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A Compact Directive CSRR based Patch Antenna in 5G Bands

Sruthi Dinesh[1], and C.K. Aanandan[2]

[1]Associate Professor, Department of Electronics and Communication Engineering, A.J. Institute of Engineering and Technology, Karnataka, India, sruthidinesh11@gmail.com
[2]Professor Emeritus, Advanced Centre for Atmospheric Radar Research, Cochin University of Science and Technology, Kerala, India, aanandan@gmail.com

*Correspondence: *sruthidinesh11@gmail.com*

ABSTRACT- This paper proposes a compact patch antenna whose directivity is enhanced by modifying the ground plane with a CSRR (complementary split ring resonator). A slot is embedded within the patch so that it resonates at millimeter wave frequencies, the lower resonance at 38 GHz and the upper one at 58 GHz designated for next-gen communication applications. As Rogers 5880 has low dielectric loss at millimeter bands, it was selected as the dielectric substrate. The structure provides a directivity of 7.04 dB and 6.35 dB at resonance, which increase to 8.68 and 10.6 dB, respectively, with the inclusion of the resonator. Insertion of CSRR also creates additional resonances at 42 and 61 GHz with directivity of 9.46 dB and 8.72 dB, respectively, without increasing the structure dimensions, making it ideal for application in compact structures such as next-gen mobile phones and tablets.

Keywords: Directive, slotted, patch, inset feed, complementary split ring resonator, 5G.

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1. INTRODUCTION

In recent years, the domain of wireless devices has seen exponential growth. The arrival of fifth and sixth-generation technologies has completely revolutionized wireless communication. Higher data rates, lower energy consumption, and a shorter latency are the main features of fifth-generation technology. Directional antennas are inevitable in next-gen communication systems since they increase the wireless communication system's range, signal quality, coverage, and reliability besides overcoming the challenges of signal propagation at high frequencies. Printed antennas are employed in compact communication equipment because of their low profile and simplicity of fabrication. A compact patch antenna with defected ground is proposed in this paper, providing high directivity for 5G applications.

2. LITERATURE REVIEW

5G millimeter wave antennas are an intriguing topic among the antenna research community [1-3]. Mm-Wave is the frequency band ranging from 24 GHz to 300 GHz. But high frequencies encounter signal propagation losses, which can be compensated for by increasing the directionality of antenna patterns.

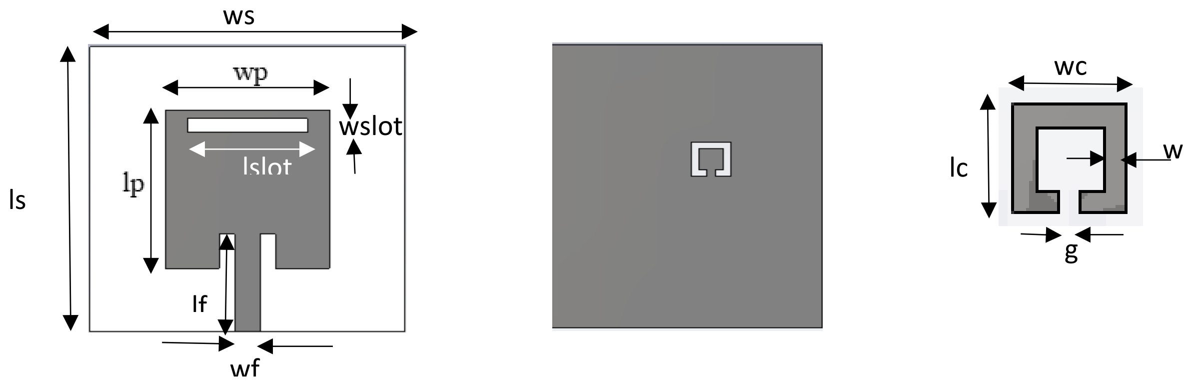
Researchers have tried a number of methods to improve the directivity of high-frequency antennas by manipulating the characteristics of electromagnetic radiation such as slots, SRRs and CSRRs (split ring resonators and complementary split ring resonators), lenses, etc., but most designs require complex array configurations and feeding networks. [4] utilized substrate-integrated waveguides in the design of a slot antenna for 5G applications, but these require complex metallic vias, spacing, and alignment, leading to increased fabrication complexity. The dimensions of the structure also increase, restricting their use in compact devices. [5] proposed a millimeter wave antenna with a meta-surface and pin loading, but the geometry is complex due to the additional layer and precise loading requirements. A MIMO array with fractal geometry and CSRR loading was developed in [6], but the design faces the challenge of high design complexity and mutual coupling.

