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A Dual Notch Band UWB Antenna for Local Area Cognitive Radio Network Applications

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ABSTRACT- Over the years, Cognitive radio technology has dramatically influenced wireless systems in which antenna plays a significant role for interviewing spectrum sensing and underlay operations. An ultra-wideband (UWB) antenna with extended dual notch band feature is proposed in this work to meet the requirements of cognitive radios without interference from the crowded spectrum. The proposed antenna consists of stair-stepped rectangular patch with circular cut off the patch at the lower edges to which a complementary split ring resonator (CSRR) and a Patch Stub are loaded to achieve notch bands. It has an optimum dimension of 18mm by 18 mm, fabricated on FR4 material which operates between 2.64 GHz and 11.87 GHz with two notch bands at 3.29–3.61 GHz and 4.95–6.05 GHz, respectively for 5G carrier and WiFi carrier. The measured results show a peak total gain of 3.93 dBi and more than 92% radiation efficiency in the entire operating range. This is well suited for Local area cognitive radio networks; the simulated and measured results were found to be in good agreement and satisfactory.

General Terms: Cognitive Radio, Antenna, Notch Band
Keywords: Complementary Split ring resonator (CSRR), CPW, Stub, UWB Antenna.

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1. INTRODUCTION

The answer to the problem of the spectrum scarcity is dynamic spectrum allocation carried out using cognitive radio networks [1]. Spectrum sensing and the utility of decision-making are two factors that are essential to the execution of the cognitive framework in interviewing technique whereas the secondary user can coexist with the licensed primary user with a low power level in the underlay technique [2]. Spectrum sensing refers to the process of determining whether or not an unoccupied licensed spectrum is available for use. If the main user is not present, the spectrum that is not being utilized for communication is given to the secondary cognitive user [3]. As a result, spectrum-sensing antennas that are suitable for cognitive radio applications are desperately needed. The spectrum bands with a frequency of less than 1 GHz and those in the UWB range are ideal for the application of cognitive radio. There are many different kinds of UWB antennas accessible in the research literature [4] for various real-time applications which includes wearable technology, remote sensing, broadband communication, and so on. Because of the high data rates, limited ranges, and low energy levels, cognitive underlay networks should employ UWB frequencies between 3.1–10.6 GHz. The Wi-Fi frequency (5.15–5.825 GHz) and the 5G carrier bands (3.3–3.6 GHz) are very congested, and as a result, cognitive radio cannot make use of them. Cognitive radio is focused on making efficient use of bands that are not being used. As a result, cutting off a notch in the WIFI and 5G bands is preferable for using reliable interviewing spectrum sensing and underlay techniques.

It has been reported in multiple works [5–12] that various single-notch, double-notch, and multiple-notch UWB antennas can be made using slots on patch or ground surfaces, attaching parasitic resonators near patch surfaces, and stubs attached to the ground planes etc. In [5] a slit in the form of an inverted U is cut into the ground surface to create the WLAN notch in a frequency range of 5–5.85 GHz (Microstrip feed, FR4, 24×30×1.6 mm^3), A circular monopole antenna with WiMax (3.3–3.8 GHz) rejection is described in [6]. This antenna employs a modified spiral mushroom EBG (Microstrip feed, FR-4, 42×52×1.6 mm^3). [7] Describes dual-notch bands for WLAN (5.05–5.90 GHz) and WiMAX (3.3–4 GHz). In order to achieve this, a U-shaped parasitic slit was etched from the feed line and an inverted T stub was inserted into the patch antenna slot (Microstrip feed, Rogers 4003, 59×73×0.8 mm^3). S Shaped slot in feed line and parasitic on either side of the patch are used in [8] for WLAN (5.52–5.9 GHz) and X-band (7.22–8.16 GHz) rejection. (Microstrip feed, FR4, 16×21×1.6mm^3). According to [9], triband rejection was achieved for C-band frequencies ranging from 3.78–4.36 GHz, lower WLAN frequencies ranging from 5.15–5.45 GHz, and X-band frequencies ranging from 7.2–7.9 GHz by inserting a U-

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shaped parasitic slot, a symmetrical split ring resonator pair (SSRP), and a C-shaped parasitic stub (Microstrip feed, FR4, 30×32.5×1.6 mm^3). In [10], frequency rejection was achieved in five narrow bands (3.5, 4.5, 5.25, 5.75 and 8.2 GHz) by inserting four CSRR in the patch area and two SRR on either side of the feed line (Microstrip feed, RogersRO5880, 30×29×2.2 mm^3). The UWB antennas described in the aforementioned literature are constructed using a Microstrip feed, and the notches are produced either by embedding resonators or slots on the feed line or by etching certain slots onto the ground plane.

