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MUTUAL COUPLING REDUCTION USING DUMBBELL DEFECTED GROUND STRUCTURE FOR MULTIBAND MICROSTRIP ANTENNA ARRAY

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Abstract—A novel design of multiband microstrip antenna array with dumbbell shape defected ground structure (DGS) is presented. The DGS is inserted into the ground plane between the two elements of the antenna array in order to suppress mutual coupling. Both simulation and measurement results verified that the DGS improved the radiation properties of the antenna array. Measurement results of the DGS antenna showed mutual coupling reduction of maximum 5 dB and gain enhancement to 3 dB.

1. INTRODUCTION

Recently, various wireless communication services have been available, which use many frequency spectrum allocations, e.g., WiMAX (Worldwide Interoperability Microwave Access), BWA (Broadband Wireless Access) and Wifi (Wireless Fidelity). For these applications, microstrip antennas are preferred because of its advantages such as low profile, lightweight and easy design with multifrequency bands. However, a common disadvantage of microstrip antenna is surface wave, which is excited whenever the substrate has dielectric permittivity greater than one ($\varepsilon_r > 1$).

Surface waves cause many disadvantages for microstrip antenna such as mutual coupling effect between elements on an array [1]. In an antenna array, the mutual coupling effect will deteriorate the radiation properties of the array. To suppress surface waves, several studies

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are conducted including defected ground structure (DGS). DGS is realized by etching the ground plane with a certain lattice shape which disturbs the current distribution of the antenna. Many shapes of DGS have been studied such as concentric ring [2], circle [3], spiral [4], dumbbells [5–8], elliptical [9] and U- and V-slots [10]. Each DGS shape can be represented as an equivalent circuit consisting of inductance and capacitance, which leads to a certain frequency bandgap determined by the shape, dimension and position of the defect. DGS gives an extra degree of freedom in microwave circuit design and can be used for a wide range of applications.

Therefore, many studies have used DGS for filter design, couplers, dividers, and microstrip antennas. Meanwhile, for antenna application, DGS is mainly applied to the feeding technique. To suppress mutual coupling between arrays, several studies of DGS in single band antenna arrays have been conducted [6–8]. However, in this study, we designed and realized DGS in multiband antenna arrays and paid attention to reduce the mutual coupling effect by proposing dumbbell shape DGS to be implemented in a multiband microstrip antenna array. The multiband microstrip antenna array of 2.3 GHz, 3.3 GHz and 5.8 GHz is used in this study [11]. Moreover, other radiation properties of the antenna are also observed.

2. ANTENNA DESIGN

The proposed antenna configuration is shown in Fig. 1. Fig. 1(a) shows the top view of the proposed antenna, whereas Fig. 1(b) shows the exploded view of the proposed antenna design. The dashed line of the structures shown in Fig. 1 indicates that the structure is located beneath the substrate. Therefore, it cannot be seen directly from the front view. This is shown for the dumbbell DGS which is depicted in Fig. 1(b). The dumbbell DGS is located on the opposite side of the feed line shown in the lower layer substrate. Therefore, it is drawn with dashed line.

The dielectric material used has the thickness of 1.52 mm with dielectric permittivity (ε_r) of 2.2 and tangential loss ($\tan\delta$) of 0.0009. The antenna consists of two substrate layers with electromagnetic couple feeding technique. On the upper layer, two element patch antenna with two U shape and S shape patches are combined and only separated by thin slots to excite coupling effect to the patches. This effect can produce multiband characteristic. The lower layer substrate consists of a microstrip line feeding system, and four dumbbell slots are inserted on the ground plane.

