Study and Analysis of a Circular Patch Antenna for Biomedical Applications

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Abstract. This paper introduces the design of a 2.45 GHz patch antenna specifically intended for biomedical applications. This compact microstrip-fed antenna comprises a planar radiating patch with a circular configuration, fabricated on a substrate made of polymer resin composite material, measuring 1.6 mm in thickness. To assess how human tissue affects the antenna system, a three-layer human model representing skin, fat, and muscle was meticulously created using CST Microwave Studio. In addition, this research aims to emphasize the suitability of the chosen polymer resin material substrate for examining the antenna's performance. The antenna's performance was assessed in two different scenarios: one in free space and the other using the human body model. In a free-space environment, the antenna resonated at an operational frequency of 2.39 GHz, delivering a noteworthy bandwidth of 610 MHz, spanning from 2.15 GHz to 2.76 GHz. When placed on the human body model, the antenna resonated at 2.4 GHz, demonstrating an even broader bandwidth extending over 1060 MHz, ranging from 2.09 GHz to 3.15 GHz. Remarkably, the antenna achieved a gain exceeding 4.2 dBi and maintained an efficiency exceeding 97% across the entire frequency spectrum. Simulation outcomes further revealed a substantial reduction in the Specific Absorption Rate (SAR) by more than 98%, equivalent to a SAR value of merely 0.024 W/kg. This substantial reduction underscores the antenna's potential for secure and efficient use in biomedical applications.

Keywords: Wireless communication systems, Patch antennas, Reflection coefficient.

1 Introduction

In recent years, there have been notable advancements in the realm of wireless communication systems [1]. Contemporary communication systems have become significantly compact [2]. The dimensions of these wireless systems are contingent upon the

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space allocation for various wireless components, which, in turn, is contingent upon the sizes of discrete components housed within these wireless devices[3]. Concurrently, antennas play a pivotal role as crucial components in facilitating efficient wireless communication systems [4]. Consequently, there is an escalating demand for small, efficient, multiband/wideband, and lightweight microstrip patch antennas, owing to the possibility of minimizing the size of wireless equipment [3, 5]. Incorporating separate antennas for distinct application bands is often impractical due to space limitations and cost constraints associated with these systems [6–8]. As a result, the design considerations for multiband antennas or antennas with broad operating bandwidth have become an area of keen interest among researchers [8, 9]. Researchers have proposed numerous design approaches to achieve the objective of expanding bandwidth to support multiple communication systems concurrently using a single antenna[10]. The documented design techniques for enhancing bandwidth include methods such as L-probe feeding [11], I-slotted rectangular patch [12], asymmetric U-slot patch [13], E-H shaped patch [14], Zig-Zag slots [15], meandering slots [16], stacked patch configuration [17], and so on.

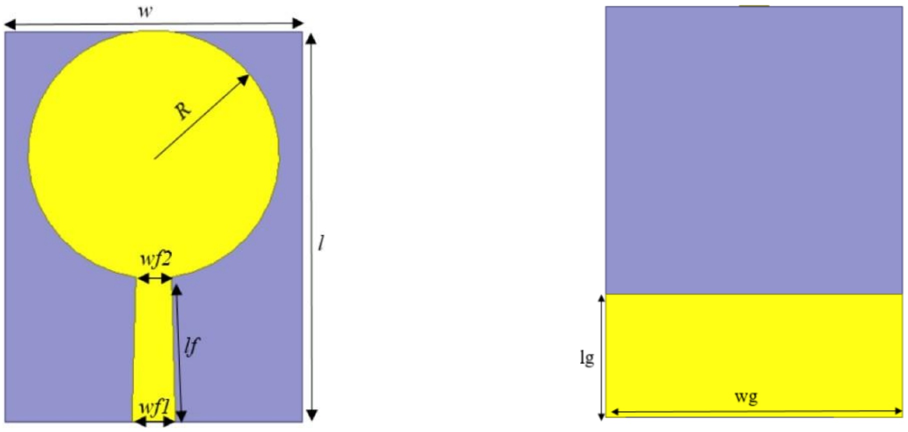
In this paper, we present a circular patch antenna fabricated on a cost-effective polymer resin composite material substrate. Specific Absorption Rate (SAR) serves as a crucial metric for assessing power absorption in human tissue and evaluating SAR is a vital aspect of antenna design, particularly for biomedical applications. Therefore, this research also aims to underscore the capability of the polymer material substrate in assessing the performance of the proposed antenna within the context of a wireless body network.

