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A High-Performance Split Ring Resonator Based Slotted Microstrip Patch Antenna for Fifth Generation Communications

Research Article

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ABSTRACT

This article presents a split ring resonator (SRR) based slotted microstrip patch antenna for 5G communications. SRR is used for increasing the resonating power and performance of the antenna. The core resonating frequency of the proposed antenna is 28 GHz. The Computer Simulation Software (CST) has been used for calculating, simulating, and optimizing the parameters and the dimension of the antenna. The structure of the antenna is very compact, having dimensions of (17 ×17× 1.6) mm^3. Substrate used for building the antenna was made of FR-4 material which has a dielectric coefficient of 4.3 and a thickness of 1.6 mm. The proposed antenna is distinguished by its low return loss of -26 dBi, high gain of 5.95 dB, wide operating band of 4.05 GHz (percentage bandwidth of 14.46%), and high radiation efficiency of almost 62%.

Keywords: *Circular patch, Microstrip antenna, Microstrip line fed, Miniaturization, Mirror SRR, Slotted antenna, Split Ring Resonator, 5G*

I. Introduction

Every day the world is introducing various wireless devices with enormous data transfer rates. The communication speed has been increased by ten times from Turbo-3G to 80 Mbps with the launch of 4G. But the data transfer rate in 4G is not quite sufficient to make up the desired speed. To solve this type of problem and the latency as the considerations, 5G comes to act with a data speed of 10 Gbps (Rashmitha et al. 2020, Abdelaziz at al. 2020). Large Area Synchronized Code-Division Multiple Access (LAS-CDMA) stimulates fifth-generation wireless communication. 5G can transfer both voice and high-speed data

