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An inset-fed rectangular microstrip patch antenna with multiple slits for sub 6GHz – 5G applications

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Abstract

This paper presents an inset feed rectangular microstrip patch antenna with multiple slits for sub 6 GHz - 5G Applications. This antenna is proposed with the development, design, running simulations, and finally a conclusion of the analysis. The antenna in this paper is implemented using a technique called "inset-feed" and multiple slits. The dielectric used as a substrate is FR-4. The proposed antenna is useful for a sub 6 GHz 5G band, which comes under the 5G band of frequency. The proposed and designed antenna gives the input match of -10.74 dB, and 5.99 dB gain at the design frequency of 5.045 GHz. These outputs are usable for 5G applications. The antenna is simulated and developed in a radio technology design software Sonnet.

Keywords: Inset-feed, FR-4, Microstrip patch, Sonnet, Antenna analysis

1. Introduction

Communications technology has developed exponentially more in the last 2 decades than in its whole history. Growing demand for communication devices and the drop in manufacturing prices changed the way we operate on a day-to-day basis. Wireless networks are used in every industry and almost every person on the planet has some type of mobile communication device. The most reliable and effective type of communication, still to this day is wired networks, be it using copper wires or fiberglass. The 5G standard is set to shift this perspective onto wireless technologies "unpublished" [1]. The wireless communication standard has increased the minimum required speed exponentially over the years. From 3G with a theoretical maximum speed of 7.2 Mbps all the way to 5G with a theoretical maximum download speed of 1-10 Gbps [2]. It is easy to imagine a world with a lot of useful devices that will rely on this type of communication. The idea of IoT (Internet of Things) has taken a lot of traction and caused all industries to align themselves with this up-and-coming paradigm shift [3]. The 5G has certain requirements that the technology has to fulfill if it will be considered a 5G device. These criteria are listed here:

1. Download speed 1-10 Gbps
2. Latency has to be less than 1 millisecond
3. It has to work in a vehicle traveling at less than 500kph
4. Connection density of 1 million devices per 1 square kilometer
5. A very reliable link connection with an uptime of 0.9999
6. And a few more details that are not the topic of this paper.

Patch antennas are increasingly popular in many fields today. Microstrip patch antennas are popular a lot because of their weight and dimension characteristics, that is they are very light, have low height requirements, and are easy to fabricate with the MMICs (MMIC is short for “Monolithic microwave integrated circuits”). Because they have such characteristics, their compact and planar structure patch antennas possess, they are very interesting and almost a must for applications that work with satellite and wireless communications [3]. The antenna that is the topic of this paper uses a very cheap substrate called FR4 and uses a planar design that can be easily produced/manufactured. The LPKF milling machine that is used by the IUS lab will be used to produce the prototype antenna that is designed and developed in this paper. Worldwide consumption of wireless networks services has risen ever since it has been brought to the awareness of the common consumer, all the possible advantages and usefulness of the technology in question and because this field has advanced so much that new and better use-cases were developed, designed and applied successfully as well across a range of influential industries. To help establish reliable and cost-effective communication protocols between devices and gadgets in close proximity, Bluetooth is instantiated and still to this day developed in many regions, which will effectively create a platform for the interaction of devices in such wireless communication networks. It goes without saying, that like with every similar device, patch antennas come with some disadvantages, things that may cause caution when dealing with this type of technology. If we could name the most obvious one, it would be this: low efficiency, narrow bandwidth, and a small amount of gain, all caused by the previously mentioned characteristics like the smaller size and high input match. Nevertheless, these antennas are still managing to stay relevant and tremendously popular in a wide range of fields of industries. In order to tackle these issues, or at least to mitigate their effect on the performance of the antenna, the researchers and developers of antennas like the one described by this paper have tried and made some progress by inserting additional modifications in their antenna projects, modifications like slot cuts and implementing different shapes [4]. Method of similar procedures has been used when developing antennas for this publication by using a variety of slits. In order to achieve an acceptable input match of the antenna a great focus must be paid to the design of the impedance of the inset-feed, the line that connects the antenna to the port, as well as the patch itself. To be successful in achieving impedance matching, one can use multiple suggested methods; out of all of them, the most popular is inset-feeding. The most impact on the patch-impedance will definitely have the location of the feed. It goes without saying that this feature is the most crucial and important part of the design.

