SSRG International Journal of Electronics and Communication Engineering
ISSN: 2348-8549/ https://doi.org/10.14445/23488549/IJECE-V12I2P106

Volume 12 Issue 2, 65-72, February 2025

Original Article

A Miniaturized Octagonal Antenna with CPW Feed for WLAN, Satellite and C Band Applications

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Received: 08 December 2024 Revised: 06 January 2025 Accepted: 07 February 2025 Published: 26 February 2025

Abstract - *The increasing demand for compact, high-performance antennas in contemporary wireless communication systems has prompted significant study into multi-frequency designs. Applications like Wireless LAN, satellite communication, and C-band services necessitate antennas that are both downsized for incorporation into portable devices and proficient in functioning across several frequency bands. This study introduces a tapered Coplanar Waveguide (CPW)-fed tiny multi-frequency antenna intended for Wireless LAN, satellite communication and C-band applications. The proposed antenna includes a projected structure of 30 × 30 × 1.6 mm^3 size and has an asymmetric octagonal radiating patch. FR4 epoxy with permittivity 4.4 is used as a dielectric medium. The antenna resonates at frequencies 5.1GHz, 6.5GHz and 7GHz with the reflection coefficients of -17.73dB, -11.81dB, -11.73dB and gains of 4.83dB, 6.92dB, 8.46dB, respectively. The antenna produced a VSWR of 1.29, 1.69 and 1.69 for the respective frequencies.*

Keywords - *Asymmetric octagonal patch, Tapered CPW, Multiband, WLAN, Satellite, C band.*

1. Introduction

These days, patch antennae will be used widely in communication hardware due to their low volume, lower cost, and capacity, which allow them to be synchronized into other microwave gadgets without any problem. The existing and next communication arrangements require electrically tiny, structurally modest antennas with high directivity properties because of the fast improvements in wireless systems for communication [1].

Multiband antennas with superior radiation properties and extensive impedance bandwidths exhibiting specified radiation patterns are essential for sophisticated communication systems. As the ground, radiator and feed are positioned on the same plane, allowing for seamless incorporation with other microwave devices, a coplanar waveguide-powered antenna provides minimal radiation leakage and reduced sensitivity of characteristic impedance to substrate material and height [2].

Miniaturization of antenna size is also critical for integration with portable devices. As the size of wireless devices becomes portable, the components of the device also have to be compact. An antenna is a critical component of a communication device, and miniaturization is highly desirable [4]. The slot is changed to rectangular with uneven cuts in the ground structure. Patches with hexagonal shapes and dual CPW feeds are employed to rejuvenate the slot and improve the gain [3]. A novel plan of a Coplanar Waveguide antenna with an integral patch placed in the middle of the resonator is proposed. Antenna shows a particular just as wide-band excitation and satisfies the interest of today's remote communication [5].

A Coplanar Waveguide fed with a C-shaped structure with rectangular etching on the patch is planned and executed. Ultra-wide bandwidth values of 3.01-10.4 GHz are accomplished using rectangular slots and C-molded stubs [6]. A little Coplanar Waveguide took care of three band-indented structures and is planned to restrict the electromagnetic impedances conveyed in narrowband use in the UWB range. The introduced antenna works over the recurrence range of UWB between 3.1 to 11 GHz for low-energy applications [7]. A new novel form of a dual-band co-planar waveguide fed (CPW) antenna is presented with a fractal to generate dual-band radiation. A matching step-impedance is applied between patch and feed to achieve improved return loss on both operating frequencies [8].

An antenna with a rectangular radiator was intended for the C band, and Global Positioning Systems was designed. The double is obtained by a coplanar waveguide with a circular slot on the patch [9]. A small novel square spiral antenna having strips in L-shape and CPW feed is explored in multiband applications. Using a spiral increases excitation, and including L-shape strips in the spiral contributes more bandwidth at higher frequencies [10].

