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doi:10.15199/48.2021.01.02

An Ultra-Wideband Rectangular Monopole with Circular Ring Antenna for Wireless Communication Applications

***Abstract**. An investigation of an ultra-wideband rectangular monopole with circular ring antenna for wireless communication systems is reported. The antenna is designed, simulated, invented, and tested experimentally. It operates over frequency range of* 2.56-13 *GHz with a return loss of* 10 *dB. The dimensions of designed antenna is* 40 *mm* × 40 *mm with an electrical size of* 0.34λ× 0.34λ *at* 2.56 *GHz frequency. It is fed by a* 50-*Ohm coplanar waveguide and printed on a single side FR*-4 *substrate with a relative permittivity of* 4.3 *and a thickness of* 1.6 *mm. This designed antenna exhibits bidirectional radiation patterns over the entire impedance bandwidth with more than* 2.8 *dB peak gain for the entire frequency range. The simulation results are reasonably in good agreement with the experimental results.*

***Streszczenie.** Przedstawiono szerokopasmową antenę z pierścieniem do bezprzewodowej komunikacji. Antena była zaprojektowana, był wtkonany jej model I przedstawiono wyniki testów. Antena pracuje w paśmie 2.56 – 13 GHz, ze stratami 10 dB. Wymiary anteny to* 40 × 40 *mm. (**Szerokopasmowa jednobiegunowa antena z pierścieniami do zastosowań w komunikacji bezprzewodowej**)*

Keywords: Ultra-wideband antenna; Rectangular monopole antenna; Circular ring antenna.
Słowa kluczowe: antena szerokopasmowa, komunikacja bezprzewodowa

Introduction

With a growing in the use of multipurpose wireless communication systems, ultra-wideband (UWB) antennas are becoming popular in recent wireless communication systems since its certified the use of UWB devices operating in the range of 3.1-10.6 GHz by Federal Communications Commission (FCC) in 2002 [1]. This tremendous bandwidth has allowed various modern applications that require high data rates and low power consumption to appear in wireless communication networking, as well as radar imaging and positioning systems, including high-speed mobile communications, in-car sensor network communication, automotive localization and tracking with high spatial resolution, emergency services, and roadside assistance [2]-[4]. Furthermore, an UWB antenna might be employed to replace multiple narrowband single antennas as well [5]-[6].

Lately, microstrip antenna have been attracted significant research interest in the designing for communication devices due to its easy integration with monolithic microwave integrated circuits [2]-[10]. Various types of UWB monopole antennas have been continuously demonstrated and discussed. Some articles discuss about different types of radiating UWB antenna design using a variety of shapes such as rectangular, triangular, circular, ellipse, hexagonal, octagonal, fork-like, and meandered strips etc., with various feed techniques such as microstrip line, tapered line, coplanar waveguide (CPW), and aperture coupling, et.al [11]-[13]. In addition, some special techniques are reported to enhance the impedance bandwidth, such as, adding rounded corners, using parasitic elements, inserting and rotating the slot etc. [6], [14]-[16]. Nonetheless, the radiation properties of several UWB antennas are degenerated especially at the higher frequency, since it propagates over very wideband. To escalate its radiation properties, numerous techniques are reported and employed, such as, using metasurface, defected ground plane, modified ground plane, and reflective surfaces, etc. [10], [17]-[20]. In this research, a compact UWB rectangular monopole with circular ring (RMWCR) antenna fed by CPW is proposed to operate over the frequency range of 3.1-10.6 GHz. In the design, the CST microwave studio [21] is used to investigate the optimal parameters. Simulation results and its validation are shown and discussed in the detail.

Antenna structure and its design

The geometry of proposed RMWCR antenna for UWB application is shown in Fig. 1. It consists of a radiating rectangular monopole (RRM) of width wr and length lr with a bottom edge-cut (BEC) of angle α for improving its impedance bandwidth. This RRM antenna is fed by a 50-Ohm CPW of feed length lf, width w_f, gap g, ground plane length l_g and surrounded by a circular ring of radius r with the thickness d to transform an omnidirectional pattern to a bidirectional pattern, as well as to enhance its gain. This presented antenna is printed on a single side FR-4 substrate of thickness h of 1.6 mm, relative permittivity 4.3 and supported by the length and width of dielectric substrate of l and w, respectively.

