ARTIFICIAL MAGNETIC SURFACE FOR CIRCULAR POLARIZATION IMPROVEMENT

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ABSTRACT: *A novel approach to improve the circular polarization properties of a small elliptically polarized (EP) radiating element is presented. The enhancement in circular polarization is obtained by mounting the radiating element close to an artificial magnetic conductor (AMC). To explain the antenna operating principle, two different typologies of radiating element have been initially considered, i.e., a small spiral antenna and a dipole. Both antennas are EP, but the excited current distribution on the AMC screen are circular and linear, respectively. We inferred that only a circular current distribution determines the XPD improvement in correspondence of the AMC resonances. The prototype of the small spiral antenna in the vicinity ($\lambda_0/18$) of the AMC screen has been manufactured and tested. Measurements confirmed a remarkable improvement in spiral cross polarization discrimination (XPD) in correspondence of the two AMC resonances. The dual-band behavior of the AMC could be exploited in applications where multifrequency operation is required. The low profile structure is characterized by an overall thickness of 1.1 cm, which corresponds to $\sim\lambda_0/12$ at the centre of the operating band.* Microwave Opt Technol Lett 52: 1782–1786, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25345

Key words: *circular polarization (CP); frequency selective surfaces (FSS); artificial magnetic conductors (AMC); cross polarization discrimination (XPD)*

1. INTRODUCTION

Many communication systems uses circularly polarized (CP) radiated signals because they provide several advantages as the possibility to easily establish a link budget avoiding the alignment of transmitting and receiving antennas and the non vulnerability to the Faraday rotation effect [1]. However, designing a CP antenna is a demanding task with respect to the linear-polarized (LP) counterpart especially if the radiating element operates in proximity of the ground plane; indeed, the presence of the electric conductor acting as ground plane results in a cumbersome structure not suitable for low-profile applications.

Research is in progress to face this issue by using high impedance surfaces (HISs), and mainly two kinds of approach are explored. Some authors used HIS as a ground plane for a CP antenna to reduce the back radiation and improve its axial ratio (AR) [2]. Others used HIS as ground plane to transform the linear polarization (LP) of the radiator into a CP one [3–6]. In the former case, however, the CP is provided by a post numerical recombination of the two linearly polarized antenna channels tested separately. In this case, a single port has been used to feed and measure the antenna polarization performance. In [3–6], the shape of the periodic element is rectangular. This characteristic, in fact, allows for a LP → CP transformation as the physical response to TE and TM mode is intrinsically different. Thus, opportunely designing the surface, a right-handed CP (RHCP) and/or a left-handed CP (LHCP) electromagnetic wave is obtained.

In this work, we present a novel approach to the same issue, by using a squared shape FSS. In this case, the AMC does not act as a polarizer, as the response to TE and TM mode is the same. Conversely, the improvement in AR is achieved by suitably exciting the AMC surface, i.e., by applying a properly matched polarized field obtained by exciting, as a source, an elliptically polarized Archimedean spiral antenna. This concept is demonstrated by comparing the XPD of two orthogonal dipoles and the XPD of the aforementioned spiral antenna, both acting at the same distance from the AMC screen. Measurements performed on the spiral breadboard have shown a 20 dB increase in the cross polarization discrimination (XPD) with respect to the antenna radiating in free space.

2. AMC SCREEN CONFIGURATION

A photo of the used AMC screen is given in Figure 1. The unit cell has a periodicity equal to 2.7 cm. The dielectric substrate has been chosen from Taconic datasheet; it has a permittivity equal to 10 and a losses factor (tan δ) of 0.0035. The thickness is 3.18 mm. The unit cell is radially symmetric and, as stated

