A parametric study on strawberry radiated shaped monopole antenna for ultrawide-band applications

Ahmed Jamal Abdullah Al-Gburi[1], Zahriladha Zakaria[1], Imran Mohd Ibrahim[1], Muhammad Firdaus Akbar[2], Aymen Dheyaa Khaleel Al-Obaidi[3], Asma Khabba[4]
[1]Center for Telecommunication Research and Innovation, Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[2]School of Electrical and Electronic Engineering, Universiti Sains Malaysia, Penang, Malaysia
[3]School of Computing, Universiti Utara Malaysia, Sintok, Malaysia
[4]Department of Physics, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakesh, Morocco

Article Info

Article history:

Received Aug 18, 2022
Revised Sep 22, 2022
Accepted Oct 22, 2022

Keywords:

Directivity
Gain
Parametric study
Strawberry shaped
Ultra-wideband

ABSTRACT

This article gives a parametric study on strawberry-shaped monopole antennas for ultra-wideband (UWB) systems. The antenna design consisted of three different parametric design steps to structure the strawberry radiated monopole antenna. The scheduled strawberry monopole antenna was simulated on an FR4 substrate in a low profile for UWB applications. The total physical dimension is 26 mm×26 mm×1.6 mm, corresponding to the centre frequency of 7.5 GHz. The strawberry antenna is fed via a coplanar waveguide (CPW) to attain the best impedance matching for UWB systems. The presented monopole antenna has an impedance UWB bandwidth of 11.0 GHz from 2.6 GHz up to 13.6 GHz at −10 dB return loss. The simulated UWB strawberry monopole antenna displays an omnidirectional radiation behaviour with a simulated gain of 7.3 dB at 13.6 GHz, a directivity of 7.5 dBi at 13.6 GHz and favourable radiation efficiency of 97%. The proposed monopole UWB strawberry antenna has the technological possibility to be used for UWB applications.

Corresponding Author:

Zahriladha Zakaria
Center for Telecommunication Research & Innovation, Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Email: zahriladha@utem.edu.my

1. INTRODUCTION

Ultra-wideband (UWB) technology was first approved by the federal communication commission (US-FCC) in 2002, and it has advanced at a fantastic rate in the last few years [1], [2]. The US-FCC has assigned the frequency band 3.1-10.6 GHz for commercial use of the UWB [3]. Many new telecommunication applications and techniques appear daily to achieve UWB response [4], [5]. The main aim of UWB technology is to transmit or receive data with more effective data rates over short-range wireless communication systems using the current communication standards [6], [7]. It is also used in military applications due to its low probability of being intercepted by undesired receivers, which makes it more secure than other communication techniques [8], [9]. The primary complications UWB technology faces are interfering with other narrow band technologies functioning in a frequency band working by the UWB band [10], [11]. Some the examples of these narrow bands are the wireless local area network (WLAN) (IEEE802) and HIPERLAN/2 WLAN operating in the 5-6 GHz band [12]–[15]. In addition to these technologies comes the worldwide interoperation for microwave access (WiMAX) service working in the 3.3-3.6 GHz band [16].

Using filters is not a practical solution due to filters complexity of filters, so the proposed antenna will be integrated with the notched filter [17], [18].

Several antenna techniques and patch shapes have been suggested and presented in recent years to obtain UWB response over wide ranges of frequencies. In [19]–[22], a super compact antenna was proposed to achieve a wide range of frequencies. An ellipsoidal was offered in [23] to obtain a UWB operation from 3.29-9.35 GHz, with a total size of 27×36×1.6 mm. On the other hand, a leaf-shaped [24] and a broken heart [25] were also presented to attain a wide impedance bandwidth. In addition, a few methods have also been investigated lately to get UWB working bandwidth response [26]–[30].

This study proposes a deep parametric study to verify the strawberry patch antenna. Three progressive stages were introduced in terms of antenna performance, such as reflection coefficient (S11), gain, directivity, efficiency and radiation patterns. All the simulations are performed employing computer simulation technology (CST) Microwave studio 2016.

2. METHOD

2.1. Parametric evolution of the UWB strawberry antenna

The suggested antenna design consists of a circular slot carved into an ironic plane burned on the FR4 laminate of a dielectric constant of 4.3 and a loss tangent of 0.02, with dimensions (26 mm×26 mm×1.6 mm). Two rectangular semi-discs with 50 Ω coplanar waveguide (CPW) tapered tubes were established to feed the circular slot to complete the sub-objective. Moreover, a comprehensive parametric study was conducted to validate the UWB design process. Presenting three progressive stages depending on the plant's genetic makeup of the monopole antenna's strawberry fruits are shown in Figure 1. The outcomes of these stages are presented next.

