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Multiband Elliptical Patch Octagon Antenna With And Without Proximity Coupling

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Abstract: This paper presents a novel multiple-band elliptical patch octagonal antenna with and without proximity coupling. The frequency bandwidth and the requirement for high data throughput are always on the rise with today'swireless communication systems and therefore, multiband antennas are highly essential. A new elliptical patch octagon arrangement is proposed for use in this case as the efficiencies gained in using this form of an antenna are that it is capable of operating on multiple bands. Multi-band Elliptical Patch Octagon Antenna with and without Proximity Coupling of dimensions 15×25×1.6 mm^3 is designed. A single-layer antenna operates at multiple frequencies from 10GHz to 300GHz, whereas a multi-layer antenna operates at 10GHz to 500GHz. For a sample at 28GHz, a Single-layer elliptical patch octagon antenna without proximity coupling antenna earned return loss (s11), gain and radiation efficiency of -21.38dB, 5.03dB and 90%, respectively. In order to enhance the bandwidth and gain of an antenna, a two-layer elliptical patch antenna with proximity coupling is designed whose return loss, gain and radiation efficiency are -24.5dB, 8.81dB and 88.69% at 29GHz frequency, respectively. The substrate employed for these two antennas is FR4, with a dielectric constant of 4.4 and a loss tangent (tanδ) of 0.002. Overall, this study provides a greater understanding of how proximity coupling influences the operation of multiband antennas, thereby paving the way to enhance the design and practical utilization of multiband antennas in today's wireless communication systems.

Introduction

The Communication Industry, in the past two decades, has undergone rapid growth. Utilizing mobile phones, laptops, and other communication devices has become a daily activity. The Communication Industry is spreading its wings from Metropolitan cities to cities, cities to towns and towns to villages. This has led to a huge demand for bandwidth and high speeds. Even the 4G speeds are not sufficient to fulfil people's needs. So, every country around the world is looking for the migration of 4G to 5G. High-frequency transmitting and receiving antennas are needed to attain high speeds and more bandwidth, which Microstrip Patch Antennas can accomplish. The three distinct bands of 5G frequencies are low, mid, and high. The low band, which is less than 1GHz, has superior coverage but slower speeds; the mid-band, which is between 1GHz and 6GHz, has moderate speeds and good coverage; and the high band, which is between 24GHz and 40GHz, has faster speeds but less coverage. Advancements in 5G enabled new technologies implemented in smart cities, driverless vehicles, and the Internet of Things (IoT) in general. Significant advantages offered by 5G under the hood are trustworthy as a wired data rate (Gbps) with extremely low latency (<20ms).

The Department of Telecommunications (DoT) has announced that the frequency range of 24.25 to 28.5 GHz will be utilized for IMT/5G (Raghav Kapur (n.d.)). Spectrums include 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 designated as 5G frequency bands

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(Telecom Regulatory Authority of India) by the Indian Department of Telecommunications (DoT).

Literature Survey

A study that compares the performance of two distinct types of microstrip planar antennas operating at 5.2 GHz and featuring S11 parameters of -16.0 dB and -15.7 dB, respectively, is designed (Sharan Bhagwati et al., 2024). Researchers proposed a uniform circular antenna array to improve OAM wave generation and observed how the radiation patterns changed when the UCA parameters were varied (Rakhee et al., 2023). Microstrip arrays, broadband, dual-band, rectangular, and circular printed microstrip antenna designs are all covered in an article (Kumar et al., 2023). Researchers have designed a 2 × 2 planar array of multi-input multi-output (MIMO) and a highly profitable multiple band-tuned slotted pentagonal THz patch antenna (Singh and Singh, 2021) to accommodate different terahertz (THz) applications. A microstrip patch antenna array (2x2, 4x4, and 8x8) with an etched ground structure and a slotted patch in the semi-elliptical shape is suggested in order to meet 5G specifications (Goshu et al., 2022). A paper addressing antenna types, designs and flexible antennas utilized in WBAN with certain design implications and contrasts was proposed by researchers (Preethichandra et al., 2023). The researchers proposed strips with arc shape (Andhe and Reddy, 2022) and split ring complimentary resonators (Andhe and Reddy, 2021) with band-notched characteristics to increase the gain and radiation efficiency. The Researcher suggests a CSRR imprinted ultra-wideband (UWB) patch antenna, which possesses four band rejection characteristics (Kalyan, 2023). In order to reduce design error, the authors examined two distinct models that feature a dynamic framework that modifies each computation step (Yiğit and Karayahşi, 2023). An antenna for vehicle radar that uses microstrip transceiver arrays and has very accurate beam-aiming capabilities has been designed (Jianqiang Bao, 2023). The ULTWAA is a uniformly linear travelling-wave antenna array with 3 × 1 array in shape, designed for milli-meter wave services in the sub-THz band (Eric et al., 2023). For attaining 5G requirements, multi-band slotted patch antennas, stacked patch antennas and MIMO with different approaches are proposed (Wang et al., 2023; Ma et al., 2023; Zhu et al., 2023). A metallic square loop and a circular ring are suggested for a frequency-selective surface with a wide bandpass that operates at the X, Ku, and Ka bands (Vanitha et al., 2023). There is an investigation of many microstrip antennas (Mahmud, 2020; Dhillon et al., 2017; Jeyakumar, 2023; Kushwaha and Karuppanan, 2021) designed using different approaches that operate in the THz band.

In this paper, two antennas with the same patch but different coupling mechanisms are designed. One antenna is built as a single-layer antenna with an octagon patch, whereas another antenna is built as a two-layer antenna with proximity coupling with the same octagon patch in order to attain good VSWR and return loss. However, to enhance gain, two rectangular patches were introduced. Fabricating a proximity coupling antenna is very complex, and this was achieved successfully here. This two-layer antenna, comparable to a single-layer one, yielded better results and exhibited a wide operating frequency range. Various parametric analyses and enhancements are carried out when designing these two antennas for the greater good.

