Innovative Design of Flexible Microstrip Patch Antenna for Implantable Application

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Abstract—
This present paper introduces a different type of approach in order to design a Parallel slotted Tri-band microstrip patch (PSMP) antenna tailored for implantable applications. Implantable technology has revolutionized various aspects of daily life, ranging from health monitoring to communication. However, traditional rigid antennas pose challenges such as discomfort and aesthetic limitations. To overcome these issues, our proposed antenna leverages advanced techniques to improve flexibility, aesthetics, and performance. Operating within the frequency ranges 2.46GHz, 4.68GHz and 5.04GHz, with reflection coefficients of -34.08dB, 25.31dB and 33.85dB respectively, this antenna showcases significant enhancements in resonance and efficiency. Furthermore, the antenna is fabricated using polyimide flexible material, ensuring its suitability for implantable wireless communication applications. This study underscores the immense potential of such antennas in seamlessly integrating with everyday attire and accessories.

Index Terms: Rigid antennas, flexibility, aesthetics, implantable applications, substrates, radiation efficiency.

I. INTRODUCTION

Flexible antennas have seen significant expansion due to their light weight, ease of manufacturing, and compatibility with densely built electronic systems, [13]. Various monopole antenna configurations have been proposed in the literature for both single-band [14] and multi-band applications [15]. A patch antenna based on polyimide is suggested in [2], while multi-band antenna topologies based on polyimide are suggested in [16], [17]. CPW feed and a triangle slot with a slit are utilized in miniaturization to achieve the required frequency. All communication and radar applications employ microstrip patch antennas. because of its ease of production, affordability, and portability. On the other hand, parallel slotted microstrip (PSM) are appropriate for increasing the gain and bandwidth. Bandpass filters are used to increase the quality factor and compactness. In the PSM-equipped patch antenna designs for reducing the return loss.

Implantable medical technology has completely changed the healthcare industry by opening up new treatment and rehabilitation options. They have great potential to improve patient care by providing focused therapies and ongoing monitoring. And then implanted antenna technology was developed. Since implantable antennas works inside human body, hence it is to be designed and simulated in such a manner so that it takes into consideration of all complex environment inside human body [6]. The risk and danger connected with surgical operations have been lessened because to implantable antenna technology, which has made it appropriate for use in medical applications [7]. The implantable devices are positioned inside the body to track bio-signals, which include temperature and blood pressure readings, and transmit the data to an external device. Information processing and signal transmission to implantable devices, including wireless power transfer and wakeup signals, can be done with an external device. [8] Nonetheless, the necessity of rethinking antenna design has been highlighted by the pursuit of more compact and flexible implanted devices. As key elements of implantable technology, microstrip patch antennas have the potential to provide dependable wireless communication inside the human body.

A comprehensive review of existing implantable antenna designs reveals a spectrum of approaches, each grappling with the uniquechallenges posed by implantable applications. These challenges range from ensuring biocompatibility to navigating stringent size constraints. In response, our study embarks on an innovative journey to engineer a flexible microstrip patch antenna expressly tailored for implantable scenarios.

II. PARALLEL RECTANGULAR SLOTTED MIRCOSTRIP PATCH DESIGN

One of the most recent developments in antenna theory is the use of microstrip antennas. Its many benefits include low profile, lightweight, and compact design, as well as simplicity of production and integration into arrays [9]. The dimensions of an antenna have a close correlation with its performance parameters [10–12]. In Fig. 1, a suggested rectangular patch with cross and parallel slots is displayed. The material considered for the proposed antenna substrate is polyimide. The substrate measures 55 x 55 mm in length and breadth, and it is 0.35 mm tall. The substrate's upper layer is metalized with a rectangular patch measuring 30.8 x 33 mm in length and breadth. Etched are two rectangular slots: a cross rectangular slot with dimensions of 15 mm by 1 mm and a parallel rectangular slit with dimensions of 24 mm by 1 mm etched on the patch. The inset feed line of length (18.1mm) and width (3.06mm) is added to the radiating patch with an input impedance of 50Ω.

