A Novel Technique for Sidelobe and Backlobe Reduction in Rectangular Microstrip Antenna Array Using Defected Ground Structures

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ABSTRACT
In this communication, first a four element rectangular microstrip antenna array is designed, with corporate feed technique for X-band frequency of 9.1GHz, with a peak gain of 10.09dB, peak sidelobe level of -10.74dB and backlobe level of -13.71dB. Then defected ground structure (DGS) slots are applied at the feed line T-junctions with appropriate size and shape. With DGS the peak sidelobe level has reduced to -14.46dB and the backlobe level has reduced to -23.12dB. The front to back ratio has increased from 13.72dB to 17.31dB. Both sidelobe and backlobe levels are reduced over 8.7 GHz to 9.3GHz, by this technique. The 3dB gain bandwidth has also increased from 1.38GHz to 1.42GHz. Slight improvement in the peak gains is also observed by this novel technique. The Simulations are carried using HFSS software.

Keywords: Defected ground structure, Front to back ratio, Return loss, Surface waves, and Sidelobe level.

I. INTRODUCTION
Design of antenna array with high gain, narrow beam width, low sidelobe level, and high front to back ratio (FBR) is very challenging in communication systems. Single element antenna cannot cater to all the needs of communication. To achieve the desired radiation parameters, array antenna is preferred, wherein desired radiation pattern can be obtained by changing the amplitude distribution, phase excitation and element spacing [1]. Microstrip antenna arrays are being used in satellites, missiles, aircrafts, and spacecraft etc. Design of microstrip antenna array with low sidelobe and back lobe is very much essential to avoid the electromagnetic interference problems. Implementing non-uniform amplitude distribution, phase variations are much complicated especially in microstrip antenna arrays. There are some limitations in implementing thin feedlines due to technology constraints [2]. Not only that, when the design is aimed at improving one parameter, the other parameters diminish.

In such scenario, defected ground structure (DGS) promise good performance without going for complicated feed designs in microstrip antenna arrays. In the paper [3], the concept of EM-EBG structure is illustrated to improve the performance of microstrip antenna array, with low sidelobe. The concept of external CSRRs is proposed to reduce the sidelobe level by 4.3dB for planar array [4]. Here complimentary split ring resonators are placed at either ends of antenna row to reduce sidelobe level. In [5], the concept of circular, triangular and pie-shaped slots is proposed to decrease the sidelobe and to increase the gain. Design of controlled feed by non-uniform excitation, for linear array is mentioned to suppress the sidelobe level [6]. Using the Co-planar rod parasitic elements, the back lobe reduction is explained in [7], for microstrip patch antenna over L band. To simultaneously reduce sidelobe and enhance the impedance bandwidth, the idea of differential-fed microstrip antenna is proposed [8]. The idea of fruit-fly optimization is proposed for array synthesis with low SLL [9]. In [10], the method of SIW cavity- backed slot is discussed to achieve FBR greater than 19dB. In this paper, a novel technique for sidelobe and backlobe reduction using DGS slots adjacent to the feed line T-junctions in the corporate feed network is presented. Section II discusses the design of 4-element rectangular microstrip array. Section III gives the description of 4-element microstrip array with DGS. In Section IV, the results and discussions are presented. Section V gives the conclusion.

II. DESIGN OF 4-ELEMENT RECTANGULAR MICROSTRIP PATCH ANTENNA ARRAY
First, a single rectangular microstrip patch antenna is designed for $f_0 = 9.1$GHz resonant frequency, on FR4 substrate with dielectric constant $\varepsilon_r = 4.4$. The height of the substrate is $h = 1.6$mm. The width and length are calculated using the following equations [1], [11].

The Width of the patch antenna is calculated as

$$W = \frac{c}{2f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \quad (1)$$

Calculation of Actual Length (L): The effective length of the patch antenna depends on the resonant frequency ($f_0$)

$$L_{eff} = \frac{c}{2f_0 \sqrt{\varepsilon_{reff}}} \quad (2)$$

Where $\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + \frac{1.2h}{w}\right]^\frac{1}{2}$

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The E-fields at the edges of the patch undergo fringing effects. Because of these effects, the effective length of the patch antenna appears to be greater than its actual length. So, actual length and the effective length of a patch antenna can be related as

\[ L = L_{\text{eff}} - 2\Delta L \]

(4)

Where \( \Delta L \) is a function of effective dielectric constant \( \varepsilon_{\text{reff}} \) and the width to height ratio \((w/h)\).

\[
\frac{\Delta L}{h} = 0.412 \left( \frac{\varepsilon_{\text{reff}} + 0.3}{\varepsilon_{\text{reff}} - 0.258} \right) \left( \frac{w}{h} + 0.264 \right)
\]

(5)

The designed values of patch antenna are \( W=10.03\text{mm}, L=7.17\text{mm} \). The patch antenna shown in figure 1 is in turn optimized for best return loss, by varying \( L \) value. At \( L=6.8082\text{mm} \), return loss of 35.6dB was achieved using HFSS software. The optimized dimensions of the rectangular patch antenna are \( W=10.03\text{mm} \) and \( L=6.8082\text{mm} \).

