1. Ahmed Jamal Abdullah Al-Gburi[1], 2. Zahriladha Zakaria[1,*], 3. Imran Mohd Ibrahim[1], 4. Asma Khabba[2], 5. Aymen Dheyaa Khaleel Al-Obaidi[3], 6. Tale Saeidi[4], 7. Liton Chandra Paul[5]

Microwave Research Group (MRG), Centre for Telecommunication Research & Innovation (CeTRI),Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer (FKEKK),Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, Durian Tunggal 76100, Malaysia (1), Instrumentation, Signals and physical systems (I2SP) Team, Department of physics, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakesh, Morocco (2)
School of Computing, Universiti Utara Malaysia (UUM), Sintok, Kedah, Malaysia (3)
Istinye University, Faculty of Engineering and Natural Sciences, Electrical and Electronics Engineering Department, Sarıyer 34396, İstanbul, Turkey (4)
Department of Electrical, Electronic and Communication Engineering, Pabna University of Science and Technology, Pabna 6600,Bangladesh (5)

doi:10.15199/48.2023.03.27

A Deep Analysis of CPW-fed Planar Antennas for Frequencies 2.6 Up to 13.6 GHz

***Abstract**. This paper presents a deep analysis of coplanar waveguide (CPW) feed Planar antenna for frequencies from 2.6 GHz up to 13.6 GHz, which covers the authorised Ultra-wideband (UWB) from 3.1-10.6GHz and the X-band from 8-12GHz applications. The Parametric analysis will help the researchers understand antenna parameters' effects on the reflection coefficient (S11) variations. These important parameters are the length of the CPW fed (Cl), the width of the substrate (W), the width of the feed-line (Wf) and the gap between the feed-line and CPW disk (g). The total physical planar antenna dimension is 26 mm × 26mm × 1.6 mm, corresponding to the centre frequency range at 7.5 GHz. The UWB CPW planar antenna is fed via a coplanar waveguide (CPW) to attain the best impedance matching for UWB systems. The presented CPW planar 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 planar 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 presented antenna has the specialised prospect to be used for UWB and X-band systems.*

Streszczenie**. W artykule przedstawiono dogłębną analizę współpłaszczyznowej anteny falowodowej (CPW) zasilającej planarną antenę dla częstotliwości od 2,6 GHz do 13,6 GHz, która obejmuje autoryzowane aplikacje ultraszerokopasmowe (UWB) w zakresie 3,1-10,6 GHz oraz pasmo X w zakresie 8-12 GHz . Analiza parametryczna pomoże naukowcom zrozumieć wpływ parametrów anteny na zmiany współczynnika odbicia (S11). Tymi ważnymi parametrami są długość podawanego CPW (Cl), szerokość podłoża (W), szerokość linii zasilającej (Wf) oraz szczelina między linią zasilającą a dyskiem CPW (g). Całkowity wymiar fizycznej płaskiej anteny wynosi 26 mm × 26 mm × 1,6 mm, co odpowiada środkowemu zakresowi częstotliwości przy 7,5 GHz. Antena planarna UWB CPW jest zasilana przez współpłaszczyznowy falowód (CPW), aby uzyskać najlepsze dopasowanie impedancji dla systemów UWB. Prezentowana antena planarna CPW ma pasmo impedancji UWB 11,0 GHz od 2,6 GHz do 13,6 GHz przy tłumieniu odbiciowym −10 dB. Symulowana antena planarna UWB wykazuje dookólne zachowanie promieniowania z symulowanym wzmocnieniem 7,3 dB przy 13,6 GHz, kierunkowością 7,5 dBi przy 13,6 GHz i korzystną wydajnością promieniowania 97%. Prezentowana antena ma specjalizowaną perspektywę do zastosowania w systemach UWB oraz w paśmie X.* (Dogłębna analiza anten planarnych zasilanych CPW pod kątem częstotliwości 2,6 Do 13,6 GHz***)

Keywords: UWB Planar antenna, Monopole antenna, CPW feed, Gain, Directivity, Return loss
Słowa kluczowe: Planarna antena UWB, Częstotliweość 2,4 – 3,6 GHz