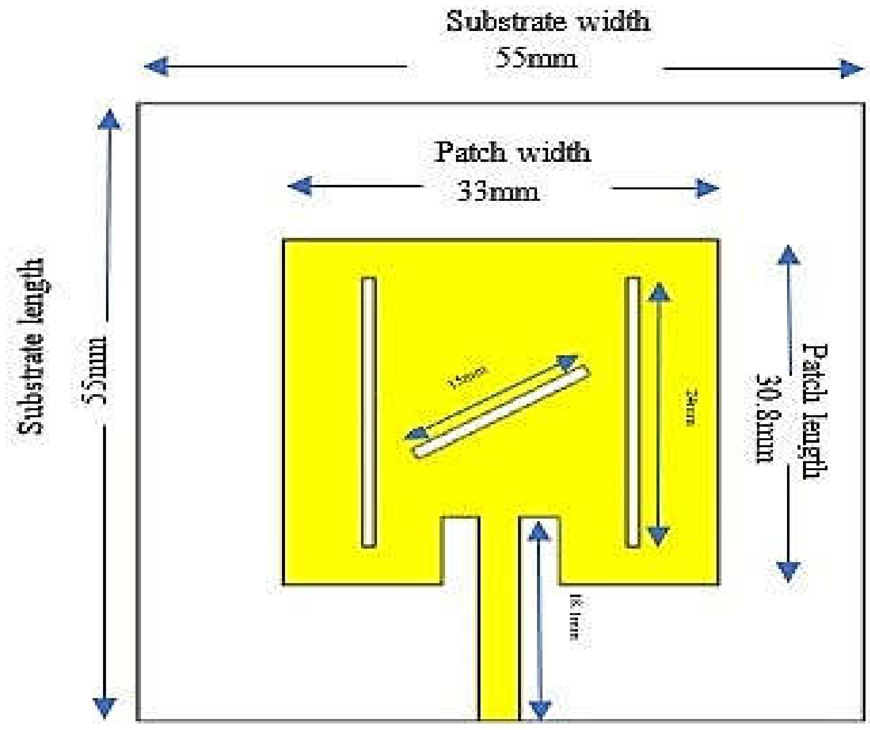


Fig. 1 Geometry design of PSM patch antenna

In terms of far-field radiation patterns, the has a relatively low susceptibility to bending effects, which qualifies it for integration within contemporary flexible electronic systems [18]. To increase the gain, a polyimide-based antenna array was suggested [19]. Sub-wavelength resonance of the patch antenna with good impedance match and radiation characteristics can be produced by modifying the geometry of the split rings [20].

TABLE-1. Optimised PSMP antenna size.

Parameters	Values (in mm)	Parameters	Values (in mm)
Substrate length	55	Parallel rectangular slots width	1
Substrate width	55	Cross rectangular slot length	15
Substrate height	0.35	Cross rectangular slot width	1
Patch length	30.8	Insert feed line length	18.1
Patch width	33	Insert feed line width	3.06
Parallel rectangular slots length	24		

In Fig. 1 The antenna design is meticulously crafted with careful consideration of key parameters. The substrate height is set at 0.35mm, providing a suitable platform for the antenna structure. A thin patch height of 0.035mm is chosen to achieve compactness while maintaining structural integrity. The slots are strategically positioned, optimizing the antenna's impedance matching and radiation characteristics.

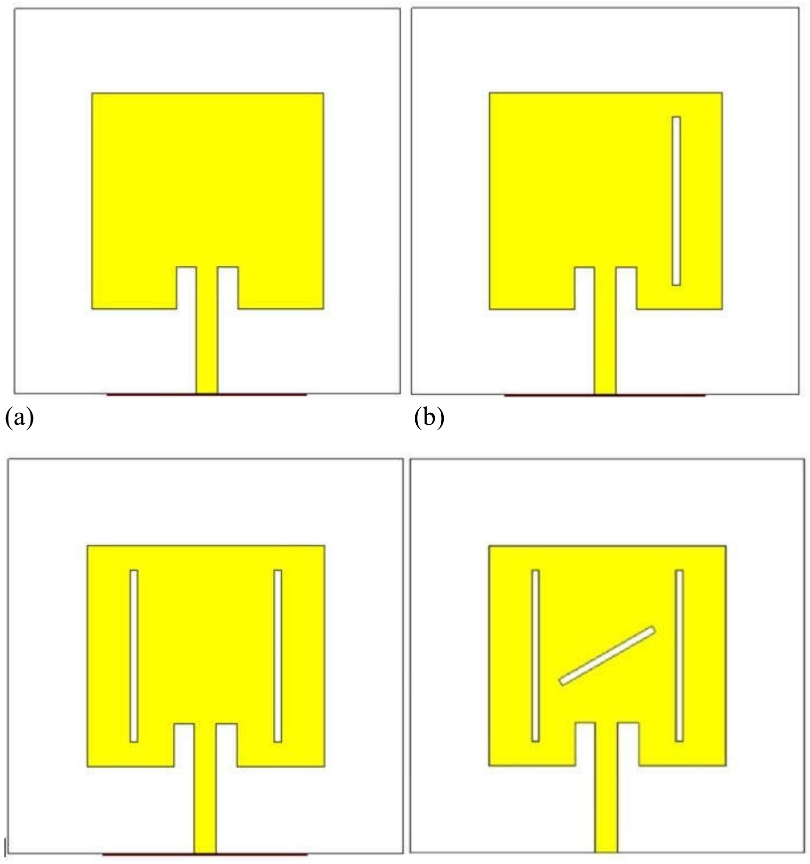


Fig. 2. Evolution process of PSMP antenna (a) Ant.1, (b) Ant. 2, (c)Ant. 3, (d) Ant. 4(proposed antenna).

