Faculty of Electronic and Computer Engineering

FR4 ANTENNA DESIGN FOR TROPICAL HAILSTORM DETECTION IN RELATION TO LIGHTNING OCCURRENCE

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**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in
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DECLARATION

I declare that this thesis entitled “FR4 Design For Tropical Hailstorm Detection in Relation to Lightning Occurrence” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………………………….…

Name : Dinesh A/L Periannan

Date :……………………………………………..…

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature : ……………………………………

Supervisor Name : Dr. Mohd Riduan bin Ahmad

Date : …………………………………...

DEDICATION

My beloved parents Mr and Mrs Periannan for great support

My beloved sisters Sanjeeta Periannan and Tanasula Periannan

My beloved Supervisors Dr. Mohd Riduan bin Ahmad and PM Dr. Mohamad Zoinol Abidin bin Abd Aziz

My beloved friends and family

ABSTRACT

Lightning flash is an electrical discharge in air (dielectric breakdown) which emits electromagnetic (EM) fields across very wide spectra from a few Hertz up to visible wavelength. Lightning remote sensing has been used widely to measure the EM fields in various frequencies bands. Circular metal plate capacitive antenna made of iron or aluminum have been used widely for the front-end design of the remote sensing system. The circular metal plates are arranged in parallel and separated by insulators made of Teflon. However, three common problems encountered with the existing setting. First, both metals rust easily and could affect the reading of the EM fields. Second, the insulation Teflon separating the metal plates could become weak conductor and thus distort the EM fields reading. Third, the use of Teflon in between the parallel plates changes the overall permittivity value. The second problem is when most of the hailstorm were recorded at higher altitude. Through studies on meteorology context of NBEs in Florida and Great Plains showed strong correlation between lightning rates and ordinary lightning flash rates. Stronger storms have been observed to produce higher percentage NBEs while weaker storms produce less or no NBEs. In this thesis, in order to overcome these problems, we propose a cheaper and lighter alternative to iron and aluminum plates by changing to FR4 copper plate. Rectangular FR4 copper plate capacitive antenna A3 have been designed and constructed. The rectangular A3 FR4 copper plate has been found to have comparable impedance and capacitance values to the iron-based circular metal plate. Analysis of the wave shape and peak amplitude ratio showed comparable performance between both antennas. Secondly, there is no studies has been done in tropical region, so this thesis is motivated to provide the first studies of Tropical hailstorm in mid latitude. After replacing the antenna for lightning measurement system, data were collected using buffer circuit (fast field and slow field system) connected with picoscope (PC based oscilloscope) and presented the evolution (5-minute flash rate) of two tropical hailstorms that occurred in Malaysia at two sites namely Bukit Jalil (approximately 112 km from exact location) and Sungai Udang (approximately 22 km from exact location) with the objective to understand the relationship of the hailstorms with Negative Narrow Bipolar Event (–NBE) and Positive Cloud-to-Ground (+CG) flashes. For Bukit Jalil hailstorm, within 5 minutes period between 10:30 and 10:35, 16 –NBEs have been detected where else for Sungai Udang hailstorm, starting 18:55 until 19:35, 60 +CGs flashes were detected when the hails were reported to hit the ground in duration of 40 minutes. First conclusion for the antenna, rectangular A3 FR4 copper plate antenna can be used as replacement for the existing iron- or aluminium-based circular metal plates antenna. Second conclusion for the hailstorm, based on the results of these 2 tropical hailstorms, clearly stronger convection does not relate only to higher –NBEs flash rate but also highly correlated to +CGs flash rate.