A miniaturized patch array was proposed in [7] but involves multiple elements and complex feeding networks, leading to a larger effective size. [8] proposed a CPW-fed dual-band MIMO antenna involving complex geometry and a low gain of 5 dBi. P. Jha et al. [9] proposed a compact textile antenna loaded with CSRR with a defected ground for 5G applications. But the structure had the drawback of low gain, that is, 0.05- 1.59 dB in the 5G band. [10] proposed a dielectric lens antenna with wide bandwidth for 5G applications. Though they could achieve high directivity, the structure is bulky and also comes with integration challenges. [11] developed a dielectric resonator MIMO antenna for 5G applications. Though high directivity could be achieved, it comprises multiple antenna elements and complex feeding networks, increasing the complexity of the design. An ultra-compact millimeter wave antenna was developed by Kumar et al. [12]. Though the design is compact and involves only a single element, a gain of only 4.5 dB could be attained at 28 GHz and hence cannot be used for high directivity applications.

In this work, we are considering an inset-fed patch with resonance at millimeter-wave frequencies. An increase in directivity to 10.6 dB was attained from a simple compact single antenna element by just employing a defected ground plane, that is, by incorporating a complementary split-ring resonator.

3. DESIGN

A patch antenna resonating at 52 GHz was designed on RT Duroid 5880 ($\mathcal{E}_r$=2.2, thickness = 0.254 mm, tan δ = 0.0009). An inset feeding mechanism was used since it is compact with a short feed line and provides good impedance matching. The front side comprises a slotted patch. On the backside, CSRR is etched. This is detailed in *figure 1*. The directivity has improved highly in comparison to structures with comparable size which were previously reported in literature. *Table 1* presents a comparison study with the latest related works.



*(**Geometrical dimensions**: substrate: ls = 10 mm, ws = 10 mm, patch: lp = 5.57 mm, wp = 5.2 mm, slot: lslot = 3.8 mm, wslot = 0.5 mm, feedline: lf = 3.42 mm, wf = 0.8 mm. CSRR dimensions: lc = 1.4 mm, wc = 1.4 mm, w = 0.3 mm, g = 0.3 mm)*

Figure 1. Schematics of inset fed antenna (a) Front view, (b) Back view with CSRR, and (c) CSRR dimensions

The resonance of the unslotted patch was obtained at 52 GHz. Current flow is maximum at the top of the patch. Hence, when a slot is cut near this edge, it changes the path of current flow, which in turn alters the fundamental resonance mode to produce dual resonance, the lower one at 38 GHz and the upper one at 61 GHz, both of which are 5G frequencies. These bands provide a huge data rate with minimum interference and least delay.

To calculate the width wp and length *lp* of the patch, the following equations have been used [13]:

$$w_p = \frac{c}{2f_r}\left(\frac{2}{\epsilon_r + 1}\right) \quad (1)$$

$$l_p = l_{eff} - 2\Delta L \quad (2)$$

l_{eff} is the effective length and ΔL is the change in length due to fringing effects. f_r is the resonant frequency and ε_r is the substrate dielectric constant.

$$l_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{eff}}} \quad (3)$$

The substrate's effective permittivity ϵ_{eff} is approximately $\frac{(\epsilon_r + 1)}{2}$.

A complementary split ring resonator is the inverse of a split ring resonator. While an SRR is a metallic wire with a gap, CSRR comprises a slot in the metallic plane. CSRR is excited by applying an electric field perpendicular to its plane.

The slot in CSRR has a capacitive effect and stores electric energy, while the metallic part has an inductive effect and stores magnetic energy, creating an LC resonator circuit. The formula for the frequency of resonance is

$$f = \frac{1}{2\prod\sqrt{L_{eff}C_{eff}}} \quad (4)$$

L_{eff} and C_{eff} are the effective inductance and effective capacitance respectively [14].

$$L_{eff} = \mu_0 . l.\left(ln\ \frac{2l}{w+t} + K\right) \quad (5)$$

where μ_0 is the permeability of free space. l, w, and t are the current path length, ring width, and ring thickness, respectively, and K is a geometrical constant.

C_{eff} includes gap capacitance C_{gap} and surface capacitance.

$$C_{gap} = \epsilon_0\epsilon_{eff}\ \frac{A}{G} \quad (6)$$

where ϵ_{eff} is the effective substrate permittivity, ϵ_0 is the permittivity of free space, A and G are the effective surface area and gap area, taking into account the fringing effects.

To obtain maximum directivity at the resonant frequencies, a parametric study was conducted on the number and dimensions of CSRRs to be etched. In each case, the directivity has been optimized for the resonant frequency corresponding to that dimension.

