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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 quasi-elliptical patch antennas 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 quasi-elliptical patch antennas 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, reducing signal fading and enhancing overall system performance. quasi-elliptical patch antennas are also adept at customizing radiation patterns. The developed QEPA exhibits the following characteristics at its resonant frequency

Keywords: quasi-elliptical Patch antenna (QEMA); 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 7.05 جيجاهرتز، عرض نطاق ترددي مُحاكى بنسبة 5.7% وعرض نطاق ترددي مُقاس بنسبة 4.28%. يُظهر فقدان عائد يبلغ -42 ديسيبل، ومطابقة معاوقة 50 أوم، ومكسب إشعاعي 8.57 ديسيبل، ونسبة موجة دائمة للجهد (VSWR) تبلغ 1.016. تم بحث تقنيتين لتحسين عرض النطاق الترددي: تقليل حجم المستوى الأرضي ودمج فتحات داخل الرقعة. حقق المستوى الأرضي الجزئي تحسينات في عرض النطاق الترددي المُحاكى والمُقاس بنسبة 146% و 167% على التوالي. أسفرت الرقعة ذات الفتحات عن تحسينات بنسبة 160% و 180% على التوالي.

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 in a unique manner [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 used to improve the bandwidth in elliptical Patch antenna by including double of the dielectric layer, make slots within patch, using a material with a low dielectric constant, partial cutting with 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-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]. In addition to this, microwave antenna researchers globally have tried to come up with ultra-wide-band antennas through various bandwidth extension approaches [19]. 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 devices and 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 systems.

3. PROPOSED ANTENNA

The proposed antenna is an quasi-quasi-elliptical-shape patch antenna, built on a flat surface substrate, known as an quasi-elliptical microchip antenna (QEMA). It's smaller radius denoted by V and the larger radius denoted by M and was modeled using the CST Studio Suite 2023 program. This proposed antenna is fed using the microchip line and usually includes a single substrate layer with a thickness h = 1.6 mm and a dielectric constant $\varepsilon_r = 4.3$. QEPA is designed to operate at a resonant frequency of 7.05 GHz for 5G and UWB mobile applications.

Figure (1) shows the front view of the proposed QEPA antenna design. It consists of an quasi-elliptical radiating patch on an FR-4 substrate material. 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:

V = 8 mm: the smaller radius (the smaller half-axis) of the quasi-elliptical patch. **M = 10 mm:** the largest radius (half of the largest axis) of the oval patch. **Lf = 20 mm:** the length of the micro patch feeding line. **W_{strl} = 3mm:** width of the micro patch feed line. **X = 40 mm:** width of the rectangular ground level. **Y = 44 mm:** the length of the rectangular ground level.

The diagram also includes a key indicating that the patch and the ground level are made of copper, while the material of the base layer is FR-4. This figure provides a visual representation of the QEPAgeometry and its main dimensions.

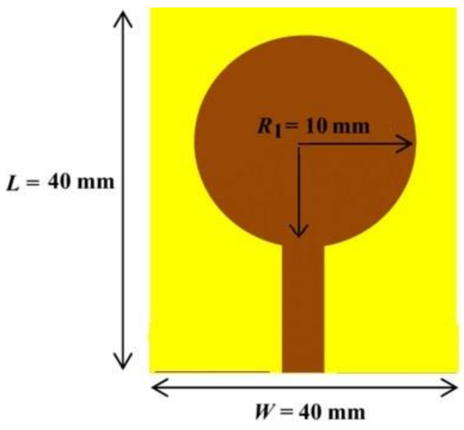

Fig. 1 The basic proposed antenna

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

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

Where C represents the speed of light is about 299,792,458 m/s. It is crucial in physics and calculations.
The size of patch L_p can be calculated using Equation (1) [216]. If L_p is 16 mm (where 2*V is the smaller diameter), then V can be determined as 8 mm and M as 10 mm. The ground plane is sized at (40×50) mm^2. The QEPA is fed using the strip line method as shown in Fig. (2). 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 [218], ε_{eff} can be calculated using Equation (3), typically yielding a value around 1.82, this value is used to find k in eq (2).

