INTEGRATION OF A PRINTED DIPOLE ANTENNA WITH A CLL-BASED VOLUMETRIC METAMATERIAL AMC BLOCK

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Metamaterials are artificial materials that have electromagnetic responses which are not generally found in nature. Examples include frequency selective surfaces (FSSs), electromagnetic bandgap structures (EBGs), negative index metamaterials (NIMs), and double negative (DNG) metamaterials. These structures exhibit rather unusual properties that can be engineered for use in many antenna designs. One class of metamaterials, for instance, can be designed to achieve realizations of artificial magnetic conductors (AMCs). The main reason that AMCs have garnered so much attention is that they can produce in-phase reflections at a specified operating frequency, i.e., the absolute value of the reflection coefficient is 1 and the corresponding phase is found to be 0. This property, of course, has significant implications for antenna applications.

It has been found that a volumetric metamaterial (MTM) constructed from a periodic arrangement of capacitively loaded loops (CLLs) acts as an artificial magnetic conductor (AMC) when a normally incident plane wave first interacts with the capacitor side of the CLLs and acts as a perfect electric ground (PEC) from the opposite direction [1], [2]. The CLL elements are simplified forms of the split ring resonators (SRRs) used successfully in several double negative (DNG) metamaterial realizations [3]. In contrast to most current realizations of AMCs, such as the mushroom and the UC-PBG surfaces, the CLL-based MTM block does not require the use of a PEC ground plane. The advantages of an AMC slab without a ground plane in an antenna application include the absence of the associated image and scattering-induced currents on the back side of a finite ground plane, the nonexistence of PEC fostered surface waves, and lighter weight. An antenna can be positioned extremely close to such an AMC structure, and it can be designed to produce a factor of two (or better) increase in the electric field value in the far-field region. Correspondingly, its radiation into the back direction should be dramatically decreased. Investigations into combining an ideal dipole antenna with the CLL-based AMC block have shown these improvements [4].

To combine a realistic dipole antenna with the CLL-based AMC block, we have considered the integration of a printed dipole antenna directly into the MTM. First, each unit layer of the AMC block was arranged to have 10 CLL elements in a 5×2 array on a 31 mil sheet of Rogers 5880 Duroid $(\varepsilon_r = 2.2, \mu_r = 1.0)$, with five CLL elements being oriented along the z-direction and two CLL elements being positioned along the y-direction as shown in Fig. 1. Six total unit layers were used to construct the block. A final dielectric layer was included to make a structure that was symmetric in the x-direction about its center. The incident plane wave was assumed to

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have its magnetic field oriented along the x-direction, orthogonal to the plane containing the CLL elements. The distance between each CLL element in each row was set to 40 mils. The distance between the edge of the AMC block and each CLL element as well as the gap between each CLL element in every column was set to be 20 mils. Each CLL element was 160 mils long in the z-direction and 100 mils along the y-direction. The traces were set to be 18 mils. The gap between the capacitive legs was set to be 30 mils and their depth was 49 mils. The resulting CLL-based AMC block produced an in-phase reflection at 10 GHz. A printed dipole was then designed to lay in the center CLL-element layer. As shown in Fig. 1, two CLL elements were removed to make room for the transmission lines that feed the dipole. The printed dipole itself was then sandwiched between two layers of the duroid substrate as shown in Fig. 1 to make a symmetric structure to match the symmetry of the block. The thickness of the dipole antenna was set to be 0.3 mils in the x-direction to allow the proper inclusion of a feedline source into the HFSS model.