Antenna Design Procedure-

Materials & Methods

The formula (1) is used to determine the patch's radius in order to construct an elliptical patch octagon antenna (Balanis, 2016).

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

Where

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

The patch becomes larger electrically due to the fringing effect. Hence, The radius of the patch that is considered effective is determined by

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

ε_r- Substrate Dielectric constant, h- Substrate Height, f_r- Resonant frequency, r- Patch Radius

r_e-Effective Radius

The desirable centre frequency for the current antenna design is fc=28 GHz. The FR4 substrate with a relative permeability of εr = 4.4 and a thickness of t=1.6mm is used to build the antenna that is being suggested. The above equations have been updated by employing these values. The result of the substitution is a 28GHz working frequency with a radius of 1.6 mm. Parametric analysis is performed for radius to obtain greater gain and increase bandwidth. The 3 mm radius has produced satisfactory outcomes. Hence, a 3 mm radius is selected. In order to gain more and increase bandwidth, a parametric analysis of the radius is carried out. The radius 3 mm has given good results. So, radius 3 mm is chosen.

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Antenna Geometry

1. Single Layer Elliptical Patch octagon antenna

A monopole octagon patch antenna with two elliptical patches on either side is designed with radius 3 mm whose dimensions are 15×25×1.6mm^3. Table I shows various parameters used in the design of this antenna. Based on the antenna geometry, a single-layer elliptical Patch Octagon Antenna is designed and simulated in HFSS. A microstrip patch antenna is formed by sandwiching a substrate FR4 between the ground and patch with a dielectric constant 4.4 and thickness 1.6 mm.

Two elliptical patches are introduced and added at the octagon's left and right sides, resulting in a Multi-band Elliptical Patch Octagon Antenna, as shown in Figure 1(a) above. Figure 1(b) 1(c) indicates the microstrip patch antenna's ground structure and side view. Figure 2 displays the fabricated antenna and its dimensions with the help of a scale. The addition of Elliptical Patches increases the bandwidth and gain of the antenna. Gain of this antenna is 5.03db and its radiation efficiency is 89.67%. Its operating frequency is 28 GHz.

(a) (b) (c)

Figure 1. Elliptical Patch octagon antenna. (a) Top view (b) Back view (c) Side view.

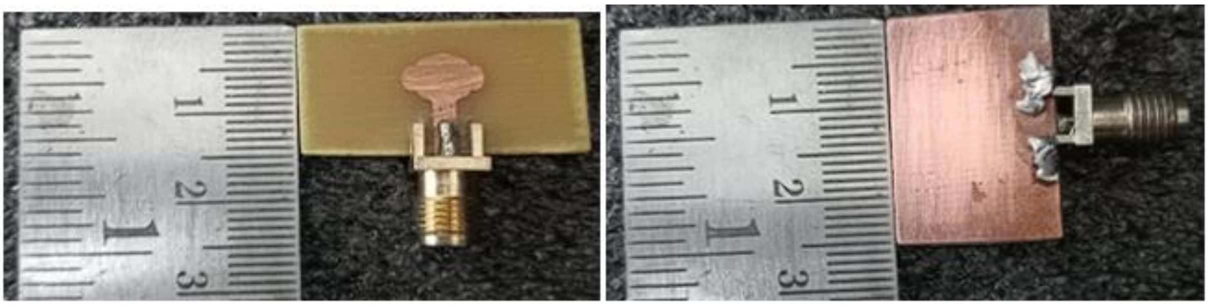

Figure 2. Elliptical Patch octagon antenna dimensions.

Table 1. Single Antenna Parameters.

Parameters	Dimension(mm)
Ground Width (W)	25mm
Ground Length (L)	15mm
Feed Line Width (W_f)	2.15mm
Feed Line Length (L_f)	6mm
Bottom Substrate	1.6mm
Substrate Width (W_s)	25mm
Substrate Length (L_s)	15mm
Octagon Radius (r)	3mm
Ground Width (W)	25mm

Table 2. Two Layer Antenna Parameters.

Parameters	Dimension
Ground Width (W)	25mm
Ground Length (L)	15mm
Feed Line Width (W_f)	2.15mm
Feed Line Length (L_f)	6mm
Bottom Substrate Thickness	1mm
Bottom Substrate Width (W_s)	25mm
Bottom Substrate Length (L_s)	15mm
Top Substrate Thickness (t2)	0.6mm
Top Substrate Width (W_s)	25mm
Top Substrate Length (L_s)	15mm
Octagon Radius (r)	3mm
h1	1.6mm

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(a) **(b)** **(c)**

Figure 3. Two Layer Elliptical Patch octagon patch antenna (a) Top view with both first and second layers (b) Ground Plane (c) Side View

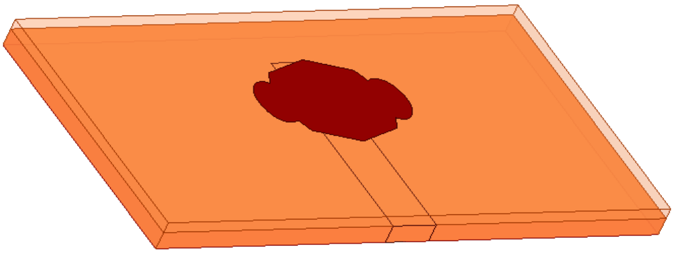

Figure 4. Two Two-layer elliptical Patch octagon patch antenna.

