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Design and Analysis of 5G Broadband Elliptical Cut Octagon Patch Antenna

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ABSTRACT- In this paper, a 5G Broadband Elliptical Cut Octagon Patch Antenna is designed whose operating frequency band is from 20.82- 22.95GHz, 25.13-28.46GHz. In this antenna, FR4 substrate whose dielectric constant is 4.4 and loss tangent (tan δ) is 0.002 is utilized as substrate. This antenna has a compact size of 15×25×1.6mm^3 and has a radiation efficiency of 92.1%. In order to increase the band of frequency of an antenna, two similar elliptical cut octagon patches are added to form a Broadband Antenna. The resultant microstrip patch antenna is a 5G Broadband Elliptical Cut Octagon Patch Antenna.

General Terms: Microstrip patch antenna, 5G Networks, Wireless communication, Broadband antenna.
Keywords: High Frequency Structure Simulator (HFSS), Millimeter wave, Subminiature version A (SMA), Flame Retardant (FR4), Fifth generation (5G), extreme reality XR

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1. INTRODUCTION

In the present world, the deployment of 5G is booming in many nations, especially to the incessant infrastructure development by service providers. 5G wireless technology aims to provide more users with a consistent experience, better peak data rates (multi-Gbps), enormous network capacity, ultra-low latency, good reliability and high availability. 5G will open up new sectors to the mobile ecosystem. This will help bring forth state-of-the-art user experiences like limitless extreme reality XR, smooth IoT capabilities, new business apps, local interactive content, and immediate cloud access, among many other things. International Telecommunication Union (ITU) has allocated frequency range of K band as 18 to 27GHz and Ka band as 27 to 40GHz. The Department of Telecommunications (DoT) has announced that the frequency range of 24.25 to 28.5 GHz will be utilized for IMT/5G [1].

5G frequency bands 600 MHz (n71), 700 MHz (n28), 800 MHz (n5), 900 MHz (n8), 1,800 MHz (n3), 2,100 MHz (n1), 2,300 MHz (n40), 3,300 MHz, 3,500 MHz, and 26 GHz have been put up for sale by the Department of Telecommunications (DoT). The lower-band, middle-band, and upper-tier millimeter-wave frequencies that are compatible with 5G in India are listed in table below.

Table 1. List of Supported 5G Bands in India [2]

5G bands	Frequency Allocated
n71	600MHz
n28	700MHz
n5	800MHz
n8	900MHz
n3	1800MHz
n1	2100MHz
n40	2300MHz
n41	2500MHz
n78	3300MHz – 3800MHz
n77	3300MHz – 4200MHz
n79	4400MHz – 5000MHz
n258	26GHz (24.25MHz - 27.5 GHz)
n257	28 GHz (26.5MHz - 29.5 GHz)
n261	28 GHz (27.5MHz - 28.35 GHz)

Frequency Bandwidth 27.5GHz to 29.5GHz is used for Mobile & Fixed Satellite Applications. Aperture antennas Bowtie, hourglass, H and rectangle were discussed for the integration of a suspended rectangular patch and an epoxy glass substrate [3]. The researchers proposed strips with arc shape [4] and split ring complimentary resonator [5] with band notched characteristics in order to increase the gain along with radiation efficiency. The Researchers have discussed and proven Multilayer Patch Antennas [6] increases efficiency. To increase the gain several methods can be used by creating a slot in patch of antenna can increase the gain [7] [8]. A rectangular patch microstrip antenna [9] which is slotted has designed to reach the increased need for 5G mobile communication services. A 5G network 30GHz square patch microstrip antenna with high gain, better VSWR and good bandwidth, good radiation efficiency is designed [10]. An upgraded ground plane back side and an f-shaped radiating monopole is the new broadband circularly polarized (CP) monopole antenna that is suitable for broadband applications is designed [11]. A novel dual-band circularly polarized (CP) monopole antenna that utilizes coplanar-waveguide feeding to generate wide dual-band axial ratio bandwidth (ARBW) along with impedance bandwidth (IBW) is presented which features half-elliptical and rectangular slots [12]. Researchers discussed different shaped broadband antennas like Wheel-shaped miniature wideband microstrip antenna, L1-slotted microstrip patch antenna, TMPA with and without Tap shaped DGS [13-15].

