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Research Article

A Jug-Shaped CPW-Fed an Ultra-Wideband Printed Monopole Antenna for Wireless Communications Networks

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Abstract: A type of telecommunication technology called an ultra-wideband (UWB) is used to provide a typical solution for short-range wireless communication due to large bandwidth, low power consumption in transmission and reception. Printed monopole antennas are considered as preferred platform for implementing this technology because of its alluring characteristics like light weight, low cost, ease of fabrication, integration capability with other systems, etc. Therefore, a compact size an ultra-wideband (UWB) printed monopole antenna with improved gain and efficiency is presented in this article. Computer simulation technology microwave studio (CSTMWS) software is used to build and analyze the proposed antenna design technique. This broadband printed monopole antenna contains a jug-shaped radiator fed by a coplanar waveguide (CPW) technique. The designed UWB antenna is fabricated on a low-cost FR-4 substrate with relative permittivity of 4.3, loss tangent of 0.025, and a standard height of 1.6 mm, sized at 25 mm × 22 mm × 1.6 mm suitable for wireless communication system. The designed UWB antenna works with maximum gain (peak gain of 4.1 dB) across the whole UWB spectrum 3–11 GHz. The results are simulated, measured and debated in detail. Different parametric studies based on numerical simulations is involved to arrive to the optimal design through monitoring the effects of adding cuts on the performance of the proposed antennas. Therefore, these parametric studies are optimized to achieve maximum antenna bandwidth with relatively best gain. The proposed patch antenna shape is like a Jug with handle that offers greater bandwidth, good gain, higher efficiency, and compact size.

Keywords: Printed Monopole; CPW-fed; UWB; Wireless Communication.

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1. Introduction

An ultra-wideband (UWB) is a telecommunications technology that is utilized in radio communication networks to achieve high-speed bandwidth connections with minimal energy consumption. Primarily, the UWB was intended for commercial radar. Wireless personal area networks (WPANs) and consumer electronics are two main applications of UWB technology. UWB wireless develops an emerging skill with limited smart structures such as radar, wireless communications, and medical engineering domains after its initial achievement in the middle of the 2000s [1]. Until to 2001, UWB was significantly used for military purposes. The Federal Communications Commission (FCC) permits the public to use UWB bandwidth for commercial purposes after 2002. Furthermore, the FCC approved the usage of the UWB spectrum, which is allocated between 3.1-10.6 GHz in the United States [2]. The low spectral density of UWB is responsible for short-range of communication. This function, however, demands high gain antennas with relatively stable radiation characteristics [3]. Planar antennas, primarily monopoles, are used in UWB electrical devices [4,5], for its compact sizes, low profile, and low cost, as well as its ultra-wide impedance bandwidth. Moreover, when these antennas are placed near metallic surfaces, they can cause severe impedance mismatch. Low-profile antennas also transmit limited frequency signals with low gain and poor directivity [6,7].

However, the cost and size of the UWB antennas increases with discreet filters [8]. Frequencies from 5.2-5.8 GHz were notched by etching an omega type slot on the surface of the antenna in [9]. Similarly, in [10] U- and inverted U-shaped slots were embedded in printed monopole to stop multiple frequencies. A curved shaped slot is introduced in [11] to achieve notching features in WiMAX and WLAN bands. To attain notching characteristics in 5.10-5.94 GHz, S-shaped slot is applied in the feedline of the monopole antenna in [12]. Split ring resonators can act both as a band stop and band pass filters for different frequencies [13]. In [14] uplink and downlink satellite frequency bands were rejected by introducing a single SRR slot in the patch of the antenna. WLAN band is rejected by inserting split ring resonators in [15]. Three different frequencies were notched in [16] by embedding multiple split rings near the feedline of the antenna model. Notching has been achieved by using SRR in [17]. Tri-notching using frequency selective surface (FSS) of an ultra-wideband antenna with gain augmentation was reported in [18]. Another compact size UWB planar antenna using truncated ground plane was presented in [19]. The antenna covers large bandwidth but the size was still large as compared to our design. A broadband overleaf shaped antenna using beam tilt characteristics is presented in [20]. The reported size of the antenna is large as well as small bandwidth achieved as compared in Table 1. Another Vivaldi antenna resonative over a wide frequencu range is reported in [21]. The antenna is antipodal and the miniaturization had been achieved by using exponential strip arms technique.

Table 1. Comparison with the previous research.

Ref. No.	Frequency Range (GHz)	Area (mm^2)	Electrical Size (λ_0^2)	Antenna Type	Substrate Material	Efficiency (%)	Gain (dB)
[11]	3.4-7, 8-11.4	40×30	0.94×0.705	Split Ring Resonator Patch	FR-4	<95	<5
[12]	3.1-10.6	38.31×34.52	0.82×0.74	Monopole	FR-4	<95	<5
[13]	4.05-5.1, 6-13	32×36	0.89×1.01	Circular Patch	FR-4	-----	<4
[14]	2.5-19.8	36×25	0.62×0.43	Slotted Patch	FR-4	-----	<3
[15]	2.8-18	50×38	0.96×0.73	Tapered Slotted Patch	FR-4	-----	<4.32
[16]	1.9-5, 6-10.6	48×55	0.63×0.72	Monopole	FR-4	-----	<5
[17]	1.2-9.8	53×63.5	0.21×0.25	Anti-Spiral Shaped Patch	FR-4	<85	<5.2