III. RESULTS

TABLE-2: Comparison of each evolution of PSM antenna.

Configuration	*Resonance frequency and band (GHz)*	*Reflection coefficient (dB)*	*Impedance Bandwidth (MHz)*	*Gain (dB)*
Ant.1	2.57	-22.39	114	5.54
	4.47	-21.61	211	6.22
	5.83	-24.85	217	6.65
Ant.2	2.57	-21.12	109	5.55
	5.5	-13.29	96	6.39
Ant.3	2.56	-15.59	87	5.51
	4.73	-11.53	51	5.85
	5.3	-23.44	196	5.24
Ant.4 (Proposed)	2.45	-34.9	106	5.38
	4.67	-29.22	105	5.56
	5.03	-33.96	240	6.24

The CST microwave studio was used to simulate the suggested antenna model. Fig. 2 displays the antenna's simulated outcome with regard to return loss. Three resonant bands at frequencies of 2.46GHz, 4.68GHz, and 5.04GHz are shown in the simulated data. At two working frequencies, a return loss of -34.08dB, -25.31dB, and -33.85dB is noted.

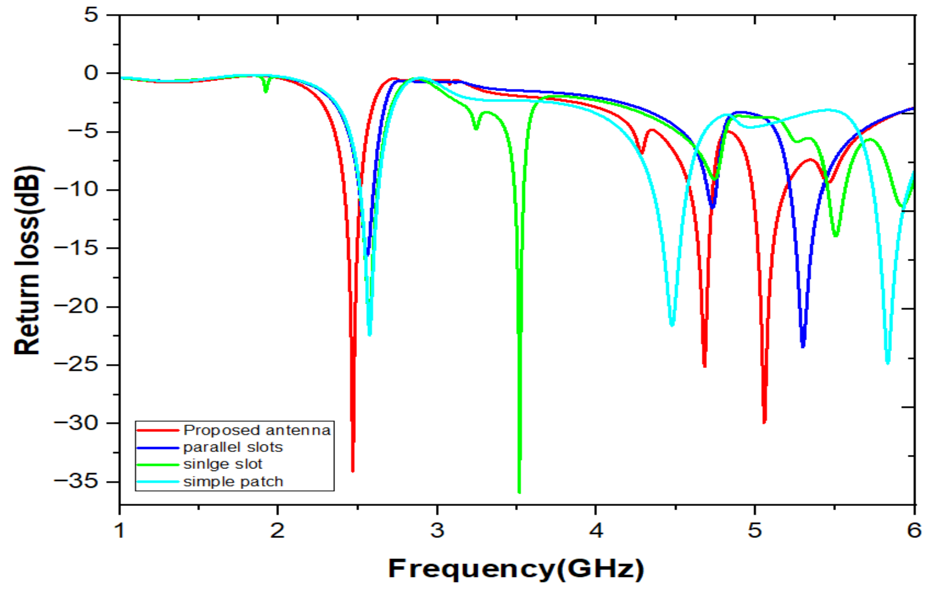


Fig.3 The Reflection coefficient response of slots on PSMP antenna.

The evolution process of PSMP antenna was shown in Fig.2, For that reflection coefficient responses when the slots are added one by one. The simple antenna is shown in Yellow, when a rectangular slot was added the one-slot antenna is shown in Blue, then parallelly another rectangular slot was added the parallel slot antenna is shown in Green and at last A cross slot was added to the antenna which is shown in Red.

