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Innovative Double H Metamaterial Structure for Amelioration in Patch Antenna Parameters

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Abstract

A rectangular microstrip patch antenna along with a SSRR based "Double H" shaped metamaterial is proposed and analyzed at a height of 3.2mm from the ground plane. This work is mainly focused on increasing the potential parameters of microstrip patch antennas. The patch antenna along with the proposed metamaterial structure is designed to resonate at 1.84GHz. The impedance bandwidth of the patch antenna along with the proposed metamaterial structure is improved by 12.9MHz and return loss is reduced by 9.89dB. All the simulation work is done by using CST-MWS Software. Double-Negative properties (Negative Permeability and Permittivity) of the proposed metamaterial structure have also been verified using Nicolson-Ross-Weir method (NRW).

Keywords: *SSRR (Square Split Ring Resonator), rectangular microstrip patch antenna (RMPA), impedance bandwidth, return loss, Nicolson-Ross-Weir (NRW)*

1. Introduction

Patch antennas is very helpful in today's world of wireless communication systems. A Microstrip patch antenna is very simple in the construction using a conventional Microstrip fabrication technique. But it has several drawbacks like narrow-bandwidth, low gain, Omni directional pattern etc [1]. Several researches have been done to overcome their drawbacks. Victor Vesalago [2, 3] was the first to introduce the theoretical concept of metamaterial in that context. Metamaterials are generally manmade materials engineered to provide properties, which are not found in readily available materials in nature [4, 5]. Pendry [6] added more to the theory of Vesalago. They proved that the array of metallic wires can be used to obtain negative permittivity and split ring resonators for negative permeability.

Later in 2001, Smith [7] fabricated a structure which was a composition of split ring resonator and thin wire. The structure possessed the negative values of permittivity and permeability simultaneously and was named as LHM [8, 9]. Microstrip patch antenna parameters like bandwidth and gain can be ameliorated by using split ring resonator and wired based structure [9].

In this work Double H shape metamaterial structure has been introduced for ameliorating the antenna parameters. Along with these improvements it has been observed that, this structure also possesses negative values of permeability and permittivity within the operating frequency range, which has been verified by employing modified NRW approach.

2. Design Specifications

The RMPA parameters are calculated from the formulas given in equations (1)-(5). The desired parametric analyses [10, 11] are:
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

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ε_r = Dielectric constant of substrate

The effective dielectric constant of the rectangular microstrip patch antenna.

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

The actual length of the Patch (L)

$$L = L_{eff} - 2L\,\Delta L \quad (3)$$

Where:

$$\text{Leff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (4)$$

Calculation of Length Extension

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

3. Analysis of Rectangular Microstrip Patch Antenna and Metamaterial Structure with Simulated Results

The Rectangular Microstrip Patch Antenna is designed on FR-4 (Lossy) substrate. The parameter specifications of rectangular microstrip patch antenna are mentioned in Table 1. The seared calculated from the above discussed formulae.

Table 1. Rectangular Microstrip Patch Antenna Specifications

	Dimensions	Unit
Dielectric Constant (εr)	4.3	-
Loss Tangent (tan∂)	0.02	-
Thickness (h)	1.6	mm
Operating Frequency	1.84	GHz
Length (L)	35.846	mm
Width (W)	46.072	mm
Cut Width	5	mm
Cut Depth	9.9231	mm
Path Length	25.036	mm
Width Of Feed	3.00	mm

A rectangular microstrip patch antenna (RMPA), with a microstrip feed line is shown in Figure 1. The antenna is designed to resonate at 1.84GHz.

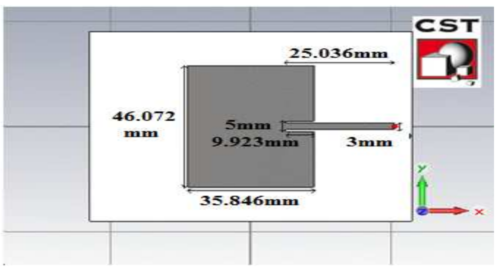

Figure 1. Rectangular Patch Antenna at 1.84GHz

Return loss S_{11} and Impedance Bandwidth of Rectangular Microstrip Patch Antenna is shown in Figure 2.

