

# Design Of Self-diplexing Antenna Using Meandered Open-loop Resonators

S Imaculate Rosaline<sup>1\*</sup>, Namitha K S<sup>1</sup>, and Alphones Arokiaswami<sup>2</sup>

<sup>1</sup>Department of ECE, Ramaiah Institute of Technology, Bengaluru

<sup>2</sup>NTU, Singapore

\*Corresponding author. E-mail: [rosaline@msrit.edu](mailto:rosaline@msrit.edu)

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This work introduces a compact microstrip self-diplexing antenna tailored for dual-band application at 1.5 GHz and 2 GHz employing meandered open-loop resonators (MOLRs). The design incorporates two MOLRs linked through a centrally positioned T-junction acting as a power divider, enabling effective separation of frequency channels within a reduced footprint. The antenna is fabricated on a FR-4 substrate characterized by a dielectric constant of 4.4, a loss tangent of 0.02, and a thickness of 1.6mm. The complete layout occupies a 50 x 50 mm<sup>2</sup> area, making it well-suited for use in compact RF front-end modules where space is limited. Each resonator is dimensioned to achieve its respective resonance frequency while maintaining undesired coupling effects. According to the simulated S-parameters, the return loss remains better than -15 dB, and the isolation between the two channels exceeds -40 dB. The fabricated prototype showed strong agreement with the simulation data upon measurement. To ensure human safety, a Specific Absorption Rate (SAR) performance analysis was also performed using a human phantom model for the associated antenna. Owing to its compact nature and effective performance metrics, the proposed diplexer is a promising candidate for L-band wireless systems, including GPS, telemetry, and Internet of Things (IoT) applications.

**Keywords:** Self-diplexing Antenna; Meandered open loop Resonator; Isolation; Specific Absorption Rate; Defected ground plane.

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## 1. Introduction

As wireless communication technologies keep progressing, there is a crucial need for compact, affordable, and high-performing RF front-end solutions. One area gaining significant attention is the integration of diplexers directly into antenna systems. In this context, diplexers have become essential in RF and microwave circuit design, enabling the routing of multiple signals through shared components while maintaining sufficient isolation and preserving overall signal integrity [1]. In addition to simplifying the system architecture, diplexers also help to reduce the number of components, lower hardware costs, and improve integration [2-4]. Therefore, researchers are in-

vestigating novel resonator configurations that can provide better performance metrics inside lower form factors due to the necessity for compact, planar, and easily integral designs [4, 5]. Using T-shaped and ring resonators in conjunction with meandering line topologies, a recent study presented a space-efficient lowpass-dual bandpass diplexer that showed good isolation and low insertion loss [6]. In order to attain high isolation levels exceeding 75 dB without the need for intricate circuitry, recent developments have investigated co-linearly polarized full-duplex antenna designs that incorporate defective ground structures (DGS) [7]. For narrowband, closely spaced channel applications, a small self-diplexing antenna that uses

dual-mode excitation in a single SIW square cavity has proven to be an excellent port isolation method without the need for external filters [8]. A compact dual-band self-duplexing antenna has been proposed for head implants, enabling simultaneous transmission and reception without a diplexer, while maintaining low coupling and high isolation through miniaturized design techniques [9]. A low-loss microstrip diplexer design employing open-loop resonators and T-junction coupling has shown excellent selectivity and strong isolation, making it suitable for closely spaced frequency channels in wireless systems [10]. A high-isolation diplexer antenna design has been developed for co-site full-duplex systems, offering over 53 dB isolation by integrating open-loop and step-impedance resonators without the need for external matching circuits [11]. A highly compact self-duplexing antenna employing quarter-mode SIW cavities has been introduced, offering independent frequency tuning and over 40 dB isolation, making it a strong candidate for dual-band wireless systems [12]. A coaxially fed microstrip antenna with a defected ground structure (DGS) placed near the feed point has been shown to significantly suppress harmonic radiation without degrading fundamental performance, offering a compact and efficient solution for harmonic control [13]. A compact microstrip diplexer utilizing open-loop resonators has been developed to achieve low insertion loss, sharp selectivity, and high isolation, making it suitable for multi-band wireless systems such as ISM and WiMAX [14]. A miniaturized microstrip diplexer using modified meander line resonators has been proposed to support dual-channel operation with compact size, low insertion loss, and strong isolation, making it well-suited for wireless and computer communication systems [15]. External diplexers or discrete filtering stages are commonly used in conventional RF front ends, increasing the overall footprint, insertion loss, and design complexity. In order to improve miniaturization and frequency selectivity while attaining high port isolation, a number of researchers have looked into SIW topologies, cavity-backed and substrate-integrated waveguide structures, and resonant loading employing CSRR/DGS approaches [16][17]. Simultaneously, diplexing structures based on Square OLR been investigated as compact solution for channel separation and dual-band operation in planar technology [18].

