Design and Analysis of Rectangular Microstrip Patch Antenna using Metamaterial for Better Efficiency

Rekha Kumari Bagri
M.Tech scholar, Department of Electronics and Communication Engineering
Govt. Mahila Engineering College
Ajmer(Raj.), India

Santosh Meena
Assistant Professor, Electronics and Communication Engineering
Govt. Mahila Engineering College
Ajmer(Raj.), India

Abstract— This paper show Design and analysis of patch antenna using metamaterial (MTM) structure is proposed for better improvement in the impedance bandwidth and reduction in the return loss at operating frequency 1.98GHz. The proposed antenna is designed on FR-4(lossy) substrate at 50 Ω matching impedance and height from the ground plane d=1.6mm by using CST Software. This paper show comparison between Rectangular microstrip patch antenna alone and Rectangular microstrip patch loaded with metamaterial with enhancement in gain, bandwidth, Directivity and Return loss at same resonant frequency.

Keywords— Rectangular Microstrip Patch Antenna (RMPA), Left Handed Metematerials, Return Loss, Directivity, Impedance Bandwidth.

I. INTRODUCTION

Patch antennas have attractive properties including the low profile, light weight, compact and conformable in structure, and easy to be integrated with solid-state devices [2]. Application of a conventional antenna always limited since they are governed by the 'right hand rule' which determine how electromagnetic wave should behave. However, a metamaterial substrate offers an alternative solution to a wider antenna applications using the 'left hand rule' [3]. Metamaterials are composite materials with unique electromagnetic properties due to the interaction of electromagnetic waves with the finest scale periodicity of conventional materials [4]. The important parameters of any type antenna are impedance bandwidth and return loss. The impedance bandwidth depends on parameters related to the patch antenna element itself and feed used.

II. DESIGN SPECIFICATIONS

The RMPA parameters are calculated from the following formulas. Desired Parametric Analysis "[9-10]"

2.1 Calculation of Width (W)-

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

Where

C = free space velocity of light

ε_r = Dielectric constant of substrate

2.2 The effective dielectric constant of the rectangular microstrip patch antenna

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

2.3 Actual length of the patch

$$L = L_{eff} - 2\Delta L \tag{3}$$

2.4 Calculation of length extension

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

III. ANALYSIS OF PATCH ANTENNA AND METAMATERIAL STRUCTURE WITH SIMULATED RESULTS

The Rectangular Microstrip Patch Antenna is designed on FR-4(lossy) substrate at 50 Ω matching impedance, dielectric constant=4.3 and height from the ground plane d=1.6mm.The parameter of rectangular microstrip patch antenna are L= 32.441 mm, W= 44.32 mm, Cut Width= 5mm, Cut Depth= 10mm, length of transmission line feed= 26.3mm, with width of the feed= 3mm shown in figure1. The simple RMPA is inspired by metamaterial structure at 1.98GHz.

Table-1 Rectangular Microstrip Patch Antenna parameter

Parameter	Value	Unit
thickness of substrate h	1.6	Mm
Fi	10	Mm
Gpf	1	Mm
Lf	26.3	Mm
lenght of substrate	32.441	Mm
Mt	0.1	Mm
W	44.32	Mm
Wf	3.00	Mm