The basic disc globose-shaped monopole antenna with CPW fed (globose design antenna A), globose-conic shaped monopole antenna with CPW-fed (globose-conic design antenna B), strawberry-shaped monopole antenna with CPW-fed (strawberry design antenna C) and all these three stages of antennas were planned and simulated utilising CST. Afterwards, the investigation done, and the final antenna design (design C) has been carefully chosen and fabricated in the fabrication laboratory. The five different development stages for the UWB monopole antenna (design antenna A to design antenna C) are shown in Figure 2.

Figure 1. Morphology characteristics of some strawberry leaves

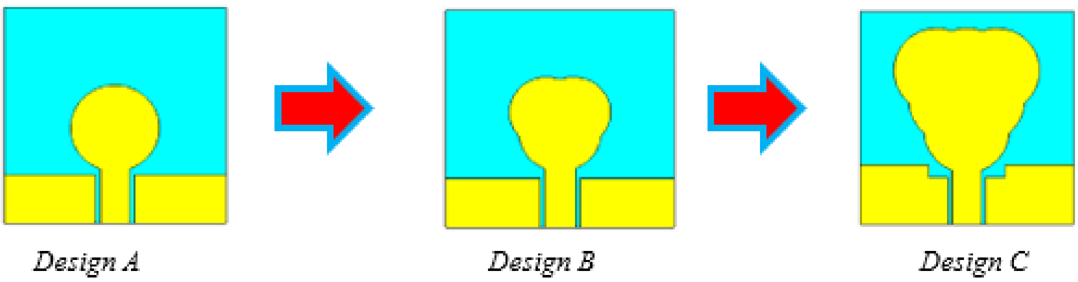
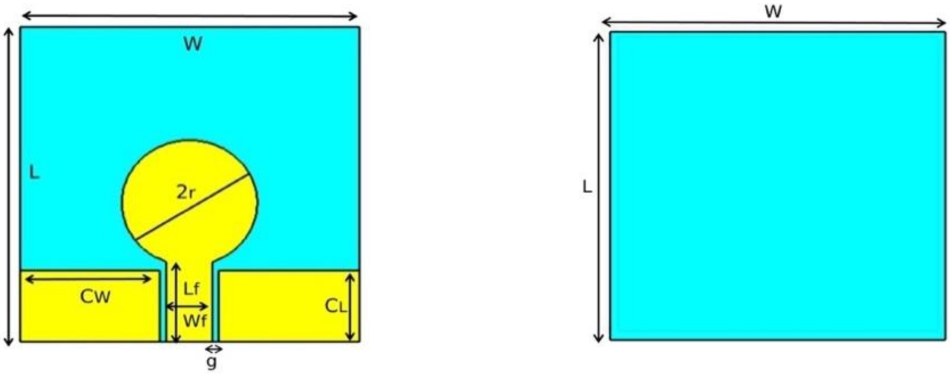


Figure 2. The design development stage of the UWB strawberry crop guide monopole antenna (design antenna A to design antenna C)

In addition, some relevant results have been considered to make sure the performance of the monopole antenna is suitable for UWB applications. These results are shown in terms of return loss (dB), antenna gain (dB), directivity (dB), radiation pattern, and efficiency (%), including the e-field and h-field of the suggested antenna. The good condition of return loss performance must be less than –10 dB to cater to at least 90% of the signal for transmitting and receiving activity.

2.2. Globose-shaped monopole antenna with coplanar waveguide fed (design antenna A)

The first stage in this study consists of a primary circular monopole antenna with CPW fed (design antenna A). The basic antenna dimensions are 26x26 mm with a copper thickness of 0.02 mm, while the FR-4 substrate thickness is 1.6 mm. When the radius (r) equals 5.4 mm, the disc's diameter is equal to 10.8 mm, as presented in Figures 3(a) and (b), which means by the one-sixth wavelength at the first resonant frequency about 19.0 mm.



(a) (b)

Figure 3. Globose-shaped monopole antenna with CPW fed (design antenna A); (a) front view and (b) back look

The feed line length is 6.8 mm and 3.65 mm of his width, connecting with the SMA connector. Moreover, the loss tangent of the FR4 laminate is 0.02. Figure 4 shows the return loss of the globose-shaped monopole antenna's performance with CPW fed (design antenna B). From Figure 4, it can be observed that the antenna bandwidth is wide, and it operates between 3.6 GHz and 8.5 GHz of frequencies with 4.87 GHz bandwidth performance. It also radiates at 4.66 GHz of WLAN frequency point with a return loss performance of –28.76 dB, while it has a resonant frequency at 6.37 GHz with –29.6 dB.

