Circularly Polarized Microstrip Antenna Based on Waveguided Magneto-Dielectrics

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Abstract- **In this paper, we make an investigation on the waveguided magneto-dielectric materials (WG-MDM) based on the embedded meanderline structure. As verified by retrieval results of effective medium parameters, the WG-MDM exhibits nearly the same magneto-dielectric property with respect to the orthogonally applied TEM wave excitations. The WG-MDM is utilized as the artificial substrate of square microstrip patch antenna and the patch is perturbed at two corners to realize circularly polarized radiation. Simulation results show that the impedance and axial ratio bandwidths of the resulting novel circularly polarized patch antenna have increased by 78% and 71%, compared with those of pure-dielectric-substrate-based patch antenna with the same size.**

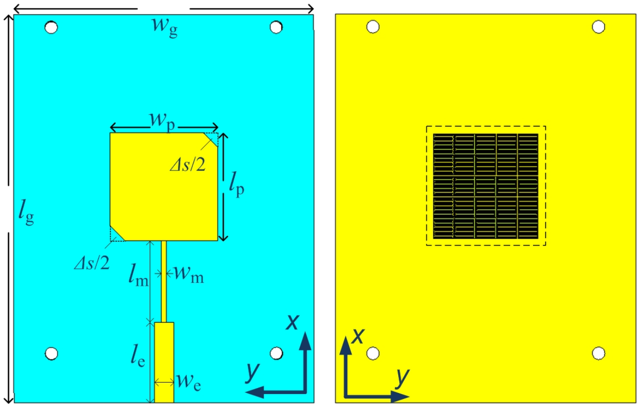
Index Terms—**Circular polarization, microstrip atenna, waveguided metamaterial, magneto-dielectrics.**

I. INTRODUCTION

Bandwidth improvement of microstrip antennas is attractive in the antenna community. Recently, increasing the bandwidth of patch antenna by loading artificial magneto-dielectric substrate has aroused interest among researchers [1]-[12]. Generally, replacing conventional dielectric substrate by magneto-dielectric substrate will decrease the electromagnetic energy stored under the patch at resonance, and accordingly leads to lower quality factor and broader bandwidth of patch antenna [1],[2]. Compared with many other broadbanding techniques, the magneto-dielectric substrate technique has theoretically no influence on the radiation chracteristics of microstrip patch and hence may be preferred in many applications. However, researches about this technique have been limited to broadbanding of linearly polarized microstrip antennas up to now. It is due to the fact that common artificial magneto-dielectric materials are not suitable for creating two orthogonal degenerate TM modes required by circularly polarized radiation, since those materials are composed of anisotropic inclusions such as split ring resonators [13], [14], [5],[6] and spiral resonators [13], [15], [4].

This paper introduces a waveguided metamaterial which exhibits nearly the same magneto-dielectric property with respect to the orthogonally applied TEM wave excitations in microstrip plane. This waveguided magneto-dielectric material (WG-MDM) is used to fill in the volume between a perturbed square patch and a ground plane and the resulting novel circularly polarized patch antenna proves to have both improved impedance bandwidth and axial ratio bandwidth. To our knowledge, it is the first report on broadbanding of circularly polarized patch antenna by artificial magneto-dielectric loading.

The proposed patch antenna loaded with the WG-MDM comprises three layers: a normal dielectric layer 1.43mm thick and two metallic layers attached to the two sides of the dielectric layer. The permittivity and loss tangent of the dielectric layer are 2.65 and 0.001, respectively. Fig. 1(a) and (b) illustrate the metal arrangement on the top and the bottom side of the dielectric layer. The circular polarization characteristic is realized by perturbing the square patch at two diagonal corners (Fig. 1(a)). The effective magneto-dielectric material loading is implemented by etching periodic array composed of electrically small planar unit cells in the ground plane right under the patch (Fig. 1(b)). The patch is singly fed by microstrip and a matching line is inserted between the patch and the 50Ω feeding line to achieve good matching (Fig. 1(a)). The whole structure is compact and simple and could be fabricated on copper clad laminate with normal PCB process.



(a) (b)

Figure 1. Circularly polarized patch antenna loaded with waveguided magneto-dielectric material.(a) Top view of perturbed square patch and feeding network. (b) Bottom view of ground plane with periodic etching. The region of etching is indicated by a dashed square.

