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Design of Broadband Microstrip Patch Antennas For Wireless System

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Abstract: ***Due to the requirement for small, high-speed, and wide-bandwidth systems, communication technologies have been pushed towards the fifth generation (5G). These types of radio communication systems demand new antenna designs that are more efficient. Because of this, the new system will be able to work with more devices and meet the higher quality standards that modern applications require. In this paper, Microstrip patch antenna designed in CST software, which is the better for time domain based simulation. According to simulated results return loss of rectangular patch antenna with slotted is -49.80 dB at 28 GHz and gain is 7.58 dBi, return loss of circular patch antenna is -12.42 dB at 37.52 GHz and gain is 5.57 dBi, which are the best results got by comparing the microstrip patch and slots antenna. The designed antennas can be used for aircraft, spacecraft, satellite, and missile applications, applications. The proposed antenna would work well for 5G mobile communication because it has the high throughput that is needed. The antenna is small and light, which makes it a good choice for devices with limited space.***
Keywords: vswr, return loss, bandwidth, frequencies bands, cst, gain, microstrip antennas.

I. INTRODUCTION

New call-handling technologies are being developed to meet the increased demand for telecommunication services. Improved connection quality and new features have come with each iteration of mobile technology. Since 2009, fourth generation (4G) technology has been widely available. The Internet of Things (IoT) and "smart cities" will be made possible by the fifth-generation (5G) wireless network. There are advantages and drawbacks to each of the frequency bands that the new technology will utilise. The widespread 5G network rollout, on the other hand, demands new technological solutions and the building of antenna infrastructure. A substantial number of antennas will be erected within buildings, particularly public utility facilities such as stadiums, train stations, and retail malls, aside from the antennas used for mobile devices. Antennas erected in areas where people congregate would be smaller than those currently used in macrocell transmitters, which are larger.

The 5G network will operate in three frequency bands, namely low, medium, and high, according to the present state of standardization, which is presented in fig 1. The application of a specific band depends on its features, which include two variables in particular: radio signal propagation and spectrum resource capacity. Due to its great bandwidth, gain, and efficiency, we have chosen to employ a microstrip patch antenna that resonates between 26 and 38 GHz.

Major service kinds, such media and virtual experiences and vast connectivity machine type communication, have been recognized for the requirements of key 5G applications. This service's examples include high-quality 8K UHD (Ultra-High-Definition) distribution, video-based security, broadcast services, smart cities, smart homes, and smart offices, as well as smart metering for things like energy, gas, and e-health and online real-time education. Our 5G technical requirements for this include an increase in data throughput (Bandwidth of 1Gbps per user), high connection, more availability, and greater efficiency. When a case like COVID-19/Lockdown arises, all of these requirements will be helpful.

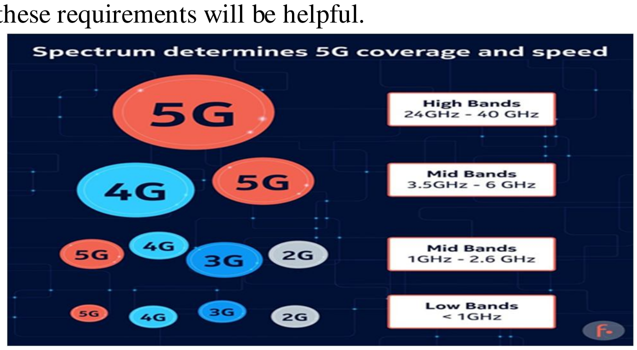

Fig. 1: 5G Frequency Band

In the upcoming sections the theory and design of Microstrip patch antennas (Section II) is discussed. Section III elaborates the methodology of Rectangular and Circular patch antenna. Section IV illustrates the experimental results and Section V concludes the work

II. THEORY AND DESIGN OF MICROSTRIP ANTENNA

A. Theory Of Micrstrip Patch Antennas

Upgrading the worldwide network would necessitate quick changes of devices to ensure interoperability with the new network. It is critical to reconfigure all communication systems, or else the new network will become obsolete. In any case, fast development will result in antenna alterations. As a result, it is essential to recognize the importance of developing a 5G antenna. Microstrip patch antennas (MPAs) are one of the most extensively used and sought-after antennas in the world of communication because they are compact and readily made, light-weight, and therefore the favored option for most communications businesses. The ability to reduce the complete circuit is considered a crucial feature of most smartphone modifications. The components of a microstrip patch antenna are a substrate plane, ground plane, microstrip feed, and a patch that might be elliptical, circular,
rectangular, etc. Copper and gold, two conducting materials, are used to make the patches.

Our microstrip patch antenna has a Rectangular and circular shape, a ground plane with dielectric substrate sandwiched between the two. RT/Duroid 5880 substrate having dielectric constant εr =2.2 have used for the design because it gives low dielectric loss which is applicable for high frequency and broadband applications.

B. Design Of Micrstrip Rectangular Patch Antennas

The rectangular microstrip patch antenna has the best configuration among all geometry of patches available and therefore it is widely used. To design that which is most suited for 5G applications such as e-learning, selecting the best electric substrate with a lower dielectric constant is critical, which is why Rogers RT/Duroid substrate materials with a substrate height of 0.787 mm and a dielectric loss tangent of 0.0010 were utilized, Which is shown in Fig 2.