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

In order to achieve Z∘=50 Ω impedance, the microstrip line width (W_{trl}) can be determined by Eq. (4) [219]. The value of W_{trl} is typically around 3 mm.

$$Z_\circ = \frac{87}{\sqrt{\varepsilon_r + 1.41}} \ln\left(\frac{5.98h}{0.8W_{trl} + t}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (4)$$

4 Simulated Results

The matching must be done at 50 Ω which is the input impedance. Zin is a significant parameter. The value of reactance becomes zero at resonant frequency; fr=7.05G Hz 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.

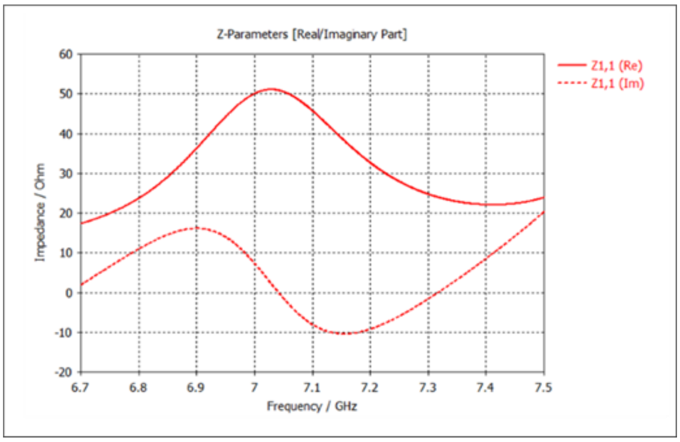

Fig. 2 The input impedance (Real), and (Imaginary))

The simulation program has predicted that the return loss of the designed antenna will be -42 DB, as shown in Figure (3). To make sure that this result is correct, the antenna is usually fabricated, the return loss is measured in practice and the measured value is compared with the calculated one.

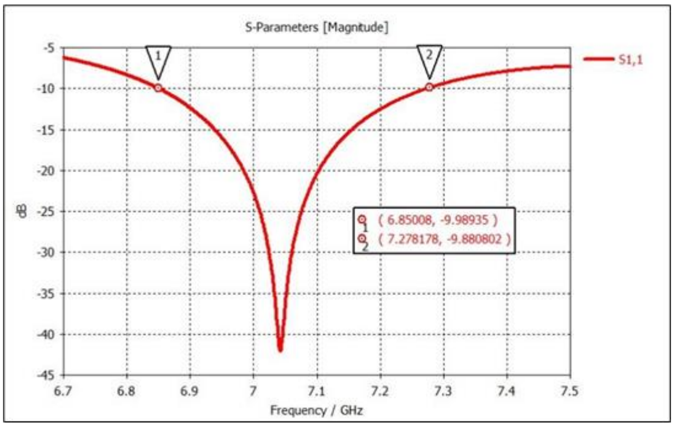

Fig. 3 Simulated return loss (S11)

The frequency range at the two opposite corners of the return loss at -10dB is used to compute the bandwidth. A percentage of bandwidth for the proposed antenna (5.7%) is described in Eq. (5).

Where represents the larger frequency and is the smaller frequency. [220]

At a resonance frequency of 7.05 GHz, The Voltage Standing Wave Ratio (VSWR) is 1.016 as shown in Figure (4).

