SRR Loaded Wideband Antenna 5G Application

Kiran Chand Ravi
School of electronics engineering
VIT-AP University
Amaravathi, AndhraPradesh-522237, India.
b4uchandu2011@gmail.com

Vadym Slyusar
CSRI AW, Armed Forces of Ukraine
Principal research fellow
Kyiv, Ukraine
swadim@ukr.net

Jayendra Kumar
School of electronics engineering
VIT-AP University
Amaravathi, AndhraPradesh-522237, India.
jayendra854330@gmail.com

***Abstract*—5G communication systems ensure high data rate, low latency, network reliability, and energy efficiency and high throughput that require new and very efficient antenna designs. In this paper, we proposed a simple and very effective antenna with centre frequency 28GHz designed on an RF4 substrate of 1.6mm thickness. The performance characteristics of the antenna-like reflection coefficient (S11), voltage standing wave ratio (VSWR), radiation pattern and impedance have been investigated using HFSS. Optimization techniques are applied to achieve significant results. A defective ground structure was chosen for obtaining proper impedance matching. The simulated results are satisfactory and the proposed antenna is a good candidate to operate in the millimetre wave frequency band that is 28GHz range for 5G application.**

***Index Terms*—5G antenna, Microstrip antenna, Millimeter-wave antenna, Split-ring-resonator, Wideband antenna.**

I. Introduction

Mobile technology usage has been drastically increasing day by day for the last few years' results in more congestion of frequency spectrum. As the existing mobile technology is not able to support such heavy traffic led to the alternate and work towards future mobile technology that is the fifth generation (5G) mobile technology. The capabilities of 5G communication systems include realizing high-speed connectivity, the internet of things(IoT), augmented virtual reality and tactile internet and many more. The requirements of 5G can be met with a new spectrum in the microwave frequency bands (3.3 - 4.2 GHz) and effectively utilizing larger bandwidths in the millimetre wave frequency bands (24 -100 GHz). In this range, 26 GHz and 28GHz are important bands because high frequency provides better bandwidth in turn very high data rate and very low latency. The challenging task is the fabrication of the antenna due to the reduction in the antenna dimensions at high frequencies [1-2]. Many researchers have been focusing on the design of these antennas. Different approaches and techniques have been proposed and developed like patch antennas on electrically thick substrates, probe fed antenna, the slotted antenna [3-4]. It is most challenging to design a high gain antenna at high frequencies. The proposed antenna in this paper is simple, compact and effective as well with minimum modification to ensure ease of fabrication.

The defects in ground is found very effective to improve the bandwidth, cross-polarization [5], and miniaturization. Incorporating the defects in the ground plain leads radiation on both sides of the substrate which is found useful for wireless communication systems. The 28 GHz frequency band has been made available by the Federal Communications Commission (FCC) by reallocating the local multipoint block distribution service (LMDS) A1, which is 850 MHz wide and

