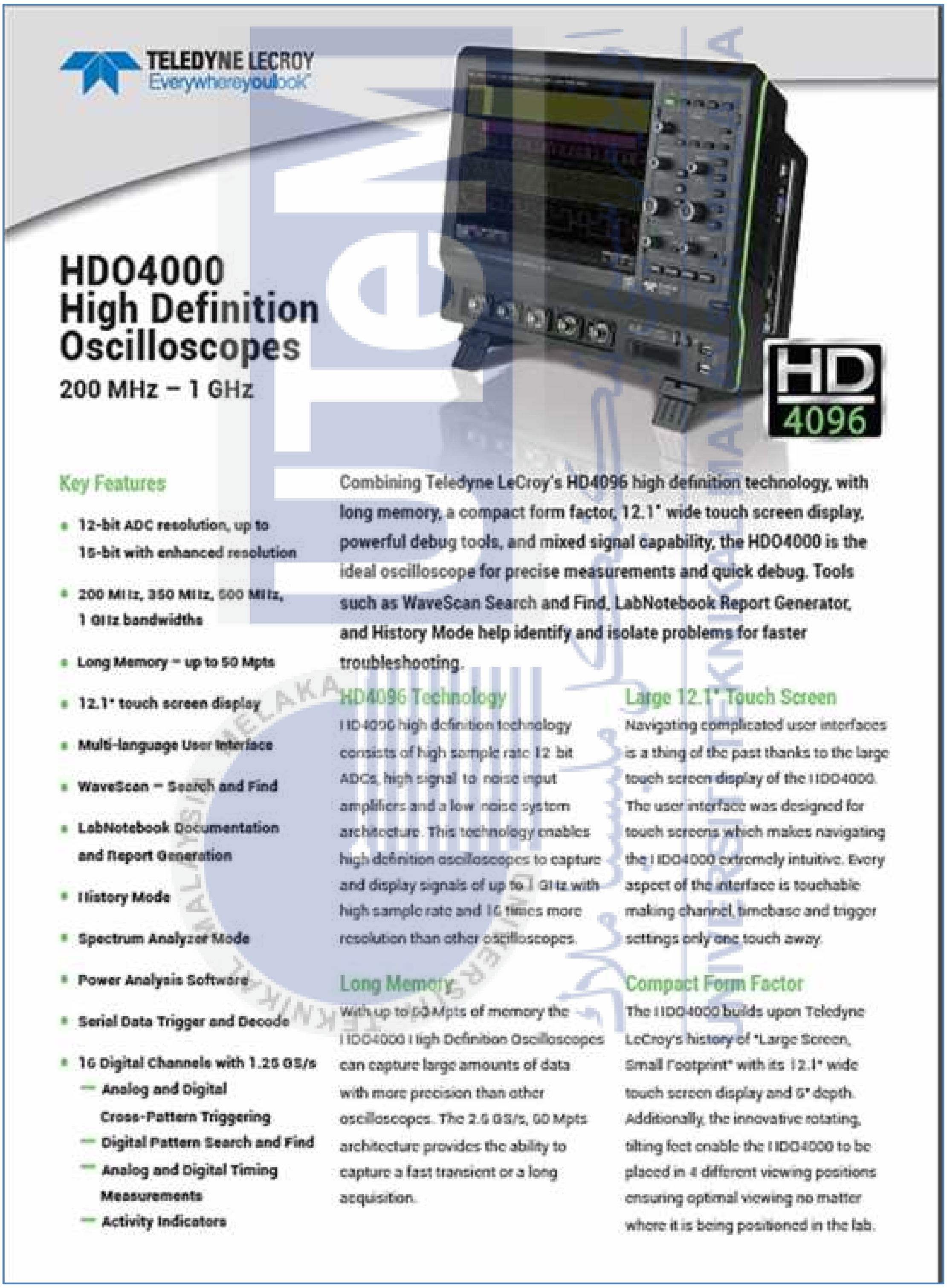
- **Amplifier Case Style:** DIP
- **Bandwidth:** 80MHz
- **MSL:** -
- **No. of Amplifiers:** 1
- **No. of Pins:** 8
- **Op Amp Type:** Low Offset Voltage
- **Operating Temperature Max:** 85°C
- **Operating Temperature Min:** -25°C
- **Packaging:** Each
- **SVHC:** No SVHC (17-Dec-2014)
- **Slew Rate:** 135V/µs
- **Supply Voltage Range:** ± 4.5V to ± 18V

