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An Ultra-Wideband CPW-Fed Monopole Antenna Design for Wireless Devices

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ABSTRACT

This paper presents a new coplanar waveguide-fed (CPW-fed) Ultra-Wideband antenna design suitable for wireless terminal devices. Specifically, it consists of a modified radiation patch with a circular-ring schematic arranged in a single layer, as well as a half-oval-shaped ground plane. The patch is fed with a coplanar waveguide (CPW) feeder. This configuration is implemented using FR- 4 substrate material, which possesses a tangent loss of 0.02 and a dielectric constant of 4.4, with a thickness of 1.6 mm. This antenna is designed to operate in the frequency range of 2.3 - 18 GHz. The simulated results and relevant measures show a satisfactory degree of agreement. The performance of the proposed structure is compared to similar techniques available in the literature and it is found that it has superior performance regarding the ultra-wideband span as well as the fractional bandwidth. It has a comparable performance regarding gain and efficiency.

1. Introduction

The introduction of wireless communication systems operating in ultra-wideband (UWB) modes made it necessary to develop antennas capable of operating in such bands. Various antenna designs with different geometrical configurations were proposed to operate at UWB frequencies [1-5]. Printed, microstrip and planar antennas, were highly regarded in this respect for their compact dimensions and simplicity while meeting design requirements [6-11].

Zerrad *et al.,* [12] introduce low-profile aperture-stacked patch antennas (LP-ASPs) that utilized three substrate layers and were fed by a feeding structure consisting of fork-shaped strips, H-shaped slots and defected ground planes. In a study published by Subhash *et al.,* [13], the authors proposed an antenna design that incorporated a tapered slot ground, a rectangular slotted patch and four parasitic elements in the shape of stars. This design was implemented to improve the bandwidth and gain of the antenna. Pandey *et al.,* [14] presented a nonagon-shaped monopole antenna equipped with an imperfect ground structure. To achieve a wide ultra-wideband, the radiator was etched with

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a circle in its centre and a series of circles around its edges. Additionally, the ground plane was lowered and featured horizontal slits, which help to broaden the impedance bandwidth. A wearable circularly polarized UWB monopole antenna for use in body area networks (WBANs) was proposed by Nejdi *et al.,* [15]. This antenna used microstrip feeds and a concentric ring-based design for its radiator. To create this antenna, an altered concentric ring radiator and an altered ground plane were used in tandem. The wideband characteristics of the proposed antenna were achieved through the use of a modified ground plane with a monopole pair. A fractal monopole patch for wireless communication applications was introduced by Al-Gburi *et al.,* [16], which achieved UWB operation through a fractal ring resonator and a ground plane comprising a rectangular portion, a half-disk part with a rectangular slot and multiple modifications. The initial design of a circular antenna was modified by integrating four rings into a circular ring, followed by the integration of four additional rings in each ring. The ground plane was redesigned to improve the antenna's adaptability, resulting in a compact, lightweight and efficient patch antenna suitable for various wireless communication applications.

In Kiani *et al.,* [17] an UWB modified circular printed monopole (MCPM) antenna was presented, featuring four circular discs connected to the MCPM structure to increase the antenna's impedance bandwidth. This MCPM antenna was fed using a coplanar waveguide (CPW) to achieve a 50 Ω impedance matching and offered a broad enough bandwidth for use in UWB and radio communication applications. CST Microwave Studio [18], a compact, tilted-frame monopole antenna with a square cut in the top middle section of the ground plane was introduced, enabling a wideband response ranging from 3.3 to 11.6 GHz. The impact of various parameters, such as ground slot and transmission line length and width, was continuously analysed. The effect of the ground slot on the resonance response of the antenna was particularly noteworthy, as well as the distance between the square and the antenna on resonance. As the ground slot increased in size, the resonance response became wider and higher frequency responses were generated. However, there is still a demand for new antenna structures that are capable of covering a larger span of the spectrum allocated for wireless applications. This study presents a new and simple monopole antenna with a modified structure and improved bandwidth performance to cope with UWB wireless applications. The primary goal of this study is to introduce the design and implementation of a CPW-fed monopole antenna that exhibits a desirable UWB characteristic.