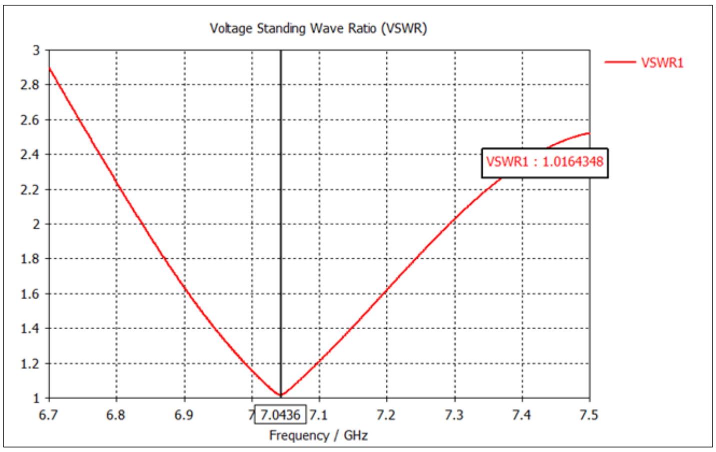

Fig. 4 Simulated VSWR

Figure (5) shows the three-dimensional distribution of electric fields in both E-plane and H-plane. The radiation pattern represents the standard normalized values of the field patterns. The Broadside radiation pattern is characterized by the absence of side lobes. The radiation pattern of an antenna is a fundamental property that expresses the direction and strength of the concentration of energy or radiation, whether it emits from one direction or all directions in the physical medium or space. As such, it is possible to determine the direction of the antenna orientation during transmission or reception based on the radiation pattern.

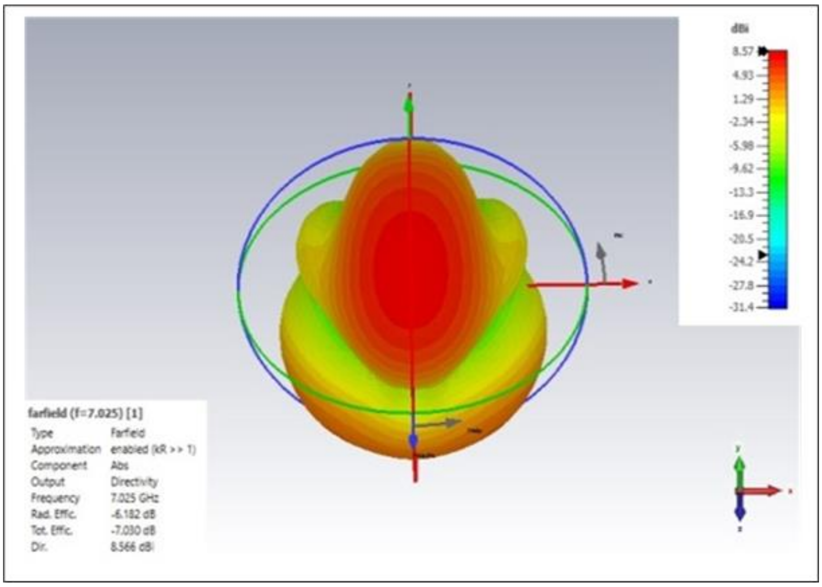

Fig. 5 Simulated radiation pattern

4.1 BW Improvement of QEPA

The first improvement of the QEPA was achieved by miniaturizing the ground plane to partial to the size of (40 × 22) mm^2 and a square notch with the size of (N×N=3×3) mm^2 on top of the base layer was placed. The modified ground plane design is shown in Fig. (6).

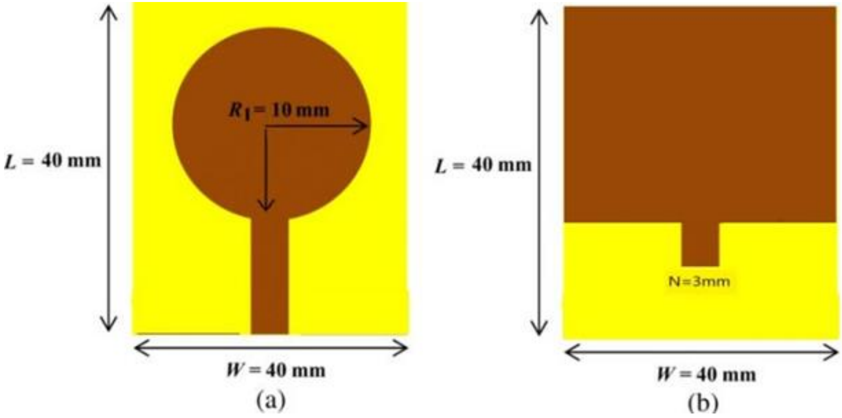

Fig. 6 QEPA antenna (a) front view, (b) modified ground plane

Figure (7) shows the return loss of the QEPA antenna with the calculated partial ground level. The resonance range is between 2 GHz to 13 GHz. From the width of the simulated yield loss band of 146% used in UBW applications.

