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ASIM Shape Wide band High-Gain Patch Antenna Integrated with Frequency-Selective Surface as Super Strate for Sub-6GHz 5G Applications

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Abstract
This shows a wideband antenna with a FSS as a substrate. Initially, a Sim-Shape microstrip patch antenna is designed using an Fr4 substrate having 4.4 permittivity and a height of 1.6 mm with a dimension of 30 x 35 mm square at 4.5 GHz. The simulated result shows a wide band from 3.0 to 6.2 GHz. The bandwidth gain varied from 3.3 dB to 4.2 dB at these frequencies, and the result of a sim-shaped microstrip pattern phenna is improved after the integration of FSS as a substrate. A unit cell of the FSS periodic structure with a 6x7 array is designed using FR4 material. The simulated result shows a wide bandwidth ranging from 3.2 GHz to 6.8 GHz, with a gain improvement of 2.5 dB to 6.5 dB.

Keywords: Antenna, FSS, Wave Frequency.

I. INTRODUCTION

It is expected that data traffic will grow by a factor of seven over the next five years. This is because more people are using cell phones, smart phones, broadband internet, fast networks, and many other mobile consumer trends. Mobile networks will be even more strained by video traffic, which consumes a lot of bandwidth and accounts for 78% of all mobile traffic [1–3]. Due to these problems, terahertz bands will be used in the future for 5G wireless transmission services. It will also be able to send data at up to 10 Gbps, have low latency (ms), a huge number of users (106 per km2), and move very quickly (500 km/h) [4-6]. The new 5G radio access networks should be able to support many connections at the same time and work across a wide range of frequencies [6]. A low-frequency spectrum (maximum 1 GHz), a moderate frequency band of 3.5 GHz (less than or equal to 6 GHz), as well as a high-frequency spectrum band (mm-wave), were defined by the FCC to enable 5G. While the flow frequency band effectively modifies the 5G and medium frequency bands, the mm-wave provides maximum data rates of more than 2 GB/s. The mm-wave frequency band allows for higher data speeds and a larger capacity, while the low band provides strong coverage, and the mid-band combines coverage and capacity.

Therefore, the lower band of 5G is the best alternative for technology that is ready to be implemented in the first place. It is appropriate for use in both urban and rural locations due to the sub-6 GHz 5G bands' frequency range, which allows for the transmission of high data rates across long distances. As the 5G communication system has been warmly welcomed throughout the world, the demand for the antennas designed for 5G access points and smart phones is growing. Antenna design for 5G communication systems faces significant challenges given the range of the allocated frequency band. The antenna construction for 5G operation should be small enough to be internally integrated with smart devices [7]. Antennas are widely employed in sub-6 GHz frequency ranges because they have benefits such as compact size, reduced costs, and wider bandwidth [8]. However, a negative aspect of using this antenna/radiator is that when they are installed close to metallic things and electro-magnetic equipment, they suffer from a high mismatch of impedance. Another disadvantage is that at lower frequency regions in the microwave range, there is poor gain and weaker directivity. As a result, researchers are now interested in antennas and are always working to enhance their performance. One method to enhance its performance is frequency-selective surfaces (FSSs), described in [9] as metal surfaces that just show an electric response [10]. According to antenna and microwave engineering concepts, such surfaces are constructed from planar, regular arrangements of metal patches or strips in a variety of configurations. Different methods for determining optimal EM properties employ various element types and geometrical structure parameters, structural element dimension changes (patches or holes), a dielectric substrate,

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and cross-spacing in the proposed work. It is designed the first SIM-shaped microstrip rectangular antenna with a partial ground. Parametric analysis for the dimension of the rectangular microstrip patchantenna was observed using HFSS simulation to identify the optimum configuration.
Furthermore, incorporating the frequency-selective surface (FSS) as a superstructure improves the performance of the proposed antenna, which is designed to span the desired 5 GHz middle band by achieving a wide bandwidth as well as a stable high good gain. A superstrate layer with a periodic structure will improve the planar wideband antenna's bandwidth, gain, and radiation pattern. A unit cell is made up of a single square ring and an adjacent square patch. This composing structure of the antenna obtains wide bandwidth ranges from 3.2 to 6.8 GHz, which is appropriate for the sub-6 GHz frequency application.