2. Methodology

The methodology adopted in developing the proposed antenna is based on choosing an ultra-wideband monopole antenna as a base for the design. The design of the proposed configuration comprises a circular ring schematic and a half-oval-shaped ground plane, which are arranged in a single layer, as depicted in Figure 1. This configuration is implemented using FR-4 substrate material, which possesses a tangent loss of 0.02 and a dielectric constant of 4.4, with a thickness of 1.6 mm.

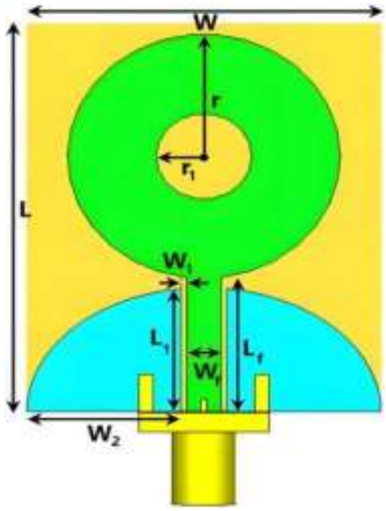

Fig. 1. The proposed UWB antenna schematic diagram

The optimized dimensions are detailed in Table 1. Coplanar waveguide (CPW) feeding which is widely favoured for UWB antennas due to its multiple advantages has been used for the proposed antenna structure. The CPW-feeding technique offers a wide bandwidth crucial for UWB systems, enabling seamless data transmission. Its simple single-layer design on printed circuit boards (PCBs) facilitates cost-effective fabrication and easy integration into compact devices. It can also minimize radiation losses, ensuring efficient energy transfer and high data rates [19,20]. The various components of the antenna design, such as the circular-ring radiator and half-oval-shaped ground plane, exhibit a significant level of activity in terms of their contribution to the generation of resonances and alteration of the current directions.

Table 1
Value of the proposed design parameter

Parameter	L	h	L1	W1	W	W2	Wf	Lf	r
Values in (mm)	26	31.8	1.6	10	1.8	11.3	2.6	11	10

2.1 The Design's Essential Characteristics

The present antenna investigates the key attributes of ultrawideband antennas fed CPW ultrawideband antennas, focusing on diverse designs of a proposed monopole antenna [21,22]. These designs include a fundamental structure featuring a circular ring schematic and a half-oval-shaped ground plane arranged in a single layer. Figure 2 illustrates these different configurations.

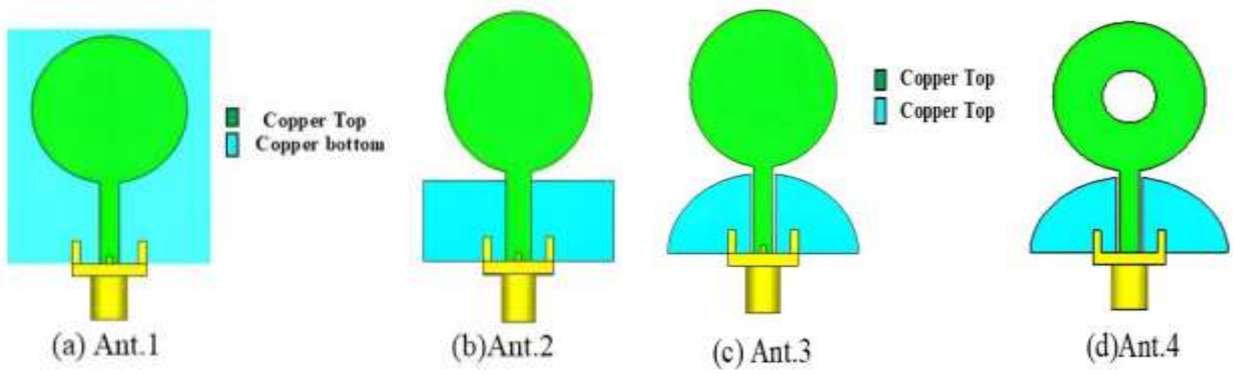

Fig. 2. Different schematics for suggested design (a) Basic structure with circular patch (b) The antenna with the defected ground plane (c) Antenna with an oval ground shape (d) Proposed antenna structure

Figure 3 displays the relationship between the frequency and reflection coefficient of the printed monopole antenna based on various assessments. The implementation of the ground plane is modified and extended towards the patch, leading to the formation of a half-oval-shaped ground, resulting in an overall enhancement of the antenna's performance, bandwidth and stable radiation pattern. Additionally, impedance matching is achieved to meet the frequency requirements of UWB systems [23-26]. The results indicate that the proposed monopole design exhibits a significant impedance bandwidth, covering frequencies within the 2.3 up to 18 GHz range of the UWB spectrum.

