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IMPROVEMENT OF PARAMETERS OF STACKED MICROSTRIP PATCH ANTENNA USING EDGE COUPLED PARASITIC PATCHES AND METAMATERIAL SUPERSTRATE

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Abstract

High directive stacked multilayer and edge coupled planar microstrip patch antenna made from a single-layer helical resonating metamaterial superstrate has been investigated. Metamaterials are artificial materials whose properties not found in nature. These materials have negative permittivity and permeability and negative index of refraction over a frequency band. In this paper, an innovative design of stacked rectangular microstrip patch antenna using four edge coupled parasitic patches and helical resonating metamaterial superstrate is explored. The Rogers RO3003 material of dielectric constant 3 has been used as the substrate of the antenna. Investigation is carried out related to bandwidth, gain and directivity enhancement by using edge coupled patches and metamaterial superstrate also the study of highest reduction in the size of helical resonator is carried out and highest reduction in size of helical resonator is achieved at a metallic fill ratio of 0.2. The proposed antenna exhibits wide percentage bandwidth of approximately 72.62%.

Keywords:

Edge Coupled Patches, Metamaterial, Helical Resonator, Gain, Band Width, Return Loss

1. INTRODUCTION

Microstrip antenna has advantages such as small size, light weight, easy to manufacture, very low fabrication cost, supports for linear and circular polarization. In spite of these advantages microstrip patch antennas have some disadvantages such as narrow bandwidth and low gain [1] [2] [3]. There are various methods to increase the bandwidth and gain of antennas, including increase of the substrate thickness, the use of a low dielectric substrate, the use of various impedance matching and feeding techniques, the use of multiple resonators, use of superstrates [6] [7], and use of edge coupled patches [1] [2] [3]. To overcome the above problem, a multi-layer stacked microstrip antenna structure with edge coupled patches and one layer helical resonating metamaterial superstrate is proposed. This method is chosen to investigate how the multilayer stacked and edge coupled Parasitic patches with single layer single turn helical resonating metamaterial superstrate configuration can improve the bandwidth, gain and other parameters of a microstrip antenna.

The idea of metamaterial or negative index of refraction was first proposed theoretically in 1968 by Veselago. Metamaterials are artificial materials synthesized by embedding specific inclusions, for example, periodic structures, in host media [4] [5]. Some of these materials demonstrate the property of either negative permittivity or permeability. If both happen at the same time, then the composite exhibits an effective negative index of refraction and is referred to as left-handed metamaterials (LHM) [4] [5]. The name was given because the electric field, magnetic field and the wave vector formed a left-handed system. The negative permittivity is easily obtained by an array of metallic wires and was theorized in 1996. It was shown that the structure is having a plasma frequency in the microwave regime. Because of its low plasma frequency, this structure can produce an effective negative permittivity at microwave frequencies while suffering relatively small losses [4] [5]. Pendry also theorized the structure of negative permeability which is established in 1999 with split ring resonator (SRR) structure [4] [5]. The first negative index medium was developed when both of these structures were combined and it was shown that the negative index of refraction is existed in the region where both the real parts of the electric permittivity and magnetic permeability were simultaneously negative typically, in a structure composed of SRRs and strip wires [4] [5].

In this paper a new design of multilayer stacked patch antenna system with edge coupled parasitic patches, in which single layer helical resonating metamaterial structure composed of single turn square helical rings is introduced as the superstrate and optimum design of single turn square helical resonator which can be used to form negative permeability material with higher degree of size reduction. The return loss, bandwidth, gain, VSWR, impedance, radiation pattern, and directivity of the new patch antenna are studied by simulations. The simulation results show that the gain and bandwidth of the antenna with edge coupled parasitic patches and metamaterial superstrate is improved and the antenna directivity is enhanced obviously.

2. SQUARE HELICAL RESONATOR

The magnetic resonant particles are the components used for metamaterial design to achieve negative magnetic permeability [8]. The Split ring resonator (SRR) was used for the realization of a negative permeability medium or backward wave medium [4] [5]. The physical size of split ring resonator is one-tenth of the free space wavelength at resonance [8]. The general unit cell structure of single turn square helical resonator is shown in Fig.1.