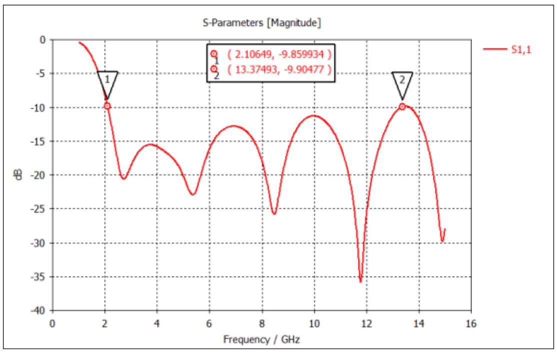

Fig. 7 Simulated return loss of QEPAwith a partial ground plane

The VSWR is between (1 and 1.5) for the entire resonance range. The gain is (6.22 DB) as shown in Figure (8).

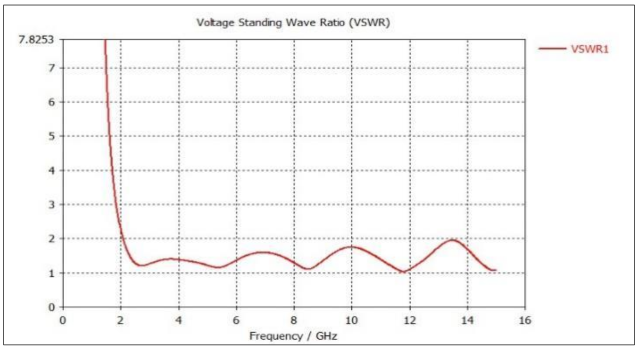

Fig. 8 Simulated VSWR of QEPAwith a partial ground plane

The radiation pattern as shown in Fig. (9).

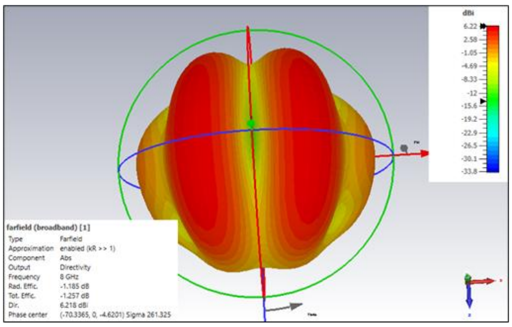

Fig. 9 Simulated radiation pattern of QEPAwith partial ground plane

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 quasi-elliptical patch with the remaining on a partial ground plane. The dimensions and size of these slots are shown in Fig. (10).

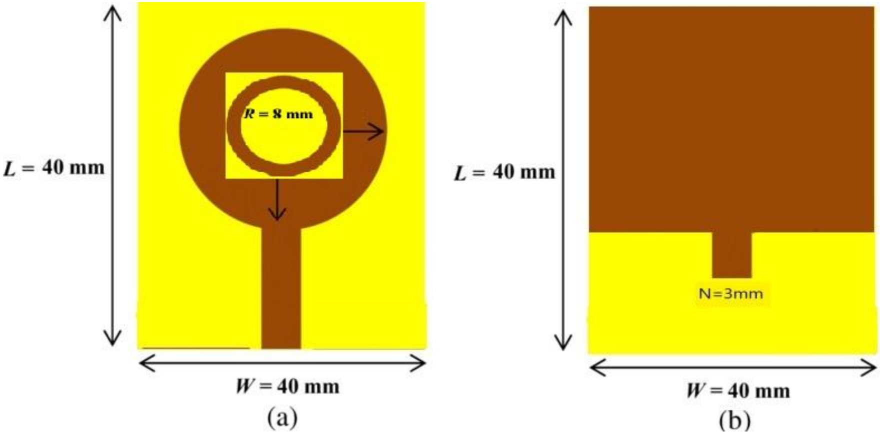

Fig. 10 QEPA with slots in patch (a) top side (b) bottom side

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 2 to 18.

