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Defected Grounded Rectangular Patch Antenna with Rhombic-Shaped Slots for Early Phase 5G Applications

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Abstract

This study presents a novel design of a rectangular patch antenna with rhombic shaped slots (RSS) on the radiating part and five additional slots on the ground plane to create defected ground structure. The first prototype is a conventional inset fed rectangular patch antenna operating at 3.51 GHz which is among the early phase 5G frequency spectrum. The antenna has a return loss level of -37.97 dB and a 10 dB bandwidth of 114.8 MHz. In order to achieve lower return loss levels and improved bandwidth RSS are etched on the radiating part and ground plane. Detailed analysis of the effects of RSS on the characteristics of patch antenna are performed. The results have shown that the final antenna has a 10 dB bandwidth of 116.4 MHz with a return loss level of -55.42 dB which is a 1600 Hz increase in bandwidth and 17.45 dB decrease in return loss levels compared to the reference antenna. As a result of these improved radiation characteristics, the proposed antenna is a suitable candidate for the early phase 5G applications.

1 Introduction

In near future, specific demand for faster communications will be the main focus of development. According to the Cisco Visual Networking Index (VNI) there will be 12.3 billion mobile-connected devices by 2022, including M2M (Machine-to-Machine) modules-exceeding the world's projected population at that time (8 billion) by one and a half times. In addition, by 2022, a 5G (fifth generation) connection will generate 2.6 times more data traffic than the average 4G (fourth generation) connection [1]. So, we will need communication systems with wider bandwidths and better coverage. At this point 5G wireless communication will be a new era for the mobility and connection between humans and their devices. The frequency spectrum for 5G is divided mainly in three regions which are millimeter wave (mm-wave) band, mid-band also called sub 6 GHz band or early phase 5G band and low-band covering 600 MHz - 800 MHz [2]. For mm-wave bands there is almost a standard between the countries. However, for the sub 6 GHz bands different countries plan to use different bands, for example in Europe many countries have defined 3400-3800 MHz range as the primary band and 4400-5000 MHz band is planned to be assigned for 5G by China and Japan [3]. Both for mm-wave and sub 6 GHz bands efficient antenna structures to provide efficient communication for various applications are needed. For this purpose, microstrip patch antennas present great features by having low profile, being light weight, compatibility with different circuits and ease of fabrication. These types of antennas have one main disadvantage and that is their narrow bandwidth, however, in order to overcome this problem solutions such as etching slots on the patch and also on the ground plane have been presented. Etching slots on the ground plane is called defected ground structure (DGS). DGS is an etched defect in the ground of a planar transmission line which can be in different shapes. This defect effects the shield current distribution in the ground plane. The characteristics of a transmission line such as line capacitance and inductance are also affected and this defect in the ground plane yields to increase effective capacitance and inductance [4]. With the help of DGS a gain increase of 3 dB and a return loss change of -17.436 dB for a 3.5 GHz operating patch antenna is attained [5]. To generate two orthogonal electric field components in order to achieve circular polarization is another aim of defected ground [6]. Furthermore, in millimeter wave frequencies using DGS yields multiband operation and improved performances [7-8].

This study proposes a new design of a rectangular patch antenna with rhombic shaped slots (RSS) and defected ground because there are few studies about patch antennas with DGS operating at early phase 5G bands compared to the ones operate at mm-wave bands. The design consists of four steps; step one is to design the reference antenna according to the design equations, step two is etching of four RSS are etched on the radiating part for improved radiation, step three is etching a RSS in the center of the ground plane and step four is etching of four additional slots with equal distances from the corners of the slot in the center of the ground plane. Detailed parametric analyses have been performed about the dimensions and coordinates of all slots. With the new structure, we obtain significant return loss decrease and bandwidth enhancement which are both important for 5G networks where fast and efficient communication is crucial.

2 Design

The design considerations have been made according to the steps of the design of rectangular microstrip patch antenna transmission line model [9]. Equations 1-4 are describing the design procedure of a rectangular microstrip patch antenna.

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

$$\frac{\Delta L_p}{h} = 0.412\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

$$L_p = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad (4)$$

Here W_p and L_p show the width and the length of the patch, respectively. Effective dielectric constant is shown as ε_{eff} and ΔL_p shows the extension in the L_p because of the fringing effects.

