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Original Article

Wideband Monopole Pentagon Shaped Slotted Antenna for WiFi6E Applications Based on Partial Ground Structure

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Abstract *- In this paper, a pentagon-shaped slotted monopole antenna for WIFI6E applications based on a partial ground structure is designed, and its performance is evaluated. The pentagon-shaped slotted antenna has a dimension of 44 × 36 × 1.6 mm3 and exhibits good radiation characteristics most suitable for wifi6E applications. The designed structure is fabricated on FR4 high dielectric substrate material to evaluate the antenna characteristics. Four arc slots are removed from the pentagon patch to resonate at wideband frequencies. Simulation has been done in ANSYS HFSS SOFTWARE 19v. A peak gain of 6.2 dBi is attained by the pentagon-shaped slotted antenna, and the antenna produces a bi-directional radiation pattern.*

Keywords *- Partial ground structure, UWB, Wifi6E, Monopole antenna.*

1. Introduction

Different communication systems are often combined to promote multi-communication in the development of modern communication. 5G wireless broadband networks provide high-speed wireless connectivity and comprehensive area coverage. Wifi is mainly preferred for indoor use with less deployment cost [1]. Wifi 5, Wifi6, and Wifi 6E Technologies provide high-speed internet connectivity up to a 6GHZ frequency band. Such Large bandwidth, high speed, and data rate are achieved by UWB antennas to support multiple applications [2, 3]. The growth of wireless technologies created the demand to develop the UWB antenna. FCC (Federal Communication Commission) Recommends that the spectrum range from 3.1-10.6 GHZ for UWB applications in 2002. Microstrip patch antenna is more attractive and widely used in UWB applications due to its compact structure.

2. Literature Survey

Several Monopole configurations of microstrip antenna in different shapes (square, hexagon, Triangle, etc.) have been implemented due to their reduced size and stable radiation characteristics. The author proposed the antenna model (Figure 1) in the paper [4], which consists of double circular split. The designed monopole structure is compact and operated in the frequency range of 3.3–3.6 GHz and 5.15–5 GHz.A lever joins the double circular split. A closed loop is created by making a hole in one of the arms of the circular split. The antenna works in the 3.3-6 GHz and 5.5-5.9 GHz. The concept model does not contain complex SRRs or metamaterials, so antenna design is simple. A good design of an asymmetrical monopole antenna with a T strip is analysed in the reference paper [5]. The total length of the ground is 34.9 *20.9* 1.6 mm^3. The antenna is made up of material FR4 and fed by 50-ohm microstrip lines. This structure produces many resonance frequencies, which enhances the antenna bandwidth. Its coverage area includes Bluetooth operates at 2.4 GHz, WLAN at 5.1 to 5.8 GHz, WiMAX at 2.3-5.7 GHz, and ISM at 2, 4, 5, and 5.8 GHz.N. A. Jan *et al.* proposed a high gain and increased bandwidth monopole antenna for wideband applications [6].

An inverted triangle pattern and adding two small I-shaped lines to the patch achieves optimized radiation. The ground structure was placed in the square hole, and the measurements were adjusted to observe the UWB resonance. An inverted triangle pattern structure attains a peak gain of 4 dBi.The reference paper [7] shows that the octagonal-shaped antenna can eliminate interference. In addition to that octagonal shape patch, C-slot and CSRR have been implemented to obtain rejection characteristics in the design. This structure is compact in nature and also effectively suppresses interference from many wireless applications like Wi-MAX and WLAN. An elliptical antenna stimulated by a disc monopole is shown in the paper [8].

In the UWB spectrum's frequency range, the antenna may achieve ultra-wideband and bidirectional electrical properties. This elliptical antenna has a peak gain 3.9dBi and has many advantages, such as being economical, compact, and easy to fabricate. The fractal antenna's [9] complete ground plane design was updated to reduce return loss and increase efficiency. A half ground with length (Lg) and width (Wg) has a 3-6 GHz bandwidth. Modification in the ground has been done by extending it in horizontal and vertical axes. The S parameter and bandwidth of the fractal antenna increase due to these extensions. The value of the S parameter, gain and standing, the length of the ground, extended ground plane, and geometry of the proposed antenna control the wave ratio of the fractal antenna. The good unipolar fractal antenna [10] was designed and manufactured based on enhanced WPAN and UWB communication bandwidth. The antenna is appropriate for high-speed data transmission because it has steady impedance and power characteristics in the 2.9 to 15 GHz range with a value of gain up to 5 dBi.The fractal antenna and modified ground structure provide a wide variety of possibilities. In order to reduce the loss that occurs in miniature antennas, [11] a basic hexagonal patch shape is needed. Stubs for matching purposes are employed to improve the antenna's bandwidth, while two hexagonal fractal patches are introduced to increase the bandwidth.

