Regular Article

Mutual Coupling Reduction in Microstrip Antennas using Defected Ground Structure

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Abstract—A Multiple Input Multiple Output (MIMO) antenna with high isolation is proposed in this paper. The proposed antenna includes two sets of four elements (2 × 2) and it is yielded at the central frequency of 5.5 GHz for Wireless Local Area Network (WLAN) applications. Based on RT5880 with height of 1.575 mm, the overall size of MIMO antenna is 140 × 76 × 1.575 mm3. To get high isolation between antenna elements, a Defected Ground Structure (DGS) is integrated on ground plane. Besides, the MIMO antenna witnesses a large bandwidth of 9.1% and an efficiency of 90% while the peak gain is 8.5 dBi. The measurement results are compared to simulation ones to verify the performance of the proposed antenna.

Keywords—Array antenna, MIMO antenna, defected ground structure, dgs, mutual coupling.

1 INTRODUCTION

Nowadays, microstrip patch antennas are commonly used in modern wireless systems thanks to their advantages, for example: light weight, easy fabrication and integration into PCB circuits. However, there are some performance limitations in them such as narrow bandwidth, low efficiency and gain. Many different solutions have been proposed, for instance: gain enhancement including: defected ground structure (DGS) [1], reflective surface [2], electromagnetic band gap (EBG) [3], bandwidth enhancement consisting of DGS [4], parasitic strips [5] and so on. One of the most attractive method to improve antenna parameters is DGS because of its ease in fabrication and low cost. DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line, e.g., microstrip, coplanar and conductor backed coplanar wave guide [6]. By adjusting sizes of DGS, we can obtain the desired resonant frequency.

Besides, along with the rapid development of mobile communication technology, people’s demand on high data rates and high reliability is becoming an urgent issue. There are two ways to increase the data transmission rate that is enhancing the channel bandwidth or increasing the number of transceiver antenna [7]. Multiple Input Multiple Output (MIMO) is a technology which allows increasing capacity and spectral efficiency through signal processing in both time and space domain. Currently, MIMO technology has been considered the best solution for most of the problems in wireless communication [8]. However, when antennas are placed close together, mutual coupling appears. Mutual coupling is the electromagnetic interaction between antenna elements in array. Mutual coupling decreases not the antenna efficiency, but also can change the radiation pattern of antenna as well. Therefore, mutual coupling is an urgent problem that needs to be solved. Many works have been conducted to improve parameters for antenna [9–11]. In [9], although the isolation between antenna elements is quite high (30 dB), gain of antenna is only under 6 dBi. In another document [10], although the bandwidth percentage of antenna is very high (96.2%), mutual coupling of antenna is quite high (14 dB). In addition, the peak gain of antenna in this work is only 4 dBi. Similarly, the bandwidth percentage of antenna in [11] only achieves 5% (at central frequency of 5.8 GHz) although the isolation of antenna is acceptable (19 dB).

For this reason, this paper proposes a DGS to improve parameters for antenna. The proposed DGS is a compact and planar; therefore, it is easy for fabrication. The proposed structure is applied for a MIMO antenna including two sets of four elements (2 × 2). The antenna is yielded at the frequency of 5.5 GHz for Wireless Local Area Network (WLAN) applications with the bandwidth of 500 MHz corresponding to the bandwidth percentage of 9.1%. In addition, the mutual coupling between elements is under -20 dB while the gain and efficiency are 8.5 dBi and over 90%, respectively. The characteristics of the proposed antenna are demonstrated by Computer Simulation Technology (CST) software and validated by the measurements.

2 DESIGN OF MIMO ARRAY ANTENNA

2.1 The Proposed Defected Ground Structure

Firstly, the model of the proposed DGS and its equivalent circuit are shown in Figure 1. The idea of the
The proposed DGS is derived from the dumbbell-shaped DGS in [12]. By modifying the shape of structure, the paper has got a new structure. The proposed structure includes two rectangular shapes and they are connected to each other by a microstrip line. The proposed DGS is a planar structure, and it is, therefore, easy fabrication and low cost. To make a variety of parasitic capacitances (C) and inductances (L), the paper utilizes both the compensation structure and the proposed structure. While the compensation structure generates capacitances, the proposed structure produces inductances. This leads to an ease in optimization and achieves the better parameters for antenna.

2.2 Design of Single Array

Initially, a single array is designed for WLAN and its geometry is illustrated in Figure 2. It consists of four microstrip patch elements (2×2) connected together through power dividers placing on the dielectric substrate and the proposed DGS integrated on metal plane ground. Being on Rogers RT/Duroid™ 5880 substrate with thickness of 1.575 mm, \( \varepsilon_r = 2.2 \) and \( \tan \delta = 0.0009 \), the overall size of the proposed antenna is \( 72 \times 72 \times 1.575 \text{ mm}^3 \) while the distance between elements is approximately \( \lambda_0/2 \), where \( \lambda_0 \) is the wavelength in free space at the frequency of 5.5 GHz. Based on formulas in [13], the paper get a patch dimension of \( 20.5 \times 12 \text{ mm} \). Meanwhile, the proposed DGS is integrated on the backside of the substrate layer.

