Evaluation of Air-Gap Stacked Capacitive Antennas for Lightning Remote Sensing

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Abstract. This paper evaluates the capacitive antenna performance (sensitivity and frequency shifting) as a lightning sensor in different antenna design structures. Two experiments were carried out, Experiment A – using two different structure antennas, an A3 size capacitive antenna and a quarter A4- sized capacitive antenna, capturing the electric field (E-field) generated by the small spark at a distance of 1 meter away from both antennas. The results were taken in a ratio form of the 1st pulse amplitude captured by quarter A4 size antenna verses 1st pulse amplitude of the waveform captured by A3 antenna for each corresponding spark. Same set up and measurement were taken during the Experiment B except for the quarter A4 size antenna was now being slotted with 6 copper plates were slotted within the gap between the top plate and bottom plate. The result from Experiment A showed an average ratio at 0.1957 with a range of 0.0333 to 0.3085 while the results of Experiment B showed the average value laid at 0.2606 within the range of 0.1581 to 0.4510. The comparison results of Experiment A with Experiment B gave an increment of the sensitivity of the quarter A4 antenna from no stack to fully stacked antenna. However, there was also a significant frequency shifting of the quarter A4 antenna with the change of antenna structure (15% for quarter A4 capacitive antenna without stack; 20% for quarter A4 stacked capacitive antenna).

1. Introduction

Lighting studies had been carried out ages ago by using various types of antennas as the lightning sensor or detector such as helical antenna, dipole antenna, parabolic antenna, ceramic patch antenna and so on to capture the radiation produced by lightning [1, 2, 3, 4, 7, 11]. Field mill, whip antennas and capacitive antennas were commonly used in lightning remote sensing system due to their omnidirectional receiving area and frequency independence properties [6, 7, 8, 9, 10, 13]. These sensors are mainly focused on capturing the vertical components due to the propagation of the E-field produced by a lightning discharge tends to be in vertical manner as based on Maxwell's Ampere Law, the direction of electric field is always following the direction of the current flow (atmospheric sign convention) [13]. However, the flat parallel plates antennas used in previous studies were costly and limited its flexibility to be portable. Alternatively, FR4 was chosen to make the parallel plates antenna due to its cheap production cost and the flexibility of manufacturing in such a various shape of the conducting areas [12]. Throughout the previous studies, it shows that the larger the common area of the capacitive antenna, the higher the sensitivity of the antenna [5]. However, the authors were constructing the antenna in such a size (quarter A4) that is smaller than previous antenna (A3 and A4) in order to reduce the space occupied. This leads to the unidentified of the sensitivity and the frequency shifting (compared to A3 size antenna) of the quarter A4 size antenna. Therefore, the authors would like to study the efficiency of the quarter A4 parallel plates antenna (FR4) with and without stacks compared to A3 parallel plates antenna (FR4).

2. Methodology

Two experiments were conducted where the observations on the derivative electric field change (dE/dt) of antenna without stacks and multi-stacked antenna respectively. An A3-size FR4 antenna was set up as the standard value of the derivative field change to the quarter A4 size antenna throughout these two experiments.

In Experiment A, a quarter A4-sized FR4 antenna with the dimensions of 10cm x 15cm with 3.5cm air gap (as shown in Figure 2) was constructed by having both top and the bottom plates connected to the BNC port via single core wire. The bug killer was constructed with 2 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 was set to 1 meter to ensure the EM wave generated by the spark will beam at both antennas simultaneously. The setup of the measurement was shown in Figure 4. This FR4 antenna (quarter A4 size) was then slotted with 6 pieces of copper plates with an equivalent gap size of 0.5cm each within its air gap during Experiment B.

Figure 1: Example of copper plates

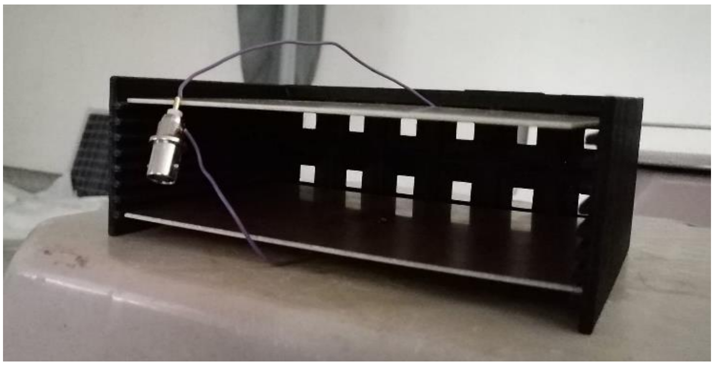

Figure 2: Example of quarter A4 size antenna (without stack)

