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Stepped impedance patch antenna for sub-6GHz 5G range

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Abstract

This article presents the design of a stepped impedance patch antenna for fifth generation mobile communication networks application. A large tendency towards the new generation is what drives this research. The antenna is designed and simulated in Sonnet Suites software. The overall dimensions of the antenna are 10.7x22.5 mm^2. The antenna design is fed via a probe. The simulation is done in the range from 0 to 6GHz. The results achieved are compatible with 5th generation standards. The magnitude of input matching is -14.35dB and the maximum gain, at the radiating frequency of 4.82GHz, is found to be 5.045dB. The cross-polarization level is as low as -30dB. The goal of the research is achieved and presented in this paper.

Keywords: antenna, 5G, gain, frequency, design, parametric, Sonnet Suites, simulation

1. Introduction

Since the first generation of mobile communications, there was a need for faster and more reliable data transfer between devices [1]. The capabilities of the first generation were quite limited, with speeds not exceeding 2.4 Kbps [2]. The communication protocol was based on FDMA, frequency division multiple access, which simply meant that each user occupied its own radio channel for communication not to mention that it was all analogue [3]. The basic applications that 1G supported included voice calls and simple data messaging [4]. With the second generation, which appeared in 1991, the speeds increased up to 64 Kbps along with the improvement of voice quality [5]. The communication protocol in use was CDMA, Code Division Multiple Access, which means that multiple users are occupying the same radio transmission channel, which meant that fewer bandwidths were used [6]. Also, CDMA employed analog-to-digital conversion as well and could support low-rate data transfer, SMS messages and calls [7]. In 2001 the third generation appeared with a somewhat enhanced version of CDMA protocol capable of supporting high speed packet access enabling rich data content [8]. With the deployment of fourth generation in 2010, the speeds of data transfer peaked at around 100 Mbps with the capability of video transfer and streaming [9]. The communication protocol of 4G is LTE, Long-Term Evolution [10]. This protocol brings much higher data transfer speeds, increased download speeds and higher coverage [11]. It works on a different frequency spectrum compared to 2G and 3G and consequently requires different infrastructure [12]. One of the most prominent characteristics of mobile communication networks is latency [13]. Latency, sometimes known as lag, is described as the time required for a signal or information in general, to be sent, transformed, manipulated by devices and finally given to the receiver at the end of the communication chain [14]. From the perspective of latency, the advancements are seen from 1G to 4G as well [15]. The first generation had extremely high latency, the 2G had around 300-1000ms latency, 3G around 100-500ms latency and finally

4G managed to narrow latency down to as little as under 100ms [16]. Nowadays, it is of utmost importance to have reliable, fast and high coverage mobile communication networks which is especially pushed by mobile video streaming and IoT, Internet of Things [17]. The increase in demand of such a mobile communication network is expected to grow at an annual rate of around 45% from 2016 to 2022 with even more industry applications and IoT connected devices [16]. A new era of mobile communications, the fifth generation, is expected to fulfill the needs of this growth [18]. The protocol used in 5G networks is MQTT, which stands for Messaging Queuing Telemetry Transport, although there is no message queuing in 5G [19]. MQTT works in a different manner compared to standard client-server architecture, where the sender of a message is decoupled from the receiver, and the communication in between is handled by third parties known as brokers [17]. MQTT is very common in IoT applications, which are increasingly becoming very widely used and the advantages of MQTT include: quick to implement, efficient data transfer, low network usage and uses less power [17].