The size of the DGS is \( w_{dgs} \times l_{dgs} \) while the length of the microstrip line for connecting two rectangles is \( l_{dgs1} \). In addition, an indispensable component in antenna array is power dividers. To match impedance for them, transformers of \( \lambda/4 \) are utilized, then, the impedance of transformers of \( \lambda/4 \) is calculated as formula in [14]. These are equal power dividers, therefore, they are designed in order that the parameters of S21 and S31 are -3 dB. In other words, the power level at port 1 is twice times the one at port 2 and 3. Table I shows some parameters of the proposed single array while Figure 3 presents S-parameters of the power divider. Here, the reflection coefficient at port 1 and power levels at port 2 and 3 of the power divider at the frequency of 5.5 GHz are approximately -28 dB and -3.2 dB, respectively.
Table I
SOME PARAMETERS OF THE PROPOSED SINGLE ARRAY (DEFINED IN FIGURE 2) OF THE PROPOSED ANTENNA ARRAY

| Parameters | Value (mm) | Parameters | Value (mm) |
|------------|------------|------------|------------|
| W          | 72         | L          | 72         |
| Wp         | 20.5       | lp         | 12         |
| ws         | 1          | ls         | 5          |
| de         | 27         | wdgs       | 40         |
| ldeg1      | 20         | c          | 4          |
| l100       | 29         | l50        | 4.5        |
| l70        | 9.3        | l100_2     | 14         |
| l50_2      | 3          | l70_2      | 9.3        |
| dgs        | 1          | ldeg2      | 2.5        |
| ldeg3      | 10         | wdgs4      | 13.75      |

Figure 3. The parameters of the power divider.

2.3 Design of MIMO Array Antenna

The model of the MIMO array antenna is shown in Figure 4. The proposed antenna consists of two symmetrical sets of four elements (2 × 2) on the top of the substrate. The distance between radiation patches in the MIMO antenna is approximately λ/2 while the closest gap from edge to edge of the two arrays is 6.5 mm. The antenna is realized on Roger5880™ substrate with the dimension of 140 × 76 × 1.575 mm³.

In order to enhance isolation for MIMO antenna, the DGS is integrated into the ground plane. The ground plane includes 3 cells of DGS with the distance from center to center between them of 42.5 mm. Here, the size of the DGS is 32 × 57 mm. By adjusting some parameters such as wdgs2, ldeg2, ldeg3, ddeg, lc, wc, we can obtain the desired resonant frequency. Table II shows some parameters of the MIMO array antenna.

Table II
SOME PARAMETERS OF THE MIMO ARRAY ANTENNA

| Parameters | Value (mm) | Parameters | Value (mm) |
|------------|------------|------------|------------|
| W          | 72         | L          | 140        |
| da         | 5.05       | wc         | 32         |
| ldeg2      | 18         | ldeg3      | 21         |
| ddeg       | 42.5       | wc         | 35         |
| lc          | 59         |             |            |

Figure 4. The model of the MIMO array antenna: (a) top view; (b) bottom view.

3 Results and Discussions

A. Simulation Results

3.1 Single array antenna

Figure 5 shows the reflection coefficient of the single array. From Figure 5, we can see that the return loss of the antenna at the frequency of 5.5 GHz is -28 dB while the bandwidth is 830 MHz. In this case, the bandwidth is extended by making at least two consecutive resonant modes. It is clear that use of DGS on ground plane...
made consecutive cavity resonators and this leads to creating resonant modes. Utilizing DGS not only enhances bandwidth for antenna, but also keep efficiency at high level. Here, the gain and efficiency of the antenna reach 7.3 dBi and 87%, respectively.

Figure 6 illustrates the xz and yz planes of the proposed. The antenna has the directivity of 7.8 dBi while the angular width (3 dB) is 40.5 degree.

3.2 MIMO Array Antenna

As mentioned above, the goal for using DGS in MIMO array antenna is to reduce mutual coupling. This characteristic is illustrated in Figure 7, which displays a comparison of S-parameters in two cases of without and with the DGS.

As shown Figure 7, the isolation of antenna without DGS is only 10 dB while with case of DGS, this value is greater than 20 dB although the distance between elements is 30 mm (the distance between elements with DGS is 27 mm). It is clear that there is a significant improvement in mutual coupling between antenna elements when DGS is used. This can be explained as following: The use of DGS causes a disturbance in current distribution [15] and this leads to current re-

Figure 8 illustrates simulated gain, S11 and S21 for the different widths of DGS. Although the S21 values are guaranteed under -20 dB in three cases, gain and S11 achieve the best values with \( w_{dgs2} = 32 \).
Figure 9 shows the xz and yz planes of the proposed MIMO array antenna. The gain of the proposed array antenna gets 8.5 dBi while the angular width (3 dB) is 37.4 degree. Besides, another important parameter in MIMO system to determine diversity performance is the envelope correlation coefficient (ECC). Here, ECC is defined as follows [17]:

$$
\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{\left(1 - |S_{11}|^2 - |S_{21}|^2\right) \left(1 - |S_{22}|^2 - |S_{12}|^2\right)}.
$$

Figure 10 and Figure 11 display the ECC and current distribution of the proposed antenna. From Figure 10 we can see that the ECC of the antenna is very small in a wide frequency range (under 0.0025 from 5.15 GHz to 5.8 GHz). This shows that the isolation of the proposed antenna is quite high. Move to Figure 11, there are some places that the energy flows are concentrated higher other places (red color).