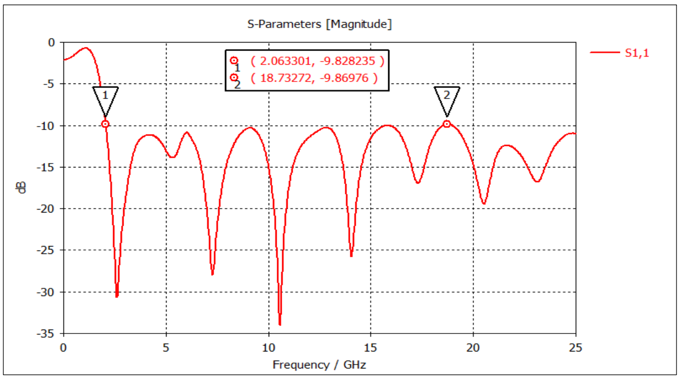

Fig. 1 Simulated return loss of QEPA with slots in patch GHz.

VSWR between 1 and 2 along of the resonant range and gain is 6.36 dB as shown in Fig. (12). Radiation pattern as shown in Fig. (13).

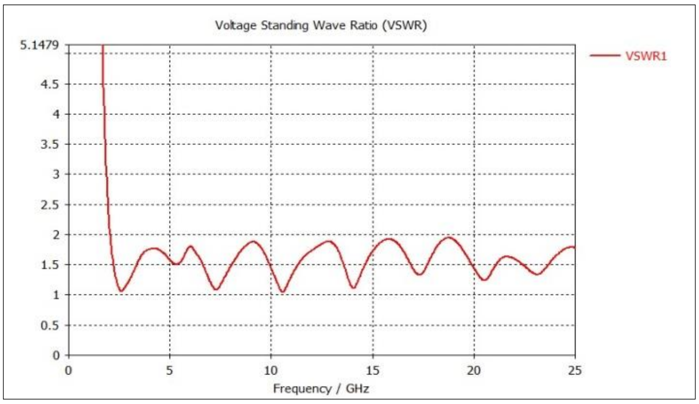

Fig. 12 Simulated VSWR of QEPA with slots in patch

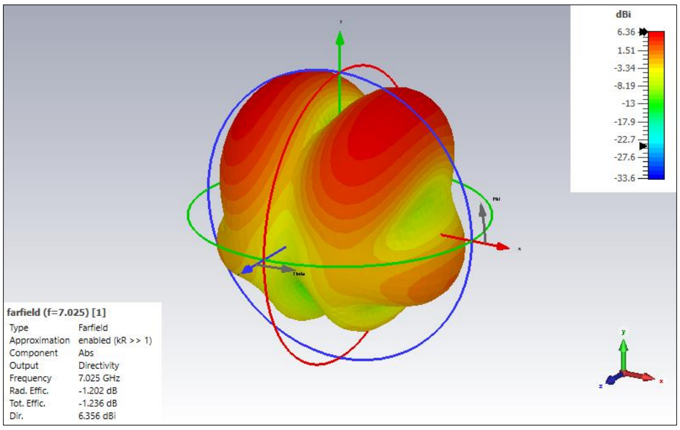

Fig. 13 Simulated radiation pattern of QEPA with slots in patch

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=fr=7.05GHz, the reactance value becomes 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 -42 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 5.7% for the proposed antenna and 4.28% for the measured results.
- The introduction of a partial ground plane with a square notch significantly enhances antenna performance. The bandwidth achieved ranges from 2 GHz to 13 GHz (146% improvement) in simulated results and from 1.5 GHz to 18 GHz (167% improvement) in measured results, facilitated by miniaturizing the ground plane to a partial configuration with a gain of 6.22 dB.
- The use of two slots drilled on either side of the patch led to substantial bandwidth improvement. The bandwidth ranges from 2 GHz to 18 GHz (160% improvement) in simulated results and from 2 GHz to 20 GHz (180% improvement) in measured results, achieving a gain of 6.36 dB.

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