II. DESIGN METHODFORANTENNA

It was possible to simulate the proposed antenna design using analysis HFSS software.When designing the antenna, its primary properties, including its reflection coefficient, frequency resonance, gain, bandwidth, and polarisation parameters, are taken into account. The final antenna is constructed and developed utilising an inexpensive FR4 material with a relative permittivity of 4.4 and a thickness (h) of 1.6mm.The substrate is a key component in the antenna design process. The substrate's thickness, dielectric constant, and other characteristics can affect an antenna's bandwidth, resonant frequency, and ability to match impedance. The suggested antenna is designed with FR4 as a substrate material because of its remarkable electrical properties, inexpensive cost, and widespread availability. In thesuggested design, the substrate materials are positioned above the partial ground plane. Theantenna in this proposed structure is excited by a lumped port. Table 1 shows the FR4 substrateparameter

Table1:SubstrateFR4MaterialSpecification

S.No.	Parameter	Value
1	The substrate's thickness (h)	1.6
2	constant of dielectric (ε_r)	4.4
3	Losstangent(δ)	0.02

The antenna's design selects a frequency of 4.5 GHz. using simple equations and the transmission line model of the microstrip antenna as a primary standard. In the first part, we developed a rectangular microstrip patch antenna depending on the transmission line concept [11]. The dimension of the antenna is calculated by the following equations.

A. Height of the patch:

The formula is used to determine the height of the patch.

$$h = \frac{0.3c}{2\Pi f\sqrt{\varepsilon_r}} \qquad (1)$$

C =3.0 x 10^8 m/s (speed of the light),ε_r= dielectric substrate equal to 4.4, and h 1.6 mm height.

B. Width of the patch (W):

The patch width is determined by the formula.

$$w = \frac{c}{2f}\sqrt{\left(\frac{2}{\epsilon_{r+1}}\right)} \qquad (2)$$

W=width (mm)

C. The effective dielectric constant calculation (ε_{eff}):

The actual dielectric constant is an important factor to consider when building a rectangular patch antenna because the fringing effect causes certain waves from the radiating patch that are removing toward the ground plane to enter the substrate. The effective dielectric constant has to be known in order to calculate the velocity of an EM wave. The effective dielectric constant is computed with the above equation:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \qquad (3)$$

W = Patch width h = Patch height
ε_{eff}= The effective dielectric constant

D. Calculation of patch length expansion (ΔL):

The term "length expension" describes the extra length at the end of the patch that results from the fringe field running over its whole length. The following equation is used to determine it.

$$\Delta L = 0.412\frac{[\varepsilon_{eff}+0.3][\frac{w}{h}+0.264]}{[\varepsilon_{eff}-0.258][\frac{w}{h}+0.8]} \qquad (4)$$

Δ L= Extension of the patch length (mm)
h= height w= breadth, and ε_{eff} is effective dielectric constant

E. Calculation of the patch's effective length (Leff).

The patch's effective length is calculated by the given formula (Leff).

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} \qquad (5)$$

F. Patch length calculation (L);

The given equation is used to determine real patch length.

$$L = L_{eff} - 2\Delta L \qquad (6)$$

G. Ground plane dimensions calculation;

The given equation for calculation of length and width of

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the ground plane

Lg=L+6h (7)

Wg=W+6h (8)

L=Patch length W= patch width.

The overall dimensions of the antenna are 30 x 35 x 1.6 mm, and it is fed by an an impedance of 50 ohms, as previously mentioned [12]. It is constructed with a partial ground of Lg = 9.8 mm, and the designed frequency of the antenna is 4.5 GHz. The partial ground is used to achieve a wide bandwidth. Figure 1 parametric analysis was taken out to optimise the dimension of the patch, as shown in Table 1. The simulation results for the gain, S11 reflection coefficient, and VSWR of the antenna were analysed. Figure 1 shows that the antenna produced a reflection coefficient of less than 10 over the frequency range of 3.0-6.5 GHz.