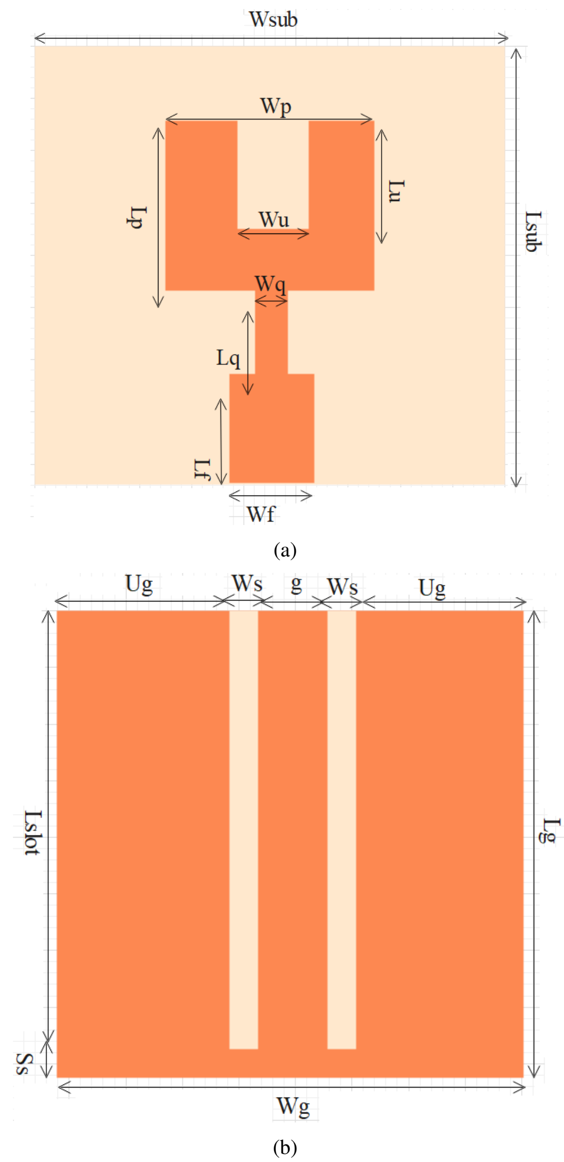


Fig. 1. Layout of the antenna configurations (a) Top view (b) Bottom view.

TABLE I
DIMENSIONS OF DESIGN ATTRIBUTES OF THE PROPOSED ANTENNA

Parameter	Unit (mm)	Parameter	Unit (mm)
L_p/W_p	4	L_{slot}	8.52
L_{sub}/L_g	11.26	W_s	0.3
W_{sub}/L=W_g	12.86	L_f	W3.2
L_u	2.6	W_f	0.75
W_u	1.2	S_s	0.18
L_q	1.5	U_g	5.78
W_q	0.3	G	0.7

lies between 27.50 and 28.35 GHz bands. Many researchers have been proposed several designs of the antenna operating at the 28 GHz band. The directional single element slot antenna operating at 28 GHz has been proposed in [6]. The broadband antenna centred at 28 GHz, optimized using FEKO software for LMDS use has been proposed in [7]. H-shaped MIMO antenna resonates at 25 GHz has been discussed in [8]. Insert fed compact slotted microstrip antenna operating 28 GHz proposed in [9]. Teaching Learning-Optimization (TLBO) algorithm based dual-band E-shaped antenna has been proposed in [10]. An investigation focusing on radiation characteristics of a quad-core MMIC based phased array at 28 GHz is presented in [11]. Bandwidth improvement is necessary to ensure a high data rate, low latency, particularly for the wireless mobile communication systems. Artificial materials are special and most interesting research topic these days. Researchers have been focusing on the design of antennas loaded with Split Ring Resonator (SRR) structures that can be utilized to enhance the bandwidth of an antenna [13-15]. However, the partial ground plane antennas [16-17] has naturally wideband response but omnidirectional pattern and lower gain. The two modes have been combined to improve the bandwidth in [17]. The engineered material, metamaterial are found very effective in improving the performance of the microstrip antennas [18]. Among different metamaterial structures, the split-ring-resonator (SRR) are popular due to its stable performance and ease of designs [19]. In [20], electronic band-gap structure is used to minimize the mutual couling. In this work, a simple tuning fork-shaped and effective SRR loaded patch antenna with multiple tiny slits in the ground layer has been proposed.

This paper is organized as follows: geometry of patch antenna, design aspects, parameters with specifications in tabular form and design of SRR is described in section II. Result analysis of antenna parameters like return loss, VSWR, gain and pattern is given in section III. The conclusion is given in section IV.

II. ANTENNA DESIGN

In this section details of the antenns design procedure and their attributes are discussed. The results are presented and discussed. The proposed antenna is designed on FR-4 epoxy substrate material with a thickness of 1.6 mm. The length and width of the ground and the substrates are the same. The layout of the proposed antenna model is shown in Fig.1 and Fig.2.