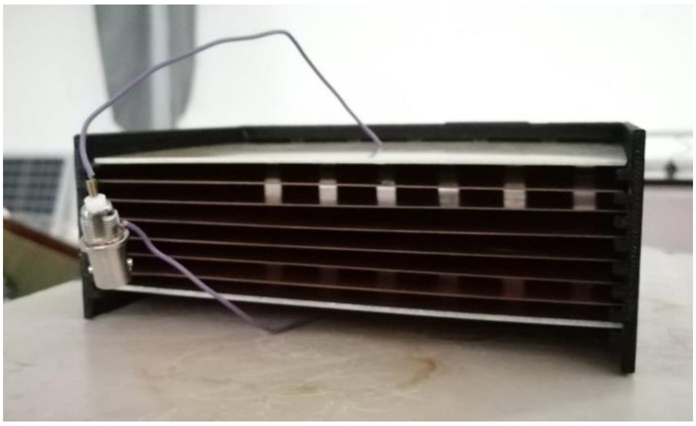

Figure 3: Example of quarter A4 size antenna (fully stacked)

Figure 4: Measurement setup of Experiment A and B

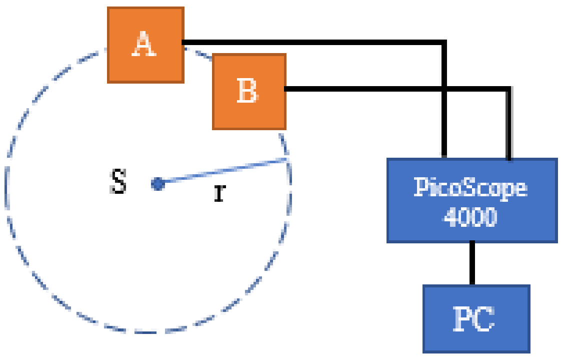

Figure 5: Schematic diagram of the measurement setup in Experiment A and Experiment B. (A: quarter A4 size antenna; B: A3 size capacitive antenna; S: small spark source)

3. Results, analysis and discussion

The results obtained were analysed from two aspects, the performance ratio of the 1st pulse amplitude captured by quarter A4 size antenna verses 1st pulse amplitude of the waveform captured by A3 antenna and the presence of frequency shifting for each corresponding spark.

Note that the statistical distribution of the ratio which studied about the sensitivity of the antenna with different structure were done by taking the first ten samples with slightly and very slightly frequency shifting while the frequency shifting of the quarter A4 antenna was taken from the first twenty samples from each experiment and classified into four classes as shown in Table 1. *The first ten samples used in the analysis of performance ratio are included in the first twenty samples.

Table 1: Classification of the frequency shifting property of quarter A4 parallel plates antenna

Class	Description
Yes	Different onset polarity; the polarity of each gradient within 1st pulse of quarter A4 sized and A3 sized antennas were not same.
Multipeak	Same onset polarity but drastic changes in gradients' polarities before the end of the 1st pulse.
Slightly	Same onset polarity and each gradient within 1st pulses but different polarity of the gradient after 1st pulse.
Very Slightly	Same polarity for onset, and each gradient of increment or decrement throughout the whole discharge waveform.

The detail of the waveform for each types of classification were shown in Figure 6 until Figure 9 which were taken directly from the PicoScope software (Note that the blue colour is the waveform captured by A3 capacitive antenna while the red colour is the waveform captured by quarter A4 capacitive antenna). As shown in these figures, "Yes" class shows the waveforms with different onset polarity. These might be due to there were some frequency components that could only detect by an antenna with larger dimension instead. These abilities to capture the missing frequency components is one of the factors affecting the efficiency and sensitivity of the antenna itself. As for the Figure 8, it shows a similar waveform for both antennas but there is a slightly different in the polarity of the gradient at the end part due to unknown reason. These cases were classified as "Slightly" frequency shifting waveforms. For the "very slightly" class signals, their gradient at each particular point are the same slope polarity although there are different in the E-field changes amplitudes.