ABSTRAK

Pancaran kilat adalah pelepasan elektrik di udara iaitu pecahan dielektrik yang memancarkan medan elektromagnetik (EM) di seluruh spektrum yang sangat luas dari beberapa Hertz sehingga panjang gelombang yang dapat dilihat. Sistem penderia jauh kilat telah digunakan secara meluas untuk mengukur medan EM dalam pelbagai jalur frekuensi. Antena kapasitif plat logam bulatan yang diperbuat daripada besi atau aluminium telah digunakan secara meluas untuk reka bentuk hadapan sistem penginderaan jauh. Plat logam bulatan disusun secara selari dan dipisahkan oleh penebat yang diperbuat daripada Teflon. Walau bagaimanapun, terdapat tiga masalah biasa yang sering dihadapi dengan tetapan yang sedia ada. Pertama, kedua-dua logam plat selari mudah berkarat dan ia boleh mempengaruhi bacaan medan EM. Kedua, Teflon penebat yang memisahkan plat logam tersebut boleh menjadi konduktor yang lemah dan dengan itu akan mempengaruhi bacaan medan EM. Ketiga, penggunaan Teflon di antara plat selari akan mengubah nilai kebertelusan keseluruhan. Masalah seterusnya adalah apabila sebahagian besar hujan batu tercatat pada ketinggian yang lebih tinggi. Melalui kajian mengenai konteks meteorologi NBE di Florida dan Great Plains menunjukkan korelasi yang kuat antara kadar kilat dan kadar kilat biasa. Ribut petir kuat telah diperhatikan untuk menghasilkan peratusan NBE yang lebih tinggi manakala ribut petir yang lemah menghasilkan NBE yang kurang ataupun tidak. Bagi mengatasi masalah tersebut, tesis ini mencadangkan alternatif yang lebih murah dan lebih ringan untuk plat besi dan aluminium dengan menukar kepada plat tembaga FR4. Plat kapasitif antena FR4 segi empat tepat tembaga bersaiz A3 telah direka dan dibina. Plat tembaga segi empat tepat A3 FR4 didapati mempunyai nilai impedans dan kapasitif yang setara dengan plat besi bulatan yang berasaskan besi. Analisis bentuk gelombang dan nisbah amplitud puncak menunjukkan prestasi setanding antara kedua-dua jenis antena. Kedua, setakat ini tidak ada kajian yang dilakukan di rantau tropika, jadi tesis ini bermotivasi untuk memberikan kajian pertama mengenai hujan batu tropika di latitud tengah. Selepas menggantikan antena untuk sistem pengukuran kilat, data dikumpulkan menggunakan litar penampan (medan cepat dan sistem medan perlahan) yang berkaitan dengan picoskop (osiloskop berasaskan PC)dan dibentangkan dalam evolusi (kadar kilat 5 minit) dari dua badai tropika yang berlaku di Malaysia di dua tempat iaitu Bukit Jalil (kira-kira 112 km dari stesen kami) dan Sungai Udang (kira-kira 22 km dari stesen kami) dengan matlamat untuk memahami hubungan ribut petir hujan batu dengan Acara Bipolar Negatif (-NBE) dan kilauan Awan-ke-Bumi (+ CG). Bagi kawasan Bukit Jalil, dalam tempoh 5 minit antara 10:30 dan 10:35, 16-NBE telah dikesan manakala bagi hujan lebat di Sungai Udang, bermula 18:55 hingga 19:35, 60 kilauan +CG dikesan apabila hujan batu dilaporkan memukul tanah dalam tempoh 40 minit. Kesimpulan pertama bagi antena, tesis ini menyimpulkan bahawa antena plat FR4 tembaga segi empat tepat bersaiz A3 boleh digunakan sebagai pengganti antena plat logam bulatan berasaskan besi atau aluminium yang sedia ada. Kesimpulan kedua bagi hujan batu, berdasarkan hasil daripada 2 hujan batu di tropika ini, konveksi yang lebih kuat tidak hanya berkaitan dengan kadar flash NBE yang lebih tinggi tetapi juga sangat berkorelasi dengan kadar kilat +CG.

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LIST OF ABBREVIATIONS

+CG	-	Positive Cloud to Ground
-CG	-	Negative Cloud to Ground
+NBE	-	Positive Narrow Bipolar Event
-NBE	-	Negative Narrow Bipolar Event
CAPPI	-	Constant Altitude Plan Position Indicator
CG	-	Cloud to Ground
CIDs	-	Compact Intra-cloud Discharges
EM	-	Electromagnetic
IC	-	Intra-cloud
LF	-	Low Frequency
NBE	-	Narrow Bipolar Event
NBPs	-	Narrow Bipolar Pulses
PAR	-	Phase Array Radar
PBP	-	Preliminary Breakdown Pulses
VHF	-	Very High Frequency

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CHAPTER 1

INTRODUCTION

1.1 Background

Lightning flash is one of the world captivating marvels. Despite safeguarded records on naked eyes perception of lightning flashes in old texts, we do not generally comprehend crucial instruments of lightning flashes. Even until today, certain types of lightning flash remain uncertain due to the fundamental mechanisms of lightning flashes.

What is lightning flash? Lightning flash is an electrical discharge happens in the air that radiates electromagnetic waves (EM) over wide spectra from a several Hertz up to visible wavelength that consists of several processes within 0.5 to 1 second typical record. Recent discovery uncovers that lightning flashes discharge X-rays and gamma rays and furthermore is believed to create positrons that is known as anti-matter particles.

Typically, lightning is produced from within a thundercloud. The thundercloud consists of a tripole charge structure. It has three main charge regions namely main positive charge region that located at the cloud top, negative main charge region in the middle and pocket positive charge region at the cloud base. Figure 1.1 shows the tripole charge structure inside a thundercloud. The movement of the charges (known as current flow) and the polarity determine the types and characteristics of captured lightning flash waveforms.

