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Perturbed T-shaped patch antenna with slits and a floating metal for 5G.

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Abstract

This research paper highlights the process of designing and simulating a novel antenna. Our antenna is meant to be used in 5G applications (sub-6 Ghz). Simulating and designing was done using the Sonnet Suites software. The substrate used in our antenna is 1.55mm thick FR-4 substrate, that has a εr of 4.4. The antenna center frequency is 4.06 GHz. At the center frequency, S11 is -39.46 dB. Furthermore, the antenna has an E-θ of 5.75 dB, and E-Φ of -9.99 dB. This antenna can be used in devices that use 5G technologies. This antenna has the benefit of being cheap to produce, while boasting good performance during operation.

Keywords: Antenna, 5G, Fr-4, Microstrip, Sonnet Suites

1. Introduction

In the past few years, more and more research has been conducted in the field of mm-wave technology, to be employed in 5G systems. Due to the elevated interest in 5G, there has been a demand for multi-band minituarized antennas that will serve systems that operate in lower GHz bands (sub 6 GHz). 5G will satisfy the requirements for lower time delays, IoT, small size and high data rates [1]. 5G will support faster communications in the mobile department, while at the same time providing a high speed data rate. Antennas are needed that can be used for stable and disturbance free communications, while having an improved bandwidth, power, gain and insensitivity to noise. Due to this, unique solutions are needed for designing antennas [2].

Most modern systems for mobile communication have become widely used after the 2000s. They have progressed at a most rapid pace alongside other technologies over the past three decades. Initially it began with the 1G which was analog-based. And then progressed to the fourth generation. The fourth generation is an IP based technology (4G). LTE-A (Long term evolution - advanced) is becoming redundant due to an extreme increase in demand for data, which is caused by a surge in smart devices (IoT) [3]. Designing a transciever for 5G applications can pose numerous challenges. Considering that the antenna is one of the most critical element of a 5G system, therefore it has a crucial role in the determination of the whole performance of the system.

There are several requirements for antennas for 5G systems: first and foremost, it has to maintain a small size in order to provide a simple and effortless integration with the frontend. Furthermore, keeping the design compact is essential in orfer to make the antenna compatible for array based configurations when dealing with a MIMO architecture [4]. Most commonly used of all microstrip patch antennas, are rectangular patch antennas, although circular patch antennas are also commonly used [5]. Advantages of microstrip patch antennas include low cost, low profile, low cost, suitable for array implementation etc. However some significant disadvantages include the low gain, narrow bandwidth and relatively large size for low frequencies [6].

Microstrip patch antennas are a great option for sub-6 Ghz uses, owning to their superb RF and MW characteristics. A patch antenna is essentially a substrate that has one side occupied with a metal conductor and the flip side is consisted of a ground plane made of conductive materials [7]. Microstrip patch antennas can be fed using different ways. These ways include a microstrip line feed, coaxial feed, aperture coupled feed and proximity coupling [8]. Although, the most commonly used feeding way is microstrip line feeding, due to it's simple nature. Thus, the antenna in this paper will also use a simple microstrip line feed.

The antenna was designed in and simulated in Sonnet® Suites™ program by Sonnet Software, which is implemented using a Method-of-Moments (MoM) EM analysis, which in turn is based on Maxwell's equations [9].

Numerous other designs have been proposed by other works, for antennas exist that allow the implementation of dual band capabilities [10], in our case the antenna is a mono band antenna. Another paper demonstrates how to implementat a metamaterial inspired antenna [11]. Our antenna is a single antenna, but could potentially be implemented in an array configuration, which is demonstrated in a paper which describes a circular array antenna for WLAN and 5G applications [12] alongside a paper which explains the process of implementing a miniaturized antenna array for 5G [13].

Numerous wideband examples have also been proposed, such as a paper that demonstrates a low-band wideband microstrip antenna for 5G [14]. Unlike some designs, such as the UWB Patch Antenna for Sub-6 GHz Communications [15] or the Wideband Small Fractal Antenna for 5G Sub-6-GHz Communications [16] which have a defected or partial ground plane, but instead has a full ground plane. We chose FR-4 as the substrate due to its wide availability and low cost, but other authors have used for instance RT/Duroid 5880 substrate which has a lower dielectric loss for better bandwidth and higher efficiency [17]. RT/Duroid 5880 has a εr of 2.2 which is better compared with the value for FR-4, which is 4.4 [18].

