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STUDY OF PATCH ANTENNA ARRAY USING SINGLE NEGATIVE METAMATERIAL STRUCTURE

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Abstract

The planar antenna configurations such as microstrip antennas, patch antennas etc. are preferred for their low profile and ease of fabrication in communication devices. However, the major drawback of a microstrip antenna is its low bandwidth. In order to overcome this bandwidth limitation, this paper illustrates a microstrip patch antenna array consisting of two antenna elements operating at a frequency of 5.19 GHz placed in close proximity of 0.3 λ0, which is less than half the operating wavelength. However, the main shortcoming of the antenna array is that the limited space at the terminals introduces high mutual coupling between the antennas. A planar metamaterial configuration is investigated to increase the isolation between the closely spaced antennas in array form. A Single Negative (SNG) metamaterial split ring resonator array is designed for such purpose. An FDTD (Finite Difference Time Domain) based simulation software is used to simulate the structure and its characteristics. The results show that the metamaterial structure has negative permeability and positive permittivity at the desired frequency band and show the improvement of isolation by 9.4 dB with the metamaterial structure. In addition to this, the antenna bandwidth increases to 430 MHz as compared to the bandwidth of 160 MHz for the array without metamaterial.

INTRODUCTION

Planar antenna configurations such as microstrip antennas, patch antennas etc. have several advantages such as low cost, low profile and ease of fabrication. However, the main limitation of these antennas is that they have very narrow frequency bandwidth. It is preferred to have large channel capacities and high data rates in contemporary wireless communication systems to cater to the demands of users. This could be obtained through systems supporting good bandwidth. In order to meet the demand of a larger bandwidth, arrays of planar antenna configurations were proposed [1]. However, the main shortcoming of an antenna array is that the limited space at the terminals introduces high correlation between the antennas. The mutual coupling of the antennas placed closely affects the isolation of the signals of the different antennas. Moreover, the antennas are strongly coupled with each other as they share the common surface current [2]. Many techniques have been reported in the literature to reduce the mutual coupling between the antenna elements such as using a resonating slot on the ground plane [3] and using decoupling elements between the antennas [4]. However, these techniques limit the available space for other components in the system and do not assure a uniform radiation pattern. Metamaterials have become a new area of research in electromagnetism. Recent advances in modeling of electromagnetic metamaterials make it a suitable approach to control the antenna performance. Theoretical aspects and many important applications of metamaterials in microwave, terahertz and optic regions have been investigated during the last decade [5-7]. Metamaterials are artificial materials engineered to have properties that may not be found in nature. The greatest potential of metamaterials is the possibility to create a structure having either (but not both) permittivity (ε) or permeability (μ) negative and such a structure is called as SNG metamaterial structure and is opaque to electromagnetic radiation at the operating frequency band. The SNG considered in this work has a real ε and a negative μ, over the frequency band where we desire decreased coupling between the antennas. In this paper the design of a split ring resonator array comprising of five elements is proposed for improving the bandwidth and isolation between the patch antennas placed in close proximity to one another.

MATERIALS AND METHODS

Antenna Array Design

The microstrip patch antenna array is designed on FR4 Epoxy substrate with ε_r=4.4 and loss tangent=0.02 using the design equations given below. The width of the microstrip patch is given by equation (1) [8]

$$W = \frac{c}{2\,fr}\sqrt{\frac{2}{\in_{reff}+1}} \qquad (1)$$

where,

c = free space velocity of light

$\in_{reff}$ = effective dielectric constant to account for fringing field

$$\in_{reff} = \frac{\in_r+1}{2}+\frac{\in_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \qquad (2)$$

where,

$\in_r$ = dielectric constant of the substrate

h = height of substrate

The length of the microstrip patch antenna is calculated as

$$L = \frac{c}{2\,fr\sqrt{\in_{reff}}} \qquad (3)$$

where fr = resonant frequency

Using the above mentioned equations, the patch dimensions calculated are L=25.8mm and W=12.63mm at a frequency of 5.19 GHz. The dimensions of the substrate are 65.91mm×31.25mm ×1.6mm. The length and width of the microstrip feed line are 12mm and 1.5mm respectively to meet the criteria for 50 Ω line. The distance between the antenna elements in the array is considered to be $0.3\lambda_0$. Figure 1 illustrates the antenna array structure.