In the process, the substrate dimension of width × length × height of 40×40×1.6 mm^3 is chosen and fixed. Then, take into account the fringing effect the width wr and length l_r of RRM are calculated by using (1)-(2) [22] to resonate around the centre UWB frequency of 6 GHz; w_r of 14 mm and l_r of 10 mm are initially set in the design. In addition, a circular ring of radius r of 14.6 mm surrounded the RRM is included together with a CPW to control the radiation pattern propagating in forward and backward directions. Note that, the radius r is designed to provide the dominant mode TE_{11} at the operating frequency of 6 GHz. For the feeding section, a quarter-wavelength l_f and width wf is designed for 50-Ohms impedance matching by using (3) [22]. Hence, l_f of 8.9 mm and w_f of 3 mm are set and fixed throughout the paper.

$$w_r = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

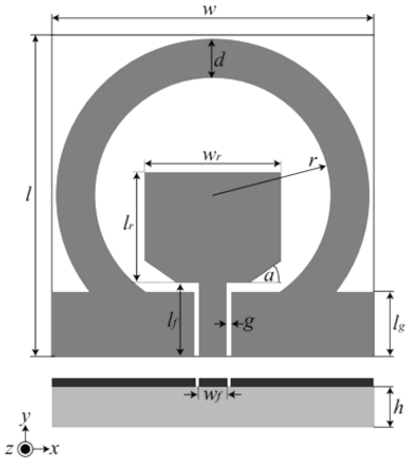
$$l_r = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 0.824h\left[\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{w_r}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{w_r}{h}+0.8\right)}\right] \tag{2}$$

where ε_{reff} is an effective dielectric constant and $\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{\frac{w_r}{w_r+12h}}$.

(3) $$w_f = \frac{2h}{\pi}\left[B - 1 - \ln(2a) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(a) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right]$$

where $a = \frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}} - 1$ and $B = \frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}}$.

a)



b)

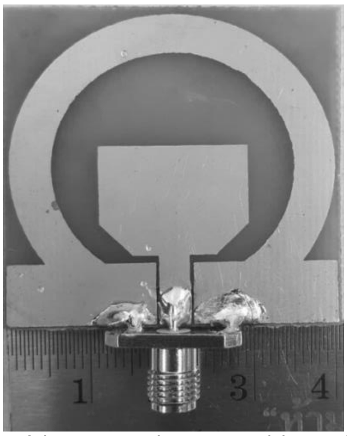


Fig.1. Geometry of the proposed antenna: a) its model and b) photo of its prototype

By using an electromagnetic simulation tool, all appropriated parameters are obtained and tabulated in Table 1.

Table 1. Parameters of design antenna

Parameter	Physical size (mm)	Parameter	Physical size (mm)
w	40	r	14.6
l	40	l_g	8
w_r	18	g	0.45
l_r	14	d	5
w_f	3	α	45°
l_f	8.9		

Parametric Study

This section shows the simulation results of the designed antenna as tabulated in Table 1. This designed antenna is printed on a single side FR4 with the height of 1.6 mm, ε_r of 4.3. In the process, it initially begins with the RRM of w_r = 14 mm and l_r =10 mm with a 50-Ohm CPW fed length of 8.9 mm and width of 3 mm. To investigate the effect of RRM length l_r to the impedance bandwidth, l_r is varied over the frequency of 2-14 GHz as shown in Fig. 2, where α is firstly excluded ($\alpha = 0$). It is obvious that the longer l_r shifts down the resonant frequency to the lower frequency; i.e. l_r of 8 mm, 10 mm, 14 mm, and 18 mm provide the resonance frequency at 6.07 GHz, 5.07 GHz, 3.48 GHz and 2.85 GHz covered the frequency bands of 4.05-8.69 GHz, 3.5-8.31 GHz, 2.5-7.44 GHz and 2.41-3.35 GHz, respectively. Consequently, l_r of 14 mm is selected because it provides a widen impedance bandwidth and tends to cover the lower edge of UWB frequency as well.

