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Low Profile Dipole Antenna Backed by Isotropic Artificial Magnetic Conductor Reflector

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Abstract— In this paper, the design of high gain low profile antenna backed by isotropic Artificial Magnetic Conductor (AMC) with an overall height of 0.045\( \lambda \) is introduced. First the AMC structure, which utilizes the well known Jerusalem Cross Frequency Selective Surface (JC−FSS) deployed on a grounded dielectric slab, is studied and investigated. It is shown that the JC−FSS offers stable resonance frequency with respect to the plane wave angle of incidence as an isotropic AMC medium, very compact size and acceptable bandwidth \( \approx 13\% \). The return loss of wire dipole antennas placed closely and parallel above an ideal PEC (perfect electric conductor) and JC−FSS AMC structure are investigated and compared to each other. Both Ansoft HFSS™ and Ansoft Designer™ have been used to predict the reflection phase stop band of the JC−FSS structure and the dipole antenna characteristics.

I. INTRODUCTION

Antenna designs have experienced enormous advances in the past several decades and they are still undergoing monumental developments. Many new technologies have emerged in the modern antenna design arena and one exciting breakthrough is the discovery (development) of electromagnetic band gap (EBG) structures. EBG structures have attracted increasing interests because of their desirable electromagnetic properties that can not be observed in natural materials. In this respect, EBG structures are a subset of metamaterials [1-3]. Diverse research activities on EBG structures are on the rise in the electromagnetics and antenna community, and a wide range of applications have been reported, such as low profile antennas, active phased arrays, TEM waveguides, and microwave filters [4,5]. An EBG surface has been used to mimic a Perfect Magnetic Conductor (PMC) over a finite frequency range for use as a ground plane in low profile antenna configurations. This physical realization of a PMC is known as an Artificial Magnetic Conductor (AMC).

AMCs are electromagnetic (EM) surfaces designed to imitate the behaviour of a hypothetically PMC at resonance. Currently, they are widely under study as prospective antenna substrates [6-9]. They are occasionally referred to as EBG ground planes or high impedance surfaces (HIS) [10]. When plane waves illuminate an AMC surface, the reflection phase continuously changes from 180° to −180° with increasing frequency. Especially at the 0° reflection phase in a certain frequency band, the surface shows the property of a PMC, i.e., the tangential component of the magnetic field (\( H_t \)) becomes zero with high real surface impedance (\( \text{Re} (Z_s) > 120\pi \Omega \)).

Dipole antennas do not function effectively when positioned very closely and parallel above a PEC ground plane due to the reverse image currents which reduce the radiation efficiency. An ideal PMC ground plane will create the positive image currents of the parallel dipole antenna above it. Therefore, low profile antennas can be designed over an AMC plane without any image cancellation. In this paper JC-FSS structure [11, 12] is used as an AMC reflector to design a low profile wire dipole antennas with good radiation characteristics. The electrical characteristics of the embedded AMC structure are evaluated using FEM (finite element method) and MoM (method of moments) techniques and the length of the dipole antenna are optimized to obtain satisfactory 50Ω input matching characteristics around 3.35 GHz. For each case investigated, a finite ground plane is used and the antenna return loss and input impedance are computed and compared.

II. JC−FSS REFLECTION PHASE CHARACTERISTICS

The theory of the grid of metal JC−FSS is presented in [13]. The mesh unit cell contains both reactive capacitance C (due to the strong capacitive coupling of adjacent crosses) and inductance L (due to straight portions of crosses) as depicted in Fig.1.
To accurately identify the electromagnetic properties of the JC–FSS AMC structure, the finite element method (FEM) and method of moments (MoM) techniques are used to analyse its performance. Determining the reflection phase characteristics of the JC–FSS AMC structure is an important point. The HFSS model used to compute the reflection phase characteristics of the JC–FSS AMC structure is shown in Fig. 2. This model is based on simulating scattering parameters of a single port air filled waveguide with two perfect electric conductor (PEC) and two perfect magnetic conductor (PMC) walls to model an infinite periodic structure. The propagating plane wave is polarized parallel to the PMC walls and normal to the PEC walls. The waveguide is then terminated to a single unit cell of the JC–FSS AMC structure and the reflection phase is obtained by calculating the scattering parameters (S11) at the input of this single port waveguide. There are several methods for computing the AMC reflection phase [14, 15]. Compared to conventional methods, the main advantage of this model is its simplicity and accuracy. The dimensions of the analyzed JC–FSS AMC structure are: A=6.6mm, B=6.4mm, C=4mm, D=0.2mm and W=0.8mm. To reduce the overall unit cell size, the JC–FSS AMC structure is embedded in a high dielectric material with $\varepsilon_r=10.2$ and 2.54 mm thickness.

![HFSS model used for JC–FSS AMC reflection phase computation.](image)

The reflection phase of an AMC surface is defined as the phase of the reflected electric field (E_r) normalized to the phase of the incident electric field (E_i) at the reflecting surface. It is known that a PEC has an 180° reflection phase and a PMC has a 0° reflection phase. It is observed that the reflection phase of the JC–FSS AMC surface decreases continuously from 180° to −180° as frequency increases as shown in Fig. 3. At low frequency and high-frequency regions, the JC–FSS AMC surface shows a similar phase to a PEC case, which is 180° (or −180°). At frequencies around 3.52 GHz, the JC–FSS AMC surface exhibits a reflection phase close to 0° (with high reflection coefficient as in Fig. 3 (b)), which resembles a PMC surface. In addition, other reflection phases can be also realized by the JC–FSS AMC surface. For example, a 90° reflection phase is achieved around 3.28 GHz. Although the HFSS™ and Designer™ results show a small frequency shift, they exhibit the same reflection phase pattern and reasonably good agreement. The high surface impedance of the JC–FSS AMC structure is very clear in Fig. 3 (a) where the structure exhibit a real surface impedance close to 1900Ω ($\gg 120\pi$, the free space intrinsic impedance). Its important to note that the JC–FSS AMC unit cell size is only 6.6mm which $\approx 0.077\lambda$. It is useful at this point to define a method of determining the percent bandwidth of JC–FSS AMC operation, which can be specified as the frequency range for which the phase of the reflection coefficient is within some limit.