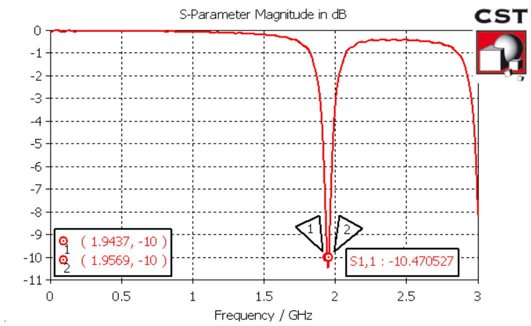

Figure 2. Simulation of Return Loss S_{11} and Impedance Bandwidth of Rectangular Microstrip Patch Antenna

Three-Dimensional Radiation Pattern of Rectangular Microstrip Patch Antenna is shown in Figure 3.

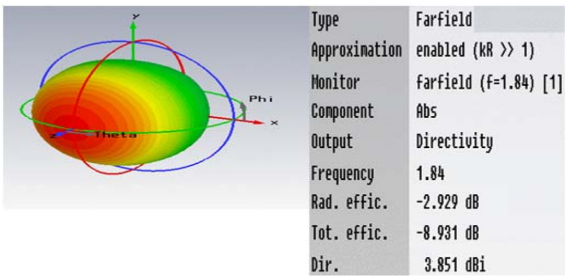

Figure 3. Radiation Pattern of a Rectangular Microstrip Patch Antenna

S-Parameter Smith Chart of Rectangular Microstrip patch antenna is shown in Figure 4.

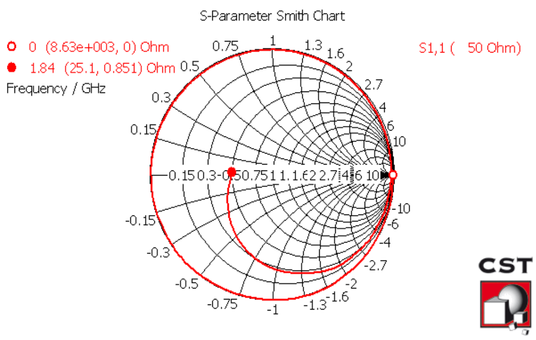

Figure 4. Smith Chart of Rectangular Microstrip Patch Antenna

In this paper the proposed metamaterial structure is introduced to form the super-state of a rectangular microstrip patch antenna (Figure 1). The required specifications of this design are shown in the Figure 5.

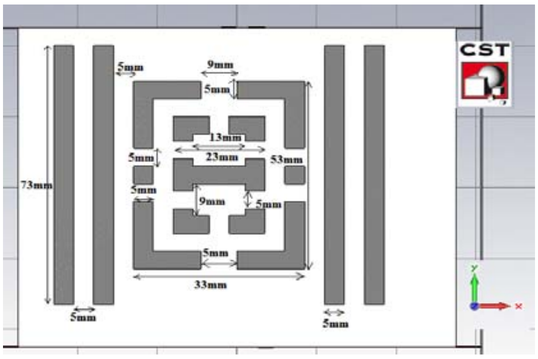

Figure 5. Design of Proposed Metamaterial Structure

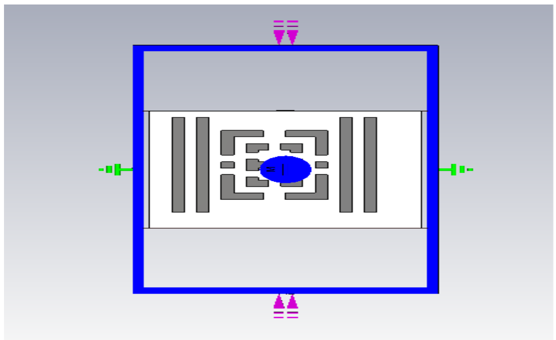

Figure 6. Proposed Metamaterial Structure between the Two Waveguide Ports

The proposed metamaterial structure is placed between the two waveguide ports [12, 13] at the left and right hand side of the Y axis (shown in Figure 5), in order to calculate the S-Parameters. In Figure 6, X-Plane is defined as Perfect Electric Boundary (PEB) and Z-Plane is defined as the Perfect Magnetic Boundary (PMB). The simulated S-Parameters are then exported to Microsoft Excel Program for verifying the Double-Negative properties of the proposed metamaterial structure.

In this work, Nicolson-Ross-Weir (NRW) technique [14, 15] has been used to obtain the values of permittivity and permeability.

4. Nicolson-Ross-Weir (NRW) Approach

Equations used for calculating permittivity and permeability [16-21].

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

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

$$V_1 = S_{11} + S_{21} \quad (8)$$

$$V_2 = S_{21} - S_{11} \quad (9)$$

Where

$\varepsilon\, r$ = 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 2 and 3, whereas Figure 7 and Figure 8 show the graph between permeability and frequency and permittivity and frequency respectively.