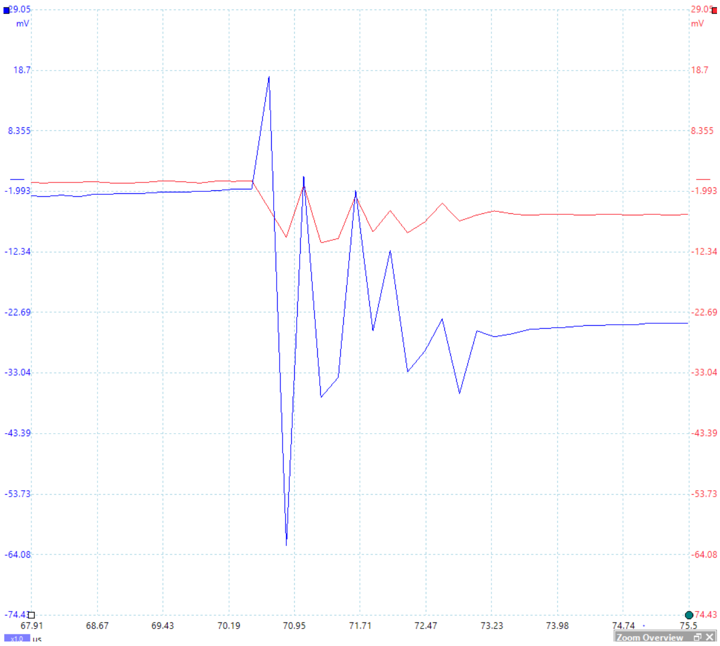

Figure 6: Example of "Yes" classical waveform

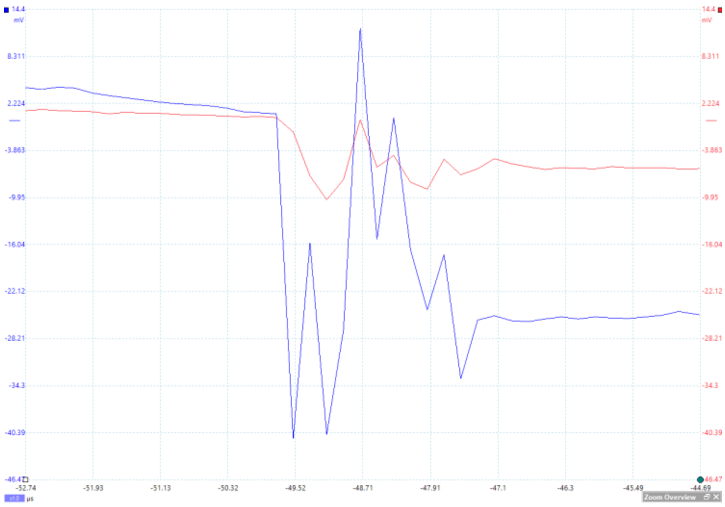

Figure 7: Example of "Multipeak" classical waveform

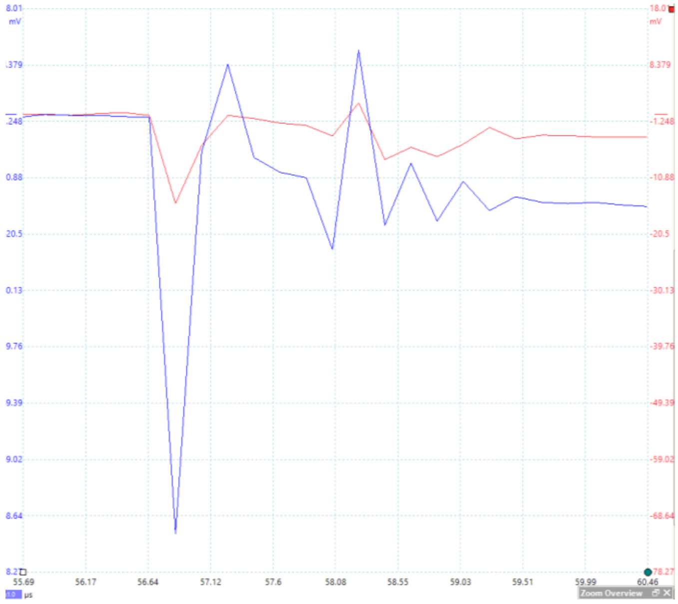

Figure 8: Example of "Slightly" classical waveform

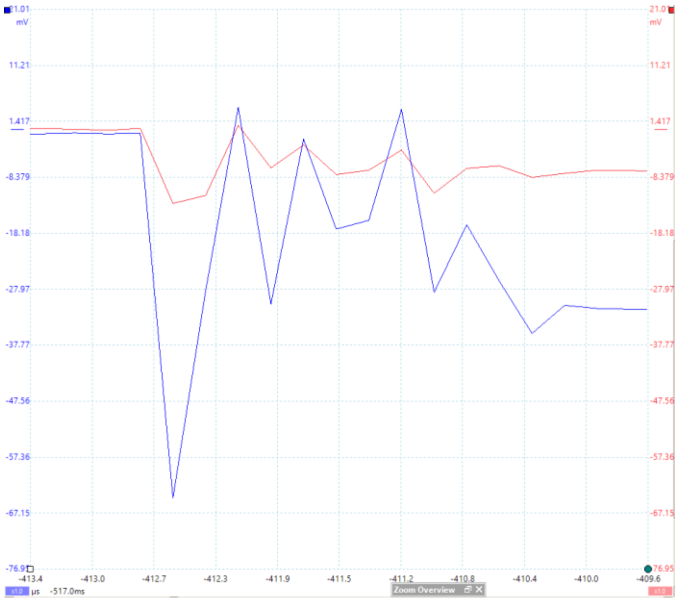

Figure 9: Example of "V. slightly" classical waveform

Figure 10 shows the amplitude ratio of quarter A4 without stack to A3 antenna which have the similar waveform of their first pulse (same polarity). Comparing Figure 10 and Figure 11 with Figure 12 and Figure 13 respectively, it shows that stacking the air gap of the parallel plates antenna with copper plates will have an increment in its sensitivity about 33.16 percent in average, but this will also lead to a frequency shifting to the