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concurrently and more accurately. 5G ensures low latency (10X less than the previous generation) which is necessary for live streaming, cloud gaming, etc. Some low latency demanded applications can be benefitted through 5G. 5G comes into the picture to influence robotic surgery, virtual reality, and augmented reality demand for an HD video with a very low latency of less than 10ms. 5G network is more efficient to help IoT in many ways (Punith et al. 2020). Ultra-Wideband is a technology for transmitting data at a very high rate of 110 Mbps ranging up to 10 meters with low cost and low power consumption. It can be suitable for short-distance applications such as PC peripherals and radio-frequency-sensitive environments, such as a hospital. It also can be used to capture highly accurate spatial and directional data (Bakali et al. 2021). Because microstrip patch antennas can be printed directly onto a circuit board, they are becoming more popular. Microstrip antennas are becoming increasingly used in the mobile phone industry. Microstrip antennas comprise lightweight, smaller size, low fabrication cost, low radiation power, the capability of dual and triple frequency operations, and easy integration with microwave integrated circuits. The functioning principle of a microstrip patch antenna is that electromagnetic waves are formed when current travels through the feed line and reaches the strip of the antenna. The patch's waves begin to be radiated from the width side (Falade et al. 2020). Furthermore, numerous efforts have been made to achieve excellent directivity and a broadside emission pattern using a single microstrip patch antenna to minimize the need for a feeding network (Anguera et al. 2019). The challenging features of UWB microstrip antennas are the key interferences to achieve a compact 5G antenna. To overcome the interference, recently notch antennas have become more popular. To design a compact UWB antenna that rejects interference at high selectivity, multiple notch bands and a pair of SRRs are required. In this paper, the 5G and WLAN bands are indented by employing a match of electromagnetic band gap (EBG) structures whereas the partisan downlink band is indented by utilizing two split-ring resonators (SRRs). The overall dimension of this triple rectangular notch UWB antenna is $20 \times 26 \times 1.52 mm^3$, but the maximum gain is 3.86 dB which is not that much expected. The practical design will be more complex because of using two different technologies (EBG and SRR) together (Abbas et al.2020). A Split Ring Resonator (SRR) is a structure that is artificially produced common to metamaterial likely to have negative permeability and permittivity. It is used to produce magnetic responses up to 200 terahertz. The application of SRR contributes to the increase of antenna efficiencies in terms of reflection and transmission coefficient (Abdelhamid et al. 2020). A rectangular-shaped Microstrip patch antenna operating from 28GHz to 30GHz for 5G mm-wave Wireless Communication is designed. Rogers RT substrate is used which gives the radiation efficiency of 98% with a gain of 10 dB and with a relative permittivity of 2.2 and a loss tangent value of 0.0009, the total dimensions are $4.8 \times 5 \times 0.508$ mm^3 (Ahmad et al. 2020). A circular shaped Microstrip patch antenna operating from 1GHz to 4GHz for 5G applications is designed using PET substrate. It gives the radiation efficiency of 99% with a gain of 2. 78dB.The gain of this antenna is much lower than expected (Rahman et al. 2020)]. An antenna with a gain of more than 6 dB is built on two stacked substrates with three metallic layers. Within the working band, the radiation patterns are steady, and the cross-polarization is less than -23 dB. However, due to manufacturing limitations with two types of substrates, the working frequency is somewhat greater than the simulated one (Zhang et al. 2019). The Kapton polyimide substrate is used to construct a small, wideband, and flexible rhombic antenna utilizing CMA for WBAN/WLAN and 5G applications running at 2.45GHz and 3.42GHz, with radiation efficiency of 90% and 83% and gains of 3dB and 5 dB, respectively (Elias et al.). A helix-shaped Microstrip patch antenna operating at 5.8GHz and 5.9GHz for 5G applications is designed using Teflon material substrate gives the radiation efficiency of 72% and 68% with a gain of 11.25 dB and 12.6 dB. However, the gain can be altered by input impedance matching, and it could be owing to design parameters such as the antenna length, which is 530mm in total (Zeain *et al.* 2020). A biconvex-shaped Microstrip patch antenna operating at 27.6GHz for 5G applications is designed using FR-4 epoxy substrate gives the radiation efficiency of 79.7% with a gain of 4. 69dB.A square-shaped metallic ring of one side thicker than the other is used to enhance the gain. A ground plane with dimensions of 40mm × 40mm and a height of 0.01mm is employed, and the material for the ground plane is copper (Panda et al. 2019). An elliptical dual-band Microstrip patch antenna operating from 26.59GHz to 31.18GHz and from 35.29GHz to 39.43GHz for 5G applications is designed. A Rogers-RT substrate is used on top of the other Rogers-RT substrate which gives the radiation efficiency of 93.63% and 91.08% with a gain of 6dB and 6.3dB respectively. In this designed antenna, a defective or partial ground has been used which enhanced the antenna performance (Mpele et al. 2019). A rectangular-shaped broadband Microstrip patch antenna for 5G wireless systems operating at 28GHz is designed using Rogers-RT Duroid substrate gives the radiation efficiency of 80.18% with a gain of 5.06dB. The antenna has a compact structure with dimensions 6.2 ×8.4× 1.57 mm^3 (Przesmycki et al. 2021). Two designs of the split-ring resonator (dual-polarized antenna and circularly polarized antenna) cover the 5G-N78 band (3.3-3.8 GHz). The gain of the dual-polarized antenna and circularly polarized antennae are 5.0 dBi and 5.62 dBi. But dual-polarized antenna suffers from large size and narrow bandwidth. It appears that these antennas are unable to strike a good balance between miniaturization and performance (S. Liu et al. 2021). A metamaterial-based antenna to enhance performance for MIMO system applications with two patches has been proposed. To address the isolation issue, the installation of a new metamaterials structure between the two antennas has been proposed, consisting of a linear array of 5 identical SRR unit cells. Each SRR consists of two rings. A parametric study has been done based on the spacing between two rings, size of the rings, and radiation permittivity. The increasing size of the rings from 0.3mm to 0.9 mm has enhanced the resonance frequency from 10.72 GHz to 11.71 GHz. The increasing rate of space between two rings from 0.15mm to 0.30mm has enhanced the resonance frequency from 10.71GHz to 13.72 GHz. The reduced permittivity from 4.4 to 2.2 has enhanced the resonance frequency from 10.71 to 13.51 GHz. In this design, the dimension of the antenna 48×35 mm^2 is taken and got the gain from 2 to 8 dB. The radiation efficiency has been dramatically increased up to more than 80% after using the SRR in between the two antennas (Sakli et al. 2021). Due to the array pattern used with different dimensions on both sides of the FR-4 substrate, the designed structure, which is a circularly polarized scanning phased array antenna, is made up of metal SRR. The axial ratio (AR) is less than 3 dB, with an effective bandwidth of 4.80 GHz from 5.10 GHz to 5.20 GHz and a maximum gain of 25 dB (Kakepoto et al. 2020). This work presents a multiband decagon ring-based 1 × 1 and 2 × 2 MIMO antenna with no decoupling construction. 2.4–2.52 GHz, 3.66–4GHz, and 4.62–5.52 GHz are the working frequency bands for the proposed antenna, which span 2.4/5.2GHz WLAN, 2.5/5.5GHz WiMAX, 3.6–3.8GHz 5G, and 4.9GHz for public safety applications. For all operating frequencies, the orientation of the antenna produces strong isolation values of -30.5 dB and -18.5 dB for 1 × 1 and 2 × 2, respectively. More than 85% of the simulated efficiency is achieved (D. Dileepan et al. 2021). This proposed antenna is built on a FR-4 substrate with dimensions of 20×34×1.6 mm^3. The proposed antenna operates in two bands, 1.78GHz to 1.90GHz and 3.45GHz to 6.58GHz.1.83GHz resonating band is created because complementary SRR(CSRR) is engraved in the radiating element. This band totally depends on the CSRR geometric parameters. The antenna element produces high isolation values of −37.68 dB. It covers almost the whole operating band (S. Christydass et al. 2021). A metamaterial-coated antenna over Teflon material is proposed for 5G communication. Microstrip antenna designed without metamaterial gives the return loss of -41.65 dB whereas a single layer of MM-coated antenna gives the return loss of -50.31 dB which is much better and the gain of 7.66 dB and 8.32 dB respectively. Using the two layers of metamaterial (SRR) over Teflon material gives the return loss, gain, and HPBW of -38.78 dB,8.42 dB, and 67.4 degrees respectively which reflects a comprehensive increase in the overall performance over the one layer of SRR antenna (Jahangiri and Rajebi 2021). The designed miniaturized patch antenna resonating at 3.5 GHz gives the relative bandwidth of 2.28% and the antenna gain of 7.43 dB. 10 SRR is symmetrically etched on the patch of the antenna. The size of the antenna without using these 10 SRRs was 40×45 mm^2.After using SRRs the size reduces to 35×40 mm^2 which provides a high gain than the previous. Antenna using 10 SRRs symmetrically gives the return loss of -25.94 dB which is quite appropriate for the 5G communications (Li et al., 2019). Rogers-588substrate and EBG (mushroom-like, slotted) as a ground plane are used to design the antenna. The conventional antenna without metamaterial surface ground gives the return loss, gain, and efficiency of -20 dB,6.59 dB, and 89% respectively. But the antenna using EBG (slotted and mushroom-like) as the ground plane produces the return loss of -30 dB and -35 dB, the gain of 7.5 dB and 8.91 dB, and efficiency of 90% and 94% respectively. The total volume of the antenna is 10×6×0.254 mm^3 (J. Khan *et al.* 2019). This research proposes a small Y-shaped MIMO antenna array for 5G bands utilizing SRR. The 3.3-3.6 GHz and 4.8-5 GHz frequency bands are covered by this antenna for 5G communications. After adding the SRR it gives the better impedance matching derived from return loss of -25 dB which was closer to -10 dB in the conventional antenna design. The total dimension of the antenna is 23×19×0.406 mm^3 and Rogers 4003C is used as the substrate (Xu et al. 2019).

