# VHF AND MICROWAVE RADIATION EMITTED BY LIGHTNING AND ITS EFFECT TOWARDS 4G LTE WIRELESS COMMUNICATION

SHAMSUL AMMAR BIN SHAMSUL BAHARIN



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**Faculty of Electronics and Computer Technology and Engineering**

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**SHAMSUL AMMAR BIN SHAMSUL BAHARIN**

**A thesis submitted**
**in fulfillment of the requirements for the degree of Doctor of Philosophy**



**Faculty of Electronics and Computer Technology and Engineering**

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**2024**

**DEDICATION**

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

Thanks for the supports from my parents;

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

Along the journey of completing this thesis.

# ABSTRACT

Electric breakdown process starts with electron avalanche, and then streamer and lastly become leader. They initiate almost all types of lightning flashes except narrow bipolar event (NBE) that was believed to be initiated by fast breakdown. This thesis explores the temporal characteristics of microwave and very high frequency (VHF) electric field radiations associated with the conventional breakdown of stepped leader pulses (SLPs) from negative cloud-to-ground (-CG) flash and fast breakdown of NBEs. The primary motivation is to discern whether both microwave and VHF radiations emitted from the same process or originated from different sources. In existing literature, propagating streamers are identified as the source of VHF radiation emission, while microwave radiation from lightning resulted from head-on collisions of streamers and electron avalanche/corona breakdown at the tip of the leader. Considering that The Fourth Generation Long Term Evolution (4G LTE) mobile links operate in the microwave band, potential interference effects during data transmission need to be investigated as lightning also radiated well at microwave band. To address these objectives, three different measurement setups were designed. First, an experimental setup consisted of fast and slow-varying antennas and radio sensors to capture the temporal characteristics of microwave and VHF radiation associated with SLPs and NBEs. Additionally, a VHF interferometer was implemented to observe the direction and propagation of velocities as well as the altitude height of the VHF radiation sources of NBEs. Furthermore, the study integrated measurements of lightning electric field and 4G LTE performance to assess potential interference effects during data transmission. The noteworthy findings of this study reveal that the sources of microwave and VHF radiation associated with both electrical breakdowns originate from different sources, as evidenced by the temporal analysis of the onset time differences. Further analysis indicates that positive NBEs exhibited a 46% bigger for onset time difference between microwave radiation and VHF emissions, compared to SLPs. In contrast, negative NBEs demonstrated an even more remarkable 85% bigger in the same context. Moreover, when examining the VHF radiation associated with positive and negative NBEs in relation to the onset of fast electric field, positive NBEs displayed a 62% bigger compared to SLPs while negative NBEs exhibited an astonishing 88% bigger. These results suggest that the speed of electron avalanches and streamers of fast breakdown of NBEs is faster compared to the conventional electron avalanches and streamers of SLPs. Additionally, the VHF interferometer mapping reveals that the VHF radiation sources for NBEs propagate bidirectionally with a propagation speed reaching $10^8$ $ms^{-1}$. After comparing the performance of 4G LTE data transmission in both fair weather and thunderstorms, minimal impact was observed during fair weather. However, disruptions were reported during three reported thunderstorms, affecting either the client or server nodes. Furthermore, -CG and intra-cloud (IC) flashes were identified as the main factors that interrupted the data transmission.