The design of the antenna, for 5G applications and under 6GHz operation range, proposed by the author is inspired by paper [20]. In the paper, a patch antenna which resembles a triangular shape is presented, with overall dimensions of 10.7x22.5 mm^2. Its structure is made up of a patch on the upper side and a ground plane below. The patch consists of a 1.6 mm thick dielectric with the value of relative permeability of 4.3 and the value of loss tangency of 0.02 [20]. The antenna is fed by a microstrip line which is 3.1 mm wide and 10.5 mm long, with an added strip line, 1.55x2.7 mm^2 in dimensions, added in between the microstrip and a periodic patch to increase the input matching [20]. The maximum gain of the antenna obtained by the simulation and measurement results is 2.3 dB at 3.8 GHz. Both the simulation and measurements satisfy the bandwidth of -10 dB, ideal for 5G communications [20]. Maximum gains of the antenna presented in [20] are seen in E and H radiation planes, and it can be concluded that the antenna radiates almost in all directions at the value of frequency of 3.5GHz

The authors` goal for the purpose of the paper is the presentation of an antenna design for fifth-generation mobile systems that are currently slowly but certainly gaining an advantage in the market. The paper is structured as follows: Introduction, where the history of mobile networks is briefly discussed, Research Method, where the design proposed by the author is presented along with simulation results, Results and Discussions, where the variations on the dimensions of the antenna are presented along with the values obtained with those variations, Conclusion and References.

2. Research method

The authors` design is shown in Figure 1. It can be observed that the antenna, designed by the authors`, is different from the design presented in [20]. The main difference is that the design in Figure 1. is not triangular in shape and does not contain a ground plane under the antenna. The overall dimensions of the antenna are 10.7x22.5 mm^2. There are three significant parts of the design. The first part is the strip on which the port is located, the second strip is the vertical strip on top of the port strip and the third part are the horizontal strips which intersect the vertical one. The port strip is 3.25 mm in width and the separation between the horizontal strips is 1.5 mm. Figure 2. shows the 3D representation of the antenna design.

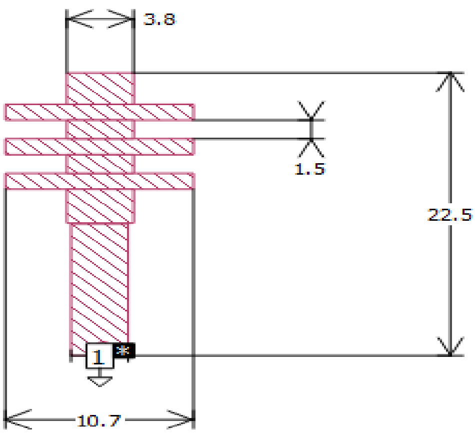

Figure 1. Proposed design

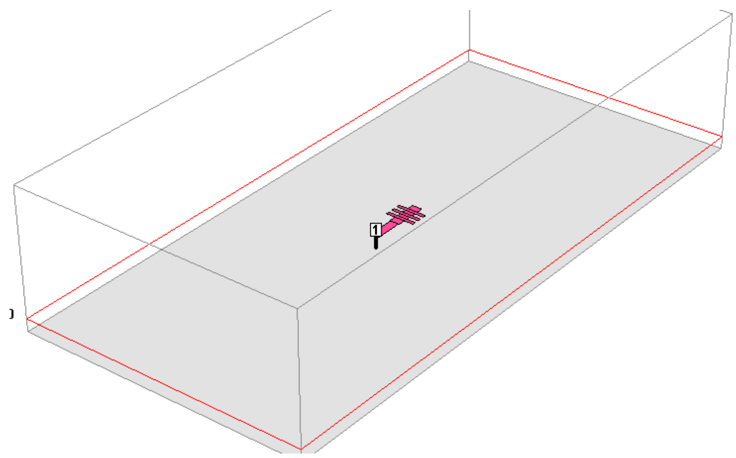

Figure 2. 3D representation of the design

The antenna design is fed via a probe. The box around the antenna is ten times larger than the overall dimensions of the antenna and filled with air. The FR4 substrate is 1.55mm in thickness with relative permeability of 4.4. The probe diameter is 1mm. The cell size used in the simulation is 0.25mm in width. The goal of the simulations is to achieve a value of input matching less than -10dB which is the bandwidth used in 5G applications. The results are presented in the Results and Discussions section.

