2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

A Square Microstrip Patch Antenna with Enhanced Return Loss through Defected Ground Plane for 5G Wireless Networks

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Abstract

In this paper, we design an inset fed square microstrip patch antenna with defected ground plane for 15 GHz which is one of the projected 5G frequency bands. The first design concept is a conventional inset fed square microstrip patch antenna which has a return loss level of -35.339 dB and a bandwidth of 1.04 GHz at 15 GHz. For lower return loss level and higher bandwidth requirements the proposed antenna is modified by etching diamond-shaped slots on the radiating patch. The coordinates of the etched slots are determined using parametric analysis to meet the objectives of large impedance bandwidth and low return loss in the desired frequency. For this second prototype, we observe a bandwidth of 1.08 GHz and a return loss of -53.147 dB. To obtain the effects of defected ground on the characteristics we etch a diamond - shaped defect on the ground plane with an area of 0.005 mm^2. This defect results in additional return loss with 9.81 dB at the same frequency with the same bandwidth. As a result the proposed antenna provides an increment of 40 MHz in the bandwidth and a decrement of 27.618 dB in return loss level at the resonant frequency. Due to these novel characteristics, the proposed antenna can be a good candidate for 5G wireless networks as a transmitter or receiver where bandwidth and high impedance matching for maximum power transfer is an important issue.

1. Introduction

Today, the broadband capability of mobile networks should be expanded and with these improvements consumers and enterprises will be able to work faster and more efficiently. When 5G is in use new applications, such as wearables, traffic safety, industry processes, smart homes, will make life easier and healthier for humans. The Internet of Things developments will also be accelerated [1]. In addition, machine to machine communication will be utilized by huge number of devices which is 10000 or more in a single macrocell [2].

To meet all these huge amounts of numbers about utilizing the mobile network system there will be needed efficient antenna structures with compact sizes, easy fabrication and high bandwidth. Microstrip patch antennas are one of the most suitable candidates for this purpose. They have compatible dimensions with a variety of surfaces, circuits and devices. However, narrow bandwidth features are the main disadvantage about microstrip patch antennas. This drawback can be overcome by using different techniques such as etching slots on the radiating patch or ground plane which is called defected ground structure (DGS). DGS is an etched defect in ground of a planar transmission line which can be in different shapes. This defect effects on the shield current distribution in the ground plane. The characteristics of a transmission line such as line capacitance and inductance are also effected and this defect in the ground plane yields to increase effective capacitance and inductance [3]. DGS can also be used for dual frequency operations by adjusting the coordinates of the etched slots using parametric analysis [4]. In addition, this method can be used in millimeter wave frequencies and also the defected parts cause multiple frequencies in this band [5]. Moreover, there is no limitation about the shape of the radiating patch. For example, when the patch is circular the result is again increasing the bandwidth of the antenna [6].

The operation frequencies are still being debated but 6 GHz, 10 GHz, 15 GHz, 28 GHz and 38 GHz bands are among the expected ones [7]. In addition, Federal Communication Commission (FCC) approved the allocation of large bandwidths at 28, 37 and 39 GHz in July 2016 [8]. However, serious practical tests have been made at 15 GHz. For example, the tests performed by AT&T were in millimeter waves at 15 GHz, at its trial site in Austin, Texas. In the lab, AT&T has achieved peak data speeds of 14 gigabits per second at 15 GHz. Additionally, Sprint reached at 4 Gb/s data speed on 15-GHz band at the 2016 Copa América Centenario soccer tournament, in Philadelphia. In Japan, NTT Docomo has designated another 5G technology called MIMO (multiple-input, multiple output), to achieve 20 Gb/s at 15 GHz [9].