Table 1. Comparison study with latest similar works

Work	Frequency band, Dimensions	Directivity/ Gain (dB)	Key observations
[15]	30 GHz 11 x 10 x 0.5 mm^3	7 dB	Simple CPW structure with defected ground but moderate gain
[16]	28 to 46 GHz, 44 x 70 x 0.8 mm^3	6.8 to 8.5 dB	Good gain, but high design and fabrication complexity, complex feeding network
[17]	26 to 31 GHz, 9 x 18 x 1 mm^3	7.79 dB	Compact design but moderate gain
[18]	28 GHz 40 x 40 x 0.5 mm^3	7.9 dB	Compact design but not so high directivity, integration challenges
[19]	28 and 38 GHz 15 x 15 x 1.52 mm^3	5.91 and 4.57 dB	Simple structure but low gain
[20]	27-28.75 GHz, 36-42 GHz 8 x 7 mm^2	7 dB	Compact design with stubs and slots, but moderate gain
[21]	28 GHz 10 x 10 x 1.575 mm^3	7.38 dB	Simple circular patch with SRR but moderate gain
[22]	23, 28, 41, 51, 65 GHz $1.05\lambda L \times 1.05\lambda L \times 0.057\lambda L$	3-6 dB 5-8 dB	Compact structure but moderate gain
Our work	38, 42, 58 and 61 GHz 10 x 10 x 0.254 mm^3	8.68 to 10.6 dB	Compact and simple, defected ground, high directivity

3.1. Parametric study on the dimensions of CSRR

The effect of outer length and width, gap width, and ring width of CSRR on the antenna's directivity was analyzed and detailed in *figures 2(a), 2(b),* and *2(c)*, respectively. The optimum outer length and width were graphically determined as 1.4 mm, which resulted in a maximum directivity of 10.6 dB at the resonant frequency. Besides, the optimum ring width and gap were determined graphically as 0.3 mm to produce the same directivity. All other dimensions resulted in reduced directivity.

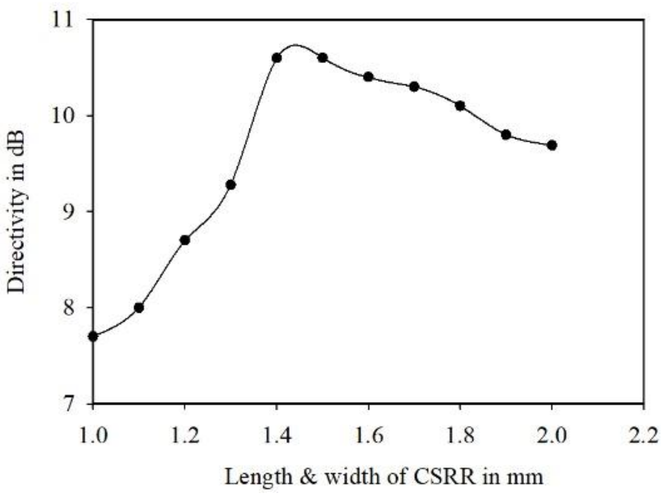
3.2. Parametric study on the number of CSRRs

Subsequently, a study was conducted on the no. of CSRRs to be etched to check how they affected the directivity, and is depicted in *figure 2(d)*. It was found that the maximum directivity was obtained by a single ring and that the directivity decreased as the number of rings and splits increased.

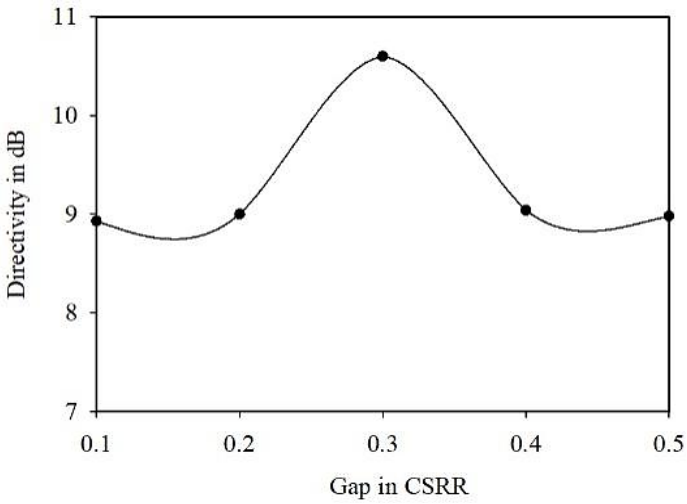
After analyzing the findings of the parametric study, a single split square CSRR was etched on the back side near the inset notch on one side to change the nature of the electromagnetic waves and to produce an enhanced directivity. When CSRR is etched into the ground plane, it reduces surface wave leakage so that the majority of the power is radiated into the main beam, thereby improving the pattern's directivity. Here the CSRR improves directivity to 10.6 dB.

