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Research Article

A Semi-Circular Polygonal Monopole Antenna for Ultra-Wideband (UWB) Applications

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ABSTRACT

In this paper, a new semi-circular polygonal monopole antenna with partially grounded plane to cater the needs of next generation mobile navigation is proposed. The designed semicircular polygonal slot radiator provides desired S11 parameter's greater than -10 dB in the UWB frequency range. As for the proposed antenna, it has been designed on an FR4 substrate with a dimension of 30 x 28 x 1.6 mm. It is used in the frequency bandwidth of 3.3GHz to 13.4 GHz. At 4 GHz, 5.3 GHz, 6 GHz, 8 GHz the design has reciprocal radiation that can be described as omnidirectional. Thus, the antenna provides a bandwidth of gain in a range of 3.0-6.5dB. In this study, development of a compact printed rectangular monopole antenna suitable UWB application is proposed because it possesses several benefits such as small size in terms of antenna dimension, enhanced impedance matching, relatively ease of fabrication, and high gain.

Keywords: : High gain, Monopole, Semi Circular Polygonal antenna, UWB

INTRODUCTION

With fast progress in wireless communication technologies, high performance antennas with high bandwidth, efficiency, compactness are required so as to meet its demand. Ultra-wideband (UWB) antenna has drawn some much attention because it has several advantages including high data rates, low power consumption, easy fabrication among others. It is an area of great interest as the rise up of such advanced wireless applications based on 5G and beyond, demands the design of antennas with enhanced gain, directivity and beam steering. There are many researches that have been carried out in designing UWB monopole antennas along with filtering mechanisms to enhance their performance in wireless communicating systems. Within wireless communication systems, a bandwidth of 31 - 106 GHz of a UWB monopole antenna with built in filtering has been achieved in a paper of 30 x 20 mm² [1]. The other study constructed a high gain UWB antenna array which is suitable for 5G and beyond application with a bandwidth of 24 to 40 GHz, with antenna size of 50 × 50 mm² [2] and for radar application a high gain microstrip array antenna with beam steering capability which covers X band frequency range (8 to 12 GHz) with antenna size of 100 × 100 mm²[3]. This was also combined with a rectangular microstrip patch antenna based on FR-4 substrate that has a size of 40 × 30 mm² and wireless bandwidth of 2.4–5 GHz [4]. A rectangular linear microstrip patch antenna array was designed for 5G communications with a bandwidth of 5 MHz at a range of 26 to 30 GHz [5]. An octal annular ring shaped planar monopole antenna is presented in another study which is optimized for use with Wi-Fi and UWB applications having a bandwidth of 3–11 GHz with an antenna area of 35 × 25 mm2 [6]. They proposed a wideband and widebeam high gain unidirectional dipole antenna for next generation WLAN applications that operates over 5–10 GHz with size of 50× 40 mm2 [7]. An UWB patch antenna with a bandwidth of 0.78–4.22 GHz was designed and realized with the compact size of 45 × 35 mm² [8]. A UWB planar monopole antenna based on a ribbon shape slot for compact design was proposed, and it covers a bandwidth of 3–12 GHz with a size of 28 × 22 mm² for its performance [9]. There was a proposed compact microstrip patch

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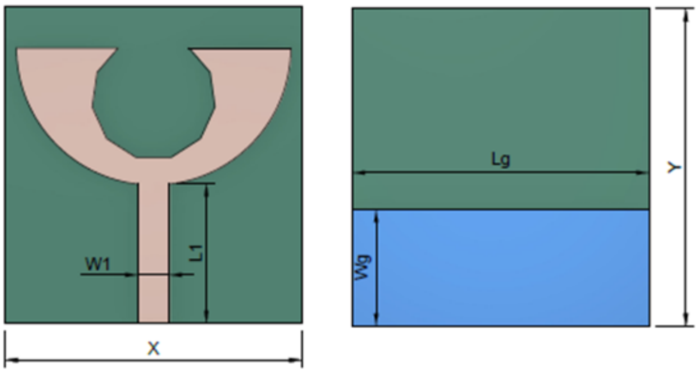
antenna for wideband application from 1.8 to 6.5 GHz, with antenna size of 38 × 28 mm² [10]. A tri band circular patch microstrip antenna with different shapes embedded in a defected ground structure (DGS), was designed for Ku and K band applications, and has bandwidths ranging from 12–14 GHz and 18–22 GHz with a compact size of 48 × 32 mm² [11]. Finally, a satellite application asymmetrical coplanar strip semicircular ring patch antenna was analysed that occupies 40 × 30 mm² and has a bandwidth of 3.5–10 GHz [12]. These studies demonstrate significant progress in the development of compact, high-gain, and wideband antennas catering to various wireless communication applications.