Following these applications, in this study we propose a square microstrip patch antenna operating at 15 GHz. For 5G applications the high bandwidth capability is the most important issue. In addition, the return loss level of the antenna should be as low as possible to be able to work efficiently as a transmitter or receiver. For improved bandwidth and return loss level we propose diamond shaped slots on the radiating patch and on the ground plane. The dimensions of the slots play a great role on the operating frequency and also the return loss level. For the best optimized values the proposed antenna is created in three iterations;

Iteration 1: According to the design formulas a 15 GHz square microstrip patch antenna is designed and optimized for the desired resonance frequency.

Iteration 2: For improved bandwidth and return loss levels diamond - shaped slots are etched on the radiating patch.

Iteration 3: At the center on the ground plane there is etched a diamond - shaped defect with an edge dimension of 0.07 mm.

2. Design

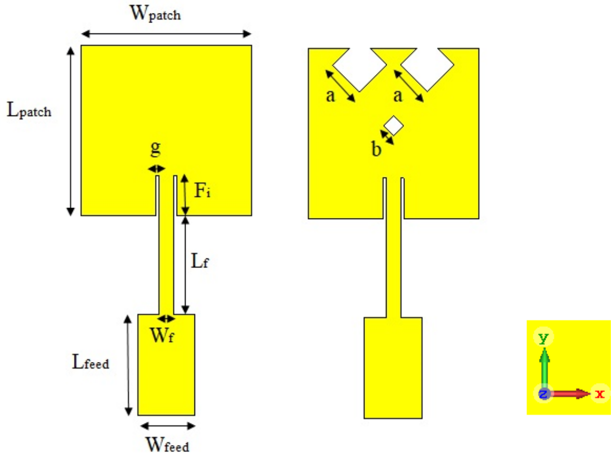
The design procedure is the same with the one of rectangular patch antenna design by taking the dimension of the width equal to the dimension of the length [10]. According to (1) we can calculate the width and the length of patch.

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

Here W is the width of the patch, L is the length of the patch, c is the velocity of the light in free space, f_r is the operating frequency of the antenna, ε_r is the dielectric permittivity of the substrate. For the proposed antenna, we use Rogers RT 6002 as the substrate with ε_r = 2.94, electrical conductivity δ = 0.0012, height h = 1.524 mm, width W_{subs} = 24 mm and length L_{subs} = 14 mm. Figure 1a shows the geometry of the square patch antenna. The feeding is done with a microstrip feed line W_{feed} x L_{feed} = 1.705 mm x 3 mm and a quarter wave impedance matching line W_f x L_f = 0.42 mm x 2.91 mm through an inset point with the dimensions F_i x g = 1.2 mm x 0.1 mm. For impedance matching conditions with the SMA (SubMiniature version A) connector of 50 ohms the width of the line is optimized. Antenna design parameters are summarized in Table I.

Table 1. Optimized antenna design parameters

ε_r	W_{patch} (mm)	L_{patch} (mm)	h (mm)	W_{subs} (mm)	L_{subs} (mm)	a (mm)
2.94	5.05	5.05	1.524	24	14	0.8
F_i (mm)	g (mm)	L_f (mm)	W_f (mm)	L_{feed} (mm)	W_{feed} (mm)	b (mm)
1.2	0.1	2.91	0.42	3	1.705	0.3



(a) (b)

Figure 1. (a) Conventional square patch antenna, (b) Proposed square patch antenna with diamond – shaped slots.

For improved return loss levels and bandwidth, we propose two diamond slots at the top and a diamond slot near the middle point of the radiating patch. The slots at the top part are shifted 0.3 mm in the +y direction and 1 mm +x and -x directions after they were designed in the middle on the top edge of the patch. The other diamond slot was shifted 2 mm in -y direction after it was designed in the middle on the top edge of the patch. All these coordinate parameters effect on the resonant frequency and return loss level so an optimization should be carried out. The proposed patch antenna is shown in Figure 1b. We search also the DGS effects in millimeter wave frequencies. From previous studies, it is known that defects in ground plane causes increasing the effective capacitance and inductance [3]. We show in this study even just a small defect with an area of 0.005 mm^2 can yield a significant decrease in return loss level.

