

Improving Principle Design of Rectangular SRR based Metamaterial Structure with Negative μ and ϵ for Characteristics of Rectangular Microstrip Patch Antenna

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Abstract- This work is mainly focused on improving the principle characteristics of RMPA. Here design of rectangular SRR based metamaterial structure is proposed, which has been superimposed on RMPA at a height of 3.2mm from its ground plane. The resonating frequency of the proposed antenna is 1.896GHz. Simulation results are suggested that the impedance bandwidth of RMPA with proposed metamaterial structure is improved by 20.9MHz and return loss is reduced by 33.83dB. For proving double negative properties (Negative Permeability and Permittivity) of proposed metamaterial structure within the operating frequency range, Nicolson-Ross-Weir method (NRW) has been employed. All the Simulation results have been obtained by using CST-MWS Software.

Keywords: Rectangular Microstrip Patch Antenna (RMPA), Impedance bandwidth, Return loss, Nicolson-Ross-Weir (NRW), Split Ring Resonator (SRR).

1. Introduction

These days many researchers are showing their interest in RMPA due to the fact that it is low profile, lightweight, low cost antennas. In spite of having several advantages these antennas have some drawbacks like narrow-bandwidth, low gain, high return loss etc. [1]. To overcome these drawbacks several researches have been done on patch antennas. In this context, Victor Veselago [2]-[3] gave the theory of metamaterials. According to this theory metamaterials are generally manmade materials used to provide properties, which are not found in readily available materials in nature [4]-[5]. Later on J.B. Pendry and his colleagues [6] added more information. They concluded that, for obtaining negative permittivity and negative permeability array of metallic wires and split ring resonators can be used respectively. On the basis of this information a structure has been made by D. R. Smith and his colleagues in 2001 [7], which was a composition of split ring resonator and thin wire. It had been observed that the structure proposed by them possessed the negative values of permittivity and permeability simultaneously and was named as LHM [8]-[9].

In this work "Rectangular SRR" based metamaterial structure has been introduced for improving the principle characteristics of RMPA. Along with these outcomes, it has also been seen that this structure satisfied double negative properties (Negative Permeability and Permittivity) within the operating frequency range.

2. Antenna Designing Procedure and Simulation Results of RMPA with & without Metamaterial Structure

The RMPA parameters are calculated from the formulae given below.

A. Desired Parametric Analysis [10]-[11].

Calculation of Width (W)

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

Where

c = free space velocity of light

ϵ_r = Dielectric constant of substrate

The effective dielectric constant of the rectangular microstrip patch antenna.

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

The actual length of the Patch (L)

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

Where

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

Calculation of Length Extension

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

The Length and width of RMPA are $L=35.441\text{mm}$, $W=45.643\text{mm}$ respectively, these are calculated from the formulae discussed in preceding section. For cut width, cut depth, length of transmission line and width of the feed, some specific values have been chosen to obtain the specific resonating frequency. These values can be varied to change the resonating frequency. The parameter specifications of rectangular micro-strip patch antenna are mentioned in Table-1.

TABLE- 1

Rectangular Microstrip Patch Antenna Specifications

	Dimensions	Unit
Dielectric Constant (ϵ_r)	4.4	-
Loss Tangent ($\tan\delta$)	0.02	-
Thickness (h)	1.6	mm
Operating Frequency	1.896	GHz
Length (L)	35.441	mm
Width (W)	45.643	mm
Cut Width	4.04	mm
Cut Depth	10	mm
Path Length	32.821	mm
Width Of Feed	3.009	mm

Fig. 1 shows the Dimensional view of Rectangular microstrip patch antenna.

