ARTIFICIAL MAGNETIC CONDUCTOR AND ELECTROMAGNETIC BAND GAP PERFORMANCE OF METALLODIELECTRIC ARRAYS

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Abstract: Planar periodic metallic arrays behave as artificial magnetic conductor (AMC) surfaces when placed on a grounded dielectric substrate and hence they introduce a zero degrees reflection phase shift to incident waves. In this paper the AMC operation of single-layer arrays without vias is studied in conjunction with their electromagnetic band gap (EBG) performance. An approximate ray analysis is employed in order to give physical insight into the performance of AMCs and derive useful design guidelines. The bandwidth and centre frequency of both AMC and EBG operations are investigated for different spacing of the array elements.

INTRODUCTION

Passive periodic arrays of metallic patches on dielectric substrates have been used over the past few decades as artificial dielectrics and Frequency Selective Surfaces (FSS) [1]. During the last few years the Electromagnetic Band Gap (EBG) properties of similar structures have been studied [2]. The presence of band gaps similar to those obtained from dielectric photonic crystals has been demonstrated. Metallodielectric EBG (MEBG) structures have been used for suppression of surface waves and performance enhancement of printed antennas and circuits. Recently metallic arrays printed on grounded dielectric substrates and connected to the ground plane with vias have been presented as high impedance surfaces [3]. Due to the high surface impedance the magnetic field tangential to the surface vanishes. Such a structure behaves as a perfect magnetic conductor (assuming no losses), i.e. it fully reflects incident waves with a zero degrees reflection phase. However, a broadband simultaneous AMC and EBG operation obtained from an array without vias could be advantageous.

In this paper, we present a study on the AMC and EBG characteristics of surfaces comprised of a single layer array of patches printed on a grounded dielectric substrate. An approximate ray model is initially introduced in order to provide a valuable physical insight of the functioning of the AMC as a resonant cavity effect. A rigorous investigation with respect to the AMC and EBG operating frequencies as a function of the array periodicity and the substrate thickness is presented using full-wave analysis. The study is focused on the bandwidth of the AMC and EBG regions and the coincidence of these two operations in the frequency domain.

AMC STRUCTURES AS RESONANT CAVITIES

A simple geometrical optics model can be used to describe the functioning of resonant cavities. The ray optics analysis is widely used in the description of the Fabry-Perot interferometer, which consists of two highly reflective surfaces that form a resonant cavity. This analysis can be carried over to the design of high-gain microwave antennas [4]. The same ray model is used in order to provide an interesting explanation to the function of an AMC structure as a resonant cavity.

Consider the case where a radiating source is placed outside the cavity adjacent to the PRS array (Fig. 1). Following the paths of the direct and the reflected waves and taking into account the various phase shifts introduced to them, the resonance condition of the cavity can be easily derived:

$$\phi_2 - \phi_1 = 2\phi_p - \frac{2\pi}{\lambda} 2S - \pi = 2N\pi , \quad N = 0, 1, 2...$$ (1)

This resonant cavity behaves as a PMC (at normal incidence) since it reflects normal incident waves with zero phase shift. Consequently, placing a simple point source on top of the PRS will produce highly directive radiation at the cavity resonance. The approximate model described in section II can be employed in order to produce useful guidelines for the design of AMC surfaces (without vias). Considering (1) as the condition for AMC operation, a relationship between the transmission phase of the PRS, the substrate thickness and the centre (or PMC) operating frequency is obtained.
Two different PRSs that have same reflection and transmission characteristics at frequency \( f_0 \) are interchangeable in an AMC cavity that operates at \( f_0 \). This is demonstrated in Fig. 2, Fig. 2a which shows the reflection coefficient (magnitude and phase) of two capacitive screens consisting of square patch arrays (Fig.1). The geometries of the 2 arrays are: \( L = 4.15 \text{mm}, W = 4.15 \text{mm}, D = 4.50 \text{mm} \) for the first screen named PRS1 and \( L = 6.00 \text{mm} W = 6.00 \text{mm}, D = 10.00 \text{mm} \) for the second screen named PRS2. PRS1 resonates at 60.5GHz and PRS2 at 26.0GHz. The reflectivity and transmission phase shift at 21.7GHz is identical for the two screens. In order to have good agreement between the ray model and the full-wave results, we are working at the 2\(^{nd}\) \((N=1)\) rather than the 1\(^{st}\) \((N=0)\) resonant mode of the cavity (see eqn. 1). Full wave simulation results for these AMC are shown in Fig. 2b. The success of the ray model is demonstrated by the fact that, as predicted, the AMC operations are centred at the same frequency 21.7GHz, where the transmission phase values are common.

