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A stub microstrip patch antenna for sub 6GHz - 5G applications

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Abstract

The paper presents a stub microstrip patch antenna for sub 6 GHz, that is used in 5G applications. The background of each part of the theory and the rules of the design of the antenna are described. 5G technology and its advantages are mentioned in this paper. Also, the reason why the microstrip patch antenna is used in this project, and what effect it has on the results, is described. The physical structure can be different, and it can behave differently. This paper uses a rectangular shape. The antenna also has tunning stub, and slits and slots, which are discussed in the paper. The antenna is simulated and analyzed, using Sonnet Suites Software [1]. The changes that were analyzed are geometry, dielectric thickness, and dielectric constant. The substrate that is used for designing the antenna is an FR-4. The antenna operates at 5.5 GHz with S11 of -12.605 dB, E-θ of 4.646 dB, and E-Φ of -7.508 dB. These values are suitable for 5G applications.

Keywords: microstrip patch antenna, 5G, antenna analysis

1. Introduction

The need for communication and information has been getting more demanding in the past few years. The antenna is the main component of wireless communication, and it cannot function without an antenna. Antennas have the function of transmitting one energy to another and there are many types of antennas based on their physical structure and purpose [2]. The development of receiving and transmitting the waves in free space should be developed to be faster as technology advances over time. That is one of the main reasons why we are designing antennas that can be used for 5G applications [3]. 5G technology is being developed as a new technology that will create new opportunities for future services. This technology will increase flexibility and faster networks in many important fields of life, such as education, healthcare, security, and many other industries.

The 5G has 8 specifications, and those are:

- Low Latency (less than 1 ms)
- Access Technology (BDMA and FBMC)
- Frequency bands
- Mobility (≥500km/h)
- Spectrum Efficiency (up to 9 bit/s/Hz)
- Forward Error Correction Code – LDPC
- Connection density (1 million/km^2)
- Connection reliability: link outage of 0.99999
- Data Rate (2 - 20 Gbps) [4].

Patch antennas are popular in modern technologies. Patch antennas two sides on the dielectric substrate, one side is a patch of some geometry, and on the other side is a ground plane [5]. They are low profile, low fabrication cost, low weight, and easy to integrate; this is all necessary for communication systems. The simplicity of these antennas has brought them to be used in air traffic control, high-resolution mapping, radars for speed detection, space research services, mobile satellite services, radio navigation, etc. [6]. These antennas have a gain between 5 and 6 dB. Microstrip elements have the same features as patch antennas', as mentioned before, some other features are simplicity, conformability, and ruggedness. The designs of the antenna can be done from easiest to very difficult and challenging, due to that information, polarization can be different in this type of antenna [7]. Even next to those advantages, these microstrip antennas have some disadvantages which have to be overcome during the designing process of the antenna. The problems that can occur are lower gain, narrow bandwidth, large ohmic loss, etc. The most usual problem is getting the desired gain, which is necessary to be able to fabricate the antenna that will be able to effectively transmit and receive the waves. It can be fixed by array configuration [8].

As mentioned before, there are different types of antennas, based on their physical structure; the most popular ones are square, rectangular, circular, triangle, dipole, and elliptical. The most popular are rectangular and circular [9]. These two antennas are the simplest to design and fabricate, are low cost, can be designed small, and support both linear and circular polarization. The designs can work with the simplest and most complex applications [10]. Predicting the radiation of the rectangular antenna is done in [8], but there is no unique mathematical expression that can be used for every antenna possible, and there is no correct solution. The feeding line used in this project is the microstrip line feeding. Other techniques include coaxial probe feed, proximity coupling, and aperture coupling [11].

Another important role in techniques is the substrate. The substrate requires low relative permittivity and low loss tangent, in order to have higher gain, efficiency, mutual coupling value, wide bandwidth, and smaller power loss. Relative permittivity affects the magnitude of the electric field. Consider that the relative permittivity is high, the magnitude of the electric field reduces, and the gain of the antenna reduces. The tangent of a substrate affects the power loss, so if the tangent is low, the power loss is low, which is what is desirable [12]. If the substrate has low permittivity, it has a high cost and is not easy to find. The thickness of the substrate plays an important role in the affecting of the results of the antenna. The goal of every antenna is to be as small and as slim as possible. In the analysis of the paper [13], it is proven that the smaller thickness, makes patch radiation better.