2 Antenna Design

The proposed planar microstrip patch antenna was designed and analyzed using the commercial CST Microwave Studio. The designed antenna was printed on a low-cost polymer resin substrate of dimensions ($w \times l \times h = 30 \times 40 \times 1.6 mm^3$), with a dielectric constant of 4.6, and $\tan\delta = 0.02$. This conventional structure is very easy to integrate and hasa very simple design. The system is fed by a microstrip line structure.

Table 1. Design parameters of the proposed antenna geometry

Parameter	**w**	**l**	**R**	**lf**
Value (mm)	30	40	12.7	15
Parameter	**wf1**	**wf2**	**lg**	**wg**
Value (mm)	3.6	4.4	12	30



(a) (b)

Fig. 1 Geometry of the proposed antenna (a): perspective and (b): top view

Fig. 1 shows the top and perspective view of the proposed antenna geometry. Table1 provides optimized dimensions for the investigated antenna.

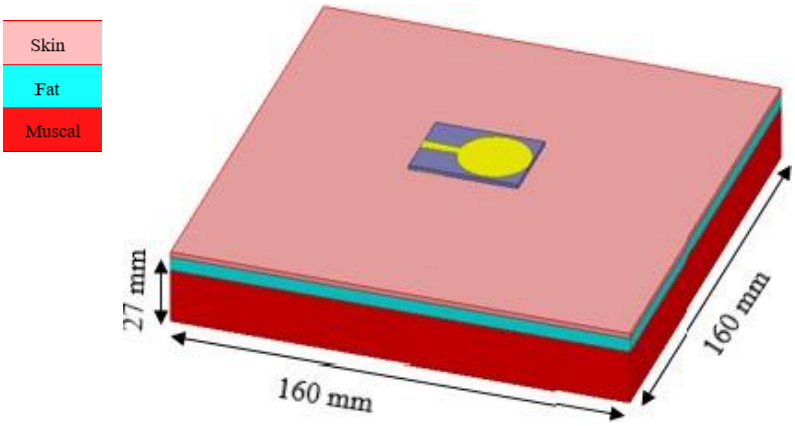


Fig. 2. Human body simulation model of comb-shaped patch antenna

Table 2. Human tissue dielectric properties at 2.4 GHz frequency [18]

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

The three-layered model illustrated in Fig. 2 is employed to investigate the performance of the presented antenna when it is placed in close vicinity to the human body as listedin Table 2.

3 Results and discussion

The performance of the developed antenna on top of a polymer resin composite material substrate is evaluated through simulations on both free space and the human body. The results show that the antenna achieves a state-of-the-art performance ratio while meetingthe key requirements of a biomedical application with a simple structure.

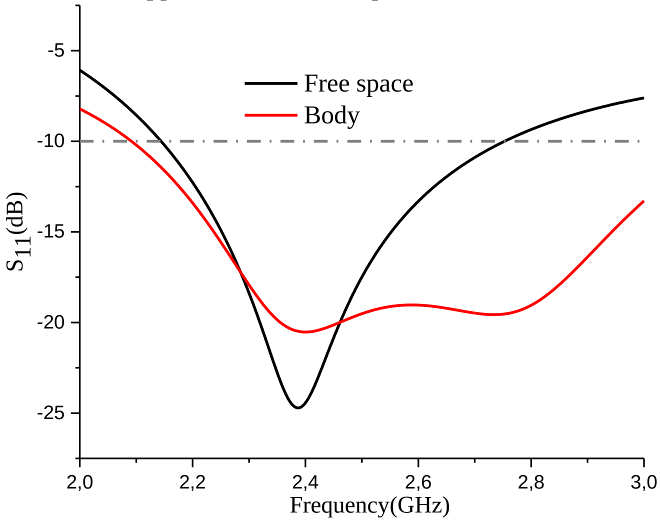


Fig. 3 Reflection coefficient (S11)

Fig. 3 shows the simulated reflection coefficient using CST. The simulation was performed and the results confirmed the suitability of the antenna designed on a low-cost polymer resin composite material substrate. The operating frequency of our antenna, for S11<–10dB, ranges from 2.15GHz to 2.76GHz, in free space. On the body, the antenna resonates at 2.4GHz and extends from 2.09GHz to 3.15GHz, which offers a bandwidth of 1060MHz and covers the requirements of ISM applications. The ISM band is privileged because of its accessibility for industrial and medical applications.