Introduction

Ultra-wideband (UWB) technology was first authorised by the Federal Communication Commission (US-FCC) in 2002, and it has grown at a remarkable speed in the last few years [1], [2]. The US-FCC has appointed the frequency band 3.1-10.6 GHz for commercial use of the ultra-wideband [3]. Numerous new telecommunication applications and processes occur daily to attain UWB response [4], [5]. The primary purpose of UWB technology is to send or receive data with more helpful data speeds over short-range wireless communication systems employing the current communication standards [6], [7]. It is also utilised in military applications due to its low chance of intercepting undesired receivers, making it more protected than other communication approaches [8], [9]. The primary difficulties UWB technology countenances are interfering with other narrow band technologies working in a frequency band by the UWB band [10], [11]. Some of the examples of these narrow bands are the WLAN (IEEE802) and HIPERLAN/2 WLAN operating in the 5-6 GHz band [12]-[15]. In addition, these technologies reach the WiMAX service performing in the 3.3-3.6 GHz band [16]. Using filters is not a reasonable solution due to filters sophistication of filters, so the proposed antenna will be combined with the notched filter [17], [18].

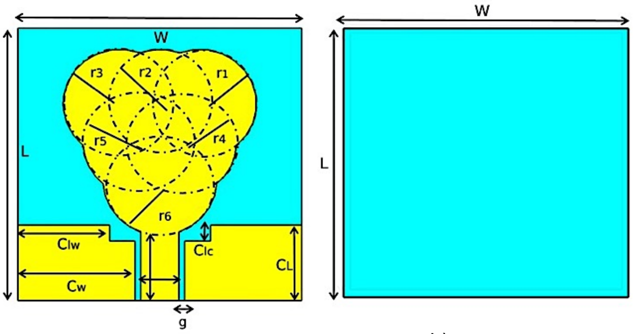
Several antenna designs and patch shapes have been proposed and presented in recent years to get UWB operation over wide ranges of frequencies. In [19]-[22], a super compact antenna was proposed to achieve a wide range of frequencies. An ellipsoidal was proposed in [23] to obtain a UWB operation from 3.29-9.35 GHz, with a total size of 27 × 36 ×1.6mm. On the other hand, leaf-shaped [24] and L-shaped [25] were also presented to attain a wide impedance bandwidth. a few methods have also been investigated lately to get UWB working bandwidth response [26-29].

This study proposes a deep parametric study to verify the planar monopole patch antenna. Four progressive parameters were introduced in terms of antenna performance, such as the length of the CPW fed (Cl), the width of the substrate (W), the width of the feed-line (Wf) and the gap between the feed-line and CPW disc (g). All the simulations are conducted utilising CST Microwave studio 2016.

Antenna design

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×1.6mm). To accomplish the first sub-objective, a coplanar waveguide feed with 50Ω CPW tapered lines were placed to feed the proposed antenna.

Fig.1 characterises 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 disc 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 Fig. 1. The bandwidth expands due to the available space between the feed line and the CPW, which allows the creation of the certified ultra-wideband 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)

Fig. 1. The design geometry of the UWB planar antenna; (a) front look, (b) back look

Table 1. The specifications of the UWB planar antenna

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

Parametric study and the effect of the design parameters

The modelled planar antenna operational bandwidth is mainly affected by:

- The CPW fed length (Cl)
- The substrate width (W)
- The feed-line width (Wf)
- The gap between feed-line and CPW disc (g)

The variables mentioned above should be carefully obtained for better impedance bandwidth. In the simulations process, we do not consider a 50 Ohm SMA connector to reduce the computational needs. It is observed that this SMA connector primarily influences the fourth and fifth resonances by moving their resonant commonnesses.

The length influence of the CPW fed (Cl)

A parametric study was carried out through a Cl parameter in this section. Fig. 2 plots the simulated return loss curves with several sizes of CPW fed when W is set at 26mm and r at 5.4 mm [30]. Sequentially, their identical input impedance swivels have schemed in Fig. 3. It is clear from Fig. 2 that the reflection coefficient (S11) arcs are similar for the four other feed spaces. Nevertheless, the -10 dB impedance bandwidth varies greatly with the interpretation of Cl of the modelled antenna. The CPW ground alters the input antenna impedance and working bandwidth, which functions as a standalone impedance matching equivalent circuit.

