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Multi–Stub Loaded Tri-Band Flexible Antenna Based on PDMS for Heterogeneous Applications

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Abstract

This work presents the muti-stub-loaded compact flexible antenna with a simple geometrical configuration for wireless applications. The recommended work is engineered by using silicon-based flexible substrate material Polydimethylsiloxane (PDMS), which is suitable for on-body applications and wearables. The recommended design offers a tri-band that covers Wi-Fi 6E, Wi-Fi 7, and Wi-Fi 8, with IEEE standards 802.11ax, 802.11be, and 802.11bn, respectively. To validate this work for wearable applications, conformal and SAR analyses were carried out. Moreover, a detailed comparison of the proposed work is also carried out with recently published work. Thus, due to the various advantages possessed by the proposed design, including its compact size, multi-band operation with broad bandwidth, conformability, and low SAR value, it is the best candidate for heterogeneous wireless applications.

1. Introduction

Development in wireless communication systems has shown a direct impact on the development and construction of electronic devices. Numerous electronic gadgets are being used by humans for various applications, consequently increasing the need for flexible electronics [1]. These changes and advances also impact designing antennae for those devices, the antenna being a key component that plays a vital role in communicating devices. To design and investigate flexible antennae for wearables and on-body applications in general, researchers explore various flexible materials [2–3].

To design a flexible antenna for wearable applications, silicon-based polymers are used to develop materials like Polydimethylsiloxane (PDMS) [4]. Besides flexibility, PDMS has the advantages of light weight, low fabrication cost, and low losses [5–6]. In the literature, a number of antennas are designed using PDMS for wearable applications [3–14]. Some of the proposed antennas operate over a single band [7] or dual wideband [8]. It is noteworthy that to investigate the flexible antenna suitable for wearable applications, conformal (bending) analysis and SAR analysis are important.

The dual band antenna reported in [9] offers dual band ranges of 2.13–3.39 GHz and 5.3–3.39 GHz. The antenna has a small dimensions of 42 mm × 22 mm, with a simplified structure. The antenna fails to provide the SAR analysis and bending analysis to claim it for wearable applications. Another dual-band antenna discussed in [10] offers two bands at 2.3–2.7 GHz and 3.9–5.3 GHz. The antenna offers a SAR value of 0.76 W/Kg. Although the reported work covers good bandwidth along with the good value of SAR analysis, the structure is complex, resulting in high fabrication error.

In [11], a dual-band antenna having an overall geometry of 24 mm × 24 mm × 1 mm is reported. The antenna covers the good value of bandwidth 900 MHz and 1000 MHz at central frequencies of 2.45 GHz and 5.4 GHz, respectively. The antenna lacks investigation in terms of SAR and conformal analysis. A dual-mode antenna for body-centric applications is presented in [12]. The antenna offers dual-band ranges of 2.42–2.48 GHz and 5.7–5.9 GHz. The antenna is compact and simple , but the conformal analysis is not performed as well as the antenna offers a narrow bandwidth as compared to other works presented in literature.

In [13-14] PDMS is further utilized for the designing of dual-band antennas. These antenna designs provide bending analysis and cover reasonable bandwidth. The setbacks of these works are large geometrical structures and complex structures. Moreover, Table–I illustrates the comparison of flexible antennas designed by using PDMS with the proposed antenna presented in this manuscript.

The discussion above and the comparison table show that there is still some gap in designing and investigating flexible antennas having compact size, simple geometrical structures, multi-band operation with wide operational bandwidths, low SAR, and stable performance during bending analysis. Keeping in mind these considerations, in this paper, a triband flexible antenna is constructed by using flexible substrate material PDMS. To make it suitable for wearable applications, the conformal and SAR analysis is performed.