Due to the smaller dielectric constant, the bandwidth of the antenna increases because they are inversely proportional [19]. Due to inevitable manufacturing errors and tolerances, along with feed line soldering and an inaccurate value of relative dielectric permittivity, if we were to manufacture the antenna, our simulated results would not precisely match up with the experimental ones [20]. The antenna was simulated and iteratively improved by observing the filter parameters in each iteration.

2. Research method

The final proposed antenna design can be seen in Figure 1. In section 3 of this paper, we can read about the iterative process and steps that led us to this final iteration of the design. A stub was added to improve the antenna's gain. The overall size is 36.5 x 39.75 mm, so it can be said that the antenna is a relatively compact design, with a center frequency of 4.06 GHz, for the simulation the parameters were chosen so the sweep is from 2 to 6 GHz. The cell size for the simulation was 0.25 in both x and y directions. The dielectric thickness is 1.55 mm, with a relative dielectric permittivity of 4.4. The topology of the filter can be seen in Figure 1, while the 3D layout of the design is visible below, in Figure 2. The design is single sided, with no defected ground plane.

The design has been labeled with the letters A to E, along with dimensions. The letters are markers that indicate points of interest for our parametric study, in the section 3, we can see the results of our parametric study, and through them we can see the way the iterative improvement process has worked.

In Figure 3 we can see the current density visualization of the antenna. The current is crowded in the center square and L-shaped metals.

