The Performance Evaluation of Capacitive Antenna with Various Structures and Permittivity Values

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Abstract—**This paper evaluates the capacitive antenna performance as a lightning sensor. The performance is evaluated by looking at two aspects, antenna structures and the background permittivity value of the antenna. Two experiments were carried out, Experiment A – using two different structure antennas, one with its Bayonet Neill–Concelman (BNC) connector's core direct touching the top plate (DBNC) while the other was connected via single core wires (WBNC), capturing the electric field (E-field) generated by the small spark at a distance of 1 meter away from both antennas. Furthermore, both capacitive antennas with top plates directly soldered to their BNC cores were used to study their performance with and without being covered by plastic (dielectric constant of 2.25) during Experiment B. The result from Experiment A showed that WBNC has different onset polarity and significant decreased in amplitude of the signals captured compared to DBNC (mean ratio is 1.095 with range between 0.5838 and 4.528). Meanwhile, Experiment B shows that a comparable average ratio of 0.7835 and 0.7447 during the measurement where antenna A_{wc} with and without the presence of plastic cover respectively.**

Keywords—capacitive antenna, lightning sensor, small spark, dielectric constant.

I. INTRODUCTION

Lighting sensors have been widely used in studying the electric field intensity (E-field) produced by lightning flashes such as vertical conductor, sphere antenna, and parallel plate antenna [1]. According to Maxwell's Ampere Law, the direction of E-field always follows the direction of the current flows (Atmospheric sign convention) [2]. The E-field produced by lightning discharges will be propagating in such a vertical manner hence, parallel plates antenna is used to measure the vertical E-field of lightning flashes at ground level. FR4 copper plates are chosen as lightning sensor as they have the flexibility in choosing the shape of the conducting area while the surrounding dielectric edges can act as the shield to keep the capacitance of the antenna constant during the rainy day [3, 4, 5, 6]. Since we do know that the water droplets (dielectric constant = 80.4) do interfere the measurement reading of the sensors when it comes in contact with the conducting area of the antenna, waterproof material such as plastic bag is commonly chosen to wrap the sensor in order to avoid the interference from water completely. However, plastic or polyethylene also have a dielectric constant of 2.25. Therefore, the authors are inspired to study the efficiency of the parallel plates antenna (FR4) under different design structures and dielectric constant background.

II. METHODOLOGY

A. Experiment A – Effect of antenna structures on E-field change

Both FR4 antennas are in A4 size (20 cm x 30 cm) with 1.6 cm air gap. Antenna A was drilled and equipped with the BNC port and its core was directly touching the top plate (DBNC) while antenna B was connected to the port with single core wire (WBNC). Both FR4 antennas were grounded to the metal board. The bug killer was constructed with 1 mm gap to produce a small spark, acting as the electromagnetic

(EM) wave source throughout the experiment. The distance between antennas and the source of the spark is set to 1 meter to ensure the EM wave generated by the spark will beam at both antennas simultaneously.

Two experiments were conducted under this section which were observation on the derivative electric field change of both antennas and the other one was the observations on the electric field signals of both antennas with fast field buffer circuit connected.
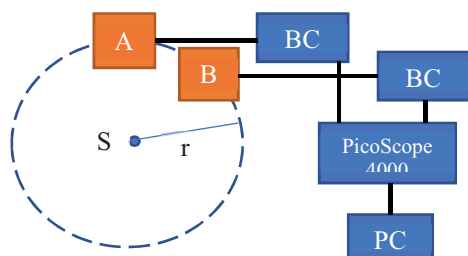

Fig. 1: Schematic diagram of the measurement set up (A is DBNC or Awc; B is WBNC or Anc; BC is fast E-field buffer circuit; S is the small spark)

Fig. 2 Measurement Set Up for Experiment A

B. *Experiment B – Effect of background dielectric constant on the E-field change*

During this section, 2 mm small spark was acting as the EM wave source throughout this experiment. Both FR4 capacitive antennas were now having their BNC cores directly soldered onto the top plates of each antennas respectively. The first experiment was conducted where both FR4 antennas were uncovered by plastic material to observe the performance of the antennas under the condition of dielectric constant equal to 1. The second experiment was carried out with the antenna A_{wc} covered by plastic material which turned its background dielectric constant to be 2.25 instead while the other antenna A_{nc} was under a normal background dielectric constant. The results were compared in term of their amplitudes ratio.

