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Design and Development of Miniaturized Microstrip Patch Antenna for Ultra Wideband Applications

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Abstract

In this study, a novel rectangular patch antenna is designed specifically for Ultra-Wide Band (UWB) applications. The antenna exhibits a compact and small size, measuring 20 mm x 21.5 mm, with a 50-Ω feed line and a partial ground plane, resulting in a simplified geometry. To construct the antenna, FR4 material with a depth of 1.60 mm and a relative permittivity of 4.3 is employed. To assess the antenna efficiency the CST Microwave Studio software, is employed and various results are obtained. The antenna demonstrates operation within a frequency range of 3 GHz to 11.51 GHz and also from 13.45 GHz to 14.65 GHz, ensuring a return loss of less than -10 dB, a voltage standing wave ratio (VSWR) of less than 2 and a maximum gain of 4.97 dB. Additionally the antenna is fabricated and the measured and simulated outcomes exhibit a strong level of agreement.

Keywords: Computer Simulation Tool, Ultra Wideband Antenna, Microstrip Patch Antenna, Return loss, Gain, VSWR, Radiation Patterns

I. Introduction

Ultra-Wide Band (UWB) communication technology has gained immense popularity in the field of radio communications in recent times. Extensive research conducted on this subject has not only made it possible to define and create electronic circuits tailored for specific applications, but also made them achievable for implementation. One remarkable advantage of UWB technology is its ability to enable high data rates communication over short distances while operating at an extremely low power density. Ultra-Wide Band (UWB) technology operates by utilizing signals that are spread across a broad frequency range. Typically, this range extends from 500 MHz to several GHz. Notably, in 2002, the Federal Communications Commission (FCC) established regulations governing the utilization of the frequency spectrum within the 3.1-10.6 GHz band. Since then, there has been significant focus on UWB systems due to their ability to provide high data rates, accuracy, position tracking, imaging, and remote sensing capabilities. Extensive research has been conducted to develop UWB systems that possess specific characteristics necessary to cover-up the essential UWB spectrum [1-3]. Various antenna structures have been proposed and analyzed, comprising ultra wide band filters, MIMO antennas, and signal processing techniques. These advancements successfully meet the requirements for a wide range of applications, such as indoor communication. Specifically, coplanar and microstrip structures with band notched rejection in the WiMax (5-6 GHz) band have been explored [4-10].

The literature contains several research studies dedicated to UWB applications. For instance, in [11], authors have presented a patch antenna that emits radiation in the form of a ring. In [12], authors have proposed a novel UWB design utilizing a quarter circular microstrip monopole antenna. Ref. [13] showcases a crescent-shaped printed antenna. Ref. [14] introduces a compact UWB planar antenna where ground plane is of a corrugated ladder form, achieving bandwidth of 2.40-11.40 GHz. In [15], a CPW-fed UWB antenna with dimensions of 40.0 x 50.0 x 1.60 mm^3 is described, achieving bandwidth of 2.7-9.3 GHz.