4. FABRICATED PROTOTYPE

Simulation was done using the specialized electromagnetic software CST Microwave Studio. Following parametric study and optimization, the prototype was fabricated as depicted in *figure 3*. The photolithography technique is used for fabrication, with subsequent PCB etching. While soldering a 1.85 mm coaxial connector to the feed-point, the center conductor of the coax is soldered to the radiating patch, while the outer conductor is connected to the bottom ground plane. The measurement of antenna parameters was performed with Agilent 67 GHz Performance Network Analyzer (PNA).



(a)



(b)

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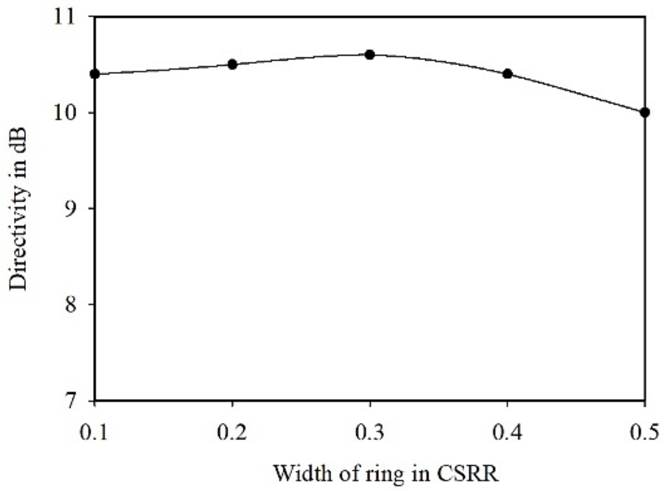

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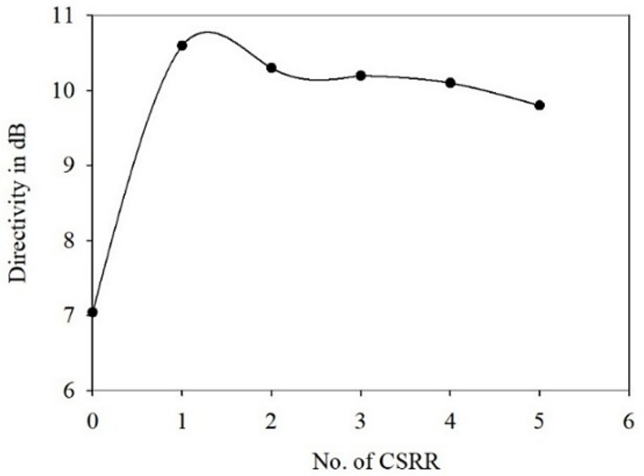
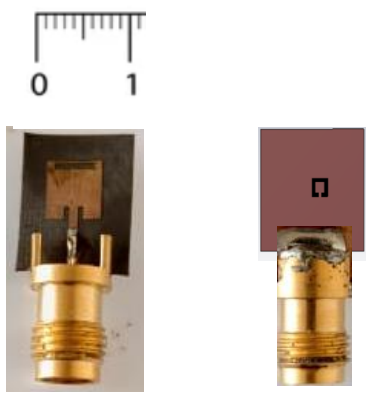


(d)

Figure 2. Effect of CSRR parameters on antenna directivity (a) Outer dimensions, (b) split gap width (c) ring width, and (d) no. of CSRR elements



(a) (b)

Figure 3. Fabricated antenna prototype (a) Front view (b) Back view with CSRR

5. SIMULATION AND EXPERIMENTAL RESULTS

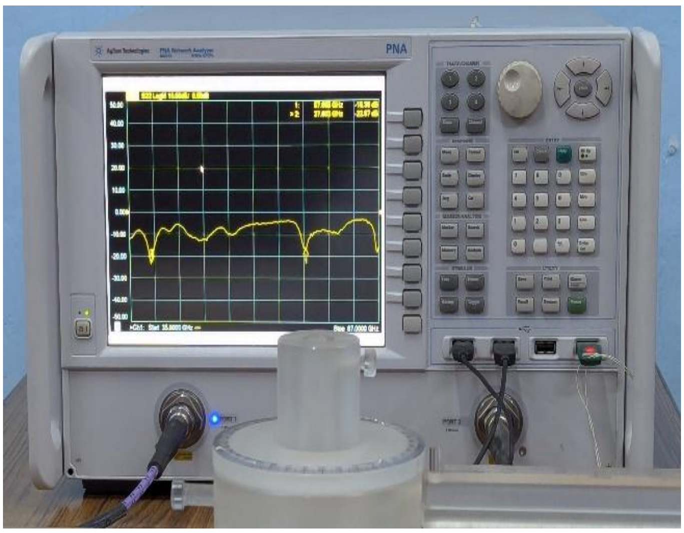
Various antenna parameters, namely S-parameters, directivity and efficiency were analyzed before and after the inclusion of CSRR to examine the impact of metamaterial integration. The results after simulation and measurement are almost in good agreement. RF components are highly sensitive at millimeter bands, thereby causing slight deviations in the measured resonant frequencies. *Figure 4(a)* shows the setup of S_{11} measurement and *figure 4(b)* depicts the pattern measurement using 67 GHz PNA and 67 GHz reference horn antenna. Higher gain can be observed at resonance.

