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Novel Planar AMC for Low Profile Antenna Applications

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Abstract— In recent years, the realization of Artificial Magnetic Conductors (AMCs), also designed as high impedance surfaces (HISs) or Perfect Magnetic Conductors (PMCs), has been an active area of research as they can replace perfect electric conductors (PECs) for low profile antennas and other microwave applications. In this paper a planar AMC using circular split ring resonators (SRRs) printed on grounded dielectric substrate is proposed. The simulation results verify that the magnetic conductor is successfully accomplished over narrow bandwidth ≈ 0.25 GHz. As an antenna application, the return loss of a horizontally positioned dipole antenna placed above the proposed AMC and the conventional PEC ground planes are investigated. The results confirm that the split ring resonators can successfully be used to replace the antenna conventional ground plane in order to improve the strength of the radiating fields and to reduce the global thickness of the low profile antennas. The performances of the proposed AMC are studied using finite element method ANSOFT-High Frequency Structure Simulator (HFSSTM v.10) and numerical simulation model is developed to predict the reflection phase profile of such structures.

I. INTRODUCTION

The growing number of wireless communication systems continuously challenges antenna engineers to create novel antenna structures and improve existing antenna designs. Due to the advancements in computational electromagnetics and fabrication technologies, antenna engineers nowadays are capable of exploiting complex engineered electromagnetic materials in antenna designs. Light weight low profile antennas with good radiation efficiency are greatly desired in modern commercial and defence wireless communication systems because they could be easily integrated with RF and microwave circuitry and built conformal to installation platforms such as vehicles and vessels [1]. The low profile design usually refers to an antenna structure whose overall height is less than one-tenth of the operating wavelength [2]. A fundamental challenge in low profile wire antenna design is the coupling effect of a nearby ground plane. In recent years, development of Artificial Magnetic Conductors (AMCs) has led to significant advancement in low profile antenna applications. AMC structure provide high impedance surface ($R_e(Z_s) > 120\pi \Omega$) with reflection phase changes from 180° to -180° as the frequency increases. Hence, sometimes its considered as High Impedance Surface (HIS) or Perfect

Magnetic Conductor (PMC). Because of this unusual boundary condition, AMC surface can function as a new type of ground plane for low-profile antennas. An example is the electric linear wire antenna near a PEC reflector, its separation must be a quarter-wavelength ($\lambda/4$) for optimum radiation due to the reverse image currents which reduce the radiation efficiency [3]. For PMC, on the other hand, the dipole can be placed immediately above the reflector, which reduces its profile to about $\lambda/20$ without affecting its performance. This is due to the fact that the reflection coefficient of the PEC surface is $R = -1$, but that of the PMC is $R = +1$. Moreover, the reflection phase of AMC is $R = +1$ at a certain frequency, which resembles an ideal PMC that does not exist in nature. This means that all surfaces reflect the incident wave totally; however, a PEC causes a phase reversal, while an AMC does not. To illustrate the fundamental principle, Fig. 1 compares the AMC ground plane with the traditional PEC ground plane in wire and microstrip antenna designs [4, 5].

Options	Efficiency	Low Profile	Antennas
PEC			Monopole
PEC			N/A
PEC			Microstrip antennas
EBG			New frontier: Wire-EBG

Fig. 1 Comparison of conventional PEC and AMC Ground Planes [4]

Surveying the literature, one observes that various engineered materials have been investigated and numerous antenna applications have been proposed. For example, in [6] the PMC effect was realized using an array of metal protrusions on a flat metal sheet. The protrusions are arranged in a two-dimensional lattice and can be visualized as mushrooms or thumbtacks protruding from the surface. The metal plates shorted to the ground using vias, which made their fabrication more difficult. Advanced structures without vias, consisting of square pads and narrow lines with insets,

have also been proposed in [7, 8]. Recently, simpler AMC structures were also realized using only square patches [9]. All these surfaces exhibit the same scattering properties as an AMC surface.

Since their introduction by Pendry et. al. [10] in 1996, split ring resonators (SRRs) have attracted great interest among the scientific community [11,12]. When the magnetic field vector ($\mathbf{H}$) is perpendicular to the plane contain the SRR surface, strong magnetic materials like responses are produced around its resonant frequencies and, hence, its effective permeability (μ_{eff}) becomes negative [13, 14]. Figure 2 shows single SRR along with its equivalent circuit which can be simply configured as parallel RLC resonant circuit, the resonance occur when $L = C$ and the real part of its impedance becomes maximum. The possibility of using SRRs for the AMC surface was very briefly mentioned in [15], where the magnetic field vector ($\mathbf{H}$) was normal to the rings surface. However, another possibility, which is considered in this paper, is to make the magnetic field vector ($\mathbf{H}$) of the incident plane wave parallel to the SRR plane.

Fig. 2 (a) Split ring resonator and (b) its equivalent circuit [11].

Due to the design complexity and cost factor associated with 3-D mushroom type AMC, researchers are focusing on planar AMC structures. In the present paper, a planar AMC surface is designed using 2D array of SRRs inclusions as shown in Fig. 3 where the propagation vector $\mathbf{k}$ is assumed to be perpendicular to the rings surface and thus the magnetic field vector ($\mathbf{H}$) becomes parallel to it. As an application of the proposed magnetic conductor, the performance of dipole antenna placed above the SRRs surface are also studied.

