Circular Planar Antennas with Horizontal and Vertical Shaped DGS Pairs

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1. Introduction

Defected Ground Structure (DGS) technique has been largely investigated in recent years, particularly in the development of planar antennas [1]-[5]. The technique has been proven to improve some characteristics of the antenna for certain applications such as reduce mutual coupling in a microstrip array, and reduce cross polarization radiation on a single element. The approach employs simple and easy designs to be etched on the ground plane, that disturbs the current distribution but improve the performance of the antenna. The work of [2] has been further investigated with two different sets of DGS slots. This paper presents the design of two sets of microstrip circular patch (MCP) antennas with variations of horizontal and vertical DGS slot elements. Each set began with a pair of short rectangular slots, and proceeded to increasing the slot sizes to form long rectangular slots, and finally U- and T-shaped DGS slots. The antennas were named MCP_DH and MCP_DV antenna sets. The effects of introducing DGS pair of slots into the MCP ground plane have been successfully investigated [6].

2. Microstrip Circular Patch with DGS Vertical and Horizontal Slot Pairs, MCP_DH and MCP_DV, Antennas

The basic MCP antenna is first designed using formulae available in the literature [2],[7],[8]. The chosen microwave laminate is the Tarconic substrate with relative permittivity = 2.33, loss tangent = 0.0012, dielectric layer = 1.575 mm, copper thickness = 0.035 mm, and copper conductivity = 5.887 X10^7 S/m. The effective radius is given by [2]:

\[ a_e = a \sqrt{1 + \frac{2h}{\pi a e} \ln \frac{\pi a}{2h} + 1.7726} \]  

where \( a \) is the physical radius less than \( a_e \), \( h \) is the thickness of the dielectric layer, and \( \varepsilon_r \) is the relative permittivity. The desired resonant frequency \( f_{res} \) at TMnm mode is 3.6 GHz and \( a_e \) is first calculated from the equation [8]:

\[ f_{res} = \frac{\chi_{nm} c}{2\pi a_{phys}} \]  

where \( \chi_{nm} \) is the zero of the derivative of Bessel function of order \( n \), and \( c \) is the velocity of light in free space. The antenna dimension \( a_e \) is then computed as ~16 mm, giving the antenna physical radius of ~ 15 mm.

A coaxial probe type feed has been selected. Its location corresponds to an input impedance of 50 ohms at resonance, indicating excellent impedance match at the input. The location was computed using equations from [7],[8], as 4 mm from the origin. Through simulations, variations of input impedance along the radius of the patch from the origin to its right most edge can be used to locate the optimum feed point. The value is high close to the edge, reduces towards near the center. It was found that, the optimum feed location of the MCP antenna agrees with theory.

A DGS slot pair is then embedded into the ground plane of the MCP antenna. General circuit model for modelling a wide range of DGS structure is available in [9]. Variations of the DGS
slot pair are then introduced in order to optimize the antenna performance, particularly in suppressing the undesired inherent cross-polarization. Two DGS slot pairs have been considered, the vertical and horizontal and variations. An example of the MCP antenna geometry with an embedded DGS slot pair is illustrated in Figure 1. Each antenna has been successfully numerically simulated using em software [12].

The MCP_DH antenna was first simulated for its return loss behaviour with varying horizontal DGS slot pairs. The DGS DH slot pairs are horizontal short rectangular, horizontal long rectangular, horizontal L-shaped, and horizontal U-shaped. The final optimized performance is comparable to [11]. The MCP_DV antenna was first simulated for its return loss behaviour with varying vertical DGS slot pairs. The DGS DV slot pairs are vertical short rectangular, vertical long rectangular, vertical short T-shaped, and vertical long T-shaped. The final optimized performance of the antenna is then compared to MCP_DH antenna.

3. Performances of the MCP_DH and MCP_DV Antennas

3.1 MCP_DH Antenna

Figure 3 shows the return loss responses of the MCP and MCP_DH antennas. All antennas operate well at similar operating frequencies, close to the desired 3.6 GHz, with excellent return losses of below -25 dB and narrow operating bandwidths in the range of 2.7 %. The corresponding VSWR and input impedance are close to 1.1 and 47 Ohm, respectively. These agree well with that of the MCP antenna, indicating excellent impedance match. The DGS slot has slight effect on the resonances of the MCP_DH antennas. DGS slot sizes of 2 X (2 mm$^2$) = 4 mm$^2$ and 2 X (8 mm$^2$) = 16 mm$^2$ did not shift the resonance. However, DGS slot sizes of 2 X (8 mm$^2$) = 20 mm$^2$ and 2 X (17 mm$^2$) = 34 mm$^2$ have shifted the resonance by 10 MHz and 30 MHz, respectively. These correspond to slight size reduction factors of 0.01:3.65 = 0.0027 or 0.27 %, and 0.03:3.65 or 0.0082 or 0.82 %, respectively. The lower shift may be attributed to the change of the input reactance of the dominant mode under the patch caused by significant introduced defects on the ground plane [2],[10]. Despite similar resonance performances, MCP_DHU antenna operates with the least size of 0.82 % reduction factor. The observations are similar to circular shaped DGS [2].