APPENDIX B

Close view parallel plate antenna

Process making printed circuit board (PCB)

APPENDIX C



HDO4000 High Definition Oscilloscopes

200 MHz – 1 GHz

Key Features

- 12-bit ADC resolution, up to 15-bit with enhanced resolution
- 200 MHz, 350 MHz, 500 MHz, 1 GHz bandwidths
- Long Memory – up to 50 Mpts
- 12.1" touch screen display
- Multi-language User Interface
- WaveScan – Search and Find
- LabNotebook Documentation and Report Generation
- History Mode
- Spectrum Analyzer Mode
- Power Analysis Software
- Serial Data Trigger and Decode
- 16 Digital Channels with 1.25 GS/s
  - Analog and Digital Cross-Pattern Triggering
  - Digital Pattern Search and Find
  - Analog and Digital Timing Measurements
  - Activity Indicators

Combining Teledyne LeCroy's HD4096 high definition technology, with long memory, a compact form factor, 12.1" wide touch screen display, powerful debug tools, and mixed signal capability, the HDO4000 is the ideal oscilloscope for precise measurements and quick debug. Tools such as WaveScan Search and Find, LabNotebook Report Generator, and History Mode help identify and isolate problems for faster troubleshooting.

HD4096 Technology

HD4096 high definition technology consists of high sample rate 12-bit ADCs, high signal-to-noise input amplifiers and a low-noise system architecture. This technology enables high definition oscilloscopes to capture and display signals of up to 1 GHz with high sample rate and 16 times more resolution than other oscilloscopes.

Long Memory

With up to 50 Mpts of memory the HDO4000 High Definition Oscilloscopes can capture large amounts of data with more precision than other oscilloscopes. The 2.5 GS/s, 50 Mpts architecture provides the ability to capture a fast transient or a long acquisition.

Large 12.1" Touch Screen

Navigating complicated user interfaces is a thing of the past thanks to the large touch screen display of the HDO4000. The user interface was designed for touch screens which makes navigating the HDO4000 extremely intuitive. Every aspect of the interface is touchable making channel, timebase and trigger settings only one touch away.

Compact Form Factor

The HDO4000 builds upon Teledyne LeCroy's history of "Large Screen, Small Footprint" with its 12.1" wide touch screen display and 5" depth. Additionally, the innovative rotating, tilting feet enable the HDO4000 to be placed in 4 different viewing positions ensuring optimal viewing no matter where it is being positioned in the lab.

APPENDIX D

Gantt chart													
Main activities of the project based on month(s).													
	2014							2015					
Project Activities	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mac.	Apr.	May.	June.	July.	Aug	
Analyse and understand the title project													
Literature Review and basic principle													
Proceeding with project discussion.													
Final Year Project 1 report													
Submission project report FYP 1													
Conducting experiment and measurement (hardware & software)													
Analysis and discussion of result.													
Completing final report and presentation for FYP2													

APPENDIX E

A Comparative study against cloud-to-ground lightning flashes in Malaysia and Spain under the influence of pollution.

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Abstract-This paper present a comparative study against cloud-to-ground lightning flashes in Malaysia and Spain under the influence of pollution. PM_{10} and SO_2 concentration were used as gross indicator of CCN and examined in relation to the urban increase in CG lightning activity. PM_{10} concentration recorded in Subang, Ipoh and Bayan Lepas were 51, 50 and 49µgm/m³ respectively. Meanwhile, SO_2 concentration recorded were 8, 7.9, 7.7µgm/m³. The three urban areas have average number of CG lightning flashes of 200, 197 and 184. An analysis related number of CG flashes against pollutants show positive correlation in Malaysia with reading of 0.94. This indicates PM_{10} and SO_2 concentration have high influential factor in enhancement of CG lightning activity in Malaysia.

