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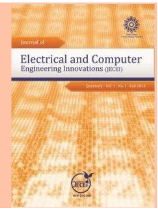
Journal of Electrical and Computer Engineering Innovations

JECEI, Vol. 5, No. 1, 2017

Regular Paper



Microstrip Antenna Gain Enhancement using Near Zero Refractive Index Metamaterials

Shahram Mohanna[1,*], Abdolshakoor Tamandani[2], and Sara Soltani[1]

[1]Faculty of Electrical and Computer Engineering, University of Sistan and Baluchestan, Zahedan, Iran.

[2]Department of Engineering, Velayat University, Iranshahr, Iran.

*Corresponding Author's Information: mohana@ece.usb.ac.ir

ARTICLE INFO

ARTICLE HISTORY:
Received 26 May 2017
Revised 22 August 2017
Accepted 27 August 2017

KEYWORDS:
Rectangular microstrip patch antenna
Near zero refractive index
Metamaterial

ABSTRACT

Some useful features of microstrip patch antennas are low profile, low weight and easy fabrication. However this type of antenna suffers from having a low gain, caused by propagation surface waves. In this paper, a new near zero refractive index metamaterial (MTM) unit cell is designed and fabricated as a superstrate over a Rectangular Microstrip Patch Antennas (RMPA). In order to obtain a maximum gain, the distance between the superstrate and the microstrip of the antenna has been optimized. Additionally, the feed position has been optimized to minimize the return loss. The operation frequency set at 10.3GHz and there are two resonance frequencies, one at 10.1GH and the other one at 11.68GHz. The simulations and measured results indicated that the superstrate MTM structure, designed to place horizontally over the antenna, increases the gain to almost 2.4dB and 2.62dB at 10.1GHZ and 11.68GHZ respectively. Moreover, the radiation efficiency and directivity of the antenna are improved significantly.

1. Introduction

Some useful features of microstrip patch antennas are low profile, low weight, and easy fabrication but it suffers from having a low gain, caused by propagation surface waves [1]. The use of metamaterials (MTM) to improve the gain of antenna is of interest. MTM is an artificial material that shows negative permittivity and/or negative permeability over a limited frequency bandwidth [2]. Effective permittivity and effective permeability are the two basic parameters of MTM. The metamaterial which has negative value for the real value of one of these parameters is called single negative (SNG). Thin wire (TW) structure and the split ring resonator (SRR) show negative permittivity (ENG) and negative permeability (MNG) respectively. By Combining ENG structure with TW and MNG structure (SRR), a double negative structure (DNG) can be made [3]. This is known as left handed metamaterials (LHM) which introduced by Veselago in 1969 [4]. As refractive index of MTM is negative, the emitted field would be perpendicular to the slab and consequently the gain would increase [5]. Recent studies have proposed use of metamaterial as superstrate for antennas to achieve gain enhancement [6-7].This can be achieved by using cavity model, reciprocity theory or transmission line [8]. In this paper, a new near zero refractive index MTM structure is designed in order to be used as a superstrate to obtain high gain on RMPA. The simulation results are presented in section 3. Section 4 provides the fabrication and measurement results and conclusion is given in section 5.

2. Problem Statement

The use of metamaterials to improve the gain of antenna is of interest. MTM is an artificial material that has negative permittivity and/or negative permeability over a limited frequency bandwidth. Effective permittivity and effective permeability are the two basic parameters of MTM. The metamaterial which has negative value for the real part of permittivity or permeability is called single negative (SNG). For the design and analysis of metamaterials, two methods have been proposed [9]. The first technique employs an analytical method such as the Lorentz theory or circuit models of metamaterials whereas the second method is based on full-wave simulations such as finite element method (FEM) or finite integration technique (FIT). The first method can be used only for a limited number of metamaterial structures and often could not accurately predict the macroscopic behavior of the metamaterial. In this paper, the design and analysis of the proposed near zero refractive index metamaterials (NZR) structures is performed by the second technique employing HFSS. A rectangular microstrip patch antenna (RMPA) having improved gain is designed using two stages. In the first step, a new NZR element is designed and in the second step, the patch antenna is designed. After that, the new NZR unit cells used as a superstrate on the patch antenna for enhancement of the gain of antenna.

