A Hand-Pump Microstrip Patch Antenna for Sub 6GHz - 5G Applications

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Abstract

The purpose of this paper is to explore the presented design of a single element hand-pump shape microstrip patch antenna for sub 6GHz, 5G applications. This paper will first provide a brief overview of the antenna design and its capabilities. Meaning, overall dimensions of 25.25 mm x 20.75 mm x 1.55 mm, with S11 being -16.82 dB at operating frequency of 5.16 GHz. Next, the paper will discuss the design of the antenna and how it can be optimized with sub 6 GHz operating frequency, along requirements. To reach required specifications, inc. E-$\theta \geq$ 5 GHz $\geq$ E-Φ; S11 $\leq$-10, various geometrical parameters, among others, have been tested, resulting in two slots being added (slot a and slot b), in combination with various slits. Finally, antenna is fabricated and experimentally tested for the validation of results. Further discussing potential benefits and drawbacks of using this antenna design for 5G applications.

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Keywords: *hand-pump antenna, microstrip patch antenna, 5G, antenna analysis, sonnet software*

1. Introduction

5G networks operate in a higher frequency range than previous generations, allowing for faster speeds and more capacity. 5G signals are able to travel further and penetrate buildings better than previous generations, making it ideal for coverage in dense urban areas. 5G technology is also more energy efficient than earlier generations, meaning that service providers can deploy more 5G base stations without increasing power consumption. In terms of frequencies being used, from the sub-6 GHz spectrum, 3.4 GHz–3.8 GHz band is in the spotlight. It is the combination of a long-term evolution (LTE 42) band (3.4 GHz–3.6 GHz) and LTE 43 (3.6 GHz–3.8 GHz). Many nations regard this band take it as a pioneer to realize the 5G technologies like massive MIMO arrays and antennas. [1] – [3]. In recent literature, there has been significant interest increase towards microstrip antennas, inc. single element antennas, MIMO antennas and arrays, for 5G application. [4] This paper is focused towards single element hand-pump shape microstrip patch antenna, using fr4 dielectric, which is known to have return loss is much lower comparing to the other dielectric materials typically being used. [5] Based on the researches, we can see that both square and rectangular shaped microstrip patch antenna offer satisfactory value of return loss (S11), that can be reduced by proper selection of material and shape of the antenna. [6] – [7] Antenna's shape fine design usually includes various slits and slots, which alter antenna parameters, by change of current distribution, along with use of different thicknesses. [8]-[9]. Based on the findings, we can conclude that using a substrate material with a greater dielectric constant degrades antenna performance while reducing antenna size. With increase of substrate thickness, the resonance frequency results in decrease, in contrast to the bandwidth, which increases.[10] In this novel approach for building moderately thick antennas, presented in [11], smart choices for patch size and probe position can compensate for probe reactance without the requirement for an external matching network, which would add to the antenna analysis and construction complexity. Paper [12] even suggests use of U Slotted Patch, along Air substrate, for better performance in terms of Gain. However, focus of this paper will achievement of desired parameters, which includes specifical vertical and horizontal polarization required values (- E-$\theta \geq 5$ GHz $\geq$ E-Φ), along with return loss (S11 $\leq$-10). Most of the wireless networks such as 5G require multiband MIMO-supported Base Station Antennas and achieve this with use of multiple ports, supporting wider range of frequencies, leading to multiple arrays within one compact antenna enclosure [13]. "The MIMO antenna is also characterized by a good envelope correlation coefficient (ECC), low Channel Capacity Loss (CCL), and high diversity gain, which proves that the presented antenna can be seamlessly housed in miniaturized 5G smart devices" [14] Paper [15] also considered the effect of the dielectric housing on the radiation performance to optimize the placement of the mmWave 5G beamforming array antennas, while paper [16] suggests employment of a single layer cross bow-tie dual-band tunable HIS (high-impedance surface) ground plane with a printed wideband monopole antenna designed to cover the UHF band. There is also the potential use of a waveguide simulator to characterize approximately the performance of the proposed metamaterial structure.[17] Smart antenna which is designed by planer array can be used to synthesize a required pattern that cannot be achieved with a single patch element.[18]. However, this structures of antennas require larger space, some of them have smaller operational bandwidth, and poor radiation efficiency. Therefore, the focus of this paper, along others (S11, E-θ, E-Φ) will be achievement of smaller size, higher bandwidth, and radiation efficiency at LTE 42/43 (3.4 GHz–3.8 GHz) band for 5G applications. This single band antenna is going to be designed and analyzed in sonnet software [19], but also experimentally made. In addition, there is a lack of literature describing geometrical optimization of similar antennas. Researches [20] and [21] comparison to optimize the spacing between circular patches, but they do not considered it for optimizing the individual geometrical parameters of a single band antenna. Moreover, designed antenna exhibits optimized results used for fabrication and measurement results, respectively.

