A Zero Index Metamaterial Lens for Gain Enhancement of Patch Antenna and H-plane Horn Antenna

Yue-Long Lv[1)], Fan-Yi Meng[1)*], Fang Zhang[1)], Lei Zhu[1)], Jia-Hui Fu[1)], Kuang Zhang[1)] and Qun Wu[1)]

[1)]Department of Microwave Engineering, Harbin Institute of Technology, Harbin 150001,China
Email: blade@hit.edu.cn

***Abstract* — A zero index metamaterial lens (ZIML) is proposed in this paper for antenna directivity and gain enhancement. The zero index metamaterial (ZIM) is constructed from both electric metamaterial with near-zero permittivity and magnetic metamaterial-modified split ring resonator (MSRR)-with near-zero permeability. The ZIM unit cell is numerically simulated in CST MWS. The scattering parameters show that there is a wide pass band where both permittivity and permeability are small enough to achieve wave collimation. Particularly, both of the two parameters are of the same value of 0.25, which not only obtains near-zero refractive index but also makes the relative characteristic impedance to be 1 and match that of air. A patch antenna and an H-plane horn antenna are also implemented to examine the directivity and gain enhancement ability of the ZIML. The E-plane radiation patterns are both sharpened greatly. The gain enhancement of patch antenna and H-plane horn antenna are 6.6 dB and 4.3 dB, respectively. The universality of the ZIML for both patch antenna and H-plane horn antenna indicates a more flexible application of the ZIML compared with traditional ones.**

***Index Terms* — Zero index metamaterial (ZIM), lens, wave collimation, gain enhancement, patch antenna, H-plane horn antenna.**

I. INTRODUCTION

Metamaterials are artificial materials engineered to have properties (such as negative refraction) that may not be found in nature [1]. In recent years, metamaterials have been widely investigated for miniaturization and performance enhancement of microwave device and antenna [2, 3]. Zero index metamaterial (ZIM) has been presented to realized zero index metamaterial lens (ZIML) for antenna directivity and gain enhancement [4], after which many groups investigated the propagation characteristic of the ZIM [5] and varieties of ZIMs and ZIMLs are designed [6-8]. However, traditional ZIMs obtain near-zero refraction-index by only implementing electric metamaterial with near-zero permittivity which is also referred as "ENZ" (epsilon near zero) [8, 9], or by only magnetic metamaterial with near-zero permeability [10]. However, these kinds of ZIMs or ZIMLs are bulky and hard to control characteristic impedance to match that of air. Even though J. P. Turpin *at al.* present a kind of ZIML which is constructed from both magnetic metamaterial with near-zero permeability and electric metamaterial with near-zero permittivity to achieve impedance matching for better antenna gain enhancement, the structure of the ZIM unit cell is cubic and too complex to fabricate [11].

In this paper, a ZIML composed of ZIM based on both magnetic metamaterial with near-zero permeability and electric metamaterial with near-zero permittivity in the unit cell is proposed for wave collimation to improve antenna directivity and gain. As a result of the property of impedance matching, the return loss of the antenna will be affected slightly after loading the proposed ZIML. A patch antenna and an H-plane horn antenna operating at 9.9 GHz are implemented to examine the directivity and gain enhancement ability of the ZIML. Obviously sharpened E-plane radiation patterns and significantly gain enhancement are observed with the return losses of the antennas slightly affected.

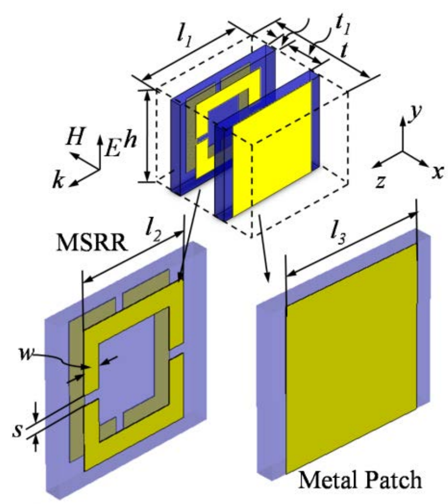

Fig. 1. The structure of ZIM unit cell.