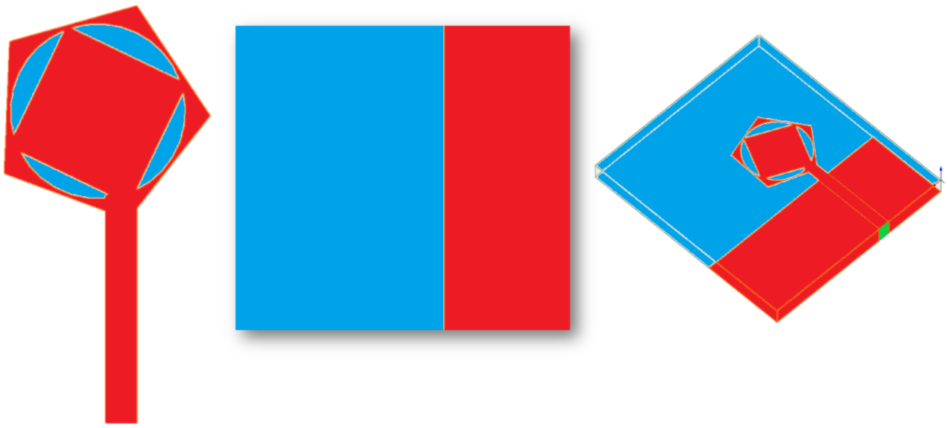
This antenna individually rejects the UWB region's two subbands (4-5.78 GHz and 6.83-8.22 GHz) without degrading its overall performance. With a small size and steady gain, the proposed antenna has shown superior performance compared to existing antennas discussed in the literature for similar applications, making it an excellent option for wifi applications. A simple MCP antenna with a dumble slot [12] on the ground structure has been implemented for various wireless applications having wide bandwidth. In order to get UWB resonance characteristics, a circular patch is created on top of the substrate, and a flawed ground plane is on the substrate's underside. With a gain of 8.4 dBi, and semi-omnidirectional and omnidirectional radiation characteristics, the antenna resonates at 2.9 GHz and 9.1 GHz.A ring-shaped antenna[13, 14] with a cutting-edge 50-ohm feed line and modified ground plane with slots. For UWB applications, this antenna provides outstanding performance and has a bandwidth of 3.088 to 12.497 GHz.

In the article [15], the notch band (1.8-2.3 GHz) is produced by positioning a stub on the bottom side of the patch, and WiMAX bandwidth is accomplished by cutting a tiny slit from the patch. Constructing a U slot for the IEEE 802.11 / HIPERLAN spectrum (5.6-6.1 GHz) is acquired. This self-orienting notch band UWB antenna is intended for many practical UWB applications. A monopole antenna with a printed disc supplied by a 50-ohm line is analysed. Feed differences in frequency response characteristics, ground width, and disk size determine the characteristics of the antenna. Over the whole bandwidth, this antenna produces omnidirectional radiation characteristics. The hexagonal unipolar element is designed [17, 18] for UWB communication in the wideband of 3.1GHZ to 10.6 GHz range. Negative return characteristics are investigated and compared with those of a typical hexagonal monopole antenna in a parametric analysis of antenna characteristics. A rectangular slot in a microstrip patch produces a compact monopole antenna.

Regarding the prototype antenna measurement results, it is shown that there is an increase in impedance bandwidth from 6.63 GHz to 10.04 GHz.The defective hexagonal patch has a radiation pattern comparable to the PRHMA but with 35% less surface area. A planar wideband microstrip slot antenna can produce appropriate radiation properties and impedance matching [19, 20]. It takes up 25% of the 50 mm x 80 mm ground surface throughout its length. A circular monopole antenna with optimized geometry is developed for wireless applications [21]. It has a gain of 2.8dB and omnidirectional radiation patterns all over the impedance bandwidth, making it excellent for UWB. In paper [22], a monopole antenna in a circular shape with notch characteristics in dual frequencies can be implemented with compact SRR. Without adjusting the ground surface or the radiator, minor adjustments to the SRR's size by themselves produce a wideband notch. Many antennas described in these papers have good gain with wideband characteristics. In the proposed article, a pentagonal-shaped slotted patch monopole antenna with a partial ground structure is designed for wifi 6E applications. With a dimension of 40*36*1.6mm^{3,} the monopole antenna produces 6.15 dbi gain with good radiation characteristics. The designed antenna simulation has been done in ANSYS HFSS version 19, and the results are tested using a network simulator.