The single turn square helical resonator with the dimensions outer length dout and strip width w are placed on dielectric material whose dielectric thickness t. The helical resonator has a higher value of self-capacitance and thus the physical size of helical resonator can be reduced as compared to SRR [8]. The square helical resonator has larger value of inductance and capacitance, and hence a lower resonant frequency, thus the size of helical resonator can be maximum minimized [8]. The corners of square helical resonator add the additional inductance. When the substrate is thin ($t << w$), the size of a helical resonator at resonance will be very small [8] [9]. The Equivalent electrical LC circuit of single turn square helical resonator is shown in Fig.2 [8] [9].

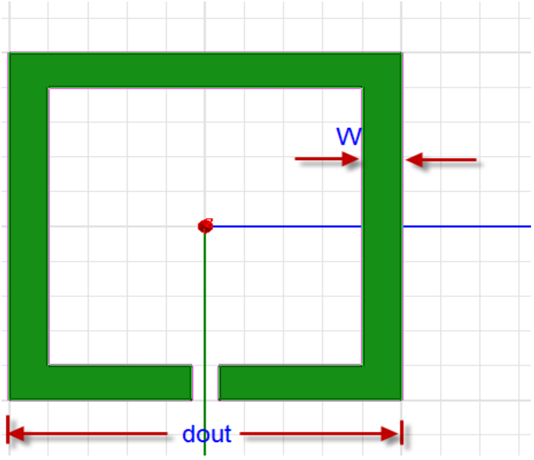

Fig.1. Unit Cell Layout of single turn square helical resonator

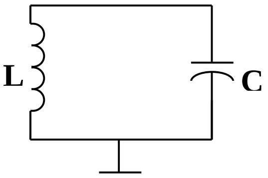

Fig.2. Equivalent LC Model of single turn square helical resonator

The metallic fill ratio of a helical resonator as $\alpha = w/d_{out}$. The fill factor is the fraction of core window area that is filled by copper. The fill factor must be less than 1 ($\alpha < 1$) for this optimum width w_{opt}, the optimal fill ratio derived [8] [9]

$$\alpha_{opt} = \frac{w_{opt}}{d_{out}} = \frac{-2+\sqrt{4+3p_2}}{3p_2} \tag{1}$$

This optimal ratio α_{opt} is only a function of the coefficients p_1 and p_2 which is independent of the detailed dimensions. For square rings incorporating corner corrections are $p_1 = 2.37$ and $p_2 = 1.89$ [8]. The normalized electrical size of helical resonator is given as $\Lambda = d_{out}/\lambda_0$, where λ_0 is the free space wavelength at resonance [8]. For the optimized resonator, the minimum resonant frequency [8] [9] and related normalized electrical size are given by Eq.(2) and Eq.(3)

$$f_{\min} = \frac{1}{2\pi}\sqrt{\frac{t\left(1+p_2\alpha_{opt}\right)}{4p_1\mu_0\varepsilon_0\varepsilon_r\left(1-\alpha_{opt}\right)^3\alpha_{opt}d_{opt}^3}} \tag{2}$$

$$\Lambda = \frac{1}{2\pi c}\sqrt{\frac{t\left(1+p_2\alpha_{opt}\right)}{4p_1\mu_0\varepsilon_0\varepsilon_r\left(1-\alpha_{opt}\right)^3\alpha_{opt}d_{opt}}}, \Lambda \alpha t^{1/2}, d_{out}^{-1/2} \tag{3}$$

Therefore from Eq.(3) greater reduction in size can be obtained by increasing the outer length and decreasing the substrate thickness of resonator.

3. OPTIMUM WIDTH OF SQUARE HELICAL RESONATOR

The unit cell strip of single turn square ring helical resonator is shown in Fig.1. The outer length of strip $d_{out} = 3.5$ mm and strip width w. This unit cell is used to form a metamaterial superstrate of array of size 7×14 in rectangular lattice. These unit cells helical resonators placed on three layer microstrip patch antenna as a superstrate which improves the parameters of antenna such as bandwidth and gain. The centre to centre spacing between two helical resonators is = 4.01mm. The metallic fill ratio of a helical resonator is given by Eq.(1). For this optimum width w_{opt}, the optimum fill ratio calculated from Eq.(1) is, $\alpha_{opt} = 0.196 \approx 0.2$, the optimum strip width $w_{opt} = \alpha_{opt} \times d_{out} = 0.196 \times 3.5 = 0.685$mm. For Optimum fill ratio the minimum resonance frequency is the centre frequency of multilayer broadband patch antenna.

