Gain enhancement for circularly polarized double layered printed hemispherical helical antenna arrays

Tarik Abdul Latef[a]*, Salam Khamas[b] and Ahmed Wasif Reza[a]

[a]*Faculty of Engineering, Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia;* [b]*Departement of Electronic and Electrical Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD, UK*

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To improve the performance of mobile satellite communications, such as for INMARSAT-M mobile vehicles, antenna with high gain and circular polarization over a wide angular range is important. With only 3-elements circularly polarized double-layered printed hemispherical helical antenna arrays that incorporated with parasitic helical wire in the structure, the array can produce significant improvement where it has been demonstrated that the gain and the 3 dB axial ratio (AR) bandwidth and beam width can be increased by properly adjusting the relative angular displacement δ_1, δ_2, δ_3, and the inter-element spacing d_x and d_y. Experimental and theoretical results demonstrate that the array can produce a gain of 11 dBi, the 3 dB AR bandwidth of more than 11% with AR beam width of ~136°, and the mutual couplings between each element less than −23 dB at required 3 dB AR bandwidth frequency range. The antenna design is performed in computer simulation technology and verified by measurement.

Keywords: antenna array; hemispherical helical antenna; circular polarization

1. Introduction

In certain applications, such as in modern commercial cellular communication systems, desirable radiation characteristics may be achieved with a single antenna element. However, characteristics such as high gain and shaped pattern capability are only possible when single elements are combined in an array structure. The elements arrangement can be in a linear, circular, or planar pattern where the fields from individual antennas interfere constructively in the desired direction and destructively in the remaining space in order to provide high gain. For example, when a circularly polarized antenna with a higher gain is needed,[1,2] arrays are introduced to increase the gain such as circular loop arrays,[3–5] helical arrays,[6–9] a hemispherical helical antennas array [10], and microstrip patch antenna arrays.[11–16] It has been shown in [6] that the gain of the helical antennas array can be increased from 17.78 dBi for a 4 × 4 array to 23.46 dBi for an 8 × 8 array. This demonstrates that by properly combining the elements, array offers the ability to form high-gain antennas for high-power applications. It should be noted that mechanical rotation of each helical antenna and proper spacing between the elements suppress the side lobes to increase the gain up to 34 dBi.[8] Additionally, it has been demonstrated that the gain of a 2 × 2 free-space hemispherical helical antenna

*Corresponding author. Email: tariqlatef@um.edu.my

array can be increased to 15 dBi while maintaining the circular polarization bandwidth of a single element.[10]

The principle operation of the proposed antenna array is to reduce the mutual coupling that affects the characteristics of the array by properly choosing the inter-element separation and the relative angle between the array elements. The mutual coupling has always been scrutinized for the array operation. Mutual coupling could cause impedance mismatch between the feeds and the corresponding individual elements, which results in degradation of polarization and distortion of the radiation pattern. Hence, the study of the mutual coupling effects is necessary to properly predict the overall characteristics of the array, especially the axial ratio (AR). To simplify the investigations, the following assumptions have been made as follows:

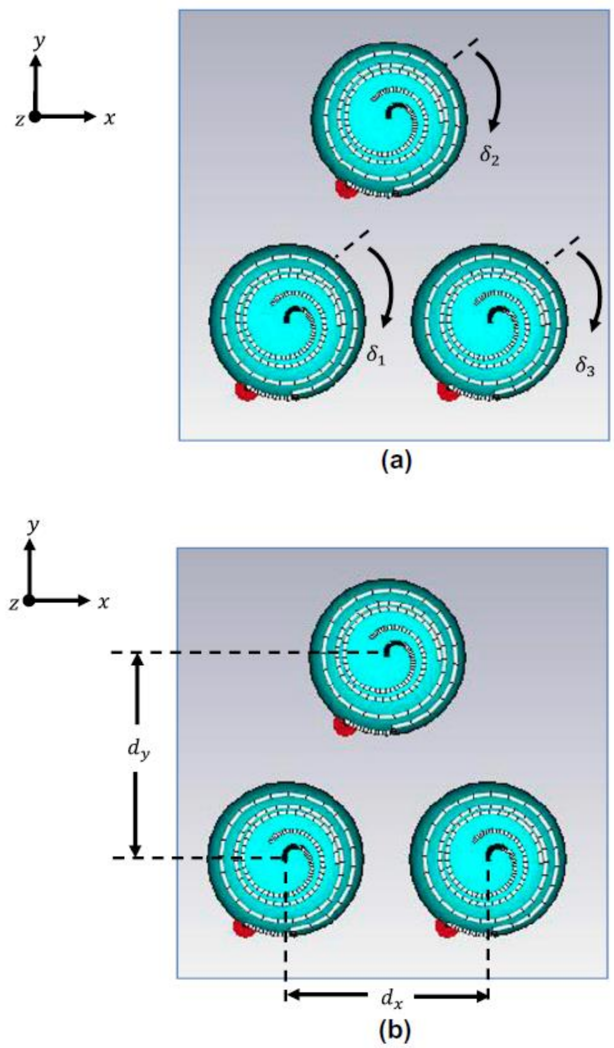

Figure 1. An array of double-layered helical antennas with parasitic wires. (a) Relative angular displacements and (b) inter-element spacing.

- Antenna array consists of identical elements.
- The orientation of the elements is the same, which is the relative angular displacements are equal.
- The elements are uniformly spaced.
- All elements spaced symmetrically about the origin with equal excitation magnitude and phase.

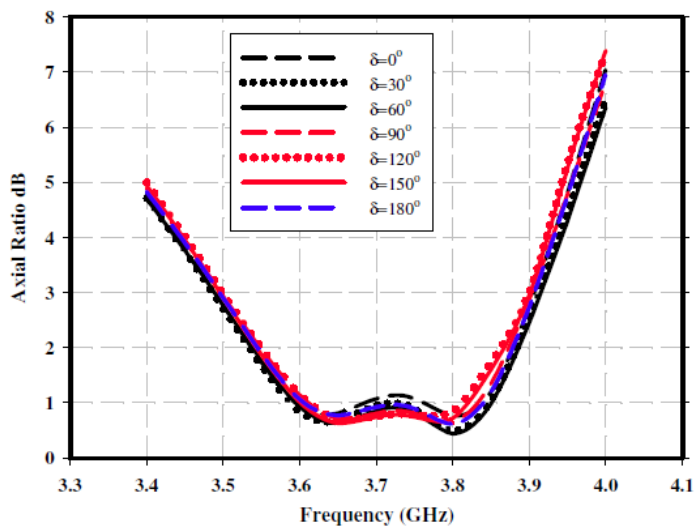

Figure 2. Variations of the 3 dB AR bandwidth with the relative angular displacement δ.

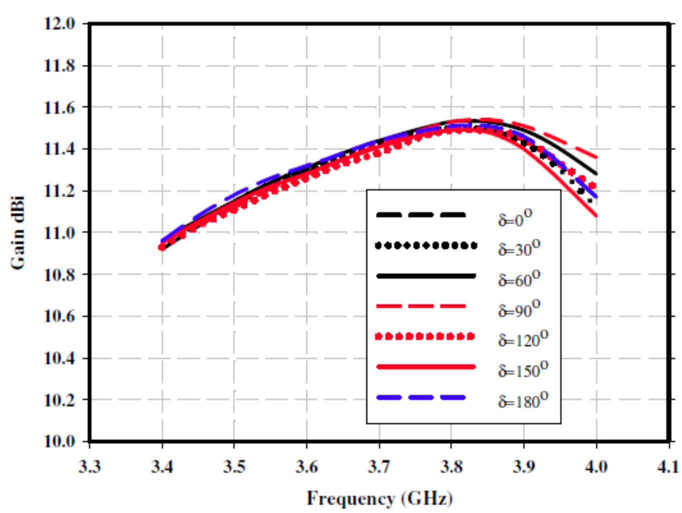

Figure 3. Variation of the gain with the relative angular displacement δ.