3. Antenna Design Methodology

A partial ground structure based on a pentagonal-shaped monopole antenna with slots in the patch is designed for WiFi6 applications. It produces a resonant frequency from 4.1GHz to 8.4GHz. FR 4 material with $\epsilon_{r=}$=4.4 and (tanδ) =0.02 and 1.6mm thickness is preferred for the antenna substrate for the design. A partial ground structure-based pentagon-shaped slotted antenna is obtained in different stages. Initially, a pentagon-shaped polygon of 6mm radius is introduced on the substrate over which a diamond shape of the same dimension is printed on it. Then Four slots were implemented, resulting in wide operating bandwidth. At the bottom, the defective ground structure is implemented for a width of 15mm. The footprint measure of the designed antenna is 40 x 36mm. The feedline of length 16.6mm and width of 2.2mm is fed with the patch of the impedance of 50ohm.



(a) (b) (c)

Fig. 1 Proposed antenna (a) Front view (b) Back view (c) Isometric view

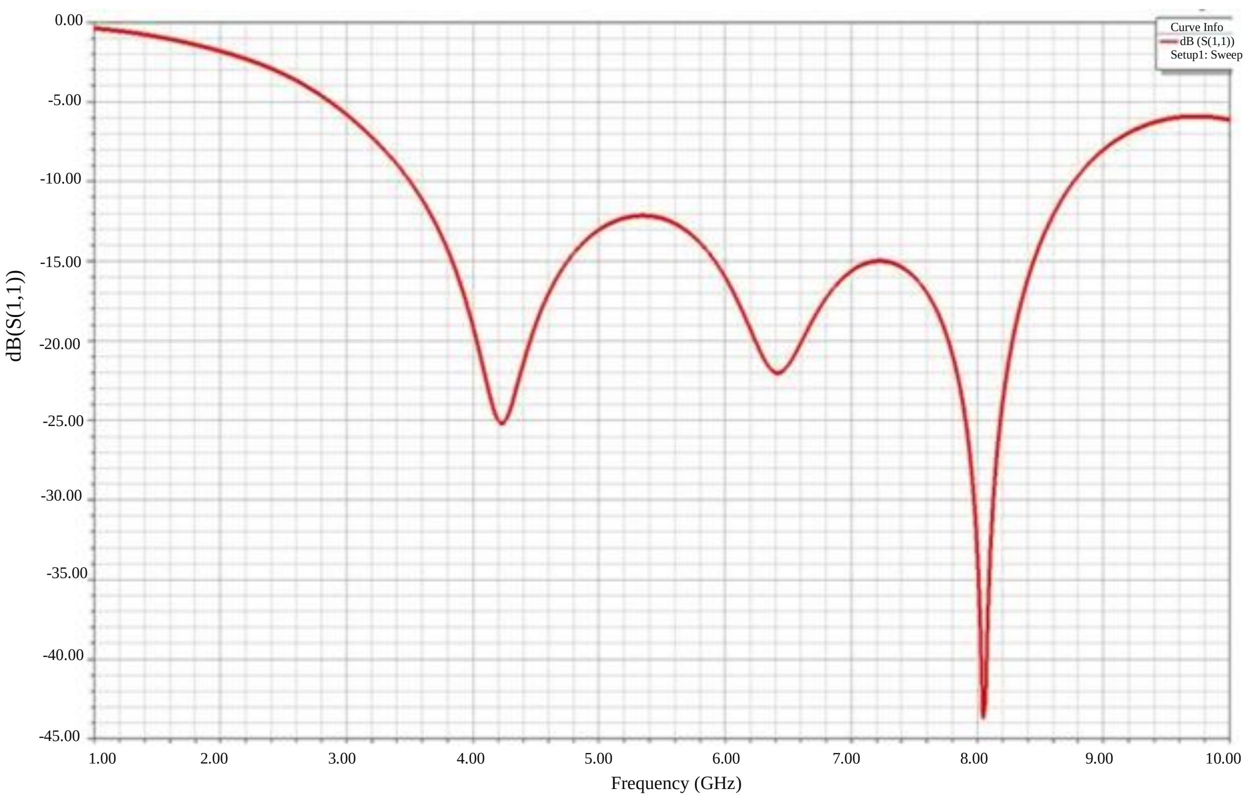


Fig. 2 Simulation reflection coefficient of the proposed antenna

4. Results and Discussion

