Design of Square Split Ring Resonator Shaped Metamaterial Structure for Enhancing the Microstrip Patch Antenna Parameters

Abhishek Singh Kuswaha, H. P. Sinha

Abstract— In this work, Rectangular Microstrip Patch Antenna (RMPA) along with metamaterial which has Square Split Ring Resonator (SSRR) and Horizontal Rectangular Strip (HRS) structure is proposed at hight of 3.2 mm from the ground plane. The RMPA with proposed metamaterial structure is designed to resonate at 2.097 GHz frequency. This work is mainly focused on increasing the potential parameters of microstrip patch antenna. Proposed metamaterial structure is significantly reduced the return loss and increased the bandwidth and directivity of the antenna with compare to RMPA alone. These improvements are due to the Double-Negative (DNG) properties of metamaterial structure that acts as a lens when placed in front of the RMPA. All the simulation work is done by using CST-MWS Software. For verifying DNG properties of proposed metamaterial structure Nicolson-Ross-Weir (NRW) technique is used.

Index Terms— Rectangular Microstrip Patch Antenna (RMPA), Square Split Ring Resonator (SSRR), Horizontal Rectangular Strip (HRS), Double-Negative (DNG), Nicolson-Ross-Weir (NRW).

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1 Introduction

THE Microstrip Patch antenna is the most demanding antenna for their attractive properties and applications such as its low outline, light weight, dense and resilient in structure, and simple to be integrated with solid-state devices “[2]”.

A metamaterial is a structure composite with unique electromagnetic properties such as the backward wave and the negative refraction “[3]”. In 1967 the concept of metamaterial had been discovered by Vector Veselago “[1]”. Veselago found the existence of unknown materials which has the value of permittivity and permeability are simultaneously negative at the resonate frequency. Later on J.B. Pendry and his colleagues gave the information related to negative properties of metamaterial “[4]”. According to them the array of metallic wires can be used to obtain negative permittivity and split ring resonators for negative permeability “[4]”.

Shelby Smith and Schultz invented the first structure to prove the existence of meta materials was split ring structure in 2001 “[7]”. Three new structures were also proposed now, starting with symmetrical ring structure, then omega structure and finally S structure “[8]”. In this paper square split ring resonator and horizontal rectangular strip structure was used as a Meta material substrate for enhancing the parameters of rectangular micro-strip patch antenna. In particular the complementary split ring resonator which establishes a negative permittivity at resonance “[15]”. Computer Simulation Technology (CST MWS) Software has been used for simulation and Microsoft Excel Software has been used for verifying the Double Negative properties of the proposed design.

2 Design Specification

The RMPA parameters are calculated from the formulas given below.

A. Desired Parametric Analysis “[5], [6]”

Calculation of Width (W)

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Where,
c = free space velocity of light
ε_r = Dielectric constant of substrate

The effective dielectric constant of the RMPA

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \qquad (2)$$

The actual length of the Patch (L)

$$L = L_{eff} - 2\Delta L$$

(3)

Where

$$L_{eff} = \frac{C}{2f_r\sqrt{\varepsilon_{eff}}} \qquad (4)$$

Calculation of Length Extension

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \qquad (5)$$

The RMPA is designed using the parameters calculated from the above discussed formulae.

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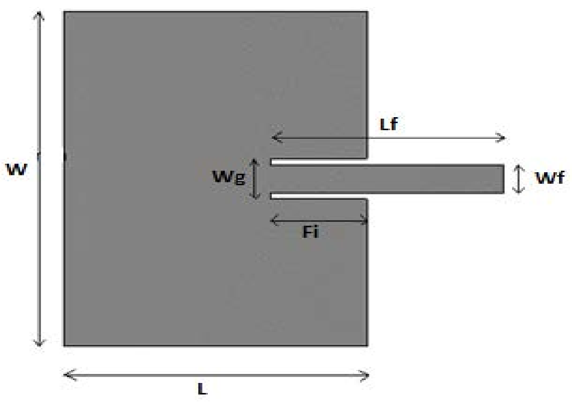


Figure 1: Dimension of Rectangular Microstrip Patch Antenna

Figure 1 illustrates the dimension of RMPA. The RMPA is designed on FR4 Lossy substrate which has the dielectric constant 4.3, thickness 1.6 mm and loss tangent 0.02. The length and width of RMPA are L=32.54 mm, W=41.88 mm respectively, which are calculated from the formulae discussed earlier. The cut width, Wg is 5 mm, cut depth, Fi is 5.57 mm, path length, Lf is 25.07 mm and width of feed, Wf is 3.6 mm, these values have been chosen to obtain the resonate frequency of the proposed antenna at 2.154 GHz.

