Design and Analysis of Microstrip Antenna for Wireless Applications using Metamaterial

Rudra Umesh Kolwalkar[1], Hassanali Virani[2]

[1]*Student, Dept. of Electronics and Telecommunication Engineering, Goa College of Engineering, Goa, India*
[2]*Professor, Dept. of Electronics and Telecommunication Engineering, Goa College of Engineering, Goa, India*

Abstract – *This paper proposes a microstrip antenna of inverted L stubs and a semi-circle shaped patch with the help of a metamaterial planar structure, i.e. a complementary split ring resonator (CSRR) in the 3-6 GHz frequency range using a High Frequency Structure Simulator (HFSS) for wireless applications. The presence of metamaterial on the ground plane improves the antenna parameters. The antenna has dimensions of 60 mm x 45 mm designed on a 1.6 mm thick FR4 substrate with microstrip line feeding. It has a CSRR ring of 4 mm etched on the ground plane. It resonates at frequencies of 3.54 (3.39 3.76) GHz and 5 (4.62-5.65) GHz with a bandwidth of 370 MHz and 700 MHz and a return loss of –14.2023 dB and –34.7791 dB, respectively. The antenna has an average gain of 1.89 dBi. It can be used for C Band, WiMAX, Wi-Fi, and WLAN applications. The antenna's performance was analyzed in terms of return loss, VSWR, bandwidth, radiation pattern, gain and radiation efficiency.*

Key Words: Microstrip antenna, Metamaterial, CSRR, Inverted L Stubs, C band, WiMAX, Wi-Fi, WLAN.

1. INTRODUCTION

Microstrip patch antennas are popular for wireless communication applications like mobile and satellite due to their light weight, low profile, ease of fabrication and feed [1]. The use of a thick dielectric substrate with a low dielectric constant is preferred for good antenna performance since it provides better efficiency [2]. Microstrip patch antennas can be in any arbitrary shape, such as a triangular patch antenna [3].

Metamaterial is an artificial material that has a negative dielectric constant. These materials are periodic which are not found in nature. It has negative dielectric permittivity (ε) and negative magnetic permeability (μ) [4]. Complementary split ring resonators (CSRR) and split ring resonators (SRR) are widely used as metamaterial elements. A Swastik slotted hexagonal patch antenna with metamaterial based complementary split-ring resonators is proposed. The unit cell structure of the CSRR metamaterial antenna has been optimized to enhance the antenna's performance in terms of bandwidth, resonant frequency, gain, and miniaturization [5]. A dual-feed CSRR-loaded multiband microstrip patch antenna with a single layer dielectric constant for ITS and other wireless applications is reported [6].

A compact tri-band antenna based on inverted-L stubs for smart devices was designed with three inverted L stubs and a triangular shaped monopole antenna. The longest stub portion is printed on the substrate's back and connected to the other portion via a metallic pin. The antenna resonates at multiband frequencies of 2.4 GHz, 3.5 GHz and 5.5 GHz [7].

In this paper, a microstrip antenna of inverted L stubs and a semi-circle shaped patch with a metamaterial planar structure complementary split ring resonator (CSRR) on the ground plane is designed. The proposed antenna exhibits dual frequencies at 3.54 GHz and 5 GHz in the 3-6 GHz frequency range. The resonant frequency is tuned by changing the stub length and CSRR position. It is applicable for WiMAX, C band (n77, n78, n79) and Wi-Fi applications.

2. METAMATERIAL STRUCTURE

The complementary split ring resonator (CSRR) is one of the most famous metamaterial structures. It is composed of two concentric metallic rings with slits etched in each ring on its opposite side. The gap between the rings restricts the current flow around the rings, which considerably increases the resonance frequency of the structure. The resonant frequency can be easily tuned by changing the position and geometry parameters of the CSRR [8].