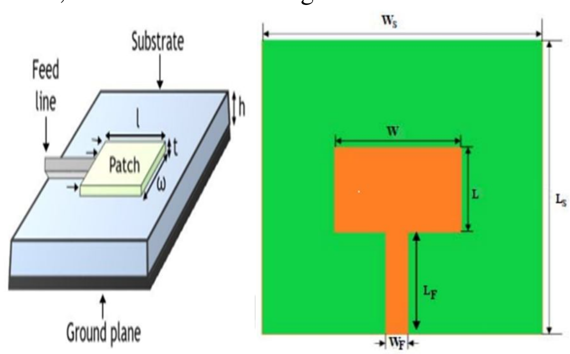

Fig.2 Proposed Structure and geometry of Microstrip Rectangular Patch antenna

The patch's length and width must be determined from equations (2) and (1), respectively.

$$W=\frac{c}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \qquad (1)$$

where c is the velocity of light, fr is the resonant frequency and εr is the dielectric constant of substrate.

$$L=Leff-\Delta L \qquad (2)$$

where Leff is effective length of the patch

$$Leff=\frac{c}{2fr\sqrt{\varepsilon eff}} \qquad (3)$$

where εeff is the effective dielectric constant

$$\varepsilon eff=\frac{\varepsilon r+1}{w}+\frac{\varepsilon r-1}{w}\left(1+\frac{12h}{w}\right)^{-1/2} \qquad (4)$$

and ΔL is the extended incremental length

$$\Delta L=0.142h\frac{(\varepsilon eff+0.3)(\frac{w}{h}+0.264)}{(\varepsilon eff+0.258)(\frac{w}{h}+0.8)} \qquad (5)$$

The Fig. 2 shows the proposed microstrip patch antenna geometry with dimensions (Ws×Ls). The dimensions used have shown in TABLE I.

TABLE I : Design parameter for Rectangular Patch

Antenna Components	Symbol	Dimensions[mm]
Length of ground plane	Lg=Ws	6
Width of ground plane	Wg=Ls	0.0175
Height of Substrate	h	0.787
Length of Patch	L	3.063
Width of Patch	W	4.2363
Length of feeding	Lf	1.4685
Width of feeding	Wf	0.3

C. Design Of Micrstrip Rectangular Patch Antennas With Inset And Line Slots

The non-radiating edge of the patch is often carved into a notch for the planar feeding mechanism in an inset-feed patch antenna. Typically, a microstrip line that is coplanar with the patch serves as the feeding mechanism. The slots on the ground plane or on the patch will aid in the development of an antenna with increased bandwidth and effectiveness.

A patch antenna's most basic configuration consists of a ground plane and radiating element that are separated by a dielectric substrate. Equations (1)– (5) are used to compute all of the antenna's dimensions. The Fig 3 depicts the proposed geometry of microstrip rectangular Patch antenna with Inset and Line slots. The Fig. 3 shows the proposed microstrip patch antenna geometry with dimensions (Ws×Ls). The dimensions used have shown in TABLE II and TABLE III.

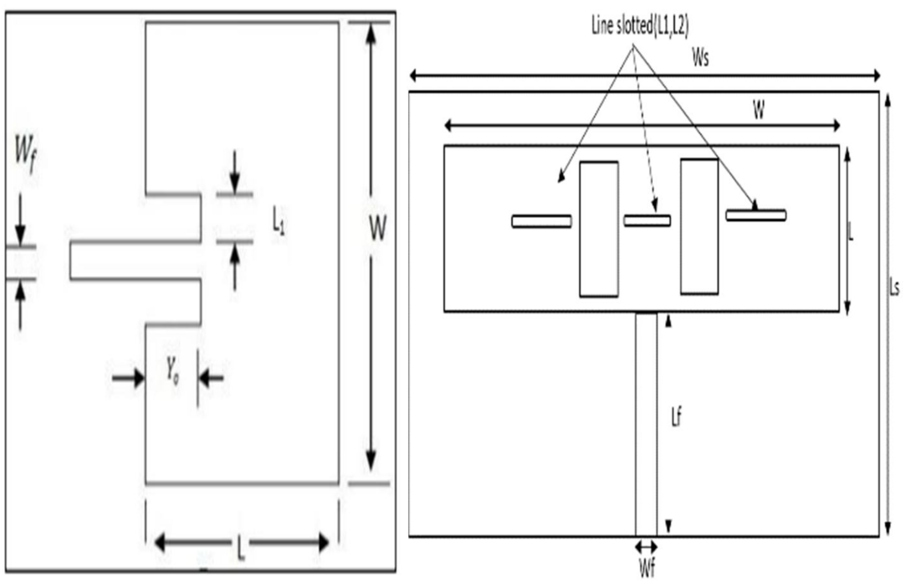

Fig.3 Proposed geometry of microstrip Rectangular patch antenna with Inset Feed and Line slots

We calculate the inset feed gap using the relationship shown below.

$$f_{gap} = \frac{4.65*10^{-8}.c.fr}{\sqrt{2\varepsilon eff}} \quad (6)$$

where f_{gap} is a feed gap

The feed line's size must be determined. We begin determining auxiliary variables a and b by computing the size of a microstrip feed line with characteristic impedance ZC = 50 as follows:

$$a = \frac{Zc}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \frac{\varepsilon r-1}{\varepsilon r+1}(0.23+\frac{0.11}{\varepsilon r})$$

$$b = \frac{60\pi^2}{Zc\sqrt{\varepsilon r}} \quad (7)$$

The following relationships are used to establish the feed line's width and length.

$$Wf = \frac{2}{\pi}\left\{b-1-\ln(2b-1)+\frac{\varepsilon r-1}{2\varepsilon r}\left[\ln(b-1)+0.39-\frac{0.69}{\varepsilon r}\right]\right\}.h \quad (8)$$

$$Lf=3.h \quad (9)$$

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TABLE II : Design parameter for Rectangular Patch with Inset

