

Design of Double-E Shaped Metamaterial Structure with Negative μ and ϵ for Enhancement of Patch Antenna Parameters

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Abstract

In this paper RMPA along with Double-E Shaped resonator as a metamaterial structure is proposed at a height of 3.2mm from the ground plane. Rectangular microstrip patch antenna along with the proposed metamaterial structure is designed to resonate at 1.944GHz, which exhibits -21.976dB return loss at operating frequency and has impedance bandwidth from 1.933 to 1.958GHz. The return loss and impedance bandwidth of the patch antenna along with the proposed metamaterial structure is improved by 11.876dB and 19.1MHz respectively. All the simulation work is done by using CST-MWS Software. Here Nicolson-Ross-Weir method (NRW) has been used to verify Double-Negative properties (Negative Permeability and Permittivity) of the proposed metamaterial structure.

Keywords: *Double E Shaped resonator (DER), Left-handed Metamaterial Structure (LHM), NRW method, Rectangular Microstrip Patch Antenna (RMPA).*

1 Introduction

There are many kinds of materials used to improve the parameters of microstrip patch antenna. In these materials, metamaterials [7] are found most suitable. Victor Vesalago [1] has given the theoretical concept of metamaterial. According to him, these materials are generally artificial materials used to provide properties

which are not found in nature [6], [13]. Rectangular microstrip patch antenna is one of the most commonly utilized antennas in reality. It is widely used due to its low profile, low cost and omni directional radiation patterns. In spite of having these advantages it has some drawbacks like narrow bandwidth and low gain. To improve its performance many research processes on the patch antenna have been done. In this context Pendry and his colleagues [4] added more information that the array of metallic wire can be used to obtain negative permittivity and split ring resonator for negative permeability and in year 2001 smith et al [5] fabricated a structure, which was a composition of split ring resonator and thin wire, it is named as LHM [11], [14].

In this work proposed metamaterial structure has been introduced for ameliorating the antenna parameters like return loss and bandwidth. It has also been seen that with these improvements this structure also possesses double negative properties within the operating frequency range.

2 Design Specifications

The RMPA parameters are calculated from the formulas given below.

Desired Parametric Analysis [2], [3]

2.1 Calculation of Width (W).

$$W = \frac{1}{2f_r \sqrt{\mu_0 \epsilon_0}} \sqrt{\frac{2}{\epsilon_r + 1}} = \frac{C}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

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.

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

2.3 The actual length of the Patch (L).

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

Where

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

2.4 Calculation of Length Extension.

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

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

The parameters of rectangular microstrip patch antenna are $L= 36.2413\text{mm}$, $W=46.4435\text{mm}$, Cut Width= 5mm, Cut Depth= 10mm, length of transmission line feed= 36.42175mm, with width of the feed= 3.009mm shown in figure 1. The rectangular microstrip patch antenna is designed on the one side substrate with $\epsilon_r = 4.3$ and height from the ground plane $d= 1.6\text{mm}$. The proposed design is based on “Double-E Shaped resonator”.

Table 1: Rectangular Microstrip Patch Antenna Specifications

	Dimensions	Unit
Dielectric Constant (ϵ_r)	4.3	-
Loss Tangent ($\tan\delta$)	0.02	-
Thickness (h)	1.6	mm
Operating Frequency	1.935	GHz
Length (L)	36.2413	mm
Width (W)	46.4435	mm
Cut Width	5	mm
Cut Depth	10	mm
Path Length	36.42175	mm
Width Of Feed	3.009	mm

Fig. 1 shows the dimensional view of Rectangular microstrip patch antenna at a resonating frequency of 1.935GHz.

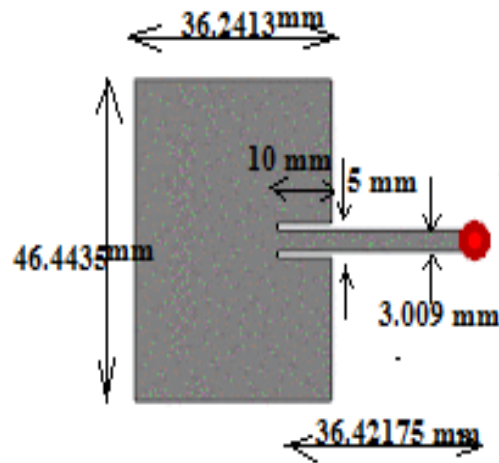


Figure 1: Dimensional view of Rectangular microstrip patch antenna resonating at 1.935GHz.

The return loss characteristics of RMPA at 1.935GHz have been studied in Fig. 2. Relatively narrow bandwidth of 5.9MHz & return loss of -10.1dB exhibited for conventional RMPA.