2. Antenna Design and Analysis

Figure 1. represents Schematic Diagram of the Microstrip Patch Antenna, along with antenna dimensions.

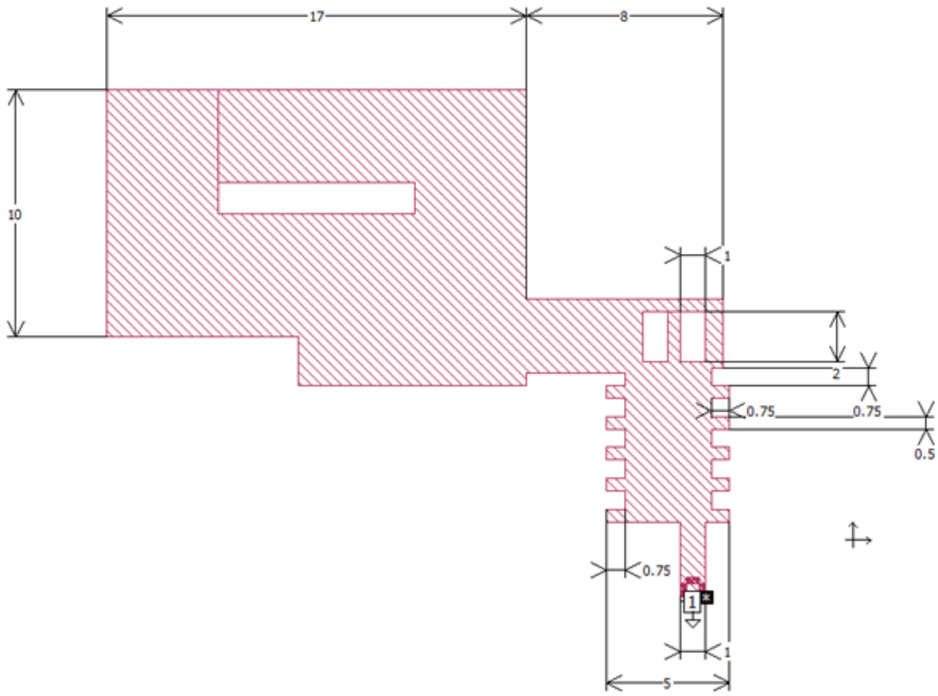

Figure 1. Schematic Diagram of the Microstrip Patch Antenna

Figure 2. represents 3D view of the antenna.