II. WAVEGUIDED MAGNETO-DIELECTRIC MATERIAL

The planar unit cell referred in the last section is called embedded meander line (EML). It characterizes a meander line embedded in a square area defect in the ground, as shown by Fig.2. Dimensions of the EML in this paper are listed in Table I. The periodicity of the EML array is 4.2 mm along both x and y directions. As stated in [12], when the size of EML element is much smaller than the wavelength, the volume occupied by the EML array right under the patch can be taken as an effective magneto-dielectric medium. This effective medium belongs to a special category of metamaterial: waveguided metamaterial, since it resides in a planar waveguide environment constituted by the ground plane and the upper patch [12],[16],[17].

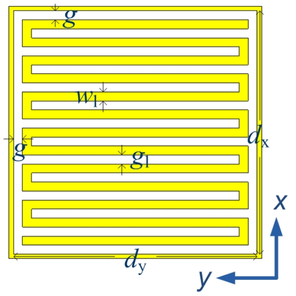
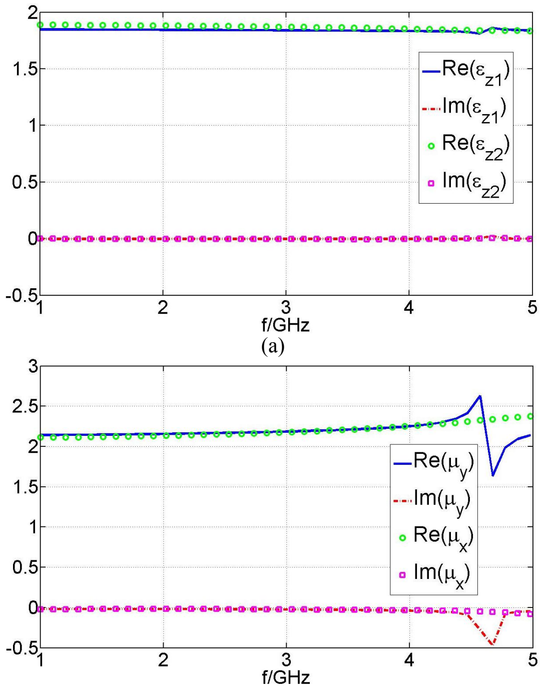


Figure 2. Depiction of the unit cell of embedded meander line structure.

TABLE I
DIMENSIONS OF EML UNIT CELL

d_x	d_y	g	w_l	g_l
4.05mm	4.05mm	0.15mm	0.15mm	0.15mm



(a)

(b)

Figure 3. The effective medium parameters of the EML-based waveguided metamaterial, where ε_{z1} and μ_y are retrieved when the incident wave is from *x* direction and ε_{z2} and μ_x are retrieved when the incident wave is from *y* direction.

Though the EML is an asymmetric structure, the EML-based waveguided magneto-dielectric material (WG-MDM) exhibits nearly isotropic magneto-dielectric property within a broad band with respect to the plane waves travelling along two orthogonal directions (i.e. *x* and *y* directions) in the microstrip plane. As verification, the effective medium parameters of the WG-MDM with those two excitation manners are retieved seperately and compared in Fig. 3. It is apparent that the two sets of effective medium parameters are very similar to each other in the band below 4 GHz. Here the effective medium parameters are retrieved using the technique introduced in [17],[18].

Fig.3 also shows that the self resonance of the WG-MDM is very weak and the effective medium parameters are almost non-dispersive in the band below 4 GHz. Besides, though the defect in the ground plane causes energy leakage, the effective medium loss (seen from the imaginary part of the retrieved medium parameters) of the WG-MDM is resonably low in this band. These two cases are advantageous to improving the bandwidth and efficiency of the WG-MDM-based antenna.

III. DESIGN OF CIRCULARLY POLARIZED PATCH ANTENNA

The design of the proposed circularly polarized patch antenna shown in Fig.1 contains three main stages which could be carried out with the aid of numerical simulation tool.

1). Determine the scale of the EML array and the size of the square patch according to the working frequency of the antenna.