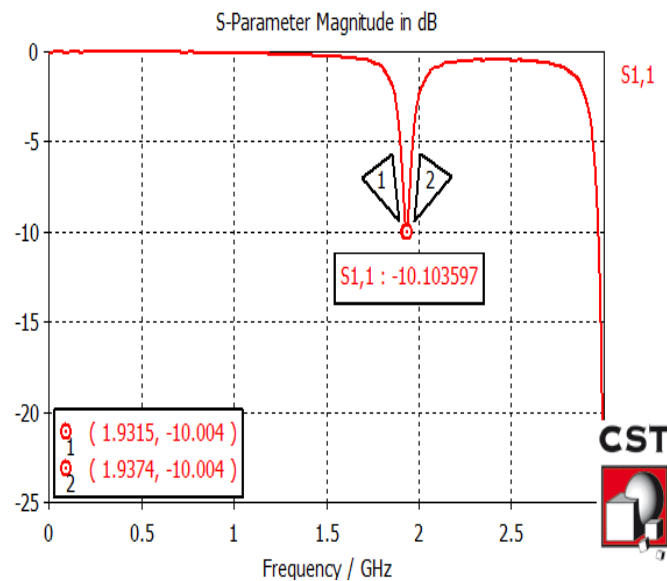


Figure 2: Rectangular microstrip patch antenna showing Return Loss of -10.1dB and Bandwidth of 5.9MHz.

3D radiation pattern of the rectangular microstrip patch antenna at 1.935GHz shown in figure 3. The radiation pattern shows directivity of 7.289dBi.

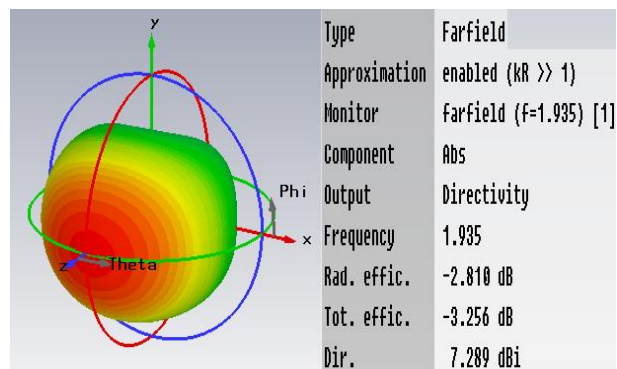


Figure 3: Radiation Pattern of rectangular microstrip patch antenna showing 7.289dBi directivity.

3.1 Nicolson-Ross-Weir (NRW) Approach

The proposed “Double-E Shaped resonator” as a metamaterial structure is placed between the two waveguide ports [15]-[16] at the left & right of the X-Axis (shown in Fig. 4) in order to calculate the S11 and S21 parameters, so as to verify the Double-Negative properties of the proposed metamaterial structure. In Figure 4, Y-Plane was defined as Perfect Electric Boundary (PEB) and Z-Plane was defined as the Perfect Magnetic Boundary (PMB).

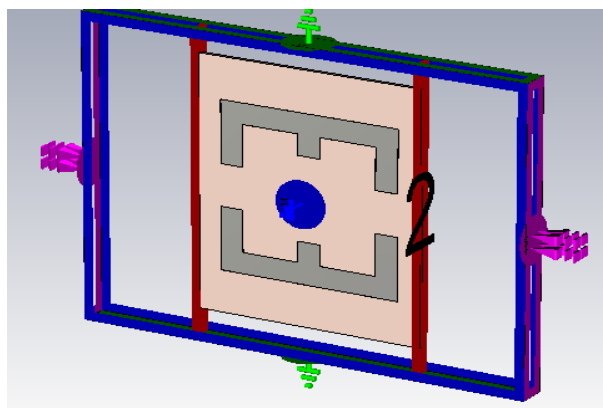


Figure 4: Proposed metamaterial structure placed between the two Waveguide Ports at the left & right of the X-Axis.

Equations used for calculating permittivity & permeability using NRW approach [8]-[10], [12], [17]-[18].

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

$$\epsilon_r = \mu_r + \frac{2.S11.c.i}{\omega.d} \quad (7)$$

$$v_2 = s_{21} - s_{11} \quad (8)$$

Where

ϵ_r = Permittivity

μ_r = Permeability

ω = Frequency in Radian,

d = Thickness of the Substrate,

c = Speed of Light, and

v_2 = Voltage Minima

Fig. 5 & 6 shows the negative value of permittivity & permeability at the operating frequency.