A new semi-circular polygonal cut shape antenna is presented in this paper along with its modified defected ground structure which produces suitable gain and impedance bandwidth performance for UWB operations. A modification process of ground plane adds functionality for observing UWB resonance characteristics.

The plan of this following paper follows this sequence. Section 2 shows a detailed description of the proposed planar monopole antenna's geometrical layout together with comprehensive discussions about design evolution steps as well as parametric modelling. The paper contains discussions about simulated outputs and measured outcomes in Section 3 before offering a conclusion in Section 4.

PROPOSED ANTENNA DESIGN

A fabrication process for the antenna takes place on an FR4 substrate with dimensions of 1.6 mm height and electrical constants of 4.4 relative permittivity and 0.02 loss tangent. The overall dimensions of the antenna are 30 × 28 mm². The antenna designed from semi-circular patch to polygonal slot shape shown in figure 1. Input impedance of an antenna from 3.3-13.4 GHz frequency band. The performance of UWB is enhanced by a portion of the ground plane. The antenna's design as seen in Figure 1 are Y=30mm, X=28mm, W1=3mm, L1=12mm, Lg=28mm, Wg=11mm.



Frant View   Back View

Figure 1: UWB Single element antenna

2.1 Steps in Antenna Design

This section discusses the proposed single element structure evolution steps, as illustrated in Fig. 2, and compares their reflection coefficients in Fig. 3. The first stage involves designing a basic half-circular Single element antenna that operates at a resonance frequency of 4 GHz and has a partial ground plane. The bandwidth response attained at step one is transformed into a wideband ahead of 6.5 GHz by the introduction of an octagonal shape slot at stage two. In third design steps introduces a polygonal form, which makes the response attained at stage two ultra-wideband, encompassing the frequency range of 3.3 to 13 GHz.

