A Multiband “Hexagon Shape” Metamaterial Structure with Increased Efficiency for Microwave Application

Suprabhat Vishwakarma[1], Bimal Garg[2]
Department of Electronics
[1, 2] mits gwalior (m.p.) india.

Abstract- *The concept of double negative material (left handed material) is that, it will improve the characteristic parameter of rectangular microstrip patch antenna (RMPA) without changing its dimension. Double negative material is also called metamaterial. These Materials are the artificial material which exhibits double negative properties, which means that it will have dielectric permeability and dielectric permittivity are negative simultaneous. So to improve the characteristic parameter of RMPA, it is loaded with “hexagon shape” metamaterial structure at a height of 3.276mm from the ground plane. After this process, in the return loss result of RMPA with metamaterial structure return loss is dipped out at three frequency Value (1.146, 2.475, 2.646) GHZ. In which the lowest dip is shifted to a frequency other than the operating frequency, i.e. (1.146 GHZ), which will provide the profit in size, minor profit in return loss and provide the increment in efficiency with multiband response. This structure only one which provide four advantage.The design and optimization of rectangular microstrip patch antenna (RMPA) with and without proposing metamaterial structure were carried by using CST microwave studio application and MS-EXECL is used for proving metamaterial property.*

Keywords- Left Handed Metamaterial (LHM), Rectangular Microstrip Transceiver (RMT), Double Negative Metamaterial (DNG), Impedance Bandwidth, Return loss, Nicolson-Ross-weir (NRW).

I. INTRODUCTION

The fastest growing and most recent field of communication involves the use various wireless communication system. In modern wireless communication system, better “characteristic parameter” performance of RMPA is a very important factor [7] [10]. Due to many advantages like as the low profile and cost, light weight and small size, it is very popular [1]. But sometimes it sticks out from the many problems like efficiency, gain, return loss, directivity, bandwidth, etc., to improve these types of characteristic parameter, the technique is used. Recently, Pendry has opened the door to new design strategies by metamaterial based structure. The theoretical concepts on metamaterial is presented by Victor Veselgo (1968) Engheta [1] [4] [5] and Ziolkowski (2006), which will overcome the drawbacks of RMPA. The Property of metamaterial is that, it will have the value of permittivity (ε_r<0) and permeability (μ_r<0) should be negative [1]. In which the pointing vector would be parallel to the direction to the phase velocity. Application of metamaterial based antenna is in space communication, space vehicle navigation and satellite.

II. DESIGN SPECIFICATION

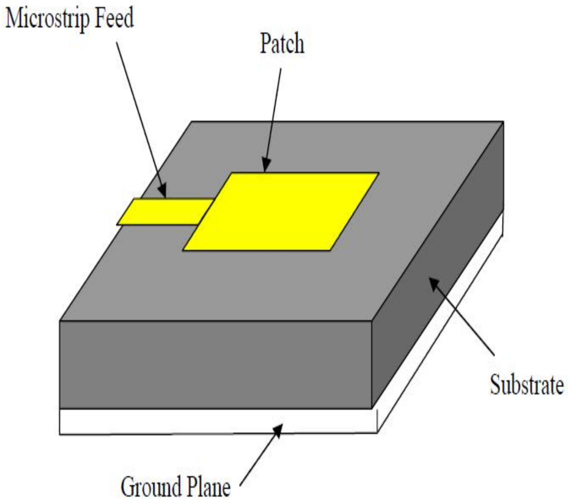


Fig.1: General block diagram of rectangular microstrip patch antenna.

Fig.1 shows the general block diagram of the rectangular microstrip patch antenna.

The parameters of RMPA are calculated by the following formulas [2].