Keywords-Urban areas, Cloud-to-ground lightning.

INTRODUCTION

The air pollution effect on the enhancement of lightning activity remains a controversial topic. The first indication of the effect of urban areas on the enhancement of the cloud-to-ground (CG) lightning activity over and downwind of cities has begun with the first publication of [1]. Then, it was followed by many others publications in Europe, Asia, USA and Brazil such as [2], [3], [4], [5], [6], [7], [8], [9] and [10]. There are two factors used by them to explain about their findings; the increase of cloud condensation nuclei (CCN) due to anthropogenic emission of 10µm particulate matter (PM_{10}) and sulfur dioxide (SO_2) and the enhancement of the convergence due to heat island effect. In general, most studies discuss on particular topic related to CCN interactions with cloud microphysics and the increase of temperature in urban areas or well known as urban heat island (UHI). Typically, UHI is related to many physical differences between urban and rural areas such as absorption of sunlight, increased heat storage of artificial surfaces, obstruction of re-radiation by buildings, absence of plant transpiration, and differences in air circulation [11]. In the other hand, it also can be concluded that urban effect is combination of an increased pollution concentration in the local air caused primarily by human activities and a thermodynamic effect due to differential heating of the city surface [9]. Previous study related to urban effect in Houston, Texas on lightning characteristics found that, a decrease of 12% in the percentage of positive flashes and no significant effect on the peak current of negative and positive CG flashes [3]. The concentration of cloud condensation nuclei (CCN) over urban area can be uplifted by the pollution over the cities, thus it may change the cloud microphysical processes. Consequently, it also may change the charge separation processes in thunderclouds because of its close association with concentration, phase and the size of cloud particles. In addition, the increased of pollution is expected to be effective in suppressing the mean droplet size in the boundary layer, and more cloud water would therefore be operative in isolating the electric charge and finally leading to the production of enhanced CG lightning flashes [2].

However, it should be stressed that study on enhancement of lightning activity under the influence of pollution in Malaysia is limited compared to the study that have been carried out in the United States, Brazil and others. This study will focus on two types of pollutants that contribute to enhancement of cloud-to-ground lightning in Malaysia and Spain, which are particulate matter (PM_{10}) and sulfur dioxide (SO_2). The purpose of this study is to analyze that pollution contribute to enhancement of lightning activities by comparing studies of cloud-to-ground lightning flashes in Malaysia and Spain under the influence of pollution. The information offered here excluding of population size and urban size.

Data Analysis

In Malaysia, CG lightning data were obtained from Malaysian Meteorological Department (MMD) website which provides the data from 2004 to 2007. The way they observed the lightning has been described in [12]. Meanwhile, CG lightning data in Spain were obtained from the lightning detection network deployed on the Iberian Peninsula that belongs to the Institute National de Meteorology. It uses ALDF model 141-T, manufactured by Lightning Location and Protection Inc. This lightning sensor has been described in depth by several authors [13, 14]. Note that all flashes, both negative and positive cloud-to-ground lightning, were included. A lightning flash may include several strokes, but the multiplicity was ignored in this study.

Air pollutant data were collected from Clean Air Initiative-Asia Secretariat [15] comprising of data from 1996 – 2004. Malaysia's air quality monitoring network measures PM_{10} and SO_2 by 51 Continuous Air Quality Monitoring (CAQM) stations that are linked via public telephone lines to National Environmental Data Center (EDC). In Spain, air pollutant data were obtained from the study of Luis Rivas Soriano and Fernando de Pablo form University of Salamanca, Spain [4]. They obtained data for the year of 1994 because that is the only available data.

For the present studies, measures PM_{10} and SO_2 over urban areas in Subang, Selangor, Ipoh, Perak and Bayan Lepas, Penang were considered. All of these three urban areas are located in Malaysia.

Overall, CG lightning data and result are based on three years period. Note that, concentration pollutant data and result are only available on one year.