Antenna Components	Symbol	Dimensions[mm]
Length of ground plane	Lg=Ws	6.20
Width of ground plane	Wg=Ls	8.40
Height of Substrate	h	1.57
Length of Patch	L	2.14
Width of Patch	W	3.66
Length of feeding	Lf	3.10
Width of feeding	Wf	1.26
Inset feed gap	Y0	0.50
Width feed gap	X0	0.68

TABLE III : Design parameter for Rectangular Patch with Line Slot

Antenna Components	Symbol	Dimensions[mm]
Length of ground plane	Lg=Ws	20
Width of ground plane	Wg=Ls	8.04
Height of Substrate	h	0.035
Length of Patch	L	2.75
Width of Patch	W	18.50
Length of feeding	Lf	4.0
Width of feeding	Wf	0.80
Line slot_1 Length	L_ls1	0.10
Line slot_1 Width	W_ls1	1.90
Rectangular slot Length	L_rs	2.35
Rectangular slot Width	W_rs	1.90
Line slot_2 Length	L_ls2	0.10
Line slot_2 Width	W_ls2	1.50

D. Design Of Microstrip Circular Patch Antenna

After rectangular patch antenna, it is a second common shape for microstrip patch antenna. Compared to the rectangular patch antenna, it is considerably smaller.

The expression provided as determines the circular patch antenna's radius.

$$a = \frac{F}{\sqrt{\{1+\frac{2}{\pi \varepsilon r F}[\ln\left(\frac{\pi F}{2h}\right)+1.7726]\}}} \qquad (10)$$

$$\text{where } F = \frac{8.791 * 10^{9}}{fr\sqrt{\varepsilon r}} \qquad (11)$$

In this formula, fr is the resonant frequency in GHz, r is the substrate material's relative permittivity, a is the radius of the circle and F stands for a logarithmic function.

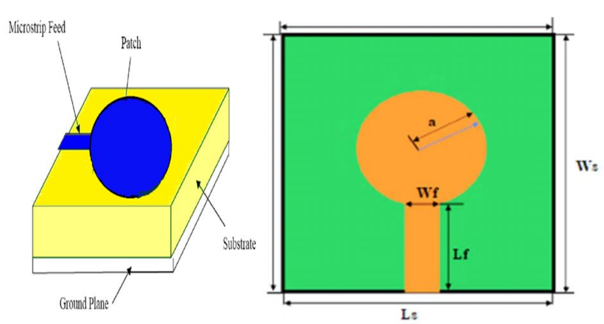

Fig.4 Proposed structure and geometry of microstrip circular patch antenna

The Fig. 4 shows the proposed microstrip Circular patch antenna geometry with dimensions (Ws×Ls). The dimensions used have shown in TABLE IV.

TABLE IV : Design parameter for Circular Patch

Antenna Components	Symbol	Dimensions[mm]
Length of ground plane	Lg=Ws	17
Width of ground plane	Wg=Ls	10.55/10.88
Height of Substrate	h	0.508
Length of Patch	L	18
Width of Patch	W	17
Length of feeding	Lf	7.03
Width of feeding	Wf	1
Radius of Circular Patch	a	5

III. DESIGN METHODODLOGY

The design methodology is proposed is represented in Fig 5 and is explained in follow steps.

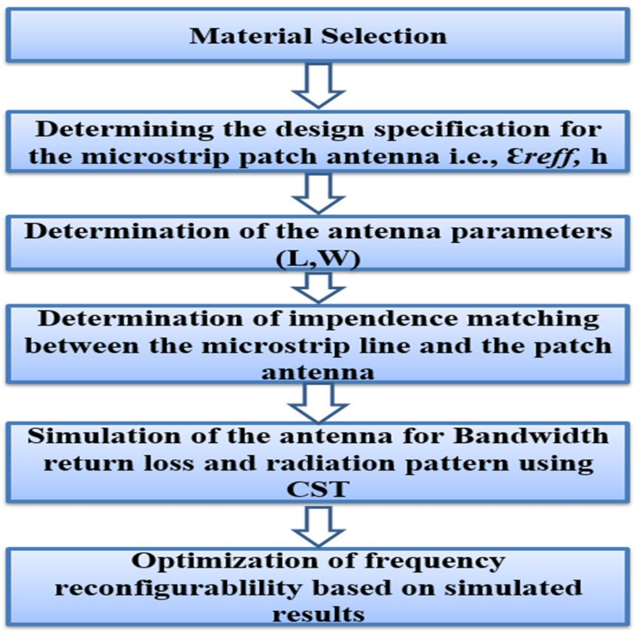

Fig. 5: Proposed Design Methodology

The first step in designing a Microstrip patch antenna is to select a substrate with a lower dielectric constant than necessary since this will increase the radiation efficiency. Furthermore, thicker substrates provide a wider bandwidth. As a result, we have selected RT/Duroid 5880 substrate material, which has a dielectric constant of 2.2 with substrate thickness with respect to antenna model. Second the most important step of the design is determination of the parameters of the patch antenna, which is explained in terms of equation in Section 2. Choosing the resonant frequency from the 5G frequency spectrum, which ranges from 26 GHz to 38 GHz, is the third and most crucial part of the design process. We have chosen 28 and 38 GHz from this range since we felt it was better and more beneficial for 5G wireless communication. Simulation of the antenna for Bandwidth return loss and radiation pattern using CST.

A. *Implementation Of Microstrip Patch Antenna*

The implementation is done by CST software, which is better for time domain based simulations. Fig 6 depicts the implemented structure of Rectangular patch antenna, taking Roggers RT Duroid 5880 as substrate having 2.2 dielectric constant. Our proposed antenna uses line feeding technique. The parameters are calculated by the equation 1 to 5, and dimensions are prescribed in Table I.