II. AMC REFLECTION PHASE CHARACTERIZATION

In order to achieve good return loss and high efficiency, low profile antennas are generally placed horizontally close to an AMC surface which is designed in such a manner that the zero degree reflection phase frequency coincides with the operating frequency of the antenna. Therefore, determining the reflection phase characteristics of the proposed AMC structure is important. To accurately characterize the in-phase reflection coefficient, finite element method (FEM) technique is used to analyse the proposed AMC structure. Figure 3 shows a unit cell and 2D array of the proposed AMC surface. The dielectric board is an Roger RT/duroid 6010 with $\epsilon_r=10.2$, loss tangent = 0.0023 and thickness = 1.5 mm. The deposit metal is copper with 17 μm thickness. The geometrical

parameters of the SRR are: $r= 2.4 \text{ mm}$, $w = 1 \text{ mm}$, $d = 0.3 \text{ mm}$, unit cell size $a = \lambda/7.7 = 10 \text{ mm}$ ($\lambda \approx 77 \text{ mm}$ at 3.9 GHz).

Fig. 3 Unit cell and 2D array of the proposed AMC .

Fig. 4 HFSS Model For PMC reflection Phase computation

Fig. 5 HFSS Model wave port setting

The HFSS model to compute the reflection phase characteristics of the proposed AMC structure is shown in Fig. 4. This model is based on simulating scattering parameters of a single port air filled waveguide with two perfect electric conductors (PECs) and two perfect magnetic conductors (PMCs) walls. The propagating plane wave is polarized parallel to the PMC walls and normal to the PEC walls as in Fig. 5. The waveguide is then terminated to a single unit cell of the proposed SRR/AMC structure and the reflection phase is obtained by calculating the scattering parameter at the input of this single port waveguide. There are several methods for

computing the AMC reflection phase [16, 17]. Comparing to conventional methods, the main advantage of this model is its simplicity. Moreover, this model also shown to be fast and accurate. Figure 6 shows the computed return loss, reflection phase profile and the surface impedance of the proposed AMC structure for a normally incident plane wave. It is known that a PEC has an 180° reflection phase and a PMC has a 0° reflection phase. In contrast, the reflection phase of the AMC surface decreases continuously from 180° to -180° as frequency increases. The proposed AMC surface exhibits a 90° reflection phase around 3.85 GHz and a 0° reflection phase around 4 GHz. It is important to mention that the reflection phase varies with incident angles and polarization states.

Fig. 6 (a) S_{11} (b) Reflection phase (c) impedance versus frequency of the unit cell in Fig. 2

III. DIPOLE ANTENNA ON THE PROPOSED AMC

The complete antenna system including the dipole antenna and AMC ground plane was simulated using ANSOFT-HFSS. To illustrate the in-phase reflection feature of the proposed planar AMC a cylindrical dipole of 0.5 mm radius and 30.76 mm length was simulated above ground plane consists of 7 cells $\times$ 7 cells array of the proposed AMC. For comparison purposes, the return loss of the same dipole antenna on solid PEC ground plane is also simulated and plotted. The overall height of the dipole antenna from the bottom conductor of the proposed AMC structure is 3 mm which is $\approx 0.04 \lambda$ at 3.9 GHz. The distance between the dipole antenna and the top surface of the proposed AMC structure is 1.5 mm as shown in Fig. 7.

Fig. 7 (a) side view and (b) top view of the antenna over AMC surface. Total size is 70×70 mm.

Fig. 8 Simulated antenna return loss over PEC and AMC

When the dipole is located above PEC ground plane, the return loss is only -0.4 dB. PEC surface has a 180° reflection phase so that the direction of the image current is opposite to that of the original dipole. The radiations from the image current and the original dipole cancel each other, resulting in a very poor return loss. When the proposed AMC surface is used better return loss of -25.6 dB is achieved. The reflection phase of the AMC varies with frequency from 180° to -180° . In a certain frequency range, particularly when the AMC reflection phase changes from 90° to -90° usually results in the best match, the AMC surface successfully serves as the ground plane for the dipole antenna because the image current will enhance the current in the dipole resulting in higher radiation efficiency and lower profile antenna compared to the conventional PEC ground plane as depicted in Fig. 8.

Fig. 9 Dipole antenna return loss and AMC reflection phase

Both the dipole return loss and the proposed AMC reflection phase profile are plotted in Fig. 9. As mentioned in [4] the useful operational frequency band of an AMC structure is the frequency region inside which the AMC structure shows quadratic reflection phase ($90^\circ \pm 45^\circ$) which agreed with the results presented here. Another resonance frequency is noticed around 4.25 GHz which is because of the finite size ground plane used and by optimizing the ground plane size (the number of AMC unit cells in x and y directions) this second resonance could be controlled.

IV. CONCLUSIONS

In this paper, novel planar AMC surface using circular split ring resonators is proposed and its reflective properties are investigated using finite element method (FEM) technique. The return loss of linear dipole antenna positioned horizontally above the proposed AMC and the conventional PEC ground plane are compared. It is clear from this comparison that the SRR/AMC surface is a good ground plane candidate for low profile antenna designs.

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