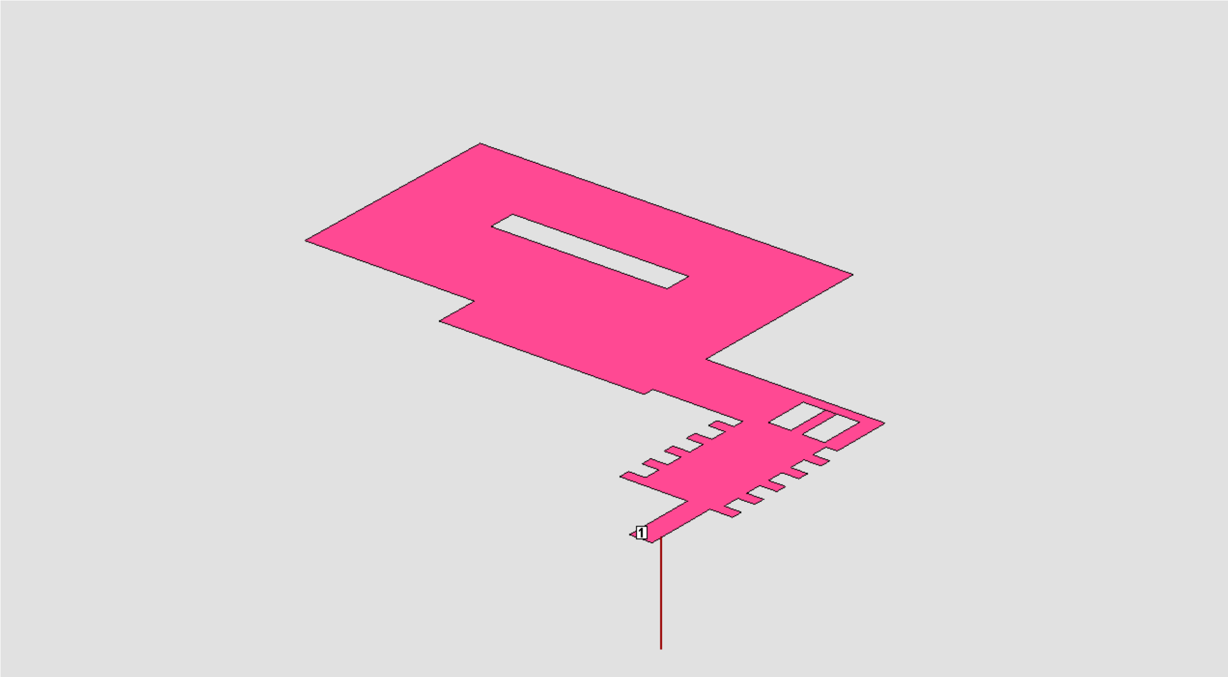

Figure 2. 3D View of the Microstrip Patch Antenna

S-parameters are shown below (Figure 3.), specifically S-11, representing reflection loss of the antenna.

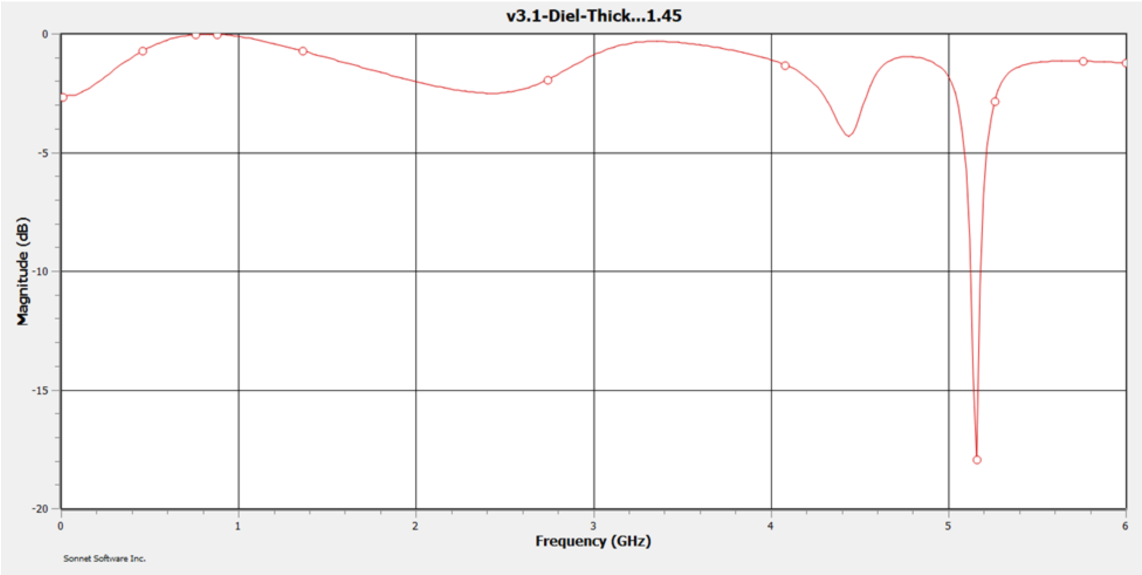

Figure 3. S-parameters of the Microstrip Patch Antenna

Vertial polarization component (E-θ) is presented in Figure 4. below.