2. ANTENNA DESIGN PROCEDURE

To design an Elliptical cut octagon antenna, first the patch radius is calculated using the following *equation (1)* [16].

$$r = \frac{F}{\{1 + \frac{2h}{\varepsilon_r \pi F}\left(\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right)\}^{1/2}} \qquad (1)$$

Where,

$$F = \frac{8.791 * 10^9}{f_c\sqrt{\varepsilon_r}} \qquad (2)$$

The patch becomes larger electrically due to fringing effect. Hence, the effective patch radius is chosen and it is given by

$$r_e = r\{1 + \frac{2h}{\varepsilon_r \pi F}\left(\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right)\}^{1/2} \qquad (3)$$

Here ε_r - Substrate Dielectric constant, h- Substrate Height, f_r - Resonant frequency, *r*- Patch Radius, r_e-Effective Radius.

The intended resonant frequency of the proposed antenna design is fr =22 GHz. The antenna that has been suggested is built on FR4 substrate, which has a relative permeability of ε_r = 4.4 and a height of h =1.6mm. The above equations are updated using these values. The result of this substitution is an operating frequency of 26.6 GHz with a radius of 1.75 mm. In order to get more gain, the parametric analysis is carried out for radius. The chosen radius is 3.6 mm since it has produced satisfactory results. Parametric analysis is carried out not only for radius, for parameters such as thickness and length variation of feed line. By increasing feed line width and length its efficiency its gain and efficiency is reduced. Only for the parameters which are shown in table II this antenna finally acquired good results.

3. ANTENNA GEOMETRY

3.1. 5G Broadband Elliptical Cut Octagon Patch Antenna

A monopole octagon patch antenna features a radius 3.6mm whose dimensions are 15×25×1.6mm^3. A microstrip patch antenna is formed by sandwiching FR4 substrate between the ground and patch whose dielectric constant is 4.4 and height of 1.6mm. First an octagon of radius 3.6mm is chosen based on parametric analysis carried out in HFSS. An elliptical slot is created on top side of octagon in order to increase the gain. The resultant shape is an Elliptical cut Octagon patch. Two more Elliptical cut Octagon patches are added to the design. On the right side, one is superimposed and on the left side, another one. The adding of these two octagons increases the bandwidth. In order to get good VSWR and to increase the Bandwidth two rectangular slots are created. One rectangular slot L1 is created on left side of center antenna patch whose length is 2mm and width is 0.1mm. Another rectangular slot L2 is created on the middle of left side patch with length 1.41mm, width 0.1mm and tilted angle of 4^0.

