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Original Article

A Disk-Shaped Complementary Split Ring Resonator Antenna for 5G Mid-Band Applications

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Abstract — *The designed antenna prototype communicated in this work is best suited for 5G communication in Sub-6 GHz.The proposed work's objective focuses on developing a compact antenna demonstrating high gain and directivity with improved return loss. In this paper, a slotted structure patch antenna fabricated on a circular substrate with Circular Complementary Split Ring Resonator (C^2SRR) ground is realized. The C^2SRR is used to study the Metamaterial (MTM) function in the ground for high performance. A disk-shaped structure with a circular slot at the patch center is utilized to optimize the 5G antenna operation at 3.5 GHz in the sub 6GHz band. The proposed antenna covers a dimension of 22.6 mm diameter and proves the compactness. Moreover, the loop and MTM structured in patch and ground, respectively, provide a stable directional radiation pattern. The fabricated prototype is tested to verify the agreement of simulated results with measured results.*

Keywords — *5G, Sub-6 GHz, C^2SRR, Metamaterial*

I. INTRODUCTION

An antenna plays a significant role in the area of wireless communication. The advancement of wireless technology demands the design of an integrated antenna supporting multiple functions. The size of the antenna is a major concern for usage in satellite and wireless communication. An antenna operating at low frequencies with high performance and compact size is challenging in antenna design. The Microstrip Patch Antenna (MPA) is preferred for most applications due to its small size and low cost [1]. The microstrip antenna can be designed using multiple patch shapes such as circle, square, triangle, and hexagon [2]. Various designs have been demonstrated for the performance improvement of microstrip patch antenna [3, 4]. The microstrip patch antenna with defected ground structure helps achieve an accurate target band operation [5]. DGS can be realized as a metamaterial structure by embedding Split Ring resonator and Omega Shaped Resonator [6, 7]. The usage of artificially structured MTM exhibits a negative or low refractive index and alters the functioning of conventional MPA [8,9]. The miniaturization of the antenna is achieved with high gain performance due to the introduction of metamaterial and loop structures in antenna design [10, 11]. The achievement of high performance and compact size antenna without design complexity is the note-worthy contribution of MTM [12, 13]. The design methodology of the proposed compact printed antenna is carried out in three phases.

i. Implementation of conventional microstrip circular patch antenna
ii. Employing a slot embedded structure in the radiating element
iii. Addition of Circular Complementary Split Ring Resonator (C^2SRR) in the ground to improve the SCPA characteristic with C^2SRR MTM ground

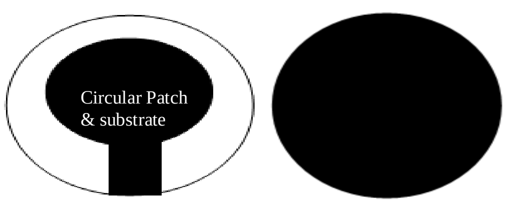
The iterative design process helps realize a modified version of MCPA with slots acting as a loop in the patch and metamaterial in the ground [14,15,18]. The effect of the modified structure is explored by analyzing the return loss, gain, and 5G performances. Section 2 illustrates the iterative antenna design procedure, and section 3 compares MCPA, SCPA, and SCPA with C^2SRR MTM ground. The comparison of measured and simulated results is also presented in section 3 to validate the design [16,17].

II. ITERATIVE ANTENNA DESIGN METHODOLOGY

The iterative design method is carried out to realize a compressed structure exhibiting Sub 6 GHz performance. The step-by-step design process commences from the conventional microstrip circular patch antenna design and continues progressively by adding a loop structure in the patch and a metamaterial structure in the ground. The front-line design methodology focuses on improving antenna performance without modification of the size of the antenna. The analysis carried out in every step of antenna design helps us value the impact of elements such as loop and metamaterial on antenna performance. The commercially accessible High-Frequency Structural Simulator (HFSS) software is used for design and simulation purposes.