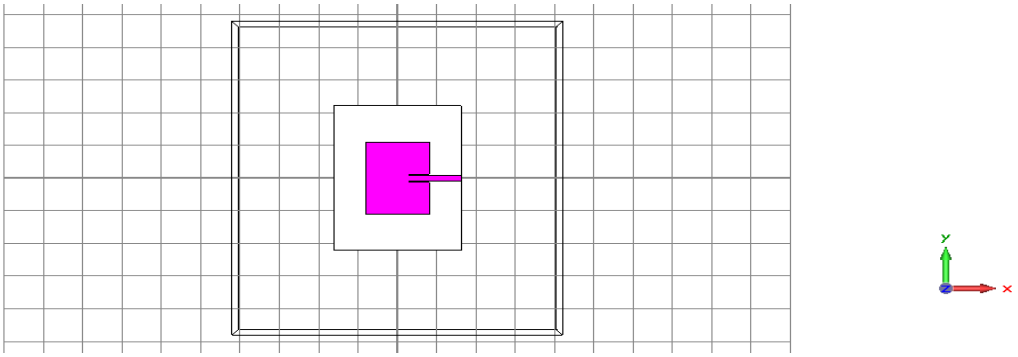


Figure 1. Design of Rectangular microstrip patch antenna

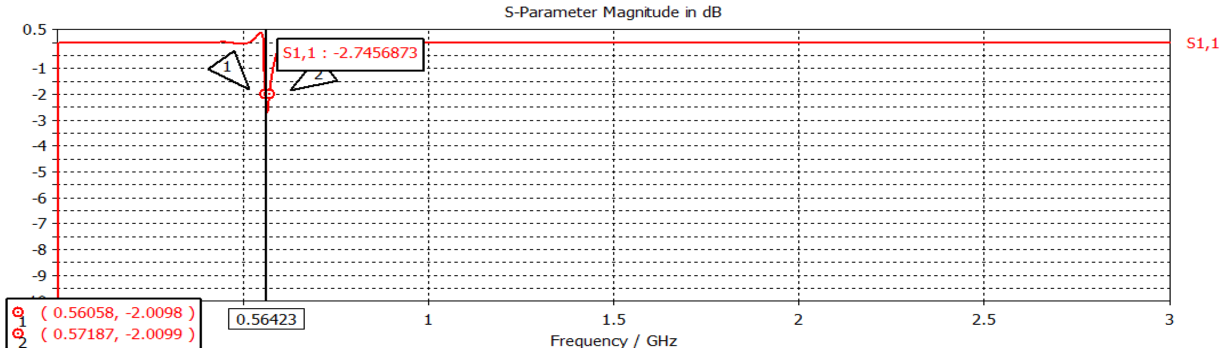


Figure2. S-Parameter Magnitude of Rectangular microstrip patch antenna at 0.56423GHz.

The bandwidth of simple RMPA is 11.29MHz and Returnloss is -2.7456873dB.

Table 2. Metamaterial specification

Parameter	*Value*	Unit
thickness of substrate	1.6	Mm
lenght of ring1	72	Mm
lenght of ring3	36	Mm
lenght of solid 1	8	Mm
lengh of substrate	85	Mm
lenght of wire	5	Mm
gap1	66	Mm
lenght of ring2	54	Mm
split wid	1	Mm
width of ring	3	Mm
width of solid 1	18	Mm
width of solid1	2	Mm
gap2	6	Mm
gap3	6	Mm

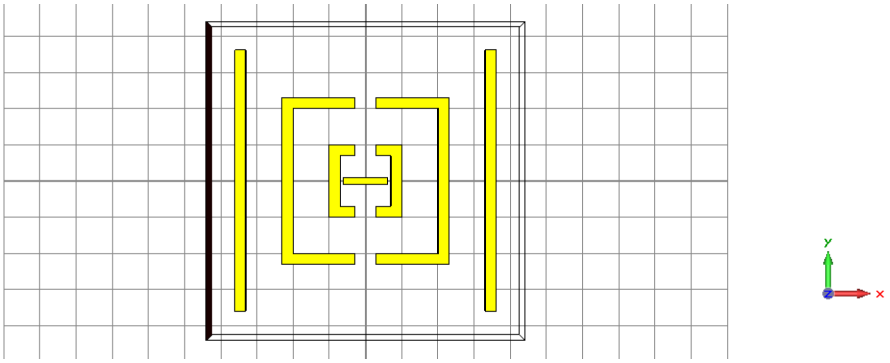


Figure3. Design of proposed Metamaterial structure at the height of 1.6 mm from ground plane.

In this metamaterial design, a split RMPA is design on substrate with 3 mm width. This design gives the better improvement in impedance bandwidth and reduction in return loss.

