TEMPORAL CHARACTERISTICS OF MICROWAVE RADIATIONS EMITTED DURING STEPPED LEADERS PROCESS OF NEGATIVE GROUND FLASHES

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SHAMSUL AMMAR BIN SHAMSUL BAHARIN

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in Electronic Engineering

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DECLARATION

I declare that this thesis entitled "Temporal Characteristics of Microwave Radiations Emitted During Stepped Leaders Process of Negative Ground Flashes" 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.

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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.

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DEDICATION

Gratitude towards the past of myself for all the time and effort had been spent;

Thanks for the supports from my parents;

Thanks, God, for granting me the opportunity to collect data from the thunderstorms;

Along the journey of completing this thesis.

ABSTRACT

Electrical breakdown is a mechanism that initiate lightning flash and consists of electron avalanches, streamers, and leader processes. The lightning type that brings down negative charges to ground is called negative cloud-to-ground (-CG) flash. The -CG flash starts with initial breakdown (IB) followed by stepped leader (SL) and return stroke (RS) processes. In this thesis, temporal characteristics of microwave and Very High Frequency (VHF) electric field radiations associated with SL process are studied. Stepped leader is an example of conventional breakdown that consists of a special pilot system called space stem that can develops into bidirectional streamer. This study is driven by motivation to understand whether both microwave and VHF radiations are radiated by the same process or not. The VHF radiation is known to be associated with propagating streamer. In literature, propagating streamer is the source of VHF radiation emission while sources of microwave radiation from lightning are from the head-on collisions of streamers and electron avalanche/corona breakdown at the tip of leader. Therefore, this study aimed to design and deploy a measurement system to measure both the microwave and VHF radiations associated with SL process. Then, the collected electric field data are analyzed in time domain to evaluate the relationship between microwave and VHF radiations and electron avalanches and corona breakdown process. The measurement set up consists of four sensors namely fast antenna (FA) (10 Hz to 3 MHz), slow antenna (SA) (1 Hz to 1 kHz), microwave (0.97 GHz) and VHF (60 MHz) systems. A total of ten very close -CG flashes (within reversal distance) accompanied by both VHF and microwave radiations have been chosen and analyzed. Moreover, to validate the existence of lightning thunderstorm on the day of the measurement campaign, the collected data are compared with Tenaga Nasional Berhad Research (TNBR) lightning locations. The first significant analysis is that all microwave radiations were observed to lead SL process with average leading time of 0.423±0.378 µs and around 80.41% of microwave radiation bursts lead VHF radiation bursts with average leading time of 0.540±0.596 µs. The second significant analysis is that microwave radiation temporal characteristics can be classified into three categories during Quiet Period (QP). The first category consists of two microwave bursts during QP while second category has one microwave burst only. For Category 3, no microwave burst detected. The first and second microwave bursts of Category 1 are suggested to be associated with electron avalanches and corona breakdown at the tip of negative leader and space stem, respectively. Microwave burst in Category 2 is suggested to be radiated by electron avalanches and corona breakdown at the tip of negative leader while space stem was absent. As space stem process was absent the QP duration in Category 2 is shorter than Category 1, 2.319 µs compared to 4.573 µs, respectively. In Category 3, the detected VHF burst is suggested to be emitted by upward propagating positive streamers. To conclude, the analyses done in this study provide strong suggestion that microwave and VHF radiations are emitted by different breakdown process.