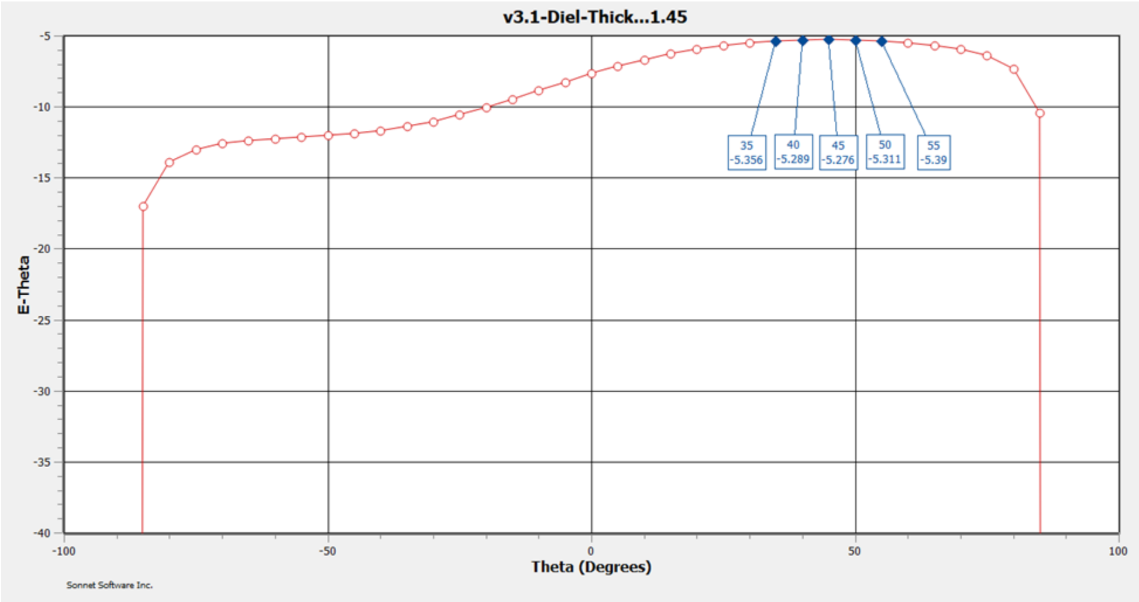

Figure 4. E-θ of the Microstrip Patch Antenna

Horizontal polarization component (E- Φ) is presented in Figure 5. below.