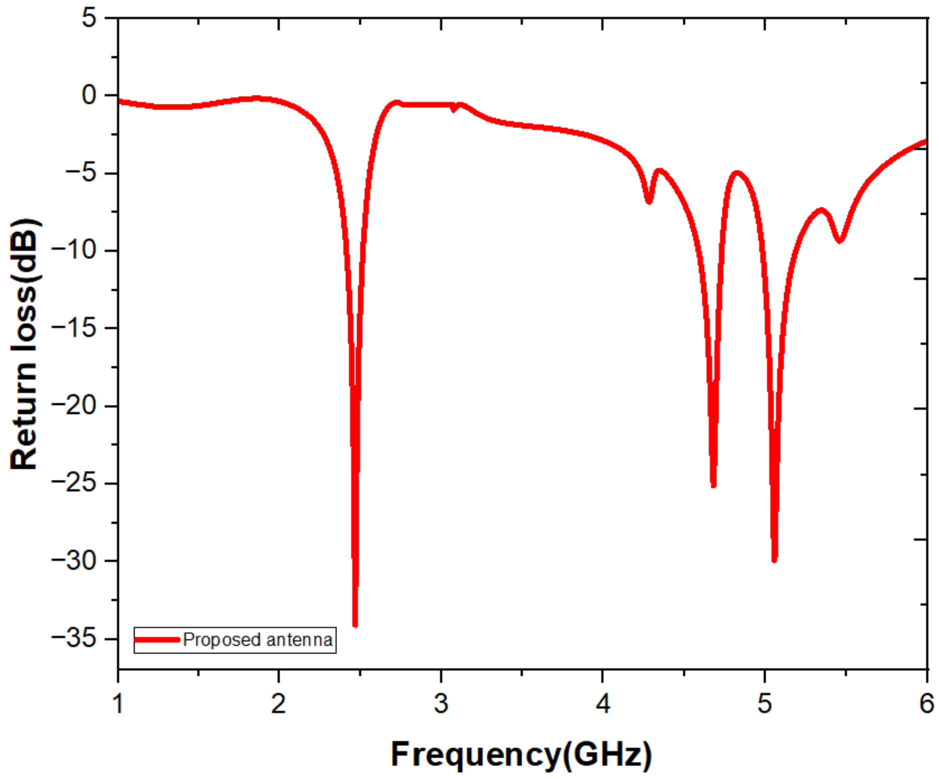
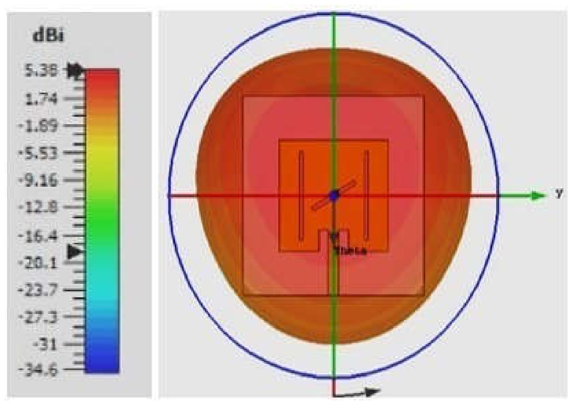
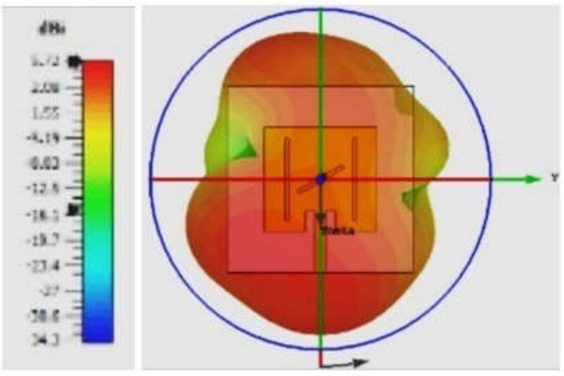


Fig.4 The PSMP antenna return loss (S_{11} (dB)).

Figure 4 displays the PSM patch antenna's gain plot. It is discovered that the resonant frequencies are 2.45GHz at 4.67dB, 5.03GHz at 5.38dB, and 5.56GHz at 6.24dB. For these three bands, the VSWR is 1.13, 1.48, and 1.28, correspondingly.



(a)



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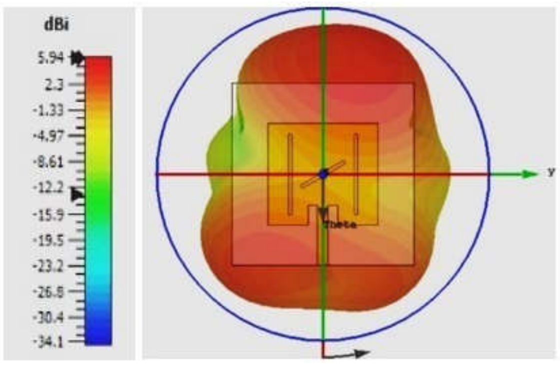


(c)

Fig. 5 The PSMP antenna gain at (a) 2.4GHz, (b) 5.04GHz and (c) 4.6GHz.

TABLE-3. Comparison of the proposed PSMP antenna's planar and bending configurations' reflection coefficients and gains.