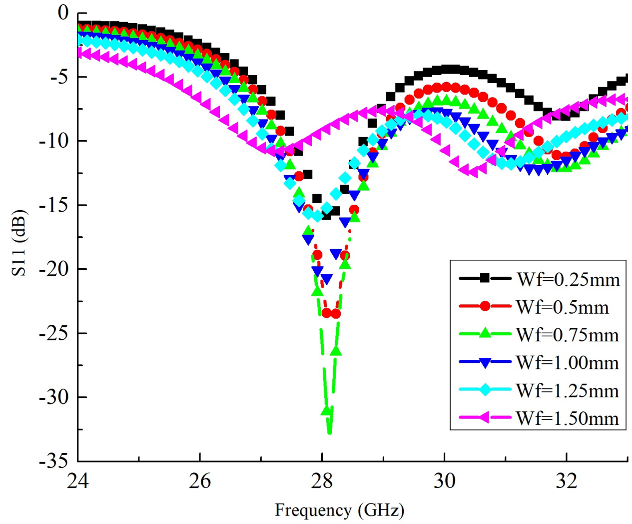


Fig. 2. Scattering parameter (S11) versus width (W_f)

The patch is fed by a 50 Ω microstrip line. The quarter-wave transformer and all other parameters are given in table.1.

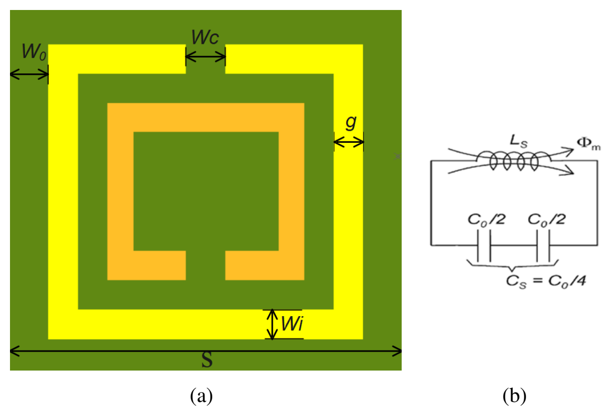


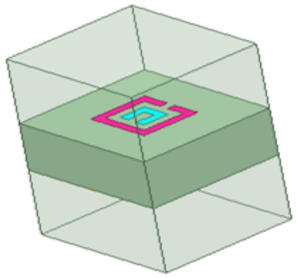
Fig. 3. Split-ring-resonator and its equivalent circuit (a) Layout (b) Equivalent circuit.

TABLE II
DIMENSIONS OF DESIGN ATTRIBUTES OF THE SRR

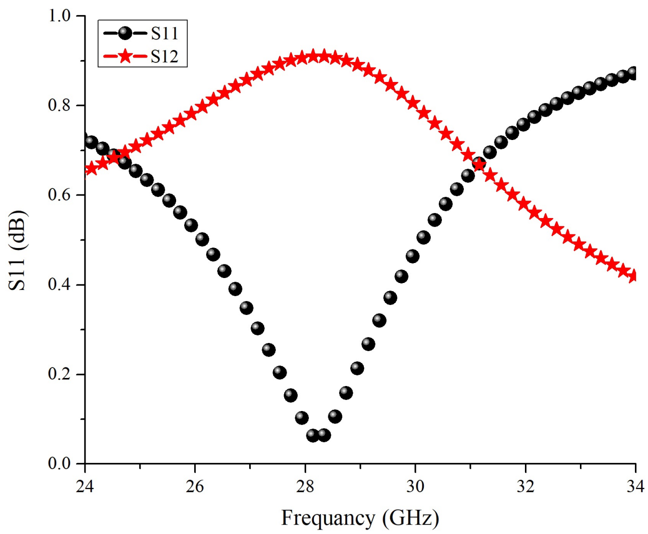
Parameter	W_0	W_i	W_c	S	g
Dimensions (mm)	0.2	0.2	0.2	1.46	0.2

The antenna is optimized to achieve significant results. The proposed antenna structure is simulated using HFSS (High-Frequency Structure Simulator) software. The optimization technique is applied by taking the width of the microstrip feed line (Wq) as a varying parameter and the corresponding reflection coefficient characteristics (S11) are shown in Fig.3. Two tiny slits beneath the tuning fork-shaped patch are introduced in the ground to achieve compactness and impedance matching.

