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The Evaluation of Parallel Plate Antenna with Variation of Air Gaps Separation and Copper Plate Area

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Abstract
Lightning detection system uses antenna as its sensor to capture the electric fields produced by lightning flashes. In this paper, four different designs of parallel capacitive Flame Retardant 4 (FR4) antenna are simulated in Computer Simulation Technology (CST) to observe and later verified the direction of electric field is vertical at the center point of the antenna given the various distances of air gap. Three antennas have the same dimension with A3 size with gaps of 30 mm (Antenna A), 50 mm (Antenna B), and 100 mm (Antenna C) accompanied by a smaller area of antenna with 100 mm gap (Antenna D). Existing antenna used during lightning measurements has 30 mm gap between its parallel plates as it follows the common practice during the collection of electric fields. With the variation of air gaps and area, return stroke waveforms are measured using all four antennas with the same digitizer (Picoscope 4000). In this study, the amplitude and shape of the waveforms captured by all four antennas were analyzed. Cross correlation method has been used for the shape analysis. It is found that the lagging is less than 4, which means the largest air gap at 10 mm (Antennas C and D) does not change the frequency component of the return stroke waveforms. Furthermore, the amplitudes of the return strokes for 10 mm air gap (Antennas C and D) are the highest when compared to other antennas (Antennas A and B).

Keywords: *Parallel capacitive antenna, air gaps, waveform amplitudes*

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1. Introduction

During a lightning flashes occurrence, vertical electric field component is generated where it can be observed with different method such as a field mill, or a flat plate antenna [1-5]. There are several aspects that could be considered when developing the flat plate antenna which could increase the effectiveness of the reading. Based on previous studies, electric fields measurement using a metal-based capacitive antenna such as iron or aluminum where used, where then change to FR4-based material due to higher reliability, cheaper and lighter [6-8]. The introduction of different permittivity values also had been studies where it compares the initial design using air as gap between the plates of the antenna to a plastic-based gap that shows a decrease in the amplitude of captured signals [9]. Another study also suggested a variation of designs of the plate antenna where it compares various area configurations as well as stacking them in slotted manner [10]. Increment of area does give a higher amplitude reading while stacking antenna plates increase its sensitivity, but by doing so, a significant frequency shifting were present with the slotted configuration [10].

In this paper, we are motivated to design an antenna that could precede the previous studies results by observing the amplitude and shape of the waveforms captured from real lightning strikes. The parameters that we investigate in this study are the area of the antenna and the variation of air gap between the parallel plate. Cross correlation method was used to compare the shape of the waveforms of existing antenna and improved antenna design together with the amplitude of the peak waveforms, we could observe almost similar shape and a higher reading of amplitude from the waveforms of the improved antenna design.

2. Methodology

In this paper, four sets of parallel plate antenna were studied based on two parameters which are the air gaps between the parallel plate and the surface area of the antenna. The area of the antennas is set to 420 mm × 297 mm × 1.6 mm for antenna one two and three which is approximately the size of A3 paper while the fourth antenna has the dimension of 190 mm × 190 mm × 1.6 mm where we would like to study the effects of a smaller area of copper Flame Retardant 4 (FR4). The gaps of antennas are set to 30 mm, 50 mm, 100 mm and 100 mm for the smaller surface area of the antenna. For the plates, it has been decided during the previous study to use single sided FR4 material for the construction of the antennas as it is cheaper, lighter and more portable compare to steel based materials. For each construction of the antenna, two plates were used and configured to face each other with only air as its gap between the plates. The bottom plate is constructed as grounding for all of the antennas with a Bayonet Neill–Concelman (BNC) socket attached at the center of it. The core of the BNC socket is then soldered to the top plate.

The process of constructing the antenna starts with simulations in Computer Simulation Technology (CST), using components of static and low frequency solver. Using both of the components, electric field was applied between the plates, where total charges for both plates were defined. Positively charge denoted as +Q for the upper plate is set to 1 Coulomb and negatively charge denoted by –Q is set to -1 Coulomb for the lower plate.