[18]	2.6-10.58	38.3×34.5	0.33×0.3	Sharp triple notched	FR-4	------	<5
[19]	1.5-10.4	64×37.4	0.32×0.19	Planar patch	F4BM	------	>2
[20]	2-5	100×78	0.67×0.52	Leaf Shaped Patch	Taconic TLY-5	------	>3
[21]	0.83-9.8	161×140	0.45×0.39	Ex-potential Strip Arms	$\varepsilon_r = 2.3$	------	>2.5
[This Work]	**3-11**	**25×22**	**0.25×0.22**	**Printed Monopole**	**FR-4**	**>85**	**<4.1**

In this research article, a simple CPW based an ultra-wideband antenna having impedance bandwidth ranging from 3 GHz to 11 GHz (8 GHz) for wireless communication networks is presented. It is very hard to achieve UWB band with compact size, however, in this design, the UWB band is achieved through a CPW technique and the design optimization. The total size of the designed UWB antenna is 25mm × 22mm × 1.6mm. This printed broadband monopole antenna is manufactured using a less-priced FR-4 Duroid material. The antenna presents good efficiency with suitable gain. This article is described as: the presented antenna design is presented in section II. Results and discussion in section III, and the conclusion in section IV.

2. Antenna Design Analysis

The schematic diagram of the designed ultrawideband antenna is presented in Figure 1. The structure of the UWB antenna involves the jug-shaped printed monopole with handle at the right side of radiator is designed, sized at Ls × Ws × hs. The printed monopole is fed by a coplanar waveguide (CPW) feedline of length 'Lf' and width 'wf'. The width of the CPW feedline is kept 3 mm to attain 50-Ω input impedance. The antenna is design on a less priced FR-4 substrate having relative permittivity (ε_r) of 4.4 and loss tangent (tanδ) of 0.025. The design is simulated in computer simulation technology (CST-2018) software. On the front view of the substrate a rectangular ground plane is designed having dimension Lg× Wg and the ground plane. The third dimensional (3D) view of the antenna is depicted in Figure 1, and its optimized dimensions are given in Table 2.

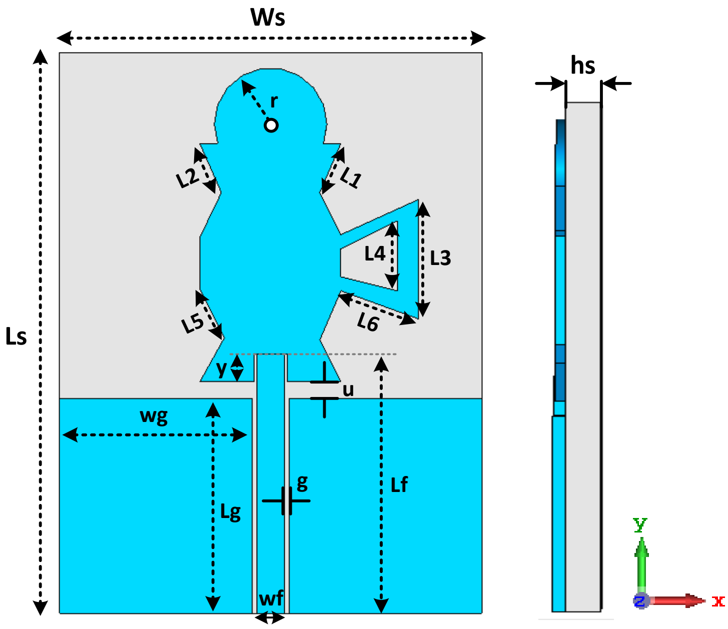


Figure 1. Schematic diagram of the presented UWB Antenna.

Table 2. Different design parameters of the presented Antenna.

Parameters	Values (mm)	Parameters	Values (mm)
Ls	25	Ws	22
Lf	14.65	Wf	1.58
Lg	12.14	Wg	10.85
L1	3.02	L2	2.75
L3	6.73	L4	3.96
L5	3.05	L6	4.64
g	0.24	y	1.58
u	0.95	hs	1.6

2.1 Different Design Steps

Figure 3 shows the S_{11} behavior for the different design steps of the designed monopole is given in Figure 2. In the first step, the basic design consists of a simple rectangular printed monopole radiator excited by a coplanar waveguide (CPW) feedline as shown in ANT I. Then in the second step, the simple rectangular radiator is truncated from its upper and lower sides to keep its shape like a body of the Jug that helps to keep the S_{11} [dB] close to -10dB but the antenna only operates at 3.5 GHz and 10.5 GHz. Again, in the third step, a semi-circular shaped patch is introduced in the ANT II that keeps some portion of the UWB band below -10dB but the antenna works from 3.3 GHz to 9 GHz and 9.3 GHz to 12 GHz as can be seen in ANT III (Fig .3) and this is not a required frequency band. Now, in order to achieve the whole UWB spectrum from 3 GHz to 11 GHz, a C-shaped resonator is introduced in the final step to make the shape like a handle of the jug as shown in ANT IV.