A versatile double band and double enraptured Coplanar Waveguide-feed monopole antenna having fascinating recurrence re-configurability is proposed. To achieve a double band, a U-formed opening is set inside the CPW-took care of the monopole in the presented antenna. The radio wire is manufactured utilizing a flexible substrate, which is useful for conformal applications. The presented receiving wire can be used in multiband framework and intellectual radio applications [11]. For RFID applications, a Coplanar Waveguide-fed semi-fractal structure with a curve line feed is presented. This design resonated at multiband frequencies of 3.8GHz, 5.8GHz, 8.2GHz and 9.7GHz respectively [12]. An inkjet patch antenna with a circular monopole with a volume of 158.6 mm3 is presented. It resonates at bands of 3.04GHz to 10.7GHz and 15.18GHz to 18GHz. This structure unveiled omnidirectional radiation features and generated 3.94 dB of peak gain [13]. The antenna has a volume of 69.6mm3. It consists of an oval shape patch, a double T structure, concentric rings and a J slot. This structure operated at 5.15 GHz to 7.29 GHz and Wireless-Fidelity 6 (5.92 GHz to 7.12 GHz). It also exhibits a gain of 2.25dB and an efficiency superior to omnidirectional radiation characteristics [14].

An antenna with CPW feed and meta-material is aimed at the applications of S and Ku bands. The meta-material and SIW are utilized to enhance the bandwidth, gain and antenna efficiency. The structure resonates at 4.23 GHz, 13.63 GHz and 17.05 GHz, respectively. A linear polarization is achieved for both frequency bands with improved gain and efficiency [15]. A Mercedes-Benz logo positioned at an adjusted distance was effective in generating a center frequency of 2.45GHz. The radiation characteristics have been improved by the integration of a metal plate along with a reflector and a CPW feed. This structure produced a bandwidth of 360 MHz from 2.2 GHz to 2.56 GHz. The attained gain at 2.45GHz is 7.3dB. [16].

The antenna comprises a revised upright bow-tie radiator with a coplanar L-shaped ground plane. The gain is improved after the incorporation of coplanar feed [17]. An antenna measuring 33 × 17 × 1.6 mm³ is documented for WLAN and Wi-MAX applications, achieving frequency bands of 2.47 to 2.77 GHz, 3.3 to 3.7 GHz, and 5.10 to 6.62 GHz [18].

Despite its uneven design, the antenna's radiation patterns throughout the two bands are perfectly symmetrical, and it doesn't have any rear lobes either. The fundamental advantage of symmetric patterns is that they concentrate radiation in the vertical direction compared to the antenna axis, where frequency fluctuations have little effect. As a result, the antenna's half-power beam width in the E and H planes is quite wide. The H-plane pattern's cross-polarization level is more noticeable at 3.375 GHz [19].

2. Antenna Formulae

Width of the antenna

$$W=\frac{C_0}{2f_r\cdot}\sqrt{\frac{2}{\varepsilon_r+1}}$$

f_r - resonant frequency
ϵ_r - relative permittivity
c_o - Speed of light

The effective dielectric constant

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}-\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2}$$

The extension of length (ΔL)

$$\frac{\Delta L}{h}=0.412\,\frac{(\varepsilon_{reff}+0.3)(\frac{h}{w}+0.264)}{(\varepsilon_{reff}0.258)(\frac{w}{h}+0.8)}$$

The patch length

$$L=\frac{C_0}{2f_r\sqrt{\varepsilon_{reff}}\,.}-2\Delta L$$

3. Antenna Structure

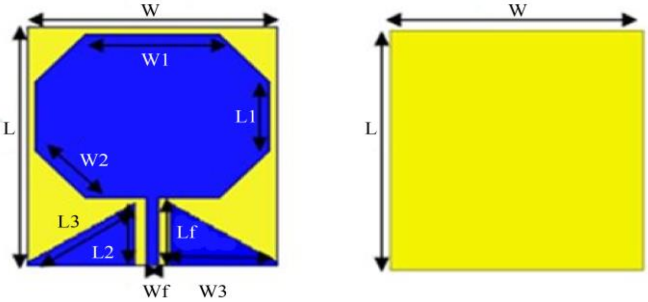


Fig. 1 Top view and ground plane of the antenna

The front and back perspective on the proposed scaled-down asymmetric octagonal antenna with a fixed coplanar waveguide feed is portrayed in Figure 1. The antenna was designed on the substrate of FR-4 epoxy, which has a permittivity of 4.4 with a loss tangent of 0.02. The dielectric's width, length, and height are 30mm, 30mm and 1.6mm respectively. The asymmetric octagonal patch of L1 = 8.5mm, W1 = 16 mm and W2 = 6mm is constructed. The patch is fed by a micro-strip having length and width of 8.5mm and 1.25mm respectively. The coplanar waveguide is constructed on both sides of the microstrip feed on the same plane, having dimensions L2=7.8mm, L3= 12.97mm and W3=12.975mm.

