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A gain and bandwidth enhanced metamaterial based surface antenna for wireless communication

Neha Rajak* (1), Neela Chattoraj(1), and Raghvendra Kumar(1)
(1) Department of Electronics and Communication Engg., Birla Institute of Technology, Mesra, Ranchi

Abstract

A new metamaterial based surface patch antenna is designed in this paper which enhances the gain and bandwidth of the patch antenna. The metamaterial is designed using two hexagonal ring resonators which form a double negative medium. The dimension of the metamaterial is 11 x 11 mm^2 which forms a surface over the patch antenna, which results in increment of the gain from 4.15 to 7.88 dBi and bandwidth from 200 MHz to 420 MHz. The metamaterial is made on RT Duroid 5880 substrate and patch antenna on FR4-Epoxy.The designed antenna is useful for WiFi application.

1. Introduction

The interest in metamaterial is increasing day by day due to its uncommon electromagnetic properties which can be manipulated by the design parameters [1]. In the word Metamaterial, meta means beyond or above the normal material which can engineer the magnitude, phase and polarization of the microwave devices[2].Double negative medium(DNG.) or left handed medium ,near zero index medium, zero index medium and single negative medium are the different types of metamaterial. Metamaterial is used in beam forming, absorber, imaging, reflection less sheet and in high directive antennas[3], [4].
Microstrip antenna (MSA) is the basic type of antenna which is easy to fabricate, analyze, feed and is low cost. The major disadvantage of MSA are surface wave excitation, narrow bandwidth, back radiation and low gain. Partial ground, electromagnetic band gap structures (EBG),multi layering, artificial soft structures, defected ground structures ,micro-machining technology(MMT) are the techniques to suppress the demerits of MSA[5],[6].Artificial soft structures, MMT and EBG structures is costly to manufacture. In the case of multi-layering, there is downgrading of gain and efficiency with increment in bandwidth of the antenna[7]. So in order to overcome these problems, metamaterial as a surface can be used as it decreases the surface waves leading to enhancement in gain and bandwidth at a low cost. The metamaterial surface controls the waves emerging out from the patch antenna which further simulates the waves of the metamaterial to form an additional resonance and thus enhancing the antenna performance[8].

Metamaterial based surface antenna has been proposed in this work. The proposed metamaterial is double negative material in which the effective permeability and permittivity are simultaneously negative in the required frequency domain. Five metamaterial unit cells are scattered on the surface. The unit cell consists of two closed ring hexagonal resonator which works in the frequency band of 5.5GHz to 6.4 GHz. The metamaterial surface is placed above the patch antenna at a particular height ,forming a cavity resonator. In order to obtain maximum gain, the height of the metamaterial surface is optimized.

2. Design of the antenna

The antenna structure consists of designing of the metamaterial unit cell and placing it in the form of surface at an optimum height above the hexagonal patch antenna.

2.1 Designing of Metamaterial

The unit cell is made of two concentric hexagonal ring resonator on Rogers RT Duroid 5880 of thickness 0.787 mm and relative permittivity of 2.2. This metamaterial acts as a reflective metamaterial. In order to get double negative (DNG) material properties in the required frequency region, the width and radius of the rings are optimized. The electrical equivalent of proposed structure can be represented as inductor for the rings and capacitor for the gaps between the rings.
In order to analyze the unit cell, it is placed in the center of waveguide having two ports. The floquet port is assigned above and waveport below the unit cell and the walls of the waveguide are treated as master and slave to execute the boundary condition. The material parameters are extracted using the Scattering coefficients as shown in equation (1-5)[9].

$$Z = \pm\sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad (1).$$

$$e^{jnk_o d} = X \pm j\sqrt{1-X^2} \quad (2).$$

$$X = \frac{(S_{11}^2 + S_{21}^2)}{2S_{21}} \quad (3).$$

$$\mu_r = nZ \quad (4).$$

$$\varepsilon_r = {}^{n}/_{Z} \quad (5).$$

Where Z is impedance, S_{11} is return loss, S_{21} is transmission coefficient, n is refractive impedance ,k_o is wave number, d is thickness of the substrate of the unit cell, ε_r is the relative permittivity and μ_r is the relative permeability. DNG material is formed when the imaginary part and real part of refractive index and impedance is greater than or equal to zero respectively.

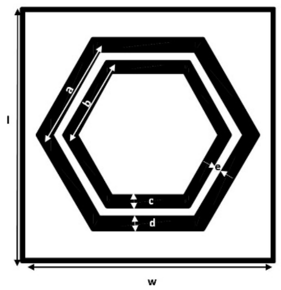
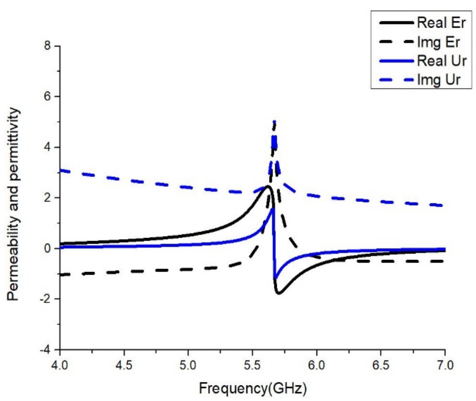