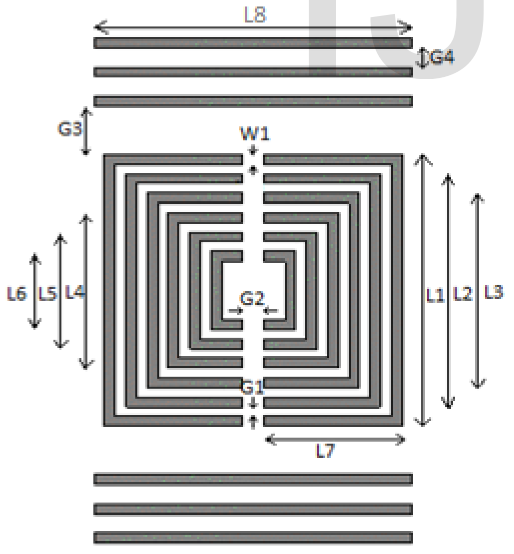


Figure 2: Dimension of proposed metamaterial structure consists of SSRR and HRS

Figure 2 illustrates the dimension of proposed meta material structure consists of SSRR and HRS.

The widths and gaps of the SSRR transmission lines, W1 and G1 are fixed to 1 mm. The gap G2 is 2 mm and the gap between the SSRR and HRS, G3 is 4 mm. The gap between the two HRS, G4 is 3 mm. The most outer length of SSRR, L1 is 28 mm, L2 is 24 mm, L3 is 20 mm, L4 is 16 mm, L5 is 12 mm, inner length of SSRR L6 is 8 mm. L7 is 12 mm. The length of HRS, L8 is 28 mm. The dielectric constant of the FR4 (Lossy) substrate is 4.3, thickness is 1.6 mm and loss tangent is 0.02.

3 ANALYSIS AND SIMULATION RESULTS OF RMPA ALONE AND RMPA WITH METAMATERIAL STRUCTURE

Return loss S_{11} and Impedance Bandwidth of RMPA is shown in Fig. 3. The return loss is -10.425 dB and bandwidth is 17 MHz.

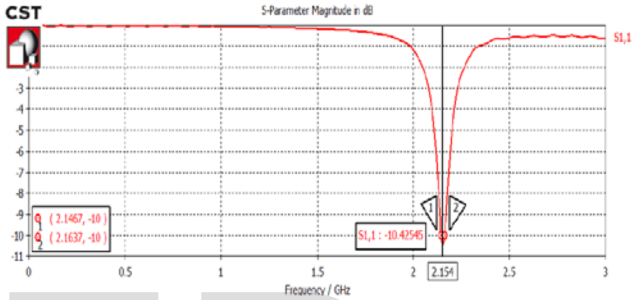
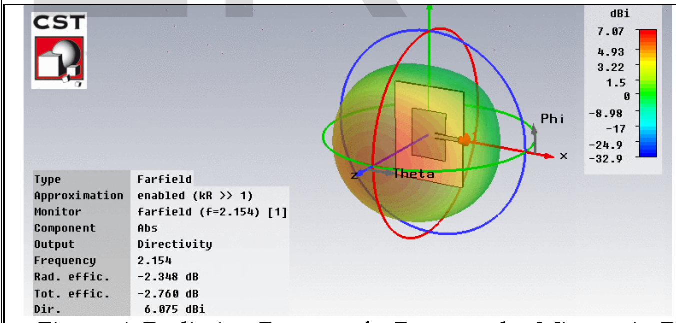


Figure 3: Simulation of Return loss S_{11} and impedance bandwidth of Rectangular Microstrip patch antenna

3-Dimensional Radiation Pattern of RMPA showing directivity of 6.075 dBi is shown in Fig. 4.



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Type           Farfield
Approximation  enabled (kR >> 1)
Monitor        farfield (f=2.154) [1]
Component      Abs
Output         Directivity
Frequency      2.154
Rad. effic.    -2.348 dB
Tot. effic.    -2.760 dB
Dir.            6.075 dBi
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Figure 4: Radiation Pattern of a Rectangular Microstrip Patch Antenna

RMPA with proposed meta material is given below in Fig 5.

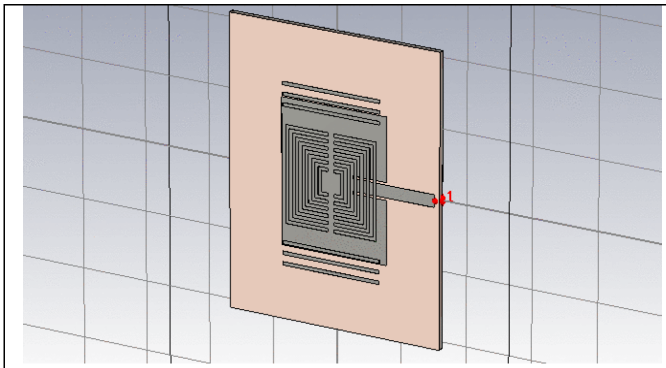


Figure 5: Rectangular Microstrip Patch Antenna with proposed metamaterial structure.

