4^{th} URSI AT-RASC, Gran Canaria, 19-24 May 2024

PDMS Based Dual Band Flexible Antenna for ISM and WLAN Portable Applications

Musa Hussain [(1)], Hijab Zahra [(2)], Mohsen Asadnia [(2)], Syed Muzahir Abbas [(2)], Yong Zhu [(1)]

(1) School of Engineering and Built Environment, Griffith University Gold Coast Campus, QLD Australia

(2) School of Engineering, Faculty of Science and Engineering, Macquarie University, Sydney, NSW 2109, Australia

musa.hussain@griffithuni.edu.au

Abstract

In this paper, a miniaturized and simple structured antenna designed using Poly-Di-Methyl-Siloxane (PDMS) as substrate is proposed for multi-frequency based wireless portable applications. The antenna offers dual bands around 2.45 GHz for ISM and 5.4 GHz for WLAN spectrum. The antenna has a small size of 24 mm × 24 mm with low profile. The antenna geometry contains a coaxial probe and T-shaped stubs loaded rectangular resonator. The design offers peak gain up to 5.6 dBi and radiation efficiency up to 96%. Whereas, for both operating bands it demonstrates gain > 5 dBi and radiation efficiency > 82%. Further, to demonstrate its significance the antenna performance in terms of bandwidth, gain, efficiency, and size has also been compared with recently published papers. The presented design is suitable for future portable electronic devices.

1. Introduction

Wireless portable electronic devices with the recent technological advancements are a keen requirement for future communication systems, supporting various frequency bands including 5G frequencies. Such devices are intended to be compact, low profile, lightweight, low cost, and multi-technology compatible, while having good performance. These varying requirements in portable devices have also altered the requirements in designing antenna, because as it is one of the most important components of a communication system [1]. This all makes it challenging for antenna designers considering space constraints and to have good performance along with multi-technology supportive designs. Moreover, it becomes more challenging with the requirements in terms of placement, long battery life as well as high data rate and flexibility [2].

Different types of substrate materials are used to design the flexible antennas, and recently polymers are used to design flexible antenna. Poly-Di-Methyl-Siloxane (PDMS) is one of the widely used polymers for flexible antennas [3–7]. A flexible PDMS based antenna operating at 2.45 GHz for wearable biomedical applications has been presented [3]. This antenna is light weigh; however, the impedance matching is limited at operating frequency. Similarly, another flexible optically transparent slotted metamaterial backed microstrip antenna using PDMS, operating at 2.45 GHz has been reported for breast tumor detection [4]. In literature various antennas are presented and designed which offer flexibility and compactness along with wide operational bandwidth and high gain [5-7]. Antennas with wideband characteristics using PDMS as substrate material show that this flexible and optically transparent material is also suitable for higher frequencies and wideband operations as well as under bending conditions [5–8].

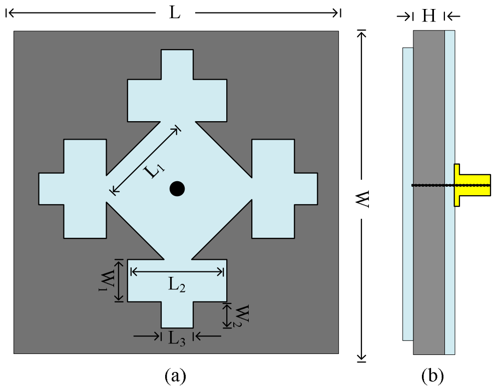

Figure 1. Geometrical configuration of proposed dual band PDMS based antenna (a) top view (b) side view.

