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Design and Optimize a Quasi-Elliptical Patch Antenna for Wireless Communications

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Abstract

This work presents a new method for modeling, and bandwidth optimizing of the Quasi-Elliptical Patch Antenna (QEPA) using Computer Simulation Technology (CST) tool. the modifying shape allows for polarization control, enabling the generation of linear and circular polarized. This flexibility proves invaluable in fields such as satellite communication and radar systems where polarization alignment is essential. Another significant advantage of QEPA is their ability to offer wider impedance bandwidths compared to certain other patch antenna shapes. This makes them well-suited for applications demanding broadband communication, especially those involving high-speed data transmission. Their compact form factor makes QEPA ideal for use in contraindicated environments and devices, enhancing integration possibilities. Additionally, in wireless communication systems employing multiple-input, multiple-output (MIMO) or diversity techniques, these antennas can provide polarization diversity, reduce signal fading and enhance overall system performance. QEPA is also adept at customizing radiation patterns. The developed QEPA exhibits the following characteristics at its resonant frequency 6.346 GHz, operating bandwidth 6.7%, return loss -40 dB, impedance matching

Keywords: quasi-elliptical Patch antenna (QEPA); Slot-loaded; Bandwidth Enhancement; UWB; Partial Ground Plane.

الخلاصة:

تُقدم هذه الدراسة طريقة تصميم جديدة لهوائي رقاقة مُتناهية الصغر بيضاوية الشكل (QEMA) لتحسين عرض النطاق الترددي. يوفر هوائي QEPAالمُقترح تحكمًا متعدد الاستخدامات في الاستقطاب، مما يُتيح توليد استقطاب خطي ودائري. تجعله عروض النطاق الترددي للمعاوقة الأوسع، مقارنةً ببعض هوائيات الرقعة الأخرى، مناسبًا للاتصالات واسعة النطاق. يُسهل حجمه الصغير دمجه في الأجهزة ذات المساحة المحدودة. بالإضافة إلى ذلك، فإنه يوفر تنوع الاستقطاب مما يُقلل من تلاشي الإشارة. يُحقق هوائي QEPA المُصنّع، الذي يعمل بتردد 6.346 جيجاهرتز، عرض نطاق ترددي بنسبة 6.7% . يُظهر فقدان عائد يبلغ -40 ديسيبل، ومطابقة معاوقة 50 أوم، وكسب محقق يصل الى 11.63 ديسيبل، ونسبة موجة الجهد الواقفة (VSWR) تقريبا 1.06. استُخدمت طريقتان لتحسين عرض النطاق الترددي. حُقق التحسين الأول باستخدام طبقة أرضي جزئي مُحسَّن، بينما أُنجز التحسين الثاني بحفر شقوق في الرقعة. وحُقق عرض نطاق ترددي بنسبة 146% بتصغير وتغير وتحويرشكل طبقة الأرضي. أما تحسين عرض النطاق الترددي، فقد تحقق بحف تجويف مربع في داخله حلقة موصلة في مركز رقعة الهوائي.

1. INTRODUCTION

An antenna plays a critical role when energy needs to be sent across a system with many speaking points [1]. Here, the energy wave efficiency transfer increases along with gain wave interference that is reduced from different sources [2]. The industry of multi-band communication systems is expanding today; it is doing so in order to meet evolving developmental demands [3]. Different forms of information transmission include video, email, text, and audio. The elliptical-shaped Patch antenna is thus important in various applications due to the significant revolution in the communications world where it can play a role [2-4]. The elevated mono-pole sleeve antenna has its metallic coating (copper) very thin and placed just above the ground plane of conductivity (copper); both are separated by an FR-4 dielectric substrate [5, 6]. An elevated mono-pole sleeve antenna has a thin copper coating placed uniquely [7]. Just above the ground plane of conductivity (also copper), they are placed close together but not in direct contact due to the presence of an FR-4 dielectric substrate [8-10]. Many methods are used to improve the bandwidth in elliptical Patch antenna by including a double layer of the dielectric layer, making slots within the patch, using a material with a low dielectric constant, partial cutting of the patch or ground, and slotted work [11, 12]. patch antennas achieve performance goals by introducing openings or cuts in the radiating patch, a technique known as quasi-elliptical notch [13] .The bandwidth of the antenna may be impacted by the half ground plane configuration [14, 15]. Designers need to optimize the dimensions to achieve the desired bandwidth for the application [16]. The antenna is meant for operation in Ultra-Wide Band (UWB) [17]. UWB technologies are typically high-data-rate and wide-bandwidth in microwave systems, allowing transmission of video, audio, and data files at a much faster pace [18]. Numerous papers on different antenna designs have been presented as real-world wireless communication applications to showcase the benefits of UWB [19]. To enhance the bandwidth of an elliptical microstrip antenna, researchers have employed various techniques, such as creating slots in the patch, using materials with low dielectric constants, or implementing partial cuts in the patch or ground plane [20]. There are several key requirements that significantly impact the performance of radio systems. One of the most important requirements, perhaps, is the radiation efficiency of antennas. However, all variables that are related to the radiation efficiency of single-port antennas are well documented in previous research [21]. In this paper, the antenna is specially designed for UWB applications in wireless and satellite communications. Its compact size is suitable for limited-space applications. The compact size enhances its suitability for integration into various systems.