The pentagon-shaped patch attached to the 50-ohm feed line is taken into the antenna assessment procedure. The patch's diameter is presumed to be 12 mm, and its length is considered to be 16.6 mm. Figure 2 shows the plot simulated reflection coefficient (S11) of the pentagon-shaped slotted antenna. A pentagon-shaped surface linked to a 50-ohm impedance line is seen to resonate at three different resonant frequencies, 4.2GHZ, 6.4GHZ, and 8GHZ, with UWB. The operational frequency spectrum of the antenna extends from 3.5 GHz to 8.7 GHz, covering wireless applications like WLAN (5.15–5.9 GHz) and WiFi 6E (5.92–7.125 GHz)[23]. Compact structures with higher bandwidth and gain are obtained using partial Ground structure. The slotted antenna of a simple manufacturing process achieves enhanced gain and increased bandwidth compared to other techniques. The partial ground structure has been implemented for a 15 mm width at the bottom for improved antenna performance. The reflection coefficient for different ground width of 13mm, w=13.5mm, w=14mm, w=14.5mm, w=15mm, w=16mm has been measured and compared as shown in Figure 3. The partial ground structure below the microstrip line modifies the power line's impedance concerning resistance and inductance.

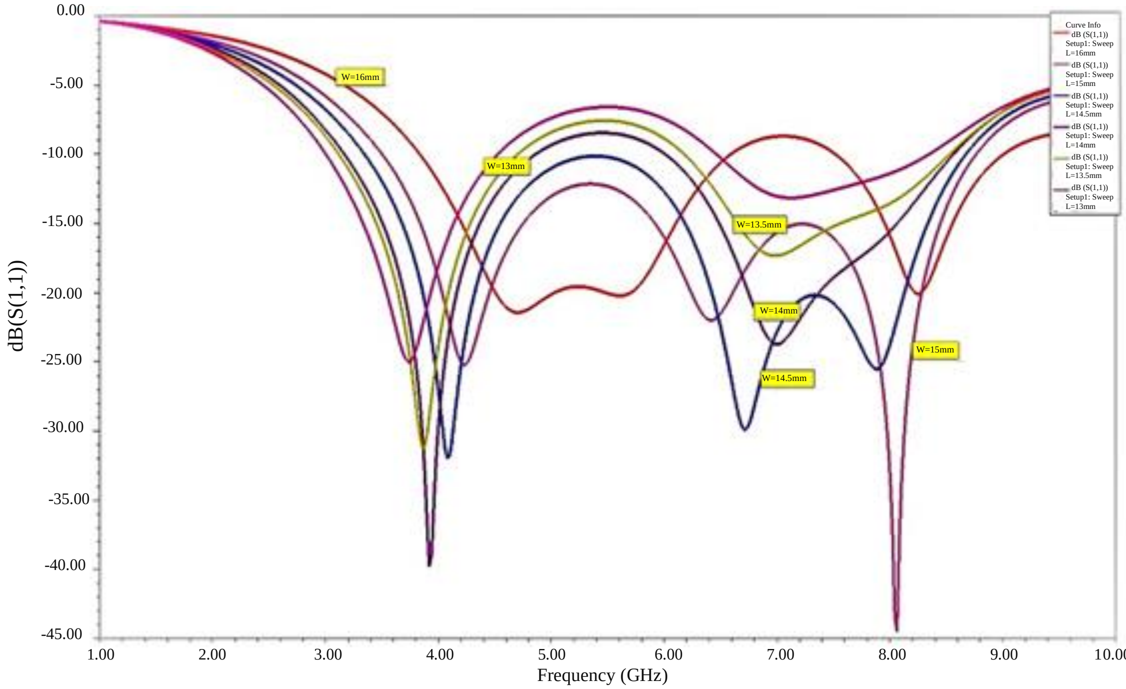


Fig. 3 Reflection coefficient for different widths of ground w=13mm,w=13.5mm,w=14mm,w=14.5mm,w=15mm,w=16mm