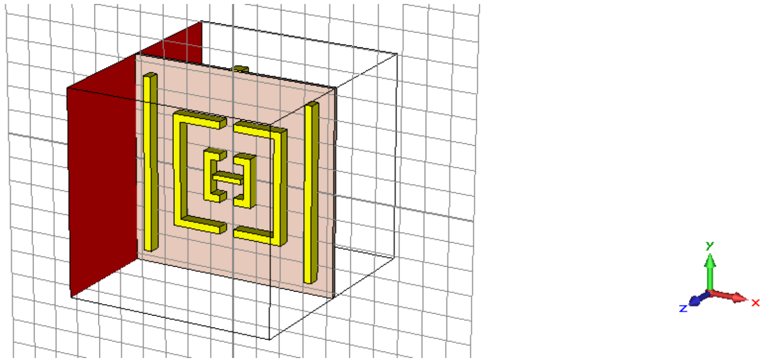


Figure 4. Rectangular microstrip patch antenna with proposed Metamaterial structure.

Simulation result of Return loss and bandwidth of Rectangular microstrip patch antenna loaded with metamaterial structure is shown in Fig 5. The proposed metamaterial structure reduces the return loss by -11.262902dB and increases the bandwidth up to 26.3MHz.

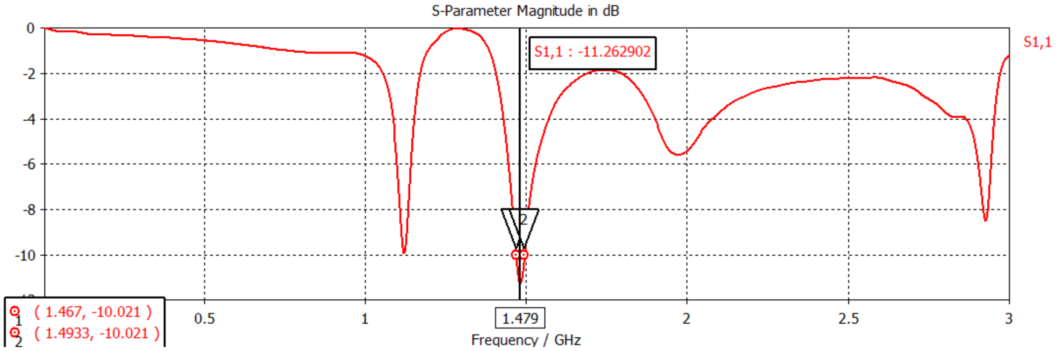


Figure5. Simulation of Return loss and impedance band width of RMPA with proposed Metematerial structure at operating frequency .

The maximum power deliver to rectangular microstrip patch antenna is .46857996 watt . As compared to RMPA alone, maximum power deliver to proposed antenna is increased up to 0.92523303 watt.

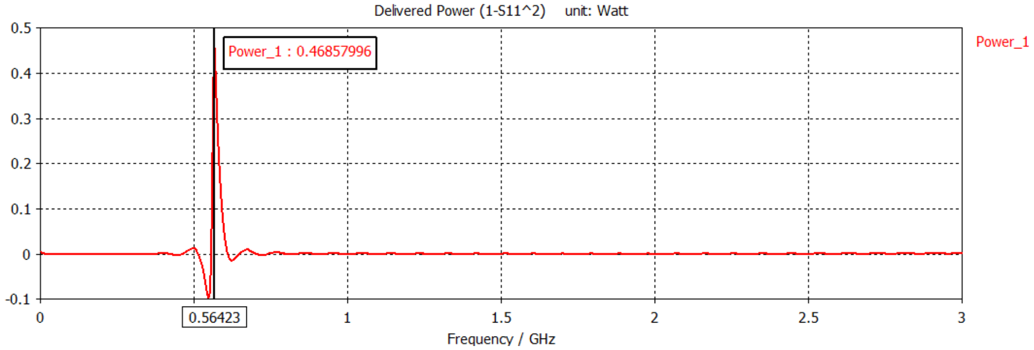


Figure6. Delivered power to reduced size RMPA is showing above .46 watt.