In this paper, the designed antenna has a tunning stub which can help control phase shift and polarization, because the rectangular patch antenna can be sensitive when it is fabricated and can cause an error [14]. The polarization and radiation are controlled by the tunning stub. It does not have an effect on its dimensions, rather on the excitation of 2 orthogonal near-degenerate modes [15]. The design used U-shape open stub, which is suitable for wireless local area networks (WLAN), in which frequency can be tuned with stubs, and ultra-wideband (UWB) operations [16]. The slits and slots have a huge impact on the antenna gain, in the case of the antenna in this paper, it can be concluded that slits and slots, in some cases, could have a major impact on the output, and so it can be seen in many antennas that length, width, and position have an impact on the gain of the antenna [17]. Including slots and slits, engineers can have many different designs that can help in designing modern antennas. Modern antennas with slots have been studied for more than 4 decades. Their implementation is wide, because of their savings in cost, size, and weight. Applications that they are used at are energy harvesting, wearable applications, biomass permittivity determination, etc. Another advantage of using slots and slits is solving several issues in communication sensing, and antenna performance [18]. An example of an application in energy harvesting is the invention of antennas that allow total exposure of solar cells to sunlight [19].

In the paper [20], a 20 mm long square slotted antenna was designed. A comparison of non-slotted square and slotted square patch antennas was done. Non-slotted square patch needs feedings that can control resonant frequencies, which depend on the current distribution of each mode. A slotted square patch has a resonant frequency that depends on the length of the slots and their width.

The next generation of wireless networks will have requirements, such as high speed, submillisecond latency, and ensure good quality of service for a large number of devices. The future generation will have different techniques that will be used in communication systems. Application of the next generation of communication systems will be in smart homes, smart cities, smart devices, vehicles, data analytics, etc. [21].

This paper is organized as follows: Section 2 describes the design of the antenna; Section 3 describes the results of the simulation and the parametric analysis of the slots and slits of the antenna. In the final, Section 4 concludes the results and findings of the project.

The purpose of this research is to design an antenna that is small and has low weight, but can be used in 5G applications, which will be used in our life. The advantages of this antenna are mentioned in previous sentence, and it has a low price due to its substrate, which is not expensive, and the design is simple. The rectangular shape does not require a lot of precision, while in some of the mentioned papers, the design is complex, and requires high precision. For the inspiration of the design of the antenna, paper [22] is used.

2. Method

The proposed antenna is presented in Figure 1 and it is simulated using Sonnet Suites program. It has U-shaped slot on the patch and rectangular symmetrical slots. The frequency of the patch antenna that operates is 5.5 GHz. The geometry can be seen in Figure 1. The unit for length is mm. The dimensions of the antenna are 27 mm in width and 44 mm in height. The box size of the antenna is 10 times bigger than the patch, so it is 270×440 mm, and the cell size is 0.25×0.25 mm. The frequency range is from 0 GHz to 6 GHz. The selected dielectric substrate is FR-4 with a thickness of 1.55 mm.