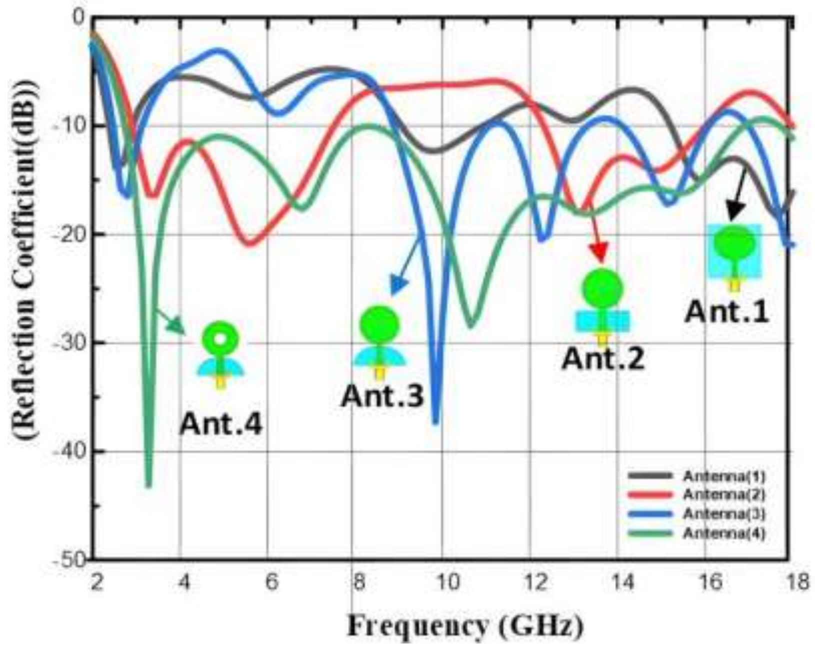

Fig. 3. Reflection coefficient relation for the suggested antenna with various configurations and evaluations are shown in Figure 2

2.2 Parametric Study of the Ring Slot Radius Optimization

This section presents the parametric study of the ring slot in an antenna geometry. To get a continuous UWB operation, this step in the design is needed. This step involves the insertion of a concentric circular slot into the circular patch. The radius of this slot r1 is swept from 3mm to 9mm to determine its impact on the return loss of the antenna. As depicted in Figure 4, five different sizes were tested and the results indicated that the optimum response was achieved when the radius lies between 3 to 4 mm. Within these limits, the return loss is less than -10dB over a frequency range of 2.3GHz up to 18GHz, covering all the allocated frequencies and for UWB communication [27].

