A Novel Design of Metamaterial to Enhance the Characteristics of a Rectangular Microstrip Patch Antenna

Baljeet Singh Sinwar, Mithilsh Kumar

Abstract: A Rectangular Microstrip Patch Antenna with "Circular Rings" shaped metamaterial connected with each other using strip lines, is designed at a height of 3.276mm from the ground plane. The antenna along with the proposed metamaterial cover is designed to resonate at 2.72 GHz frequency (in S-Band). Proposed metamaterial cover significantly increases the return loss and reduces the size of the antenna in comparison to rectangular microstrip patch antenna (RMPA) alone. This metamaterial also improve the gain and directivity of rectangular microstrip patch antenna. The objective of this paper is to design and simulate the proposed artificial structure with simultaneous negative permittivity and permeability and design a RMPA using this structure to enhance the performance of RMPA. Nicolson-Ross-Weir approach has been used for verifying the double-negative properties of the proposed metamaterial. The proposed structure is fabricated on dielectric substrate FR-4 using conventional microstrip integrated circuit technology. The fabricated antenna was tested and compared the results. The simulated and measured results are having close agreement.

Key words — Nicolson-Ross-Weir method (NRW), Rectangular Microstrip patch antenna (RMPA), Return Loss. Directivity, Gain,

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1 INTRODUCTION

SINCE the invention of the microstrip antenna a half-century ago, the demand for its application has been increasing rapidly, especially within the past two decades. Because of the microstrip antenna's many unique and attractive properties. These properties include low profile, light weight, compact and conformable to mounting structure, easy fabrication and integratable with solid-state devices. These antennas have some drawback like narrow-bandwidth, low gain etc. Many researchers have done research to improve these drawbacks. Many significant advances in improving the inherent narrow operating bandwidth of microstrip antennas have been published in the open literature since 1997. In this field of research, the theoretical concept of metamaterials was introduced by Victor Veselago (1968) Engheta and Ziolkowski (2006).

According to the theory of Vesalago, these materials are generally providing properties which are not found in readily available materials in nature [1]-[2]. They are also called as the Negative Refractive Index materials or Left handed materials LHM because they have Negative Refractive Index (NRI) [3]-[5].

The first structure of LHM is made by Smith [6]. The Metamaterial, are left-handed metamaterial (LHM) will be mainly used to focus on the radiation of an antenna.

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LHM enhance the gain in the microstrip technology, reduce patch antenna size, adjust the bandwidth and also used for filtering the unwanted signals.

In this work, a new metamaterial structure has been introduced. In this structure there are three circular rings connected each other using strips lines. This metamaterial structure shows the double negative properties. And it improves the different characteristics of a rectangular microstrip patch antenna. The return loss of rectangular microstrip patch (RMPA) increased using this metamaterial structure. And it also improves the size of RMPA. This structure when used to design a RMPA it also improve the gain and directivity of antenna.

Computer Simulation Technology (CST-MWS) Software has been used for all the simulation. Authors use the MS-Excel program ware for verifying the Double Negative properties for the proposed design [6].

The proposed structure is fabricated on dielectric substrate FR-4 using conventional microstrip integrated circuit technology. The fabricated antenna was tested and compared the results. The simulated and measured results are having close agreement.

2 ANTENNA AND METAMATERIAL DESIGN

The rectangular microstrip patch antenna parameters are calculated using conventional method and also designed using this method [11]. The dimensions of rectangular microstrip patch antenna, which are calculated from conventional method, are shown in table I. and dimensional view is shown in Fig. 1.
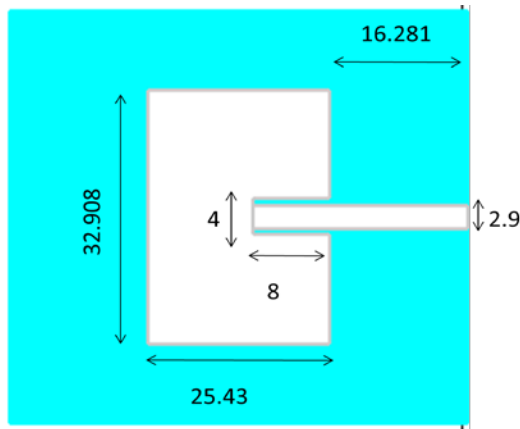
Fig. 1: Dimensional view of RMPA (All dimension in mm)

This rectangular microstrip patch antenna is designed and fabricated on FR4 (Lossy) substrate of thickness h= 1.6 mm from the ground plane and dielectric constant of the substrate is εr=4.3 and loss tangent 0.02 by using copper material as the conducting plane. This antenna is matched using 50 Ω impedance matching line. The fabricated structure of antenna is shown in Fig. 2. The dimension of the substrate is 60×80 mm.