5.1. Results without CSRR in ground plane

The simulated and experimental S_{11} curves for the patch antenna without CSRR are depicted in *figure 5*. Simulated resonance is at 38 GHz and 61 GHz respectively while measured resonance is at 38 and 58 GHz respectively. Bandwidths at lower and higher resonant frequencies were 1 and 2 GHz, respectively. Total efficiency was obtained as 80% using the Wheeler cap method. Polar plots of radiation patterns at resonance are illustrated in *figures 6(a)* and *6(b)*. Directivity values are 7.04 dB and 6.35 dB at the lower and upper resonance. The pattern is broadside, with the main lobe directed perpendicular to the axis.

5.2. Results with CSRR in ground plane

The antenna is modified into a defected ground structure by incorporating a complementary ring resonator in its ground plane. This acts as a metamaterial and introduces additional inductive-capacitive effects, modifying the current distribution. It can manipulate electromagnetic fields by confining and enhancing them, leading to the creation of directional radiation patterns.



(a)

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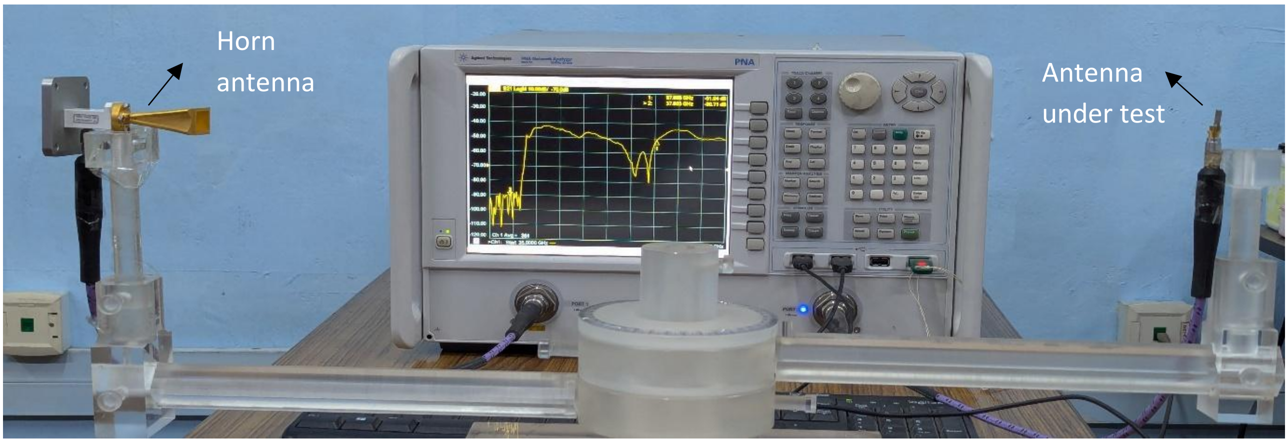


(b)

Figure 4. (a) S11 measurement showing dip at resonance, and (b) Pattern measurement setup with PNA and reference horn antenna