III. EVOLUTION OF 5G ANTENNA GEOMETRY

A circular patch antenna is designed to resonate at 3.5 GHz based on theoretical formulas [8].FR4 is selected as substrate material due to its advantages, such as low cost and easy availability [9]. The geometry of the initial design comprises a substrate and ground of diameter 22.6 mm. A circular patch of radius 6.5 mm is employed as radiating element of the basic Microstrip Circular Patch Antenna. The designed MCPA shows resonance at 3.53 GHz with a return loss of – 14.80 dB. Nowadays, antenna operation at an accurate operating frequency band is the prime requirement in wireless communication. The challenging task of realizing 5Gantennas is achieved by employing a loop of dimension 14 x 12 mm in the patch of MCPA. The designed Slotted Circular Patch Antenna (SCPA) is a simple modification of the initial structure showing a remarkable performance by resonating at the sub-6 band at 3.5 GHz with a gain of 1.8 dB. The achievement of sub-6 GHz functionality is an essential requirement in modern communication. The modified SCPA with SCSRR MTM ground operates strictly at sub-6, 5G frequency with a total gain of 4.6 dB. Employing the C^2SRR structure in the ground helps to improve the gain and performance improvement of SCPA. The evolution of the proposed SCPA geometry with C^2SRR MTM ground is shown in Figure 1.



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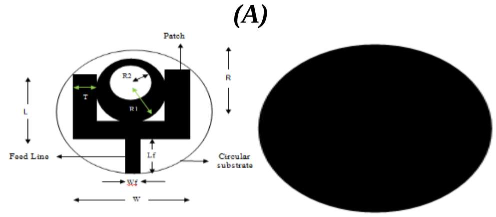

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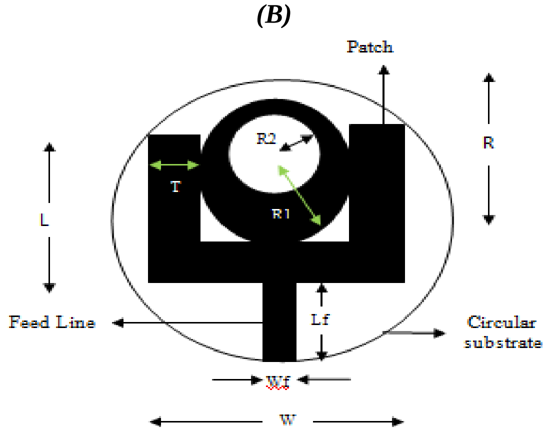
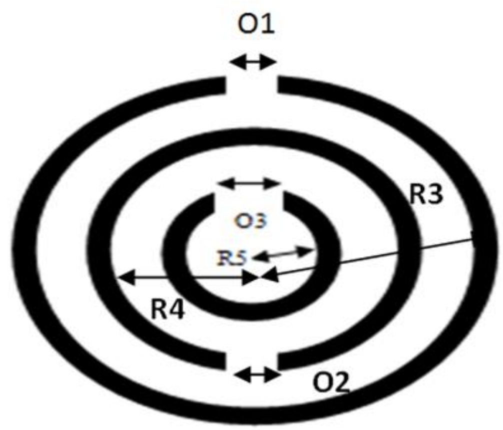




CCSRR Ground

(C)

Figure 1. Step by Step evolution of proposed geometry: Top and bottom view A) MCPA B) SCPA C) SCPA with C^2SRR MTM ground

As mentioned, the final antenna comprises three sections.

Table 1. Dimension of SCPA with C^2SRR MTM ground in mm

R1	R2	W	L	R	Lf	Wf
6.5	3	12	14	11.3	10	3
T	O2	O1	R4	R3	O3	R5
2	2	2	7.3	11.3	2	3.3

a. Circular FR4 substrate with a dielectric constant of 4.4 and loss tangent of 0.0012

b. A circular patch above the substrate with a loop structure forming the top portion of the antenna

c. A C^2SRR structure below the substrate forms the bottom ground portion of the antenna

The spacing between rings of C^2SRR ground structure and the circular ring's thickness is chosen as 2 mm. The C^2SRR dimensions are formulated from equation (1) based on expected resonant frequency [10].

$$\omega = c\sqrt{\frac{3(o)}{\pi\left(\frac{2WR^2}{s_1}\right)}} \qquad (1)$$

Where ωdenotes the angular frequency, o denotes the split gap, W represents the split width, $s_1$means the separation between rings, and R denotes the ring radius. The C^2SRR MTM structure has a dimension of 22.6 mm with two inner rings of dimension 14.6 and 6.6 mm, respectively. This arrangement of a looped patch and C^2SRR does not affect the size of the antenna but improves the antenna's performance.

