

Design of CPW-Fed Flexible Fractal Shape Circular Ring Patch Antenna for Biomedical Applications at ISM Band

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Abstract: “A CPW-Fed flexible flexible flexible fracture shape circular ring patch (FSCRCP) antenna is presented and optimized for biomedical applications in the ISM band”. While working on 2.46 GHz, the antenna exhibits excellent impedance “bandwidth and stable spherical polarization, making it suitable for implantable medical devices (IMD)” and wireless body area network (WBANS). In the free location, the antenna receives a .933.9 dB reflection coefficient with 390 MHz bandwidth, while on a human hand structure, it offers 36.97 dB with 800 MHz bandwidth. The proposed design displays favorable axial ratio performance, acceptable SAR level, and reliable advantage, proves its gratitude to biotelemetry applications.

Keywords: CPW-Fed Flexible Fractal, Antenna, Biomedical application, IMD, Internet of Medical Things.

1. Introduction

With the increasing demand of “Employed Medical Divisions (IMD) in Healthcare”, the development of compact, skilled and biocampical antennas has become important. These antennas act as a communication bridge between transplanted devices and external monitoring systems. Major requirements include compact size, low power consumption, polarization stability and patient safety (Kiureti and Nikita, 2012; Rad et al., 2016). Fractal structures are being used rapidly in antenna miniatures due to their self-respect geometry, which enable multi-band behavior and enhanced bandwidth (Punkuzali et al., 2016). In addition, the Coplanar Waveguide (CPW) -Fed structures provide better impedance matching and lower profiles than traditional microstrip -carried out designs (Naik et al., 2017). However, it is important to ensure circular polarization (CP) in biomedical antennas, as it reduces multipath disappearance and increases orientation-freedom communication (yang et al., 2017). This research introduces a “flexible fractured circular ring patch (FSCRCP)” antenna designed on a polyamide substrate, adapted to the ISM band operation on 2.46 GHz. Both simulation and measurement validate its suitability for biomedical telemetry applications.

2. Literature Review:

The development of implantable and wearable antennas for biomedical applications has greatly attracted considerable attention due to their important role in ensuring reliable wireless communication between medical devices and external monitoring systems in recent decades. Initial studies mainly focused on miniaturized strategies using high dignified constant substrates and slot-loaded geometries, which to reduce antenna dimensions while maintaining operational efficiency (kuratti and nikita, 2012). Flexible designs, such as loops and monopole patch antenna, were introduced to the patient's comfort and body-enemy surfaces to improve adaptability (Alarshadeh et al., 2015; 2015; Naik et al., 2017). The inclusion of fractal geometries, including coaches and ring -shaped configurations, was offered additional benefits of multiband resonance and better impedance bandwidth, which addresses the challenges of compactness and performance stability (Pungujali et al, 2016). For body area

networks, antennas with artificial magnetic conductors and asymmetric slot structures reduced the specific absorption rate (SAR) and increased separation from tissue loading (yin et al., 2019). Circular Polarization (CP) emerged as an important design feature to reduce multipath fading and orientation dependency, with several studies reported a 2.4 GHz ISM band (Yang et al., 2017; Joo et al, 2015). Researchers examined advanced configurations like Kundalakar ring, PIFA and spiral geometric for applications ranging from telemetry to pacemaker communication, obtained better radiation efficiency and comprehensive axial ratio bandwidth (slave and mitra, 2020; Ramadan et al, 2023). In addition, the recent developments in the Internet of Medical Things (IOMT) have insisted on integrating the sensor in Flexi. (Yao et al., 2016).

Research Gap:

Despite these progresses, boundaries remain in balance of compactness, efficiency and safety, especially under the harmful tissue environment. As a result, there has been a scope of innovative designs for combining flexible geometric, cpw-fed structures, and flexible biocompatible substrates, which are felt with better bandwidth, polarization purity and patient safety to the next generation biomedical antennas, which are felt with better bandwidth, polarization purity and patient safety.