There are just a few published works available for the coplanar feed that has expanded functions. The ultra-wideband (UWB) antenna shown in [11] is constructed using a loading of inverted L-type strip on the patch, and it has an operating frequency range of 2.6–13.04 GHz (CPW feed, FR4, 25×25×1.6 mm^3). In [12], the UWB antenna is designed with a rectangular slot for a band notch of 5–6 GHz. Here, the antenna is excited with a T-shaped stub with three different configurations, including embedding an isolated slit of half the wavelength of the notch frequency inside the stub; in another design, two-quarter wavelength slits are inserted at the top edge; and in the final design, two half the wavelength of the notch frequency are appended to the parasitic strips (CPW feed, FR4, 13×23×1.6 mm^3). In the aforementioned body of research, a variety of approaches to the development of UWB antennas with notch band functionality are outlined. The structure has been modified by including a variety of slots, which has allowed the notched band characteristics of radiating patches to be realized. When parasitic components are included in printed antennas, a notch frequency band is produced either through the use of faulty ground structures or through the use of electromagnetic band gaps [13–15].

This research introduces a novel UWB antenna with dual notch bands at both the 5G carrier and the WiFi band, making it well-suited for spectrum sensing and underlay cognitive radio. The proposed antenna Impedance ranges between 2.64 GHz and 11.87 GHz, excluding notch bands. The higher band frequencies (5–6 GHz) are rejected by CSRR, cutting a circular incision into the radiating patch adjacent to the feed line. In contrast, the radiated patch connected with a patch stub so that it may reject the lower band (3.3–3.6 GHz). Each notch element of the radiating patch operates independently to filter out their respective bands. The suggested antenna is a great solution for cognitive radio, with a peak gain of 3.93 dBi and an extraordinary radiation efficiency of over 92% in the operating range.

Table 1 gives a detailed look at how the proposed antenna design outperforms with the existing literature. A proposed 18×18mm^2 UWB antenna is developed with a dual-notch band of the WiFi and 5G/Wimax spectrums with maximum gain of 3.93 dBi, and its radiation efficiency is above 92%.

2. ANTENNA DESIGN

Due to its single resonance, the bandwidth of a Microstrip antenna is often rather small. When two or more resonant components are combined, each of which operates at a distinct resonance, UWB characteristics may be achieved. Broadband or multiband functioning is the result of the blending of various resonances. The suggested antenna built on the FR4 material with a thickness of 1.6 mm and is feed via coplanar waveguide.

Table 1: Comparison of Previous Work with the Proposed Antenna

Reference	Size (mm^3)	Notch Type	Notch Band (GHz)	Frequency range (GHz)	Gain in dBi
[5]	24×30×1.6	Single	5–5.85	3.1–10.6	3.1
[6]	42×50×1.6	Single	3.3–3.8	3.1–10.6	-
[7]	42×52×1.6	Dual	3.3–4, 5.05–5.90	2.8–11	-
[8]	16×21×1.6	Dual	5.52–5.9, 7.22–8.6	3.77–11.64	4.32
[9]	30×32.5×1.6	Tri	3.78–4.36, 5.15–5.45, 7.2–7.9	2.73–11.05	3.72
[10]	30×29×2.2	Penta	3.5,4.5, 5.25, 5.75 and 8.2	3–11	-
[17]	16×21×1.6	Dual	7.28–7.66, 9.53–11.17	3.73–16.7	2– 4.26
[18]	29×35×0.764	Dual	3.01–3.63, 4.48–5.85	2.66–14.86	2.65–3.6
Proposed Antenna	18×18×1.6	Dual	3.29 – 3.61, 4.95–6.05	2.64–11.87	1.57–3.93

As can be seen in *figure 1*, the radiating patch is located close to the flawed ground plane. To achieve enough impedance bandwidth in the ultra-wideband region, a rectangular radiating patch, horizontal steps, and a circular area are used. A coplanar feed arrangement is used with a width of *d* mm. *Table 2* provides the dimensions for the antenna parameters.