According to the analysis, for a wideband AMC, an optimum PRS would require its reflection coefficient phase to linearly increase with frequency, with a gradient of 4\( \pi \)S/c [4]. This would result in a wideband cavity that would satisfy the resonance condition (1) for all frequencies. While increasing transmission phase with frequency is not feasible for a capacitive screen, this conclusion suggests that among two screens with equal reflectivity, greater AMC bandwidth will be observed for the one with slower varying transmission phase. This is demonstrated using full wave results in the example mentioned above (Fig. 2). PRS1 has slower transmission phase variation with frequency compared to PRS2 (Fig. 2a). The AMC bandwidth for PRS1 is 30% wider than that of PRS2, for the same substrate thickness (Fig. 2b).

### AMC AND EBG PERFORMANCE: EFFECT OF ARRAY PERIODICITY

A parametric study on the effect of the periodicity of the PRS array to the AMC performance is presented here for a capacitive screen of square patches. Full wave method of moments has been employed for the simulated results. Square patches of side 6.1mm and periodicities of 6.9, 7.9, 8.9 and 9.9 mm have been considered. The periodicities have been kept small enough for the grating lobe region to be above 30 GHz.

The electric field was polarised on the y-axis. As shown in Fig. 3, PRSs with smaller periodicities result in AMCs operating at lower frequencies. In addition to the AMC response, the EBG performance has been studied, by means of dispersion diagrams, produced with the modal analysis. In Fig. 3, the variation of the band gap along the \( \Gamma \X \) direction with the array periodicity is presented. As shown, the EBG frequency drops with increased unit cell, while the AMC frequency increases. Furthermore full-wave analysis shows that the EBG bandwidth is also reduced with increased periodicity. There is a region in the periodicity of the lattice where the two pairs of curves overlap. This region corresponds to the frequencies where, for the particular periodicity of the lattice, simultaneous AMC and EBG operations occur.

To validate this result, the array with unit cell 9.9mm has been fabricated and measured. The measured EBG responses are shown in Fig. 4. Very good agreement between prediction and measurement is observed. The TM mode has a cutoff at 13.1 GHz and the TE mode at 13.8 GHz. Common TE and TM bandgap is found between 13.8 and 14.9 GHz in the \( \Gamma \X \) direction. The absolute band gap is somewhat narrower, 14.4 GHz to 14.9 GHz. The measured and simulated AMC response of this structure for incident field along the y-axis are shown in Fig. 5. Note that there are 2 pairs of curves for the AMC measurement and simulation. One pair of measurement and simulation is taken assuming reflection at the ground plane (REF:GROUND) and another assuming reflection at the array plane (REF:ARRAY). In both cases, very good agreement between simulated and experimental results is observed. The AMC band (-90° to 90°) lies between 13.3 -16.45 GHz and 12.55 -15.2 GHz respectively. The band gap region is highlighted in the graph. Simultaneous AMC and EBG (\( \Gamma \X \)) operation of 1.1 GHz (~7.5%) bandwidth has been achieved. The simultaneous AMC and absolute EBG operation has a bandwidth of about 3.5%.

### REFERENCES

Figure 1: Resonant cavity formed by PEC and PRS with excitation outside the cavity, and unit cell of square patch array.

![Diagram of resonant cavity](image)

Figure 2: (a) Reflection magnitude and phase of PRS1 and PRS2 (b) AMC responses for same cavity with PRS1 and PRS2

![Graphs of reflection magnitude and phase](image)

Figure 3: Lower and upper frequency for EBG and AMC performance for square patch array (edge 6.1 mm) with varying unit cell size.

![Graph showing EBG and AMC performance](image)

Figure 4: Measured EBG performance for square patch array. In mm: patch 6.1, unit cell 9.9, dielectric thickness 1.15 (er=2.2). Shaded is the bandgap region (FX).

![Graph showing measured EBG performance](image)

Figure 5: Measured AMC response for square patch array. In mm: patch 6.1, unit cell 9.9, dielectric thickness 1.15 (er=2.2). Shaded is the bandgap region (FX).

![Graph showing measured AMC response](image)