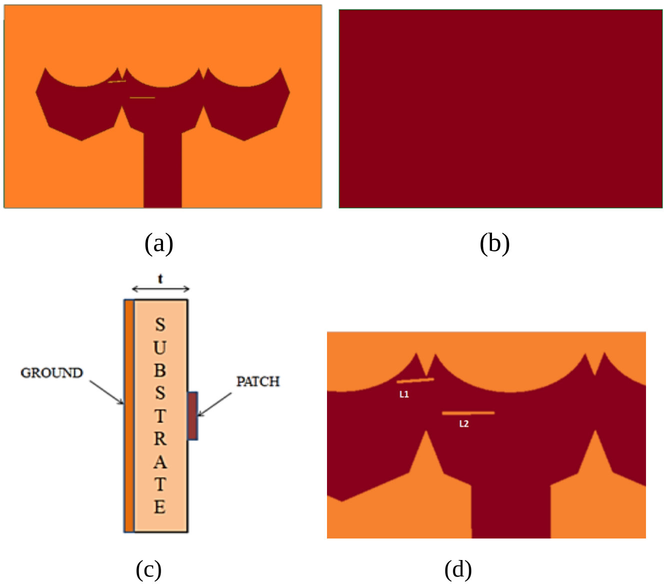


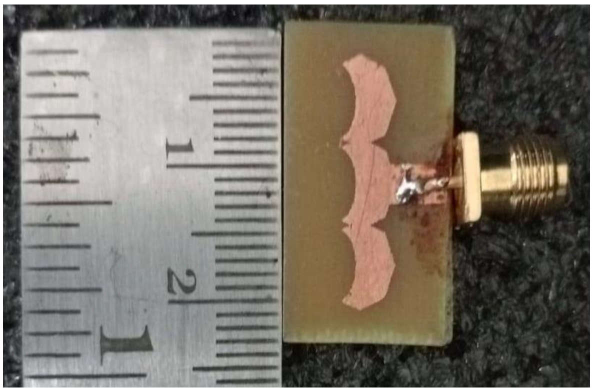
Figure 1. Broadband Elliptical Cut Octagon Patch Antenna (a) Top view (b) Back view (c) Side view (d) Rectangular slots L1, L2

Table 2. Broadband Antenna Parameters

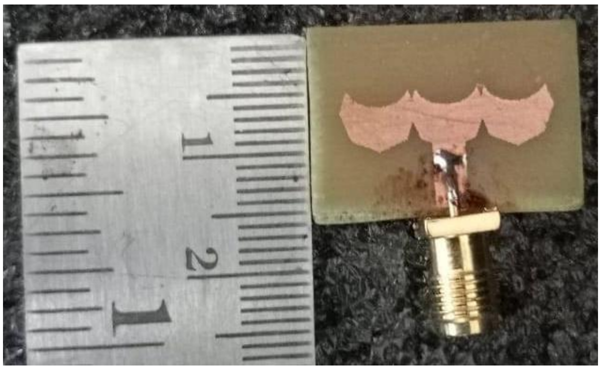
Parameters	Dimension(mm)
Ground Width (W)	25
Ground Length (L)	15
Dielectric constant of the substrate (ε_r)	4.4
Feed Line Width (W_f)	3
Feed Line Length (L_f)	5.6
Substrate Width (W_s)	25
Substrate Height (h)	1.6
Substrate Length (L_s)	15
Octagon Radius (r)	3.6mm
Slot Width	1.41mm
Slot Height	0.2mm

The electrical conductivity and these antenna characteristics are subsequently input into the validation-focused Finite Element Method (FEM) version of Ansoft's High Frequency Structure Simulator (HFSS). An octagon patch antenna with a single layer of elliptical cuts is proposed and tested in HFSS according to the antenna geometry.

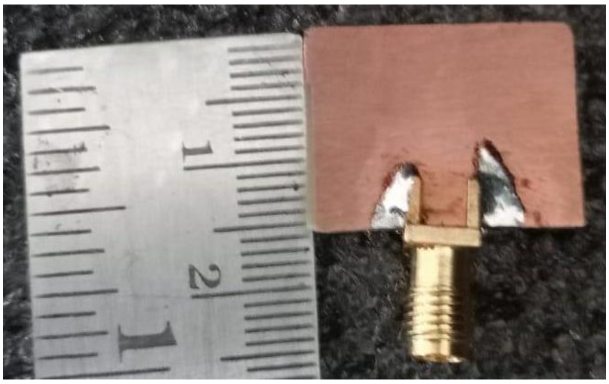
Printing the Single Layer Elliptical cut octagon patch requires exporting the HFSS model to a Gerber file, which is then sent to the printer along with the substrate and the distances between the nozzles [17]. The next step is to apply thermal curing, and then feed. Later solder SMA connector to the microstrip antenna's transmission line feed [18] [19]. In the next phase, the patch is soldered to the inner conductor of the coaxial cable, and the ground plane is soldered to the outer conductor [20]. The fabricated broadband elliptical cut octagon patch antenna is shown below and its dimensions are compared with scale.