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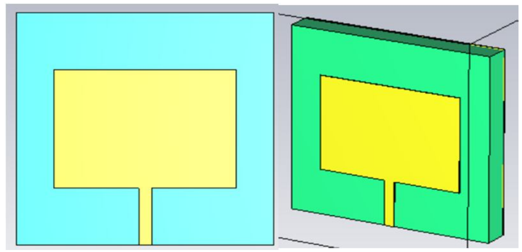


Fig 6: Front and Tilted view of Rectangular Patch antenna

Fig 7 depicts the inset feed for rectangular patch, which dimensions are tabulated in Table II. The substrate is used is roggers RT Duroid 5880 of thickness is 1.57.

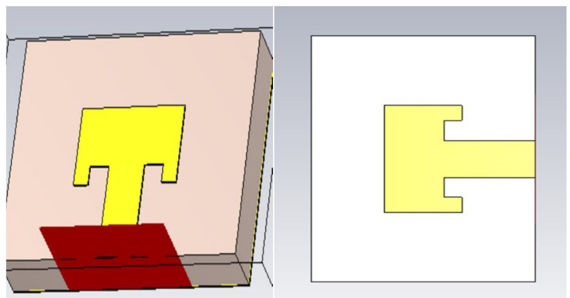


Fig 7: Front and Side view of Rectangular Patch antenna with Inset

Fig 8 depicts the Slotted rectangular patch antenna for 5G frequency bands, which is useful for wireless system. The dimensions are tabulated in Table III. Which has the dielectric constant of 2.2, Substrate thickness is 0.035. Our proposed model, we implemented wave guide ports, which provide a unique type of boundary condition for the computation domain. Infinitely long waveguides connecting to the structure are simulated by this type of port. Leaving the computing domain with extremely low levels of reflections are the waveguide modes as they move away from the structure and approach the boundary planes.

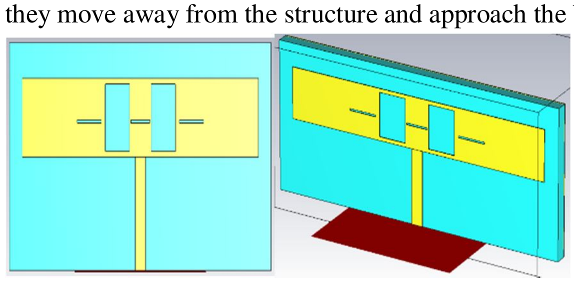
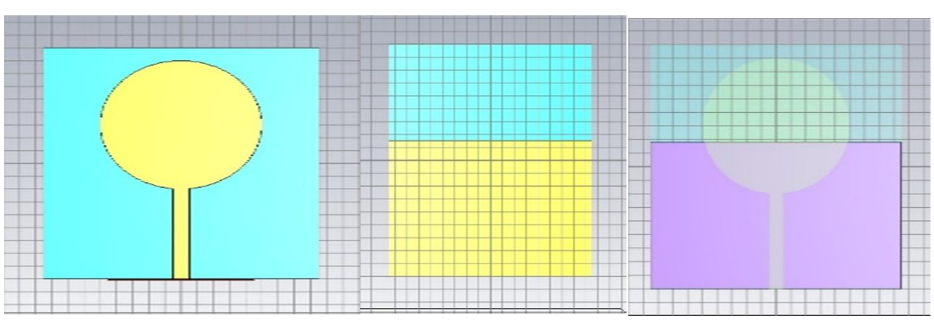


Fig 8: Front and Tilted view of Rectangular Patch antenna with Line slots

Fig 9 describes the implementation of circular patch antenna, which can be resonant at 28GHz and 38GHz, the dimensions are tabulated in Table IV, fig 9(a) front view, it is same for both frequencies, only ground value will be change.



(a)Front view for 28GHz (b) Back side for 28GHz (c) Back side 38 GHz &38 GHz
Fig 9: Front and Back view of Circular Patch antenna for 28GHz and 38GHz

IV. SIMULATION RESULTS AND ANALYSIS

A. Return Loss

The reflection coefficient, another name for the return loss, is represented by the symbol (S11). It is a major necessity for 5G communication. Essentially, it is a measured in decibel(dB), ratio of an antenna's incident power to its reflected power (dB). For optimal performance, the antenna's reflection coefficient should be at least -10 dB or more than -15 dB. An antenna performs better the lower the reflection coefficient. For instance, nothing has radiated if the reflection coefficient is 0 dB since the antenna has reflected all of the power.

As a result, as shown in Fig. 10, our suggested antenna Microstrip patch antenna has a reflection coefficient of -18.96 dB at 26.9 (~28GHz) GHz. Fig. 11 shows the result of microstrip patch antenna with Inset has the reflection coefficient of -32.190 at 26.73 GHz. Fig. 12 shows the result of microstrip patch antenna with Line Slots has the reflection coefficient of -49.80 at 28 GHz. Fig. 13 shows the result of microstrip circular patch antenna has the dual resonating reflection coefficient of -12.97 at 28 GHz & -10.87 at 22.57 GHz. Fig. 14 gives the result of microstrip circular patch antenna has the reflection coefficient of -12.97 at 37.5 GHz.