In contrast, when the feed gap is changed. We observed that the inferior edge of the -10 dB antenna bandwidth rises when Cl becomes more diminutive. The modified CPW feed length is found to be at Cl=7.5mm.

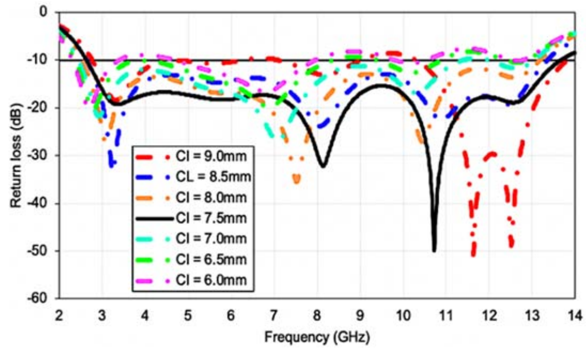


Fig. 2. Predicated return loss arcs with various numbers of Cl parameter

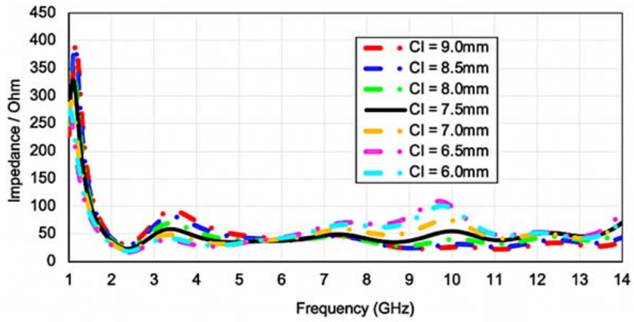


Fig. 3. Simulated input impedance for different numbers of Cl parameter

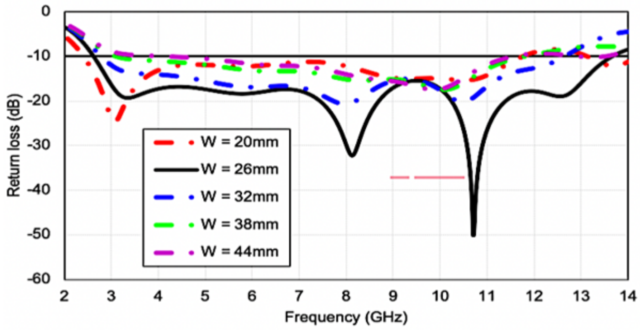


Fig. 4. Predicated return loss arcs with various numbers of W parameter

The influence of ground width plane (W)

The fundamental principles of planar antennas are radiated from the width of the ground plane. The antenna performance is basically disconnected from L. The disk radius value is r=5.4mm, and the most reasonable feed-gap Cl is found to be 7.5mm for various widths (W) of the ground-planes are illustrated in Fig. 4. It is regarded that the reflection coefficient arcs differ substantially and no longer have identical curve forms for the five different (W), unlike those for the seven other Cl, as given in Fig. 2. Also, this can be readily comprehended while the ground plane is acted as an impedance matching circuit. In this case, the ground plane's intrinsic impedance seems to be influenced mainly by its width W. When W is adjusted, the first resonant frequency does not vary much; the more elevated resonant frequencies vary substantially, showing deviations in the antenna's working bandwidth. It is also noticed that when W is equivalent to 26mm, the operational antenna bandwidth attains UWB properties, from 2.6 GHz to more than 13.7 GHz. Yet, when W increases to 32mm, 38mm, and 44mm, respectively. The bandwidth of the inferior edge reduces tardily from 3.1 GHz to 3.0 GHz and 3.1 GHz, respectively. Moreover, the upper side decreased smoothly from 10.6 GHz to 10.3 GHz and 10 GHz, respectively, showing a noticeable bandwidth limit. The best width of the ground plane is found to be at W=26mm.

The effect of the width of the feed-line (Wf)

A parametric study was carried out through a Wf parameter, and it's presented as follows: 1) The increasing width of the feed-line (Wf) functioning to shift the resonant frequency into the lower frequency, and 2) when decreasing the Wf leads to changing the resonant into the highest frequency [31]. In those cases, ten parametric studies with different numbers of Wf widths are considered to simulate in the CST simulation software. The different Wf width is from 3.85 mm to 3.45 mm, with a variation of 0.5 mm. It shows that the more extended width of Wf will make the antenna resonates at its lower frequency range of the antenna. The graph shows that the resonant frequency is shifted from 3.18 GHz to 3.05 GHz at a width feed of 3.85 mm compared to the chosen feed (3.65 mm), with a return loss performance of – 19.2 dB to – 26.9 dB.