The design and construction of a compact dual-band diplexer based on meandering open-loop resonator (MOLR) structures, manufactured on a common low-cost FR-4 substrate, is suggested in this study as a solution to the above-mentioned problems. Dual-band operation with effective isolation and low insertion loss is made possible by folding the resonator arms into a meandering geome-

try, which maintains the effective electrical length without expanding the circuit area. This arrangement provides a viable way to integrate RF modules with little space, meeting the increasing needs of contemporary wireless systems without sacrificing electrical performance.

The following are the proposed work's distinctive contributions.

- (i) We present a self-diplexing antenna based on a meandering open-loop resonator (MOLR) that eliminates the need for external filters by concurrently integrating radiation and the diplexing function in a single compact device.
- (ii) Meandered MOLRs, which have not been reported at L-band frequencies, offer notable size reduction while preserving excellent isolation ( $> 40$  dB) and good return loss ( $> 15$  dB).
- (iii) By combining MOLRs with a centrally situated T-junction power divider, the miniaturization problem in previous MOLR diplexers is overcome and inherent frequency separation is achieved within a  $50 \times 50$  mm<sup>2</sup> footprint.
- (iv) In addition to RF performance, the suggested design incorporates SAR analysis, which shows compatibility for human-centric wireless systems and is rarely reported for MOLRbased diplexing antennas.

## 2. Methods

### 2.1. Open-loop resonator

An open-loop resonator (OLR) is a well-established passive element commonly utilized in microwave and RF applications. It typically comprises a conductive path arranged in a loop, often square or circular, with a deliberate discontinuity introduced via a narrow gap. This interruption in the loop enables the structure to support standing wave formations and resonate at specific frequencies determined by both its geometry and the dielectric environment surrounding it. In this work, we focus on a square-shaped open-loop resonator fabricated on a dielectric substrate.

The core operational principle of the OLR arises from the interaction between its inductive loop and the capacitive effect introduced by the gap. Together, these characteristics form a resonant LC circuit. To reduce the physical footprint while preserving electrical length, a meandered design can be adopted. This layout allows the resonator to maintain compactness without compromising performance. The design emphasizes the fundamental mode of resonance. Although numerous variations in shape and loading strategies exist, the squared configuration is due to its simplicity and reliable behavior, particularly in dual-band filtering scenarios such as diplexers.

The effective resonator length,  $L_{eff}$ , for resonance at a given

frequency typically approximates half the guided wavelength, which is calculated as [7]:

$$L_{\text{eff}} = \frac{\lambda g}{2} = \frac{c}{2f_0\sqrt{\epsilon_{\text{eff}}}} \quad (1)$$

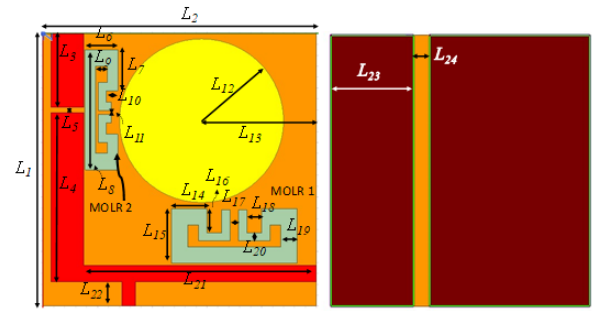
**Table 1.** Parameters of The Proposed Self-Diplexing Antenna

Parameter	Value(mm)	Parameter	Value(mm)
L1	50	L12	15
L2	50	L13	18
L3	13.5	L14	6.5
L4	31	L15	10
L5	1	L16	4.4
L6	6	L17	1.6
L7	7.5	L18	2.7
L8	22	L19	3
L9	2	L20	1.5
L10	2	L21	42.5
L11	0.8	L22	4.4

Where  $c$  is the speed of light in vacuum,  $f_0$  is the target resonant frequency, and  $\epsilon_{\text{eff}}$  represents the effective dielectric constant.