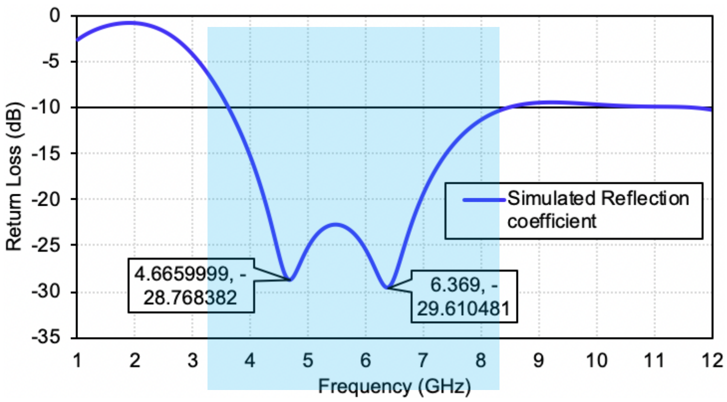
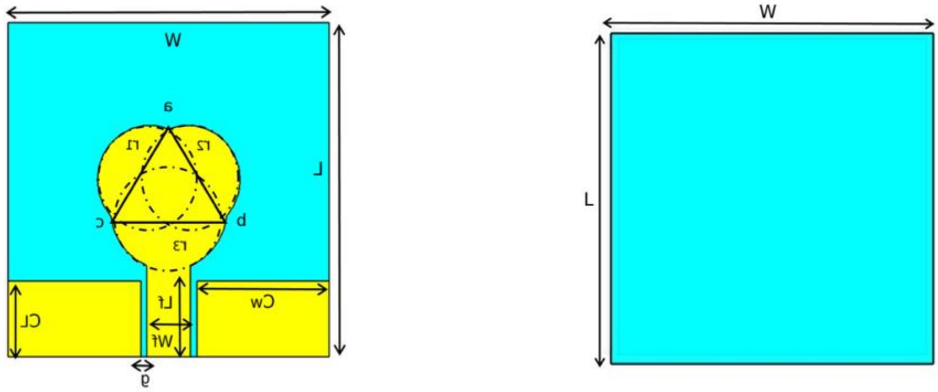


Figure 4. Return loss performance of the globose-shaped monopole antenna with CPW fed (design antenna A)

2.3. Globose-conic shaped monopole antenna with coplanar waveguide fed (design antenna B)

Next, the second stage consists of designing a globose-conic-shaped monopole antenna with CPW-fed (design antenna B), as presented in Figures 5(a) and (b). At this stage, there are three-circular radius has been added to shape the globose-conic radiated patch. These circular patches are r1, r2, and r3. The r1 value is about 5.4mm. A triangle is created from the intersection between three circles to measure each circle's total area. These triangles are (a, b, c); the famous formulas are used to calculate the total area of a circle and triangle, respectively. Where A=πr2, A=(hb×b)/2, A referred is the entire area, and r is the radius. Whereas hb is the height of the triangle, and b is the triangle base. The globose-conic radiated patch technique is used to improve the bandwidth of the UWB frequencies. Moreover, once r equals 5.4 mm, the diameter of the conic (2×(r1/2+r2/2+r3/2)) is 16.2 mm.



(a) (b)

Figure 5. The design geometry of globose-conic shaped monopole antenna with CPW fed (design antenna B); (a) front view and (b) back look

Figure 6 presents the return loss performance of the globose-conic shaped antenna with CPW fed (design antenna B). The results from Figure 6 indicated that the antenna is radiated at a wide range of frequencies with a bandwidth of 4.6 GHz (3.03 -7.63 GHz), and it also emits at a resonant frequency of 3.86 GHz with –28.51 dB. Furthermore, the return loss performance at 5.2 GHz is –23.37 dB.