Table 1: Average Number of CG Flashes (2004 - 2007).

Urban Area/ State	Average Number of CG Flashes
Subang, Selangor	200
Ipoh, Perak	197
Bayan Lepas, Pulau Pinang	184

Table 2: Annual Average Concentration of PM_{10} and SO_2 in Malaysia for the year of 2004.

Urban Area/ State	Annual Average Concentration of Pollutant	
	PM10 (µgm/m³)	SO2 (µgm/m³)
Subang, Selangor	51	8
Ipoh, Perak	50	7.9
Bayan Lepas, Pulau Pinang	49	7.7

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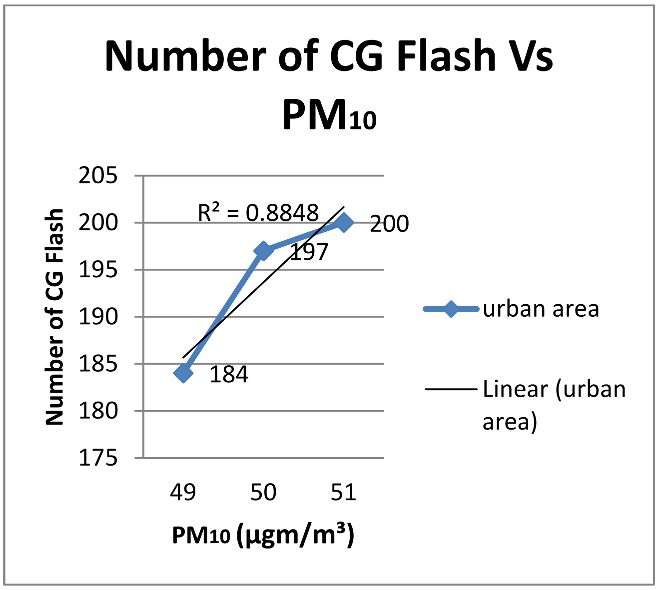

Figure 1: Number of CG Flash Vs. PM_{10}

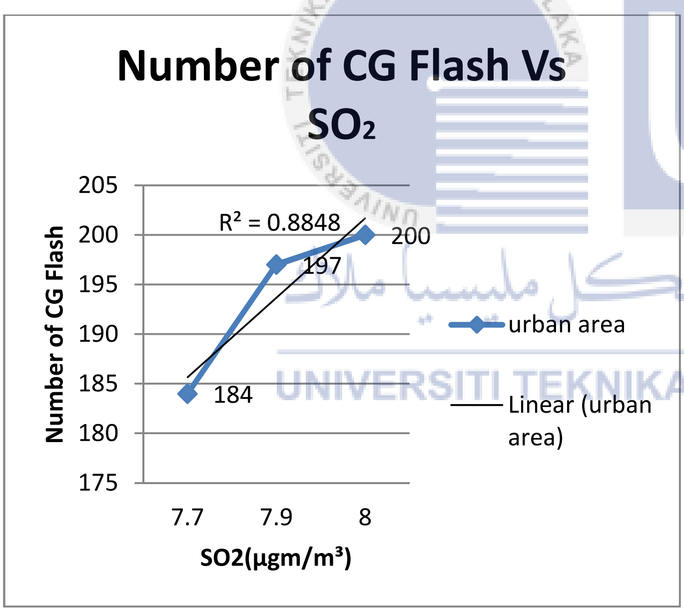

Figure 2: Number of CG Flash Vs. SO_2

Result and Discussion

Table 1 shows the average number of CG flashes recorded within the urban areas in Malaysia for the year 2004 to 2007. Number of CG flashes in urban areas of Subang, Ipoh and Bayan Lepas are 200, 197 and 184. Note that, the major industries in Subang, Ipoh and Bayan Lepas such as light manufacturing industry, heavy manufacturing industry, tin mining and smelting have contributed to a strong source of pollution [15]. In addition, number of CG flashes recorded in Miranda de Ebro, Burgos and Leon are 203, 354 and 158, respectively [4]. The main activities in those urban areas are clothes manufacturing, timber, and the production of metal and non-metal minerals product [16]. These activities have contributed to enhancement of air pollution thus indirectly enhanced the production of CG lightning.