Antenna Design

In this proposed antenna, a 17×17 mm^2 substrate is taken as the originator element. The substrate is made of FR-4 lossy materials. The thickness of the substrate is 1.6 mm. The FR-4 substrate contains the loss tangent of 0.025 and the electric permittivity (ε_r) or dielectric constant of 4.3. The substrate has a thermal conductivity of 0.3 (W/(m·K)). The ground plane and radiating patch are located on opposite sides of the substrate. Figure-1 displays the proposed antenna's geometric layout. Because of its simplicity and excellent physical handling, the transmission line model is well-suited to antenna planning and analysis. The antenna size (H and W) is estimated by employing the simplified formula derived from the transmission line model (Przesmycki et al. 2021)

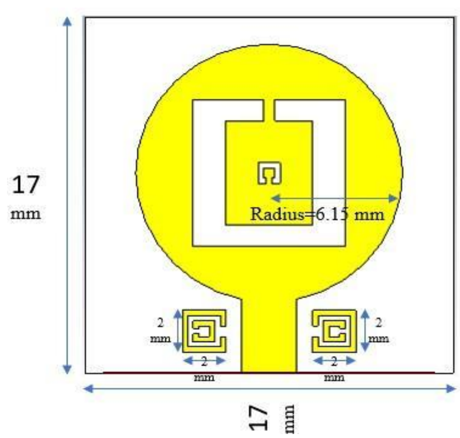
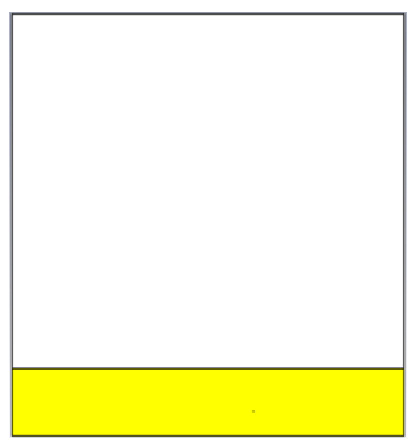


Figure 1(a): The front side geometric layout



(b) The ground plane

The ground plane of the proposed antenna is shown in **figure 1(b).** The antenna has a partial ground of length (L_{gnd}) 2.75 mm which originates from the lower part of the Y-axis. The ground plane has a width (W_{gnd}) of 17 mm. The height or the thickness of the ground is 0.036 mm. The ground plane of the antenna consists of copper (annealed) materials. It is one kind of lossy material. It has the thermal conductivity of 401 (W/(m·K)). It has the heat capacity of 0.39 $KJ \cdot kg^{-1} \cdot K^{-1}$ and has the diffusivity of 0.000115141 m^2/s. The ground plane has the Poisson’s ratio of 0.33. A circular radiating patch is designed in front of the squared substrate which have the radius of 6.15 mm. A square-shaped slot is cut at the middle of the circular radiating patch which has the dimension (L_{slot}×W_{slot}) of 7x7 mm^2. A rectangular stub of dimension (L_{stub}×W_{stub}) 5x4 mm^2 is protruding down from the top middle edge of the square slot towards the center of the square slot created in the circular radiating patch. An open-ended square slit ring of dimension (L_{slit}×W_{slit}) 1x1 mm^2 is created on the top of the protruding stub. The detailed structure of the radiating patch is shown in **figure 2(b).** For achieving the high-frequency band 5G antenna, a simplified version of unit cell SRR (Split Ring Resonator) is introduced. The dimension of the outer side of the SRR is (L_{SRR}×W_{SRR}) 2x2 mm^2 and the dimension of the inner side is 1x1 mm^2. Both sides are open-ended. The distance between the two SRRs is 0.928 mm. There are two-unit cell SRRs used in the proposed antenna, one is on the left side of the feed line and the other is on the right side of the feed line. The two SRRs are mirrors of each other. The two SRRs are placed 1.25 mm away from the feed line. The square-shaped SRR is presented in **figure-2(a).** The radiating element is fed by a 50-Ω microstrip transmission line also known as feed line of length L_f=5 mm and width of W_f=2.5 mm. The feed line carries a small thickness of 0.036 mm. **Table-1** summarizes all of the optimum design characteristics of the proposed antenna in mm**.** The fabricated prototype is shown in figure-3. The antenna is designed and simulated using CST STUDIO SUITE.

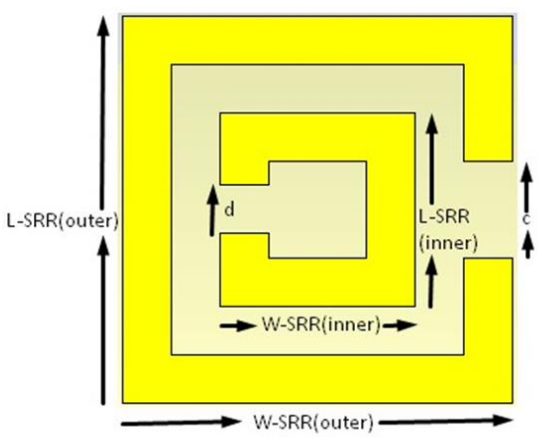
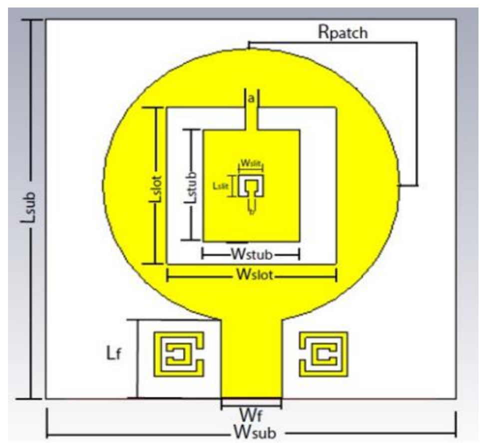