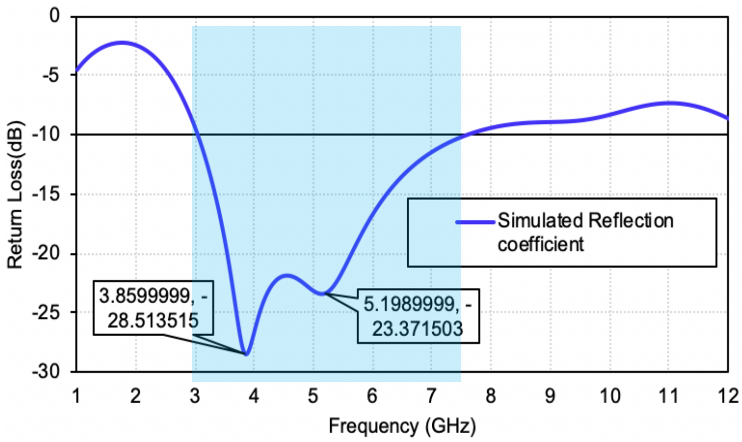
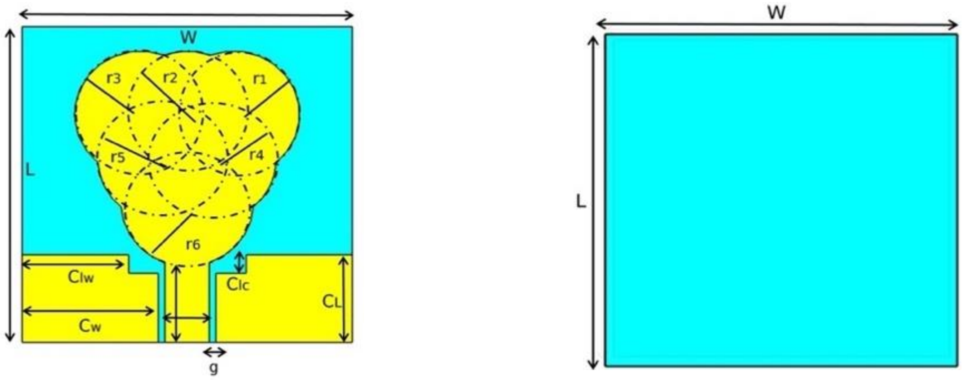


Figure 6. Return loss performance of the globose-conic shaped monopole antenna with CPW fed (design antenna B)

2.4. Strawberry-shaped-monopole antenna with modified coplanar waveguide fed (design antenna C)

The suggested planar antenna was simulated by employing CST-studio software. The proposed antenna structure consists of a circular slot etched into a metallic plane printed on the FR4 substrate of a dielectric constant of 4.3 and a loss tangent of 0.02, with dimensions (26 mm ×26 mm×1.6 mm). To accomplish the first sub-objective, a CPW feed with 50Ω CPW tapered lines were placed to feed the proposed antenna.

Figures 7(a) and (b) characterise the design of the UWB planar antenna with CPW fed. The total size of the modelled antenna is 26 mm ×26 mm ×1.6 mm. The planar radiated patch is made from a seven circular discs to structure the modelled antenna. In this stage, the CPW fed was cut off from the inner side and denoted as Clc, as illustrated in Figure 7. The bandwidth expands due to the available space between the feed line and the CPW, which allows the creation of the certified UWB from 2.6 up to 13.7 GHz; besides that, it enhances the impedance matching between the feed and the emitted patch. Table 1 records all the antenna specifications.



(a) (b)

Figure 7. The design geometry of the UWB strawberry antenna; (a) front look and (b) back look

Table 1. The proportions of the UWB strawberry antenna (design antenna C

Antennas description	Variables	Sizes (mm)
Substrate width	*W*	26
Substrate length	*L*	26
The four cylinders radius	*r1, r2, r3, r4, r5, r6*	5.4
The spacing between cylinder radius	*S*	*3.8*
Feed-line width	*Wf*	3.65
Feed-line length	*Lf*	6.8
CPW width	*Cw*	11.15
CPW length	*Cl*	7.5
CPW adjusted length	*Cwc*	8.7
The gap between CPW and the fed line	*g*	0.525
CPW adjusted height	*Clc*	1.6
Thickness of copper	*Tc*	0.02
Thickness of substrate	*Ts*	1.6

3. RESULT AND DISCUSSIONS

In this stage, the simulated outcomes of the CPW-fed UWB strawberry antenna have been validated to determine the best characteristics design of the simulated strawberry-shaped monopole antenna. Figures 8(a) to (d) present the simulated reflection coefficient, gain, directivity and efficiency of the proposed UWB strawberry antenna. The simulated antenna obtained a bandwidth of 11.1 GHz from 2.6 GHz to 13.6 GHz. It resonates at three main frequencies as follows: i) 3.35 GHz with -19.24 dB of return loss performance for simulation; ii) resonant frequency at 8.16 GHz with -32.12 dB of return loss performance for simulation, and iii) third resonant frequency at 10.7 GHz with return loss performance of -50 dB. The proposed antenna achieved a gain value of 7.3 dB at 13.6 GHz and high directivity of 7.5 dBi at the same frequency, which is 13.6 GHz. The UWB strawberry antenna obtains a high radiation efficiency of 97%.

