

**WAVELET ANALYSIS OF THE ONSET OF VHF AND
MICROWAVE RADIATION EMITTED BY LIGHTNING**

SHAMSUL AMMAR BIN SHAMSUL BAHARIN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**WAVELET ANALYSIS OF THE ONSET OF VHF AND
MICROWAVE RADIATION EMITTED BY LIGHTNING**

SHAMSUL AMMAR BIN SHAMSUL BAHARIN

**This report is submitted in partial fulfilment of the requirements
for the degree of Bachelor of Electronic Engineering with Honours**

**Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka**

2018

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Wavelet Analysis of the Onset of VHF and
Microwave Radiation Emitted by Lightning
Sesi Pengajian : 2017/2018

Saya SHAMSUL AMMAR BIN SHAMSUL BAHARIN mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

SULIT*

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD*

(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan.)

TIDAK TERHAD

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: Lot 8696, Sg. Lui
2, 27600 Raub
Pahang.

Tarikh : 25 May 2018

Tarikh : 25 May 2018

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this report entitled “Wavelet Analysis of the Onset of VHF and Microwave Radiation Emitted by Lightning” is the result of my own work except for quotes as cited in the references.

Signature :

Author :

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 Bachelor of Electronic Engineering with Honours.

Signature :

Supervisor Name :

Date :

DEDICATION

Dedicated to my beloved families that love and support me unconditionally; to my supervisor that guides me regardless; to all my teammates and friends that stay beside me and most especially to Allah SWT The Almighty and Most Merciful.

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. Electrical breakdown process is an important event that initiates lightning. For electrical breakdown process to occur, it must fulfill two conditions which are at least has one free electron and the electric field region is more than 3 MV/m. This process starts with electron avalanche in millimeter scale then grows into streamer in centimeter scale. Lastly, from streamer it will grow into leader in meter scale. It has already established that streamer emits intensely at Very High Frequency (VHF) band as it's already proven both theoretically and experimentally. A study by Cooray and Cooray (2012) theoretically proved that emission of electron avalanche peaks at microwave band. Air-gap parallel plate antenna which could operate at 1 GHz with remote sensing is designed and simulated to measure the microwave radiation emitted by lightning. Both temporal and wavelet analyses are used to compare the onset of microwave radiation and VHF radiation in both time and frequency domains to determine electron avalanche appears at which electromagnetic band.

ABSTRAK

Kilatan petir adalah pelepasan elektrik di udara (pecahan dielektrik) yang memancarkan medan elektromagnetik (EM) di seluruh spektrum yang sangat luas dari beberapa Hertz hingga panjang gelombang yang boleh dilihat. Proses pemecahan elektrik adalah peristiwa paling penting yang memulakan kilat. Untuk proses pemecahan elektrik berlaku, ia mesti memenuhi dua syarat iaitu sekurang-kurangnya mempunyai satu elektron bebas dan rantau medan elektrik melebihi 3 MV/m. Proses ini bermula dengan runtuh elektron dalam skala milimeter kemudian berkembang menjadi pelapis dalam skala sentimeter. Akhir sekali, dari pelapis ia akan berkembang menjadi pemimpin dalam skala meter. Ia telah menegaskan bahawa pelapis melepaskannya dengan kuat pada band VHF kerana ia telah terbukti secara teoritis dan eksperimen. Penyelidikan oleh Cooray dan Cooray (2012) secara teorinya membuktikan bahawa puncak gelombang runtuh elektron ialah di gelombang mikro. Antena plat selari udara yang boleh beroperasi pada 1 GHz dengan penginderaan jauh direka dan disimulasi untuk mengukur radiasi gelombang mikro yang dipancarkan oleh kilat. Kedua-dua analisis temporal dan wavelet digunakan untuk membandingkan permulaan sinaran gelombang mikro dan radiasi VHF dalam domain masa dan kekerapan untuk menentukan longkang runtuh elektron muncul di jalur elektromagnet yang mana.