Figure 2(a): The unit cell of SRR



(**b)** The detailed structure of radiating patch

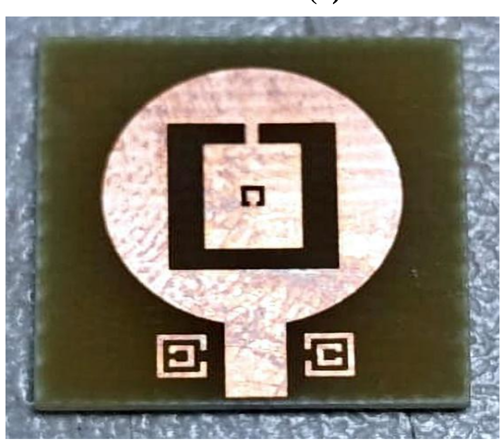


Figure 3: Fabricated Prototype

Table1. Optimized design parameters of the proposed antenna

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
$\mathbf{L}_{sub}$	17	$\mathbf{L}_{slot}$	7	$\mathbf{L}_{SRR}$(outer)	2	a	0.25
$\mathbf{W}_{sub}$	17	$\mathbf{W}_{slot}$	7	$\mathbf{W}_{SRR}$(outer)	2	b	0.5
$\mathbf{H}_{sub}$	1.6	$\mathbf{L}_{stub}$	5	$\mathbf{L}_{SRR}$(inner)	1	c	0.5
$\mathbf{L}_{gnd}$	2.75	$\mathbf{W}_{stub}$	4	$\mathbf{W}_{SRR}$(inner)	1	d	0.25
$\mathbf{W}_{gnd}$	17	$\mathbf{L}_{slit}$	1	$\mathbf{L}_{f}$	5		
$\mathbf{R}_{patch}$	6.15	$\mathbf{W}_{slit}$	1	$\mathbf{W}_{f}$	2.5		

2. Parametric Study

A complete parametric analysis was carried out to investigate the influence of various factors on impedance matching characteristics. The effect of embedding SRR (split-ring resonator) on the left side of the feedline and its mirrors on the right side of the feedline is demonstrated. According to the best result from the first step, then changing the size of the feedline is performed to enhance the performance and the required bandwidth in the second step.

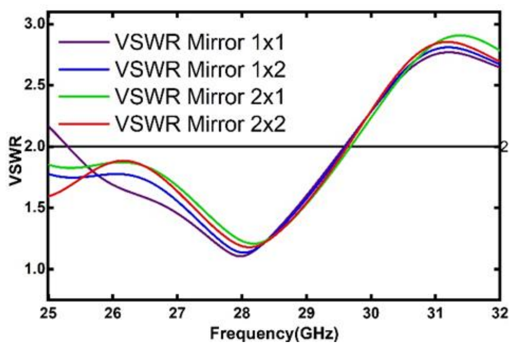


Figure 4(a): VSWR

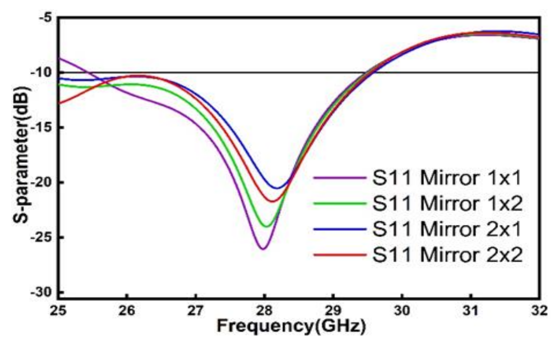


Figure 4(b): S-parameter

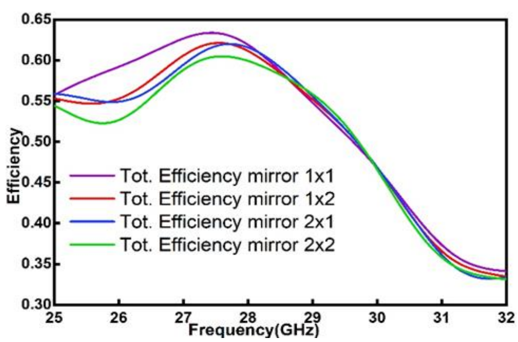


Figure 4(c): Efficiency

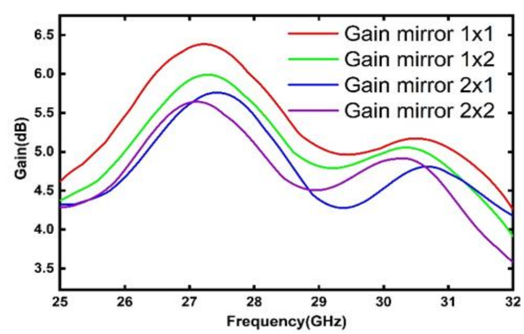


Figure 4(d): Gain

After adding SRRs on both sides, the maximum VSWR is 1.21. This result is found when using (2×1) SRR shown in **figure 5(b)**. According to **figure 4(a),** The lowest VSWR is 1.10, which is found when one SRR is embedded on each side of the feed line. It gives the best performance. The amount of power reflected from the antenna is represented by the return loss. It is also called S

(scattering) parameter. It is used to characterize electrical networks using matched impedances. The scattering value (S parameter) is better when using (1×1) SRR shown in **figure 5(a)** and the value is -26 dB. According to **figure 4(b),** much return loss is found when (2×1) mirror SRRs are used shown in **figure 5(b)**. The return loss on this phenomenon is -20.53 dB.

