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

Tarik Abdul Latef\textsuperscript{a}, Salam Khamas\textsuperscript{b} & Ahmed Wasif Reza\textsuperscript{a}

\textsuperscript{a} Faculty of Engineering, Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
\textsuperscript{b} Departemen of Electronic and Electrical Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD, UK

Published online: 26 May 2015.

To cite this article: Tarik Abdul Latef, Salam Khamas & Ahmed Wasif Reza (2015): Gain enhancement for circularly polarized double layered printed hemispherical helical antenna arrays, Journal of Electromagnetic Waves and Applications, DOI: 10.1080/09205071.2015.1044126

To link to this article: http://dx.doi.org/10.1080/09205071.2015.1044126
Gain enhancement for circularly polarized double layered printed hemispherical helical antenna arrays

Tarik Abdul Latef\textsuperscript{a}\textsuperscript{*}, Salam Khamas\textsuperscript{b} and Ahmed Wasif Reza\textsuperscript{a}

\textsuperscript{a}Faculty of Engineering, Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia; \textsuperscript{b}Department of Electronic and Electrical Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD, UK

(Received 3 June 2014; accepted 19 April 2015)

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 $\delta_1$, $\delta_2$, $\delta_3$, 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,\cite{1,2} arrays are introduced to increase the gain such as circular loop antennas,\cite{3–5} helical arrays,\cite{6–9} a hemispherical helical antennas array \cite{10}, and microstrip patch antenna arrays.\cite{11–16} It has been shown in \cite{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.\cite{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 $\delta$.

Figure 3. Variation of the gain with the relative angular displacement $\delta$. 
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>
<thead>
<tr>
<th>Angular (°)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular (°)</td>
<td>0</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td>120</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>AR bandwidth (%)</td>
<td>10.49</td>
<td>10.76</td>
<td>10.76</td>
<td>10.52</td>
<td>10.63</td>
<td>10.96</td>
<td>10.52</td>
</tr>
<tr>
<td>AR beam width (°)</td>
<td>103</td>
<td>95</td>
<td>99</td>
<td>104</td>
<td>117</td>
<td>136</td>
<td>115</td>
</tr>
<tr>
<td>Gain at lowest AR (dBi)</td>
<td>11.50</td>
<td>11.50</td>
<td>11.53</td>
<td>11.53</td>
<td>11.35</td>
<td>11.35</td>
<td>11.51</td>
</tr>
<tr>
<td>Half-Power beam width (°)</td>
<td>52.3</td>
<td>52.8</td>
<td>52.7</td>
<td>52.1</td>
<td>52.7</td>
<td>53.1</td>
<td>52</td>
</tr>
</tbody>
</table>

Figure 4. The 3 dB AR beam width of the three-elements array.
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 $\delta$ 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 $\delta = 150^\circ$.

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

<table>
<thead>
<tr>
<th>Inter-element spacings (cm)</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR bandwidth (%)</td>
<td>10.96</td>
<td>9.33</td>
<td>3.48</td>
</tr>
<tr>
<td>AR beam width (°)</td>
<td>136</td>
<td>85</td>
<td>78</td>
</tr>
<tr>
<td>Gain at lowest AR (dBi)</td>
<td>11.35</td>
<td>12.41</td>
<td>12.80</td>
</tr>
<tr>
<td>Half-power beam width (°)</td>
<td>53.1</td>
<td>45.5</td>
<td>40.4</td>
</tr>
</tbody>
</table>

Figure 8. Fabricated 3-elements array of double-layered helical antennas with parasitic wires.
2.1. Determination of the relative angular displacements

In order to carry out the parametric study of the optimum relative angular displacements, the rotation angle of each element has been varied from 0° to 180°. Due to practical reasons, it is too difficult to fabricate a 3-elements array with inter-element spacing less than 4 cm. As a result, $d_x$ and $d_y$ have been fixed at 4 cm at this stage. It should be noted that increasing the relative angular displacements more than 180°

![A 1-to-4 port power divider.](image)

Figure 9. A 1-to-4 port power divider.

![Frequency response of the first array element of a matched helical antenna printed on a double-layered dielectric hemisphere.](image)

Figure 10. Return losses of the first array element of a matched helical antenna printed on a double-layered dielectric hemisphere.

2.1. Determination of the relative angular displacements

In order to carry out the parametric study of the optimum relative angular displacements, the rotation angle of each element has been varied from 0° to 180°. Due to practical reasons, it is too difficult to fabricate a 3-elements array with inter-element spacing less than 4 cm. As a result, $d_x$ and $d_y$ have been fixed at 4 cm at this stage. It should be noted that increasing the relative angular displacements more than 180°
produces the same results at certain angles, e.g. $210^\circ = 30^\circ$, $240^\circ = 60^\circ$... and $330^\circ = 150^\circ$.

Figure 2 shows the variations of the 3 dB AR bandwidth for various relative angular displacements, where it can be seen that varying $\delta$ has a marginal effect on the 3 dB AR bandwidth, which is approximately 10.5% in all cases. These results show that the array configurations offer a wider AR bandwidth compared to a single helical antenna.[19] It also has been noticed that an array gain of 11.5 dBi has been achieved irrespective of the chosen $\delta$, as shown in Figure 3. However, the 3 dB AR beam width changes considerably as $\delta$ varies. This is illustrated in Figure 4, where it can be seen that a 3 dB AR beam width of $136^\circ$ has been obtained when $\delta = 150^\circ$ with an 11.35 dBi gain at the lowest AR frequency point of 3.80 GHz.