## 2.2. Assembly of the Proposed Self-diplexing Antenna.

The self-diplexing antenna designed in this study incorporates two meandered open-loop resonators, named as MOLR 1 and 2, both compactly arranged and linked to a common input port through a T-junction. Each resonator is carefully dimensioned to achieve resonance at distinct frequencies of 1.5 GHz and 2 GHz, enabling dual-band operation. The T-junction divides the input signal and routes it along two different paths, each tuned to a specific frequency band. Adjustments to the symmetry and position of the junction help minimize signal reflection and ensure uniform power distribution. To prevent unwanted coupling between the two resonators, adequate spacing is maintained. This is a special arrangement that ensures channel isolation, which is critical for maintaining performance integrity in multiband systems. Notably, these benefits are achieved without resorting to complex fabrication methods or multilayered designs. This diplexer is well-suited for compact RF front-end modules used in portable or integrated dual-band communication systems, offering a combination of size efficiency, frequency selectivity, and practical manufacturability. Fig. 1 shows the geometrical layout (top view and bottom view) of the proposed self-diplexing antenna design, and the dimensions of the parameters are listed in Table 1.



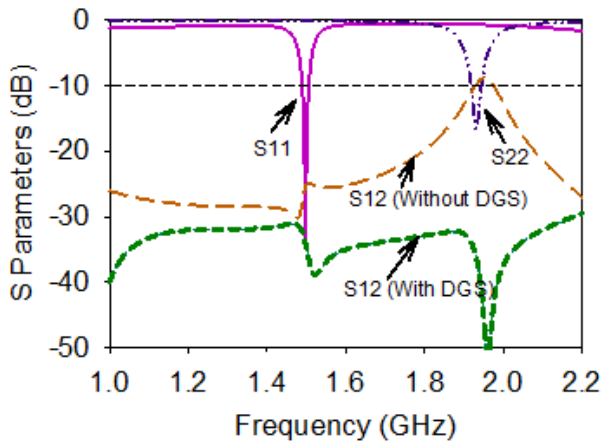
**Fig. 1.** Geometric layout of the proposed Antenna

## 2.3. Implementing the Defected Ground structure

To enhance the isolation and overall efficiency of the self-diplexing antenna, a defected ground structure (DGS), by etching a slot of width 'L24', was strategically incorporated beneath the coupling zone of the resonators. The introduction of this structure alters the current distribution in the ground plane, effectively minimizing mutual coupling between adjacent transmission paths. Functionally, the DGS imposes a band-stop effect at specific frequencies, which aids in better separation between the two operating bands. In this design, the DGS comprises a rectangular slot etched directly below the coupled microstrip lines. This modification increases the local inductance and capacitance in the ground plane, thereby suppressing the propagation of surface currents and mitigating unwanted electromagnetic interaction between the resonators. As shown in Fig. 2, the simulation outcomes demonstrate a significant improvement in port isolation (S12) due to the presence of the DGS. Initially, the system exhibited an isolation of approximately -8.75 dB at 2 GHz. After incorporating the DGS, the isolation dramatically increased to around -50 dB, an improvement of nearly 20 dB. This sharp enhancement validates the effectiveness of the DGS in reducing coupling and improving the frequency selectivity of the diplexer system. Thus, the use of the DGS proves to be a reliable and space-efficient technique for achieving superior inter-channel isolation in compact dual-band antenna designs, without adversely affecting their radiation characteristics or miniaturization goals.

The following is a representation of the design guidelines:

- Open-Loop Resonator Configuration:** To achieve the resonant LC behavior, an open-loop resonator (OLR) with a narrow capacitive gap and a square form is used. In order to attain physical miniaturization while preserving the effective electrical length necessary for the fundamental resonance mode, a meandering structure is used.