For the dielectric substrate, we have used FR4 with the permittivity, ε_r of 4.3 and the height, h of 1.5 mm, the width W_{gp} and the length L_{gp}. W_{gp} and L_{gp} are calculated after series of parametric analysis and taken as W_{gp} x L_{gp} = 47.46 mm x 36.57 mm. The radiating part is modelled as a lossy conductor and its thickness, t, is set to 0.035 mm. The antenna is excited through a microstrip feed line which has a width of W_f and the length of L_f together with an inset feeding part with the dimensions of the length F_i and the width g. For proper fabrication and impedance matching conditions with 50 ohms connector W_f is taken as 3 mm. Due to the same reason the width of the inset feeding, g is calculated together with W_f, h and ε_r to match 50 ohms. The length of inset feeding, F_i is obtained through optimization steps. The final parameters of the reference antenna or Antenna #1 are summarized in Table 1 and Figure 1 shows the main structure of the antenna.

Table 1. Optimised parameters of Antenna #1

W_p	L_p	W_{gp}	L_{gp}
26.06 mm	20.02 mm	47.46 mm	36.57 mm
g	F_i	W_f	L_f
0.14 mm	8.2 mm	3 mm	5.86 mm

To have better radiation characteristics we propose a modification on the antenna in three steps: i) It is etched four RSS on the radiating patch, ii) The modification for ground plane is performed with a rhombic shaped defect at the center point and iii) Four additional rhombic shaped defects are etched around the center slot with definite distances from the corners of the first slot on the ground plane.

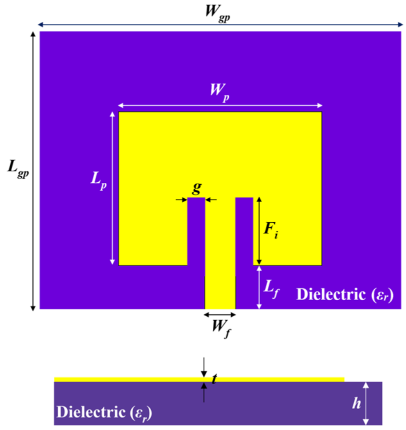

Figure 1. Top view and side view of Antenna #1.

Each step creates new antenna structure and they are called Antenna #2, Antenna #3 and Antenna #4, respectively. In the subsections, the detailed information is given.

A. Antenna #2

To improve the radiation characteristics of the antenna we propose four RSS on the patch. They are designed on the right and left edges on the radiating patch having the starting point distance of $L_p/4$ from the corners. Figure 2 shows the antenna structure. The slot edge dimensions are shown with parameter edge_1, the spacing between the slots and the antenna edge on x-direction is shown with parameter distance_x and parameter distance_y shows the location of the slot compared to the reference point of $L_p/4$ on y-direction, e.g. -2 mm means 2 mm in -y direction and 2 mm means 2 mm in +y direction. These parameters have effects on the resonant frequency and other radiation characteristics of the antenna. So, we have performed a detailed parametric analysis to obtain the effects and find the best values for the antenna to radiate.

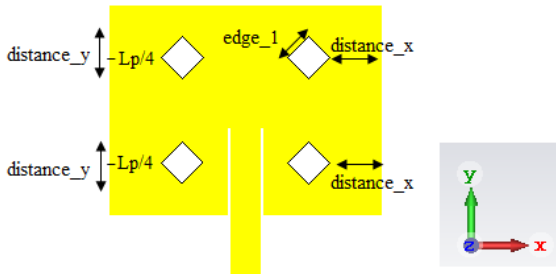

Figure 2. Antenna #2 front view.

B.Antenna #3

To obtain the effects of DGS we etch another RSS at the centre point of the ground plane with an edge dimension of parameter edge_2. Figure 3 shows the structure of the antenna. We have performed an optimisation for the best results and also to see further effects, we change the value of parameter edge_2 having other parameters on the patch fixed with their best results.

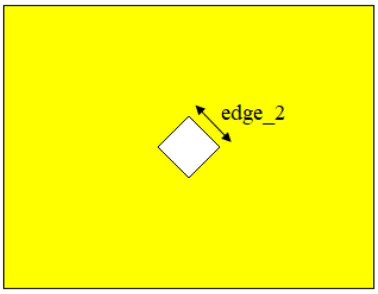

Figure 3. Back view of Antenna #3.