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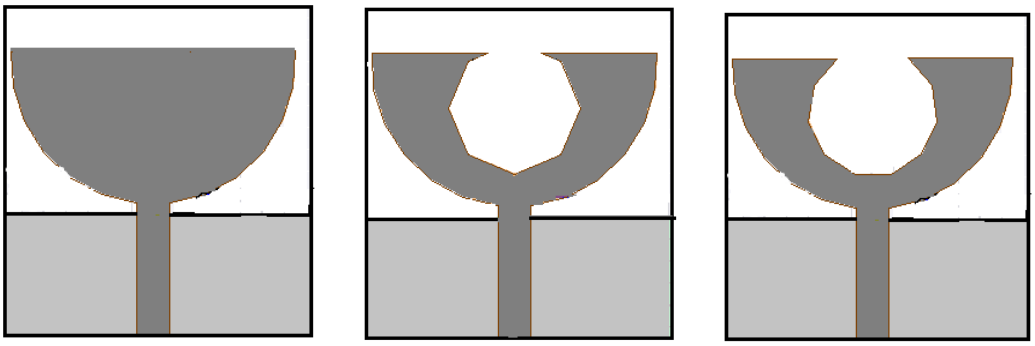
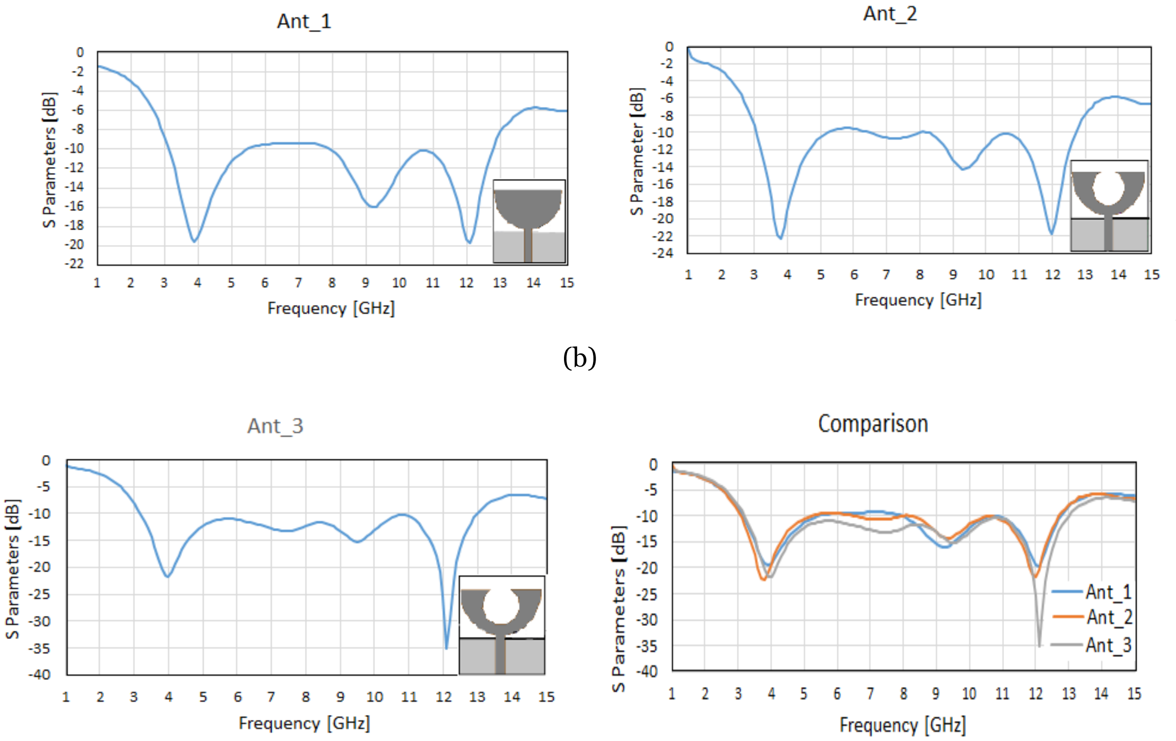


(a) (b) (c)

Figure 2: Single element antenna design. (a) The first step, (b) The second step, and (c) The third step



(c) (d)

Figure 3: Single element antenna coefficient of reflection comparison. First stage (a), second stage (b), third stage (c), and overall comparison (d)

2.2 Ground Plane improvement

The design elements of the suggested design are examined parametrically in order to produce a UWB response. This section discusses the ground plane, one of the primary design elements. Fig. 4 shows the S-parameter response for the study mentioned above. The simulation shows a relationship between the antenna's frequency band and return loss. Electromagnetic coupling has been introduced by using the step size structure and distinct ground cutting planes of 9 mm, 10 mm, and 11 mm, respectively. The lowest return loss value is around -35 dB at 12 GHz with an 11mm ground plane Due of the substantial reliance of bandwidth on size of the ground plane dimensions are crucial design factors for these antennas. Figure 4 displays the return loss for a range of ground plane length Lg values. (Width is constant as Wsub = 28mm).It is evident that GP length has a significant impact on bandwidth. The GP width of 28 mm is used in order to create a small UWB antenna. The length then changed for 9mm, 10mm, and 11mm values. Lg = 11mm has the best impedance bandwidth.