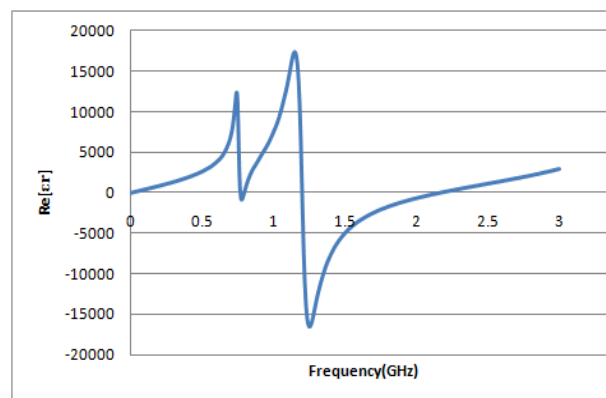


Figure 5: Permittivity versus Frequency Graph obtained from Microsoft Excel Software.

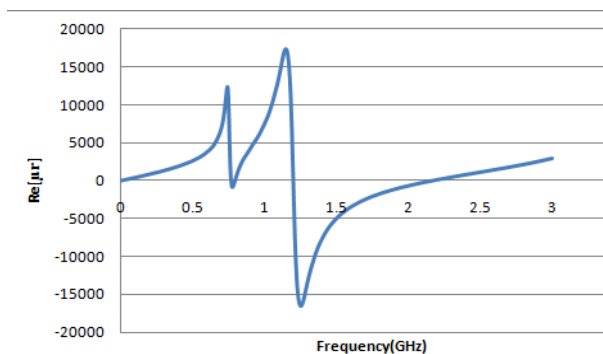


Figure 6: Permeability versus Frequency Graph obtained from Microsoft Excel Software.

The proposed metamaterial structure is placed above the patch antenna at a height of 3.2 mm from ground plane in order to study its influence, and the results are compared with those of the patch antenna alone.

Fig. 7 shows RMPA loaded with “Double-E Shaped Resonator” as a metamaterial structure at a height of 3.2mm from the ground plane.

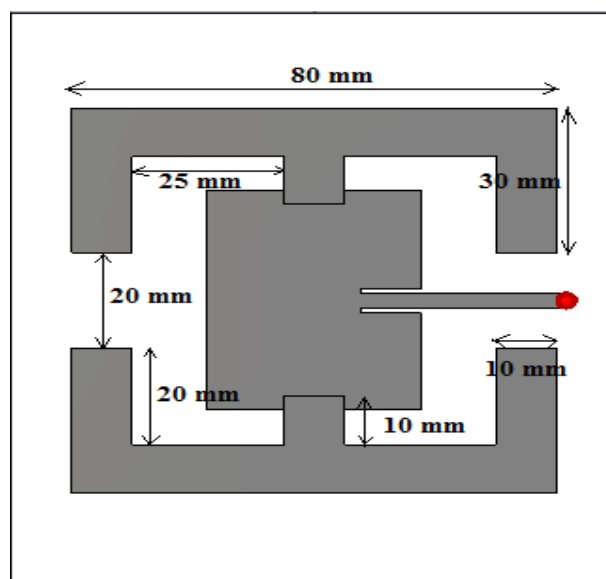


Figure 7: Dimensional view of Rectangular microstrip patch antenna loaded with “Double-E Shaped Resonator” as a metamaterial structure at a height of 3.2mm from the ground plane.

The proposed metamaterial structure reduces the return loss by 11.876dB and increases the bandwidth up to 19.1MHz.

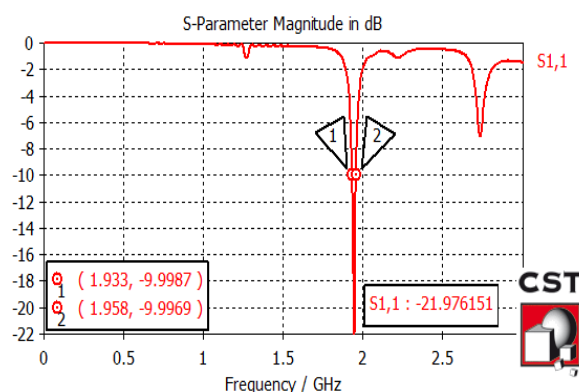


Figure 8: Simulated results of Rectangular microstrip patch antenna loaded with “Double-E Shaped Resonator” as a metamaterial structure showing Return Loss of -21.976dB and Bandwidth of 25MHz.

By using the proposed metamaterial structure it has been seen that the directivity is almost unaffected.

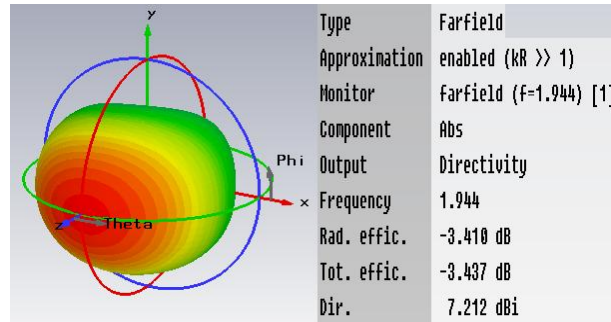


Figure 9: Radiation Pattern of rectangular microstrip patch antenna showing 7.212dBi directivity.

