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A small slotted rectangular microstrip patch antenna for Sub 6GHz - 5G applications

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Abstract

This paper discusses various challenges related to the antenna design process for sub 6 GHz, 5G communications. In the first example, the design is a square, simple antenna with two slots. Their parametric studies are made to see which parameters have affected the results. On the other hand, the second design for the antenna is represented as well, the design is still like a square, but the number of slots is bigger. The circular design of the antenna is also one of the most popular for 5G, but the results are not so good. For this kind of antenna below 6 GHz, a few slots are important, and a circular design is not the best idea. This antenna, the second design operates at 3.23 GHz with S11 of -14.3 dB, E-θ of 5.73 dB, and E-Φ of -11.6 dB.

Keywords: microstrip patch antenna, rectangular design, reflection, a parametric study

1. Introduction

In the past two decades, people start changing from analog sharing data to digital. First of all, they use a standard form, cable form, but nowadays new worldwide wireless use everybody [1]. Based on it, moving from standard to wireless was the first step, from 1 to 4G [2]. They spent years moving from one to one. Now, the situation is different [3]. Technology is easy to use, and we are able to design our own antenna to see is there any reaction [4]. To achieve the best possible results, low gain, and other features that one antenna should meet; it is necessary to work on the design. Adding the number of elements and other components has a big impact on the final result [5]. One good software for this kind of design is Sonnet Suites [6]. There is other commercial electromagnetic software, easy to use, for a new design of 5G antennas [7]. We can make our own antenna, and test and build it later on [8]. The term 5G refers to the fifth generation of mobile telecommunications networks with associated infrastructure and devices. Their main features are a new jump in data transfer speeds and the possibility of a larger number of connected devices [9]. Over time, networks should be further developed, speeds increased, and the offer of supported devices will be expanded to lower price ranges, and perhaps to a wider range of Internet of Things (IoT) devices.

As far as the frequency spectrum is concerned, 5G networks are divided into two groups - the one below 6 GHz and above that limit. In the first group, the European Union accepted the spectrum of 700 MHz and 3.5 GHz, and in the second - 26 GHz. The 700 MHz frequency will be used in rural and less populated areas, on open roads, and at sea, as the longwave, or lower frequency, has a longer range [10].

Speed for 5G is 10 gigabits per second. The conclusion from the literature between 4 and 5 G is that there is a big difference [11]. The latency of 4G varies from carrier to carrier, on the other hand, 5G has extremely low latency capabilities [12]. 5G is also 20 times faster than 4G in terms of peak speed. The minimum peak download speed for 4G is 1Gbps, and for 5G is 20 Gbps. G promises low latency under 1 ms, while 4G latency ranges from 60 ms to 98 ms. The U.S. 5G top speed was 2.7 times higher than its 4G LTE top speed, while Australia's 5G speeds were slower than their 4G speeds. As such, when 5G appears all over the world we can notice unequal maximum speeds in different countries. However, these numbers are not accurate representations of the average user experience. To reliably understand how fast 5G is currently, we need to look at real-world tests and examples.

OpenSignal conducted research in South Korea, a country that has strong 5G potential. In their article "5G smartphone users experience 111.8 Mbps average download speed", they saw that South Korean users have an average speed of 111.8 Mbps, which is faster than the "real" 4G speeds. This speed is significantly increased compared to the leading 4G phones that have a speed of 75.8 Mb / s. This is an even more significant jump from the general 4G phones, which recorded a speed of 47.7 Mb / s.