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

$$L = L_{eff} - 2\Delta L \qquad (2)$$

$$L_{eff} = \frac{C}{2\ f_r\ \sqrt{\varepsilon_{eff}}} \qquad (3)$$

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

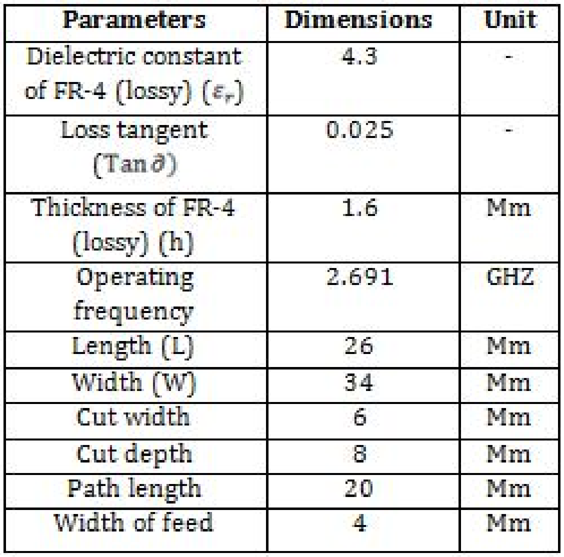
$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12\,h}{w}}}\right) \quad (5)$$

Where

ε_{eff} = Effective dielectric constant.
ε_r = Dielectric constant of substrate.
H = Height of the dielectric substrate.
W = Width of patch.
L = Length of the patch.
ΔL =Effective length.
f_r = Resonating frequency.

After the dimension calculation it will be simulated at the height of 1.638mm from the ground plane, but where rectangular patch and ground plane are the perfect conductor and substrate is between of both them.

Table.1: Dimension of the rectangular patch.



Parameters	Dimensions	Unit
Dielectric constant of FR-4 (lossy) (ε_r)	4.3	-
Loss tangent (Tan ∂)	0.025	-
Thickness of FR-4 (lossy) (h)	1.6	Mm
Operating frequency	2.691	GHZ
Length (L)	26	Mm
Width (W)	34	Mm
Cut width	6	Mm
Cut depth	8	Mm
Path length	20	Mm
Width of feed	4	Mm

Where, Table.1 shows the dimensions of simulated RMPA.

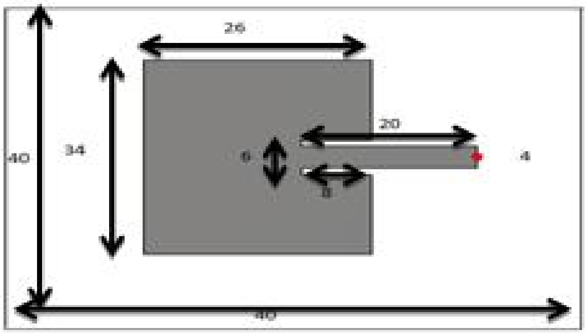


Fig.2: RMPA at the height of 1.638mm from the ground plane (all the parameters in mm).

Fig.2 shows the simulation structure of the RMPA. Which will simulate with CST-Software, where the position of the port is (X=25mm, Y=0, Z= 0 to 1.676mm).

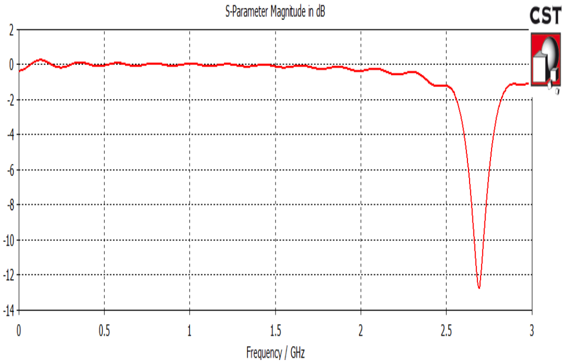
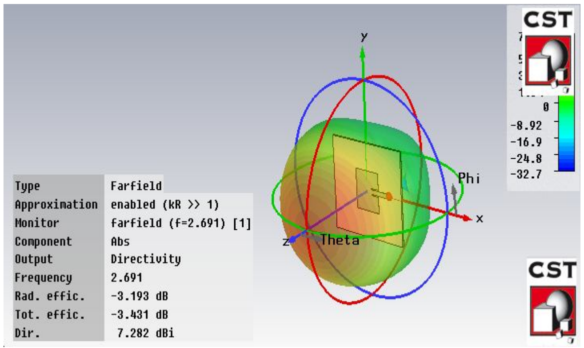


