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Novel high-gain and compact UWB microstrip antenna for WIFi, WIMAX, WLAN, X band and 5G applications

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Abstract

In this paper, we use a new technique to improve the gain and the bandwidth of a small size ultra-wide-band (UWB) circular microstrip antenna. The technique is based on a non-uniform microstrip line feed width and using a partial rectangular ground plane. The compact structure is printed on the economical FR4 substrate material with a relative permittivity 4.4 and loss tangent 0.02 with a degree of miniaturization $39.3 \times 30 \times 1.6\ mm^3$ compatible with the integration technology of components in communications systems architecture. The proposed antenna is simulated and optimized using electromagnetic simulators high frequency structure simulator, results show a good characteristics and radiating behavior within the UWB frequency. The simulated results established that our design has a very important gain (10 dB), and huge bandwidth: from 2.74 to 76.83 GHz for return loss $S11 < -10$ dB and covered multi-band for many applications such as: wireless fidelity system, wireless local area network: operate within the UWB band, worldwide interoperability for microwave access, the 5th generation mobile network (5G). The measured antenna parameters are presented and discussed, confirming the simulation results in the interval [0.1, 20]GHz using ZNB 20 vector network analyser 100 KHz–20 GHz.

Keywords Ultra-wide-band (UWB) · Partial ground · Compact microstrip antenna · HFSS simulator

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1 Introduction

With the increasing demand for communication services, the Ultra Wide Band (UWB) technology has attracted a great deal of attention due to their exclusive advantages including high data rate, large bandwidth, and low power spectral density (Li et al. 2019). It is well known that a conventional antenna presents a small bandwidth and moderate gain which limit their use in the UWB communication systems (Sang et al. 2020). Therefore, there is a huge demand to implement antennas with wide bandwidth.

During the past few decades, UWB microstrip antenna has attracted lots of study interest of many researchers due to its advantages such as: high data rate, inherent security, low sensitivity to fading, and low power consumption (Zhang et al. 2021). In Zhang et al. (2019), an UWB dipole antenna is realized with bandwidth of 1.7–2.7 GHz for the (2G/3G/4G) generation and 3.4–3.6 GHz for the (5G). And authors in Abdelghani et al. (2015) have proposed an UWB antenna with bandwidth from 2.83 to 13.0 GHz with switchable single notched bands of the applications of WIMAX (3.3–3.9) and WLAN (4.8–5.8) GHz.

Due to its advantages, UWB antenna is used in many applications, in Zhou et al. (2021), multiple-input multiple-output (MIMO) UWB antenna has been developed with a working bandwidth of 9.46 GHz (2.36–12) GHz, and notched bands cover (3.37–3.98) GHz and (4.71–5.51) GHz. And in Gilan et al. (2019), a wideband microstrip nano-antenna has been proposed at terahertz frequencies, its operating frequency is 3.3 THz corresponding to a wavelength of 91 µm. In Nissanov and Singh (2021), authors have studied a design of an UWB reconfigurable microstrip antenna for the frequency range of 100–302.85 GHz for beyond 5G wireless communication at the mmWave/THz band. The UWB antenna is also used in the WBAN network to reduce the power spectral range, which translates into better battery life and decreased electromagnetic sensitivity for constant on-body operation (Mahmood et al. 2020).

Some techniques are used to improve the performances of the UWB antenna like: the metamaterial is used in Alnaiemy and Lajos (2018) to ameliorate an UWB antenna in term of bandwidth and gain. and in Wang et al. (2019), an UWB antenna has been proposed using polyimide (PI) as a substrate. The antenna structure was fabricated by surface modification and in situ self-metallization technique at room temperature, this antenna presents an impedance bandwidth of 15 GHz (1.40–16.40) GHz. In Yesilyurt and Sayan (2020), an ultra-wideband metasurface lens has been designed and integrated into an antipodal Vivaldi antenna to improve its radiation directivity without affecting its efficiency and return loss characteristics.

It can be seen that the most important performances of the UWB antenna are: the bandwidth with multi applications. In this paper, we propose an UWB antenna with a compact size and a very wide bandwidth that covers more than 74 GHz. In addition, it also presents a better performance of high gain which is favorable for today wireless devices.

2 Description of ultra wide band antenna

The proposed ultra-wide-band (UWB) antenna structure is illustrated in Fig. 1, which consists of a circular patch of radius $R = 10.975$ mm, it is fed by a non-uniform microstrip line with a widths $d_2 = 3.5$ mm and $d_1 = 2.625$ mm to achieve input impedance of 50 Ω.

