Metamaterial Inspired SSHSS Planar Antenna

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Abstract. In this paper, a metamaterial inspired split semi-horseshoe structure (SSHSS) antenna is designed and analyzed. Material effective parameters are extracted using modified NRW approach which proved the metamaterial property of the new unit cell. Proposed antenna shows enhanced bandwidth (31.5% at 11.43 GHz), high directivity (11.9 dBi at 11.43 GHz) and moderate gain (3.9 dBi) at the resonance frequency. A prototype of the proposed antenna is fabricated on RT duroid. This antenna shows multiband characteristics. This antenna can be used as metamaterial inspired (X band) as well as normal patch antenna (Ku band). Experimental results show good agreement with simulated results.The proposed antenna has been simulated using IE3D electromagnetic simulator.

Keywords: Metamaterial, multiband, Split Semi- Horseshoe Structure (SSHSS), negative permeability

1. Introduction

Metamaterials were first proposed by Russian Prof. Veselago in 1968[1]. Advancement in present-day communication technology demands compact wireless systems. Antenna designing is very challenging for present-day wireless systems. Initially, researcher focuses on the realization of metamaterial now they are looking for the incorporation of the metamaterial in real-world applications. Now multiband operation, beam tilting, & frequency switching is possible by loading of these periodic structures to patch antenna [4]. A large number of split ring resonator (SRR) were designed so far after first proposed by Pendry in 1999[2]. Joshi proposed an offset fed diamond shaped split ring (DSSR) based metamaterial inspired planar antenna [5] for bandwidth enhancement. Sharma et. al. proposed a phi shaped antenna (PSA) inspired by metamaterial property [7]. In [8], a triangular shaped split ring resonator (TSR) showed the left-hand property at 14.4 GHz proposed. Every structure has its own advantages and disadvantages. In [9] presented a planar antenna for ISM band using new unit cell structure looks like a horseshoe (SSHSS). In order to change the resonance frequency of ISM band to X band split vertical length and stub length has changed in present work. This SSHSS does not have metallic rod (i.e. planar) for getting negative permittivity. In present work, authors aim is to design a high bandwidth, highly directive, and moderated gain metamaterial inspired antenna for radar communication.

This paper is organized into four sections. Design specifications of the antenna are presented in section II. Simulation, experimental results and use of simulation results to verify the metamaterial property is presented in section III. Section IV shows the conclusion of this paper.

2. Geometry of proposed antenna

This section presents the physical specifications of split semi-horse shoe structure. The geometrical dimensions of the proposed antenna are given in Table 1. RT Duroid 5880 substrate of relative permittivity 2.20, loss tangent=0.0009 and thickness h = 1.575 mm is used to simulate and fabricate the prototype of proposed antenna. Figure 1 shows the geometry of proposed split semi-horse shoe structure with both rings has vertical split cut in Y-axis.

3. Results and discussions

The proposed SSHSS antenna is coaxially excited at x=-8.8 mm, y=2.0mm and x=2.0mm, y=9.0mm. Figure 2 shows the reflection coefficient (S_{11}) and phase reversal (S_{12}) characteristics of designed antenna. As seen from the Figure 2**,** the return loss at 11.43 GHz frequency is -17.80 dB, it is also clear that structure exhibits phase reversal in the resonant frequency band which implying that the wave vector changes its phase by an angle of 180^0 at the interface. This antenna shows metamaterial behavior at first two resonant frequency while showing normal behavior at the third resonance frequency. Table 2 shows the summary of the simulated results.

Table1 Physical dimension of the proposed antenna

Antenna Parameters	r_1	r_2	r_3	r4	W	S	w	L	D
Present Design Values(mm)	6	8	9	11	2	1	3.6	20.59	2
Ref.[9]	6	8	9	11	2	1	4	23.47	2