CIRI-CIRI TEMPORAL PEMANCARAN RADIASI GELOMBANG MIKRO SEMASA PROSES PENERAJU LANGKAH KILAT BUMI NEGATIF

ABSTRAK

Pemecahan elektrik adalah proses pencetus kilat dan terdiri daripada longsoran elektron, penjurus, dan pemimpin. Jenis kilat yang menurunkan cas negatif ke tanah disebut kilat awan-ke-tanah negatif (-CG). Kilat -CG bermula dengan pemecahan awal (IB) diikuti dengan proses pemimpin berlangkah (SL) dan panahan kembali (RS). Tesis ini menganalisa ciri-ciri masa gelombang mikro dan radiasi medan elektrik Frekuensi Sangat Tinggi (VHF) yang berkait dengan proses SL. Pemimpin berlangkah adalah contoh pemecahan konvensional yang terdiri daripada sistem khas yang disebut sebagai ruangan unik yang dapat tumbuh menjadi penjurus dua arah. Kajian ini dijalankan untuk memahami sama ada radiasi gelombang mikro dan VHF dipancarkan oleh proses yang sama atau tidak. Gelombang VHF dikaitkan dengan pergerakan streamer. Dalam literatur, pergerakan penjurus adalah sumber radiasi VHF sementara sumber radiasi gelombang mikro dari kilat adalah dari perlanggaran hujung penjurus dan pemecahan logsoran elektron / korona di hujung pemimpin. Oleh itu, kajian ini bertujuan untuk merancang dan menggunakan sistem pengukuran untuk mengukur radiasi gelombang mikro dan VHF yang berkaitan dengan proses SL. Kemudian, data medan elektrik yang dikumpulkan akan dianalisisa dalam domain masa untuk mengkaji hubungan antara radiasi gelombang mikro dan VHF dengan longsoran elektron dan proses pemecahan korona. Aturan pengukur terdiri daripada empat pengesan iaitu antena cepat (FA) (10 Hz hingga 3 MHz), antena perlahan (SA) (1 Hz hingga 1 kHz), gelombang mikro (0.97 GHz) dan sistem VHF (60 MHz). Sebanyak sepuluh kilat panah ke tanah negatif (-CG) yang sangat dekat (dalam jarak pembalikan) disertai dengan kedua-dua VHF dan radiasi gelombang mikro telah dipilih dan dianalisa. Tambahan lagi, untuk mengesahkan adanya ribut petir pada hari kempen pengukuran, data yang dikumpulkan telah dibandingkan dengan lokasi kilat yang dilaporlan oleh Tenaga Nasional Berhad Research (TNBR). Analisa signifikan pertama adalah semua radiasi gelombang mikro didapati mendahului proses SL dengan purata waktu memimpin 0.423 ± 0.378 µs dan sekitar 80.41% daripada radiasi gelombang mikro memimpin ledakan radiasi VHF dengan purata waktu memimpin 0.540 ± 0.596 µs. Analisa signifikan kedua adalah bahawa ciri-ciri masa radiasi gelombang mikro dapat dipecahkan kepada tiga kumpulan berpandukan Fasa Senyap (QP). Kategori pertama dikesan dengan dua gelombang mikro manakala kategori kedua dikesan dengan satu gelombang mikro sahaja semasa QP. Untuk Kategori 3, tiada gelombang mikro yang dikesan semasa QP. Gelombang mikro pertama dan kedua dari Kategori 1 dikaitkan dengan longsoran elektron dan pecahan korona di hujung pemimpin negatif serta di ruangan unik. Manakala, satu gelombang mikro dalam Kategori 2 disarankan dipancarkan oleh longsoran elektron dan pemecahan korona di hujung pemimpin negatif sahaja, bukan di ruangan unik. Disebabkan ruangan unik tiada, tempoh masa QP untuk Kategori 2 lebih pendek daripada Kategori 1 iaitu 2.319 µs berbanding 4.573 µs. Radiasi VHF masih dapat dikesan walaupun tiada gelombang mikro bagi Kategori 3 dan disarankan dipancarkan oleh penjurus positif yang bergerak ke atas dari permukaan bumi. Kesimpulannya, analisis yang dilakukan dalam karya ini mencadangkan bahawa radiasi gelombang mikro dan VHF dipancarkan oleh proses pemecahan yang berbeza.

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LIST OF ABBREVIATIONS

BQP	-	Burst quiet period
BNC	-	Bayonet Neill–Concelman
BPF	-	Bandpass filter
CAPPI	-	Constant Altitude Plan Position Indicator
CID	-	Compact Intra-cloud Discharge
CG	-	Cloud-to-Ground
CPT	-	Chaotic pulse train
CST	-	Computer Simulation Technology
dB/dt	-	Time derivative magnetic field
dE/dt	-	Time derivative electric field
EHF	-	Extremely high frequency
ET	-	End time
FA	-	Fast electric field antenna
FR4	-	Flame Retardant 4
GPS	-	Global Positioning System
IB	-	Initial breakdown
IC	-	Intra-cloud
LNA	-	Low noise amplifier
MMD	-	Malaysia Meteorological Department
NBE	-	Narrow Bipolar Event
OT	-	Onset time
PBP	-	Preliminary Breakdown Process
PCB	-	Printed circuit board

PD	-	Pulse duration
QP	-	Quiet phase
RT	-	Rise time
RS	-	Return Stroke
SA	-	Slow electric field antenna
SHF	-	Super High Frequency
SL	-	Stepped Leader
SRS	-	Subsequent return stroke
TI	-	Time interval
TPD	-	Total pulse duration
UHF	-	Ultra High Frequency
VHF	-	Very High Frequency
ZCT	-	Zero-crossing time
+CG	-	Positive Cloud-to-Ground
+NBE	-	Positive Narrow Bipolar Event
-CG	-	Negative Cloud-to-Ground
-NBE	-	Negative Narrow Bipolar Event

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the background of research work in this thesis, extensive introduction to the mechanism of lightning physics and formulated problem statement together with the objectives and scopes.