Fig. 4 illustrates the gain and efficiency plots in the entire frequency band of interest.The simulated gain is above 2.40 dBi and efficiency is above 97% for ISM applicationsbands.

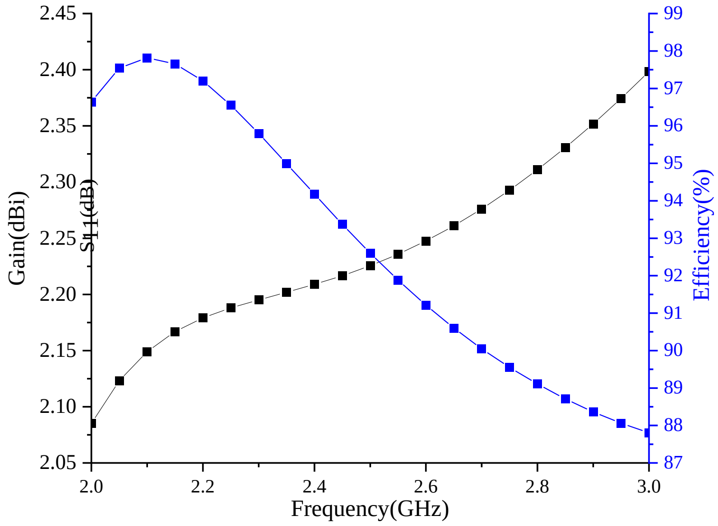


Fig. 4. Simulated gain and efficiency of the proposed antenna

The current density at the resonant frequency shows a greater amount of accumulated current on the radiating patch as shown in Fig. 5.

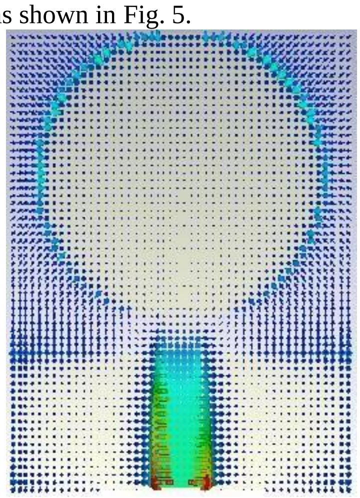


Fig. 5. Surface current distribution at 2.45 GHz

The SAR shows the rate of energy absorbed by the human tissue when the antennais analyzed in the human body. In wearable antennas, the human body absorbs a part of the radiation and gives off the remaining part of the radiation. The SAR value is needed to comply with international safety standards (FCC & ICNIPR), an average overa volume of tissue (either 1g or 10g) measured in W/Kg. Standard SAR values are 2 W/kg for 10 g and 1.6 W/kg for 1 g of body tissue [19, 20].