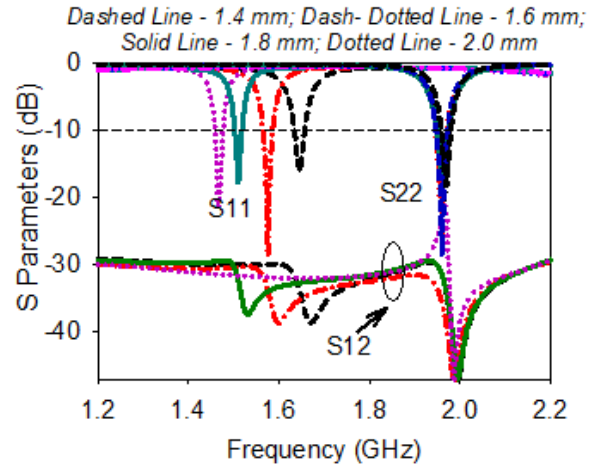


**Fig. 2.** S Parameters of the proposed antenna with DGS and without DGS

- ii. Frequency Bands: MOLR-1 and MOLR-2, two meandering OLRs, are sized to resonate at 1.5 GHz and 2.0 GHz, respectively. The gap capacitance and the loop perimeter, which control the resonance, are tuned using full-wave simulations to provide exact dual-band operation.
- iii. Feeding and Signal Division: A T-junction connects the two resonators to a single input port. To minimize impedance mismatch, lower return loss, and guarantee equal power distribution across the two frequency channels, the junction's geometry is meticulously tuned.
- iv. Mutual Coupling Mitigation: To reduce unwanted coupling effects, MOLR-1 and MOLR-2 are positioned symmetrically and with adequate distance. In order to improve inter-channel isolation, the arrangement is made to restrict current flow along separate routes.
- v. Defective Ground Structure (DGS) Integration: To reduce surface currents, a rectangular slot is etched into the ground plane underneath the coupling region. By offering an efficient bandstop characteristic, this DGS greatly enhances the isolation between the two resonators. Simulation results show that after the DGS is implemented, the isolation improves from about -8.75 dB to almost -50 dB at 2.0 GHz.
- vi. Manufacturing and Useful Considerations: To ensure cost-effectiveness and ease of fabrication, the total design is kept on a single-layer substrate. Compactness, dual-band operation, and excellent isolation are provided by the suggested structure without requiring intricate or multilayered production procedures.

#### 2.4. Parametric Analysis

A comprehensive parametric study was conducted to evaluate the performance sensitivity of the proposed self-



**Fig. 3.** Parametric analysis on the slot width of MOLR 1, 'L17'

diplexing antenna, focusing on three key design parameters: the circular stub radius (L12), the slot widths of the MOLRs 1, 2 (L17, L11), and the MOLRs 1. These factors have a significant effect on both impedance matching and resonant frequencies.

##### 2.4.1. Effect of slot width of MOLR1 on frequency response:

Slot width was changed in increments of 0.2 mm from 1.4 mm to 2.0 mm to examine the influence of slot width on the resonant behavior of the MOLR 1 structure. A distinct pattern emerged from the simulation results, as illustrated in Fig. 3: the lower resonant frequency moved into a lower frequency range as the slot width rose, whereas the upper resonant frequency remained unchanged. This phenomenon is explained by the wider slots' greater capacitive loading, which lowers the resonance frequency and effectively extends the current route. Among the tested values, a slot width of 1.6 mm demonstrated optimal performance. Therefore, 1.6 mm was chosen as the optimal slot width for the final design configuration.

##### 2.4.2. Effect of slot width of MOLR2 on frequency response:

Following the approach adopted in the earlier study, the slot width of MLOR 2, 'L11', was varied from 0.4 mm to 1.0 mm to analyze its impact on the resonant characteristics. The results consistently indicated that an increase in slot width led to a reduction in the lower resonant frequency, as shown in Fig. 4. This frequency shift can be attributed to the enhanced capacitive effect introduced by wider slots, which effectively modify the electromagnetic behavior of the structure. Among the evaluated values, a width of 0.8 mm was found to provide the most favorable resonant response, and was thus selected as the optimal value for

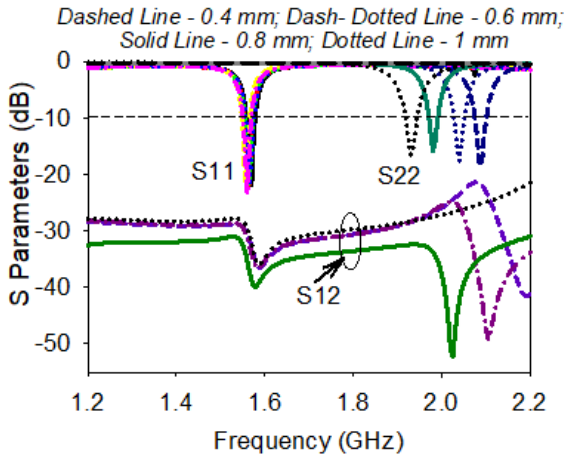


Fig. 4. Parametric analysis on the slot width of MOLR 2, L11.