The design process of the printed monopole antenna is explained as follows:

The primary antenna design (ANT I) shown in Figure 3 (a), contains a 50-Ω CPW feedline, a jug-shaped monopole, and the ground plane. The printed monopole's width and length are calculated using (1) and (2) [13], as follows:

$$Wp = \frac{\lambda_o}{2(\sqrt{0.5(\varepsilon_r+1)}} \quad (1)$$

where ε_r and λ_o are the relative permittivity and the wavelength of the substrate in free space at the operating frequency. The best option of Wp tends to the perfect impedance matching. The length of the printed monopole can be evaluated by using equation (2).

$$Lp = \frac{c_o}{2f_o\sqrt{\varepsilon_{eff}}} - 2\Delta L_p \quad (2)$$

where c_o, ΔL_p, and ε_{eff} are the velocity of light, change in the length of the printed monopole due to its fringing effect, and the effective dielectric constant, respectively. The effective relative permittivity can be calculated using equation (3):

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

where hsub is the height of the substrate. At the end, the fringing effect can be calculated using equation (4):

$$\Delta Lp = 0.421\text{h}_s \frac{(\varepsilon_{eff}+0.300)(\frac{Wp}{hs}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{Wp}{hs}+0.813)} \quad (4)$$

with the placement of $\varepsilon_r = 4.3$, hs = 1.6 mm in (1)-(4), the initial parameters of the rectangular printed monopole are Lp = 15 mm and Wp = 12 mm.

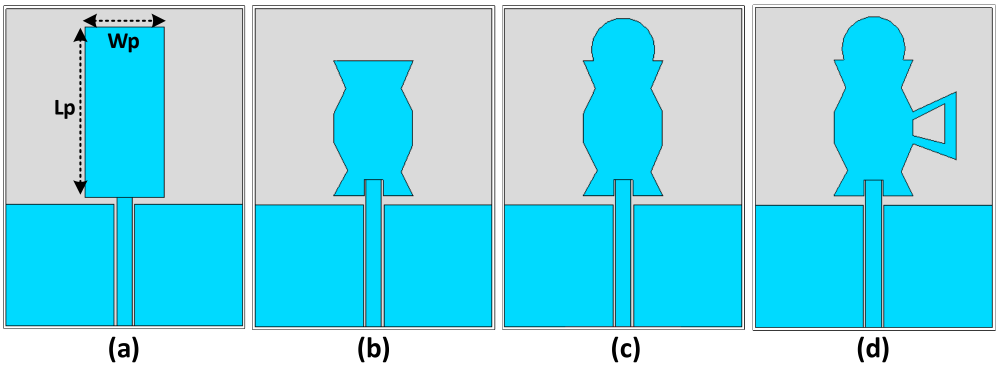


Figure 2. Design Steps of the presented ultra-wideband Antenna, (a) rectangular printed monopole only (ANT I), (b) Truncated monopole (ANT II), (c) Addition of semi-circular printed monopole (ANT III), (d) Presented design (ANT IV).

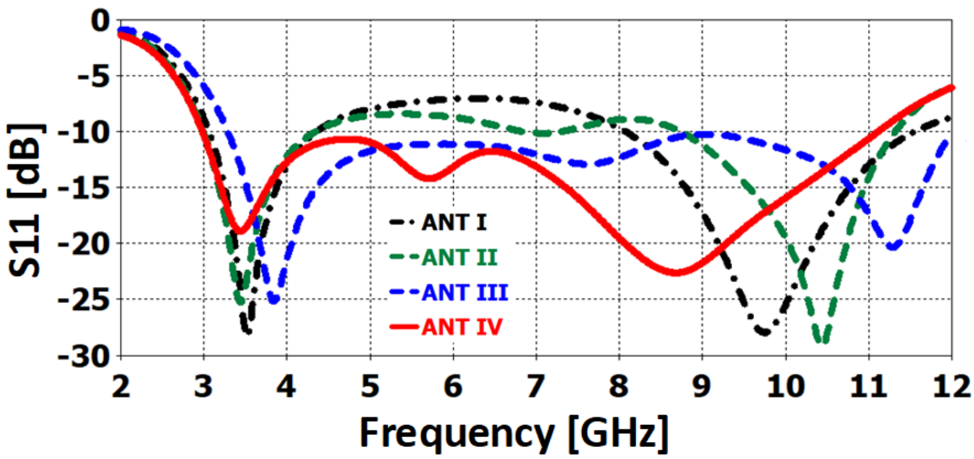
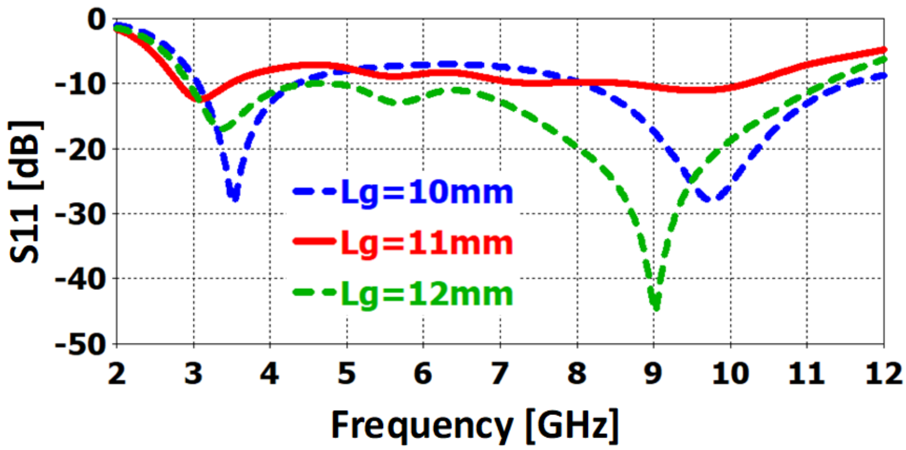


Figure 3. S_{11} [dB] of the different design steps of the presented UWB antenna shown in Fig. 2.