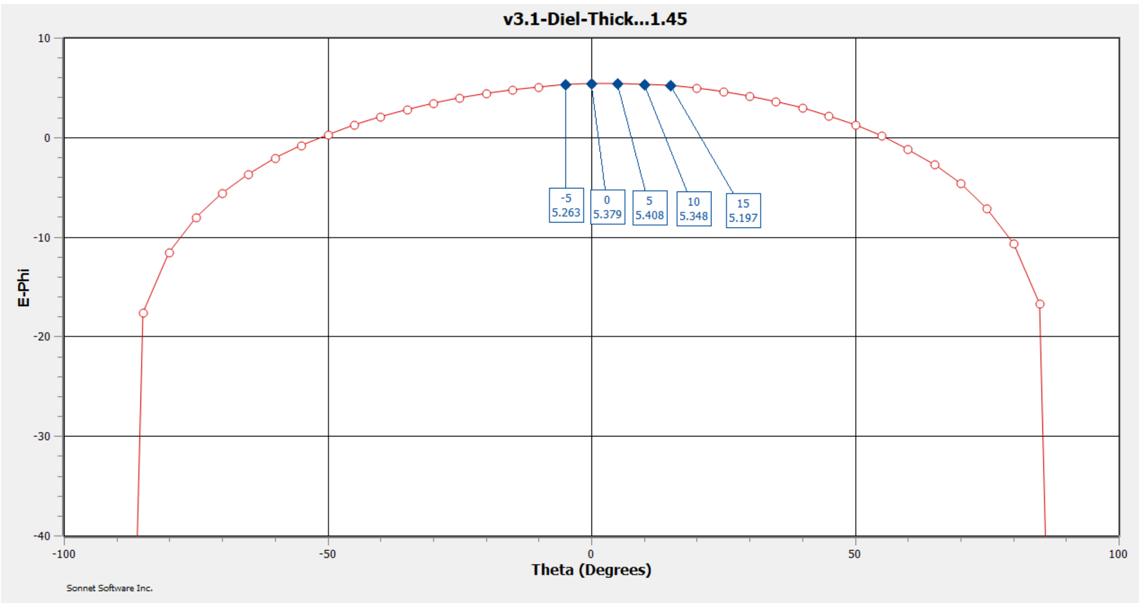

Figure 5. E-Φ of the Microstrip Patch Antenna

Figure 6. represents current distribution diagram of presented antenna design, at 5.16 GHz