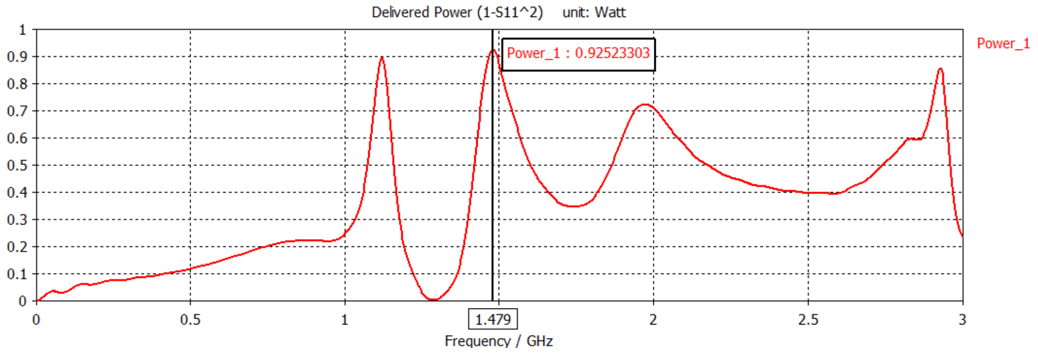
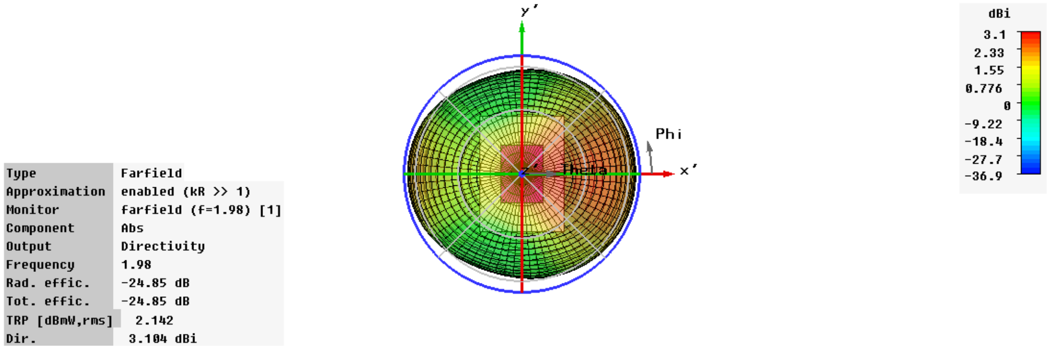
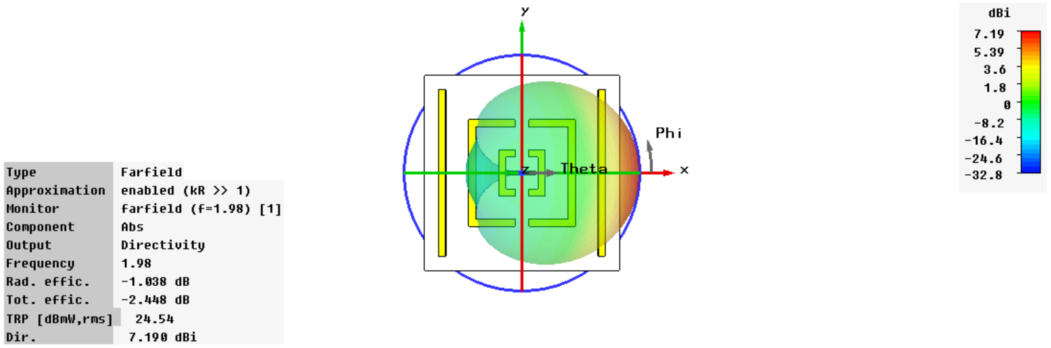


Figure7. Delivered power to reduced size RMPA loaded with Metamaterial structure.