IV. PRACTICAL TESTING OF FABRICATED SCPA WITH C²SRR MTM GROUND

The conceived SCPA with a C²SRR MTM ground antenna of 22.6 mm diameter is fabricated on FR4 substrate possessing relative permittivity εr = 4.4. The top side of the substrate has a circular patch with a loop structure as radiating element connected to the feed line. The other side of the substrate is engineered with C²SRR ground. The proposed geometry is fabricated and tested with an Anritsu vector network analyzer to validate the functioning of the proposed structure. The prototype is fed by SubMiniature version A connector, and return loss measurement at operating frequencies is observed.

The simulated return loss measurement of iteratively designed antenna geometries obtained from the S_{11} plot is presented in Figure 2. From the S_{11} characteristics, the reduced return loss of -34.16 dB is interpreted, which proves the sub-6 band performance of the proposed antenna. The optimized SCPA with C²SRR MTM ground obtained as the final version of the iterative design procedure shows reduced return loss than the basic

Table 2. Comparison of return loss and VSWR of designed antennas

Antenna	Resonant Frequency (GHz)	Return loss (dB)	VSWR
MCPA	3.53	- 14.8082	1.43
SCPA	3.5	- 22.6654	1.28
SCPA with C²SRR MTM ground	3.5	- 34.1569	1.04

structures.

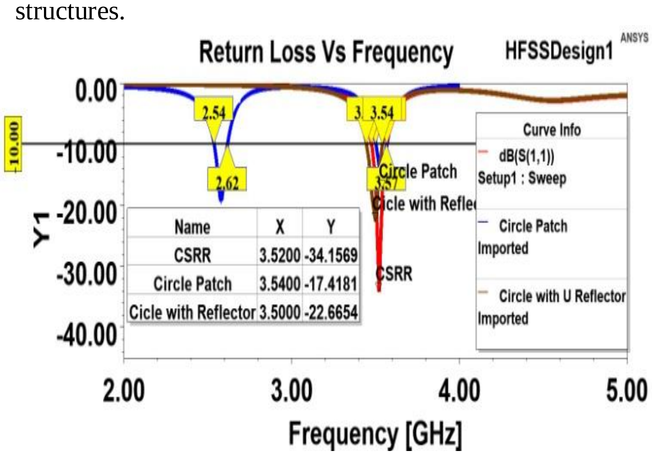


Figure 2. Represent the comparative return loss in the 2D plot

The operation of SCPA with C²SRR MTM ground at 3.5 GHz is observed from the S_{11} performance plot of the antenna. The designed structure is marked off for industrial application based on Voltage Standing Wave Ratio (VSWR) by validating the tuning and matching antennas to mitigate power reflection. The VSWR plot of designed geometries is described in Figure

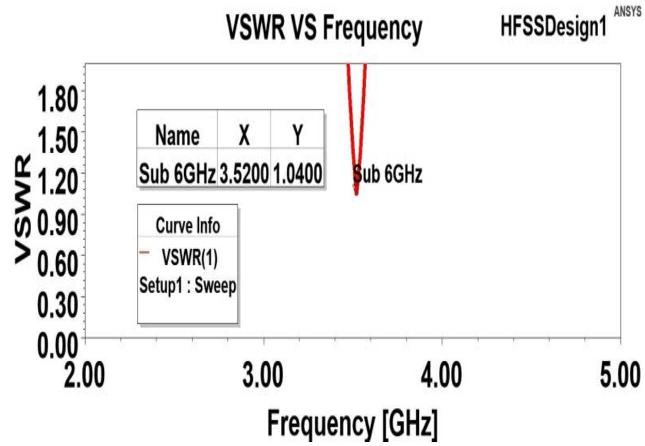


Figure 3. Represent the VSWR for SCPA with C²SRR MTM ground

The perk-up return loss performance of the proposed antenna compared to basic structures is due to metamaterial elements, outlined in Table 2.

The VSWR value of the antenna should be less than 2 for real-time applications [11]. TheVSWR values describe the potential of proposed SCPA with C2SRR MTM ground to radiate near unity at the operating bands.The gain improvement achieved by the proposed antenna without affecting the size of basic CPA is validated in Figure 4.