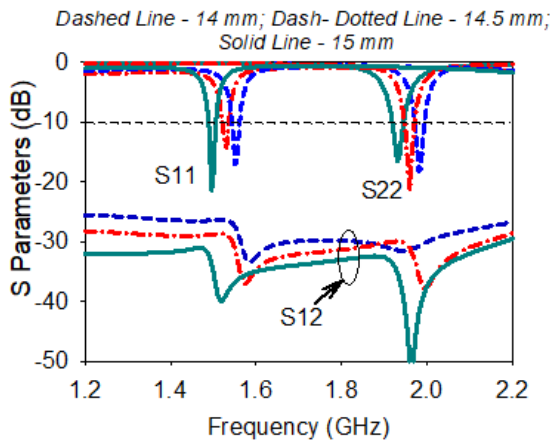


Fig. 5. Parametric analysis on the circular stub radius, L12.

further implementation.

2.4.3. Effect of circular stub radius on frequency response:

The influence of the circular stub radius on the frequency response was also examined by varying the radius from 14 mm to 15 mm in increments of 0.5 mm. As shown in Fig. 5, it was observed that as the radius increased, both resonant frequencies shifted toward the lower frequency range. This behavior is attributed to the increased electrical length introduced by the larger stub, which enhances the effective loading of the structure. Additionally, an improvement in isolation between the resonant modes was noted with increasing radius, indicating better suppression of mutual coupling.

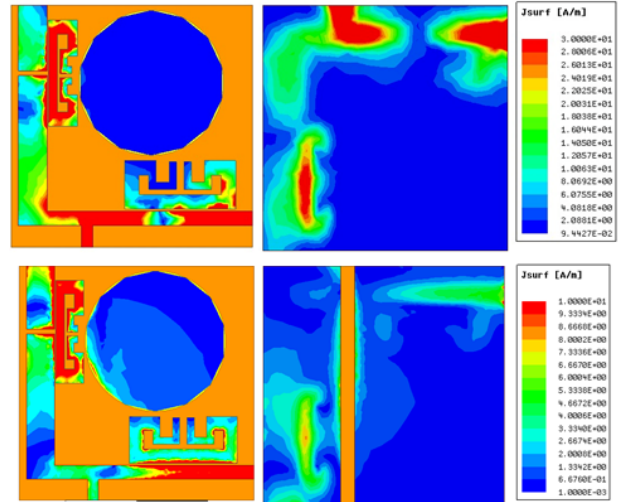


Fig. 6. Simulated surface current distributions on the proposed antenna at 2 GHz (a) without DGS (b) with DGS.

2.5. Surface Current distribution

The isolation mechanism of the proposed self-diplexing antenna with and without DGS are explained using the simulated surface current distribution at 2 GHz in Fig. 6. Without DGS, both the MOLRs have dense current distribution, which signifies poor isolation. Whereas, with DGS, the MOLR 1 shows very little current excitation, but the surface currents are heavily concentrated on the MOLR2. The undesired coupling paths between the two resonators are disrupted by the DGS, which effectively reduces surface current flow through the ground plane. The DGS considerably lowers mutual interaction, leading to an isolation level better than -40 dB, as confirmed by this strong current confinement.