There are many different types of antennas, based on physical design: square, rectangular, circular, triangle, dipole, and elliptical [13]. The most popular are rectangular and circular [14]. Based on results found in different papers, it is possible to see how design can change results a lot [15]. In case we have a circular microstrip patch antenna, we can get good results, but the time for simulation is huge [16]. Also, dimensions can be small, but places for slits and slots are small [12]. On the other hand, with a rectangular antenna, we can make many different designs. The one half of a wavelength within the dielectric medium is the effective length of patch antenna. The E-fields is moving undergo fringing effects [9]. As it is mentioned before the most important to know for one antenna is reaction. Idea is to send signal without any change and to have maximum gain and speed [17]. The patch antenna radiation scheme is a broad topic. The characteristics are low radiation power and have a narrow frequency range, and there is less focus. For greater directivity, a string can be formed using these patch antennas [18]. The antenna pattern is the most important parameter. Power density is wave far away from our transmit antenna. The radiation resistance is the power radiated from our antenna [19]. Some radiation conditions are below.

First is radiation impedance, which is a real part of the Poynting vector. If it has radiation impedance that means the antenna can radiate and receive electromagnetic waves.

Other radiation conditions are:

- bandwidth (the range of frequencies that the antenna can radiate or receive),
- input matching, (how effectively transfer to the antenna),
- polarization matching (two antennas match by direction of electric field one relative to another in one of two actions, those are transmitting and receiving.

Also, we can calculate electric current density as

$$J=n*H \tag{1}$$

And magnetic density as

$$M=-n*E \tag{2}$$

2. Research method

In this paper, the designed antenna has a small rectangular shape. In the following text and pictures, it is possible to see designs for the first and second designs of the microstrip patch antennas for 5G applications. The difference is in the number of slots, but that one changes our results a lot. Height and width are also different, via port positions are the same. Based on it, we will see the results difference in the next section. Idea is to see results for different number of slots. Design is for both small squares. Figure 1 has the microstrip patch antenna with dimensions of 45x39 mm.

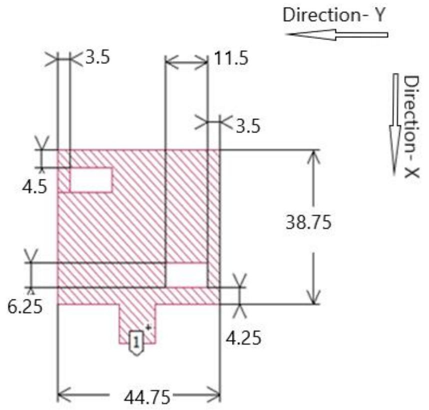

Figure 1. The first design of the patch antenna

Via-port feeding is seen in Figure 2. Via-port feeding is implemented on microstrip transmission line stub which responsible for the feeding of the square patch antenna. The most suitable point for impedance matching is found and the excitation is made via the via-port. In this way, the antenna is fed without any additional transmission line design for impedance matching. Despite the parametric study method mentioned above, it is also understood that changing the parameters of the microstrip square patch antenna changes the impedance of the radiant part, so the via-port feeding point can also be re-determined to ensure impedance matching. There is an implementation of slots structure on basic square patch antenna. There is more than a single slot on patch so maybe it is more convenient to think there is a slot array on it. At simulation part of this study dual slotted and triple slotted types of patches are design and simulated. The triple slotted patch design is given as a top view but the simulation results are not discussed. This simulation study is run to investigate the idea that slots somehow might cause the whole structure act as an antenna array. Despite the idea that "more slots provide more gain for a specific direction" parametric study is done on the dual slot patch configuration for simplicity. The second design is in the picture below (Figure 3) with 90 x 121 mm dimensions with three slots.