There are different formulae for the design of the antenna. The dimensions of the patch antenna are calculated using the and corresponding S11 plot is shown in Fig. 5. In Fig. 5, it is observed that the proposed structure is well suited to operate at the 28 GHz frequency band. The effect due to the presence of SRR on the top layer of the substrate near the patch has been investigated. Initially, a single SRR cell is placed near the patch that results in minor changes in the resonant frequency of the antenna. Now two SRR elements are placed on either side of the conducting patch, there is a slight shift in the resonant frequency has been observed and also the improvement in the bandwidth as well.

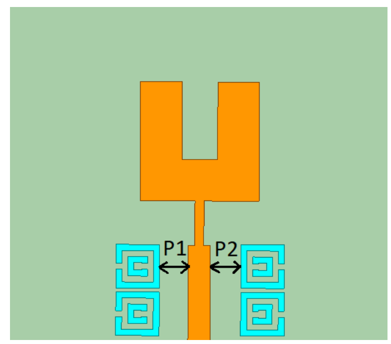


(a)

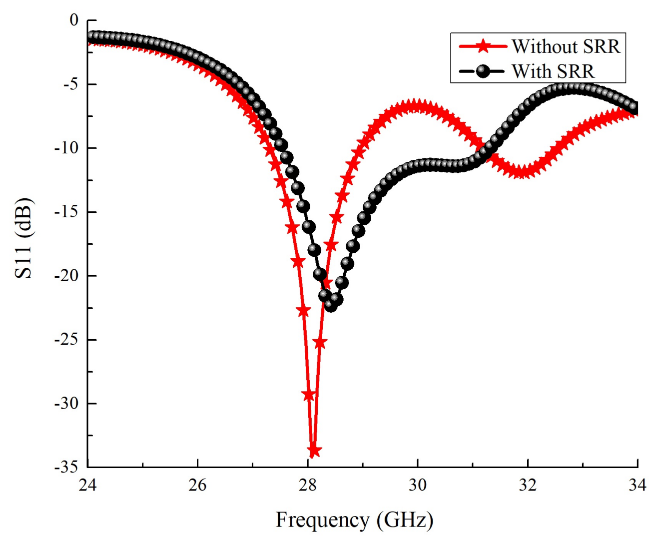


(b)

Fig. 4. Characterization of SRR (a) Simulation setup in high-frequency-structural-simulator (b) Reflection coefficients, S11 and S12.



(a)



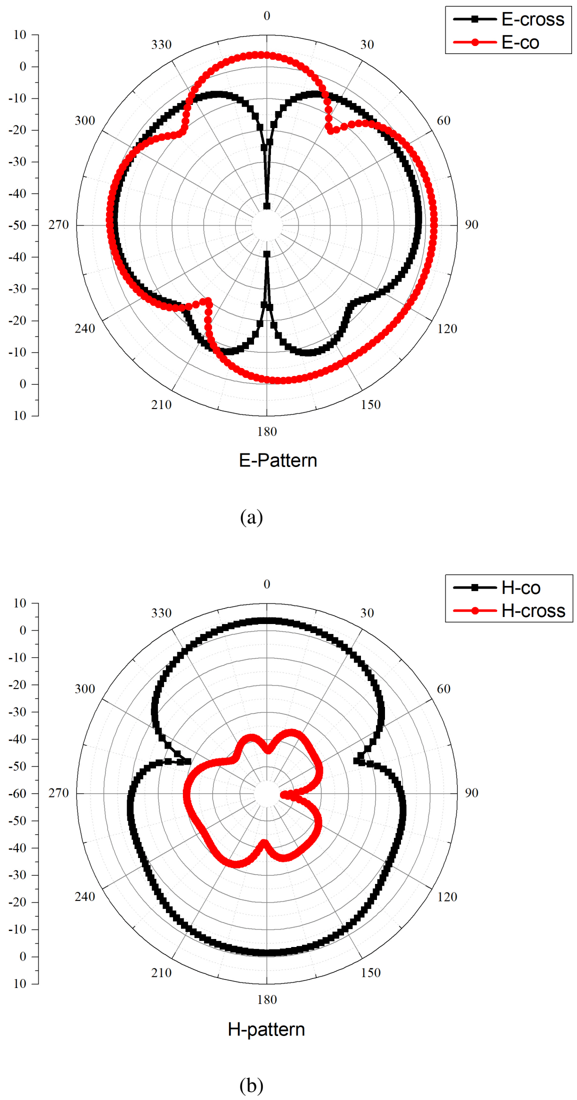
(b)