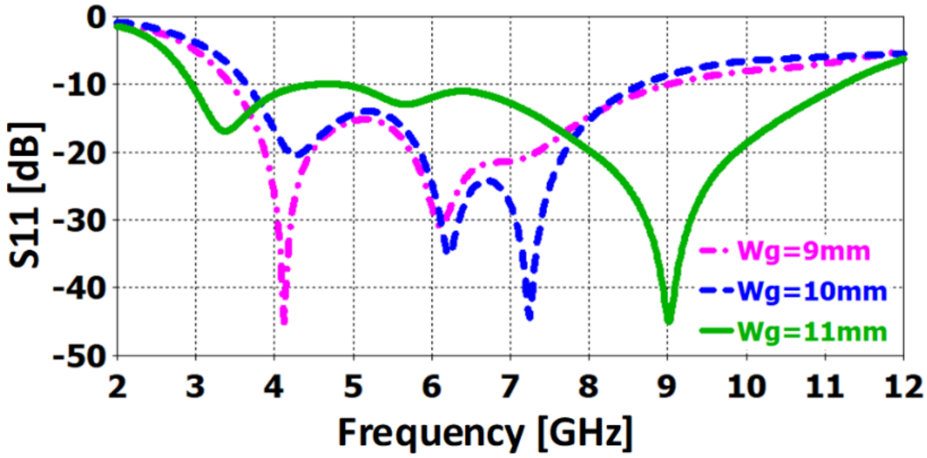
With a simple rectangular monopole (ANT I), the antenna works only works at 3.5 GHz and 9.8 GHz as proved in Figure 4. By ANT II, the bandwidth of the antenna is increased but unable to achieve UWB band, Then, in the third step (ANT III), with the help of semi-circular printed monopole on the top of the truncated printed monopole, the antenna has achieved most of the UWB band. Since the antenna has achieved band from 3 GHz to 11 GHz.

2.2 Parametric study of the presented design

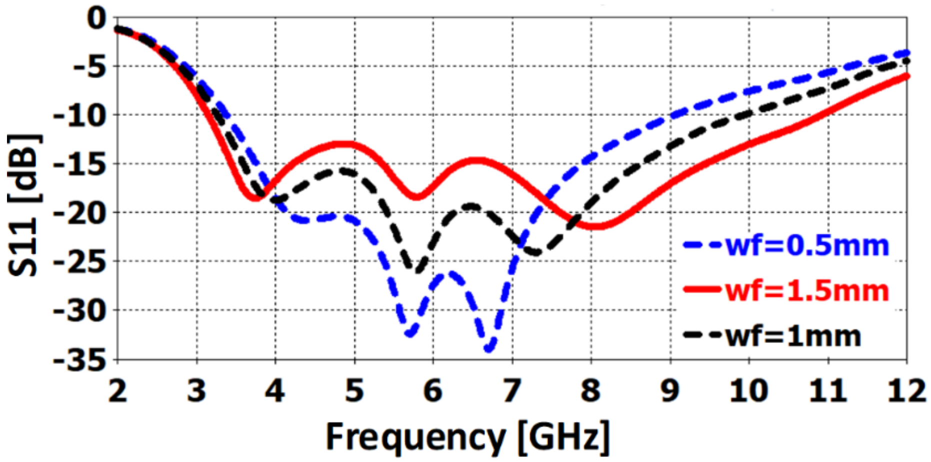
The presented design is finalized after performing a number of parametric optimizations on different variables as shown in Figure 4. The first parametric study is performed on the length and width of the ground plane. By increasing the length of the ground plane 'lg' from 10mm to 12mm the impedance matching of the antenna improves with suitable bandwidth. And when the width of the ground plane 'wg' is varied from 9mm to 11mm then the bandwidth of the antenna increased from 4.1 GHz to 8 GHz. The next parametric study is performed on the width of the feedline 'wf'. Gradually increasing the width of the feedline improves the impedance bandwidth from 5.8-8 GHz. A parametric study of the C-shaped radiator is also performed. By varying the lengths 'L6 and L3' the bandwidth of the antenna is improved as depicted in Figure 4.



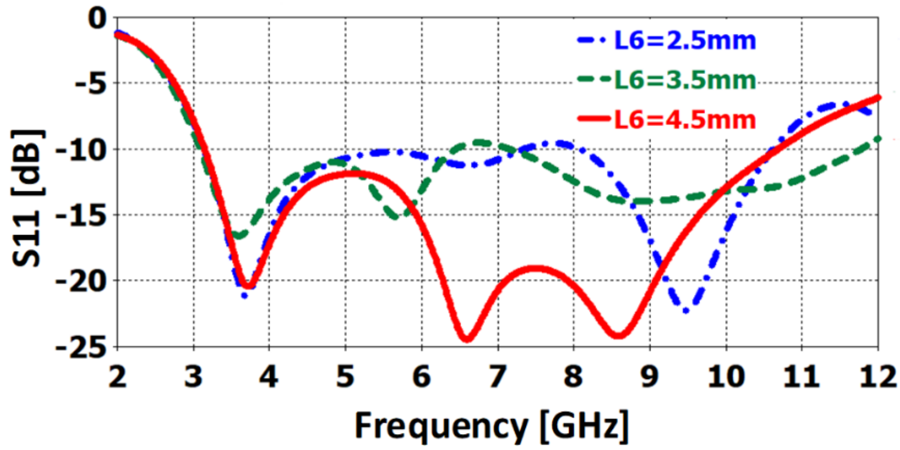
(a)