Antenna performance is affected by a range of different parameters. Many of them will allow adjustment just by varying the feeding technique and range and the feed location to the patch [5]. Technological implementations of these antennas in recent years became absolutely popular and in high demand. The reason behind this fact is the relative ease of fabrication and easy importing into the software that operates the Monolithic Microwave Integrated Circuits (MMICs). In spite of the improvements that have occurred in the recent past in the field of wireless communications, antenna technological innovations that can operate at multiple-band frequencies have become a point of interest and many requests. Even to this day, there are still antenna designs that are using the technology of a microstrip patch still in many wireless communication systems. The reasons behind these events could be summed in these antennas having a low profile and being lightweight [6] [7]. The compactness and planar structure of these antennas have caused the designers to take steps in the design process and make these antennas usually used for wireless communication applications that consider radar, satellite, and mobile communications [8].

If someone would like to alter the size of these antennas, there are possible solutions and techniques that will allow for high permittivity and also significantly reduce the size of the antennas, and its overall footprint. The miniaturization methods, as they are called, managed to find fine usefulness and are therefore very pragmatic for the development of mobile terminal antennas and similar designs as per design specifications [9]. With the usual setup, the consisting parts of a patch antenna are conducting layer and dielectric layer which is also referred to as the substrate. The biggest effect on the antenna design will undoubtedly have the selection of the proper substrate. This is due to the fact that its conducting characteristics are going to state for us the design in the general form [8] [10] [11]. The layer called the “substrate layer” is utilized in a way that it divides the microstrip patch from its counterpart, usually on the bottom side called “the ground plane”. What is commonly used to create a patch, is a set of different metals. A few examples would be silver, gold, and copper. This highconductivity set of metals can be shaped to form different areas. As an example, the most commonly found today are rectangles, ellipses, circles, squares, triangles, and similar [12]. It depends on the choice of geometry that we prefer to use, and how our radiation pattern will be in the end result. In addition to the radiation pattern, an important aspect of the antenna is that the current distribution will be affected by the choices we make in the geometry of the design, and development step of the process. This is due to the fact that we are making such compact antennas. The antennas that use the feeding technique "inset-feed" and a patch (microstrip patch) are customarily milled by a router or printed by the use of the LKV milling machine. If done right, this is done on the substrate that is covered by a layer of metal (conducting material), as aforementioned [13]. In order to match the input impedance, a set of techniques can be used to achieve this characteristic. By managing the impedance of the feed line (inset-feed), we can control different aspects of the antenna behavior, for example, it would be the return loss of our antenna and a selection of other characteristics. This and other characteristics can be improved and enhanced at the design step of placing and choosing the inset-feed location [14]. Feed variations exist and can be used to achieve the matching of the antenna patch to inset-feed line. This will help achieve a wide range of bandwidths of the antenna [15], thanks to the development skills of managing different feeds such as inset-feed, aperture coupled feed, coaxial-feed, and proximity coupling.

As a part of this paper, for the antenna that we are developing, we are going to go with a design choice of an inset-feed specific variation. We will use this method because of various reasons explained previously in this publication and also because of the reason that this design method is one of the most usually seen ways today that is usually used for bringing a feed line to rectangular-shaped patch antennas as is displayed in Figure 1.

2. Research method

The geometrical shape and overall outer dimensions are fundamentally impacted by our choice of the frequency the antenna will operate in. The contours and shape of the patch and its dimensions are determined by inputting our design requirements in different mathematical calculations [5]. The dimensions of the microstrip structure are determined approximately by using these empirical formulas, which are frequently encountered in academic publications on transmission line theory. To obtain the expected output characteristic at the targeted operating frequency, parametric studies are performed by performing a series of sequential analyzes on the calculated dimensions of the microstrip structure in the 3D simulation environment.

3. Results and discussion

The outer contours, main dimensional characteristics of the antenna (W=4.1cm and h=3cm) as well as the contours of every small slit are highlighted using the Sonnet software tool for drawing contour dimensions.