The patch and the feeder are printed on a FR4- epoxy dielectric slab with thickness of $H = 1.6$ mm, a relative permittivity $\epsilon_r = 4.4$ and a dielectric loss tangent $\tan\delta = 0.02$.

On the other side of the substrate, we show a partial rectangular ground plane with length of $L = 15$ mm and the same width of the substrate $Ws = 30$ mm is printed. The overall antenna dimension is $39.3 \times 30 \times 1.6\ \text{mm}^3$.

The optimal design parameters of our structure are presented in Table 1.

The UWB model antenna simulated results were carried out using the commercially simulation software HFSS (High Frequency Structures Simulator) based on finite element method. It has been widely used in the design of RF/wireless antenna, waveguide designs and filters.

3 Simulation results and discussion

3.1 Return loss coefficient

The simulated results are concerning the return loss coefficient (S_{11}), voltage standing wave ratio (VSWR), the input impedance, and the radiation pattern of the UWB microstrip structure of Fig. 1. Figure 2 shows the simulated return loss of the proposed antenna as a function of frequency. From this figure, we can observe that the antenna bandwidth for 10 dB is from 2.74 to 76.83 GHz. These results show that the proposed antenna exhibits an ultra-wide bandwidth in a frequency interval greater than 74.0 GHz. With this very wide interval (ultra-Wide Band), our proposed antenna is able to cover some suggested bands used in many applications such as:

- Wireless fidelity system (WiFi) at: 2.45 GHz and 5 GHz,
- Wireless local area network (WLAN) for resonant frequencies: 2.4, 3.6, 4.9, 5, 5.2, 5.3, and 5.8 GHz.
- Worldwide interoperability for microwave access (WIMAX) (3.5/5.5) GHz bands (3.4–3.7/5.2–5.8) GHz range.
- The 5th generation (5G) at: 3.3–3.8 GHz, 4.8–4.99 GHz, 5.150–5.925 GHz, 5.925–7.025 GHz, 7.235–7.25 GHz, 7.750–8.025 frequencies ranges and at the bands: 24.25–24.45 GHz, 25.05–25.25 GHz, 27.5–28.35 GHz, 29.1–29.25 GHz, 31–31.3 GHz, 38.64–40 GHz. 60 GHz band: 57–64 GHz and at the resonance frequency 70 GHz.
- X band (8–12 GHz).

Table 1 The optimal parameters of proposed antenna

	Parameters	Values (mm)
Patch	R	10.975
Ground plan	L	30
	W_s	15
Microstripline	d1	2.625
	d2	3.5
	l1	8
	l2	7.35

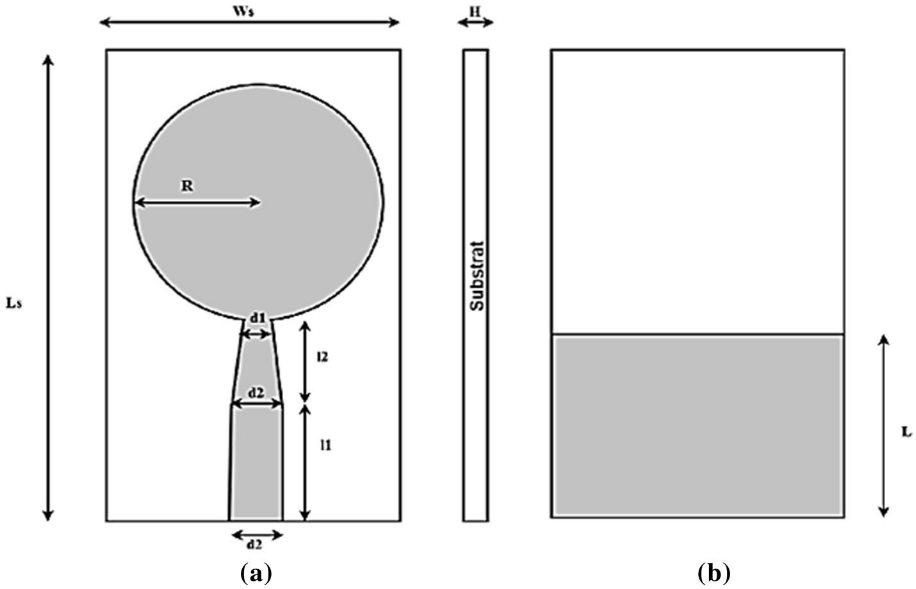

Fig. 1 Proposed UWB antenna geometry. **a** Top view (the patch and the feeder). **b** Bottom view (the partial ground UWB antenna)