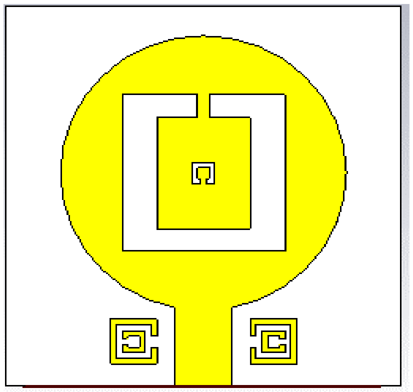


Figure 5(a):1×1 SRR

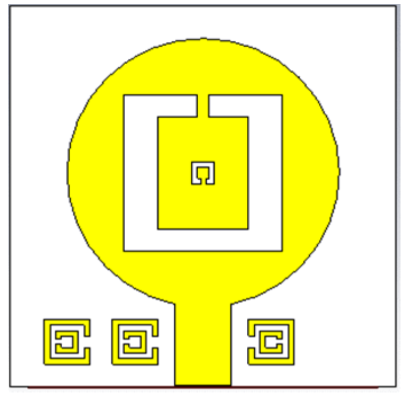


Figure 5(b):2×1 SRR

The ratio of power emitted by the antenna to power provided to the antenna is known as antenna efficiency. According to **figure 4(c)**, the maximum efficiency is 61.91% after embedding one SRR on each side of the feedline (1×1) and the minimum efficiency is 59.60% when (2×2) mirror SRRs are used depicts on **figure 5(d)**. The gain is the fundamental performance metric that combines the directivity and electrical efficiency of an antenna. According to **figure 4(d)**, the maximum gain is 5.95 dB after embedding (1×1) SRR. The minimum gain is 4.99 dB when (2×2) SRR is used. The more SRR is added on each side, the more performance is reduced e.g: VSWR is increased, the gain is decreased, return loss is escalated and efficiency is dropped down. That's why the design which contains one SRR on each side is the finest. In the second step, the modification of the feed line will be done with the design which contains one SRR on each side of the feed line. The parametric results after modifying the feed lines of the antenna are shown **in Figures 6(a),6(b),6(c), and 6(d).** In **Figure 6(a),** the VSWR (Voltage Standing Wave Ratio) is smaller than two for all the modified feedlines where the size varies from 1.5mm to 3mm. A better result is found when the feedline size is 3mm which is 1.05 <2. The VSWR of the proposed antenna is 1.10 when the width of the feedline is 2.50mm which is very much closer to the better result of 1.05. The feedline size of 1.5mm gives the worst result of 1.31 among the following seven modified feedlines.

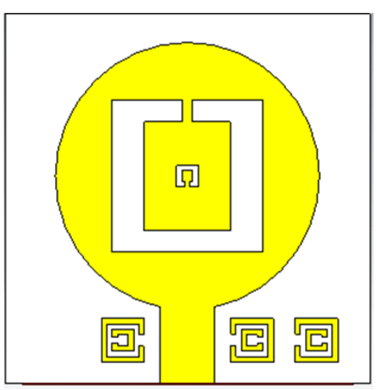


Figure 5(c):1×2 SRR

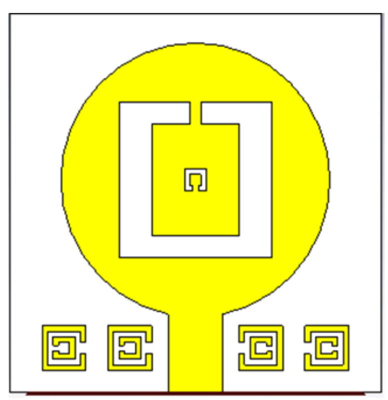


Figure 5(d):2×2 SRR

The least return loss of -32.59dB is shown in **figure 6(b)** which gives the best performance. This result is found when the width of the feedline is 3 mm. The value closer to -10dB defines the minimum impedance matching. The scattering value which is greater than 10 dB indicates no impedance matching. The Return loss -17.70dB is near about -10dB which gives the minimum impedance matching and the performance is not finer. This result is found when the width of the feedline is 1.5mm. The return loss of the proposed antenna is -26dB which is more appropriate over the whole frequency band. The width of the feedline 2 mm gives the best result according to **figure 6(c)** of efficiency of 62.31%. The feedline width of 3 mm gives the lowest efficiency of 61.13%. The efficiency of the proposed antenna is closer to 62% which is not far away from the highest efficiency of 62.31%.