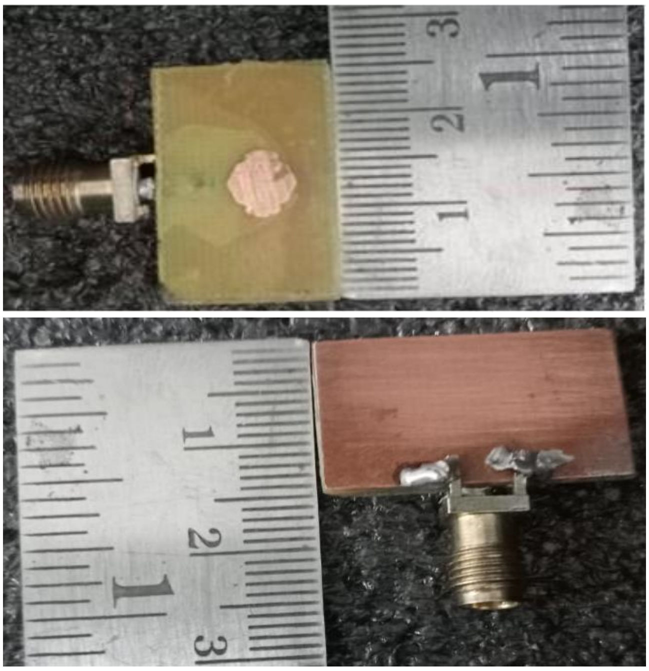

Figure 5. Two-Layer Elliptical Patch octagon patch antenna dimensions.

2. Two Layer Elliptical Patch octagon antenna

In order to increase the number of bands of a single-layer elliptical patch octagon antenna, a two-layered proximity coupling approach has been designed. First, a bottom layer with FR4 substrate height of 1mm is chosen, keeping length and width the same as a single layer. A feed line of length 6mm and width 2.15mm is introduced on the top of the bottom layer. Next, a top layer with an FR4 substrate with a height of 0.6mm is chosen to keep the length and width same as a single layer. On this top layer's top side, an octagon with a radius of 3mm and two elliptical patches is introduced at the centre. The resultant antenna is a Two Layer Elliptical Patch octagon antenna. The total height of this two-layer antenna is 1.6mm, the same as single-layer antennas. Figure 3 displays the top, bottom and side view of the Two Layer Elliptical Patch octagon antenna. Table II shows various parameters for designing the Two-layer antenna.

The bottom and top layers combine to form a Two Layer Elliptical Patch Octagon Antenna, as shown in Figure 4 below. Figure 5 shows the fabricated antenna and its dimensions with the help of a scale.

Table 3. Single Layer Elliptical Patch Octagon.

Parameters	Results
Operating Frequency Range	10-300GHz
Overall Bandwidth	290GHz
Sample Frequency	28GHz
Sample Bandwidth	26 GHz -28.91 GHz
Gain	5.03 db
Radiation Efficiency	90%
Front To Back Ratio	8.09
Return Loss	-21.38 dB
VSWR	1.48

Results and Discussion

The Single Layer Elliptical Patch Octagon Antenna achieved return loss and gain of 21.38dB and 5.03dB, respectively. This single-layer Elliptical Patch Octagon Antenna attained a radiation efficiency of 90%. The results of various parameters of single layer Elliptical Patch Octagon Antenna are shown in Table 3.

This Single Antenna's Return loss, VSWR, Gain and radiation pattern's graphs are shown in Figures 6, 7, 10 and 11. The Single Layer Antenna's measured and simulated Return Loss and VSWR from 25GHz to 45GHz are shown in Figure 8, 9. The return loss and VSWR measured results are taken by testing the proposed single-layer antenna in the Anechoic chamber, as shown in Figure 12(a) and 12(b), respectively.

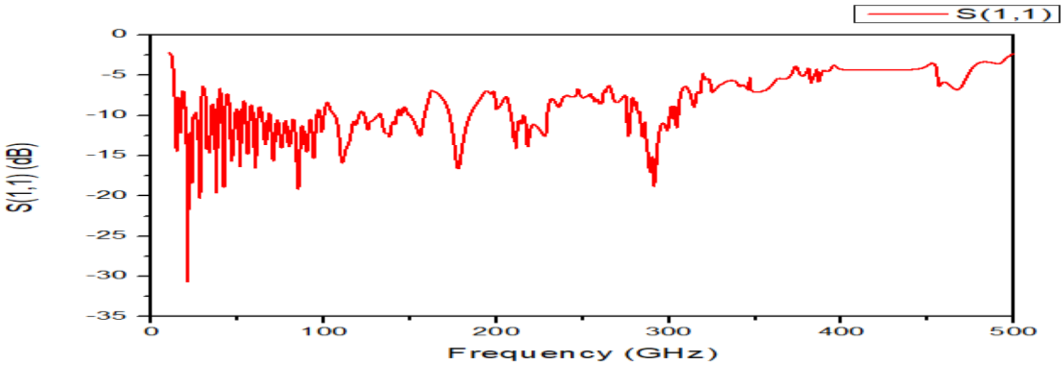

Figure 6. Single Antenna Return Loss from 10GHz to 500 GHz.