4. ANTENNA DESIGN

The schematic, top view and three dimensional view of proposed multilayer stacked patch antenna using edge coupled parasitic patches with helical resonating metamaterial superstrate is shown in Fig.3, Fig.4 and Fig.5. The dimensions of this MSA are designed for the resonant frequency of 6GHz. This multilayer antenna composes three layers. The lower layer, above the ground is consisting of Rogers RO3003 Substrate of dielectric constant 3 with height of 3.048mm and patch size of 15.25mm × 9.07mm is implemented on this layer. It is fed by coaxial feeding at position (6.93mm, 0). Four edge coupled parasitic patches are placed near the edges of the lower original patch. These new patches may be coupled to the main patch electro-magnetically or through the direct coupling technique. Each patch can be designed in a similar manner to the original patch. The lengths of the parasitic patches will determine their resonant frequency and their width will determine the bandwidth they display at resonance. In this design we use four parasitic patches to enhance the bandwidth of antenna.

Two patches are along radiating side and other two are along non-radiating side. Active patch has greater length and width than other four patches. Patch along non-radiating side has smaller dimension than others. The dimensions of radiating side edge coupled parasitic patches are (9.83mm × 9.07mm, 11.26mm × 9.07mm) and the dimensions of non radiating side edge coupled patches are (7.07mm × 7.07mm, 7.07mm × 7.07mm), these four side edge coupled patches are used for broadband (72.62%) and impedance matching. The middle layer, above the lower layer is consisting of Rogers RO3003 Substrate of dielectric constant 3 with height of 3.048mm and patch size of 12.5mm × 9.07mm implemented on this layer. The upper layer, above the middle layer is consisting of Rogers RO3003 Substrate of dielectric constant 3 with height of 1.524mm and patch size of 12.5mm × 9.07mm implemented on this layer. On the top of upper layer metamaterial superstrate composed of helical single turn square ring SRR structure that is placed on foam substrate with permittivity 1.05. The metamaterial superstrate consists of 7×14 array of helical resonating single SRR shaped square rings as shown in Fig.4. By making use of stacked patch, edge coupled patches and metamaterial superstrate concept one can obtain enhanced bandwidth and gain of antenna. All patches ate tightly electromagnetically coupled with each other with coupling factor of 1. Optimization of superstrate layer is the most important stage in antenna design and it is between $\lambda/3$ to $\lambda/2$ for tight coupling and perfect reflection from the metamaterial layer. The Fig.5 shows three dimensional configuration of microstrip antenna with edge coupled patches and helical resonating metamatrial superstrate layer.

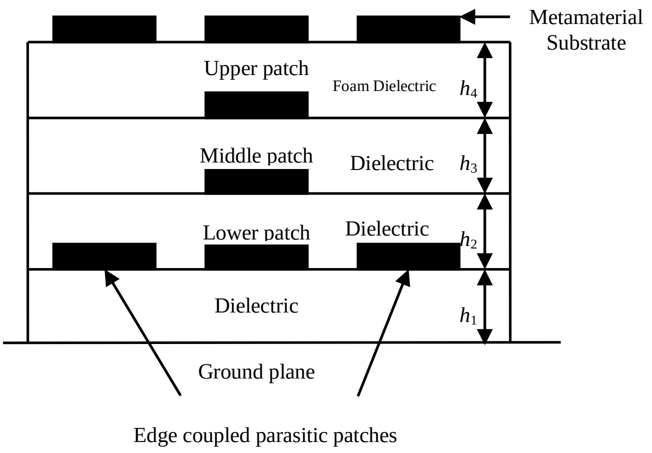

Fig.3. Schematic of proposed multilayer stacked patch antenna using Edge coupled parasitic patches and helical resonating metamaterial superstrate