Fig. 5. SRR loaded antenna configuration (a) Layout (b) Reflection coefficient ($P_1 = P_2 = 1mm$).

formulae given in [11]. To achieve more gain square shape patch can be chosen. For effective radiation the width of the feed line is varied. In 1967, Victor Veselago, the Russian Physicist speculated the possible existence of Left handed (LH) material that does not exist in nature. After 30 years, in 1998, J.B.Pendry proposed and demonstrated experimentally the existence of meta-material (MTM) which is not a natural substance, but an artificial effectively homogeneous substance.

Its cell size is required to be less than one-quarter of the guided wavelength. When a wave propagates inside the MTM, the refractive phenomenon dominates over the diffraction or scattering phenomenon. SRR comprises two concentric conducting rings having split in each separated by a gap between the inner and outer rings. The SRR behaves like a parallel LC resonating circuit, the resonating current flow along with the rings with charges prevents the current from flowing around the ring and the circuit is closed across the capacitive gap between the rings. The performance of the SRR can be analyzed with the HFSS tool that is whether the proposed structure is suitable for the desired band of frequency or not. The reflection coefficient is the primary parameter for the performance analysis of the SRR structure. The layout

Two SRR cells on either side of the patch near the feed line at a distance of 1 mm on each side resulting in significant improvement in the bandwidth and gain as well. The shift in the resonant frequency (increase) is due to the reduction in the capacitance of the structure and the gap between the rings. The resonant frequency may decrease by adding the additional capacitance in parallel to the outer ring of the system. The layout of the SRR loaded antenna and its corresponding reflective coefficient plot is shown in Fig. 6.