(a)



(b)



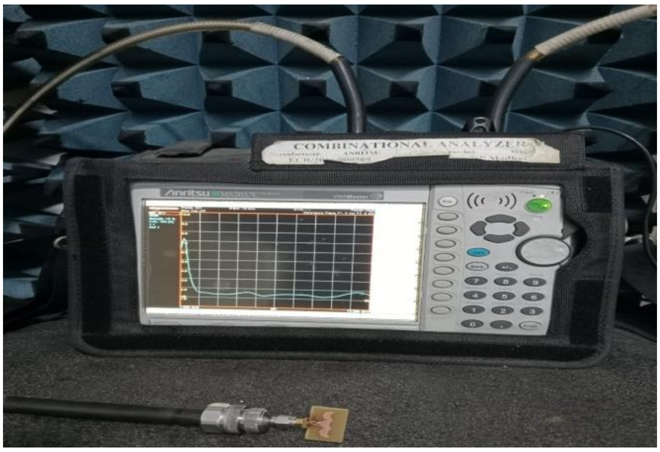
(c)

Figure 2. Fabricated Broadband Elliptical Cut Octagon Patch Antenna Measurements (a) Length (b) Width (c) Ground

4. RESULTS AND DISCUSSION

A Vector Network Analyzer (VNA) is employed to measure $S11$ and VSWR [21]. A short 50Ω load-open circuit caliper kit is employed to calibrate the VNA [22]. The test is carried out in the frequency range of 20 GHz to 30 GHz. Figure 3 depicts the antenna mounted on a foam box to prevent near-field interactions and the 50 Ω coaxial cable that feeds it to the VNA.

(a)



(b)

Figure 3. Measurement of $S11$, VSWR by utilizing a Vector Network Analyzer

Table 3. 5G Broadband Elliptical Cut Octagon Patch Antenna Results

Parameters	Results
Operating Frequency	20.82-22.95GHz, 25.13-28.42GHz (21.5GHz, 22GHz, 26GHz, 28GHz)
Bandwidth	2.13GHz, 3.33GHz
Gain	8.5dB
Radiation Efficiency	92.1%
VSWR	1.01, 1.16, 1.04
Return Loss	-25.41dB, -23.42dB, -24.23dB
Front To Back Ratio	10.19
VSWR	1.01, 1.16, 1.04

The return loss of -25.41dB, -23.42dB, -24.23dB and gain of 6.29dB, 7.5dB, 4.61dB, 1.5dB are achieved by this Single Monopole Elliptical cut octagon patch antenna respectively. This 5G Broadband Elliptical Cut Octagon Patch Antenna attained a radiation efficiency of 92.1%. The results of various parameters of 5G Broadband Elliptical Cut Octagon Patch Antenna are shown in *table 3*.

This Single Monopole Elliptical cut octagon patch antenna's simulated and measured Return loss, VSWR, radiation pattern's graphs are shown in *figure 4, 5, 6*.

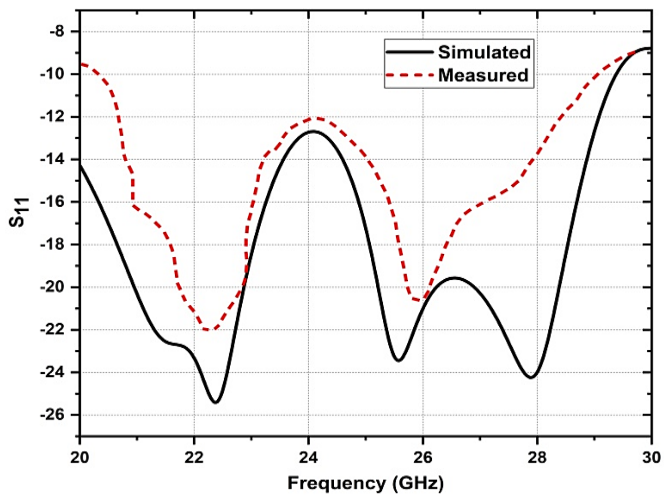


Figure 4. Broadband Antenna Return Loss

The Single Monopole Elliptical cut octagon patch antenna's simulated and measured Return Loss graph is shown above. This antenna is operated from 20.82-22.95GHz and 25.13-28.42GHz. For this operating frequency the simulated and measured VSWR is between 1 and 2 which is shown in the *figure 5*.