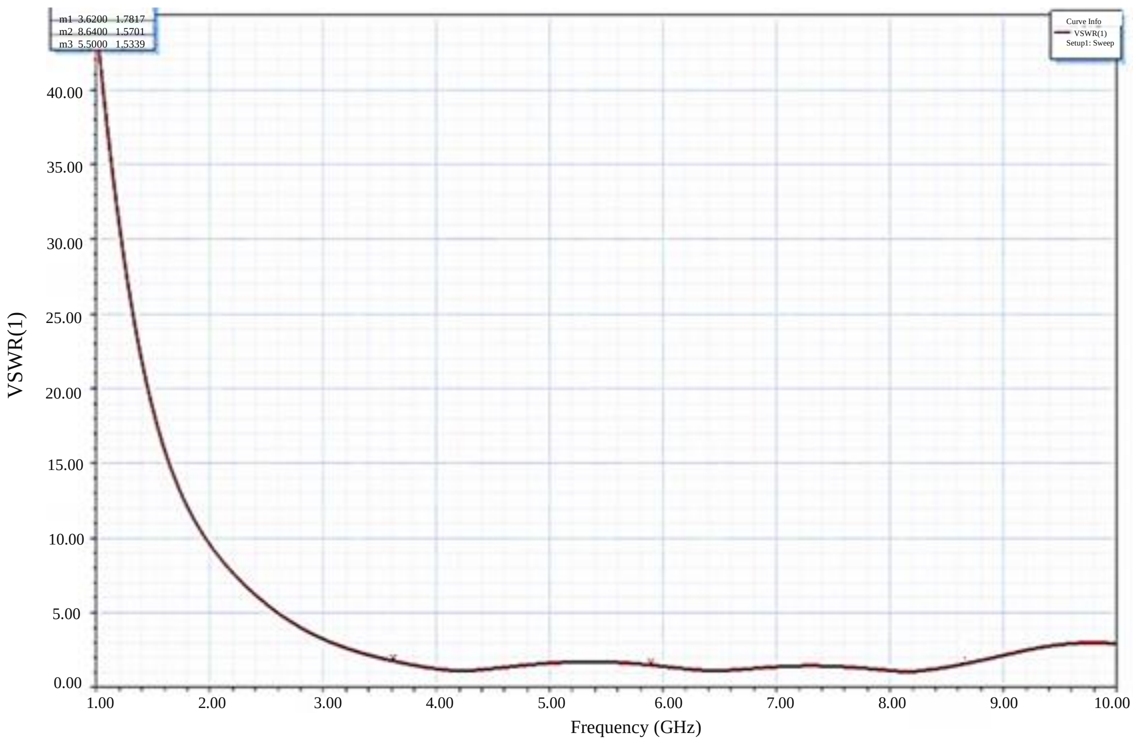


Fig. 4 VSWR of antenna

4.1. VSWR and GAIN

The voltage standing wave ratio of the pentagon-shaped slotted antenna is shown in Figure 4. According to the simulation's output, the value of the VSWR is under two throughout the operational frequency range of 3.5 GHz to 8.7 GHz. Figure 5(a-d) shows a 3D gain of the proposed antenna at different frequencies. The antenna provides a peak gain above 4dBi for all the frequency ranges. In the antenna modelling in HFSS, the highest gain of 6.25dBi is attained. When compared, using a more expensive microwave substrate other than low-value FR4 can increase the gain and efficiency.