Table 1 summarizes the optimization procedure. It should be noted that varying $\delta$ has no effect on the half-power beam width where $\sim 52^\circ$ has been attained in all cases.

Figure 11. Radiation pattern of the 3-elements array of a matched helical antenna printed on a double-layered dielectric hemisphere (a) $\phi = 0^\circ$ and (b) $\phi = 90^\circ$ at a frequency of 3.80 GHz.
Therefore, the relative angular displacements have been chosen as \( \delta = \delta_1 = \delta_2 = \delta_3 = 150^\circ \) in the next section’s investigation to determine the optimum inter-element spacing \( d \).

2.2. Determination of the inter-element spacing

The variation of the array’s gain with different separation distances between the centers is shown in Figure 5 when \( \delta = 150^\circ \). It can be seen that increasing the inter-element

![Figure 12](image1.png)

Figure 12. AR beam width of the 3-elements array at the \( \phi = 0^\circ \) plane at a frequency of 3.80 GHz.

![Figure 13](image2.png)

Figure 13. AR and gain of the 3-elements array of a matched helical antenna printed on a double-layered dielectric hemisphere.
spacing $d = d_1 = d_3$ from 4 to 6 cm increases the gain at the lowest AR and from 11.35 to 12.8 dBi at the lowest AR point. However, changing the separation reduces both the 3 dB AR bandwidth and beam width where the 10.96% of AR bandwidth has been reduced to 3.48% and the 136° of AR beam width has been reduced to 78° as illustrated in Figures 6 and 7. Table 2 shows the summary of the 3 dB AR bandwidth, beam width, and gain against the inter-element spacing. It can be noted that increasing the inter-element spacing from 4 to 6 cm also reduces the half-power beam width from 53.1° to 40.4°, which is expected since the gain and beam width are inversely proportional to each other. Therefore, a gain of 11.35 dBi and optimum values of 3 dB AR bandwidth and beam width and have been achieved using the relative angular displacements of $\delta_1 = \delta_2 = \delta_3 = \delta = 150°$ and inter-element spacing of $d = d_1 = d_3$ of 4 cm. In the next section, the construction of an array is presented by employing the aforementioned values of $\delta$ and $d$.

3. Experimental results
To validate the simulation results obtained in the previous section, an array was constructed using the optimum relative angular displacement of 150° and an inter-element spacing of $d$ of 4 cm. Figure 8 illustrated the fabricated 3-elements array of double-layered helical antennas with parasitic wires. To feed the array, a 1-to-4 port power divider has been used as shown in Figure 9. The inlet of the power divider has been connected to the servo controller, and the antenna elements have been fed via SubMiniature version A (SMA) connectors to the output ports. Figure 10 illustrates the measured and simulated return losses for each array element. It can be seen that return losses of less than $-10 \text{ dB}$ have been achieved over bandwidths of approximately 12 and 11% in the computed and measured results, respectively.

Good agreement has been achieved between the computed and measured far field patterns as shown in Figure 11, where an isolation of more than 30 dB has been achieved between the right-hand and left-hand polarization field components. Since the

---

Figure 14. Measured AR and return losses of the 3-elements array of a matched helical antenna printed on a double-layered dielectric hemisphere.
Right-hand polarization field component is the dominance as shown in Figure 11, therefore, the type of circular polarization for the proposed antenna will be the right-hand circularly polarized antenna. The radiation patterns are side lobes free with a half-power beam width of 53°. Figure 12 shows that a circular polarization angular coverage over an angle of 136° has been achieved in both theory and experiment. The AR and gain are illustrated in Figure 13, where it can be observed that AR bandwidths of 10.96 and 11.29% have been achieved in the simulated and measured results, respectively. Additionally, the array offers a gain of 11.35 dBi at the minimum AR frequency point. Therefore, using a 3-elements array increases the gain by 3.55 dBi, which is by more than 45%, compared to the single element where only 7.8 dBi gain has been achieved. Figure 14 shows the frequency responses of the measured AR and return losses where 100% of the overlap region between AR < 3 dB and the S\textsubscript{11} < –10 dB bandwidths have been achieved as shown in the shaded region.

4. Conclusion

3-elements double-layered helical antenna array has been designed and measured, where it has been demonstrated that the gain can be significantly increased to 11.35 dBi by properly adjusting the relative angular displacement $\delta_1, \delta_2, \delta_3$ and the inter-element spacing $d_x$ and $d_y$. This has been achieved with an enhanced AR bandwidth of approximately 11% when compared to previous work in [20] where only ~8% of AR bandwidth and ~8 dBi of gain has been achieved. Furthermore, an AR beam width of ~136° has been achieved, which is the same as that of a single element. The optimized relative angular displacement and inter-element spacing has reduced the mutual couplings to less than ~23 dB at required 3 dB AR bandwidth frequency range. Since the array elements have been matched using integrated impedance matching sections,[19,20] the 12% impedance matching bandwidth has been maintained and covered the AR bandwidth of 10.96% over a frequency range of 3.5–3.9 GHz, where an overlap of 100% has been achieved between the AR and impedance matching bandwidths. Other formations of the array, such as two linear arrays, three linear arrays, and four square arrays have been used in the design, where in spite of the fact that the gain has been increased by 15% compared to single element, the 3 dB AR bandwidth and beam width reduced significantly.

Funding

This research work is supported by the University of Malaya Research Fund Assistance (BKP) BK045-2014.

References


