Suthasinee LAMULTREE[1], Chalee JANSRI[1], Chuwong PHONGCHAROENPANICH[2]

Rajamangala University of Technology Isan Khonkaen Campus, Faculty of Engineering (1), King Mongkut's Institute of Technology Ladkrabang, Faculty of Engineering (2), Thailand

doi:10.15199/48.2020.04.09

Investigation of 3.1-10.6 GHz Circular Monopole Antenna with Modified Partial Ground Plane

***Abstract**. A circular monopole antenna with modified partial ground plane for ultra wideband (UWB) applications is investigated in this paper. The proposed antenna is fed by a 50 Ω tapered microstrip line, and printed on a FR4 substrate with relative permittivity of 4.3 and height of 1.6 mm. All optimal parameters have been achieved to accomplish S_{11} better than -10 dB with a nearly omnidirectional pattern and maximum gain of 3.83 dBi over 3.1-10.6 GHz. In addition, antenna prototype was fabricated and conducted experiment to verify the simulation. Apparently, simulated results are in very good agreement with the experimental results.*

Streszczenie.** W artykule przedstawiono badania szerokopasmowej anteny ze zmodyfikowaną konstrukcją. Osiągnięto wzmocnienie 3.83 dBi w paśmie 3.1 – 10.6 GHz. Porównano wyniki symulacji z badaniami wykonanego modelu. **Badania cyrkularnej jednobiegunowej anteny o paśmie 3.1 – 10.6 GHz

Keywords: circular monople; modified ground plane; UWB antenna.
Słowa kluczowe: antena szerokopasmowa, antena jednobiegunowa, antena cyrkularna

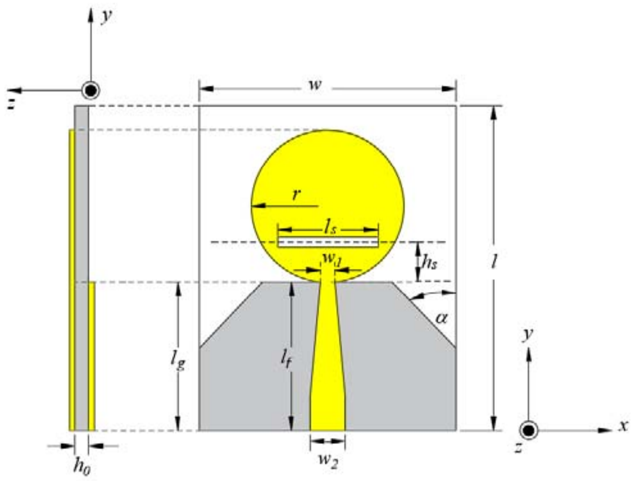
Introduction

In 2002, the Federal Communications Commission (FCC) in USA certified the use of ultra wideband (UWB) devices operating in the frequency range 3.1–10.6 GHz [1]. This enormous bandwidth has allowed many new 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]-[7]. A number of works have been conducted in designing such UWB systems because of the unique benefits about UWB systems. As an important part of the UWB communication systems, UWB antennas have attracted significant research interest in lated years [4]-[12]. Various types of UWB monopole antennas have been 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, bowtile, fork–like, and meandered strips etc., with various feed techniques such as microstrip line, coplanar waveguide (CPW), aperture coupling. Moreover, some special techniques are also applied for larger operating bandwidth, such as adding round corners, rotating the slot, and the impedance bandwidth is enhanced [13]-[16]. Nonetheless, the radiation patterns of the many UWB antennas are deformed in the upper frequency band, since it propagates very wideband. To enhance the radiation property, various techniques are used, such as using metasurface, defected ground plane, modified ground plane, and reflective surfaces, etc. [17]-[20]. In this paper, a compact UWB monopole antenna with modified partial ground plane for improving radiation properties is presented. In the design, the CST microwave studio [21] is used to investigate the optimal parameters. Simulation results and its validation are reported in the paper.