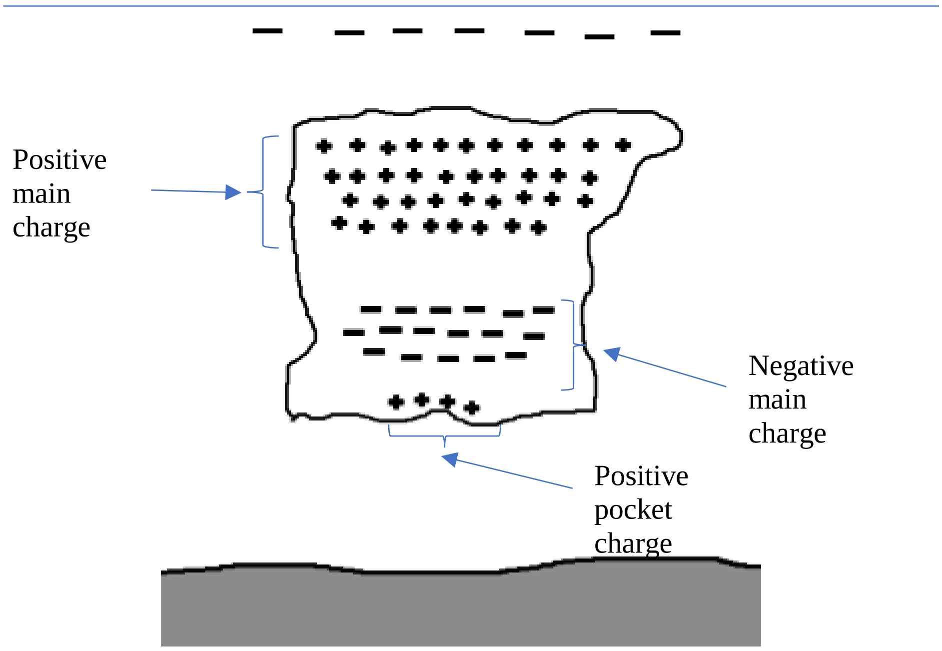

Figure 1.1: Tripole cloud structure and its charge region

In general, lightning type is divided into 2 parts that are cloud to ground (CG) flash and cloud flash. The CG consists of positive CG (+CG) flash and negative CG (–CG) flash. The cloud flash has 2 subtypes of flashes that are Inter-cloud or cloud to cloud flash and intracloud (IC) flash. The IC flash has 2 subtypes of flashes that are the normal IC and Narrow bipolar Event (NBE). The NBE is also known as Narrow Bipolar Pulses or NBPs and Compact Intra-cloud Discharges or CID's. The NBE consists of Positive Narrow Bipolar Event (+NBE) and Negative Narrow Bipolar Event (–NBE).

Remote sensing has been utilized broadly to capture the electric (E) and magnetic (B) fields at different frequency bands. To quantify gradually varying E-field that showing the moderate development of electrical charges, slow field antenna system (limited by frequencies between few Hertz up to 100 Hz) has been used. To show the acceleration of the electrical charges, fast-field antenna system (from several tens of Hertz up to several tens of Megahertz) has been used. One second and 13 millisecond decay time constants are used respectively to capture the lightning flashes at that particular event.