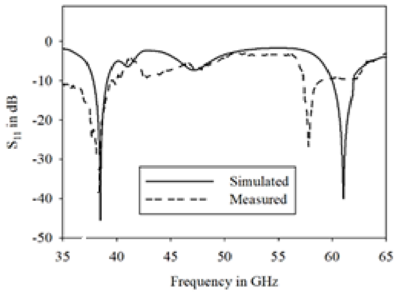
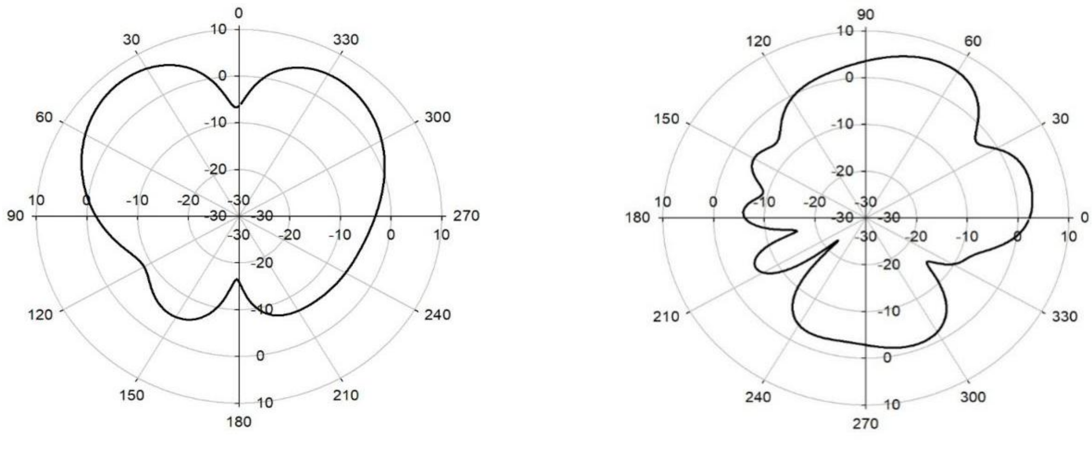


Figure 5. Simulated and measured S11 plot of antenna without CSRR Attained -10 dB bandwidth: 1 to 2 GHz



(a) (b)

Figure 6. Radiation patterns of antenna without CSRR at (a) 38 GHz, Directivity:7.04 dB, and (b) 58 GHz, Directivity: 6.35 dB

The addition of CSRR slightly shifts the resonance besides creating additional resonances, and the modified S-parameter curve is depicted in *figure 7*. Now S11 values are -15 dB, -12 dB, -22 dB, and -15 dB at 38, 42, 58, and 61 GHz respectively. Improved values of directivity are 8.68 dB, 9.46 dB, and 8.72 dB at 38, 42, and 61 GHz, respectively, and are presented in *figures 8(a), (b),* and *(c)*. The pattern with maximum directivity 10.6 dB is obtained at 58 GHz and is illustrated in *figure 8(d)*. The 3D pattern at 58 GHz is demonstrated in *figure 8(e)*. The measured efficiency is 85% using the Wheeler cap method.

Hence, directivity and efficiency have improved, and sidelobes and back radiation have reduced. Here comes the novelty and practical application of the work because the design does not involve complex geometries, arrays, or feeding networks. With the help of a simple slotted patch antenna and defected ground structure, an improvement in directivity to 10.6 dB was achieved. The defected ground was realized by etching a complementary ring resonator.

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As discussed in parametric analysis in *section 3*, the directivity of the radiation emanating from the antenna depends on various parameters of the CSRR such as its length, width, gap, etc. CSRR exhibits metamaterial behavior by altering the current distribution, preventing the leakage of surface waves, and by focusing the majority of the radiation into the broadside direction. Since the impedance matching and directivity are influenced by the dimensions of the CSRR, these parameters can be optimized and the design can also be scaled to higher frequencies. In 5G systems, where path loss degrades signal quality, this improvement in directivity is highly beneficial.

6. APPLICATION

The proposed antenna finds applications in 5G and 6G phones, tablets, IoT equipment, and wearable devices. Other applications at millimeter frequencies, such as micro- and nano-satellites, compact RFID devices, and autonomous cars, also require directional antennas. mmWave bands encounter high path loss and signal attenuation, so miniaturized directional antennas are inevitable. Signals must reach the targeted user with least interference. It also increases the range and reduces transmission power.

7. CONCLUSION AND FUTURE DIRECTIONS

A patch antenna has been designed on RT Duroid 5880 to resonate at mmwave bands, which are ideal for 5G and 6G applications. A slot was added near the top of the patch to modify the current paths and create two resonant 5G frequencies. By etching a complementary split ring resonator in the ground plane, directivity has improved to 10.6 dB due to confinement of the electric field, resulting in highly focused radiation.

The distinctive aspect of the prototype is that, despite its compact size, it provides more directivity than other structures of comparable size due to metamaterial integration. Since RT Duroid 5880 is selected as the substrate, there is little dielectric loss.

Hence, by integrating metamaterials, the characteristics of electromagnetic waves can be modified to obtain highly directed beams. This also leads to miniaturization, thereby providing a huge scope for further work in this direction. Highly directional pattern reconfigurable arrays can be developed by loading CSRRs in combination with RF switches. The concept of utilizing defected ground structures for gain improvement can also be scaled to terahertz frequencies, and machine learning techniques can further optimize the dimensions of CSRR.