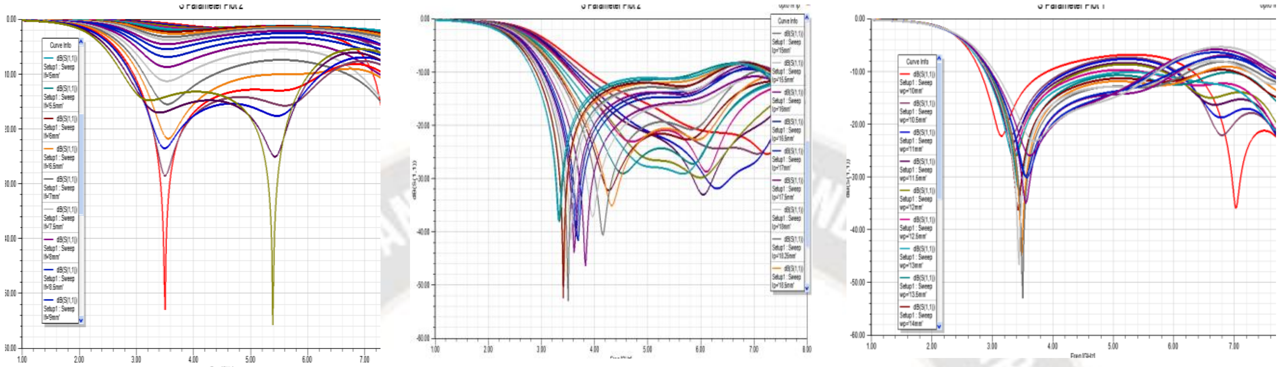

Figure1: (a)Parametric Study with variation of LF (b) Parametric Study with variation of Lp (c) Parametric Study with variation of Wp

Table2: Different Measurement of the suggested antenna

Variable for the antenna	Value(mm)	Variable for the antenna	Value(mm)	Variable for the antenna	Value(mm)
ws	30	hs	1.6	lf	11.5
ls	35	wf	2.7	wp	15
lg	9.8	wss	30	lss	1.6
hgap	6				

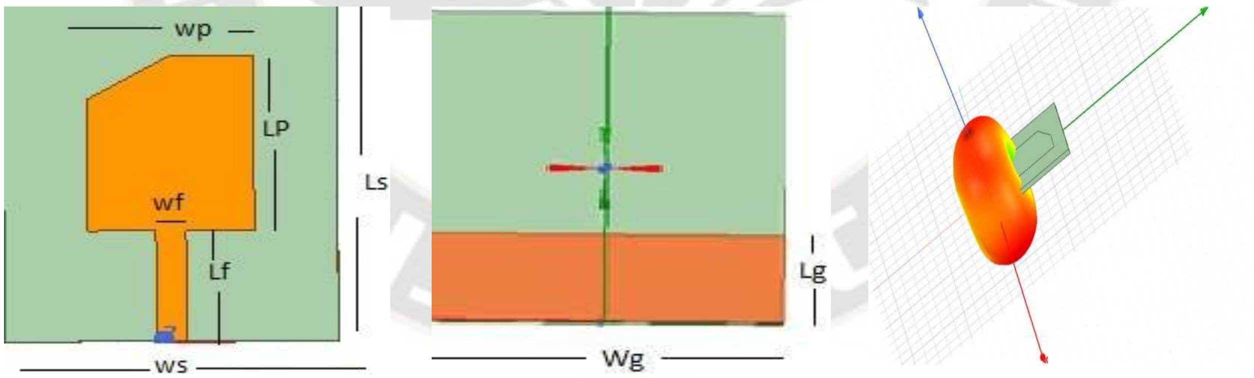

Figure2: Proposed SIM-shaped patch antenna (a) Top View (b) BottomView

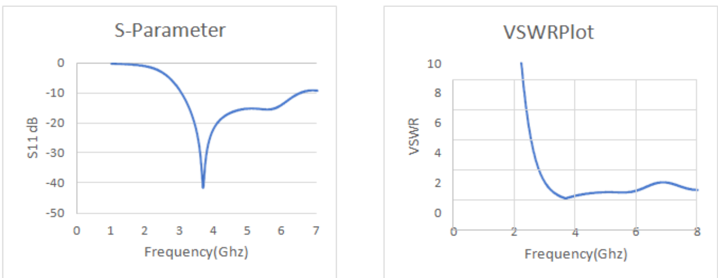

Figure3: (a) Simulated S-parameter (b) Simulated VSWR

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III. METHODOLOGY

The initial step in the design process is to determine the appropriate dimensions for the antenna and FSS structure at the target frequency. The design is simulated using HFSS Software. The design is optimized by taking into account antenna properties including resonance frequency, return loss, gain, and directivity.