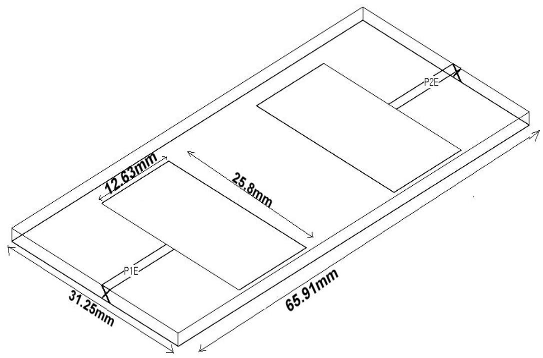

Figure 1. Two element Microstrip Antenna Array Structure

Metamaterial Structure Design

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A split ring resonator structure (SRR) is used to design the SNG metamaterial. The SRR is modeled as a resonant structure of L_{srr} and C_{srr} with a resonant frequency given by (4) [9]

$$f_0 = \frac{1}{2\pi\sqrt{L_{srr}C_{srr}}} \qquad (4)$$

The unit cell is designed on FR4 Epoxy substrate with ε_r =4.4 and loss tangent = 0.02. The dimensions of the unit cell in x, y and z directions are 6.25mm × 6.25mm ×1.6mm. Metallic inclusions are made of copper with thickness 0.035mm. The schematic view of the proposed split ring resonator unit cell is shown in Figure 2. Figure 3 shows the five-element metamaterial split ring resonator structure placed in between the two patch antennas.

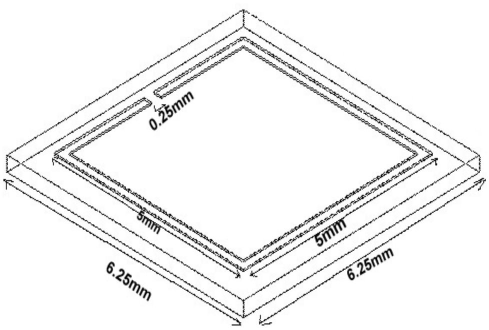

Figure 2. SNG Metamaterial Unit Cell Structure

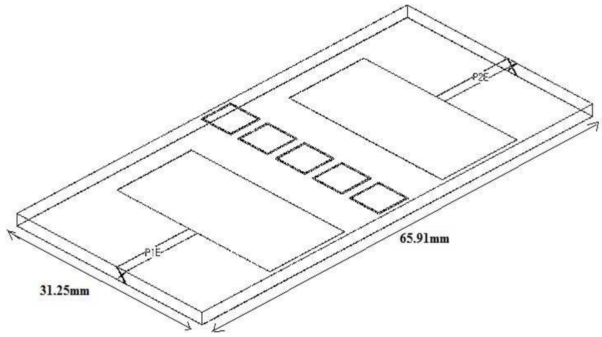

Figure 3. Microstrip Antenna Array with SNG Split Ring Resonators

SIMULATED CHARACTERISTICS AND RESULTS

Complex S-parameters *S*21 and *S*11 of the proposed SNG metamaterial structure are obtained by FDTD based simulation software, Empire Xccel 6.0[10]. The directions of the propagation constant (k), electric field (E) and magnetic field (H) are x, y and z respectively. A cubic computational region of side length 7.5mm is used in the simulation procedure. The PEC type boundary conditions are applied at the boundary surfaces perpendicular to the E field while the PMC type boundary conditions are applied at the boundary surfaces perpendicular to the H field. Remaining boundaries are defined as input and output ports. As shown in Figure 4, the proposed design indicates a stop band over the desired frequency band. To evaluate the metamaterial characteristics, the Nicolson Ross-Weir method is used for the extraction of material parameters from the complex scattering parameters [11]. Results as shown in Figure 5 demonstrate that the real part of permittivity is positive while the real part of permeability is negative over the desired band and this makes the proposed structure SNG which is opaque to the electromagnetic radiation over the operating frequency band.

