Faculty of Electronics and Computer Engineering

LIGHTNING CHARACTERIZATION AND MAPPING USING MICROWAVE INTERFEROMETER SYSTEM

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in fulfillment of the requirements for the degree of
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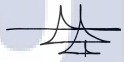
DECLARATION

I declare that this thesis entitled "Lightning Characterization and Mapping using Microwave Interferometer System" 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 : ……  ……

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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 Doctor of Philosophy.

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Supervisor Name : Professor Dr. Badrul Hisham Bin Ahmad

Date : ……25/9/2021……

DEDICATION

First and foremost, Alhamdulillah Almighty for all the blessings of health, wisdom and patience to overcome all the difficulties that I faced in my PhD journey.

I would like to dedicate these years of hard work and absence to the spirits of my mother Sahar Saadi, my sisters Raghda and Ayat, and for my fabulous father Raad Khaleel Al-Shaikhli for all his help, supporting and praying to complete my study.

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ABSTRACT

A lightning flash starts with the very first process called electron avalanche followed by streamer and leader. A leader is suggested to radiate intense electromagnetic fields below medium frequency (MF) bands while streamers are suggested to radiate intense very high frequency (VHF) electromagnetic fields. On the other hand, simulation results suggested that electron avalanches radiate strong microwave electromagnetic fields at around 1 GHz. In this thesis, a microwave interferometer system has been developed, fabricated, and deployed with the aim to evaluate the temporal and spatial (2D mapping) characteristics of electron avalanches development during narrow bipolar event (NBE) discharges. So far, nothing has been published about microwave interferometer system with the purpose to map lightning microwave radiation. As the streamer is preceded by electron avalanches, detecting microwave radiation before the onset of VHF radiation could be used as a method to prove that electron avalanches radiate strong microwave radiation. In order to establish a microwave interferometer system, three finite-length capacitive antennas with resonance frequency around 1 GHz, low noise amplifier (LNA) operating between 0.9 and 1.2 GHz, bandpass filter (BPF) operating between 0.95 and 1.05 GHz have been designed and fabricated. Microwave radiations associated with 98 NBEs have been recorded and analysed. Out of 98 NBEs, only 18 high amplitude and low noise NBEs were selected with 17 +NBEs and one -NBE. About 11 from 18 microwave radiations have been detected earlier than VHF and NBEs onset time with average lead time of 211.55±82.49 ns. This is a strong indication of electron avalanches detected around 200 ns before the streamer formation. Moreover, clear bipolar pulses with duration less than 50 μs have been observed during the initial stage (IS) of the main burst. It can be suggested that electron avalanches process behave impulsively before the propagating streamers formed. Furthermore, three NBEs with associated microwave radiations have been mapped where the azimuth and elevation angles can be determined. The maps proved that all three NBEs were the result of fast positive breakdown where the electron avalanches (microwave) propagated upward while the positive streamers propagated downward.

PENCIRIAN DAN PEMETAAN KILAT MENGGUNAKAN SISTEM INTERFEROMETER GELOMBANG MIKRO

ABSTRAK

Sebuah kilat bermula dengan proses pertama yang dikenali sebagai longsoran elektron diikuti oleh pengalir dan pemimpin. Pemimpin memancarkan medan elektromagnetik yang kuat di bawah jalur frekuensi sederhana (MF) sementara pengalir memancarkan medan elektromagnetik frekuensi sangat tinggi (VHF). Sebaliknya, hasil simulasi menunjukkan bahawa longsoran elektron memancarkan medan elektromagnetik gelombang mikro yang kuat pada sekitar 1 GHz. Dalam tesis ini, sistem interferometer gelombang mikro telah dikembangkan, dibuat, dan digunakan dengan tujuan untuk menilai ciri-ciri masa dan ruang (pemetaan 2D) pengembangan longsoran elektron semasa pelepasan kejadian dwipolar sempit (NBE). Sejauh ini, belum ada yang diterbitkan mengenai sistem interferometer gelombang mikro dengan tujuan untuk memetakan sinaran gelombang mikro kilat. Oleh kerana pengalir didahului oleh longsoran elektron, mengesan radiasi gelombang mikro sebelum bermulanya radiasi VHF dapat digunakan sebagai kaedah untuk membuktikan bahawa longsoran elektron memancarkan radiasi gelombang mikro yang kuat. Bagi mewujudkan sistem interferometer gelombang mikro, tiga antena kapasitif dengan frekuensi resonans sekitar 1 GHz, penguat kebisingan rendah (LNA) yang beroperasi antara 0.9 dan 1.2 GHz, penapis jalur lebar (BPF) yang beroperasi antara 0.95 dan 1.05 GHz telah dirancang dan dibuat. Sinaran gelombang mikro yang berkaitan dengan 98 NBE telah direkodkan dan dianalisis. Daripada 98 NBE, hanya 18 NBE dengan amplitud tinggi dan kebisingan rendah yang dipilih dengan 17 +NBE dan satu -NBE. Kira-kira 11 dari 18 radiasi gelombang mikro telah dikesan lebih awal daripada masa permulaan VHF dan NBE dengan purata masa petunjuk 211.55±82.49 ns. Ini adalah petunjuk kuat berkaitan longsoran elektron yang dikesan sekitar 200 ns sebelum pembentukan pengalir. Lebih-lebih lagi, denyutan dwipolar yang jelas dengan jangka masa kurang dari 50 µs telah diperhatikan semasa peringkat awal (IS) radiasi gelombang mikro utama. Hal ini dapat menunjukkan bahawa proses longsoran elektron berkelakuan impulsif sebelum penyebaran pengalir terbentuk. Selanjutnya, tiga NBE dengan radiasi gelombang mikro yang berkaitan telah dipetakan di mana sudut azimut dan ketinggian dapat ditentukan. Peta membuktikan bahawa ketiga-tiga NBE adalah hasil pemecahan positif yang cepat di mana longsoran elektron (gelombang mikro) merambat ke atas sementara pengalir positif bergerak ke bawah.

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ADS	-	Advanced Design System
BNC	-	Bayonet Neill–Concelman
BPF	-	Band Pass 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
DP	-	Damping Phase
FA	-	Fast electric field Antenna
FB	-	Fast Breakdown
FNB	-	Fast Negative Breakdown
FPB	-	Fast Positive Breakdown
FR4	-	Flame Retardant 4
IB	-	Initial Breakdown
IC	-	Intra-Cloud
IS	-	Initial Stage
LD	-	Lightning Detector
LF	-	Low Frequency
LMA	-	Lightning Mapping Array
LNA	-	Low Noise Amplifier

MDF	-	Magnetic Direction Finder
MMD	-	Malaysia Meteorological Department
NBE	-	Narrow Bipolar Event
PCB	-	Printed Circuit Board
PD	-	Pulse Duration
PTD	-	Pulse Train Duration
RT	-	Rise Time
RP	-	Raising Phase
SMA	-	Sub Miniature version A
TOA	-	Time of Arrival
TPTD	-	Total Pulse Train Duration
UHF	-	Ultra High Frequency
VHF	-	Very High Frequency
VLF	-	Very Low 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