A CPW-Fed Wearable Dual-Ring Patch Antenna at ISM Band for Biomedical Applications

Mohamed Lamine Bouknia[1], Chemseddine Zebiri[1], Rami Zegadi[1], Djamel Sayad[2], Issa Elfergani[3,4], Chahrazad Bensid[1], Nor Elhouda Mehenni[1] , Said Mosbah[1] and Jonathan Rodriguez[3]

{ml.bouknia@univ-setif.dz, czebiri@univ-setif.dz, ramizegadi@univ-setif.dz, d.sayad@univ-skikda.dz, i.t.e.elfergani@av.it.pt[3], [1]cbenzaid@gmail.com, yasmine.nour0660@gmail.com, bensaidmosbah@gmail.com, jonathan@av.it.pt}

[1]Laboratoire d'Electronique de puissance et commande industrielle (LEPCI), Department of Electronics. University of Ferhat Abbas, Setif -1-, 19000 Setif, Algeria,
[2]Laboratoire d'Electrotechnique de Skikda (LES), Department of Electrical Engineering, University of 20 Aout 1955, Skikda, 21000 Skikda, Algeria;
[3]Instituto de Telecomunicações, Campus Universitário de Santiago 3810193 Aveiro, Portugal,
[4]Faculty of Engineering and Informatics, University of Bradford, Bradford, UK.

Abstract. In this work, a dual-ring, co-planar waveguide (CPW) fed antenna is suggested for use in the ISM band. The suggested antenna is extremely flexible achieving a body isolation using a biocompatible RO4350 (εr = 3.6) substrate. CST Microwave Studio software is used to obtain the simulation results for the proposed antenna's return loss, impedance matching, gain, and radiation pattern. Results are presented and discussed.

Keywords: CPW-fed, dual-ring, flexible antenna, ISM band, Biomedical.

1 Introduction

Over the past years, wearable and implantable electronics have seen enormous growth in their potential applications [1]. Flexible electronic devices are frequently used in information communication, biomedicine, emergency rescue, military warfare systems, consumer electronics, etc [2-4]. A built-in antenna is frequently needed for wearable devices, and these antennas must be small, flexible, and conformal in order to operate adequately. The performance of these antennas must also be outstanding. In addition, an antenna is a crucial part of any wireless communication system that is essential to ensuring the consistent operation of wearable technology [5]. Coplanar waveguide (CPW) feeding and microstrip feeding are the two feeding techniques used most frequently with printed monopole antennas [6-7]. Using a CPW feed line broadens the bandwidth of the antenna.

The requirement for medical applications such as patient monitoring and body diagnostics remotely has lately brought wearable antennas to the attention of researchers in the field of medicine [8-12]. Therefore, an antenna that operates in the Industrial, Scientific, and Medical bands, specifically between 2.35GHz and 2.45GHz [13], is required. The performance of wearable antennas is hampered by coupling to the human body. The performance of an antenna varies depending on its proximity to the human body, random body motions, the position of the antenna on the body, and even from person to person. Therefore, it is crucial to manage how the

IMDC-IST 2023, October 25-27, Yola, Nigeria

DOI 10.4108/eai.25-10-2023.2348741

body affects the performance of the antenna. Utilizing meandered line and meandered slot antenna topologies may increase the wearable antennas' robustness [14]. Compactness, compatibility with the human body, low specific absorption rate (SAR), reduced backward wave reduction, and high gain are the essential requirements for constructing an antenna for a medical purpose [15].

In this study, a co-planar waveguide (CPW) feeding technique is used to create a two-ring patch antenna employing Roger RO4350 flexible material as the substrate. S11 is less than -10 dB at the working frequency of 2.45 GHz, demonstrating its suitability for implantation. Simulation is carried out to confirm the antenna's radiation performance under various bending radians. The antenna design should also consider on-body analysis and use a simulated human tissue model. The suggested design exhibits a broad range of applications and covers the ISM band.

2 Antenna Design

The proposed antenna has dimensions of $25\times32.5\times1.5mm^3$. The model is made up of a two-ring patch that is fed by aco-planar waveguide (CPW) feeding technique employing Roger RO4350 flexible material as substrate. Due to its dependability, affordability, and accessibility, the Rogers RO4350 substrate, which has a dielectric constant of 3.6 anda loss tangent of 0.0027, has been recommended in this research. The proposed planar microstrip patch antenna was analyzed using the commercial CST Microwave Studio. The Geometrical parameters are shown in Figure 1. In Table1, the work's optimal parameters are presented.

