Reduction of mutual coupling in microstrip array antennas using concave rectangular patches

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Abstract – Using rectangular patches, this paper proposes a new solution to reduce mutual coupling in microstrip array antennas. The patch is made concave in horizontal, vertical or both sides. Applying the proposed structure to a microstrip array antenna having two elements, the effect of using the patches on mutual coupling and return loss is simulated and studied. The patch length and width as well as the amount of horizontal and vertical concavity are optimized using an enhanced genetic algorithm. Simulation results demonstrate that the optimal array antenna has a low amount of mutual coupling and return loss.

Keywords - microstrip antenna array, mutual coupling, concave patch, optimization

I. Introduction

Microstrip array antennas are used widely because of their simple manufacturing, small size, light weight and low cost [1-4]. They are used in phased array antennas such as pattern beam forming, smart antennas, and electronic scanning radars [4]. To calculate the radiation pattern of an array the mutual coupling effect must be considered. Without considering this effect, large errors in beam forming and null string are resulted [5-6]. To decrease the mutual coupling effect, several methods such as changing feed position and feed structure, and replacing ordinary patches by fractal patches have been reported [7-9]. This paper proposes a new solution to reduce mutual coupling using concave rectangular patches. The effect of patch concavity on return loss is also investigated. In addition, the patch length and width as well as the amount of horizontal and vertical concavity are optimized employing an enhanced genetic algorithm.

II. Structure of the array antenna

The array structure includes three conductive and two dielectric layers. The lower conductive layer is assumed to be an infinite ground plane, while the second one is set to be a feed layer and the top one is a patch microstrip antenna. In the simulation the thickness of dielectric layers, D1, D2, are set to 0.5mm. The dielectric relative permittivity, εr, and the dielectric permeability, μr, are equal to 3 and 1, respectively. Figure 1 shows the side view of the antenna.

Figure 2 illustrates the array structure and its dimensions. The length of the feed line is 10.63mm, which 2.53mm of the length overlaps with the patch. The patch dimensions can be specified the frequency and the bandwidth of the antenna [1-2]. In this study, the antenna is designed for X band applications. The central frequency is 8.37GHz, resulting in the length and width of the patches to be L=9.45mm and W=11.55m. The patches are fed by proximity coupled mechanism, having a line impedance of 50 ohm. The array antenna is made of two elements of the above-mentioned microstrip antennas, which placed horizontally and the distance between them is 14.08mm (<λ/2).

III. Patch concavity effect

In this research we use the structure described in the previous section. In this section, the effect of concavity in width, length, and both sides on the mutual coupling and return loss is simulated. Employing the Advanced Design System (ADS) software, the antenna parameters are obtained based on the Method of Momentum (MOM) [10].

A. Effect of width concavity

The effect of the width concavity of the patches on mutual coupling and return loss is investigated. As can be seen in Figure 3, the depth of the width concavity is shown by the parameter “h1”. The mutual coupling and
return loss is calculated for \( h_1 = 0.3, 0.6, 0.9, 1.2, 1.5 \) mm. The patch without concavity is shown by \( h_1 = 0 \).
The results depicted in Figure 4 show that the return loss is minimized in \( h_1 = 0.6 \) and the mutual coupling is decreased by increasing the amount of concavity. The results show that the width concavity can decrease the effect of mutual coupling and return loss, however, the central frequency is also changed. To compensate this effect and move the resonant frequency back to its initial value, patch dimensions should be changed.

Fig3. Width concavity

Fig4. Mutual coupling (a) and return loss (b) for width concavity

B. Effect of length concavity

As shown in Figure 5, the depth of the length concavity is shown by the parameter “\( h_2 \)”. The effect of the length concavity on the mutual coupling and return loss are shown in Figure 6. The results show that the mutual coupling is decreased and the return loss is increased by increasing the amount of the length concavity. Similar to the previous case, the central frequency is changed and should be moved back to its initial value by changing the dimensions of the patches.

Fig5. Length concavity

Fig6. Mutual coupling (a) and return loss (b) for length concavity

C. Effect of two-side concavity:

Figure 7 shows patches with two-side concavity. The depths of concavity in both sides, shown by the parameter “\( h \)”, are considered to be the same. The effect of the two-side concavity on the mutual coupling and return loss are shown in Figure 8. It is shown that the return loss is minimized in \( h = 0.9 \) and the mutual
coupling is decreased by increasing the amount of concavity. Like the previous cases, the central frequency is changed. It can be concluded from all the three cases considered in this section that the concavity can reduce the mutual coupling effect and return loss. However, the central frequency is changed and needs to be kept constant at 8.37 GHz. Therefore, the amount of concavity and the dimensions of the patches should be computed, simultaneously. This will be studied in the next sections.

IV. Resonant frequency change compensation
Considering a two-side concavity, it can be seen from Figure 8 that the resonant frequency is shifted up by increasing the value of concavity, $h$. It is aimed to move the resonant frequency back to its initial value, 8.37GHz. To do this, the dimensions of the patches must be increased. Here, patch dimensions are calculated by a trial and error procedure. The dimensions of patches are calculated for different values of the parameter, $h$, and the results are shown in Table 1.

<table>
<thead>
<tr>
<th>$h$</th>
<th>0</th>
<th>0.3</th>
<th>0.6</th>
<th>0.9</th>
<th>1.2</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w$</td>
<td>11.55</td>
<td>11.77</td>
<td>12.17</td>
<td>12.52</td>
<td>12.87</td>
<td>13.22</td>
</tr>
</tbody>
</table>

To verify that the above dimensions lead to the desired central frequency, the mutual coupling and the return loss are computed and plotted in Figure 9.

As the above procedure is based on trial and error, it is time-consuming. More importantly, if the concavity in each side is considered to be different, the trial and error procedure will be more complicated. Therefore, it is proposed to employ an optimization procedure to determine the optimal values of the patch length, the patch width as well as the concavity parameters.
V. Antenna optimization

The enhanced genetic algorithm [11] is employed to reduce the amount of mutual coupling and return loss in the array antenna. To keep the resonant frequency constant, the optimization problem has a constraint. Optimization variables are the dimensions of the patches and the concavity parameters. Considering the optimal array antenna shown in Figure 10, the optimal parameters are \( W = 10.11 \), \( L = 10.98 \), \( h_1 = 1.24 \), and \( h_2 = 0.38 \). The mutual coupling and return loss are shown in Figure 11.

VI. Conclusions

Using rectangular patches, this paper proposed a new solution to reduce mutual coupling and return loss in microstrip array antennas. By simulating different concavity modes, it was shown that the resonant frequency alters when a concave patch is used. To move the resonant frequency back to its normal value, the patch dimensions should be changed. To do this, two methods were used, one based on a trial and error procedure and another based on an optimization method. Considering a constraint to keep the resonant frequency constant, the aim of optimization was to reduce the amount of mutual coupling and return loss in the array antenna. Employing an enhanced genetic algorithm, the patch length and width as well as the amount of width and length concavities were optimized. Simulation results demonstrated that the optimal array antenna has a low amount of mutual coupling and return loss.

References