A simple PDMS based wideband antenna operating over 3.43–11.1 GHz has been presented [5]. The conductive fibers are used via embroidery to construct the metallic parts on a PDMS composite based substrate. Bending analysis performed show that variations are within 1% and wideband characteristics are well preserved. Similarly, a wideband antenna with bending analysis covering 3.25–15 GHz, having good gain up to 6.56 dB and an omnidirectional radiation pattern has been presented [6]. Another PDMS based wideband antenna for biomedical applications has been published in [7]. The antenna covers a broad frequency range of 2.7-8.8 GHz. The antenna's geometry is basic, but half the ground plane is used to get the wideband. A stretchable dual band, PDMS based antenna with high radiation efficiency and gain around 4.1 dBi is presented in [8]. The antenna offers radiation efficiency of 94% and is operational over 2.13-3.39 GHz and 5.30-6.23 GHz. In [9], a dual band antenna supporting multi-technologies (i.e. ISM, 4G, 5G, Bluetooth, WLAN), designed on flexible dielectric material of thickness of 0.2 mm is reported. The antenna has overall footprint of 40 mm × 44 mm with operational bandwidth of 2.38–2.81 GHz and 4.2–5.1 GHz. The antenna offers dual wide band and has simple geometry, but large size and low radiation efficiency. The antenna has setback of large size and complex geometrical structure. Furthermore, a dual band antenna reported in [10] operates at 2.32–2.6 GHz and 5.66–5.94 GHz and offers peak value of gain of 3.24 dBi and 5.83 dBi, respectively. The antenna has large dimensions of 50 mm × 50 mm, which are further reduced to 30 mm × 30 mm by incorporating Defected Ground Structure (DGS) and has a complex structural setback.

In this study, a dual band, geometrically simple, compact, low profile, high gain, and radiation-efficient antenna for wireless portable devices is presented. Additionally, a comparison table shows the performance of suggested antenna in contrast to designs already presented in literature. The antenna design is discussed in Section II, and the outcomes of design are explained in Section III along with a performance comparison table. In Section IV, the suggested work is concluded.

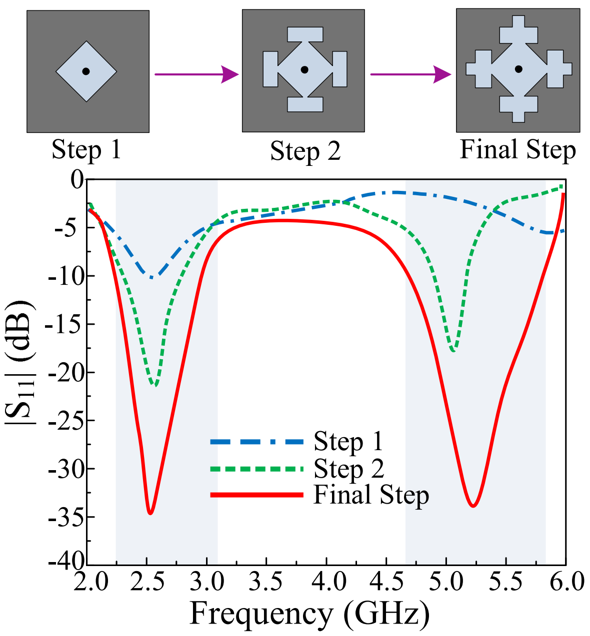

Figure 2. Antenna designing steps and its reflection coefficient (S11) responses of the various design steps.

2. Antenna Design and Methodology

Figure. 1 presents the structure and shape of proposed antenna for wireless portable devices operating at ISM and WLAN band. The flexible substrate material, PDMS, with a thickness of 1 mm and a relative partitivity of 3, has the antenna positioned on its upper side. The antenna dimensions are L × W = 24 mm × 24 mm overall. Four T-shaped patches and a rectangular radiator make up the antenna geometry. The antenna is excited using the coaxial feeding method. The optimized parameters of antenna are; *L=24 mm, W=24 mm, H=1 mm,* L_1*=10 mm,* L_2*=8 mm,* L_3*=3 mm,* W_1*=4 mm,* W_2*=3 mm.*

After completing several design stages, the antenna's final geometry and dual operational bandwidth are achieved. Figure 2 presents various design evolution stages. The square radiator's initial design was intended for 2.45 GHz targeted frequency. A strip is loaded and then positioned at