Figures 9(a) and (b) show the radiation pattern of the strawberry-shaped monopole antenna with CPW fed (design antenna C) at 2.911 GHz and 7.74 GHz. It presents that the radiation pattern at 2.911 GHz for H-filed looks like omnidirectional while the e-field looks pear-shaped. Moreover, the radiation pattern looks different at 7.74 GHz. Meanwhile, for the h-field, it seems kidney-shaped, with a minor lobe at the bottom part.

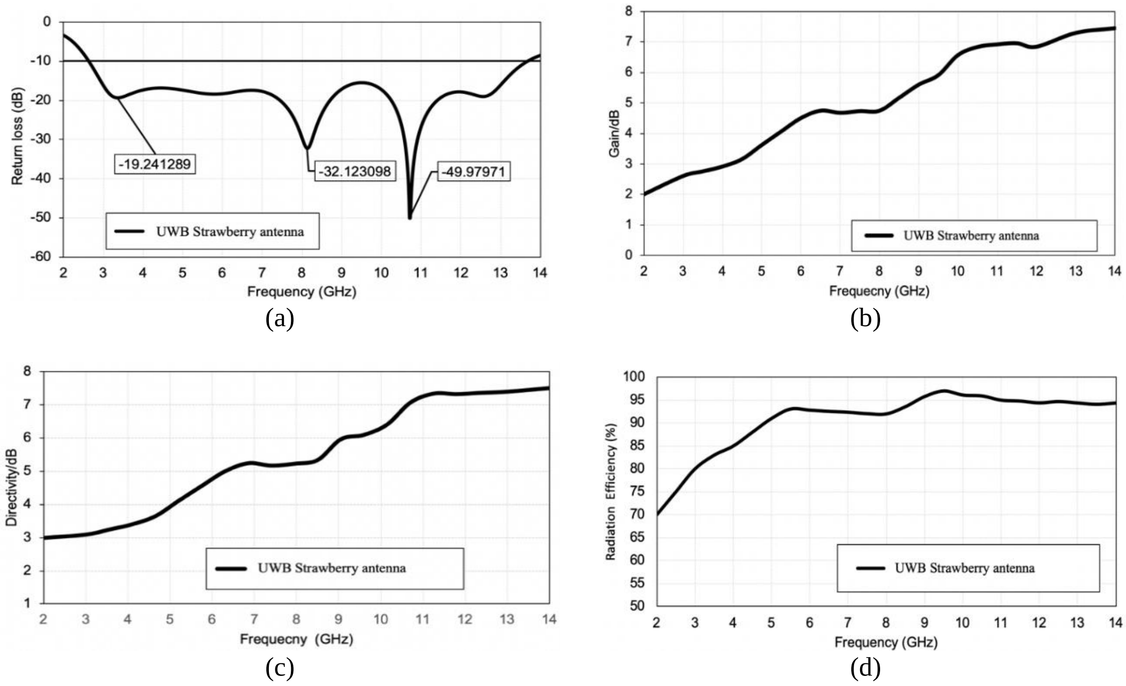


Figure 8. Simulated results of (a) reflection coefficient (S11), (b) gain, (c) directivity and (d) radiation efficiency

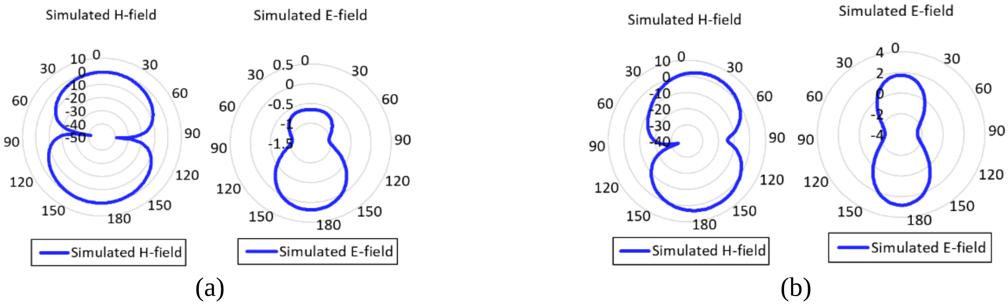


Figure 9. H-field and e-field radiation patterns of the strawberry-shaped monopole antenna with CPW fed (design antenna C) at (a) 2.911 GHz and (b) 7.74 GHz

4. CONCLUSION

A deep parametric study to verify the strawberry patch antenna is proposed in this paper. Three advanced stages were introduced to structure the strawberry antenna (design A to design D), in terms of antenna performance, such as reflection coefficient (S11), gain, directivity, efficiency and radiation patterns. The proposed strawberry UWB antenna achieved a good performance. For example, a gain of 7.3 dB was received at 13.6 GHz, with a high directivity of 7.5 dBi. The simulated UWB antenna achieved an excellent efficiency of 97%, with a Fractional bandwidth of 93%, making the proposed UWB strawberry antenna suitable to be operated for UWB systems.