Antenna design

Figure 1 shows a geometry of proposed UWB circular monopole (CM) antenna with modified partial ground plane (MPGP). It consists of a radiating circular monopole with slot (CMWS) and modified partial ground plane for improving antenna gain. For the radiating section, a circular monopole of radius r with a narrow slot of length l_s is printed on a coper layer of 0.035 mm which supported by a FR-4 substrate of thickness 1.6 mm and relative permittivity 4.3.

a)



b)

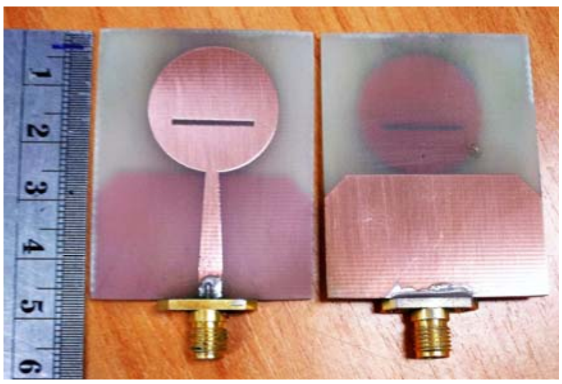


Fig.1. Geometry of the proposed antenna: (a) model and (b) prototype

The length and width of dielectric substrate denote l and w, respectively**.** This slot is located above the feed point attached the radiating CMWS with a height of h_s**.** In order to further enhance the impedance bandwidth, the CMWS is fed by a tapered microstrip line [15], which can be regarded as an impedance transformer that smoothly transforms the impedance of the CMWS to 50 Ω of an SMA connecter [10], [15]. Thus, the width of the microstrip feed line is fixed at w_1 **=** 2 mm and w_2 **=** 3.8 mm**.** While the length of feeding line l_f is set around $\lambda_L/4$, where λ_L is the wavelength at 3.1 GHz**.** This feed line lays on the same side of radiating CM**.** At the bottom of the substrate, a PGP with a length l_g covers the feeding section and this PGP is modified by using technique of a diagonal cut at the top corners (DCTCs) with the angle α **.** In this work, the length l_g is designed to be the same length of the feeding line l_f**.**

In the design, the radius *r* of CM is designed by using (1) [15].

$$f_r = \frac{72}{2.25r} GHz \quad (1)$$

where, f_r is the resonance frequency at 3.1 GHz. From (1), *r* of 11 mm is chosen [10]. Note that the unit of *r* in (1) is in mm. All propered parameters are accomplished by using the CST simulation, and tabulated in Table 1. To validate the simulation, a prototype UWB CMWS with MPGP antenna as shown in Fig. 1(b) was fabricated with the designed dimensions as in Table 1. This prototype antenna was connected to a coaxial feeding port via SMA 50-ohm connector. Using an E5063A network analyzer, impeadance and radiation characteristics of the proposed antenna are measured and discussed.

Table 1. The parameters of the designed antenna

Parameters	Physical size (mm.)	Parameters	Physical size (mm.)
w	37	r	11
l	47	α	45°
l_s	14	h_s	8
w_1	2	h_0	1.6
w_2	3.8	l_g	21
l_f	21		

Impedance and radiation characteristics

This section discloses the simulated and measured results of designed antenna as tabulated in Table 1. The design initially begins with the appropriated parameters CM of radius r_1 of 11 mm with 50 ohms taped fed line of length 21 mm and width w_1 and w_2 of 2 mm and 3.8 mm respectively. To improve the impedance and radiation properties, the narrow slot of length l_s is included at the height h_s of 8 mm above the feeding point. Obvious that the longer l_s provides a worsened $|S_{11}|$ in the frequency below 7.5 GHz, contrary the shorter l_s provides a degenerated $|S_{11}|$ at the high frequency. For $|S_{11}| < -10$ dB over the UWB frequency, l_s of 14 mm is selected [10].