Fig.3: Simulation result of RMPA in return loss -12.73dB at 2.691GHZ frequency.

Fig.3 shows the return loss of RMPA at 2.691GHZ, which will increase.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.691) [1]
Component	Abs
Output	Directivity
Frequency	2.691
Rad. effic.	-3.193 dB
Tot. effic.	-3.431 dB
Dir.	7.282 dBi

Fig.4: 3D radiation pattern of RMPA.

Fig.4 shows the 3D radiation pattern of RMPA, in which the efficiency of the RMPA is low at 2.691 GHZ frequency.

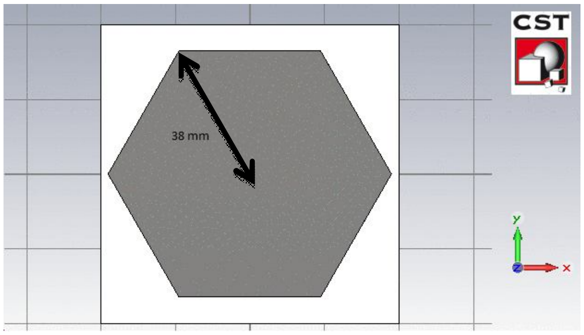


Fig.5: Proposed metamaterial structure at the height of 3.276mm from the ground plane.

In fig. 5 after the simulation of RMPA, hexagon shape metamaterial structure is loaded on the patch antenna at the height of 3.276mm from the ground plane. After this process it is proved that the material which is used to reduce the size of RMPA is a metamaterial. It is possible by NRW (Nicolson Ross weir) approaching.

III. NICOLSON- ROSS -WEIR METOD

In fig. 6, the proposed structure is mounted between the two port waveguide. It is mounted in such a manner both sides of the antenna on X- axis of the waveguide to calculate S11 and S21 parameter. But where Y and Z planes are defined as perfect electric (PE) and perfect magnetic (PM) boundary respectively.

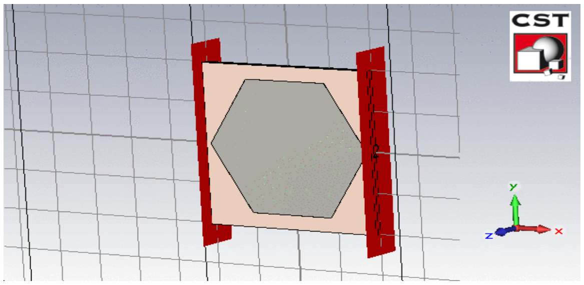


Fig.6: Proposed metamaterial structure between the two port wave guide.

In this waveguide the wave was excited towards the port (2) from port (1). After the calculation of S11 and S21 parameters, find the complex value of μ_r And ε_r. After this process the real value of μ_r And ε_r Export to MS-EXCEL software for proving of structure that it is metamaterial. The result of NRW approach, showing negative permeability and permittivity.

The equation used for calculating permittivity and permeability in NRW approach [6] [8] [9].

$$\mu_r = \frac{2\,c\,(1 - v_2)}{\omega di\,(1 + v_2)} \qquad (1)$$

$$r = \frac{2\,c(1 - v_2)}{\omega di\,(1 + v_1)} \qquad (2)$$

$$V_2 = S_{21} - S_{11} \qquad (3)$$

$$V_1 = S_{11} - S_{21} \qquad (4)$$

Where
εr= Permittivity, μr= Permeability
C = Speed of Light, ω = Frequency in Radian
D = Thickness of the Substrate,
I = Imaginary coefficient.
V1=voltage maxima.
V2= voltage minima.