So, with relatively little energy, maximum power is sent to the antenna

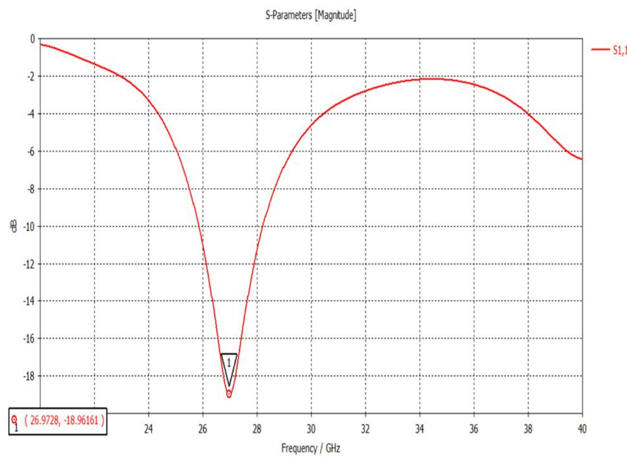


Fig 10: Graph of Return Loss for rectangular microstrip patch antenna

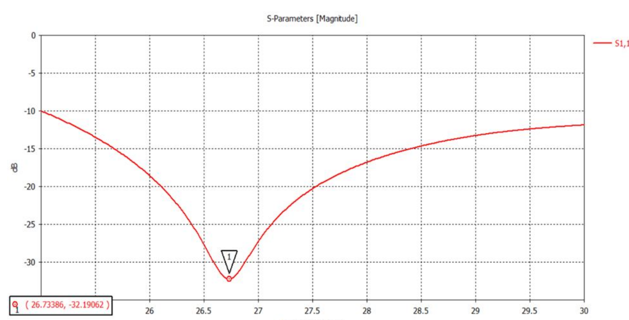


Fig 11: Graph of Return Loss for rectangular microstrip patch antenna with Inset

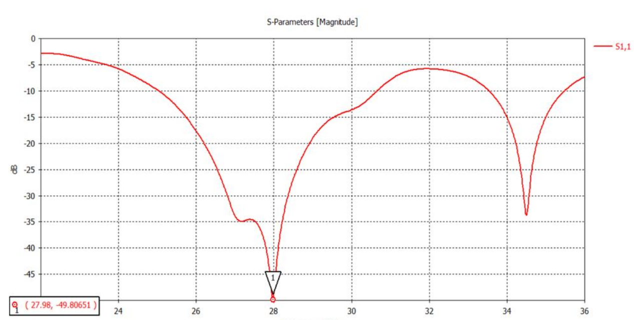


Fig 12: Graph of Return Loss for rectangular microstrip patch antenna with Line slots

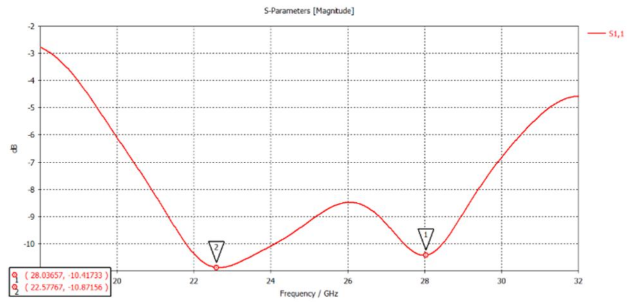


Fig 13: Graph of Return Loss for circular microstrip patch antenna for 28 GHz

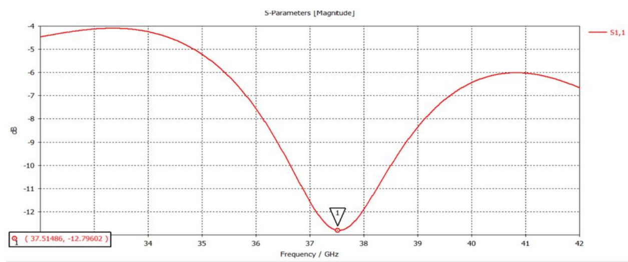


Fig 14: Graph of Return Loss for circular microstrip patch antenna for 37.51(~ 38) GHz

B. Voltage Standing Wave Ratio

It is also known as the standing wave ratio (SWR). It denotes the antenna's ability to reflect power and its impedance-matching with the transmission line. This ratio is always real and positive when taking antenna design into account. For 5G requirements, the value of VSWR should be 1≤VSWR≤2, ensuring that all power is radiated rather than being reflected. For instance, if the VSWR is more than 2, we might conclude that the antenna is not adequately matched to the desired frequency.

As can be seen from Fig. 14, the VSWR value of our suggested microstrip patch antenna is 1.25 at 26.9 GHz. Fig. 15, the VSWR value of microstrip patch antenna with inset is 1.05 at 26.74 GHz, Fig. 16, the VSWR value of microstrip patch antenna with line slots is 1.01 at 28 GHz, Fig. 17, the VSWR value of circular microstrip patch antenna is dual band of 1.86 at 28 GHz and 1.80 at 22.87 GHz, Fig. 18, the VSWR value of circular microstrip patch antenna is 1.25 at 26.9GHz, Fig. 14, the VSWR value of our suggested microstrip patch antenna is 1.25 at 26.9GHz, Fig. 14, the VSWR value of our suggested microstrip patch antenna is 1.59 at 37.5GHz, which satisfies the criteria for 5G applications.