To further increase its radiation performance, a technique of DCTCs of PGP with the angle of α is supplemented and investigated as shown in Fig. 2. Apparently, cutting the top edges of PGP with the angle α slightly affects the impedance banwidth for the small α of 45 degree. For the large α of 60 degree, S_{11} is much better at the frequency higher than 7 GHz, on the contrary the worst S_{11} at the lower frequency is achieved. Moreover, the larger α provides a slightly increasing gain espectially at the frequency higher than 4 GHz. Despite the increasing gain for larger α, S_{11} should be gathered consideration. Accordingly, DCTCs of PGP with the angle of 45 degree is chosen for $|S_{11}| < -10$ dB over the UWB frequency with minimum and maximum gains of 1 dBi and 3.83 dBi, respectively.

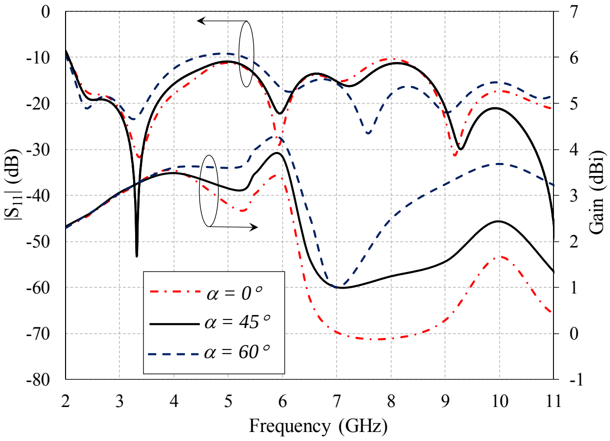


Fig.2. S_{11} and maximum gain for various α

a)

b)

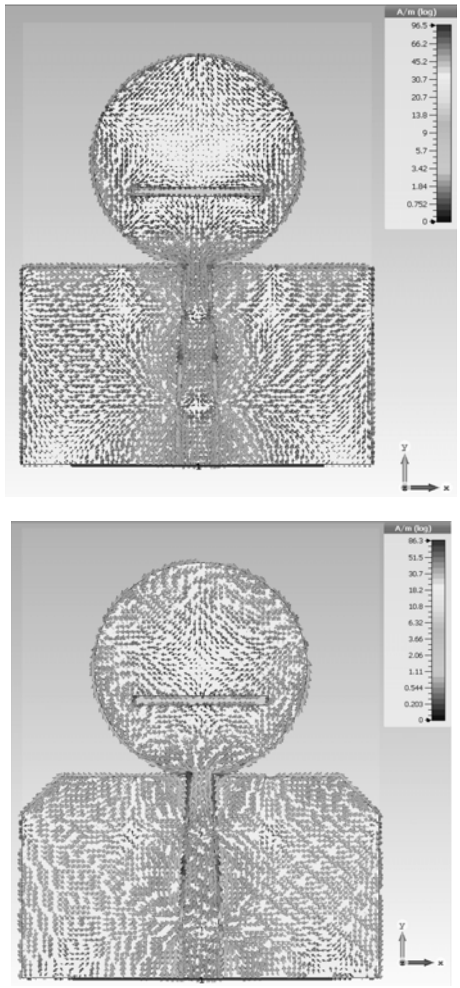


Fig.3. Surface current densities of the proposed antenna with (a) non-modified ground plane, (b) modified ground plane.

It should be noted that the current distributions of proposed CMWS with and without modified ground planes are different especially around the edge of their ground plane. Cutting its corner affects the surface current distribution along the feeding line to the radiating patch flowing more uniform and more strengthen than the other one as shown in Fig. 3. As that result, its radiation performance gets better and increases gian especially at the high frequency.