C.Antenna #4

For additional bandwidth and improved return loss levels we etch four more slots on the ground plane with the edge dimension of parameter edge_3. Figure 4 shows the structure of the Antenna #4 which is also the final design and the proposed antenna. The spacing from the corners of the first slot on the ground plane is shown with the parameter dist_dgs. To obtain the effects we have performed a detailed parametric analysis about these parameters having all the other parameters fixed. The final optimised parameters for the Antenna #4 are given in Table 2.

Table 2. Optimised parameters of the proposed antenna

edge_1	edge_2	edge_3
2 mm	0.9 mm	0.6 mm
distance_x	distance_y	dist_dgs
5 mm	-2 mm	15 mm

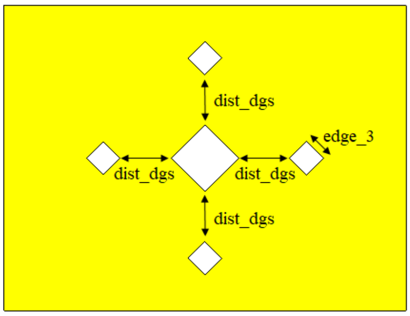

Figure 4. Back view of Antenna #4.

3 Results and Discussion

The simulation results are performed using the Computer Simulation Technology (CST) [10] software and the S_{11} results for the Antenna #1 and #2 are shown in Figure 5. The reference antenna, Antenna #1, resonates at 3.50 GHz with a return loss level of -37.97 dB and a bandwidth of 114.8 MHz. After the slots are etched, -56.89 dB return loss level with a bandwidth of 115.1 MHz at 3.53 GHz are obtained.

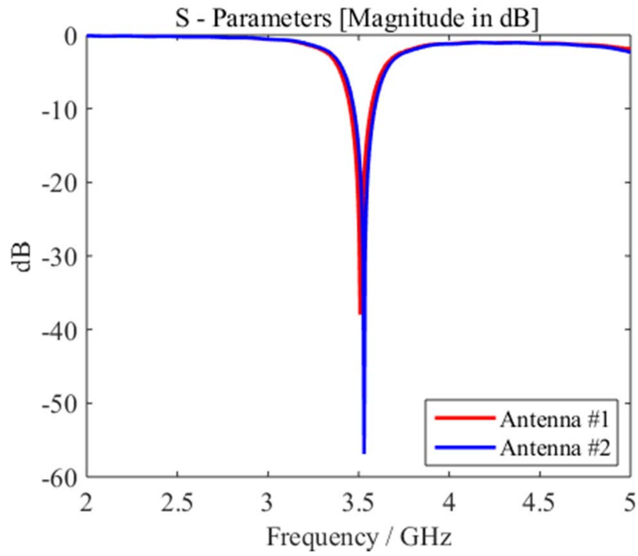

Figure 5. S_{11} results for the Antennas #1 and #2.

To obtain the effects of DGS and to have additional bandwidth the antenna is etched with a RSS at the centre of the ground plane which is the Antenna #3 in this study. The S_{11} results are shown in Figure 6. Antenna #3 has attained 200 Hz bandwidths increase with 115.3 MHz at the same resonant frequency of 3.53 GHz with a return loss level of -51.48 dB. The final design, denoted with Antenna #4, has four additional slots on the ground plane located with equal distances from the corners of the first slot. With this modification, we reach at -55.42 dB in return loss level and 116.4 MHz bandwidth which result in additional decrease of 3.94 dB in return loss and 1100 Hz increase in bandwidth compared to the Antenna #3. Figure 7 shows the S_{11} results of the Antenna #4 and Figure 8 shows the far field pattern results of the Antenna #4.