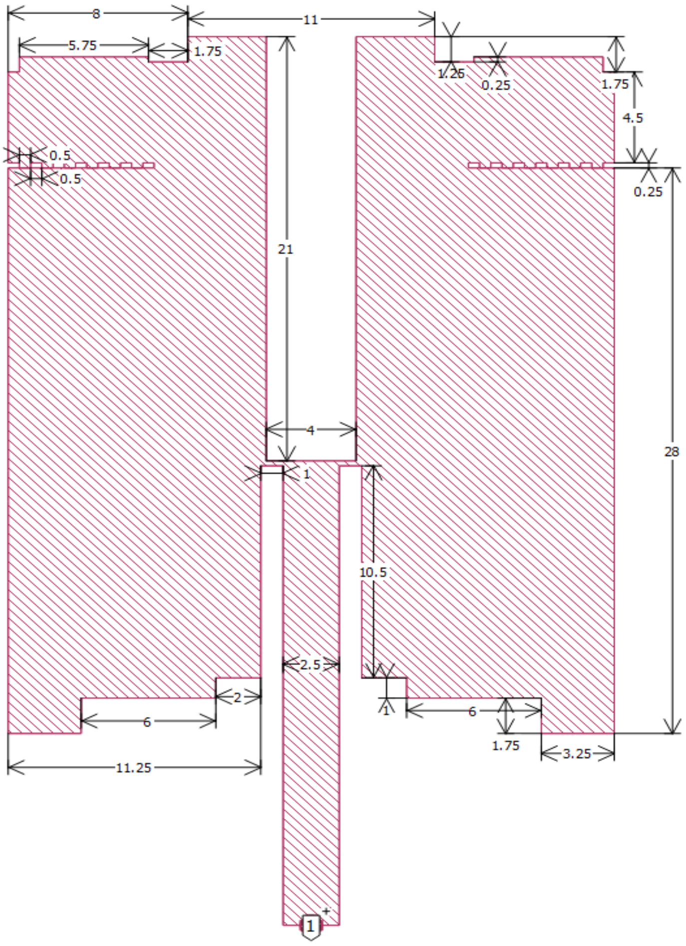

Figure 1. Schematic diagram of the microstrip patch antenna

The antenna has 7 rectangular slots on each side of the patch. Its dimensions are 0.25×0.5 mm. Another important part of the geometry is a slit on the upper part of the antenna; its dimension is 4×21 mm. It has a big effect on the gain of the antenna. There are 2 more important slits on the bottom part of the antenna; their sizes are the same, 1×10.5 mm. On the bottom part of the antenna is a feeding line with its port and via. In Figure 2, the 3D model of the antenna is presented.

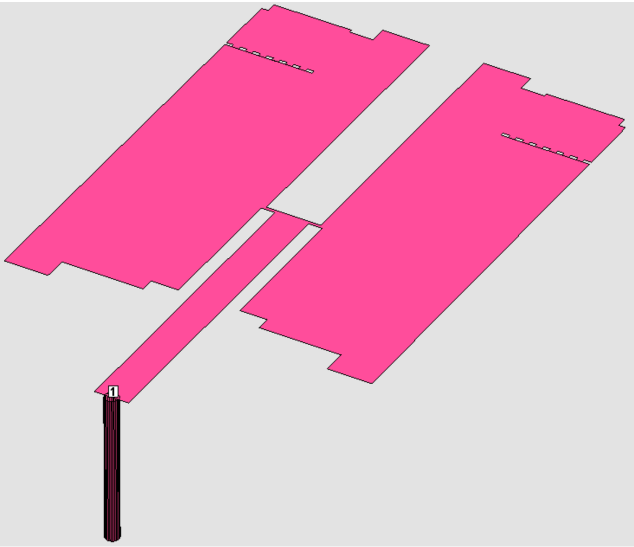

Figure 2. 3D view of the microstrip patch antenna

3. Results and discussion

The S-parameter of the coupler is shown in Figure 3. The goal of the antenna in this graph is to get the frequency that has the magnitude of the S11 lower or equal to -10 dB. In the case of this antenna, there are 3 frequencies that have a magnitude of S11 less than -10 dB, and those are 2.24 GHz with a magnitude of -16.741 dB, 4.28 GHz with a magnitude of -16.594 dB, and 5.5 GHz with a magnitude of -12.605 dB. The frequency that met the design specifications was 5.48 GHz.

