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A novel Slotted Rectangular Microstrip patch antenna based on Zero-index metamaterial multilayer Superstrate

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Abstract

A zero index metamaterial (ZIM) is proposed in this work for antenna directivity and gain enhancement, this ZIM is developed, characterized and employed of slotted rectangular microstrip patch antenna at 2.4GHz . The unique property of the metamaterial gathers the wave radiated from the antenna and collimates it towards the normal direction when used as a superstrate , the effective permittivity and permeability of the (ZIM) are designed to synchronously approach zero, which leads the ZIM to having an effective wave impedance matching with air and near-zero index Simultaneously.

Keywords: *Zero index metamaterial (ZIM), patch antenna, directivity and gain improvement, effective permittivity, effective permeability.*

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1. Introduction

Metamaterial has many extraordinary properties, such as negative index, backward wave, inverse Doppler effect and backward Cerenkov radiation. The computation method of retrieving the constitutive effective parameter, including permittivity, permeability and refraction index of metamaterial was discussed[1]Among the different kinds of metamaterials, near-zero index metamaterials (NZIM) have the ability to control the direction of radiation[4].A low profile high directivity antenna is designed in [5], where Artificial Magnetic Conductor (AMC) substrate is used to reduce the height of antenna and NZIM lens (NZIML) is used to increase the directivity of antenna.in this paper slotted rectangular microstrip patch antenna [2]witch suffer from three major disadvantages such as narrow bandwidth, low gain and lower power handling capability loaded by multilayer unit cell zero-refrative-index metamaterial(ZIM)[3] based high-gain and directivity superstrate will be develloped .The aim of this work is to exhibit the advantage of metamaterial, The proposed design provides a directivity and gain enhancement about 5 dB using three layer's when The distance between antenna and the (ZIM) is adjusted. The ZIM unit cell is numerically simulated in CST MWS[7] which uses the finite element method, The scattering parameters show that there is a wide pass band where both permittivity and permeability are small enough to achieve wave collimation. it is shown that the beamwidth of antenna with the ZIM cover becomes more convergent and the gain is much higher. Hence it can be concluded that the metamaterials used in microstrip patch antennas improves various performance parameters and gives a low profile structure that can be easily integrated in communication devices[6]. A comparison between the conventional antenna and the metamaterial antenna is given. The results show that both the gain and directivity of the antenna are effectively improved based on the MTM multilayer superstrate.Therefore, the highgain antenna is effectively enhanced based on the near-zerorefractive- index metamaterial.

2. Antenna Design

Fig. 1 shows the geometry and the dimension of reference Slotted Rectangular Microstrip patch antenna. The antenna is constructed on FR4 substrate with permittivity of 4.3 and dielectric loss tangent of 0.025.This antenna is connected to a 50 SMA connector for signal transmission.The configuration of the zero-index metamaterial unit-cell is displayed in Fig.2.

It's consists of a single open electric field coupled resonator realized on Rogers R04350B laminate with dielectric permittivity 3.48, loss tangent 0.0031 and thickness 0.762mm with the defined boundaries, it signifies that electric field of incident wave will be polarized along y-axis and magnetic field of incident wave will be polarized along x-axis.the unit-cell consist of 5×5 element spacing by 0.75mm.the separation between slotted rectangular microstrip patch antenna and and superstrate layer's metamaterial is 30mm.

Dimensions of the designed antenna are listed in Table I.

