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Miniaturized Tunable Artificial Magnetic Conductor for Low LTE Band

Nebil KRISTOU, Jean-François PINTOS
CEA-LETI, MINATEC Campus, 38054 Grenoble, France
Nebil.KRISTOU@cea.fr

Kourosh MAHDJOUBI
IETR, Université de Rennes 1, 35042 Rennes, France
kouroch.mahdjoubi@univ-rennes1.fr

Abstract—Antennas operating in the lower band of the LTE spectrum (700–960 MHz) have conventionally required thicknesses around a hundred millimeters when placed over metallic reflectors. Miniaturized Artificial Magnetic Conductors (AMC) metasurfaces have been shown to reduce the profile (height) of these antennas while maintaining compact lateral dimensions, but at the expense of operating bandwidth. Adding tunability restores the possibility of adjusting the operating frequency over a large bandwidth. In this paper, a highly miniaturized and tunable AMC covering the lower LTE band is proposed. The novel unit cell achieves an 83 % reduction in the largest dimension compared to conventional unit cell at the highest frequency $f_0=960$ MHz. Simulation results show that the proposed AMC surface has the potential to be used with either tunable or broadband low profile electrically small antennas.

Keywords— Artificial Magnetic Conductor; AMC; miniaturized AMC; tunable AMC; metasurface.

I. INTRODUCTION

Artificial Magnetic Conductors (AMC) and High Impedance Surfaces (HIS) have received a lot of attention since their introduction by Pr. D. Sievenpiper in the past decade [1], due to their special electromagnetic properties. AMC presents an attractive substrate for low profile antennas, because it mimics the behavior of Perfect Magnetic Conductor (PMC) with zero-degree reflection phase at the operating frequency. This allows the enhancement of low profile antenna performances [2]. Main drawback of such structure remains the size of the unit cell which is close to half-wavelength in free space. Several works have been widely proposed in the literature with various miniaturization techniques like complex engineered patterns (some of these include interdigital capacitors or meandered inductors) [3], volumetric structures with superposed layers [4] and lumped element loading [5]. Nevertheless, the immediate shortcoming of these miniaturized HISs is the bandwidth reduction. Within this context, reconfigurable AMCs have recently attracted a lot of attention, since the working frequency of these structures can be easily tuned by locally modifying the control voltage of some lumped elements inserted between neighbor patches [6] or between the patches and the ground plane [7]. Such an approach enables a narrow instantaneous operation channel that can be tuned across a much wider communications band.

In this paper, a miniaturized tunable AMC surface is proposed, based on initial design proposed in [8]. Full-wave simulations are performed, using ANSYS Electronic Desktop

(HFSS), to analyze the performance of the proposed AMC. The tunability of the structure over the low LTE band (700–960 MHz) is shown and the impact of ohmic losses is studied.

II. DESIGN AND SIMULATIONS

A. Unit cell design

The proposed unit cell is composed of two substrates, a metallic ground plane, an air gap layer and a set of four square metallic vias crossing the entire thickness of the structure. Each of these metallic vias comprising an upper end in contact with the top metallic patch and a lower end reaching a microstrip line at the bottom layer of the bottom substrate. Each via passes through one of the holes of the ground plane with no electrical contact.. This results in creating a network lines at the bottom side of the structure that connect every single unit cell to its near neighbors. At an initial stage a lumped capacitance is mounted at the middle of each microstrip line to further miniaturize the unit cell. In this work, the capacitance network is mounted below the ground, as shown in Fig. 1, rather than mounted directly between neighbor metallic patches on top layer. The presented approach offers the flexibility for expanding the capacitance network as needed without strong geometry or technology limitations (shape of metasurface, gap...).

The geometry of the metallic patch (Fig. 1.) is based on square spiral which provides a wide bandwidth in comparison of its surface [3]. Unit cell dimensions are 11.8×11.8 mm² ($\lambda_0/27 \times \lambda_0/27$). Rogers 3003 dielectric substrate with relative dielectric permittivity, $\epsilon_r = 3$, loss tangent around 0.0013 and a thickness of 0.75mm is used for the top and the bottom substrates. The air gap layer is used to ensure the minimum thickness needed with a lightweight structure. The overall thickness is about 7.75 mm ($\lambda_0/40$). The dimensions of the proposed unit cell are given in Fig. 1 and summarized in Table 1.