II. THE ZIM UNIT CELL DESIGN

As shown in Fig. 1, the unit cell of the ZIM is composed of two parts: the magnetic metamaterial consisting of modified split ring resonators (MSRRs) with strong magnetic resonance [12] and the metal patch which will act as electric metamaterial similar to metal wire array to

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achieve strong electric resonance [13]. The MSRR consists of two square loops and each loop has two slots at the opposite sides. One of the two square loops is generated by rotating the other one 90°. And the two loops are etched on the opposite sides of the dielectric substrate. The ZIM unit cell structure is much simpler than the one in [11] and much easier to fabricate. All the geometry parameters are as below: l_1 = 8 mm, l_2 = 5.4 mm, l_3 = h = 6.6 mm, t = 8.2 mm, t_1 = 2.9 mm, t_2 = 0.8 mm, w = 0.8 mm

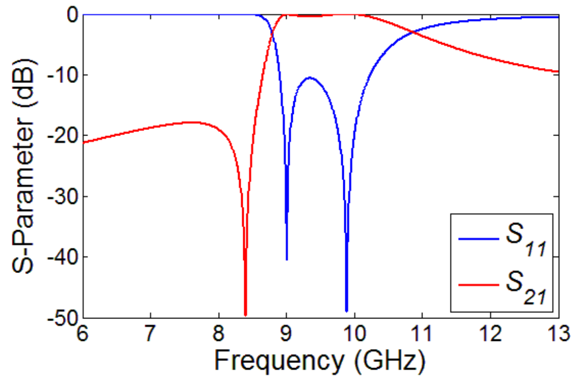

Fig. 2. Scattering parameters of the ZIM unit cell.

and s = 0.4 mm. The relative permittivity of the substrate is 2.2.

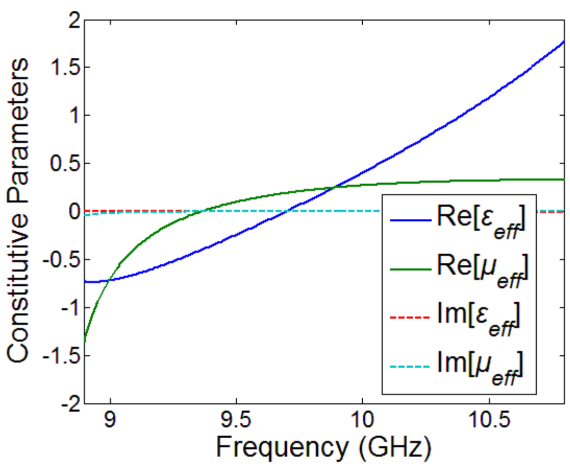

Fig. 3. Constitutive parameters of the ZIM unit cell.

The scattering parameters are obtained after modeling and simulating the ZIM unit cell in CST MWS and are depicted in Fig. 2. A wide pass band can be observed where the ZIML composed of the ZIM unit cell can be used to achieve antenna directivity and gain enhancement. Using the calculation procedure in [14], the effective permittivity and permeability can be extracted from scattering parameters and depicted in Fig. 3. One can find that both of the two constitutive parameters are of the same value of 0.26 (small enough for wave collimation [11]) at 9.9 GHz, which means that both directivity enhancement and impedance matching are achieved. The effective refractive index is also calculated and depicted in Fig. 4. Both of its real part and imaginary part are small and varies smoothly. One can predict that the directivity and gain enhancement ability is powerful around 9.9 GHz, and weakened in the upper and lower frequency band as the refractive index grows larger.

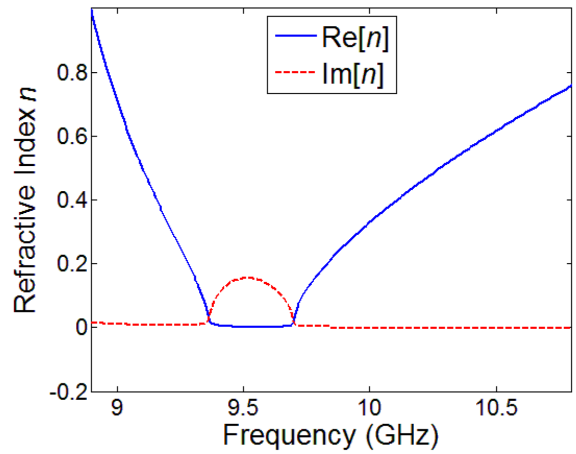

Fig. 4. Refractive index of the ZIM unit cell.