On the other hand, while decreasing the Wf parameter of 3.45 mm, it shifts to the highest frequency. Moreover, it shows that the resonant frequency had been moved from 13.65 GHz to 13.7 GHz at a width feed of 3.45 mm compared to the chosen feed (3.65 mm). Fig. 5 represents the return loss and resonant frequency of the UWB monopole antenna with an adjusted Wf width.

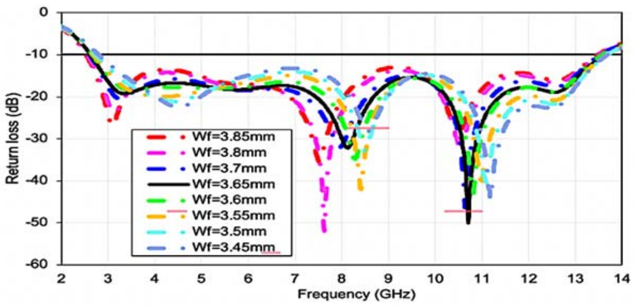


Fig. 5. Simulated return loss curves with different numbers of Wf parameter

The effect of the gap between the CPW fed and feed-line (g)

Another important parameter was carried out through a parametric study to clarify the antenna performance, which is the gap between the CPW fed and the transmission line. The optimised g parameter of 0.525 mm was chosen for the ideal design when cl is constant at 7.5 mm. W is fixed at 26 mm, Wf=3.65mm. Fig. 6 presents the simulated S11 for the different gaps of g. It can be realised that when g decreases to 0.325 mm, the frequency of 3 GHz becomes more resonant at about -40 dB of its return loss performance. Moreover, at a higher frequency of 10.75GHz, the resonant becomes less resonant. To more understand the effect of the g parameter. It was further reduced to 0.125 mm, which can also realise that at 3 GHz, the resonant frequency is very poor, around -11 dB of its performance. The higher part is almost out of -10dB; this is happening because of the impedance mismatch between the transmission line (feed-line) and the CPW ground plane. On the other hand, when g is increased to 0.725 mm, and 0.925 mm, the resonant frequency at 3 GHz is changed to resonant at 4.2 GHz for the lower part of frequency and from 10.2 GHz to 11.2 GHz, respectively.

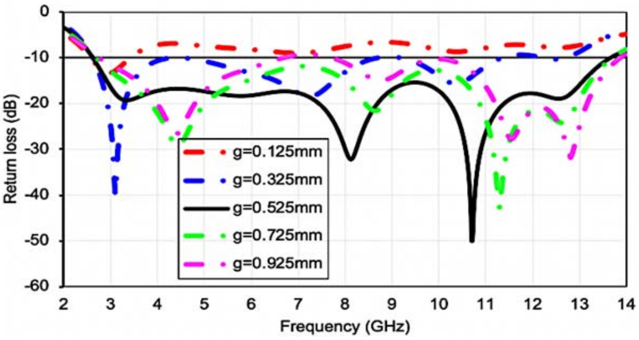


Fig. 6. Predicated return loss arcs with diverse numbers of g parameter.

The effect of the current distributions

The predicted antenna current distributions at various ranges of frequencies are demonstrated in Fig. 7. From Fig. 7, it is clear that shows that the current is primarily spread along the perimeter of the antenna circular ring, which means by the first resonant frequency, which is established based on the antenna circular ring proportions. In other words, the current is mostly circulated along the z-direction of the upper cutter. This represents the quantity of power that has already been saturated around the ground plane, which acts as part of the radiating design. Therefore, the antenna's execution is mainly conditional on the width of the antenna radiated ground plane.