![Fig. 3](image)
Fig. 3 (a) surface impedance,(b) $S_{11}$ and (c) reflection phase profile of JC-FSS calculated using Ansoft Designer and Ansoft HFSS. for a normally incident plane wave ($\theta = 0^\circ$).

For the purposes of this paper, the usable bandwidth will be taken to be where the phase of the reflection coefficient is between $\pm 90^\circ$. Therefore, the percent bandwidth is defined as in equation 2.1.

$$BW = \left(\frac{f_U - f_L}{f_C}\right) \times 100\%$$

$$= \left(\frac{3.75 - 3.28}{3.52}\right) \times 100\% = 13\%$$

Where $f_U$ is the upper frequency such that the reflection phase equals $-90^\circ$ (3.75 GHz), $f_L$ is the lower frequency where the reflection phase equals $+90^\circ$ (3.28 GHz), and $f_C$ is the centre frequency where the reflection phase equals $0^\circ$ (3.52 GHz).

Isotropic materials are those materials whose response to the incident EM waves is not a function of the angle of incidence. The incident angle, defined as the angle between the propagation vector $k$ and the $z$ axis as in Fig. 4 (a). When the JC-FSS AMC structure illuminated with incident plane wave with incident angle varies from $0^\circ$ to $60^\circ$ degrees it behaved as isotropic medium. The JC-FSS AMC dimensions are the same as before and Fig. 4(b) compares the results for $0^\circ$, $30^\circ$, $45^\circ$ and $60^\circ$ degrees of incidence. When the incident angle increases, the resonant frequency (where the reflection phase is equal to zero) of the JC-FSS AMC structure exists at the same frequency of normal incidence at 3.52 GHz. It is important to note that the reflection phase profile of the mushroom EBG structure [15] and UC-PBG [16] structure varies with incident angles and polarization states. Its very clear that the JC-FSS AMC structure is isotropic AMC since it has nearly the same reflection phase profile for all incident angles.

III. LOW PROFILE ANTENNA DESIGN

Because of the attractive electromagnetic properties, AMC structures have been applied in various antenna applications. In this section, the in-phase reflection coefficient feature of the JC-FSS AMC structure is exploited to increase the radiation efficiency of low profile wire antennas. The low profile design usually refers to an antenna structure whose overall height is less than one-tenth of the operating wavelength, which is desirable in many mobile communication systems. As shown in Fig. 5, a simple cylindrical wire dipole antenna is horizontally positioned above a JC-FSS AMC ground plane to obtain a low profile configuration. The dipole length is 29 mm and its radius is 0.4 mm. The overall height of the dipole antenna from the bottom conductor of the JC-FSS AMC structure is 4.04 mm (0.045$\lambda_{3.35GHz}$). The height of dipole from the top surface of the JC-FSS AMC structure is 1.5 mm (0.016$\lambda_{3.35GHz}$) as shown in the analyses. The complete antenna system including the dipole antenna and AMC ground plane was simulated using ANSOFT-HFSS™. The dimensions of the JC-FSS AMC structure are the same as those given in section II. For comparison purposes, the performances of dipole antennas on PEC ground plane are also simulated and plotted.
Fig. 6 shows the return loss of the dipole antenna over PEC and JC−FSS ground planes. When the dipole is located above the PEC ground plane, the return loss is only ~0.8 dB. The 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. A return loss of ~24.2 dB at 3.35GHz is achieved by the dipole antenna over the JC−FSS ground plane.

The reflection phase of the JC−FSS ground plane varies with frequency from 180° to −180°. In the JC−FSS ground plane the image current behind the surface would be in phase with the wire current thus enhancing the radiation of the antenna instead of suppressing it. In a certain frequency range, the JC−FSS surface successfully serves as the ground plane for a low profile dipole, resulting in very good return loss. It is clear from this comparison that the JC−FSS surface is a good ground plane candidate for low profile wire antenna designs.

By observing the return loss value of the dipole at different frequencies, one can find a useful operational frequency band of the JC−FSS ground plane for low profile wire antenna designs. Figures 7 and 8 shows the return loss ($S_{11}$) and the real part of the input impedance of a dipole with its length varying from 25 mm to 33mm. In contrast to the 180° reflection phase of a PEC surface or the 0° reflection phase of a PMC surface, if one chooses the 90° ± 45° reflection phases as the criterion for the JC−FSS ground plane, a frequency region from 3 to 3.45 GHz is identified. It is revealed from this comparison that the operational frequency band of a JC−FSS ground plane is the frequency region inside which the JC−FSS surface shows a quadratic reflection phase (90° ± 45°) which usually results in the best match. Both the dipole return loss and the proposed AMC reflection phase profile are plotted in Fig. 9 for dipole of 29 mm in length. The electric field distribution on the JC−FSS ground plane unit cells is plotted in Fig.10.
IV. CONCLUSIONS

In this paper, novel isotropic AMC surface using JC–FSS structure is proposed and its reflective properties are investigated using finite element method (FEM) and method of moments (MoM) techniques. The return loss of very low profile linear dipole antenna positioned horizontally above the isotropic JC–FSS AMC and the conventional PEC ground plane are compared. It is clear from this comparison that the isotropic JC–FSS surface is a good ground plane candidate for low profile antenna designs.

REFERENCES


