INVESTIGATING THE DESIGN AND USE OF APERIODIC ANTENNA ARRAYS FOR ENHANCED PERFORMANCE

Lim Yu Jie Jayden[1], Lim Wei Yee[1], Ang Teng Wah[2], Lim Zi Wei[2]
[1]Raffles Institution, 1 Raffles Institution Lane, Singapore 575954
[2]DSO National Laboratories, 12 Science Park Drive, Singapore 118225

ABSTRACT

Aperiodic antenna arrays employ methods such as uneven geometries, excitations, and phases of individual elements to provide enhanced performance as compared to periodic antenna arrays. This is often done to save resources and adapt to spatial constraints. This project proposes a diamond shape arrangement of patch antenna arrays in place of rectangular/square arrays. They can radiate in the desired direction and had viable S11 performance. Furthermore, the gain levels were up to 3dB higher and sidelobes were lower by up to 10dB, implying better directivity. An excitation weightage method was implemented, extending the linear binomial array to two dimensions which successfully reduced sidelobes by 8dB. Furthermore, this project investigated the ideal spacing and excitation of linear monopole antenna arrays. The half wavelength principle was experimentally verified. Overall, the aperiodic antenna arrays designed provide a simpler alternative to arrays generated using optimisation algorithms, making it suitable for applications requiring quick deployment with low computational requirements.

INTRODUCTION

Periodic antenna arrays are frequently used due to their simplicity. However, an attempt to increase the gain of the arrays by increasing the spacing of the elements results in increased sidelobe levels, propagating energy in unwanted directions. Therefore, aperiodic antenna arrays have gained traction as a viable alternative. By varying the parameters of individual elements, the array's performance can be enhanced in multiple aspects, namely the reduction of sidelobes. This is important because energy radiated to the sidelobes is wasted and can be intercepted by unwanted parties. Also, antennas will receive signals from multiple directions, increasing the amount of noise present. In this paper, we propose a new geometric arrangement of 2D patch antenna arrays, as well as an implementation of uneven excitations. We subsequently demonstrated the augmented performance of this array. Lastly, we experimentally verify the properties of linear monopole antenna arrays.

LITERATURE REVIEW

The binomial linear array is a common type of linear antenna array. The coefficients of the binomial expansion of $(1+x)^n$ are used to weight the excitation of individual elements in the array. Doing so allows the suppression of sidelobes. This is understood through the simple relationship:

$$E_{ff} \cong \varepsilon(\theta,\phi)F(\theta,\phi)$$

where E_{ff} is the power distribution pattern of the array at the far field, ε is the pattern of a single element and F is the array factor. As the maxima and minima of both ε and F occur at the same direction, the power distribution pattern can maximise the mainlobe and minimize the sidelobes. In other words, the radiated waves interfere constructively mainly in one direction. Experimental verification has been carried out as shown in [1]. However, this was only carried out for a linear array, thus, we decided to expand this to 2 dimensions.

Furthermore, another common principle in array design is the "half wavelength" principle, where elements are separated no further than half the wavelength of the frequency they are operating at. This is because significant sidelobes will be produced once the elements are too far apart. Since this is a cornerstone to most array designs, we decided to experimentally verify it.

MATERIALS AND METHODS

Our patch antenna arrays were designed and simulated within openEMS. Patch antennas of dimensions 32.86mm × 41.37mm were generated on a substrate with dielectric constant 4.2, and their different configurations are displayed in Fig. 1 below. We analysed the effect of the different configurations on the performance of the array. Then, we investigated the effect of changing the magnitude of excitations of individual elements on the performance of the array as shown in Fig. 2.

Furthermore, a linear array of monopole antennas with varying element spacing was fabricated to investigate the ideal element spacing and excitation weightage. As our frequency used was 10GHz, antennas with height 7.5mm were made according to the quarter wavelength principle. The active S11 performance of individual elements was checked with a Vector Network Analyser (VNA). Then, the linear array was created with half wavelength, full wavelength, and double wavelength element spacings. The gain plot of the arrays was then measured in an anechoic chamber to see their distribution patterns.