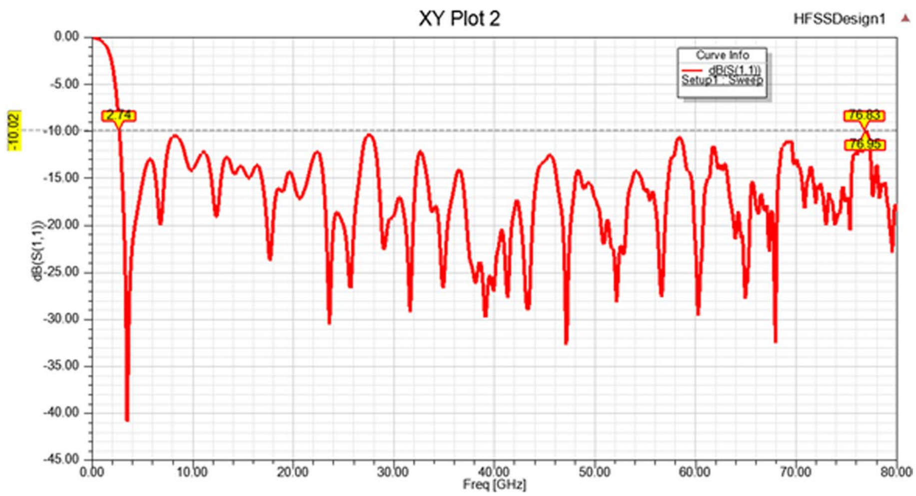

Fig. 2 Simulated return loss of the proposed UWB antenna

3.2 Voltage standing wave ratio (VSWR)

Figure 3 illustrates the simulated results of a VSWR of an UWB antenna. From this curve, it can be noted that the VSWR is less than 2, from 2.56 to 75 GHz.

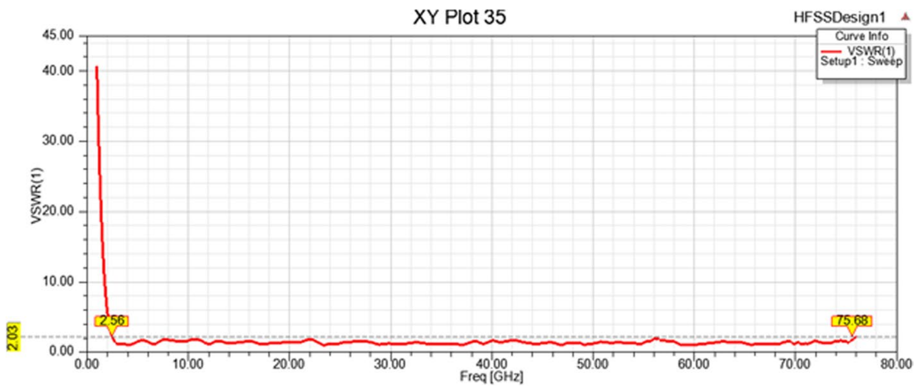

Fig. 3 Simulated VSWR of the proposed UWB antenna versus frequency

3.3 Input impedance

The simulation results of the real and the imaginary part of the input impedance of the proposed antenna are shown in Fig. 4. The input impedance is an important parameter to define the performances of the microstrip antenna. Consistency with the return loss S_{11} and voltage standing wave ratio (VSWR) plots are observed; smaller dB values of the return loss and VSWR less than 2 occur when the real part and the imaginary part of the input impedance are close to 50Ω and 0Ω, respectively.

3.4 Radiation pattern

The radiation pattern is one more essential parameter to describe the performance of the microstrip antenna because the role of any antenna is the radiation. The main purpose of the radiation patterns is to show that the antenna actually radiates over a wide frequency band.

The 2D and 3D far field gain in dB along both E-plane and H-plane of the UWB proposed antenna are also investigated along both E-plane ($\theta = 0°$) and H-plane ($\theta = 90°$)

