International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-3, Issue-3, February 2014

Microstrip Array Antenna with Left Handed Metamaterial at C-Band

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Abstract*— Left-handed Metamaterial (LHM) is an artificial material where the permittivity and permeability are simultaneously negative at a certain range of frequency. One of the unique properties of the LHM is its negative refraction index which produces focusing effect to the wave propagating through the LHM. With this unique property, the LHM structures are used to increase the low gain of the microstrip antenna. In this work, an LHM structure consists of a modified split ring resonator (MSRR) and two capacitance loaded strip (CLS) is proposed. The MSRR has four slots in the middle of the structure which create wider range of negative permittivity and permeability. The MSRR exhibits negative permeability while the CLS exhibits negative permittivity. For the simulation process CST MICROWAVE STUDIO has been used. The metamaterial antenna presented in this paper is designed to operate at 7.3328 GHz and is employed for ultra-wideband (UWB) applications; which operates in C band. The substrate used is FR4 Board (Fire Retarded 4) with a dielectric constant of 4.7, thickness of 1.6 mm and a tangential loss of 0.019. The design yields return loss <-30dB. Simulations also show that the metamaterial antenna has improvement in gain compared to the arrray patch antenna.

***Index Terms*— Array antenna, Left-handed Metamaterial, Ultra-wideband, slip ring resonator, capacitance loaded strip.**

I. INTRODUCTION

Metamaterials are artificial media which exhibits unusual and useful properties. They have been applied in various guiding and radiating structures [1].

It is well known that small physical size, low cost, broad bandwidth, and good efficiency are desirable features for an integrated antenna. Antennas are used to launch energy into free space. Metamaterial-based antennas are a class of antennas inspired by metamaterials to enhance their capability or to achieve novel functions.

The advent of micro-system technologies and nanotechnologies has enabled artificially structuring of materials for electromagnetic and optical applications in manners, which was previously unimaginable. Among probably the best known examples of novel electromagnetic structures are photonic crystals and the negative refractive index metamaterials, popularly known as ‘left-handed’ materials [2].

Left handed metamaterial (LHM) is an artificial material (periodic metallic structure) where the permeability and permittivity were simultaneously negative at a certain range of frequency.

These enabled extension of the operation of passive and active elements for microwave and optical applications. Another result was an extreme miniaturization of components, sometimes even three to four orders of magnitude [3].

The main structures utilized to obtain NRM include thin metallic wires, metal cylinders, ‘Swiss roll’ structures, split ring and complementary split ring resonators (SRR), omega structures, broadside-coupled or capacitivelly loaded SRRs, capacitivelly loaded strips, space-filling elements, etc[3].

II. METAMATERIAL UNIT CELL STRUCTURE

A. Description of the Structure

An S-shaped split ring resonator has been proposed here. The basic S-SRR structure along with a periodic array of such structures is shown below[4]. The copper/metallic strips form a 'S' shape. Capacitive coupling is achieved through the addition of a reversed S-shaped strip printed back to back with a separation *d*.

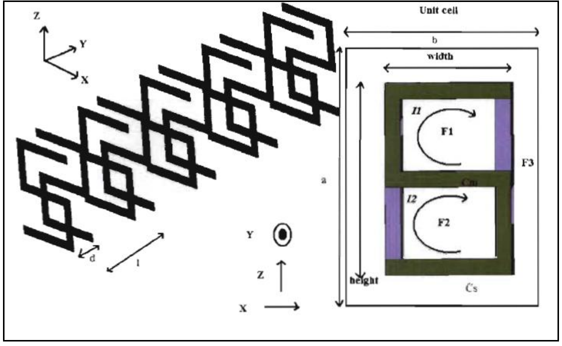

Figure 1 2D and 3D diagrams of S-shaped SRR structure

The area of a periodic unit cell A, is given by $A = xy$. The numeric '8' shaped pattern formed by the back to back split rings is shown in Figure 1.

The S-SRR structures may also be modeled with a PECIPMC waveguide model. One s-shaped copper structure may be embedded in a dielectric medium [5]. To generate the mirrored S shape, the mirror and move commands are used. Again modal S-parameters are generated using 2 wave ports with one dominant mode as described by the integration line. As per the simulations, a unit cell of S-SRR is given below in figure 2.