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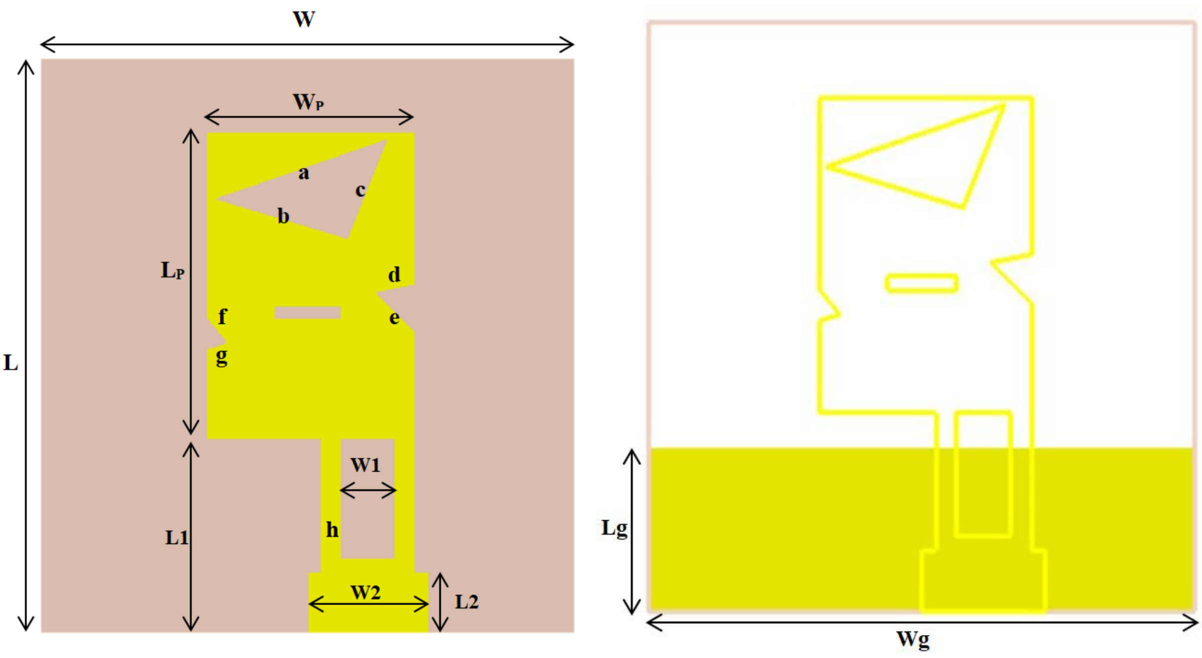
This study introduces a compact and miniaturized design tailored for ultra-wideband applications. The projected antenna design incorporates a rectangular-shaped patch, a microstrip tapered feed line with a slot and a partial ground plane. With dimensions of 20 × 21.5 mm², the antenna demonstrates a notably reduced size. Moreover, it surpasses the earlier reported papers by providing a broader range of impedance. Overall, the proposed design offers the advantages of compactness and improved impedance performance, making it a promising solution for ultra-wideband applications.

II. ANTENNA DESIGN

The antenna design we propose utilizes a rectangular shape radiator fed by a microstrip-line having a width of 3 mm to accommodate a 50 Ω power supply. The structure of the projected antenna is depicted in Figure 1. It comprises a rectangular patch with slots, printed on the top surface of an FR4 substrate. The substrate possesses a relative permittivity of 4.3, a loss tangent of 0.0250, and a thickness of h = 1.60 mm. The ground plane is a partial planar structure printed on the bottom surface of the substrate. The slit at the center of the patch has width of 2.5 mm and length of 0.5 mm. The specific dimensions of the proposed antenna are summarized in Table 1.



(a) **(b)**

Figure 1: Geometry of the structure (a) Top view. (b) Bottom view

Table 1: Geometric parameters of the antenna

Parameter	Value (in mm)	Parameter	Value (in mm)
Wg	20	L2	2.25
Lg	6.14	a	6.88
W	20	b	5.22
L	21.5	c	4.04
Wp	7.75	d	1.53
Lp	11.5	e	2.12
W1	2.0	f	1.17
W2	4.5	g	0.78
L1	7.27	h	0.75

III. Results and Discussion

The assessment of antenna performance involves the evaluation of key antenna parameters such as voltage standing wave ratio,return loss, gain and patterns.To simulate the antenna, we employed a powerful 3D full-wave electromagnetic field simulation tool, CST MWS.

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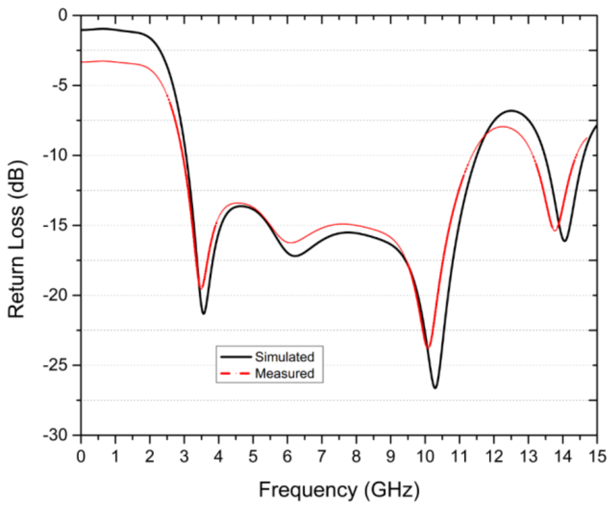


Figure 2: Simulated and measured return loss of the proposed antenna

A comparison between the simulated and measured results related to reflection coefficient is depicted in Figure 2. The findings demonstrate that the antenna operates effectively from the frequency range of 3 GHz to 11.51 GHz and 13.45 GHz to 14.65 GHz. Figure 3 shows the simulated voltage standing wave ratio, where we observe that the value of VSWR is less than 2 from 3 GHz to 11.51 GHz and also from 13.45 GHz to 14.65 GHz.