The cause behind choosing the Coplanar Waveguide feed is its advantages on microstrip line feed like low scattering, less radiation loss, capacity of limiting its characteristic impedance, and simplicity of joining with solid microwave ICs and other Radio Frequency devices. The antenna prototype is illustrated in Figure 2.

Table 1. Antenna measurements

Surface	**Measurements**	
Substrate	Length L	3 mm
	Width W	30mm
	Height	1.6mm
Patch	Length L1	8.5mm
	Width W1	16mm
	Width W2	6mm
Feed	Length Lf	8.5mm
	Width Wf	1.25mm
Ground Plane	Length L	30mm
	Width W	30mm
Coplanar feed	Length L2	7.8mm
	Length L3	12.97mm
	Width W3	12.975

4. Prototype of the Antenna

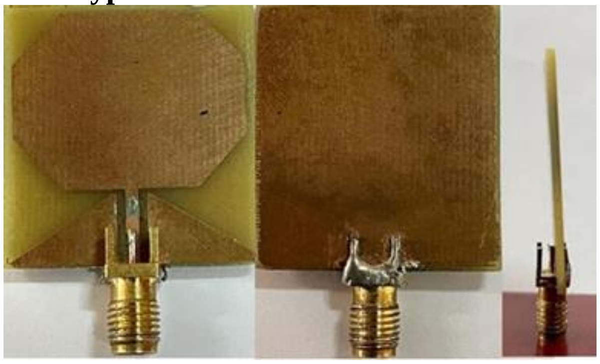


Fig. 2 Antenna structure

The frequencies obtained are 5.1GHz, 6.5GHz and 7GHz. The return loss for the frequencies are - 17.73dB, -11.81dB and -11.73d B, respectively.

5. Results

The S_{11} graph of the asymmetric octagonal antenna demonstrates its effective multi-frequency performance at 5.1GHz, 6.5GHz, and 7GHz, with reflection coefficients of -17.73dB, -11.81dB, and -11.73dB, correspondingly. These data illustrate optimal impedance matching. The antenna has a constrained but adequate bandwidth at each resonance, indicating its suitability for Wireless LAN, satellite communication and C-band applications. The small design and efficient CPW-fed setup provide impressive performance. The antenna effectively achieves its designated goals.

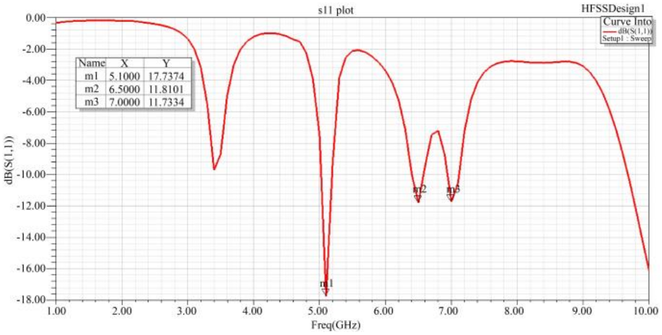


Fig. 3 S_{11} of asymmetric octagonal antenna

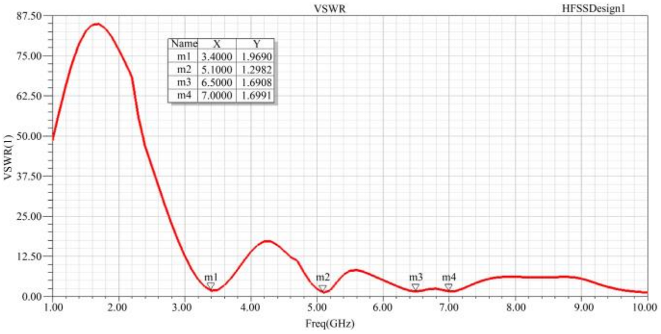


Fig. 4 VSWR

The VSWR plot indicates that the asymmetric octagonal antenna demonstrates effective impedance matching at frequencies of 5.1 GHz (VSWR = 1.29), 6.5 GHz (VSWR = 1.69), and 7 GHz (VSWR = 1.69), with all measurements remaining significantly below the acceptable limit of 2. This demonstrates low power reflection and efficient power transfer at the specified frequencies. The results confirm the antenna's appropriateness for Wireless LAN, satellite communication, and C-band applications. The above figures give the simulated antenna parameters.