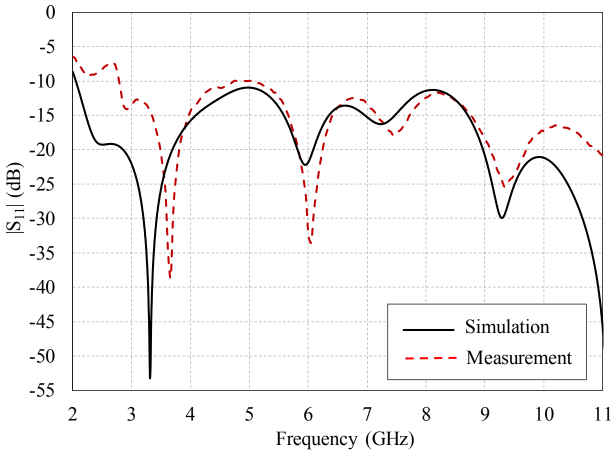
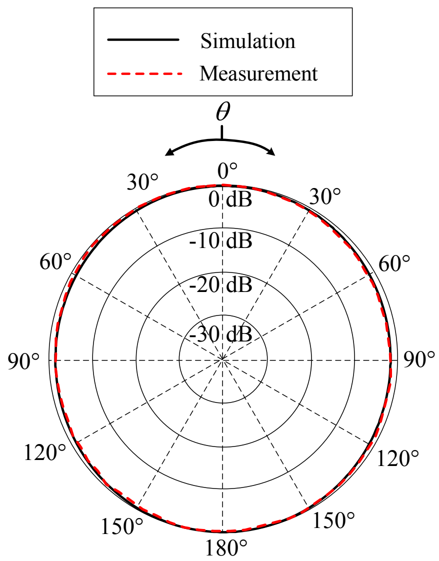


Fig.4. Simulated and measured S_{11}

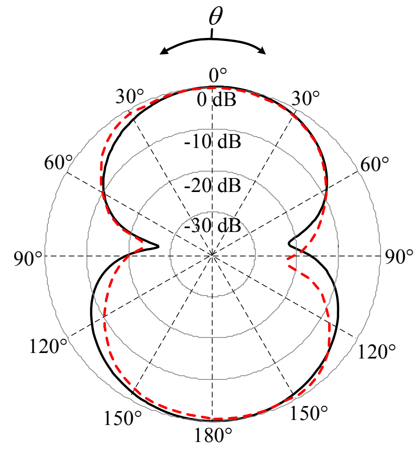
To validate the simulation, a prototype of proposed antenna was fabricated and measured. Figure 4 shows the simulated and measured $|S_{11}|$ versus the frequency ranging from 2 GHz to 11 GHz. Obviously, simulated $|S_{11}|$ is reasonaly in good agreement with measured one, and they are less than -10 dB over the frequencies range of 2.06 GHz–11 GHz and 2.81 GHz–11 GHz for the simulation and the measurement respectively covered the UWB frequency.

In addition to the impedance matching, the radiation properties are also confirmed. The plot of simulated and measured radiation patterns in *xz*- and *yz*-planes at the frequencies of 3.1 GHz, 6.5 GHz and 10.6 GHz are depicted in Fig. 5. Apparently, this CMWS antenna with MPGP provides nearly omnidirectional pattern with maximum simulated gains of 3.14 dBi, 1.64 dBi and 1.94 dBi and measured gains of 2.86 dBi, 1.9 dBi and 1.44 dBi at 3.1 GHz, 6.5 GHz and 10.6 GHz, respectively. Furthermore, the simulated radiation patterns are similar figure and reasonably in good agreement with experimental results.

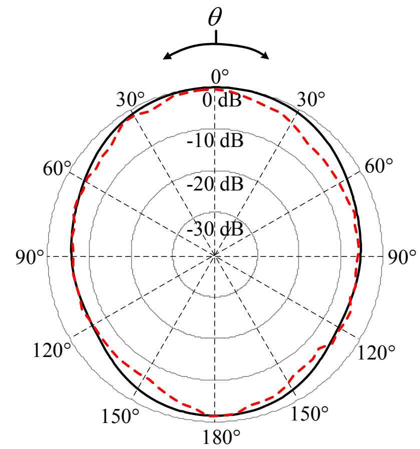
a)