3. Simulation Results

A. Design of metamaterial unit cell

In this section, a new near zero refractive index MTM unit cell is designed. The metamaterial unit cell is shown in Fig. 1. This structure is symmetrical, whereas $S_{21}=S_{12}$ and $S_{11}=S_{22}$. The design is performed on a Rogers.5880 substrate with a thickness size of 1.6 mm. The substrate dimensions are 4.5 mm by 4.5 mm, in x, y directions respectively. The parameter g=0.3 mm is very important as it effects the return loss and the gain of the antenna and acts as a capacitor at resonance frequency. HFSS is employed for simulations using perfect electric conductor (PEC) boundary conditions set on Y-axis, perfect magnetic conductor (PMC) boundary conditions set on x axis, and z axis is set as an open boundary condition.

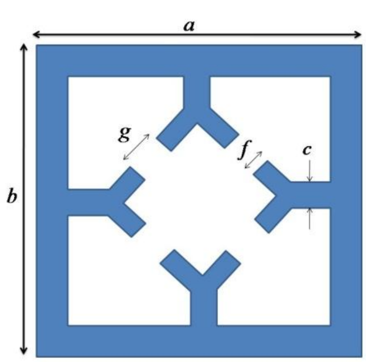


Figure 1: The proposed metamaterial unit cell (a=b=4.3mm, g=f=c=0.35mm).

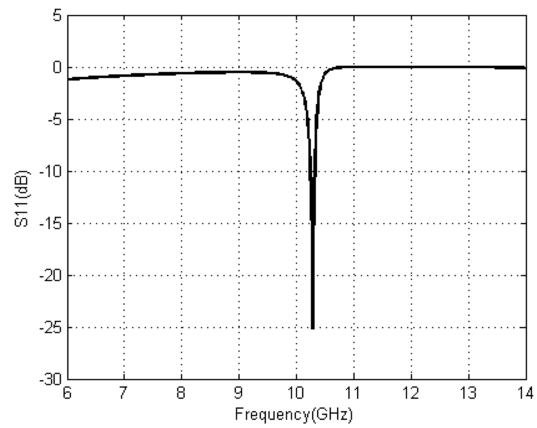


Figure 2: Simulated S_{11} (in dB) of MTM structure vs. frequency.

The reflection coefficient S_{11} as a function of frequency is shown in Fig 2. It can be seen in this figure that the resonance frequency of the unit cell is almost 10.3 GHz. Based on the parameters of the design and simulation results, the magnetic permeability and the electric permittivity coefficients, and the refraction index (n) are calculated using Nicolson Ross Weire (NRW) method [10-14] by the following equations:

$$\mu_r \approx \frac{2(1-V_2)}{jk_0 d(1+V_2)} \tag{1}$$

$$\varepsilon_r \approx \mu_r + j\frac{2S_{11}}{k_0 d} \tag{2}$$

$$v_2 = S_{21} - S_{11} \tag{3}$$

where,

ε_r =Permittivity

μ_r =Permeability

k_0 = Wave number in free space,

d=Thickness of substrate

v_2= Minimum Voltage

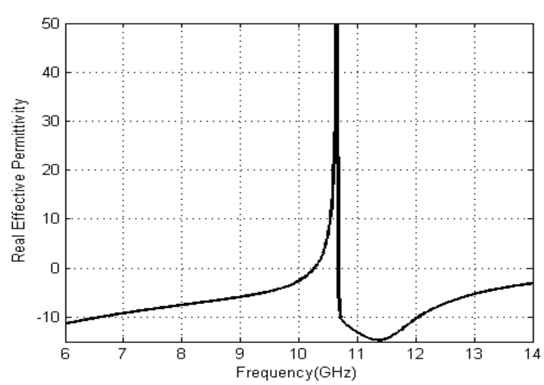


Figure 3: Permittivity of MTM vs. frequency.

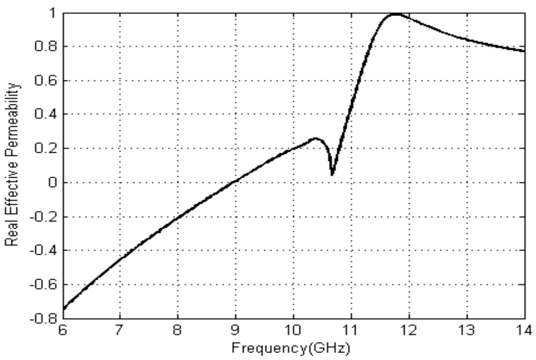


Figure 4: Permeability of MTM vs. frequency.