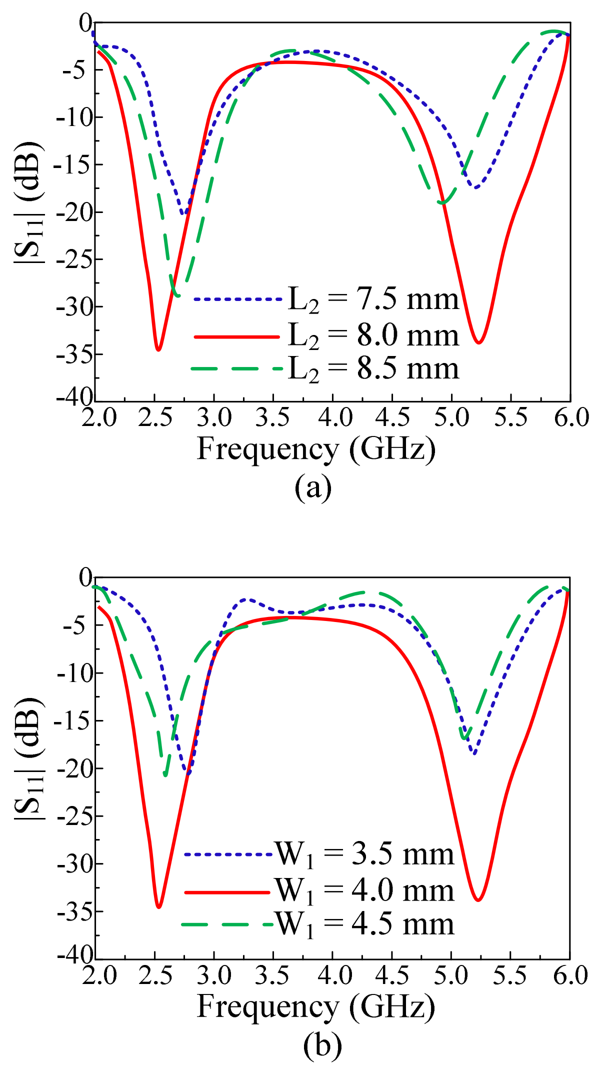

Figure 3. Parametric analysis of proposed antenna (a) effect of length of strip (L_2) (b) effect of width of strip (W_1).

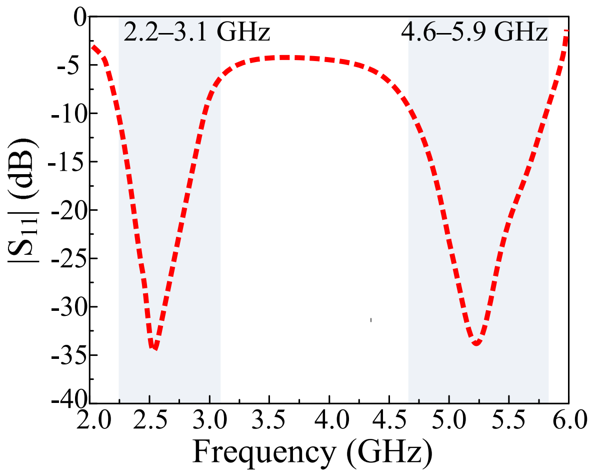

Figure 4. Return loss of proposed antenna operating at ISM and WLAN band.

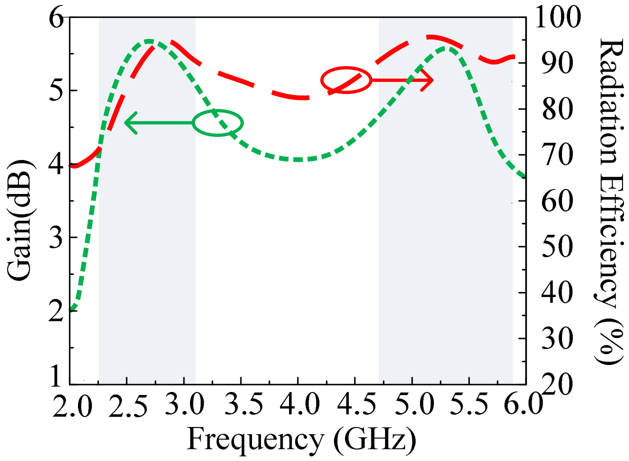

Figure 6. Gain and radiation efficiency of proposed antenna operating at ISM and WLAN band.

each corner of the square patch. The length of strip (L2) is calculated for 5.2 GHz targeted frequency, which is 8 mm. By performing this step, the impedance matching at 2.45 GHz is improved resulting in better return loss, and a new band appeared at 5.2 GHz. The stubs are added to strip which make it like T-shaped in the final step, when stubs are added. This step is performed for matching extension. As seen in Figure 2, this final step allows the antenna to operate in dual bands of 2.45 GHz and 5.4 GHz with a return loss of about -35 dB.