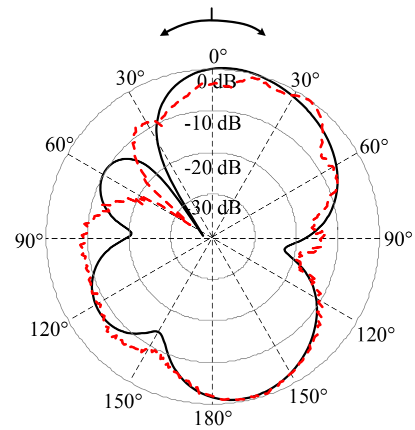
b)



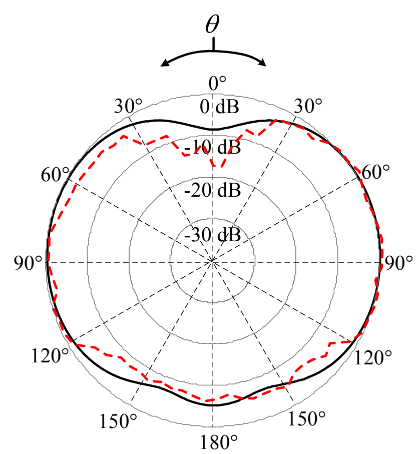
c)



d)



e)



f)

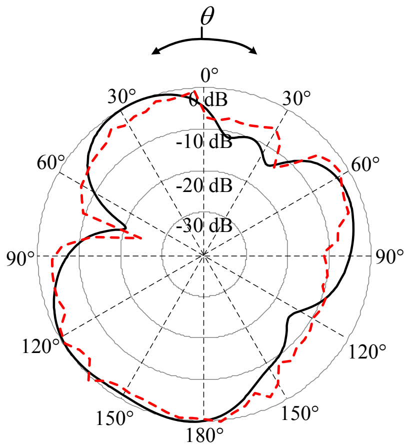


Fig.5. Radiation pattern: (a) *xz*-plane at 3.1 GHz (b) *yz* plane at 3.1 GHz (c) *xz*-plane at 6.5 GHz (d) *yz* plane at 6.5 GHz (e) *xz*-plane at 10.6 GHz (f) *yz* plane at 10.6 GHz

Conclusions

A compact circular monopole with slot and modified ground antenna for UWB applications is presented. This CMWS prints on top of FR4 substrate of height 1.6 mm with relative permittivity of 4.3. It backs by a MPGP to supplement the S-parameter and antenna radiation efficiency over the frequency range from 3.1 GHz to 10.6 GHz. This antenna is fed by using 50-ohms tapered microstrip line. Apparently, this compact antenna provides a nearly omnidirectional pattern with minimum and maximum gains of 1 dBi and 3.83 dBi, respectively. In addition, the $|S_{11}|$ is better than -10 dB over the UWB frequency. These simulation results are validated by the experimental results, and they are in a very good agreement. As its properties of compact size, wide impedance bandwidth, and good radiation properties, this proposed antenna can be one of good candidates for the UWB applications.

Acknowledgements

This research project is supported by Rajamangala University of Technology Isan. Contract No. ENG27/63.

***Authors**: Suthasinee Lamultree, Department of Electronics and Telecommunication Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khonkaen Campus, Khonkaen, 40000, Thailand, E-mail: suthasinee.la@rmuti.ac.th; Chalee Jansri, Department of Electronics and Telecommunication Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khonkaen Campus, Khonkaen, 40000, Thailand, E-mail: chalee.ja@rmuti.ac.th; Chuwong Phongcharoenpanich, Department of Telecommunications Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, 10250, Thailand. E -mail: chuwong.ph@kmitl.ac.th, pchuwong@gmail.com.*