5.1. Intermediate Steps

Initially, a basic rectangular patch can generate 3.3GHz, 4.9GHz, 6.3GHz, 8.4GHz and 8.7GHz with a reflection coefficient of - 12.21dB, -10.68dB, -25.61dB -14.9dB and -13.84dB respectively. For the frequency 4.9GHz, the return loss is high.

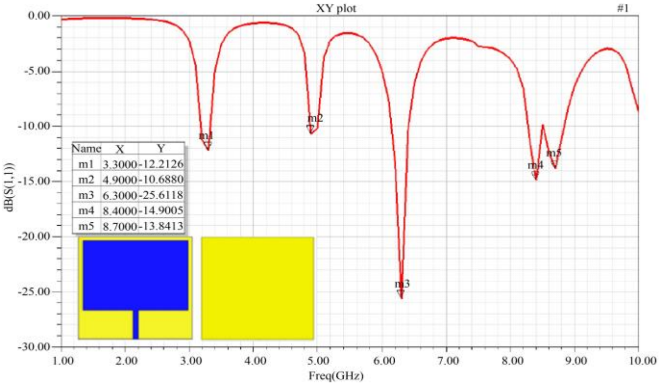


Fig. 5 Rectangular patch antenna

The device's capability for multi-frequency operation renders it appropriate for various wireless communication applications. The optimal resonance observed at 8.7 GHz indicates superior matching capabilities and the design facilitates both compactness and multi-band functionality. The frequencies 8.4GHz and 8.7GHz are close to -10dB return loss.

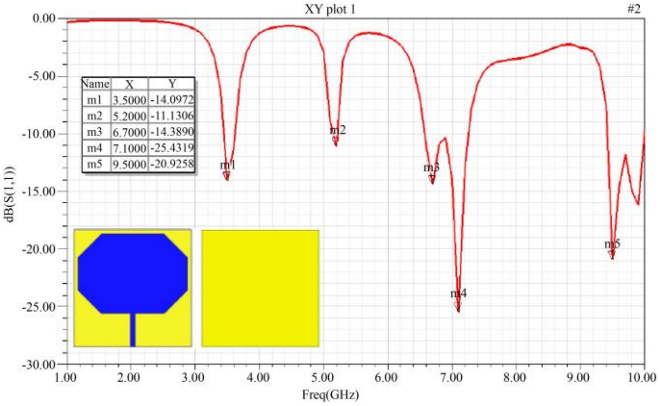


Fig. 6 Asymmetric octagonal antenna

The asymmetric octagonal antenna facilitates effective multi-frequency operation with resonances at 3.5 GHz, 5.2 GHz, 6.7 GHz, 7.1 and 9.5 GHz, all exhibiting $S_{11} < -10$ dB. The most robust match occurs at 7.1 GHz (-25.43 dB). The antenna's design illustrates its appropriateness for multi-band applications across several wireless communication frequencies.

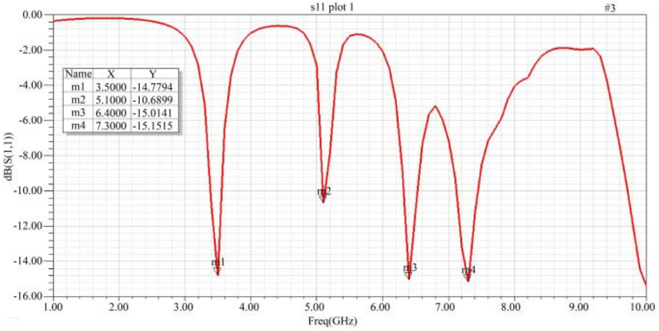


Fig. 7 Octagonal patch with CPW feed

In order to decrease the return loss, a rectangular coplanar waveguide feed with an asymmetric octagonal patch is introduced, after which the frequencies obtained are 3.5GHz, 5.1GHz, 6.4 GHz and 7.3GHz. Still, for the frequency of 5.1GHz, the return loss is high. To improve the gain and reduce the return loss, a coplanar waveguide was made tapered. The obtained frequencies are 5.1GHz, 6.5GHz and 7GHz. The gains obtained are 4.83dB, 6.92dB and 8.46dB, respectively, as depicted in Figure 8.