Fig. 3: Measurement Set Up for Experiment B

III. RESULTS, ANALYSIS AND DISCUSSIONS

A. *Experiment A*

The sign of the signals is classified based on the onset polarity of DBNC. Fig. 4 shows the derivative electric field change, dE/dt (mV) of the DBNC and WBNC. However, DBNC in this case was not soldered, putting a rock on the antenna top to ensure the top plate is touching the BNC core. The result shows that some of the signals captured were having different polarity although both DBNC and WBNC were capturing the same EM source at the same time. Most of the negative sign from DBNC started with small overshoot instead of an ordinary peak amplitude. The authors are forced to conclude that the inconsistence of the signals polarity captured might be due to the influence from the dielectric constant of the rock and the possibility of an improper contact between the top plate and BNC core of that DBNC antenna.

Fig. 5 shows the dE/dt of DBNC and WBNC. The difference of DBNC in this case which is its BNC core had been soldered direct onto the top plate instead of pressing its top by a rock. The result clearly shows us that the polarities of signals captured by WBNC are all the same as the signals from DBNC although there are still some cases where the 2nd amplitude of the 1st pulse from WBNC is very low. The performance of the FR4 antennas are compared in term of their 1st amplitude ratio respectively as shown in Fig. 6, an average 1.0952 with the range from 0.5838 to 4.528. Only six out of twenty-two samples have the 1st amplitude of WBCN signals higher than DBNC signals. Note that the average ratio becomes 0.9317 if the sample with ratio of 4.528 is excluded.
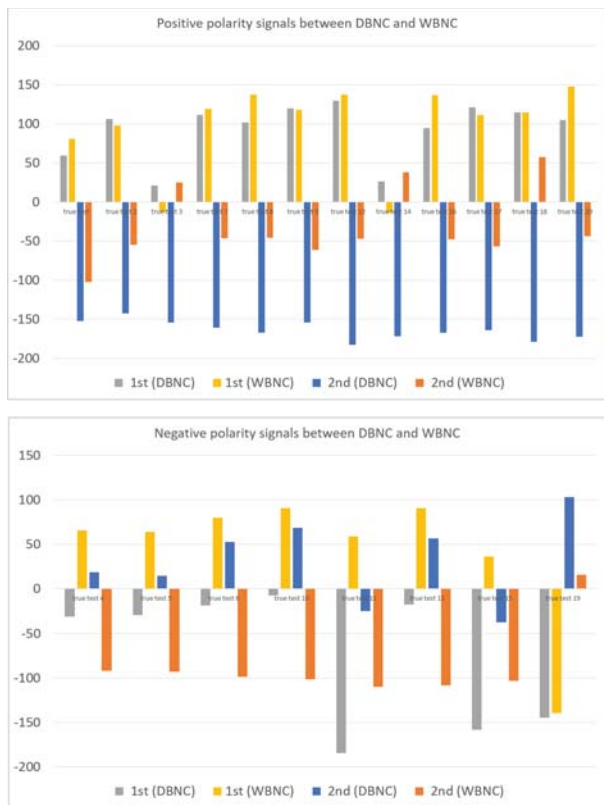
Fig. 4: Comparison between 1st pulse amplitude of WBNC and DBNC (Note that 1st (DBNC)/ (WBNC) means the 1st amplitude of the 1st pulses while the 2nd represents the second amplitude of the first pulse detected by each antenna.
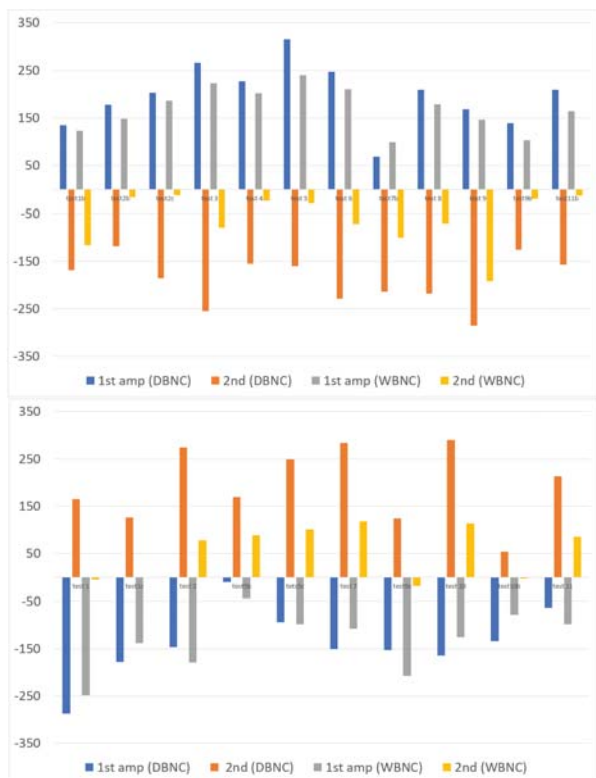