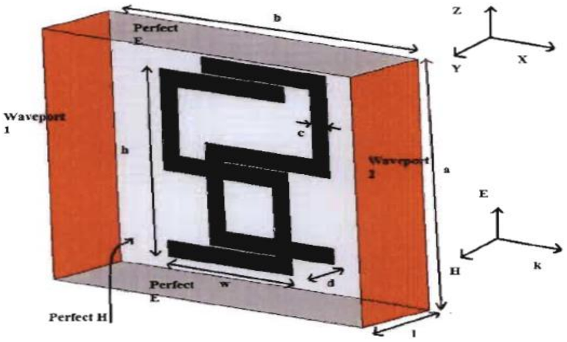

Figure 2 A synthesized S-SRR Unit cell

Manuscript received February 2014.

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A description of the S-SRR parameters is given in the Table 1 below.

Table 1 S-SRR Parameters

Parameters	**Dimension(mm)**
Patch width	0.4
Patch height	2.4
Patch material	PEC
Thickness of substrate	0.5
Substrate Length	4
Substrate width	5.4
Substrate Material1(e 4.4)	FR-4(Lossy)

B. *Retrieving the Constitutive Effective Parameters*

1) *S-Parameter Results*

The following plot shows the S-parameters as a function of frequency.

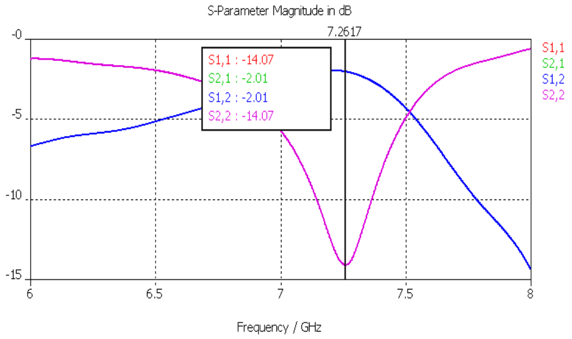


Figure 3 Simulated Result showing S parameter

2) *Permittivity, permeability and refractive index of Unit cell*

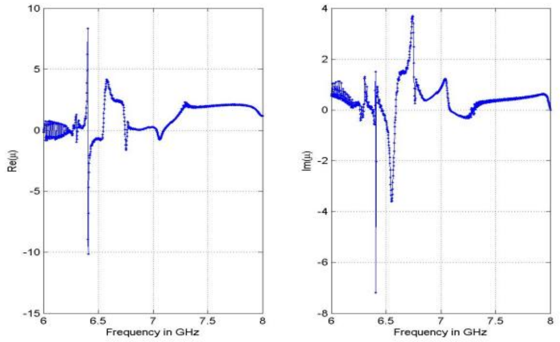


Figure 4 Result for permittivity simulated in MATLAB

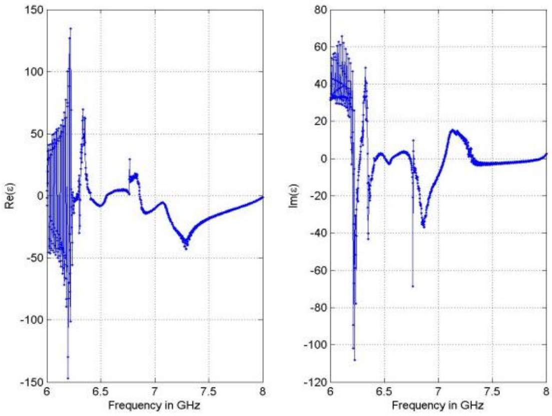


Figure 5 Result for permeability simulated in MATLAB

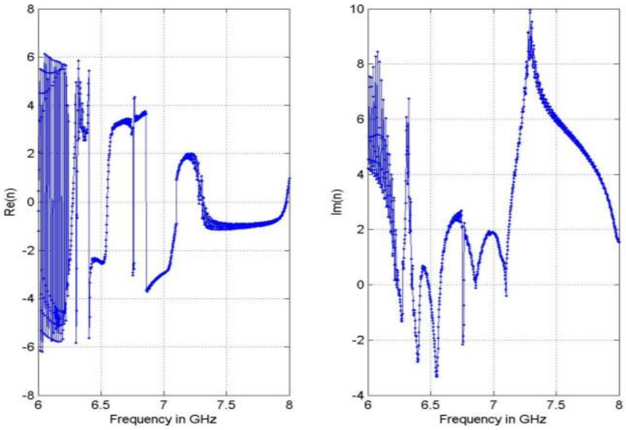


Figure 6 Result for refractive index simulated in MATLAB

All above figures show the simulation result of LHM unit cell. It is observed that at 7.26GHz maximum reflection occurs and thus this unit cell is an ideal candidate for constructing S-SRR structure.