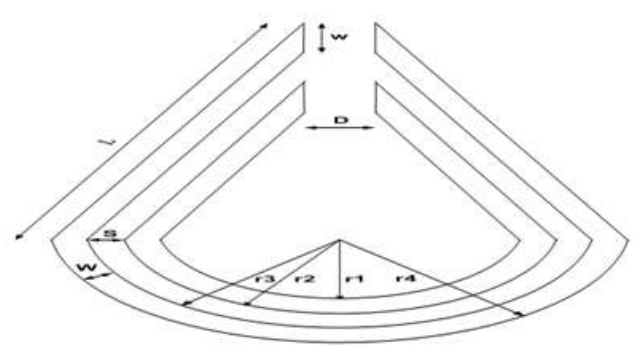

Fig.1. Geometry of split semi-horse shoe structure (SSHSS)

Table 2 Summary of the simulated results

Resonance Frequency(GHz)	Return Loss S_{11} (dB)	Bandwidth (MHz)	% BW
11.43	-17.80	360	31.5
13.34	-16.58	355	26.6
15.73	-15	923	58.67

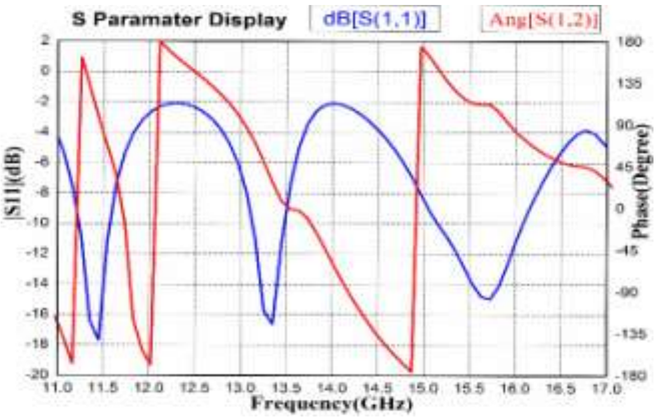

Fig.2. S_{11} (dB) and S_{12} (phase angle) of the SSHSS antenna

Figure 3 depicts the polar radiation pattern of the SSHSS design in azimuth and elevation plane at first resonance frequency 11.43 GHz. Figure 4 shows the gain and directivity versus frequency plot. It is clear that directivity is high while gain is moderate at all resonance frequencies.