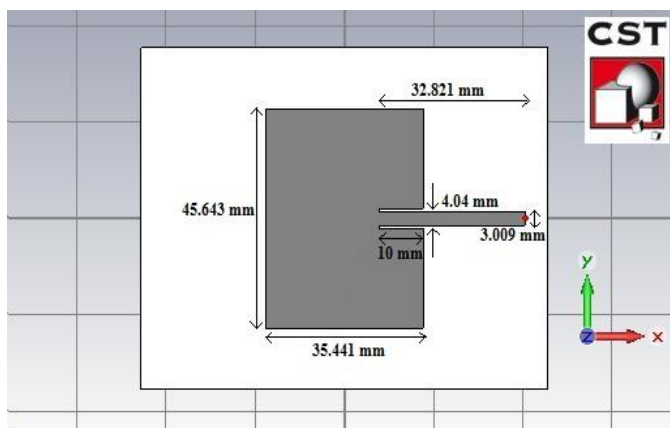


Figure 1: Rectangular Microstrip Patch Antenna

Fig.2 shows the return loss S_{11} and impedance bandwidth of RMPA. These are -10.7453dB & 20.4MHz respectively.

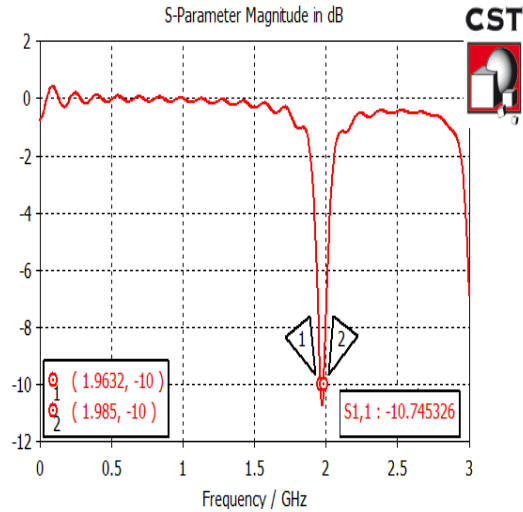


Figure 2: Simulation of Return loss S_{11} and impedance bandwidth of RMPA.

Dimensional view of the proposed metamaterial structure is shown in the Fig. 3.

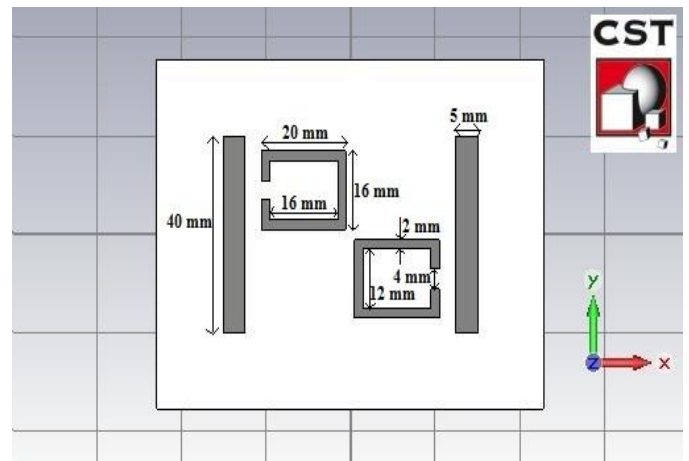


Figure 3: Design of proposed metamaterial structure.

3. Nicolson-Ross-Weir (NRW) Approach

In this work Nicolson-Ross-Weir (NRW) technique [12]-[13] has been used to obtain the values of permittivity and permeability as this is a very popular technique to convert S-parameters due to the fact that this technique provides easy as well as effective formulation and calculation. Here in this work for extracting the S-Parameters, proposed metamaterial structure is placed between the two waveguide ports [14]-[16] at the left and right hand side of the X axis as shown in Fig.4. In Fig. 4, Y-Plane is defined as Perfect Electric Boundary (PEB) and Z-Plane is defined as the Perfect Magnetic Boundary (PMB), which creates internal environment of waveguide. The simulated S-Parameters are then exported to Microsoft Excel Program for verifying the Double-Negative properties of the proposed metamaterial structure [17].