FSS Design

FSS is another interesting structure that contributes significantly to enhancing antenna gain. It was originally created to regulate a radiation wave's characteristics of transmission and reflection.dielectric that has an infinite planar array of periodically spaced unit cells [13–14]. The primary function of the FSSlayer is to act as a conducting patch to improve electromagnetic wave transmission and thus increase antenna efficiency. The suggested FSS basic unit cell is made of FR4 dielectric substrate material with a relative permittivity of 4.4 and a thickness of 1.6 mm.As shown in Figure 3, the suggested FSS is a combination of two basic structures, one of which is a square ring and the other a square patch. The FSS electromagnetic characteristics are directly influenced by the substrate thickness as well as the substrate permittivity of the unit cell. Finally, a FSS unit cell's maximum dimension must be less than 10 in order to meet the homogenization standard based on the antenna working frequency (4.5 GHz) and its wavelength in free space, which is equal to 66 mm. Therefore, a parametric analysis was done to calculate the ideal FSS unit cell dimensions and the overall hybrid structure dimensions, which are given in Table 3.

Table3: Dimensions of the proposed unit cell configuration

Variable	A1	B1	A2	B2
Value(mm)	5	5	4	4
Variable	A3	B3	A4	B5
Value(mm)	4	4	0.5	0.5

Figure 3 displays the transmission and reflection properties of the suggested FSS unit cell. The simulated result of the S-parameter S21 values is less than 20 dB across the entire working frequency band, which indicates reflective behaviour.