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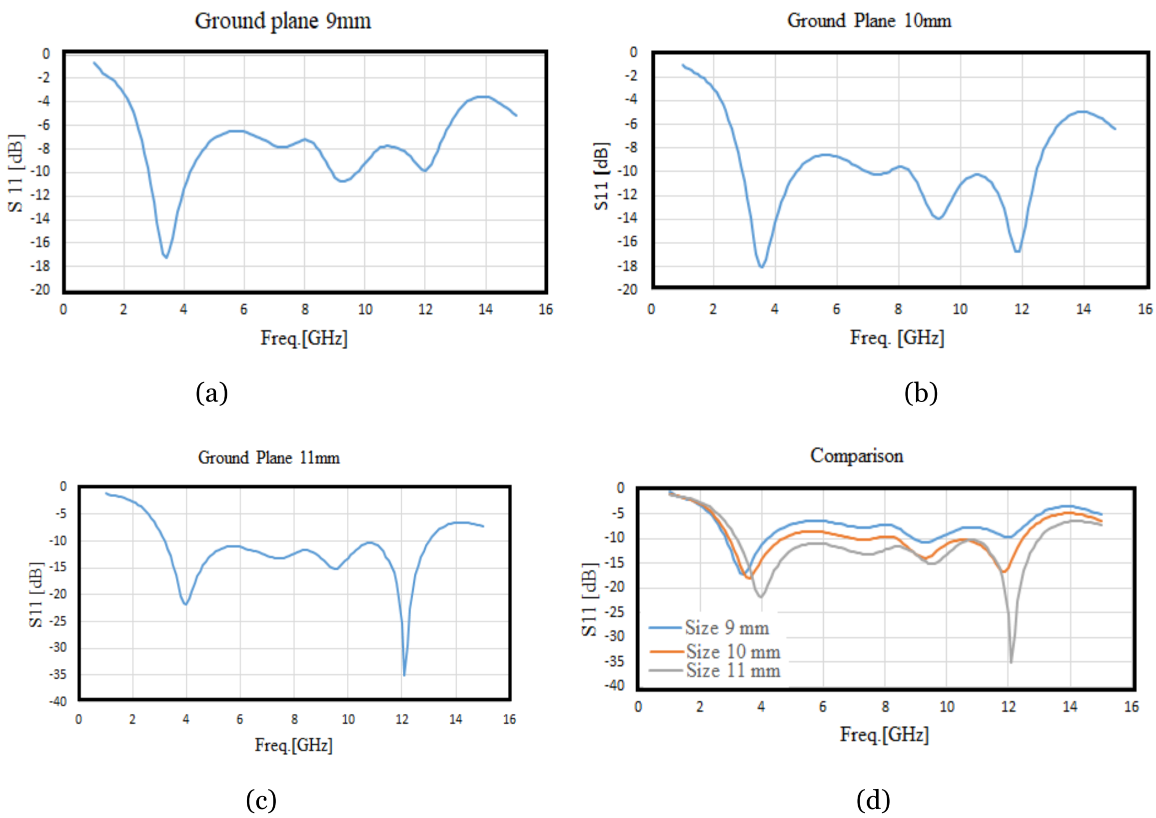

Figure 4: S11vs Freq. response with different ground plane (a) 9mm, (b) 10mm , (c) 11mm, (d) Comparison all Ground Plane

2.3 Effect of Substrate

In the given polygonal antenna, FR4 shows better S11performance than Teflon and silicon due to its balanced dielectric constant [εr≈4.4], which facilitates better impedance matching to a typical 50-ohm system. Teflon, with a lower [εr≈2.1] can result in impedance mismatches unless the antenna is specifically optimized for it. Silicon's high [εr≈11.9] causes strong impedance mismatches and surface wave losses, degrading S11.Antennas are often designed and optimized for FR4, which is widely used in PCB fabrication, making it easier to achieve good results. In contrast, silicon introduces higher dielectric losses and changes the effective electrical dimensions, causing detuning. Overall, FR4's properties and compatibility with common design practices lead to better S11results in this scenario.