S11 [dB]
Frequency [GHz]
Wg=9mm
Wg=10mm
Wg=11mm

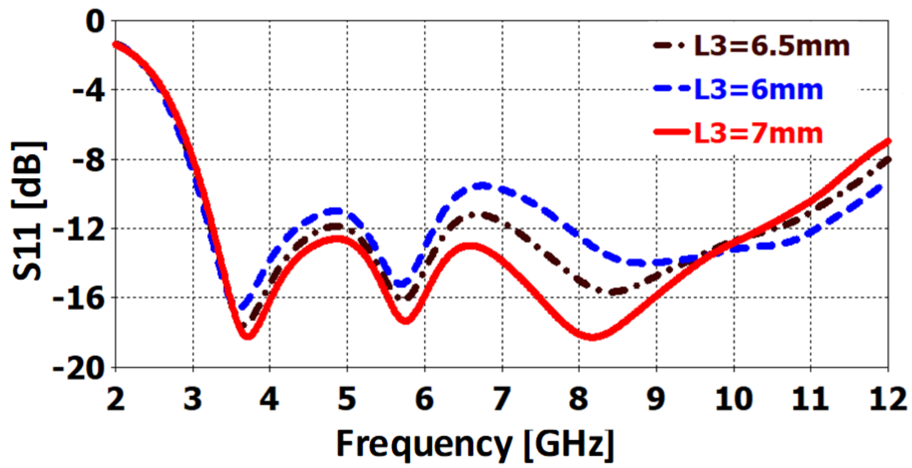
(b)


S11 [dB]
Frequency [GHz]
wf=0.5mm
wf=1.5mm
wf=1mm

(c)


S11 [dB]
Frequency [GHz]
L6=2.5mm
L6=3.5mm
L6=4.5mm

(d)



(e)

Figure 4. Different parameters optimization, (a) variation in 'Lg', (b) variation in 'wg', (c) variation in 'wf', (d) variation in 'L6', (e) variation in 'L3'.

The surface current density of the UWB antenna at different frequency bands are taken into consideration. This indicates that the antenna is playing a significant role in making it to resonate at the desired frequency bands. For example, the surface current density at 3.5 GHz is illustrated in Figure 5(a). The most of the current seems to flow through the radiator at 3.5 GHz (see Figure 5(b)), while at 4.1 GHz the current only flows through the C-shaped resonator and some amount of current through the feedline (see Figure 5(c)). At 8 GHz the current flows through the outer lower edge of the printed monopole and some amount of current flow through the CPW ground at 10.5 GHz (see Figure 5(d)).

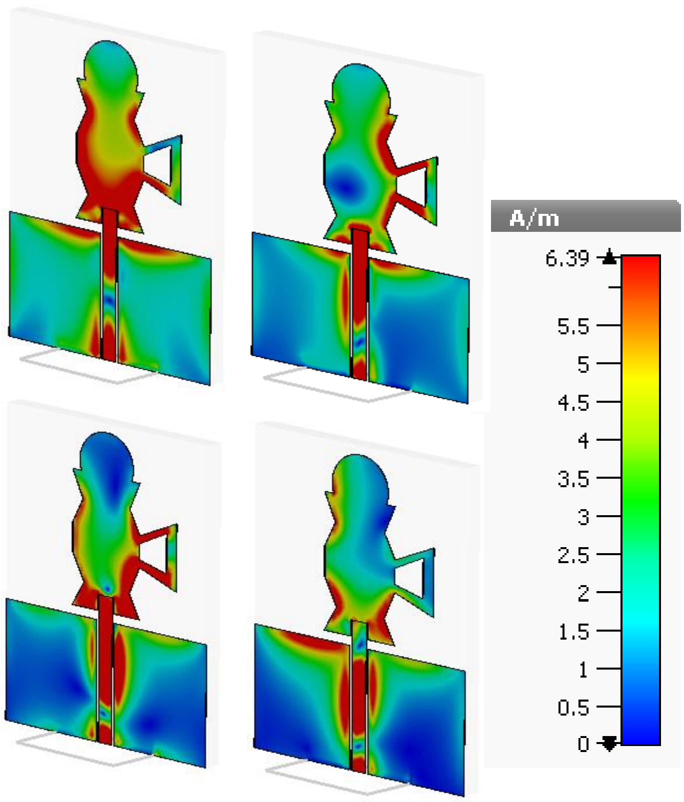
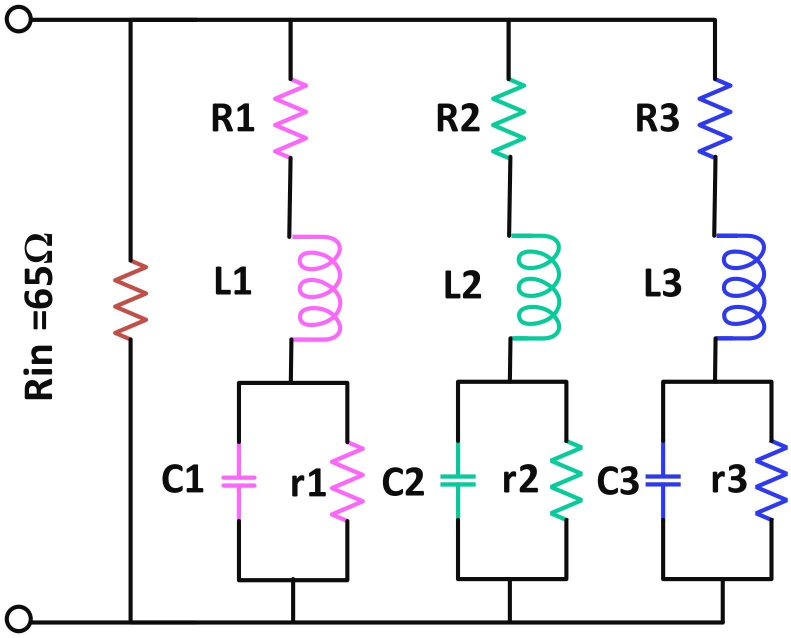