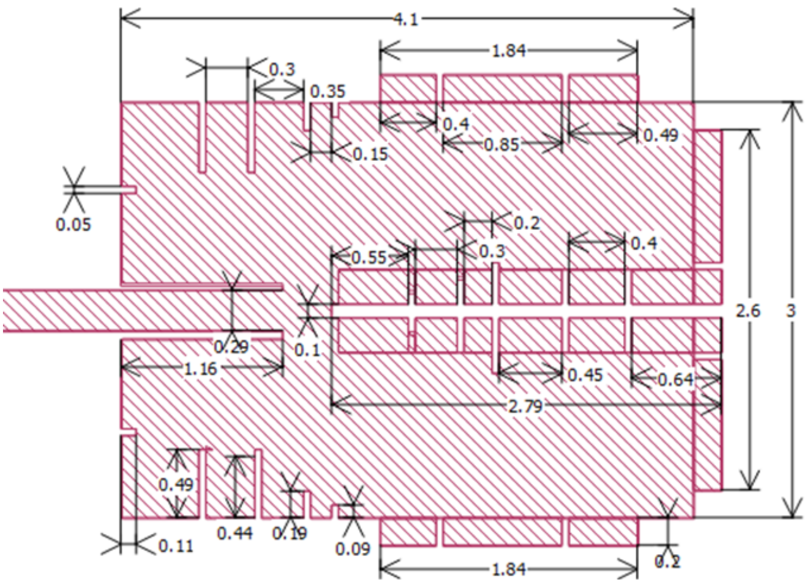

Figure 1. Geometry

3.1. Parametric studies

The geometrical features of the design ought to be adjustable enough to be ready for the errors in production that occur more frequently than we usually expect. We need the antenna to perform well and to be able to still work as per the design and in the design frequency bandwidth that we developed it for, even with such errors in the production step. The width and height of the outer contours of the antenna bound to one selected frequency in which our antenna will work the best; henceforth the only possible changes that can be made are the characteristics of the slits, slots, and height of the layer that consists of dielectric. Playing with the outer dimensions like the height or width of the project would definitely influence the frequency in which the antenna operates. Parametric study is as follows:

In Table 1 the dielectric layer height is changed up and down by 0.05 mm. It can be seen that with the change in thickness, the overall results are lower than with the original one, which is 1.66 mm.

Table 1. The dielectric layer height

Height in mm	F in GHz	S11 in dB	E-θ in dB	E-Φ in dB
1.66	5.045	-10.7474	5.7620	-41.3290
1.70	5.010	-10.7613	5.2100	-42.4540
1.75	4.990	-11.2474	5.6941	-44.4666
1.60	5.040	-11.2810	5.8437	-40.8511
1.55	5.040	-11.2770	5.9111	-50.9040

In Table 2 the constant feature of the dielectric layer is modified by 0.05 in value. We can conclude from what is presented that when we modify, i.e. change the constant of the dielectric layer, the overall output features become lower in comparison to the original input of the layer that composes the dielectric layer, which was in our case 4.4.

Table 2. Dielectric material constant

Dielectric const.	F in GHz	S11 in dB	E-θ in dB	E-Φ in dB
4.3	4.996	-11.198	5.749	-44.537
4.35	4.996	-11.239	5.778	-44.524
4.4	5.045	-10.747	5.762	-41.329
4.45	4.996	-11.318	5.835	-44.501
4.5	4.996	-11.389	5.901	-44.519

In Table 3 the width of the line that connects the patch to the port, the inset-feed gets modified in dimension by 0.5 mm. We can conclude from the results obtained when changing width, the outputs in general are not higher than at the initial setup, which is at 29 mm. When we put in a different width, the output characteristics do not decrease by much.

Table 3. Width of the inset-feed line

W in mm	F in GHz	S11 in dB	E-θ in dB	E-Φ in dB
29.0	5.045	-10.747	5.762	-41.329
29.5	4.997	-10.402	5.992	-44.834
30.0	4.997	-10.218	5.899	-44.754
28.5	4.997	-10.510	5.870	-44.867
28.0	4.997	-10.347	5.899	-44.730

In Table 4 the length of the two slits around the inset-feed is modified so that it differs by 0.5 mm. We can conclude from the table data that when the height is differentiated by some error, the output in the table decreases. The initial output, for which this antenna is designed, and the best one is at 116 mm.

Table 4. Height of two vertical slits next to the inset-feed line

h in mm	F in GHz	S11 in dB	E-θ in dB	E-Φ in dB
11.60	5.045	-10.747	5.762	-41.329
11.65	4.997	-10.492	5.992	-44.766
11.70	4.997	-10.499	5.761	-44.830
11.55	4.997	-10.258	5.985	-44.703
11.50	4.997	-10.389	5.811	-44.620

Table 5 below tells us similar knowledge in the width alteration in the case of two cuts at the top of the metal on both the left and right sides. In conclusion, when the width change occurs, the decrease in the outputs is minor. End results are not affected significantly. The design requirements specified were achieved with 279 mm in width.