CSRR can be represented as an L-C circuit. The resonance frequency of CSRR can be calculated [9] using Equation (1).

$$f_r = \frac{1}{2\pi\sqrt{L_{CSRR}C_{CSRR}}} \quad (1)$$

$$C_{CSRR} = \frac{N-1}{2}[2L-(2N-1)(w+d)]C_0 \quad (2)$$

$$C_0 = \varepsilon_0 \frac{K\sqrt{1-k^2}}{K(k)} \text{ and } k = \frac{d}{2w+d} \quad (3)$$

$$L_{CSRR} = [L-(N-1)(w+d)]4\mu_0\left[ln\left(\frac{0.98}{\rho}\right)+1.84\rho\right] \quad (4)$$

$$\rho = \frac{(N-1)\,(w+d)}{L-(N-1)\,(w+d)} \quad (5)$$

Where L = 11 mm is the average length, N = 2 is the number of CSRR rings, w = 2 mm is the width of metallic rings, d = 4 mm is the distance between the slots, $K(k)$ is the first order complete elliptical integral, ε_0 is vacuum permittivity, μ_0 is vacuum permeability and ρ is the filling ratio. Hence the inductance L_{CSRR} = 5.0403x10^{-8} Henry and the capacitance C_{CSRR} = 2.2797x10^{-14} Farad. Therefore, the resonance frequency is f_r = 4.6951 GHz.

CSRR is placed in the waveguide setup as shown in Fig. 1. The scattering parameters S_{11} and S_{21} of this unit cell are extracted using the appropriate boundary conditions specified. The waveguide's left and right faces are set to the perfect magnetic conductor (PMC) boundary condition. The waveguide's top and bottom faces are set to the perfect electric conductor (PEC) boundary condition. Ports are set at the sides of the waveguide. The negative permittivity and negative permeability of the CSRR are extracted using the retrieved scattering parameters S_{11} and S_{21} using the Nicolson Ross Weir (NRW) equation [10].

$$\varepsilon_r = \frac{2}{jk_0 d} * \frac{1-V_1}{1+V_1} \tag{6}$$

$$\mu_r = \frac{2}{jk_0 d} * \frac{1-V_2}{1+V_2} \tag{7}$$

where $V_1 = S_{21} - S_{11}$, $V_2 = S_{21} + S_{11}$, k_0 = wave number of free space and d = substrate thickness.

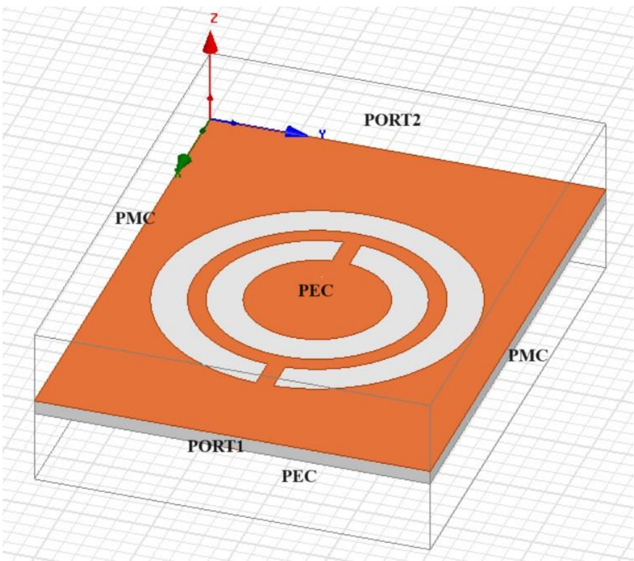


Fig -1: S parameter extraction setup of the proposed CSRR

Fig. 2 shows the negative permittivity of the proposed CSRR at 4.46 GHz and other resonant frequencies. The negative permeability of the proposed CSRR is shown in Fig. 3 at 4.58 GHz and other resonant frequencies. The proposed metamaterial structure, CSRR is etched on the ground plane. The proposed CSRR produces negative permittivity and negative permeability, which are the main features of metamaterial.