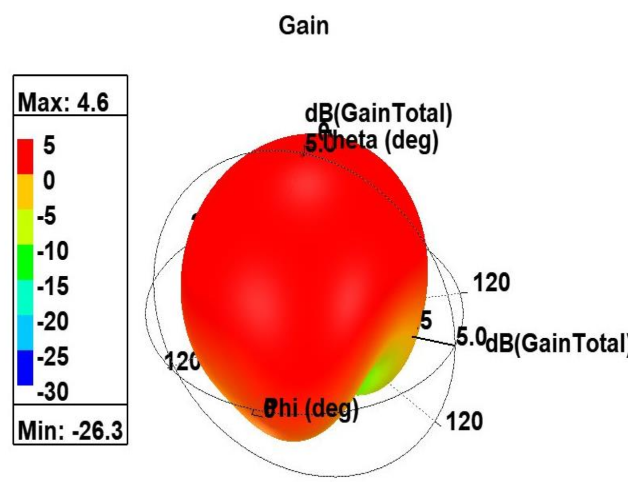


Figure 4.3D Gain for SCPA with C²SRR MTM ground

A gain of 2.91 dB and 1.8 dB are offered by the CPA and SCPA structure, respectively. The optimized SCPA with

C^{2}SRR MTM ground portrays a gain of 4.6 dB, which shows the improvement in the performance of SCPA due to the addition of MTM ground. The simulated radiation pattern with E plane and H plane measurements of SCPA with C^{2}SRR MTM ground is shown in Figure 5. The radiation patterns measured for3.5 GHz at various angles depict the stable radiation performance with directional nature.

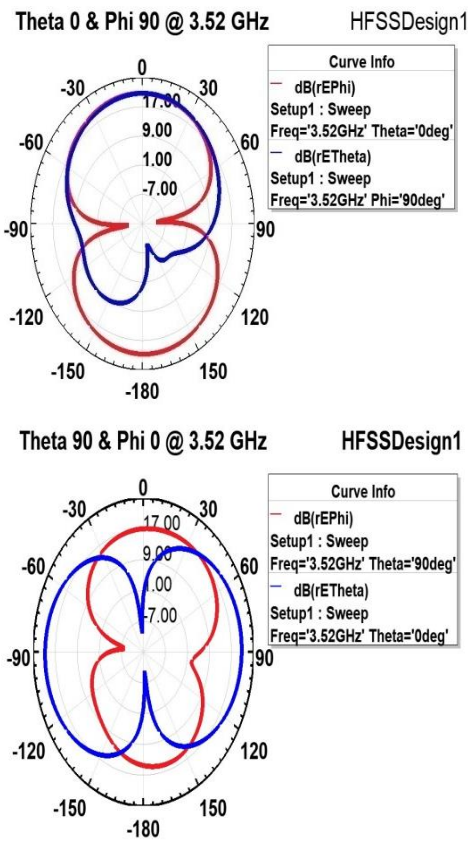


Figure 5. The radiation pattern of C^{2}SRR MTM ground

The prototype of the designed SCPA with C^{2}SRR MTM ground is shown in Figure 6. The proposed geometry is compared with a one INR coin to exhibit the miniaturization of a 5G antenna.

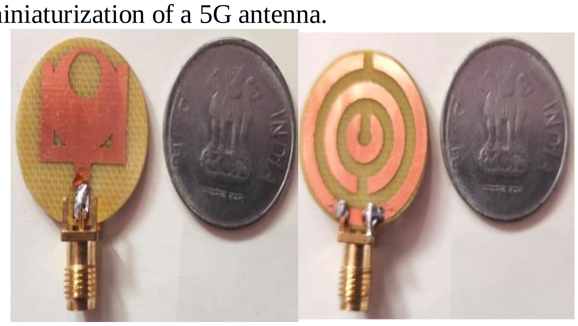


Figure 6. Prototype of SCPA with C^{2}SRR MTM ground

The simulated S_{11} plot of the proposed antenna is compared with the measured result, as shown in Figure 7. A close agreement between measured and simulated results proves the proposed antenna's sub-6, 5G operation.