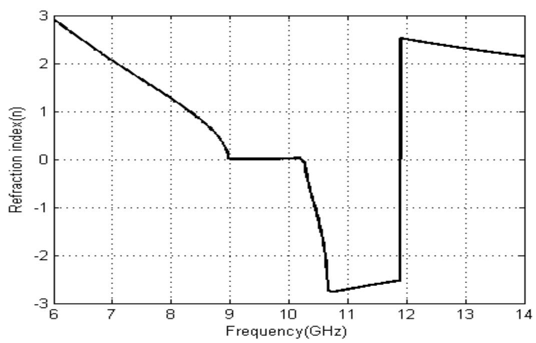


Figure 5: The refractive index (n) of MTM vs. frequency.

As shown in Figs. 3 and 4, the ε at 10.1 GHz is negative (near zero) and μ is positive (near zero), so $n = -\sqrt{\varepsilon_r \mu_r}$, which is zero at this frequency (Fig. 5).

B. Antenna Design

The schematic view of the antenna with using a 4× 4 array of MTM as a superstrate is presented in Fig. 6. The Arrays of MTM printed on both side of a dielectric layer and placed at the distance of d=1.8mm from the patch antenna. The distance for MTM superstrate, in order to obtain the highest gain, is optimized by HFSS. Increasing the number of unit cells in the superstrate, increases the gain of the antenna significantly. The RMPA consists of a metallic patch on top of a dielectric substrate (Rogers.5880) having a thickness of h_2=1.6 mm. As shown in Fig. 6, the thickness of the superstrate in z-direction is h_1=0.8mm. The antenna is designed at the same resonance frequency of the unit cell in order to have a negative refractive index for the metamaterial.

Using the formula given in [15] for patch antenna design, the dimensions of the proposed antenna are calculated giving a length of l=8.8mm and a width of w=10mm. A grounded plane is located on the other side of the substrate with dimensions of l_g=18.4mm, w_g=19.7mm. The coaxial feeding method was used to feed the patch antenna. This method creates a narrow bandwidth.

In order to find a suitable position of feeding point on the patch, to have both impedance matching and minimizing the return loss, an optimization algorithm is employed using HFSS. The position of p=2.2mm on the y-axis gives the best results, which minimizes the return loss, and consequently leads to an increase of the antenna gain and radiation efficiency. In Fig. 8, the gain of the microstrip antenna is plotted in comparison with the gain of the antenna with MTM superstrate.

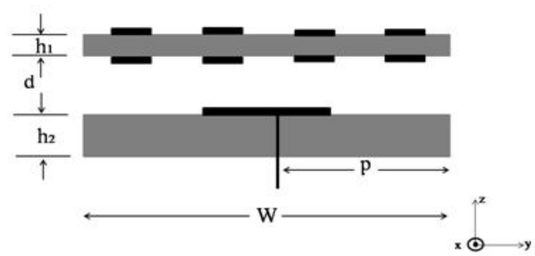
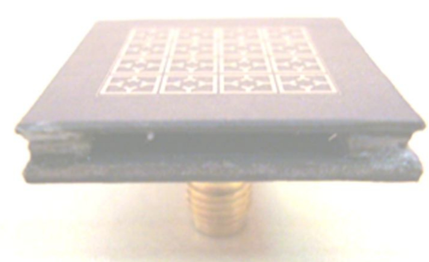


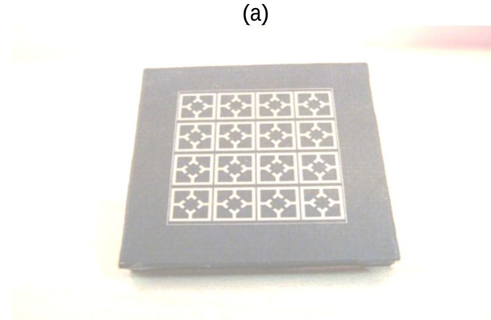
Figure 6: Side view of microstrip patch antenna covered by the metamaterial superstrate.

4. Fabrication and Measurement Results

Fig.7 shows side and top views of the fabricated microstrip antenna incorporated with MTM superstrate.