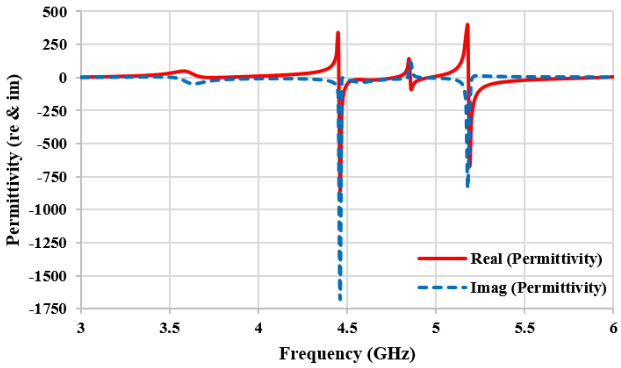


Fig -2: Negative Permittivity of the Proposed CSRR

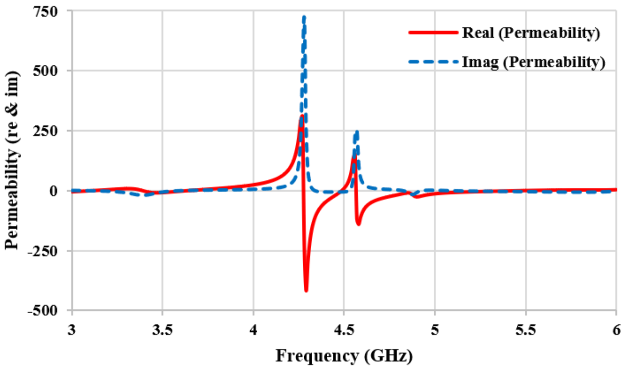
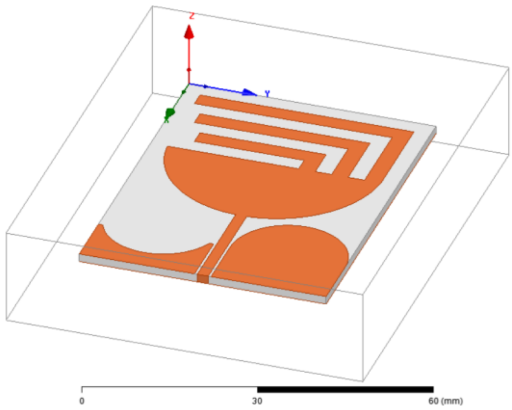


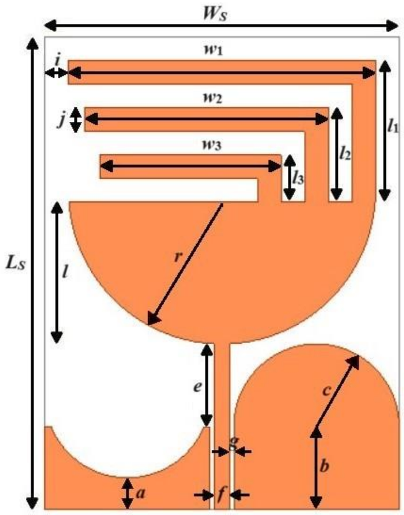
Fig -3: Negative Permeability of the Proposed CSRR

3. PROPOSED ANTENNA DESIGN

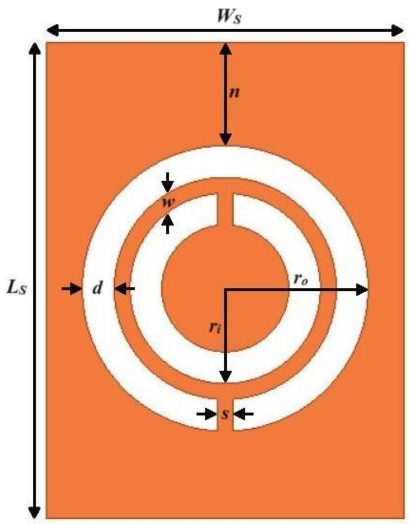
The design of the proposed inverted L stubs and semi-circle shaped microstrip patch antenna with CSRR on the ground plane using High Frequency Structure Simulator (HFSS) software is presented in this section. The proposed antenna has dimensions of 60x45 mm^2 designed on a flame retardant (FR-4) substrate of 1.6 mm thick with a dielectric constant of 4.4 and has microstrip line feeding. The CSRR of 4 mm is etched on the ground plane. Table I displays the dimensions of the proposed antenna. The Trimetric view, front view and bottom view of the proposed antenna are shown in Fig. 4 (a), (b) and (c), respectively.



(a)



(b)



(c)

Fig -4: Proposed antenna design (a) Trimetric view (b) Front view (c) Bottom view

Table -1: Dimensions of Proposed Antenna Design

Parameter	Dimensions (mm)	Parameter	Dimensions (mm)
L_S	60	a	4
W_S	45	b	10.5
w_1	39	c	10.5
w_2	31	e	10.5
w_3	23	f	2
l_1	18	g	0.5
l_2	12	w	2
l_3	6	d	4
l	18	s	2
i	3	r_o	18
j	3	r_i	12
r	19.5	n	13

4. RESULTS AND DISCUSSION

The simulated analysis of the proposed antenna is done using HFSS software in the 3-6 GHz frequency range. The proposed antenna resonates at two frequencies 3.54 GHz and 5 GHz, with a bandwidth of 370 MHz at (3.39-3.76) GHz and 700 MHz at (4.64-5.65) GHz. It was observed that when you vary the size of the stubs and the curves, the frequency bands shift. The presence of CSRR on the ground plane gives a better response compared to the ground plane.

