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Design and Analysis of a Metamaterial-Inspired Microstrip Patch Antenna Using Split Ring Resonator for Ku-Band Applications

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Abstract: This paper The aim of the project is to design microstrip patch antenna loaded with meta-material using HFSS. The main objective is to enhance gain and bandwidth of the conventional microstrip patch antenna by loading metamaterial in an improved way. To reduce the size of antenna, there are microstrip antenna technologies miniaturized by means of high-permittivity dielectric substrate, shorting walls, shorting pins. However, these methods have an disadvantage of narrow bandwidth and low gain. The new solution for this to use electromagnetic metamaterials for antenna design. Use of metamaterials not only reduces the size but can also improve other parameters such as bandwidth and gain. An unit cell Square SRR inserted along both sides of the feed achieves a maximum gain and wide triple band frequency operating at 12GHz to 18GHz (Ku-Band). Ku band is mainly used in satellite communications, Radar systems.

Keywords: Square Patch (SP), Slots, metamaterial, SRR.

1. Introduction

Wireless communication technology and communication systems, a microstrip patch antenna is widely used due to their advantages such as low profile, low cost, simple design and easy to manufacture. The metallic patch is normally made with a metal such as copper, gold and nickel. The feeding methods of the microstrip patch antenna can be classified into two categories, contacting and non-contacting. The RF power is fed directly to the microstrip line in the contacting method, whereas in non-contacting electromagnetic feed coupling is done to transfer patch between the microstrip line and radiating patch [2]. At the same time, it has various disadvantages such as narrow bandwidth, low gain, and low directivity. But for narrowband applications like Satellite communication, antenna should possess high gain. To increase gain, literature reported techniques are loading of an antenna in different aspects like Electromagnetic Band Gap (EBG) structures, Defected Ground Structures (DGS), highly-reflective surfaces (HRS), Artificial Magnetic Conductors (AMC) and Metamaterials [17]. This paper focuses on adding Metamaterial with conventional microstrip antenna that significantly improves gain and Bandwidth at Ku band. Metamaterials are artificial materials and it illustrates the properties that are not found in nature. In 1968, Veselago theoretically showed that it exhibits different properties such as negative permittivity and negative permeability compared to ordinary materials [3]. In 1999, Pendry proposes a concept of Split Ring Resonator (SRR) that will be an equivalent of the metamaterial. It is formed by two rings with a split on opposite sides, behaves as an LC resonator that can be excited by a time-varying external magnetic field component in the normal direction of a resonator. The gaps between the rings produce capacitance value, it leads to low radiation losses and high-quality factor [4]. In 2013, Mandal et al presented a high gain wideband-shaped patch antenna with two equal arms on Poly Tetra Fluoro Ethylene (PTFE) substrate. An inverted U-shaped slot is introduced on the circular or square shaped ground plane just under the U-shaped patch. Maximum impedance bandwidth of 86.79% (4.5GHz-11.4GHz) is obtained with a circular shaped ground plane with diameter 36mm. The proposed antenna is simple in structure compared to the regular stacked or coplanar parasitic patch antenna with a gain of 4.1dBi and is suitable for wireless communications [7]. Attia et al. (2009) proposed a novel engineered magnetic superstrate to enhance the gain and efficiency of a microstrip patch antenna. The patch antenna with magnetic superstrate resonating at 2.2GHz, results in 3.4dB gain enhancement and 17% efficiency enhancement. These improvements were achieved while having an insignificant effect on the antenna bandwidth [9]. In 2003, Jieh designed a single fed circularly polarized equilateral triangular microstrip antenna with enhanced antenna gain. The circular polarization design is obtained by placing three

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triangular slots below the radiating patch. The antenna gain has been increased by 3.3dBi compared to a conventional patch antenna. The proposed antenna is fabricated for experimental evaluation [10].

In 2012, Yingli et al. proposed a metamaterial unit cell with low refractive index and it is optimized to enhance the gain of the patch antenna and beam focusing ability. The effective material parameters of the unit cell are extracted, and the unit cell forms a planar three-layer metamaterial structure used as a superstrate for gain enhancement of a patch antenna at 10GHz has a 7.8dBi.