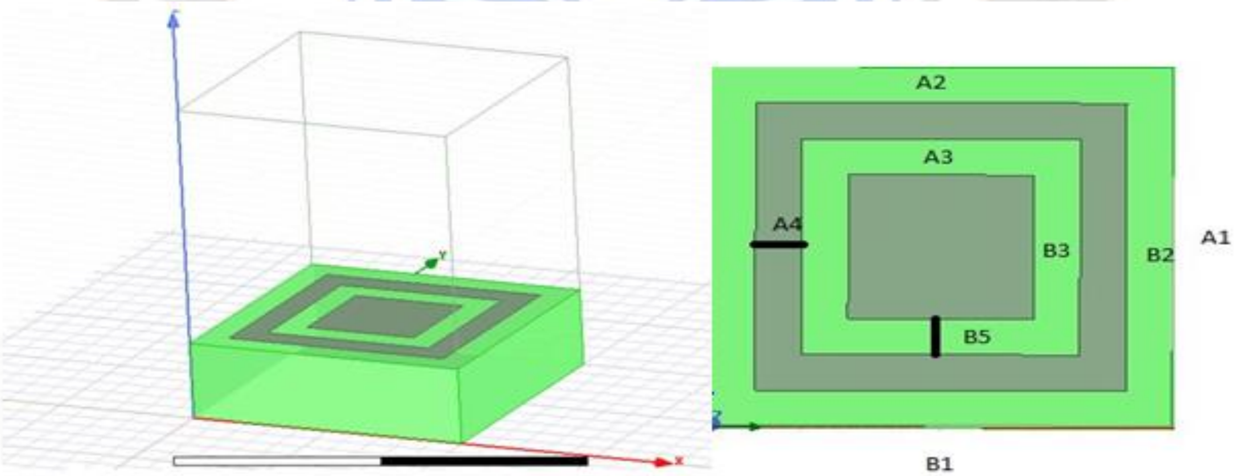

Figure3: (a) Side view of unit cell (b) Dimension of unit cell

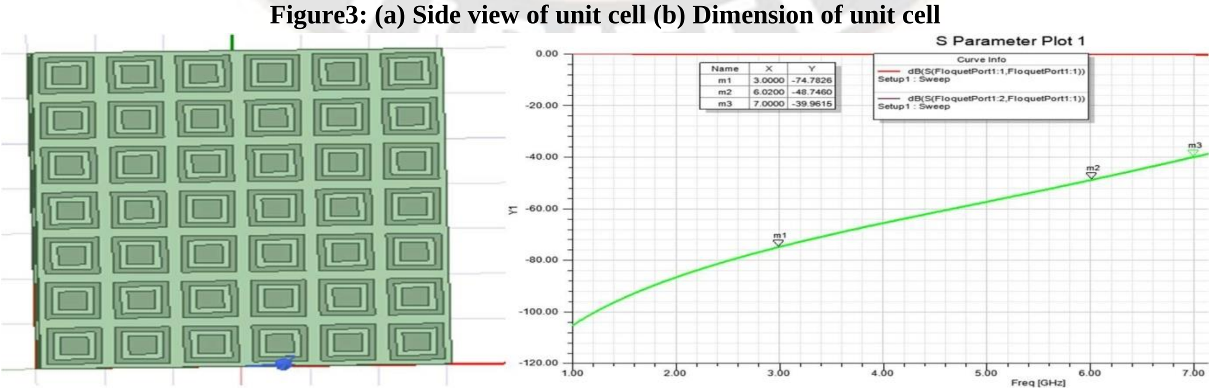

Figure4: (a) Hybrid structure (b) Reflection co-efficient S11 and Ss21

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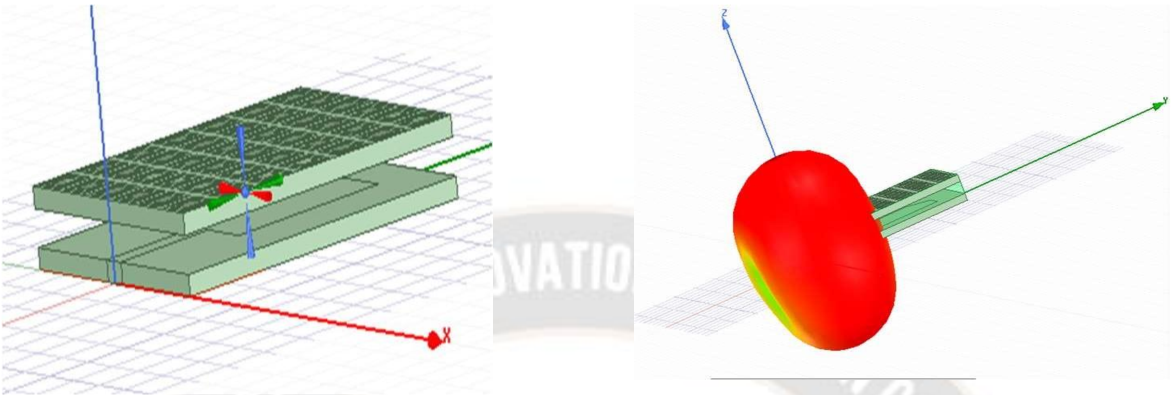
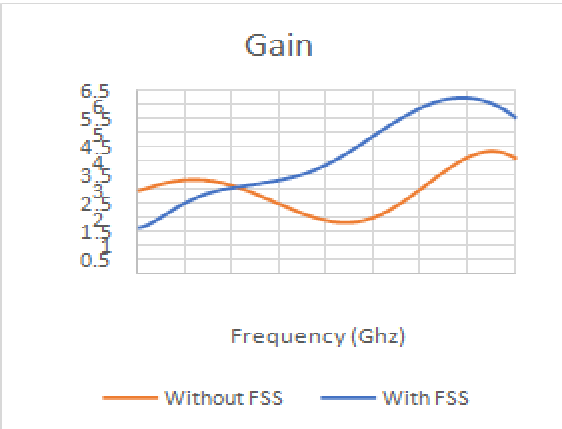
IV. SIMULATION RESULT