Wg	Lg	W	L	h
62.04	52.316	38.04	28.316	4
lf	wf	S1	S2	S3
14.8975	7.64	4.5	1.5	1.18

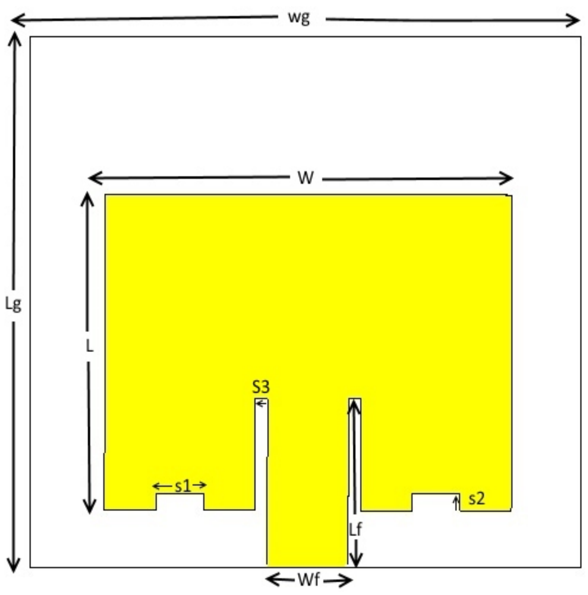

Fig. 1: Reference Slotted Rectangular Microstrip patch antenna

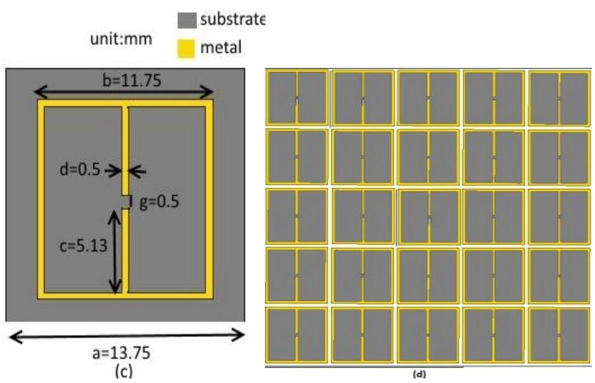

Fig. 2 (c) The geometry of metamaterial ,(d) zero-index metamaterial (ZIM) 5×5 unit-cell.

Fig. 2 shows the geometry and the dimension of the metamaterial. The unit-cell consist of 5×5 element spacing by 0.75mm.

3. Zero index metamaterial

Plasma is a system composed of a large number of charged particles, which shows neutral. The effective permittivity can be expressed as [8]:

$$\varepsilon_{(\omega)} = 1 - \frac{\omega_p^2}{\omega^2} \quad (1)$$

where $\omega_p$is the plasma frequency and ω is the frequency of the propagating electromagnetic wave. The plasma frequency $\omega_p$of the metal can be expressed as:

$$\omega_p^2 = \frac{n_e e^2}{\varepsilon_0 m_{eff}} \quad (2)$$

where n_e is the charge density, e is the electric quantity, m_{eff} is the effective mass, and ε_0 is the permittivity in free space. The plasma frequency ω_p of the metal is in the frequency of ultraviolet. Pendry proposed amechanism for the depression of the plasma frequency $\omega_p$to microwave by employing arrays of wires. Wires can depress ne and increase meff, resulting in lowering the plasma frequency ω_p. The plasma frequency $\omega_p$of the wires can be expressed as [8]:

$$\omega_p^2 = \frac{2\pi c^2}{a^2 \ln(\frac{a}{r})} \quad (3)$$

where r is the radius of the wires, a is the lattice constant, and c_0 is the speed of light in the free space. From (3), the plasma frequency ω_p can be lowered by optimizing the lattice constant a and the radius r of the wires. It can be concluded that the permittivity is negative when the frequency is below the plasma frequency [8].

4. Results and Applications

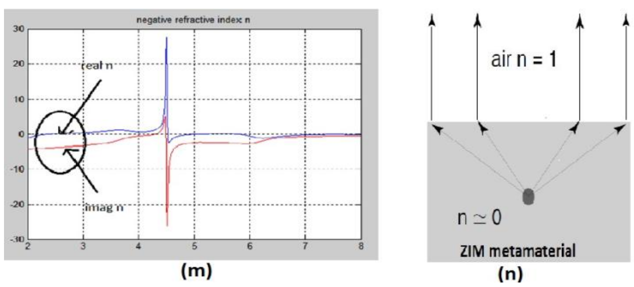

Fig. 3: (m) Zero refractive index, (n) the effect of ZIM at the incident waves.