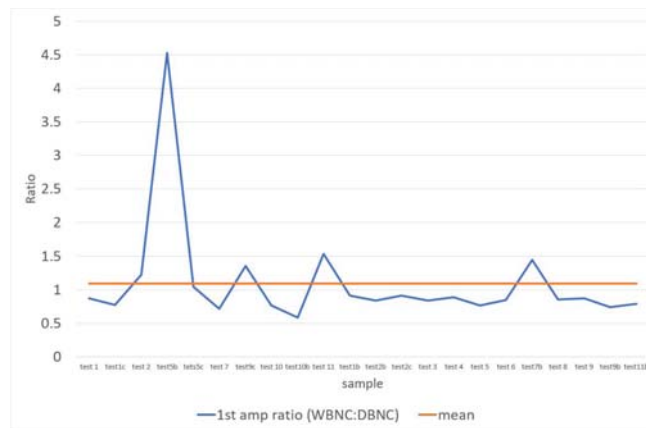*Fig. 5: Comparison between 1st pulse amplitude of WBNC and DBNC(soldered)*

Fig. 6: 1st amplitude ratio of WBNC to DBNC

Based on Fig. 7, we could observe that both first and second amplitudes of the first pulse from WBNC signals are generally associated with a slightly higher electric field change than DBNCs'. This might be due to the existence of the buffer circuit that affected the capacitance and resistance value of the whole system, causing the result to be slightly different as shown in Fig. 7. We could notice that there is a sample with negative value ratio in Fig. 8. This is because of the opposite polarity of the onset signals captured by the FR4 antennas during sample 'test2_2g' due to unknown reason.
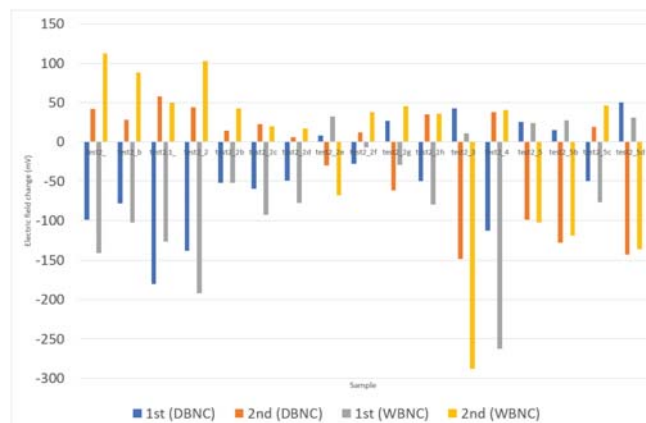