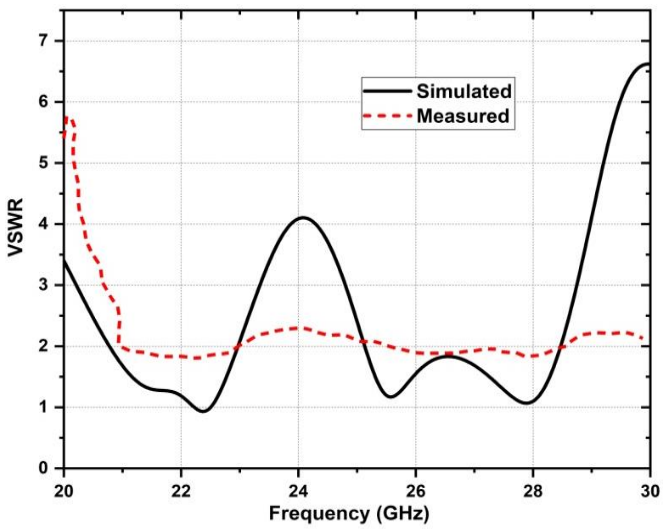
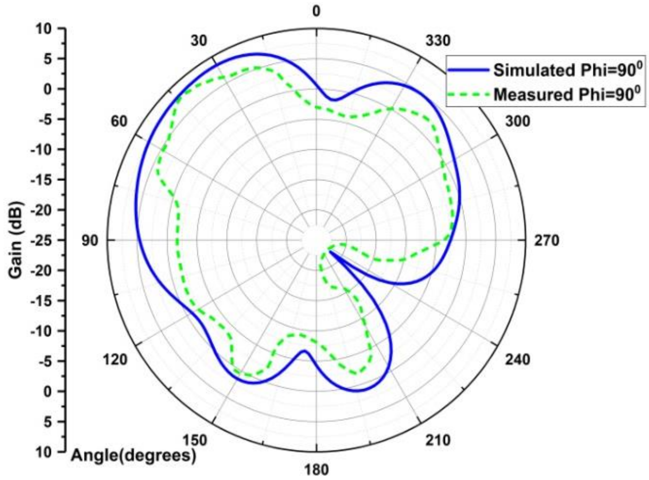
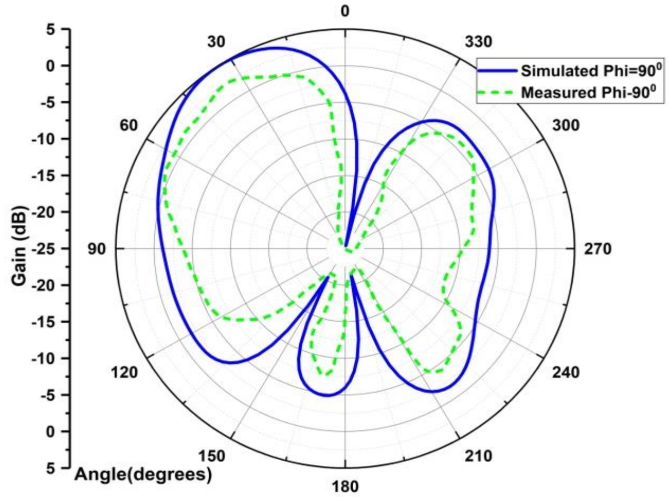