Fig. 3 shows the real and imaginary part of zero refractive index n ,this results has been simulated by CST Microwave studio and exported as a data table to MATLAB code for giving the results in fig.3 (m) .it's clair that the real(n) at the desired frequency (2.4GHz) is zero and the imaginary part of refractive index represent the loss in material is near zero.in this condition the metamaterial gather the wave and collimate it in normal direction fig.3 (n).Hence the gain and directivity of antenna will be improved.

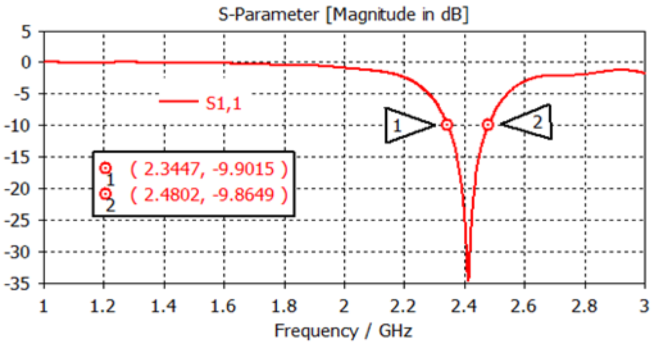

Fig. 4 S-parameter , of reference slotted rectangular microstrip patch antenna without metamaterial at2.4Ghz

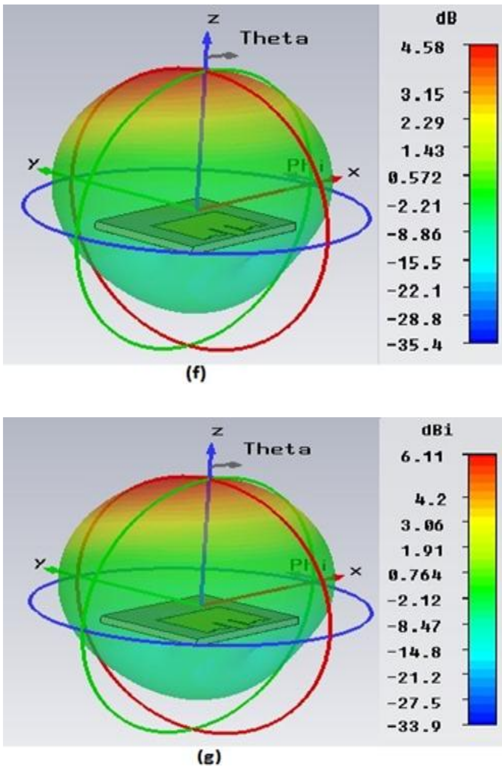

Fig. 5 the gain and the directivity of reference antenna at 2.4Ghz: (f) the gain, (g) the directivity.

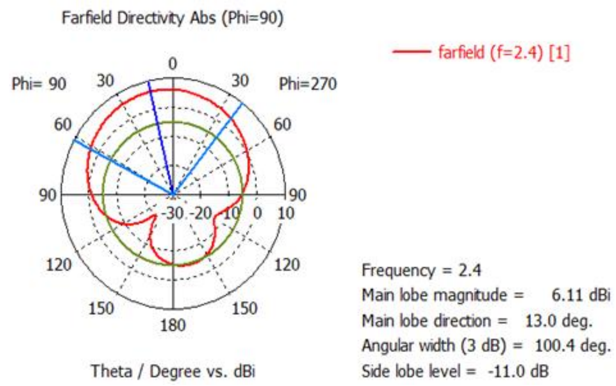

Fig. 6 Polar Plot of Radiation Pattern of reference slotted patch antenna at 2.4Ghz

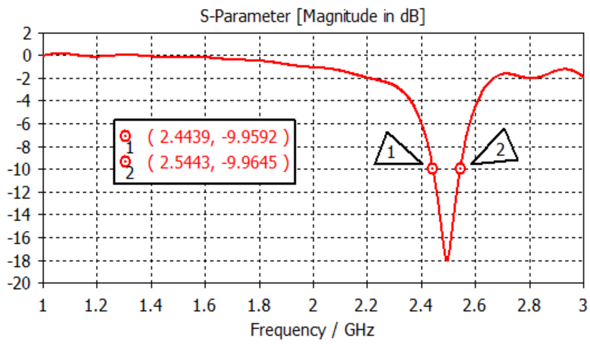

Fig. 7 S-parameter of proposed one-layer superstrate unit cell metamaterial antenna at 2.4Ghz