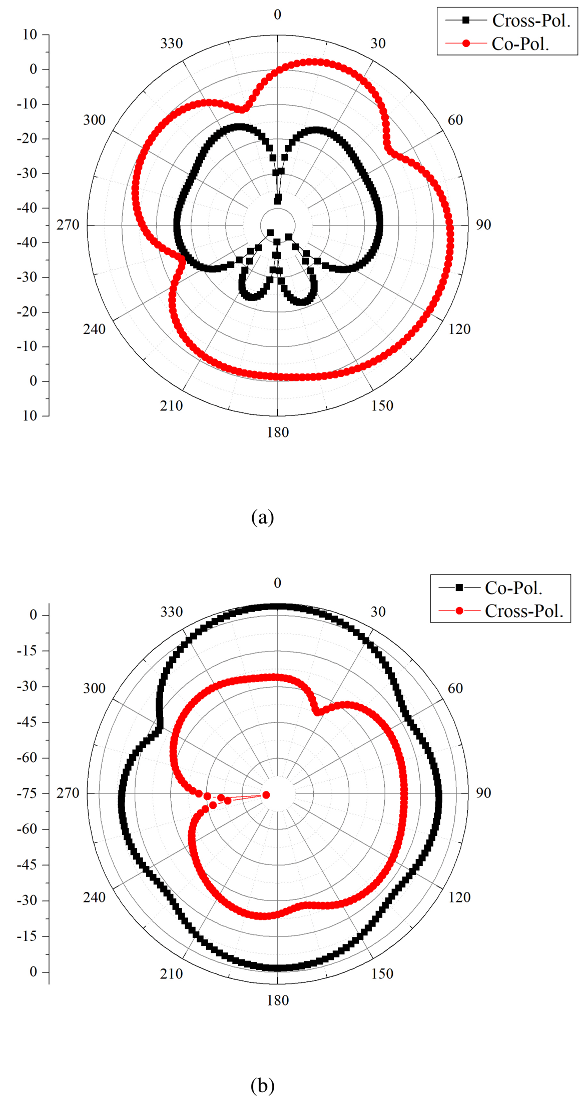


Fig. 6. Radiation pattern of the without SRR loaded antenna at 28.12 GHz (a) XZ-plane (b) YZ-plane.

Fig. 7. Radiation pattern of SRR loaded antenna at 28.12 GHz (a) XZ-plane (b) YZ-plane.

A. Results and discussion

The designed slotted antenna is simulated using the HFSS tool and corresponding results are given in Figs. 5, and 8. The simulated reflective coefficient has S11 ¡ - 10 dB bandwidth is from 27.30 to 29.03 GHz with 6.3% bandwidth with centre frequency 28.12GHz. Fig.8 indicates the simulated E-plane (XZ) and H-plane (YZ) radiation patterns at 28.12 GHz. The simulated gain is 2.7 dBi.

Fig. 8 presents the radiation pattern of the SRR loaded patch antenna at 28.12 GHz. The reflective coefficient has a value S11 ¡ - 10 dB bandwidth is from 27.50 to 31.30 GHz with 24.15% bandwidth. The comparison between the reflective coefficients of both antennas is given in Fig. 6. The simulated results show the improvement of the bandwidth is achieved with the use of SRR. The gain also improved from 2.7 dBi to 5.4 dBi. It can be observed from the fig.8 that the proposed antenna has more directional characteristics. The presence of the SRR reduces the quality factor of the antenna. As the bandwidth is inversely related to the quality factor, the bandwidth is increased. The analytically low value of the antennas quality factor confirms its ability to operate in the wide frequency range. The comparison of the performance parameters of the proposed antenna with others proposed in the literature is given in Table III.

TABLE III
COMPARISON TABLE.

Ref. No.	f_0 (GHz)	Bandwidth (GHz)	Gain (dBi)
[3]	28	5.57	5.06
[4]	25	6.68	6.4
[5]	28	2.38	5.7
This work	28	3.77	5.4

III. Conclusion

An SRR loaded microstrip patch antenna with slitted ground plane is proposed to operate in the millimeter wave range (28 GHz) for 5G application. The optimization technique is useful in fixing the dimension of the particular parameter to achieve significant results. The impedance bandwidth obtained is significantly improved from 1.73GHz (27.30 GHz -29.03 GHz) to 3.77 GHz (27.50 to 31.30 GHz) by integrating the two pairs of Split Ring Resonators (SRR). The gain of the proposed SRR loaded antenna is also improved from 2.7 dBi to 5.4 dBi when compared with that of antenna-I. The results obtained for other performance characteristics like VSWR, impedance, directional patterns are satisfactory and hence it can be concluded that the proposed antenna is suitable to use in the high-frequency range for 5G application. Bandwidth may further improve by integrating Complementary SRR (CSRR).

References

[1] J.G.Andrews, S.Buzzi, W.Choi, S.V.Hanly, A.Lozano, A.C.K.Soong, and J.C.Zhang, "What will 5G be?," IEEE J. Commun., vol. 32, pp. 1065–1082, June 2014.

[2] The FCC's , "5G FAST, Plan, Spectrum," https://www.fcc.gov/5G,2021-08-30.