ACKNOWLEDGEMENTS

All Praises to Allah, Lord of the universe. Blessings and greeting to Prophet Muhammad SAW, his entire family, his companions and the descendants of his descendants.

First and foremost, I would like to offer my highest appreciation to my supervisor, Dr. Mohd Riduan bin Ahmad for his fathomless and irreplaceable guidance. Your supervision and endless support truly guides me on progression and smoothness of my work until I succeed to complete this project. Your kindness and leadership will always be remembered closely to my heart all the time. Not to forget your willingness to spend your precious time and energy to help guide me every time I need your acquaintance.

I would like to thank my parents, Shamsul Baharin and Hanaiti for their support they have given to me along the way of finishing this project. Besides them, I would like to spare my gratitude for my brother, Arifie with his wife, Sabaria and my sister, Umi for always giving tremendous support until I finally made to complete this project.

I would wish to get hold of this chance to offer my deepest gratitude to our PSM program course coordinator, Dr. Hazli Rafis bin Abdul Rahim for his inestimable and invaluable direction. Thanks so much for holding time from your busy schedule to contribute an introduction about this PSM program and provided the sources of the modules or forms. The co-operation is much indeed appreciated. Also, not to forget thanks to all the BBNET lab members for all the guidance and cooperation provided and for such valuable experience.

Thank you, Assalamualaikum.

TABLE OF CONTENTS

Declaration	
Approval	
Dedication	
Abstract	i
Abstrak	ii
Acknowledgements	iii
Table of Contents	v
List of Figures	ix
List of Tables	xi
List of Symbols and Abbreviations	xiii
CHAPTER 1 INTRODUCTION	1
1.1 Background	1

1.2	Problem statement	2
1.3	Objectives	3
1.4	Scope of work	4
1.5	Thesis structure	5
CHAPTER 2 LITERATURE REVIEW		7
2.1	What is lightning?	7
2.2	Types of lightning	8
2.3	Charge Structure	8
2.3.1	Tripole and Dipole	8
2.4	Electrical Breakdown Process	12
2.4.1	Introduction	12
2.4.2	Electron Avalanches	12
2.4.3	Streamers	13
2.4.4	Leaders	17
2.4.5	Emitted E and B fields (Why we want to analyze the onset between VHF and UHF)	20
2.5	Electromagnetic Fields Emitted by Lightning Flashes	21
2.6	Electromagnetic Fields Measurements	22
2.7	Microwave emission by Lightning Flash	25
CHAPTER 3 METHODOLOGY		27

3.1	Introduction	27
3.2	Antenna design using CST Software	28
3.3	Lab experiment (High Voltage Lab)	33
CHAPTER 4 RESULTS AND DISCUSSION		35
4.1	Introduction	35
4.2	Performance analysis of air-gap parallel-plate antenna	36
	4.2.1 Return loss and radiation pattern evaluation	36
4.3	Temporal analysis	38
	4.3.1 Measured electric field waveforms	38
	4.3.2 Actual onset time considering cable delay factor	40
	4.3.3 Analysis of microwave, VHF & HF onset time relative to the onset time of FF for temporal method	42
4.4	Wavelet Analysis	46
	4.4.1 Measured normalized power spectrum contour	46
	4.4.2 Actual onset time considering offset time and cable delay factor	49
	4.4.3 Analysis of microwave, VHF & HF onset time relative to the onset time of FF for wavelet method	54
4.5	Discussion	58
CHAPTER 5 CONCLUSION AND FUTURE WORKS		60
5.1	Conclusion	60