3. Results and discussions

The simulation is done in the range from 0 to 6GHz in Sonnet Suites software. The S11 parameters are shown in Figure 3. below. A few information that can be seen on the S11 graph in Figure 3. Firstly, the antenna has a very narrow bandwidth and the resonant frequency is observed to be 4.82GHz where the maximum value of the input matching is found to be -14.35dB. The radiation pattern is graphed for this resonant frequency and it is shown in Figure 4. The maximum gain is found to be 5.045dB in the H plane, which is significant but not necessarily very applicable. The cross-polarization level is as low as -30dB. It is very interesting to look into the current distribution graph which can provide significant insights into the parts of the antenna that radiate the most. Current distribution is given in Figure 5. The distribution of current through the antenna is given at a radiating frequency of 4.82GHz. Figure 5. is mostly what leads the author through the process of parametric studying the antenna results which is presented in the tables below.

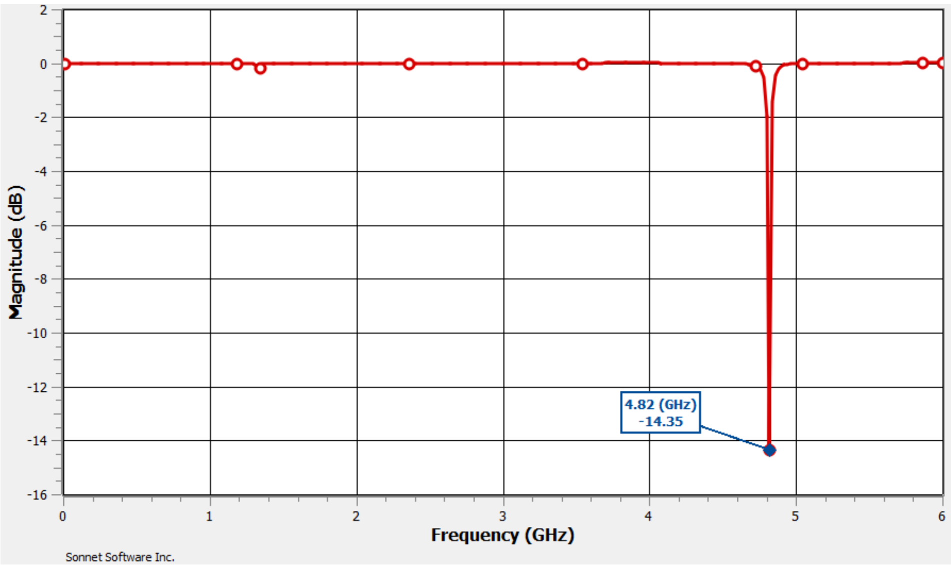

