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An Inset Fed Square Microstrip Patch Antenna to Improve the Return Loss Characteristics for 5G Applications

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Abstract

In this study, a square microstrip patch antenna operating in millimeter wave frequencies with improved return loss characteristics is proposed. The proposed patch antenna operates at 30 GHz which is among the projected 5G communication frequencies and has a novel geometry with diamond-shaped slots. The first design in this work is a conventional inset fed square microstrip patch antenna. It has a quarter wavelength impedance matching line. The dimensions are determined according to the usual design considerations. Low return loss and high bandwidth requirements motivates us to modify the antenna design. Therefore, we add diamond – shaped slots on the patch which leads to an additional increase in the system bandwidth as much as 46 MHz and a reduction in the return loss level up to 10.751 dB. Due to these novel characteristics, the proposed patch antenna design is conjectured to be a suitable candidate to address the requirements of 5G communication systems. The operating frequency of the proposed antenna can be tuned by changing the geometrical dimensions from microwave to the THz region.

1. Introduction

Wireless communication technology has been an area with intense improvement and cutting edge development in the last decade. Starting with the first - generation communication systems all the way up to today's 4G LTE systems, there has been a rapid development and need to transfer not only voice data and text, but also live video streaming, GPS data and much more between the transmit and the receive devices [3].

The specific demand for faster communication will be the main focus in the near future. According to the Cisco Visual Networking Index (VNI) global mobile data traffic grew 74 percent in 2015 and fourth generation (4G) traffic exceeded third generation (3G) traffic for the first time in 2015 [1]. In addition, VNI states that by 2020, more than three – fifths of all devices connected to the mobile network will be ''smart'' devices and there will be 11.6 billion mobile connected devices by 2020, including machine to machine (M2M) modules [1]. Therefore efficient antenna designs are paramount to the design and development for the next generation communication systems. It is clear that millimeter wave (mm - wave) frequencies of unlicensed spectra will enable to utilize a vast amount bands [3]. To this end developments in the antenna technology become a central aspect in mm – wave system design. The microstrip patch antennas are in particular importance thanks to their compatible dimensions with a variety of surfaces, circuits and devices. A major short coming of such antennas, however, is their limited bandwidth. This disadvantage can be overcome with different techniques such as inset feeding [4] or etching different geometrical shapes to the ground plane which is called defected ground plane structure (DGS) [5]. There are also studies for efficient antennas with low return loss in wideband applications by etching circular slot on the circular patch [6].

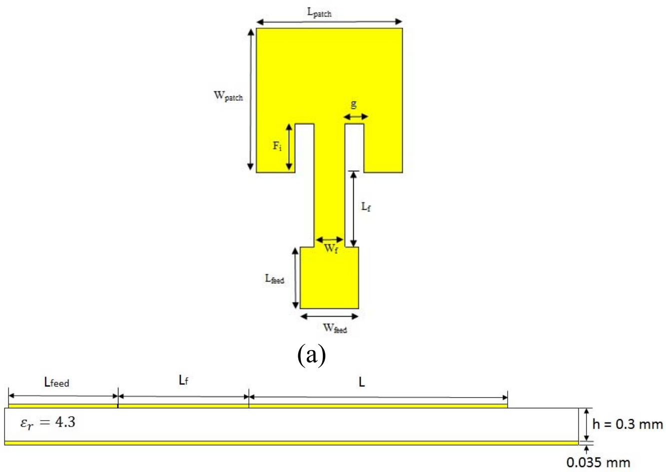
There are myriad applications as well as various proposals to improve the bandwidth of patch antennas. However, there are few studies in the mm – wave microstrip antenna technology. In particular, in [7] the detailed design aspects for 5G frequencies have been discussed. In [8] it has been focused on patch phase array antenna orientation for 5G applications. In addition, in [9] dual band printed mm – wave slot antennas are studied. [10] proposes an application for vehicle - to - vehicle (V2V) communication in mm - wave radio channel. There is a clear need for an advanced microstrip antenna technology for mm – wave applications in order to facilitate high bandwidth and low return loss levels.

Following from that we propose a novel microstrip patch antenna design which is enabled by virtue of a simulated optimization of antenna geometry. In particular it is found that a diamond shape opening carefully allotted on the antenna surface leads to a significant decrease in the return loss level and provides a substantial increase in the system bandwidth. We focus on a square microstrip patch antenna resonating at 30 GHz. [2] states that a bandwidth increase of 1 GHz or more is likely to be obtained above 30 GHz. Following from [2] we initiate our optimization procedure by selecting a central frequency of 30 GHz. It will be shown in sequel that the optimization procedure that we follow will suggest that 30.2 GHz will manifest itself as a particularly suitable frequency to accomplish the objectives of bandwidth increase and return loss reduction.