Convex configuration	Operating Frequency (GHz)	Reflection coefficient (dB)	Gain (dBi)
Planar	2.45	-34.9	5.38
	4.67	-29.22	5.56
	5.03	-33.96	6.24
Bent at 10°	2.43	-40.86	5.24
	4.63	-26.22	5.22
	4.97	-17.98	5.47
Bent at 20°	2.44	-21.28	5.20
	4.60	-18.26	5.51
	4.93	-26.39	5.48
Bent at 30°	2.43	-17.34	5.07
	4.57	-14.99	5.33
	4.91	-31.83	5.81
Bent at 40°	2.43	-16.35	4.94
	4.55	-13.11	5.09
	4.89	-22.84	5.62
Bent at 50°	2..44	-12.98	4.82
	4.51	-11.56	4.71
	4.9	-15.67	5.85

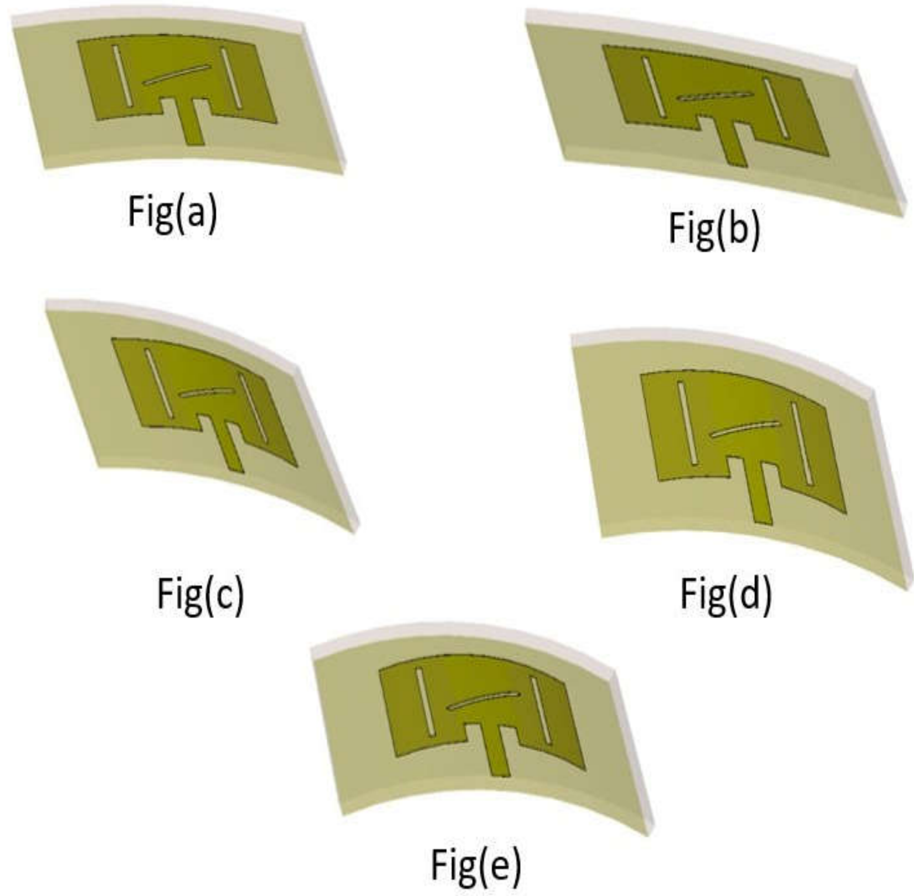


Fig 6. (a)Bending at 10°, (b)Bending at 20°, (c)Bending at 30°, (d) Bending at 40°, (e) Bending at 50°.