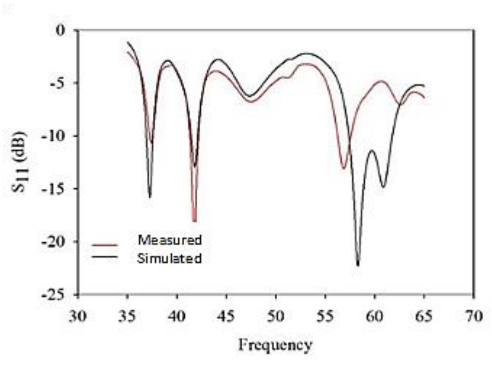

Figure 7. S_{11} plot of antenna with CSRR attained -10 dB bandwidth: 1 to 2 GHz

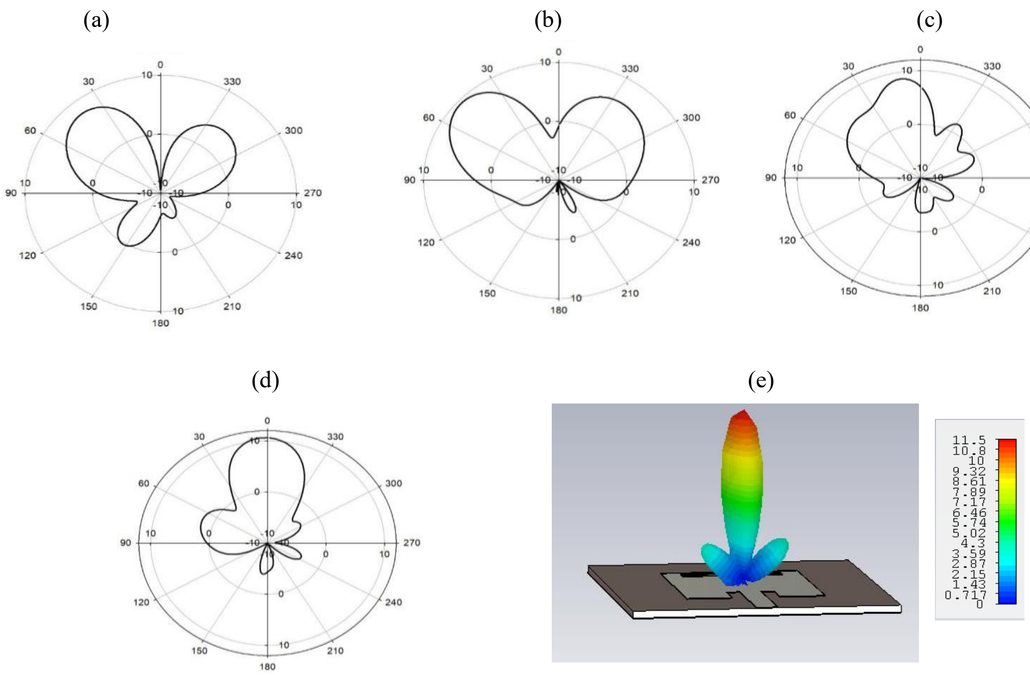

Figure 8. E-plane radiation patterns with CSRR at (a) 38 GHz: 8.68 dB, (b) 42 GHz: 9.46 dB, (c) 61 GHz: 8.72 dB, (d) 58 GHz: 10.6 dB, (e) 3D pattern at 58 GHz (Maximum directivity of 10.6 dB = 11.5)

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REFERENCES

[1] Yang Y, Mao M, Xu J, Liu H, Wang J, Song K. Millimeter-Wave Antennas for 5G Wireless Communications: Technologies, Challenges, and Future Trends. Sensors. 2025.

[2] Mehmood, F. and Mehmood, A. Recent Advancements in Millimeter-Wave Antennas and Arrays: From Compact Wearable Designs to Beam-Steering Technologies. Electronics. 2025.

[3] M. Soman, M. Sharma, Seema and P. Kumar, "A Review of the Design and Performance of Passive 5G mm Wave Multi-Port Antenna on Printed PCB," 2025 Modern Electronics Devices and Intelligent Communication Systems (MEDCOM), Greater Noida, India, pp. 1113-1118, 2025.

[4] T.R. Ganesh Babu, R. Praveena, B. Pramod Kumar, N. Harshith Sri Sai, and M. Supriya, "Substrate Integrated Waveguide Slot Antenna for 5G Application", IRO Journal on Sustainable Wireless Systems 7 (1): 90-101, 2025.

[5] S. Tariq, W.T. Sethi, A. A. Rahim et al, "A meta-surface assisted pin loaded antenna for high gain millimeter wave systems", Sci Rep 15, 12056, 2025.