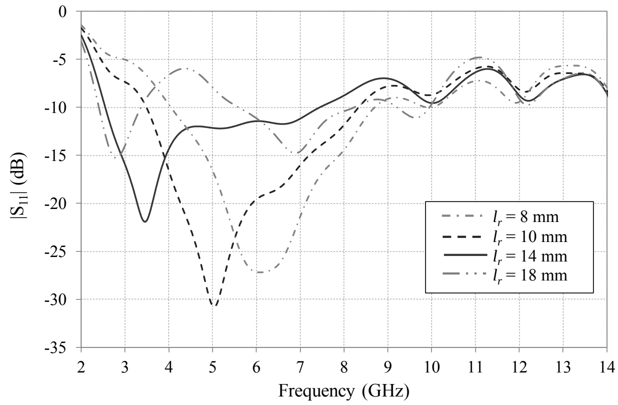


Fig.2. $|S_{11}|$ of proposed antenna for various l_r

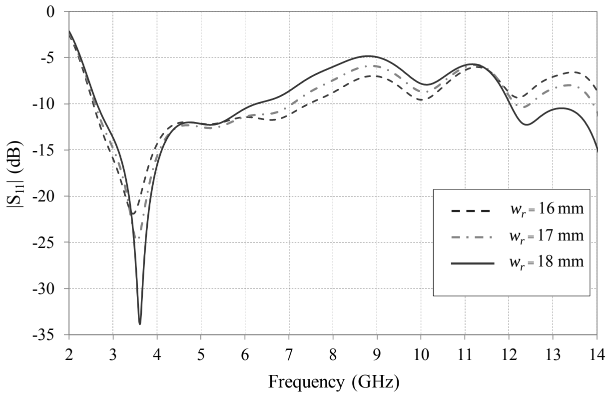


Fig.3. $|S_{11}|$ of proposed antenna for various w_r

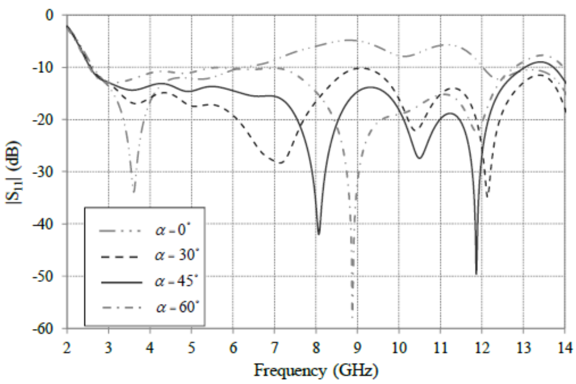


Fig.4. $|S_{11}|$ of proposed antenna for various α

While the length l_r is fixed at 14 mm, the effect of w_r to the impedance bandwidth is considered as shown in Fig. 3. Apparently, all cases provide the resonance frequency around 3.5 GHz. However, the widen rectangular width provides the better return loss; w_r of 18 mm offers the deepest $|S_{11}|$ and also widen impedance bandwidth (2.56-7.45 GHz). It should be noted that w_r of 18 mm is the widest width that the RRM does not contact the circular ring. Thus, the width of 18 mm is selected. Nonetheless, its impedance bandwidth does not cover the UWB frequency (3.1-10.6 GHz) yet. To enhance the impedance bandwidth, the bottom edge of RRM is cut with the angle α as shown in

Fig. 1. The effect of BEC with angle α to $|S_{11}|$ is plot as shown in Fig. 4. By increasing α , its impedance bandwidth is improved and covered over the UWB frequency. Nevertheless, the return loss is quite high around the frequency of 8.5-9.5 GHz, and 4-7.5 GHz for α of 30° and 60°, respectively. Therefore, BEC with α of 45° is selected and designed in this paper.