2. PAPER CONTRIBUTION

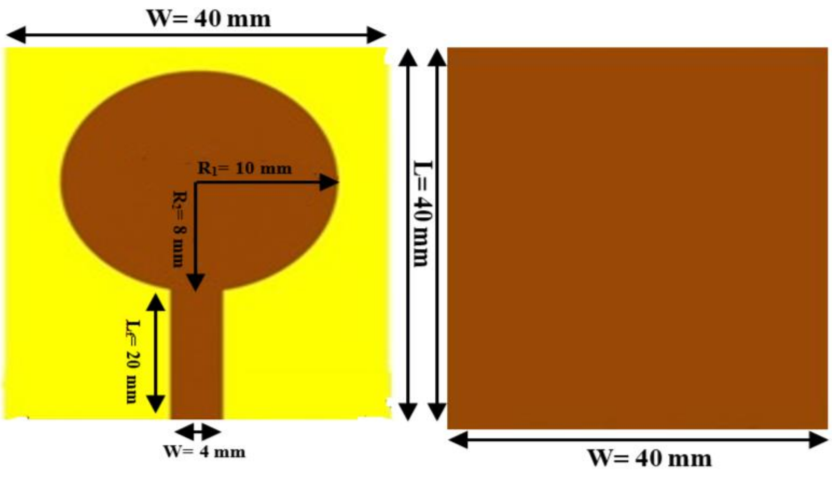
This paper contributes to the research field by offering a comprehensive design of an QEPA antenna for 5G and UWB applications, proposing two bandwidth optimization techniques. This work can be helpful for researchers working on the development of low-profile and wide-band antennas for up-to-date radio telecommunication.

3. PROPOSED ANTENNA

The proposed antenna is a quasi-elliptical-shaped patch antenna, built on a flat surface substrate. The proposed antenna was designed on a dielectric substrate of the FR4- lossy substrate with relative permittivity (ε_r) of 4.3, the substrate dimensions (**W = L ≈ 0.85λ** = 40 mm**, h≈0.035λ =** 1.6 mm). QEPA is designed to operate at a frequency range (3.1to10.6) GHz for UWB and 5G mobile applications.

Figure (1) shows both the front and back view of the proposed QEPA antenna. It consists of a simi-elliptical radiating patch. A miniature feeding line runs from the lower edge of the patch. On the right there is ground plane is represented on the underside of the substrate layer. The following are the parameter dimensions:

R_1 = (0.25*W) = 10 mm: the main radius (half of the largest axis), **R_2 =0.8*R_1= 8 mm:** the minor radius (half of the smaller half-axis) of the elliptical profile shape, **L_f = 0.5*W= 20 mm:** the length of the microstrip feeding line, **W_f = 0.1*W= 4mm:** width of the micro patch feed line, **X =W= 40 mm:** width of the rectangular ground level, **Y=L= 40 mm:** the length of the rectangular ground level.



(a) (b)

Fig. 1 The basic proposed antenna (a) front view, (b) back view

$$f_r \cong \frac{C}{2L_p.k} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

$$K = \sqrt{\varepsilon_{eff}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \quad (2)$$

Where C is the speed of light is about 299,792,458 m/s. The size of patch L_p can be calculated using Equation (1) [13]. If L_p is 16 mm (where 2*R_2 is the smaller diameter), then R_2 value should be 8 mm, and R_1 becomes 10 mm. The ground plane size (40×40) mm^2. The QEPA is fed using the strip line method as shown in Fig. (1). An important parameter is the effective permittivity (ε_{eff}); for a FR-4 substrate with ε_r = 4.3 and loss tangent (tan δ) = 0.025 [15], ε_{eff} can be calculated using Equation (3), typically yielding a value around 4, this value is used to find k in eq (2).