[6] A. Kaur and J.S. Sivia, "A MIMO Antenna for 5G Wireless Applications, Designed with Hybrid Fractal Geometry and Incorporating CSRR Loading," PIER C, Vol. 156, pp. 243-252, 2025.

[7] A. Zerrouk, M.L Tounsi, T.P. Vuong, N. Corrao and M.C.E. Yagoub, "Miniaturized Patch Array Antenna Using CSRR Structures for 5G Millimeter-Wave Communication Systems", Electronics. 14(9), 2025.

[8] Y. Mood, R Pandeeswari, "A Novel SRR Metamaterial Inspired CPW-Fed Dual Band MIMO Antenna for Sub-6 GHz 5G Application", Wireless Pers Commun 130, pp. 1277–1293, 2023.

[9] P. Jha, A. Kumar, N. Sharma and D. Saxena, "CSRR Loaded Compact Textile Antenna with Defected Ground for Wearable 5G and Wi-Fi 6E Applications," 2nd International Conference on Paradigm Shifts in Communications Embedded Systems, Machine Learning and Signal Processing (PCEMS), Nagpur, India, 2023.

[10] K. Aljaloud, Y.T. Aladadi, M.A.S. Alkanhal, W.M.Abdulkawi, R.A. Hussain, "Wideband GRIN Dielectric Lens Antenna for 5G Applications", Micromachines,14, 997, 2023.

[11] H. Ahmad, M.H. Jamaluddin, F.C. Seman, M. Rahman, "MIMO Dielectric Resonator Antennas for 5G Applications: A Review", Electronics. 12. 3469, 2023.

[12] P.Kumar, T.Ali, O.P. Kumar, S. Vincent, P. Kumar, Y. Nanjappa, S. Pathan, "An Ultra-Compact 28 GHz Arc-Shaped Millimeter-Wave Antenna for 5G Application", Micromachines, 14, 5, 2023.

[13] Balanis, C. A., Antenna Theory: Analysis and Design, 2nd edition, John Wiley and Sons Inc., 1997.

[14] J. D. Baena et al., "Equivalent-circuit models for split-ring resonators and complementary split-ring resonators coupled to planar transmission lines," IEEE Transactions on Microwave Theory and Techniques., vol. 53, no. 4, pp. 1451–1461, Apr. 2005.

[15] R.Singh, and M. Arora, "Millimeter Wave Wideband Patch Antenna with DGS Slots and Truncated Corners for 5G Applications," Progress in Electromagnetics Research C, Vol. 167, 149-154, 2026.

[16] M.K.Khan, S.Liu, M.I.Khan, M.I., "A Wideband Eight-Port MIMO Antenna with Reduced Mutual Coupling for Future 5G mm-Wave Applications",Sensors, 25, 484, 2025.

[17] M. Rajeshwari, K. Saffrine, S. Sangeetha and R. Hema, "A Compact Wideband Two-Port mm -Wave Antenna for 5G Application," PIER M, Vol. 131, 51-59, 2025.

[18] K. C. Rao, D. Nataraj, K. S. Chakradhar, G. V. Ujwala, M. Lakshmunaidu, and H. S. Dadi, "Design of a Compact Millimeter Wave Antenna for 5G Applications based on Meta Surface Luneburg Lens", Eng. Technol. Appl. Sci. Res., vol. 15, no. 2, pp. 20722–20728, 2025.

[19] S.Abubakar, M.Umar, U.S. Umar, M.M. Abubakar, A.S Hussaini, M.O. Akinsolu, C.H See, and R. A. Abd-Alhameed, "Compact Dual-Band Wearable Antenna for Millimeter-Wave Applications: Designed for Medical and IoT Device Integration," Progress In Electromagnetics Research Letters, Vol. 126, 77-85, 2025.

[20] P.S. Bhadravathi Ghouse, P. Kumar, P.R. Mane, S.Pathan,, T.Ali, A.-A.A. Boulogeorgos, J.Anguera, "Dual-Band Antenna at 28 and 38 GHz Using Internal Stubs and Slot Perturbations", Technologies 12, 84, 2024.

[21] E.A. Hajlaoui, Z. Almohaimeed, "New Compact Broadband SRR Loaded Antenna Pattern for 5G Applications", Sens Imaging 25, 27, 2024.

[22] P. Dheeraj, D. Reshmi, B. Sunandan, K.Surajit, "Design and analysis of a compact millimeter-wave pentaband antenna for 5G FR-2 band wireless technologies", AEU - International Journal of Electronics and Communications, vol.184, 155409, 2024.

[23] S. Dinesh and C.Aanandan, "Highly Directive and High Gain Multiple Beam Reconfigurable Antenna for Base Stations" IJEER 12(4), 1337-1343, 2024.