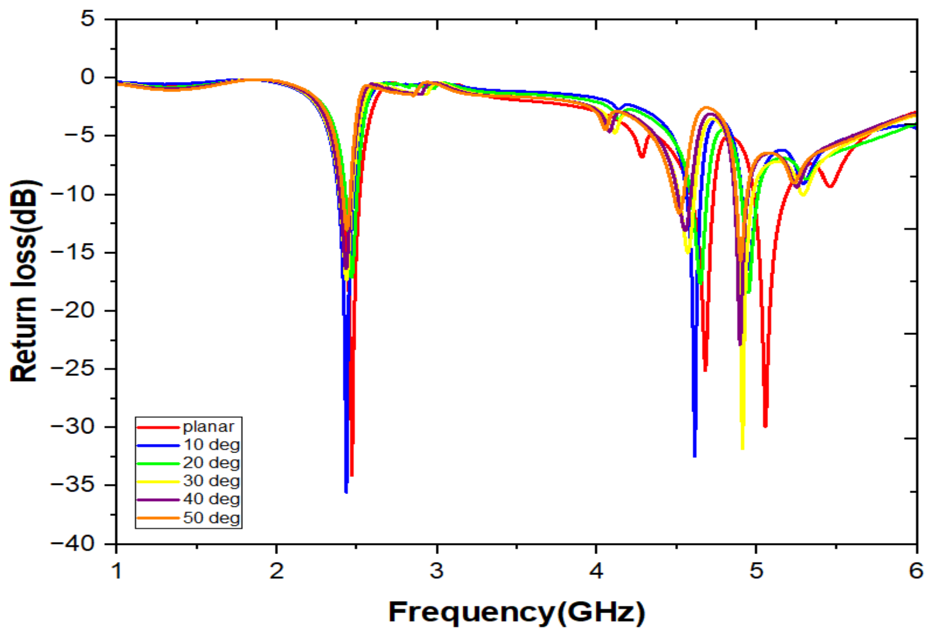
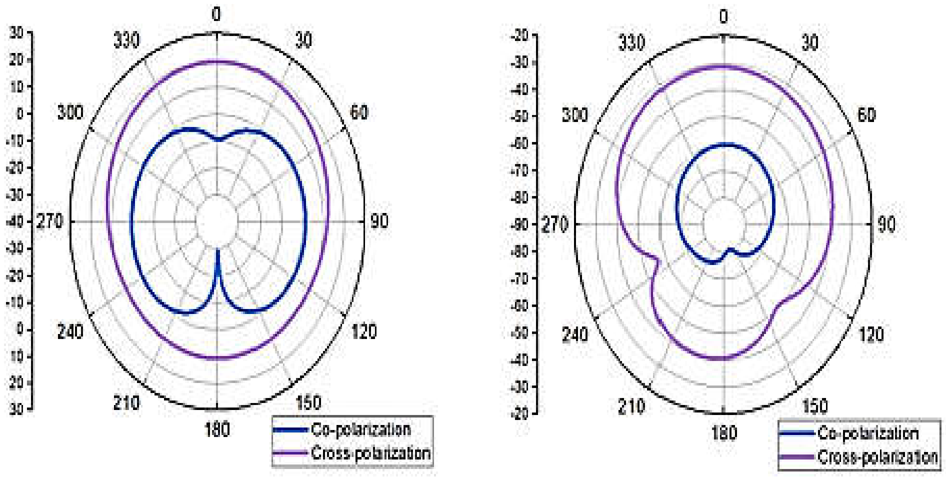


Fig. 7 PSMP antenna's reflection coefficient response in terms of its bending properties.

In figure 7, The simulated reflection coefficient comparison of the PSMP antenna at various cylindrical centre angles in convex bent configuration is displayed for each angle in the convex bent. When the posture of parallel slot microstrip patch antenna with insert feed bend at 10°(BLUE), The observed Reflection coefficient is -34.9dB, -29.22dB, -33.96dB at2.45GHz, 4.67GHz, 5.03GHz and the Gain obtained is 5.38dB, 5.56dB, 6.24dB. 20°(GREEN), The observed Reflection coefficient is -21.28dB, -18.26dB, -26.39dB at 2.44GHz,4.60GHz, 4.93GHz and the Gain obtained is 5.20dB, 5.51dB, 5.48dB. 30°(YELLOW), The observed Reflection coefficient is 17.34dB, -14.99dB, -31.83dB at 2.43GHz, 4.57GHz, 4.91GHz and the Gain obtained is 5.07dB, 5.33dB, 5.81dB. 40°(VIOLET), The observed Reflection coefficient is -16.35dB, -13.11dB, 22.84dB at 2.43GHz, 4.55GHz, 4.89GHz and the Gainobtained is 4.94dB, 5.09dB, 5.62dB. 50°(ORANGE), The observed Reflection coefficient is -12.98dB, -11.56dB, 15.67dB at 2.44GHz, 4.51GHz, 4.9GHz and the Gain obtained is 4.82dB, 4.71dB, 5.85dB.

Figure 8 displays the far field radiation maps for the patch's E and H-planes. The H-field radiation pattern is less than the E-field, according to the observation.

The Co-polarization (Co-polar) and cross-polarization (X-polar) of the E (YZ)- and H (XZ)-planes at 2.45 GHz, 4.68 GHz, and 5.03 GHz frequencies are displayed as normalised far-field radiation characteristics in Figures 8, 9, and 10.



(a)(b)

Fig. 8 Radiation plots of the PSM patch at frequency of 2.4GHz (a)E-Plane (b)H-Plane.