[3] Mohsen Khalily Rahim Tafazolli, Pri Xiao and Ahmed A.Kishk, "Broadband mm-Wave microstrip array antenna with improved radiation characteristics for different 5G applications," IEEE Trans. Antennas Propag., vol 67, pp. 1–8, 2018.

[4] Melvin C.Jose, S.Radha, B.S.Sreeja, and Pratap Kumar, "Design of 28GHz high gain 5G MIMO antenna array system," IEEE Region 10 Conf. (TENCON), pp. 1913–1916, 2019.

[5] J. Kumar, B. Basu, F. A. Tlukdar, A. Nandi"Multimode-Inspired Low Cross-Polarization Multiband Antenna Fabricated Using Graphene-Based Conductive Ink," IEEE Antennas Propag. Lett., vol. 17, pp. 1861-1865, 2018.

[6] M. Ikram, B.N.-Trong, and A. Abbosh"Multiband MIMO Microwave and millimeter Antenna System Employing Dual-function tapered slot structure," IEEE Trans. Antennas Propag., vol. 67, pp. 5705–5710, Aug. 2019.

[7] M. B. Rafal Przesmycki, Marek Bugaj and Leszek Nowosielski, "Broad band microstrip antenna for 5G wireless systems operating at 28 GHz," MPDI, Electronics, vol. 10, pp. 2-19, JDec 2020.

[8] N. Shoaib, et al, "MIMO antennas for smart 5G devices," IEEE Access, vol. 6, pp. 77014–77021, 2018.

[9] Abdul Naser F.Kaeib, Nafaa M.Shebani, and Amer R. Zarek, "Design and analysis of a slotted microstrip antenna for 5G communication network at 28 GHz," 19th Int.Conf.STA., Sousse, Tunisia, 2019.

[10] S.K. Goudas, et al, "Evolutionary design of a dual-band E-shaped patch antenna for 5G mobile communications," , 6th Int.Conf.MOCAST, U.K., 2017.

[11] Risto Valkonen, "Compact 28-GHz Phased array antenna for 5G access, " IEEE/MTT-S, Int.Microw.Symp., Pennsylvania, pp. 1334–1337,2018.

[12] C.A.Balanis, "Antenna Theory: Analysis and Design," , 3rd ed. Hoboken, NJ, USA: Wiley, 2005..

[13] J.B. Pendry, A.J. Holden, D.J. Robbins, and W.J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomenon," IEEE Trans. Microw. Theory Tech., vol. 47, . pp. 2075–2084, Nov. 1999.

[14] V.G. Veselago, "The electrodynamics of substances with simultaneously negative values of permittivity and permeability," Sov. Phys. USPEKHI, vol. 10, pp. 509-514, 1968.

[15] A. Nuthan Reddy and S.Raghavan, "Split ring resonator and its evolved structures over the past decade," IEEE –ICE-CCN, Tirunelveli, India, 2013.

[16] J. Kumar, S. S. Shirgan and D. B. Patil, "Miniature Wideband 1x2 Microstrip Antenna for 4G Application," IEEE Global Conference on Wireless Computing and Networking (GCWCN), Lonavala, India, 2014, DOI: 10.1109/GCWCN.2014.7030884.

[17] Wenquan Cao, Wenyu Ma, Wenfang Peng, and Zhi Ning Chen, "Bandwidth enhanced electrically large microstrip antenna loaded with SRR structures," IEEE Ant. Wireless Propag.Lett., vol. 18, Apr.2019.

[18] V. Slyusar, "Metamaterials on antenna solutions," International Conference on Antenna Theory and Techniques ICATT'09, Lviv, Ukraine, pp. 19-24, 2009.

[19] I. Sliusar, V. Slyusar, Y. Utkin and O. Kopishynska, "Parametric Synthesis of 3D Structure of SRR Element of the Metamaterial," International Conference on Problems of Infocommunications. Science and Technology (PIC S&T), 2020, pp. 577-582, 2020.

[20] J. Kumar, "Compact MIMO antenna," Microw. Opt. Technol. Lett., vol. 58, pp. 1294-1298, 2016.