3. Results and discussion

3.1. Fabrication and measurement

The proposed self-diplexing antenna was successfully fabricated on an FR-4 substrate with dimensions of  $50 \times 50 \text{ mm}^2$  as shown in Fig. 7. The resonating structure, which includes two meandered open-loop resonators and a T-junction feed network, was precisely patterned using conventional PCB fabrication techniques, ensuring good resolution and reproducibility of the intricate geometries involved. The fabricated prototype confirms the practical feasibility of the simulated design. Post-fabrication, measurements were performed using a Vector Network Analyzer (VNA). The 2D radiation patterns were obtained in a standard anechoic chamber environment using a calibrated measurement setup, confirming the validity of the simulation through experimental results with acceptable return loss, insertion

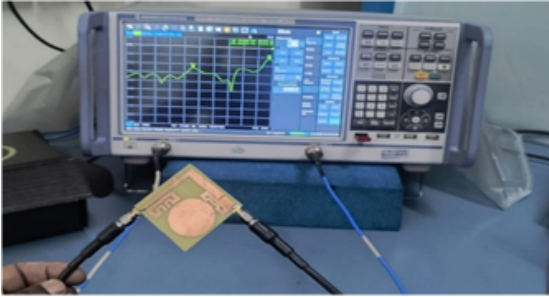


Fig. 7. VNA setup for prototype testing

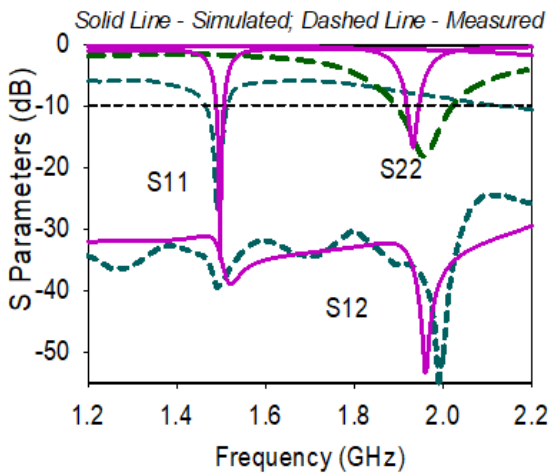


Fig. 8. Comparison of simulated and measured results

loss, isolation, and gain.

### 3.2. Return Loss and Isolation Performance Analysis

At the first resonant frequency, the measured return loss was  $-25.5$  dB at  $1.5$  GHz, which shows close agreement with the simulated results of  $-32.23$  dB at  $1.5$  GHz, as shown in Fig. 8. Similarly, at the second band, the measured  $S_{22}$  was  $-18.16$  dB at  $2$  GHz, aligning with the simulated  $-16.6$  dB at  $1.95$  GHz. These frequency shifts are attributed to fabrication tolerances, soldering irregularities, and the dielectric constant variation in the FR4 substrate. The measured isolation ( $S_{12}$ ) remained better than  $-40$  dB in both bands. The preservation of high isolation levels in the fabricated prototype confirms the effectiveness of the DGS structure in suppressing mutual coupling.

### 3.3. Gain Comparison

As shown in Fig. 9, the radiation pattern shape was largely preserved, maintaining the designed omnidirectional char-

acteristics. The radiation patterns are now described for three principal cuts: the XZ plane ( $\varphi = 0^\circ$ ), the YZ plane ( $\varphi = 90^\circ$ ), and the azimuthal XY plane ( $\theta = 90^\circ$ ). The electric field distribution over all the planes observed to be more uniform at both the operating frequencies, indicating Omni directionality. The similarity of radiation behavior at the two resonant frequencies confirms that the same dominant mode is effectively excited across the bands, making the design appropriate for practical modern wireless terminals.

Fig. 10 shows the measured gain and radiation efficiency of the proposed self-diplexing antenna. At both operating bands, the antenna shows consistent radiation performance. The antenna achieves a measured peak gain of around  $2$  dBi with an efficiency of  $82\%$  at  $1.5$  GHz, while the corresponding gain rises to about  $2.5$  dBi with an efficiency of  $81\%$  at  $2$  GHz. These results demonstrate that, in spite of its small size and dual-band functioning, the suggested structure retains good efficiency. Additionally, the antenna's viability for realistic L-band wireless applications is confirmed by the consistent gain values across both channels, which show strong power radiating capacity and negligible loss inside the feeding and resonating structures.

The table makes it obvious that, in comparison to previously published structures, the proposed self-diplexing antenna offers an easier layout and a much smaller footprint while maintaining competitive isolation performance. This shows that the suggested architecture effectively achieves a balance between port isolation and reduction in size and design simplicity, making it ideal for real-world dual-band wireless applications.