Table 5. Length of the horizontal slit (main slit)

w in mm	F in GHz	S11 in dB	E-θ in dB	E-Φ in dB
27.90	5.045	-10.747	5.762	-41.329
27.95	4.998	-11.2803	5.807	-44.307
28.00	4.999	-11.2808	5.807	-44.309
27.85	4.999	-11.2802	5.807	-44.311
27.80	4.999	-11.2802	5.807	-44.329

As displayed in Figure 2, we have designed the antenna to have S11 of -10.74dB at 5.045 GHz.

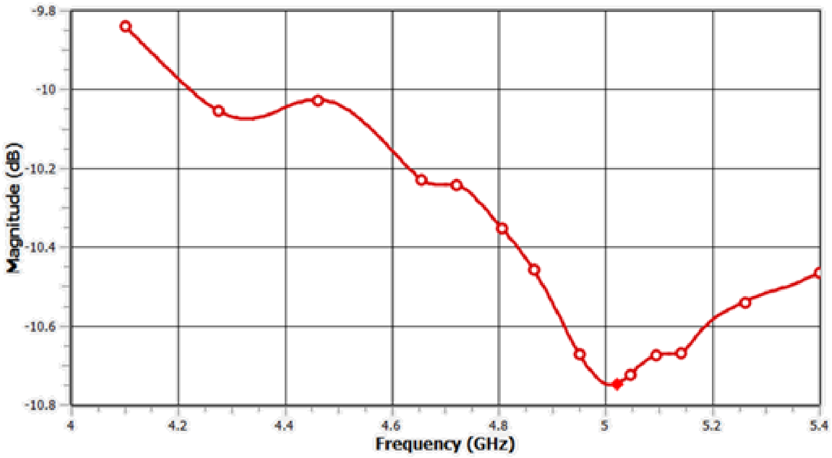

Figure 2. S11 (Reflection)

As it is displayed in the following figure (Figure 3) we can conclude that the E-theta polarization is 5.08 dB at 0 degrees.

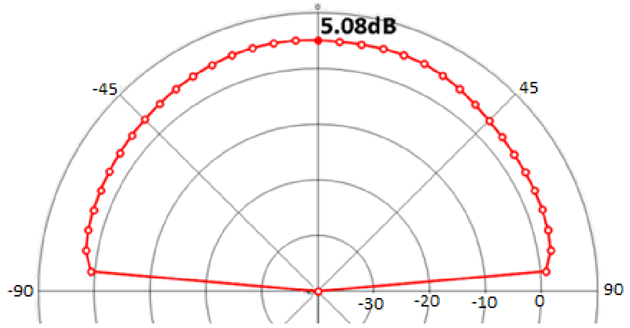

Figure 3. Theta Polarization

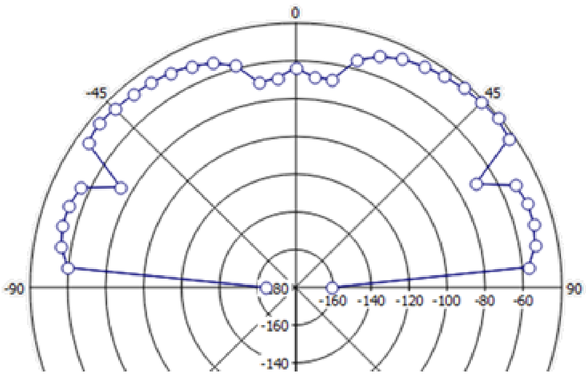

Figure 3. Phi polarization

As shown in the figure above (Figure 3) it can be determined with great precision that the E-phi polarization is -41.329 dB at 0 degrees for a 5.045 GHz design frequency.

4. Conclusions

As the core mission of this publication is the design of an antenna for 5G applications, such an antenna is designed, developed, and presented alongside its schematics and the results of simulations that were run. This project's goal is to try to develop a design that suits our needs as stated in the design specifications. After trying a variety of different approaches to design, and changing our steps along the way, we managed to come to a solution that meets our design specifications at 5.045 GHz with 5.99 dB maximum gain. Simulation results have been influenced mostly by feed indentation and dielectric thickness. We changed the dielectric thickness from 1.55 to 1.66 mm as this range is the most common in the antenna manufacturing industry to achieve better performance and more stable results in the simulations. Finally, the designed and simulated patch antenna has -10.747 dB of reflection coefficient and 5.99 dB of gain at the design frequency of 5.045 GHz. This is a significant gain for our design specifications.

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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