

Miniaturization of a Rectangular Microstrip Patch Antenna Loaded with Metamaterial

Anahita Ghaznavi Jahromi, Farzad Mohajeri, and Nooshin Feiz

Abstract—In this paper a novel structure of metamaterial is proposed in order to miniaturize a rectangular microstrip patch antenna. The metamaterial is composed of two nested split octagons which are located on a 10 mm×10 mm Rogers RT/duroid 5880 with 0.7874 mm thickness and dielectric constant of 2.2. A 3×5 array of such metamaterials is placed on the patch antenna substrate. By using this metamaterial in the antenna structure, the dimension of this proposed antenna is reduced compared to a simple microstrip patch antenna. Simulation results for return loss and radiation pattern of both proposed and conventional antenna are shown and compared. The size of the proposed patch antenna is considerably smaller than the wavelength of the operation frequency compared with the conventional patch antenna.

Keywords—Metamaterial, miniaturization, patch antenna, sub-wavelength resonance.

I. INTRODUCTION

ANTENNAS are structures to send and receive electromagnetic waves. Microstrip antennas are one type antenna which are low-profile, low weight, low cost, easy to fabricate and installation, and integrable with other microwave devices [1]. Due to these advantages, they are used in mobile radio and wireless communication systems, radars, missile applications, etc. Nowadays, the need for smaller size communication systems and small size antennas in radio sensors and radars are continuously getting increased. Therefore, antenna miniaturization is an important aspect in wireless communication systems.

Although microstrip antennas are of small thickness, their transverse dimension is in the order of half wavelength. So, they are not small enough in their transverse dimension. By now, a large number of different techniques have been used for miniaturization of microstrip antennas. Slotting the patch [2] and using shorting posts [3] are some of these techniques which are not able to miniaturize the antenna to an acceptable extent for the mentioned applications.

Another technique that is used to reduce the size of the patch antenna is the employment of high permittivity dielectric substrate [4]. Although this method well miniaturizes the antenna, it brings about some side effects. Using a substrate with a high dielectric constant increases the

flow of surface waves, which results in the gain reduction and deterioration of the radiation efficiency. Additionally, it causes the impedance bandwidth of this structure to be decreased. In order to not dealing with these problems, nowadays, metamaterial structures are used for miniaturization of the antenna.

Metamaterials are artificial structures, and their electromagnetic properties don't exist in nature. Employing metamaterials in microstrip antenna substrate will result in the improvement of the antenna parameters like bandwidth, gain, efficiency, etc. Additionally, it is possible to miniaturize the antenna as much as desired with these structures, without dealing with surface waves problems. To date, many different techniques have been proposed, based on the use of metamaterials. Applications of double negative (DNG) and single negative (SNG) metamaterials have been widely studied by some research groups in miniaturization of sub-wavelength cavities [5], waveguides [6], and antennas [7]-[9].

Recently, a CSRR¹ structure is used in miniaturization of microstrip antennas [10]. In this research the results of using CSRR and high permittivity substrate are compared with each other. In [11], the combination of only three μ -negative metamaterial unit cells with air is used as a substrate of microstrip patch antenna. The resonance frequency of this antenna decreased to the resonance frequency of the unit cell, so a sub-wavelength resonance occurred and the size of the antenna reduced by 77%. Another research that is done to miniaturize patch antenna, reduced its dimensions by about 58% [12]. Many other researches have been done on miniaturizing the patch antenna [13], [14].

In this paper, we present the possibility of miniaturization of a rectangular microstrip patch antenna by using a novel structure of metamaterial, which is placed on the substrate. First of all, the resonance structure of the metamaterial is investigated and analyzed. Then the antenna structure at the presence of this metamaterial in the substrate is investigated and the return loss and radiation pattern of the proposed antenna is compared with the conventional patch antenna with the same dimension. Incorporating this proposed metamaterial in the patch antenna reduces its resonance frequency, which means that for this resonance frequency, the antenna with proposed metamaterial would have smaller dimension compared to a conventional patch antenna. However, as a result of this miniaturization, the sub-wavelength mode of the rectangular patch antenna is narrow in bandwidth and low radiation efficiency.