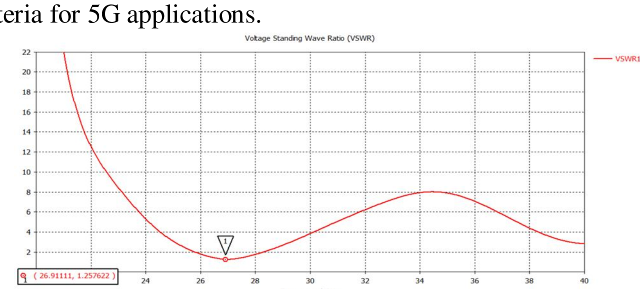


Fig 14: Graph of voltage standing wave ratio for rectangular microstrip patch antenna

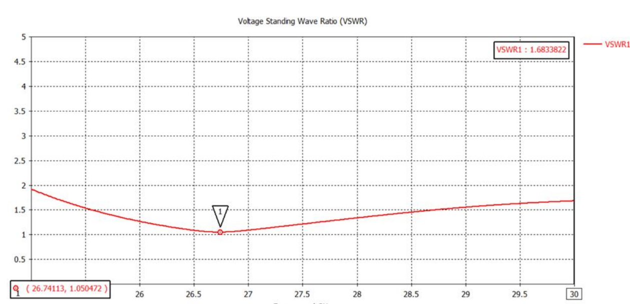


Fig 15: Graph of voltage standing wave ratio for rectangular microstrip patch antenna with Inset

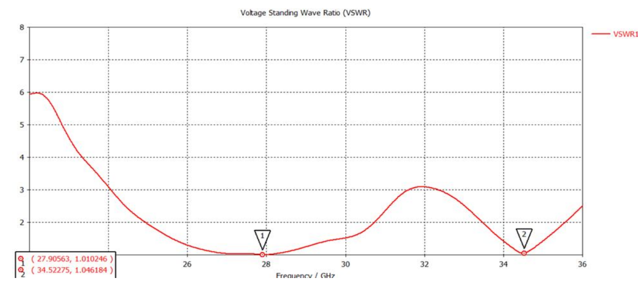


Fig 16: Graph of voltage standing wave ratio for rectangular microstrip patch antenna with Line Slots

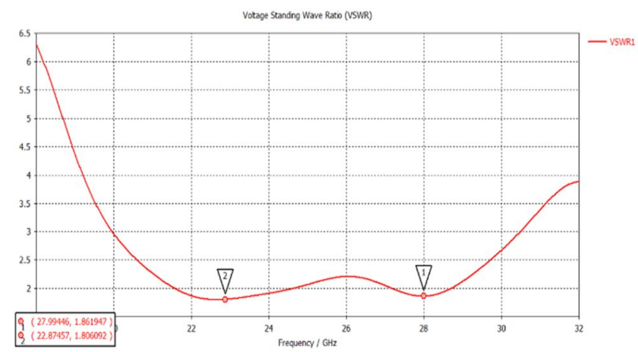


Fig 17: Graph of voltage standing wave ratio for circular microstrip patch antenna for 28GHz

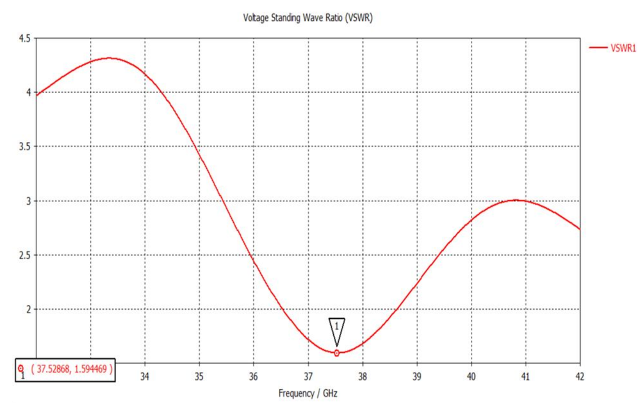


Fig 18: Graph of voltage standing wave ratio for circular microstrip patch antenna for 37.5 (~38) GHz

C. Radiation Patterns with Gain

The Gain of an antenna displays its efficiency as well as its directional capabilities, while the Radiation Pattern shows how much energy it radiates. High gain is necessary for the antenna to perform well. High gain antennas also have a restricted radio beam. When used for long-distance wireless communication, like 5G, this beam strengthens the signal, enabling extremely high data speeds.

A beam's width is essentially the angle of an aperture through which the most energy is emitted. It demonstrates that an antenna has a strong resolution capacity when comparing two sources that are separated by half of the first null beam width. Antenna radiation efficiency, which describes how well an antenna transmits and receives RF signals, is another important need for 5G applications. It is the ratio of the total power received as input to the total power emitted by an antenna, to put it another way. In high radiation efficiency antennas, the input power is effectively radiated into space, whereas in low radiation efficiency antennas, the input power is often lost owing to a variety of internal losses such as magnetic losses, dielectric losses, metal conduction, etc. within the antenna.

As a result, we obtain a high Gain of 7.88 dBi, as seen in the 1D & 3D radiation pattern in Fig. 19. As a result, we obtain a high Gain of 5.44 dBi, as seen in the 1D & 3D radiation pattern in Fig. 20. As a result, we obtain a high Gain of 7.58 dBi, as seen in the 1D & 3D radiation pattern in Fig. 21. As a result, we obtain a high Gain of 3.68 dBi, as seen in the 1D & 3D radiation pattern in Fig. 22. As a result, we obtain a high Gain of 5.57 dBi, as seen in the 1D & 3D radiation pattern in Fig. 23.