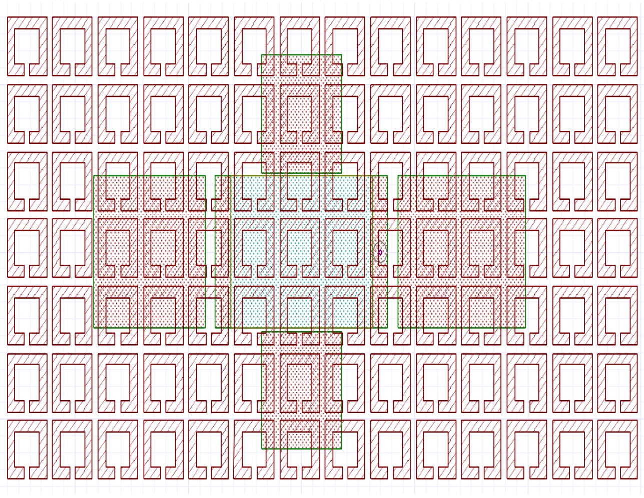

Fig.4. Top view of multilayer stacked patch antenna using edge coupled patches and helical resonating metamaterial superstrate

5. SIMULATION RESULTS

All of the simulations are performed by a soft designer software. The return loss of the proposed multilayer rectangular microstrip patch antenna using edge coupled parasitic patches and helical resonating metamaterial superstrate at the ultra wide band frequencies is shown in Fig.6. The obtained result shows that the bandwidth at -10dB of this antenna is in the frequency range from 4.12GHz to 8.39GHz, which covers the bandwidth of the Ultra wide band applications. The 10dB bandwidth obtained from Fig.6 is 4.27GHz. percentage bandwidth of proposed antenna is 72.62%. The resonance frequency of proposed antenna is 5.8793GHz. The radiation pattern of the gain of the proposed UWB rectangular microstrip patch antenna using edge coupled parasitic patches and helical resonating metamaterial superstrate is as shown in Fig.7. The gain of the proposed microstrip antenna is 4.5403dBi, at the center frequency of operation 5.8793GHz. It is obvious the metamaterial superstrate cause to increase the directivity of the antenna, particularly when single layers helical resonating metamaterial superstrate are used. The Fig.8 shows the voltage standing wave ratio (VSWR) of the proposed antenna. The VSWR of proposed microstrip antenna at resonance frequency is 1.4163. The Fig.9 shows the smith chart of proposed antenna, which shows the input impedance of $1.0398 + j0.3545\Omega$ at resonant frequency 5.87GHz. The smith chart in Fig.9 shows that the antenna is linearly polarized.

6. CONCLUSION

In this paper, an ultra wide band multilayered planar microstrip antenna using edge coupled parasitic patches and helical resonating metamaterial superstrate is presented. The antenna achieves extremely wide frequency bandwidth and good radiation characteristics in terms of gain. Mathematically an optimal metallic fill ratio of around 0.2 is obtained for square helical resonators, by simulation, the antenna demonstrated a bandwidth of 72.62% for a VSWR < 2 and the gain is up to 4.5403dBi. According to the results obtained, using the design method presented in this paper can extremely increase the impedance bandwidth and gain of a microstrip antenna.

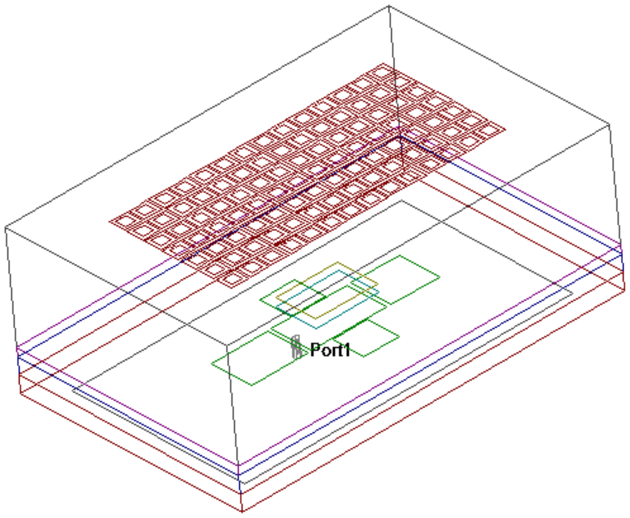

Fig.5. Three dimensional configuration of multilayer stacked patch antenna using edge coupled patches and helical resonating metamaterial superstrate