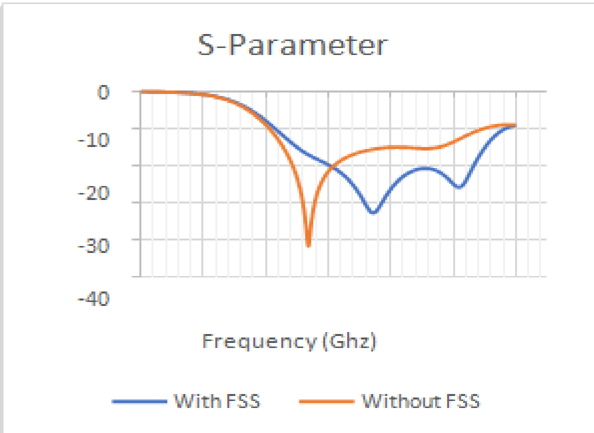
The HFSS simulations used in the design of the proposed SIM-shaped antenna and FSS structure as super strate are located above the antenna; the position of the FSS varies from 1mm to 10mm; the obtained result indicates that the super strate is 6mm away from the antenna



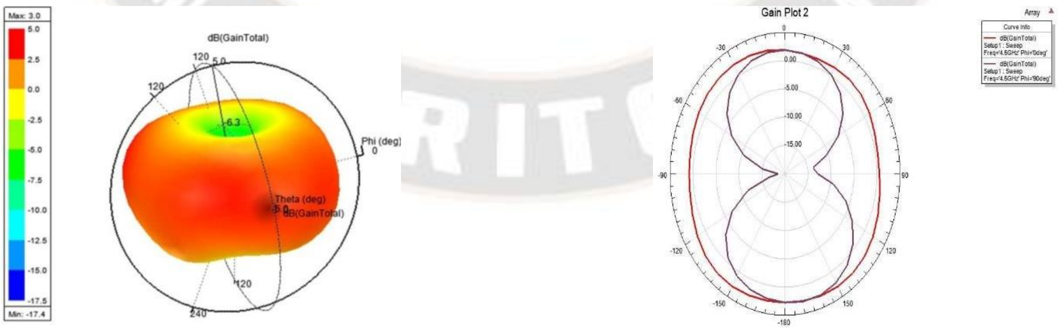
(a)



(b)



(c)



(d)

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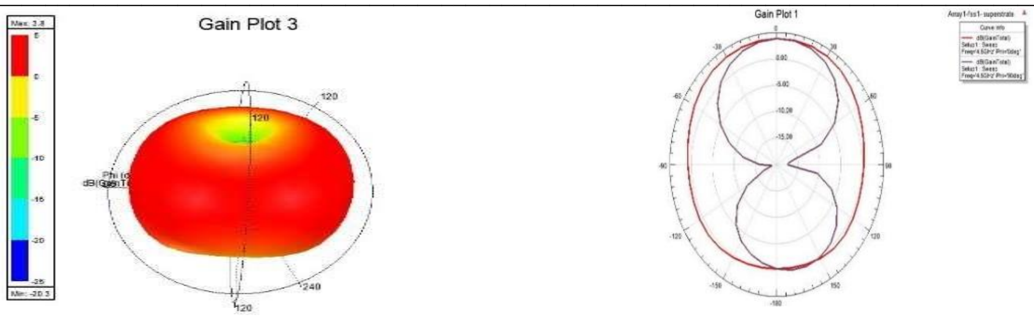

(e)

Figure4: (a)Proposed antenna with super strate (b) Gain (c) Reflection Coffeicent (d) Radiation pattern without FSS Layers (d) Radiation pattern with FSS Layers

Table 4: Comparison Result antenna with and without FSS

S.No	**Sim Shaped Microstrip patch antenna at 4.5 Ghzwithout FSS**	**Sim Shaped Microstrip patch antenna at 4.5 Ghz without FSS**
Bandwidth	3.2 Ghz	3.6 Ghz
VSWR	Lessthan2	Lessthanto6.8Ghz
2D Gain (over the band width)	At 3 Ghz -3.3 dBAt6.3Ghz-4.2dB	At 3.2Ghz - 2.5dBAt6.8Ghz- 6.2.dB

V. CONCLUSION

The proposed antenna has resonances in the 6 GHz range (3.2-6.5GHz).This is advantageous for sub-6 GHz 5G applications. The incorporation of the FSS layer increased bandwidth and gain, according to the simulation results. Implementing the FSS layer over the antenna has the effect of delivering a low-profile, low-cost, compact construction, and high-gain antenna in a simple and quick manner.

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