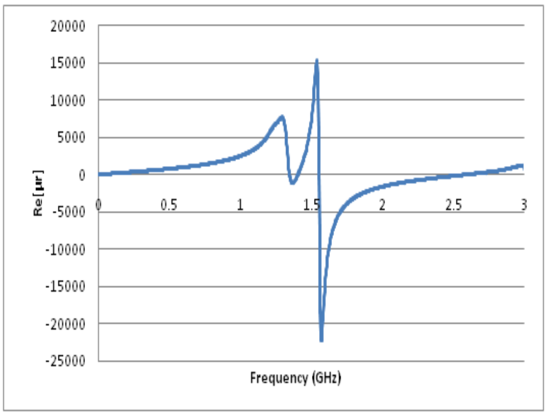

Figure 7. Permeability versus Frequency Graph

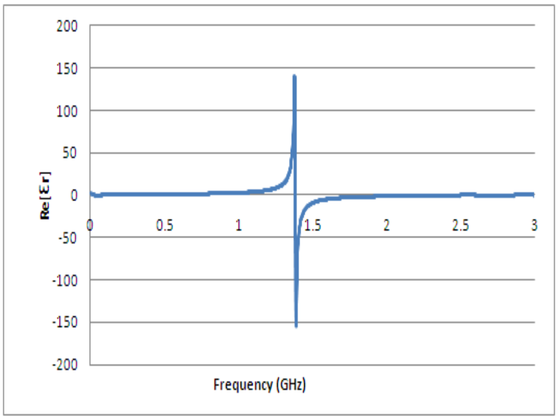

Figure 8. Permittivity versus Frequency Graph

Table 2

Frequency [GHz]	Permeability [μr]	Re[μr]
1.836	-2731.88756381109-102.512799227287i	-2731.887564
1.8389999	-2701.94483777295-100.978648323704i	-2701.944838
1.8419998	-2672.53289930103-99.6145384219818i	-2672.532899
1.8449999	-2643.66138986874-98.3837844894441i	-2643.66139
1.8479998	-2615.40540483632-97.2626073871634i	-2615.405405
1.8510001	-2587.74034428367-96.2015297218084i	-2587.740344

Table 3

Frequency [GHz]	Permittivity [?r]	Re[?r]
1.836	-2.19968484411828-0.0511749354231342i	-2.199684844
1.8389999	-2.18213990848817-0.0510683892065196i	-2.182139908
1.8419998	-2.16483191501718-0.0509798272412469i	-2.164831915
1.8449999	-2.14775533577134-0.0508925768642976i	-2.147755336
1.8479998	-2.1309102789696-0.0507898688681639i	-2.130910279
1.8510001	-2.11427745366918-0.0506615806156164i	-2.114277454

Generated excel sheet has number of data but here some data has been shown which lies within operating frequency range [16-17].

Rectangular Microstrip Patch Antenna with proposed metamaterial is given below in Figure 9.

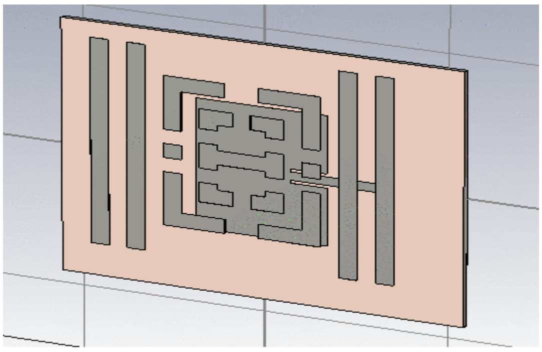

Figure 9. Rectangular Microstrip Patch Antenna with Proposed Metamaterial Structure

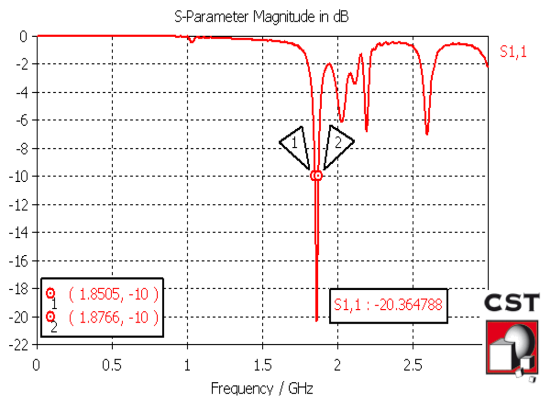

Figure 10. Simulation of Return Loss S_{11} and Impedance Bandwidth of RMPA with Proposed Metamaterial Structure

Return loss S_{11} and Impedance Bandwidth of Rectangular microstrip Patch Antenna with proposed metamaterial structure is shown in Figure 10.