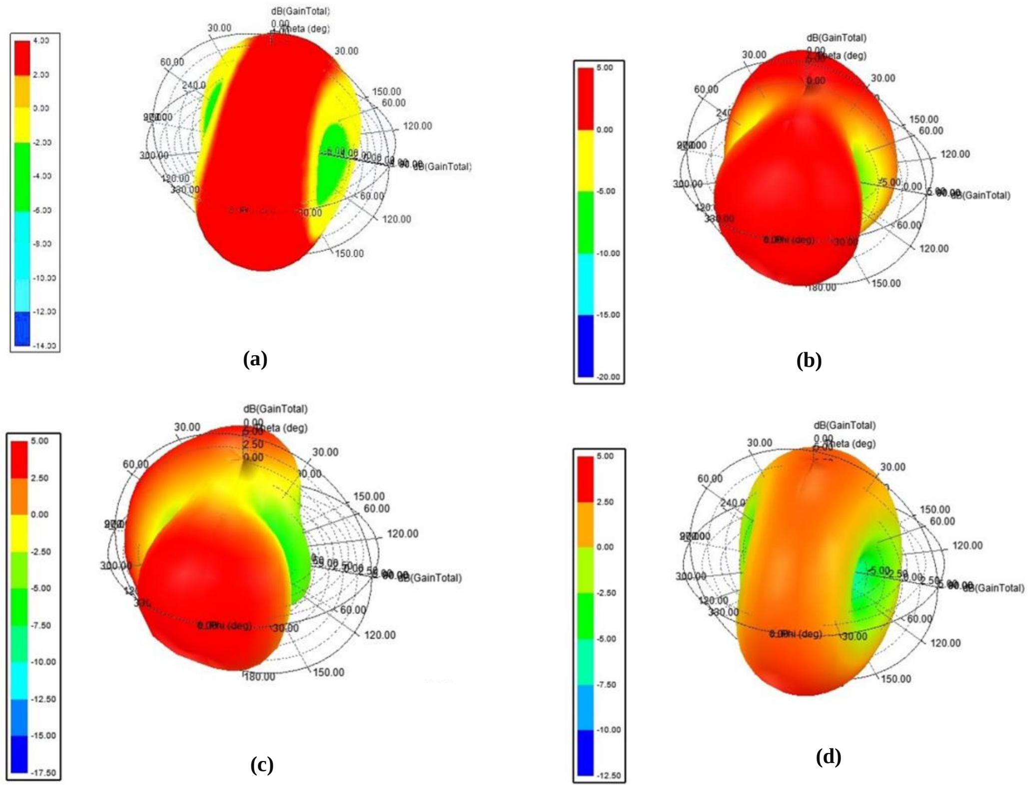


Fig. 5 3D Gain pattern at different frequency (a) 5GHz (b) 6.4GHz (c) 8.1GHz and (d) 4.25GHz

4.2. Radiation Characteristics

Figure 5 shows the 3D dimensional radiation pattern of the designed antenna in both E and H planes at various resonant frequencies. It has been observed that the antenna simulation in HFSS gives consistent results in 2D plots, as shown in Figure 6(a)-6(d). At the frequency of interest, the radiation pattern in the E-plane is omnidirectional, and the radiation pattern in the H-plane is unipolar, making it suitable for many wireless applications. The radiation patterns in both planes will be affected for the frequencies above due to non-uniform phase and higher-order patterns. The radiation pattern in both planes can be modified by deploying a low-voltage and thin substrate and exploring the ground plane.

4.3. Field Distribution

In Figure 7 field distribution of the pentagon-shaped slotted antenna is shown. From the observation of output images, the maximum current distributed in the microstrip patch has been observed. It is noticed that the microstrip patch has more current density, which is observed in Figure 7a. The feed line connected to the pentagon-shaped patch has a scattered distributed current throughout the line, which causes the significant contribution of radiation of the antenna. Uniformly distributed current appears across the partial ground structure over the width of 15 mm. The Efield distributions rotated in a pentagon-shaped patch at selected points along the feed line and pentagon patch for 0° and 360° phase angles. The field current is distributed at both pentagon-shaped slot antenna, feed line, and partial ground structure.

4.4. Comparison of S Parameter

Figure 8a-8b shows the fabricated image of a pentagon-shaped slotted patch antenna. The fabrication is done using low-cost FR4 material. The S parameter of the prototype antenna is measured using an Anritsu MS2027C vector network analyzer (VNA) in the frequency range of 5 KHz to 15 GHz. Its S parameter is measured and compared with the simulated S parameter value in Figure 9.

Table 1 shows the Comparative measurements of the S parameter of the simulated and measured S value of the prototype antenna and its bandwidth. It is readily apparent that the simulated and observed S11 exhibit good agreement. Measured bandwidth of 4.6 GHz and a simulated bandwidth of 4.9 GHz were observed for S11.In terms of comparability between the simulated and measured findings, the suggested pentagon-shaped slotted monopole antenna performs efficiently. In the 3.8 GHz to 8.7 GHz band, measured findings outperform simulated outcomes when analyzed with the network analyzer. The Pentagon-shaped slotted monopole antenna based on partial Ground structure performance is compared with the recent antenna with its gain and operating frequencies shown in Table 2.