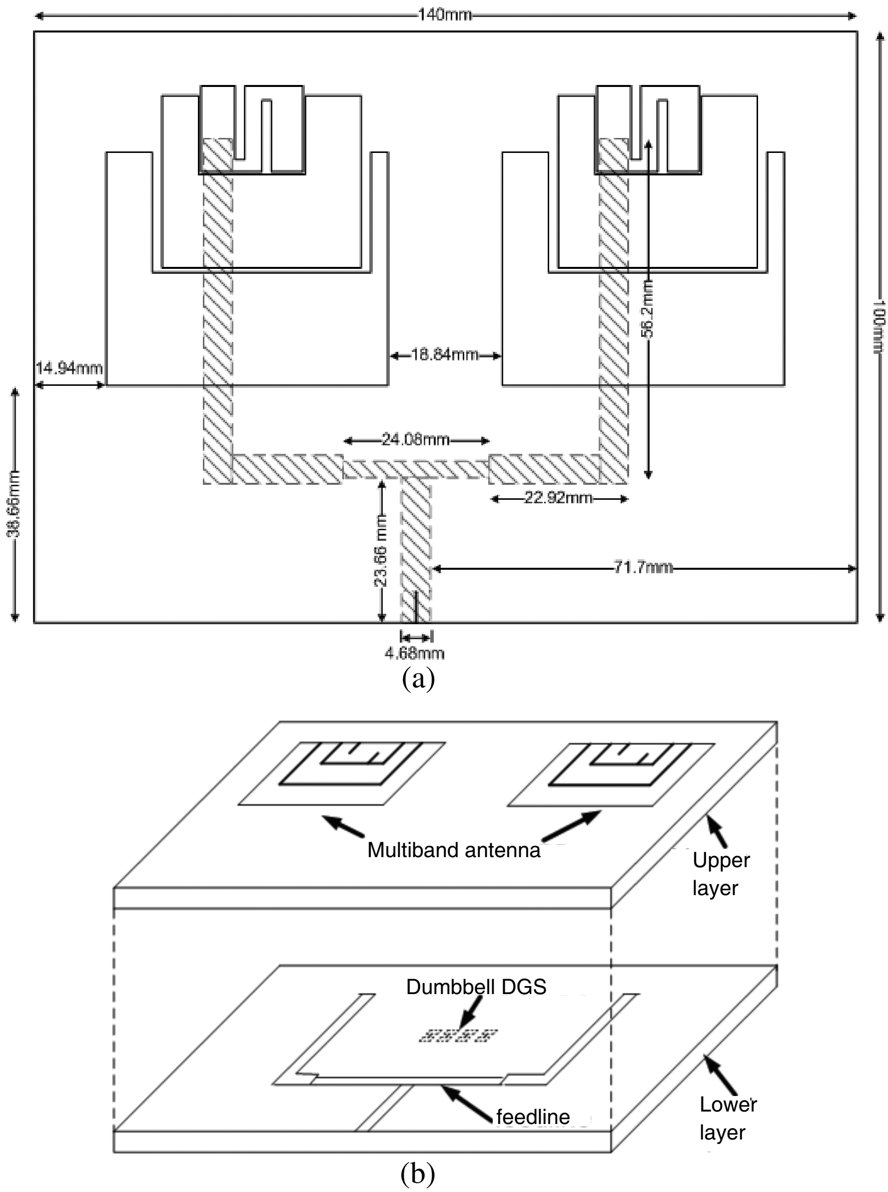


Figure 1. Configuration of dumbbell DGS antenna design. (a) Top view geometry, (b) exploded configuration.

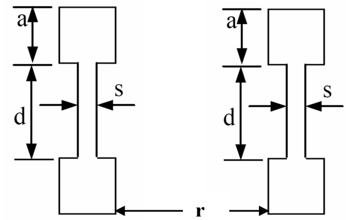


Figure 2. Dumbbell DGS configuration.

3. THE DUMBBELL DGS CHARACTERISTIC

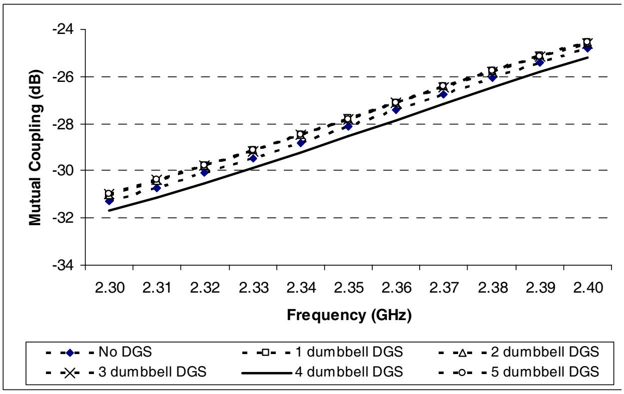
In designing the dumbbell DGS, the dimension of the DGS consists of the dumbbell head (a), slot length between the dumbbell (d) and slot width (s). The dumbbell configuration is depicted in Fig. 2.