antenna. Based on the description in Table 1, we know that the signals with very slightly frequency shifting could be consider as no shifting as their signals waveforms are nearly the same. There are ten samples out of twenty samples were found to be very similar (very slightly waveforms) captured by the quarter A4 antenna without stack. However, this number decreases to seven only when the antenna was stacked with 6 pieces of copper plates. The overall number of signals with significant frequency shifting by one sample per twenty samples.

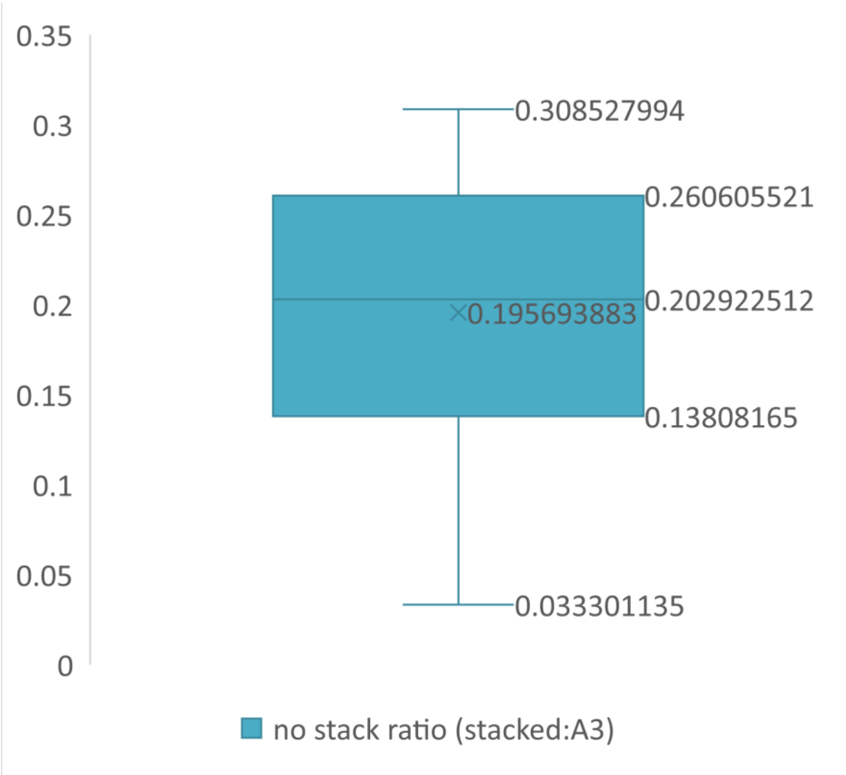

Figure 10: Statistical distribution of the ratio of the 1st pulse amplitude captured by quarter A4 size antenna without stack verses 1st pulse amplitude of the waveform captured by A3 antenna for each corresponding spark