3. Materials And Methodology:

3.1. Antenna Geometry

The FSCR antenna is designed on a polyimide substrate ($\epsilon_R = 3.5$, thickness = 0.07 mm), which has been selected for its flexibility and biocompatibility. The design consists of a circular ring structure with triangular fractal elements integrated into the geometry as shown in Figure 1. The antenna is CPW-fed with a 50Ω input, ensuring wide bandwidth and effective impedance matching. Table 1 summarizes the optimized dimensions of the antenna, where the outer diameter (d_1) is 16 mm, the fractal patch dimensions (h_1 , h_2) are 4 mm and 1.8 mm, respectively, and the overall substrate size is $26 \times 22 \text{ mm}^2$. The circular polarization is achieved by introducing triangular slots within the circular patch, which excite orthogonal modes with a phase shift of 90° . When tested on human tissue models (skin, fat, and muscle layers with dielectric constants 37.45, 5.22, and 52.06, respectively), the antenna maintained stable resonance and efficient radiation characteristics (Table 2).

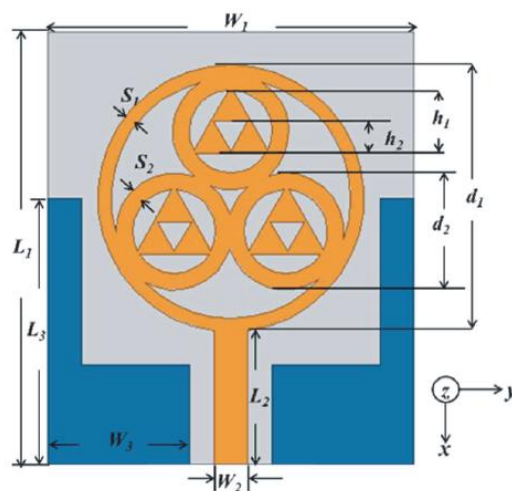


FIGURE 1. The FSCR antenna model.

TABLE 1. Geometric value of FSCR antenna model

Parameter	Value (mm)	Parameter	Value (mm)
L_1	26	d_1	16
W_1	22	d_2	7
L_2	8	h_1	4
W_2	2	h_2	1.8
L_3	16	S_1	0.8
W_3	8.5	H	0.07

“TABLE 2. Human tissues properties at 2.45 GHz frequency.”

Biological Tissue	Permittivity (ϵ_r)	Conductivity (S/m)	Height (mm)
Skin	37.45	1.74	2
Fat	5.22	0.13	4
Muscle	52.06	2.14	4

3.2. Evaluation Process of Proposed Antenna

The FSCR antenna was designed through a step-by-step iterative process as depicted in Figure 2. In the first stage (Ant-1), a basic circular ring antenna with a full ground plane achieved $S_{11} = -8.7$ dB at 2.48 GHz. In Ant-2, additional circular rings shifted resonance to 2.7 GHz but resulted in poor impedance matching. The introduction of CPW feed in Ant-3 improved the bandwidth (2.41–2.8 GHz) with $S_{11} = -15.78$ dB. By integrating triangular patches in Ant-4, the reflection coefficient improved to -20.7 dB at 2.48 GHz. Finally, Ant-5, which included triangular slots, achieved optimal resonance at 2.46 GHz with $S_{11} = -33.7$ dB and 380 MHz bandwidth. Figure 4 presents the S_{11} plot for the antenna designs, confirming the improvement in impedance characteristics through the iterative process.

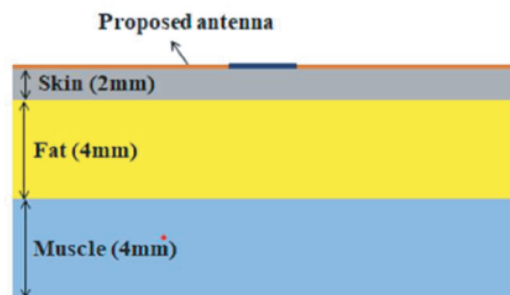


FIGURE 2. Layered model of the human tissue.

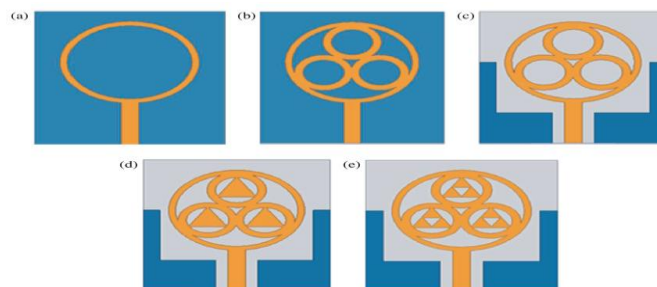


FIGURE 3. Evaluation process of the FSCR antenna model, (a) to (e).