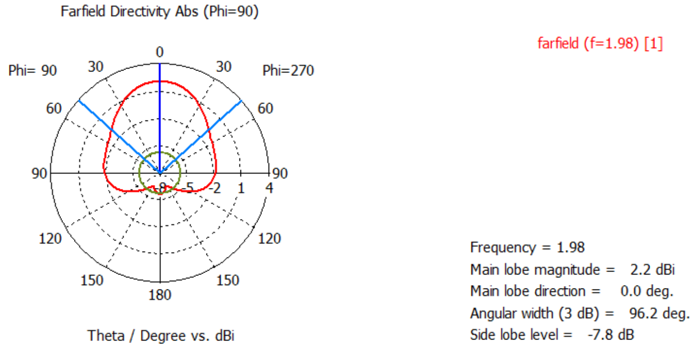
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.98) [1]
Component	Abs
Output	Directivity
Frequency	1.98
Rad. effic.	-24.85 dB
Tot. effic.	-24.85 dB
TRP [dBmW,rms]	2.142
Dir.	3.104 dBi

Figure 8. Radiation pattern of RMPA at 1.98 GHz showing directivity of 3.104 dBi.



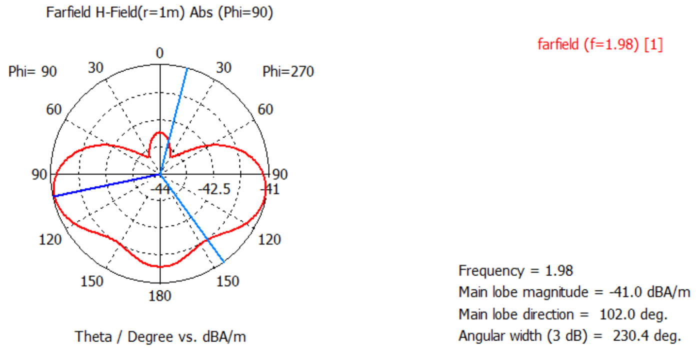
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.98) [1]
Component	Abs
Output	Directivity
Frequency	1.98
Rad. effic.	-1.038 dB
Tot. effic.	-2.448 dB
TRP [dBmW,rms]	24.54
Dir.	7.190 dBi

Figure9. Radiation pattern of proposed antenna showing Directivity of 7.190 dBi.



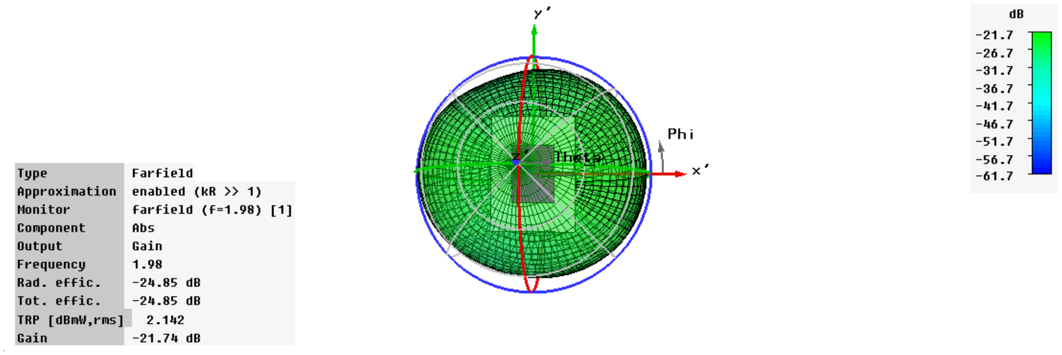
Frequency = 1.98
Main lobe magnitude = 2.2 dBi
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 96.2 deg.
Side lobe level = -7.8 dB

Figure 10. Directivity of RMPA alone (polar view).