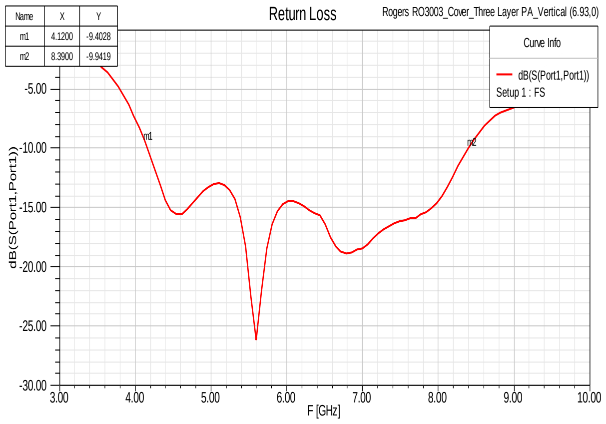

Fig.6. Return loss plot of the proposed antenna with edge coupled patches and single layer helical resonating metamaterial superstrate

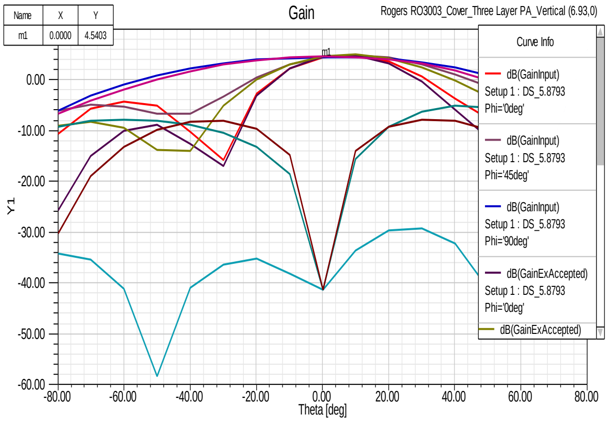

Fig.7. Gain plot of the proposed antenna with edge coupled patches and single layer helical resonating metamaterial superstrate

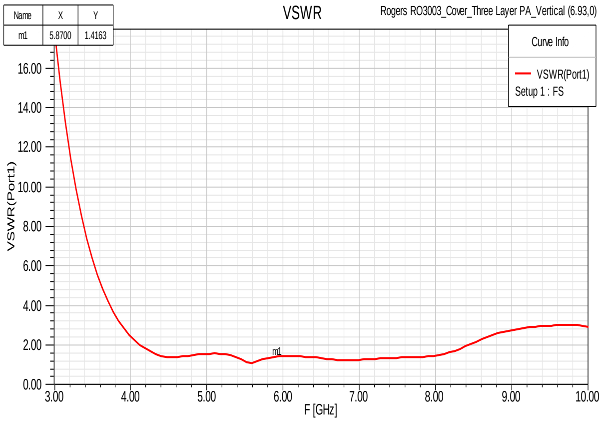

Fig.8. VSWR plot of the proposed antenna with edge coupled patches and single layer helical resonating metamaterial superstrate

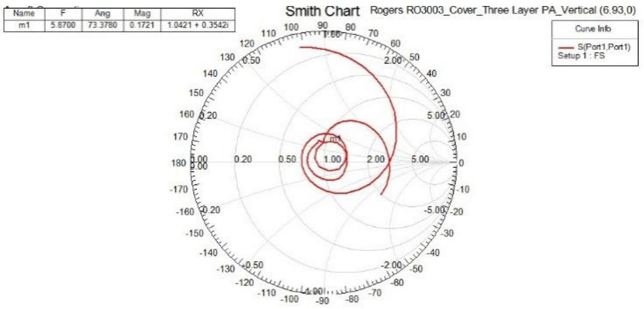

Fig.9. Smith chart of the proposed antenna with edge coupled patches and single layer helical resonating metamaterial superstrate

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