¹ Complementary Split Ring Resonator

A. Ghaznavi Jahromi is with the Electrical and Electronic Engineering Department, Shiraz University, Shiraz, Iran (email: anahitaghaznavi7@gmail.com).

F. Mohajeri is with the Electrical and Electronic Engineering Department, Shiraz University, Shiraz, Iran (email: mohajeri@shirazu.ac.ir)

N. Feiz is with the Electrical and Electronic Engineering Department, Shiraz University, Shiraz, Iran.

II. METAMATERIAL AND ANTENNA DESIGN

A. Metamaterial Unit Cell Structure

The configuration of the novel metamaterial model that is investigated in this paper is shown in Fig. 1. As it is seen from the figure, this metamaterial unit cell is composed of two nested split octagons which are etched on a dielectric substrate.

The substrate is Rogers RT/duroid 5880 with dielectric constant equal to 2.2. Dielectric dimensions, $L_s \times W_s$, are 10 mm \times 10 mm and the thickness, t , is 0.7874 mm. The strip width of each octagon is 0.6 mm. The sides of the octagons, from the outer side to the inner side, (S_1, S_2, S_3, S_4) are 4.0 mm, 3.5 mm, 2.8 mm and 2.3 mm respectively. Both of the gaps, g , in the octagons are 0.3 mm and the distance between octagons, d , is 0.845 mm. To analyze this structure, it is embedded at the middle of a TEM waveguide, which has proper magnetic and electric boundary conditions on walls. This is shown in Fig. 2.

The results of the return loss and relative constitutive parameters of the unit cell (permittivity and permeability) are shown in Fig. 3 and Fig. 4 respectively. The constitutive parameters are calculated from S-parameters by using retrieval method introduced in [15]. As it is seen from Fig. 4, both of the permittivity and permeability parameters are negative in a specific frequency band. So this structure shows double negative property and it can be used as a DNG medium.

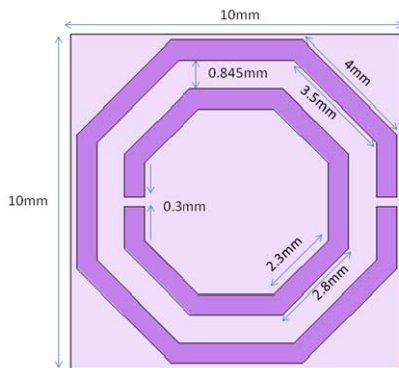


Fig. 1 The unit cell structure and its dimensions:
 $L_s=W_s=10$ mm, $S_1=4$ mm, $S_2=3.5$ mm, $S_3=2.8$ mm, $S_4=2.3$ mm,
 $g=0.3$ mm, $d=0.845$ mm