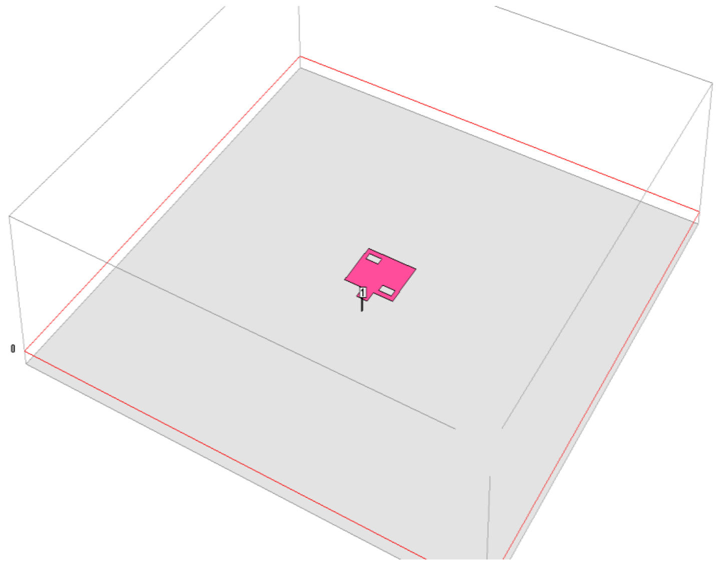
Figure 2. 3-Dimensional views of the antenna

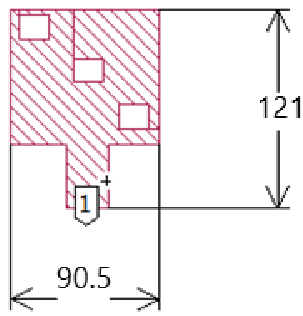

Figure 3. Second design of the antenna

3. Results and discussion

Figure 4 has the current results from the parametric study of the first designed antenna and represents flow of the current at 3.23 GHz. Red represents place with the highest amount of current, on the other hand blue is the lowest. As seen in Figure 4, the closest slot of the feed line plays an important role in the antenna radiation pattern characteristics due to the intense current flow.

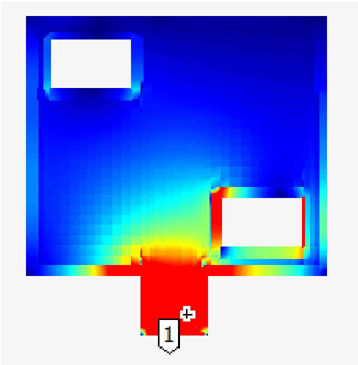

Figure 4. Current graph for the first design

Figures 5,6 and 7 show S11 graphs of different parametric studies. For example, in case when we increase dimensions and thickness, gain is much better. Results in the region below -10 dB are good for this study, but it does not mean that there is a decent gain on that resonant frequency. The S11 graph is displayed in Figure 5 belongs to the parametric study step which the closest slot of the feeding line has dimensions 11.5, 6.25 mm.

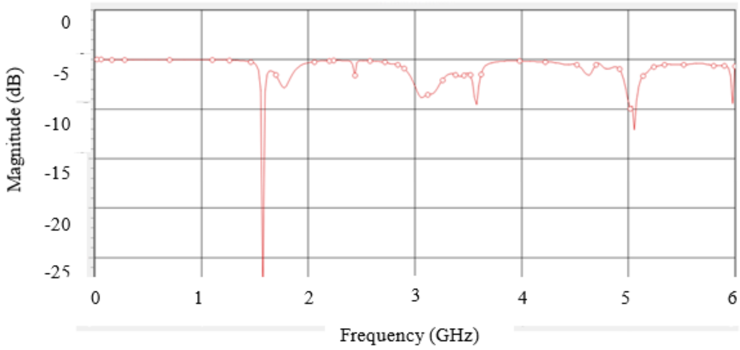

Figure 5. S11 graph for first design (11.5, 6.25mm)

The S11 graph is displayed in Figure 6 shows the results of the parametric study step which is the patch dimensions are 44.75x48.75 mm2. The best return loss performance at 3.23 GHz is seen based on this configuration respect to other parametric changings. Also, there are some other bandwidth regions which have acceptable return loss value within the frequency range of 4.5 GHz to 5.5 GHz.

