Wavelet Analysis of the Onset of VHF and Microwave Radiation Emitted by Lightning

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***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, 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.**

Keywords*— *electron avalanche, lightning, microwave, VHF, wavelet

I. INTRODUCTION

Electrical breakdown process is the main mechanism that initiates lightning [2]. 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 [3-7]. The problem of this paper is driven by two school of taught which are electron avalanche and streamer emitted intensely in VHF band or electron avalanche intensely emits in microwave band alone. So, the main research question is it true electron avalanche emitted simultaneously with streamer or at microwave radiation only? In this paper, 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.

II. METHODOLOGY

A. Introduction

Three parts of methods used for this paper are simulation, experimental method and analysis method. The visual diagram of methods used is as follow;

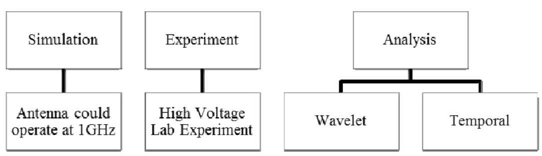

Fig. 1: Diagram of method used

B. *Antenna design*

The air-gap parallel plate antenna is designed using CST software. The parameters of the air-gap parallel plate antenna are as follows:

TABLE I. SPECIFICATIONS OF ANTENNA

Parameters	Value
Width	500 mm
Length	500 mm
Patch W	286 mm
Patch L	286 mm
Air Gap D	16 mm
Copper thickness	0.035 mm
Dielectric constant	1.0 F/m

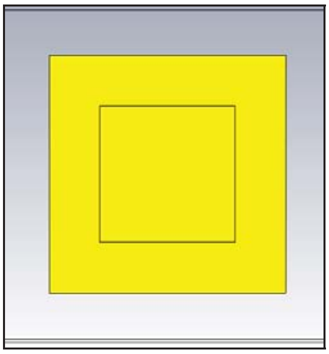

Fig. 2: Top view of the air-gap parallel plate antenna

Fig. 3: Side view of the air-gap parallel plate antenna

C. *Lab experiment (High Voltage Lab)*

1. The lab set up for the experiment is as follows:

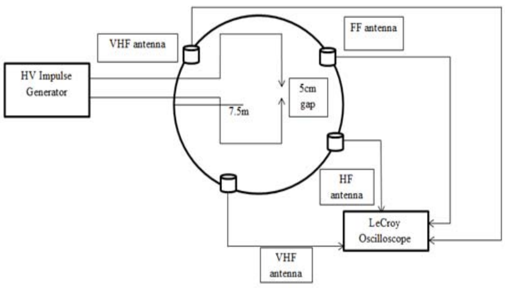

Fig. 4: Visual diagram of high voltage lab experiment

2. As the experiment is conducted in a special lab which gave out very high voltage power, safety and precaution must be taken before carry out the experiment.
3. To measure lighting radiation in lab experiment, the input source is not from the natural lightning but from high voltage impulse generator which could mimic the real lightning.
4. The high voltage impulse generator could produce spark which mimic lightning flashes. It coming from the 5 cm metal gap connected to the high voltage impulse generator.
5. Then, four antennae which are FF antenna, HF antenna, VHF antenna and microwave antenna are placed around the metal gap within the same radius from the spark source. Metal gap is the source as it is connected to the high voltage generator and will produce the spark.
6. All the antennas must be placed 7.5 cm from the source and the distance must be ensured the same so that the electric field waveforms produced by the spark will arrive on the antennas at the same time.
7. Then, all the antennas are connected to the LeCroy Wavesurfer 2054 oscilloscope using cable wires. The length of cable wires used for FF and VHF are 10 m while length of cable wires used for HF and microwave are 1 m and 5 m respectively.
8. Next, the cable wires for FF, HF, VHF and microwave are connected at channel A, B, C and D respectively.

III. RESULTS AND ANALYSIS

A. *Antenna performance*

The air-gap parallel plate antenna has been evaluated and simulated by using CST software. Based on the results from S (1,1) or return loss, we could analyze the air-gap parallel plate antenna parameters which are the reflection coefficient, radiation pattern, bandwidth and resonant frequency. The marker plotted at -10 dB as reference to show that 90% of the energy from input is transferred to the radio component and only 10% of them are reflected.