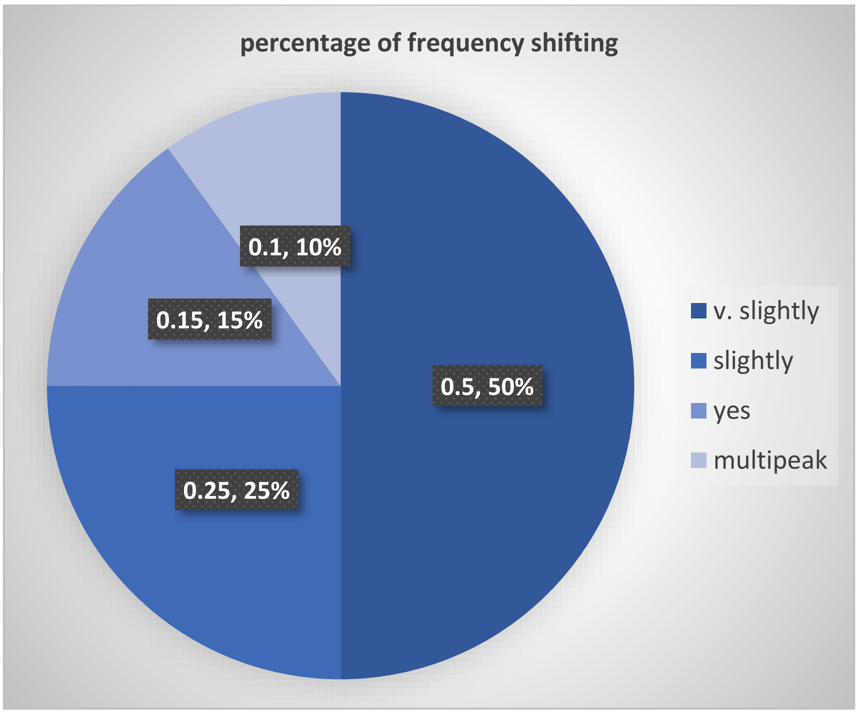

Figure 11: Percentage of frequency shifting of quarter A4 antenna without stack

Unlike the antenna without stacked, the statistical distribution of the stacked antenna shows a skewed distribution among the twenty samples taken. One of the samples proves that stacking the antenna will enable the antenna to reach nearly half of the sensitivity of A3 size capacitive antenna although it had been improved about one-third of the performance from quarter A4 antenna without stacks.