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12(h/W_f)}}\right) \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (3)$$

In order to achieve $Z_\circ$=50 Ω impedance, the microstrip line width (W_f) can be determined by Eq. (4) [16]. The value of W_f is around 4 mm.

$$Z_\circ = \frac{87}{\sqrt{\varepsilon_{eff} + 1.41}} ln\left(\frac{5.98h}{0.8 * W_f + t}\right) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \quad (4)$$

4 Simulated Results

The matching between the power source and the antenna should occur at Zin = 50 Ω, which is the antenna input impedance. The value of reactance becomes zero at resonant frequency; fr= 6.346 GHz and Zin = 50 Ω. The simulation results are illustrated in Fig. (2) for both resistance (real) and reactance components (imaginary) of the impedance at this frequency.

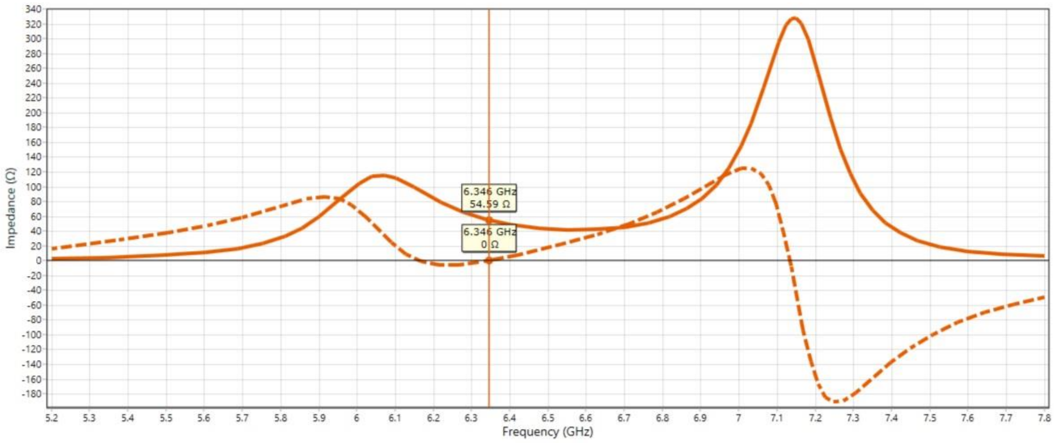


Fig. 2 The input impedance (Real) and (Imaginary)

The simulation program has predicted that the return loss of the designed antenna should be approximately -31 dB, as shown in Figure (3).

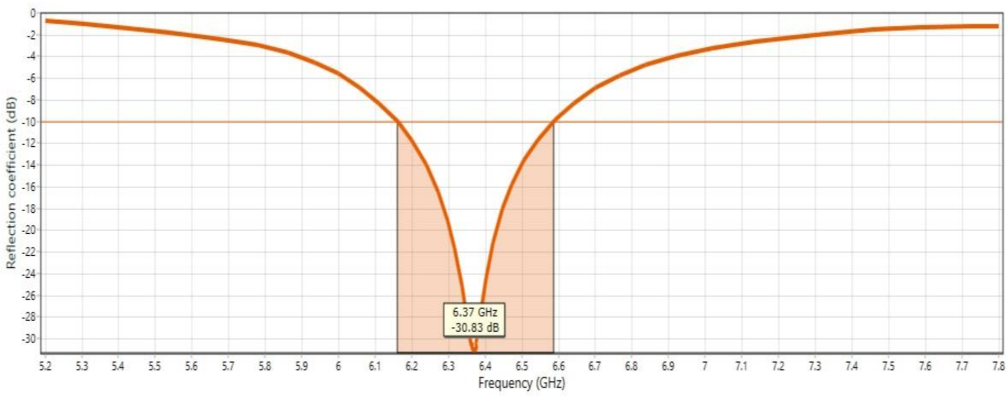


Fig. 3 Simulated return loss (S11)

The frequency range at the two opposite corners of the return loss at -10dB is used to compute the bandwidth as shown in Figure (3). A percentage value of the proposed antenna's bandwidth is reached (6.7%).

The Voltage Standing Wave Ratio (VSWR) at 6.346 GHz is 1.06, as presented in Figure (4).