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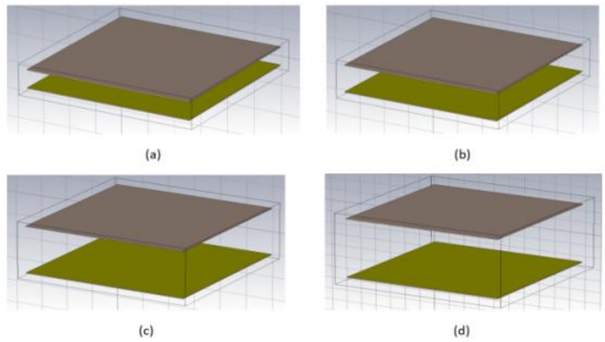

Figure 1: The gap is 30mm for Antenna A (a), 50mm for Antenna B (b), 100 mm for Antenna C (c) (all dimensions is 420 mm × 297 mm × 1.6 mm) and 100 mm for Antenna D dimensions of 190 × 190 mm × 1.6 mm (d).

Based on four configurations in figure 1, different gaps and area are simulated between the plates. After the simulation of the antennas is verified to the expected results, the next phase is to construct the antennas. Antenna is etched based on the dimensions stated above. Before the etching process, waterproofing the desired area of copper surface of the FR4 is done carefully before dipping them into the etching solution. It is crucial to make sure there are no as damage to the antenna. Any imperfection mainly caused by etching solution seeping through the waterproofing tape can affect the reading of the waveform. This is due to small edges giving out small radiation that could interrupt the reading of electric field from the lightning strike. Antennas are usually placed at an open space and on high ground with no metal structure nearby. Using the same fast field buffer circuits for each antenna, they are connected to the digitizer (Picoscope 4000), and to the computer to store the captured waveforms.

Measurement Campaign

Measure campaigns were conducted at the rooftop of faculty in Universiti Teknikal Malaysia Melaka (UTeM) to capture real data from lightning strikes. The system consists of four antennas with fast field buffer circuit connect to them passing through a digitizer (Picoscope 4000) to the main computer. Each of the antenna has different air gaps that differentiate from one another.

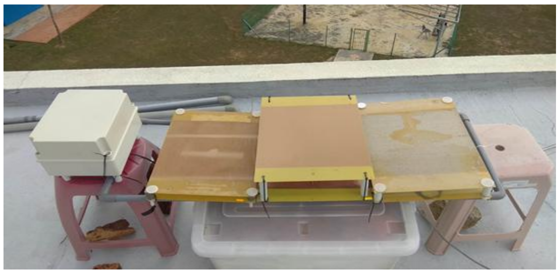

Figure 2: Constructed antennas placed on a PVC rack and stool. From the left: Antenna D with 100 mm gap with smaller area (antenna inside box), Antenna A with 30 mm gap, Antenna C with 100 mm and, Antenna B with 50 mm gap.

After characterizing the desired waveform which focused on return strokes, each waveform is analyzed based on its highest amplitude [11-20]. Figure 2 shows the setup of the antennas that were placed together on a single plastic-based shelf. Antenna A with the air gap of 30mm is the common practice used when measuring the lightning flashes where in this study, it is set as the reference antenna to compare with other antenna configurations.

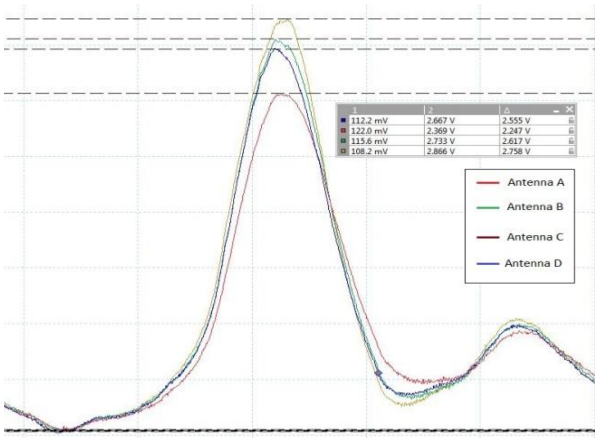

Figure 3: Captured waveform on 11 April 2019 samples no 8 at 2:02:40 p.m. From the top to bottom of the table: (1) Blue: 100 mm gap with