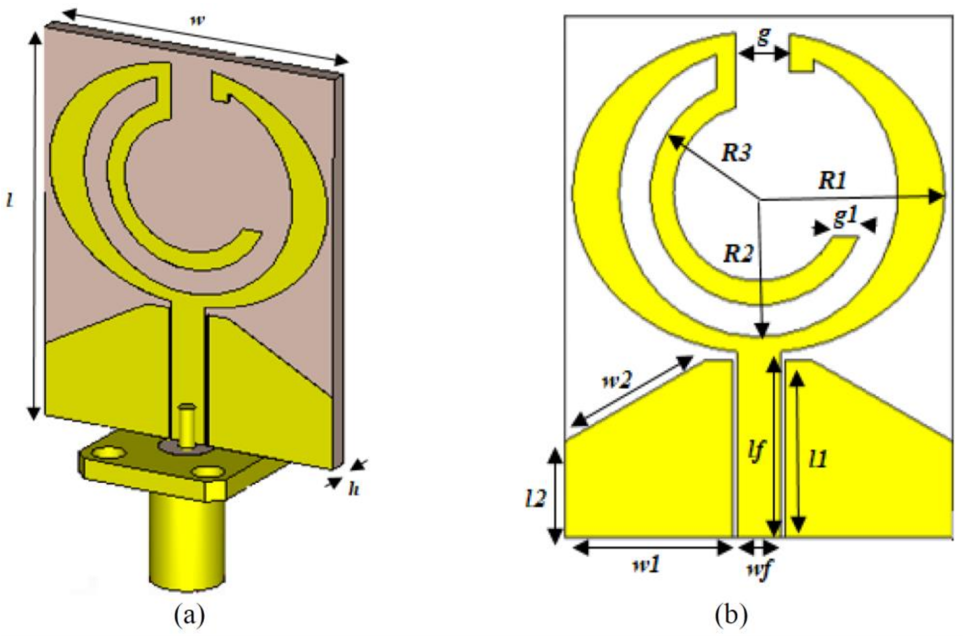

Fig. 1. Architecture of a typical wireless sensor node.

Table 1. Design parameters of the proposed antenna.

Param.	Value (mm)	Param.	Value (mm)	Param.	Value (mm)	Param.	Value (mm)
w	25	**l1**	11	**R1**	12	**w2**	10.3
l	32.5	**l2**	6	**R2**	9	**g**	3.5
h	1.5	**w1**	10.83	**R3**	7	**g1**	1.67
w	25	**l1**	11	**lf**	11.57		
l	32.5	**l2**	6	**wf**	2.84		

3 Results Analysis

3.1 Off-Body Analysis

When creating a microstrip patch antenna, selecting the right substrate material is crucial. The substrate's permittivity and thickness have an impact on the microstrip patch antenna's bandwidth, efficiency and gain. By making the proper decisions, these performance characteristics can be significantly improved.

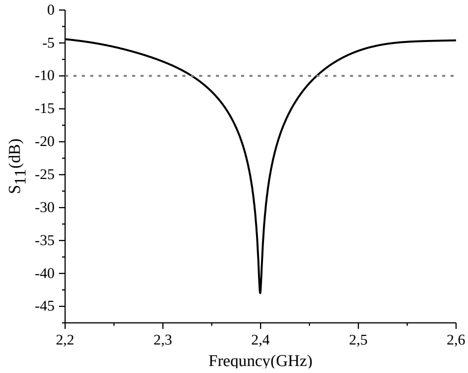

Fig. 2. S_{11} parameter of designed antenna.

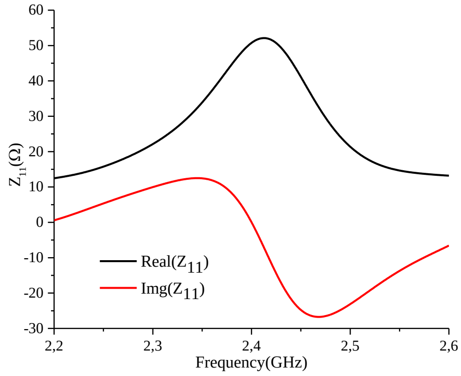

Fig. 3. Input impedance (Z_{11}) of designed antenna.