The measurements have shown that the effective refractive index of the Metamaterial under normal incidence is close to zero over a frequency range from 9.45GHz to 10.7GHz [8]. In 2018, Saravanan et al. investigated a phi-shaped metamaterial superstrate with the square patch antenna. The antenna achieves a gain of 7.94dB at its resonance frequency 2.4GHz. Phi shaped slot is etched on a square conductor is considered as a unit cell and it is validated [18]. In this paper, we consider the problem of enhancing the gain and bandwidth of an microstrip patch antenna using Split Ring Resonator based metamaterial. The metamaterial is inserted as an intermediate layer between patch and ground plane.

The edge-coupled SRR (EC-SRR) consists of two copper rings and one metal layer at the ground plane is used. The other structures of SRR are Broadside Couple Split ring resonator (BCSRR) [12], non bi-anisotropic Split ring resonator (NB-SRR) [13], Spiral Split Ring Resonator (S-SRR), Open Split Ring Resonator (O-SRR), H-shaped Split Ring Resonator (HS-SRR), Quadruple P shaped Split Ring Resonator (QPS-SRR).

2. Implementation of Proposed Method

2.1. Conventional Square Patch Antenna

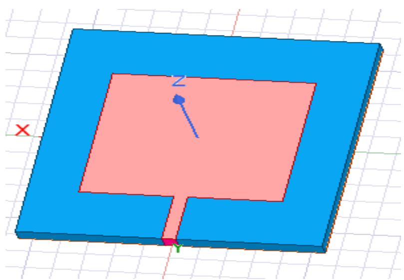

Fig.1. The geometrical design of the proposed conventional square patch antenna

The proposed antenna design starts with square patch fed by 50ohm impedance microstrip line feed with a side length of 14.6mm. A square microstrip patch antenna is a form of antenna which consists of square patch.

Table.1. Dimensions of the patch antenna

Part	Dimension (mm)
Ground length	22
Ground width	25
Height of substrate	1.6
Patch length	14.6
Patch width	14.6
Feed width	1

The parametric analysis was done to finalize the height of substrate. Iterations carried out were 1.8 mm and 1.6mm.By comparing the iterations of height of the substrate 1.6 mm is considered.

This section presents the parametric analysis and the evolution technique of the proposed antenna.

2.2. Square Patch Antenna With Plus Slot

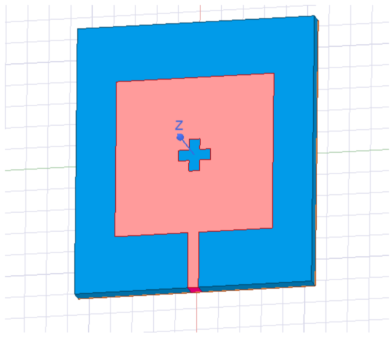

Fig.2. The geometrical design of the proposed square patch antenna with plus slot

To improve antenna performance a plus shaped slot is incorporated in the middle of the rectangular patch antenna with different dimensions as shown in Fig.2. Parametric analysis has been done considering different length and width of the slots.

Table.2. Dimensions of the plus slot

Part	Dimension(mm)
Slot length	1
Slot width	3

From the obtained results, The antenna with slot length 1mm and slot width 3mm delivers an operational band width of 580Mhz and peak resonant frequency at 14.08hz.

2.3. Split Ring Resonator

The Fig.3 illustrates the unit cell of square SRR. To consider it as metamaterial double negative property is verified from parametric values such as of permittivity (◎), permeability (μ) and refractive index (n).

