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A rectangular microstrip patch antenna with multiple slits and slots for sub-6 GHz 5G applications

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Abstract

This work puts forward a sub-6 GHz 5G microstrip patch antenna at 2.22 GHz. The simplicity and symmetry inherent in its design gives it an exceedingly high fabrication tolerance rate, and these characteristics coupled with its actual functional capabilities, makes it a much more potentially preferable device, in comparison to similar works in its specific category. The specific numerical values of the variables/parameters of this particular sub-6 GHz 5G microstrip patch antenna, which has a high fabrication tolerance, are as such:

$S_{11} = -9.77\, dB, frequency = 2.22\, GHz,\ \varepsilon_{\theta} = -28.36\, dB,\ \varepsilon_{\Phi} = 5.27\, dB.$

The inspiration for this work came from slot-based patch antenna for sub-6 GHz 5G applications discussed in the literature, which posed three slits and no slots, whereas this work has produced a geometry, with five slits and three slots, along with many other unique characteristics. The results showed that this small antenna shows significant reach and significantly lower costs due to the simple manufacturing process compared to similar devices.

Keywords: Sub- 6 GHz, 5G, Microstrip, Patch, Antenna

1. Introduction

5G technologies offer higher speed and lower latency in comparison to technologies used before them, such as 4G [1]. As various wireless communication systems become increasingly more integrated, the role of devices we call antennas becomes increasingly important [2]. Utilizing the spectrum, has recently been a challenge for the providers of wireless services [3]. The explosion of huge amounts of data traffic, makes the need for higher speed and increased capacity in data transfer, practically a must [4]. The field of wireless communication systems obviously plays a great role in every sector in the current era we reside in [5]. 5G transceivers and their performance is completely dependent on devices we know as antennas [6]. Most antenna designs that use 5G, are SIW (Substrate Integrated Waveguide) based [7]. Sub-6 GHz 5G antennas are better in things such as data rate, and in fading in rainy conditions less [8]. 5G has caused many different possible research opportunities to arise [9]. Technologies involving Multiple-Input-Multiple-Output (MIMO), are on a rise in popularity when it comes to wireless systems [10]. 5G is an innovation that not only is undeniable in its efficiency, but it is also becoming somewhat crucially necessary [11]. Machine learning has proven to be greatly useful in making the use of M-MIMO more effective [12]. Various gadgets used today by various sectors come in various shapes and sizes, and the compactness and flexibilities of antennas, consequently has become ever more necessary, not only for aesthetic purposes, but also for purposes of functionality [13]. MIMO technology can be of help to realize 5G applications, given that 5G has a data rate which is 1000 times faster than 4G [14]. If we want to implement efficient 5G technologies, it is impossible to do so, unless we have efficient antennas [15]. Given how lower latency and higher data transfer rates are the fruits of 5G, this causes it to be sort of the jewel, or rather, the backbone of wireless systems [1]. It of course goes without saying that current antennas need to be upgraded, in order to be compatible with 5G technology [16]. MIMO antennas have many advantages compared to single element antennas [17]. The rapid increase in the number of users of wireless technologies has caused traffic congestion to occur to a significant degree [18]. Since the conductivity of liquid dielectric materials is usually low, other alternatives need to be researched [19]. Since July 2016, the FCC has aimed to utilize 5G in low-band, mid-band, and high-band [20].

2. Research method

All research for this publication has been made possible with the use of *Sonnet Software*, which is a simulation tool that is widely popular in microwave circuit analyses.

As it is apparent from the three figures below, (Figures 1-3), our microstrip patch antenna design has five slits and three slots. The dimensions of the central metal part are 3 to 5 centimeters, even though the box size is much bigger in comparison. The rectangular and symmetrical nature of the design makes it significantly easier to manufacture, compared to many other designs with similar goals.

As you can see from the simulation results from Sonnet Software below (Figure 4), the design specifications were met at 2.22 GHz, where the S_{11} corresponded to -9.77 dB. Note that other resonance points below -10 dB, didn't have gain magnitudes that the design required.