The size of the proposed antenna is significantly reduced by changing dimensions of the patch which is incorporated with metamaterial structure. The dimensional comparison of both the antennas is shown in table 2 below.

Table 2: Dimensional Comparison of RMPA Alone and with Proposed Reduced Size Antenna

	Dimensions of RMPA	Dimensions of Proposed Reduced size Antenna	Unit
Length (L)	36.2413	35.44	mm
Width (W)	46.4435	45.64	mm
Cut Width	5	5	mm
Cut Depth	10	10	mm
Path Length	36.42175	32.82	mm
Width of Feed	3.009	3.009	mm

4 Conclusion

The “Double-E Shaped Resonator” as a metamaterial structure with RMPA has been designed & analyzed in this paper. Proposed metamaterial structure reduces the return loss of the patch antenna by 11.876 dB, enhances the bandwidth by 19.1MHz. The substrate used is FR-4 (Lossy) with dielectric constant of 4.3. Modified NRW approach is used for proving the DNG properties of the proposed metamaterial structure.

References

- [1] V. G. Veselago, “The electrodynamics of substances with simultaneously negative values of μ and ϵ ”, *Sov. Phys. Uspekhi*, vol. 10, no. 4 (1968), pps. 509 – 514.
- [2] Constantine A. Balanis, *Antenna Theory and Design*, John Wiley & Sons, Inc., 1997.
- [3] W.L. Stutzman, G.A. Thiele, *Antenna Theory and design*, John Wiley & Sons, 2nd Ed., New York, 1998.
- [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 (1999), pp.2075-2081.
- [5] D.R. Smith, W.J. Padilla, D.C. Vier, S. C. Nemat-Nasser, and S. Schultz, Composite medium with simultaneously negative permeability and permittivity, *Phys Rev Lett* 84 (2000), pp. 4184–4187.
- [6] J.B. Pendry, Negative refraction makes a perfect lens, *Phys Rev Lett*, 85 (2000), pp.3966–3969.
- [7] Nader Engheta, Richard W. Ziolkowski, “Metamaterial Physics & Engineering Explorations”, Wiley-IEEE Press, June 2006.
- [8] Ahmad A. Sulaiman, Ahmad S. Nasaruddin, “Bandwidth Enhancement in patch antenna by metamaterial substrate”, *European Journal of scientific research*, 2010.
- [9] Huda A. Mazid, Mohammad Kamal A. Rahim, ThelasaMasri, “Left-handed metamaterial design for microstrip antenna application”, *IEEE International RF and Microwave conference*, 2008.
- [10] Ziolkowski, R. W., “Design, fabrication, and testing of double negative metamaterials,” *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 7 (2003), pp.1516-1529.
- [11] Wu, B-I, W. Wang, J. Pacheco, X. Chen, T. Grzegorzczuk, and J.A. Kong, “A study of using metamaterials as antenna substrate to enhance gain,” *Progress in Electromagnetic Research, PIERS* 51 (2005), pp. 295-328.

- [12] 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 (2009), pp. 235-247.
- [13] Bimal Garg, Rahul Tiwari, Ashish Kumar and Tilak Chitransh, "Design of factored 'X' shaped metamaterial structure for enhancement of patch antenna gain", International Conference on Communication Systems and Network Technologies 2011.
- [14] Shah Nawaz Burokur, Mohamed Latrach and Sergre Toutain, "Theoretical Investigation of a Circular Patch Antenna in the Presence of a Left-Handed Metamaterial", IEEE Antennas and Wireless Propagation Letters, Vol. 4, 2005.
- [15] Silvio Hrabar, Juraj Bartolic, "Backward Wave Propagation in Waveguide Filled with Negative Permeability Meta Material", Antennas and Propagation Society International Symposium, vol. 1 (2003), pp. 110 – 113.
- [16] Silvio Hrabar, Gordan Jankovic, Berislav Zivkovic, Zvonimir Sipus, "Numerical and Experimental Investigation of Field Distribution in Waveguide Filled with Anisotropic Single Negative Metamaterial", Applied electromagnetics and communications (ICEcom), (2005), pp. 1- 4.
- [17] Ankit Samadhiya, Rahul Dev Verma, "Design of SSRR based Metamaterial Structure for Amelioration in Patch Antenna Parameters with Negative μ and ϵ ". International Conference on Electronic Communication & Instrumentation, Jhansi UP, 6-7 April 2012.
- [18] Bimal Garg, Ankit Samadhiya, Rahul Dev Verma, "Design of Double-F Metamaterial Structure for Enhancing Bandwidth of Patch Antenna With Negative μ And ϵ ". International Conference on Communication Systems and Network Technologies (CSNT-2012), Rajkot (Gujrat), 11-13 May 2012.