***SINARAN VHF DAN GELOMBANG MIKRO YANG DIPANCARKAN KILAT DAN KESANNYA TERHADAP KOMUNIKASI WAYARLES 4G LTE***

## *ABSTRAK*

*Proses pemecahan elektrik bermula dengan longsoran elektron, kemudian penjurus dan terakhir pemimpin. Mereka memulakan hampir semua jenis kilat kecuali peristiwa bipolar sempit (NBE) yang dipercayai dimulakan oleh pemecahan pantas. Tesis ini meneroka ciri-ciri temporal gelombang mikro dan sinaran medan elektrik frekuensi sangat tinggi (VHF) yang dikaitkan dengan pemecahan konvensional pemimpin berperingkat (SLP) daripada kilat awan-ke-tanah negatif (-CG) dan pemecahan pantas NBE. Motivasi utama adalah untuk membezakan sama ada sinaran gelombang mikro dan VHF berpunca daripada proses yang sama atau berasal dari sumber yang berbeza. Dalam kesusasteraan sedia ada, pergerakan penjurus dikenal pasti sebagai sumber pancaran sinaran VHF, manakala sinaran gelombang mikro daripada kilat berasal daripada perlanggaran depan kepala penjurus dan pemecahan elektron/korona di hujung pemimpin. Memandangkan pautan mudah alih Generasi Keempat Evolusi Jangka Panjang (4G LTE) beroperasi dalam jalur gelombang mikro yang dipancarkan sangat baik oleh kilat, potensi kesan gangguan semasa penghantaran data perlu disiasat. Pertama, persediaan eksperimen terdiri daripada antena medan electrik cepat dan lambat berubah-ubah dan penderia radio untuk menangkap ciri temporal gelombang mikro dan sinaran VHF yang dikaitkan dengan SLP dan NBE. Selain itu, interferometer VHF telah dilaksanakan untuk memerhatikan arah dan perambatan halaju serta ketinggian sumber sinaran VHF bagi kedua-dua jenis NBE. Tambahan pula, kajian ini menggabungkan pengukuran medan elektrik kilat dan prestasi 4G LTE untuk menilai potensi kesan gangguan medan elektromagnetik semasa penghantaran data. Penemuan penting kajian ini mendedahkan bahawa sumber gelombang mikro dan sinaran VHF yang dikaitkan dengan kedua-dua pemecahan elektrik berasal daripada sumber yang berbeza, seperti yang dibuktikan oleh analisis temporal bagi perbezaan masa permulaan. Analisis lebih lanjut menunjukkan bahawa NBE positif menunjukkan 46% lebih besar perbezaan masa permulaan antara radiasi gelombang mikro dan pelepasan VHF berbanding dengan SLPs. Sebaliknya, NBE negatif menunjukkan 85% lebih besar dalam konteks yang sama. Di samping itu, apabila mengkaji radiasi VHF yang dikaitkan dengan positif dan negatif NBE berkaitan dengan permulaan medan elektrik yang cepat, positif NBE menunjukkan 62% lebih besar berbanding SLPs manakala negatif NBEs menunjukkan peningkatan 88% yang menakjubkan. Keputusan ini menunjukkan bahawa kelajuan longsoran elektron dan penjurus bagi kedua-dua jenis NBE adalah lebih pantas berbanding dengan kelajuan longsoran elektron konvensional dan penjurus SLP. Selain itu, pemetaan interferometer VHF mendedahkan bahawa sumber gelombang VHF untuk NBE positif dan negatif bergerak secara dua arah dengan kelajuan mencapai $10^8$ $ms^{-1}$. Selepas membandingkan prestasi penghantaran data 4G LTE dalam cuaca cerah dan ribut petir, kesan minimum diperhatikan semasa cuaca cerah. Walau bagaimanapun, gangguan telah dilaporkan semasa tiga ribut petir yang menjejaskan sama ada nod pelanggan atau pelayan. Tambahan pula, -CG dan awan intra (IC) dikenal pasti sebagai faktor utama yang mengganggu penghantaran data.*

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| | | |
|---|---|---|
| 4G LTE | - | The Fourth Generation Long Term Evolution |
| BER | - | Bit error rate |
| BLR | - | Bit loss rate |
| BNC | - | Bayonet Neill–Concelman |
| BPF | - | Bandpass filter |
| CAPPI | - | Constant Altitude Plan Position Indicator |
| CID | - | Compact intra-cloud discharge |
| CG | - | Cloud-to-ground |
| CLD | - | Cumulative loss datagram |
| CPT | - | Chaotic pulse train |
| CST | - | Computer Simulation Technology |
| dB/dt | - | Time derivative magnetic field |
| dE/dt | - | Time derivative electric field |
| EFM | - | Electric field mill |
| ET | - | End time |
| FA | - | Fast electric field antenna |
| FR4 | - | Flame Retardant 4 |
| FNB | - | Fast negative breakdown |
| FPB | - | Fast positive breakdown |
| FSK | - | Frequency shift-keying |
| FW | - | Fair-weather |
| GPS | - | Global positioning system |
| IB | - | Initial breakdown |