The S_{11} parameter is referred to as the return loss of the antenna since the S_{11} characteristics of the proposed antenna represents the amount of power reflected from the antenna. The best outcome for an antenna is achieved when S11 is less than -10 dB since it indicates that 90% of the available power has already reached the antenna and 10% is reflected back. Figure 1 depicts the design process for the antenna working principle. Figure 2 depicts the corresponding return loss. Figure 2 shows a scan of a monopole antenna operating in the 2.4 GHz frequency band. The simulated S_{11} results show that the proposed antenna covers the ISM band frequencies. The suggested antenna's input impedance characteristics at the intended band are shown in Figure 3 indicating that the device receives at least 90% of the input power and that less than 10% of it is reflected, which is sufficient for all applications.

The E-plane and the H-plane, which represent the planes containing an electric field and a magnetic field, respectively, are essentially the principal planes for the propagation of waves or radiated fields. The proposed antenna has been simulated at 2.4 GHz. Figure 4(a) represents the E-plane graph and Figure 4(b) represents the H-plane graph at 2.4 GHz. As is evident, the antenna patterns behave in an omnidirectional manner, which is typical of this particular monopole antenna. The simulated surface current distribution at 2.45 GHz is shown in Figure 5. In the operational band, a good current distribution is attained.

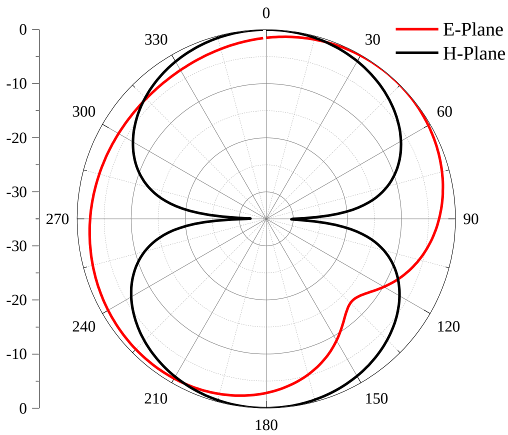

Fig. 4. Radiation pattern at 2.4 GHz

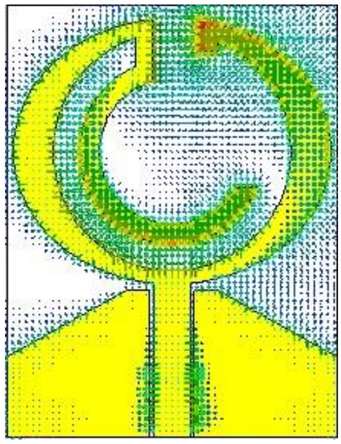

Fig. 5. Surface current distribution at 2.4GHz.

3.2 Effect of Antenna Bending

In order to examine the impact of bending (Fig. 6), a 40 mm-diameter cylinder was considered. Figure 7 compares the return loss of the antenna with flat and bending structures. As it can be seen, even though the resonance frequency and operating frequency band are slightly moved, the bandwidth is still maintained with S11 parameter <-10dB under bending conditions.

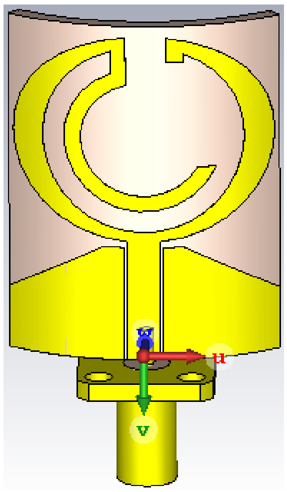

Fig. 6. Bended antenna design

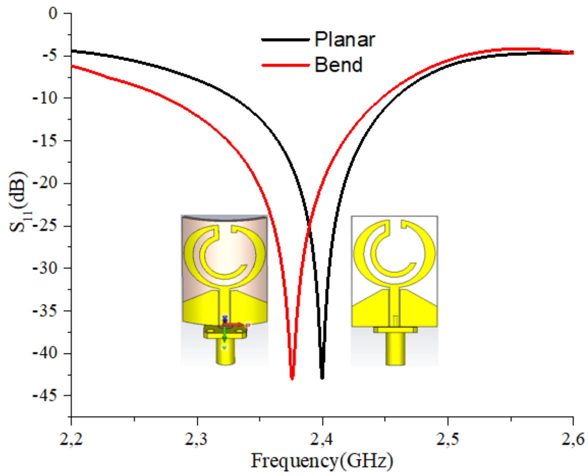

Fig. 7. S_{11} parameter of bended designed antenna.