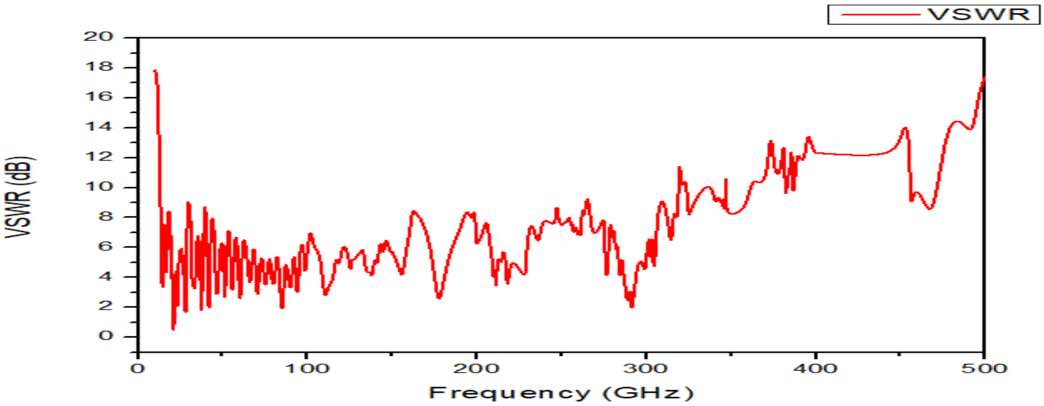

Figure 7. Single Antenna VSWR from 10 GHz to 500 GHz.

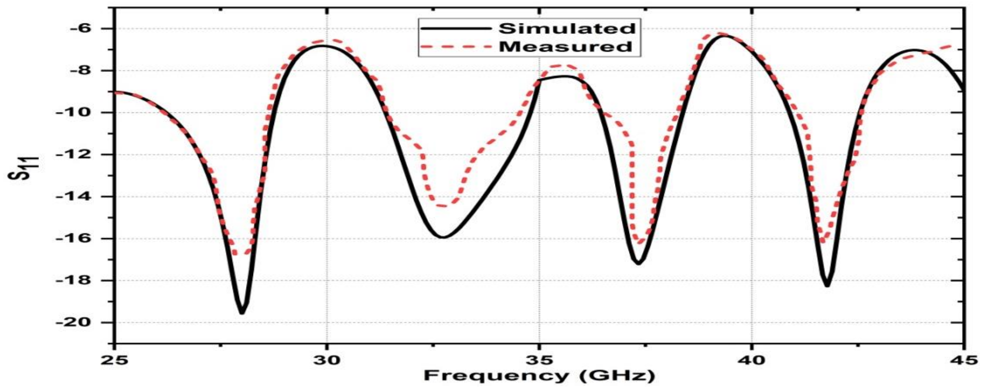

Figure 8. Single Layer Antenna Return Loss from 25 GHz to 45 GHz.

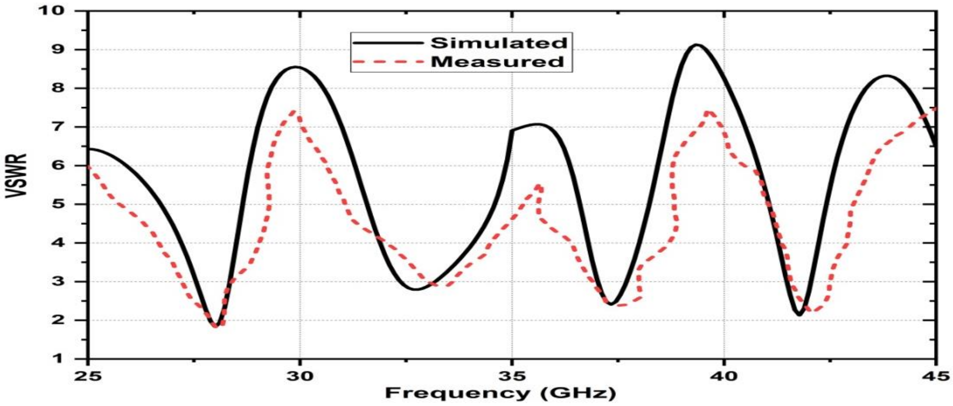

Figure 9. Single Layer Antenna VSWR from 25 GHz to 45GHz

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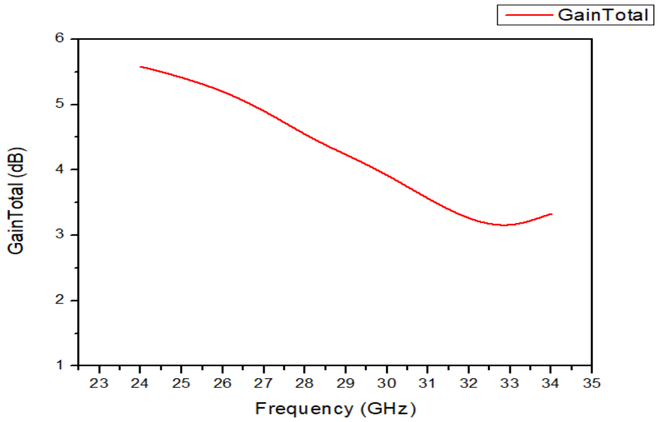


Figure 10. Single Antenna Gain Vs Frequency.

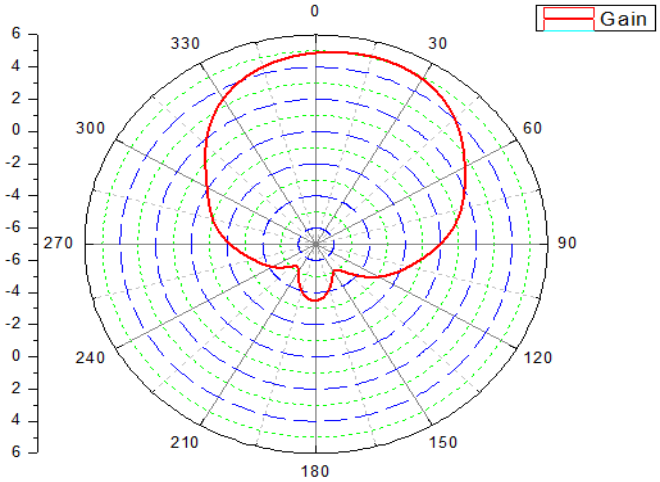


Figure 11. Single Antenna Radiation Plot.

antenna has a radiation efficiency of 82.69%. Even though the radiation efficiency is decreased in the Elliptical Patch octagon antenna layer, its gain is increased from 5.03db to 8.81db. The results of various parameters of the Two Layer Elliptical Patch Octagon Antenna are shown in Table 4.