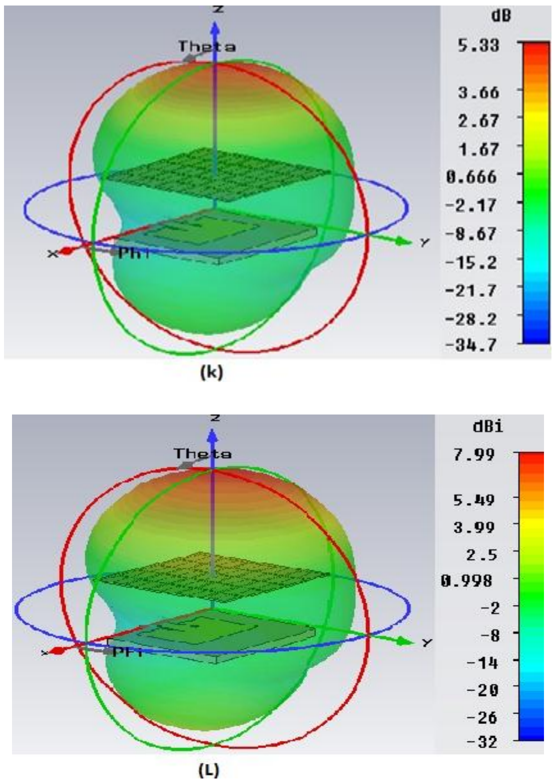

Fig. 8 the gain and the directivity of proposed one-layer superstrate unit cell metamaterial antenna at 2.4Ghz: (k) the gain, (L) the directivity

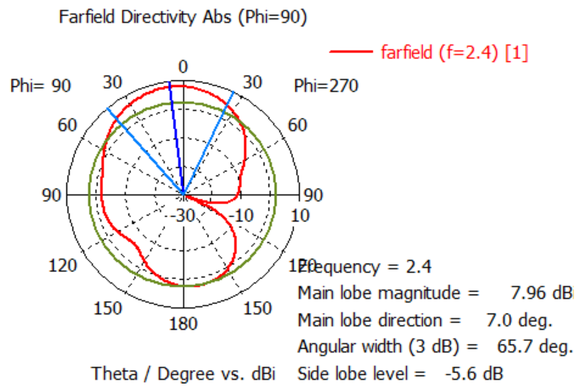

Fig. 9: Polar Plot of Radiation Pattern of proposed one-layer superstrate metamaterial antenna at 2.4Ghz

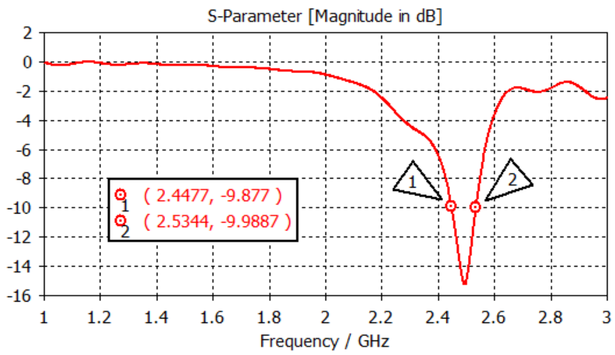

Fig. 10 S-parameter of proposed two-layer superstrate unit cell metamaterial antenna at 2.4Ghz