To calculate the S-parameters, the proposed structure of metamaterial is placed between the two waveguide ports [7], [8] at the left and right hand side of X axis. In Fig. 4, Y-plane is defined as Perfect Electric Boundary (PEB) and Z-plane is defined as the Perfect Magnetic Boundary (PMB) to create internal environment of waveguide
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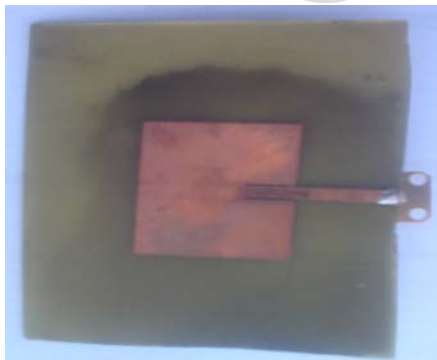
Fig. 2: Front view of fabricated antenna
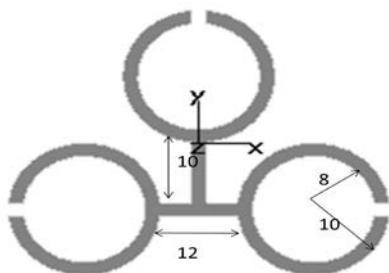
Fig. 3: Dimensional view of meta (All dimension in mm)

Subsequently, the wave was excited from the negative X-axis (Port 1) towards the positive X-axis (Port 2) [12].

The S parameters were obtained in complex form, through this arrangement, which are then exported to Microsoft Excel program for verifying the double-negative metamaterial properties of the proposed metamaterial structure by using the NRW approach.
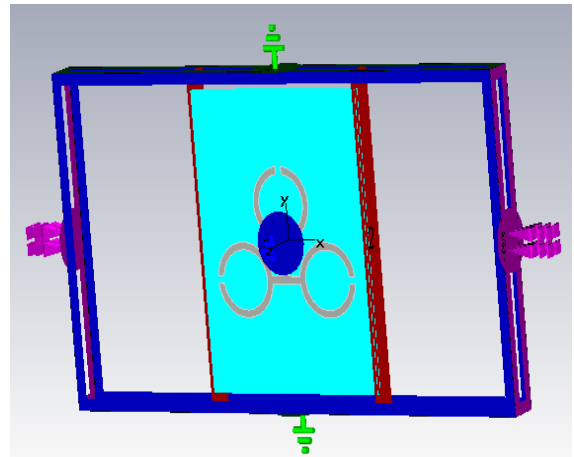

Fig. 4: Meta covered between two waveguide ports

For calculating the value of permittivity and permeability we use following formulas using NRW approach [9]-[10]:

$$\mu_r = \frac{2.c.(1-v_1)}{w.d.i.(1+v_2)} \tag{1}$$

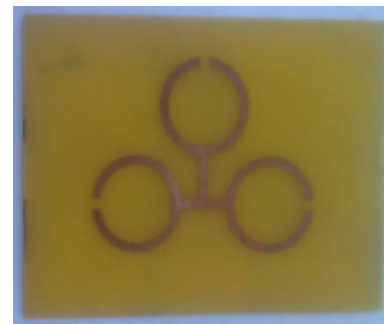$$\varepsilon_r = \mu_r + \frac{2.s_{11}.c.i}{w.d} \tag{2}$$

Fig. 5: Fabricated structure of metamaterial.

We calculated S- parameters of metamaterial structure in the MS-Excel program using the equation (1), equation (2) and from this MS-Excel program we calculate the permittivity and permeability of the metamaterial structure.