4. Results And Discussion

Simulation and experimental measurements confirm that the antenna resonates at 2.46 GHz with different impedance bandwidths depending on the environment. As shown in Table 3, in free space, a bandwidth of 390 MHz (2.38–2.77 GHz) was achieved with $S_{11} = -33.9$ dB, while on tissue layers, the bandwidth expanded to 800 MHz (2.04–2.84 GHz). Figure 3 illustrates the reflection coefficient performance. The 3D gain plots in Figure 4 indicate a maximum gain of -0.265 dB in free space and -11.78 dB on human tissue. Despite reduced gain in tissue due to absorption, the antenna still provides adequate radiation for biomedical telemetry. Specific Absorption Rate (SAR) analysis, “shown in Figure 5, confirms compliance with IEEE C95.1-1999 standards, with the antenna exhibiting 1.57 W/kg, below the 1.6 W/kg safety threshold. Surface current distribution (Figure 6) validates circular polarization, with right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) observed at orthogonal phases. The axial ratio bandwidth is 170 MHz (2.4–2.57 GHz), with simulated and measured axial ratios of 0.5 dB and 0.88 dB, respectively, as shown in Figure 7.” Figure 8 illustrates that the antenna achieves up to 75% efficiency in free space. When compared with existing models (Table 4), the FSCRCP antenna demonstrates superior performance in compactness, bandwidth, and polarization, making it an effective solution for biomedical telemetry.

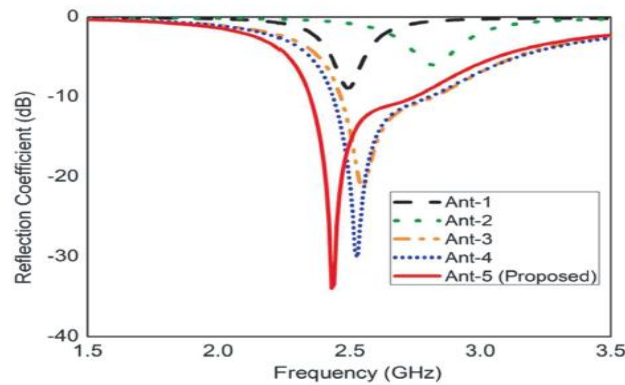


FIGURE 4. Reflection Coefficient plot for evaluation process

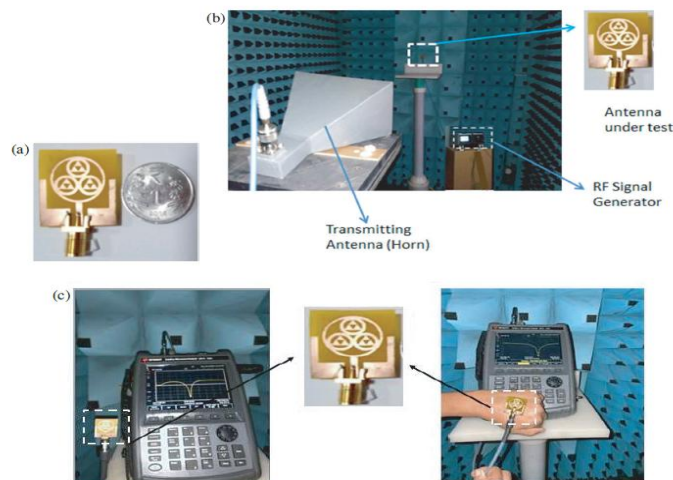


FIGURE 5. (a) Prototype of FSCRCP antenna and measurement set-up for (b) Radiation pattern, (c) reflection coefficient in free space and on-human hand.

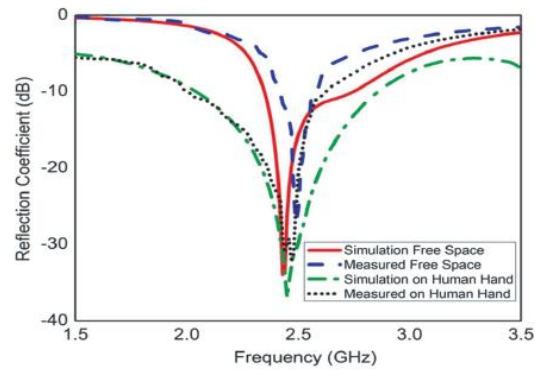


FIGURE 6. S_{11} of FSCR antenna.