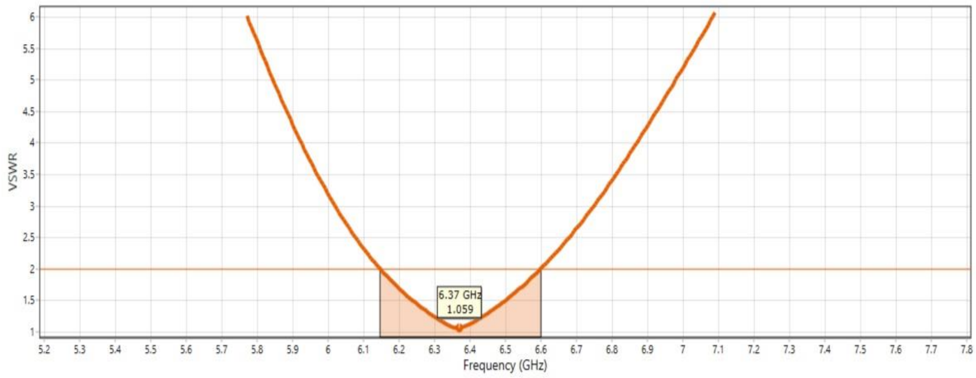


Fig. 4 Simulated VSWR

Figure (5) shows the two-dimensional gain distribution over frequency, which is called gain-bandwidth. The gain-bandwidth characteristic of an antenna is a fundamental property that expresses the direction and strength of the concentration of energy or radiation.

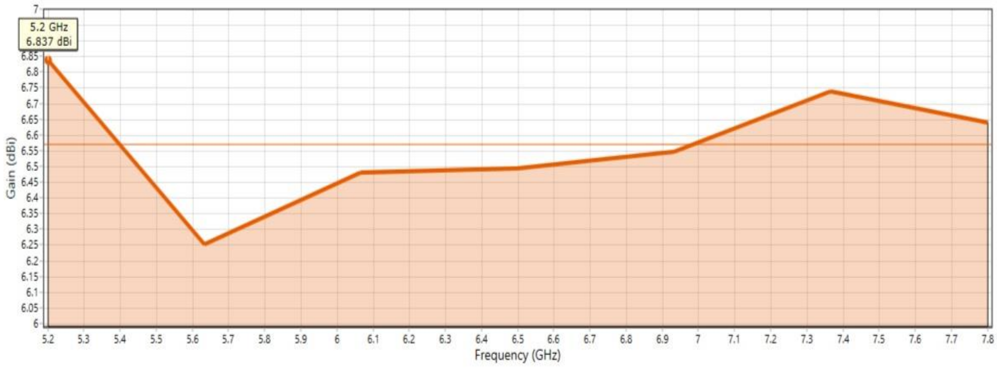


Fig. 5 Simulated radiation pattern

4.1 BW Improvement of QEPA

The first improvement of the QEPA was achieved by utilizing the partial ground plane to the size of (40 × 22) $mm^{2,}$ and two square notches, each sized (2×2) mm^2 with 4 mm gap between them. The modified ground plane design is shown in Fig. (6).

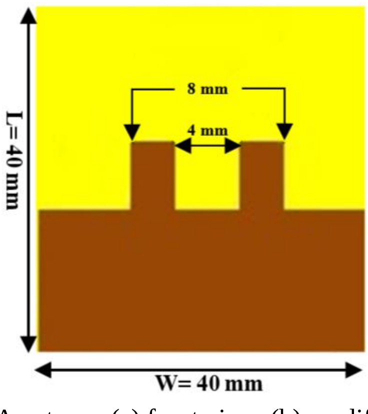


Fig. 6 QEPA antenna (a) front view, (b) modified ground plane

Figure (7) shows the return loss of the QEPA antenna with the calculated partial ground level. The resonance range is between 5.563 GHz to 12.68 GHz. From the width of the simulated yield loss band of 121% used in UBW applications and more.

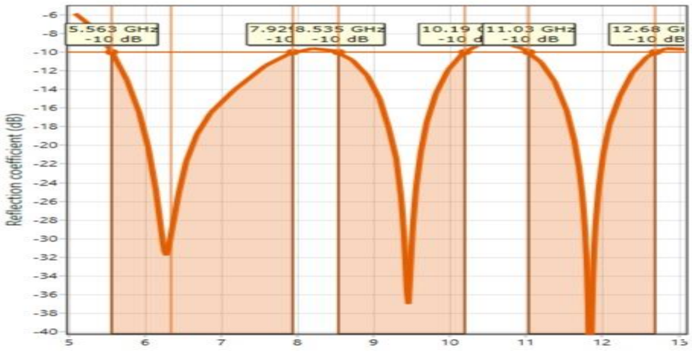


Fig. 7 Simulated return loss of QEPAwith a partial ground plane

The VSWR is between (1 and 2) for the entire resonance range as shown in Figure (8).