We modeled this integrated CLL-based AMC block-dipole structure with ANSOFT's High Frequency Structure Simulator (HFSS). The symmetry of the dipole structure and the overall integrated structure allowed us to introduce symmetry planes to minimize the simulation space. We investigated how a $0.325\lambda_0$ printed dipole antenna could be combined successfully with the CLL-based AMC block, where the free space wavelength at 10 GHz is $\lambda_0 = 30\text{ mm} = 1{,}181\text{ mils}$. An ideal dipole of this size produced the best results in [4]. As shown in [4], the distance between the arm of the dipole antenna and the edge of AMC block was optimized to achieve a resonant structure. According to the results in [4], we chose a 47 mil distance for our initial attempt. Several distances were modeled to find the one that produced the optimum enhancement in the electric field value in the far-field region and the optimum enhancement in the front-to-back ratio. Note that the lengths h_1 and h_2 shown in Fig. 1 were also changed when the distance d was optimized to maintain the lowest insertion loss into the antenna. It was found that the resonance frequency was 9.601 GHz, the ratio of the electric field strength in the forward direction with the AMC block to that of the sandwiched dipole alone was 2.73, and the corresponding front-to-back ratio was 68.3 (36.7 dB). Thus the presence of the additional dielectric layers and the dipole feedlines that were not present in the ideal dipole case caused non-trivial perturbations in the operating points of the integrated structure. Nonetheless, the basic principle that the dipole and the CLL-based AMC metamaterial block can be optimized into a resonant configuration still holds. The more than a factor of two enhancement in the forward direction and the still significant front-to-back ratio suggests that integrated dipole-metamaterial structures such as the one considered here may have many potential applications. Several of these are currently under investigation.

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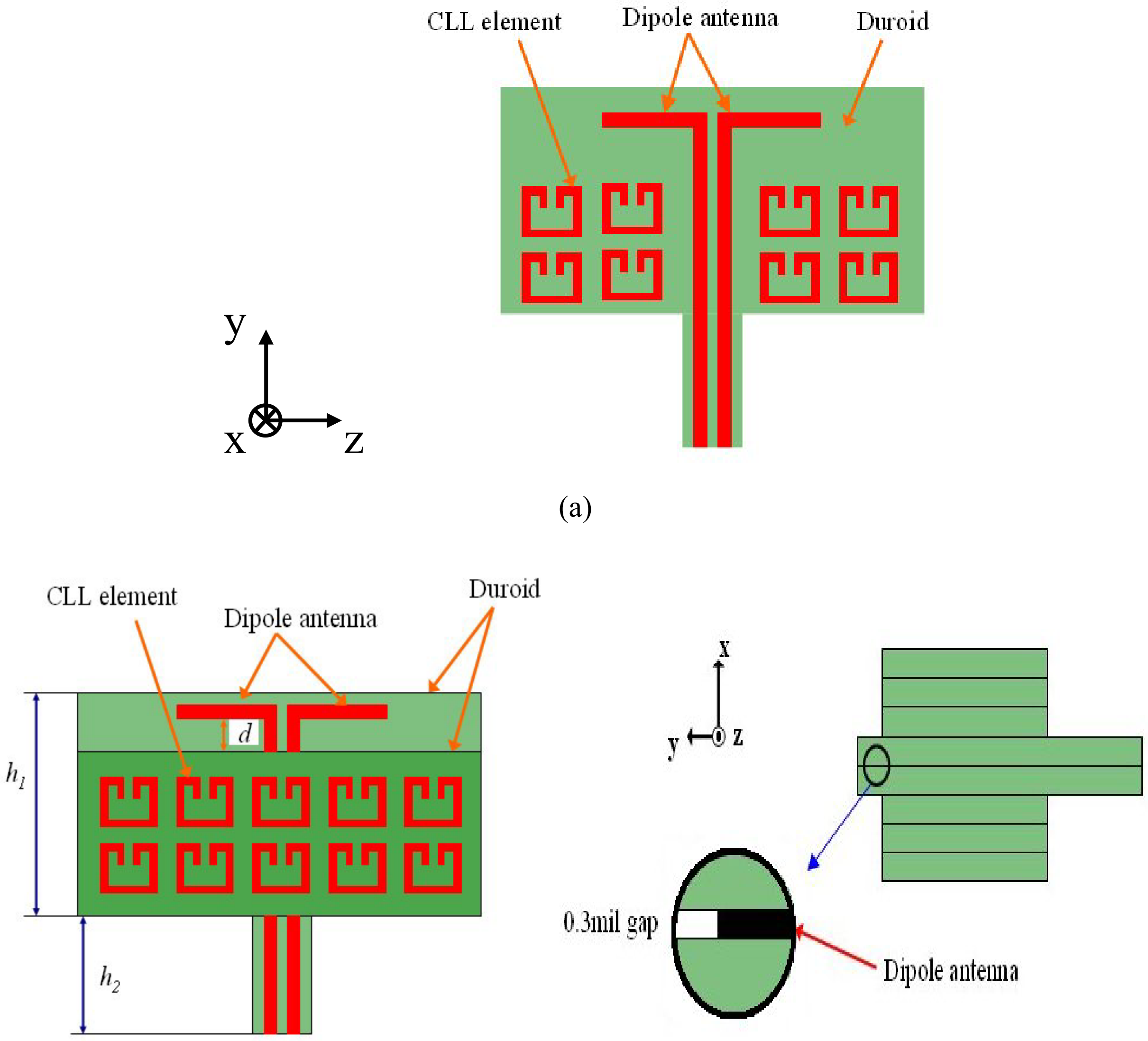
[4] A. Erentok, P. Luljak, and R. W. Ziolkowski, “Antenna performance near a volumetric metamaterial realization of an artificial magnetic conductor,” *IEEE Trans. Antennas Propagat*., vol. 53, pp. 160-172, January 2005.