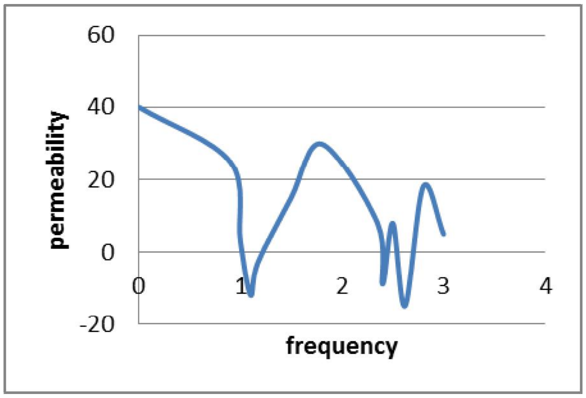


Fig.7: Permeability versus frequency graph obtained by MS-EXCEL.

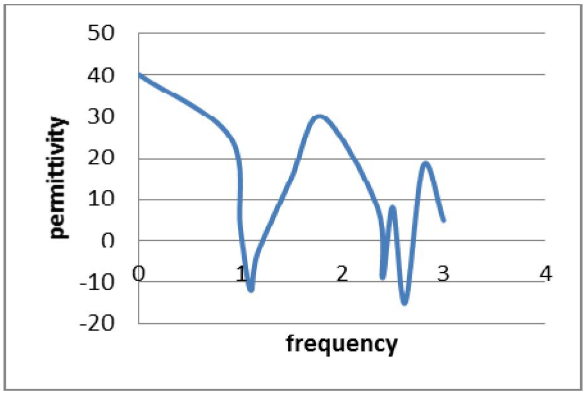


Fig.8: Permittivity versus frequency graph obtained by MS-EXCEL.

In fig. 7 and figs. 8, the negative value of permeability and permittivity by using MS-EXCEL software in the frequency range 1.146GHZ to 1.16 GHZ.

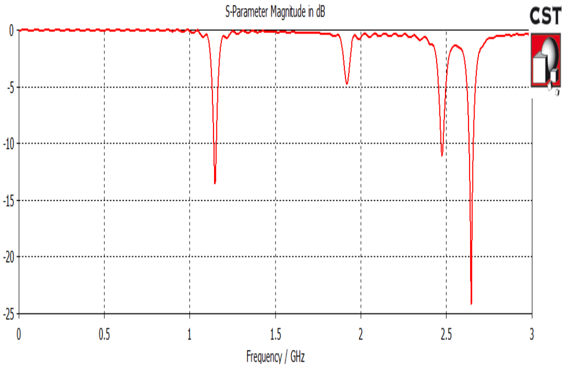


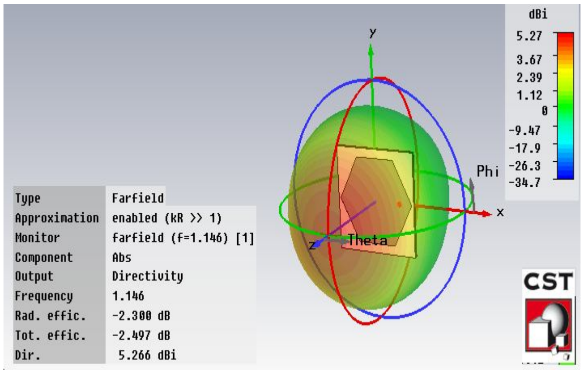
Fig.9: The simulated result is showing the return loss of -13.534db at 1.146GHZ.