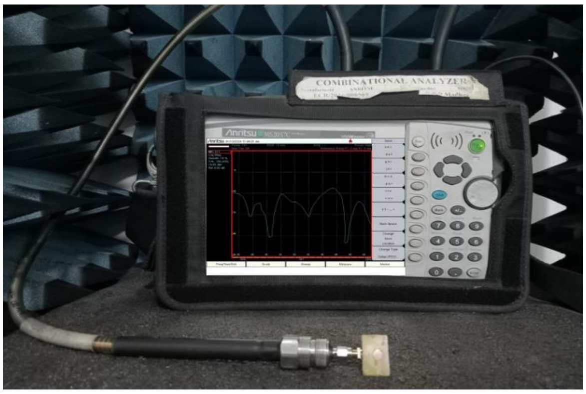
Table 4. Two-Layer Elliptical Patch Octagon. Antenna Results

Parameters	Results
Operating Frequency Range	10-500GHz
Overall Bandwidth	490GHz
Sample Frequency	29GHz
Sample Bandwidth	28.00GHz -
Gain	8.81 db
Radiation Efficiency	88.69%
Front To Back Ratio	20.70
Return Loss	-24.5 dB
VSWR	1.04

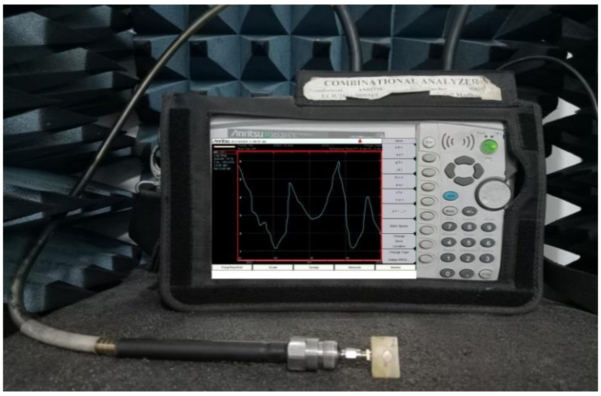
This Two Layer Antenna's Return loss, VSWR, Gain and radiation pattern's graphs are shown in Figures 13, 14, 17 and 18, respectively. The Two Layer Antenna's measured and simulated Return Loss and VSWR from 25GHz to 45GHz are shown in Figures 15 and 16. The return loss and VSWR measured results are taken by testing the proposed two-layer antenna in Anechoic chamber, as shown in Figures 19(a) and 19(b).

Comparison of Single- and Two-Layer Antennas

The single-layer antenna without proximity coupling has an operating frequency range of 10GHz to 300GHz. The Two-layer antenna with proximity coupling proposed here has an operating frequency range of 10GHz to 500GHz. Compared to single-layer antenna, a two-layer antenna has more number of bands in the operating frequency range. The Operating frequency range is increased from 300GHz to 500GHz.



(a)



(b)

Figure 12. Spectrum Analyzer output of Single Antenna (a) Return loss from 25 GHz to 45GHz (b) VSWR from 25 GHz to 45 GHz.

In order to increase the gain of an antenna, two other layers are kept on top of this Single Antenna, each separated by a distance 1 mm. The Resultant microstrip patch antenna is a Two Layer Elliptical Patch Octagon Antenna whose operating frequency, return loss and gain are 29GHz, 24.5dB and 8.81dB, respectively. This

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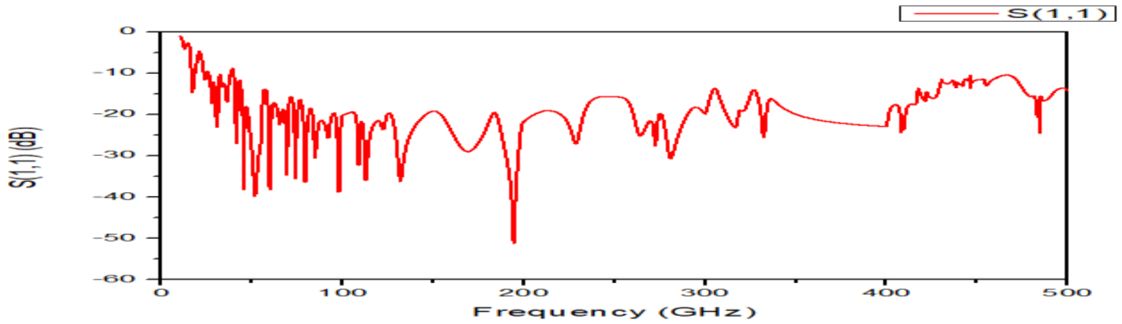

Figure 13. Two Layer Antenna Return Loss from 10GHz to 500 GHz.