Taking the optimized dimensions of single patch, 4-element array is designed using corporate feed technique as shown in figure 2.

Input will be given to 50Ω line, which is equally dived using 100Ω lines. The 100Ω lines are connected to 50Ω junction points of next stage by using quarter wave transformer of 70.7Ω lines. Each patch impedance is 250Ω. The patch and 100Ω lines are connected using quarter wave transformer of 158Ω.

III. DESIGN OF MICROSTRIP ANTENNA ARRAY USING DEFECTED GROUND STRUCTURES (DGS) FOR SIDELOBE AND BACK LOBE REDUCTION

The defected ground structure is a novel concept introduced to improve the performance of printed antennas. These are the defects created in the ground plane of microstrip antennas with different shapes and sizes. DGS can be a resonant type or non-resonant type depending on its arrangement and shape on the ground plane [12]. They can be applied for different patch structures like triangular, rectangular, circular etc. [13], [14]. DGS finds applications in filters, couplers, and diplexers etc. DGS can be used to reduce cross-polarization in microstrip patch antennas [15]. These can be used in the suppression of harmonics. Defected ground structures can suppress the unwanted modes in propagation and helps to reduce the cross polarization effects. These can be used for miniaturization of microstrip antennas [16], [17]. These defected ground structures disturb the current distribution and effect the radiation pattern of the antenna. DGS can be modelled with equivalent RLC circuit [18], [19] as shown in figure 3.
The DGS has pass band and stop band characteristics. Surface waves are the main reason for increase of sidelobes and back lobe. They scatter at the discontinuities of substrate and lead to unwanted radiation. At T-junctions of feed network, small power will get radiated at the discontinuities and disturb the main lobe radiation pattern. The stop band of DGS will suppress the surface waves and higher harmonics and lead to decrease of sidelobes and backlobe.

Here rectangular DGS slots are placed adjacent to the T-junctions of feed network as shown figures 4 and 5. In DGS configuration-1, six DGS slots are placed adjacent to the T-junctions, in the second stage of corporate feed network. The optimized dimension of type3 DGS is 1.6mmX3.0mm and that of type4 is 0.70mmX12.50mm. These are shown in figure 4. To further improve the performance in terms of sidelobe and back lobe, the type1 and type2 DGS slots are placed at the T-junction of first stage of the feed network. The optimized dimension of type 1 DGS is 3.058mmX3.058mm and that of type 2 is 0.70mmX3.058mm.

IV. RESULTS & DISCUSSIONS

Figure 6 shows the $S_{11}$ plot of the 4-element microstrip antenna array in three cases. With DGS, the resonant frequency shifts to lower frequency. Here it has shifted to 8.7GHz with DGS configuration-1 and to 8.75GHz with DGS configuration-2. A return loss of 26dB is observed with DGS configuration-2 at 8.75GHz. At resonant frequency of 9.1GHz, the return loss decreases with DGS. Without DGS, a return loss of 20.36dB is observed at 9.1GHz. Return loss of 13.57dB is obtained with DGS configuration-1 and 14.93dB is obtained with DGS configuration-2. Even though return loss decreasing, still performance has not degraded. For a practical antenna, a return loss of 10dB is minimally needed. In this case it has not violated at 9.1 GHz. It is even true at 9.0GHz and 8.9 GHz. These can be observed from tables 2 and 3 also. Return loss and $S_{11}$ differs by negative sign only when they are expressed in dB.

Figures 7, 8, 9 shows the H-plane pattern of the microstrip antenna array in three cases. In all these cases, the peak sidelobe and back lobe have decreased. At 9.1GHz, the peak sidelobe has decreased from -10.74dB to -14.46dB and the back lobe has decreased from -13.71dB to -23.12dB. These can be observed from table 1. Similarly, it is the case with frequencies from 8.7GHz to 9.3GHz. Although peak sidelobe and back lobe levels decreases over this frequency range, here only three sample frequencies are discussed. The decrease in peak sidelobe and back lobe levels can also be observed from table2 and table 3.
Fig. 8. H-plane pattern at 9.0GHz

Table 1. Comparison of the radiation parameters of 4-element array at 9.1GHz

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter</th>
<th>Without DGS</th>
<th>With DGS Configuration-1</th>
<th>With DGS Configuration-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S₁₁ (dB)</td>
<td>-20.36</td>
<td>-13.57</td>
<td>-14.93</td>
</tr>
<tr>
<td>2</td>
<td>Peak gain (dBi)</td>
<td>10.09</td>
<td>10.21</td>
<td>10.38</td>
</tr>
<tr>
<td>3</td>
<td>Peak sidelobe level (dB)</td>
<td>-10.74</td>
<td>-13.69</td>
<td>-14.46</td>
</tr>
<tr>
<td>4</td>
<td>Back lobe level (dB)</td>
<td>-13.71</td>
<td>-20.06</td>
<td>-23.12</td>
</tr>
<tr>
<td>5</td>
<td>Radiation efficiency (%)</td>
<td>72.47</td>
<td>69.48</td>
<td>69.53</td>
</tr>
<tr>
<td>6</td>
<td>Front to Back Ratio (dB)</td>
<td>13.72</td>
<td>15.52</td>
<td>17.31</td>
</tr>
</tbody>
</table>