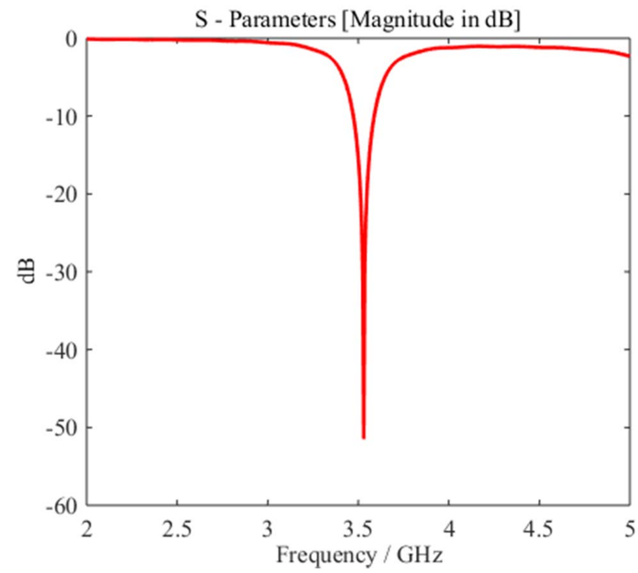

Figure 6. S_{11} results for the Antenna #3.

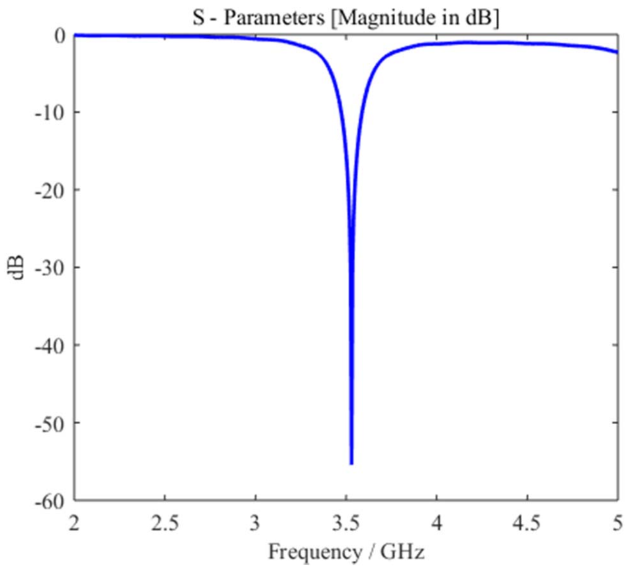

Figure 7. S_{11} results for the Antenna #4.

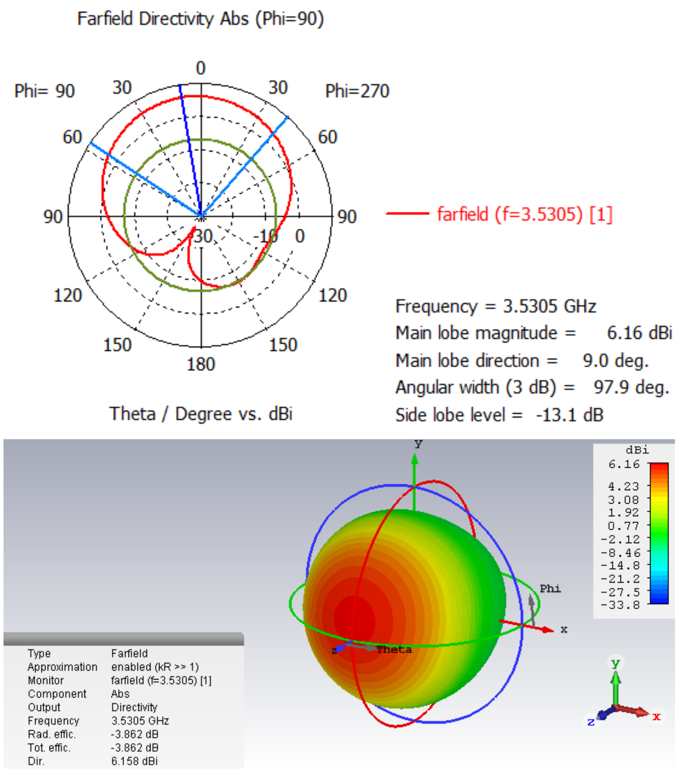

Figure 8. Far field pattern results for the Antenna #4.

4 Conclusion

In this study a rectangular microstrip patch antenna is designed and simulated at 3.5 GHz. For improved radiation characteristics, RSS and defected ground with five additional slots are proposed. This novel design has increased the 10 dB bandwidth by 1600 Hz from 114.8 MHz to 116.4 MHz and the return loss level has decreased by 17.45 dB from -37.97 dB to -55.42 dB. The final design is a promising candidate fort the early phase 5G wireless applications due to having good radiation characteristics.

5 References

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