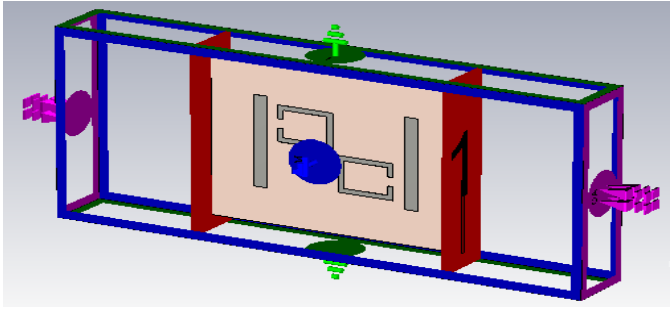


Figure 4: Proposed metamaterial structure between the two waveguide ports.

B. Equations used for calculating permittivity and permeability using NRW approach [17]-[19].

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

$$r = \frac{2c(1-v_1)}{\omega \cdot d \cdot i(1+v_1)} \quad (7)$$

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

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

Where

ϵ_r = Permittivity

μ_r = Permeability

c = Speed of Light

ω = Frequency in Radian

d = Thickness of the Substrate

i = Imaginary coefficient

V_1 = Voltage Maxima

V_2 = Voltage Minima

For satisfying Double Negative property, the values of permeability and permittivity should be negative within the operating frequency range. The obtained values of these two quantities from the MS-Excel Program are given in Table 2 & 3, whereas Fig. 5 & Fig. 6 shows the graph between permeability & frequency and permittivity & frequency respectively.

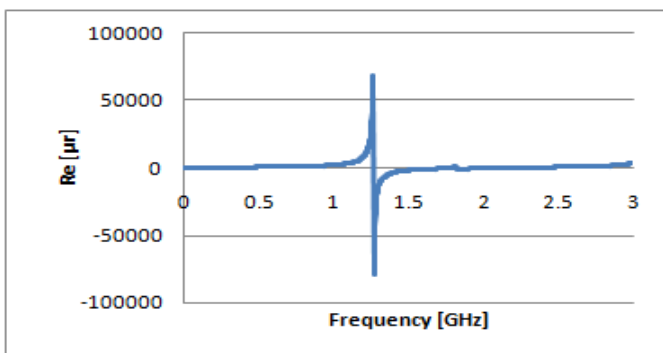


Figure 5: Permeability versus Frequency Graph.

TABLE- 2

Frequency[GHz]	Permeability[μ_r]	Re[μ_r]
1.89	-729.045448846679-91.9746398326313i	-729.045
1.8929999	-703.02608600106-94.8782511430091i	-703.026
1.8959998	-679.598725185741-98.5704850281327i	-679.599
1.899	-658.617918899477-102.805653408168i	-658.618
1.902	-639.925601463539-107.341910339569i	-639.926

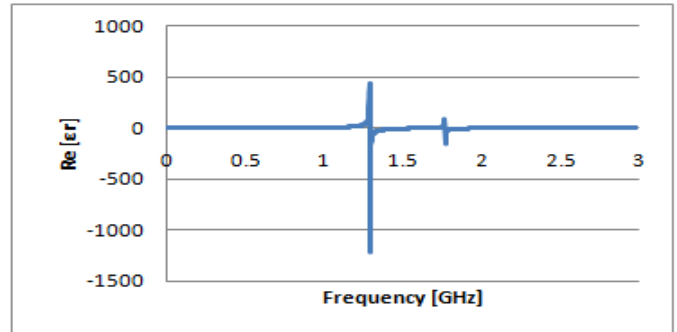


Figure 6: Permittivity versus Frequency Graph.

TABLE- 3

Frequency[GHz]	Permittivity[ϵ_r]	Re[ϵ_r]
1.89	-4.86462350587723-0.0441902233535667i	-4.86462
1.8929999	-4.76971969874913-0.0891058802805168i	-4.76972
1.8959998	-4.68660405359837-0.134108182021441i	-4.6866
1.899	-4.61462368207038-0.178161031038322i	-4.61462
1.902	-4.55303596468154-0.220306635565021i	-4.55304

Rectangular Microstrip Patch Antenna with Proposed metamaterial is given below in Fig. 7.