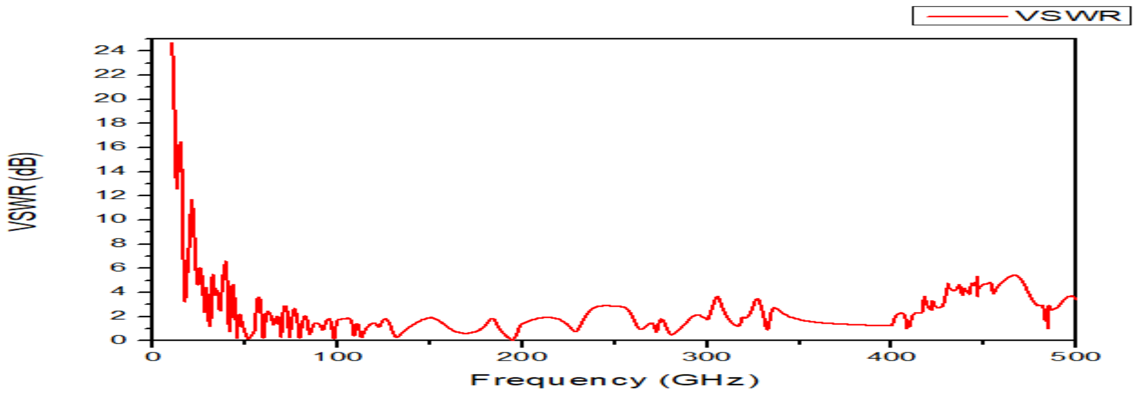

Figure 14. Two Layer Antenna VSWR from 10 GHz to 500 GHz.

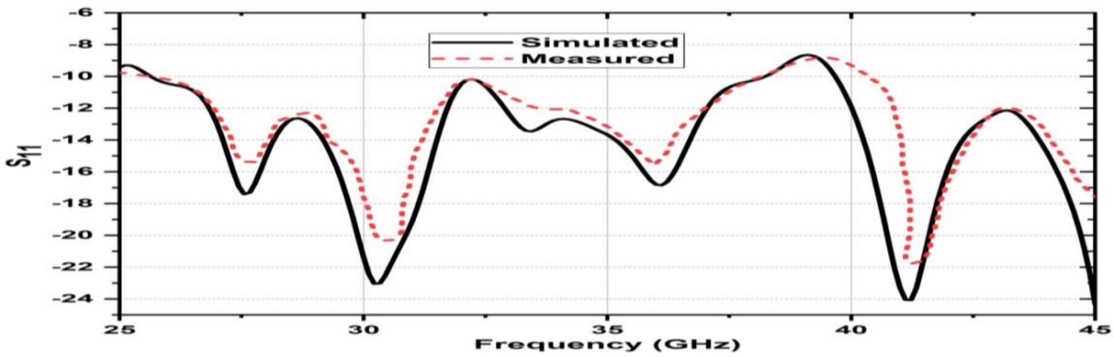

Figure 15. Two Antenna Return Loss from 25 GHz to 45 GHz.

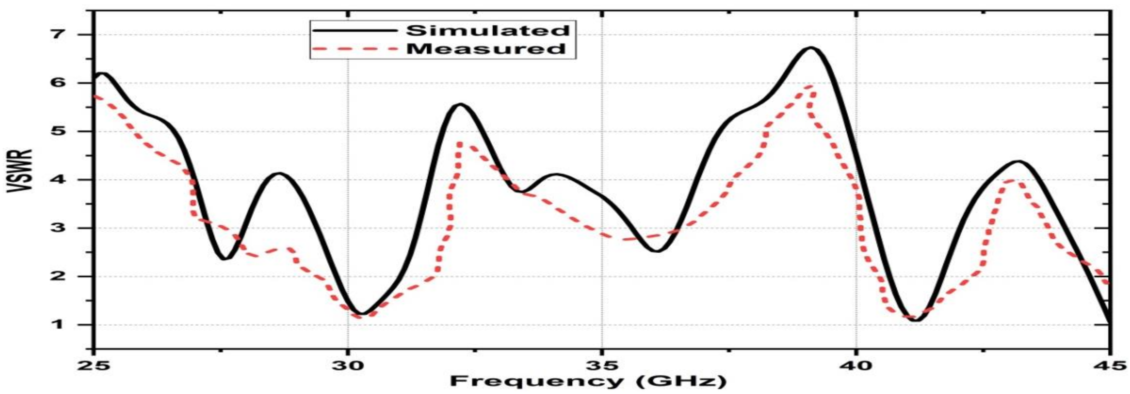

Figure 16. Two Antenna VSWR from 25 GHz to 45 GHz.

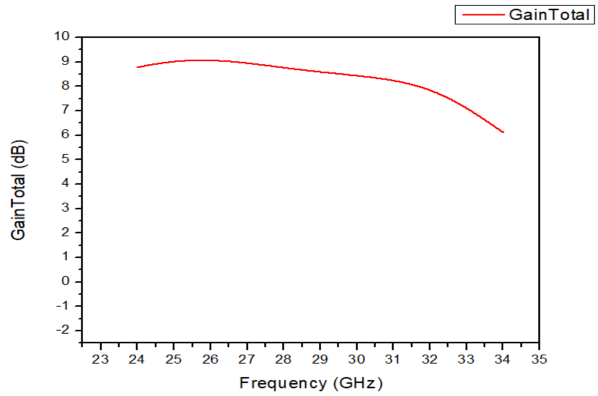

Figure 17. Two-Layer Antenna Gain.

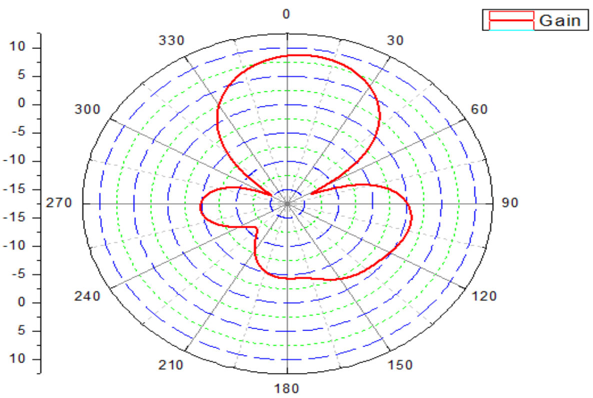

Figure 18. Two-Layer Antenna Radiation Plot.