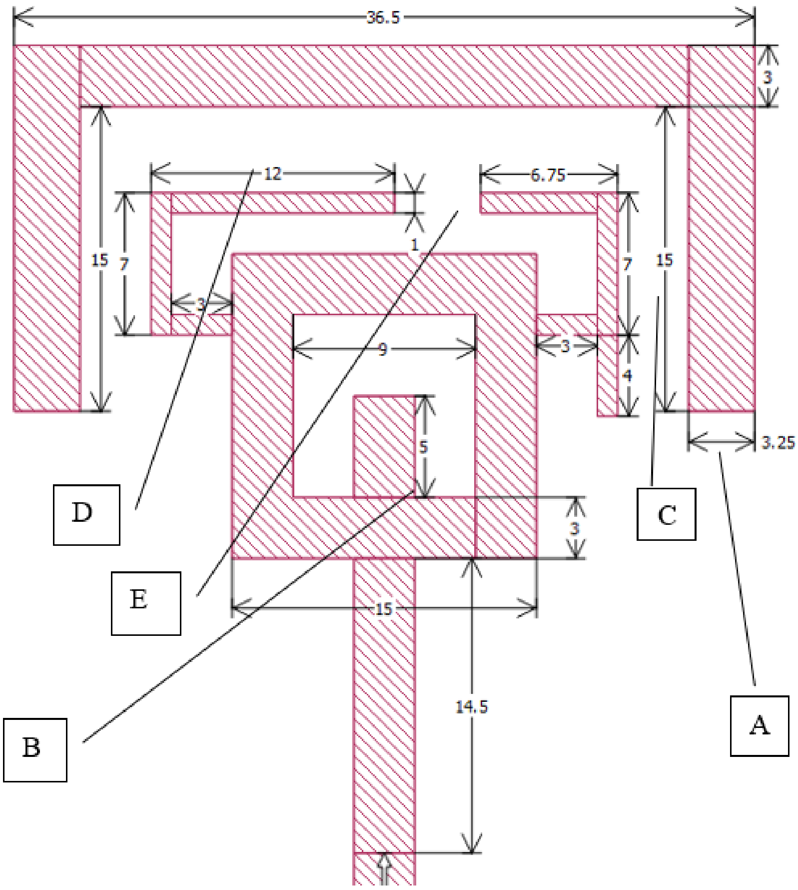

Figure 1. Antenna topology

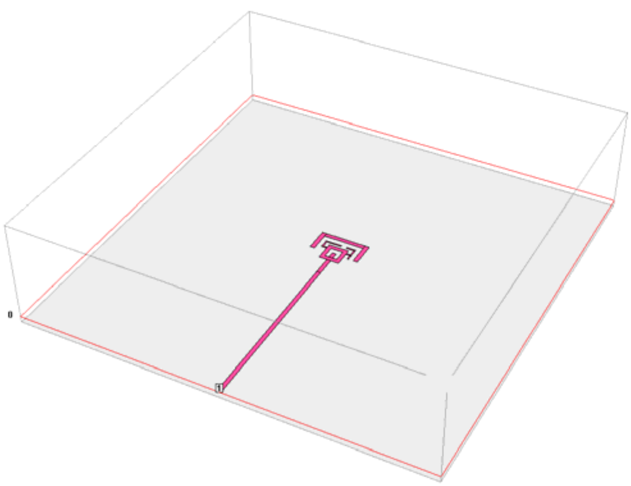

Figure 2. 3D antenna topology

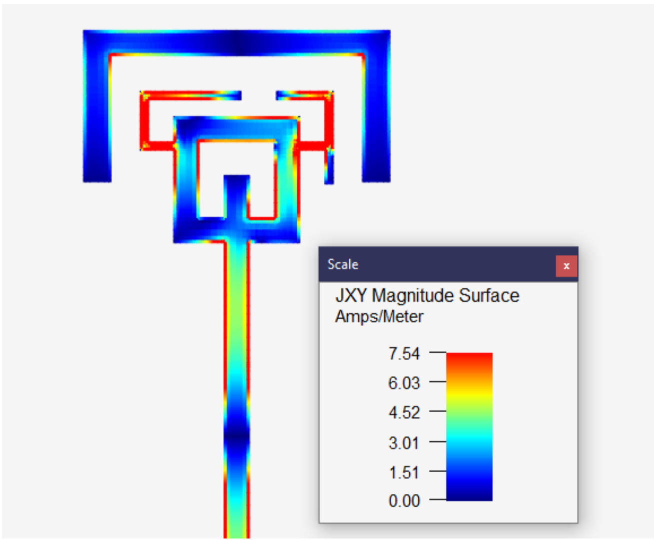

Figure 3. Current density plot

3. Results and discussion

Figure 4 shows the reflection coefficient graph. The goal was to get the S11 magnitude to be lower or equal to -10 dB. can be seen in figure 4. 4.06 GHz is the antenna's center frequency, with a S11 reflection coefficient of -39.46 dB. In figure 5, we can see the polar graph of E-θ (dB) and E-Φ (dB), in red and blue respectively. The requirement was set to be that E-θ should be larger or equal to 5 dB, while E-Φ lower than or equal to -5 dB.