The tapered CPW-fed antenna operates efficiently at 5.1 GHz, 6.5 GHz, and 7 GHz, with excellent impedance matching ($S_{11} < -10$ dB). Its compact design and multi-frequency functionality make it ideal for Wireless LAN, satellite, and C-band applications, with the strongest matching observed at 5.1 GHz.

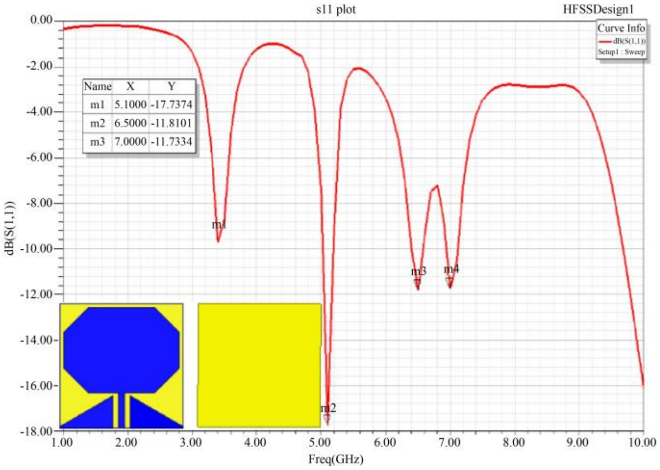


Fig. 8 Antenna with tapered CPW feed

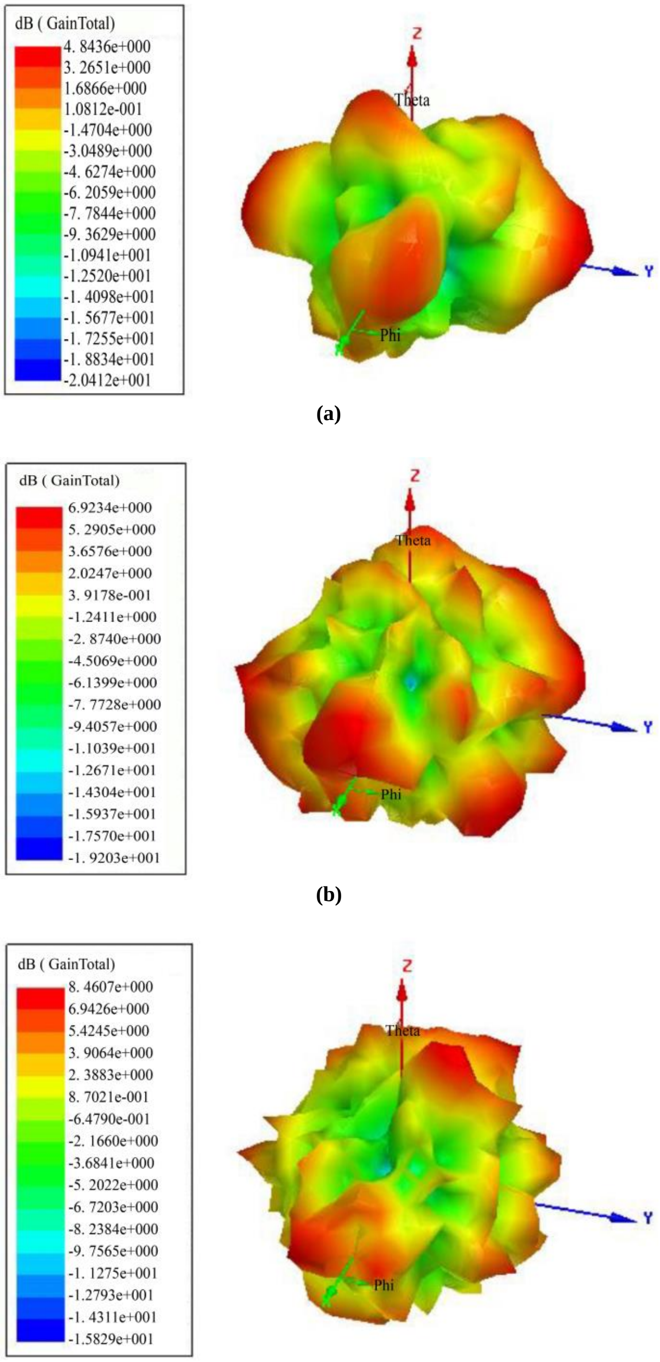
The antenna design evolves from a rectangular patch to a tapered CPW-fed octagonal patch**,** with each step improving impedance matching and gain, as shown in Table 2**.**