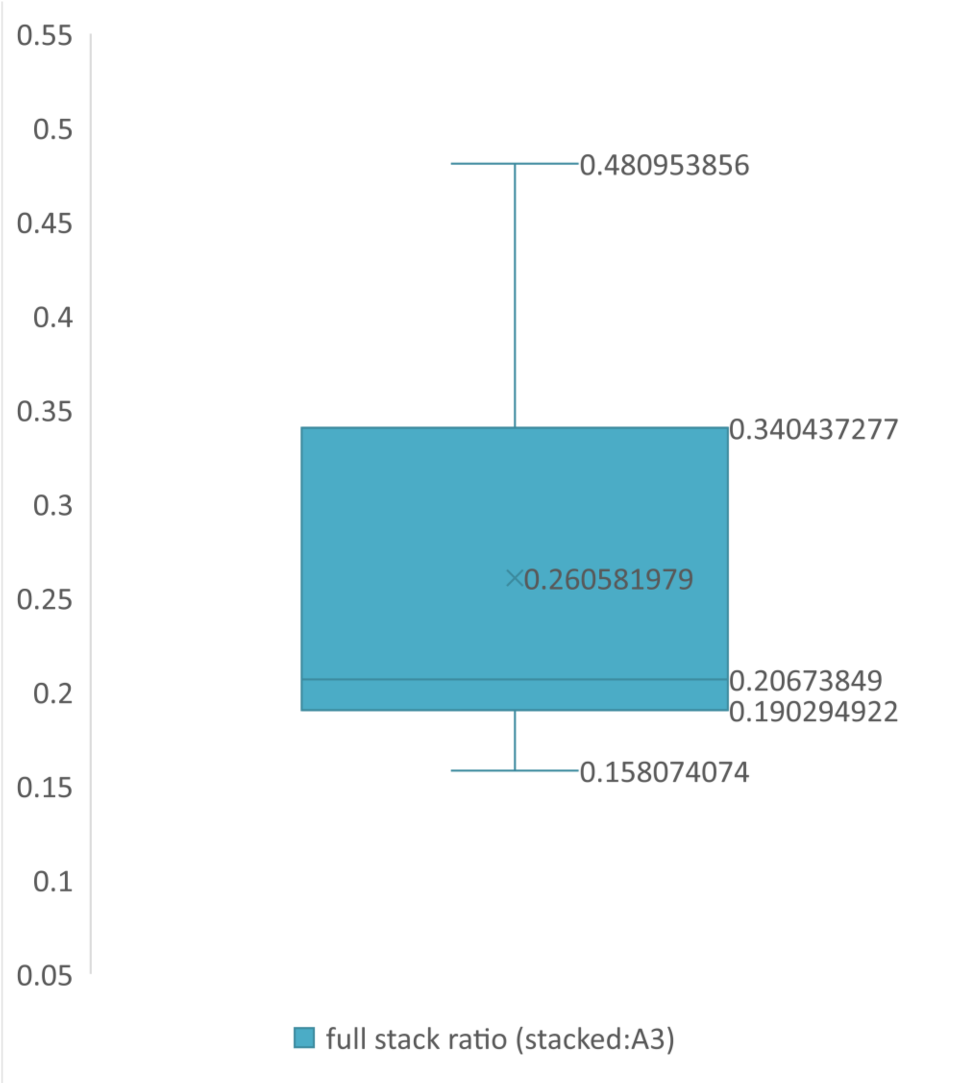

Figure 12: Statistical distribution of the ratio of the 1st pulse amplitude captured by fully stacked quarter A4 size antenna verses 1st pulse amplitude of the waveform captured by A3 antenna for each corresponding spark

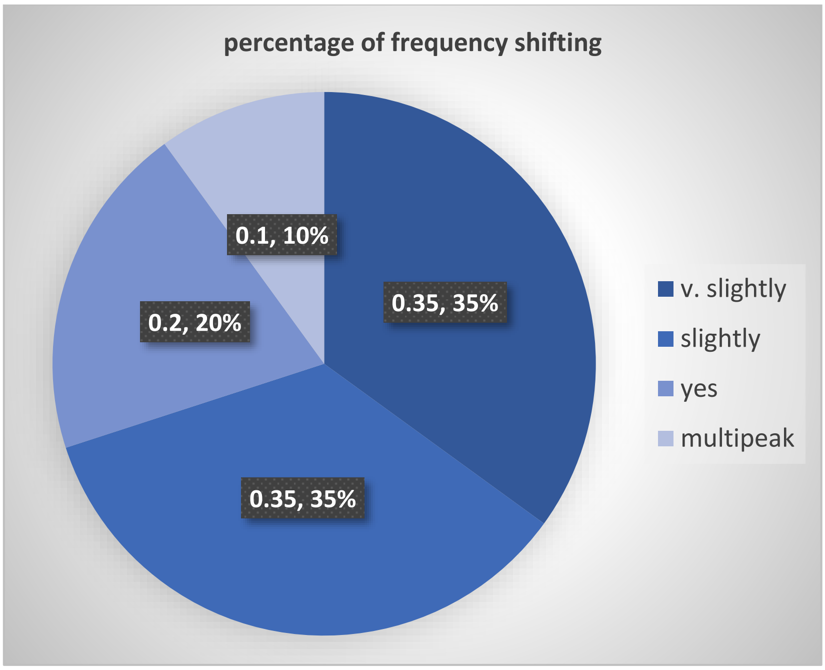

Figure 13: Percentage of frequency shifting of the fully stacked quarter A4 antenna

4. Conclusion

The authors have analysed the ratio of the 1st pulse amplitude of the EM waves from small spark by considering the first ten samples with Slightly and Very slightly frequency shifting properties that captured by the quarter A4 antenna for Experiment A and Experiment B. The waveforms (captured by quarter A4 antenna) were classified into four classes, Yes, Multipeak, Slightly, and Very slightly for their frequency shifting properties. As a conclusion, the smaller the size of the antenna, the lower the sensitivity of the antenna itself. The presence of the stack components (copper plates) will not only increase the sensitivity (33.16%) but also the percentage of frequency shifting of the antenna (33.33%). Studies in detail about the performance of the smaller size antenna could be done by normalizing and analyzing the E-field change captured by both antennas (A3 and quarter A4) in future.

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