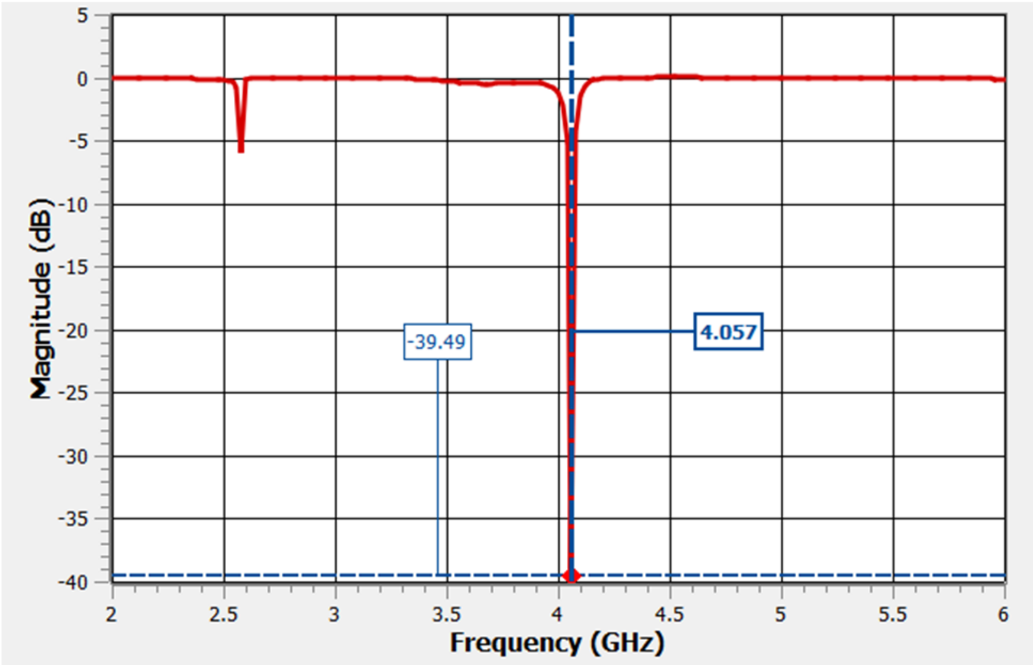

Figure 4. Graph of S11 reflection parameter

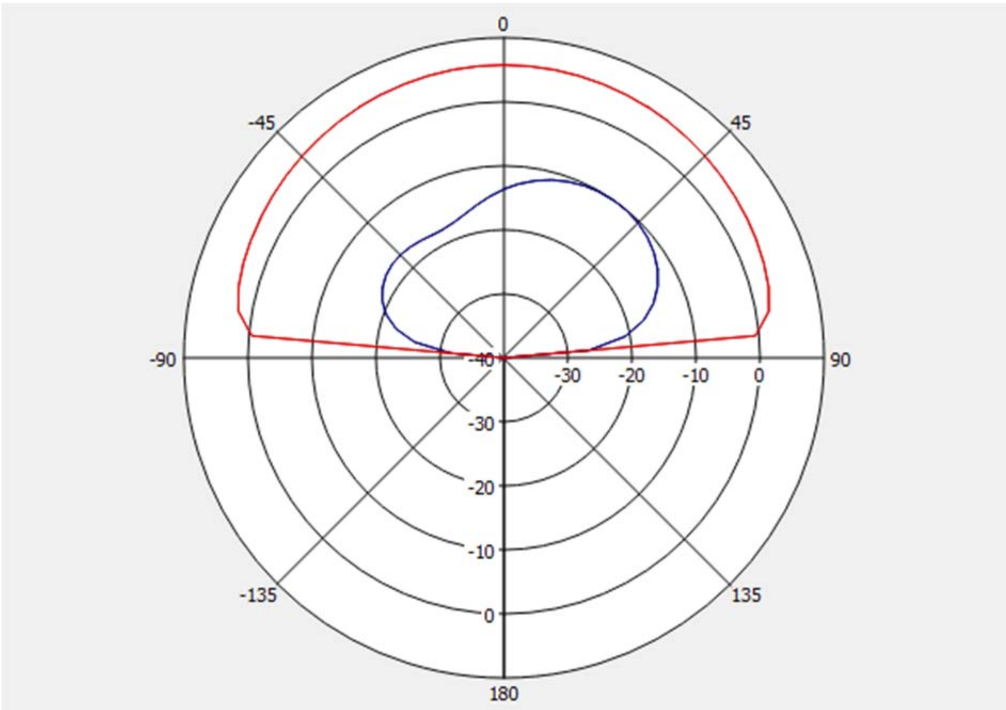

Figure 5. Polar plot for antenna

As mentioned previously, the antenna was designed in stages, with each state's results being used in the next stage, to finally achieve a workable design which has a good balance of size, optimal parameters and complexity.

The first parametric study's results are visible in Table 1, the "A" rectangle (for legend, see Figure 1.) was incrementally increased in size by 0.5 mm. For each increase (S11) that was in the range of (-10dB, infinity) in the antenna center frequency, and near 0 in all other areas. Once we have selected the best version, which in this case was the one with length 4 mm. We move on to the next phase, and begin doing the parametric study for rectangle B.

Table 1. Results of first parametric study

Length of rectangle A	S11 (dB)	E-θ (dB)	E-Φ (dB)	Frequency (GHz)
1	-15.5	5.62	-9.55	4.06
1.5	-13.91	5.62	-9.5	4.06
2	-12	5.61	-9.24	4.06
2.5	-10.15	5.68	-9.98	4.06
3	-12.07	5.67	-9.85	4.06
3.5	-14.71	5.66	-9.69	4.06
4	-16.84	5.66	-9.48	4.06
4.5	-14.38	5.66	-9.21	4.06
5	-10	5.66	-7.26	4.06

For the second parametric study, rectangle B was changed by 0.5 mm. In the end with all parameters considered, the case where the length is 5 mm was chosen, and the process moved on to the next stage. The results are outlined below in Table 2. As we can see based on these results, the case that has a rectangle length of 5mm was chosen as the one that will be used in following iterations of the design process. It was chosen because it is the best one, according to the parameters.