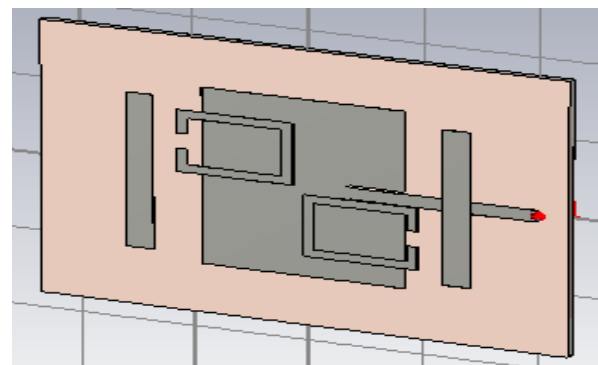


Figure 7: Rectangular Microstrip Patch Antenna with proposed metamaterial structure.

Fig.8 shows the Return loss S_{11} and Impedance Bandwidth of Rectangular microstrip Patch Antenna with proposed metamaterial structure. These values are -44.582dB & 42.7MHz respectively.

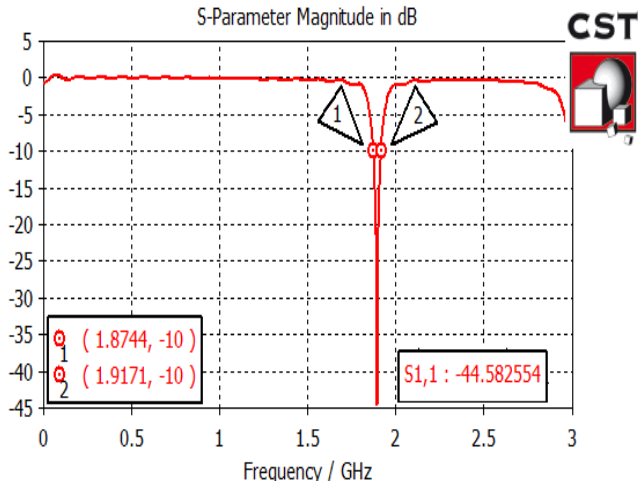


Figure 8: Simulation of Return Loss S_{11} and impedance bandwidth of RMPA with proposed metamaterial structure.

From Fig. 2 & 8 it has been observed that the return loss has significantly reduced by 33.83 dB and bandwidth has increased by 20.9 MHz by incorporating proposed metamaterial structure with RMPA.

From Fig.9 & 10 it is clear that the RMPA with the proposed metamaterial structure provides better impedance matching at 1.896 GHz, when compared to RMPA alone.

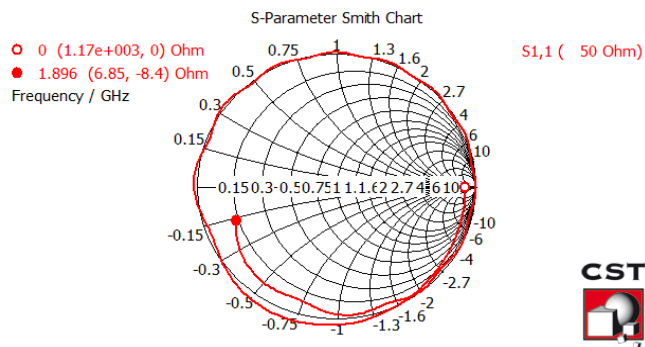


Figure 9: Smith chart of Rectangular Microstrip patch antenna.