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smaller area, (2) Red: 30 mm gap, (3) Green: 50mm gap, and (4) Brown: 100 mm gap

Figure 3 shows one of the captured results from site measurement based on figure 2 for all of the antennas. When lightning strike, electric field is captured and digitized using the Picoscope 4000. The amplitude of the waveform denoted by volt (V), is measured by setting the lower boundary of each waveform at the initial part of the return stroke while the upper boundary is set at the peak of the return stroke. Based on this measurement, the amplitude of each antenna obtained from upper and lower boundaries of return strokes from captured waveform were tabulated and averaged to the reference antenna shown in figure 6 and 7.

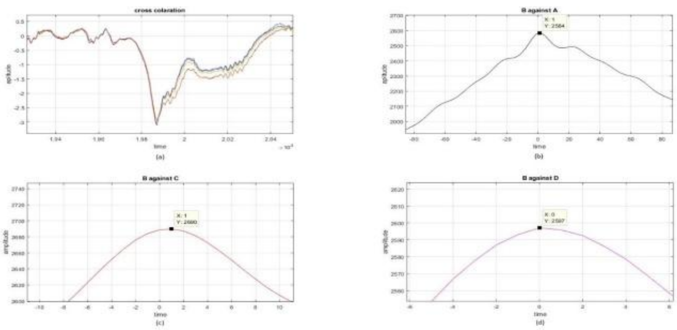

Figure 4: Using Matlab software, 4 figures were plot. (a) Normalized waveforms at the peak (b) (c) and (d) cross correlation between reference antenna result to other antennas

Based on figure 4, further analysis using cross correlation method is applied to the captured waveform. This method will help to identify if either the waveforms are the same during the time of the cross correlation at 0 [21]. If the peak of the cross correlation is the highest at 0, it means the signals matched to the reference waveform.

3. Results and Discussions

Results

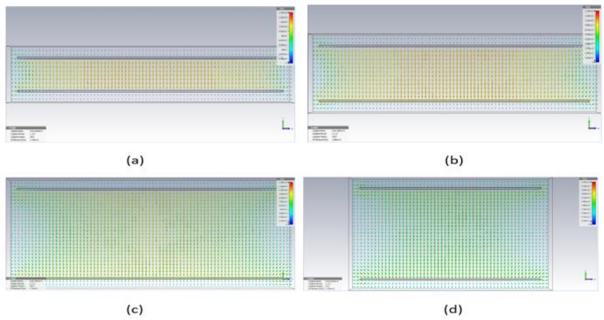

Figure 5: Direction of electric field for simulation results of parallel plate capacitive antenna with different air gaps spacing. (a) Antenna A with 30 mm air gaps (b) Antenna B with 50 mm air gaps (c) Antenna C with 100 mm air gaps (d) Antenna D with 100 mm air gaps with smaller area.

Figure 5 shows the simulation results in CST for four different configuration of antenna. Antenna (a), (b) and (c) have similar area of copper on the FR4 plates that faced each other to form a parallel plate while (d) have a smaller surface area compared to others. By observing the results, electric field directions for all antennas show little fringing effects that were present at all of the antennas. As mentioned before, the electric field reading is tapped at the center of the antenna using a BNC socket, where the direction of electric field shows a uniform vertical electric field.