The effective permittivity and permeability, which are obtained from MS-Excel program, of the substrate are shown in Fig. 6 and Fig. 7, respectively. As shown in figures these values are negative. So this structure follows the metamaterial characteristics.
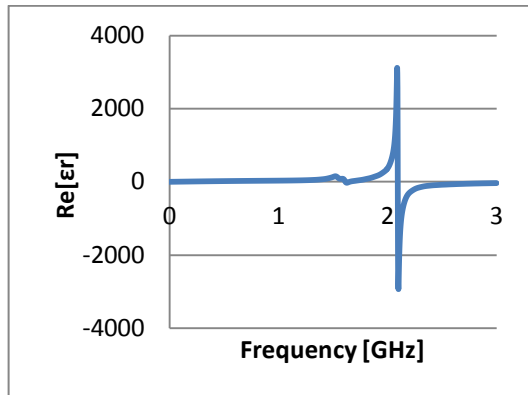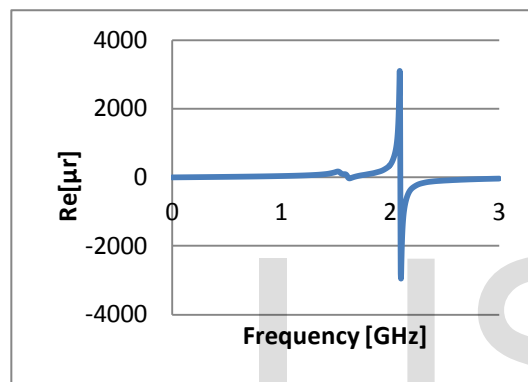
Fig. 6: Graph between permittivity and frequency

Fig. 7: Graph between permeability and frequency

3 RESULT AND DISCUSSION

After the simulation and fabrication of antenna and metamaterial structure using simulator CST microwave studio and using dielectric substrate FR-4 by conventional microstrip integrated circuit technology, respectively. We have obtained the different results of antenna. The results of antenna are simulated and measured with and without proposed metamaterial structure. The comparison of different characteristics, with and without metamaterial, is also shown in this section.
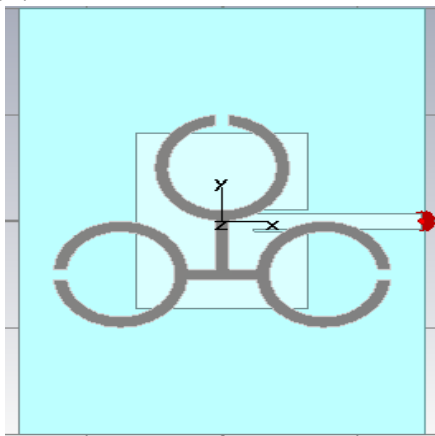

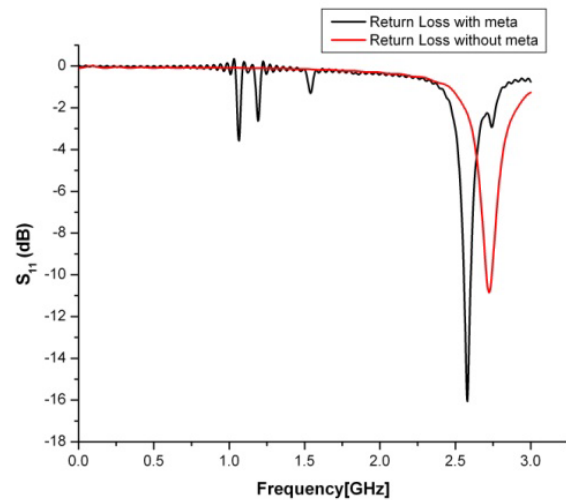Fig. 8: Antenna incorporated with metamaterial.

Fig.9: Measured return loss antenna with and without metamaterial.