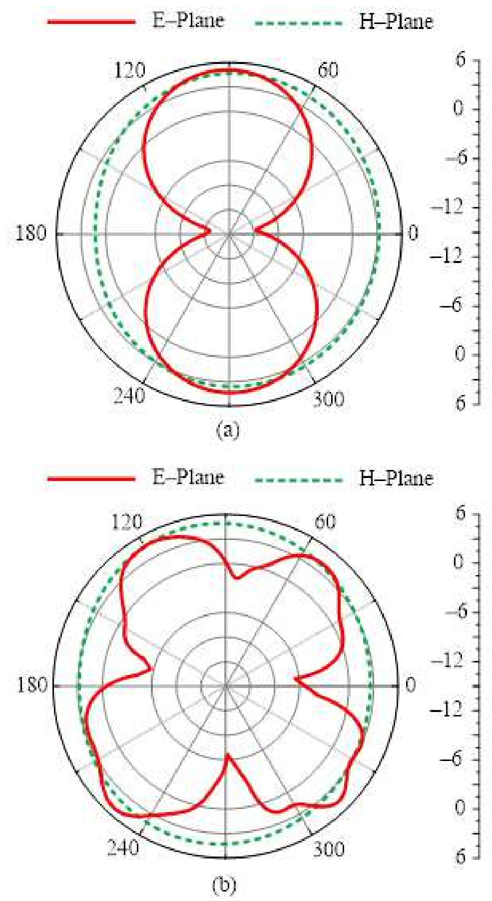

Figure 5. Radiation pattern of proposed work at (a) 2.45 GHz (b) 5.4 GHz.

The parametric analysis in term of length of strip (L2) and width of strip (W3) are given in Figure 3. It can be noted from Figure 3 (a) that the variation in length of strip effects the return loss of the antenna. At optimal value of L2 = 8 mm, the antenna offers dual wide band covering 2.2–3.1 GHz and 4.6–5.9 GHz. At these values the antenna offers return loss of around -35 dB. If the value is decreased from optimal value and fixed at 7.5 mm, the bandwidth and return loss of antenna both are affected. Similarly, when the value of L_2 is increased to 8.5 mm, again the return loss and bandwidth is affected, as illustrated in Figure 3(a).

Another important parameter is width of the strip (W_1), which offer dual band and desired results at optimal value of 4 mm. If the value is decreased to 3.5 mm, the slight shift in lower band (at ISM band) is observed along with improvement in return loss. At this value the antenna offers 2.7 – 3 GHz and 5.1 – 5.55 GHz with return loss value of about -20 dB. On another hand, when the value of W_1 is increased to 4.5 mm, again the bandwidth and return loss is affected, as shown in Figure 3(b).

3. Results

This section discusses the results in terms of S-parameter, gain, radiation efficiency, and radiation pattern. The presented antenna's S-parameter is depicted in Figure 4. In can be observed that the antenna exhibits a dual band operation covering 2.2–3.1 GHz and 4.6–5.9 GHz bands. Higher Frequency Structure Simulator (HFSS), an infinite element based electromagnetic simulation tool, is used to simulate antenna with suitable boundary conditions.

Figure 5 displays the radiation patterns of the proposed design at 2.45 GHz and 5.4 GHz. It can be inferred that the antenna provides an omnidirectional pattern in the H-plane at both operating frequencies. The radiation pattern at 5.4 GHz has a butterfly structure, which could be the result of several stub insertions. Figure 6 shows the gain and radiation efficiency results. It offers 5.5 dBi at 2.45 GHz and 5.4 dBi at 5.4 GHz. Furthermore, over the whole operating bandwidth, the antenna provides gain > 5 dBi. At resonant frequencies of 2.45 GHz and 5.4 GHz, the antenna offers radiation efficiency of 94% and 96%, respectively, with an overall radiation efficiency > 82% over the operational bandwidths.