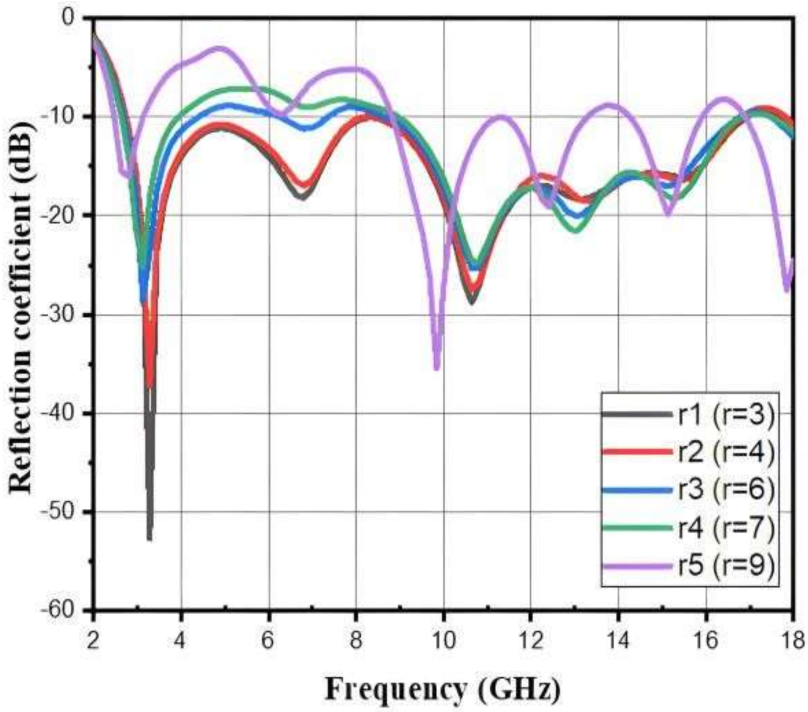

Fig. 4. Ring Size optimization s-parameter optimization for S11

3. Performance Analysis

Figure 5 shows the antenna current distributions at different operating frequencies 3, 10 and 18 GHz, where the antenna resonates. Several components in the antenna design are highly active, such as the circular-ring radiator and the half-oval ground plan. These are active components that contribute to the generation and direction of resonances in the antenna [28-31].

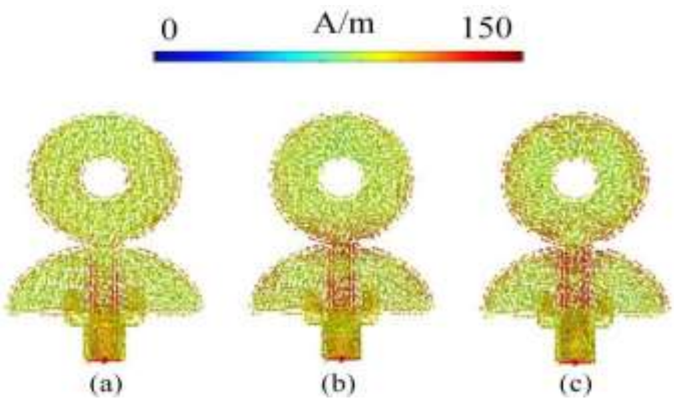

Fig. 5. UWB antenna current distributions for different operating frequencies (a) 3 GHz, (b) 10 GHz and (c) 18 GHz

Figure 6 illustrates the outcomes of both the radiation and overall efficiency for the antenna components proposed. The results demonstrate that the antenna exhibits satisfactory performance, with a radiation efficiency exceeding 75% and a total efficiency of 70%. Moreover, it is worth noting that the antenna achieves even higher efficiencies, surpassing 80%, particularly at lower frequencies.

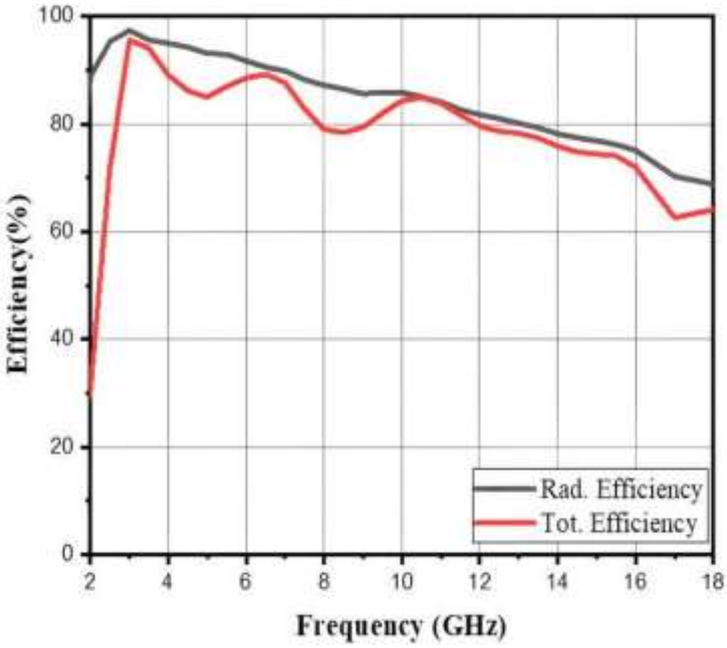

Fig. 6. Radiation and total efficiency results of the proposed antenna

Figure 7 depicts the three-dimensional radiation patterns generated by the printed monopole antenna elements at 3, 10 and 18 GHz frequencies. This antenna emits radiation in an omnidirectional pattern, covering different sides of the substrate [32].