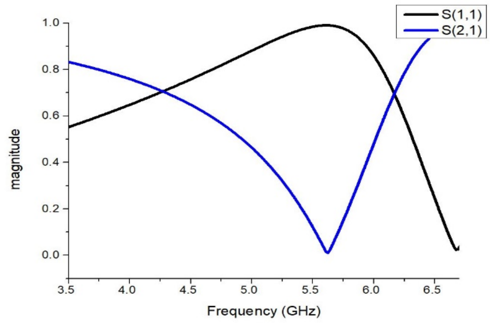
Figure 1.unit cell

Table 1 . Dimension of the unit cell

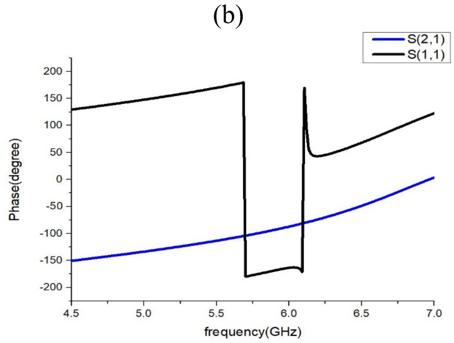
parameters	Dimension(mm)
l	11
w	11
a	4
b	3
c	0.6
d	0.7
e	0.4



(a)



(b)



(c)

Figure 2. material parameters (a) relative permeability and permittivity (b) magnitude of S parameters (c) phase diagram of S parameters.

From Figure 2(a),it is seen that the real part of relative permeability and permittivity are coming negative in the desired frequency region which depicts that the unit cell is behaving as a DNG material .The unit cell is acting as a reflector as shown in the Figure 2(b). At 5.7 GHz, there is phase reversal i.e $\pm$ 180^o as shown in Figure 2(c).

2.2 Metamaterial surface with antenna

The unit cell is scattered on the surface forming metamaterial surface. The surface is placed at an optimum distance above the hexagonal shaped patch antenna. The hexagonal shaped patch antenna was formed by modifying circular patch antenna [10].

The substrate used for patch designing is FR4 Epoxy of thickness 1.6mm and relative permittivity of 4.4.The total dimension of the patch antenna is 0.29λ_o x 0.35λ_o where λ_o is free space wavelength. The metamaterial surface and ground sheet of the patch antenna acts as a parallel plate cavity in which multiple reflection occurs.

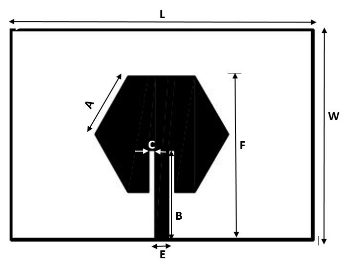


Figure 3. Hexagonal patch antenna

Table2 . Dimension of the hexagonal patch antenna

parameters	Dimension(mm)
A	8
B	10.6
C	0.8
E	1.6
F	19.3
L	36
W	25

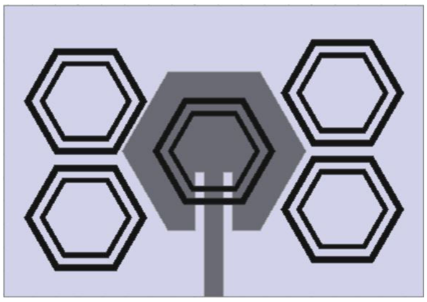


Figure 4. Top view of the proposed metamaterial surface antenna.

3. Effect of variation in height of metamaterial surface

At an optimum height of 8mm, the designed antenna is able to provide maximum bandwidth without shift in the resonating frequency of 5.7 GHz as shown in Figure 5. Beyond this point there is decrement in bandwidth of the antenna as there is decrease in multiple reflection within the cavity. The leaky waves coming out from the metamaterial and the multiple reflections within the cavity leads to enhancement in the gain and bandwidth.

Table 3 . Effect of height change of metamaterial surface on the bandwidth of the antenna.

Design parameter	Bandwidth(MHz) Simulated
only patch antenna	200
Patch + metamaterial surface (with variation in height of the surface)	
4mm	210
6mm	250
8mm	420
10mm	230

4. Results and Discussion.

Ansoft HFSS software is a simulator,based on Finite element method. The bandwidth enhances from 200MHz to 420 MHz with the use of metamaterial surface above the patch antenna without affecting the resonating frequency of 5.7 GHz as shown in the Figure 6(a).By using the surface 7.71%(5.45-5.87) increment in the bandwidth is observed

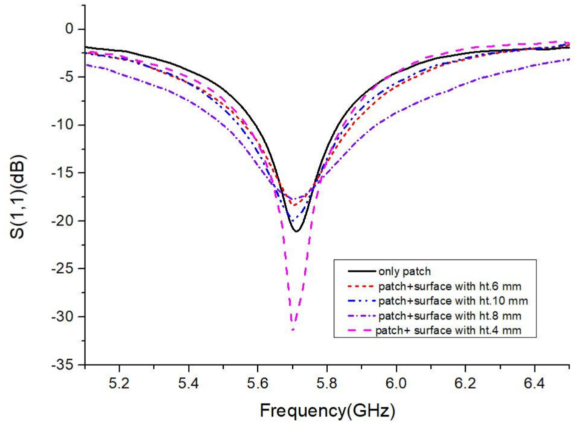


Figure 5.bandwidth of the antenna with variation in height of the metamaterial surface.