The proposed dumbbell DGS configuration was achieved experimentally by varying the dimension and locating the position of the DGS on the ground plane of the lower layer using HFSSv11 simulator.

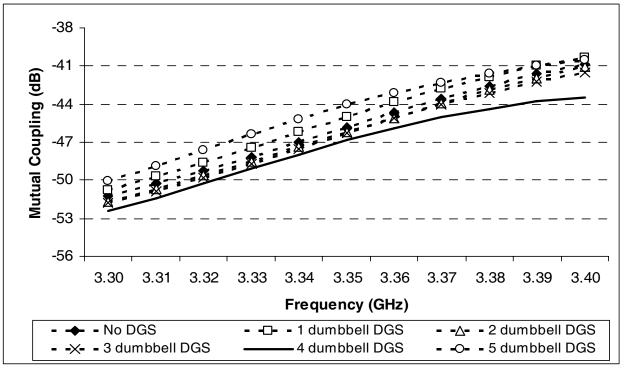
The position of the DGS on the ground plane is located between the two element multiband patches, but underneath the lower layer. This location of the dumbbell is chosen from the current distribution of the reference antenna which shows that mutual coupling effect strongly occurs between the two element multiband patches.

In this study, we used dumbbell shaped DGS of one-to-five elements. The distance between dumbbells, (r), is shown in Fig. 2. The number of unit element DGS was increased to observe the influence to the reference antenna which was designed without DGS. In designing the proposed multiband antenna array with DGS, three different frequencies were observed to find the greatest influence of the DGS towards mutual coupling reduction. The simulation results of mutual coupling reduction from 1–5 dumbbell DGS units are shown in Fig. 3. The dumbbell DGS from one unit until five were characterized here with the same size and distance. The dumbbell DGS has a square head with dimension 2×2 mm and spacing of 2 mm between dumbbells. Therefore the overall dimensions of the DGS are $a = 2$ mm, $d = 7.2$ mm, $s = 0.4$ mm and $r = 2$ mm.

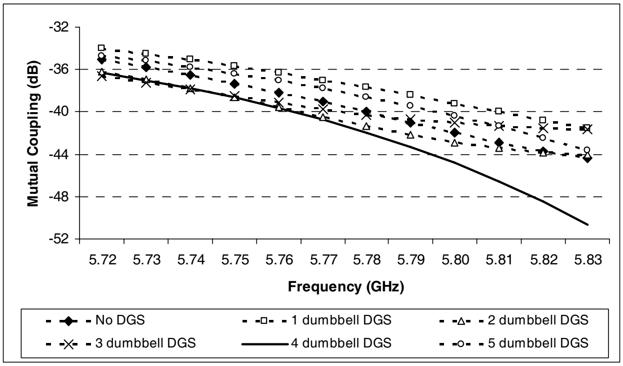
Figure 3 shows that all three frequencies have the best mutual coupling reduction from the four dumbbell DGS unit designs. The Fig. 3(a) shows that the simulated mutual coupling reduction for the frequency 2.3 GHz–2.4 GHz has a slight reduction between the antenna with and without DGS. However the 4 unit dumbbell DGS has the lowest mutual coupling effect. Fig. 3(b) shows that at frequency 3.3 GHz–3.4 GHz, a mutual coupling reduction of 1.18 dB–



(a)



(b)



(c)

Figure 3. Simulated mutual coupling from 1–5 dumbbell DGS units result at (a) frequency 2.3 GHz, (b) frequency 3.3 GHz, (c) frequency 5.8 GHz.

2.65 dB occurs for the 4 dumbbell configuration, and at frequency 5.72 GHz–5.83 GHz, as shown in Fig. 3(c), the best mutual coupling reduction also occurs from the 4 dumbbell DGS of 1.24 dB to 6.19 dB. Therefore, from the simulation, the best result achieved was from four unit dumbbells.

4. RESULTS AND DISCUSSION

The antennas with and without DGS were simulated and verified by measurement results. Simulation and measurement results showed that both antennas have multiband characteristics with three resonant frequencies at 2.3 GHz, 3.3 GHz and 5.8 GHz as shown in Fig. 4.