1.2 Research background

Lightning is one of the intriguing natural phenomena on earth. It could happen in daily life whether during daylight or rainy season. The momentary light that can be observed with the naked eyes is called a flash which is later followed by a loud sound called thunder. However, depending on the location of the observant, a thunder could be heard at the time the lightning strike occurred. Numerous parts of lightning phenomenon remained unknown and yet to be discovered due to its interdisciplinary nature.

What is lightning? Lightning flash is an electrical discharge that happens in the air that emits electromagnetic fields, x-rays, gamma rays and optical radiations that made up of several processes within typical records of 0.5 to 1 second. A thundercloud that produces these lightning flashes consists of three charge regions known as tripole charge structure. The configuration of the charge inside the cloud is the main positive charge at the top of the thundercloud, the main negative charge at the center of the thundercloud and the pocket positive charge at the bottom of the thundercloud as illustrated in Figure 1.1.

Based on the movement and direction of electrical charges, lightning flashes could be divided into two main types namely cloud to ground flashes and cloud flashes. Cloud to ground flash can be divided into two types which are Positive Cloud to Ground flashes (+CG) and Negative Cloud to Ground flashes (-CG). In case of the +CG flash, it brings down positive charges to the ground while for -CG flashes, negative charges are brought down to the ground. The CG is initiated by preliminary breakdown process (PBP) that happens inside the cloud as shown by electric field measurements. The PBP is followed by another process called stepped leaders (SLs) which bring the electrical charges further down to the ground. The stepped leader is then accompanied by another process called return stroke (RS) which is a neutralization process that takes place not long after the downward stepped leaders make a contact with an upward connecting leader from earth's surface.

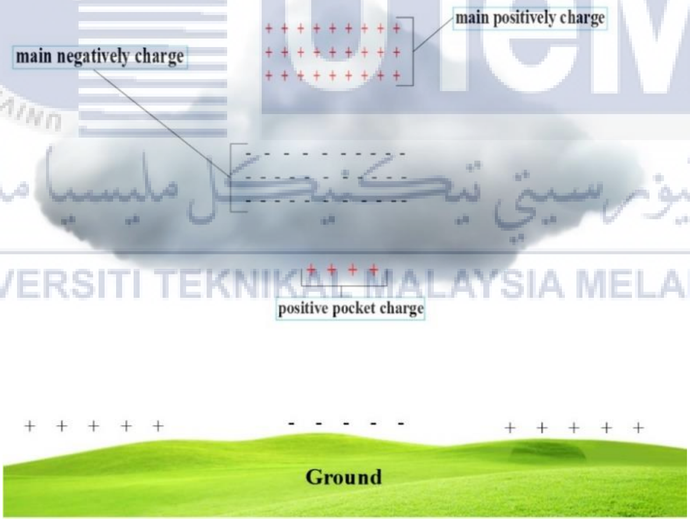

Figure 1.1: Tripole charge structure typical for a thundercloud to exist before lightning happens (Figure created by author)

For cloud flash, it can be divided further into 3 subtypes: narrow bipolar event (NBE) flashes, inter-cloud and intra-cloud (IC) flashes. The NBEs are a special type of IC flashes because electric field produced by them falls in a distinct category. Intra-cloud flash is a lightning flash that happens between main charge regions in the same cloud while inter-cloud is a type of cloud flash that happens between charge region of different clouds.

Electrical breakdown process is a process that initiates a lightning flash which consists of three stages of electrical charges development. It starts with electron avalanches in millimeter scale which produce microwave radiation. Next, fusion of many electron avalanches grows into propagating streamers in centimeter scale which produce Very High Frequency (VHF) radiation. After that, streamers grow and develop to become leaders in meter scale which at this stage, it could observe with the naked eyes as bright light emitted intensely.

In order to carry out measurement campaign to detect electromagnetic fields that emitted by lightning flashes, remote sensing application has been used. Radiation component from lightning flashes is measured by using fast electric field antenna (FA) which is used to determine the type of lightning flashes. The FA sensor operates from several hertz up to 10 megahertz with a decay time constant of 13 milliseconds. The specifications of the radio sensors that have been used are between 50-70 MHz and between 800-1050 MHz to measure VHF and microwave radiations, respectively. As the electromagnetic wave signals that received by the sensors are in analog form, PC based oscilloscope (PicoScope 4000, 5000 series and 6000 series) are used to digitize and store the signals. The detail setup and explanation of measurement campaign will be discussed in Chapter 3.

1.3 Problem statement

The problem statement for this study is driven by two schools of taught. The first school of taught suggests that both electron avalanche and streamer events radiate intense VHF bursts as reported by Rison et al. (2016) and Tilles et al. (2019). On the other hand, the second school of taught suggests the electron avalanche event radiates intense microwave