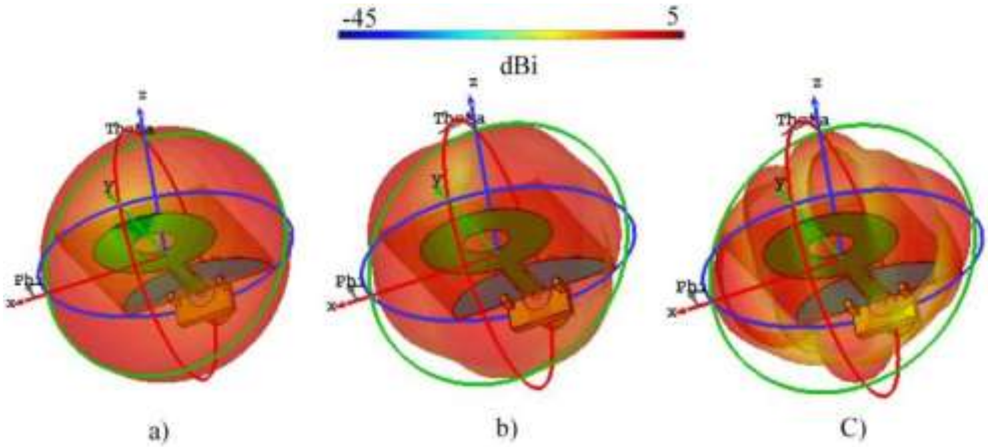

Fig. 7. 3D radiations of the proposed antenna at different frequencies of (a) 3 GHz, (b) 10GHz (c) 18 GHZ

Figure 8 illustrates the maximum gain result of the proposed antenna. As shown, sufficient maximum gain characteristics varying between 2 to 5 dBi (from 3 to 16 GHz) have been observed for the suggested UWB CPW-fed antenna.

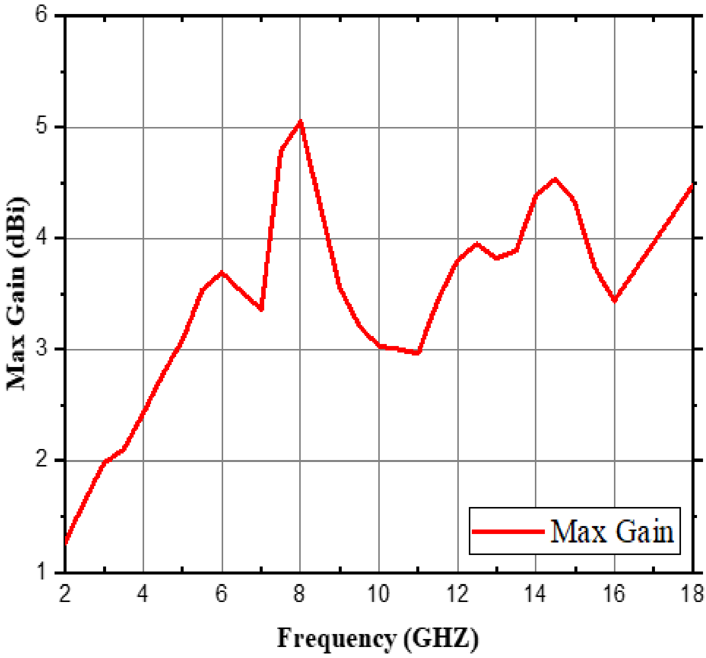

Fig. 8. Maximum gain of the proposed antenna4. Results

The proposed antenna underwent fabrication and measurements to verify the design further. A network analyser with a 50Ω SMA connector at the feed point was used to measure the antenna. The setup for measuring the proposed antenna in the anechoic chamber and the prototype is illustrated in Figure 9.

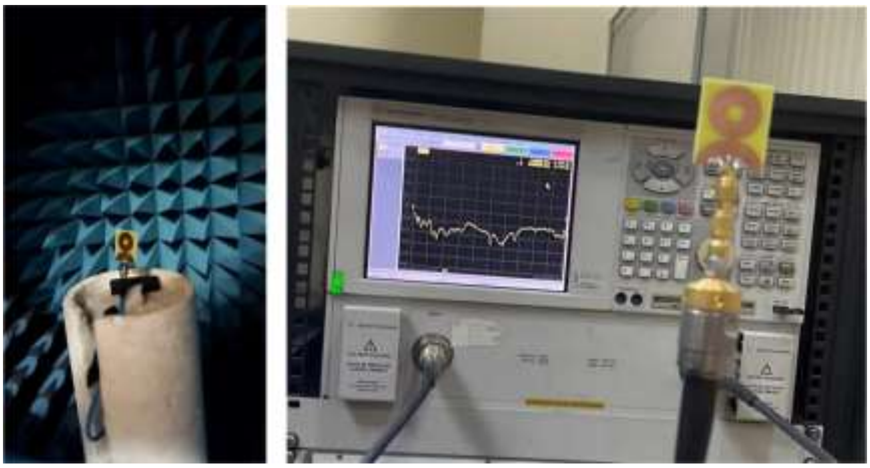

Fig. 9. The measurements set (a) the proposed antenna in the anechoic chamber and (b) S11 measurements

Figure 10 displays the simulated return loss and the measured return loss, along with their corresponding bandwidth values. The measurement and simulated results show a high level of agreement across the entire bandwidth.