(a)



(b)

Figure 7: Fabricated antenna (a) side view, (b) top view.

Fig. 9 shows the comparison of the simulation and the measured results of the reflection coefficient where the frequency range is almost 3GHz. Fig. 10 compares the gain of the patch microstrip antenna with the gain of the antenna enhanced by the MTM superstrate. It is evident that the gain is improved significantly at the two frequencies of f_1=10.1GHz and f_2=11.68 GHz. The obtained gains at these two frequencies are 8.99dB and 9.3dB, respectively.

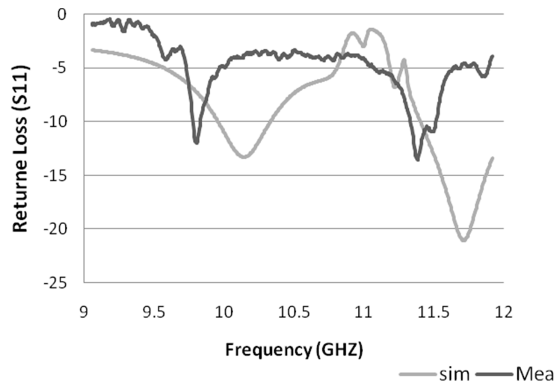
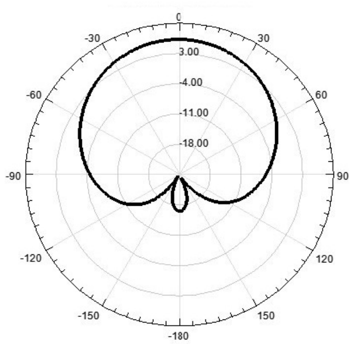
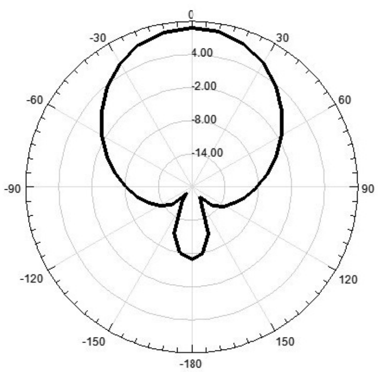


Figure 9: S_{11} (in dB) vs. frequency for simulation and measured results.



(a)



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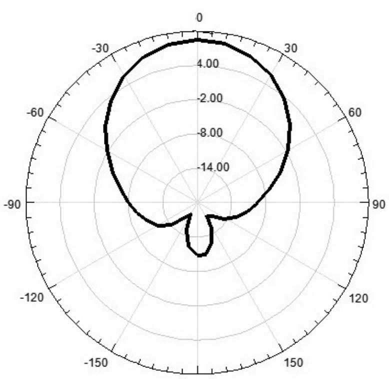
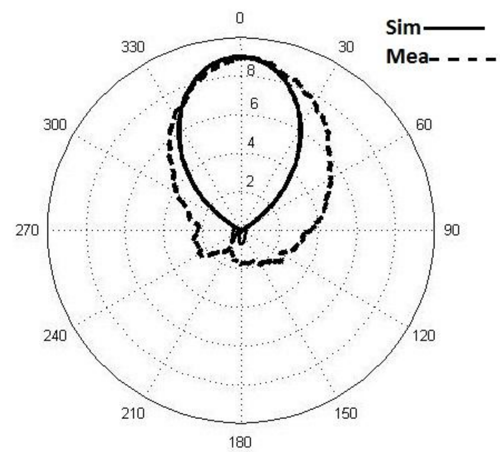
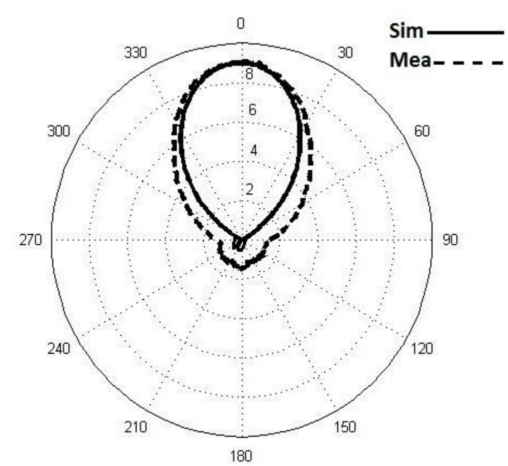


(c)

Figure 8: Gain of the microstrip patch antenna (a) without MTM (b), with MTM in 10.1GHz, (c) with MTM in 11.68GHz.