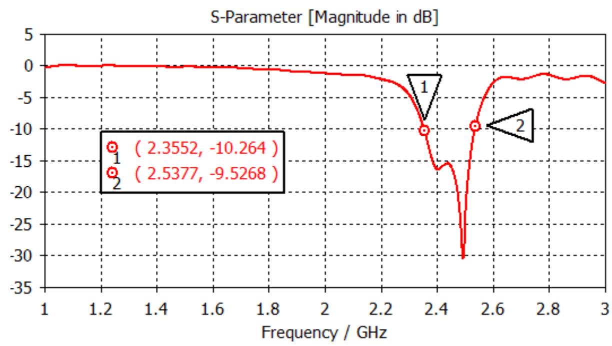

Fig. 13 S-parameter of proposed three-layer superstrate unit cell metamaterial antenna at 2.4Ghz

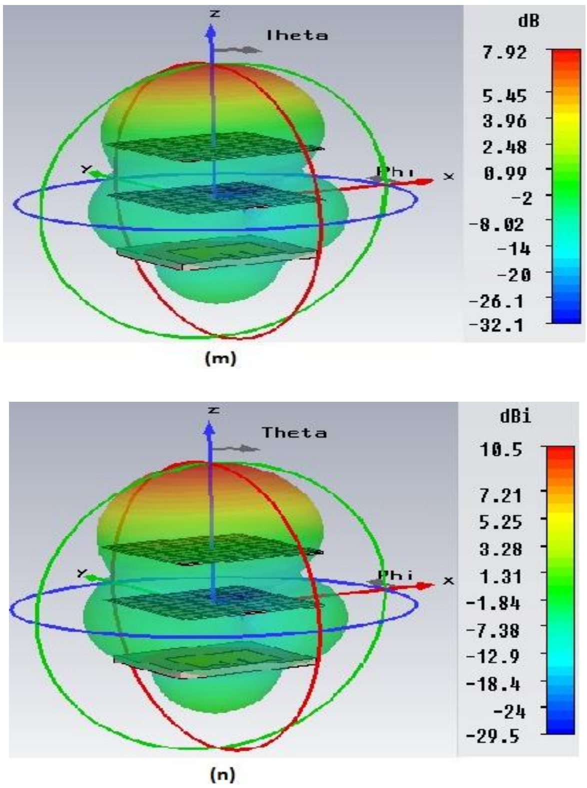

Fig. 11 the gain and the directivity of proposed two-layer superstrate unit cell metamaterial antenna at 2.4Ghz: (m) the gain, (n) the directivity

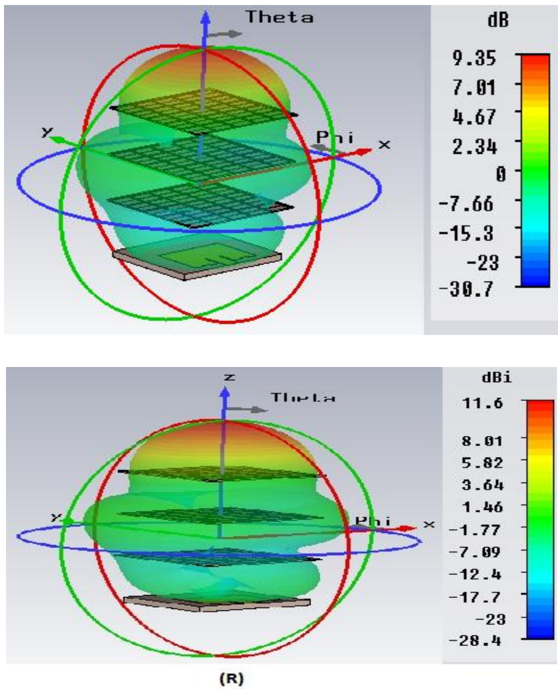

Fig. 14 the gain and the directivity of proposed three-layer superstrate unit cell metamaterial antenna at 2.4Ghz: (P) the gain, (R) the directivity

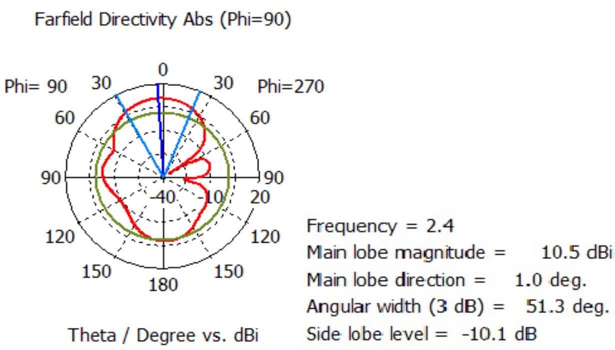

Fig. 12 Polar Plot of Radiation Pattern of proposed two-layer superstrate metamaterial antenna at 2.4Ghz