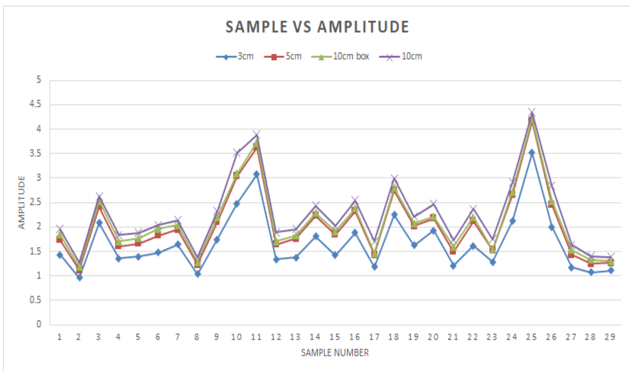

Figure 6: Amplitude of return stroke in voltage (V) which were recorded based on the sample

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number. A total of 29 return stroke samples from various date in April.

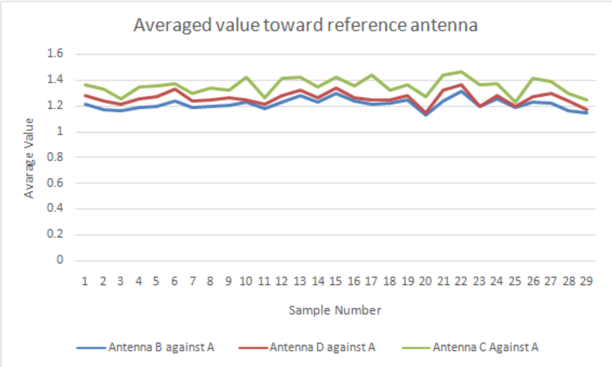

Figure 7: Amplitudes of antenna B, C and D is divided with amplitude of Antenna A to obtain average value

Figure 6 and figure 7 are collection of samples where individual return stroke were analyzed to obtain the value of the peak amplitude with unit of volt, V. The amplitude height is based on how strong or close the lightning strikes to the lightning detection system. Based on these figures, reference antenna, Antenna A with 30 mm gap shows the lowest reading of electric field in terms of amplitude followed by Antenna B, Antenna D and the highest Antenna C. In figure 7, each of the antennas is average out with the reference antenna where the mean percentage of Antenna B to Antenna A is 35.442%, Antenna D to Antenna A is 42.793% and Antenna C to Antenna A is 58.207%. Based on the calculation between amplitude of each antenna to reference antenna amplitude, Antenna C mean percentage results shows the highest difference where the air gap is set to the highest at 100mm with area of 420 mm × 297 mm × 1.6 mm.

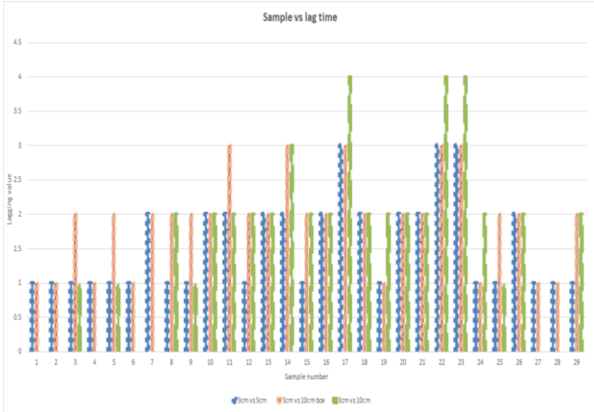

Figure 8: Cross correlation method is applied to all the selected return stroke waveform. Blue dotted line represents 50 mm air gap averaged out to reference, Brown double dash lines represents 100 mm air gap averaged to reference and green long dash lines represent 100 mm air gap averaged out to reference.