5.2 Future work

62

REFERENCES

64

LIST OF FIGURES

Figure 2.1: Types of clouds in dipole charge [2]	9
Figure 2.2: Visual diagram of tripole charge [2]	10
Figure 2.3: Graupel ionization [2]	11
Figure 2.4: Mechanism of positive streamers [2]	15
Figure 2.5: Mechanism of negative streamer [2]	17
Figure 2.6: Mechanism of positive leaders [2]	19
Figure 2.7: Principle of vertical antenna [2]	23
Figure 2.8: Direction of B Field at the point of lightning strike (Adopted from [2])	24
Figure 3.1: Diagram of methods used	27
Figure 3.2: Choose antenna application	28
Figure 3.3: Select a workflow for the template	29
Figure 3.4: Choosing solvers for the selected workflow	29
Figure 3.5: Standard units for the template	30
Figure 3.6: Determine range of frequency to define the e-field	30
Figure 3.7: Summary of the template	31

Figure 3.8: Top view of the air-gap parallel plate antenna	32
Figure 3.9: Side view of the air-gap parallel plate antenna	32
Figure 3.10: Visual diagram of high voltage lab experiment	33
Figure 4.1: The return loss evaluated for the air-gap parallel plate antenna operating at 1 GHz with bandwidth measured at 40 MHz	36
Figure 4.2: Radiation pattern of the air-gap parallel plate antenna	37
Figure 4.3: Fast field electric field waveform	38
Figure 4.4: High frequency electric field waveform	38
Figure 4.5: Very high frequency electric field waveform	39
Figure 4.6: Microwave electric field waveform	39
Figure 4.7: Line graph of delta onset time for Microwave, VHF and HF electric field waveforms correspond to onset time of FF electric field waveform	44
Figure 4.8: Box and whisker graph for delta onset time for microwave, VHF and HF electric field waveforms correspond to onset time of FF electric field waveform	45
Figure 4.9: Normalized power spectrum of FF electric field waveform	46
Figure 4.10: Normalized power spectrum of HF electric field waveform	46
Figure 4.11: Normalized power spectrum of VHF electric field waveform	47
Figure 4.12: Normalized power spectrum of microwave electric field waveform	47
Figure 4.13: Line graph of onset time from Table 4.14	56
Figure 4.14: Average Difference Onset Time of microwave, VHF, HF with the Onset of FF	57

LIST OF TABLES

Table 3.1: Specifications of the Antenna	31
Table 4.1: Onset time of electric field waveform for FF and HF	40
Table 4.2: Onset time of electric field waveform for VHF and microwave	40
Table 4.3: Actual onset time of electric field waveforms for VHF and microwave	41
Table 4.4: Delta (time difference) of microwave, VHF and HF in second scale	42
Table 4.5: Parameters calculated using Microsoft Excel to plot line graph and Box & Whisker	43
Table 4.6: Starting time FF and HF	49
Table 4.7: Starting time VHF & Microwave	49
Table 4.8: No. of points on contour for FF and HF	50
Table 4.9: No. of points on contour for VHF and microwave	50
Table 4.10: Offset time for FF and HF	51
Table 4.11: Offset time for VHF and microwave	51
Table 4.12: Exact onset time for FF and HF	53
Table 4.13: Exact onset time for VHF and Microwave	53
Table 4.14: Delta (Time difference) of microwave, VHF and HF in Second	54

Table 4.15: Parameters Calculated Using Microsoft Excel

55

LIST OF SYMBOLS AND ABBREVIATIONS

CC	:	Cloud to cloud
CG	:	Cloud to ground
CF	:	Cloud flash
IC	:	Intra cloud
NBE	:	Narrow bipolar event
FF	:	Fast field
HF	:	High frequency
VHF	:	Very high frequency
MW	:	Microwave
LNA	:	Low noise amplifier
CST	:	Computer simulation technology
UTM	:	University Technology Malaysia
UTeM	:	University Technical Malaysia Malacca
E field	:	Electric field
B field	:	Magnetic field

- STEPS : Severe storm Electrification and Precipitation Study
- UHF : Ultra-high frequency
- h : Height
- R : Resistor
- C : Capacitor
- RF : Radio frequency

CHAPTER 1

INTRODUCTION

1.1 Background

A sudden electrostatic discharge that caused by imbalances between clouds and the ground or within the clouds themselves can cause lightning. Basically, lightning flashes could be divided into 3 types based on the movement and direction of electrical charges namely positive cloud-to-ground flash (+CG), negative cloud-to-ground flash (-CG) and Cloud Flash (CF). For CF, it can be divided further into 2 subtypes: narrow bipolar event (NBE) flash and intra-cloud (IC) flash.