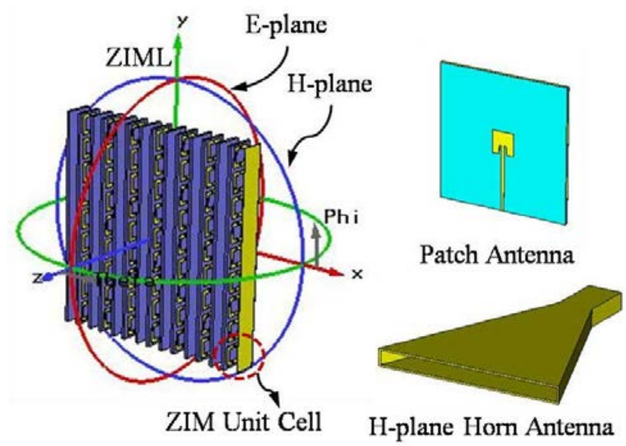

Fig. 5. Schema of ZIML and antennas. The antenna (a patch antenna or H-plane horn antenna) should be placed right behind the ZIML with a proper distance.

III. The Simulation and Test of the ZIML

The ZIML is planar structure consisting of ZIM unit cells and also simulated in CST MWS. A patch antenna operating at 9.9 GHz and an H-plane horn antenna with a center frequency of 9.9 GHz are used to examine the directivity and gain enhancement of the ZIML. Both of the simulated return losses and radiation patterns of the two antennas and the result discussion are given as below.

A. The gain enhancement of the ZIML for patch antenna.

For the patch antenna, the size of the ZIML is 7×9 ZIM unit cells to cover the antenna aperture. After placing the patch antenna behind the ZIML, the return losses of the patch antenna with and without the ZIML are given in Fig. 6. One can observe that the return loss varies little after loading the ZIML. It demonstrates that the impedance matching property of the ZIML is good enough to not largely weaken the total efficiency of the system of antenna and ZIML. E-plane radiation patterns are simulated and shown in Fig. 7. The main lobe width of E-plane radiation pattern is reduced remarkably from 123.5° to 31.2°, and the gain enhancement is 6.6 dB, which display the powerful directivity and gain enhancement of the ZIML for the patch antenna.

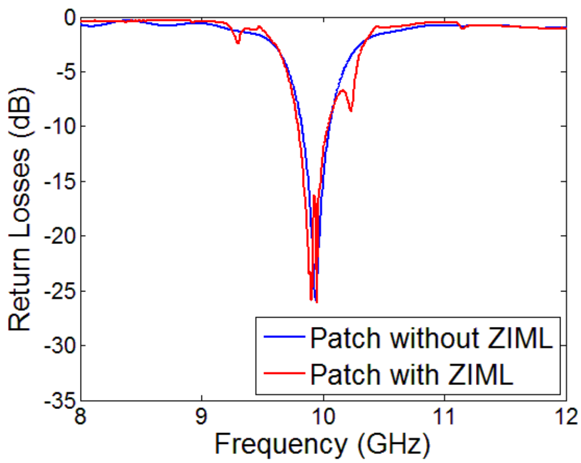

Fig. 6. Return losses of patch antenna with and without ZIML.

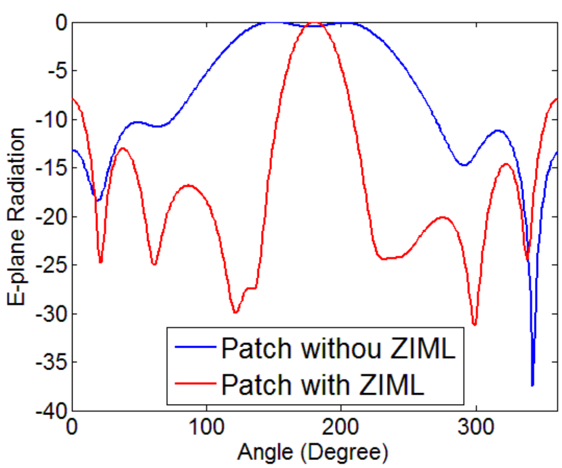

Fig. 7. E-plane radiation patterns of patch antenna with and without ZIML.