B. Measurement Results

For verification, the prototypes of the MIMO array antenna, as shown in Figure 12, are fabricated on Rogers RT/Duroid® 5880 substrate with thickness of 1.575 mm, $\varepsilon_r = 2.2$ and $\tan\delta = 0.0009$. The overall sizes of the fabricated single and MIMO antennas are $72 \times 72 \times 1.575$ mm$^3$ and $140 \times 76 \times 1.575$ mm$^3$, respectively. The measured and the CST computed results for the fabricated MIMO and single array are given in Figure 13.

As displayed in Figure 13(a), the measured impedance bandwidth for $|S_{11}| < -10$ dB is from 5.19 GHz to 5.6 GHz corresponding the bandwidth in percentage of approximately 7.4%. Switch to Figure 13(b), the bandwidth of the MIMO antenna is
Table III
THE COMPARISON BETWEEN THE PREVIOUS WORKS AND MY WORK

| References | [18] | [19] | [20] | [21] | My work |
|------------|------|------|------|------|----------|
| Frequency [GHz] | 5.4 | 5.8 | 28/38 | 5.8 | 5.5 |
| Bandwidth [%] | 38 | 4.7 | 14.3/5.26 | 7.7 | 9.1 |
| Isolation [dB] | 19 | 22 | 20 | 34 | 20 |
| Efficiency [%] | x | x | 73 | 53.7 | 90 |
| Gain [dBi] | x | x | 7.5 | 5.3 | 8.2 |
| Size | 1.98λ × 0.972λ | x | 2.4λ × 1.8λ | 1.87λ × 0.54λ | 2.56λ × 1.39λ |

500 MHz (9.1%, from 5.16 to 5.66 GHz). In addition, the mutual coupling of the antenna is under -20 dB over a wide frequency range. In these cases, there are differences between measured and simulated results. This difference can be attributed to the tolerances of the fabricated antenna array. In addition, the SMA soldering can cause an impedance variation of antenna and this directly affects to impedance matching. As a result, with MIMO antenna, there are a shift in frequency (S11) and the significant change between simulated and measured S21. However, there is a better result in measurement with single antenna when the second resonant mode is very close the simulated result and as a result, this mode is also the resonant frequency of antenna. Therefore, the frequency band for operating of the antenna is still ensured and this result is acceptable.

Figure 14 illustrates the measured results of gain of the proposed antenna. While the simulated results of the single array and MIMO array are 7.3 dBi and 8.5 dBi, the measured ones for these figures are 7 dBi and 8.2 dBi, respectively. The gain values of antennas in measurement are lower than the figure in simulation. This cause may be due to insertion loss of SMA connectors. However, the difference is very small. The results in this work have also been compared with the previous works as shown in Table III. From Table III, we can see that although the isolation of antenna [19] is quite high with of 22 dB, however, the bandwidth percentage is not high (under 5%). In addition, the parameters of efficiency and gain did not show in these documents [18, 19]. This is similar
in [20] when the percentage of bandwidth is only 5.26. Besides, the efficiency and gain of antenna in [20] are not high (73% and 7.5 dBi) although the antenna is yielded at frequencies of 28 and 38 GHz. In another studying [21], the gain and efficiency are very low (5.3 dBi and 53.7%) although the mutual coupling between elements in antenna very low (-34 dB). Moreover, there is a narrow percentage of bandwidth in [21] (7.7%). With document [18], the parameters are quite good (the bandwidth of percentage: 38% and the isolation: 19 dB).

4 Conclusion

In this paper, a MIMO array antenna including two sets of four elements (2 × 2) and the proposed DGS for WLAN applications is investigated. The prototype, with an overall dimension of 140 × 72 × 1.575 mm³, yielded a measured bandwidth of 5.16-5.66 GHz (at -10 dB). In addition, by using DGS integrated on ground plane, the antenna achieves a low mutual coupling (under -20 dB) in a wide frequency range. Moreover, the proposed antenna resulted in a peak gain of 8.2 dBi for measurement (8.5 dBi for simulation) and a total radiation efficiency of 90%. With advantages consisting of low profile, easy fabrication with low cost, high isolation, wide bandwidth, and compact size, the proposed antenna is a quality candidate for using in wireless communication systems in practice.

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