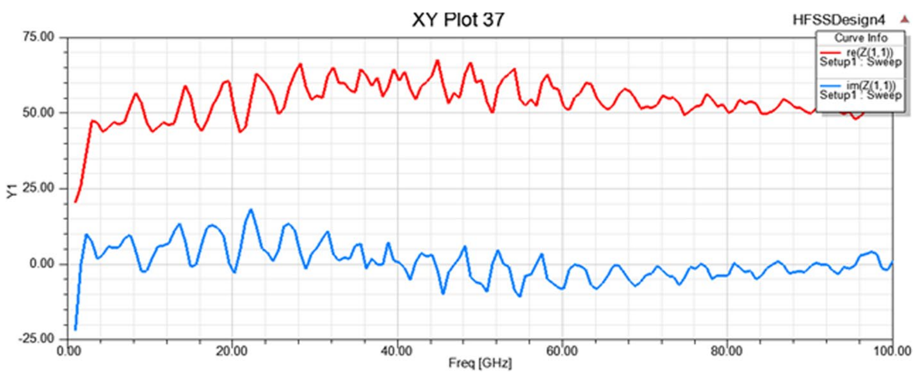

Fig. 4 Simulated Input impedance versus frequency (the real part, in red line and the imaginary part in blue line)

for several resonance frequencies: 2.45 GHz (WiFi system), 3.6 GHz (WIMAX), 5.2 GHz(WLAN), and 40 GHz (5th generation (5G)) are presented in Fig. 5a–d, respectively.

From these figures we can observe that the radiation pattern in the (H-plane) has nearly directional diagram behavior and a bidirectional behavior in the E-plane. Moreover, we can also observe, from the simulated results that the side lobs are emergent, especially in the H-plane, due to height frequencies: 40 GHz, For these frequencies we can notice also that the UWB proposed antenna has a better gain :10 dB for the height frequency. This gain is reasonable and enough at this frequencies, compared to published works (Mehrdadian and Forooraghi 2018; Pozar and Schaubert 1995; Tomar et al. 2020).

4 Equivalent circuit

For more performance perception of the proposed UWB antenna, lumped-element equivalent circuit model for the proposed antenna is applied.

Using the Advanced Designing System (ADS) software, the parameters of an equivalent circuit model for the proposed ultra wide band antenna are estimated. As demonstrated in Fig. 6, the developed equivalent circuit consists of lumped elements for the UWB antenna structure. Optimum values of the equivalent circuit elements were determined, and the overall simulation results were compared with simulated results (Fig. 7). There is a slight difference between results in two methods which is attributed to the accuracy of the element values in the circuit model.

5 Experimental measures and results

The aim in this section is to valid the proposed antenna results, experimentations have been performed at the Institute of Electrical and Electronic Engineering,(INELEC) Boumerdes, Algeria.

AZNB 20 vector network analyser 100 KHz–20 GHz has been used for measurements of several parameters: the return loss coefficient (S_{11}), voltage standing wave ratio (VSWR), and the input impedance.

The considered structure is a circular microstrip antenna with a non-uniform feeding microstripline; they were fabricated using photo-etching processing techniques and were alimented by coax-feed. Both front and back views of the proposed ultra-wideband antenna are shown in Fig. 8.

The dielectric substrate used in this study is an FR4 substrate with a thickness of 1.6 mm, permittivity $\epsilon_r = 4.4$, and a dielectric loss tangent $\tan\delta = 0.02$. The detailed dimensions of the antenna are presented in Table 1.

The return losses coefficient (S_{11}), voltage standing wave ratio (VSWR), and the input impedance of the simulations with Ansoft-HFSS and the measurements are shown comparatively in Figs. 9, 10 and 11 respectively.

The simulation and measurement results had a much better agreement, and are almost identical in most of the frequency range (from 2.56 to 20 GHz). According to the measured return loss, the UWB antenna covers the band assigned for the UWB application such as : WIFI System at 2.45 GHz, WLAN 2.4/5.2/5.3/ 5.8 GHz, WIMAX fir 3.5 and 5.5 GHz