Figure 5. Broadband Antenna VSWR

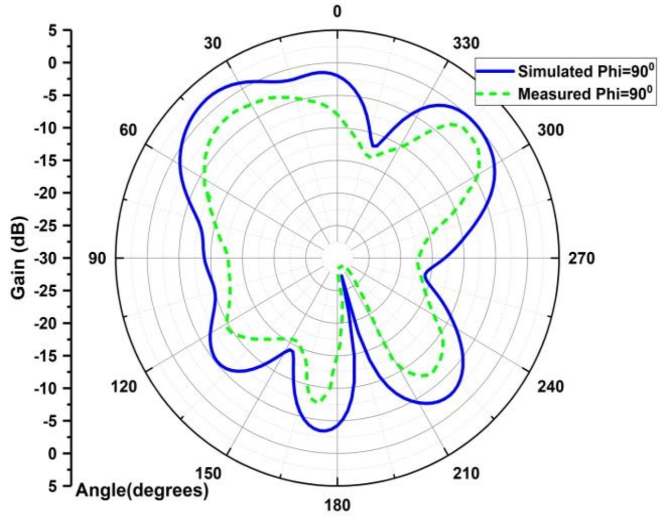
The simulated and measured Radiation Plots at 22.37GHz, 25.5GHz and 27.88GHz are shown in *figure 6*.



(a) 22.37GHz Radiation Plot



(b) 25.5GHz Radiation Plot



(c) 27.88GHz Radiation Plot

Figure 6. Broadband Antenna simulated and measured Radiation Plots

Table 4. Comparisons of Proposed Antenna Designs with Previous Antenna Designs

Antenna Design	Operating Frequency (GHz)	Return Loss S11 (dB)	VSWR	Bandwidth (GHz)	Gain (dB)	Efficiency %
Circular microstrip antenna [23]	632MHz – 1142MHz	-18 dB	Within 1-2	510MHz	5.5dB	85%
Cow-head-shaped MIMO antenna [24]	3.3GHz -5.0GHz	-47dB	Within 1-2	1.7GHz	4.6dB	91%
Triband Slot Antenna [25]	2.24GHz, 2.97GHz, 3.66GHz	-45dB	Within 1-2	1.4GHz	3.29dB	90%
Reconfigurable dual-band microstrip antenna [26]	2.4GHz 2.6GHz	-16.41 dB -18.09 dB	Within 1-2	100MHZ	6.98dB	-
S-band microstrip antenna [27]	3.5GHz	-50.4227	1.0061	0.1221 GHz	7.43dB	-
Triband Compact Antenna [28]	3GHz, 6GHz, 7GHz	-29.64, -26.37 -27.58	Within 1-2	400 MHZ, 490 MHZ, 420 MHZ	2.79dB, 2.51dB 2.64dB	-
Reconfigurable key-shape antenna [29]	1.9GHz, 2.4GHz, 3.1GHz	-19.2	Within 1-2	1.8 GHz -2.6 GHz	2.5dB	-
Multibeam slot antenna [30]	2.4GHz, 2.9GHz, 3.3GHz	-40	Within 1-2	2.18–3.55 GHz	8.02dB	-
Proposed Broadband Antenna	20.82- 22.95GHz, 25.13-28.46GHz (22.37GHz, 25.5GHz, 27.88GHz)	-25.41dB, -23.42dB, -24.23dB	1.01, 1.16, 1.04	2.13GHz, 3.33GHz	8.5dB	92.1%

Compared to Antennas in References from [23-30] proposed antenna attained greater overall bandwidth of 5.46GHz with a gain of 8.5dB. So, this antenna has achieved high bandwidth and high gain when compared to other antennas which are shown in table IV. Without feedback network and by combining slots of different modes bidirectional radiation with higher gain to area ratio can be obtained [31, 32].

5. CONCLUSION AND FUTURE SCOPE

5G Broadband Elliptical Cut Octagon Patch Antenna operating at frequency of 20.82- 22.95GHz, 25.13-28.42GHz and its gain of 8.5dB respectively and radiation efficiency of 92.1% is designed. This antenna attained return loss of -25.41dB and an overall bandwidth of 5.46GHz. This antenna is best useful for Inter-Satellite communication, Mobile & Fixed Satellite communication and Inter-satellite communication applications apart from 5G applications.

In future this antenna's bandwidth, gain, efficiency can be increased by introducing new techniques. By incorporating multiple shaped slots or different shapes various parameters can be enhanced. Especially by using different dielectric materials like Duroid, Megtron etc. the radiation efficiency can be increased. MIMO design of this antenna can increase the directivity, bit rate thereby speeds increases.

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