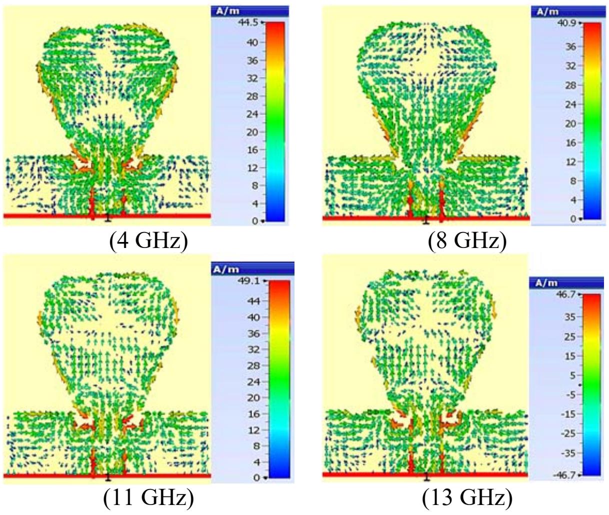


Fig. 7. Simulated current distributions of the investigated antenna at 4 GHz, 8 GHz, 11 GHz and 13 GHz

Results and discussion

In this stage, the simulated outcomes of the CPW-fed UWB planar antenna have been validated to determine the best characteristics design of the simulated planar monopole antenna. Fig. 8 presents the predicted return loss, Gain, Directivity and efficiency of the suggested UWB planar 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: 1) 3.35 GHz with -19.24 dB of return loss performance for simulation, 2) resonant frequency at 8.16 GHz with -32.12 dB of return loss routine for simulation, and 3) third resonant frequency at 10.7 GHz with return loss performance of -50 dB. The proposed antenna performed 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 planar antenna obtains a high radiation efficiency of 97%.

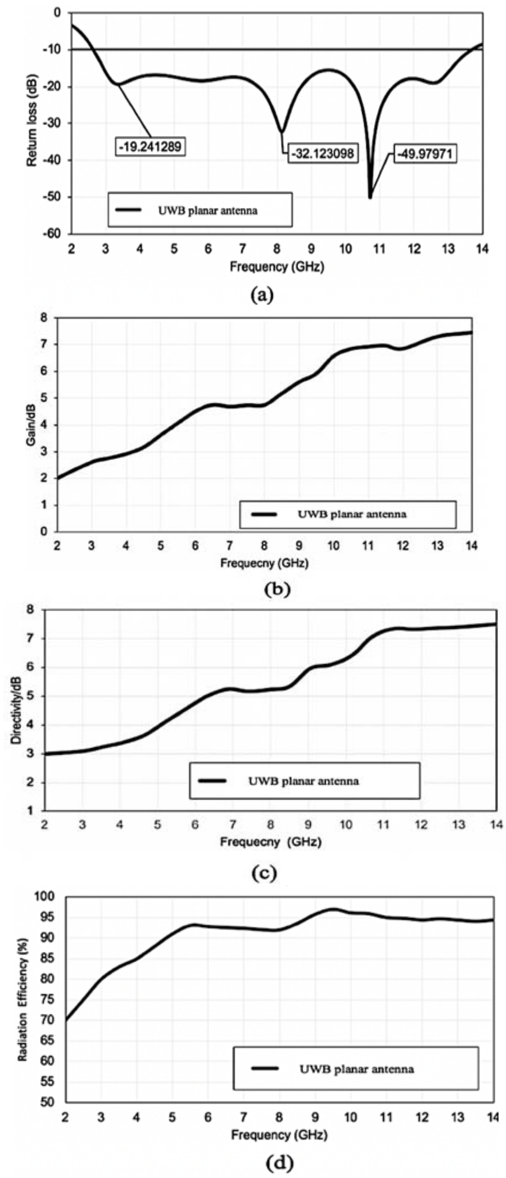
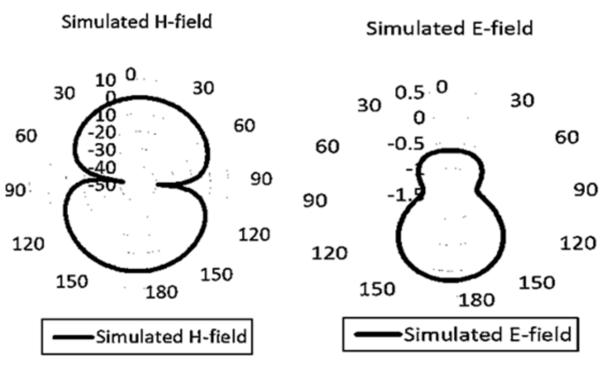
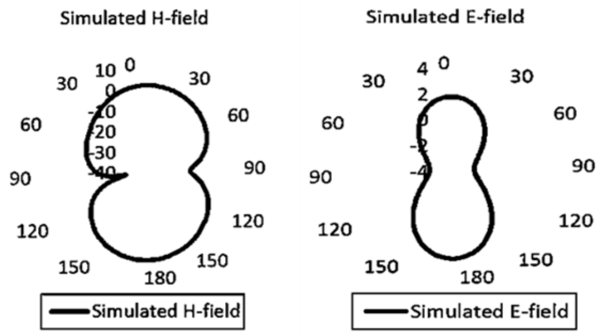