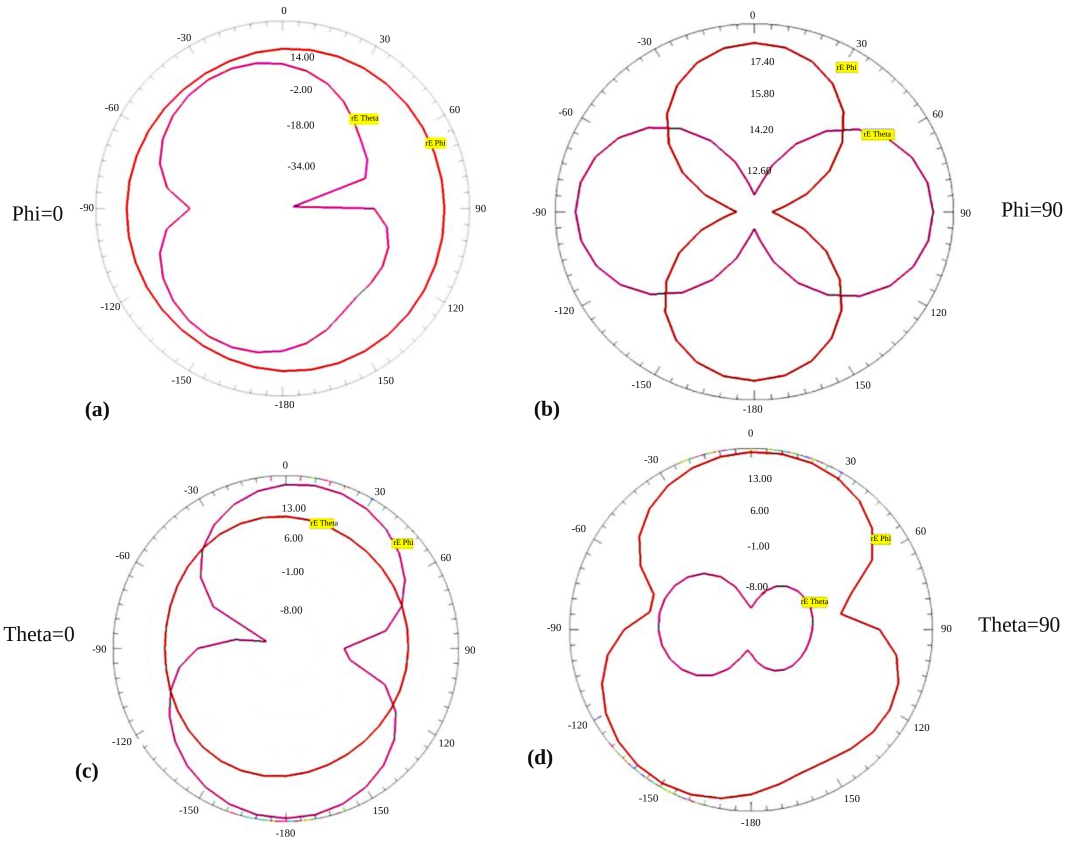
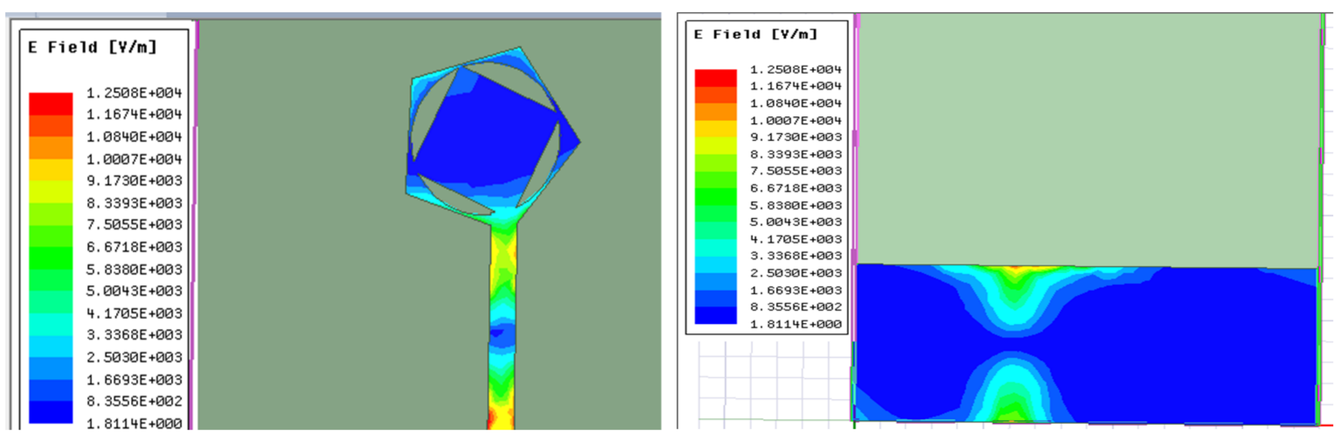


Fig. 6 Radiation pattern at different cases of the proposed antenna



(a) **(b)**

Fig. 7(a) Surface current distribution in the patch (b) Surface current distribution in the ground

Table 1. Simulated and measured reflection coefficient (S11) comparison table

S.No	Measurement	S11	Operating Frequency (GHZ)	Bandwidth (GHZ)
1	Simulated	≥ -10 dB	3.8-8.7GHZ	4.9GHZ
2	Measured	≥ -10 dB	3.8-8.4GHZ	4.6GHZ

Table 2. Comparison of antenna size, gain and bandwidth with recently designed antenna