The final design demonstrates the best performance at 5.1 GHz, 6.5 GHz, and 7 GHz**,** making it suitable for Wireless LAN, satellite communication, and C-band applications.

Table 2. Intermediate design procedural steps

Steps	**Frequency (GHz)**	**Return Loss (dB)**	**Gain (dB)**
Rectangular patch	3.3 4.9 6.3	-12.21 -10.68 -25.61	2.97 0.26 4.27
Asymmetric Octagonal patch antenna	3.5 5.2 6.7 7.1 9.5	-14 -11.1 -14.38 -25.43 -20.92	3.5 0.99 5.89 2.81 8.96
Octagonal patch Antenna with rectangular coplanar waveguide feed	3.5 5.1 6.4 7.3	-14.77 -10.68 -15 -15.15	5.95 -0.72 5.59 5.67
Octagonal patch Antenna with tapered coplanar waveguide feed	5.1 6.5 7	-17.73 -11.81 -11.73	4.84 6.92 8.46

5.2. Gain



(a)

(b)

(c)

Fig. 9 Gain at (a) 5.1GHz, (b) 6.5GHz, and (c) 7GHz.

Figure 9 represents the 3D gain plots at three different frequencies. Below is the summarized analysis.

5.2.1. Peak Gain

The gain increases with frequency: 4.84dB at 5.1GHz, 6.92dB at 6.5GHz, and 8.46dB at 7GHz. This demonstrates the antenna's improved radiation efficiency at higher frequencies.

5.2.2. Radiation Pattern

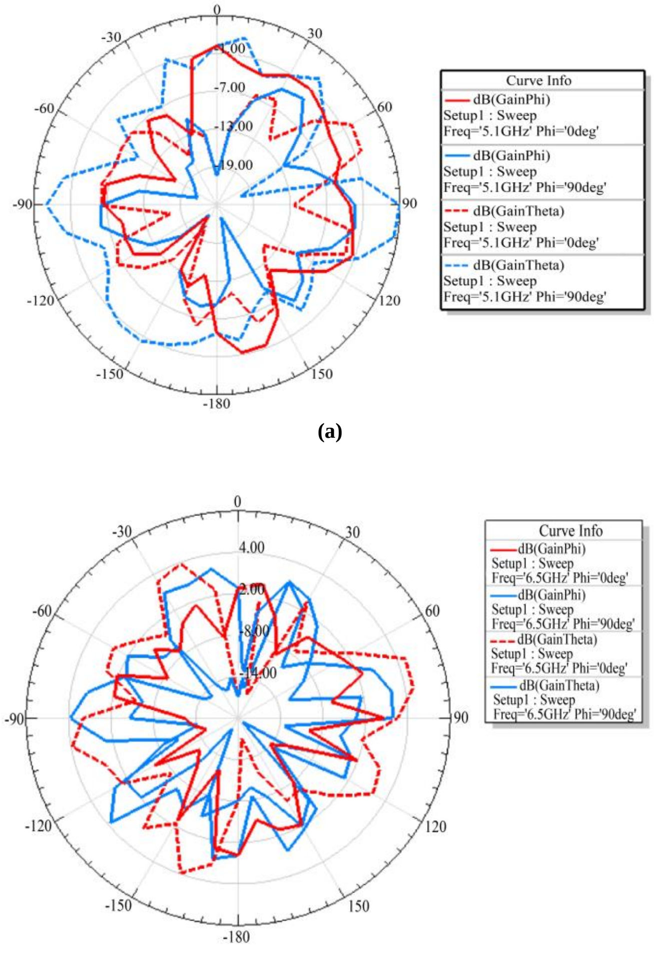
The radiation becomes more focused and directional as frequency increases. At 5.1 GHz, the pattern is broader and less concentrated, while at 7 GHz, it is highly directional with stronger lobes.