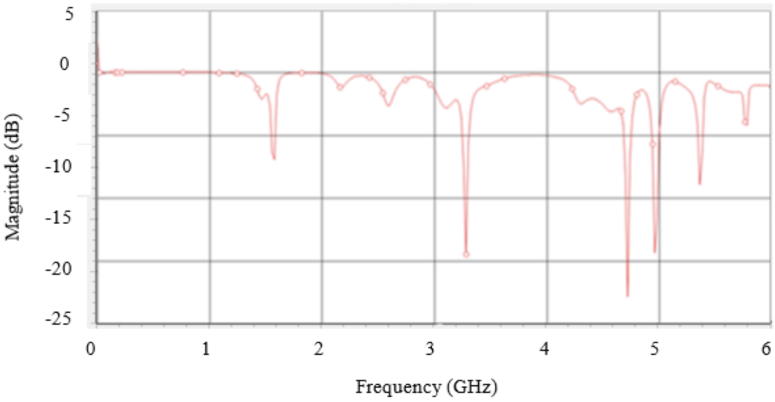

Figure 6. S11 graph for first design (44.75x48.75(10))

The S11 graph is displayed in Figure 7 shows the simulation results after setting the thickness of the antenna to 1.8 mm. It is obvious that the return loss at 3.23 GHz is not acceptable. On the other hand, this antenna has around 15 dB return loss and the gain is observed more than 5 dB for this configuration at 5.5 GHz. There is another frequency bandwidth region which has better return loss performance between the range of 4.5-5 GHz.

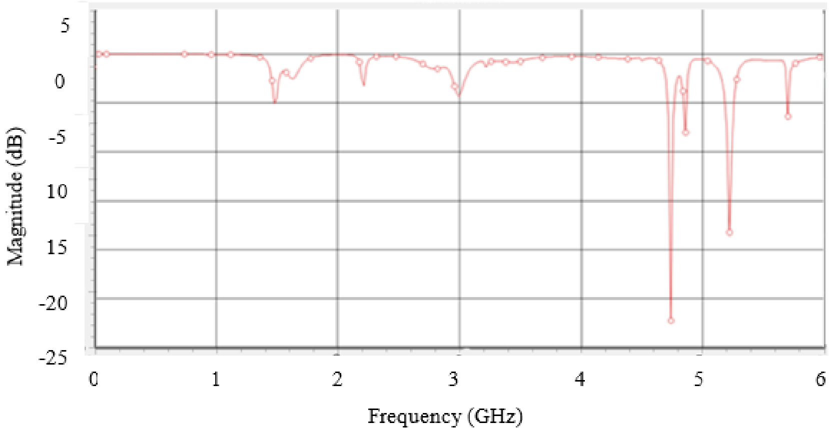

Figure 7. S11 graph for first design (dielectric thickness 1.8)

The polar graph seen in Figure 8 shows antenna gain at 3.23 GHz. The red thick line represents E-θ and the blue thin line represents E-Φ. The antenna focuses the radiated power in two specific directions with its almost symmetric lobes. It shows an unusual characteristic, having two symmetrical lobes instead of a single main lobe, side and back lobes. This type of radiation pattern plots can be seen in dipole antenna array applications because of the end-fire radiation conditions. It can be observed that two symmetrical lobes appear when the scanned radiation direction of the phased antenna array approaches the end-fire radiation direction.