S.No	Reference Number	Size of antenna in mm^3	Operating frequencies in GHZ	Bandwidth in GHZ	Gain in dB
1	[13]	350 × 240 × 1.6	4.5 9.5	9.2(3.1–12.3)	4.2 6.8
2	[16]	50 × 42 × 1.5	3 6.5	7.47(2.69–0.16)	< 8
3	[21]	28.1 × 17.1 × 1.4	5.2 10.8	(4-40)	2.8
4	[34]	30 × 30 × 1.6	4.1 8.8	6(4-10)	< 5
5	[35]	22 × 24 × 1.6	3.4 7.5	8.2 (3–11.2)	< 5.4
6	[36]	44 × 46 × 1.6	4 7.8	10.87 (2.83–13.7)	2-5
7	Proposed work	44 × 36 × 1.6	4.25 6.4 8.1	8.65-3.5	6.25

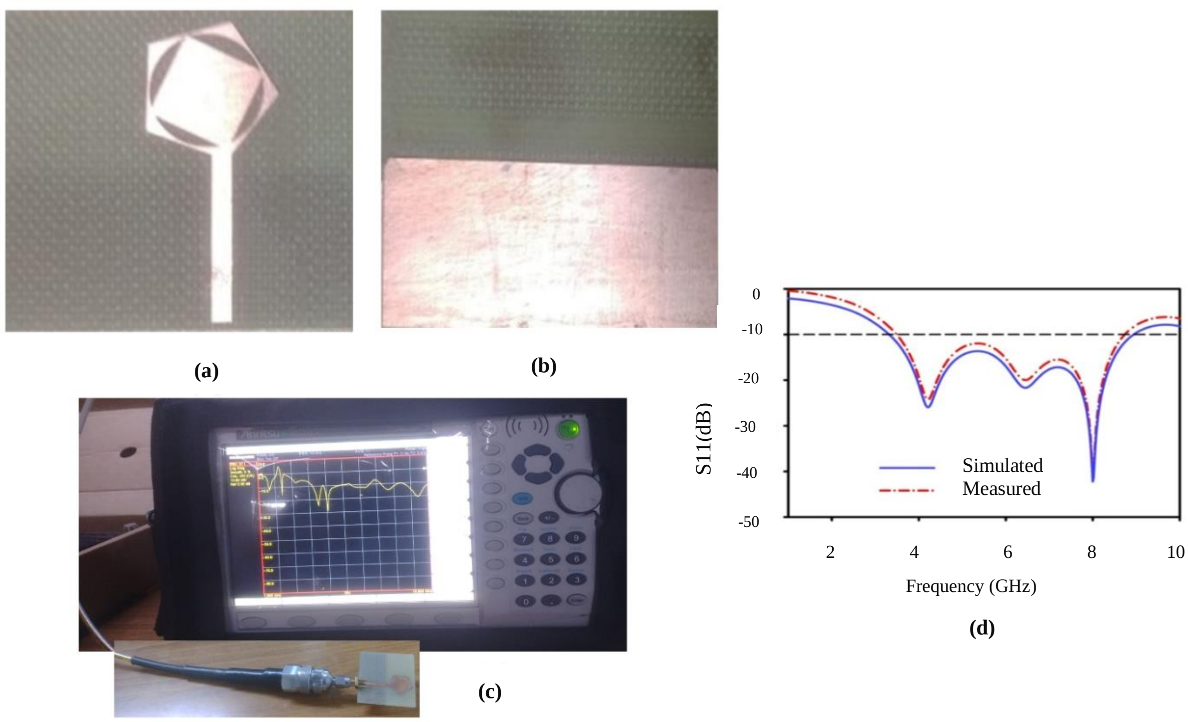


Fig. 8 Fabricated and measured results of proposed antenna (a) Front view (b) Back view (c) Measurement set up of VNA (d) Simulated and measured reflection coefficient results

5. Conclusion

A pentagon-shaped slotted monopole antenna based on a partial Ground structure has been implemented and investigated in this paper. The partial ground structure in the geometry performs the task of improving VSWR bandwidth over a wide bandwidth. The patch connected to the feed and slot deployed in the patch achieves optimal resonance frequencies at 4.2 GHz, 6.4 GHz, and 8.4 GHz, respectively. The antenna provides a reflection coefficient of S11=-50db and a gain of 6.2dbi, which is suitable for Wifi 6E applications to provide a wide operating bandwidth of (5.925-7.125 GHz). The MIMO technique may be a two or four-port antenna, could be implemented in this design for future research work.

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