3.3 On-Body Analysis

A three-layer structure model is loaded at the base of the antenna structure to simulate human skin, fat and muscle tissues, respectively. Simulation is then carried out using the antenna system, with the model structure shown in Figure 8, using the relevant electrical parameters of the human tissue structure [15] (Table 2).

Table 2. Human tissue dielectric properties at 2.4 GHz frequency [16].

Tissue	Dielectric Constant	Conductivity (S/m)	Thickness (mm)
Fat	5.27	0.11	5
Skin	37.95	1.49	2
Muscle	52.67	1.77	20

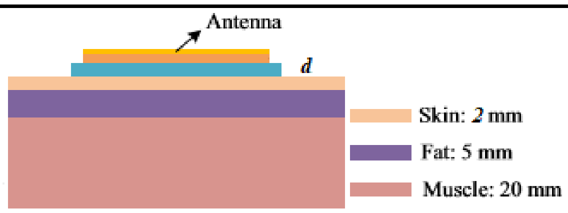

Fig. 8. Structure of the human tissue model.

The performance of on-body antennas is evaluated with the antenna at 3 and 5 mm from the human body arm, respectively. Figure 14 depicts the simulated S11 parameter of an antenna with a gap (d). The resonance occurred in the frequency band 2.27 GHz (2.2-2.36 GHz) for d=5mm.The antenna resonates at 2.38 GHz (2.28-2.46 GHz) and has an S11 of -27.6 dB, for d=3 mm.

Figure 10 shows the set-up for a far-field radiation pattern simulated at 2.38 GHz for an on-body scenario. The radiation pattern shows a semi-omnidirectional shape in the E-plane, while omnidirectional radiation patterns are observed in the H-plane.

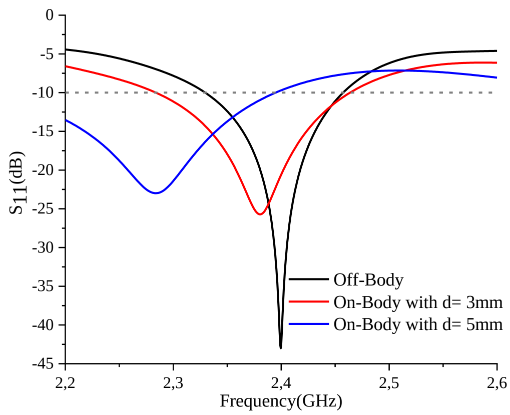

Fig. 9. S_{11} parameter on-body scenario with a gap "d"

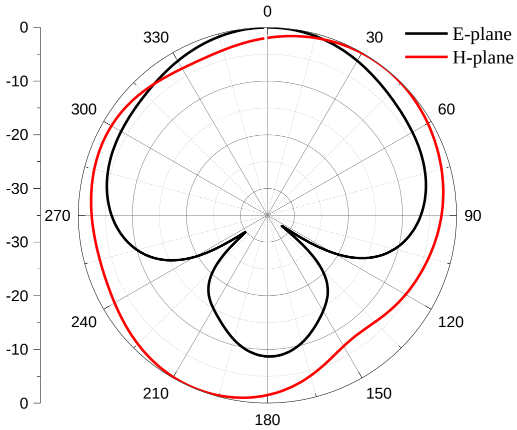

Fig. 10. Radiation pattern at 2.38 GHz for on-body scenario

4 Conclusion

The proposed work presents a CPW-fed wearable antenna and its design procedure, which is suitable for low-cost biomedical applications. In order to function, this antenna is distinguished by its small size, durability, flexibility, and conformity. The proposed antenna exhibits good radiation pattern characteristics. Since the antenna covers the ISM band range, it is intended for biomedical applications. Furthermore, the integrated antenna loaded with a human tissue model was evaluated. The results demonstrated that the proposed antenna has sufficient bandwidth and is suitable for wearable devices in wireless body area networks.