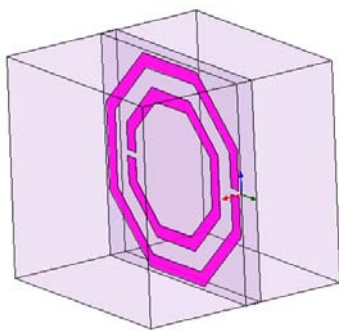


Fig. 2 The metamaterial structure embedded in a TEM waveguide

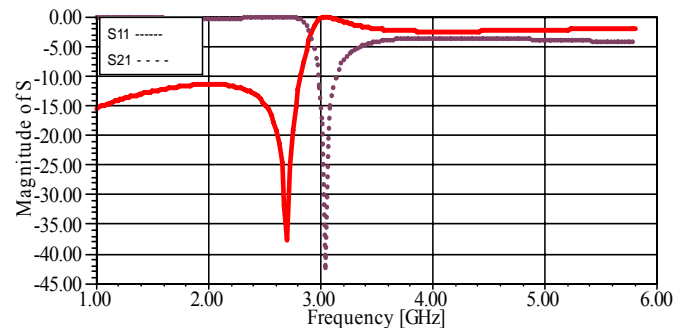
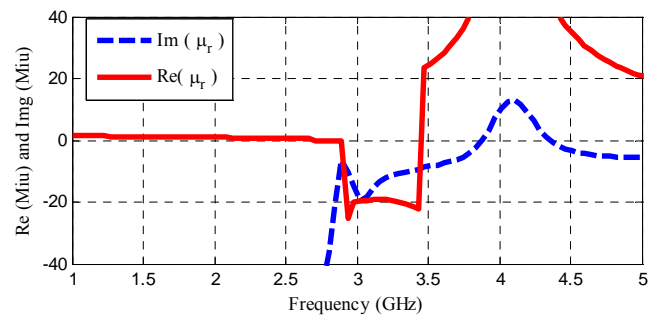
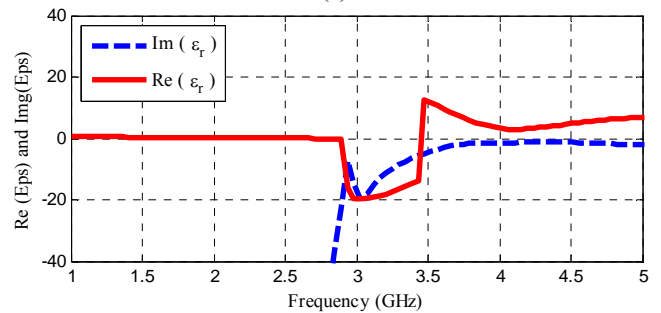


Fig. 3 Magnitude of S parameters



(a)



(b)

Fig. 4 Constitutive parameters of the unit cell (a) permeability (b) permittivity

The resonance frequency of this structure depends on the gap dimension (g). By increasing the gap, the capacitance in LC circuit model of the unit cell decreases. The decrement of the capacitance, results the increment of the resonance frequency of the structure.

B. Antenna Design

Fig. 5 shows the geometry of the proposed antenna. A 3×5 array of metamaterial which was described in section A is placed in the substrate of a patch antenna. The substrate width (W_g) is 50 mm and its length (L_g) is 30 mm. The patch dimensions of this structure, $w \times l$, are 18.4 mm \times 15.9 mm. This antenna is fed by a microstrip line inset feed. The width of the feed line (W_0) and the depth of the inset (d) have been adjusted to match the antenna impedance to 50 Ω . The size of W_0 is 4.08 mm and d is 5 mm. The distance between inset line and the patch (y) is 1.8 mm.

When the patch antenna is loaded with this metamaterial, its resonance frequency depends on the metamaterial constitutive parameters. It means that the antenna resonates when the constitutive parameters become negative. Therefore the antennas resonance frequency shifts to the metamaterials resonance frequency. In the proposed antenna, it is shown that by loading a conventional rectangular patch antennas substrate with a DNG metamaterial, a sub-wavelength resonant mode on the patch will be excited.

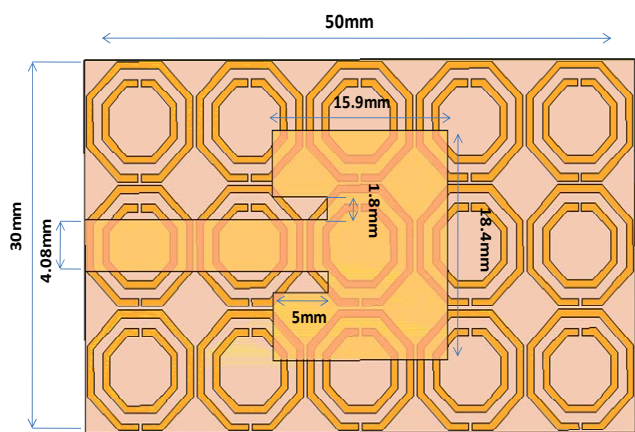


Fig. 5 The patch antenna structure in the presence of metamaterial
 $W_g=50$ mm, $L_g=30$ mm, $W_0=4.08$ mm, $d=5$ mm, $w=18.4$ mm,
 $l=15.9$ mm, $y=1.8$ mm

III. SIMULATION RESULTS AND COMPARISONS

Simulation result for return loss of the proposed antenna is shown in Fig. 6. These simulations are obtained by using Ansoft HFSS software.