As shown in Figure 20, the return loss (s11) of the two layers is very good compared to the single layer. Rather than a single layer, two layers have good VSWR, i.e., between 1 and 2, shown in Figure 21. For example, considering a single-layer antenna at a frequency of 28GHz, it has a return loss, VSWR, Gain and efficiency of -21.38dB, 1.48, 5.03dB and 89.67%. Now, consider two two-layer antennas at the frequency of 29GHz. They have a return loss, VSWR, Gain and efficiency of -24.5dB, 1.04, 8.81dB and 82.69%. When compared to these two, the return loss and gain of a two-layer antenna with proximity coupling is great. Here, the novelty lies in designing a two-layer antenna with proximity coupling, which achieved good results over a wide bandwidth.

Results Comparison

The single-layer antenna has multiple bands over a frequency range of 10GHz to 300GHz. It covers frequencies of 20.8GHz, 21.2GHz, 27.8GHz, 28GHz, 37.4GHz, 41.8GHz, 84.8GHz, 85GHz, and 291.33GHz. Even though it covers a wide range, it has only 9 operating frequencies. The two layer antenna overcomes this problem. Its proximity coupling structure enables it to cover frequencies 29GHz-31GHz, 40.8GHz-41.8GHz,

Figure 19. Spectrum Analyzer output of Two-layer Antenna (a) Return loss from 25 GHz to 45 GHz (b) VSWR from 25 GHz to 45 GHz.

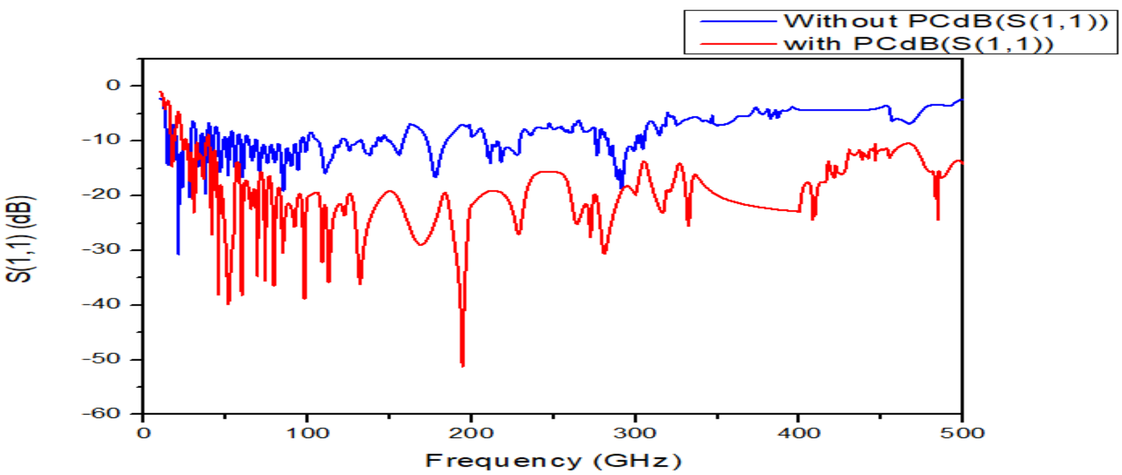

Figure 20. Single and Two-layer Antenna's return loss from 10 GHz to 500 GHz.

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44.8GHz-48.8GHz, 55GHz, 58GHz-60.8GHz, 63.8GHz-70GHz, 72.8GHz-75GHz, 77.6GHz-78.4GHz, 80.2GHz-83.8GHz, 85.8GHz-96.6GHz, 98.6GHz-111.3 GHz, 115.33GHz-128.88GHz, 137.33GHz-160.66GHz, 177.55GHz-187.33GHz, 198GHz -226.44GHz, 230.44GHz-233.77 GHz, 259.55GHz-263.11GHz, 265.11GHz - 271.55GHz, 273.11GHz- 278.22GHz, 285.33GHz-292 GHz, 297.55GHz-300.88 GHz, 310.66GHz-321.77GHz, 330.66GHz -332 GHz, 332.88GHz -334GHz, 344.88GHz-402GHz, 407.33GHz-410.88GHz, 482.88GHz-484.66GHz. Thus, these two-layer antennas cover a frequency range of 10GHz to 500GHz.

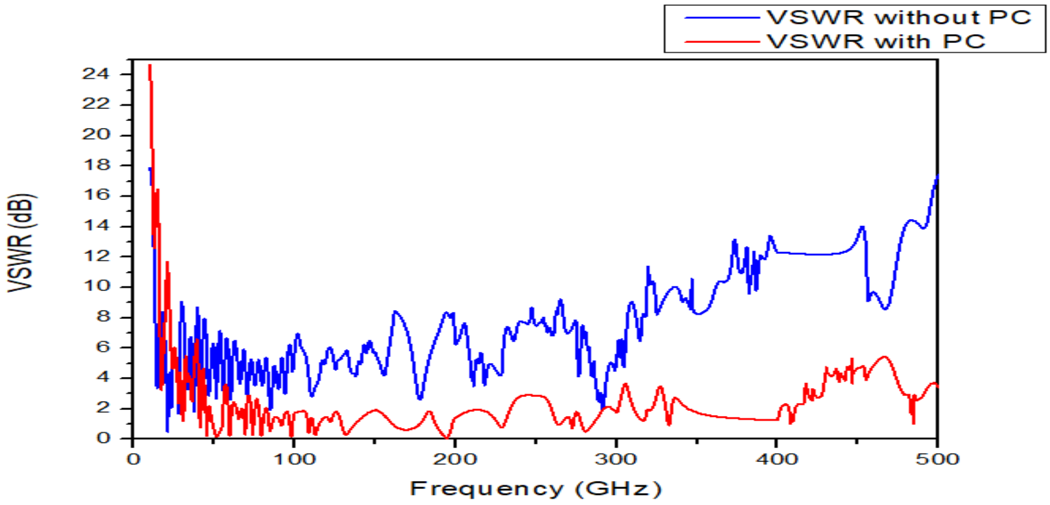

Figure 21. Single- and Two-layer Antenna's VSWR from 10 GHz to 500 GHz.