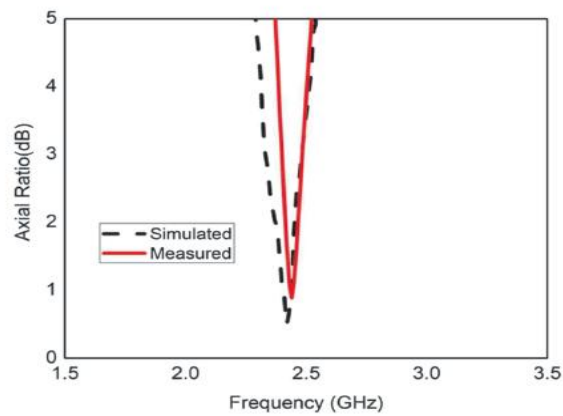


FIGURE 7. Axial ratio of FSCR antenna

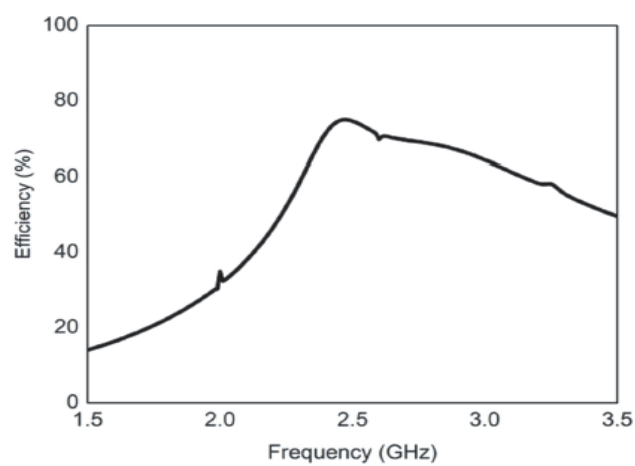


FIGURE 8. Efficiency plot of FSCR antenna.

TABLE 3. Simulated and measured results of FSCR antenna.

		Operating Frequency (GHz)	Reflection Coefficient (dB)	Bandwidth (MHz)
Simulated	Free Space	2.46	−33.9	390 (2.38 GHz to 2.77 GHz)
	On Layers	2.46	−36.97	800 (2.04 GHz to 2.84 GHz)
Measured	Free Space	2.42	−27.05	160 (2.35 GHz to 2.51 GHz)
	On Layers	2.46	−32.31	610 (2 GHz to 2.61 GHz)

TABLE 4. Comparison of FSCRP antenna model with the existing models.

Antenna Size (mm ³)	Substrate Material	Operating Freq. (GHz)	Impedance Bandwidth (GHz)	Application
20 × 18.8 × 0.762	Rogers R04350	2.43, 5.2	-	WLAN
26 × 26 × 4		2.45	2.40–2.48	On-body communication
24 × 22 × 0.07	Polyimide	2.41	2.01–2.82	ISM
32 × 40 × 0.07	Polyimide	2.45	2.27–2.76	WBAN
27 × 27 × 1.6	FR-4		4.25–12.5	WBAN application
70.4 × 76.14 × 3.11	Ro3003C (Semi-flex)	1.57, 2.435	(1.56–1.59) (2.434–2.451)	GPS/WLAN
26 × 22 × 0.07	Polyimide	2.46	(2.38–2.77)	ISM band

5. Applications And Future Scope

The FSCRP antenna can be applied in implantable medical devices, “wireless body area networks (WBANs), and Internet of Medical Things (IoMT) systems”. Its compact, flexible structure allows seamless integration into wearable and implantable platforms. Potential future developments include integration with biosensors and temperature sensors for real-time health monitoring (Yao et al., 2016), use of metamaterials for improved gain in lossy environments, dual-band optimization for “ISM (Industrial, Scientific and Medical) and MICS (Medical Implant Communication Services)” applications, and fabrication methods enabling biocompatible encapsulation. These improvements could significantly enhance the antenna’s utility in next-generation biomedical telemetry systems.

6. Conclusion

“A novel CPW-fed flexible fractal shape circular ring patch (FSCRP)” antenna has been designed and validated for ISM band biomedical applications. With excellent impedance bandwidth, circular polarization, acceptable SAR values, and compact geometry, the antenna demonstrates strong potential for IMDs and WBANs. Its superior performance compared to existing models in Table 4 confirms its applicability in modern biomedical telemetry systems.

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