As it is seen in Fig. 6, the resonance frequency of the proposed antenna is 3.0 GHz. By this patch dimension, the conventional antenna resonates at 6.0 GHz. When the metamaterial is incorporated, the antenna resonates at a frequency where the permittivity and permeability are negative (Fig. 4). This reduces the resonance frequency of the antenna from 6.0 GHz to 3.0 GHz. By reducing the resonance frequency of the antenna, miniaturization happens, because, the dimensions of the proposed antenna is smaller than a conventional antenna which resonates at 3 GHz. This miniaturization brings about 50% size reduction. The dimensions of the proposed patch antenna are as small as $0.273\lambda \times 0.236\lambda$.

Because these metamaterial structures are narrowband, the bandwidth of the proposed antenna is smaller than the conventional antenna. The -10dB return loss Bandwidth of the proposed antenna, which is standard define for antenna engineering applications, is 0.01 GHz, while the bandwidth of the conventional antenna is 0.18 GHz.

The radiation pattern of the proposed antenna and the conventional antenna at frequencies 6.0 GHz and 3.0 GHz are shown in Fig 7. The gain of the antenna at frequencies 6.0GHz and 3.0 GHz are 6.53 dB and -4.72 dB, respectively.

It shows that by reducing the size of the antenna, its gain decreases. So there is a tradeoff between gain and size of the antenna. The comparison between the resonance frequency and gain of the conventional antenna and proposed antenna are depicted in Table I.

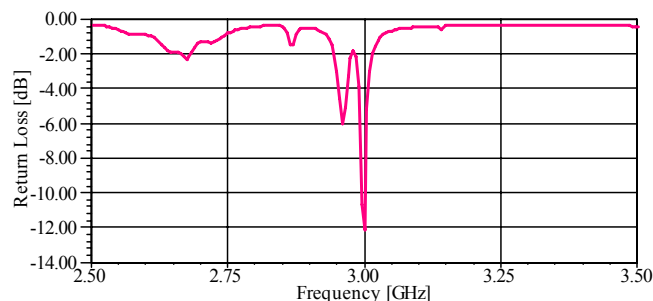


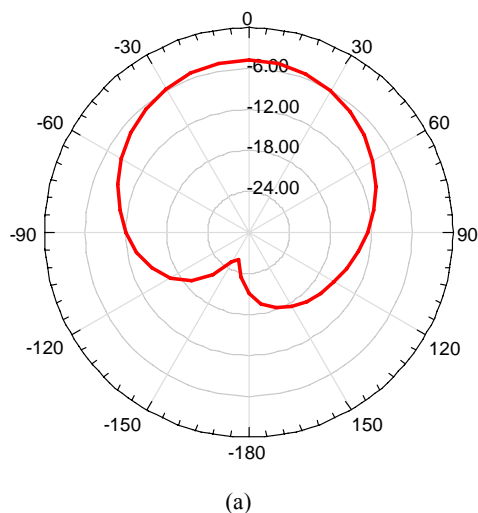
Fig. 6 Return loss of the proposed patch antenna

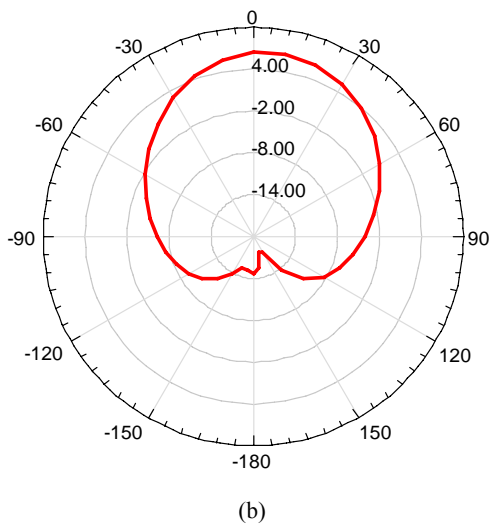
TABLE I
 COMPARISON OF TWO ANTENNAS

Options	Patch dimensions	Resonance frequency (GHz)	Gain (dB)
Conventional antenna	$0.565 \lambda \times 0.48 \lambda$	6	6.53
Proposed antenna	$0.273 \lambda \times 0.236 \lambda$	3	-4.72

IV. CONCLUSION

A miniaturized microstrip patch antenna loaded with a DNG metamaterial was investigated. The overall dimension of the proposed antenna reduced about 50%. The location of the operating frequency is tuned effectively by the resonance of the metamaterial; therefore a sub-wavelength resonance was produced by the help of metamaterials. The radiation pattern and gain of the proposed antenna was deteriorated by size reduction. So there is a tradeoff between size reduction and gain of the antenna.