Acknowledgement

This publication has received funding from the European Union's Horizon Europe research and innovation program under grant agreement HE-MSCA-SE-6G-TERAFIT- 101131501, in another part by the General Directorate of Scientific Research and Technological Development (DGRSDT)–Ministry of Higher Education and Scientific Research (MESRS), Algeria,

References

[1] Huang, Siya, et al. "Flexible electronics: stretchable electrodes and their future." *Advanced Functional Materials* 29.6 (2019): 1805924.

[2] Wagih, M., Y. Wei, A. Komolafe, et al., "Reliable UHF long-range textile-integrated RFID tag based on a compact flexible antenna filament," Sensors, Vol. 20, 12, 2020.

[3] Tariq, F., Q. Amjad, A. Kamran, A. Hassan, and R. Karim, "A flexible antenna on cost-effective PEN substrate for sub-6GHz 5G wireless transceivers," International Conference on Frontiers of Information Technology, FIT, 89–895, 2019.

[4] Zhu, S. and R. Langley, "Dual-band wearable textile antenna on an EBG substrate," IEEE Trans. Antennas Propag., Vol. 57, No. 4, 926–935, Apr. 2009.

[5] Rais, N. H. M., et al. "A review of wearable antenna." *2009 Loughborough antennas & propagation conference*. IEEE, 2009.

[6] Patel, A., Desai, A., Elfergani, I., Vala, A., Mewada, H., Mahant, K., ... & Ali, E. (2022). UWB CPW fed 4-port connected ground MIMO antenna for sub-millimeter-wave 5G applications. *Alexandria Engineering Journal*, *61*(9), 6645-6658.

[7] Lashab, M., Eddine, C., Jan, N. A., Benabdelaziz, F., Abd-Alhameed, R. A., & Child, M. (2014, November). CPW-Fed antenna based on Metamaterial for Broadband application. In 2014 Loughborough Antennas and Propagation Conference (LAPC) (pp. 144-147). IEEE.

[8] Smida, Amor, et al. "Wideband wearable antenna for biomedical telemetry applications." *IEEE Access* 8 (2020): 15687-15694.

[9] Yadav, Ajay Kumar Singh, et al. "Wearable Antennas for Biomedical Applications." Wearable and Neuronic Antennas for Medical and Wireless Applications (2022): 217-248.

[10] Saha, Pujayita, Debasis Mitra, and Susanta K. Parui. "Control of Gain and SAR for Wearable Antenna Using AMC Structure." *Radioengineering* 30.1 (2021).

[11] Behera, Santanu Kumar, and Nemai Chandra Karmakar. "Wearable chipless radio-frequency identification tags for biomedical applications: A review [antenna applications corner]." *IEEE Antennas and Propagation Magazine* 62.3 (2020): 94-104.

[12] Al-Adhami, Ammar, and Ergun Ercelebi. "A flexible metamaterial based printed antenna for wearable biomedical applications." *Sensors* 21.23 (2021): 7960.

[13] Raju, Mudunuri Padmanabha, DS Phani Kishore, and B. T. P. Madhav. "CPW fed T-shaped wearable antenna for ISM band, Wi-Fi, WiMAX, WLAN and fixed satellite service applications." *Journal of Electromagnetic Engineering and Science* 19.2 (2019): 140-146.

[14] Aun, Nur Farahiyah Mohamad, et al. "Revolutionizing wearables for 5G: 5G technologies: Recent developments and future perspectives for wearable devices and antennas." *IEEE Microwave Magazine* 18.3 (2017): 108-124.

[15] Abdul-Al, M., Amar, A. S., Elfergani, I., Littlehales, R., Ojaroudi Parchin, N., Al-Yasir, Y., & Abd-Alhameed, R. A. (2022). Wireless electromagnetic radiation assessment based on the specific absorption rate (SAR): A review case study. *Electronics*, *11*(4), 511.

[16] Kiani, Sina, Pejman Rezaei, and Mina Fakhr. "A CPW-fed wearable antenna at ISM band for biomedical and WBAN applications." *Wireless Networks* 27 (2021): 735-745.