A Metamaterial based Microstrip Patch Antenna with Improved Directionality

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Abstract— This paper focuses on improving the directive properties of a conventional patch antenna by using a known technique of applying metamaterial slab as a cover. The metamaterial under consideration is a modification of Pendry's SRR structure and is equivalent to two SRRs connected back to back. The unit cells were arranged in an array configuration, investigation of S- parameters was done for checking the Negative index property. As expected with the use of metamaterial as a cover, directionality of conventional patch antenna improved significantly and the 3 dB beam-width reduced. A conventional patch antenna generally shows 3 dB beam-width of ~80deg while the antenna presented in this paper with the metamaterial shows improved 3dB beam-width of 45 deg.

Key words: HFSS, Patch Antenna, Metamaterial, Reduced Beam-Width

I. INTRODUCTION

Recently, there has been a growing interest in the field of metamaterials both theoretically and experimentally. Metamaterials are artificial materials engineered to have properties that may not be exhibited by its own constituting materials. In 1968 V. G. Veselago first proposed the idea of metamaterials with simultaneously negative values of dielectric permittivity and magnetic permeability [1]. However positive permittivity and permeability are the basic properties of conventional materials available in nature known as Double positive (DPS) materials. Metamaterials are termed as Double negative (DNG) materials due to the property of negative permittivity and permeability [2-4].

A microstrip patch antenna (MSA) in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. Radiation from the MSA occurs from the fringing fields between the radiating patch and the ground plane. Deschamps first proposed the concept of MSA in 1953 [5] and practical MSA was developed by Munson and Howell in the 1970s [6]. The MSA offers numerous advantages for various applications which include low weight, small volume and ease of fabrication [7]. However MSAs suffer from some disadvantages also as compared to conventional microwave antennas such as narrow bandwidth, lower gain and broad beam-width.

In recent years increasing interest has been focused on the use of metamaterials for improving the performance of conventional patch antennas [8-9]. A quick literature survey shows that DNG Materials can be used for directivity enhancement, radiated power enhancement, antenna performance improvement and bandwidth enhancement of the conventional patch antennas. In this paper work is done in order to reduce the beam-width and thus improve the directionality of a conventional patch antenna. The structure of the metamaterial unit cell is covered in [10], and in this paper unit cells of the metamaterial structure are combined to form an array to be used as a cover for reduction of 3 dB beam-width of patch antenna at 14 GHz.

II. PROPOSED STRUCTURE

A. Metamaterial-

Figure 1 shows a unit cell of the proposed structure. It consists of 2 Split ring resonators connected back to back and a rectangular strip. It has been shown in various papers that a single SRR provides magnetic resonance and supports negative effective permeability. The split ring resonator (SRR) structure is printed on a dielectric substrate of thickness 0.9 mm and dielectric constant 5.7 (mica). Radius of the outer and inner ring of the SRR is 2.9 mm and 2.7 mm respectively. The length and width of the rectangular strip are taken as 5.4 mm and 0.2 mm respectively. The unit cell is simulated by HFSS by using PEC and PMC boundary conditions. The PEC boundary conditions are applied to those surfaces which are perpendicular to incident electric field vector whereas the PMC boundary conditions are applied to the surfaces perpendicular to the incident magnetic field vector. Two waveguide ports were set at the top and bottom of the Z- axis, where the wave penetrates the material [10-11].

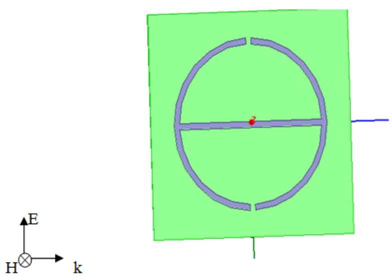


Fig. 1: Metamaterial Unit Cell

B. The Patch Antenna:

An inset fed microstrip patch antenna is designed to operate at the frequency of 14 GHz. The dimensions of patch antenna were obtained by applying some basic formulae of patch antenna design [12] as given below. The structure of the patch antenna is shown in figure 2.

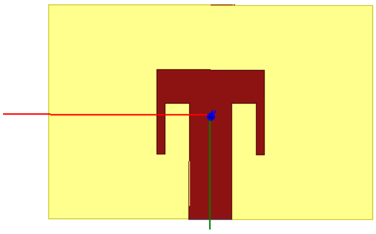


Fig. 2: A Microstrip Patch at 14 GHz.

Width (W):

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

Where, c = free space velocity of light, f_r = frequency of operation, ε_r = dielectric constant

Effective Dielectric constant:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \quad (2)$$

where h= height of dielectric substrate, w =width of patch

Effective Length:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

Patch Length Extension:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.33)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (4)$$

Actual length of patch:

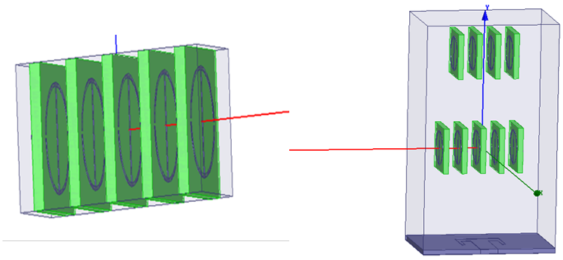
$$L = Leff - 2\Delta L \quad (5)$$

Properties	Dimensions(mm)
Patch Width, W	**7.6**
Patch Length, L	**6**
Substrate Width, W_g	**22.8**
Substrate Length, L_g	**15.2**
Feeder Width, W_f	**3**
Feeder Length, L_f	**8.25**

Table 1: Properties

C. Metamaterial cover:

The unit cells of metamaterial structure are combined to build up a 3D array topology. Since the metamaterial considered here is a Negative Index material, the metamaterial cover acts as a converging lens and instead of diverging the electromagnetic waves which is normally the case with a slab of positive index material it converges the EM waves entering into it. The separation between the unit cells obtained after optimization process is 3.2mm. The constructed 3D array structure is located in two layers, at a distance'd' from the patch antenna to act as a cover. The optimized value of'd' is found to be 15mm which is approx. three quarter wavelength long. The combination of metamaterial array and patch antenna is shown in figure 3.