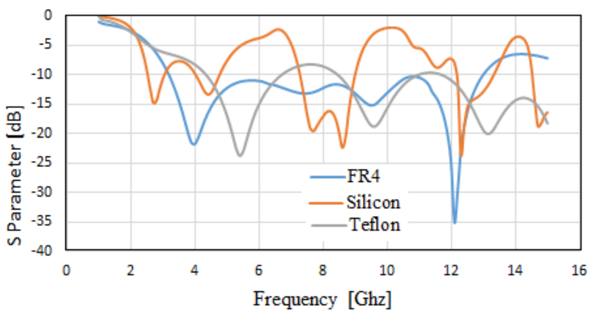

Figure 5: Effect of Substrate with Comparison

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RESULTS AND DISCUSSIONS

3.1 S-Parameter

Figure 3 [c] displays the Return Loss plot for the above suggested design. Return Loss is the plot of Reflection Coefficient (dB) against Frequency (GHz).According to the produced graph, At 3.32 , 3.93 GHz, and 12.21 GHz, the recommended antenna's return loss is -10.11 , -31.25 dB, and -35.13 dB, respectively. The bandwidth found for the resonant frequency starts at 3.3 GHz and ends at 13 GHz.

This section discusses the findings of the suggested ultra-wideband antenna, including the radiation efficiency, patterns, and reflection coefficient. Figure 6 displays the measured return loss of the suggested antenna. This graph makes it clear that the return loss value between 3.3 GHz and 13 GHz is less than -10 dB, which is consistent with the outcome of our simulation.

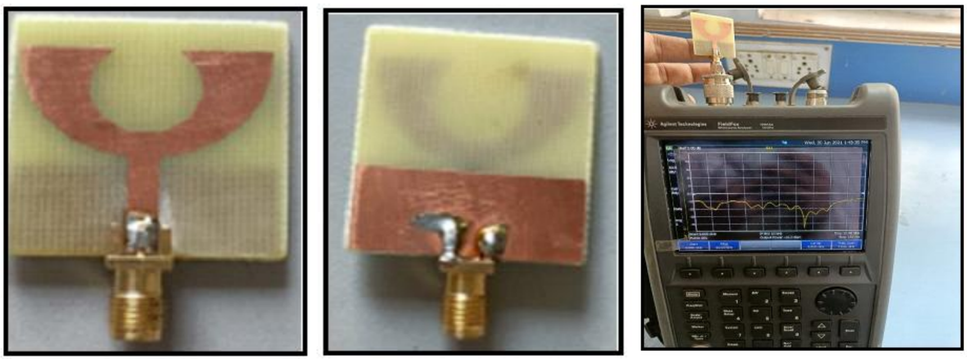

Fig. 6 Antenna measurement setup

3.2 Pattern of Radiation

Simulated radiation patterns are shown in Fig. 7. The two principle planes, or E and H planes, are used to evaluate the gain patterns for the frequency ranges of 4, 5.3, 6 and 8 GHz. It is evident that at the targeted frequency ranges, The patterns of radiation are nearly omnidirectional. A slight discrepancy is caused by production flaws or the inevitable use of cables during the measurement process, but overall there is good coherence across the patterns. With a 4 dB peak gain, the desired ultra-wideband is achieved.