Return loss S_{11} and Impedance Bandwidth of RMPA with proposed metamaterial structure is shown in Fig. 6. RMPA with proposed metamaterial structure reduces the return loss from -10.425 dB to -28.15 dB and increases the bandwidth from 17 MHz to 36.2 MHz compare to RMPA alone.

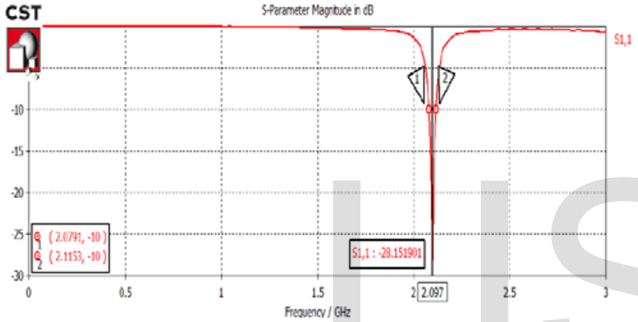
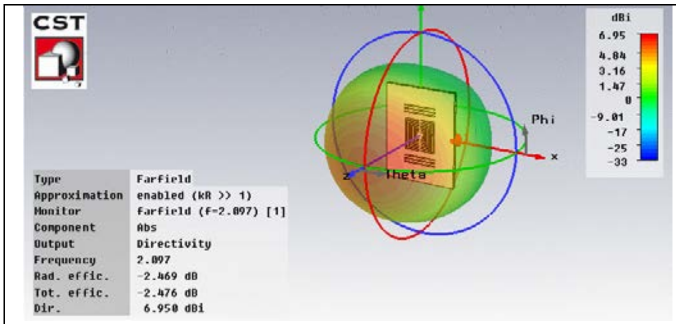


Figure 6: Simulation of Return Loss S_{11} and impedance bandwidth of RMPA with proposed metamaterial structure.

3-Dimensional Radiation Pattern of RMPA with proposed metamaterial structure showing directivity 6.950 dB is shown in Fig.7.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.097) [1]
Component	Abs
Output	Directivity
Frequency	2.097
Rad. effic.	-2.469 dB
Tot. effic.	-2.476 dB
Dir.	6.950 dBi

Figure 7: Radiation Pattern of RMPA with proposed meta material structure.

S-Parameter Smith Chart of RMPA with proposed metamaterial structure is shown in Fig.8.

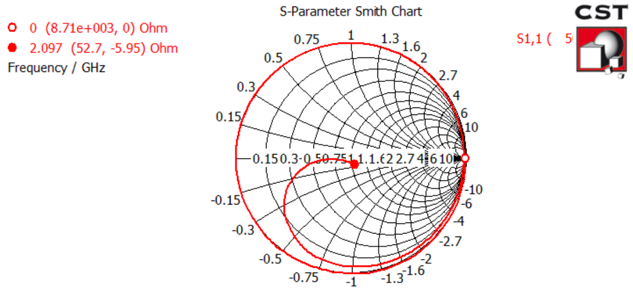


Figure 8: Smith chart of RMPA with proposed metamaterial structure.

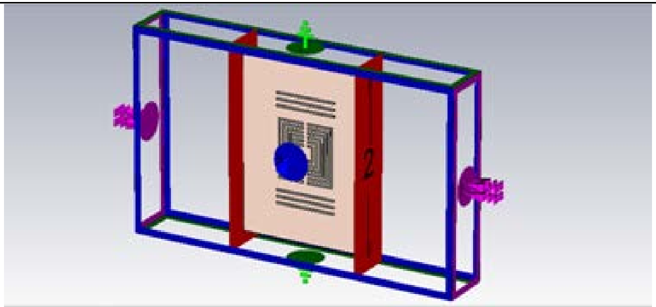


Figure 9: Proposed metamaterial structure between the two waveguide ports.

In figure 9, proposed metamaterial structure is placed between two waveguide ports "[13], [14]" at the left and right side of the X axis, in order to calculate the S-Parameters and Y-Plane is defined as Perfect Electric Boundary (PEB) and Z-Plane is defined as the Perfect Magnetic Boundary (PMB). The simulated S-Parameters are used to obtain the values of permittivity and permeability, Microsoft Excel Program has been used for calculating and verifying the values of permittivity and permeability.