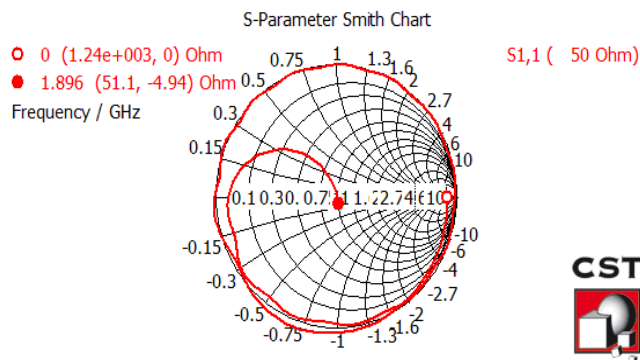


Figure 10: Smith chart of RMPA with proposed metamaterial structure.

The Radiation Pattern of the RMPA operating at 1.896GHz is shown in Fig. 11, which shows that the directivity is 6.432dBi and total efficiency is 26.41%, whereas Fig. 12 shows that the directivity of the RMPA with the proposed metamaterial structure is 6.382 and total efficiency is 51.34%. These results are showing that there is an improvement in total efficiency of RMPA by incorporating proposed metamaterial structure and directivity is almost unaffected.

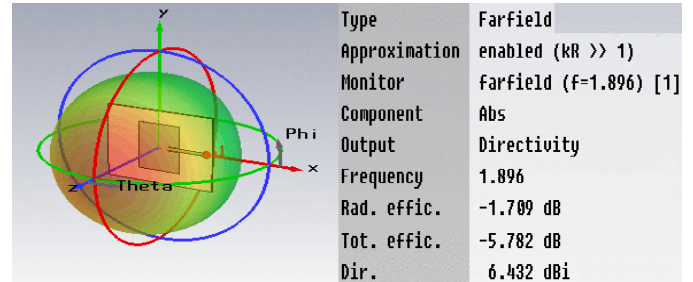


Figure 11: Radiation Pattern of a Rectangular Microstrip Patch Antenna.

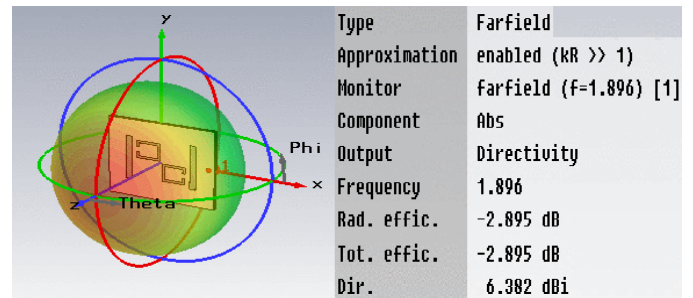


Figure 12: Radiation Pattern of RMPA with proposed metamaterial structure.

Fig. 13 & 14 shows the E field and H field pattern of the proposed antenna respectively at the operating frequency, which gives the information about distribution of E field and H field by the antenna.

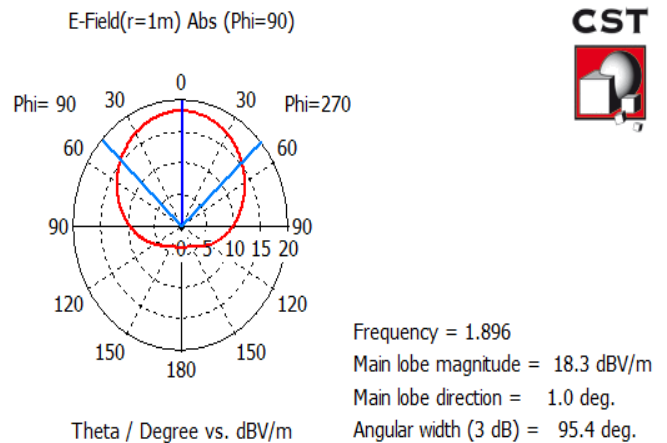


Figure 13: E Field pattern of the proposed antenna at 1.896 GHz.