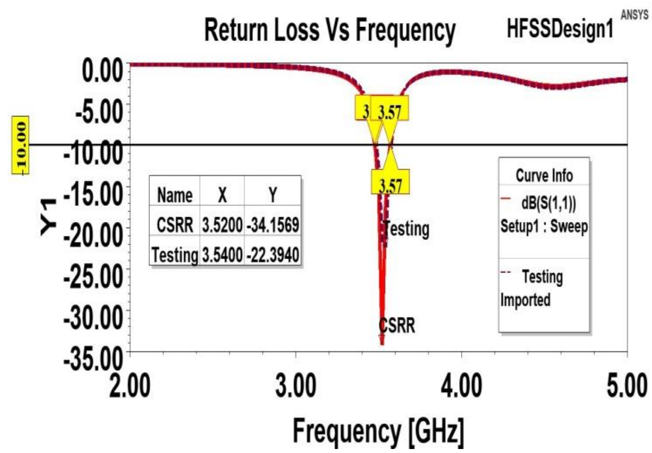


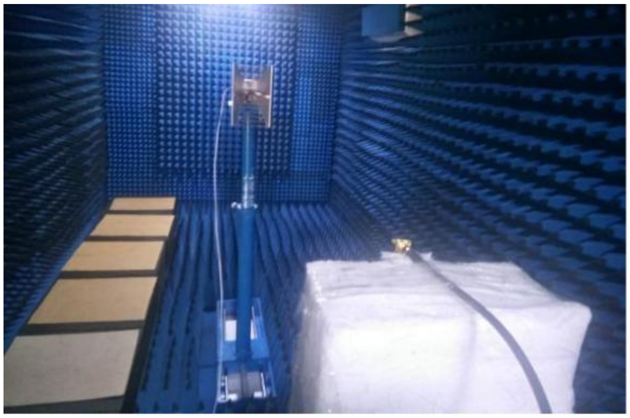
Figure7. Comparison of simulated and measured return loss performance of SCPA with C^{2}SRR MTM ground

The proposed antenna is compared with various 5G antennas in Table 3 to best part the novelty, compactness, and performance.

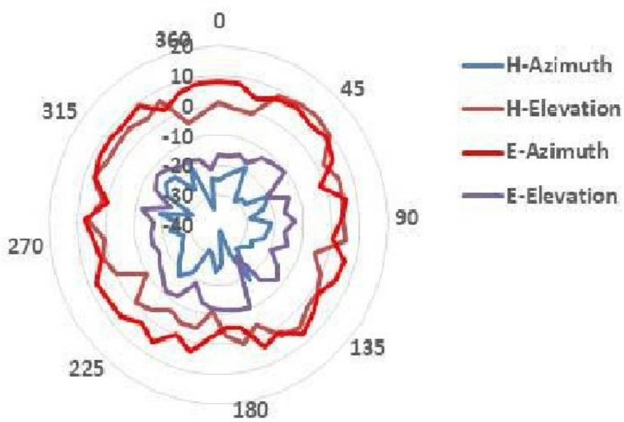
Table 3. Comparison of Proposed antenna with existing antennas.

Antenna model	Gain	Size mm^2
Shark-Fin Antenna [12]	6.4 dBi	163 ×61.9
Eight element antenna array [13]	-5.51 dBi	138 x 68
Eight-element MIMO antenna [14]	3.1 dBi	130 x 100
Proposed SCPA with C^{2}SRR MTM ground	4.6 dB	22.6x22.6

The proposed design is initially simulated in the ANSYS EM suite, fabricated using the FR4 dielectric material, and tested in the Vector Network Analyzer. The fabricated prototype is tested in the chamber, and validation of the radiation pattern is depicted in figure 8 (B).



(A)



(B)

Figure 8 Represent (A) Antenna in the chamber (B) Tested radiation pattern

V. CONCLUSION

A circular patch antenna is modified in this paper for realizing multi-band operations with high performance. The multi-band operation and high performance are achieved by adding loop structure in the patch and C^2SRR in the ground. The C^2SRR structure confers the advantages of metamaterial in antenna design. Return loss less than -10 dB is observed in the operating 5G sub-6 frequency band with high gain. The compact structure with good impedance matching and stable radiation pattern validates the proposed SCPA with C^2SRR MTM ground. The presented design operating is authenticated by all the above performance characteristics and VSWR of less than 2. The identical measured performance of the antenna is capable of supporting 5G communication at sub-6 GHz.

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