2. Antenna Design and Methodology

The geometrical structure of the proposed tri-band flexible antenna is displayed on Fig. 1. The antenna's central substrate layer is composed of PDMS, which has a relative permittivity of 2.77 and a loss tangent of 0.02; both the front and the back sides are composed of copper, which has a thickness of 0.035 mm. The total dimensions of the antenna are 38 mm × 32 mm × 3 mm. The structure of the antenna contains a microstrip feedline and multiple stubs. Multiple stubs are loaded to the antenna to obtain a wideband as well as triple operational bands. The antenna is appropriate for wearable applications since its backside features a complete ground plane.

Table 1. Comparison of the proposed work with recently published works

Ref	Size (mm²)	Bandwidth (GHz)	SAR W/Kg	Bending Analysis
[9]	42×22	2.13–3.39 | 5.3–6.2	–	No
[10]	40×32	2.3–2.7 | 3.9–5.3	0.76	Yes
[11]	24×24	2.2–3.1 | 4.9–5.9	–	No
[12]	38×38	2.42–2.48 | 5.7–5.9	0.69	No
[13]	58×54	2.43–2.45 | 5.8–6.0	0.3	Yes
[14]	56×56	2.4–2.6 | 5.6–5.6	–	Yes
Prop.	**38×32**	**2.2–2.5 | 4.9–5.5 | 6.5–8.1**	**0.56**	**Yes**

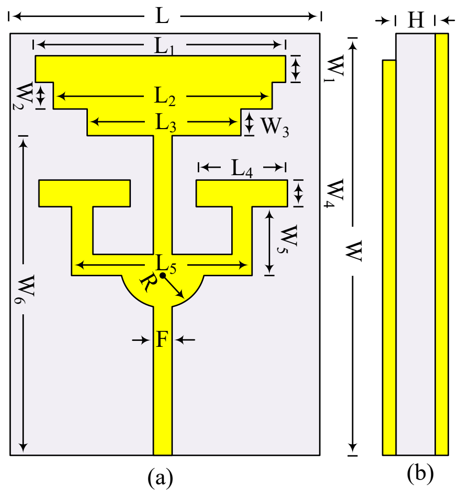

Figure 1. Geometrical configuration of the proposed PDMS Tri-Band Antenna (a) Front View (b) Side View.

$L = 38$; $W = 32$; $H = 3$; $L_1 = 24$; $L_2 = 20$; $L_3 = 12$; $L_4 = 6$; $L_5 = 16$; $W_1 = W_2 = W_3 = W_4 = 2$; $W_5 = 6$; $W_6 = 29$; $F = 2$; $R = 4$. (all units are in mm)

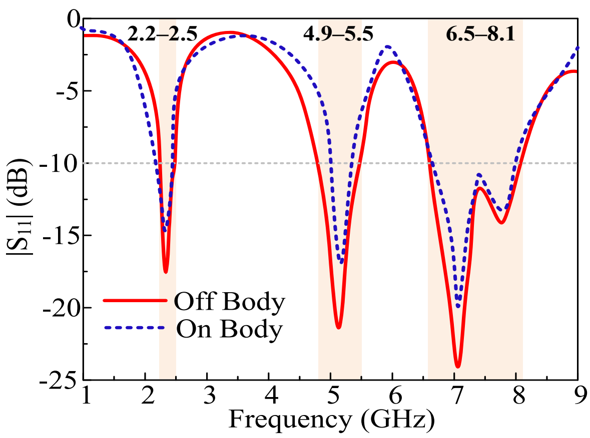

Figure 2. S-Paramter of the proposed antenna On and Off Body.

3. Results and Discussion

The antenna's results are demonstrated by SAR analysis to examine the antenna on a human body phantom, bending analysis to assert flexibility, and S-Parameter simulation both on and off the body.

3.1 S-Parameter

Figure. 2 represents the S-parameter plot of the proposed flexible tri-band antenna. It can be seen from the given figure that the antenna offers triple bands at 2.4 GHz, 5.2 GHz, and 7.0 GHz with bandwidth ranging from 2.2–2.5 GHz, 4.9–5.5 GHz, and 6.5–8.1 GHz, respectively. The proposed antenna covers the ISM band, WLAN, and C-band, which is suitable for healthcare, medical services, emergency services, Wi-Fi, Bluetooth, Zigbee, and future WiFi6 and WiFi7 applications. Moreover, the figure also provides a comparison of the S-parameter with ON and OFF body, which shows that the antenna offers the same results with negligible differences when placed on the human body. These results and comparisons make the proposed antenna suitable applicant for wearable devices.