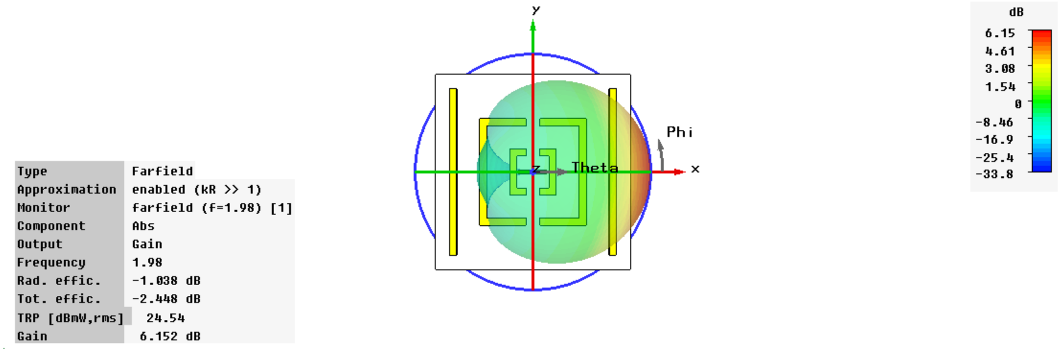
Frequency = 1.98
Main lobe magnitude = -41.0 dBA/m
Main lobe direction = 102.0 deg.
Angular width (3 dB) = 230.4 deg.

Figure11. Directivity of RMPA loaded with Metamaterial (polar view).



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.98) [1]
Component	Abs
Output	Gain
Frequency	1.98
Rad. effic.	-24.85 dB
Tot. effic.	-24.85 dB
TRP [dBmW,rms]	2.142
Gain	-21.74 dB

Figure12. Gain of RMPA alone (3D view).



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.98) [1]
Component	Abs
Output	Gain
Frequency	1.98
Rad. effic.	-1.038 dB
Tot. effic.	-2.448 dB
TRP [dBmW,rms]	24.54
Gain	6.152 dB

Figure13. Gain of RMPA with Metamaterial structure (3D view).

The gain plot of RMPA alone gives the gain = -21.74dB at a frequency of 1.98GHz. As compared to RMPA alone the gain of proposed patch antenna is increased up to 6.152dB at dual band frequency. Antenna gain is the ratio of maximum radiation intensity at the peak of gain beam to the radiation intensity in the same direction which would be produced by an isotropic radiator having the same input power.

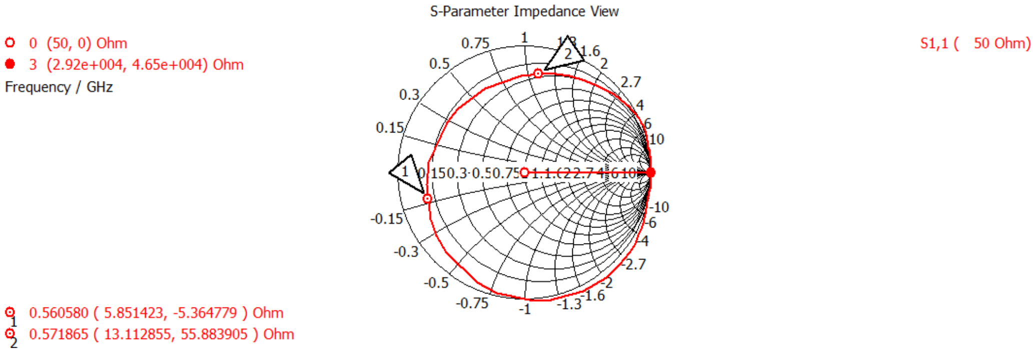


Figure 14. Smith chart of simple Rectangular microstrip patch Antenna.

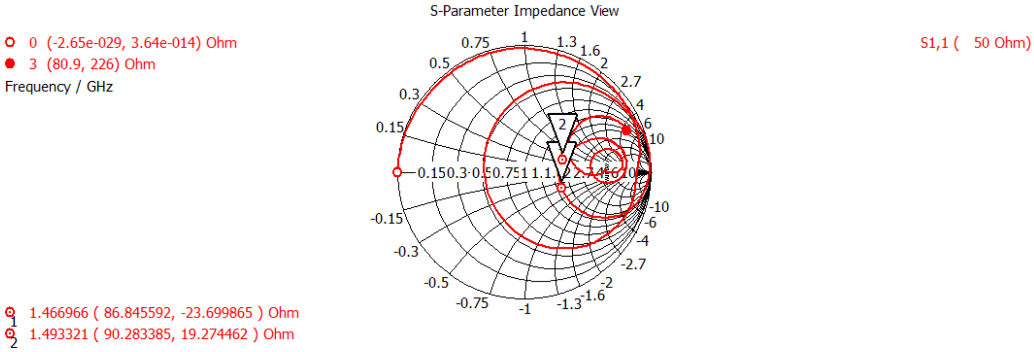


Figure15. Smirth chart of RMPA loaded with Metamaterial.