Fig. 8. Simulated results of (a) Return loss, (b) Gain, (c) Directivity and (d) radiation efficiency.

Fig. 9 delivers the radiation behaviour of the planar monopole antenna with CPW fed 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 H-field, it seems kidney-shaped with a minor lobe at the bottom part.



a)



b)

Fig. 9. H-field and E-field radiation patterns of the planar monopole antenna with CPW fed at (a) 2.911 GHz, and (b) 7.74 GHz.

Conclusion

This paper outlined antenna parameters' effects and studied the impact on the antenna performance in term S11. Four advanced stages were introduced in terms of antenna performance such as reflection coefficient (S11), gain, directivity, efficiency and radiation patterns. The proposed planar 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 antenna suitable to be operated for UWB and x-band systems.

Acknoweledgements

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

The correspondence address is:
Zahriladha Zakaria, Microwave Research Group (MRG), Centre for Telecommunication Research & Innovation (CeTRI),Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer (FKEKK),Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, Durian Tunggal 76100, Malaysia. E-mail: zahriladha@utem.edu.my.

REFERENCES

[1] First Report and Order: 'Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems'. FCC 02-48, February 2002.

[2] D. Dardari, A. Conti, U. Ferner, A. Giorgetti and M. Z. Win, "Ranging with ultrawide bandwidth signals in multipath environments", Proceedings of the IEEE, vol. 97, no. 2, pp. 404-426, 2009.

[3] W.S.YeohandW.S.T.Rowe,"An UWB conical monopole antennafor multiservice wireless applications," IEEE Antennas Wireless Propag. Lett., 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 Wire- less Propag. Lett., 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 Commun. Lett., vol. 17, no. 5, pp. 896–899, May 2013, doi: https://doi.org/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 Trans. Commun., vol. 53, no. 7, pp. 1123–1126, Jul. 2005, doi: https://doi.org/10.1109/TCOMM.2005.851606.

[7] C. Marchais, G. Le Ray and A. Sharaiha, "UWB antennas time domain characterization", 11th Int. Symp. Antenna Technology and Applied Electromagnetics, pp. 136-137, 2005-Jun.

