Performance Analysis of Stacked Capacitive Antenna for Lightning Remote Sensing

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***Abstract*—Antennas are the important elements in the lightning detection system. To improve performance of the lightning detection system, it is so necessary to improve the efficiency of the antennas. There are two types of antennas used in the system which are capacitive antenna for electric field sensing and loop antenna for magnetic field sensing [1]. Both of these antennas are big in size and causing inconvenient during set up. Thus, small and portable antennas are designed. It is so important to remain or improve the sensitivity of the antennas even though it is small in size. Stacking method is used in capacitive antenna by increase copper plate layer in between the parallel plate antenna. After prototype the multi-stacked capacitive antenna, performance analysis is carried out. Performances of the antennas are compared using CST simulation and hardware set up. Multi-stacked capacitive antenna is compared with the single plate antenna and found that the performance of the antenna increases as the stacked number increases.**

Keywords—Capacitive antenna, lightning remote sensing.

I. Introduction

As reported, single plate capacitive antennas have lower sensitivity in Computer Simulation Technology (CST) software and the radiation pattern of the induced electric field is not satisfied. This dedicate that the performance of antennas may having low sensitivity and can be improved. Besides, dimension of single plate capacitive antennas in lightning detection system is big in sizes.

To cut down the size and increase sensitivity of the antennas, stacked capacitive antennas are proposed. Therefore, there is objectives to be investigated in this paper which are the relationship between stacked capacitive antennas and resulted electric field strength compared to single plate antenna [2].

II. Methodology

A. Stacked Capacitive Antenna

Design process of multi-stacked capacitive antenna is focus on software and hardware. It starts from software simulation which is important to determine the relationship between antenna specifications and the result of E-field strength. In this case, top and bottom layer used for the antenna are same sized FR4 parallel plate. There are a few layer of copper plates slotted in between the FR4 to create higher capacitance value [3].

Simulation processes always start from basic which mean started with single plate antenna. First of all, dimension (cross sectional area) of the parallel plates are determined through the simulation. The dimension of parallel plates which contributes to higher electric field strength is chosen and proceeds to next stage of simulation. After obtain the better dimension of parallel plate, single plate antennas with different air gap distance is designed. The antennas with different air gap in between have different E-field strength. The antenna with highest performance of the E-field strength and radiation pattern is chosen and used as the basic design of stacked capacitive antennas.

Stacked capacitive antennas are designed by adding copper plate in between the single plate antenna by division of contain air gap. The simulation results of the antennas are tabulated inside the table for performance analysis. Stacked capacitive antenna fabrication is carried out after obtained the optimum stack number of capacitive antennas.

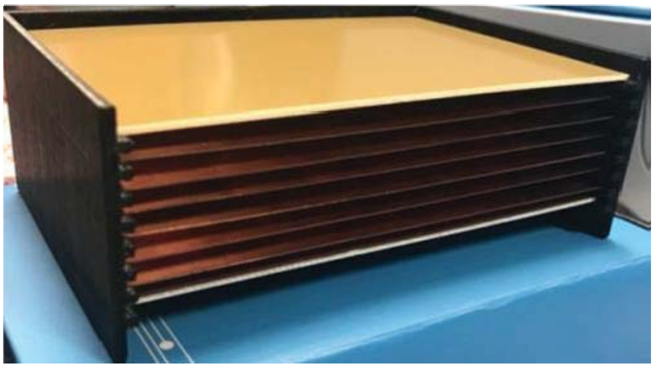


Fig. 1. Stacked Capacitive Antenna.

III. Results and Analysis

After obtained the most optimum dimension of antennas and distance of air gap, stacked capacitive antenna is designed. Different numbers of copper plates are slotted between the parallel plate antenna and each air gap distance from plate to plate is constant.

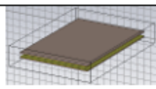
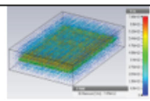
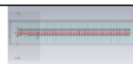
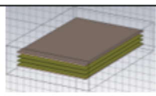
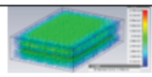
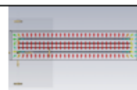
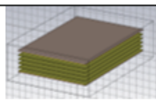
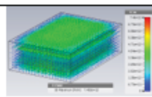
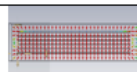
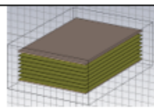
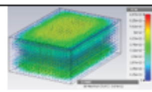
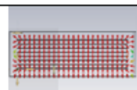
In this case, parallel plate antenna with 10 cm x15 cm dimension and 0.5 cm air gap is used as the basic design of stacked capacitive antenna. The simulation of the stacked antenna is manipulated by increasing the number of copper plates in between the FR4 by 2 layers, 4 layers and 6 layers.