Simulation result shows that the antenna without DGS has impedance bandwidth ($RL \leq -10$ dB) from 2.29–2.42 GHz, 3.29–3.40 GHz and 5.49–6.14 GHz. The DGS antenna also shows similar impedance bandwidth of 2.3–2.42 GHz, 3.29–3.4 GHz and 5.46–6.13 GHz.

Measurement results of the impedance matching show a similar result to simulation. It is shown that the impedance matching improvement of the antenna with DGS is accomplished. The measurement shows that the antennas with and without DGS have return loss of −23.2 dB and −19.1 dB at frequency 2.386 GHz. At frequency 3.35 GHz the return loss of the antenna without DGS is −16 dB whereas −23.6 dB for that of the DGS antenna. For the last band, the antenna without DGS at frequency 5.8 GHz has return loss of −11.5 dB while −13.04 dB for that of the DGS antenna.

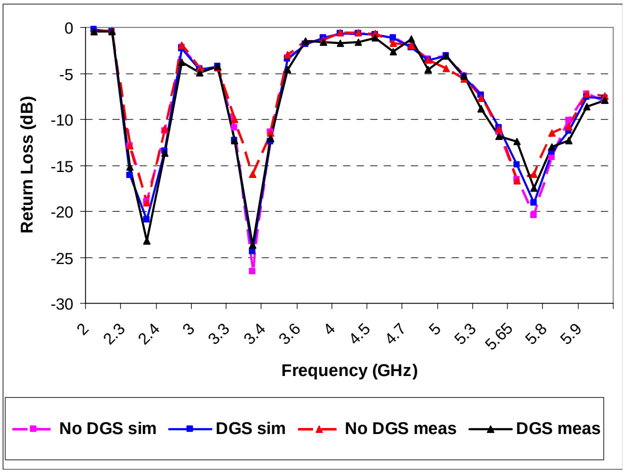
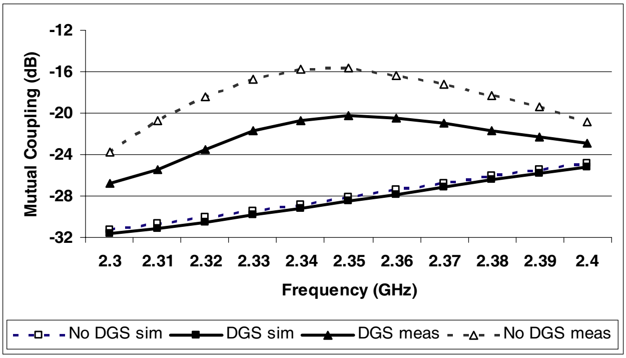
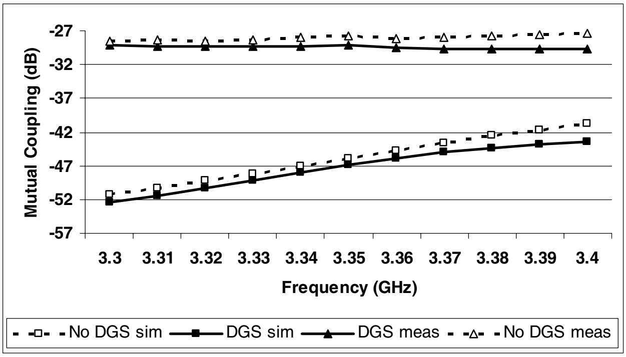


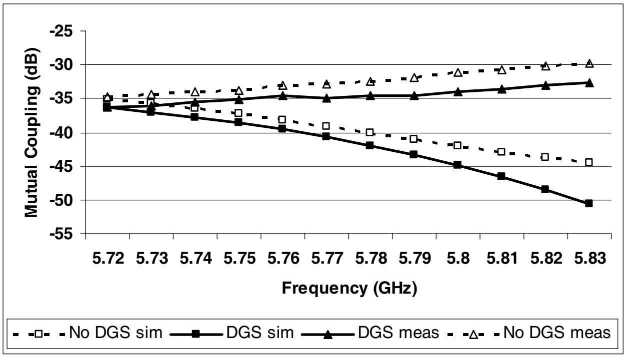
Figure 4. Return Loss of proposed antenna.