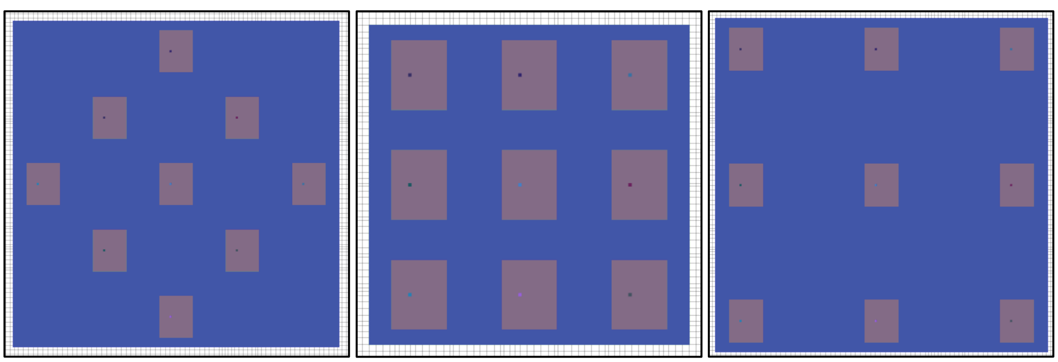

Fig. 1a, 1b and 1c: Design of diamond, square and enlarged square array

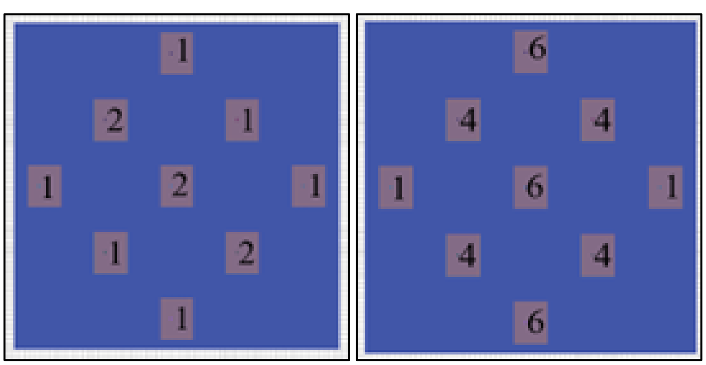

Fig. 2a and 2b: Design A and B with different excitation

Fig. 3: Monopole antenna used

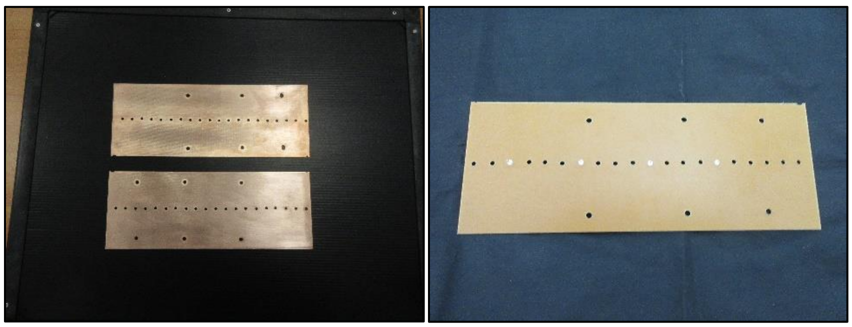

Fig. 4a and 4b: Fabricated monopole antenna array (each interval is 1.5cm apart)

RESULTS

Since we are using patch antennas, the main lobe should be located at θ = 0° for the best performance (radiate vertically upward as shown in figure). For all our designs, this was observed, serving as a baseline requirement for a well-performing array. Also, the S11 graph plotted for the 9-element diamond array shows that there was indeed a range of frequencies at which S11 is less than -10dB (generally acceptable return loss value). The exact frequency range can be adjusted by changing the parameters of individual elements. Thus, we conclude that our diamond array meets the baseline requirements of a patch antenna array.

The gain of our 9-element diamond array is higher than the gain of our 3 by 3 square array; the main lobe of the former is 17.6dBi while the latter is 14.7dBi. The former also has a narrower half-power beamwidth (HPBW) of 42.8° compared to the latter's one of 50.8°. Although the diamond array presents a greater number of side lobes than the square array, its side lobe levels at both φ = 0° and 90° (azimuthal angle) are much lower than the latter's. At φ = 0° the diamond array's main lobe and highest side lobe has a difference in intensity of 22.84dBi (hereby referred to as sidelobe level difference), much greater than the square array's difference of 15.8dBi. Likewise, at φ = 90°, the diamond array's sidelobe level difference is 25.7dBi and the square array's sidelobe level difference is 15.2dBi.