Cross correlation method is used to compare the shape of the captured waveforms to the shape of the reference antenna waveform. By doing this, it can be assured that the variation of gaps does not change the shape of the waveform thus change the frequency components of the captured signals. The aim of cross correlation method is to ensure the highest peak value is at 0, that indicates the compared waveforms is identical to each other. If the value of the highest peak situated other than at 0, the compared waveform does have leading or lagging. Figure 8 shows the results of cross correlation method for 29 selected samples in the period of the month April. Upon inspecting the results, almost all the 50 mm gap and 100 mm gap with smaller area have laggings while some of the 100 mm gap have peaks at 0. The present of lagging is undesirable but based on the samples, the highest lagging is at 4 which still is an acceptable value to consider the use of these data. The height of the amplitude does not affect the value of the lagging by comparing the results in figure 6 and figure 8. The highest peak amplitude is sample number 25 in figure 6, but the highest peak of cross correlation method is at sample number 17, 22 and 23 which has the same lagging value.

There are still rooms of improvements that could be done to further this study in the future. Among them is to increase the frequency of data collection, where we spread out the measurement of lightning strikes throughout the year for different monsoons seasons. By increasing the number of measurements, a more profound conclusion could be done to support the objective of this study. The site of measurement is also important to the understanding of the effects of gaps in this study. Optimal condition for site measurement can be listed down such as no interference near the parallel plates antenna and good conductivity for grounding. A good example is near the shore of the sea where lower noise is present for the lacking of high rise building or tall trees with good conductivity near the sea water where the antennas could capture undisrupted and clear signals.

4. Conclusion

The aim of this study is to find out either the change of air gaps between two FR4 plates in a parallel manner would affect the height of the amplitude reading during lightning strike measurements. Four configurations of parallel capacitive antennas where constructed after undergo the process of simulation, fabrication and followed by real lightning testing in the fields. 29 return stroke samples were analyzed for its amplitude height and cross correlation method analysis. Upon inspecting the results, it gave out a readable pattern where the lowest amplitude is from 30 mm gaps, followed by 50mm gaps, 100mm gaps for area of 190 mm × 190 mm × 1.6 mm, and the highest amplitude from 100 mm. This shows that the increment of the gaps gives out a higher reading of amplitude of the captured waveforms. In the meantime, higher amplitude does not give out a higher lagging value using the cross correlation method. This method of analyzing waveforms can help to compare the shape of the reference antenna to other varied antennas reading. Based on the analyzed samples, almost all of the waveforms have a lagging value with the highest value of 4. This is an acceptable value where we can still see the shape of the waveform is similar to each other. The study of incrementing air gap between parallel plates that result in the increment of amplitude height was successfully archived when the biggest air gap of 100mm shows the highest percentage amplitude reading compared to the reference amplitude reading.

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Reference

[1] Cooray V. Lightning Electromagnetics. United Kingdom: Institution of Engineering and Technology; 2012.

[2] Galvan A and Fernando M. Operative characteristics of a parallel-plate antenna to measure vertical electric fields from lightning fields from lightning flashes. Report UURIE 2000: 285-00.

[3] Sharma SR, Cooray V, Fernando M. Unique lightning activities pertinent to tropical and temperate thunderstorms. Journal of

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ISSN: 0193-4120Page No. 5663 - 5670

Atmospheric and Solar-Terrestrial Physics, 2011; 73(4):483-7.

[4] Cooray V, Lundquist S. On the characteristics of some radiation fields from lightning and their possible origin in positive ground flashes. Journal of Geophysical Research: Oceans, 1982; 87(C13):11203-14.

[5] Cooray V, Lundquist S. Characteristics of the radiation fields from lightning in Sri Lanka in the tropics. Journal of Geophysical Research: Atmospheres 1985; 90(D4):6099-109

[6] Periannan D, Mohamad SA, Ahmad MR, Esa MR, Sabri MH, Seah BY, Lu G, Yusop N, Ismail MM, Abdul-Malek Z, Cooray V. Performance Analysis of Flame Retardant 4 Copper Plate Antenna for Lightning Remote Sensing. In: IOP Conference Series: Earth and Environmental Science 228(1):012006; Jan 2019.