5.2.3. Applications

The pattern at 5.1 GHz is suitable for applications requiring broad coverage. The 6.5 GHz and 7 GHz patterns are better for applications needing higher directionality and gain, such as long-distance or targeted communications.

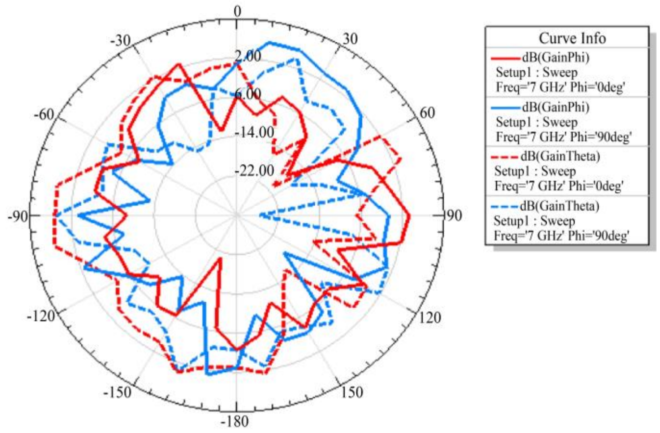
5.3. Radiation Pattern

Figures 10 illustrate the radiations of the antenna at 5.1 GHz, 6.5GHz, and 7GHz in both the Phi = 0° and Phi = 90° planes, showing gain variations in different directions. The antenna's radiation pattern evolves with frequency, becoming more directional and efficient at higher frequencies. At 5.1 GHz, the broad pattern supports multi-directional coverage, while 6.5 GHz provides moderate directionality, and 7 GHz achieves high efficiency for focused applications. This progression highlights the antenna's versatility for Wireless LAN, satellite communication, and C-band operations.



(a)

(b)

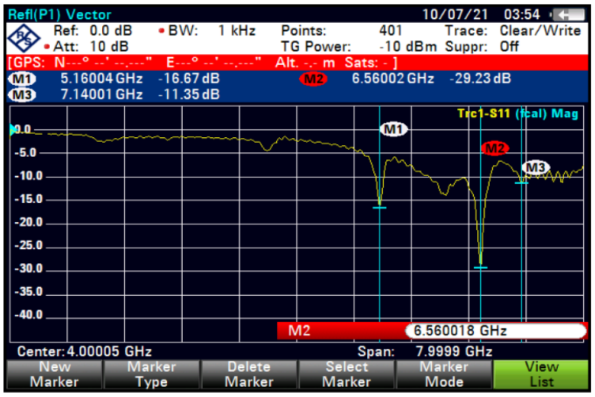


(c)

Fig. 10 Radiation at (a) 5.1GHz, (b) 6.5GHz, and (c)7GHz.

The patterns also depict gain in terms of co-polarization and loss in terms of cross-polarization. The patterns have side lobes, too.

5.4. Measured Results


Refl(P1) Vector 10/07/21 03:54

Ref: 0.0 dB • BW: 1 kHz Points: 401 Trace: Clear/Write
• Att: 10 dB TG Power: -10 dBm Suppr: Off

[GPS: N---° --' --.---" E---° --' --.---" Alt. -.- m Sats: -]

M1 5.16004 GHz -16.67 dB M2 6.56002 GHz -29.23 dB
M3 7.14001 GHz -11.35 dB

M2 6.560018 GHz

Center: 4.00005 GHz Span: 7.9999 GHz

Fig. 11 Measured return loss in dB using VNA


Refl(P1) Vector 10/07/21 03:56

• BW: 1 kHz Points: 401 Trace: Clear/Write
• Att: 10 dB TG Power: -10 dBm Suppr: Off

[GPS: N---° --' --.---" E---° --' --.---" Alt. -.- m Sats: -]

M1 5.16004 GHz 1.35 M2 6.56002 GHz 1.08
M3 7.14001 GHz 1.74

M1 5.1600355 GHz

Center: 4.00005 GHz Span: 7.9999 GHz

Fig. 12 Measured VSWR using VNA

The antenna prototype is validated for the parameters return loss and VSWR using ZVH08 Vector Network Analyzer (VNA). The values of the measured results closely match the simulated results. The comparison of the same is illustrated in Figure 13 and also tabulated in Table 3.