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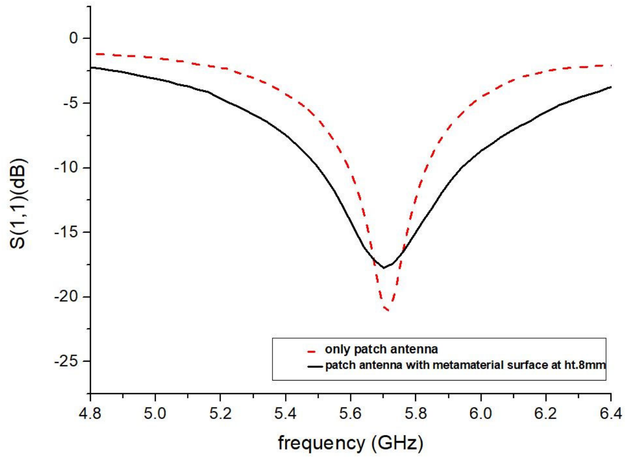
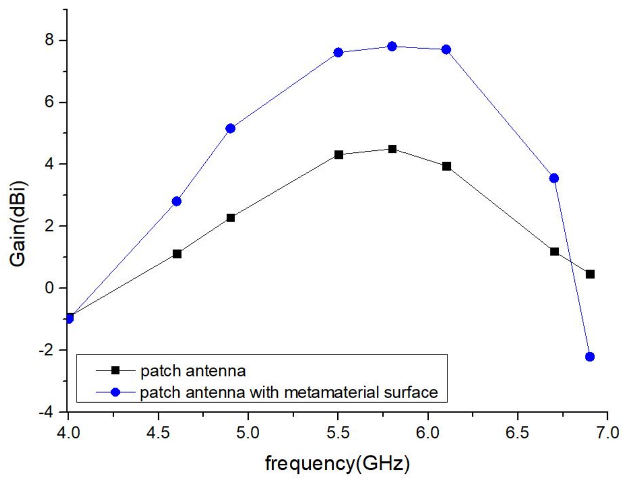


(a)



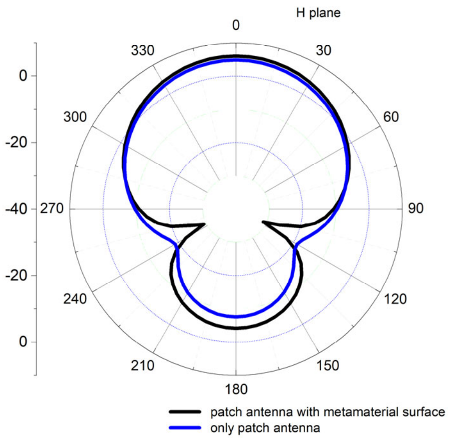
(b)

Figure 6. Comparision graph of (a) Bandwidth (b) Gain

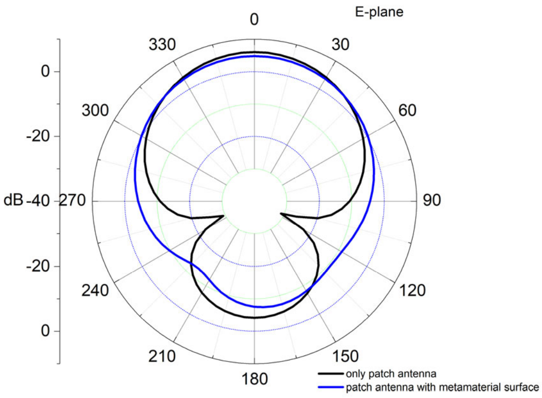
The gain of the patch antenna is 4.15 dBi and patch antenna with surface is 7.88 dBi as displayed in the Figure 6(b).The improvement of 3.73 dBi is achieved due to multiple reflection within the parallel plate cavity. From Figure 7. it can be seen that both E and H plane are broadsided and the back radiation reduces with the use of metamaterial surface

4. Conclusion

Here we have developed a metamaterial unit cell by placing two concentric hexagonal ring resonator .Further multiple number of unit cells are placed in a scattered manner to form a metamaterial surface. By placing the developed metamaterial surface above the hexagonal patch antenna at the height of 8mm, it is observed that the gain is enhanced by 3.73 dBi and bandwidth by 220 MHz. The radiation pattern is broadsided and has an application in WiFi.



(a)



(b)

Figure 7. Radiation pattern (a) H-plane (b) E-plane at 5.7GHz.

6. Acknowledgements

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