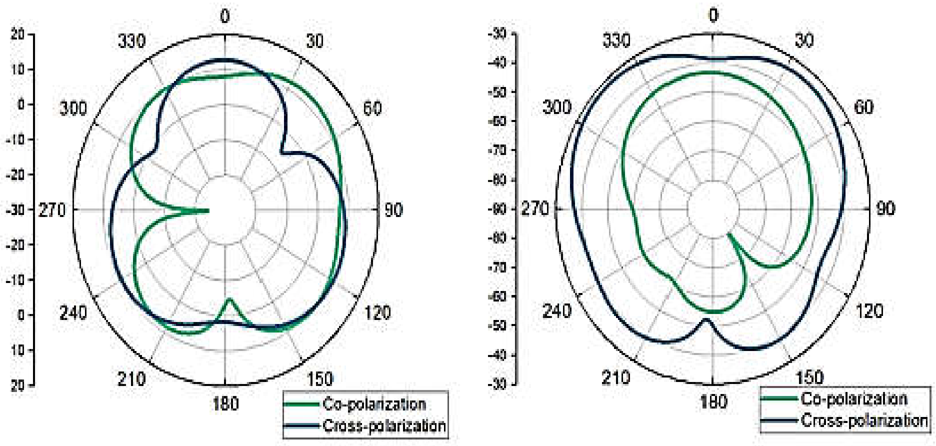


Fig. 9 Radiation plots of the PSM patch at frequency of 4.6GHz (a)E-Plane (b)H-Plane.

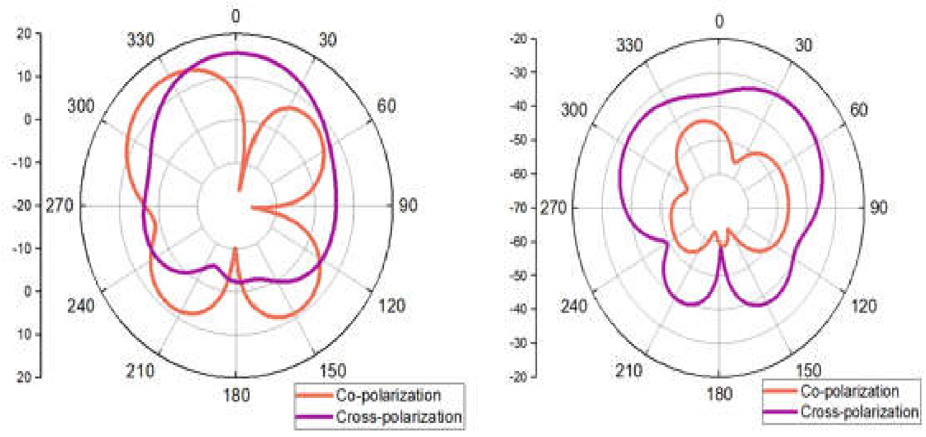
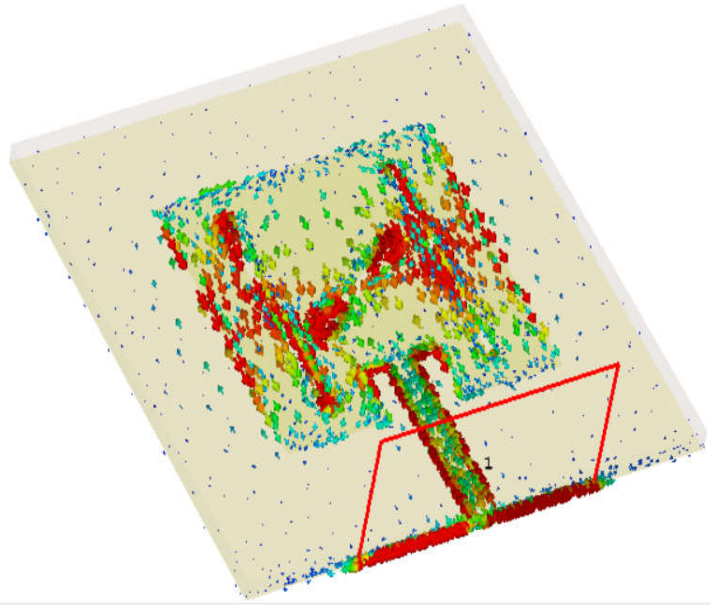
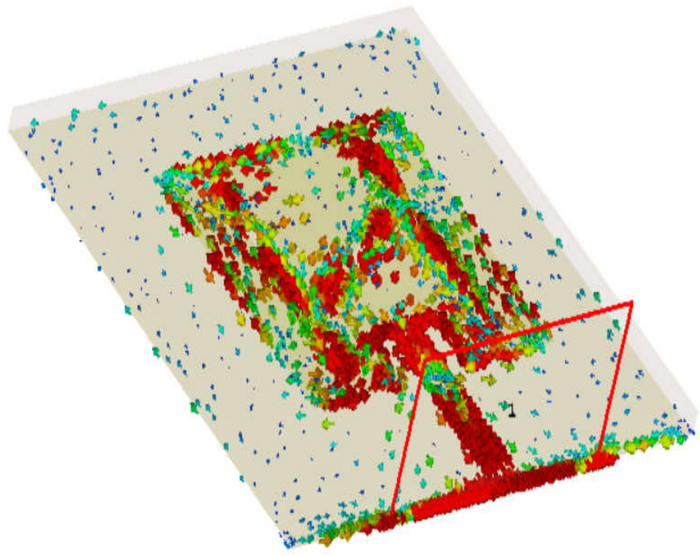


Fig. 10 Radiation plots of the PSM patch at frequency of 5GHz (a)E-Plane (b)H-Plane.