Table I. Comparison of proposed designs with recent published work.

Ref.	Dimension (mm^3)	Bandwidth (GHz)	Gain (dBi)	Radiation Efficiency (%)
[3]	65 × 44 × 1	2.4 – 2.5	–	–
[4]	38 × 32 × 1	2.39 – 2.61	2.5	96
[6]	24 × 28 × 1.5	3.2 – 5.4	4.6	–
[8]	42 × 22 × 2	2.13 – 3.39 5.3 – 6.2	4.1	94
[9]	40 × 44 × 0.2	2.38 – 2.81 4.2 – 5.1	2.68	79
[10]	50 × 50 × 2	2.32 – 2.61 5.6 – 5.94	3.22	–
This Work	**24 × 24 × 1**	**2.2 – 3.1 4.9 – 5.9**	**5.5**	**96**

4. Conclusion

A compact antenna designed on flexible and optically transparent PDMS substrate is proposed with dual band characteristics. The antenna offers dual band supporting communications at 2.45 GHz for ISM applications and 5.4 GHz for WLAN applications. The antenna also provides peak gain up to 5.5 dBi and radiation efficiency up to 96%. Moreover, the gain is > 5 dBi and radiation efficiency is > 82% over the entire operational bands. The proposed work in terms of results, and geometrical characteristic is also compared with recently published work. The results and comparison show that the proposed antenna is suitable for portable wireless electronic devices.

References

[1] W. A. Awan, A. Ghaffar and S. I. Naqvi, "PDMS Based Compact Antenna for 2.45 GHz Application having Wide Band Harmonic Suppresion," *IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI)*, 2022.

[2] M. Hussain, U. Rafique, H. Zahra, S. M. Abbas and Subhas Mukhopadhyay, "A Compact and Geometrically Simple CPW Fed Antenna for 2.4/5.4 GHz ISM and WLAN Applications," *IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI)*, 2023.

[3] T. A. Karthikeyan, M. Nesasudha and S. Saranya, "Design and Development of Light Weight Antenna Using Polydimethylsiloxane (PDMS) for Biomedical Applications," *International Symposium on Lightweight and Sustainable Polymeric Materials*, Singapore: Springer Nature Singapore, 2023.

[4] T. A. Karthikeyan, M. Nesasudha, and G. S. Let, "Investigations on Slotted Metamaterial Backed Wearable Antenna for Breast Tumor Detection," *Plasmonics*, 2023.

[5] S. M. Abbas, S. C. Desai, K. P. Esselle, J. L. Volakis, R. M. Hashmi, "Design and characterization of a flexible wideband antenna using Polydimethylsiloxane (PDMS) composite substrate", *International Journal of Antennas and Propagation*, 2018.

[6] V. A. S. Ponnapalli, G. S. Reddy, P. S. R. Goud, P. Saharsh, and A. Praveena, "A Flexible Wideband Spiral Antenna using Polydimethylsiloxane Substrate for Wearable Applications," *IEEE International Conference on Computer Communication and Informatics (ICCCI)*, 2023.

[7] N. Y. Li, Z. Zakaria, N. A. Shairi, H. Alsariera, and R. Alahnomi, "Design and investigation on wideband antenna based on polydimethylsiloxane (PDMS) for medical imaging application," *Przegląd Elektrotechniczny,* vol. 1, no. 3, 2020.

[8] W. Belgacem, B. Miloud, and M. S. Mohemmed, "Stretchable Dual Band PDMS Wearable Antenna Design for ISM Band," *IEEE Conference on Antenna Measurements & Applications (CAMA)*, 2021.

[9] Yu, Zhen, Ruirong Niu, Guodong Zhang, Runzhi Sun, Ziheng Lin, Yao Li, and Xiaoying Ran. "A Wearable Self-Grounding Slit Antenna for ISM/4G/5G/Bluetooth/WLAN Applications." *IEEE Access*, 2023.

[10] N. A. Shamsudin, and S. M. Shah, "Miniaturized dual-band dual-mode microstrip patch antenna with defected ground structure for wearable applications," *Journal of Electronic Voltage and Application,* vol. 2, no. 2, 2021.