We note that simply increasing the distance between elements in the 3 by 3 square array increases the gain marginally while producing much larger sidelobes. In this case, the spacing between elements was doubled. The sidelobe level difference of the array is 4.8dBi and 10.8dBi at φ = 0° and 90°, significantly worse than the two arrays in the paragraph above.

The gain for our 25-element diamond array compared to a 5 by 5 square array displays a similar trend too. The main lobe for the diamond array is 21.5dBi with HPBW of 27.2° compared to 18.4dBi and 37.5° HPBW of the square array's main lobe. The sidelobe level difference for the diamond array is 28.2dBi and 24.5dBi when φ = 0° and 90° respectively while the square array's sidelobe level difference is 13.4dB for both φ.

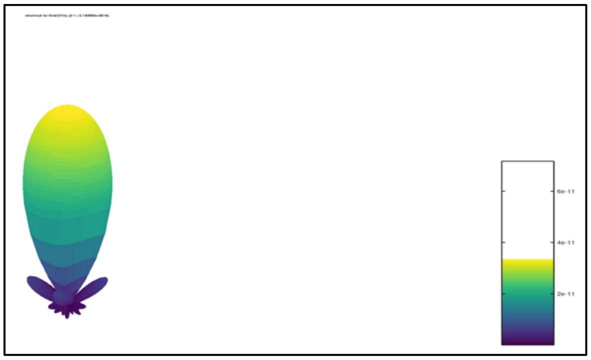

Fig. 5: 3d plot for 9 element diamond array

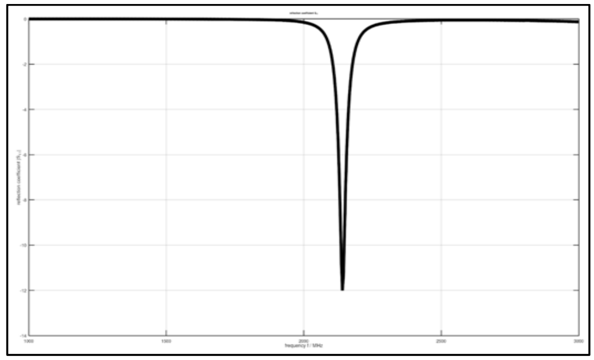

Fig. 6: S11 plot for 9 element diamond array

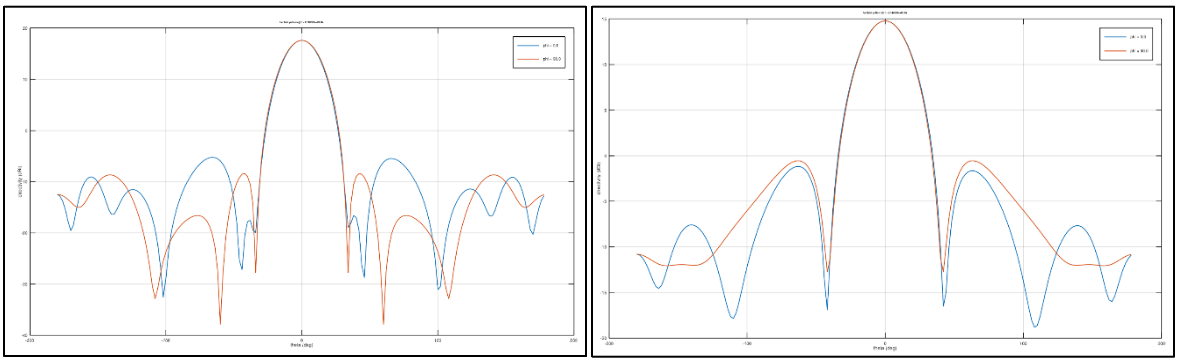

Fig. 7a and 7b: Gain plot for 9 element diamond and square array

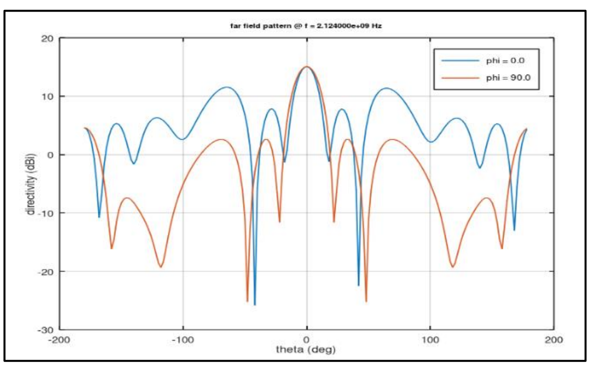

Fig. 8: Gain plot for enlarged square array. here

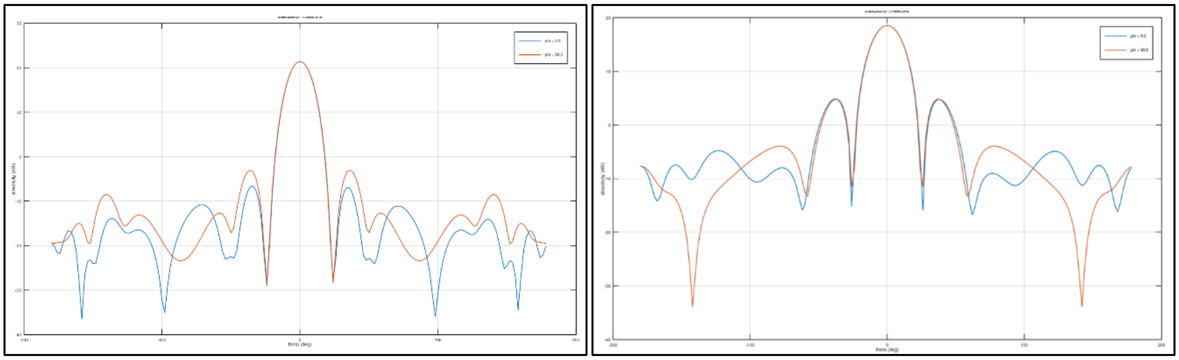

Fig. 9a and 9b: Gain plot for 25 element diamond and square array

Next, we investigate the performances of design A and B. We compared them with arrays with the same geometric configuration but with equal excitations for all elements, keeping the total excitation constant across both simulations.

For design A, we noted that its performance when φ = 0° was slightly better since its sidelobe level difference is 32.3dBi while the same array with uniform excitation had a sidelobe level of 24.4dBi. Moreover, all the sidelobes were on average lower in the first instance. When φ = 90°, the former was marginally better as it achieved a sidelobe level difference of 27.5dBi while the former had a 26.2dBi sidelobe level difference. However, the sidelobes were also generally lower in the latter. In both cases, the HPBW is around 47°.

For design B, when φ = 90°, both arrays (varied and uniform excitation) had the same sidelobe level difference of 17.5dBi. When φ = 0°, the varied array had a sidelobe level difference of 23.1dBi while the uniform array has a difference of 9.7dBi. However, its mainlobe is much wider than its uniform array counterpart, making it unsuitable for applications requiring high directivity.