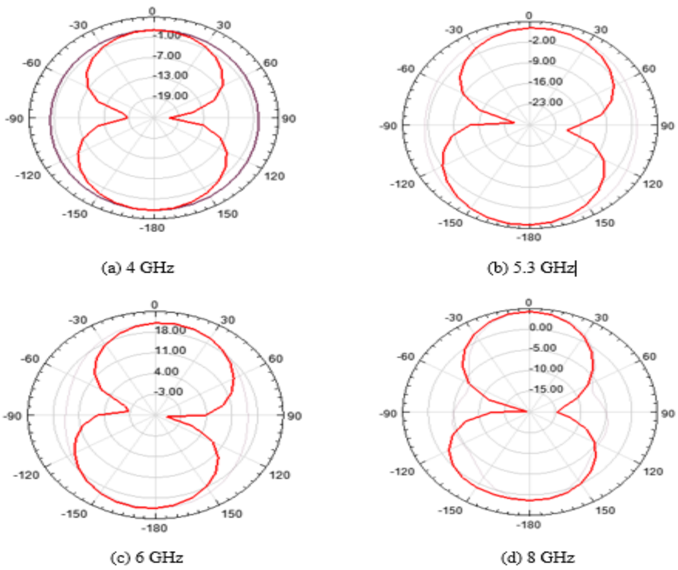

Figure 7: UWB Antenna Simulated radiation patterns at (a) 4 GHz (phi = 0 deg.), (phi = 90 deg.), (b) 5.3 GHz (phi = 0 deg.), (phi = 90 deg.) (c) 6 GHz (phi = 0 deg.), (phi = 90 deg.), (d) 8 GHz (phi = 0 deg.), (phi = 90 deg.),

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3.3 Surface Current Distribution

As illustrated in Fig. 8, the distribution of surface currents of the suggested design is examined at the bands of frequencies of 4GHz, 5.3GHz, 6GHz and 8 GHz. The surface current distribution shows that wideband responsiveness is facilitated by both the patch and the ground plane. The current is concentrated on the lowest edges of the circular radiating element at 4 GHz. At the boundaries of its borders, surface currents induce the ground plane as a whole. The I-shaped towers show increased surface current intensity at higher frequencies, even though the surface current distribution is mostly centred at the circular radiating element's bottom.

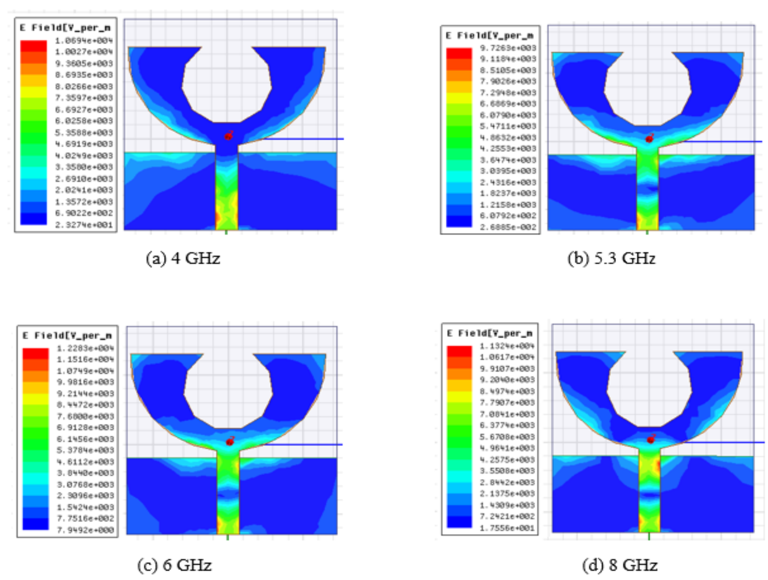

Figure 8: The distribution of UWB antenna surface current at (a) 4 GHz, (b) 5.3 GHz, (c) 6 GHz, and (d) 8 GHz