(a)



(b)



(c)

Figure 5. Mutual coupling simulation and measurement results at (a) frequency 2.3 GHz, (b) frequency 3.3 GHz, (c) frequency 5.8 GHz.

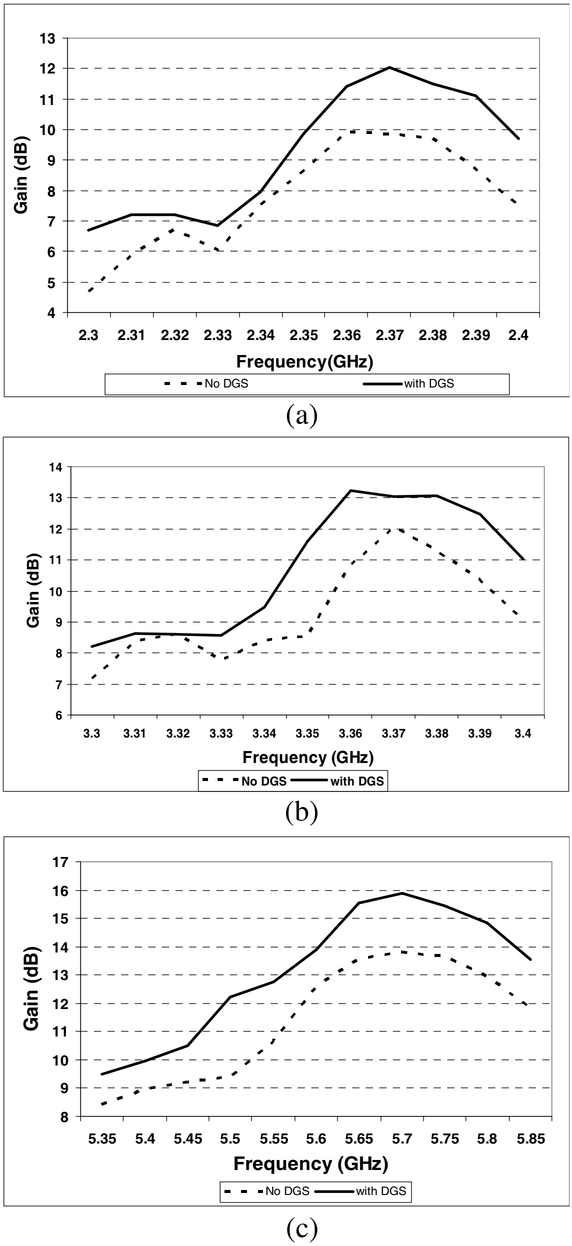


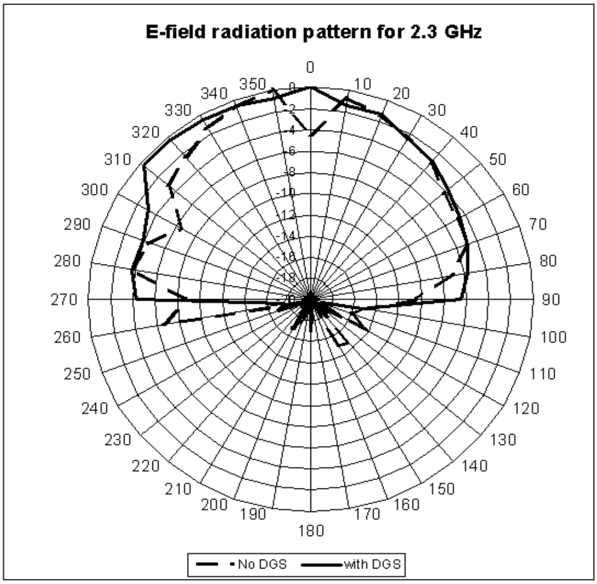
Figure 6. Gain measurement of the proposed antenna with and without DGS at frequency band (a) 2.3 GHz, (b) 3.3 GHz, and (c) 5.8 GHz.

These show an improvement of the return loss of 21.46%, 47.78% and 13.4% respectively. The improvement of the return loss indicates that the antenna efficiency will also be increased because the reflection is decreased. Therefore more power can be radiated.