[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", 2020 IEEE 31 st Annual Inter-national Symposium on Personal Indoor and Mobile Radio Communications, pp. 1-7, 2020.
[9] A. D. K. Al-Obaidi et al., "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, 2022, doi: https://doi.org/10.11591/eei.v11i4.3681.
[10] A. J. A. Al-Gburi, I. M. Ibrahim, Z. Zakaria, and A. D. Khaleel, "Bandwidth and Gain Enhancement of Ultra-Wideband Monopole Antenna Using MEBG Structure," (in English), ARPN Journal of Engineering and Applied Sciences, Article vol. 14, no. 10, pp. 3390-3393, 2019, doi: 10.36478/JEASCI.2019.3390.3393.
[11] M. Y. Zeain et al., "Design of helical antenna for next generation wireless communication," *Prz. Elektrotechniczny*, no. 11, pp. 96–99, 2020.
[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. 2021, no. 5, pp. 65–69, 2021, doi: 10.15199/48.2021.05.10.
[13] A. Sabah and M. J. Frhan, "A new patch antenna for ultra wide band communication applications," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 2, pp. 848-855, 2020.
[14] R. H. Thaher and N. B. Hassan, "Design of p-shaped microstrip patch antenna for wireless communication systems,"*Indonesian Journal of Electrical Engineering and Computer Science*, vol. 15, no. 2, pp. 861-869, 2019.
[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. 05012-1–05012-4, 2021, doi: https://doi.org/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, 2019.
[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, 2022, doi: 10.11591/eei.v11i2.3164.
[18] Al-Gburi, A.J.A.; Ibrahim, I.M.; Zakaria, Z.; Abdulhameed, M.K.; Saeidi, T. Enhancing Gain for UWB Antennas Using FSS: A Systematic Review. *Mathematics* 2021, 9, 3301.
[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] J. Ali, N. Abdullah, R. Yahya, E. Mohd, A. Joret, N. Katiran, "Bistatic Configurational Analysis of Ultra-Wideband Antenna for Detection Applications", *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 13, no. 2, pp. 702-707, Feb. 2019.
[21] Al-Gburi, A.J.A.; Ibrahim, I.M.; Zakaria, Z.; Ahmad, B.H.; Shairi, N.A.B.; Zeain, M.Y. High Gain of UWB Planar Antenna Utilising FSS Reflector for UWB Applications. *Comput. Mater. Contin*. 2022, 70, 1419–1436.
[22] AL-GBURI, Ahmed Jamal Abdullah et al. A parametric study on strawberry radiated shaped monopole antenna for ultrawide-band applications. *Bulletin of Electrical Engineering and Informatics*, vol.12, no. 1. pp. 232-239, feb. 2023.
[23] N. A. Koma'rudin, Z. Zakaria, A. A. Althuwayb, H. Lago, H. Alsariera et al., "Directional wideband wearable antenna with circular parasitic element for microwave imaging applications," *Computers, Materials & Continua*, vol. 72, no.1, pp. 983–998, 2022.
[24] Abdulhameed, M.K.; Kod, M.S.; Al-gburi, A.J.A. Enhancement of Elevation Angle for an Array Leaky-Wave Antenna. *Prz. Elektrotech.* 2021, 8, 109–113.
[25] Al-Gburi, A.J.A.; Ibrahim, I.M.; Zakaria, Z.; Nazli, N.F.M. Wideband Microstrip Patch Antenna for Sub 6 GHz and 5G Applications. *Prz. Elektrotech*. 2021, 11, 26–29.
[26] Al-Gburi, A.J.A.; Zakaria, Z.; Ibrahim, I.M.; Halim, E. Microstrip Patch Antenna Arrays Design for 5G Wireless Backhaul Application at 3. 5 GHz. *Recent Adv. Electr. Electron. Eng*. 2022, 865, 77–88.
[27] Ahmad, S.; Manzoor, B.; Paracha, K.N.; Haider, S.; Liaqat, M.; Al-Gburi, A.J.A.; Ghaffar, A.; Alibakhshikenari, M.; Dalarsson, M. Wideband Bear-Shaped Compact Size Implantable Antenna for In-Body Communications. *Appl. Sci*. 2022, 12, 2859.
[28] Abdulhameed, M.K.; Hashim, S.R.; Abdalhameed, N.K.; Al-gburi, A.J.A. Increasing Radiation Power in Half Width Microstrip Leaky Wave Antenna by using Slots Technique. *Int. J. Electr. Comput. Eng*. 2022, 12, 392–398.
[29] Al-Gburi, A.J.A.; Ibrahim, I.M.; Ahmad, K.S.; Abdulhameed, M.K.; Saeidi, T. A Miniaturised UWB FSS with Stop-Band Characteristics for EM Shielding Applications. *Prz. Elektrotech*. 2021, 1, 142–145.
[30] A. J. A. Al-Gburi et al., "Broadband Circular Polarised Printed Antennas for Indoor Wireless Communication Systems: A Comprehensive Review," *Micromachines*, vol. 13, no. 7, p. 1048, Jun. 2022, doi: 10.3390/mi13071048.
[31] A. J. A. Al-Gburi, I. B. M. Ibrahim, M. Y. Zeain and Z. Zakaria, "Compact Size and High Gain of CPW-Fed UWB Strawberry Artistic Shaped Printed Monopole Antennas Using FSS Single Layer Reflector," in *IEEE Access*, vol. 8, pp. 92697-92707, 2020, doi: 10.1109/ACCESS.2020.2995069.