III. DESIGN PROCEDURE

The 1 x 4 array microstrip patch antenna is designed with the LHM .The size of the antenna is 78mm x 36.5mm and the size of the patch is 69.5 mm x 45.5 mm . The dimension of the whole structure is 78mm x 36.5mm x 7.277 mm. The patches are fed by a transmission line feeding technique and the transmission line is connected to a single waveguide port. The substrate used is FR4 Lossy board with a dielectric constant of 4.9, thickness of 1.6 mm and a tangential loss of 0.019 [6]-[10]. Lay-outs are given in figures below.

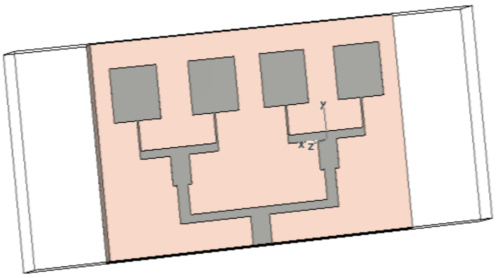


Figure 7 Layout of 1 x 4 array microstrip patch antenna

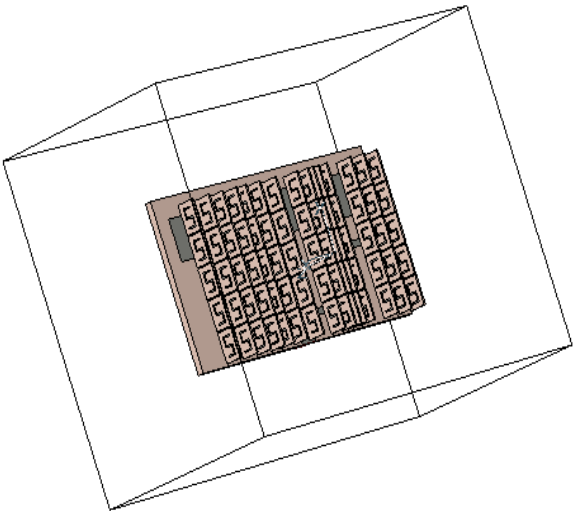


Figure 8 Linear polarized 1 x 4 array patch microstrip antenna incorporated with LHM (Perspective view)

IV. RESULT DISCUSSION

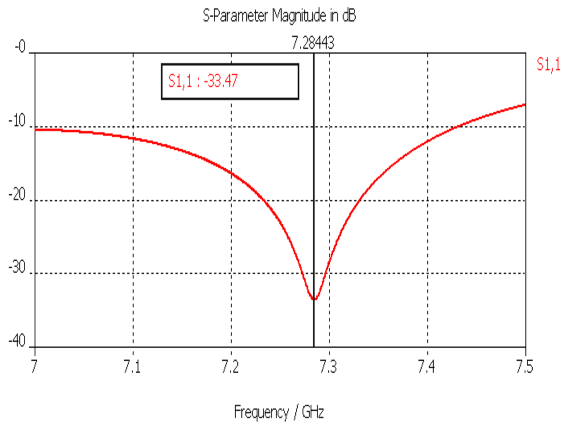
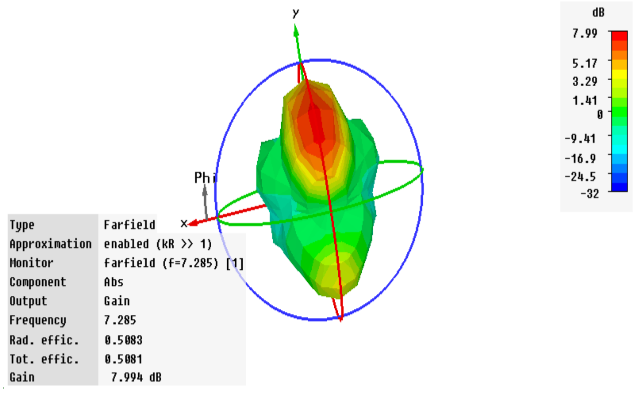


