Radiation Enhancement for Planar Omni-directional Antennas with ENZ Metamaterials

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***Abstract*—In this paper, uniaxial anisotropic epsilon-near-zero (ENZ) metamaterial, with a vanishing radial component of the permittivity tensor, has been utilized to improve the performance of planar omni-directional antennas. The radiation pattern of the TM_{01} mode patch antenna, with ground plane of two different size, has been studied when they are loaded with an annular array of electric-LC (ELC). Simulated results show that compared to the original antennas, their respective main beam has been significantly enhanced.**

Keywords—patch antennas; omni-directional antennas; metamaterials; low-profile.

I. INTRODUCTION

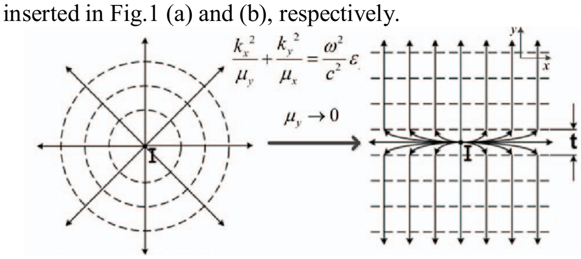
Planar antennas with omni-diretional radiation are in a great demand for some application scenarios such as broadcasting, satellite tracking, indoor wireless communication, and body-centric communication system. Typical radiators for such applications include printed dipoles, quarter-wavelength monopoles, and top loaded monopoles, etc. [1-3]. However, they share the same drawback of bulky volume, and particularly their typical vertical size being around 0.25λ to 0.5λ, where λ is the operating frequency. In contrast, circular patch antennas (CPA) at its TM_{01} mode are a good candidate due to its omni-directional radiation, low profile, light weight, and ease of fabrication [1]. However, beamwidth of conventional circular patch antennas is intrinsically wide on the vertical plane, and a large amount of power deviating from the main beam direction has been wasted.

Metamaterials with artificially designed structures have electromagnetic response that can hardly be found in nature, and they have been utilized to improve antenna performance for a long time, such as size miniaturization [4], radiation pattern modification [5], directivity improvement [6].

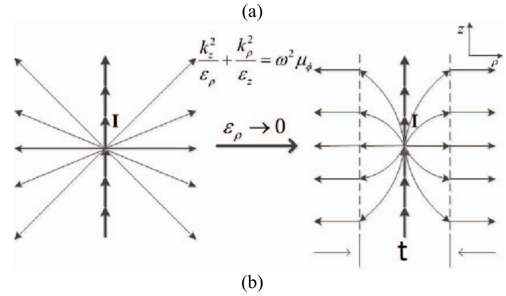
In this paper, we have studied two CPAs with ground plane of different size. Some preliminary simulated results show that, with an annular array of practically implemented ENZ metamaterial, the beamwidth of on the vertical plane of both CPAs has been reduced and main beam radiation has been significantly enhanced.

II. WORKING MECHANISM

Our work is based on the study of the wave behavior and feature of a cylindrical wave produced by an infinitely long current filament, which is embedded in a uniaxial anisotropic near-zero metamaterial [7]. It has already been shown in [7] that on the H-plane of the current filament, due to the loading of a uniaxial anisotropic mu-near-zero (MNZ) metamaterial, the original radiating cylindrical wave can be transformed into a planar wave in two opposite directions, indicating a significant potential of beam focusing. Such characteristic of an MNZ metamaterial is graphically illustrated in Fig. 1. Likewise, as the TM_{01} mode circular patch antenna can be equivalently taken as a current source along its normal, according to equivalence principle and the duality theorem, omni-directional radiation but with enhanced radiation toward the radial direction can be obtained, as shown in Fig. 1(b), if the source is surrounded by an epsilon-near-zero (ENZ) metamaterial with its radial component approaching zero. The dispersion relation of above two cases is also inserted in Fig.1 (a) and (b), respectively.



(a)

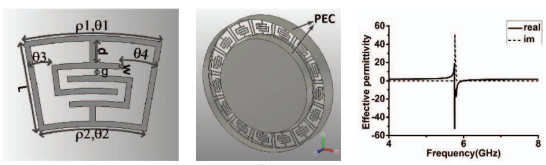


(b)

Fig. 1. The radiation of a line source in free space and uniaxsil anisotropic metamaterial medium with a thickness of t and permittivity being (a) μ_y=0, (b) ε_ρ=0.