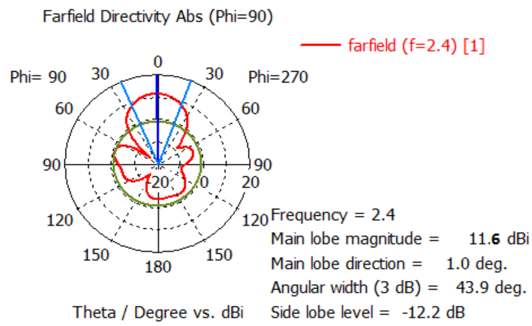

Fig. 15 Polar Plot of Radiation Pattern of proposed three-layer superstrate metamaterial antenna at 2.4Ghz

fig.4 and fig.7and fig.10 and fig.13 shows the simulated Sparameter of reference and designed multi-layer's superstrate metamaterial antenna.

This results show that the return loss of reference antenna at 2.4Ghz is -38dB and of proposed superstrate metamaterial antenna are -17dB and -28dB and -30dB respectively for one-layer's and two-layer's and three-layer's, the return loss is slightly broader compared to the reference slotted patch antenna. the bandwidth of reference antenna is 132.3Mhz and of proposed superstrate metamaterial antenna are 96.8Mhz and 119.8Mhz and 186.2Mhz respectively for one-layer's and two-layer's and three-layer's.the bandwidth is enhanced by 54Mhz in the metamaterial superstrate antenna . fig.5 and fig.8 and fig.11 and fig.14 shows the simulated gain and directivity of reference and designed multi-layer's superstrate metamaterial antenna. Simulated results show that the gain and directivity of reference slotted patch antenna at 2.4Ghz are 4.58dB and 6.11dB respectively,and of proposed metamterial antenna at the same frequency are 5.33dB and 7.99dB respectively for one-layer's metamaterial antenna,and for two-layer's metamaterial antenna are 7.92dB and 10.5dB,and for three-layer's metamaterial antenna are 9.35dB and 11.6dB respectively , it is clair that the gain and directivity are enhanced by 4.66dB and 5.49dB respectively. fig.6 and fig.9 and fig.12 and fig.15 shows the simulatedpolar plot of reference and designed multi-layer's superstrate metamaterial antenna. Simulated results show that angular width(3dB) of reference slotted patch antenna at 2.4Ghz is 100.2degree and of proposed superstrate metamaterial antenna are 65.2degree and 51.3degree and 42.5degree respectively for one-layer's and two-layer's and three-layer's.the angular width(3dB) is sharper by 57.7degree in the metamaterial superstrate antenna compared to the reference slotted patch antenna. the efficiency is 74.95% for reference slotted patch antenna and 79.65% for proposed metamaterial antenna.

Table 2 The result simulation at 2.4Ghz

Parameter	ref.ant	1layer MTM	2layer MTM	3layer MTM
Return loss (dB)	-38dB	-17dB	-18dB	-30dB
Gain (dB)	4.58dB	5.33dB	7.92dB	9.35dB
Directivity (dB)	6.11dB	7.99dB	10.5dB	11.6dB
Bandwidth (Mhz)	132.3	96.8	119.8	186.2
3-dB beamwidth (deg)	100.2°	65.2°	51.3	42.5
Efficiency %	74.95%	66.70%	75.42%	80.42%

Conclusion

The simulation results of the proposed slotted rectangular microstrip patch antenna loaded by metamaterial multilayer superstrate giving exceptional results. This MTM shaped was designed to compose a near zero refractive index metamaterial, concentrates the radiation energy in direction close to the normal of the metamaterial structure. Consequently, the gain and directivity of antenna will be enhanced, and the the 3-dB beamwidth will be sharper.

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