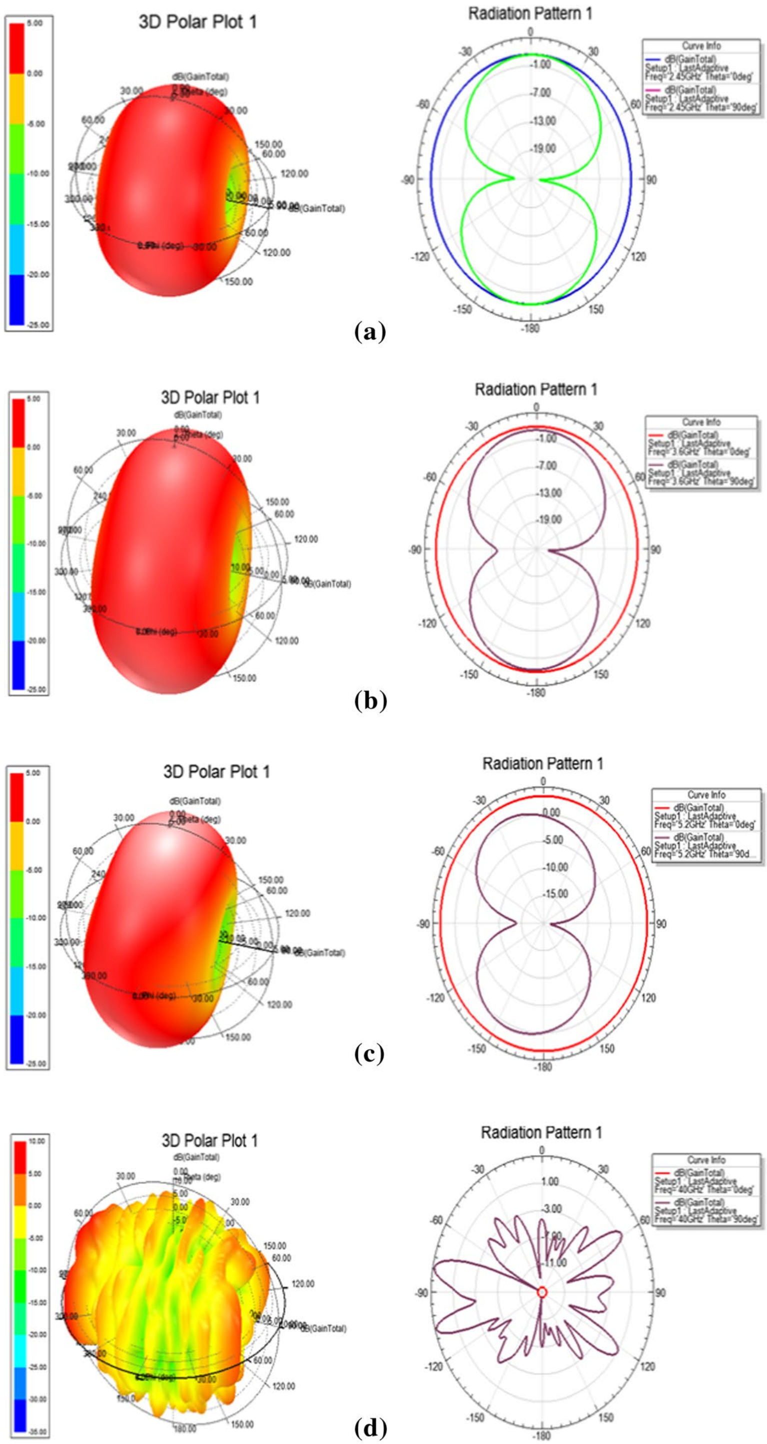

Fig. 5 Two and three dimensional gain pattern of the proposed UWB antenna at **a** 2.45 GHz (WiFi system), **b** 3.6 GHz (WMAX), **c** 5.2 GHz (WLAN), and **d** 40 GHz (5G)