Table 5. Comparisons of Proposed Antenna Designs with Previous Antenna Designs.

Antenna Design	Opera-ting Frequency Range (GHz)	Resonant Frequ-ency	Return Loss S11 (dB)	VSWR	Band Width (GHz)	Gain (dBi)	Efficiency %
Dual-band wideband high-gain antenna (Jin and Zhang, 2024)	5.18–5.52 GHz and 5.74–5.82 GHz	5.07 GHz. 5.44 GHz. 5.82 GHz. 6.48 GHz.	-27 dB	Within 1-2	5.18–5.52 GHz and 5.74–5.82 GHz	8.1 dB	85%
Circular microstrip antennas with modified ground plane (Deshmukh *et al., 2024*)	632MHz – 1142MHz	1100MHZ	-18 dB	Within 1-2	510MHz	5.5 dB	85%
Reconfigurable dual-band microstrip antenna (Bharathi and Reddy, 2023)	2.4 GHz 2.6 GHz	2.4 GHz 2.6 GHz	-16.41 dB -18.09 dB	Within 1-2	100MHZ	6.98 dB	-
Microstrip dual band hybrid directional resonator antenna (Konch *et al.*, 2023)	2.9–3.2GHz, 4–4.6 GHz	3.0 and 4.6 GHz	-17.5 dB, -15 dB	Within 1-2	1GHz	4.5 dB	-
Dual-band microstrip patch antenna (Yıldırım and Gırık Acıkaya, 2021)	2.45/5-GHz	2.45/5-GHz	-24 dB / -15.49 dB	Within 1-2	1GHz	4.5 dB	-

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Hybrid microstrip patch antenna (Maity *et al.*, 2022)	2GHz-40 GHz	289–40GHz	-36.49 dB	Within 1-2	38GHz	8.24dB	67%
Two-port hexagon shaped MIMO microstrip antenna (Agarwal *et al., 2021*)	2.1–11.4GHz	2.1–11.4GHz	-24 dB	Within 1-2	9.3GHz	1.2 dB	75%
Reconfigurable microstrip antenna (Shaw and Choukiker, 2023)	2.492GHz	2.492GHz	-24 dB	1.05	1GHz	6.46 dB	-
Triband Slot Antenna Loaded (Rajanna *et al., 2024*)	2.24GHz, 2.97GHz, 3.66GHz	2.24GHz, 2.97GHz, 3.66GHz	-27 dB, -22.5 dB, -22.5 dB	Within 1-2	290 MHz, 150 MHz, 340MHz	3.1 dB, 2.18dB, 3.29 dB	76.6%
Eyebolt shape slotted microstrip patch antenna (Merin Joshiba and Judson, 2023)	28GHz	28GHz	−38 dB	1.02	8 GHz	5.5 dB	87%
Proposed single-layer Antenna Without proximity coupling	10GHz-300GHz	28GHz (sample)	-21.38 dB	1.48	290GHz (26 GHz - 28.91 GHz)	5.03 db	90%
Proposed two layer Antenna With proximity coupling	10GHz-500GHz	29GHz (sample)	-24.5 dB	1.04	490GHz (28.00GHz - 29.90GHz)	8.81 db	88.69%

The frequency range for millimeter-wave broadcasting is 30 GHz to 300 GHz. Their wavelength ranges from 1 to 10 millimetres, hence the name millimetre wave. Traditional radio frequency communications use wavelengths in the tens of centimetres, while millimetre wavelengths are smaller. 5G networks, which use millimeter-wave frequency ranges ranging from 24GHz to 100GHz, allow for extremely fast data transfer rates, more users online at once, and more devices linked to a single network. Both single and two-layer antennas cover a frequency range of 10GHz to 500GHz. Proposed single- and two-layer antennas find application in security scanners, short-range radar systems, and telecommunication networks (Kishore and Senapati, (2022). These two antennas' wide bandwidth (coverage area) makes them the best choice for wireless short-distance communications of high-definition video and multimedia content. Some examples of its use are 802.15 wireless personal area networks (PANs) and IEEE 802.11 ad multiple gigabit wireless systems (MGWS), both of which are examples of high bandwidth LANs. Cloud gaming, Automatic vehicle communication (Md Hossain, 2023; Ullah *et al.*, 2023; Rana *et al.*, 2022) and THz imaging systems (Malhotra *et al.*, 2018) are another ideal use cases for these antennas because of their high data speeds and short-distance propagation.

Conclusion

The single-layer Multiband Elliptical Patch Octagon Antenna without proximity coupling is operated from 10GHz to 300GHz. At a frequency of 28 GHz, its gain and radiation efficiency are 5.03db and 90%. This single layer Elliptical Patch Octagon Antenna at 28GHz frequency is used for Inter-Satellite, Mobile & Fixed Satellite and Inter-satellite communication applications. Meanwhile, the Multiband Two Layer Elliptical with proximity coupling Patch Octagon Antenna operates from 10GHz to 500GHz. At a frequency of 29 GHz it attained gain of 8.81db and its radiation efficiency is 88.69%. The gain of the layer Elliptical Patch Octagon Antenna is increased by 3.78db. The Operating frequency range is increased from 300GHz to 500GHz. Thus, the usage of two other layers with hexagonal patches not only increased the gain but also helped attain suitable VSWR. This Two Layer Elliptical Patch Octagon Antenna at 29GHz frequency is used for Mobile & Fixed Satellite Applications.

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Conflict of Interest

The authors declare no conflict of interest.

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