2). Find the unloaded quality factor Q_0 of the square patch before perturbation and determine the amount of perturbation Δs initially from the following expression [19]:

$$2\Delta s/S=1/Q_0. \qquad (1)$$

where *S* is the area of the unperturbed patch. Then slightly adjust Δs to get a satisfactory circularly polarization characteristic along broadside direction (i.e. *z* direcion) around the working frequency.

3). Determine the input impedance of the perturbed square patch and the dimensions of the matching line according to this input impedance.

In our present design, the scale of the EML array is chosen as 5×5 and the size of the square patch right over the array is set as 21.5mm × 21.5mm. Such configuration makes the antenna operate at about 3.61GHz. Besides, the unloaded quality factor Q_0 of the unperturbed patch is 26.9 and the optimized value of Δs is 6.76mm^2. Accordingly, the input impedance of the perturbed patch is found to be (203.92 + j63.96)Ω at 3.61GHz and the width and length of the matching line are determined as 0.88mm and 16.3mm subsequently. Note that the working frequency is located in the useful band of the WG-MDM and the effective medium parameters at this working frequency are ε_{z1}=1.84-j0.003, ε_{z2}=1.86-j0.005 and $\mu_y \approx \mu_x$=2.22-j0.03. All the antenna dimensions involved in the three stages are listed in Table II.

TABLE II
DIMENSIONS OF CIRCULARLY POLARIZED PATCH ANTENNA

w_p, l_p	Δs	w_m	l_m	w_e	l_e
21.5mm	6.76mm^2	0.88mm	16.3mm	3.85mm	16mm

It should be noted that since loading the EML array in the ground would inevitably causes energy leakage and increase of back radiation, an additional metal shield plate is added beneath and parallel to the antenna ground, as shown in Fig. 4. The distance between the shield and the antenna ground is

5mm. The overall size of the antenna loaded with the WG-MDM is 60 mm×77.3 mm.

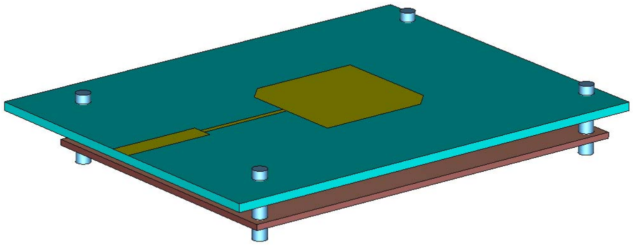


Figure 4. The EML loaded circulaly polarized patch antenna with an additional shield metal plate.

For comparison, a circularly polarized control antenna is also designed. The geometry of the control antenna is almost the same as that of the antenna with the WG-MDM except that the volume right under the patch of the control antenna is filled with an independent piece of pure dielectrics instead of artificial magneto-dielectrics, as shown in Fig.5. The permittivity of the dielectric is tuned to be 3.6 (with the loss tangent of 0.001) so that the control antenna has approximately the same operating frequency, the same patch size, and the same overall size as the antenna with the WG-MDM does.

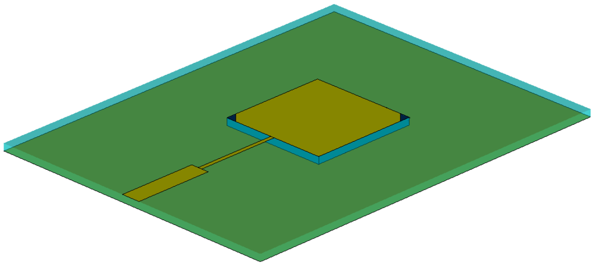


Figure 5. Geometry of the control antenna.

IV. SIMULATION RESULTS AND DISCUSSION

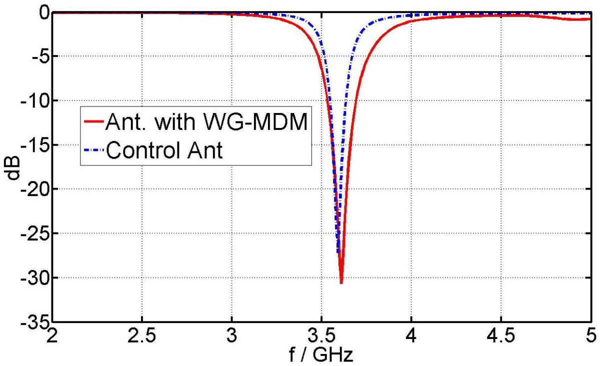


Figure 6. The simulated reflection coefficients of the antennas with and without the WG-MDM.