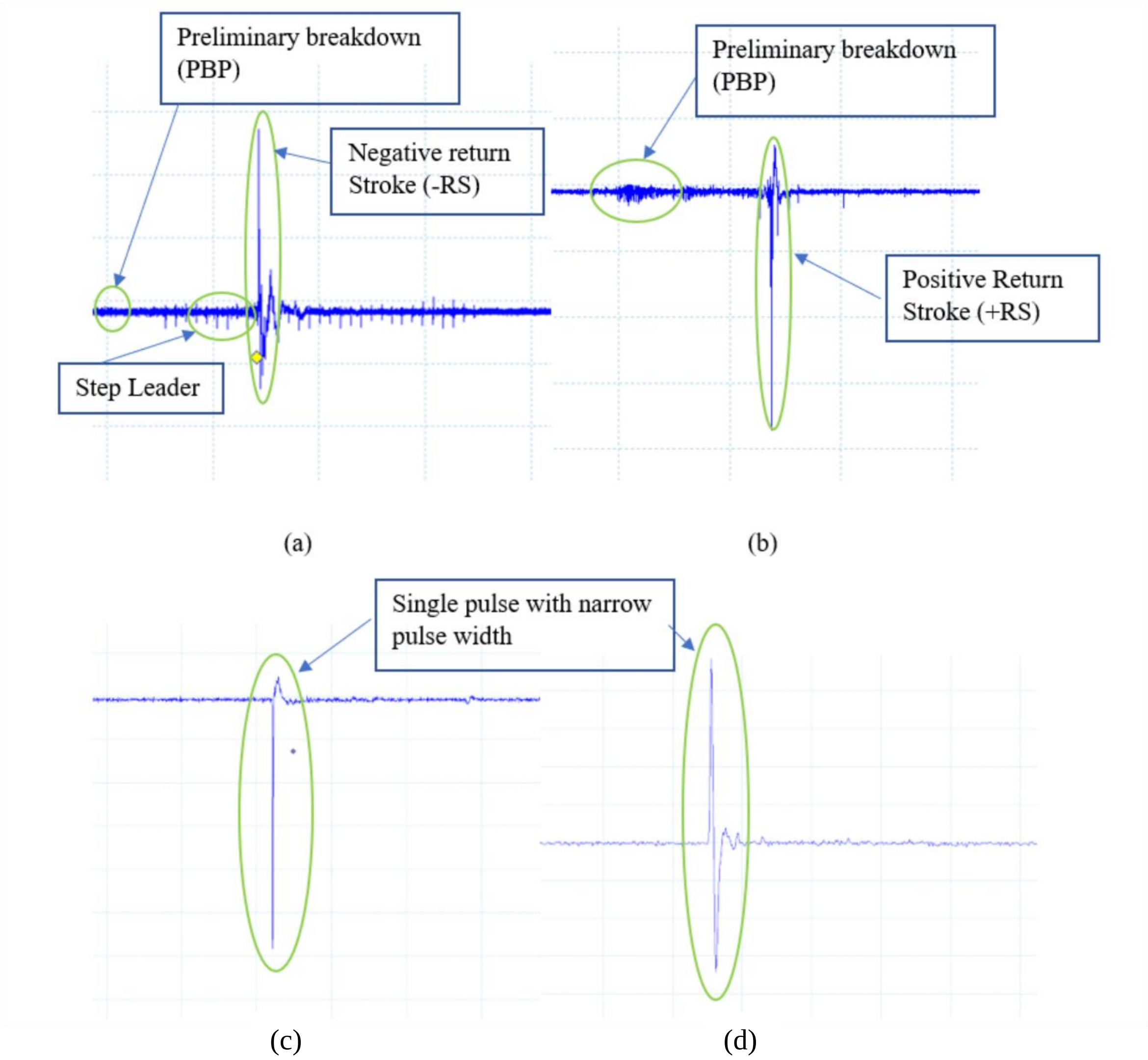

Figure 1.2: Types of flashes (a) Negative Cloud to Ground flash (b) Positive Cloud to Ground flash (c) Positive Narrow Bipolar Event (d) Negative Narrow Bipolar Event. The waveform captured using atmospheric electricity sign convention

The magnetic field sensor or known as Magnetic Direction Finder (MDF) with high sensitivity and high gain operate at frequencies between 400 Hz and 400 kHz (Zhang et al., 2016) has been used to detect the emission of radiation component emitted from lightning flashes. It has been used widely as localisation techniques to determine the lightning strike at certain areas.

After detects the emission of lightning, the captured signal is digitized by using a PC based oscilloscope called the Picoscope (Picoscope 4000 series and 3000 series have been used in this research work). Detailed explanation about the measurement set up will be explained in chapter 3.

1.2 Severe storm

A severe storm by definition is a thunderstorm that produces hails with size of 19 millimetre (around 3/4 inches) or larger (refer Figure 1.3) and when the wind reaches 26 metre per seconds (50 knots), or if funnel clouds or tornadoes (refer Figure 1.4) (Williams et al., 2001). On the other hand, hailstorm is defined when it only produces hails with size less than 19 milimeter (less than 3/4 inches) and the wind speed does not exceed 26 metre per second. The deepest convection strength determines the severity of a thunderstorm in every region.

The cause of the thunderstorm is due the moisture, atmospheric instability and updraft speed. When the warm air is rushed upwards the moisture will be lifted up and pushed into the cooler part of the atmosphere. When the updraft is intense, the moisture becomes caught in a cyclic, tumbling wind pattern. Later when the updraft is strong enough to keep the moisture high up, hail begins to form. At this time the iced crystal will be tossed upwards and grow until it is large enough for the gravity to pull downwards.

Figure 1.3: The size of the hail collected from ground at Bukit Jalil in Kuala Lumpur. Photo credits: Dayah

Figure 1.4: Example of a tornado. Photo credit: Mike Umscheid, National Weather Service