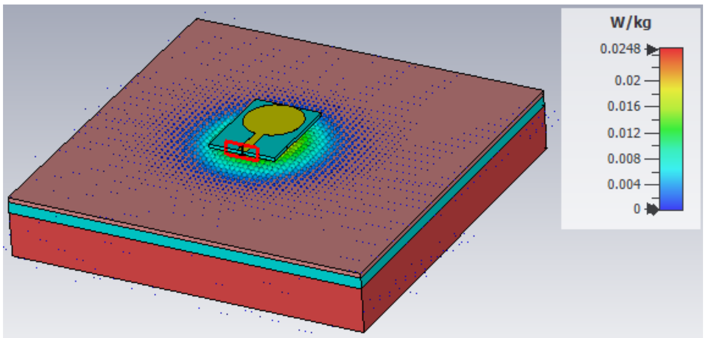
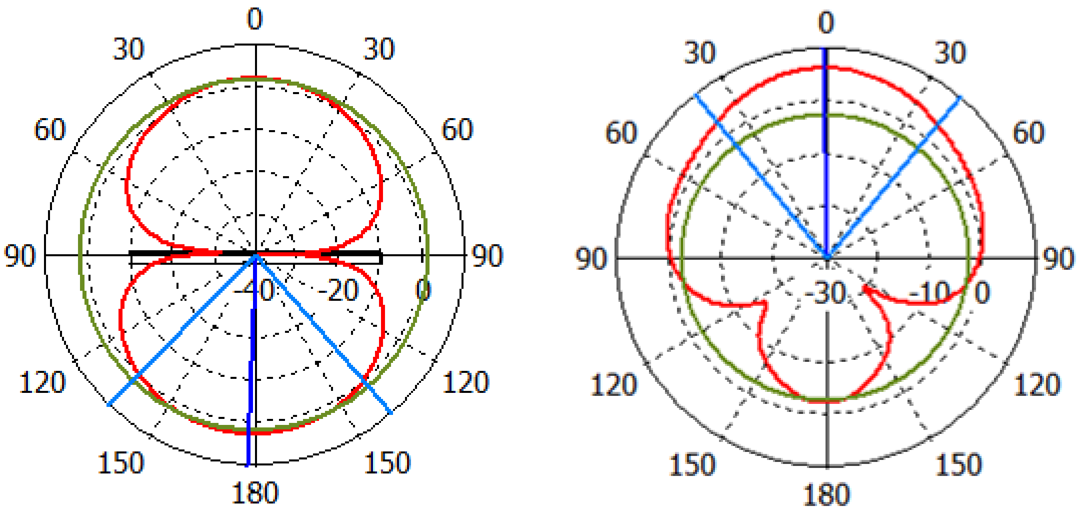


Fig. 6. Evaluation of the proposed antenna SAR at 3 mm from the human body tissue model at 2.4GHz

In Fig. 6, we can observe the Specific Absorption Rate (SAR) distribution at a frequency of 2.4 GHz for a three-layer human arm model. These SAR values have been meticulously examined using CST Microwave Studio. Notably, it's worth mentioning that the SAR values are exceptionally low, far below the absorption rate thresholds required to adhere to international safety standards such as FCC and ICNIPR, surpassing 98%. Based on this comprehensive analysis, it can be confidently stated that the proposed antenna, which is fabricated on a substrate made of polymer resin composite material, is extremely well-suited for biomedical applications when placed on the human body.

Moving on to Fig. 7, we can observe the radiation pattern of the proposed antenna operating at a resonance frequency of 2.4 GHz. This radiation pattern exhibits a remarkable omnidirectional characteristic, implying that the antenna radiates its signal uniformly in all directions.



(a) (b)

Fig. 7. Radiation pattern (a) E-plane (b) H-plane

Table 3. Comparison of the proposed antenna with previous works.

Ref	Patch size (mm)	Frequency (GHz)	SAR (W/kg)	Radiation efficiency	Max gain (dBi)
[21]	74.5×48×3.34	2.45	0.380	74.3	5.35
[22]	80×61×4.51	3.1	1.21	96.6	/
This work	30×40×1.6	2.4	0.024	97	2.42

The proposed antenna has been subjected to a thorough comparison with previous works documented in the literature. This comparative analysis encompasses various key parameters, including size, operating frequency, Specific Absorption Rate (SAR), Radiation Efficiency, and gain. The findings of this comparison have been succinctly summarized in Table 3. It is abundantly clear from this comparative study that the proposed antenna outperforms its predecessors in several aspects. Firstly, the proposed antenna boasts a notably smaller size compared to prior designs. Secondly, it operates at a frequency that aligns with the intended application. Moreover, it achieves a lower SAR, signifying a reduced rate of power absorption in human tissue. Additionally, the proposed antenna exhibits superior Radiation Efficiency and gain. Collectively, these results, in conjunction with the demonstrated favorable radiation pattern, underscore the significant potential of this innovative antenna structure for utilization in miniaturized implantable devices for biomedical applications.

4 Conclusion

This paper underscores the significance of utilizing a polymer resin material substrate for assessing the antenna's performance in the context of biomedical applications. The antenna's performance was assessed using a simulated human body model. The results of the evaluation indicate that the suggested antenna is a viable choice for biomedical applications due to its commendable bandwidth and exceptionally low Specific Absorption Rate (SAR) values, which comply with safety standards.

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