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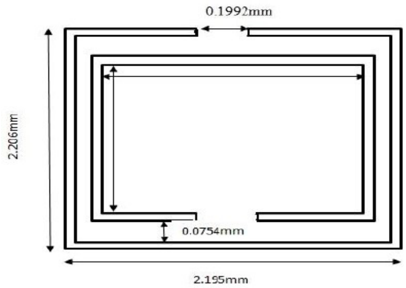
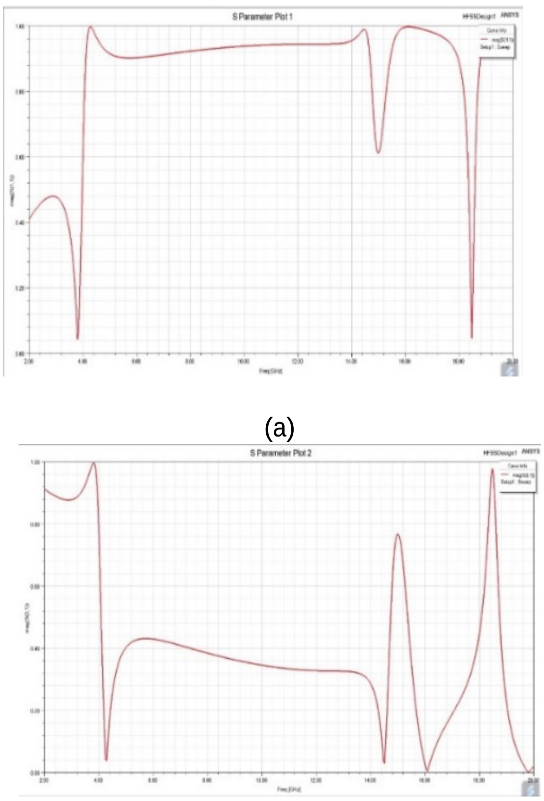


Fig.3 Design of square SRR

The square SRR has been analysed by using HFSS simulation tool as per the specifications mentioned in the table. In order to calculate the S parameters, the unit cell is placed between two waveguide ports. Y plane is defined as Perfect Electric Boundary (PEB) and the Z plane is defined as Perfect Magnetic Boundary (PMB). The SRR design is shown in Fig.3, to verify the double negative property of the unit cell MATLAB R2013b simulation tool is used to extract the values of S parameters.

Table.3. Dimensions of Split Ring Resonator

Parts	Dimension (mm)
Outer Ring width	6.7
Outer Ring length	5
Inner ring width	4.7
Inner Ring length	3
Gap	0.5



(a)

(b)

Fig.4 S Parameters of metamaterial unit cell

The Fig.4 shows that S11 and S21 parameters have phase reversal at frequency of 10GHz. Hence the designed unit cell SRR is working as a metamaterial at its resonance frequency.

3. Proposed antenna design with SRR

The SRR array is placed as a key building element between the patch and the ground plane which resonates at a frequency of 10GHz. The first requirement of the SRR array is the optimum spacing between the elements of the array. The performance of an array depends on the number of rings, pattern of arrangement and orientation of the rings. The unit cell SRR presented in section III is employed to design the Split Ring Resonator array and it can produce significant gain and bandwidth enhancement. The proposed antenna is designed on Roger RT-duroid 5880 substrate of thickness = 1.6mm, dielectric constant (εr) = 2.2 and loss tangent is 0.0009. Each square unit cell has an area of 4.84mm2. The SRR unit cells are separated by different width and length from each other according to their inter-element spacing.

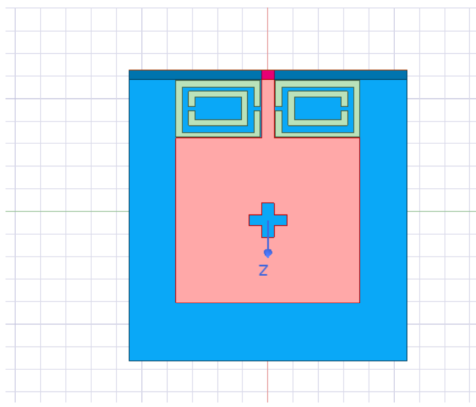


Fig..5 Design of metamaterial loaded microstrip patch antenna

4. Results and Discussion

The simulated return loss of proposed antenna is shown below.