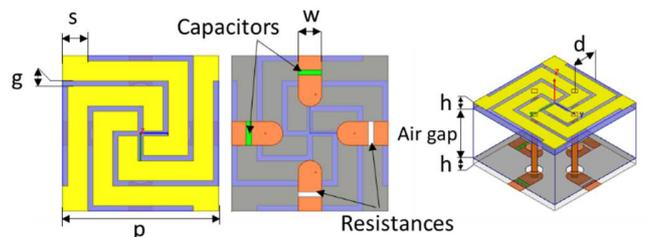


Fig. 1. Unit-cell geometry of the proposed AMC (left: top view, center: bottom view and right: perspective view)

TABLE I. DIMENSIONS (MILLIMETERS) OF THE UNIT CELL

Periodicity: p	11.8	Gap: g	0.4
Via radius: r	0.45	Via position: d	2.95
Air gap	6.25	Substrate thickness: h	0.75
Spiral section: s	1.5	μ strip line width: w	1.8

B. Simulation results

The primary characteristic of interest for the AMC is the reflection phase for a wave incident upon the surface (considered infinite). According to the computed phase profile of the proposed AMC structure illustrated in Fig. 2, the frequency corresponding to the zero-degree reflection phase is around 960 MHz (red curve). For the same dimensions (size and thickness) and with the same substrate properties, a conventional mushroom-like unit cell [1] shows a zero-degree reflection phase close to 2.75 GHz (black curve). The novel unit cell achieves then 97 % surface reduction compared to a conventional mushroom-like unit cell.

Either a Digitally Tunable Capacitors (DTC) or varactor diodes can be used to replace the lumped capacitances shown in Fig.1 and provide an electrically tunable capacitance for adjusting the operating frequency (channel) of the AMC surface.

Fig. 3 shows both the reflection phase and the magnitude for the AMC structure when both the tuning capacitance and its ohmic serial resistance are varied. The phase curves in Fig. 3 show that the operating point of the AMC, where the reflection phase angle passes through 0°, can be tuned from 960 MHz to less than 700 MHz, using commercially available varactors/DTC tuning from 0.2 to 1 pF. If the ohmic resistance of the tunable capacitance is increased, then the instantaneous phase bandwidth for a given tuning configuration decreases slightly (not observable on the graph).

The lower half of Fig. 3 shows the reflection magnitude for the same tuning range of capacitances and ohmic resistances. The reflection magnitude is important, because it indicates the relative level of RF energy that is absorbed by the AMC. With low ohmic resistance value (0.1 Ohm), a reflected wave below 620 MHz is reduced by less than 0.7 dB from that of the incident wave, and by less than 0.3 dB at frequencies up to 960 MHz. In contrast, high ohmic resistance value (2 Ohm) leads to more than 2 dB reduction from the incident wave at the lowest frequencies and 0.6 dB at the highest frequencies.

III. CONCLUSION AND FUTURE WORK

A highly miniaturized and tunable AMC metasurface, based on square spiral unit cells and a capacitor network beneath the ground plane, is proposed in this paper. The novel unit cell achieves an 83 % reduction in the largest dimension (or 97 % of surface reduction), compared with a square patch classical AMC but at the expense of operating bandwidth. Adding tunability has restored the flexibility of dynamically adjusting the narrow instantaneous operating channel over a wide range. The AMC surface cover the low LTE band from 700 to 960 MHz and has potential to be used with either tunable or broadband low profile antennas.

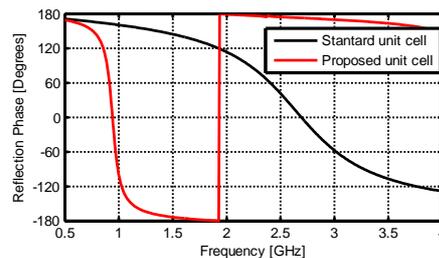


Fig. 2. Simulated reflection coefficient phase of the proposed AMC compared to a conventional mushroom-like unit cell.

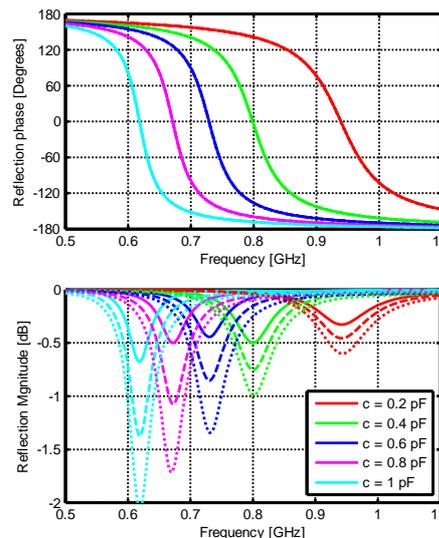


Fig. 3. Simulated AMC unit cell reflection phase (top) and magnitude (bottom) for various tuning capacitance values and various ohmic resistance values (Solid line, R=0.1 Ohm, Dashed line, R=1 Ohm. Dotted line, R=2 Ohm)

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