In this work, Nicolson-Ross-Weir (NRW) technique "[8], [10]" has been used to obtain the values of permittivity and permeability.

NRW Method:

B. Equations used for calculating permittivity and permeability "[9], [10], [11], [12]".

$$\mu_r = \frac{2.c(1-v_2)}{\omega.d.i(1+v_2)} \tag{6}$$

$$\varepsilon_r = \frac{2.c(1-v_1)}{\omega.d.i(1+v_1)} \tag{7}$$

$$V_1 = S_{11} + S_{21} \tag{8}$$

$$V_2 = S_{21} - S_{11} \tag{9}$$

Where

εr = Permittivity

μr = Permeability

c = Speed of Light

ω = Frequency in Radian

d = Thickness of the Substrate
V_1 = Voltage Maxima
V_2 = Voltage Minima

For having metamaterial properties, the values of permeability and permittivity should be negative. The obtained values of these two quantities from the MS-Excel Program are given in Table I & II, whereas Fig. 10 & Fig. 11 shows the graph between permeability & frequency and permittivity & frequency respectively.

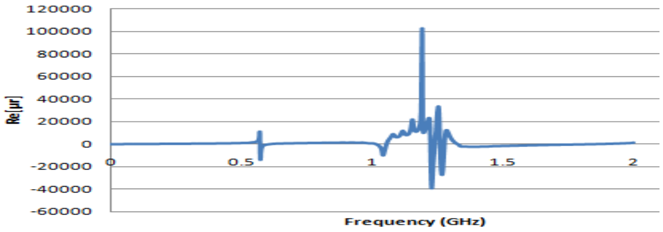


Figure 10: Permeability versus Frequency Graph

TABLE- I

Frequency [GHz]	Permeability [μr]	Re [μr]
1.5599999	-1248.71245447918-24.6564597842818i	-1248.7125
1.5619998	-1235.72817863709-18.0527220105529i	-1235.7282
1.564	-1220.85307098648-12.5932918355314i	-1220.8531
1.566	-1204.59766866701-8.81646810062187i	-1204.5977
1.568	-1187.60757301158-7.04437233340394i	-1187.6076
1.5699998	-1170.57442152016-7.36267421784434i	-1170.5744

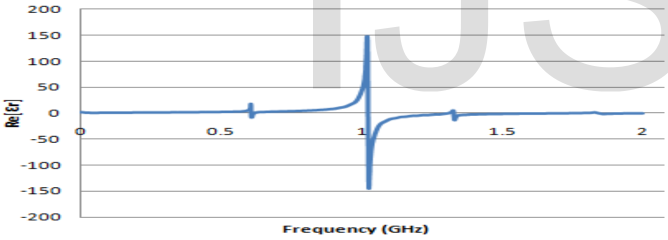


Figure 11: Permittivity versus Frequency Graph.

TABLE- II

Frequency [GHz]	Permittivity [Ɛr]	Re [Ɛr]
1.5599999	-1.64628379806763-0.0494641880757884i	-1.64628
1.5619998	-1.63873858934806-0.0600665941388673i	-1.63873
1.564	-1.63446686923797-0.0690450704398191i	-1.63446
1.566	-1.63280619888407-0.0754730239985121i	-1.6328
1.568	-1.6328343710905-0.0786629247034153i	-1.63283
1.5699998	-1.63344993771045-0.0782407883938419i	-1.63344

4 SIMULATION RESULTS

Fig. 5 shows the configuration of the Rectangular Microstrip Patch Antenna with proposed metamaterial structure. This structure is placed at the 3.2 mm layer from ground plane of the patch antenna. By simulating both the antennas on CST-MWS, the return loss has significantly reduced by 17.725 dB and bandwidth has increased by 36.2 MHz, which is clear from the Fig. 3 and Fig. 6. Radiation Pattern of the rectangular microstrip patch antenna is shown in Fig. 4, it shows that the directivity is 6.075 dBi, where as Fig. 7 shows the radiation pattern of the rectangular microstrip patch antenna with proposed metamaterial structure, which shows that the directivity is 6.950 dBi. Smith Charts of proposed antenna is shown in Fig. 8.

5 CONCLUSION

On the basis of the results it is observed that the minimum return loss obtained at design frequency of the patch antenna with proposed metamaterial structure is -28.15 dB and bandwidth is 36.2 MHz, this is remarkable improvement in C-band (1-2GHz). It is clearly observed that the antenna gain and bandwidth has improved significantly by employing proposed SSRR based metamaterial structure at 3.2 mm layer from the ground plane of the antenna. Along with these improvements this structure possesses Double negative properties i.e. negative values of permeability and permittivity.

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