From CST simulation software, the design models, radiation patterns as well as E-field strength from different stacked capacitive antenna are recorded in Table I. By using the collected data, the relationship of increasing copper plate number and the E-field strength can be investigated.

From the CST result, uniform E-field decrease when increasing the number of copper plate layer. The uniform E-field strength of stacked antenna decreases from 4.28x10^12 V/m to 1.27x10^12 V/m. This result consider failed since the formula of electric field stated that E = (σ/ε)•N [4]. From this formula, electric field strength must be increase when the number of stacked increase. This CST simulation result is against the theory. This maybe because of the CST simulation solver do not consider the properties of the copper since copper is a good conductor. The E-field penetrated through the copper plate without any polarization. The charges radiated through the gap between FR4 without consider the copper layer. As the conclusion, CST simulation results do not prove the hypothesis of increasing stacked number can increase the uniform E-field induced between the antennas. In order to further prove the hypothesis, practical measurement is set up and the results are analysed.

As the further confirmation of functionality of stacked capacitive antenna in real life, the antennas are fabricated and the experiments are carried out. To prove that the more number of slotted copper plate, the higher the E-field strength, practical antenna is set up and triggered using the sparks of bug racket zapper. The stacked capacitive antenna is triggered at the same time with the ordinary single parallel plate antenna which is 20 cm x 30 cm in dimension and 1.6 cm air gap. The antennas are connected to the Picoscope and the waveform will display at the PC.

TABLE I. Comparison Table of Stacked Capacitive Antenna

Number of copper plate	Modeling	Induced E-field	
		3D Maximum E-field (x10^12V/m)	3D Uniform E-field (x10^12V/m)
0		 7.479	 4.28
2		 6.785	 2.87
4		 7.402	 1.61
6		 6.87	 1.27

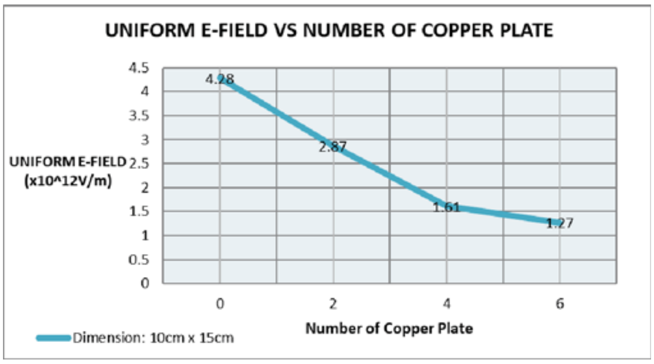


Fig. 2. Graph of Uniform E-Field against Number of Copper Plate Layer.

There are three tests carried out by using different number of copper plate. Test 1 using 2 layers of copper plate and the Picoscope display is shown in Figure 3. In Figure 4, there is the waveform detected from ordinary antenna and stacked capacitive antenna with 4 layer of copper plates. Lastly, Figure 5 shows the display waveform of Picoscope from 6 layers copper plates stacked capacitive antenna and ordinary antenna.

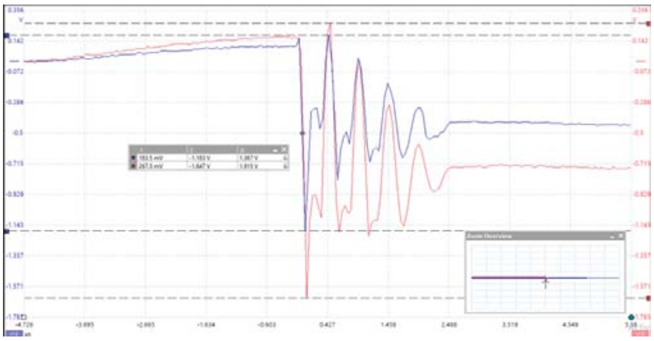


Fig. 3. Waveform Comparison of Ordinary Parallel Plate Antenna with 2 Layer Copper Stacked Capacitive Antenna.