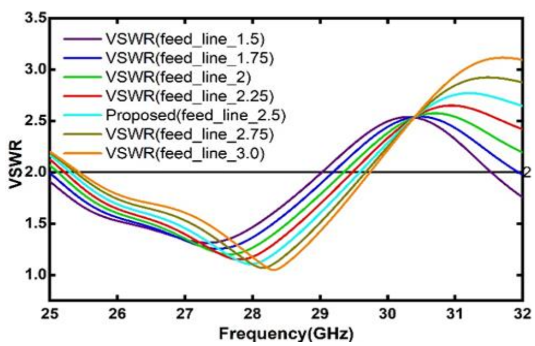


Figure 6(a): VSWR

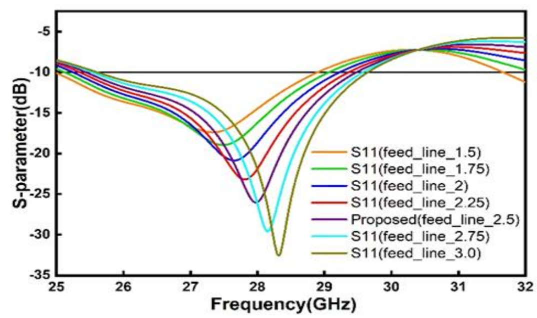


Figure 6(b): S-parameter

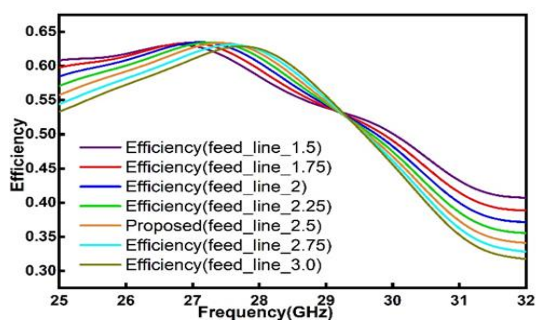


Figure 6(c): Efficiency

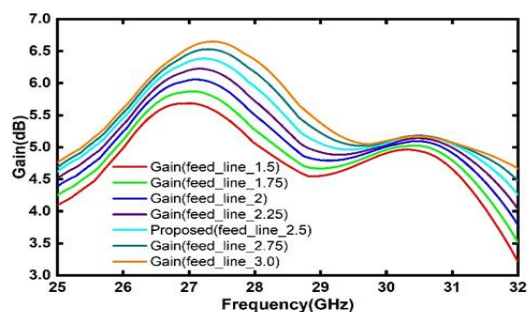


Figure 6(d): Gain

The maximum gain is shown in **figure 6(d)** is 6.08 dB for the feedline of 3 mm. The minimum gain according to the figure is 5.60 dB which is found for the width of 1.5 mm. The gain of the proposed antenna is 5.95 dB which is much closer to the highest gain of 6.08 dB. After decreasing the width of the feedline from 2.5 mm to 2.25 mm, 2 mm, 1.75mm, and 1.5 mm, it is seen that the VSWR is increased to 1.15,1.20, 1.25, and 1.31 respectively. It is known, when the VSWR is increased, the performance of the antenna is decreased, and the gain of these antennas is also minimized. The reflection coefficient is also increased which indicates lower antenna performance. After increasing the width of the feedline from 2.5mm to 2.75mm and 3mm, the VSWR decreases to 1.06 and 1.05 respectively and the reflection coefficients are decreased to -29.58 dB and -32.59 dB respectively from -26 dB. On the contrary, the antenna efficiencies are decreased. If we summarize the whole performance of these antennas according to the whole parameters of VSWR, reflection coefficient (S parameter), efficiency, and gain, it is obvious to say that the antenna resonating at 28 GHz which has the width of the feedline of 2.5mm gives the best performance in this context.

3. Results and Discussion

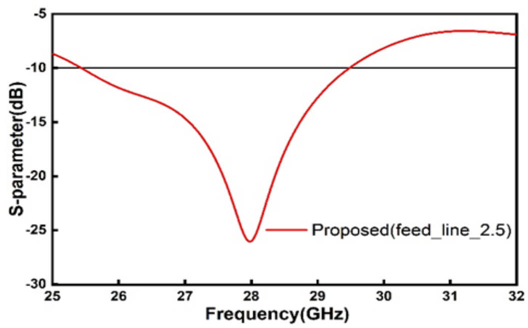


Figure-7(a): S-parameter

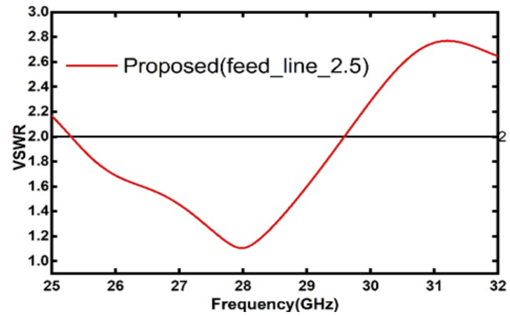


Figure-7(b): VSWR

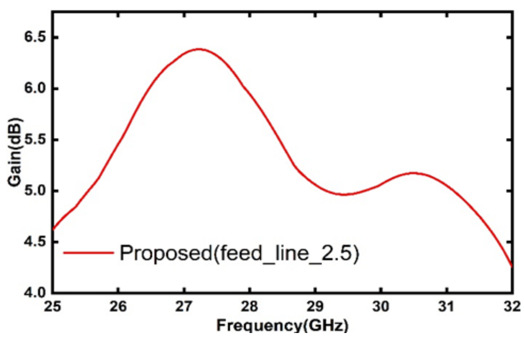


Figure 7(c): Gain

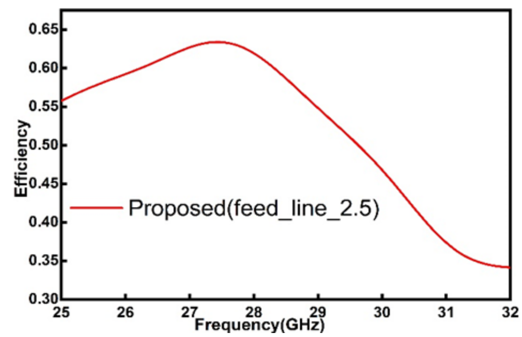


Figure 7(d): Efficiency

The reflection coefficient (S11) of the antenna is illustrated in **figure 7(a).** Optimizing the dimensional parameters of the antenna and the scale of the patch, slots ground plane, and the feedline, the desired 5G band is realized. It is evident from the figure-6(a) that when S11 is less than -10dB, the coverage frequency of the designed antenna is 25.44 GHz to 29.49 GHz which virtually covers the full recurrence scope of the 5G range. The resonance is observed at 28 GHz, the nearly middle value of the whole range. The reflection coefficient value of the resonance point is about -26dB, which ensures the viability of the design. The VSWR of the proposed antenna is 1.10<2 which is quite appreciable shown in **figure 7(b).** By embedding the split-ring resonator (SRR) the sidelobe levels are reduced, the squint effect is corrected, the gain is increased, providing improvement in antenna operating bandwidth. For this, phenomenal variations in the antenna characteristics are realized. The gain of the proposed antenna is 5.95 dB which is shown in **figure 7(c).** The range between 3 to 7 dB is the modest gain for 5G applications which assert the competent exhibition of the proposed antenna. **Figure 7(d)** depicts the radiation efficiency of 61.91% with the peak frequency 28GHz across the operating bandwidth. The performance of the proposed antenna is shown in **Table-2.** The total efficiency of an antenna is used to calculate the entire loss of energy at the antenna's input terminals and within the antenna structure. The total efficiency of this antenna is 61.91%.