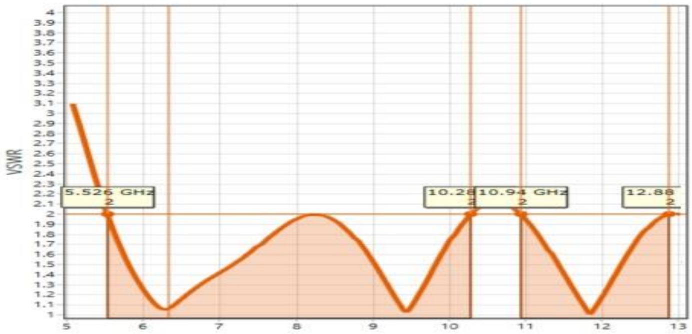


Fig. 8 Simulated VSWR of QEPAwith a partial ground plane

The radiation pattern as shown in Fig. (9). The gain is (5.825 DB) as shown in Figure (9).

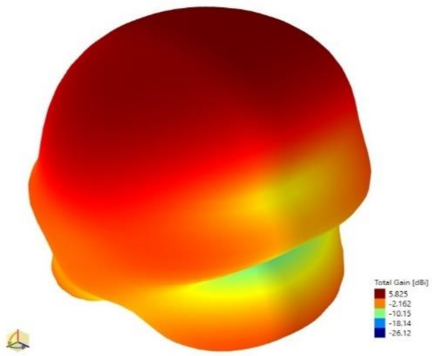


Fig. 9 Simulated radiation pattern of QEPAwith partial ground plane

4.2 Further Improvement of QEPA’s BW

To obtain a larger bandwidth that meets the requirements of the UWB applications, the proposed antenna was modified again. The second enhancement is achieved by adding two slots to the left, and the right of the simi-elliptical patch with the remaining on a partial ground plane. The dimensions and size of these slots are shown in Fig. (10).

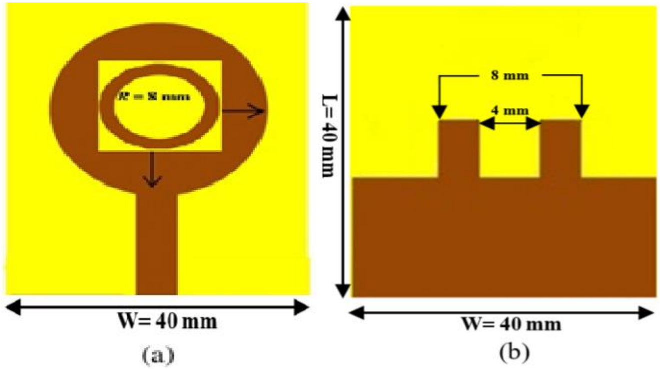


Fig. 10 QEPA with slots in patch (a) top side (b) bottom side

Figure (11) shows that the calculated value of return loss. The simulated results on bandwidth are 16 GHz or (160% percentage) with resonant frequency from 5.711 to 6.853.

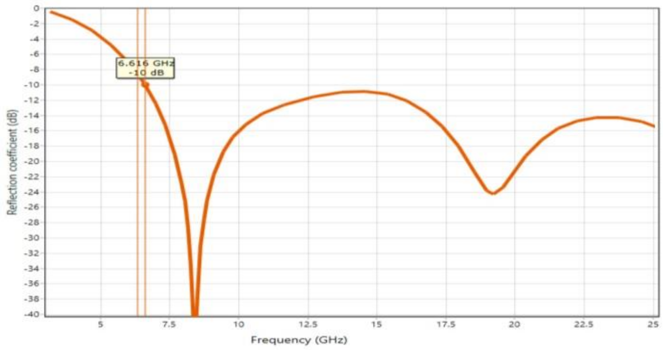


Fig. 11 Simulated return loss of QEPA with slots in patch GHz.

VSWR between 1 and 2 along of the resonant range as shown in Fig. (12), and gain is 11.63 dB, radiation pattern as shown in Fig. (13).