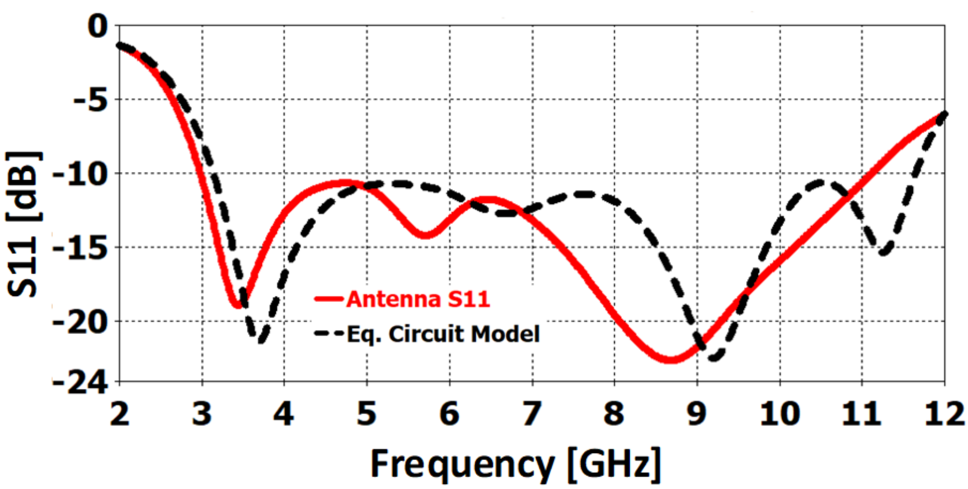
Figure 5. Surface current density, (a) at 3.5 GHz, (b) at 4.1 GHz, (c) at 8 GHz, (d) at 10.5 GHz.

2.3. Equivalent Circuit Model

A circuit model for the UWB presented antenna for wireless communications is presented in Figure 6(a). The main purpose of the circuit model is to validate the scattering parameters of the ultra-wideband antenna with the S_{11} obtained from the circuit model. The circuit model is designed by using an advanced design system (ADS) software. The circuit model consists of four inductors, four capacitors, three resistors, and three resistor-capacitor (RC) circuits connected in series with one resistor and an inductor for each as given in Figure 6(a). By varying the values of the resistors, the S_{11} of the circuit model can be varied while by fluctuating the values of the capacitors and inductors, the S_{11} of the antenna can be tuned. The values of the lumped components are given in Table 3. The S_{11} [dB] of the circuit model is illustrated in Figure 6(b). It covers the bandwidth from 3.1 GHz to 11.5 GHz.



(a)



(b)

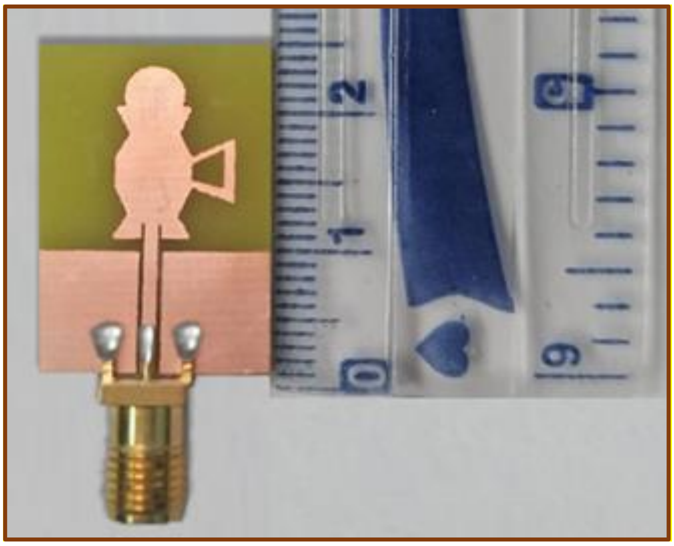
Figure 6. (a) Equivalent circuit model, (b) reflection coefficient of the equivalent circuit model.

Table 3. Values of the components used in the circuit model.