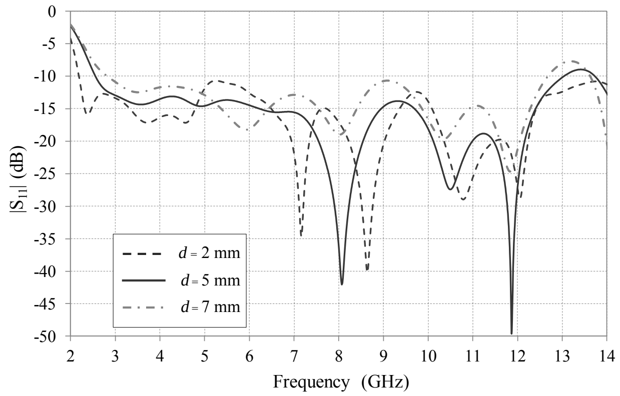


Fig.5. $|S_{11}|$ of proposed antenna for various *d*

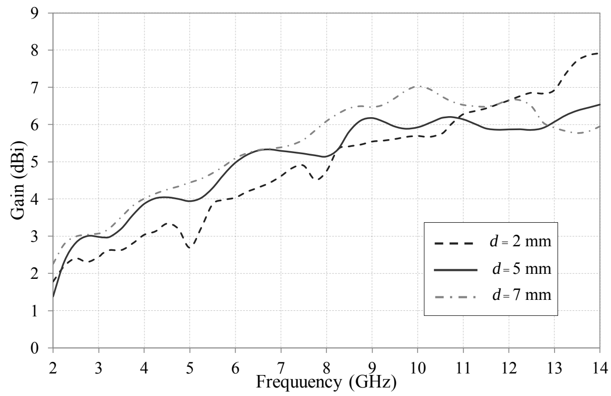


Fig.6. Gain of proposed antenna for various *d*

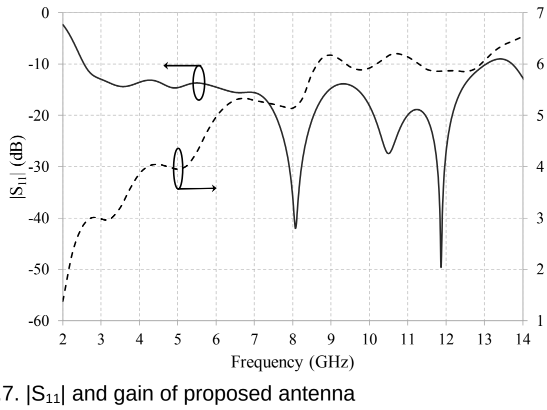


Fig.7. $|S_{11}|$ and gain of proposed antenna

Lastly, the effect of thickness *d* to its impedance bandwidth and gain is investigated as depicted in Figs. 5-6. Apparently, it has the impedance bandwidth covers the UWB frequency for the thickness d of 2 mm, 5 mm and 7 mm. However, the return loss is worse around the frequency of 5-6 GHz and 8.5-9.5 GHz for the thickness *d* of 2 mm and 7 mm, respectively. Moreover, the increasing gain is produced over the UWB frequency as the increasing thickness; i.e. minimum/maximum gains of 2.54/5.82 dBi, 2.96/6.2 dBi and 3.11/7 dBi for d of 2 mm, 5 mm and 7 mm respectively are yielded. For the reason of good return loss and antenna gain, the thickness *d* of 5 mm is selected in this paper. Accordingly, the presented antenna has a peak gain more than 2.8 dBi covered the frequency range from 2.56 GHz to 13.02 GHz over the UWB frequency as depicted in Fig. 7.