[7] Periannan D, Ahmad MR, Sabri MH, Esa MR, Mohammad SA, Lu G, York SB. Environmental Study of Tropical Hailstorm and its Relationship with Negative Narrow Bipolar Event and Positive Ground Flashes. EkolojiDergisi 2019; 1(107).

[8] Ahmad MR, Periannan D, Sabri MH, Aziz MZ, Lu G, Zhang H, Esa MR, Cooray V. Emission heights of narrow bipolar events in a tropical storm over the Malacca Strait. In: 2017 International Conference on Electrical Engineering and Computer Science (ICECOS), pp. 305-309; Aug 2017.

[9] Seah BY, Ahmad MR, Shairi NA, Periannan D, Sabri MH, Aziz MZ, Ismail MM, Esa MR, Mohammad SA, Abdul-Malek Z, Yusop N. The Performance Evaluation of Capacitive Antenna with Various Structures and Permittivity Values. In: 2018 International Conference on Electrical Engineering and Computer Science (ICECOS), pp. 457-460; Oct 2018

[10] Seah BY, Ahmad MR, Ong YJ, Shairi NA, Periannan D, Sabri MH, Esa MR, Abdul-Malek Z, Mohammad SA, Aziz MZ, Yusop N. Evaluation of Air-Gap Stacked Capacitive Antennas for Lightning Remote Sensing. In: IOP Conference Series: Earth and Environmental Science, Vol. 228(1):012002; Jan 2019

[11] Ahmad NA, Fernando M, Baharudin ZA, Cooray V, Ahmad H, Malek ZA. Characteristics of narrow bipolar pulses observed in Malaysia. Journal of Atmospheric and Solar-Terrestrial Physics, 2010;72(5-6):534-40.

[12] Bils JR, Thomson EM, Uman MA, Mackerras D. Electric field pulses in close lightning cloud flashes. Journal of Geophysical Research: Atmospheres, 1988; 93(D12):15933-40.

[13] Ahmad MR, Esa MR, Cooray V, Dutkiewicz E. Interference from cloud-to-ground and cloud flashes in wireless communication system. Electric Power Systems Research, 2014;113:237-46.

[14] Lü F, Zhu B, Zhou H, Rakov VA, Xu W, Qin Z. Observations of compact intracloud lightning discharges in the northernmost region (51 N) of China. Journal of Geophysical Research: Atmospheres, 2013; 118(10):4458-65.

[15] Nag A, Rakov VA, Tsalikis D, Cramer JA. On phenomenology of compact intracloud lightning discharges. Journal of Geophysical Research: Atmospheres, 2010; 115(D14).

[16] Smith DA, Shao XM, Holden DN, Rhodes CT, Brook M, Krehbiel PR, Stanley M, Rison W, Thomas RJ. A distinct class of isolated intracloud lightning discharges and their associated radio emissions. Journal of Geophysical Research: Atmospheres, 1999;104(D4):4189-212.

[17] Suszcynsky DM, Heavner MJ. Narrow Bipolar Events as indicators of thunderstorm convective strength. Geophysical research letters, 2003; 30(17).

[18] Wu T, Dong W, Zhang Y, Funaki T, Yoshida S, Morimoto T, Ushio T, Kawasaki Z. Discharge height of lightning narrow bipolar events. Journal of Geophysical Research: Atmospheres, 2012; 117(D5).

[19] Wu T, Takayanagi Y, Yoshida S, Funaki T, Ushio T, Kawasaki Z. Spatial relationship between lightning narrow bipolar events and

parent thunderstorms as revealed by phased array radar. Geophysical Research Letters, 2013; 40(3):618-23.

[20] Wiens KC, Hamlin T, Harlin J, Suszcynsky DM. Relationships among narrow bipolar events, "total" lightning, and radar inferred convective strength in Great Plains thunderstorms. Journal of Geophysical Research: Atmospheres, 2008; 113(D5).

[21] Knapp C, Carter G. The generalized correlation method for estimation of time delay. IEEE transactions on acoustics, speech, and signal processing 1976; 24(4):320-7.