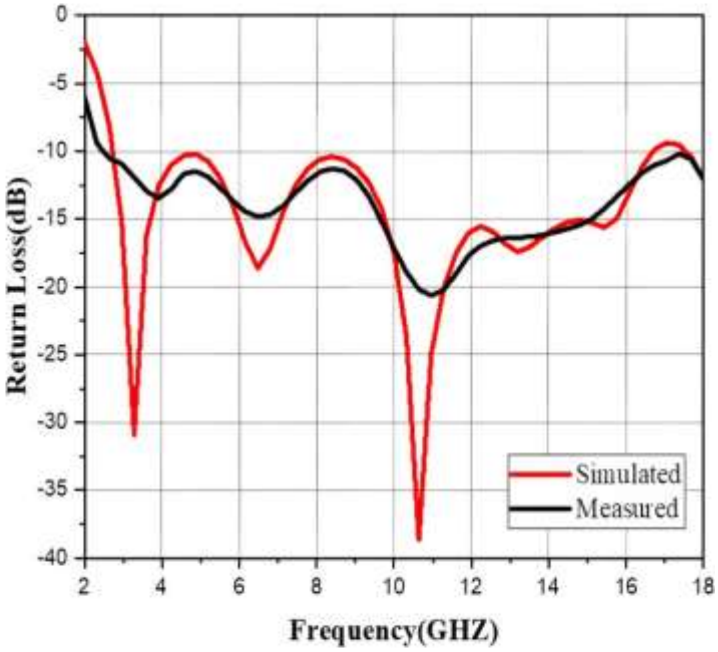

Fig. 10. Simulation and measurement data of proposed antenna return loss

The 2D radiation pattern (E-plane and H-plane) of the antenna radiations at the same operation frequencies in the polar form are represented measured at (3 GHz, 10 GHz and 18 GHz), respectively in Figure 11. As expected, omnidirectional H-plane radiation and semi-dumbbell-shaped E-plane results are discovered for the suggested monopole antenna. There is a good agreement between the simulated and measured radiation patterns.

Table 2 illustrates the comparison between the suggested antenna and the established antenna designs outlined in the literature. It can be inferred that the suggested antenna is better suited for early-stage detection for breast cancer detection by microwave imaging (MWI). The performance of the proposed antenna compared with that of the recently published works is shown to be favourable. We compare the antennas in the table based on antenna size, bandwidth, FBW, gain and efficiency values. This is necessary to present a fair comparison between them.

Table 2
Comparison the literature review for different antenna studies

Ref.	Size (mm3)	BW (GHz)	FBW (%)	Gain	Efficiency %
[12]	10×10×3.475	(2.5-15)	140	NM	NM
[13]	29×26.6×1.57	(3.8-10.1)	90.64	6.8	80
[14]	30×24×0.8	(3-17.2)	140	5.6	N/A
[15]	20 ×15 × 0.5	(3.48-15)	124.6	2.3-7.2	77-95
[16]	40×24.5× 1.6	(2.70–11)	121.1	1.7-6.25	92
[17]	15×15×1.547	(3-11)	114.2	3.2	85
[18]	14 ×18 × 1.6	(3.3-11.5)	110.8	1.2-1.4	60-68
Proposed	31.8×26×1. 6	(2.3-18)	146	5	75