Fig. 9. H-plane pattern at 8.9GHz

Table 2. Comparison of the radiation parameters of 4-element array at 9.0GHz

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter</th>
<th>Without DGS</th>
<th>With DGS Configuration-1</th>
<th>With DGS Configuration-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S₁₁ (dB)</td>
<td>-21.19</td>
<td>-14.71</td>
<td>-16.68</td>
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<tr>
<td>2</td>
<td>Peak gain (dBi)</td>
<td>10.27</td>
<td>10.29</td>
<td>10.41</td>
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<tr>
<td>3</td>
<td>Peak sidelobe level (dB)</td>
<td>-11.30</td>
<td>-14.31</td>
<td>-15.10</td>
</tr>
<tr>
<td>4</td>
<td>Back lobe level (dB)</td>
<td>-14.33</td>
<td>-23.31</td>
<td>-27.34</td>
</tr>
<tr>
<td>5</td>
<td>Radiation efficiency (%)</td>
<td>72.73</td>
<td>70.19</td>
<td>70.24</td>
</tr>
<tr>
<td>6</td>
<td>Front to Back Ratio (dB)</td>
<td>14.33</td>
<td>17.52</td>
<td>19.43</td>
</tr>
</tbody>
</table>

Table 3. Comparison of the radiation parameters of 4-element array at 8.9GHz

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter</th>
<th>Without DGS</th>
<th>With DGS Configuration-1</th>
<th>With DGS Configuration-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S₁₁ (dB)</td>
<td>-19.67</td>
<td>-16.74</td>
<td>-19.53</td>
</tr>
<tr>
<td>2</td>
<td>Peak gain (dBi)</td>
<td>10.29</td>
<td>10.32</td>
<td>10.40</td>
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<tr>
<td>3</td>
<td>Peak sidelobe level (dB)</td>
<td>-11.97</td>
<td>-14.53</td>
<td>-15.24</td>
</tr>
<tr>
<td>4</td>
<td>Back lobe level (dB)</td>
<td>-14.77</td>
<td>-25.30</td>
<td>-28.03</td>
</tr>
<tr>
<td>5</td>
<td>Radiation efficiency (%)</td>
<td>72.06</td>
<td>70.35</td>
<td>70.34</td>
</tr>
<tr>
<td>6</td>
<td>Front to Back Ratio (dB)</td>
<td>14.77</td>
<td>25.30</td>
<td>28.03</td>
</tr>
</tbody>
</table>

Fig. 10. Peak gain versus frequency plot of the array antenna
Figure 10 shows the peak gain versus frequency plot for the microstrip antenna array in three cases. There is a slight improvement in the peak gain with DGS. It can be observed from tables 1, 2, and 3. The 3dB gain bandwidth also improves by 40MHz. Figure 11 shows the front to back ratio versus frequency plot in three cases. It can be observed that the FBR increases with DGS over 8.7GHz to 9.3GHz. The front to back ratio (FBR) increases by 3.59dB, 5.1dB, and 13.26dB at 9.1GHz, 9.0GHz, and 8.9GHz respectively.

Fig. 11. FBR versus frequency plot of the array antenna

Fig. 12 shows the H-plane Co-polarization plot of the microstrip antenna array in three cases. From the fig. 13, it can be observed that the Cross-polarization level decreases with DGS configuration-2. The Cross-polarization levels less than -40dBi are observed from the plot. Similarly, it can be shown at other frequencies over 8.7GHz to 9.3GHz.

V. CONCLUSIONS

A novel method for peak sidelobe and back lobe reduction is proposed here. The effect of defected ground structures, adjacent to T-junctions of the feedline network of rectangular microstrip antenna array with corporate feed network is studied. By using both DGS configurations in the ground plane of microstrip antenna array, both peak sidelobe and back lobe have reduced. The peak sidelobe has decreased by 3.72dB, 3.80dB, and 3.27dB at 9.1GHz, 9.0GHz and 8.9GHz respectively. Similarly, the FBR has increased by 3.59dB, 5.1dB, and 13.26dB at 9.1GHz, 9.0GHz, and 8.9GHz respectively. The 3dB gain bandwidth has increased by 40MHz. The peak gain has also improved slightly. The Radiation efficiency slightly decreases, which is expected because of DGS. This novel technique of DGS can be applied in the design of microstrip planar array antennas for satellites, missiles, aircrafts etc. for low EMI applications.

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REFERENCES


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