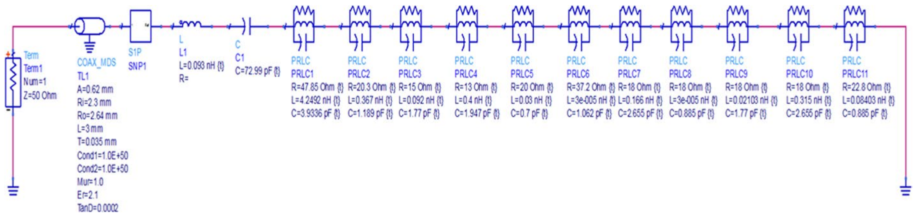

Fig. 6 Equivalent circuit model of the proposed UWB antenna

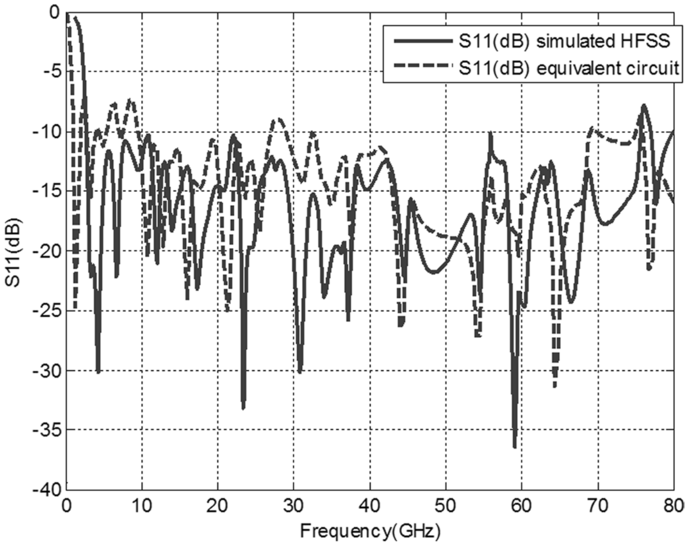

Fig. 7 Simulated and equivalent circuit Return Loss of the proposed UWB antenna

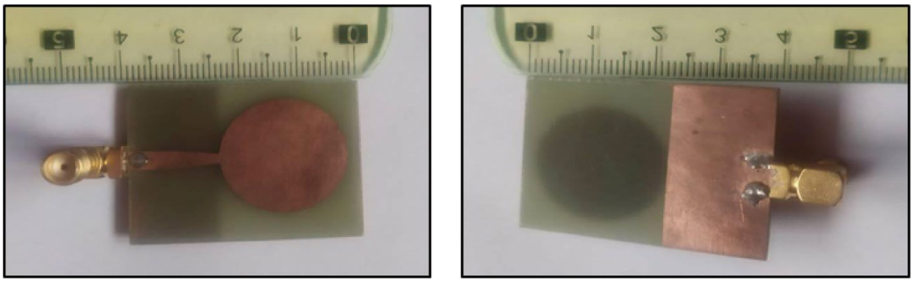

Fig. 8 Photograph of the fabricated prototype

bands, the 5th generation mobile network (5G) 3.5 GHz, 5.5 GHz, 6.4 GHz, 7.25 GHz, 7.8 central frequencies, and X band (8–12 GHz).

Figure 11 illustrates the simulated and measured impedances for the UWB antenna. The real parts are around 50Ω, while the imaginary parts fluctuate nearby zero.

The slight dissimilarities between the simulated and measured results are essentially due to fabrication errors, and the approximate boundary conditions in the computational

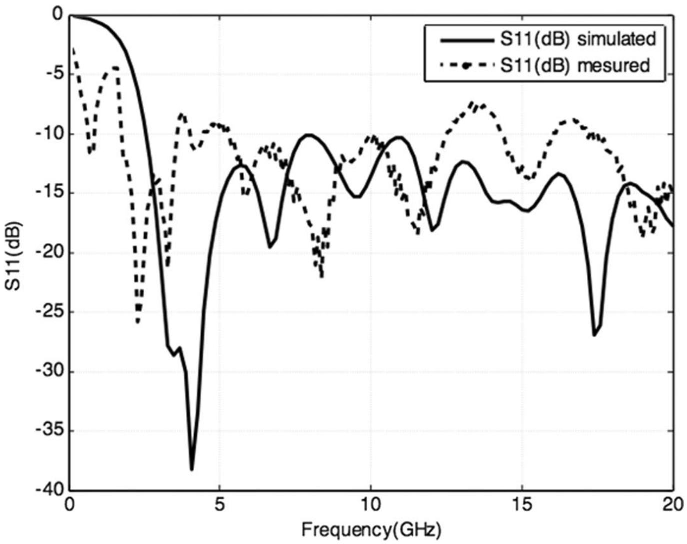

Fig. 9 Measured and simulated reflection coefficient S_{11} of UWB proposed antenna

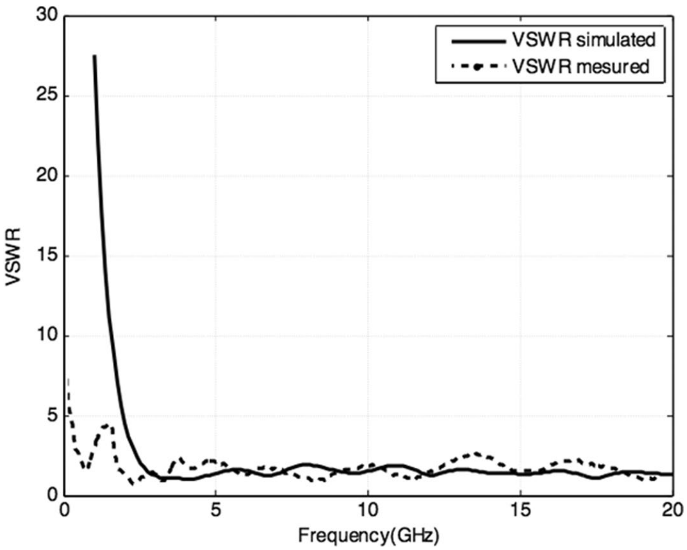

Fig. 10 The simulated and measured voltage standing wave ratio (VSWR)

domain. Also, for small antennas the RF cable and bulky SMA connectors can affect the achieved results measurements (Xiao et al. 2012; Augustin and Denidni 2012).