(a)



(b)

Figure 10: A comparison between the simulation and measurement results at (a)10.1GHz, (b)11.68 GHz.

5. Conclusion

In this paper, a new zero refractive index metamaterial structure is presented to improve the gain of the microstrip antenna. The distance between patch antenna and superstrate (d) and the coaxial cable position (p) is optimized. The results indicate that the gain enhancements of 2.4dB and 2.62dB at two frequencies of f_1=10.1GHz, f_2=11.68GHz have been achieved. The simulations and measured results show that the superstrate MTM structure, designed to place horizontally over the antenna, increases the gain to almost 2.4dB and 2.62dB at 10.1GHz and 11.68GHz, respectively.

References

[1] J. Singh, A.P. Singh, and T.S. Kamal, "On the design of triangular microstrip antenna for wireless communication," *International Journal of Computer Applications-IJCA*, A Special Issue, pp. 103-106, 2012.

[2] J.B. Pendry, "Negative refraction makes a prefect lens, "*Phys. Rev. Let.*, vol. 85 , pp. 3966–3969, 2000.

[3] D.R. Smith, W.J. Padilla, D.C. Vier, S.C. Nemat-Nasser, and S. Schultz, "A composite medium with simultaneously negative permeability and permittivity," *Phys. Rev. Let*., vol. 84, no. 18, pp. 4184–4187, May 2000.

[4] N. Engheta and R.W. Ziolkowski, Metamaterial Physics & Engineering Explorations. Wiley-IEEE Press, June 2006.

[5] J.B. Pendry, A.J. Holden, D.J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. Microwave Theory Tech*., vol. 47, no. 11, pp. 2075–2084, 1999.

[6] B. Li, B. Wuand, and C.H. Liang," Study on high gain circular waveguide array antenna with Metamaterial structure," Progress In Electromagnetic Research, PIER 60, pp. 207–219, 2006.

[7] H. Attia, L. Yousefi, M.M. Bait-Suwailam, M.S. Boybay, and O.M. Ramahi, "Enhanced-gain Microstrip antenna using engineered magnetic Superstrate," *IEEE Ant. Wireless Pro. Let*., vol. 8, pp. 1198–1201, 2009.

[8] Y. Lo, D. Solomon, and W. Richards, "Theory and experiment on Microstrip antennas," *IEEE Trans. Ant. Pro*., vol. 27, no. 2, pp. 137–145, Mar. 1979.

[9] T.J. Cui, D.R. Smith, and R. Liu, Metamaterials Theory, Design and Applications. Springer, 2009

[10] A.A. Sulaiman and A.S. Nasaruddin, "Bandwidth enhancement in patch antenna by metamaterial substrate," *European Journal of Scientific Research*, vol.44, no. 3, pp. 493-501, 2010.

[11] R.W. Ziolkowski, "Design, fabrication, and testing of double negative Metamaterials," *IEEE Trans. on Ant. and Prop*., vol. 51, no. 7, pp.1516-1529, 2003.

[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, pp. 235-247, 2009.

[13] A. Samadhiya and R. DevVerma, "Design of SSRR based metamaterial structure for amelioration in patch antenna parameters with negative µ and Ɛ," in *Proc. International Conference on Electronic Communication & Instrumentation*, Jhansi UP, India, 6-7 April 2012.

[14] B. Garg, A. Samadhiya, and R. Deverma, "Design of double-f metamaterial structure for enhancing bandwidth of patch antenna with negative µ and Ɛ," in *Proc. International Conference on Communication Systems and Network Technologies* (CSNT-2012), Rajkot (Gujrat), 11-13 May 2012.

[15] Z. Awang, Microwave Engineering for Wireless Communications: Prentice Hall.

Biographies

The Authors' photographs and biographies not available at the time of publication.

How to cite this paper:

Sh. Mohanna, A. Tamandani, and S. Soltani, "Microstrip antenna gain enhancement using near zero refractive index metamaterials," *Journal of Electrical and Computer Engineering Innovations*, vol. 5, no. 1, pp. 59-63, 2017.

DOI: 10.22061/JECEI.2017.688

URL: http://jecei.srttu.edu/article_688.html