ACKNOWLEDGEMENTS

This work was supported by Universiti Teknikal Malaysia Melaka (UTeM) under Jurnal/2020/FKEKK/Q00053.

REFERENCES

[1] Federal Communications Commission, “Revision of part 15 of the commission’s rules regarding ultra-wideband transmission systems,” 2002. [Online]. Available: http://ci.nii.ac.jp/naid/10011635689/

[2] D. Dardari, A. Conti, U. Ferner, A. Giorgetti, and M. Z. Win, “Ranging with ultrawide bandwidth signals in multipath environments,” in *Proceedings of the IEEE*, Feb. 2009, vol. 97, no. 2, pp. 404–426. doi: 10.1109/JPROC.2008.2008846.

[3] W. S. Yeoh and W. S. T. Rowe, “An UWB conical monopole antenna for multiservice wireless applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1085–1088, 2015, doi: 10.1109/LAWP.2015.2394295.

[4] R. V. S. R. Krishna and R. Kumar, “A dual-polarized square-ring slot antenna for UWB, imaging, and radar applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 195–198, 2016, doi: 10.1109/LAWP.2015.2438013.

[5] S. Kim, Y. Kim, X. Li, and J. Kang, “Orthogonal pulse design in consid- eration of FCC and IEEE 802.15.4a constraints,” *IEEE Communications Letters*, vol. 17, no. 5, pp. 896–899, May 2013, doi: 10.1109/LCOMM.2013.040213.122936.

[6] A. Domazetovic, L. J. Greenstein, N. B. Mandayam, and I. Seskar, “Propagation models for short-range wireless channels with predictable path geometries,” *IEEE Transactions on Communications*, vol. 53, no. 7, pp. 1123–1126, Jul. 2005, doi: 10.1109/TCOMM.2005.851606.

[7] C. Marchais, G. L. Ray, and A. Sharaiha, “UWB antennas time domain characterization,” in *11th International Symposium on Antenna Technology and Applied Electromagnetics [ANTEM 2005]*, Jun. 2005, pp. 1–4. doi: 10.1109/ANTEM.2005.7852122.

[8] L. Barbieri, M. Brambilla, R. Pitic, A. Trabattoni, S. Mervic, and M. Nicoli, “UWB real-time location systems for smart factory: Augmentation methods and experiments,” in *2020 IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications*, Aug. 2020, pp. 1–7. doi: 10.1109/PIMRC48278.2020.9217307.

[9] A. D. K. Al-Obaidi, O. Ghazali, M. Mahmuddin, A. J. A. Al-Gburi, M. N. M. Al-Niamey, and M. F. Mansor, “High efficiency dielectric resonator antenna using complementary ring resonator for bandwidth enhancement,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 4, pp. 2107–2114, Aug. 2022, doi: 10.11591/eei.v11i4.3681.

[10] A. J. A. Al-Gburi, I. Ibrahim, Z. Zakaria, and A. D. Khaleel, “Bandwidth and gain enhancement of ultra-wideband monopole antenna using MEBG structure,” *Journal of Engineering and Applied Sciences*, vol. 14, no. 10, pp. 3390–3393, Nov. 2019, doi: 10.36478/jeasci.2019.3390.3393.

[11] M. Y. Zeain *et al.*, “Design of a wideband strip helical antenna for 5G applications,” *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 5, pp. 1958–1963, Oct. 2020, doi: 10.11591/eei.v9i5.2055.

[12] R. A. A. Kamaruddin *et al.*, “Return loss improvement of radial line slot array antennas on closed ring resonator structure at 28 GHz,” *PRZEGLĄD ELEKTROTECHNICZNY*, vol. 1, no. 5, pp. 67–71, May 2021, doi: 10.15199/48.2021.05.10.

[13] A. A. Jabber and R. H. Thaher, “Compact tri-band T-shaped frequency reconfigurable antenna for cognitive radio applications,” *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 1, pp. 212–220, Feb. 2020, doi: 10.11591/eei.v9i1.1708.