Fig. 5 shows the return loss (S_{11}) of −14.2023 dB and −34.7791 dB at 3.54 GHz and 5 GHz, respectively. Fig. 6 shows the voltage standing wave ratio (VSWR) plot with values of 1.4843 and 1.0372, which are near one and less than 2. The values of return loss and VSWR are mentioned in Table II.

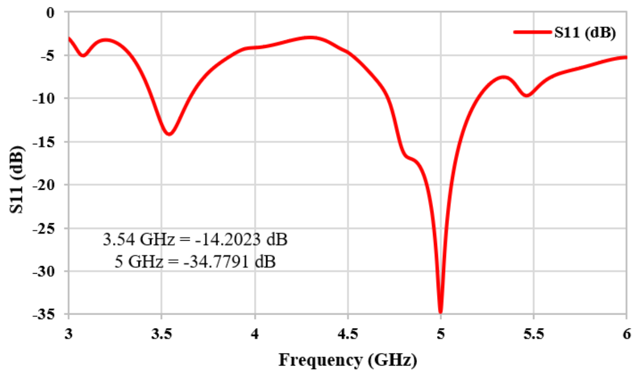


Fig -5: Return Loss (S_{11})

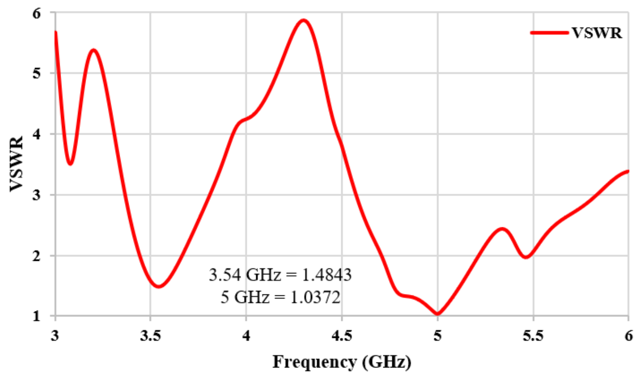
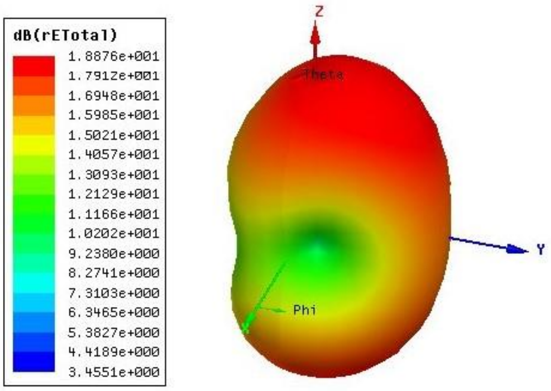


Fig -6: VSWR

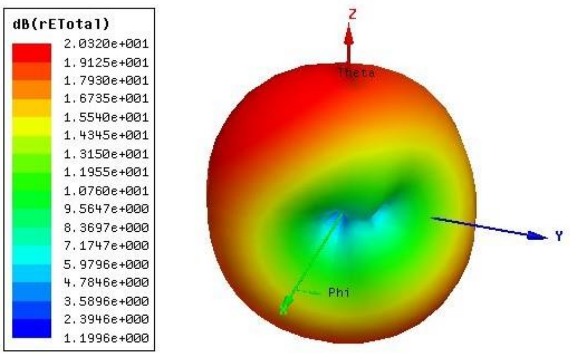
Table -2: Simulation Results

Frequency (GHz)	Return Loss (dB)	VSWR
3.54	−14.2023	1.4843
5	−34.7791	1.0372

Fig. 7 (a) and (b) show the 3D radiation pattern at 3.54 GHz and 5 GHz, respectively.