Table 2. Results of second parametric study

Length of rectangle B	S11 (dB)	E-θ (dB)	E-Φ (dB)	Frequency (GHz)
2	-10.28	5.61	-9.53	4.06
2.5	-11.75	5.63	-9.52	4.06
3	-13.39	5.64	-9.5	4.06
3.5	-15.48	5.65	-9.48	4.06
4	-18.55	5.56	-9.48	4.06
4.5	-20.84	5.67	-9.47	4.06
5	-24.24	5.57	-9.47	4.06
5.5	-18.66	5.69	-9.51	4.06

In the third parametric study, we have modified the size of the two side rectangles simultaneously, and the results were measured, this is the first time where some invalid results were obtained, we have a few different cases. For example, for the case where we had the length 12.5 mm, the result is invalid because we had a multiband antenna, with two transmission frequencies, which was not our goal for this paper. The chosen case was 15 mm. Table 3 contains the results of this parametric study.

Table 3. Results of third parametric study

Length of rectangle C	S11 (dB)	E-θ (dB)	E-Φ (dB)	Frequency (GHz)
0	-23.41	5.61	-7.41	4.06
2.5	-24.04	5.63	-7.34	4.06
5	-23.66	5.63	-7.4	4.06
7.5	-23.57	5.63	-7.4	4.06
10	-22.1	-5.57	-6.72	4.06
12.5	Not valid			Two frequencies
15	-39.46	5.75	-9.99	4.06
17.5	-31.31	5.69	-9.12	4.06
20	-22.52	5.62	-8.08	4.06
22.5	-27.38	5.68	-9.58	4.06
25	-37.03	5.69	-9.14	4.06

In the fourth parametric study, we have observed the parameter's differences when changing the position of the gap where the D marker is placed. However, this case produced a lot of invalid results, mostly due to S11 being over -10 dB. Due to the results not being very useful, the previous iteration was left unchanged. The results are visible below in Table 4.

Table 4. Results of fourth parametric study

Length of rectangle D	S11 (dB)	E-θ (dB)	E-Φ (dB)	Frequency (GHz)
4	-10.87	5.39	-8.69	4.22
6	-19.99	5.78	-10.14	4.04
8	Invalid			
10	-12.38	5.69	-12.18	3.98
12	Invalid			
14	Invalid			
16	invalid			

For the fifth and final parametric study, the gap marked by the letter E was adjusted and the results are visible below in Table 5. In this case, the best results overlap with the best result from parametric study 3, therefore nothing changes, and we have our final design. Which is the one shown in the figures above.

Table 5. Results of fifth parametric study

Length of rectangle E	S11 (dB)	E-θ (dB)	E-Φ (dB)	Frequency (GHz)
4.25	-39.46	5.75	-9.99	4.06
5.25	-13.07	5.68	-9.04	4.12
6.25	-10.02	5.56	-7.93	4.16
7.25	-14.97	5.45	7.6	4.22
8.25	-25.62	5.29	-7.15	4.28
9.25	-17.31	5.1	-6.76	4.34

4. Conclusions

In this paper, we have presented a microstrip patch antenna design, along with designing and simulating it. The antenna shows good performance according to the simulations. Alongside this, it is simple, compact, and cheap to manufacture, owning to the relatively low-cost FR-4 substrate.

Our antenna was simulated within a range of 0 to 6 GHz. Several parametric studies have been done regarding the overall antenna shape with the goal of improving the antenna behavior. By changing the geometry incrementally and observing changes, an optimal design was found, and it had the following parameters: The antenna center frequency is 4.06 GHz.

At the center frequency, S11 is -39.46 dB. Furthermore, the antenna has an E-θ of 5.75 dB, and E-Φ of -9.99 dB. 5G technologies are exploding around us, and antennas are a key element in making them work. This paper has demonstrated the procedure behind designing and simulating such an antenna.

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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