3.2 MCP_DV Antenna

Figure 4 shows the return loss responses of the MCP and MCP_DV antennas. All antennas operate well at their operating frequencies, with excellent return losses of approximately -25 dB and narrow operating bandwidths in the range of 2.7 %. The corresponding VSWR and input impedance are close to 1.1 and 47 Ohm, respectively. These agree well with that of the MCP antenna, indicating excellent impedance match. The DGS slot has slight effect on the resonances of the MCP_DH antennas. DGS slot sizes of 2 X (2 mm$^2$) = 4 mm$^2$ did not shift the resonance. However, DGS slot sizes of 2 X (10 mm$^2$) = 20 mm$^2$ and 2 X (15 mm$^2$) = 30 mm$^2$ have shifted the resonance by 140 MHz, 170 MHz, and 220 MHz, respectively. These correspond to varying size reduction factors of 0.14:3.65 = 0.039 or 3.9 %, 0.17:3.65 = 0.047 or 4.7 %, and 0.22:3.65 = 0.06 or 6 %, respectively. The lower shift may be attributed to the change of the input reactance of the dominant mode under the patch caused by significant introduced defects on the ground plane [2],[10]. Despite similar resonance performances, MCP_DVLT operates with the smallest size of 6 % reduction factor.

3.3 Discussions

From Figures 3 and 4, it can be seen that all the antennas operate well at their corresponding resonances with similar narrow bandwidths in the range of 2.7 %. Among the MCP_D antennas, MCP_DVLT antenna is the most compact due to its lower shift of resonant frequency. This may be attributed to the change of the input reactance of the dominant mode under the patch caused by significant introduced defects on the ground plane [2]. The T-shaped DGS slot is able to reduce the MCP antenna size by 6 %. It can be inferred that the optimum performance is the MCP_DVLT antenna.

Table 1 summarizes the two-port performance indices radiation patterns of the MCP and MCP_D antennas. The identical E- and H-plane patterns showed that the antennas radiate in
broadside directions with broad HPBWs in the range of 75°, which agree well with theory [7],[8] and [2]. The DGS slots have affected the E- and H-plane cross-polarisation levels of the corresponding MCP_DV antennas. The former levels were affected more. Small DGS slot size of 2 X (2 mm²) = 4 mm² has negligible effect on the cross-polarisation levels. However, DGS slot sizes of 2 X (8 mm²) = 16 mm², 2 X (10 mm²) = 20 mm² and 2 X (15 mm²) = 30 mm² have significantly lowered the E- and H-plane cross-polarisation levels. The corresponding amounts of reductions are in the range of 10 dB to 6 dB. The reduction is caused by the weakening of the orthogonal resonance that is significant in MCP antennas or when DGS are of smaller sizes, similar to [2]. In other words, the DGS patterns weakened the orthogonal fringing fields [2]. It can be concluded that MCP_DVLT is the optimum configuration with least cross-polarisation levels, thus most suppressed E- and H-plane by 9.58 dB. The former experienced more suppression.

4. Conclusions and Further Work

Two sets of MCP antennas with different DGS slot pairs are presented. Similar performances with the literature were observed. The antennas operate well at their corresponding frequencies of operations. All antennas exhibit narrow bandwidths of 2.7 %, and broad HPBWs in the range of 75°. Very slight shifts of the resonant frequencies were observed in the MCP_DH antennas, indicating reduction in antenna size. Vertical DGS configurations were able to suppress the cross-polarisation levels better, compared to the horizontal DGS configurations. The E-plane cross-polarisations were better suppressed compared to the H-plane cross-polarisations, by a factor of 2. The optimum configuration is chosen to be the MCP_DVLT antenna, despite having size reduction of 6 % which is the smallest size at the desired frequency.

Acknowledgments

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References

Figure 1: Geometry of MCP Antenna with a DGS slot pair.

Figure 2: Return Loss Responses of the MCP and MCP_DH Antennas.

Figure 3: Return Loss Responses of the MCP and MCP_DV Antennas.

Table 1: Two-Port Performance Indices of MCP and MCP_D antennas

<table>
<thead>
<tr>
<th>Antennas</th>
<th>HPBW, co-polar E- and H-planes</th>
<th>E- and H-plane co-polar gains, dB</th>
<th>E-plane cross polar level, dB</th>
<th>Relative E-plane cross polar, dB</th>
<th>H-plane cross polar level, dB</th>
<th>Relative H-plane cross polar, dB</th>
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<tr>
<td>MCP</td>
<td>73.85°</td>
<td>7.271</td>
<td>-12.03</td>
<td>19.301</td>
<td>-12.03</td>
<td>19.301</td>
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<td>MCP_DHSR</td>
<td>74.7°</td>
<td>7.269</td>
<td>-11.73</td>
<td>18.999</td>
<td>-11.73</td>
<td>18.999</td>
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<tr>
<td>MCP_DHLR</td>
<td>74.67°</td>
<td>7.263</td>
<td>-11.48</td>
<td>18.743</td>
<td>-11.49</td>
<td>18.753</td>
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<tr>
<td>MCP_DHL</td>
<td>74.68°</td>
<td>7.251</td>
<td>-11.42</td>
<td>18.671</td>
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<tr>
<td>MCP_DHU</td>
<td>74.71°</td>
<td>7.234</td>
<td>-11.79</td>
<td>19.024</td>
<td>-11.79</td>
<td>19.024</td>
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<tr>
<td>MCP_DVSR</td>
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<td>7.269</td>
<td>-11.8</td>
<td>18.348</td>
<td>-11.8</td>
<td>18.348</td>
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<td>MCP_DVLR</td>
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<td>-17.58</td>
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