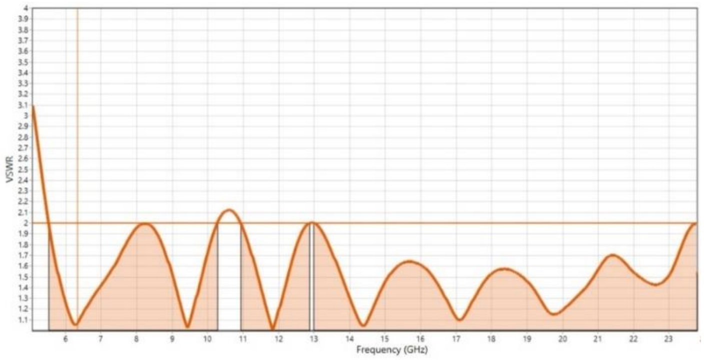


Fig. 12 Simulated VSWR of QEPA with slots in patch

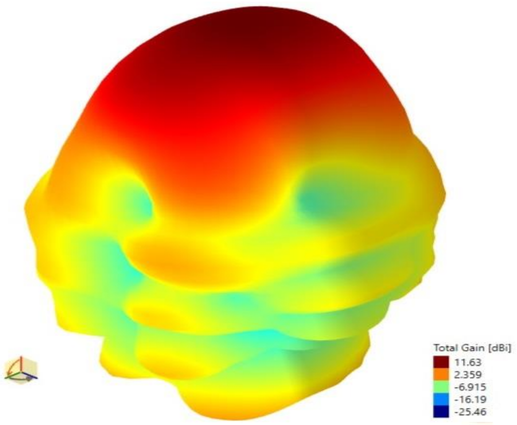


Fig. 13 Simulated radiation pattern of QEPA with slots in patch

TABLE 1. Presents a comparison with reference [20] for related work.

Parameter	(20)	(21)	This Work
Antenna Type	Elliptical Microstrip Antenna (EMSA)	Broadband Elliptical Microstrip Antenna	Quasi-Elliptical Patch Antenna (QEPA)
Dimensions (mm^2)	40×50 (ground), patch: 16×20 (diam.)	30×21×1.6	40×40 (ground), patch 16×20 (diam.)
Substrate	FR-4 (ϵr=4.3,h=1.6 mm)	FR-4 (ϵr=4.3,h=1.6 mm)	FR-4 (ϵr=4.3,h=1.6 mm)
Operating Frequency (GHz)	7.05 (base), 1.5-20 (improved)	6.95-30.94	6.346 (base), 6.616-25 (improved)
Bandwidth (%)	5.7 (base), 180% (slots + partial ground)	24 GHz (353% effective bandwidth)	6.7 (base), 168% (slots + partial ground)
Gain (dBi)	6.36 (improved)	6.8	11.63 (improved)
S11 (dB)	-42	-40	-40
VSWR	1.016 (base), 1-2 (improved)	≤2	1.06 (base), 1-2 (improved)
Bandwidth Improvement Techniques	Partial ground, slots	Slots in the ground and a patch	Partial ground with notches, slots
Applications	UWB, 5G	5G, wireless communication	UWB, 5G, satellite communication
Polarization Control	Not mentioned	Not mentioned	Linear and circular polarization
Innovation	High bandwidth (180%) with slots	Broad bandwidth (6.95-30.94 GHz)	High gain (11.63 dBi), polarization diversity

5. CONCLUSIONS

The primary conclusions drawn from the results are as follows:

- The input impedance matching at 50 Ω is a critical parameter. At the resonant frequency of fr= 6.346 GHz, the reactance value becomes almost zero, confirming that Zin=50Ω. Simulation results illustrate both the real (resistive) and imaginary (reactive) components of the impedance at this frequency, with a computed return loss of -40 dB. The bandwidth is calculated using the frequency range at the two extremes of the return loss at -10 dB, resulting in a bandwidth percentage of 6.7% for the proposed antenna.
- The introduction of a partial ground plane with a square notch significantly enhances antenna performance. The bandwidth achieved ranges from 5.563 GHz to 12.68 GHz. (121% improvement), facilitated by miniaturizing the ground plane to a partial configuration with a gain of 6.837 dB.
- The use of two slots drilled on either side of the patch led to substantial bandwidth improvement. The bandwidth ranges from 6.616 GHz to 25 GHz (168% improvement) , achieving a gain of 11.63 dB.

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