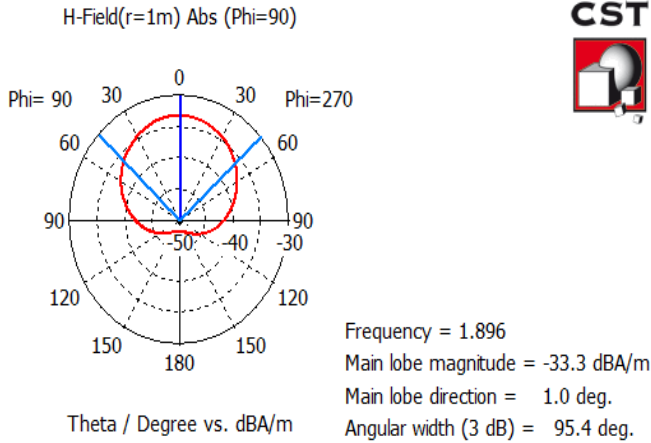


Figure 14: H Field pattern of the proposed antenna at 1.896 GHz.

4. Fabrication, Testing and Experimental Results

Fig. 8 shows the return loss pattern of RMPA with the proposed metamaterial structure within the simulated frequency range. This 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 Fig. 15&16.

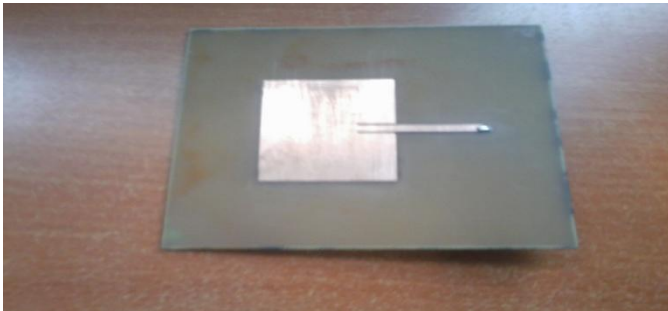


Figure 15: Fabricated RMPA on PCB.



Figure 16: Fabricated RMPA on PCB

After the fabrication of antenna, the antenna parameters like return loss and bandwidth are measured on spectrum analyzer. The setup which is used for antenna parameters measurement is shown in Fig. 17.



Figure17: Setup for measurement of antenna parameters.

Fig. 18 shows the Simulated and Measured result of proposed antenna.

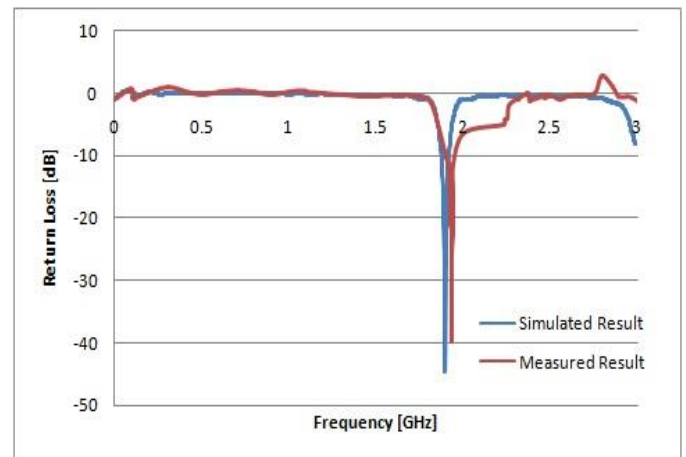


Figure 18: Combined Simulated and Measured result of proposed antenna.

According to this graph the return loss and bandwidth at 1.932 GHz are -39.689dB & 39.8MHz (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.

5. CONCLUSION

It is observed on the basis of the simulation results that the minimum return loss obtained at the operating frequency for the proposed antenna is -44.582dB and bandwidth is 42.7MHz, which is remarkable improvement in L-band (1-2GHz), when compared to the results of RMPA alone. It is clearly observed that the return loss bandwidth and total efficiency has improved significantly by incorporating the proposed metamaterial structure at 3.2 mm layer from the ground plane of RMPA. Along with these outcomes, it has also been seen that this structure satisfied double negative properties (Negative Permeability and Permittivity) within the operating frequency range.