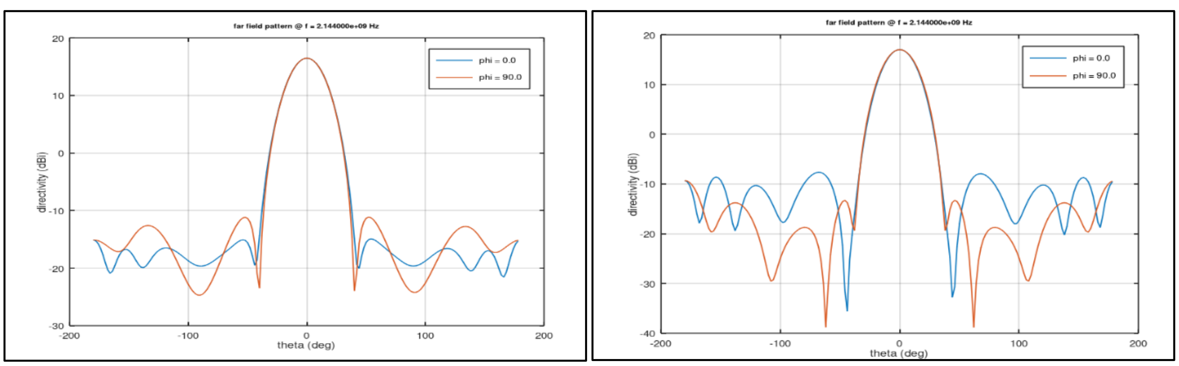

Fig. 10a and 10b: Gain plot for design A and array with equal excitation

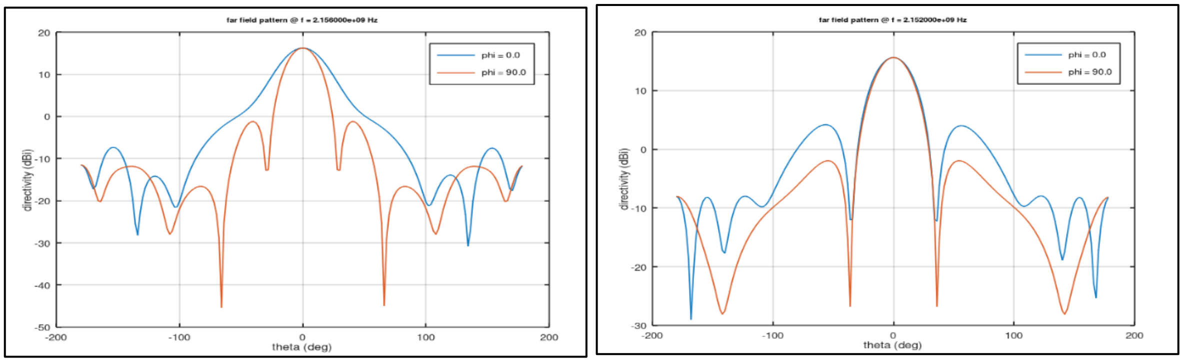

Fig. 11a and 11b: Gain plot for design B and array with equal excitation

We now start our analyses of the linear arrays. Firstly, the S11 graph of a single monopole antenna was plotted to ensure that the array would operate at the desired frequency. The sharp dip to -20dB around the 10GHz range confirms that the height we used for the antennas was suitable. In the azimuthal plane, an ideal array should have its peaks at φ = 90° and -90° (perpendicular to array), which is observed for the half wavelength array. Likewise, the number of side lobes is noticeably fewer in the aforementioned case compared to the full and double wavelength array. The elevation cut displays the pattern of a single monopole antenna. To a large extent, it resembles the distribution of an ideal monopole antenna. The discrepancies observed may be caused by the inevitable variations in the height of the antennas when manually trimming them. The crumpling of the copper tapes used to secure the antennas also added to the discrepancy. The antennas also did not exactly lie on a straight line.

Fig. 12: S11 plot for single monopole antenna

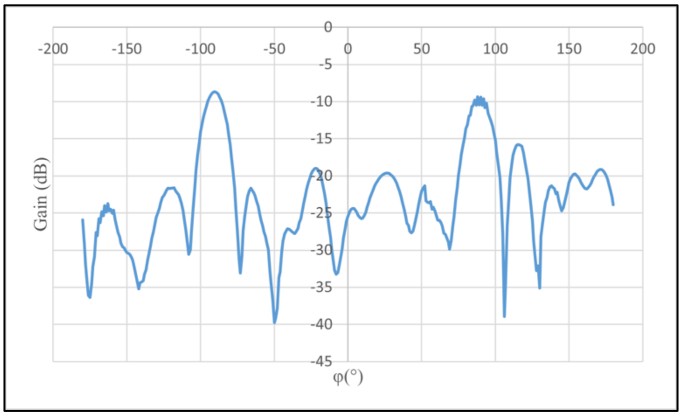

Fig. 13: Gain plot for the azimuthal cut of the array with half wavelength spacing

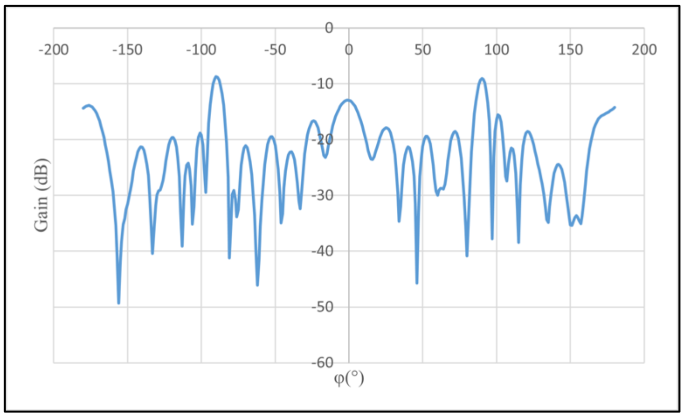

Fig. 14: Gain plot for the azimuthal cut of the array with full wavelength spacing