B. The gain enhancement of the ZIML for H-plane horn antenna.

For the H-plane horn antenna, the size of the ZIML is 19×13 ZIM unit cells. The H-plane horn antenna is also placed behind the ZIML as shown in Fig. 5. Similar to the order of the case for patch antenna. The return losses of the horn antenna is also depicted in Fig. 8. One can find that the return losses of the H-plane horn antenna is also slightly affected by the ZIML from 9 GHz to 10.1 GHz where its characteristic impedance matches that of air very well. In the upper or lower band, the return loss is weakened largely relatively as a result of the impedance mismatch between the ZIML and the air.

The E-plane radiation patterns of the H-plane horn antenna with and without ZIML are illustrated and contrasted in Fig. 9. The E-plane radiation pattern of the antenna at 9.9 GHz is obviously sharpened in the main lobe. The main lobe width is reduced from 91.4° to 14.8°. The directivity of the H-plane horn antenna is greatly enhanced. The antenna gain of the H-plane horn antenna is also enhanced by 4.43 dB, which is a significant improvement. The simulated results of both cases for patch antenna and H-plane horn antenna show great consistence with the prediction based on the theory we proposed in section II. Therefore, the ZIML we proposed has universality for both patch antenna and H-plane horn antenna with both good effects, and has more flexible application in antenna gain enhancement.

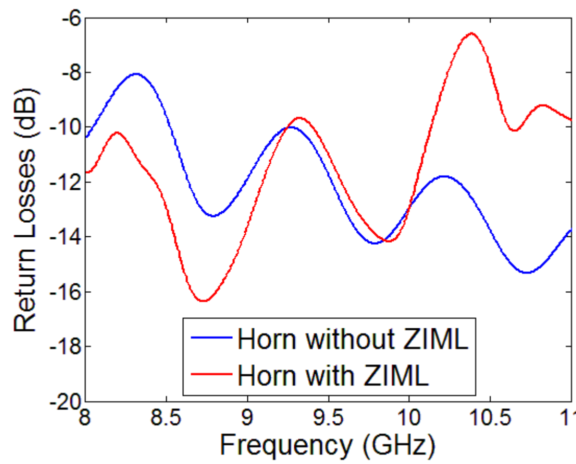

Fig. 8. Return losses of H-plane horn antenna with and without ZIML.

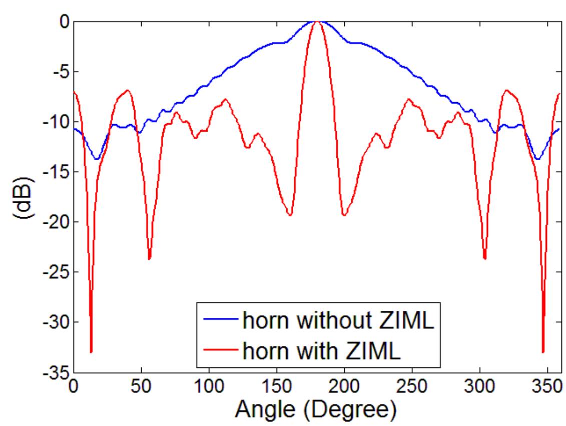

Fig. 9. E-plane radiation patterns of H-plane horn antenna with and without ZIML.

IV. CONCLUSION

In this paper, a ZIML for antenna directivity and gain enhancement is presented, using the ZIM unit cell constructed from both electric and magnetic metamaterials for both near-zero constitutive parameters. Therefore, the ZIML not only have low refractive index to achieve wave collimation but also has the property of impedance matching with air. Simulated results shows that, after placing the ZIML above the aperture of antenna, the return loss is weakened slightly, E-plane radiation pattern main lobe is sharpened obviously and the antenna gain is largely improved. The ZIML we proposed works well with both patch antenna and H-plane horn antenna and has more simpler structure with other designs.

ACKNOWLEDGEMENT

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