(a) (b)

Fig. 3 (a) Array of metamaterial unit cells, (b) Array of metamaterial placed as a cover in front of patch

III. RESULTS

A. Bandwidth:

Figure 4 below shows the return loss for conventional patch antenna without metamaterial cover and for conventional patch antenna with metamaterial cover. The bandwidth of conventional patch antenna is about 280MHz. The addition of metamaterial as cover over patch antenna does not have much effect on the bandwidth and its value is about 275MHz.

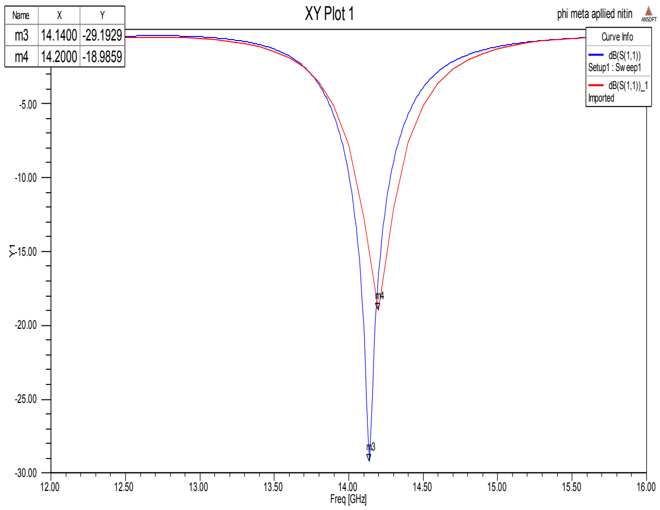


Fig. 4: S11 (dB) parameter of a patch antenna (Red), S11 (dB) parameter of patch antenna with metamaterial cover (Blue), showing resonance at ~14 GHz

B. Radiation Pattern:

The 3 dB beam-width can be significantly reduced with the addition of metamaterial as a cover. Figure 5 shows the radiation pattern of a microstrip patch antenna with or without metamaterial cover. The microstrip antenna without cover has 3 dB beam-width of 66 deg (~80 deg generally) while the antenna with metamaterial cover has 3 dB beam-width of 45 deg. The focused beam of the antenna is hence very sharp and thus increases the performance of antenna in propagating signals.

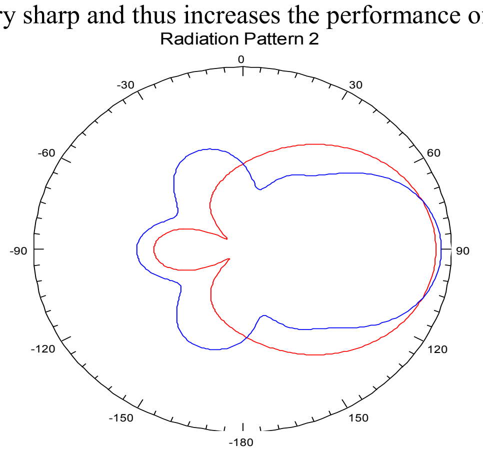
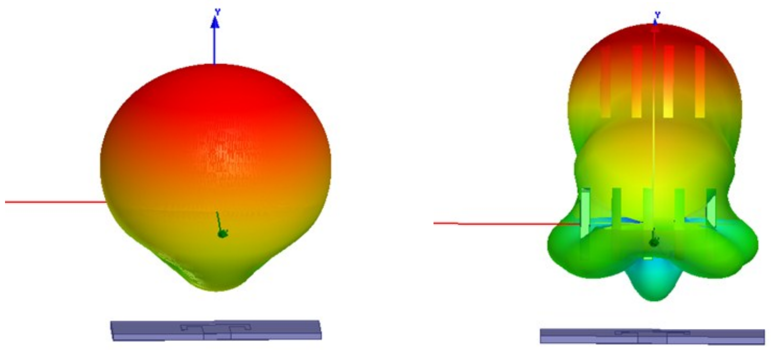


Fig. 5: Radiation pattern (Gain dB) of patch antenna with (Blue) and without (Red) metamaterial cover, showing improved directivity

C. Directive Gain

A high radiation directivity of an antenna indicates that the antenna has high power intensity. Figure 6 shows the directive gains of the antenna with and without metamaterial cover. The maximum radiation directivity of microstrip patch antenna is 7.37 dB while a maximum radiation directivity of 8.27dB is obtained for antenna with metamaterial cover.



(a) (b)

Fig. 6(a): 3D-polar plot showing directivity of a conventional patch without metamaterial cover, (b): with metamaterial cover.

IV. CONCLUSION

In this paper, a conventional patch antenna with improved directivity is realized at 14 GHz by utilizing a metamaterial slab as a cover. The improvement in directive gain of the patch antenna with the introduction of metamaterial shows that metamaterial can be used to enhance the overall performance of the conventional patch antenna. The 3 dB beam-width is significantly to 45 deg with the introduction of the metamaterial as a cover.

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