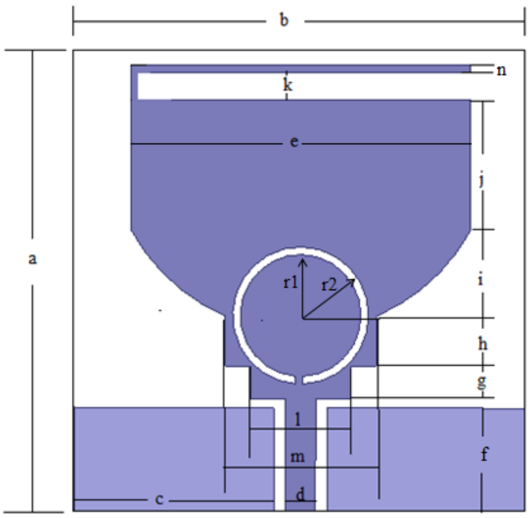

Figure 1: Antenna Geometry with Configuration

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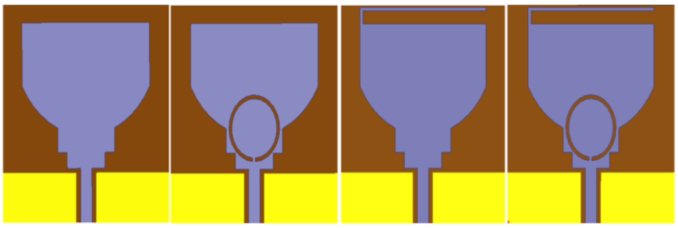
Table 2: Dimension of the Antenna Parameters

Variable	Dimension (mm)	Variable	Dimension (mm)
a	18	i	5
b	18	j	5
c	8	k	1.1
d	1.2	l	3
e	13.5	m	5
f	4.3	n	0.3
g	1.3	r1	2.4
h	2	r2	2.7



(a) (b) (c) (d)

Figure 1: Proposed Dual notch band antenna design. (a) UWB antenna, (b) Insertion of CSRR circular slot, (c) Insertion of patch stub, (d) Final Antenna with both CSRR circular slots and patch stub

Figure 2 shows how the proposed dual-notched band UWB antenna is made. To make it, a circular ring is cut out of the radiating patch and a small piece of the patch is attached to the end of the patch. The steps include *figure 2(a)* UWB antenna and *figure 2(b)* UWB antenna with insertion of a circular slot at the radiating patch for Wi-Fi (5–6 GHz) notch band, *figure 2(c)* represents UWB antenna with 5G carrier (3.3–3.6 GHz) notch band by insertion of a patch stub at the radiating patch, and *figure 2(d)* is a proposed dual notch band antenna by insertion of both.

The following part presents a parametric analysis that establishes the optimum dimensions for the proposed antenna. The UWB antenna design is the starting point for the study, followed by the positioning of the circular notch and the patch stub to account for the dual notch features.

3. PARAMETRIC ANALYSIS

3.1 UWB Antenna Design

This section describes the UWB antenna's implementation, including the numerous iterations required to achieve proper impedance matching. *Figure 3* is a representation of the VSWR curves for the antenna in its various configurations (cases 1 through 4).

In case 1, according to what can be seen in *figure 3*, there is no impedance matching for the entire UWB range. Case 2, where a circular patch meets case 1, gave better results after the structures were changed. Case 3 is obtained by appending the rectangular patch, and case 4 is obtained by further appending the rectangular patch. Case 4 has better impedance matching over the whole range of UWB frequencies chosen for the proposed antenna design.

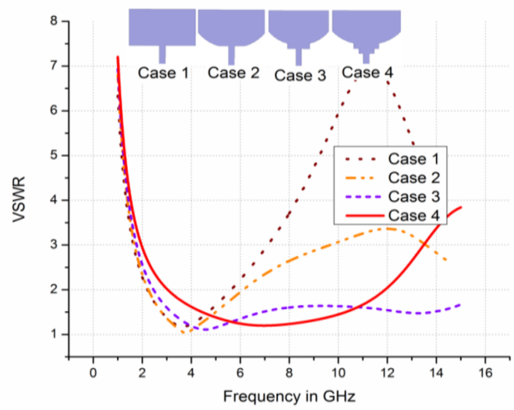


Figure 3: Curves for the Antenna Case 1 to Case 4 for achieving UWB Antenna

Based on the reflection coefficient S11 parameter having a value of less than -10 dB and the VSWR value of less than 2, the impedance bandwidth that was derived for this UWB design ranges from 3.1 GHz to 11.69 GHz.