In fig. 9 the simulated result of RMPA with proposed metamaterial structure provides the multiband response and enhance the property of RMPA. In which return loss and the size of the antenna are reduced by shifting the lowest dip to a frequency other than the operating frequency, i.e. 1.146GHZ.

Table.2: Dimension of RMPA at different frequency value.

Frequency (GHZ)	Length (mm)	Width (mm)
1.146	62.895	80.405
2.691	26	34

According to table. 2 the size of the RMPA will reduce up to 82.51%.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.146) [1]
Component	Abs
Output	Directivity
Frequency	1.146
Rad. effic.	-2.300 dB
Tot. effic.	-2.497 dB
Dir.	5.266 dBi

Fig.10: 3D radiation pattern of RMPA with proposed metamaterial structure.

Fig.10 shows the 3D radiation pattern of RMPA with proposed metamaterial structure, in which the efficiency of the antenna will increase up to 56.273%.

IV. RESULT

By stressing RMPA with “hexagon shape” metamaterial structure the size of RMPA will reduce up to 82.51%, return loss is decreasing up to 6.31%, and the total efficiency of the antenna is increased up to 56.273%.

V. CONCLUSION

To achieve high performance characteristic parameter of RMPA, the authors presented a new design methodology. In which RMPA is covered by a metamaterial structure at the height of 3.276mm from the ground plane. Which will enhance the property of RMPA and it will provide the most effective result in many applications.

REFERENCES

[1] V. G. Veselago “The electrodynamics of substances with simultaneous negative value ε and μ” Sov. Phys. Uspekekhy.10 (4), 509-514, 1968.

[2] A. Desired Parametric Analysis (Balanis, 1997; Stutzman and Thiele, 1998.

[3] H. W., R. L. Haupt, and P. L. Werner, “Fractal antenna engineering: The theory and design of fractal antenna arrays," IEEE Antennas and Propagation Magazine, Vol. 41, No. 5, 37-59, 1999.

[4] J. B. Pendry, A. J. Holden, D. J. Robbins, W. J. Stewart, “magnetism from conductors and enhanced nonlinear phenomena” IEEE Trans. Micro Tech. Vol. 47 no. 11, pp. 2075-2081, Nov. 1999.

[5] D.R. Smith, W.J. Padilla, D.C. Vier, et al, “Composite medium with simultaneously negative permeability and permittivity”, Phys Rev Lett 84, 4184–4187, May 2000.

[6] Huda A. Mazid, Mohammad Kamal A. Rahim, ThelasaMasri, “Left-handed Metamaterial design for Microstrip Antenna application”, IEEE International RF and Microwave conference, 2008.

[7] Bilotti, F., A. Alμu, and L. Vegni, \Design of miniaturized patch antennas with ¹-negative loading," IEEE Trans. Antennas Propag., Vol. 56, No. 6, Jun. 2008.

[8] H.A. Majid, M.K.A. Rahim and T. Marsi, “Microstrip Antenna gain enhancement using left-handed Metamaterial Structure” Progress in Electromagnetic Research M. Vol.8, pp. 235-247, 2009.

[9] Ahmad A. Sulaiman, Ahmad S. Nasaruddin, “Bandwidth Enhancement in Patch Antenna by Metamaterial substrate”, European Journal of scientific research, 2010.

[10] He, S., J. Xiong, H. Li, and Y. Jin, \Patch antennas based on a pair of DPS and SNG metamaterial," Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP), 1 {3, 2010}.

[11] P. K. Singhal, BimalGarg “Design and Characterization of Compact Microstrip Patch Antenna Using “Split Ring” Shaped Metamaterial Structure” published in international journal of electrical and computer engineering, Vol.2, No.5, October 2012.

[12] Garg B, Saleem D (2013). Ameliorated RMPA using ‘Squares surrounded by Hexadecagon’ shaped Double Negative Metamaterial structure in the Ultra High Frequency (UHF) Band. Amer. J. Eng. SCI. And Technol., Res. 1(1): 1-9.