REFERENCES

[1] IEEE, FCC Order and Report Revision of Part 15 Acceptance of Ultra Wideband (UWB) systems from 3.1-10.6 GHz, Washington DC, 2002.
[2] Chen, Z. N., Wu, X. H.H., Li, F., Yang, N., Chia, M. Y. W., Considerations for Source Pulses and Antennas in UWB Radio Systems, *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 7, 2004, 1739– 1748.
[3] Li, X., Bond, E., Van Veen, B., Hagness, S., An Overview of Ultrawideband Microwave Imaging via Space-Time Beamforming for Early Stage Breast-Cancer Detection, *IEEE Antennas and Propagation Magazine*, vol. 47, no. 1, 2005, 19–34.
[4] Chen, M., Wang, J., Compact CPW-fed Circular Slot Antenna for Ultra-Wideband Applications, *International Symposium on Antennas, Propagation and EM Theory*, 2008, 78-81.
[5] Haraz O., Sebak A.-R., *Advancement in Microstrip Antennas with Recent Applications*: Ch.6 UWB Antennas for Wireless Applications, In Tech, 2013, 125-152.
[6] Ren, J., Hu, W., Yin, Y. Fan, R., Compact Printed MIMO Antenna for UWB Applications, *IEEE Antennas and Wireless Propagation Letters*, vol. 13, 2014, 1517-1520.
[7] Gulam Nabi Alsath, M., Kanagasabai, M. Compact UWB Monopole Antenna for Automotive Communications, *IEEE Transactions on Antennas and Propagation*, vol. 63, iss. 9, 2015, 4204 – 4208.
[8] Kumar G., Ray K. P., *Broadband Microstrip Antenna*, Artech House Boston, London, 2013.
[9] Srivastava, G., Mohan, A., Chakrabarty, A., Compact Reconfigurable UWB Slot Antenna for Cognitive Radio Applications, *IEEE Antennas and Wireless Propagation Letters*, vol. 16, 2016, 1139 – 1142.
[10] Jansri C., Phongcharoenpanich C., Lamultree S., A Printed Circular Monopole Antenna with Slot and Modified Ground Plane for UWB Applications, *Proceedings of the International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, Chiang Rai, Thailand, July 2018, 564-567.
[11] Chandel, R., Gautam, A. K., Rambabu, K., Tapered Fed Compact UWB MIMO-Diversity Antenna with Dual Band-Notched Characteristics, *IEEE Transactions on Antennas and Propagation*, vol. 66, iss. 4, 2018, 1677 – 1684.
[12] Li, Z., Yin, C., Zhu, X., Compact UWB MIMO Vivaldi Antenna with Dual Band-Notched Characteristics, *IEEE Access*, vol. 7, 2019, 38696 – 38701.
[13] Qu, S.-W., Ruan, C. L., Wang, B.-Z., Bandwidth Enhancement of Wide-Slot Antenna Fed by CPW and Microstrip Line," *IEEE Antennas and Wireless Propagation Letters*, vol. 5, 2006, 15–17.
[14] Janand, J.Y., Su, J.W., Bandwidth Enhancement of a Printed Wide-Slot antenna with a Rotated Slot, *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 6, 2005, 2111–2114.
[15] Kumar G., Ray K. P., *Broadband Microstrip Antenna*, Artech House Boston, London, 2013.
[16] Xu, L., Guo, Y., Wu, W., Bandwidth Enhancement of an Implantable Antenna, *IEEE Antennas and Wireless Propagation Letters*, vol. 14, 2015, 1510-1513.
[17] Zhao, Y., Shen, Z., Wu, W., Wideband and Low-profile H-Plane Ridged SIW Horn Antenna Mounted on a Large Conducting Plane, *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 11, 2014, 5895–5900.
[18] Kundu, S., Chatterjee, A., Jana, S., Parui, S., A Compact Umbrella-Shaped UWB Antenna with Gain Augmentation Using Frequency Selective Surface, *Radioengineering*, vol. 27, no. 2, 2018, 448-454.
[19] Lamultree S., Jansri C., Phongcharoenpanich C., Gain Improvement of Dual-Band Circular Monopole Antenna for 2.45/5.5 GHz WLAN Applications, *Przegląd Elektrotechniczny*, R. 95 NR 5/2019, 157-160.
[20] Yuan, Y., Xi, X., Zhao, Y., Compact UWB FSS reflector for antenna gain enhancement, *IET Microwaves, Antennas & Propagation*, vol. 13, iss. 10, 2019, 1749 – 1755.
[21] CST® Microwave Studio, Research Base, 2016.