3. Results and Discussions

At 15 GHz operating square patch antenna is designed and optimized using the software CST Microwave Studio [11]. Reflection coefficient results of the conventional square patch antenna and the square patch antenna with diamond - shaped slots are shown in Figure 2. As seen the first antenna resonates at exactly 15 GHz with return loss level -35.339 dB and a bandwidth about 1.04 GHz. To increase the bandwidth and decrease the return loss level we proposed diamond – shaped slots on the patch. After these slots etched on the patch the S11 results are also shown in Figure 2. The return loss level has improved with the decrease of 17.808 dB as -53.147 dB and the bandwidth with the increase of 0.040 GHz as 1.08 GHz. However, the resonant frequency shifted to 15.2 GHz.

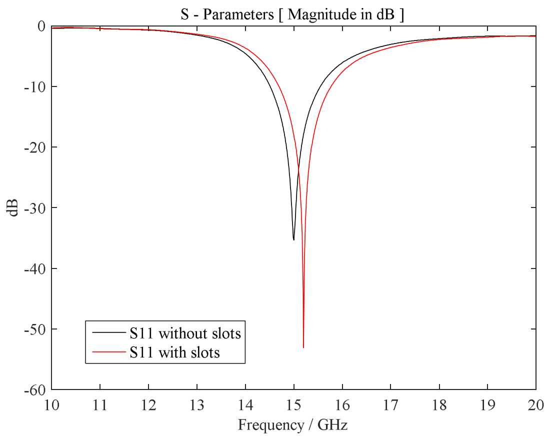
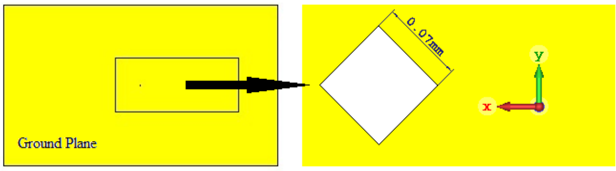


Figure 2. Return loss plot versus frequency for the conventional square patch antenna and for the square patch antenna with diamond – shaped slots.



(a) (b)

Figure 3. (a) Diamond – shaped defect on the ground plane, seen as a point at the center, (b) Bigger view of the defect with the edge of 0.07 mm.

We also investigate the effects of the defected ground on the return loss and the bandwidth of the antenna. For this purpose, we etch a diamond – shaped defect on the center of the ground plane as shown in Figure 3. For the best results, we performed a parametric analysis with the edge of the diamond – shaped defect and for the edge dimension of 0.05 mm we obtained -62.957 dB for the return loss level. The bandwidth remained the same and the resonant frequency was 15.19 GHz for the last design. Figure 4 shows the S11 results of the antenna with defected ground.

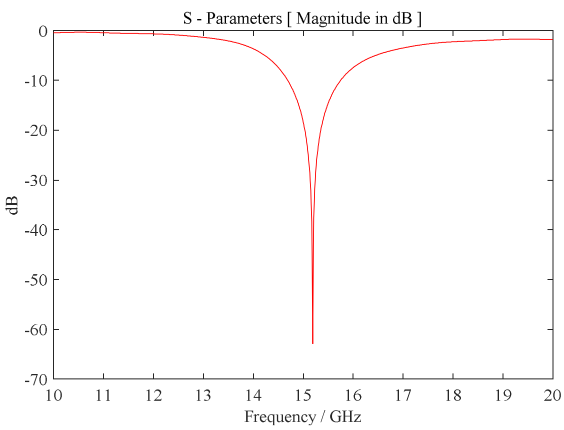


Figure 4. Return loss plot versus frequency for the square patch antenna with diamond – shaped defect on the ground plane.