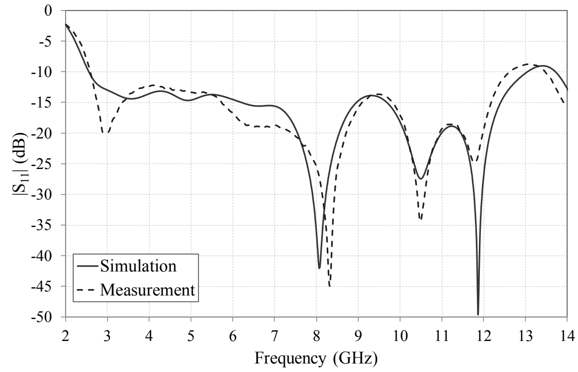
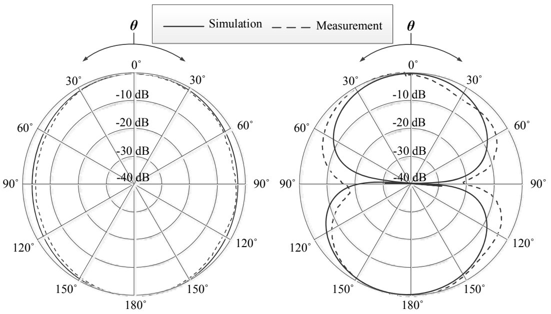
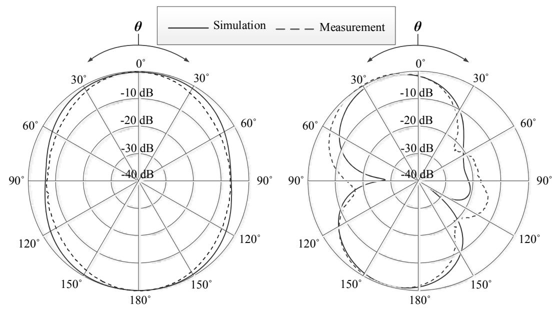


Fig.8. Simulated and measured $|S_{11}|$

a)



b)



c)

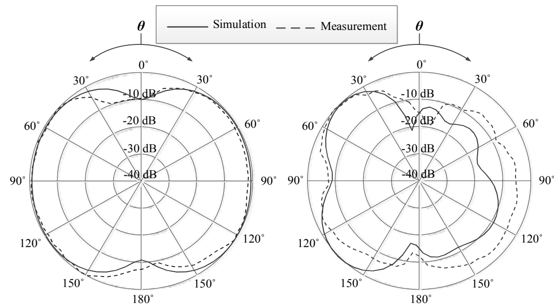


Fig.9. Radiation pattern in *xz*-and *yz*-planes at: a) 3.1 GHz b) 6 GHz c) 10.6 GHz

Experimental Results

To verify the simulation results, a prototype antenna was fabricated followed the size in Table 1 (as seen in Fig. 1(b)), and made a measurement. The comparison between simulated and measured $|S_{11}|$ is plotted in Fig. 8. Apparently, both simulated and measured $|S_{11}|$ are reasonably in good agreement. They have return loss of 10 dB bandwidth over the frequency ranges of 2.56-13.02 GHz and 2.59-12.61 GHz covering the UWB frequency for the simulation and the measurement, respectively as shown in

Fig. 8. In addition, this proposed antenna provides bidirectional pattern with different beam peaks as depicted in Fig. 9. It has half power beamwidths (HPBWs) at the operating frequency of 3.1 GHz, 6 GHz and 10.6 GHz in *xz*-plane of 152º, 114º and 128º for simulation, and 156º, 71º and 122º for measurement, respectively. For *yz*-plane, it has simulated HPBWs of 80º, 57º, 43º and measured HPBWs of 63º, 58º, 31º at the operating frequency of 3.1 GHz, 6 GHz and 10.6 GHz, respectively. In addition, simulated gains of 2.88 dBi, 5.03 dBi, 5.71 dBi and measured gains of 2.36 dBi, 3.47 dBi, 4.57 dBi are achieved at the operating frequency of 3.1 GHz, 6 GHz and 10.6 GHz, respectively. Nonetheless, for the entire UWB frequency, this proposed antenna provides a simulated peak gain over 2.8 dBi.

Conclusions

In this paper, a compact UWB rectangular monopole with circular ring antenna for wireless communication applications is presented. This RMWCR antenna is printed on a single side FR4 substrate of height 1.6 mm with relative permittivity of 4.3, and is fed by a 50-Ohm CPW. It is found that, this compact UWB antenna produces a bidirectional pattern with a peak gain over 2.8 dBi over the frequency band of 2.56-13 GHz. In addition, it has the 10 dB return loss bandwidth over the UWB frequency. The experimental results validate well the simulation results, and they are reasonably in good agreement. As its properties of compact size, wide impedance bandwidth, and good radiation properties, this proposed antenna is one of good candidates for the UWB applications along with sub band 5G, Wi-Max, WLAN, C-band, X-band, and future wireless applications.

Acknowledgements

This research project is supported by Rajamangala University of Technology Isan.

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