2. Design

The design considerations have been made according to the steps of the design of rectangular microstrip patch antenna

[3], by taking the dimension of the width of the patch equal to the length of the patch. The major disadvantage of a microstrip antenna is its narrower bandwidth. Especially in millimeter wave bands this drawback becomes more important because the antennas should send the beams in definite directions with high efficiency so we focused on improving the bandwidth with low return loss levels. For this purpose, a square microstrip patch antenna is designed with edge dimension 2.362 mm shown in Figure 1 from top and side. The patch is assembled on a FR 4 substrate with dielectric constant $\varepsilon_r = 4.3$ and dielectric loss tangent $\delta = 0.025$. We chose an FR 4 substrate because of being inexpensive, compatible with other circuits and being supplied easily. The substrate dimensions are W x L = 4.6 x 5.2 mm. The height of the substrate should be in the limits of $h > 0.06\ \lambda_{air} / \sqrt{\varepsilon_r}$ [4]. So, the thickness of the substrate was chosen as h = 0.3 mm. The thickness of the metal is 0.035 mm.



(a)

(b)

Figure 1. First design is a square inset fed microstrip patch antenna without slots (a) Top view, (b) Side view.

Antenna design parameters are summarized in Table 1. W_{subs} and L_{subs} show the width and the length of the substrate, respectively. According to the design method [11] the calculation on the dimensions of a square patch antenna is shown below.

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

Here W is the width of the patch, L is the length of the patch, c is the speed of light, ε_r is the dielectric constant of the substrate material and f_r is the resonant frequency of the antenna. As seen from the formula (1) the patch dimensions define the resonant frequency. Because the proposed antenna has a square geometry there is no need to calculate the width and the length separately. Therefore, it can be concluded that this type of geometry is easier for having one calculation to adjust the resonant frequency.

Table 1. Geometrical dimensions of the proposed antenna

ε_r	W_{patch} (mm)	L_{patch} (mm)	h (mm)	W_{subs} (mm)	L_{subs} (mm)
4.300	2.362	2.362	0.300	4.600	5.200
F_i (mm)	g (mm)	L_f (mm)	W_f (mm)	L_{feed} (mm)	W_{feed} (mm)
0.800	0.300	1.210	0.510	1.000	0.955

The antenna is fed by an inset microstrip feed line of 75 Ω with the width W_{feed} = 0.955 mm and length L_{feed} = 1 mm. The feeding is not built on the patch edge. It is created in an interior point by using a rectangular notch with the dimensions F_i x g = 0.8 x 0.3 mm. F_i and g effect on the resonant frequency and return loss level so the most suitable results should be found. In addition, the feed line is connected to the patch with a quarter wavelength impedance matching line. This line makes it easier to find the right dimensions for the feeding part. Additionally, by changing the value of W_f which is the width of the impedance matching line it is possible to get different resonant frequencies but at this time the return loss levels also change.

For improved bandwidth and low return loss level we propose a square patch antenna with diamond shaped slots with the edge dimension of a = 0.424 mm on it. This design is shown in Figure 2. The coordinates of the slots and the edge dimension effect on the resonant frequency and return loss level so an optimization should be carried out.

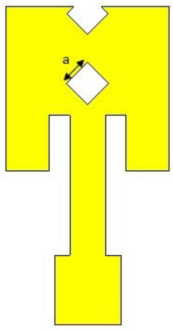


Figure 2. Second design is a square inset fed microstrip patch antenna with diamond shaped slots.

3. Results and Discussions

At 30 GHz operating square patch antenna is designed and optimized using the software CST Microwave Studio. Reflection coefficient results $|S_{11}|$ without the diamond shaped slots on the patch are shown in Figure 3. As seen the antenna resonates at exactly 30 GHz with return loss level -33.307 dB and a bandwidth of about 0.962 GHz.

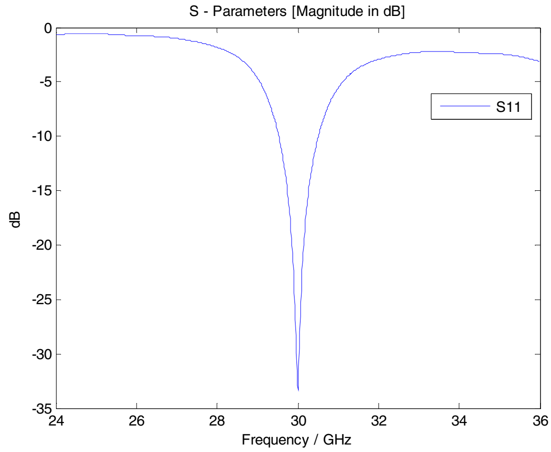


Figure 3. Return loss characteristics (S_{11}) vs frequency for the first design.