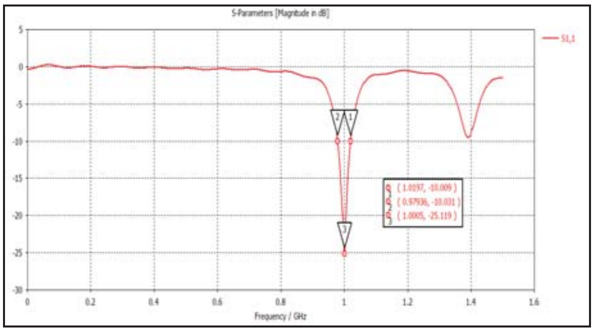

Fig. 5: The return loss evaluated for the air-gap parallel plate antenna operating at 1 GHz with bandwidth measured at 40 MHz

To ensure the antenna could work properly, it need to have at least -10 dB gain and below. For this antenna, it peaks at -25 dB which refers that the power reflected back is low. The air-gap parallel plate antenna resonates at 1.0 GHz and it satisfies the requirement to measure microwave radiation from lightning at 1.0 GHz. Bandwidth of this air-gap parallel plate antenna at the resonant frequency shown at the S(1,1) is 40 MHz.

B. Temporal analysis

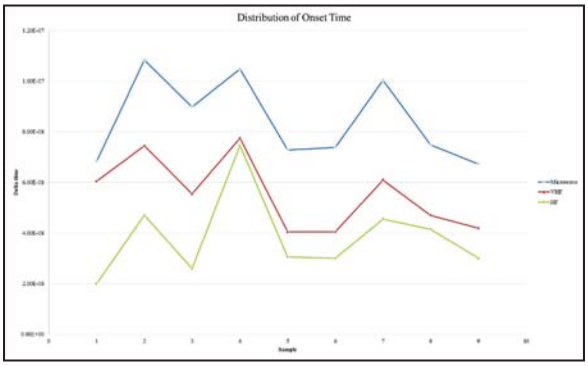

Fig. 6: Line graph of delta onset time for Microwave, VHF and HF electric field waveforms correspond to onset time of FF electric field waveform

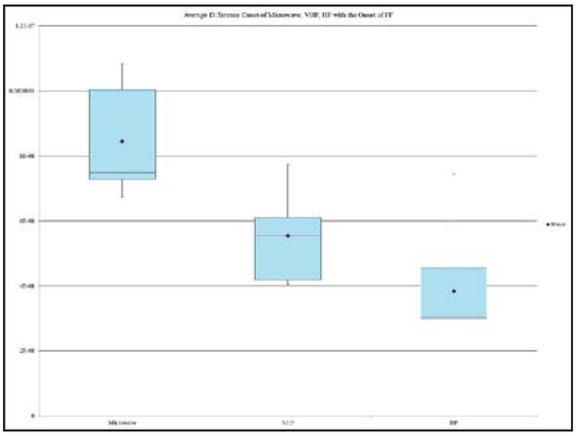

Fig. 7: Box and whisker graph for delta onset time for microwave, VHF and HF electric field waveforms correspond to onset time of FF electric field waveform

C. Wavelet analysis

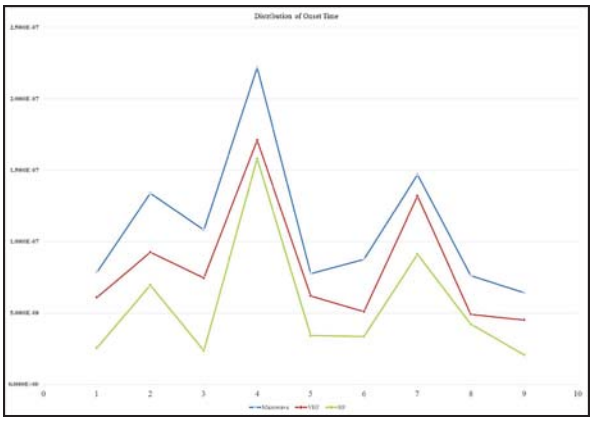

Fig. 8: Line graph of delta onset time for Microwave, VHF and HF electric field waveforms correspond to onset time of FF electric field waveform