[14] M. M. J. Abed *et al.*, “Design and characterization substrate integrated waveguide antenna for WBANS application,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 3, pp. 1390–1398, Jun. 2022, doi: 10.11591/eei.v11i3.3492.

[15] A. J. A. Al-Gburi, I. M. Ibrahim, and Z. Zakaria, “An ultra-miniaturized MCPM antenna for ultra- wideband applications,” *Journal of Nano- and Electronic Physics*, vol. 13, no. 5, pp. 1–4, 2021, doi: 10.21272/jnep.13(5).05012.

[16] A. H. Majeed and K. H. Sayidmarie, “UWB elliptical patch monopole antenna with dual-band notched characteristics,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 5, pp. 3591–3598, Oct. 2019, doi: 10.11591/ijece.v9i5.pp3591-3598.

[17] A. Q. Kamil and A. K. Jassim, “Design ultra-wideband antenna have a band rejection desired to avoid interference from existing bands,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 2, pp. 886–892, Apr. 2022, doi: 10.11591/eei.v11i2.3164.

[18] A. Abbas *et al.*, “A rectangular notch-band UWB antenna with controllable notched bandwidth and centre frequency,” *Sensors*, vol. 20, no. 3, pp. 1–11, Jan. 2020, doi: 10.3390/s20030777.

[19] A. J. A. Al-Gburi *et al.*, “Super compact uwb monopole antenna for small iot devices,” *Computers, Materials & Continua*, vol. 73, no. 2, pp. 2785–2799, 2022, doi: 10.32604/cmc.2022.028074.

[20] P. Mayuri, N. D. Rani, N. B. Subrahmanyam, and B. T. P. Madhav, “Design and analysis of a compact reconfigurable dual band notched UWB antenna,” *Progress In Electromagnetics Research C*, vol. 98, pp. 141–153, 2020, doi: 10.2528/PIERC19082903.

[21] M. O. Al-Dwairi, “A planar UWB semicircular-shaped monopole antenna with quadruple band notch for WiMAX, ARN, WLAN, and X-Band,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 1, pp. 908–918, Feb. 2020, doi: 10.11591/ijece.v10i1.pp908-918.

[22] A. A. Jabber, A. K. Jassim, and R. H. Thaher, “Compact reconfigurable PIFA antenna for wireless applications,” *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 18, no. 2, pp. 595–602, Apr. 2020, doi: 10.12928/telkomnika.v18i2.13427.

[23] H. S. Mewara, D. Jhanwar, M. M. Sharma, and J. K. Deegwal, “A printed monopole ellipzoidal UWB antenna with four band rejection characteristics,” *AEU - International Journal of Electronics and Communications*, vol. 83, pp. 222–232, Jan. 2018, doi: 10.1016/j.aeue.2017.08.043.

[24] A. Iqbal, O. A. Saraereh, and S. K. Jaiswal, “Maple leaf shaped UWB monopole antenna with dual band notch functionality,” *Progress In Electromagnetics Research C*, vol. 71, pp. 169–175, 2017, doi: 10.2528/PIERC17010801.

[25] N. Rahman, M. T. Islam, Z. Mahmud, and M. Samsuzzaman, “The broken-heart printed antenna for ultrawideband applications: Design and characteristics analysis,” *IEEE Antennas and Propagation Magazine*, vol. 60, no. 6, pp. 45–51, Dec. 2018, doi: 10.1109/MAP.2018.2870664.

[26] A. H. Majeed, K. H. Sayidmarie, F. M. A. Abdussalam, R. A. Abd-Alhameed, and A. Alhaddad, “A microstrip-fed pentagon patch monopole antenna for ultra wideband applications,” in *2015 Internet Technologies and Applications (ITA)*, Sep. 2015, pp. 452–456. doi: 10.1109/ITechA.2015.7317446.

[27] A. J. A. Al-Gburi, I. B. M. Ibrahim, Z. Zakaria, and N. F. B. M. Nazli, “Wideband microstrip patch antenna for sub 6 GHz and 5G applications,” *Przeglad Elektrotechniczny*, vol. 97, no. 11, pp. 26–29, Nov. 2021, doi: 10.15199/48.2021.11.04.

[28] S. Ullah, C. Ruan, M. S. Sadiq, T. U. Haq, and W. He, “High efficient and ultra wide band monopole antenna for microwave imaging and communication applications,” *Sensors*, vol. 20, no. 1, pp. 1–11, Dec. 2019, doi: 10.3390/s20010115.