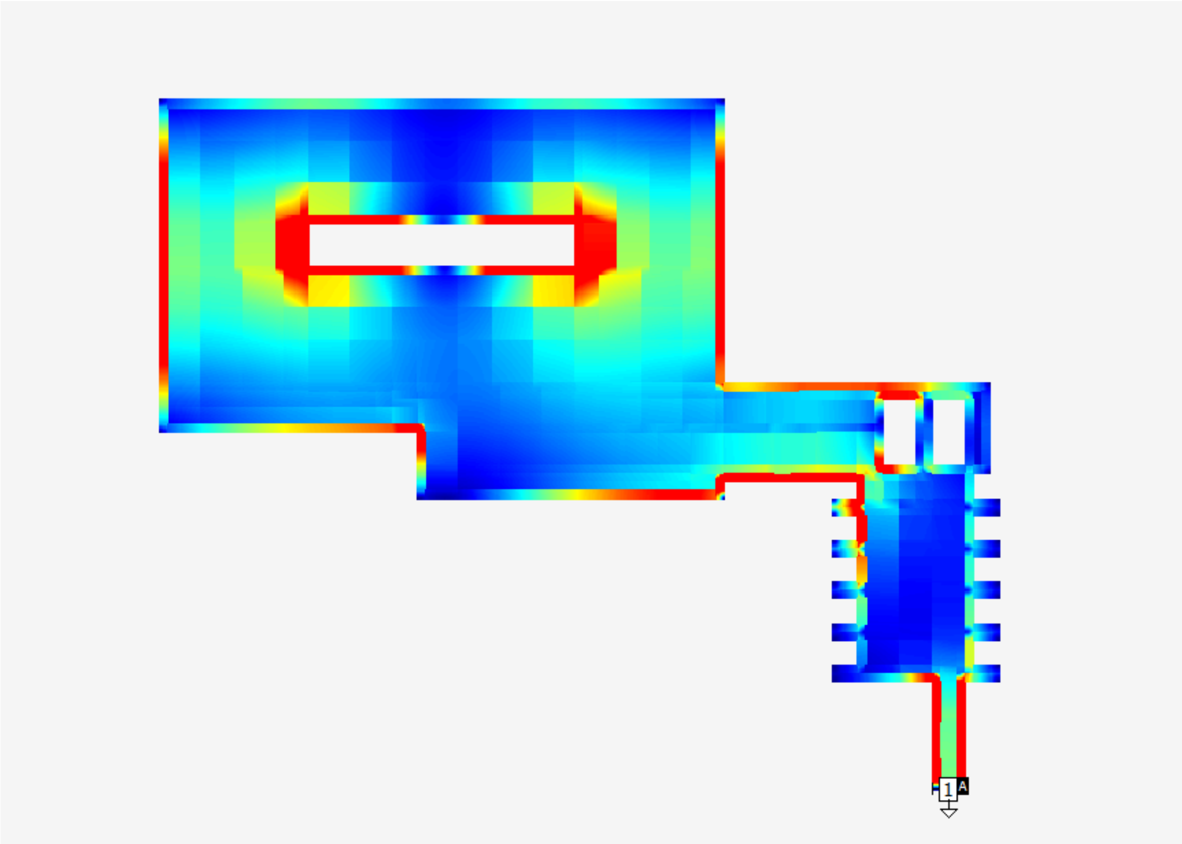

Figure 6. The Current Distribution of the Microstrip Patch Antenna

3. Parametric Analysis

Data shown bellow represents Parametric Analysis of proposed design. A parametric analysis was carried out by varying the dimensions of length and width of various antenna parts, as well as dielectric thickness and erel value. Analysis consists out of 7 tables, where first 3 tables represent size variations, Table 4 being Erel Value (ε_r in tables), Table 5 dielectric thickness and Table 6 and Table 7 are combination of previously done variations, with goal of choosing best possible value for every parameter.

Table 1. represents size variation of a Slot (a) (smaller slot on the right antenna side). It is noted that narrower slot design will result in S11 value fluctuation, with tendency to lower down, no matter the length. Value of 3 mm x 0.75 mm provided E-Φ increase, but significantly decreases S11 value, therefore dimension of 2 mm x 1 mm is chosen.

Table 1. Size of the Slot (a)

Dimension	S11	Frequency	E-Φ	E-θ
2 mm x 0.5 mm	-13.71 dB	(5.26 GHz)	5.362 dB	-5.033 dB
2 mm x 0.75 mm	-13.85 dB	(5.26 GHz)	5.372 dB	-5.035 dB
2.25 mm x 0.7 mm	-13.63 dB	(5.26 GHz)	5.382 dB	-5.037 dB
3 mm x 0.75 mm	-12.81 dB	(5.24 GHz)	5.414 dB	-5.034 dB
2 mm x 1 mm	-13.90 dB	(5.26 GHz)	5.384 dB	-5.040 dB

In Table 2., various dimensions have been proposed for Slot (b) (larger slot on the center part of the antenna), it is noted that length of the slot and S11 parameter, are directly proportional, resulting in significant S11 value increase with length increase. Although S11 value greatly increased, this option was not suitable, because E-θ value fall down bellow required (-5 dB), therefore, bolded dimensions where implemented.

Table 2. Size of the Slot (b)

Slot-(b) Size	S11	Frequency	E-Φ	E-θ
1.25 mm x 8 mm	-13.70 dB	(5.26 GHz)	5.343 dB	-5.040 dB
1.5 mm x 8 mm	-15.24 dB	(5.22 GHz)	5.379 dB	-4.956 dB
1.5 mm x 8.5 mm	-20.36 dB	(5.12 GHz)	5.262 dB	-4.859 dB
2.5 mm x 8.5 mm	-18.14 dB	(4.98 GHz)	5.145 dB	-4.705 dB
2 mm x 8.5 mm	-18.45 dB	(5.06 GHz)	5.389 dB	-4.651 dB

Table 3. represents results of various Slit dimensions (side rectangle on the bottom right of the antenna). Although some dimensions provided better E-Φ and E-θ values, dimension of 0.75 mm x 0.5 mm resulted in great S11 increase, hence it was more suitable. Less then 0.5 mm almost always resulted in E-Φ decrease, in this case S11, also decreased.