3.2 Dual Notch Design

A circular slot is etched out at the radiating patch, and a patch stub is added to the patch with a centre frequency of 5.5 GHz and 3.45 GHz to construct a dual notch at 5G and WiFi carriers. Theoretically, the centre frequency of the circular slot may be found by following the instructions in [16], and the equation that describes the notch frequency for 5.5 GHz can be seen below.

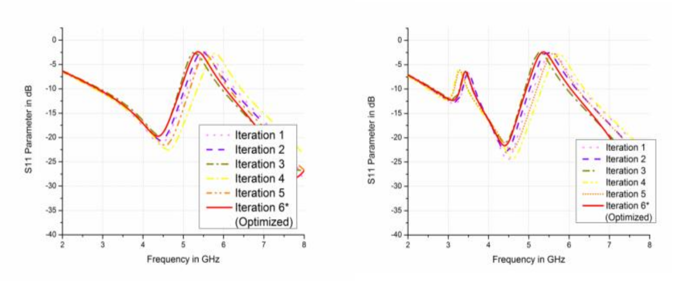
$$F = A * \frac{c}{2*\pi*R*\sqrt{\epsilon_{re}}} \quad (1)$$

Where, $A = \frac{2*R}{(R+T)+R}$;

$$\epsilon_{re} = \frac{1}{2}(\epsilon_r, sub + 1) + \frac{1}{2}(\epsilon_r, sub - 1)\left(1 + \frac{10H_s}{T}\right)^{-1/2}$$

Where ϵ_r is the substrate permittivity and ϵ_{re} is the effective relative permittivity. R and T stand for the circular ring's radius and thickness, respectively, and Hs is substrate height. The analysis is carried out in this manner in the beginning without taking into account any other notch bands, and then it is confirmed by the addition of additional notch bands. The study is made with iterating the radius of inner and outer circle such as iteration1 (2.2,2.7), iteration2 (2.3,2.7), iteration3 (2.5,2.7), iteration4 (2.2,2.6), iteration5 (2.3,2.6) and superior result for the antenna parameter was achieved in the sixth iteration (r1=2.4, r2=2.7), where the centre frequency for the notch band was 5.38 GHz, and the bandwidth ranged from 4.95 to 6.05 GHz. *Figure 4* depicts the S11 parameter shifts that occur in the notch band throughout the course of the numerous iterations. The design using the CSRR circular slot achieves the highest possible reflection coefficient of -2.4 dB at 5.38 GHz while also achieving the highest possible VSWR of 7.27 for the WiFi notch band. In the absence of taking the patch stub into account, it has been shown that the impedance bandwidth does not change over the operating range, except for the notch band.

However, with the installation of the patch stub, the impedance bandwidth changed for the operating range of the antenna to be between 2.64 and 11.87 GHz. This was the consequence of an increase in the antenna's electrical length.



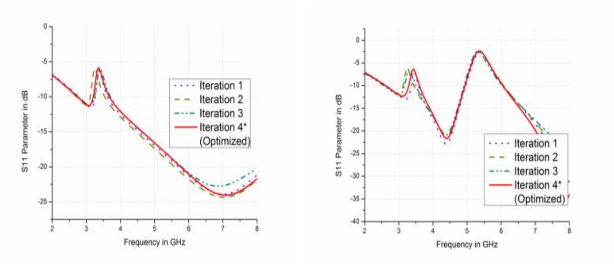
(a) (b)

Figure 4: S11 Parameter for Iteration of CSRR Circular slot radii (a) Without Patch Stub (b) With Patch Stub