3. Results and discussion

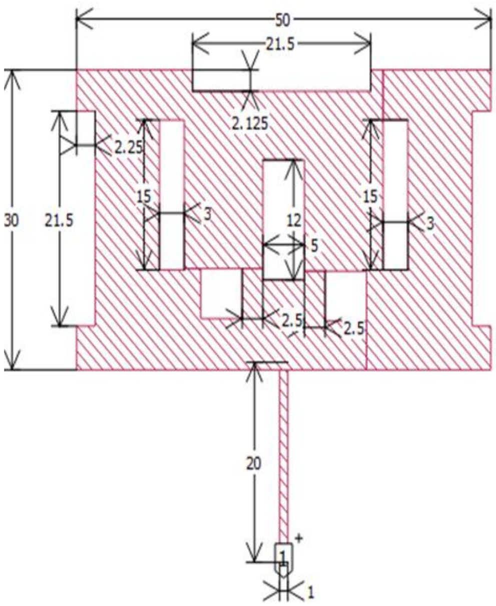

Figure 1. The top view with dimensions in mm (box not included)

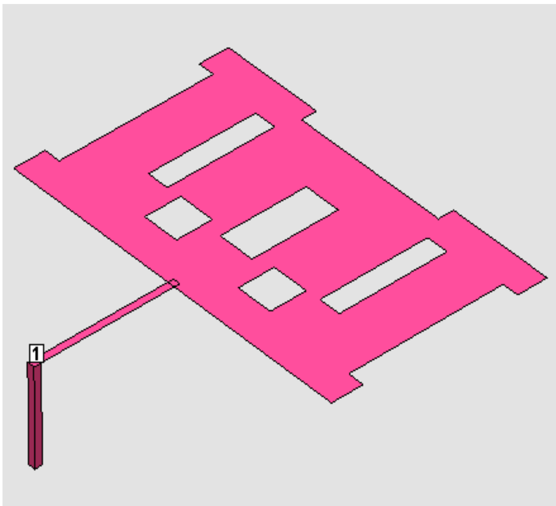

Figure 2. The 3D view (main part)

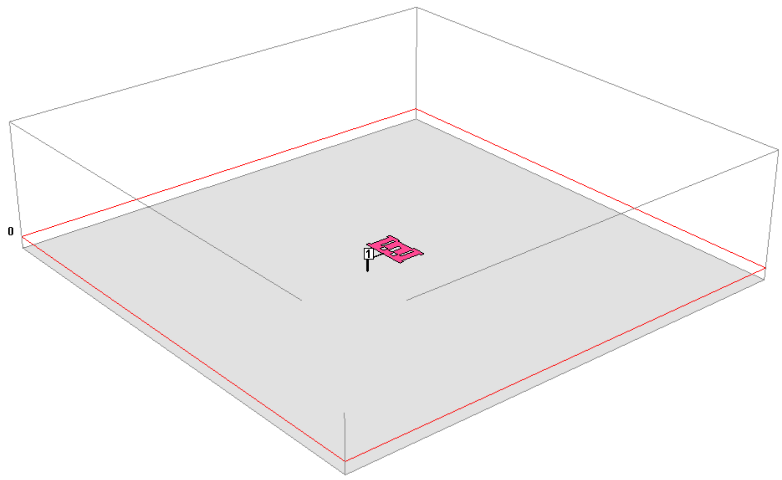

Figure 3. The 3D view (complete)

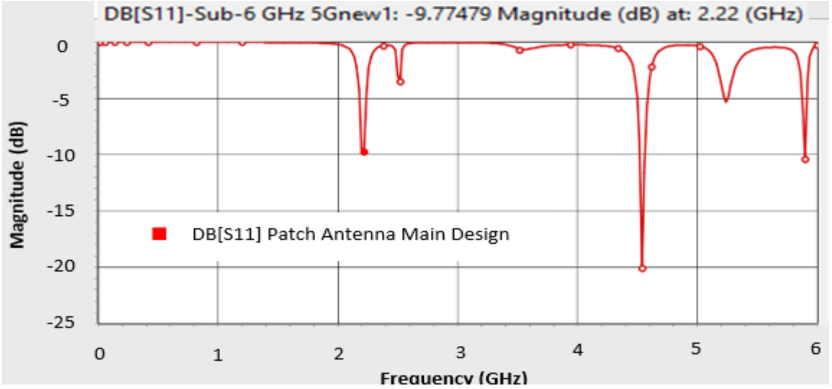

Figure 4. The S-parameters graph for the main design (**Sub-6 GHz 5G new1**)

One can observe below in (Table 1) that when we changed the dielectric constant values starting from 4.3, and going all the way up to 4.5, our frequency results almost didn't change at all, and the gain results changed slightly. The closest result to the original design came when the dielectric constant value was 4.45 (4.4 was the original value).