To increase the bandwidth and decrease the return loss level we proposed a diamond shaped slots on the patch. After these slots etched on the patch the $|S_{11}|$ results are as shown in Figure 4. The return loss level has improved with the decrease of 10.751 dB as -44.059 dB and the bandwidth with the increase of 0.046 GHz as 1.008 GHz. However, the resonant frequency shifted to 30.216 GHz.

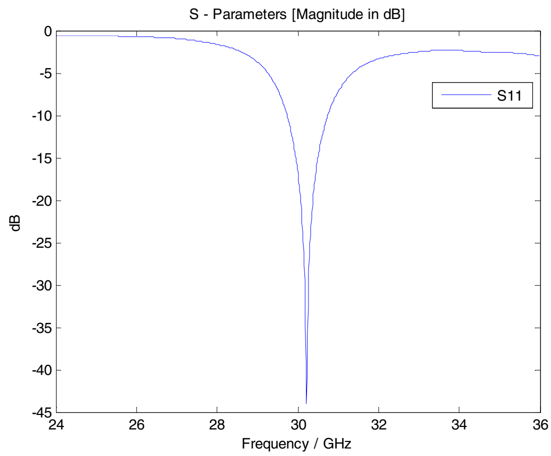


Figure 4. Return loss characteristics (S_{11}) vs frequency for the second design.

Figure 5 and 6 show the current densities on the square patch antennas with and without the slots, respectively. At the resonant frequency, it is clearly seen that the current density has increased on the antenna especially around the slot edges after the slots has been etched. It can be clearly concluded that the current density increases when surfaces are created along the edges of the patch antenna. Figure 7 and 8 show the radiation patterns at the resonant frequencies for the antennas with and without the slots, respectively. It is also clear that this novel design leaded to a decrease in the side lobe level from -8.8 dB to -8.7 dB and to an increase in the main lobe level from 6.56 dBi to 6.6 dBi. These results can be taken also as advantages for this proposed patch antenna.

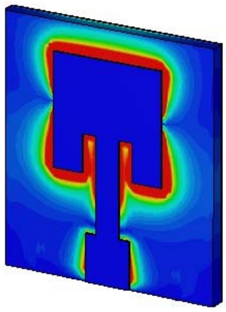


Figure 5. Current density on the square microstrip patch antenna without slots.

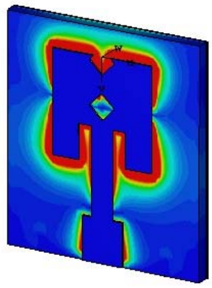


Figure 6. Current density on the square microstrip patch antenna with slots.

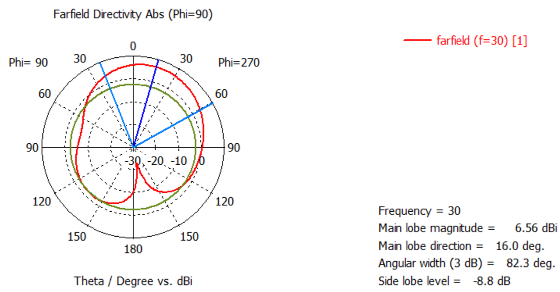


Figure 7. Radiation patterns for the square microstrip patch antenna without slots.

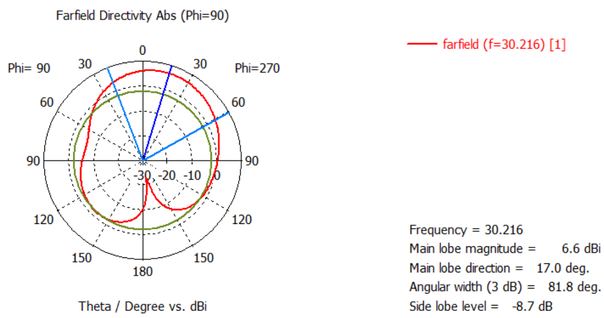


Figure 8. Radiation patterns for the square microstrip patch antenna with slots.

4. Conclusion

A square microstrip patch antenna with a novel design for the future mm – wave mobile network to improve the radiation characteristics is presented. The antenna is designed to operate at 30 GHz which is one of the frequencies of mm – wave spectrum. To obtain the enhancement in the return loss levels the optimization of the slot coordinates and dimensions is performed. The results indicate that the proposed microstrip patch antenna with the diamond slots shows lower return loss levels. The proposed geometry of the patch can be used for future mm – wave wireless applications and enhanced for other candidate frequencies in mm – wave band for further 5G applications.

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