(a)



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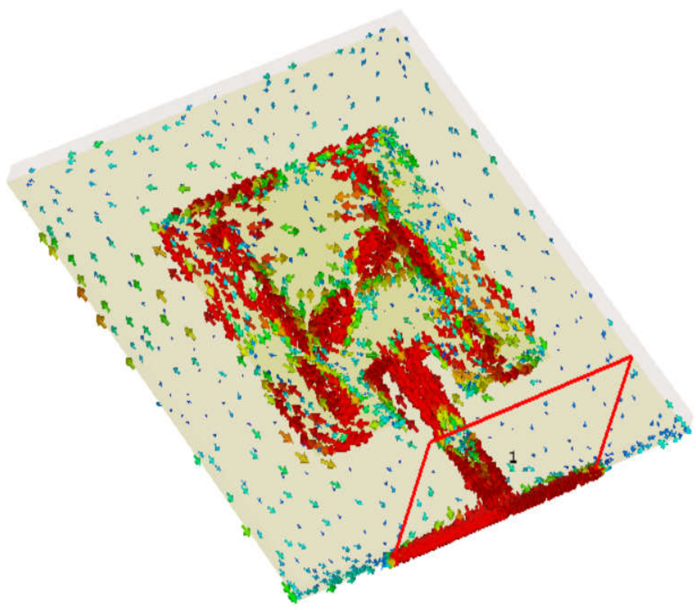

(c)

Fig. 11. Surface current distributions of PSMP antenna at (a) 2.45 GHzfrequency,(b) 4.67 GHz frequency, (c) 5.03 GHz frequency.

Figures 8, 9, and 10 show the current distributions of the PSMP antenna at each resonant frequency. The highest current concentration in Fig. 10(a) at 3, 4, and 5 slits with 223.5 Alm reaches the resonance of 2.45 GHz frequency. The current distribution is highest at 226.5 Alm for the third resonant frequency of the proposed antenna, and it is about the same as that of the first frequency (232.8 Alm) for the second resonant frequency.

TABLE-4: Comparison of existing antenna models to the proposed PSMP antenna.

Ref. No	Operating frequency (GHz)	Reflection coefficient (dB)	Operating band (GHz)	Substrate material (εr, δ)	Gain (dBi)	Band width (GHz)	Antenna size (dimensions, mm^3)	Volume (mm^3)
1	2.4	−27.1	2.33-2.76	Fr-4 (4.4, 0.02)	2.53	0.43	23 × 36.5 × 0.8	672
	3.5	−16.2	3.05-3.88		2.82	0.83		
	5.8	−15.8	5.57-5.88		2.72	0.31		
2	2.43	−14.5	2.38-2.62	Fr-4 (4.4, 0.02)	2.14	0.24	35 × 24 × 1.6	1344
	5.2	−24.2	3.4-6.41		3.59	3.01		
3	2.4	−34.3	2.07-2.77	Fr-4 (4.4, 0.02)	2.4-2.8	0.7	25 × 20 × 1.6	800
	3.5	−15.1	3.3-3.8		1.9-2.1	0.5		
	5.2	−19.8	5.15-5.35		2.9-3.5	0.6		
	5.8	−13.58	5.7-5.89		2.6-3.2	0.19		
4	1.05	−22.0	0.88-1.5	Polyimide (3.5,0.002)	−1.2	0.62	70 × 70 × 0.1	539
	2.1	−22.0	1.93-2.2		0.6	0.27		
	2.6	−40.0	2.31-2.96		2.1	0.65		
	3.3	−23.0	3.11-3.58		-	0.47		
5	3.5	−24.8	3.4-3.6	PTFE (2.2, 0.0009)	-	0.2	25 × 50 × 0.127	159
	13.8	−32.1	7.4-14.4			7		
PSMP antenna	2.45	-34.9	2.40-2.51	polyimide	5.38	0.106	55 × 55 × 0.35	1058.75
	4.67	-29.22	4.60-4.72		5.56	0.105		
	5.03	-33.96	4.97-5.14		6.24	0.24		

IV. CONCLUSION

This study presents the Tri-band square patch PSM antenna. The reported resonant frequencies are 2.45GHz, 4.67GHz, and 5.03GHz, with corresponding return losses of -34.9dB, 29.22dB, and -33.96dB. There is less than two VSWR. The suggested antenna is suitable for X-band use. The measured data and the simulation agree quite well. Flexible wireless applications can benefit from this antenna's conformability, compactness, and flexibility.

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