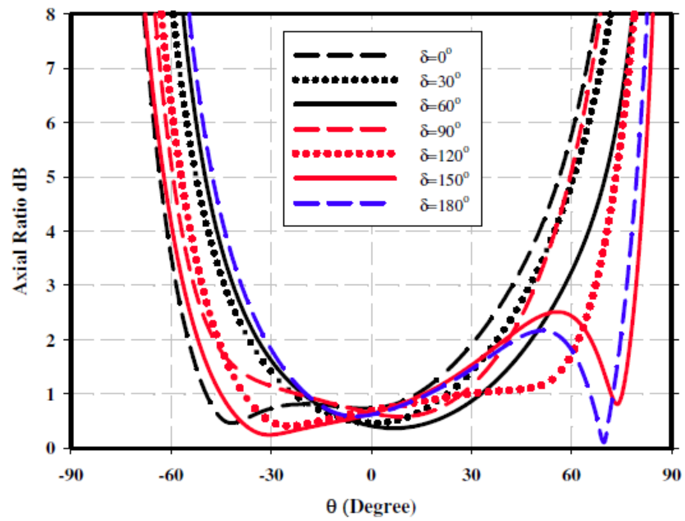

Figure 4. The 3 dB AR beam width of the three-elements array.

This paper presents an investigation of a hemispherical helical antenna array, in which the elements are printed on double-layered hemispheres. The array antenna in this work is an improvement of our earlier work mentioned [17] where in [17], only single element to be used compared to the proposed antenna that used 3-elements array with a parasitic helical wire. The results show that the improvement on a gain of 11.35 dBi with AR bandwidth of 11.35% has been achieved when compared to [17] where only 9 dBi of gain has been obtained. Therefore, the idea for bandwidth enhancement and the configuration of hemispherical helical antennas are not exactly similar to [17], but it is an enhanced version.

Even though the discussion on the relative angular displacement and the inter-element spacing [10] is similar to the proposed antenna, there is no information on AR beam width in [10] where in proposed antenna, AR beam width of ~136° at the lowest AR frequency has been achieved. In conclusion, this paper proposes an enhanced version of three printed hemispherical helical antenna with parasitic wires to achieve gain enhancement compared to existing works in the literature. The analysis has been implemented using Computer Simulation Technology,[18] and the results have been compared with measurements.

Table 1. Summary of AR bandwidth, beam width, and gain against relative angular displacement $\delta = \delta_1 = \delta_2 = \delta_3$.

Angular (°)	0	30	60	90	120	150	180
Angular (°)	0	30	60	90	120	150	180
AR bandwidth (%)	10.49	10.76	10.76	10.52	10.63	10.96	10.52
AR beam width (°)	103	95	99	104	117	136	115
Gain at lowest AR (dBi)	11.50	11.50	11.53	11.53	11.35	11.35	11.51
Half-Power beam width (°)	52.3	52.8	52.7	52.1	52.7	53.1	52

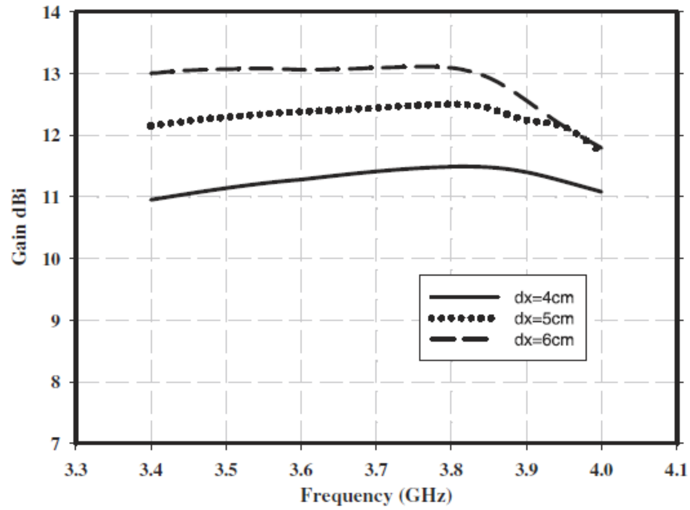

Figure 5. Variations of the gain with the inter-element spacing with $\delta = 150°$.