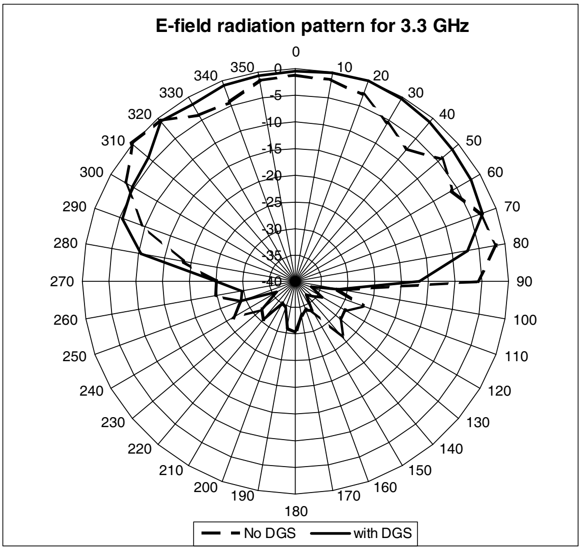
The simulation and measurement results of the mutual coupling for all three bands are depicted in Fig. 5. The simulation result of the mutual coupling was mentioned before in the DGS characterization, whereas the measurement results show a mutual coupling reduction around 2 to 5 dB at the band 2.3 GHz. For the band 3.3 GHz, a mutual coupling reduction of 0.6 dB to 2.3 dB occurs. Meanwhile, for the band 5.8 GHz, the mutual coupling accomplished to be reduced to 2.9 dB.

Therefore, the measured mutual coupling results show that the DGS antenna can reduce the mutual coupling of around 0.6 dB to 5 dB for the three bands, and the simulation result shows that the DGS antenna can reduce the mutual coupling of around 0.1 dB to 6.19 dB. These results show that there is a substantial mutual coupling reduction.

In addition, the antenna gain and radiation pattern of both antennas with and without DGS was also measured for all three bands. Fig. 6 shows the measured gain of the antenna. For the frequency band 2.3 GHz as depicted in Fig. 6(a), there is a gain enhancement from the DGS antenna to 2.4 dB. As for frequency band 3.3 GHz and 5.8 GHz



(a)



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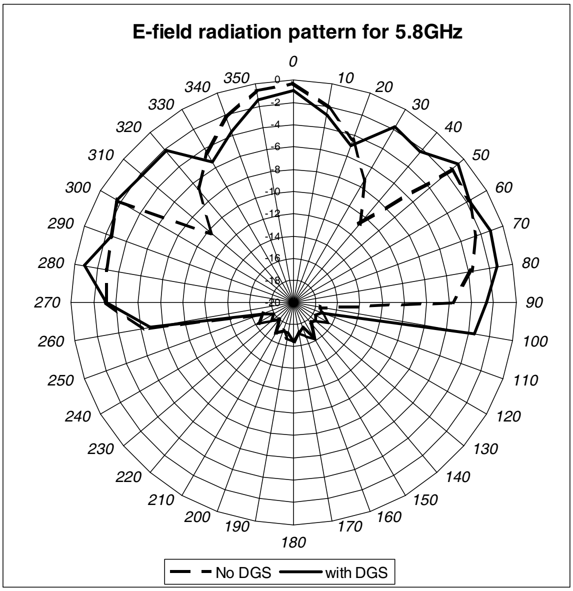

(c)

Figure 7. Radiation pattern of E-field for frequency (a) 2.3 GHz, (b) 3.3 GHz, and (c) 5.8 GHz.

a gain enhancement to 2.4 dB and 3 dB is achieved, respectively. The gain enhancement from the antenna with DGS is inline with the results of the improved return loss as aforementioned. Improved return loss indicates that efficiency can be increased; therefore, the antenna gain will also be increased.

Moreover, the E field radiation pattern measurement as depicted in Fig. 7 shows that the antenna has broadside pattern with small back lobes. Although the DGS is predicted to influence the back lobe radiation pattern of the antenna without DGS, from measurement results, no significant influence of the radiation pattern from the DGS towards the back lobe occurred.

5. CONCLUSIONS

Four dumbbell shape DGS unit have been implemented between two elements multiband microstrip antenna arrays. The antenna was simulated, designed and fabricated and shows that the DGS antenna can improve the mutual coupling reduction of the antenna without DGS. The simulation and measurement results showed a mutual coupling reduction to 6.19 dB and 5 dB is achieved, respectively.

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