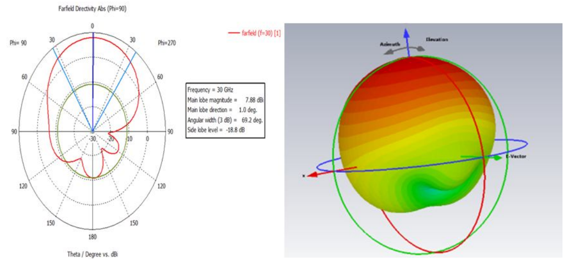


Fig 19: Graph of 1D & 3D radiation pattern for rectangular patch antenna

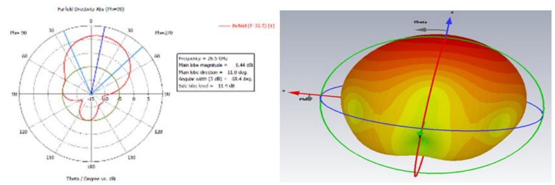


Fig 20: Graph of 1D & 3D radiation pattern for rectangular patch antenna with Inset

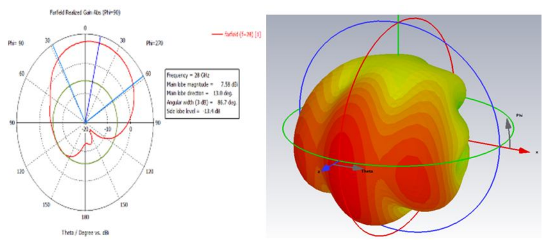


Fig 21: Graph of 1D & 3D radiation pattern for rectangular patch antenna with Line Slots

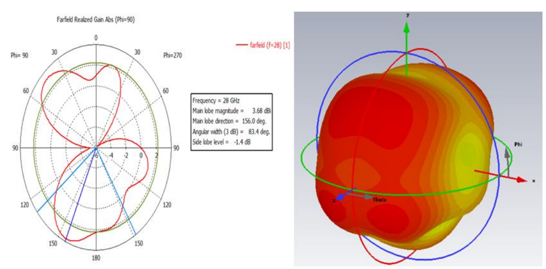


Fig 22: Graph of 1D & 3D radiation pattern for circular patch antenna for 28GHz

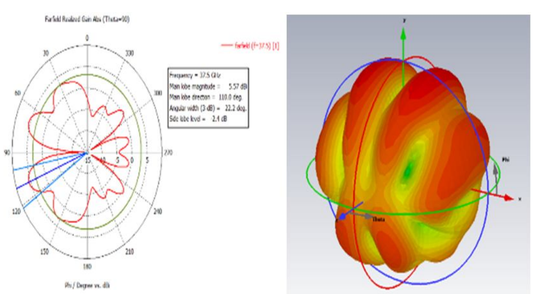


Fig 23: Graph of 1D & 3D radiation pattern for circular patch antenna for 37.5 GHz

D. Surface Current Density Distribution On Antenna

The Fig. 24 to Fig 27 shows how the current is getting distributed on antenna which is good for efficient radiation on antenna. The radiation pattern is based on the distribution of current along an antenna. The antenna polarization is reflected in the direction of net current flow when it is mostly in that direction. When currents flow one way on one section of an antenna and the other way on another section, they cancel each other out in terms of radiation directed towards the viewer (assuming they are in the same plane).

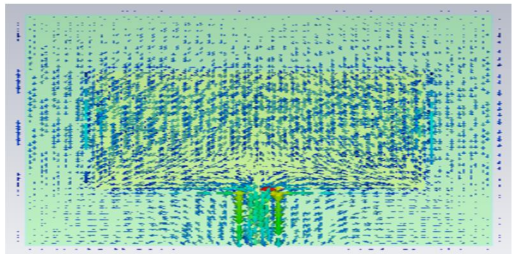


Fig 24: Graph of current density distribution of microstrip patch antenna

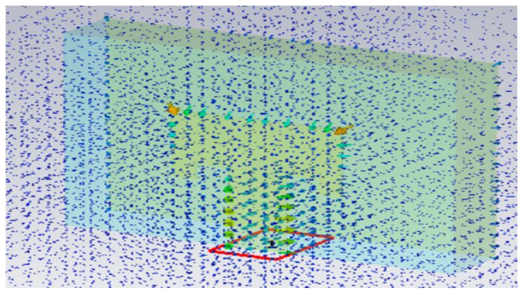


Fig 25: Graph of current density distribution of microstrip patch antenna with Inset

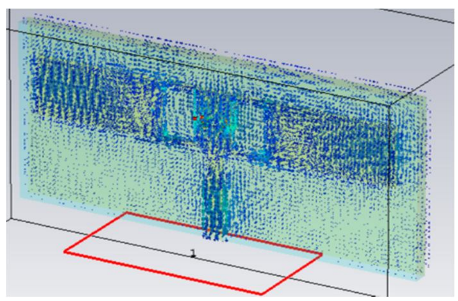


Fig 26: Graph of current density distribution of microstrip patch antenna with Line Slots

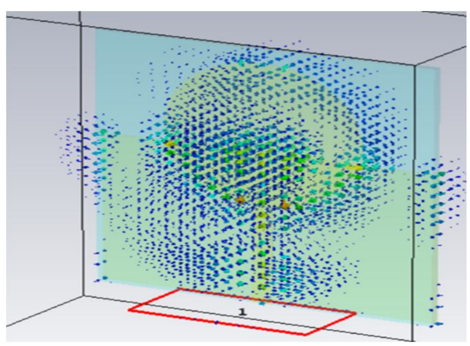


Fig 27: Graph of current density distribution of Circular microstrip patch antenna I

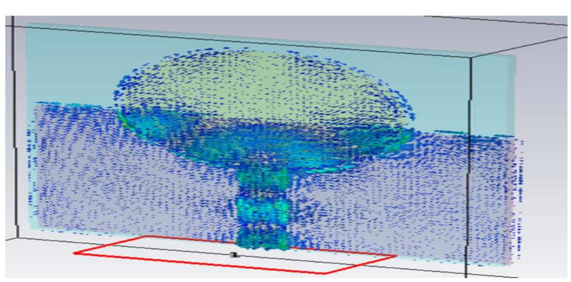


Fig 27: Graph of current density distribution of Circular microstrip patch antenna II

V. CONCLUSION AND FUTUREWORK

In this study, a proposed microstrip rectangular and circular patch antenna for forthcoming 5G applications was developed and constructed utilizing CST software with resonance frequencies ranging from 26 to 38 GHz. The designed antenna has higher gain, good signal strength, increased bandwidth for accessing, sharing, or downloading 8K ultra-high-definition (UHD) content, good return loss, required voltage standing wave ratio for efficient transmission of radio frequency power, and finally excellent antenna radiation efficiency of almost 100%, which is most important for 5G applications. Table V gives comparison of various proposed antenna un detail.