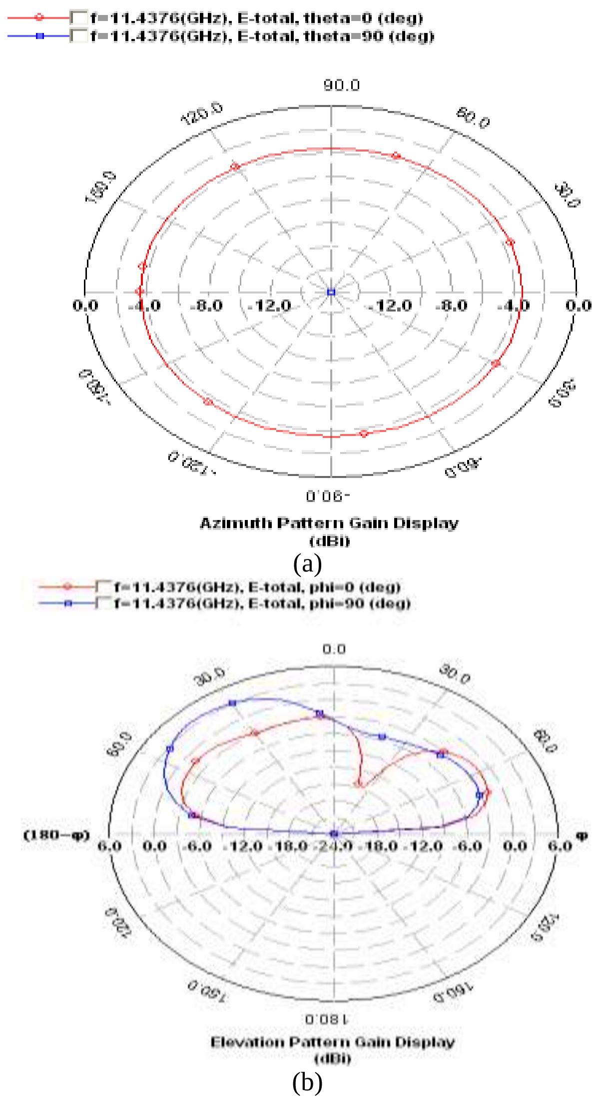

Fig.3. Radiation pattern of the SSHSS antenna (a) azimuth (b) elevation planes

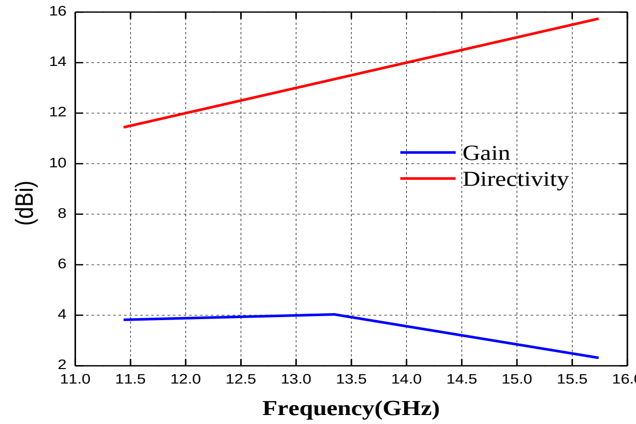

Fig.4. Gain and directivity vs frequency plot of antenna

MATLAB is used for the calculation of the permittivity and permeability of the designed structure. The modified NRW approach formulas [10, 11] are used for numerical calculation of the effective permittivity and magnetic permeability of the SSHSS. This is done by exporting the S-parameters from IE3D software to MATLAB using the Eqs. (1) and (2) [11],

$$\mu_r = \frac{2}{jk_0 d}\frac{1-V_2}{1+V_2} \quad (1)$$

$$\varepsilon_r = \frac{2}{jk_0 d}\frac{1-V_1}{1+V_1} \quad (2)$$

Where k_o is the wave number, d is the height of the substrate. V_1 and V_2 are the composite terms which are defined in Eqs. (3) and (4) [11],

$$V_1 = S_{21} + S_{11} \quad (3)$$

$$V_2 = S_{21} - S_{11} \quad (4)$$

Figure 5, Figure 6, and Figure 7 show the extracted permeability, permittivity and refractive index from S-parameters for the SSHSS metamaterial antenna at each resonance frequency. From the Figure 5, it is clear that value of permeability, permittivity, and the refractive index is negative at 11.43 GHz frequency band.