In order to explain the novelty of this paper, the proposed antenna is compared with designs of antenna in literature. The specific comparison results in: bandwidth, radiation gain, size and used technique of antenna are listed in Table 2.

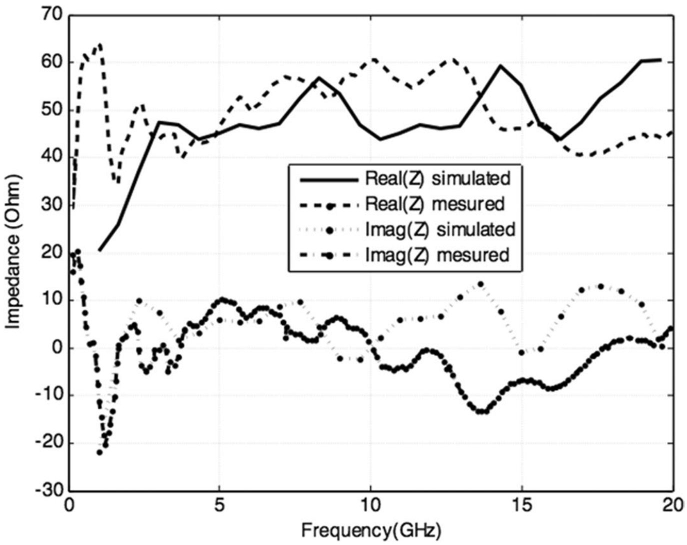

Fig. 11 Simulated and measured impedance of the UWB proposed antenna

From this comparison, we observe that the proposed antenna has: the measured impedance bandwidth defined by return loss ≤ – 10 dB (70 GHz), more reliable radiation performance and higher gain (10 dB) than the other works.

In addition, the proposed antenna is presented with compact structure and low profile. Moreover, the designed antenna operates in the higher frequency (70 GHz).

6 Conclusion

A novel low profile microstrip antenna has been proposed for WLAN, WIMAX, WIFI, and 5G applications. The antenna has a compact structure of $39.3 \times 30 \times 1.6\ mm^3$. Moreover, the proposed antenna can cover 2.78–78.6 GHz ultra-wideband and has high gain in its frequency band. Because of this ultra-wide bandwidth and the high gain, the proposed antenna is eventually useful for many applications like: WIFI system at 2.45 and 5 GHz , WLAN at 2.4/3.6 /4.9/5/5.2/5.3/ 5.8 GHz, WIMAX (3.5/5.5) GHz, and the 5th generation (5G) at: 3.3–3.8 GHz, 4.8–4.99 GHz, 5.150–5.925 GHz, 5.925–7.025 GHz, 7.235–7.25 GHz, 7.750–8.025, 40 GHz, 60 GHz and other wireless communication systems with a high gain of 10 dB. The prototype of the proposed antenna has been realized and the simulated results have been verified with measured results in the interval [0.01, 20]GHz using ZNB 20 Vector Network Analyser 100 KHz–20 GH. Measured results in terms of return loss bandwidth, VSWR and impedance have shown clearly a good agreement with the simulated results.

The novelty of the proposed antenna structure is that it has a simple and compact structure with a very wide bandwidth which may cover lot of applications wireless systems, Moreover, the proposed antenna presents good radiation performances in its entire frequency band.

Table 2 Comparisons with the other UWB antennas

Refs.	Size (mm^3)	Band width (GHz)	Gain	Technique
Dong et al. (2018)	$260 \times 254 \times 0.508$	0.7–2.7	8.3 dBi	Tapered slot
Sani et al. (2019)	$55 \times 55 \times 12.6$	3.8–6.9	6.41 dBi	Coupled dual semicylind-rical dielectric resonator
Sani et al. (2020)	$48 \times 48 \times 5.2$	6–12.2	4.72 dBi	Coplanar waveguide fed multi-permittivity and stair shaped
Tewary et al. (2021)	$52.8 \times 52.8 \times 18$	5–24.6	8.8 dB	FSS structure
Ren et al. (2022)	$82 \times 55 \times 1.6$	2.5–8.5	3.26 dBi	Planar slit gradient antenna
This work	$39.3 \times 30 \times 1.6$	3.74–76.83	10 dB	Nonuniform transmission line feed

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Abdelghani, A.M., Areed, N.F.F., Farhat, M., Hameed, O., Hindy, M.A., Obayya, S.S.A.: Design of UWB antenna using reconfigurable optical router. Opt. Quantum Electron. **47**, 2675–2688 (2015)