A patch stub is fastened to the radiating patch to create a notch in the frequency range of 3.3GHz to 3.6GHz. The notch frequency fn of the bands that are notched is approximately calculated using equation 2 [17]

$$fn = \frac{c}{4*\sqrt{\frac{\epsilon r+1}{2}}*L_T} \qquad (2)$$

Where C denotes the speed at which electromagnetic waves are transmitted and L_T denotes the length of the stub in its entirety. According to the presented equation, the length of the patch stub varied from 17.4mm to 17.9mm such as 17.4mm, 17.6mm, 17.9mm and 17.8mm (optimized) respectively from iteration 1 to iteration 4 respectively. The investigation is carried out in this manner both with and without a circular slot. As can be seen in *figure 5*, the centre frequency of 3.45 GHz is reached with the notch bandwidth ranging from 3.29 GHz to 3.61 GHz and hence the optimum length of the patch stub is 17.8 mm. The results of the parametric analysis performed on the 5G carrier notch band. With the patch stub included in the design, the notch band achieves a maximum VSWR of 3.22 and a maximum reflection coefficient of -5.48 dB at 3.38 GHz.



(a) (b)

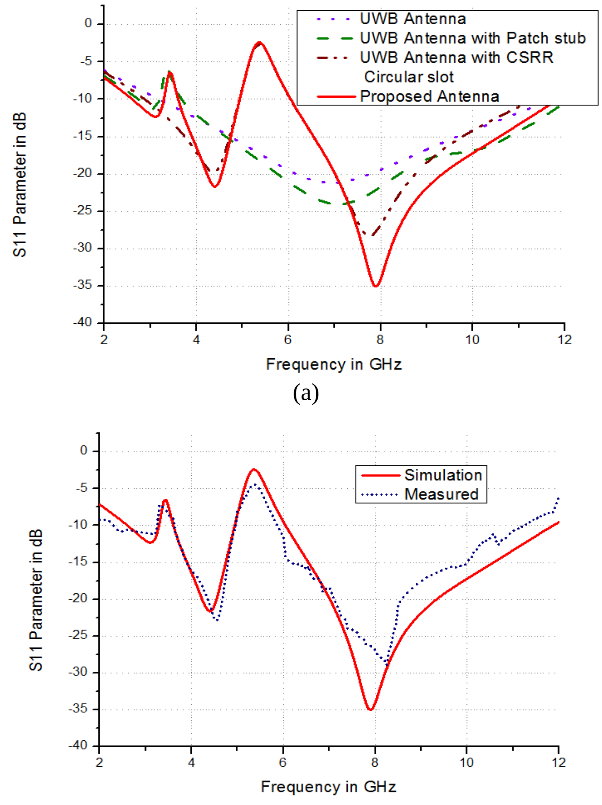
Figure 5: S11 Parameter for Iteration of patch stub length (a) Without Circular Slot and (b) With Circular Slot

4. RESULTS AND DISCUSSION

Simulation software called Ansys HFSS version 15 is used for both the design and analysis of the antenna. The frequency domain study was used to analyze the antenna's radiation pattern as well as its efficiency in terms of radiation and peak gain. The proposed antenna has a frequency range that extends from 2.62 GHz to 11.87 GHz, except the notch centre frequencies, which are 3.36 GHz and 5.38 GHz. These frequencies correspond to the notch bands that extend from 3.29 GHz to 3.61 GHz and 4.95 GHz to 6.05 GHz, respectively. The FR4 substrate is used in the construction of the antenna, and a photo of the antenna as well as a measurement setup can be seen in *figure 6*. Using the vector network analyzer Anritsu MS2027C VNA Master (5 KHz to 15 GHz), examinations of the S11 parameter, VSWR, and Smith chart were carried out.

Figure 7 depicts an S11 plot for (a) the UWB antenna, Single notch using patch Stub, Single notch using CSRR circular slot, and Suggested Dual notch UWB Antenna (b) Simulated and observed S11 parameter for the UWB antenna.

Figure 6: Photograph of Fabrication and Measuring of Proposed Antenna

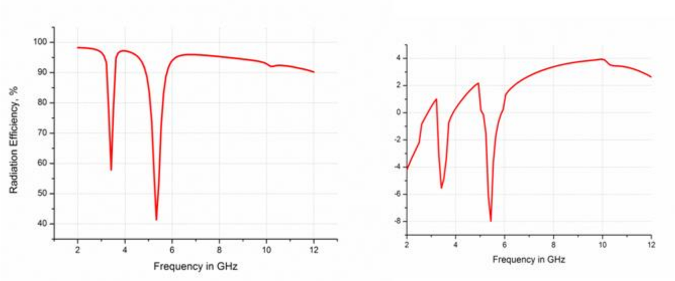


(a)