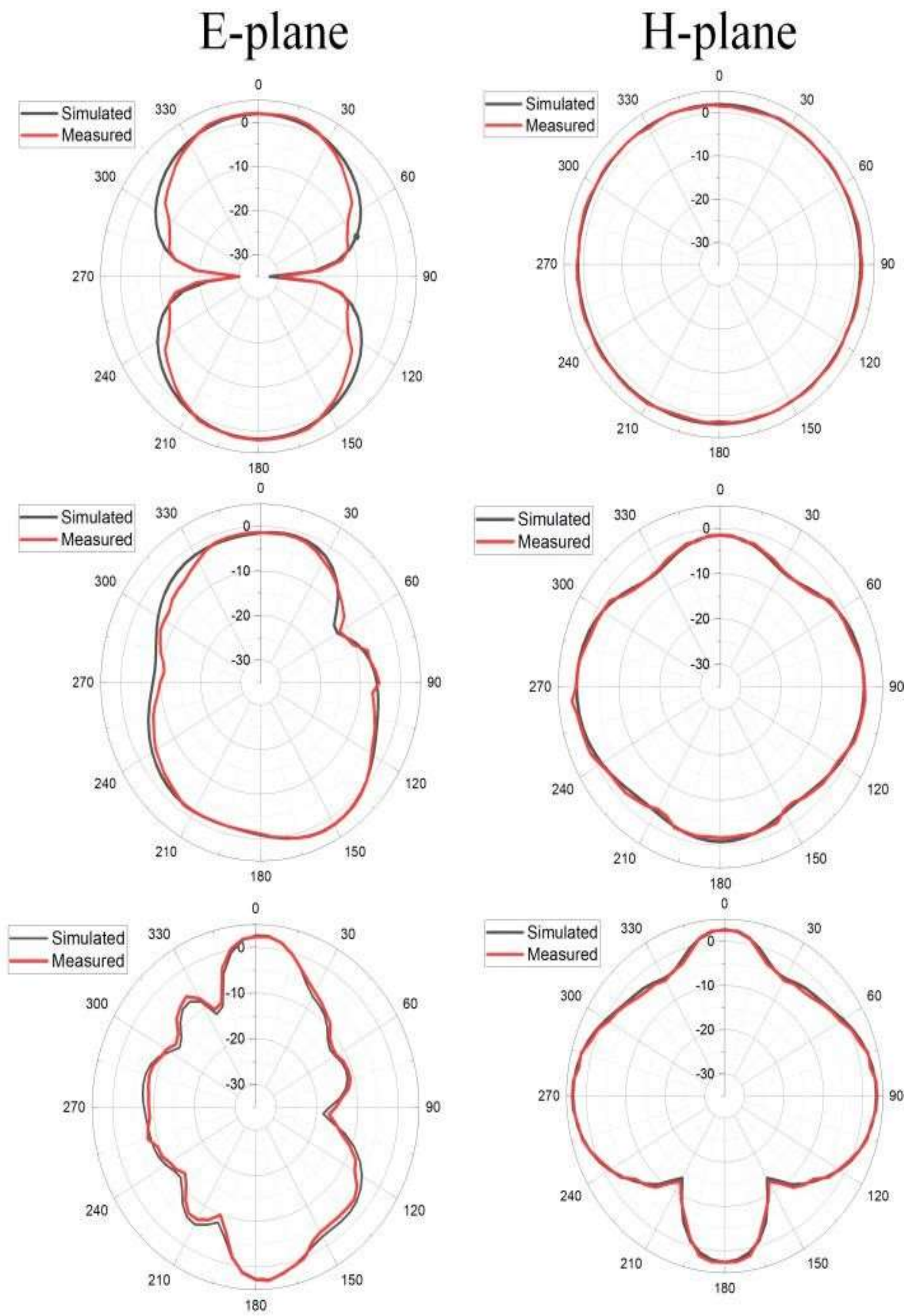

Fig. 11. Measured and simulated radiation patterns of the proposed antenna (a) E-plane (b) H-plane at frequencies (a) 3GHz (b) 10GHz (c) 18GHz

5. Conclusions

The design and analysis of a UWB CPW-fed monopole antenna suitable for use in the terminal devices of wireless communication systems was given in this paper. The antenna comprised a modified circular radiation patch with a circular ring and a half-oval-shaped ground plane arranged in a single layer, which was embedded within a low-cost FR4 substrate. The manufactured prototype measured results and the simulated results matched up reasonably well. The performance of the proposed antenna is compared with similar techniques available in the literature and it is found that it has superior performance regarding the ultra-wideband span (2.3-18 GHz), in addition to the improved bandwidth. The antenna exhibited comparable performance characteristics, including high radiation efficiency (>75%), sufficient gain (2-5 dBi) and reduced size.

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