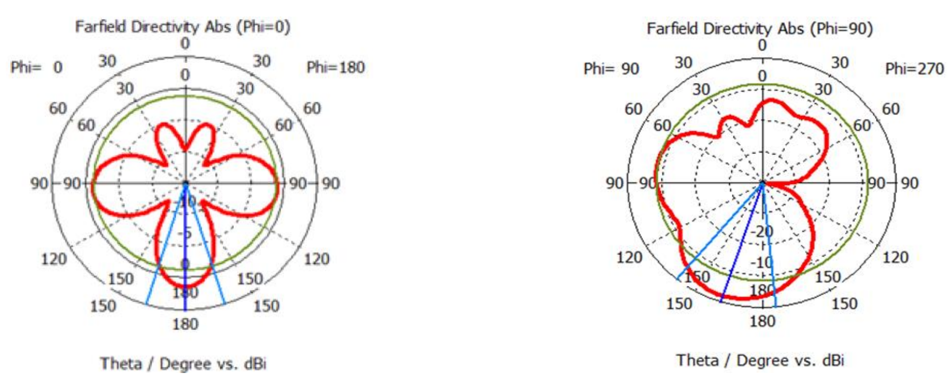
Table 2. Performance summary of the proposed antenna

Parameter (unit)	Value
Resonant Frequency (GHz)	28
Bandwidth (GHz)	4.05
Gain (dB)	5.95
VSWR	1.10
Efficiency (%)	61.91
Return loss(dB)	-26

Table 3. Performance comparison of the proposed antenna with the existing references

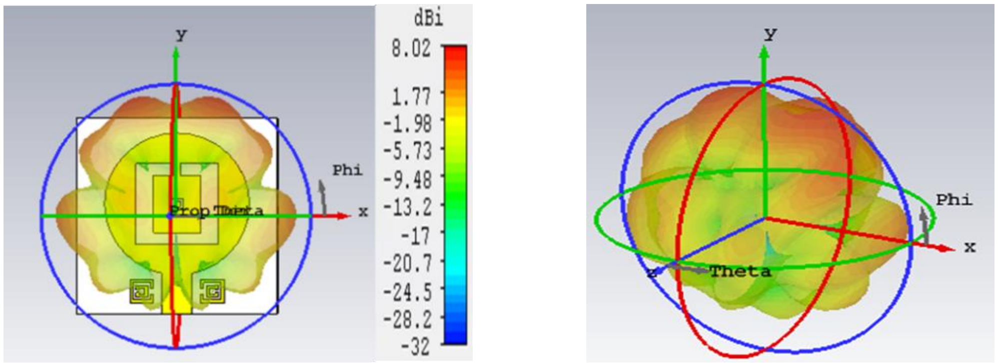
Reference antennas	Antenna size (mm^3)	Resonance frequency (GHz)	Return loss (dB)	Gain(dB)
Abbas et al.	20×26×1.52	7.25-7.75	-13	3.86
Liu et al.	50×50×0.508	3.3-3.8	-23	5-5.62
Sakli et al.	48×35×1.6	10.71-13.51	-27	2-8
Jahangiri et al.	21.34×18.54×1.58	9.6	-50.31	8.32
R. Li et al.	35×40×1.57	3.5	-25.94	7
Proposed work	**17×17×1.6**	**28**	**-26**	**5.95**

Table-3 represents the comparisons with the proposed prototypes with some recent published works in the similar application domain. The table shows that the proposed antenna is small but gives better performance at a very high resonance frequency of 28 GHz compared with the existing reference antennas without compromising return loss and gain. As per example, the antenna dimension is 50×50×0.508 mm^3 which is much bigger than the proposed antenna (S. Liu et al. 2021). In (A. Abbas et al. 2020), the antenna size is slightly bigger than the proposed one but comparatively the return loss is much higher and antenna gain is much lower which hampers the antenna performance. **Figure 8** demonstrates the radiation pattern of the proposed antenna for both co-polarizations and cross pola8izations at the resonant frequency of 28GHz.The direction of the proposed antenna is focused around 180° at phi=0° which is shown in **Figure 8(a)** and the directivity is focused around 90° at phi=90° shown in **Figure 8(b).** The 3D view of the radiation pattern for the same frequency is demonstrated in **figure 8.** The absolute directivity of the proposed antenna is shown in **Figure 10**. The directivity is virtually uniform except the fourth quartile of phi because the radiation pattern on the fourth quartile has been dragged down to the origin which is shown in **figure 8(b)**. The radiation pattern of the proposed design is omnidirectional which is one of the rudiments of antenna communications. Omnidirectional which for an antenna means that the radiation pattern is isotropic in a single plane. In this proposed antenna the radiation pattern on the x-y plane is isotropic. The current value of a microstrip antenna should be minimal at the end of the radiating element which is the edge of the patch. Depending on the current, the voltage at the edge of the patch is shifted. Hence, the edge of the patch has the maximum voltage, and the current values are close to zero. At the starting of the patch, a situation comparable to the one described above happens in the middle of the wave. The phase-shifted voltage produces fields on the antenna's edge depending on the current. The current distribution is shown in **figure 11(a)** at phase zero degree and **11(b)** at phase 90 degree.