3.2 Conformal Analysis

Conformal evaluations are carried out to verify the antenna's performance under varied bending situations in order to make the proposed antenna more appropriate for wearable applications. The antenna is bent over the X and Y axes on cylinders with radii of 10 mm, 15 mm, and 20 mm, as shown in Figure 3.

When the design is bent over the X-axis on different cylinders, the results show that the antenna offers stable performance having a triple band with a slight frequency shift. It can be seen from Figure 3 (c), that as the radius of cylinder decreased (From 20 mm to 10 mm), the shift in frequency towards lower band is noted.

On the other hand, when the proposed design is bent over the Y-axis, the antenna results remain stable at the first band of 2.45 GHz for all three cylinders, whereas a slight shift is observed in the second band at 5.2 GHz and distortion in the third band (which shifts from 7.0 GHz to >7.9 GHz). For a cylinder having a radius of 20 mm, the antenna offers overall stable results. While bending over a cylinder having a radius of 10 mm and 15 mm, the result is disturbed. This distortion in higher band (6.5-8.1GHz) is due to the significant bending in Y-axis, which affected the flow of current towards upper most stub.

3.3 SAR Analysis

Figure 4 shows the designed triband antenna's SAR (Specific Absorption Ratio) results on 1 g and 10 g of tissue. By positioning the suggested antenna on a model of a human hand, the results are examined and analyzed using the CST software tool. The figures show that antenna SAR analysis is investigated on 1 g and 10 g of tissues at 2.35

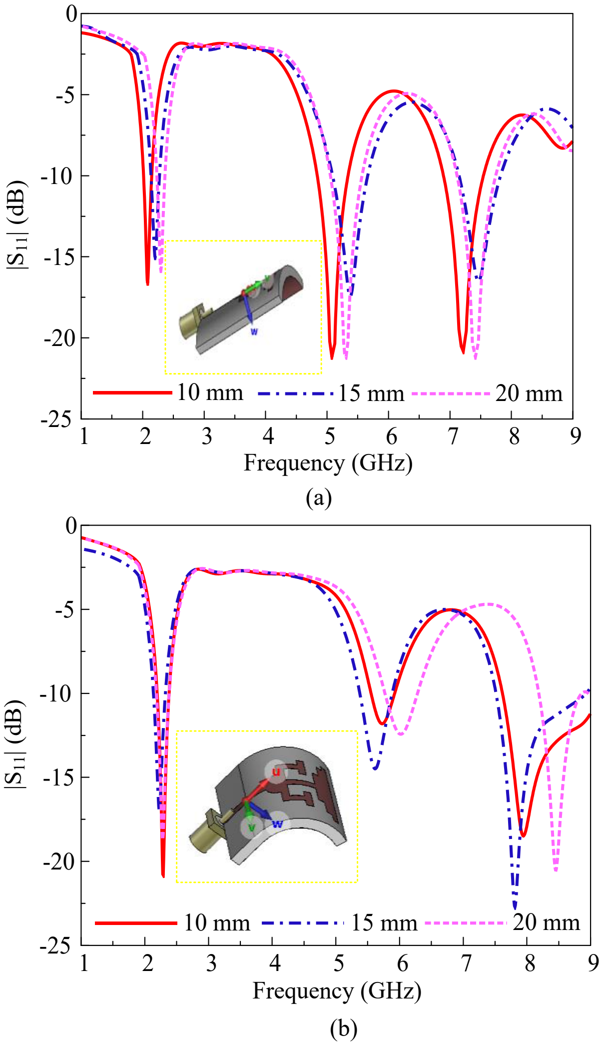

Figure 3. Conformal analysis of the proposed antenna (a) bending over X-axis (b) bending over Y-axis.