Alnaiemy, Y., Lajos, N.: Design and analysis of ultra-wide band (UWB) antennas based on metamaterial. In: 11th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), Budapest, Hungary (2018)

Augustin, G., Denidni, T.A.: An integrated ultra wideband/narrow band antenna in uniplanar configuration for cognitive radio systems. IEEE Trans. Antennas Propag. **60**, 5479–5484 (2012)

Dong, Y., Choi, J., Itoh, T.: Vivaldi antenna with pattern diversity for 0.7 to 2.7 GHz cellular band applications. IEEE Antennas Wirel. Propag. Lett. **17**, 247–250 (2018)

Gilan, M.S., Mohassel, J.R., Moghaddasi, M.N., Khatir, M.: Design of a wideband microstrip nanoantenna array. Opt. Quantum Electron. **132**, 1–9 (2019)

Li, Z., Yin, C., Zhu, X.: Compact UWB MIMO vivaldi antenna with dual band-notched characteristics. IEEE Access. **7**, 38696–38701 (2019)

Mahmood, S.N., Ishak, A.J., Ismail, A., Soh, A.C., Zakaria, Z., Alani, S.: ON–OFF body ultra-wideband (UWB) antenna for wireless body area networks (WBAN): a review. IEEE Access **8**, 150844–150863 (2020)

Mehrdadian, A., Forooraghi, K.: Design of a novel 0.2 to 40 GHz ultra-wideband high-gain combined antenna with and without dielectric lens. In: 9th International Symposium on Telecommunications (IST) (2018)

Nissanov, U., Singh, G.: mmWave/THz reconfigurable ultra-wideband (UWB) microstrip antenna. Prog. Electromagn. Res C **111**, 207–224 (2021)

Pozar, D.M., Schaubert, D.H.: Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays, Wiley, IEEE Press, pp. 417–422 (1995)

Ren, J., Fan, H., Tang, Q., Yu, Z., Xiao, Y., Zhou, X.: An ultra-wideband vivaldi antenna system for long-distance electromagnetic detection. Appl. Sci. **12**, 528 (2022)

Sang, L., Wu, S., Liu, G., Wang, J., Huang, W.: High-gain UWB vivaldi antenna loaded with reconfigurable 3-D phase adjusting unit lens. IEEE Antennas Wirel. Propag. Lett. **19**, 322–326 (2020)

Sani, M.M., Chowdhury, R., Chaudhary, R.K.: Electrically coupled dual semicylindrical dielectric resonator antenna with inverted arrangement for wideband applications. Int. J. RF Microw. Comput. Aided Eng. **29**, 1–11 (2019)

Sani, M.M., Chowdhury, R., Chaudhary, R.K.: An ultra-wideband rectangular dielectric resonator antenna with MIMO configuration. IEEE Access. **81**, 139658–139669 (2020)

Tewary, T., Maity, S., Mukherjee, S., Roy, A., Sarkar, P.P., Bhunia, S.: Design of high gain broadband microstrip patch antenna for UWB/X/Ku band applications. AEU Int. J. Electron. Commun. **139**, 1–13 (2021)

Tomar, A., Malik, H., Kumar, P., Iqbal, A.: Machine learning, advances in computing, renewable energy and communication. In: Proceedings of MARC, p. 600 (2020)

Wang, Z., Qin, L., Chen, Q., Yang, W., Qu, H.: Flexible UWB antenna fabricated on polyimide substrate by surface modification and in situ self-metallization technique. Microelectron. Eng. **206**, 12–16 (2019)

Xiao, L.S., Li, L., Cheung, S.W.: Dual-band antenna with compact radiator for 2.4/5.2/5.8 GHz WLAN applications. IEEE. Trans. Antennas Propag. **60**, 5924–5931 (2012)

Yesilyurt, O., Sayan, G.T.: Metasurface lens for ultra-wideband planar antenna. IEEE Trans. Antennas Propag. **68**, 719–726 (2020)

Zhang, Y., Zhang, Y., Li, D., Liu, K., Fan, Y.: Ultra-wideband dual-polarized antenna with three resonant modes for 2G/3G/4G/5G communication systems. IEEE Access. **7**, 43214–43221 (2019)

Zhang, X., Xu, H., Xie, Y., Wu, Q.: A dual band-notched antenna for UWB applications. Prog. Electromagn. Res Lett. **96**, 105–111 (2021)

Zhou, J.Y., Wang, Y.F., Xu, J.M., Du, C.Z.: A CPW-fed UWB-MIMO antenna with high isolation and dual band-notched characteristic. Prog. Electromagn. Res M **102**, 27–37 (2021)