Table 2 shows the annual average concentration of PM_{10} and SO_2 in Malaysia for the year of 2004. The annual average concentration of PM_{10} and SO_2 recorded in Subang, Ipoh and Bayan Lepas are 51, 50, 49 and 8, 7.9, 7.7 µgm/m³. From the observation of this study, the annual average concentration of PM_{10} in Malaysia and Spain are fairly same [4]. Meanwhile, the annual concentration of SO_2 recorded in Malaysia is lower than annual average concentration of SO_2 recorded in Miranda de Ebro, Burgos and Leon which are 19.6, 19.7 and 57.0µgm/m³ respectively. This is because since 1989, Malaysia was motivated to adhere to air quality guidelines called the Recommended Malaysian Air Quality Guideline (RMG) that was set by Department of Environment (DoE) [15]. For the urban areas considered in this study, it was expected that increased concentration of SO_2 contributes to the increase in CG flashes. Conversely, the PM_{10} does not seem to be related to the increase of CG lightning. It is because an increased concentration of SO_2 at the surface would lead to increase in sulfate ion concentration in the boundary layer [17]. In addition, Orville et al 2001 suggested that the increase in the cloud water reaching the mixed phase region of the cloud is paralleled by an increase in the separation of the electric charge therefore, it produces a greater CG lightning. Apparently, sulfate particles are generally more effective as CCN than PM_{10}, thus it is reasonable to claim that the SO_2 concentration would be better related to enhancement of CG lightning than the PM_{10}, although data from more years would be necessary to confirm this finding.

These results are consistent with result obtained by prevoius researchers who found that pollution over the cities increase the CCN due to anthropogenic emission of 10µm particulate matter (PM_{10}) and sulfur dioxide (SO_2) and the enhancement of the convergence due to heat island effect [2], [3], [4], [5], [6], [7], [8], [9] and [10].

Figure 1 and 2 shows the graph number of CG flashes in Malaysia versus PM_{10} and SO_2 in µgm/m³ respectively. In this study, the positive correlation coefficient was found between PM_{10} concentration and the number change in CG lightning flashes to the overall urban area with reading of 0.94. Besides that, the positive correlation coefficient also was found between SO_2 concentration and the number change in CG lightning flashes to the overall urban area with reading of 0.94. These results indicate a possible influence of pollution over urban areas against the number of CG lightning flashes. In this study, the positive correlation of both pollutants against number of CG flash lightning is same. In addition, this result deviate from result obtained by Soriano, L.R. and F. Pablo who have found correlation concentration of PM10 and concentration of SO2 over urban areas with reading of -0.15 and 0.55 respectively. The divergence of result is due to many factors such as wind speed, humidity, temperature and interaction between polluted gases. Therefore, it is hard to conclude that increased concentration of SO_2 contributes in enhancing the CG flashes but the increased concentration of PM_{10} does not seem to be as influential as SO_2 to the enhancement in CG lightning flashes as evident from their correlation. However, this result corroborate with Westcott (1995) who has found that large annual values of SO_2 and PM_{10} correspond generally to the large values of urban and downwind CG flash. Hence, data from other geographical locations and for more years are required to resolve this diversity in findings.

Conclusion

An analysis of the number of CG flashes in urban areas in Malaysia and Spain was performed. The results show that CG lightning activity is enhanced within of most of urban areas studied. PM_{10} and SO2 concentration were used as gross indicator of CCN and examined in relation to the urban increase in CG lightning activity. Overall, the results were fairly similar for both Malaysia and Spain except for the correlation of PM_{10} parameter in which Malaysia shows positive correlation meanwhile, Spain shows negative correlation. As previously mentioned, enhancement of lightning activity under the influence of pollution in Malaysia is limited compared to other country, thus it may affect divergence of data. Besides that, factors such as wind speed, humidity, temperature and interaction between polluted gases also affect the result. The divergence of results can be resolved by performing more research and obtain more data from other geographical locations.

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