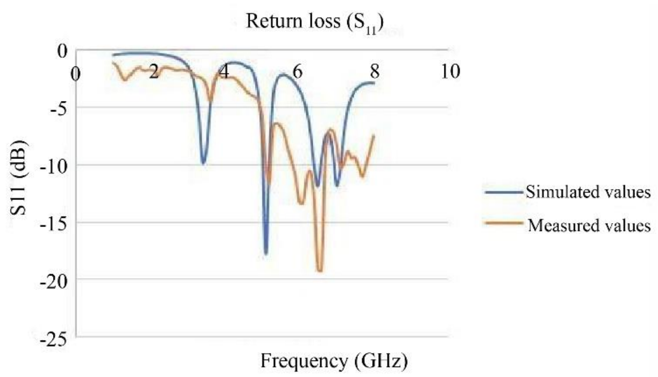


Fig. 13 Measured results vs Simulated results

Table 3. Comparison of results

Parameter	**Simulation**			**Measurement**		
Frequency (GHz)	5.1	6.5	7	5.16	6.56	7.14
S11 (dB)	-17.73	-11.81	-11.73	-16.67	-29.23	-11.35
VSWR	1.29	1.69	1.69	1.35	1.08	1.74

Table 3 compares the simulation and measurement results of the antenna's performance across three frequencies: 5.1GHz**,** 6.5GHz**,** and 7GHz**,** based on the parameters **S**$_{11}$ and VSWR**.** The measured data supports the simulation results well, confirming the antenna's robust design and suitability for operation at mentioned frequencies**.** The measured improvements at 6.5GHz indicate better-than-expected matching, further enhancing the antenna's practical performance.

Table 4. Performance comparison

Reference	**Antenna dimension (mm3)**	**Frequency (GHz)**	**Gain (dB)**
[1]	25x20x1.6	3.6, 5.8, 7.5	-1.28, 1.09, 1.53
[2]	26x26x1.6	3.9, 5.8, 6.7	2.9, 4.6, -1.5
[12]	60x40x1.27	3.8, 5.8, 8.2, 9.7	4.21, 3.2, 5.4, 3.45
[16]	35x35x0.508	2.45	7.3
Proposed	30x30x1.6	5.1, 6.5, 7	4.83, 6.92, 8.46

A comparison of the performance of the proposed work with that of related work is shown in Table 4. The proposed antenna has a volume of 1440 mm^3, which is smaller than [12, 16], yet achieves multi-band operation with high gain values. It offers a better balance of compactness and performance compared to [1, 2], which have smaller dimensions but deliver lower gain and limited frequency coverage. While [16] provides higher gain at a single frequency (2.45 GHz), the proposed design covers. The proposed antenna achieves an excellent trade-off between compactness and performance. It is more compact than large designs like [12] and offers significantly better gain and frequency coverage than smaller antennas like [1, 2]. This makes the proposed design ideal for multi-band applications requiring high gain and moderate size.

6. Conclusion

This work aims to design a miniaturized multiband asymmetric octagonal patch antenna having dimensions 30 × 30 × 1.6 mm^3 involving a tapered coplanar waveguide feed for WLAN, Satellite and C-band applications. The frequencies obtained from this design are 5.1GHz, 6.5GHz and 7GHz with the corresponding reflection co-efficient of -17.73dB, -11.81dB, -11.73dB and gains of 4.83dB, 6.92dB, and 8.46dB, respectively. The VSWR obtained for the corresponding frequencies are 1.29, 1.69 and 1.69, respectively. The fabricated antenna-derived results are similar to those of the simulated one.

Further, the performance can still be enhanced by incorporating CPW feed for the entire patch and increasing the metal on the patch. As the metal increases, the radiation characteristics of an antenna will be better in terms of directivity and gain.

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