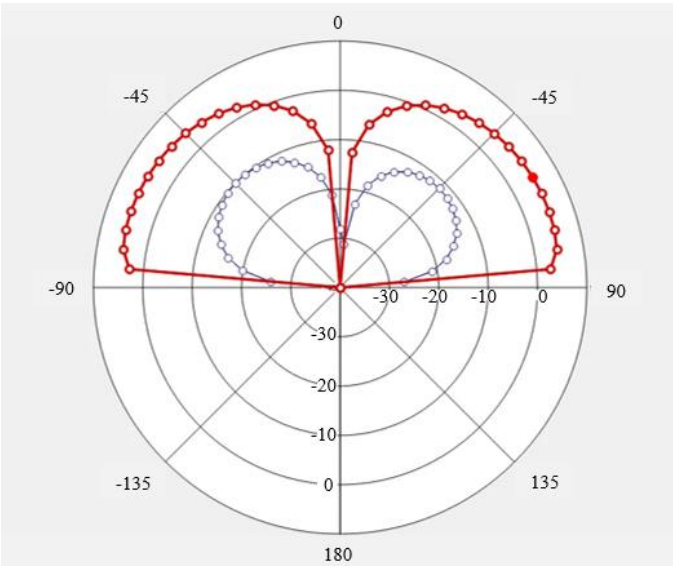

Figure 8. Polar plot of E-θ and E-Φ

Now, in the following tables there are results based on parametric study for the first antenna. It is possible to see how thickness is the most important for better design of the antenna. Also, position of slots and slits. That is possible to follow from current graph. Table 1 and 2 are on the same principle, where change in dimension of some geometry in antenna can improve results. Table 3 represents change of the constant in dielectric layer. Table 4 represents change in dielectric thickness.

The design parameters and results given in Table 1 relate to the structure with a dielectric thickness of 1.55 mm and a dielectric constant of 4.4.

Table 1. xy-direction change dimensions

X and Y(mm)	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
11.5 x 6.25	3.23	-14.5536	5.0837	-9.47175
10.75 x 5.75	3.6	-10.9685	3.15375	-9.60968
12.25 x7 .5	3.08	-8.83683	4.34299	-7.74061

The design parameters and results given in Table 2 relate to the structure with a dielectric thickness of 1.55 mm and a dielectric constant of 4.4.

Table 2. Via-port part change dimensions

Via port (mm)	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
44.75x48.75 (10)	3.23	-14.5536	5.0837	-9.47175
44.75x51.5 (12.75)	3.08	-11.3437	5.93356	-11.6704
44.75x47.5 (8.75)	3.23	-11.2788	5.20642	-10.0268

For related example whose results given in Table 3, has the fixed parameters X and Y are 11.5 and 6.25 mm, and dielectric thickness is 1.55 mm.

Table 3. Dielectric const

Dielectric constant	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
4.4	3.23	-14.5536	5.0837	-9.83939
4.5	3.06	-15.7955	5.42627	-10.6151
4.2	3.23	-14.3253	5.68712	-10.499

For related example whose results given in Table 4, has the fixed parameters X and Y are 11.5 and 6.25 mm.

Table 4. Dielectric thickness

Dielectric Thickness (mm)	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
1.55	5.52	-14.5536	5.0837	-9.83939
1.8	5.5	-15.111	5.10139	-9.8123
1.3	5.5	-11.9461	5.85216	-9.68616

While some of the design parameters are fixed, the parameters that are thought to be effective on the results are changed, and the antenna frequency response results obtained in this way are given in graphics and tables.

Due to the parametric working principle the previous simulation result, is examined. It is understood which parameter has an effect on how much. Before performing the next simulation, an estimation is made about how this parameter should be changed for better performance. With this method, the final antenna structure which has an unusual radiation pattern is approached step by step. Bandwidth is generally an important feature for all antenna design specs. One of the aims of this study is getting a multi-band antenna rather than a high-bandwidth antenna. When the results are examined, it is seen that this aim has been achieved.

4. Conclusions

Based on in previous section including the parametric study of the dual slotted patch design and the discussion of its simulation results, slots are the key for a good antenna. With small number of rectangular slots, sometimes slits, antenna can be low cost and easy to manufacture. From two designs above, results show how small, regular patch antenna can work, in sub 6 GHz range. On the other hand, small changes on the geometry of the antenna, can improve the results a lot. Although the antenna feeding point is kept constant during the parametric study, its importance is taken into consideration in terms of impedance matching. So, for minimizing the return loss perfectly matched impedance condition between port and antenna has to be provided. As a result of parametric studies and simulations carried out with this perspective, the designed antenna operates at 3.23 GHz with S11 of -14.3 dB, E-θ of 5.73 dB, and E-Φ of -11.6 dB.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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