Three-Dimensional Radiation Pattern of Rectangular Microstrip Patch Antenna with proposed metamaterial structure is shown in Figure 11.

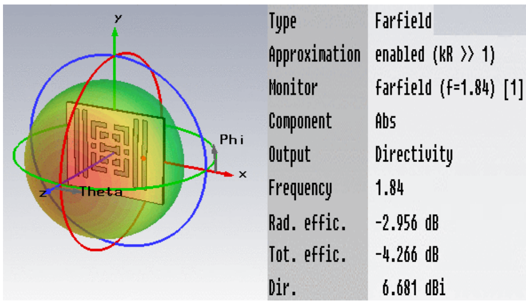

Figure 11. Radiation Pattern of RMPA with Proposed Metamaterial Structure

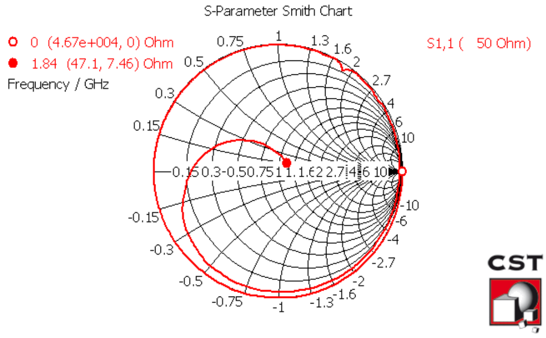

Figure 12. Smith Chart of RMPA with Proposed Metamaterial Structure

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S-Parameter Smith Chart of Rectangular Microstrip patch antenna with proposed metamaterial structure is shown in Figure12.

5. Fabrication, Testing and Experimental Results

Return loss pattern of RMPA with the proposed metamaterial structure within the simulated frequency range given in Figure 10 has been obtained from CST-MWS software, for verifying this result, hardware had been fabricated on PCB. RMPA and proposed metamaterial structure after fabrication on PCB have been given in Figure 13 and 14.

Figure 13. Fabricated Rectangular Microstrip Patch Antenna on PCB

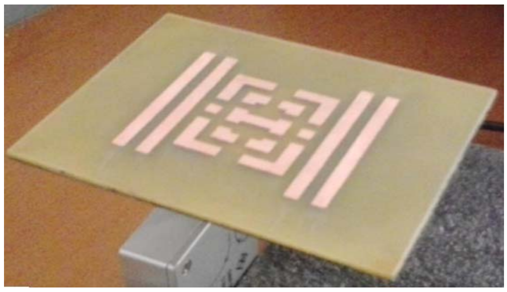

Figure 14. Fabricated Metamaterial Structure on PCB

After the fabrication of antenna the antenna parameters like return loss and bandwidth are measured on the spectrum analyzer. The setup which is used for antenna parameters measurement is shown in Figure 15.

Figure 15. Setup for Measurement of Antenna Parameters

Figure 16 shows the Simulated and Measured result of proposed antenna.

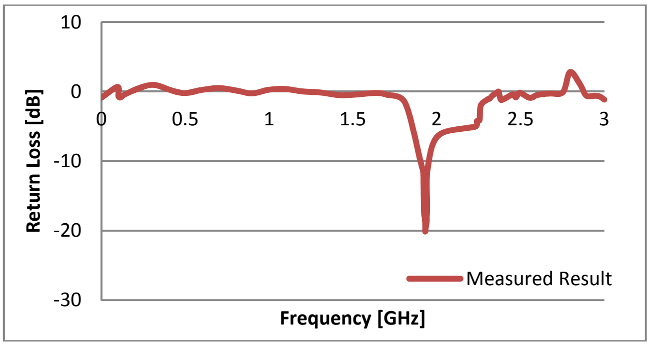

Figure16. Measured Result of Proposed Antenna

According to this graph the return loss and bandwidth at 1.84GHz are -20.12dB and 25.4MHz (approximately) for fabricated antenna. This shows that there are very less variations in practically measured results and simulated results of RMPA incorporated with proposed metamaterial structure.

6. Conclusion

On the basis of the results it is observed that the minimum return loss obtained at design frequency for the patch antenna with proposed metamaterial structure is -20.364dB and bandwidth is 26.1MHz, means bandwidth of metamaterial is double of patch antenna bandwidth. This is remarkable improvement in L-band. It is clearly observed that the antenna gain and bandwidth has improved significantly by employing proposed SSRR based metamaterial structure at 3.2mm 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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