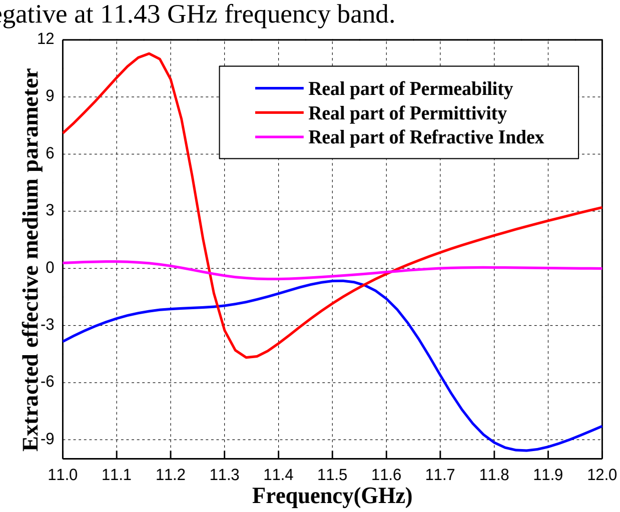

Fig.5. Extracted effective medium parameter from S-parameters

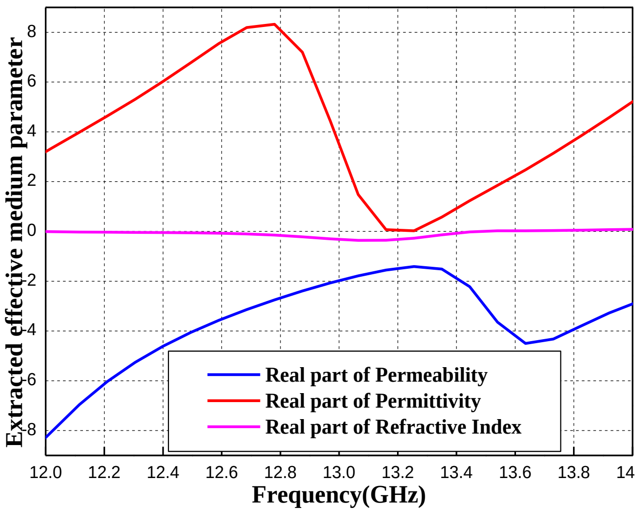

Fig.6. Extracted effective medium parameter from S-parameters

Figure 7 and Figure 8 depicts that value of permeability and index of refraction is negative at 13.34 GHz and 15.73 GHZ frequency band while value of permittivity is near zero. Figure 8 shows the top and bottom view of a fabricated prototype of proposed split semi-horse shoe structure antenna (SSHSS).

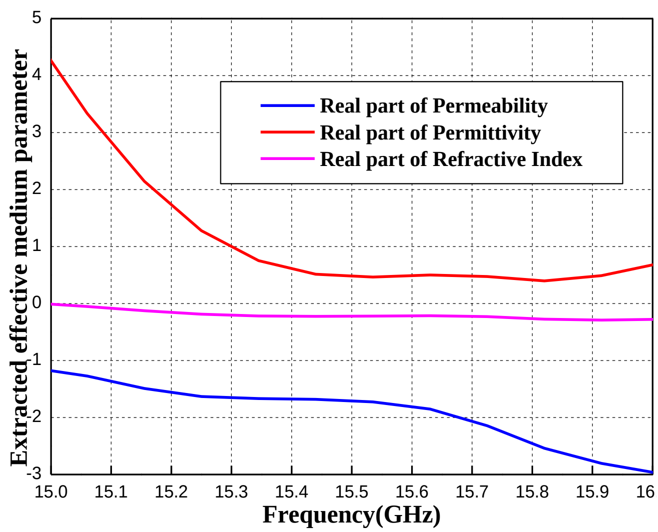

Fig.7. Extracted effective medium parameter from S-parameters

(a) Top View (b) Bottom View

Fig.8. Photograph of the fabricated SSHSS metamaterial antenna

Experimental measurement of the fabricated antenna is done by using Rohde and Schwarz vector network analyzer (VNA) up to 20 GHz. There is a good agreement between simulated and measured results for first two resonance frequency while there is an upper shift in third resonance frequency. This shift may be due to fabrication tolerances. Figure 9 shows the photograph of VNA screen. There is an extra band at 4.89 GHz which is absent in simulated results. Figure 10 shows the comparison between simulated and experimental results up to 20 GHz. It is clear from Figure 11 and 12 that the simulated and measured bandwidth is almost same for first two resonance frequency. Table 3 shows the summary of measured results.

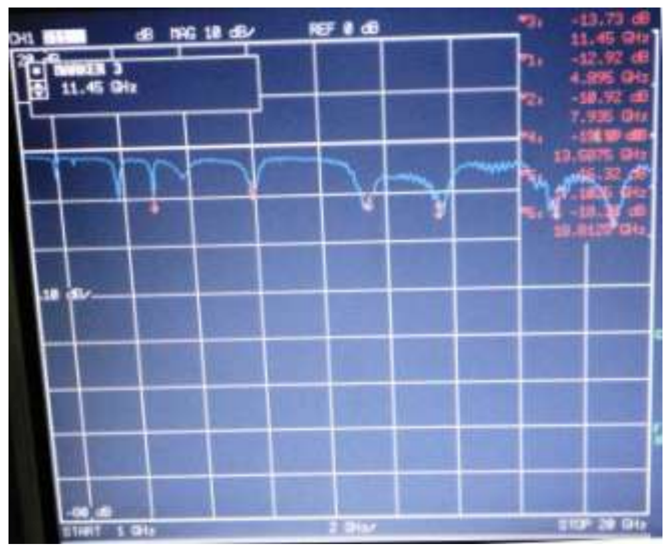

Fig.9. Measured reflection coefficient (S11) of the antenna on VNA

Table 3 Summary of measured results

Resonance Frequency(GHz)	Return Loss S_{11} (dB)	Bandwidth (MHz)	%BW
11.45	-13.73	330	28.8
13.58	-14.26	300	22.1
16.91	-14.45	340	20.10