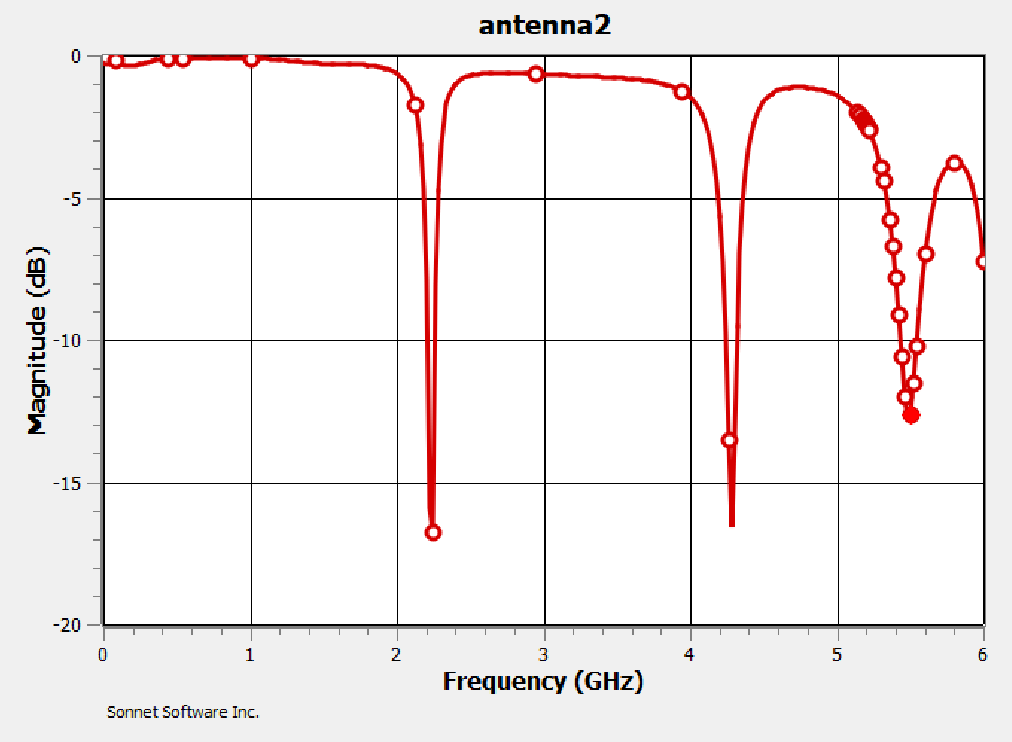

Figure 3. S-parameters of the microstrip patch antenna

Figure 4 represents the Far Field of the antenna; it shows the E-θ and E-Φ of the 5.5 GHz frequency. Antenna requirements are to have E-θ larger than or equal to 5 dB, and Φ lower than or equal to -5 dB. In the case of this antenna, the E-θ has the value of 4.646 dB, and E-Φ has the value of -7.508 dB.

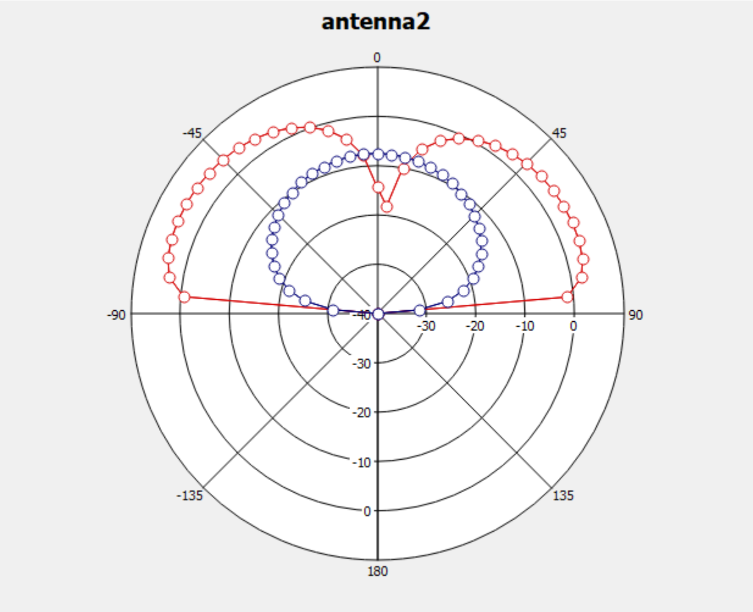

Figure 4. E-θ and E-Φ of the microstrip patch antenna

The current distribution of the antenna is represented in Figure 5. The represented current shows the flow of the current at 5.5 GHz. The current flows from the feeding line to other parts of the antenna. Red spots are the critical value of the current. The magnitude of the current is 2.85 A/m.

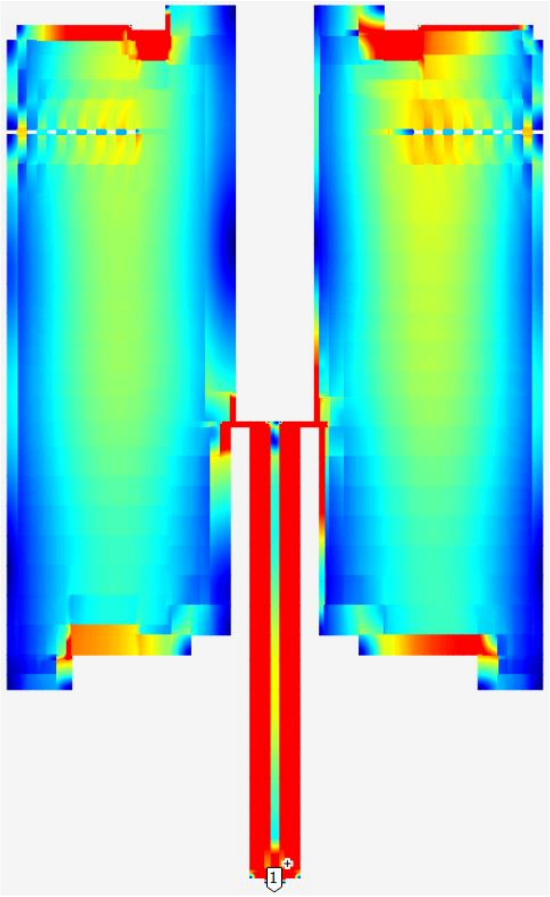

Figure 5. The current distribution of the microstrip patch antenna

The parameters in designing an antenna that are important are length, width, height, and dielectric material. This antenna is analyzed with changes in all the mentioned parameters. The analyses that were done are shown in 5 tables. Table 1 studies the change in the thickness of the dielectric layer, Table 2 studies the constant of the dielectric layer, Table 3 studies the change in the width of the vertical center slit, Table 4 studies the change of the height of the vertical slits at the bottom center of the antenna, and Table 5 studies the change of the width of the two cuts at the top of the patch (left and right).