Table 3. Size of the Slits

Slits Size	S11	Frequency	E-Φ	E-θ
1 mm x 0.5 mm	-13.90 dB	(5.26 GHz)	5.384 dB	-5.040 dB
1.25 mm x 0.5 mm	-11.89 dB	(5.26 GHz)	5.410 dB	-5.026 dB
1.5 mm x 0.5 mm	-10.12 dB	(5.26 GHz)	5.422 dB	-5.093 dB
0.75 mm x 0.5 mm	-15.56 dB	(5.26 GHz)	5.344 dB	-5.026 dB
0.75 mm x 0.25 mm	-14.92 dB	(5.26 GHz)	5.290 dB	-5.026 dB

Table 4. represents experimentation with Erel Value, it is noted that Erel Value of 4.6, although lowering the operating frequency of the antenna, increases both E-Φ and E-θ, as well as S11, to -16.92 dB. Erel being lower than 4.4 results in E-θ decrease bellow required value of -5 dB.

Table 4. Erel Value

ε_r	S11	Frequency	E-Φ	E-θ
4.4	-15.56 dB	(5.26 GHz)	5.344 dB	-5.026 dB

4.5	-15.04 dB	(5.2 GHz)	5.263 dB	-5.121 dB
4.6	-16.82 dB	(5.16 GHz)	5.350 dB	-5.147 dB
4.3	-15.17 dB	(5.32 GHz)	5.401 dB	-4.931 dB
4.2	-14.57 dB	(5.38 GHz)	5.440 dB	-4.844 dB

Table 5. represents Dielectric Thickness fluctuation, while sticking to design default Erel Value of 4.2, note that any value less than 1.70 of diel. Thickness results in S11 above -15 dB, but any value lower than 1.55, reduces E-θ to less than -5 dB. With this, we can neglect benefits of increased E-Φ and S11, and stick to value of 1.55.

Table 5. Dielectric Thickness with Erel value- (4.2)

Dielectric Thickness (ε_r- 4.2)	S11	Frequency	E-Φ	E-θ
1.55	-15.56 dB	(5.26 GHz)	5.344 dB	-5.026 dB
1.6	-13.87 dB	(5.38 GHz)	5.415 dB	-4.765 dB
1.65	-13.31 dB	(5.38 GHz)	5.393 dB	-4.683 dB
1.52	-15.02 dB	(5.38 GHz)	5.456 dB	-4.890 dB
1.45	-15.99 dB	(5.38 GHz)	5.499 dB	-4.988 dB

In Table 6., we can see that now with Erel being value of 4.6, E-θ satisfies the requirements in every case, this provided ability to start experimenting with Dielectric Thickness more freely than before, hence value of dielectric thickness greater than 1.55 is not necessary, since it has negative result on S11, E-Φ and E-θ. There is no need to lower down Diel. Thickness value, less then 1.55, since it satisfied the requirements, thicker dielectric layer can result in a more stable antenna design, while additionally increasing the power handling capability of the antenna.

Table 6. Dielectric Thickness with Erel value- (4.6)

Dielectric Thickness (ε_r- 4.6)	S11	Frequency	E-Φ	E-θ
1.55	-16.82 dB	(5.16 GHz)	5.350 dB	-5.147 dB
1.6	-15.96 dB	(5.16 GHz)	5.327 dB	-5.076 dB
1.65	-12.43 dB	(5.14 GHz)	5.117 dB	-5.106 dB
1.52	-17.26 dB	(5.16 GHz)	5.365 dB	-5.188 dB
1.45	-17.95 dB	(5.16 GHz)	5.407 dB	-5.276 dB

Hence the above, Table 7. is representation of all the combined values, the performance of the proposed antenna in terms of optimized geometrical parameters is inspected on the basis of the simulation results, to obtain best possible values.

Table 7. Final parameters with chosen values.

Parameter	Value	S11	Frequency	E-Φ	E-θ
Dielectric Thickness	1.55 mm	-16.82 dB	(5.16 GHz)	5.350 dB	-5.147 dB
ε_r	4.6				
Slot (a)	2 mm x 1 mm				
Slot (b)	1.25 mm x 8 mm				
Slit	0.75 mm x 5 mm				

4. Conclusion

5. References

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