The S11 (dB) of simulated antenna without metamaterial and antenna with metamaterial is shown in Fig. 9. As shown in Fig. 9, return loss of rectangular microstrip patch antenna is increased using metamaterial. The S11 (dB) of simulated and measured result of antenna with metamaterial is shown in Fig. 10. And it is also clear from comparison that simulated and measured results have good agreement between them. And metamaterial structure also reduces the size of antenna as shown in Fig.9.
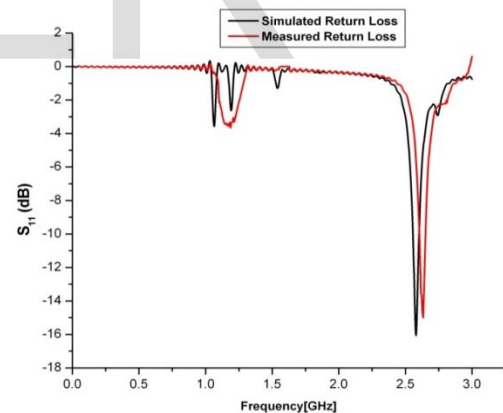

Fig.10: Simulated and measured result of antenna

The return loss of RMPA using metamaterial is about -17 dB while without metamaterial it is about -11 dB. Some of main characteristics are also enhance using metamaterial like directivity, gain, bandwidth etc. So author also compares the directivity and gain of antenna with and without metamaterial in this section. The directivity and gain of antenna with and without metamaterial are shown in Fig. 11-Fig. 13.

Fig. 11 and Fig. 12 show directivity of rectangular microstrip patch antenna without and with proposed metamaterial design, respectively. According to simulation result the directivity of rectangular microstrip patch antenna without metamaterial is 7.353 dBi and with metamaterial design is

7.179 dBi. Fig. 13 and Fig. 14 show the gain of RMPA without and with proposed metamaterial design, respectively.

According to simulation the value of gain without metamaterial is 4.652 dB and with metamaterial 3.775 dB. The simulation and fabrication shows that design of a RMPA using metamaterial gives the better performance then rectangular microstrip patch antenna without metamaterial
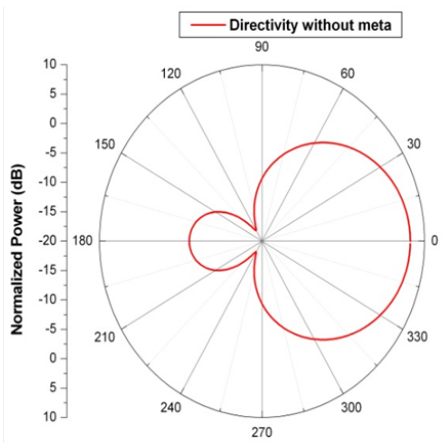