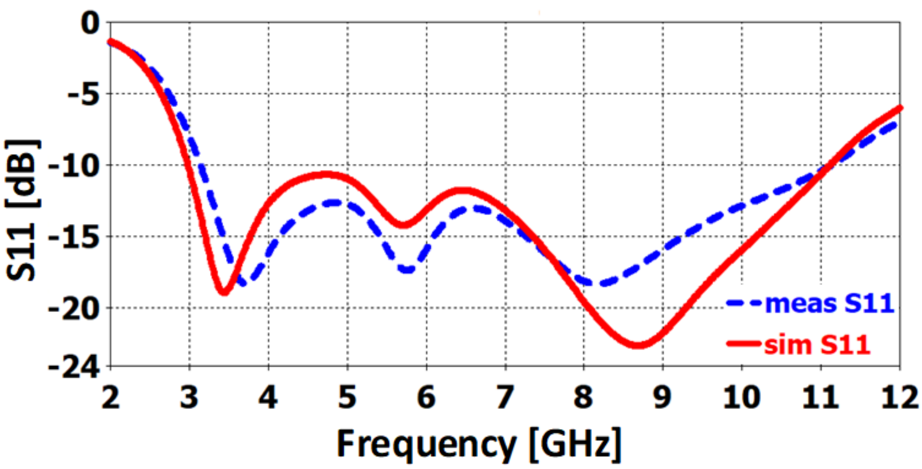
Capaci-tors	Values (pF)	Induc-tors	Values (nH)	Resistors	Values (Ω)	High Resistors	Values (Ω)
C1	1	L1	7	R1	2	r1	1500
C2	0.1	L2	0.8	R2	65	r2	1000
C3	0.5	L3	0.5	R3	65	r3	500

3. Results and Discussions

In order to measure the scattering parameters of the fabricated prototype, the port of the fabricated design is connected with a vector network Analyzer (VNA). The picture of the prototype is visible in Figure 7(a). The S_{11} [dB] of the projected antenna is accessible in Figure 7(b). Due to intolerances in the fabrication process and surrounding noises, there are some variations in the measured results. The simulated and measured S_{11} [dB] are in good agreement as both are covering the whole UWB band for wireless communications.



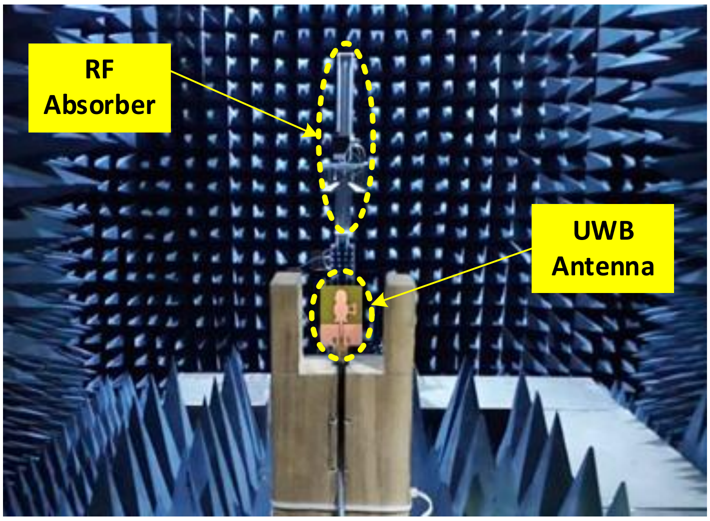
(a)



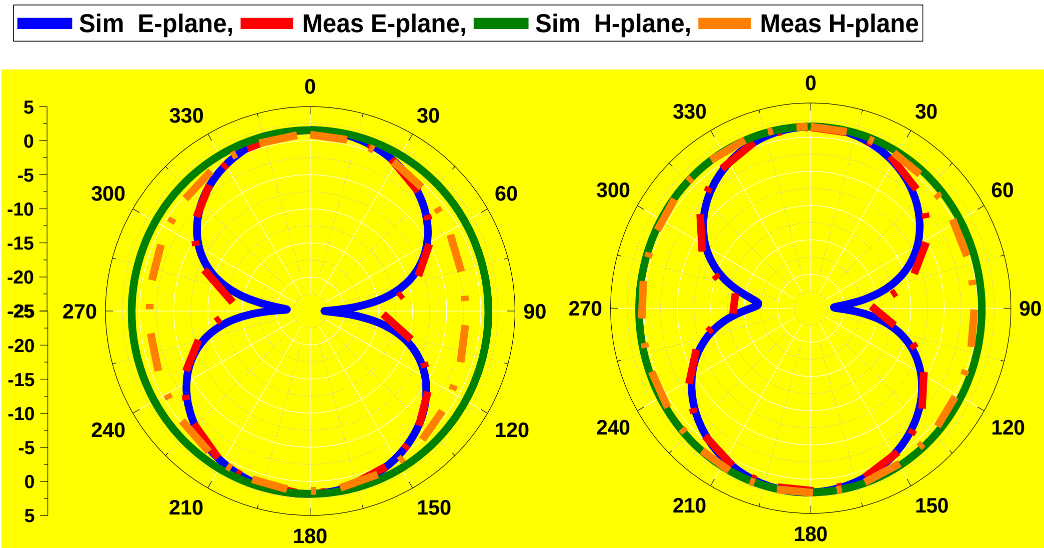
(b)

Figure 7. (a) Printed UWB prototype, (b) comparison of simulated and measured reflection coefficients (S_{11}).