Table 1. Changing the dielectric constants (main design values in **bold**)

Dielectric constant (ε_r)	Magnitude (dB)			Frequency (GHz)
	S_{11}	ε_θ	ε_Φ	
4.3	-11.49	-27.36	5.35	2.24
4.35	-12.11	-25.98	5.30	2.22
4.4	**-9.77**	**-28.36**	**5.27**	**2.22**
4.45	-11.86	-30.13	5.24	2.22
4.5	-10.37	-25.35	5.18	2.18

Note that in the following (Table 2) when we changed the dielectric thicknesses starting from 1.5 mm, and going all the way up to 1.6 mm, our frequency results literally didn't change at all. The closest results to the original design came when the dielectric thickness values were 1.57 mm and 1.6 mm [they were practically equally close (1.55 mm was the original value)].

Table 2. Changing the dielectric thicknesses (main design values in **bold**)

Dielectric thickness	Magnitude (dB)			Frequency (GHz)
	S_{11}	ε_θ	ε_Φ	
1.50	-9.69	-28.41	5.27	2.22
1.53	-9.75	-28.41	5.27	2.22
1.55	**-9.77**	**-28.36**	**5.27**	**2.22**
1.57	-9.78	-28.37	5.27	2.22
1.6	-9.78	-28.36	5.28	2.22

In the table below (Table 3), when we changed the length of the center in the y-axis starting from 49 mm, and going all the way up to 51 mm, our frequency results again, literally didn't change. The closest result to the original design came when the length of the center in the y-axis was 50.5 mm (50 mm was the original value).

Table 3. Changing the length of the center in the x-axis (main design values in **bold**)

The length of the center in the x-axis	Magnitude (dB)			Frequency (GHz)
	S_{11}	ε_θ	ε_Φ	
49	-9.26	-38.48	5.22	2.22
49.5	-9.51	-26.69	5.25	2.22
50	**-9.77**	**-28.36**	**5.27**	**2.22**
50.50	-10.02	-28.06	5.30	2.22
51	-10.27	-27.21	5.33	2.22

As it's apparent in the below table (Table 4), when we changed length of the center in the y-axis, starting from 29 mm, and going all the way up to 31 mm, our frequency and gain results practically didn't change but changed slightly. The closest result to the original design came when the length of the center in the y-axis was 29.5 mm (30 mm was the original value).

Table 4. Changing the length of the center in the y-axis (main design values in **bold**)

The length of the center in the y-axis	Magnitude (dB)			Frequency (GHz)
	S_{11}	ε_{θ}	ε_{Φ}	
29	-11.09	-22.67	5.41	2.28
29.5	-10.68	-24.10	5.33	2.24
30	**-9.77**	**-28.36**	**5.27**	**2.22**
30.5	-11.21	-29.05	5.20	2.18
31	-11.76	-28.63	5.12	2.14

As it can be seen below (Table 5), when we changed the length of the slits in the y-axis starting from 11.5 & 14.5 mm, and going all the way up to 12.5 & 15.5 mm, our frequency and gain results once again practically didn't change, in fact, the frequency and the gain stayed literally the same, in 50% of the lengths measured. The closest result to the original design came when the length of the slits in the y-axis was 11.75 & 14.75 (12 & 15 mm was the original value).

Table 5. Changing the length of the vertical slits in the y-axis (main design values in **bold**)

Length of the slits in the y-axis (mm)	Magnitude (dB)			Frequency (GHz)
	S_{11}	ε_{θ}	ε_{Φ}	
11.5 & 14.5	-9.47	-30.31	5.27	2.22
11.75 & 14.75	-9.61	-29.64	5.27	2.22
12 & 15	**-9.77**	**-28.36**	**5.27**	**2.22**
12.25 & 15.25	-11.78	-28.18	5.25	2.2
12.5 & 15.5	-11.49	-27.32	5.25	2.2

As it can be seen in the below figure (Figure 5) the current distribution seems pretty symmetrical, owing to the design's inherent geometric symmetry. The darkest blue, shows that no current is being distributed, while the darkest red, shows that the current being distributed is at the highest. This current distribution figure, happens to be showing the distribution specifically at 2.22 GHz, which is our design's frequency.