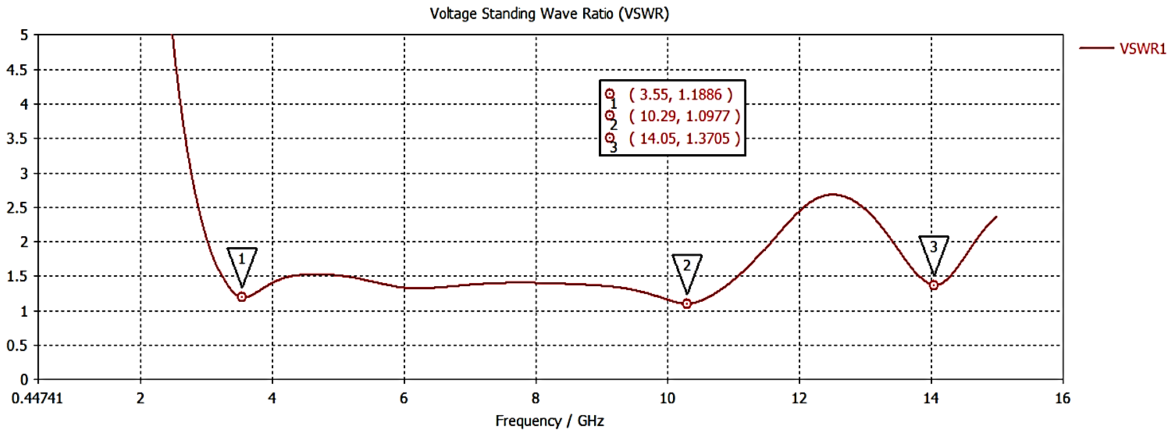


Figure 3: Simulated VSWR

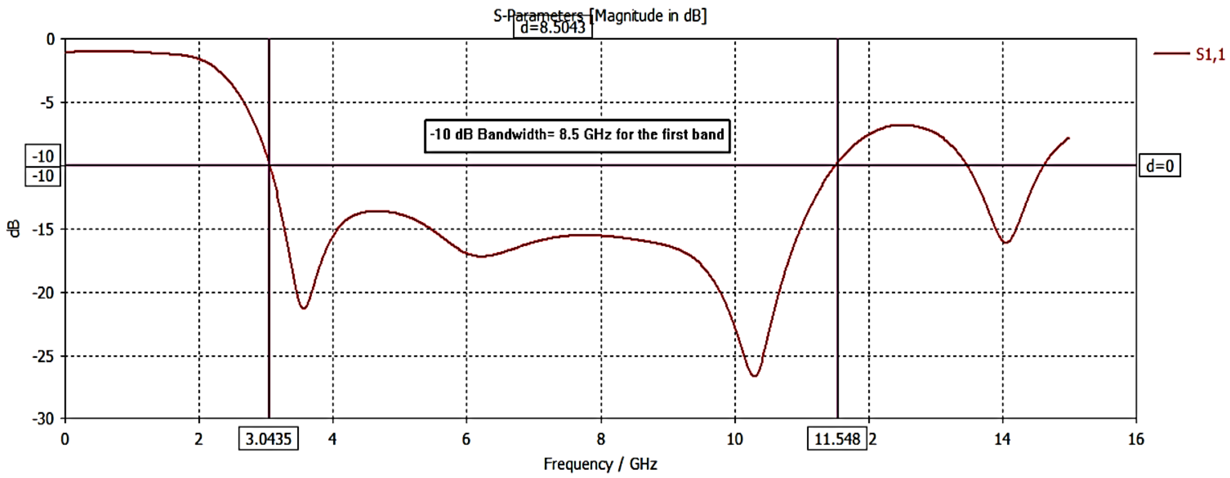
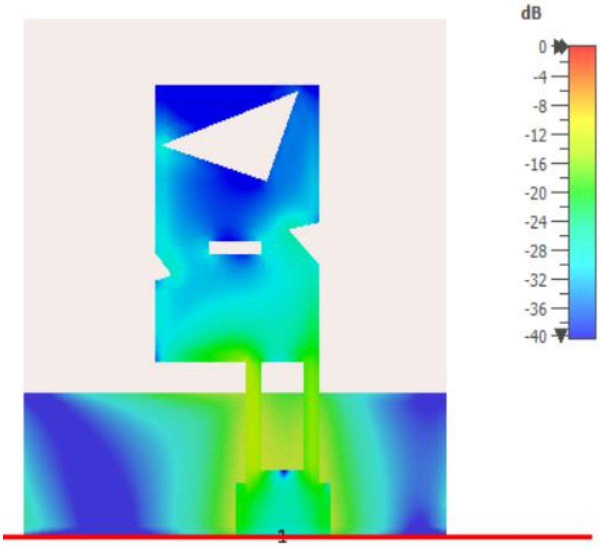
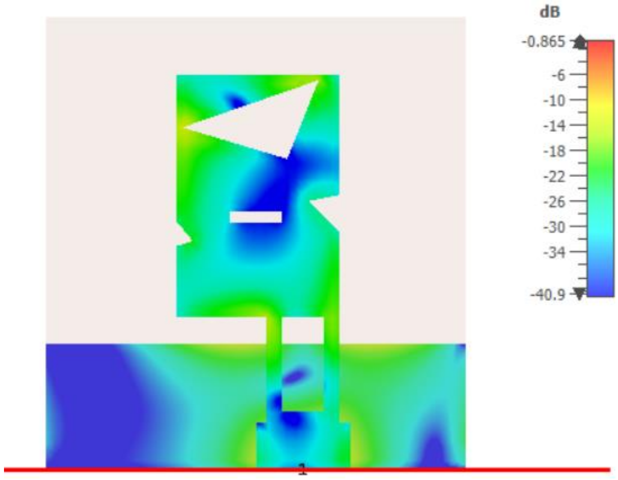


Figure 4: Simulated -10 dB bandwidth

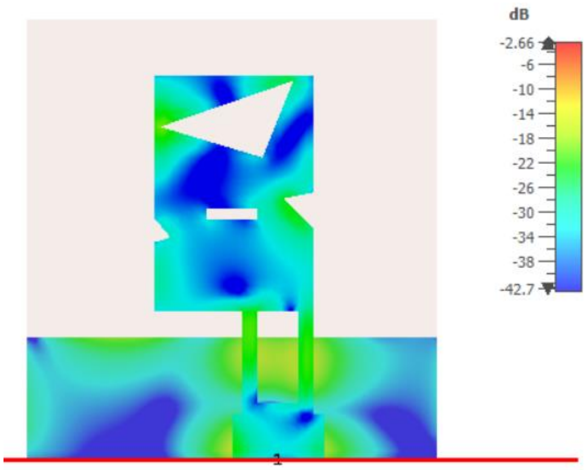
The -10 dB bandwidth representation for the projected design can be seen from figure 4 with 8.5 GHz bandwidth for the first band and bandwidth of 1.15 GHz for the second band has been obtained. The physical behavior of the proposed antenna can be analyzed by the surface current distribution. Figure 5 shows the surface current distribution at 3.55 GHz, 10.29 GHz and 14.05 GHz respectively.