III. Antenna Configuration and Simulated Results

We here use a circular array of electric-LC (ELC) resonators [8], which has electrical response to the external electric field, to implement the anisotropic ENZ with vanishing ε_ρ. Fig.2 (a) shows the topology of an ELC unit cell, with a sector shape and the original central wire being replaced by an interdigital capacitor. Fig. 2(b) shows the model in CST [9] for the constitutive parameter retrieval, and ones sees that in the figure all ELC unit cells within the annular space surrounded by PEC boundaries can be uniformly excited with the radial electric field. With the standard retrieval procedure [10], the effective permittivity of the ELC unit cell is plotted in Fig. 2(c) and it can be seen that ε_ρ is near zero at 6 GHz, which is selected to be the operating frequency in our work. Dimensions of ELC unit cell are summarized in TABLE I.



(a) (b) (c)

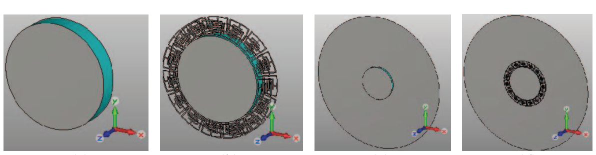
Fig. 2. The (a) geometry, (b) model for the parameter retrieval, and (c) retrieved effective permittivity of the ELC unit cell.

TABLE I
Dimensions of The ELC Unit Cell (unit: mm)

ρ1	ρ2	w	d	L	g	θ1	θ2	θ3	θ4
20.2	15.2	0.3	1.5	5	0.4	20°	20°	3°	5.5°

We have subsequently studied two circular patch antennas loaded with above ELC array but with slight difference, i.e. one with metallic ground plane identical to the patch (CPA 1) and the other of finite size (CPA 2).

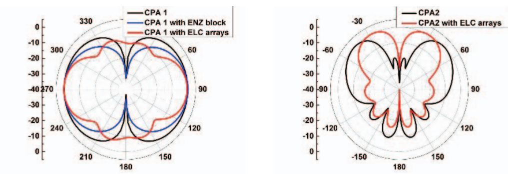
Fig.4 shows the geometry of the two CPAs, with and without the loading of the annular array of above described ELC. The radius of the patch is 14.7mm (0.29λ), and the relative permittivity and thickness of the substrate is 4.33 and 5mm (0.1λ) for CPA 1 and 1mm (0.02λ), respectively. One sees that both antennas are low-profile planar type, compared with the vertical dipoles and monopoles.



(a) (b) (c) (d)

Fig. 3. The constructed models of (a) the original CPA 1, (b) CPA 1 loaded with two layers of ELC array, (c) the original CPA 2, and (d) CPA 2 with one-layer ELC array.

All four CPAs in Fig. 3 operate at their TM_{01} mode, corresponding to a rotationally symmetrical (no variations in φ) electric and magnetic field. Fig. 4 shows the simulated E-plane pattern of the four antennas in Fig. 3 at 6 GHz. One sees that the main beam of CPA 1 is along the horizontal (θ=90º) plane, whereas that of CPA 2 (no matter whether the ELC array is loaded), as is well known, has an elevation angle above the horizontal plane, due to the existence of the finite ground plane (60mm (1.2λ)). More importantly, due to the loading of the ENZ (represented by the annular ELC array), the beamwidth of the main lobe is reduced (75º for CPA 1 and 6º for CPA 2) and consequently the desired radiation (near ground radiation for CPA 1 and conical radiation for CPA 2) is greatly enhanced. In addition, in order to verify the working mechanism in section II, we have also studied the CPA 1, when loaded with an annular effective ENZ block (cannot be shown here for brevity), with its ε_ρ being 0.1 and the radial and vertical size being 10mm (0.5λ) and 25mm (0.5λ), respectively. The simulated E-plane pattern, with a finite element method in COMSOL [11], is also plotted in Fig. 4 (a) for comparison, and one finds that our ELC array is an excellent practical implementation of the ENZ metamaterial. An examination for the H-plane pattern shows that all four radiators are omni-directional.



(a) (b)

Fig. 4. Simulated E-plane radiation pattern of (a) CPA 1 and (b) CPA 2.

Conclusion

Previously reported power convergence feature of the uniaxial anisotropic ENZ metamaterial has been studied in the cylindrical coordinate system. Simulated results have verified our scheme of radiation enhancement for the planar omni-directional antennas, where ENZ metamaterial with a vanishing ε_ρ has been applied. With the loading of the practically implemented ENZ, the antenna can still keep low-profile.

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