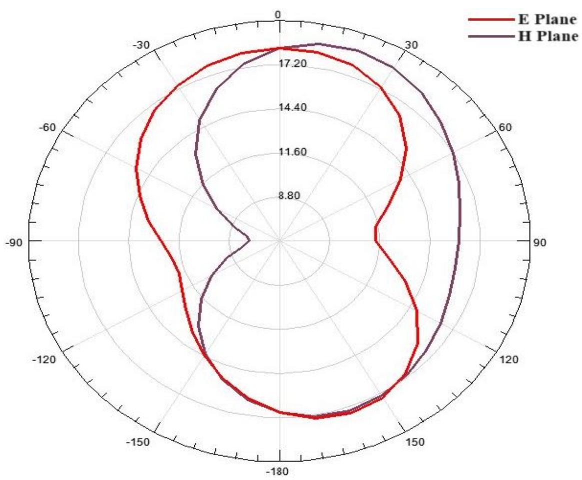
(a)



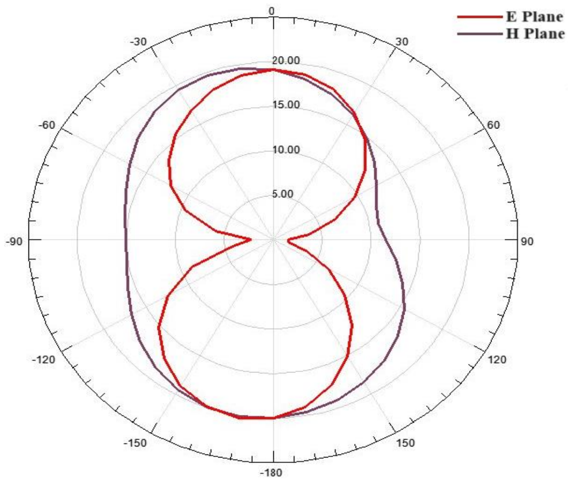
(b)

Fig -7: 3D Radiation Pattern at (a) 3.54 GHz and (b) 5 GHz

The 2D radiation pattern in the E plane with phi = 0 and the H plane with phi = 90 of the proposed antenna at 3.54 GHz and 5 GHz is shown in Fig. 8 (a) and (b), respectively. The E-field and H-field patterns are described as Omni directional in nature, so this dual band antenna is radiated in all directions.



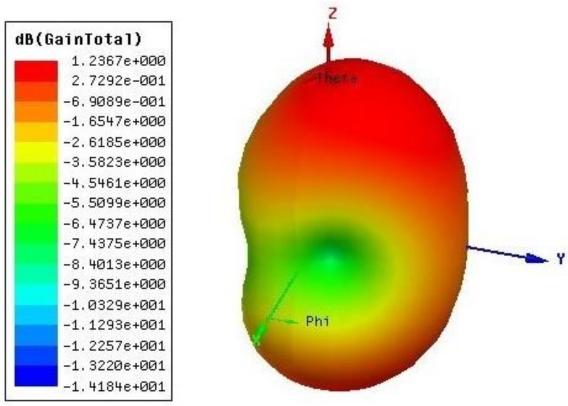
(a)



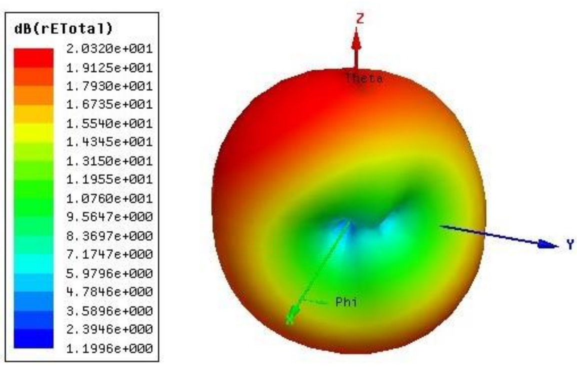
(b)

Fig -8: 2D Radiation Pattern in the E and H Plane at (a) 3.54 GHz and (b) 5 GHz

The 3D gain plot of the proposed antenna is shown in Fig. 9 (a) and (b) at 3.54 GHz and 5 GHz. It has a gain of 1.2367 dBi at 3.54 GHz and 2.5471 dBi at 5 GHz. The proposed antenna has an average gain of 1.89 dBi. It has a directivity of 2.2932 dBi and 3.7754 dBi at 3.54 GHz and 5 GHz, respectively.