Figure 3. S11 parameters

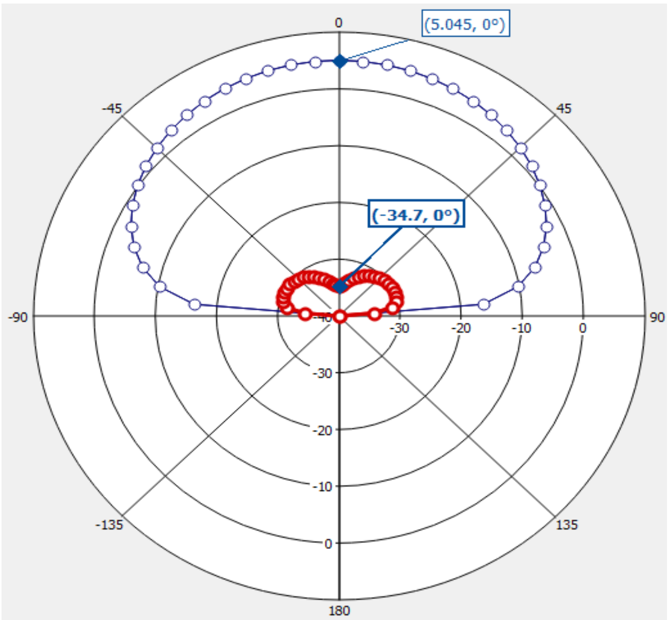

Figure 4. Radiation pattern graphs

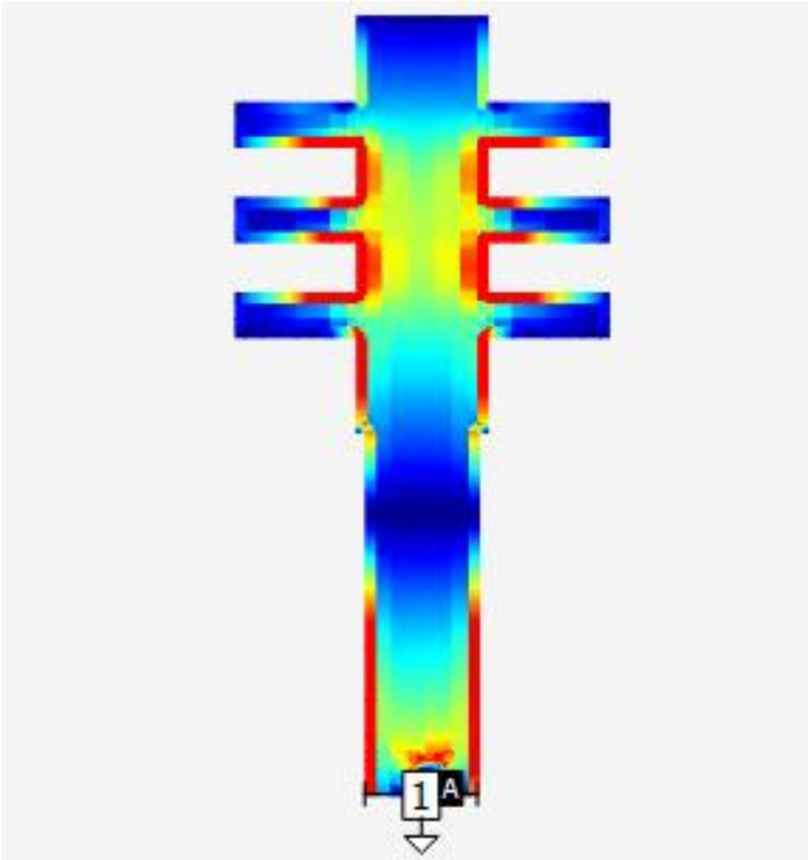

Figure 5. Current distribution of the antenna design

To validate the results obtained from the simulation it is important to use a parametric approach that alters the dimensions of the antenna and its most significant strips to check if the results will change in a dramatic manner [21]. To avoid misunderstandings with the descriptive names of the strips, Figure 6. shows the strips marked in colors that are used as the reference for the parametric study.

Parametric study results are presented in tables. Table 1. presents the changes in the width of the "central boxes" that are colored in orange in Figure 6. Table 2. presents the changes in the height of the two central boxes colored in blue in Figure 6. Table 3. presents the changes in the height of the horizontal boxes colored in red in Figure 6. Table 4. presents the changes in the width of the horizontal boxes colored in red in Figure 6. and Table 5. presents the changes in the width of the lower box colored in green in Figure 6.