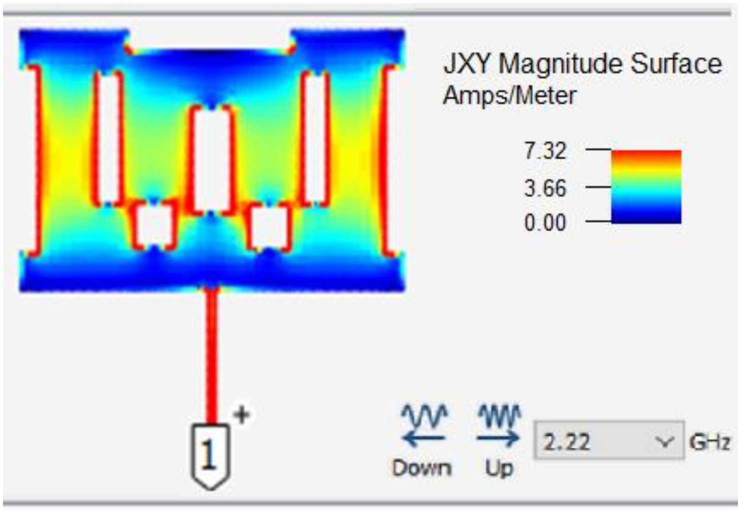

Figure 5. The current distribution

In the following two figures (Figure 6-7), the gain results of the 2.22 GHz design of ours are presented. The results are $\mathcal{E}_{\theta} = -28.36\, dB$ (figure 6), and $\mathcal{E}_{\Phi} = 5.27\, dB$ (figure 7).

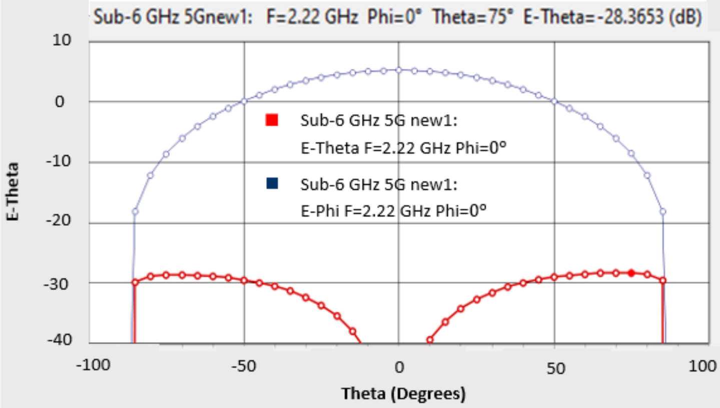

Figure 6. The phase angles graph (E-Theta) -28.36 dB

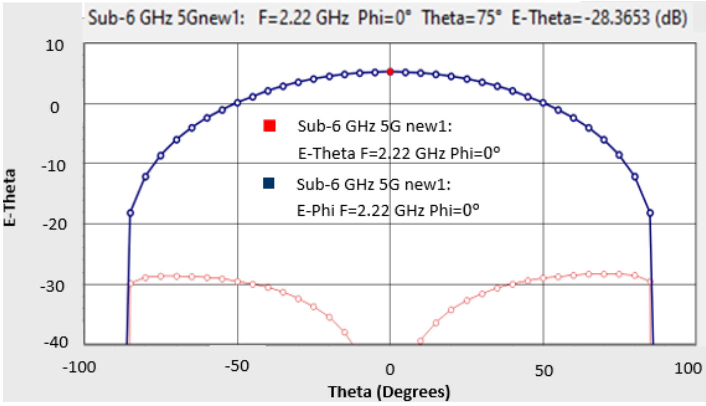

Figure 7. The phase angles graph (E-Phi) = 5.27 dB

4. Conclusions

The antenna in this paper with its particular qualities ($S_{11} = -9.77\ dB, frequency = 2.22\ GHz,\ \ \varepsilon_\theta = -28.36\ dB,\ \ \varepsilon_\Phi = 5.27\ dB.$), is a device that is fully capable of satisfying the needs it initially set out to satisfy, for the rapidly increasing customers of high speed wireless technologies. As the parametric studies above illustrate, this antenna's remarkably high fabrication tolerances, greatly prevents the need for more expensive high precision machinery, thus making it much more easy and practical to mass produce, when the cost is considered. This small device has a big reach (range), and it's quite easy and cheap to produce in comparison to many similar devices, despite its undeniably high quality, which is apparent in the above mentioned characteristics.

Declaration of competing interest

The authors declare that they haven't any known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

Mehmet Yusuf Imeci and Metehan Berk performed the simulations, drafted the paper, organized the sections, analyzed the results. S. Taha Imeci wrote the concept of the work, led the project from the starting point and did the final proofreading.

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