(a)



(b)

Fig -9: 3D Gain Plot at (a) 3.54 GHz and (b) 5 GHz

The proposed antenna's radiation efficiency was found. The radiation efficiency of 78 % is obtained at 3.54 GHz and 75 % at 5 GHz. Fig. 10 shows the radiation efficiency of the proposed antenna.

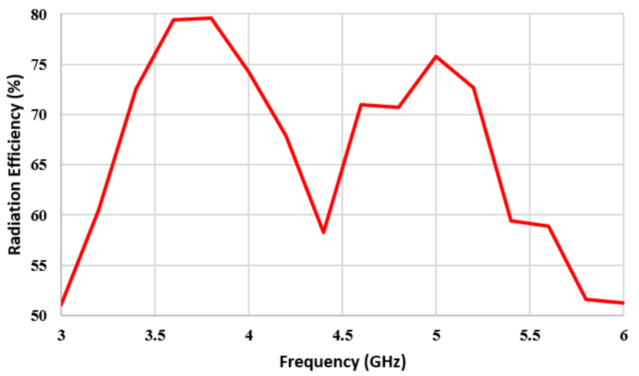


Fig -10: Radiation Efficiency

5. CONCLUSIONS

A microstrip antenna of inverted L stubs and a semi-circle shaped patch with the metamaterial planar structure CSRR on the ground plane, having dimensions of 60x45x1.6 mm^3 which operates in 3-6 GHz frequency range is proposed and designed in this paper. It resonates at frequencies of 3.54 GHz and 5 GHz having bandwidths of 370 MHz and 700 MHz with a return loss of –14.2023 dB and –34.7791 dB respectively. It has a VSWR of 1.4843 and 1.0372, which is less than 2 and an average gain of 1.89 dBi. This antenna can be used for applications such as C band, WiMAX, Wi-Fi and WLAN.

REFERENCES

[1] W. Ali, E. Hamad, M. Bassiuny and M. Hamdallah, "Complementary split ring resonator based triple band microstrip antenna for WLAN/WiMAX applications," Radioengineering, vol. 26, no. 1, pp. 78-84, April 2017.

[2] G. Bhai, M. Dubey and L. K. Tyagi, "A New Design of Dual-Band Microstrip Patch Antenna for Wireless Communication," International Research Journal of Engineering and Technology (IRJET), vol. 4, no. 6, pp. 3000-3003, June 2017.

[3] B. L. Narayana and S. N. Bhavanam, "Design & Simulation of Triple Frequency Triangular Patch Antenna by Using HFSS 14.0," International Journal of Applied Engineering Research, vol. 10, no. 20, pp. 18585-18589, April 2015.

[4] G. Vidhate, "Metamaterial loaded rectangular patch antenna for wireless communication application," International Journal, vol. 9, no. 3, pp. 193-197, March 2021.

[5] K. L. Kishore, R. R. Reddy and N. K. Darimireddy, "Swastik Slotted Hexagonal Patch Antenna with Metamaterial Based Complementary Split-Ring Resonator," ICTACT journal on microelectronics, vol. 6, no. 03, pp. 995-1000, October 2020.

[6] G. Upadhyay, N. Kishore, S. Raj, S. Tripathi and V. S. Tripathi, "Dual-feed CSRR-loaded switchable multiband microstrip patch antenna for ITS applications," IET Microwaves, Antennas & Propagation, vol. 12, no. 14, pp. 2135-2140, November 2018.

[7] N. Hussain, A. Abbas, S. M. Park, S. G. Park and N. Kim, "A compact tri-band Antenna based on inverted-L stubs for smart devices," Computers, Materials & Continua, vol. 70, no. 2, pp. 3321-3331, January 2022.

[8] A. T. Devapriya, G. Rani and S. Robinson, "Dual resonant microstrip patch antenna using metamaterial planar structures for S band and C band applications," ICTACT Journal on Communication Technology, vol. 7, no. 4, pp. 1432-1437, December 2016.

[9] R. S. Daniel and R. Selvaraj, "A low-profile spilt ring monopole antenna loaded with hexagonal split ring resonator for RFID applications," Progress In Electromagnetics Research M, vol. 92, pp. 169-179, May 2020.

[10] S. P. J. Christydass and N. Gunavathi, "Dual-band complementary split-ring resonator engraved rectangular monopole for GSM and WLAN/WiMAX/5G sub-6 GHz band (new radio band)," Progress In Electromagnetics Research C, vol. 113, pp. 251-263, July 2021.