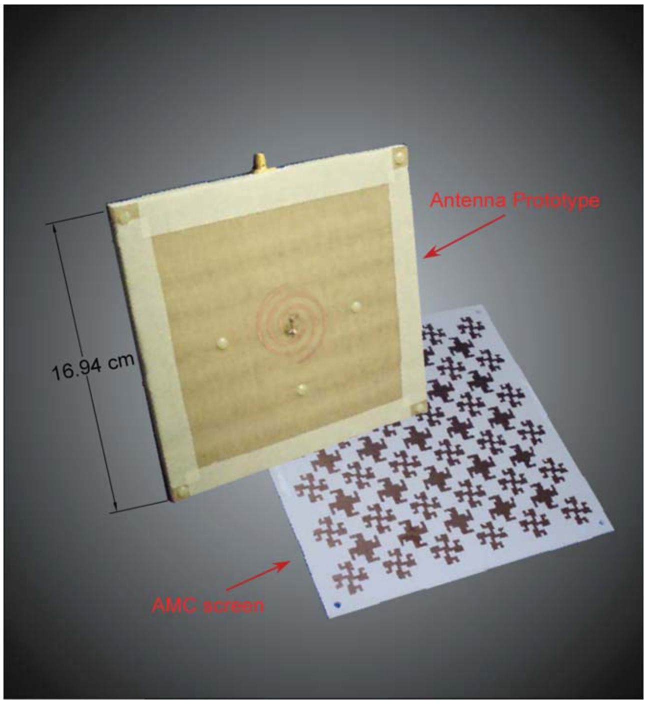


Figure 1 Photograph of the realized AMC screen and antenna prototype. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

above, this characteristic improves the antenna CP properties under suitable conditions.

In Figure 2, phase reflection coefficient vs. frequency of the proposed screen is reported. Computations have been carried out by using both our periodic Method of Moments code and Ansoft HFSS v.10. Frequency behavior for normal incidence is showed for both TE and TM polarizations. A good angular stability, both in azimuth (φ) and in elevation (θ), is provided by the magnetic surface. Thus, using it as ground plane for an antenna, its radiation performance maintains the same characteristics on a wide angular range.

3. ARCHIMEDEAN SPIRAL ANTENNA DESIGN AND TESTING

A small spiral antenna has been designed to radiate an elliptical polarization with total length L equal to 12.68 cm corresponding to 0.91 λ_0 at the lowest resonant band (2.16 GHz) and about 1.107 λ_0 at the highest resonant band (2.62 GHz). The final configuration (spiral radiating element and HIS screen) guarantees a Co-pol to X-pol ratio at least of 10 dB at the two operating bands. It is important to note that similar performance might be reached by using a freestanding spiral with larger dimensions (at least $L = 1.3\ \lambda_0$).

We remark that dimensions larger than the aforementioned ones result in a bulky structure characterized by the same properties. If the total length of the spiral is lower than the proposed one, the radiating element would radiate a linear polarized field with poor XPD factor.

The realized spiral, shown in Figure 1, is printed on a thin (0.127 mm) Taconic substrate (TLY5). The overall dimensions of the prototype are 1.35 $\lambda_0 \times$ 1.35 λ_0, with λ_0 computed at the central frequency band (2.39 GHz). In Figure 3, the cross polarization discrimination (XPD) of the prototype is shown. We can notice the remarkable increasing in XPD within these two frequency bands. The antenna, in fact, is able to efficiently radiate a CP field only in correspondence of the two AMC resonances; outside these bands, the spiral maintains its elliptic polarization. The moderate shift in frequency with respect to the expected AMC resonances is not surprising; it is due to the finite size of the screen and to the modifications of the near-field of the antenna introduced by the presence of the screen. Computations and measurements are in a good agreement. The overall thickness of the structure, equal to $\lambda_0/12$ at the central frequency band, guarantees a low-profile configuration.

The polarization purity of a CP antenna can be described both by its AR and by its Cross Polarization Discrimination

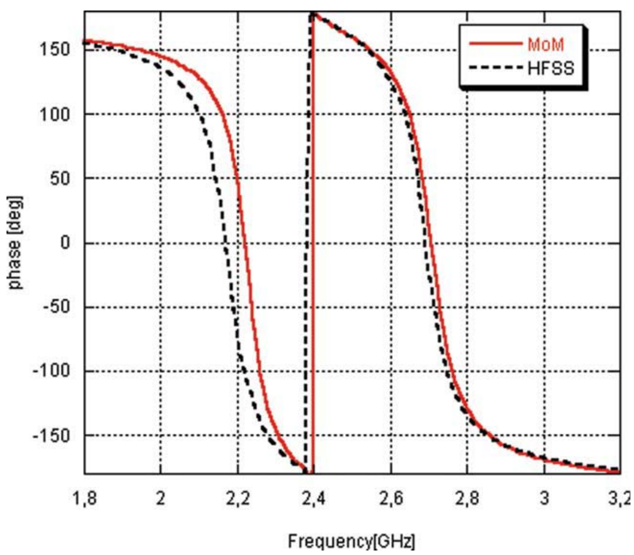


Figure 2 Reflection coefficient phase of the AMC screen (MoM code results vs. HFSS results). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