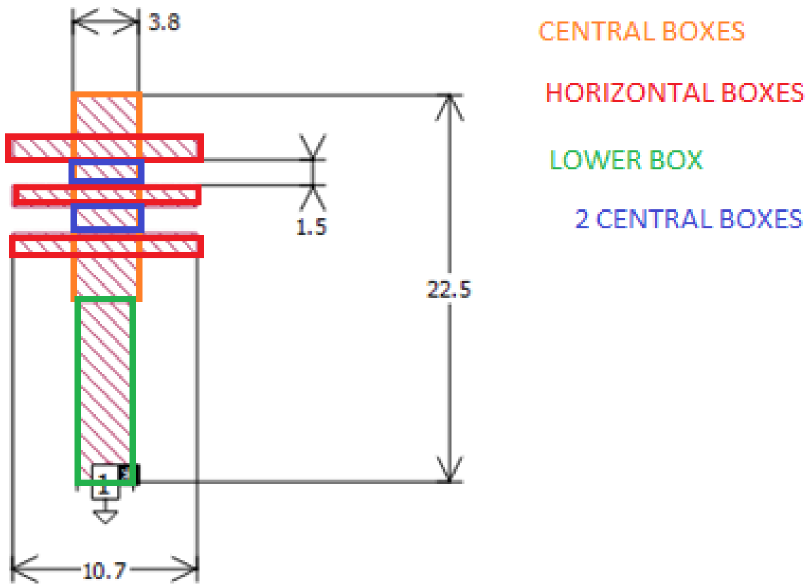

Figure 6. Strips of the design marked with colors

Table 1. Width of central boxes

Width (mm)	S11 (dB)	Frequency (GHz)	E_θ	E_φ
3.8	-14.34	4.82	-34.7	5.04
4	-6.1	4.86	-38.2	5.04
4.25	-8.7	4.88	-34.84	5.22
4.5	-7.75	4.92	-38.4	5.17
4.75	-9.97	4.94	-35.52	5.27

Table 2. Height of two central boxes

Height (mm)	S11 (dB)	Frequency (GHz)	E_θ	E_φ
1.5	-9.97	4.94	-35.52	5.27
1.75	-5.9	4.8	-35.7	5.31
2	-9.58	4.68	-36.7	5.23
2.25	-8.8	4.56	-37.2	5.197
2.5	-8.05	4.44	-25.6	5.2

Table 3. Height of horizontal boxes

Height (mm)	S11 (dB)	Frequency (GHz)	E_θ	E_φ
1.25	-9.97	4.94	-35.52	5.27
1.5	-9.33	4.76	-36.15	5.26
1.75	-4.9	4.6	-900	5.19
2	-5.96	1.18	-40	-3.4
1	-6.6	5.14	-28.98	5.18

Table 4. Width of horizontal boxes

Width (mm)	S11 (dB)	Frequency (GHz)	E_θ	E_φ
10.7	-9.97	4.94	-35.52	5.27
11	-10.6	4.92	-26.7	5.26
11.25	-8.25	4.9	-31.6	5.3
11.5	-9.05	4.88	-26.05	5.28
10.5	-8.7	4.96	-27.2	5.2

Table 5. Width of the lower box

Width (mm)	S11 (dB)	Frequency (GHz)	E_θ	E_φ
3.25(with central boxes width 3.8)	-11.17	4.8	-965	5.03
3.25 (with central boxes width of 4.75)	-8.65	4.92	-900	5.29
3.5	-12.1	4.9	-29.3	5.22
3.75	-7	4.88	-900	5.15
4	-12.33	4.84	-28.26	5.24

4. Conclusion

This research outlines the design of a patch antenna suitable for 5G mobile communication networks. The antenna is designed with an FR4 substrate 1.55mm in thickness and the value of relative permeability of 4.4. The overall dimensions of the antenna are 10.7 x 22.5mm^2. It is differentiated from [20] by the fact that it is not triangular in shape and the dimensions are somewhat different, especially the length of the antenna. The design presented in [20] has a ground plate below the antenna which is also one significant difference to the design presented in this paper. The antenna has a narrow bandwidth. The main characteristics of the results are the input matching value of -14.35dB in magnitude and the gain, which is obtained to be 5.045dB at the resonant frequency of 4.82GHz. By investigating the results parametrically, it is concluded that by changing the parameters of the dimensions, no significant changes to results occur.

Declaration of competing interests

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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