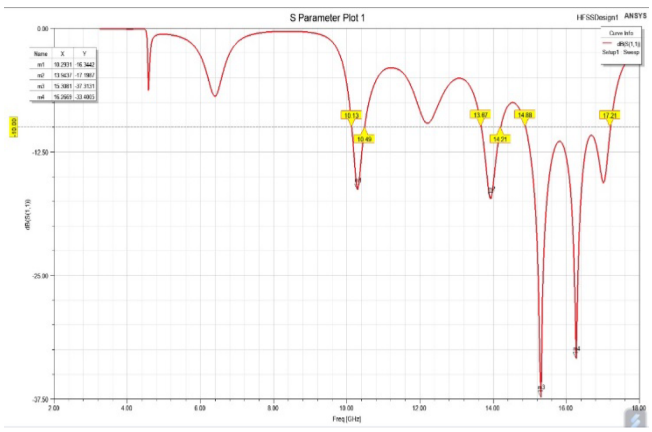


Fig..6 Return loss of the proposed antenna

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Table.5 Comparison with Literature surveys

	Gain(dBi)	Band width (MHz)
T. Sathiyapriya, V. Gurunathan And A. Shafeek “Design Of metamaterial Inspired High Gain Patch Antenna”.[1]	7.92	350
Journal of Engineering and applied science” SRR metamaterial- based broadband patch antenna for wireless communications” [2]	4.5	300
“Design of patch antennas based on metamaterials CSRRs” Nouri Keltourma LTC laboratory. [3]	5	30,320
Proposed antenna	18.8	340,540,2330

Table.4 Comparison with Designed antennas

Designed antenna	Resonant frequency (GHZ)	Bandwidth (MHz)	Gain(dBi)
Square patch antenna	12.18 13.19	420 510	17.7
Square patch antenna with plus slot	12.35 14.05	520 580	7.1
Antenna loaded with metamaterial	13.94 15.30 16.26	540 2330	18.8

Conventional square patch antenna with plus slot offers a multi band at 12.35GHz, 14.05GHz with a bandwidth of 520MHz, 580MHz and a peak gain of 7.1dBi and a return loss of -15dB, -34dB.

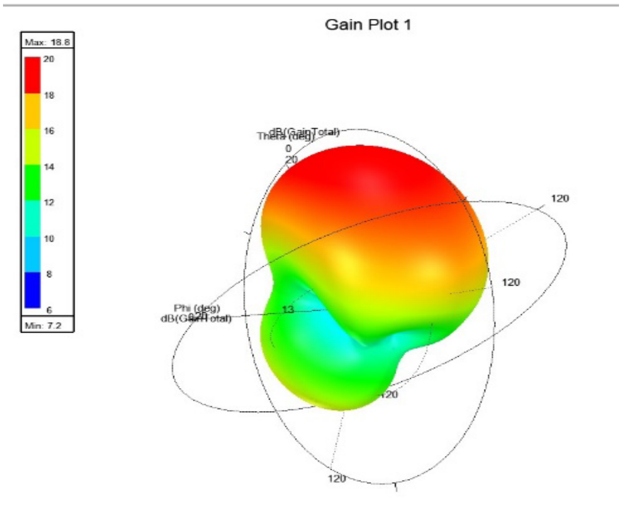

Fig..7 Gain plot of proposed antenna

Square patch antenna with plus slot and square SRR offers Multi band at 13.94GHz, 15.30GHz, 16.26GHz with a bandwidth of 340MHz, 540MHz, 2330MHz and a peak gain of 18.8dBi and a return loss of -17dB, -37dB, -33dB.

5. Conclusion

This work successfully demonstrates the design and analysis of a metamaterial-inspired microstrip patch antenna integrating a square Split Ring Resonator (SRR) structure to achieve multi-band operation in the Ku-band. By incorporating a plus-shaped slot in the radiating patch and embedding an SRR array between the patch and ground plane, the proposed antenna exhibits substantial enhancement in gain and bandwidth compared to conventional designs. The optimized antenna achieves resonances at 13.94 GHz, 15.30 GHz, and 16.26 GHz, with a maximum gain of 18.8 dBi and bandwidths up to 2.33 GHz, making it well-suited for radar and satellite communication applications. The metamaterial-based configuration effectively manipulates electromagnetic fields to realize negative permittivity and permeability, improving impedance matching and radiation efficiency. The comparative study with existing designs validates the superiority of the proposed antenna in both performance and compactness. Future work may involve experimental fabrication and measurement validation, exploring alternative SRR geometries, and extending the concept to reconfigurable or tunable metamaterial antennas for next-generation communication systems operating in millimetre-wave and 5G/6G frequency bands.

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