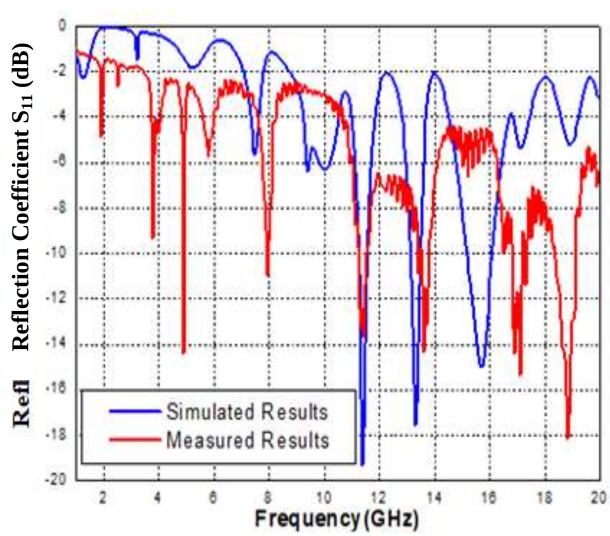

Fig.10. Comparison between simulated and measured reflection coefficient (S_{11})

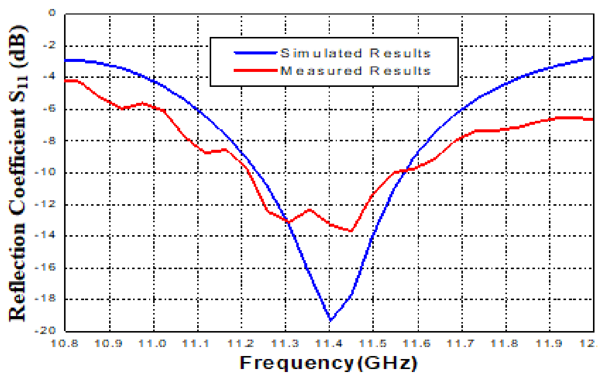

Fig.11. Comparison between simulated and measured reflection coefficient (S_{11}) at 11 GHz

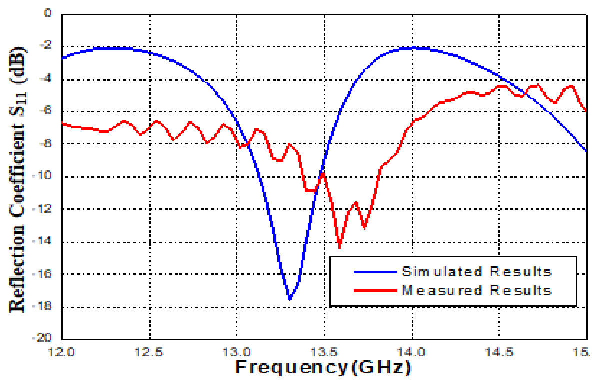

Fig.12. Comparison between simulated and measured reflection coefficient (S_{11}) at 13 GHz

4. Conclusion

This paper presents a new split semi-horse shoe structure (SSHSS) metamaterial antenna. The proposed structure is planar in shape, does not have a metallic rod on the back side, results is the simple fabrication for getting negative permittivity. Due to change in split vertical length and stub length, inductance and capacitance value changed so that resonance frequency changed from ISM band to X band in present work. The designed antenna exhibits metamaterial characteristics at 11.4376 GHz with 31.5% bandwidth and 13.3473 GHz with 26.6% bandwidth. It works as normal patch antenna at 15.7GHz with 58.67% bandwidth. Proposed design shows high directivity and moderate gain at the resonance frequency which gives the possibility of using SSHSS as the antenna. Experimental results of antenna show close resemblance to simulated results.

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Biography of the authors

Ghanshyam Singh received B.Tech. in Electronics and Communication Engineering from U.P. Technical University (presently Known as Dr. A.P.J. Kalam Technical University) Lucknow, Uttar Pradesh, India, in 2004. He received M. E. Degree in Electronics and Communication Engineering from NITTTR Chandigarh, India, in 2013. He joined the department of Electronics and Communication Engineering, Feroze Gandhi Institute of Engineering and Technology, Raebareli as lecturer in 2007. His research interest includes design and analysis of microstrip antennas, metamaterial.

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