The simulated reflection coefficients and the axial ratios of the circularly polarized antenna with and without the WG-MDM are shown in Fig.6 and Fig.7, respectively. From Fig.6, the relative -10dB impedance bandwidths of the proposed antenna and the control antenna are 4.43% and 2.49%, respectively. Hence the improvement factor of impedance bandwidth of the proposed antenna over the control antenna is about 1.78. From Fig.7, it is observed that the relative -3dB axial ratio bandwidth of the antenna with the WG-MDM is 1.5%, which is 1.71 times that of the control antenna: 0.88%.

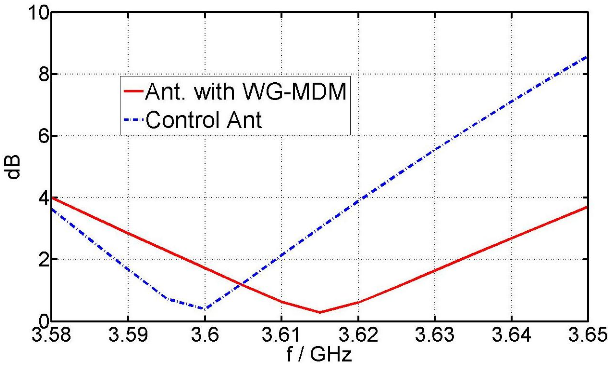
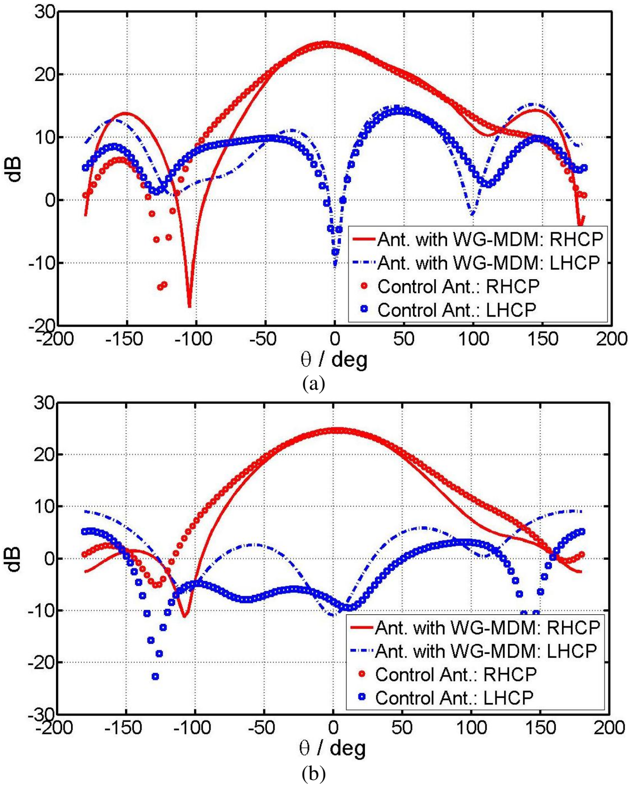


Figure 7. The simulated axial ratios of the antennas with and without the WG-MDM.

Fig.8 demonstrates the simualted radiation patterns of the antenna with the WG-MDM at 3.615GHz and the simualted patterns of the control antenna at 3.6GHz, in both *xoz* plane and *yoz* plane. Apparently, the radiation characteristics of the antenna with WG-MDM could compare favorably with the control antenna.



(a)

(b)

Figure 8. The simulated radiation patterns of the antennas with and without the WG-MDM in (a) *xoz* plane (b) *yoz* plane.

V. CONCLUSION

We have successfully improved both the impedance and axial ratio bandwidth of circulaly polarized patch antenna by loading an isotropic waveguided magneto-dielectric material based on the EML structure. The proposed broadbanding technique of WG-MDM loading is promising since it influences little on the radiation characteristic and the resulting novel circulaly polarized patch antenna is compact and easy to fabricate.

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