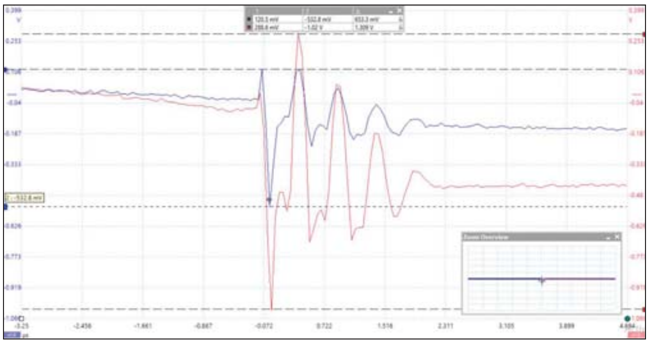


Fig. 4. Waveform Comparison of Ordinary Parallel Plate Antenna with 4 Layer Copper Stacked Capacitive Antenna

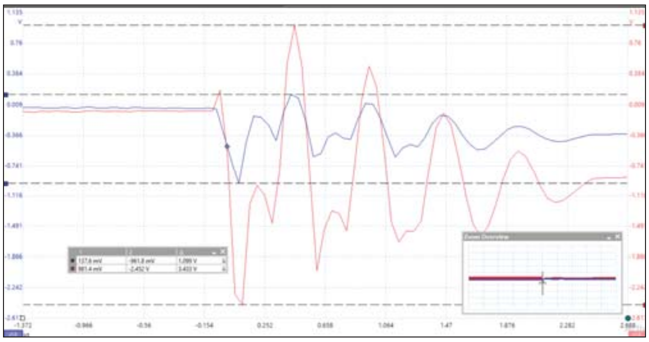


Fig. 5. Waveform Comparison of Ordinary Parallel Plate Antenna with 6 Layer Copper Stacked Capacitive Antenna

By comparing the waveform of both single plate (blue) and multi-plate (red), the peak to peak voltages of both waveforms are labeled out and analysed using formula of efficiency, Efficiency = (New antenna)/(Old antenna) [5]. Then, a comparison table of the waveform obtained from ordinary single plate antenna and stacked capacitive antenna is constructed as shown in Table II. By using the data in table II, a bar chart is drawn in Figure 6.

From the bar chart in Figure 6, this is obvious that the efficiency of multi-stacked capacitive antenna increases with the number of copper plates. There is increase in efficiency from 1.4008 to 3.12375 when the number of copper plate increases from 2 layers to 6 layers. This phenomenon can be proved using formula of electric field, $E = \sigma/\varepsilon$. N which stated that electric field strength increase when the number of stacked increase.

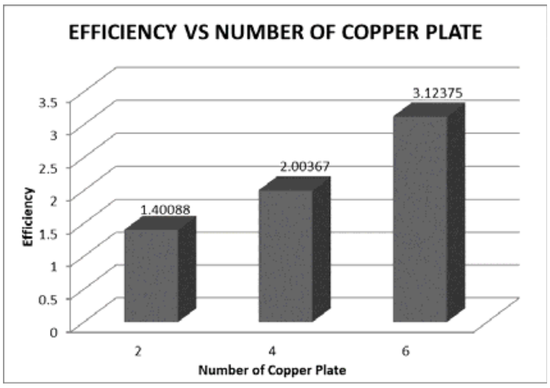


Fig. 6. Bar Chart of Efficiency against Number of Copper Plate.

TABLE II. COMPARISON TABLE OF STACKED CAPACITIVE ANTENNA

Test	$V_{p.p}$ of single parallel plate antenna (V)	$V_{p.p}$ of stacked capacitive antenna (V)	Ratio of stacked capacitive antenna to single parallel plate antenna
1	1.367	1.915 (Number of copper plate: 2)	1 : 1.40088
2	0.6533	1.309 (Number of copper plate: 4)	1 : 2.00367
3	1.099	3.433 (Number of copper plate: 6)	1 : 3.12375

In nutshell, both practical and theory prove that the number of copper layer is able to improve the antenna efficiency. By the way, the unsatisfied CST simulation results that do not obey the result in practical and theory maybe because of the limitation of the CST solver which cannot consider the properties of the copper plates during simulation.

IV. Conclusion

In conclusion, capacitive antenna and loop antennas have been improved in their performance by increasing number of stack and number of turns. The sensitivity of the antenna is increased even though the sizes of antennas are minimized to make it portable.

Besides, the performance of stacked capacitive antennas analysed using both CST software and hardware set up. CST results of stacked capacitive antennas are not recognizable due to the limitation of CST solver to consider copper plate properties. This situation can be solved by replacing layer of substrate instead of pure conductor since the dielectric constant of the substrate will not be ignored by the solver.

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