(a) **(b)**

Figure-8: Absolute directivity at (a)phi-0° and (b)phi-90° of the proposed antenna at frequency 28 GHz



(a) **(b)**

Figure 9: (a) Transparent 3D view and (b) Linear omnidirectional 3D view of the radiation

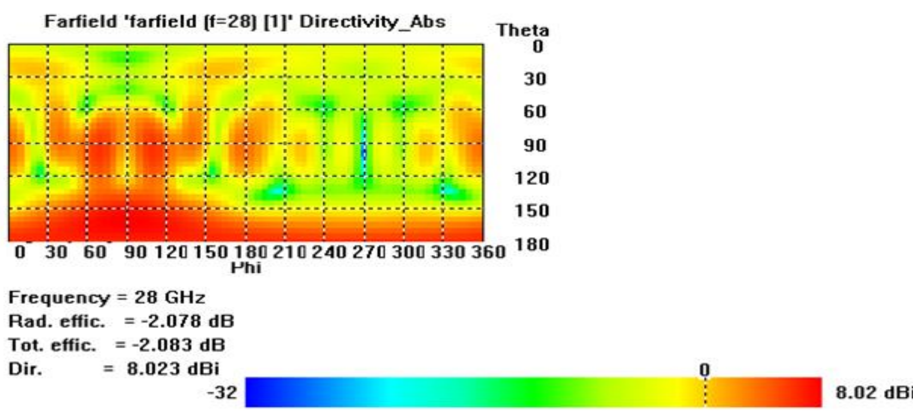
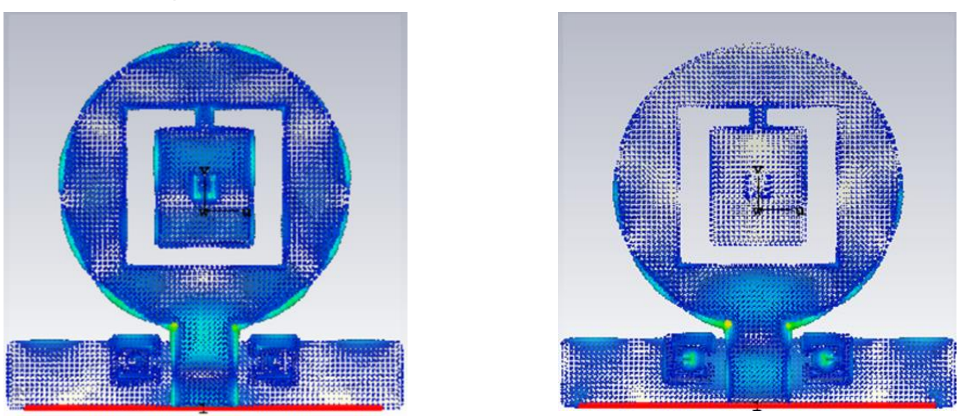


Figure 10: Absolute directivity of the proposed antenna at 28 GHz.



(a) **(b)**

Figure 11: Current distribution at (a) phase 0° and (b) phase 90^0

Agilent N5227 PNA network analyzer is used to measure the antenna s-parameter shown in **figure-12.** Simulated and Measured S-parameter of the proposed design is shown in **figure-13.** Compare to the simulated result the lower frequency bandwidth is slightly affected. The measured resonance frequency of the antenna is 27 to 32GHz. The difference between measure and simulated results is quite higher because of our measurement limitations. The PNA connector can coverage only limited frequency range. Fabrication and soldering tolerance may be the cause of the slight disproportion between the simulated and measured findings. Other than that dielectric loss of the substrate material might be another cause for deflection.

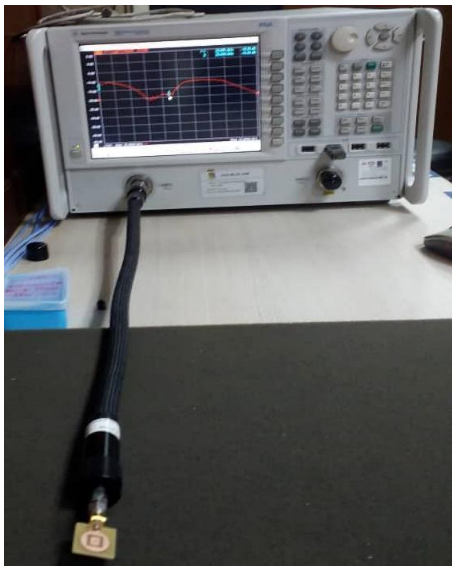


Figure 12: PNA measurement scenario

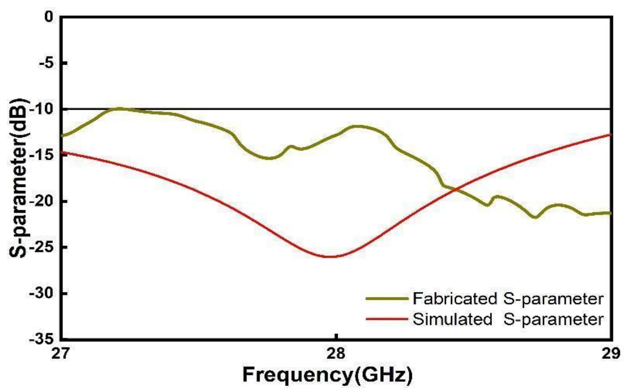


Figure 13: Simulated and Measured S-parameter of Proposed Design.

4. Conclusion

Considering the ever-increasing demand for mobile data and mobile devices, this study presents an SRR-based microstrip patch antenna design for 5G applications. A circular antenna patch with a radius of 6.15 mm with SRR slots in the center is employed. The antenna also has two-unit cell SRRs, one on the left and one on the right side of the feed line, which helps to boost resonance power and performance. The partial ground plane also contributes to increased antenna gain. The reflectivity of the antenna at its resonance frequency of 28.00 GHz is 26 dB. The suggested antenna has a radiation efficiency of 62% and an antenna gain of 5.95 dBi at the resonance frequency. The simulation shows that the antenna has a bandwidth of 4.1 GHz, which is suitable for 5G equipped devices. Because it matches the high throughput need, the developed antenna would be an excellent alternative for 5G mobile communications. The antenna is small and lightweight, making it ideal for devices with limited space. In the future, the proposed antenna prototype could be improved by adding metamaterials unit cells to increase gain and efficiency.

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