(a) At 3.55 GHz



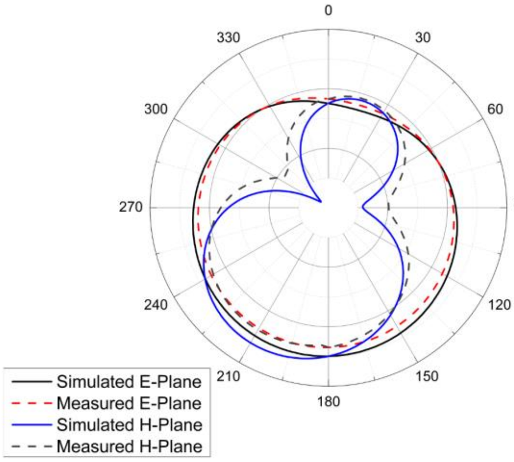
(b) At 10.29 GHz



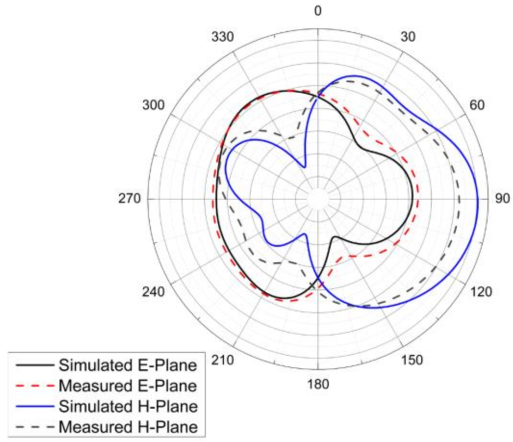
(c) At 14.05 GHz

Figure 5: Surface current distributions

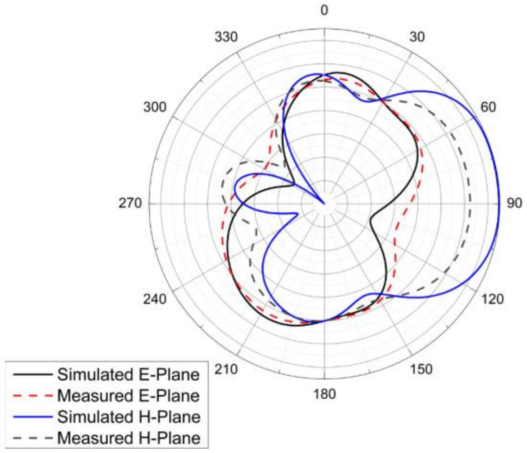
The distribution of surface current density primarily concentrates on the edges of the radiator the ground plane, and the feed line. At higher frequencies, the distribution of the current becomes more intricate, indicating the presence of higher order modes. Figure 6 illustrates the measured and simulated far-field radiation pattern of the projected antenna in both the E-plane and H-plane at three different frequencies: 3.55 GHz, 10.29 GHz and 14.05 GHz. In the E-plane, the antenna exhibits omnidirectional behavior, providing consistent radiation coverage. However, in the H-plane, the pattern displays distinctive characteristics.



(a) At 3.55 GHz



(b) At 10.29 GHz



(c) 14.05 GHz

Figure 6: Simulated and Measured E and H-planes

Figure 7 represents the simulated as well as measured gain of the proposed antenna. The antenna gain varies from 0.59 dBi to 4.97 dBi. Figure 8 represents the fabricated antenna and measurement setup. The simulated and measured results exhibit a strong level of agreement. To highlight the novelty of the designed antenna, a comparison with existing literature works is presented in Table 2. The comparison includes aspects such as antenna size, substrate material, -10 dB bandwidth, and gain. The antenna demonstrates effective operation within the frequency-range of 3.0 GHz to 11.51 GHz and 13.45 GHz to 14.65 GHz.