The future scope is to obtain better bandwidth and gain by configuring antenna with array elements.

TABLE V : Comparison of various proposed antenna

Measurements of the Performance	Antenna 1: Microstrip Rectangular patch antenna	Antenna 2 : Microstrip Rectangular with Inset	Antenna 3: Microstrip Rectangular with line slots	Antenna 4: Circular patch antenna(I)28GHz	Antenna 5: Circular patch antenna (II) 38 GHz
Center Frequency	26.9 (~28) GHz	26.7(~28) GHz	28 GHz	28 GHz	37.5(~38)GHz
BW VSWR ≤ 1.25 VSWR ≤ 1.5 VSWR ≤ 2	NA 1.423 GHz 2.390 GHz	1.6843GHz 3.25GHz 2.69GHz	2.93GHz 4.27GHz 5.73GHz	NA NA 1.6305GHz	NA NA 2.058GHz
Relative BW	11.71%	10.4%	4.88%	17.17%	18.46%
Gain	7.88 dBi	6.44 dBi	7.58 dBi	3.68 dBi	5.57 dBi

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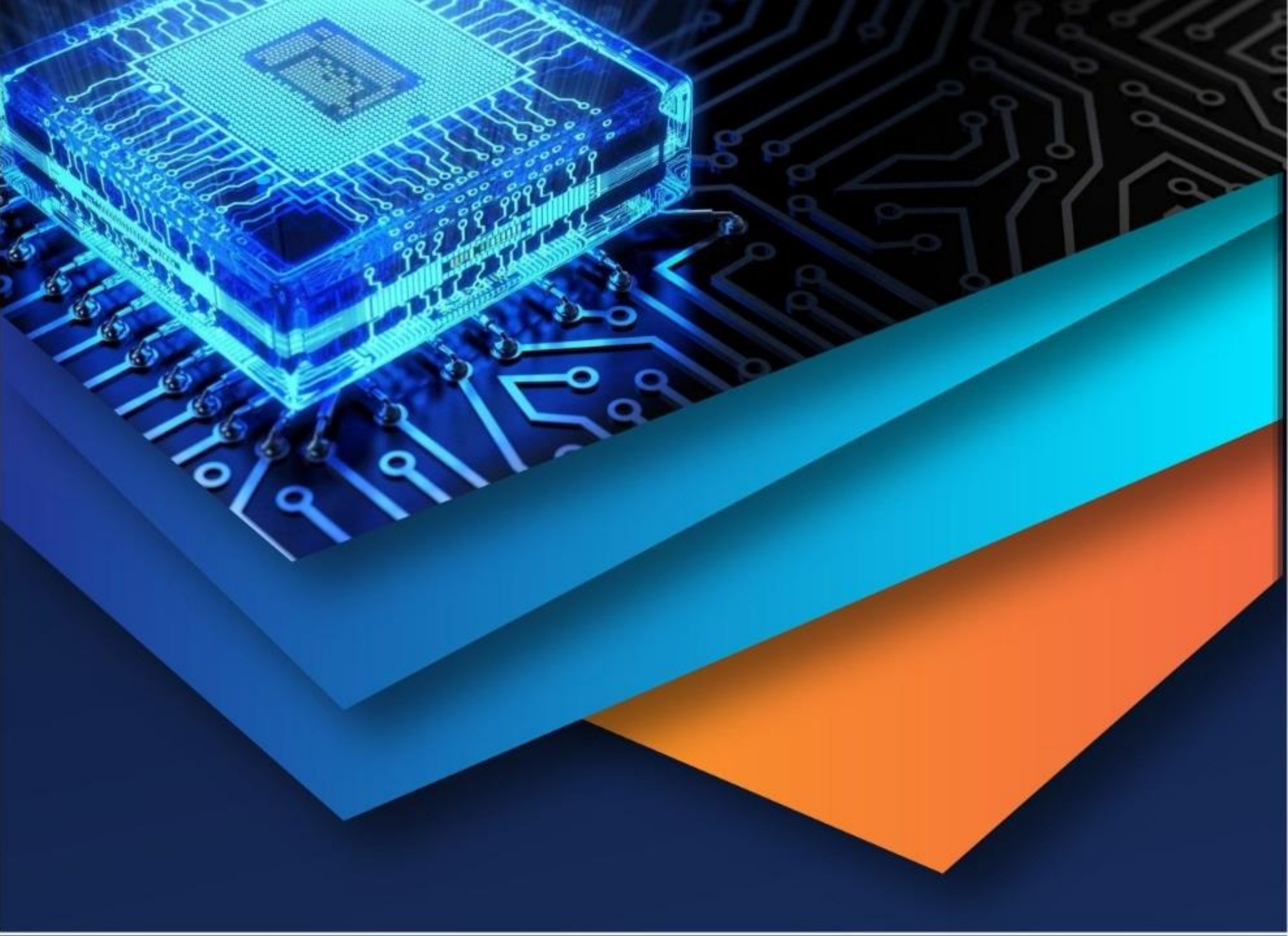

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