In Table 1, the thickness of the dielectric layer is changed by 0.05 mm. It can be seen, that with the change of the thickness, the overall results are lower than with the original one, which is 1.55 mm.

Table 1. The thickness of the dielectric layer

Thickness (mm)	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
1.45	5.52	-14.360	4.597	-8.007
1.5	5.5	-13.577	4.579	-7.688
1.55	5.5	-12.605	4.646	-7.508
1.6	5.46	-12.095	4.527	-7.063
1.65	5.44	-11.406	4.493	-6.757

In Table 2, the constant of the dielectric layer is changed by 0.05. It can be seen, that with the change of the constant, the overall results are lower than the original one, which is 4.4.

Table 2. Constant of the dielectric layer

Constant	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
4.3	5.54	-12.313	4.599	-7.157
4.35	5.52	-12.564	4.626	-7.349
4.4	5.5	-12.605	4.646	-7.508
4.45	5.46	-13.140	4.578	-7.567
4.5	5.44	-13.261	4.595	-7.732

In Table 3, the width of the vertical center slit is changed by 0.5 mm. It can be seen, that with the change of the width, the overall results are lower than at the original one, which is at 4 mm. With a smaller width, the results decrease drastically, while with bigger width, the results are not decreasing a lot.

Table 3. Width of the vertical center slit

Width (mm)	Frequency (GHz)	S11(dB)	E-θ dB)	E-Φ (dB)
3	5.36	-10.414	4.237	-7.673
3.5	5.42	-11.445	4.406	-7.515
4	5.5	-12.605	4.646	-7.508
4.5	5.54	-14.797	4.515	-7.261
5	5.6	-17.792	4.561	-7.185

In Table 4., the height of two vertical slits at the bottom center is changed by 0.25 mm. It can be seen, that with the change in height, the results decrease. The original result and the best one is at 10.5 mm.

Table 4. Height of two vertical slits at the bottom center

Height (mm)	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
9.5	5.46	-14.905	4.073	-7.237
9.75	5.46	-14.359	4.059	-7.234

10	5.48	-14.084	4.524	-7.377
10.25	5.48	-13.573	4.547	-7.379
10.5	5.5	-12.605	4.646	-7.508

In Table 5., the change of the width of the two cuts at the top of the metal on both left and right sides. It can be seen that with the change in the width, the decrease in the results is minor. It does not affect a lot the overall results. The design specifications were met at 1.75 mm in width.

Table 5. Width of two cuts at the top of the metal (left and right)

Width (mm)	Frequency (GHz)	S11(dB)	E-θ (dB)	E-Φ (dB)
1.25	5.5	-12.739	4.637	-7.513
1.5	5.48	-12.820	4.555	-7.374
1.75	5.5	-12.605	4.646	-7.508
2	5.48	-12.785	4.565	-7.380
2.25	5.48	-12.752	4.562	-7.390

4. Conclusions

In the paper, the stub microstrip patch antenna is designed, simulated, and analyzed. The antenna is designed for 5G applications. The analysis is done between 0 GHz and 6 GHz. The antenna operates between 5 GHz and 6 GHz. The frequency at which the antenna operates is 5.5 GHz, with S11 at -12.605 dB, E-θ 4.646 dB, and E-Φ -7.505 dB. In this case of the antenna, at this frequency, S11 and E-Φ have perfect magnitude, while E-θ has suitable magnitude, it is close to the desired value. The changes that were made in the analysis of the antenna had a different effect on the results. The change in S11 and E-Φ can be neglectable since it is always in the desirable range of the value E-θ is the only one analyzed and focused on. We can see that changing the values of the variables of the dielectric layer and the width of two cuts at the top of the metal does not affect a lot the results of the E-θ, while the width of the vertical center slit and height of two vertical slits at the bottom center affect the result of the E-θ more. The height of the two vertical slits at the bottom center has the most impact on the result of the E-θ. The design specifications were met at 10.5 mm, with values as stated in the analysis.

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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