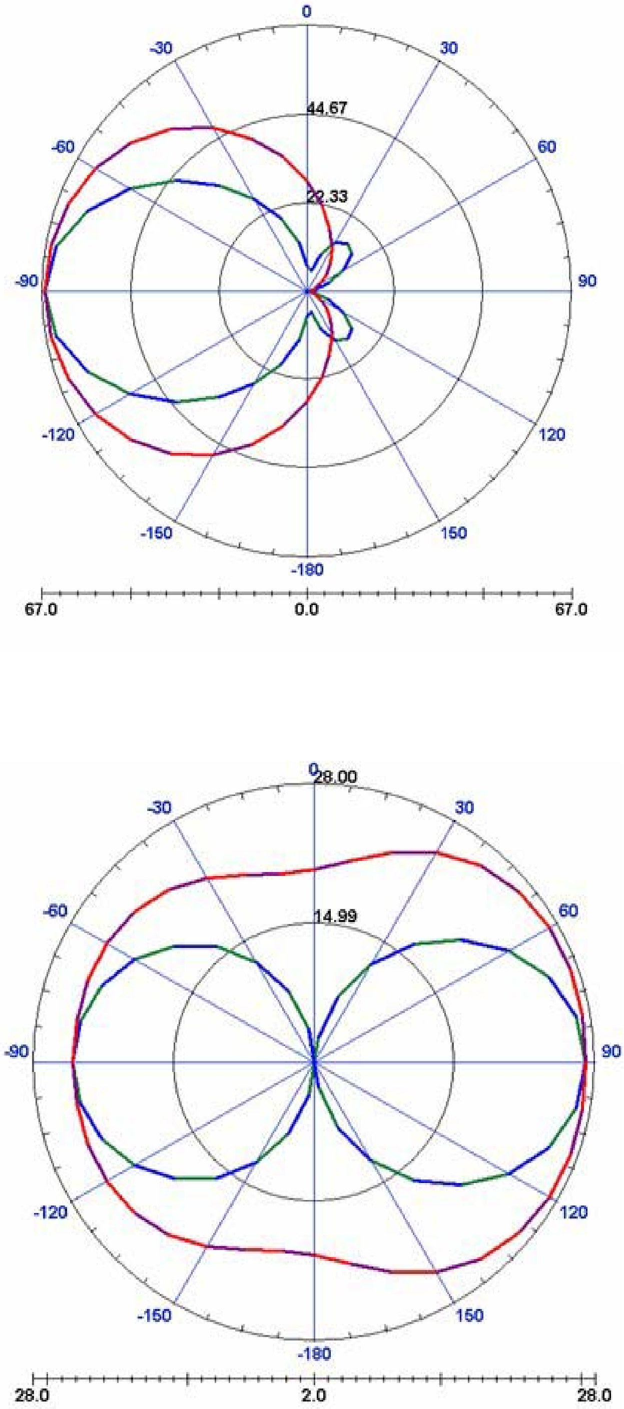


(a)

(b)

(c)

Fig. 1. Integration of a printed dipole antenna into a CLL-based AMC block. (a) printed dipole layer, (b) side view of the integrated structure, and (c) top view of the integrated structure.



(a)

(b)

Fig. 2. The radiation patterns (E-plane in blue, H-plane in red) of the $0.325\lambda_0$ dipole with d=59 mils at 9.601 GHz (a) integrated with the CLL-based AMC block and (b) in free space.