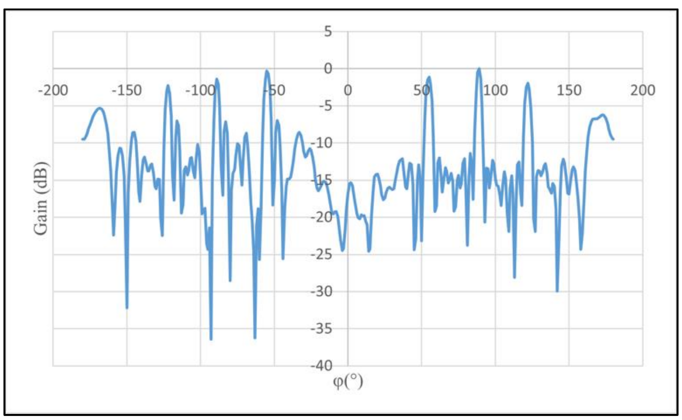

Fig. 15: Gain plot for the azimuthal cut of the array with double wavelength spacing

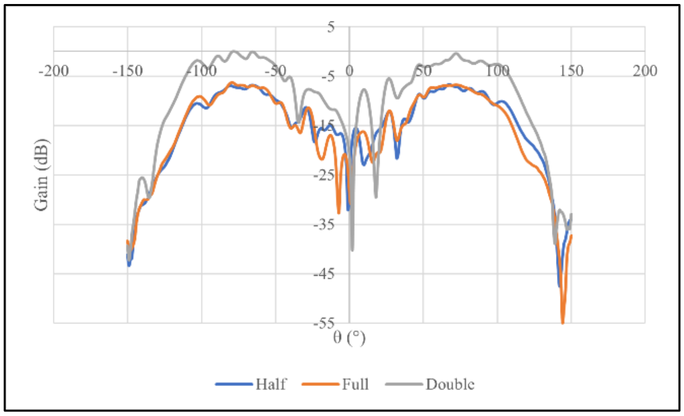

Fig. 16: Gain plot for the elevation cuts of the various arrays

DISCUSSION

Based on our results, the diamond array has proven to meet the baseline requirements for a patch antenna array, as well as display augmented performance in terms of higher gain, lower sidelobes and a narrower HPBW. This points to an application where high directivity and narrow bandwidth is required to reduce the possibility of interference from unwanted sources or parties such as in satellite technology where a high directivity ensures that signals can be directed at specific targets like ground stations and a narrow bandwidth to reduce interference and noise for clearer signals [2] and RFID tags where a high directivity increases their effective read range and a narrow bandwidth prevents interference from other nearby RFID systems [3]. Furthermore, applying Design A can suppress sidelobes effectively, reducing the loss of energy in unwanted directions.

We were unable to fabricate the patch antenna arrays due to logistical constraints. Future work may need to be done to experimentally measure the S11 and gain of the array to confirm its effectiveness. Other excitation weightage methods can be explored such as the Dolph-Chebyshev array to further reduce sidelobes.

Lastly, we managed to experimentally verify the need for the “half wavelength” principle, proving that elements should not be too far apart.

ACKNOWLEDGEMENTS

We would like to thank our mentors, Dr Ang Teng Wah and Mr Lim Zi Wei, for supporting us throughout our research project. We also express our gratitude to DSO National Laboratories for giving us this opportunity to conduct research.

REFERENCES

[1] Mahmood, A. S., & Ibrahim, D. A. (2016). Study of the Binomial Excitation of a Linear Broadside 10-Element Dipole Antenna Array. International Journal of Electronics Communication and Computer Engineering, 7(3), 147–155.

[2] Maini, A., & Agrawal, V. (2011). *Satellite Technology principles and applications* (2nd ed.). Wiley.

[3] Weinstein, R. (2005). RFID: A technical overview and its application to the Enterprise. *IT Professional,* 7(3), 27-33. https://doi.org/10.1109/mitp.2005.69