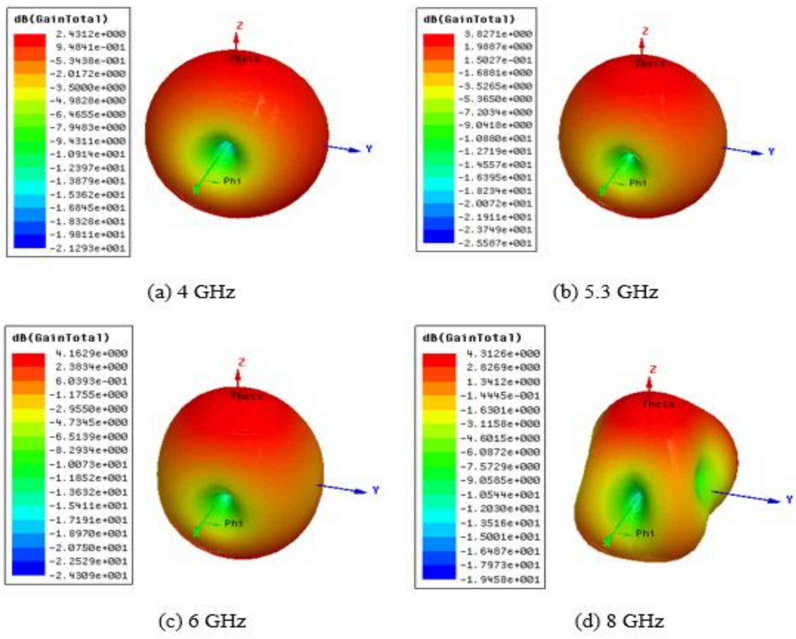

Figure 9: Single element UWB antenna 3D Polar plot of gain (a) 4 Ghz, (b) 5.3 Ghz, (c) 6 Ghz, (d) 8 Ghz

3.4 3D Polar plot of gain

This antenna property establishes the amount of total power which radiates within specific directions. The power measurement of antenna gain utilizes the dB unit that defines its logarithmic power ratio to an isotropic antenna.

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The identified resonant frequencies have their 3D polar plot illustrated in Figure 9.

3.5 VSWR

In general, VSWR is the ratio of the wave's internal dielectric storage voltage maximum to its internal voltage minimum. For optimal performance, the VSWR range needs to be between 1 and 2. The planned antenna's resonant frequencies have VSWRs of 1.75, 1.45, and 1.02 for 3.32 , 9.4 GHz, and 12.21 GHz, respectively, as seen in Figure 10.

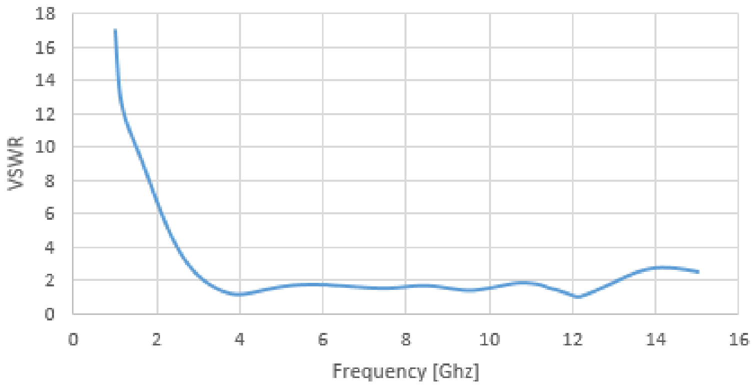

Figure10: Voltage standing wave ratio

Table 1: The suggested antenna's comparison with previous work

Ref	Antenna Size	Bandwidth	Gain	Efficiency
1	40 mm × 30 mm	3.1–10.6 GHz	4–7 dBi	>90%
6	40 mm × 30 mm	3–12 GHz	~6 dBi	~85%
9	30 mm × 28 mm	3–10 GHz	6–7 dBi	~85%
10	50 mm × 40 mm	4–8 GHz	~7 dBi	~80%
11	40 mm × 35 mm	12–20 GHz	~8 dBi	~75%
12	50 mm × 50 mm	10–15 GHz	8–9 dBi	~80%
This paper	30 mm× 28 mm	3.3 - 13 GHz	4-6 dBi	80%

CONCLUSION

The new semi-circular polygonal cut antenna design presented in this research has size of 30 x 28 x 1.6 mm3 and is supplied by a 50 ohm micro strip transmission line for UWB applications. By inserting a polygonal cut in the patch and altering the ground plane on the radiating element, the single element antenna displays a broad response and can function within the range of 3.3 to 13 GHz. Additionally, the suggested antenna achieves a 4 dB peak gain throughout the intended frequency range. Additionally, the suggested antenna is constructed, and the measured and simulated results agree well, confirming that suggested antenna is a strong candidate for UWB applications. The next step, pattern variety and isolation can be achieved by using the suggested antenna in a Multiple Input Multiple Output arrangement.

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