(b)
Fig. 7 The radiation pattern (a) proposed antenna
(b) conventional antenna

- [15] D. R. Smith, D. C. Vier, Th. Koschny, and C. M. Soukoulis, "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Phys. Rev. E* 71, 2005.

REFERENCES

- [1] C.A. Balanis. "Antenna Theory: Analysis and Design". 2nd Ed, United States of America, John Wiley & Sons, 0471592684, 1982.ch. 14
- [2] J. Huang, "A review of antenna miniaturization techniques for wireless applications," Jet Propulsion Laboratory, California Institute of Technology, 2001.
- [3] R.B. Waterhouse, S. D. Targonski, D. M. Kokotoff, "Design and performance of small printed antennas," *IEEE trans. Antennas*, 1998.
- [4] A. Trippe, S. Bhattacharya, J. Papapolymerou, "Compact microstrip antennas on a high relative dielectric constant substrate at 60 GHz," *IEEE Antennas and Propagation (APSURSI)*, Spokane, pp 519-520, July 2011.
- [5] N. Engheta, "An idea for thin sub-wavelength cavity resonator using metamaterials with negative permittivity and permeability," *IEEE Antennas Wireless Propag. Lett.*, vol. 1, no. 1, pp. 10–13, 2002.
- [6] A. Alù and N. Engheta, "Guided modes in a waveguide filled with a pair of single-negative (SNG), double-negative (DNG), and/or double – positive (DPS) metamaterial layers," *IEEE Trans. Microw. Theory Tech.*, vol. MTT-52, no. 1, pp. 199–210, Jan. 2004.
- [7] A. Alù, F. Bilotti, N. Engheta, and L. Vegni, "Sub-wavelength, compact, resonant patch antennas loaded with metamaterials," *IEEE Trans. Antennas Propag.*, vol. 55, no. 1, pp. 13–25, Jan. 2007.
- [8] F. Bilotti, A. Alù, and L. Vegni, "Design of miniaturized metamaterial patch antennas with μ -negative loading," *IEEE Trans. Antennas Propag.*, vol. 56, no. 6, pp. 1640–1647, Jun. 2008.
- [9] A. Alù, F. Bilotti, N. Engheta, and L. Vegni, "Sub-wavelength planar leaky-wave components with metamaterial bilayers," *IEEE Trans Antennas Propag.*, vol. 55, no. 3, pt. 2, pp. 882–891, Mar. 2007.
- [10] Y. Lee, Y. Hao, "Characterization of microstrip patch antennas on metamaterial substrates loaded with complementary split-ring resonators," *Microwave And Optical Technology Letters*, vol. 50, No. 8, , pp 2131-2135, August 2008.
- [11] A. Bazrkar, A. Gudarzi, M. Mahzoon, "Miniaturization of rectangular patch antenna partially loaded with μ -negative metamaterials," *International conference on Electronics, Biomedical and Its Applications (ICEBEA)*, Dubai, pp 289-292, Jan 2012.
- [12] J Ye, Q Cao, W. Tam, "Design and analysis of a miniature metamaterial microstrip patch antenna," *IEEE Antenna Technology (iWAT)*, Hong Kong, pp 290-293, March 2011.
- [13] Sh. S. Pattnaik, J. G. Joshi, S. Devi, M.R. Lohokare, "Electrically small rectangular microstrip patch antenna loaded with metamaterial," *IEEE Antennas Propagation and EM Theory (ISAPE)*, Guangzhou, pp 247-250, Nov. 29 2010- Dec 2 2010.
- [14] C. Kamtongdee, N. Wongkasem, B. Charoen, and K. Matra, "Development of compact microstrip antennas using metamaterials," *ITC-CSCC* 2009.