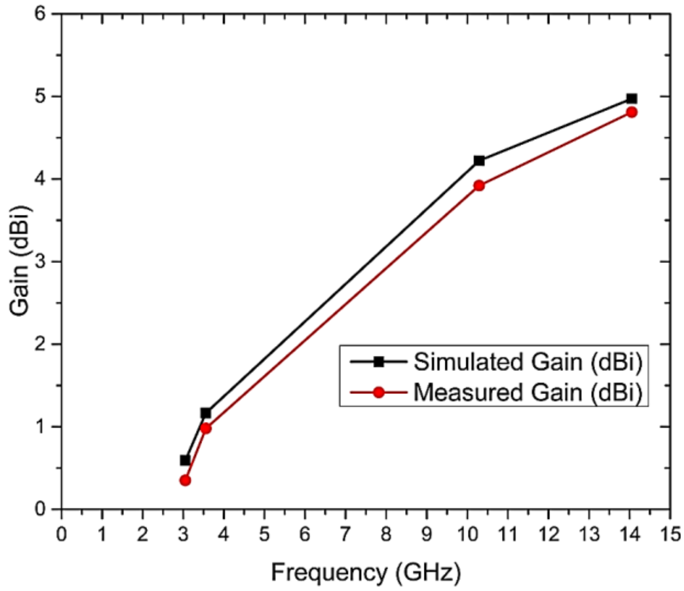


Figure 7: Simulated and measured gain

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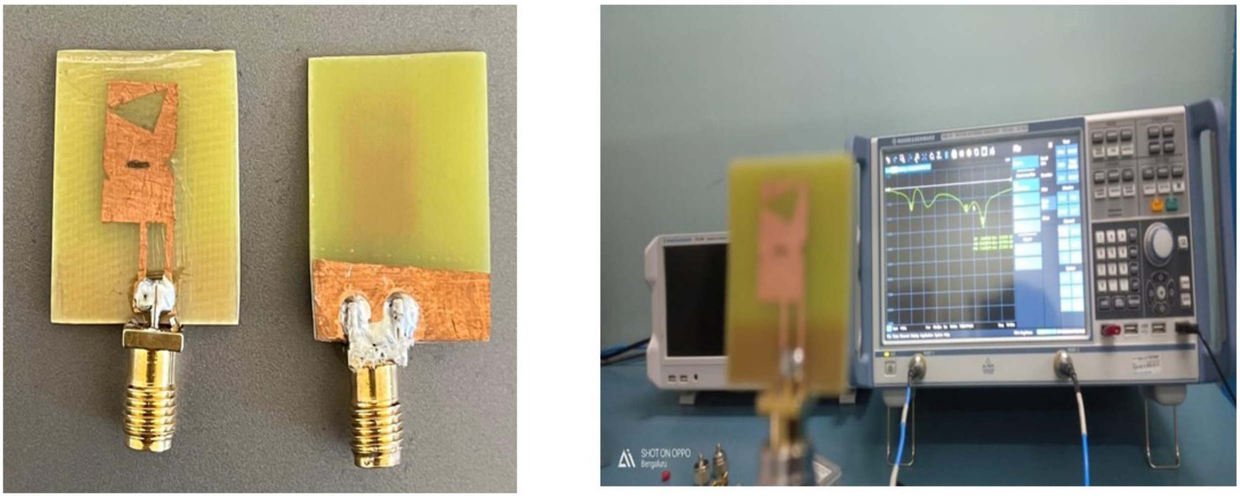

Figure 8: Fabricated antenna and measurement setup

Table 2: Antenna Size, Bandwidth, Dielectric Constant, and Gain comparison

Ref.	**Antenna Size (W x L) (mm^2)**	**Substrate Material**	**-10 dB Bandwidth (GHz)**	**Peak Gain (dBi)**
[9]	45 x 50	Rogers 4003C (3.38)	3.0 - 11.57	6.91
[10]	58 x 24	FR-4 (4.3)	3.29 -6.9, 8.76-13.27	8
[13]	31 x 31	RT/duiroid 5870 (2.33)	3.04 - 11	7
[16]	27 x 29	Rogers RT5880 (2.2)	2.8 - 11.97	4.34
[17]	60 x 40	FR-4 (4.3)	1.6 - 10	1.5
[18]	33 x 30	FR-4 (4.3)	3.25 - 11.36	4.7
[19]	30 x 30	FR-4 (4.4)	4.3 - 11.3	4.75
[20]	25 x 25	FR-4 (4.4)	3.5 - 9.25	4.5
Proposed	20 x 21.5	FR-4 (4.3)	3 - 11.51, 13.45 - 14.65	4.97

IV. Conclusion

This paper introduces a compact UWB antenna that exhibits promising characteristics. The antenna design is constructed on various triangular structures, featuring an altered feed line and a modified ground plane. This antenna demonstrates great potential for various wireless communication applications, including WiMAX (3.30 ~ 3.60 GHz), UWB (3.10 ~ 10.60 GHz), C-band (4.0 ~ 8.0 GHz), WLAN (5.150 ~ 5.820 GHz), X-band (7.90 ~ 8.70 GHz), and Satellite communication (13.450 ~ 14.650 GHz). It's simple configuration, low profile, and broad bandwidth make it highly suitable for these applications. Comparing this design with other antenna structures available in the literature, it surpasses them in terms of size and overall bandwidth, while retaining acceptable levels of electrical performances. Overall, this novel UWB antenna presents a compact and efficient solution for wideband wireless communication systems, offering superior performance characteristics compared to existing alternatives.

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