### 3.4. Specific Absorption Rate (SAR)

Fig. 11 illustrates the Specific Absorption Rate distribution averaged over  $10$ -g of tissue ( $SAR_{10g}$ ) for the proposed self-diplexing antenna operating at  $1.5$  GHz and  $2$  GHz. The antenna is placed at a distance of  $15$  mm from the human phantom model. The input power of  $1$  W is commonly adopted as a standard reference in practice. The simulation was performed using CST Microwave Studio to assess the safety and electromagnetic exposure levels associated with the proposed antenna design. The maximum SAR is observed to be  $0.521$  W/Kg at both the frequencies, which is very much below the acceptable  $1.6$  W/kg as given by the ICNIRP guidelines.

## 4. Conclusions

This work presents the design, simulation, fabrication, and validation of a compact self-diplexing antenna using meandered open-loop resonators (MOLRs) for dual-band op-

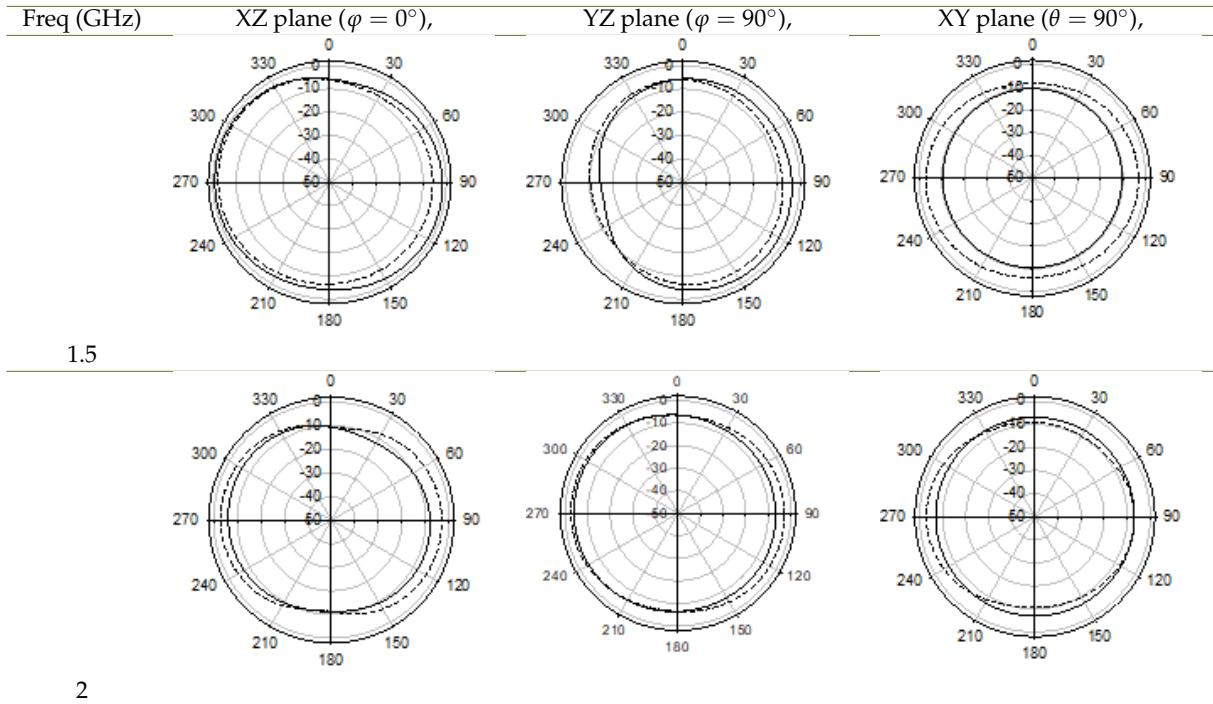


Fig. 9. Simulated and measured radiation patterns at 1.5 and 2 GHz in the XY, YZ, and XZ planes. Solid line - simulated; dashed line - measured.