REFERENCES

- [1]. Vikas Gupta, B.S. Dhaliwal "Performance Enhancement of Rectangular Microstrip Patch Antenna by Loading Complementary Split Ring Resonator in the Patch", International Journal of Electronics Engineering, vol. 3, no.1, pp. 141– 143, 2011.
- [2]. V. G. Veselago, "The electrodynamics of substances with simultaneously negative values of μ and ϵ ", Sov. Phys. Uspekhi, vol. 10, no. 4, pp. 509 – 514. 1968.
- [3]. Nader Engheta, Richard W. Ziolkowski, "Metamaterial Physics & Engineering Explorations", Wiley-IEEE Press, 2006.
- [4]. J.B. Pendry, Negative refraction makes a perfect lens, Phys Rev Lett-85, pp. 3966–396,2000.
- [5]. 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 C.S.N.T., pp.232-235, 2011.
- [6]. 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.
- [7]. 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, pp. 4184–4187, May 2000.
- [8]. Wu, B-I, W. Wang, J. Pacheco, X. Chen, T. Grzegorzczak, and J.A. Kong, "A study of using metamaterials as antenna substrate to enhance gain," Progress in Electromagnetic Research, vol.51, pp. 295-328, 2005.
- [9]. Shah Nawaz Burokur, Mohamed Latrach and Sergre Toutain, "Theoretical Investigation of a Circular Patch Antenna in the Presence of a Left-Handed Mematerial", IEEE Antennas and Wireless Propagation Letters, Vol. 4, pp. 183-186, 2005.
- [10]. Constantine A. Balanis, Antenna Theory and Design, John Wiley & Sons, Inc., 1997.
- [11]. W.L. Stutzman, G.A. Thiele, Antenna Theory and design, John Wiley & Sons, 2nd Ed., New York, 1998.
- [12]. Huda A. Mazid, Mohammad Kamal A. Rahim, Thelasa Masri, "Left-handed metamaterial design for microstrip antenna application", IEEE International RF and Microwave conference, pp. 218-221, 2008.
- [13]. Ziolkowski, R. W., "Design, fabrication, and testing of double negative metamaterials," IEEE Transactions on Antennas and Propagation", Vol. 51, No. 7, pp. 1516-1529, July 2003.
- [14]. Silvio Hrabar, Juraj Bartolic, "Backward Wave Propagation in Waveguide Filled with Negative Permeability Meta Material", Antennas and Propagation Society International Symposium, vol.1, pp.110 – 113, 2003.
- [15]. Silvio Hrabar, Gordan Jankovic, Berislav Zickovic, Zvonimir Sipus, "Numerical and Experimental Investigation of Field Distribution in Waveguide Filled with Anisotropic Single Negative Metamaterial", ICEcom, pp.1-4, 2005.
- [16]. S. Hrabar, J. Bartolic, and Z. Sipus, "Waveguide miniaturization using uniaxial negative permeability metamaterial", IEEE Trans. Antennas Propag., vol. 53, pp. 110–119, 2005.
- [17]. 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 C.S.N.T., pp. 35-39, 2012.
- [18]. H.A. Majid, M.K.A. Rahim and T. Marsi, "Microstrip Antenna gain enhancement using left-handed metamaterial structure", progress in Electromagnetic Research, Vol.8, pp. 235-247, 2009.
- [19]. Bimal Garg, Rahul Dev Verma, and Ankit Samadhiya, "Design of Rectangular Microstrip Patch Antenna Incorporated with Innovative Metamaterial Structure for Dual band operation and Amelioration in Patch Antenna Parameters with Negative μ and ϵ ", IJET, vol. 1(3), pp. 205-216, 2012.