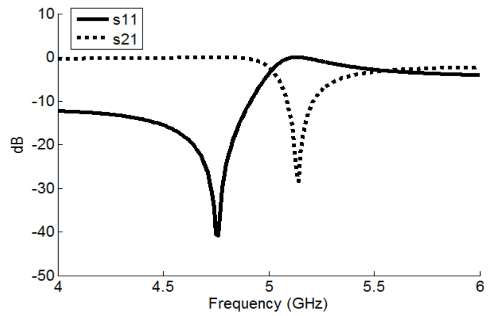

Figure 4. S parameters S11 and S21 for the SNG structure

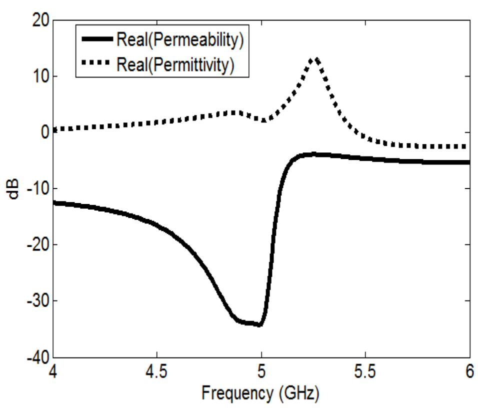

Figure 5. Real part of µ (permeability) and ε (permittivity) for the SNG structure

Figure 6 shows the return loss v/s frequency curve which is used to obtain the bandwidth for single patch, two element patch array without the poposed metamaterial structure and two element patch array with it. Results indicate the bandwidth for the single patch is 150 MHz and it improves to 160 MHz when we use two element patch array. When the metamaterial structure is incorporated between the antennas, a bandwidth of 430 MHz is obtained. Further it is observed that impedance matching is also improved over the operating frequency band when the prosed SNG is used as shown in Figure 7. Moreover, it is observed that by placing the proposed SNG structure between the antenna elements, as shown in Figure 3, an improvement in isolation by 9.4 dB is obtained as compared to that without the proposed SNG. The results are shown in Figure 8 and Table 1.

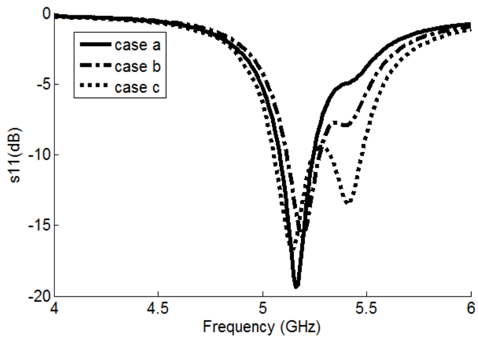

Figure 6. Return loss v/s frequency

Case a: single patch, Case b : two element patch array without SNG, Case c : two element patch array with SNG

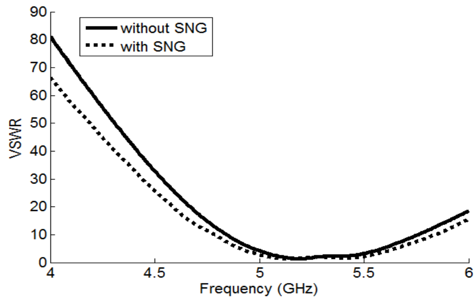

Figure 7. VSWR v/s frequency

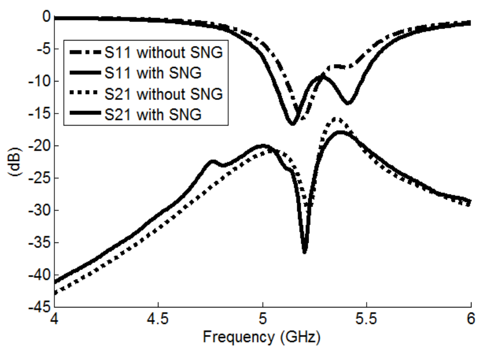

Figure 8. S parameters S11 and S21 for the array with and without SNG

CONCLUSION

In this paper, we have presented the study of use of planar metamaterial structures in the form of SNG to enhance the antenna performance. The SNG consists of five-element linear array of split ring resonators (SRR). The effect of the SNG on a two element microstrip patch antenna array is investigated. It is observed that the antenna bandwidth increases to 430 MHz by using the SNG as compared to a bandwidth of 160MHz without SNG. Further, it is observed that the use of SNG structure between the antenna elements improves the isolation by 9.4 dB. Future work focuses on the fabrication and testing of the proposed configuration to confirm the simulated results.

	S11 (dB)	S21 (dB)	Isolation (dB)
Array without SNG	-15.78	-26.82	11.04
Array with SNG	-13.45	-33.88	20.43

Table 1. S11 and S21 for array with and without SNG

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