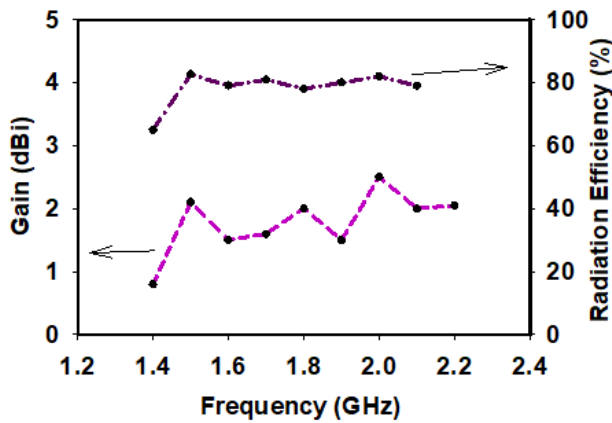


Fig. 10. Measured gain and radiation efficiency of the proposed self-diplexing antenna

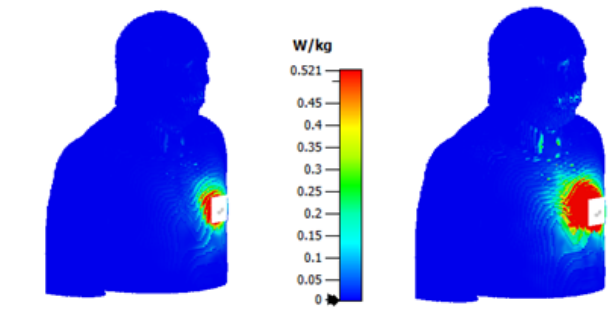


Fig. 11. SAR<sub>10g</sub> distribution of antenna near human phantom model at 1.5 GHz and 2 GHz.

eration at 1.5 GHz and 2 GHz . The integration of two independently tuned MOLRs through a centrally placed T-junction achieved efficient frequency separation while maintaining a compact footprint of  $50 \times 50 \text{ mm}^2$ . The use of a meandered geometry allowed for a reduction in physical size without compromising the electrical length required for resonance, supporting miniaturization critical to modern RF front-end modules. The incorporation of a Defected Ground Structure (DGS) in the ground plane further enhanced the diplexer’s performance by significantly improving inter-channel isolation and suppressing mutual coupling. Strong agreement was found between

**Table 2.** Comparison of the proposed antenna and similar others in the literature

Ref. No	Foot-print / Size (mm <sup>2</sup> )	Operating Bands (GHz)	Sub-strate Material	Tech-nology / Reso-nator Type	Isolation	Integration Type	Design Com-plexity
[12]	$0.08\lambda_g^2$	5.8/9.8	Rogers substrate (RO5880)	QMSIW*	> 40 dB	Self-diplex-ing antenna	High - Re-quires proper via placement and leakage control
[16]	$0.086\lambda_g^2$	2.45/3.5	RT Duroid 5880	CSRR etched QMSIW*	> 33 dB	Self-diplex-ing antenna	
[15]	$0.164\lambda_g^2$	1.8/2.45	FR 4 Substrate	Modified Meander line resonators	> 21 dB	Diplexer in-tegrated with an-tenna	Moderate - Requires ad-ditional inte-gration with antennas
[17]	$0.8\lambda_g^2$	2.51/ 2.81	Rogers TMM4	Square Open Loop Reso-nators + met-aterial (DGS, CSRR*)	> 30 dB	Diplexer in-tegrated with an-tenna	
[18]	$1.5\lambda_g^2$	1.8/2	Rogers TMM4 substrate	Squared open-loop resonator	> 49 dB	Diplexer in-tegrated with an-tenna	
Pro-posed Work	$0.275\lambda_g^2$	1.5/2	FR 4 Substrate	Meandered Open-Loop Resonators	> 40 dB	Self-diplex-ing antenna	Low- no via drilling, no additional metamaterials

\*QMSIW: Quarter Mode Substrate Integrated Waveguide; DGS: Defected Ground Structure; CSRR: Complementary Split Ring Resonator.

the measured and simulated S -parameters, with isolation < -40 dB and return loss better than -15 dB in both frequency ranges. The tunability and robustness of the design were confirmed by additional parametric simulations that showed how slot width, stub radius, and DGS location affected important performance metrics like return loss and isolation. Using a human phantom model, a Specific Absorption Rate (SAR) investigation was performed. Additionally, a measured gain of about 2.5 dB at 2 GHz is noted, and bidirectional radiation properties are maintained. All things considered, the suggested diplexer construction provides a workable option for small and reasonably priced dual-band communication systems.

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