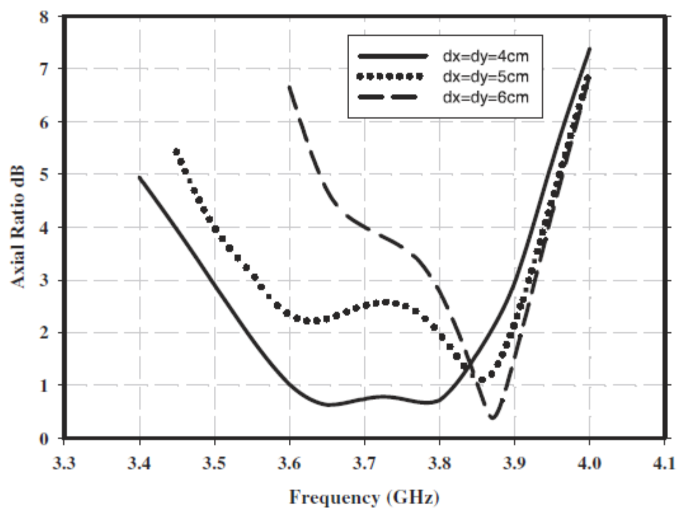

Figure 6. Variations of the 3 dB AR bandwidth with the inter-element spacing with $\delta = 150°$.

2. Design procedure

The geometry of the proposed antenna array is presented in Figure 1. An operating frequency range of 3.45–3.95 GHz has been chosen, which is similar to what has been used in [17,19,20]. In order to produce a radiation with a good AR, each element's contribution has been optimized by changing the relative angular displacement δ as well as the inter-element spacing d as shown in Figure 1. The optimization has been implemented to achieve an array configuration that provides a relatively high gain in the main-beam direction while maintaining the wideband 3 dB AR bandwidth and beam width.

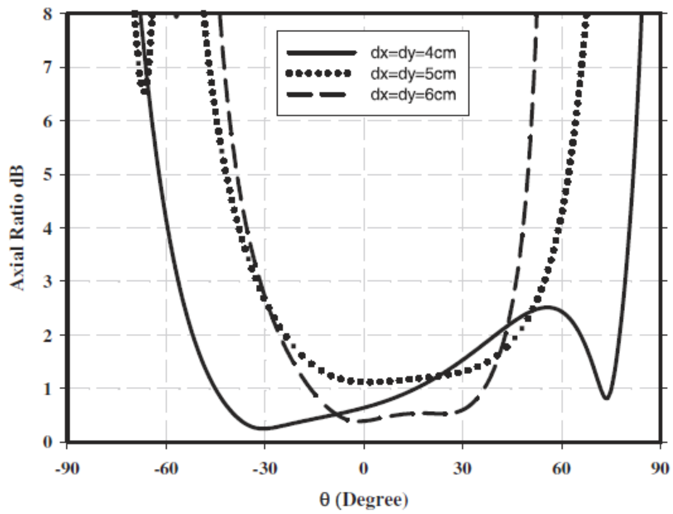

Figure 7. Variations of the 3 dB AR beam width with the inter-element spacing with $\delta = 150°$.

Table 2. Summary of AR bandwidth, beam width and gain against inter-element spacing d_x, d_y.

Inter-element spacings (cm)	4	5	6
AR bandwidth (%)	10.96	9.33	3.48
AR beam width (°)	136	85	78
Gain at lowest AR (dBi)	11.35	12.41	12.80
Half-power beam width (°)	53.1	45.5	40.4

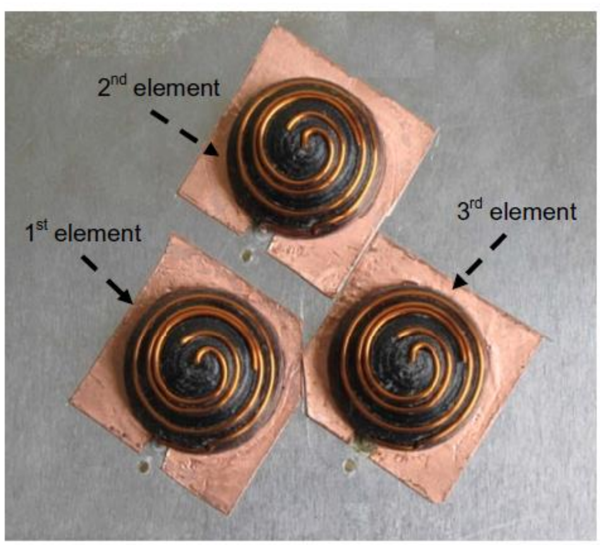

Figure 8. Fabricated 3-elements array of double-layered helical antennas with parasitic wires.

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