(b)

Figure 7: (a) The UWB antenna evolution with dual notch band (b) Simulation and measured S11 parameter

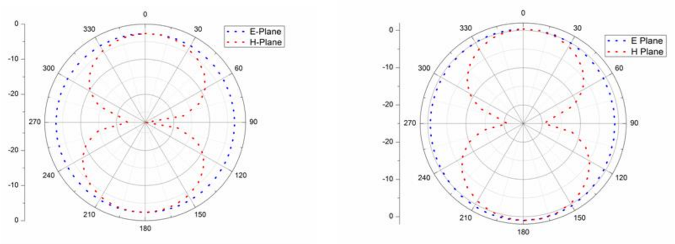
The bandwidth that was attained in the first design for the UWB ranged from 3.1 GHz all the way up to 11.69 GHz. The impedance bandwidth of the UWB antenna may be expanded from 2.9 GHz to 11.3 GHz simply by inserting a CSRR circular slot there; the only exception to this is the notch band that exists between 5.11 GHz and 6.22 GHz. The impedance bandwidth of the UWB antenna is between 2.77 GHz and 12.1 GHz when a patch stub is inserted alone, except for the notch band, which is between 3.27 GHz and 3.61 GHz.



(a) (b)

Figure 8: (a) Radiation Efficiency of the antenna and (b) Gain Total of the proposed UWB antenna

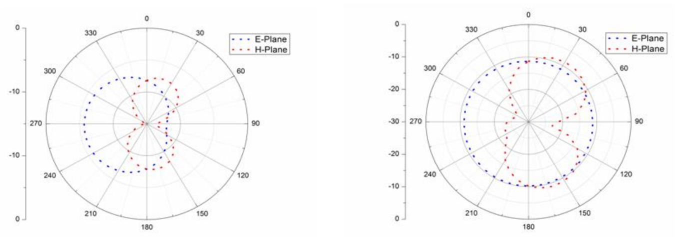
UWB antenna with a CSRR circular slot and a patch stub with impedance bandwidth below -10 dB ranges from 2.64 GHz to 11.87 GHz, and it has two notched bands across the ranges of 4.95 GHz to 6.05 GHz and 3.29 GHz to 3.61 GHz. The impedance bandwidth may be measured from 2.64 GHz to 11.87 GHz. It should be noted that the reason this design has a frequency shift from 3.1 GHz to 2.64 GHz is because the electrical length of the antenna has been made longer by etching off the circular patch and inserting a stub in the radiating patch. This has caused the frequency to shift.



(a) (b)

Figure 9: Radiation Pattern at the operational band of (a) 4.5GHz, (b) 8GHz

The radiation pattern is observed at the two operating frequencies at 4.5 GHz and 8 GHz and in the two notch frequencies at 3.45 GHz and 5.5 GHz.



(a) (b)

Figure 10: Radiation Pattern at the Notch band of (a) 3.45GHz, (b) 5.5GHz

A suitable omnidirectional pattern was observed in the E-plane, and a bidirectional pattern was observed in the H-plane in the working range of 4.5 GHz and 8 GHz, as shown in *figures 9(a)* and *9(b)*. On the other hand, the field distribution was disturbed, and less gain was observed in the notch band of 3.45 GHz and 5.5 GHz, as depicted in *figure 10 (a) and (b)*.

5. CONCLUSION

In this work, a UWB antenna with notch band characteristics is designed for spectrum sensing interviewing and underlay techniques in cognitive radio applications. Two rejection bands, WiFi (4.95–6.05 GHz) and 5G carriers (3.29–3.61 GHz) are achieved by etching a CSRR circular slot and by insertion of patch stub at the radiating patch. It is observed that due to the addition of a circular slot and patch stub, the increased electrical length of the antenna results, and hence impedance bandwidth is shifted from 3.1–11.69 GHz to 2.64–11.87 GHz. Since the antenna is designed for the Local area networks, the shifted frequency is more suitable for the application after the ISM band. The antenna performs well in the UWB range except in the notch band with the maximum peak gain of 3.93 dBi. Its radiation efficiency is more than 92% in the operating range, with a peak value of 97%. The designed antenna's simulation and experimental results show excellent agreement concerning the antenna parameters.

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