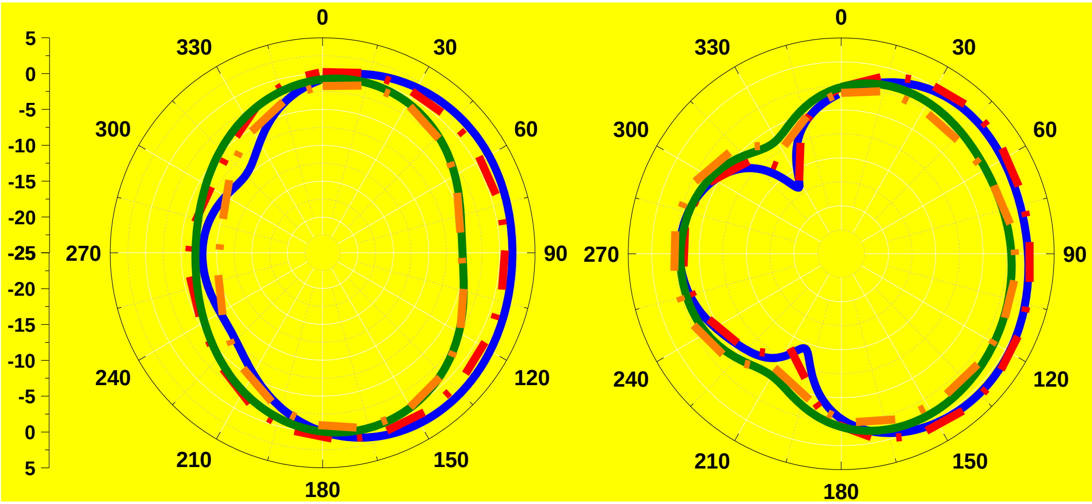
The simulated and measured (E & H)-plane of the UWB antenna at 3.5 GHz, 4.1 GHz, 8 GHz, and 10.5 GHz are given in Figure 8. It can be seen that there is an omnidirectional pattern at the frequencies of 3.5 GHz and 4.1 GHz along E-plane while elliptical along H-plane and the antenna has sided radiation pattern in both planes at the frequencies of 8 GHz and 10.5 GHz. The simulated and measured gain graph is presented in Figure 9. It can be noticed that the antenna has been attained the average peak gain ranges from 2-4.1 dB and the antenna's efficiency is attained more than 85% over the entire band. The comparison with the previous research is given in Table 1.



(a)



(b) (c)



(d) (e)

Figure 8. (a) Simulated and measured 2D radiation pattern setup inside chamber; (b) at 3.5 GHz, (c) at 4.1 GHz, (d) at 8 GHz, (e) at 10.5 GHz.

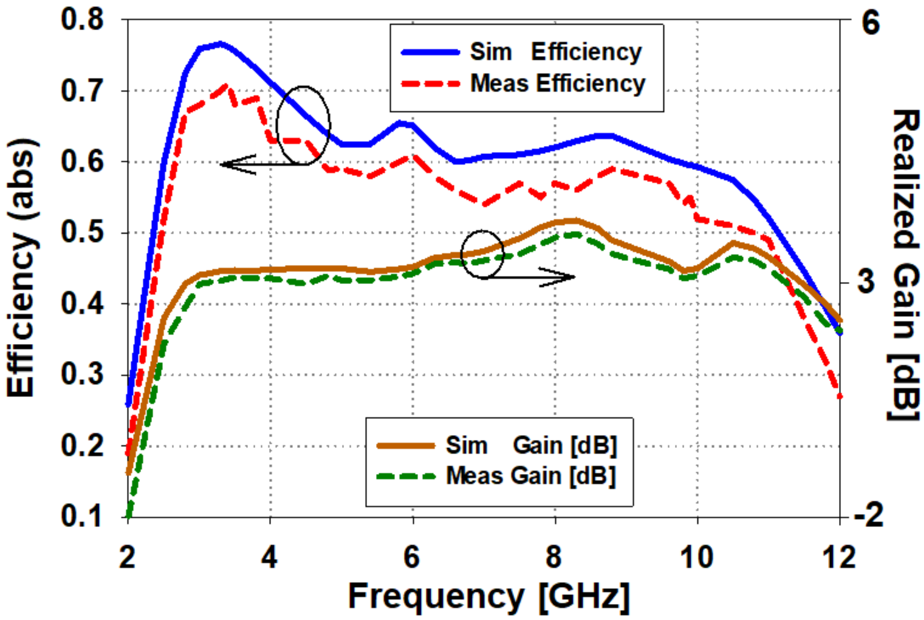


Figure 9. Comparison of simulated and measured efficiency and peak gains [dB].

4. Conclusion

A simple jug-shaped an ultra-wideband (UWB) antenna is presented in this work. The presented design is printed and measured results are also taken. The simulated results are verified by a measured result of the ultra-wideband antenna. The designed UWB antenna is printed on a less-priced FR-4 substrate with relative permittivity of 4.3, loss tangent 0.025, and a standard thickness 1.6mm, sized at 25mm × 22mm × 1.6mm suitable for wireless communication system. The designed UWB antenna works with maximum gain (peak gain of 4.1 dB) across the whole UWB spectrum 3–11GHz. The simulated and measured reflection coefficients and radiation pattern are in close agreement. The designed antenna is a good applicant for wireless communication systems portable devices.

Author Contributions: Conceptualization, S.A., S.N; M.A.Q, F.A, methodology, U.I., A.G., CHS; software, A.G., S.N., U.I; validation, M.A.Q., F.A,, U.I, and S.N.; formal analysis, S.A., and A.G.; investigation, A.G., N.O.P., S.N.; resources, A.G., U.I., S.A.; data curation, S.A.,M.A.Q, and A.G.; writing—original draft preparation, S.A., and A.G.; writing—review and editing, S.N., F.A.; supervision, NOP, CHS, and RAA; funding acquisition, NOP, CHS, and RAA.

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Conflicts of Interest: The authors declare no conflict of interest.

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