Fig.13: 2-D view of gain of antenna without metamaterials

Fig.11: 2-D view of directivity of antenna without metamaterials

Fig.12: 2-D view of directivity of antenna with metamaterials

Fig.14: 2-D view of gain of antenna with metamaterials

Fig.15: 3-D view of directivity of antenna without metamaterials
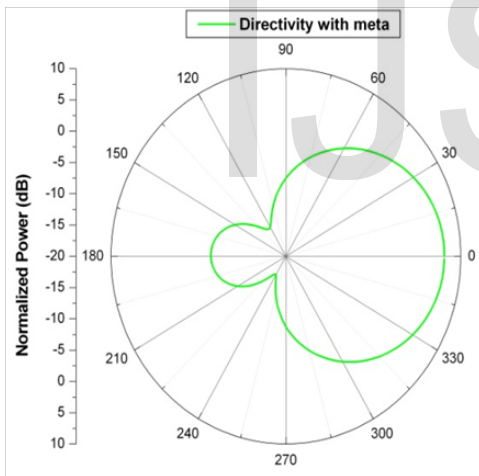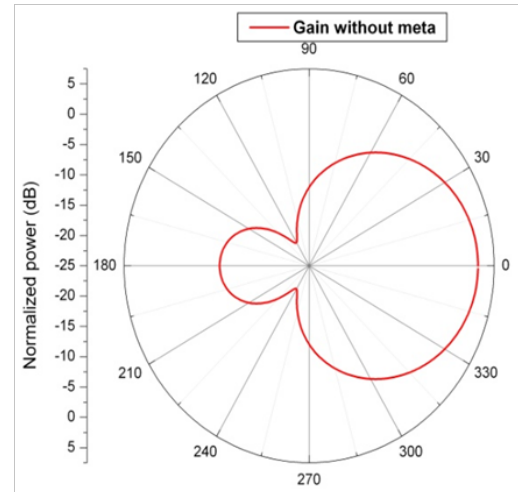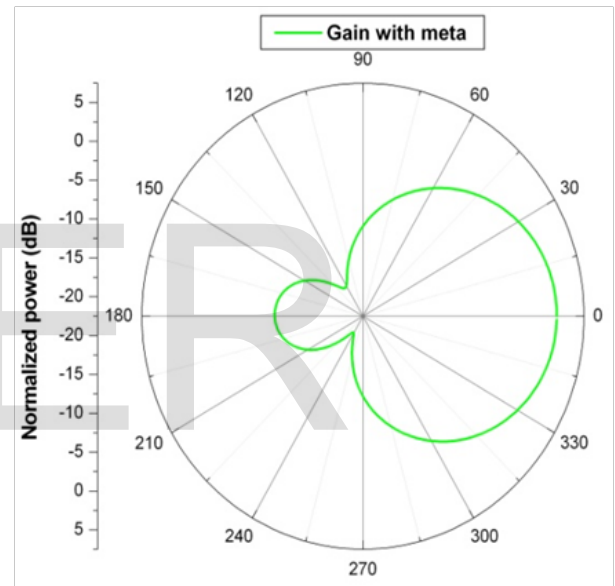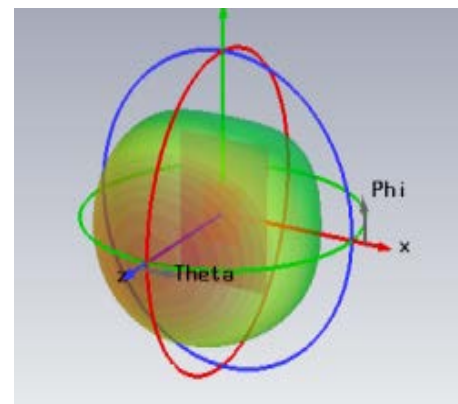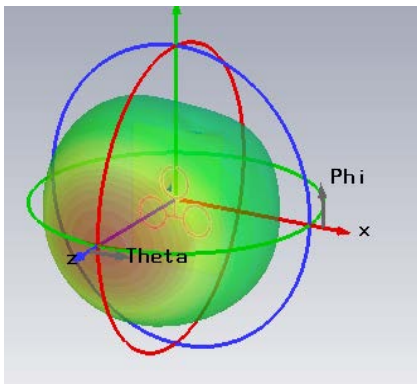
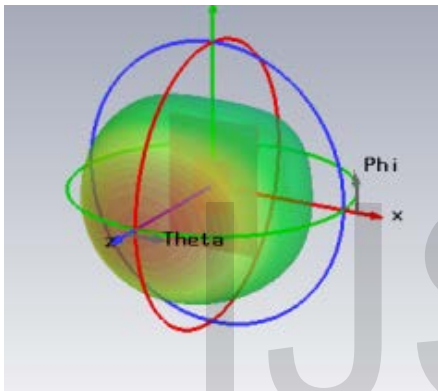Fig.16: 3-D view of directivity of antenna with metamaterials

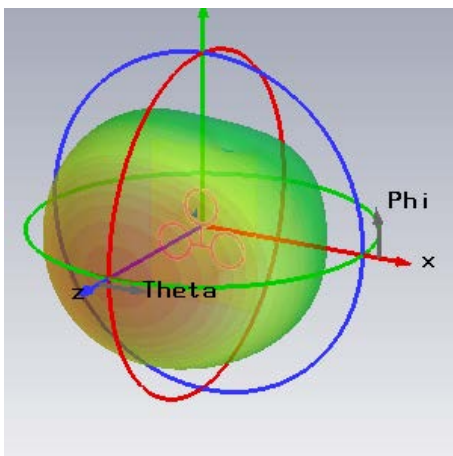Fig.17: 3-D view of gain of antenna without metamaterials

Fig.18: 3-D view of gain of antenna with metamaterials.

4 CONCLUSION

We can see that many characteristics of RMPA structure can be enhanced by using LH-Metamaterials. So that its bandwidth, efficiency, return loss and other characteristics can be improved. The work improved the antenna's gain and produced a more directional radiation pattern beam. It also improves the size of the antenna. The concept of the negative refraction index of the LHM has been proved. And using some metamaterials we can enhance the bandwidth.

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