Electrical breakdown process that initiates lightning consists of three stages. It starts with electron avalanche which operates at microwave radiation band in millimeter scale. Next, fusion of many electron avalanches grow into streamers which we believe operates at Very High Frequency (VHF) radiation in centimeter

scale. After that, streamers grow and develop to become leaders in meter scale which at this state, we could observe it with our naked eyes.

Wavelet technique is used to compare the onset of microwave radiation and VHF radiation in both time and frequency domains to get precise and accurate results. Comparison is made to determine which frequency band the electron avalanches appear. Besides, comparison also could be done between wavelet and temporal analysis to see if the results matched for more accuracy. All the data is obtained from the setup of antenna, bandpass filter, Low Noise Amplifier (LNA) and buffer circuit in high voltage lab which we generate spark that mimic the natural lightning flash.

1.2 Problem statement

There are still many undefined and unproven theories about lightning and research is still on going. It is very important to fully understand mechanism of lightning so that we can be prepared from any destruction caused by lightning. As we know, taller buildings usually have chances of being attacked by this very high voltage of electricity coming from the cloud and some case, same building can be attacked by lightning as many as 54 times in 84 minutes like Toronto CN Tower [1].

Electrical breakdown process is the main mechanism that initiates lightning. This process starts with electron avalanche, streamer then leader. For this process to occur, it must meet two requirements which are must at least have one free electron and the electric field region is more than 3 MV per meter. Electron avalanche starts with one free electron then collide with another electron and grows in millimeter scale. Then, electron avalanche grows into streamer in centimeter scale. Streamer

then grows into leader in meter scale. Leader is the lightning that we could observe with our naked eyes.

Streamer is already theoretically and experimentally proven happens at VHF band while electron avalanche only theoretically proven happens at microwave band. The problem of this project is driven by two school of taught which are;

- i. Electron avalanche and streamer emitted intensely in VHF band
- ii. Electron intensely emits in microwave band alone

So, the main research question is: Is it true electron avalanche emitted simultaneously with streamer or at microwave radiation only?

1.3 Objectives

The objectives of this thesis are:

- To design and simulate a parallel plate antenna that could work with a microwave sensor which consists of LNA and bandpass filter that suitable for sensing application with center frequency 1 GHz antenna.
- Next, to capture lightning electric field radiation component at 1 GHz and 60 MHz.
- Lastly, to analyze and made comparison between the onset of microwave and VHF radiation waveform in both time and frequency domains.

1.4 Scope of work

The research scopes consist of three main parts. The first part focuses on designing and simulating a parallel plate antenna that could work with a microwave sensor which consists of LNA and bandpass filter that suitable for sensing application with center frequency 1 GHz antenna. The process of designing and simulation will be using Computer Simulation Technology (CST) software and format. Performance of the antenna will be observed based on the frequency, bandwidth, radiation pattern and return loss of the antenna. All these four antenna parameters must meet the specification of the 1 GHz antenna requirements so that it will function at maximum performance.

The second scope involves the comparison of the onset of VHF and microwave radiation that emitted by the lightning using wavelet and temporal method. Comparison of the onsets in both time and frequency domains could determine which school of thought is true and proved. But early hypothesis is already come out which I believe that electron avalanches and streamers radiate separately. Electron avalanche intensely operates at microwave radiation while streamer radiates at VHF radiation. To be exact, this hypothesis is already theoretically proven but not experimentally. That's the reason why I make comparison between the two onsets.

The third scope is to identify which frequency band the electron avalanche appears based on the onset of the VHF and microwave radiation. Method used to analyze all the data are temporal and wavelet analysis. All the data is collected from the experiment conducted in the high voltage lab at UTM Skudai. The purpose to use