| | | |
|---|---|---|
| IC | - | Intra-cloud |
| IEEE | - | Institute of Electrical and Electronics Engineers |
| Iperf3 | - | Internet Performance Working Group Version 3 |
| LOS | - | Loss of sight |
| LNA | - | Low noise amplifier |
| MCMC | - | Malaysian Communications and Multimedia Commission |
| MDF | - | Magnetic direction finder |
| MFB | - | Mixed fast breakdown |
| MMD | - | Malaysia Meteorological Department |
| NBE | - | Narrow Bipolar Event |
| OT | - | Onset time |
| PBP | - | Preliminary breakdown process |
| PC | - | Personal computer |
| PCB | - | Printed circuit board |
| PD | - | Pulse duration |
| PER | - | Packet error rate |
| PMR | - | Private mobile radio |
| PPS | - | Pulse per second |
| QP | - | Quiet period |
| RT | - | Rise time |
| RS | - | Return stroke |
| RSSI | - | Received signal strength indicator |
| SA | - | Slow electric field antenna |
| SINR | - | Signal-to-Interference-Noise Ratio |
| SLP | - | Stepped leader pulse |
| SRS | - | Subsequent return stroke |
| ST | - | Station |
| TD | - | Total duration |
| TPD | - | Total pulse duration |

UDP - User datagram protocol

UHF - Ultra high frequency

USB - Universal serial bus

VHF - Very high frequency

VNA - Vector network analyzer

Wi-Fi - Wireless fidelity

ZCT - Zero-crossing time

+CG - Positive cloud-to-ground

+NBE - Positive narrow bipolar event

-CG - Negative cloud-to-ground

-NBE - Negative narrow bipolar event

## LIST OF PUBLICATIONS

Baharin, S.A.S., Ahmad, M.R., Sabri, M.H.M. and Cooray, V., 2024. Very high frequency radiation emitted by negative narrow bipolar events occurred over Malacca strait. *Journal of Atmospheric and Solar-Terrestrial Physics*, 259, p.106252. (Q3 WoS SCOPUS).

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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

This chapter serves as an introduction to the research work in this thesis, focusing on the lightning initiation process with microwave and very high frequency (VHF) radiation emitted by lightning. Subsequently, the objectives are formulated to address the identified problem statement in this study. Specific scopes exclusive to this study are outlined to maintain focus and relevance. The contributions of this research are delineated for clarity in reading. Finally, a detailed explanation of the overall structure and configuration of this thesis is provided to enhance understanding.

## 1.2 Research background

Lightning stands out as one of the captivating natural phenomena on Earth, occurring in our daily lives regardless of during daylight or the rainy season. The fleeting burst of light visible is known as a flash, often accompanied by the subsequent booming sound of thunder. Notably, depending on the observer's location, the sound of thunder may be heard either simultaneously with the lightning strike or after a perceptible delay. The interdisciplinary nature of lightning has left numerous aspects of this phenomenon unknown and ripe for exploration. Lightning is an electrical discharge that occurs in the atmosphere, emitting electromagnetic fields, x-rays, gamma rays, and optical radiation. A lightning flash is composed of several processes within typical durations ranging from 0.5 to 1 second.

The process that initiated lightning flashes is called the electrical breakdown process and begins with electron avalanches peaked at microwave radiation band on a millimeter scale. Subsequently, the fusion of multiple electron avalanches leads to the formation of streamers, believed to operate at VHF radiation on a centimeter scale. As these streamers grow, they develop into leaders on a meter scale, becoming visible as intense and bright light. A recent discovery has unveiled a new type of breakdown process known as fast breakdown. This process differs significantly from conventional breakdown, primarily in the absence of a hot conducting leader channel and the occurrence of higher propagation velocities. Notably, fast breakdown has been identified in association with the high power of a particular type of cloud flash referred to as a narrow bipolar event (NBE) (Cooray, 2015; Rison et al., 2016; Tilles et al., 2019; Huang et al., 2021).

The radiation component from lightning flashes is measured utilizing a fast electric field antenna (FA), which plays a crucial role in determining the type of lightning flashes. The sensor operates within a frequency range spanning from several hertz up to 10 MHz, with a decay time constant of 13 ms. Radio sensors, with specifications between 50 to 70 MHz and 800 to 1050 MHz, are deployed to measure VHF and microwave radiation, respectively. A VHF interferometer with a two 5 m perpendicular baseline has also been constructed to observe the direction of propagation of VHF radiation sources. This setup allows for the measurement of propagation velocities and the altitude of the recorded NBEs. Additionally, a measurement campaign has been planned and conducted to observe the effects of lightning interference on Fourth Generation Long Term Evolution (4G LTE) mobile communication links. This is particularly relevant as 4G LTE data transmission predominantly operates in the microwave band and above.