Figure 5, Figure 6 and Figure 7 show the radiation patterns for the conventional square patch antenna, for the square patch antenna with diamond – shaped slots on the radiating patch and for the square patch antenna with defected ground structure, respectively. The square patch antenna without slots has a main lobe magnitude of 8.04 dBi and 3 dB angular width of 71.3 degrees. After the slots has been etched the main lobe magnitude level decreases 0.01 dBi with 70.9 degrees which means the antenna can send or receive signals almost with the same magnitude with a narrower angular width. Defected ground resulted in a lower return loss level but the main lobe magnitude decreased to 7.97 dBi with 72.2 degrees which means lower signal magnitude is sent or received with a wider angular width.

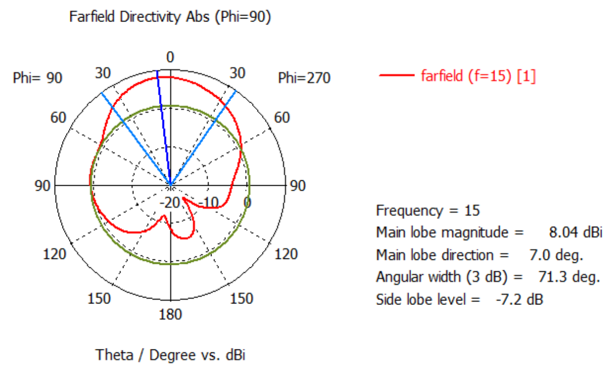


Figure 5. Radiation patterns for the conventional square patch antenna.

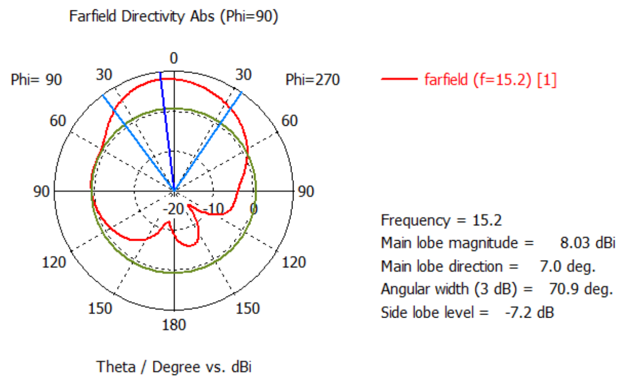


Figure 6. Radiation patterns for the square patch antenna with diamond – shaped slots on the radiating part.

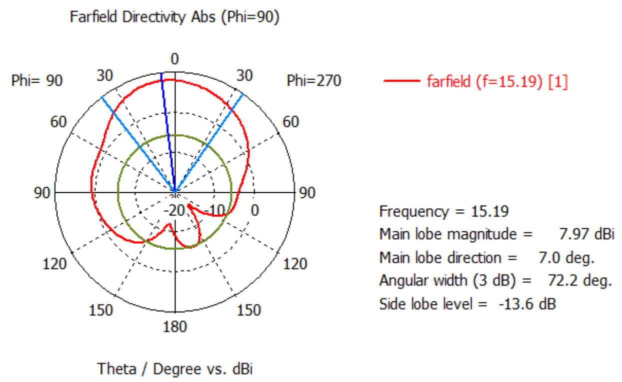


Figure 7. Radiation patterns for the square patch antenna with diamond – shaped slots on the radiating part and with defected ground.

4. Conclusions

A square patch antenna with a novel design for future mm-wave wireless networks is presented. The antenna is designed to operate at 15 GHz. To improve the bandwidth and return loss characteristics diamond - shaped slots are etched on the patch and on the ground plane which is called DGS. For the best results an optimization is performed about the coordinates and edge dimensions of the slots. The results indicate that the proposed patch antenna with diamond slots and DGS shows lower return loss levels and higher bandwidth. The proposed geometry of the patch can be used for future 5G applications and can be enhanced for other candidate frequency bands by modifying the dimensions of the antenna.

5. References

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