Figure 9 Return loss, S_{11} of the 1 x 4 array patch microstrip antenna

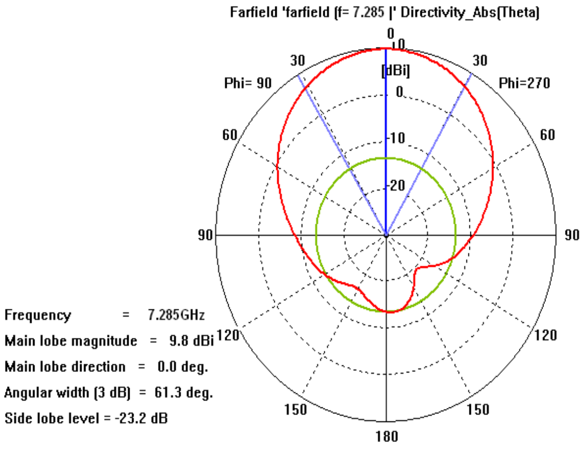
Figure 9 shows the return loss, S_{11} of the linear polarized 1 x 4 array microstrip patch antenna .The antenna is resonating at 7.285 GHz with a 20 dB bandwidth from 7.25 GHz to 7.34 GHz.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=7.285) [1]
Component	Abs
Output	Gain
Frequency	7.285
Rad. effic.	0.5083
Tot. effic.	0.5081
Gain	7.994 dB

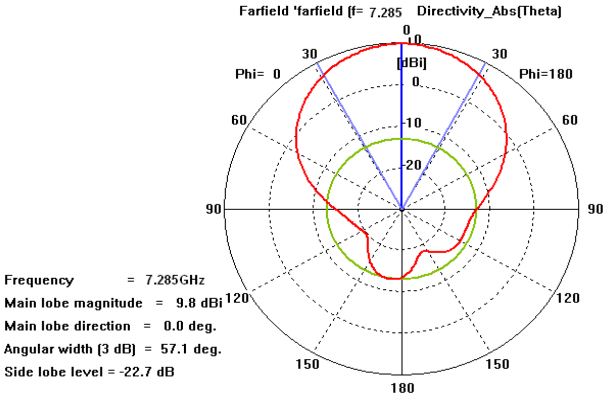
Figure 10 3D Radiation pattern at 7.285 GHz

The radiation pattern of the antenna is shown in Figure 10. The gain of the antenna is 7.994 dBi at 7.285 GHz and the total efficiency is 50.8 %. The low total efficiency of the antenna is due to the substrate loss where the value of the tangential loss is large. Meanwhile, Figure 11(a) and 11(b) show the E-plane and H-plane of the radiation pattern of the antenna. The 3dB beam-width of the antenna in E-plane is 61.3^0 and at the H-plane, the 3 dB beam-width is 57.3^0.



Frequency = 7.285GHz
Main lobe magnitude = 9.8 dBi
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 61.3 deg.
Side lobe level = -23.2 dB

(a)



Frequency = 7.285GHz
Main lobe magnitude = 9.8 dBi
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 57.1 deg.
Side lobe level = -22.7 dB

(b)

Figure 11. (a) Polar plot of radiation pattern at 7.285 GHz in E-plane (b) Polar plot of radiation pattern at 7.285 GHz in H-plane

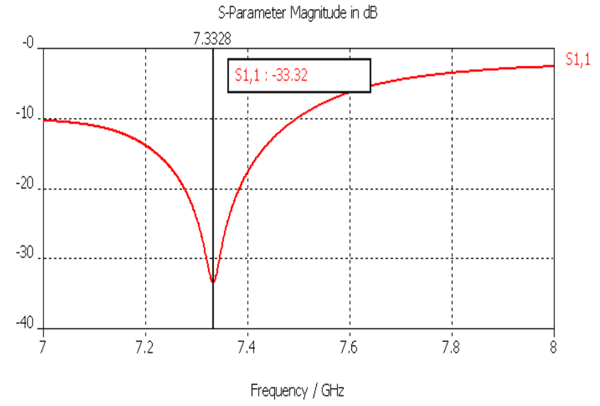
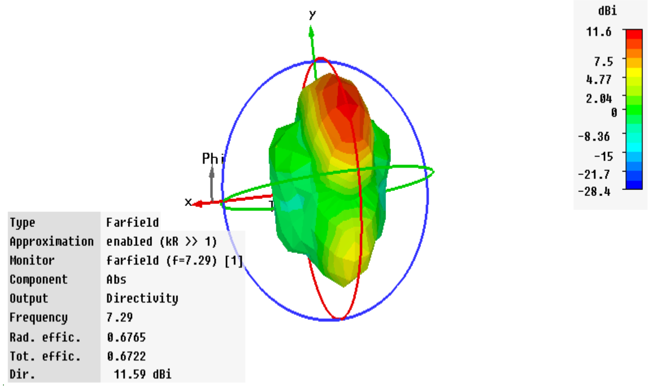