The Smith chart plot represents that how the antenna impedance varies with frequency which is normalized at 50 ohm for perfect matching.

2.5 Nicolson-Ross-Weir Metho (NRW)-

One methodology that makes use of the scattering parameters S11 and S21 to calculate the mentioned complex parameters of samples is named Nicolson-Ross-Weir (NRW) (Nicolson and Ross, 1970; Weir, 1974). The NRW modelling is the most common used method to perform the calculation of complex permittivity and permeability of materials. The obtained S- parameters are then exported to Microsoft Excel Software for calculating the value of the Permittivity and permeability of the proposed design, using the Nicolson-Ross-Weir (NRW) approach. The proposed structure is placed between the two waveguide ports [12][13] at the left & right of the X-Axis in order to calculate the S11 and S21 parameters so as to prove that The proposed structure possesses Double Negative Metamaterial properties. In figure Y-Plane was defined as Perfect Electric Boundary (PEB) and Z-Plane was defined as the Perfect Magnetic Boundary (PMB). Subsequently, the wave was excited from the negative X-axis (Port 1) towards the positive X-axis (Port 2) Equations used for Calculating Permittivity & Permeability using Modified NRW Approach [6]-[8].

$$\mu_r = \frac{2.c(1 - v2)}{\omega.d.i(1 + v2)}$$

$$\varepsilon_r = \mu_r + \frac{2.s11.c.i}{\omega.d}$$

Where
V2 = S21 - S11
d = Thickness of the Substrate

ω= Freaquency in radian
i = imaginary coefficient
c = Speed of Light
V2 = Voltage Minima

IV. SIMULATION RESULTS

In this paper, Rectangular microstrip patch antenna loaded metamaterial structure is found that the potential parameters of the proposed antenna is increased. This design is operated at 1.98 GHz. At 1.98GHz, the bandwidths are increased up to 26.3MHz in comparison to 11.29MHz of RMPA alone. The Return loss of proposed antenna are reduced by -11.262902dB at dual band frequency as comparison to -2.7456873 dB of RMPA alone. The gain plot of RMPA alone gives the gain = -21.74dB at a frequency of 1.98GHz. As compared to RMPA alone the gain of proposed patch antenna is increased up to 6.152 dB at dual band frequency. The directivity of proposed antenna is increased up to 7.190dBi as comparison to directivity of RMPA alone is 3.104dBi. The maximum power deliver to proposed rectangular microstrip patch antenna is 0.92523303watt

V. CONCLUSION

The main drawback of Patch Antenna was less impedance bandwidth. For this purpose, Design and analysis of patch antenna using Metamaterial structure has been proposed and analyzed in this paper. The simulated results provide bandwidth and directivity improvement, which encourages fabricating the structure. In this paper, I have investigated the improvement of the Rectangular Microstrip Patch Antenna performances using new proposed Rectangular Microstrip Patch antenna with Metamaterial Structure. I have shown that left handed Metamaterial improves the gain as well as reduces return loss of this Patch Antenna. The proposed antenna provide the better improvement in the impedance bandwidth and reduction in the return loss at 1.98GHz. The drawback of Patch Antenna was impedance bandwidth. For this purpose, Rectangular microstrip patch antenna loaded with metamaterial structure has been proposed for improving the bandwidth by using CST MICROWAVE STUDIO in this paper.On making some variations in antenna parameter gain can be improved up to desired limit but some practical limitation should be taken care while fabricating the structure on CST- MWS software.

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