Fig. 7: Comparison of signals between DBNC and WBNC (with fast E-field buffer circuit)
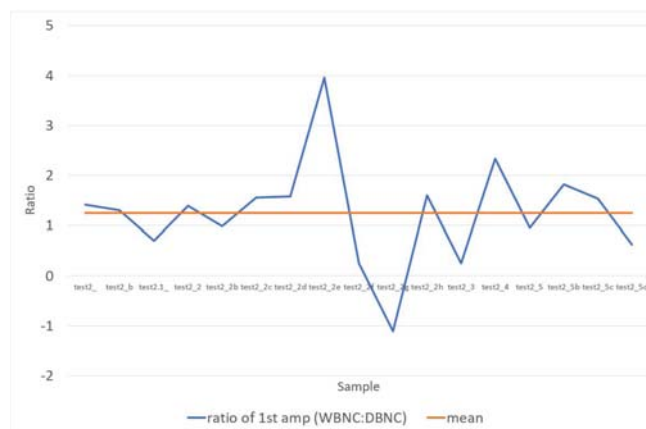

Fig. 8: Ratio of the 1st amplitude of WBNC to DBNC (with fast E- field buffer circuit)

B. Experiment B

In Fig. 9, 9 successful small spark discharges were captured by both FR4 antennas under normal dielectric condition and the ratio of antenna A_{wc} to A_{nc} varied within 0.6584 to 0.825 with the mean value of 0.7447. However, Fig. 10 shows us that the mean ratio would be increased with the increasing of the dielectric constant from 1 to 2.25 (plastic cover). 19 samples of EM wave successfully captured by both FR4 antennas (same setup as in Fig. 3) were plotted corresponding to their 1st amplitude ratio with the mean value of 0.7835, varying from 0.5318 to 0.9961.
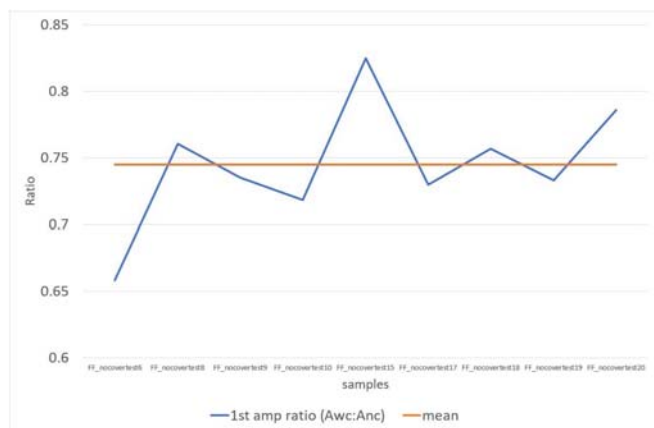

Fig. 9: 1st amplitude ratio of both antennas without cover

Fig. 10: 1st amplitude ratio of antenna with cover to antenna without cover

IV. CONCLUSION

In this study, we have analysed the amplitudes of the EM waves from small spark by using different antenna design under different dielectric constant background. The signals in Experiment A are characterised into positive and negative polarity based on the onset peak of DBNC. Without soldering the BNC core onto the antenna top plate, DBNC gives a various of inconsistent polarity corresponding to the polarities of the WBNC signals. The presence of plastic cover will slightly increase the performance ratio (A_{wc}: A_{nc}) from 0.7447 to 0.7835. The readings of WBNC are higher than DBNC with the presence of the fast E-field buffer circuit and vice-versa. In a nutshell, soldered DBNC provides a more stable and accurate readings than WBNC. The presence of plastic cover does not affect the readings of the sensor significantly.

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