[29] H. Alwareth, I. M. Ibrahim, Z. Zakaria, A. J. A. Al-Gburi, S. Ahmed, and Z. A. Nasser, “A wideband high-gain microstrip array antenna integrated with frequency-selective surface for Sub-6 GHz 5G applications,” *Micromachines*, vol. 13, no. 8, pp. 1–19, Jul. 2022, doi: 10.3390/mi13081215.

[30] K. H. Sayidmarie and Y. A. Fadhel, “UWB fractal monopoles of rectangular and triangular shapes,” in *2011 4th IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications*, Nov. 2011, pp. 709–712. doi: 10.1109/MAPE.2011.6156214.

BIOGRAPHIES OF AUTHORS

Ahmed Jamal Abdullah Al-Gburi Received an M.Eng. and PhD degrees in Electronics and Computer Engineering (Telecommunication systems) from Universiti Teknikal Malaysia Melaka (UTeM), Malaysia, in 2017, and 2021, respectively. He is currently a Postdoctoral Fellow with the Microwave research group (MRG), Faculty of Electronics and Computer Engineering, UTeM university. He has authored and co-authored a number of WoS/Scopus journals. His research interests include antennas, microwave sensors and machine learning. He can be contacted at email: ahmedjamal@utem.edu.my.

Zahriladha Zakaria is currently a Professor at Universiti Teknikal Malaysia Melaka. He earned a bachelor's degree in Electrical and Electronic Engineering from Universiti Teknologi Malaysia (UTM) in 1998. In 2004, he pursued a master also in Electrical and Electronic Engineering course from the same university. Then, he received his PhD in the field of Microwave Engineering from The University of Leeds in 2010. His research areas include RF/microwave, antenna and propagation, energy harvesting, sensors, photonics, and wireless communications. He can be contacted at email: zahriladha@utem.edu.my.

Imran Mohd Ibrahim is an Associate Professor at Universiti Teknikal Malaysia Melaka and now serve as Head of Microwave Research Group. He received his bachelor, master and doctoral degree from Universiti Teknologi Malaysia, all in electrical engineering, in 2000, 2005, and 2016, respectively. He served as faculty's first Deputy Dean (Research and Post Graduate Study) and contributed to the early development of research activities at faculty and institution. He has lead several grants from industry, government and university in antenna research and wireless communication. He is also a committee member to draft the Technical Code in 5G Safety Radiation to Malaysia Technical Standard Forum Berhad. He has published more than 80 journals and conference papers. He also supervised a PhD and Master students by research in antenna design for 5G and medical application. He can be contacted at email: imranibrahim@utem.edu.my.

Muhammad Firdaus Akbar received the B.Sc. degree in Communication Engineering from the International Islamic University Malaysia (IIUM), Malaysia, in 2010, and the M.Sc. and Ph.D. degree from the University of Manchester, Manchester, U.K, in 2012 and 2018, respectively. From 2010 to 2011, he was with Motorola Solutions, Pulau Pinang, Malaysia as Research and Development Engineer. From 2012 to 2014, he was an Electrical Engineer with Usains Infotech Sdn Bhd, Penang, Malaysia. He is currently a Senior Lecturer with the Universiti Sains Malaysia (USM). His current research interests include electromagnetics, microwave nondestructive testing, microwave sensor and imaging. He can be contacted at email: firdaus.akbar@usm.my.

Aymen Dheyaa Khaleel Al-Obaidi currently is a postdoctoral researcher at UUM School of Computing, Universiti Utara Malaysia, Kedah, Malaysia. He received the BS.c in Computer Communication engineering, in 2009, from Al-Rafidain University College, Baghdad, Iraq. In 2013, he received an M.Sc. in Electrical Engineering from Universiti Tenaga Nasional (uniten), Kajang, Malaysia. In 2019, he received a PhD in Electrical, Electronics and Systems Engineering, from Universiti Kebangsaan Malaysia (UKM), Faculty of Engineering and Built Environment, Department of Electrical, Electronics and Systems Engineering. His current research interests on antenna and propagation and wireless communication. He can be contacted at email: a.dheyaa.khaleel@uum.edu.my.

Asma Khabba is currently pursuing the studies toward the Ph.D. degree in telecommunication and signal processing in Cady Ayyad University, Marrakech, Morocco. She received the bachelor of sciences in physics and the Master degree in control, industrial computing, signals and systems in 2015 and 2017 respectively from Cadi Ayyad University. Her research interests include 5G antenna, microwave/millimeter wave antenna, phased array and MIMO antenna. She can be contacted at email: asma.khabba@edu.uca.ac.ma.