Figure 12 Return loss, S_{11}

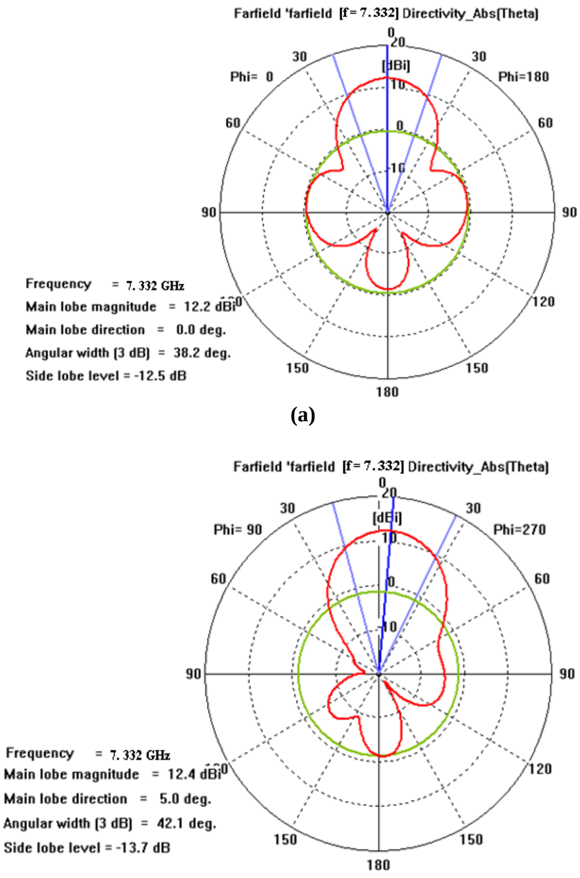
Figure 12 shows the simulated return loss, S_{11} of the antenna incorporated with LHM. The deepest dip of return loss is at 7.3328 GHz with -33.3 dB and the 20 dB bandwidth is from 7.29 GHz to 7.38 GHz.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=7.29) [1]
Component	Abs
Output	Directivity
Frequency	7.29
Rad. effic.	0.6765
Tot. effic.	0.6722
Dir.	11.59 dBi

Figure 13 Simulated radiation patterns at 7.3 GHz

The 3D radiation pattern at 7.3 GHz frequency is shown in Figure 13. The 3D radiation pattern has been observed at the operating frequency of 7.29 GHz. The directivity of the antenna at 7.29 GHz is 11.59 dBi and the total efficiency of the antenna at 7.29 GHz is 67.22%. Meanwhile, Figure 14(a) and 14(b) show the E-plane and H-plane of the radiation pattern of the antenna. The 3dB beam-width of the antenna in E-plane is 38.2^0 and at the H-plane, the 3 dB beam-width is 42.1^0.



(a)

(b)

Figure 14 (a) Polar plot of radiation pattern at 7.332 GHz in E-plane and (b) Polar plot of radiation pattern at 7.332 GHz in H-plane

The important parameters can be summarized in Table 2 given below:

S. No	Antenna Type	Resonating Frequency	Return Loss (dB)	Directivity (dBi)	Total Efficiency (%)
01	1x4 Array Patch	7.285	-33.47	7.994	50.81
02	1x4 Array Patch incorporated with LHM	7.3328	-33.32	11.59	67.22

V. CONCLUSION

It is observed that the integration of metamaterial with patch array causes a frequency-shift to higher value. In this paper, frequency-shift is from 7.285 GHz to 7.3328 GHz. But the value 7.3328 lies within the 20dB bandwidth of patch array i.e. 7.25-7.34 GHz. Hence this design is acceptable. The metamaterial antenna has better results in terms of directivity and total efficiency with almost same return loss as compared with the patch array. Thus integration of metamaterial improves the performance of the patch array antenna

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