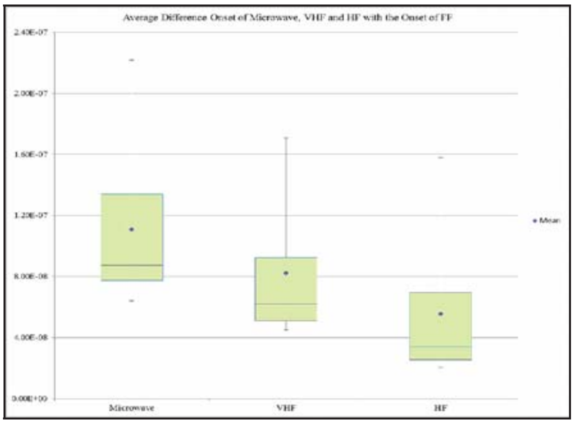

Fig. 9: Box and whisker graph for delta onset time for microwave, VHF and HF electric field waveforms correspond to onset time of FF electric field waveform

IV. Discussion

After analyzing performance of the air-gap parallel plate antenna, more than 90% of the energy from the input is transferred to the radio component and less than 10% of them are reflected back. The resonant frequency peaked at -25 dB return loss shown by S (1,1) parameter indicating a good performance of antenna. The air-gap parallel plate antenna resonant frequency is 1.0 GHz and it satisfied my requirement to measure microwave radiation from lightning at 1.0 GHz. Bandwidth of the resonant frequency at 1 GHz of the air-gap parallel plate antenna is 40 MHz.

Although the air-gap parallel plate antenna meet the requirements to operate at 1 GHz, the dimension of ground and patch which are 50 cm × 50 cm and 28.4 cm × 28.4 cm respectively are quite big and not practical for commercial use. In the future work, the air-gap parallel plate antenna requires upgrade and modification to make it compactable and transportable. It is better for the air-gap parallel plate to be powerful but easy to carry around to measure lightning radiation anytime and anywhere.

Besides the size, bandwidth of the air-gap parallel plate antenna which is 40 MHz also demands enhancement as to carry more data and information from the input signal. One of the techniques that can be used to improve the antenna parameter is by using parametric study. For purpose of measurement radiation emitted by lightning, the radiation pattern of the antenna must be in omnidirectional. This is due to the lightning flash which could strike from any direction in 360°.

Based on the line graph (refer Figures 6 and 8) and boxplots (refer Figures 7 and 9) for both temporal and wavelet analysis method, we can observe the gap between microwave point and zero is the largest for all the samples. This shows that the onset time of microwave is the longest compare to onset time of VHF and HF. Comparison between the onset time of FF, VHF and microwave with zero is made because FF act as a reference and on the line graph, the reference is zero. Then, the size gap between VHF and zero is smaller than microwave but bigger than HF while the gap between HF and zero is the smallest. This shows that microwave starts earlier than VHF and HF while VHF starts earlier than HF.

The purpose of analyzing the results in two methods is to compare which give the best diagram. Line graph from wavelet analysis gives better visual compared to line graph from temporal analysis. The gap between onset time of Microwave, VHF and FF to the onset time of FF is more uniform and neat.

V. Conclusion

In the nutshell, this paper covers both temporal and wavelet analysis on the onset of microwave, VHF and HF radiation emitted by lightning. An antenna that could operate at 1 GHz for remote sensing is designed to detect microwave radiation. The onset of the three parameters corresponding to the onset of FF as it is the main reference as to which lightning that is detected is referred to. If HF, VHF and microwave electric field waveforms are detected but FF electric field waveform is not detected, the sample is not considered as lighting flash.

Comparison is made between the onset time of microwave and VHF to see which appears first to prove which school of taught is true and also to answer the research question. Based on the both temporal and wavelet analysis, it could be concluded that electron avalanche intensely emits in microwave band alone. This is due to the onset time of electric field waveform from microwave referring to zero is the longest compared to onset time of electric field waveforms from VHF and HF while onset time of electric field waveform from VHF reference to zero is shortest than onset time of microwave but bigger than onset time of HF. Onset time of electric field waveforms from HF to the point of zero is the shortest. It can be concluded that microwave starts earlier than VHF and HF while VHF starts earlier than HF but later than microwave. HF electric field waveforms start the latest and before the FF electric waveform.

Both analysis which are temporal and wavelet analysis show the same results. This is to get an accurate result so that solid conclusion could be made. So, the answer for the research question is electron avalanche emits intensely at microwave band alone followed by streamer intensely emits at VHF band and leader intensely emits at HF band.

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