GHz, 5.10 GHz, and 6.95 GHz. The figure shows that on 1g of tissue, the antenna provides an exceptionally low SAR values of 0.135 W/Kg, 1.38 W/Kg, and 0.631 W/Kg at 2.35 GHz, 5.10 GHz, and 6.95 GHz, respectively.
Additionally, SAR analyses are performed with the antenna on 10 g of tissue, yielding values of 0.0575 W/Kg at 2.35 GHz, 0.665 W/Kg at 5.10 GHz, and 0.279 W/Kg at 6.95 GHz. The SAR value that is being supplied is extremely low and falls within an acceptable range. According to these findings, the suggested tri-band antenna is a suitable candidate for cutting-edge flexible electronics using the 5G and next 6G band spectrums. The SAR value summary provided by the suggested antenna is displayed in Table 2.

Table 2. Summary of SAR Values of Proposed Antenna

Frequency (GHz)	**SAR (W/Kg)**		**Max. allowed Power (mW)**
	1g	**10 g**	
2.35	0.136	0.0575	250
5.10	1.38	0.665	250
6.95	0.631	0.279	250

4. Conclusion

In this work, a tri-band antenna having a compact size and simplified geometry is proposed. The antenna is constructed on flexible substrate material, and good performance in terms of tri-band with good impedance matching is obtained after loading multiple stubs in consecutive design stages. To make the proposed design suitable for wearable and on-body applications, conformal and SAR analysis are performed. The antenna offered stable results in terms of bending along the x-axis and y-axis over 10 mm, 15 mm, and 20 mm cylinders. The

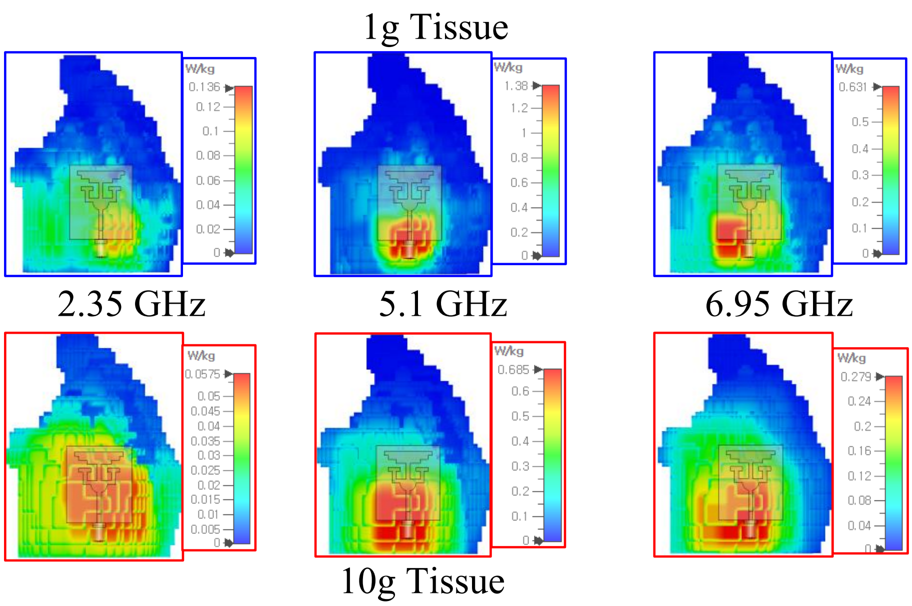

Figure 4. SAR analysis of proposed antenna on 1g and 10g tissue at (a) 2.35 GHz (b) 5.10 GHz (c) 6.95 GHz.

proposed antenna offers low SAR values at all three resonant frequencies, meeting the standards of WHO and FCC. Moreover, the results of the antenna are also compared with recently published works, showing that the proposed antenna offers a relatively compact size along with a tri-band mode and wide operational bandwidths. The results and comparison with the literature show that the proposed antenna is a suitable applicant for present and future wearables and conformal electronic devices operating over 5G and 6G frequency band spectrums.

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