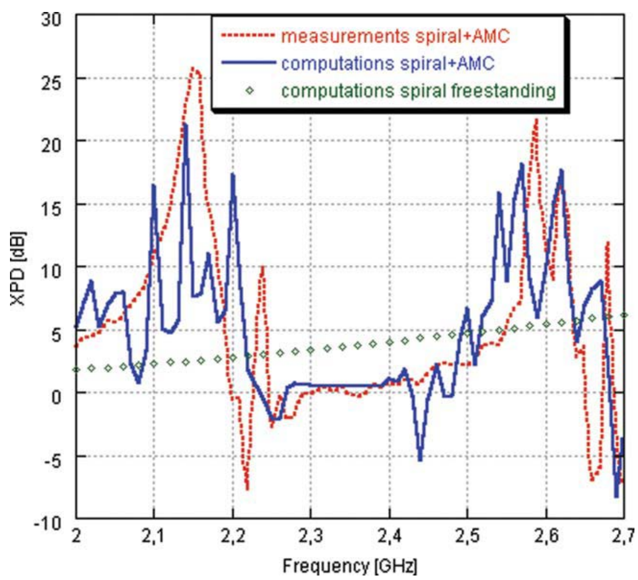


Figure 3 Comparison between the cross polarization discrimination (measured and computed) of the AMC backed spiral and the freestanding spiral, in the boresight direction. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

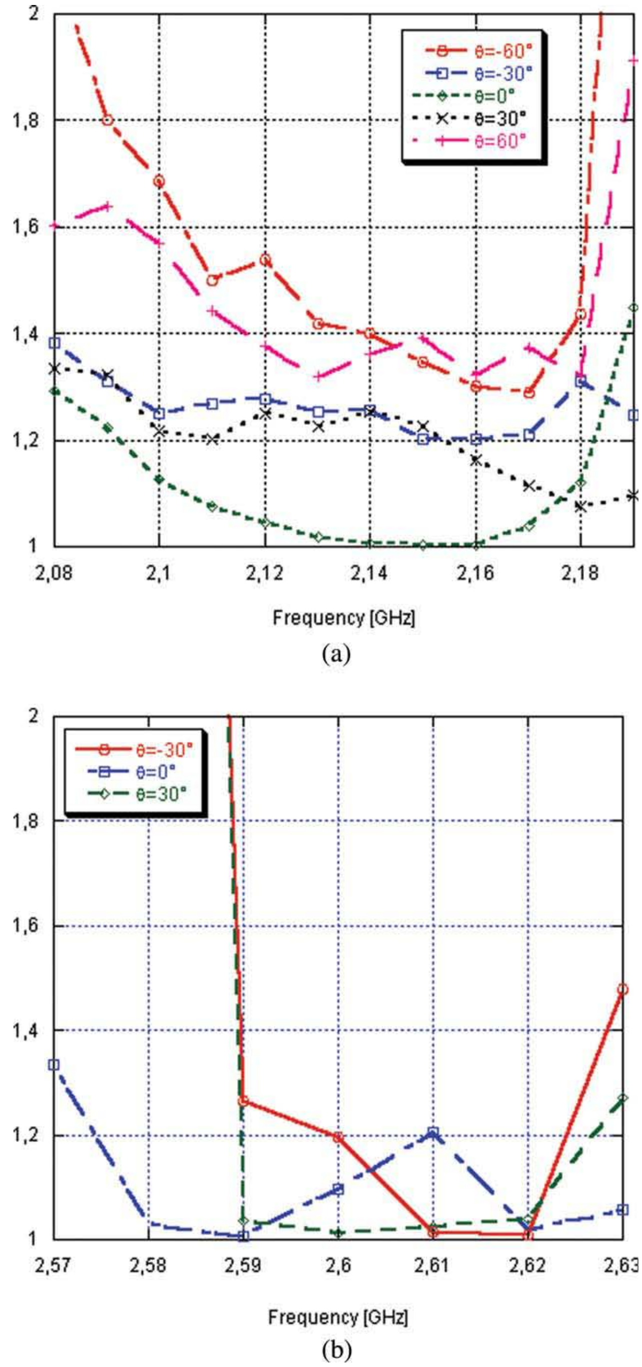


Figure 4 (a) Axial ratio of the spiral closed to the AMC screen vs. elevation angle in the E plane ($\varphi = 0°$) inside the first AMC band, (b) Axial ratio of the spiral closed to the AMC screen vs. elevation angle in the E plane ($\varphi = 0°$) inside the second AMC band. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

(XPD). Analyzing the AR versus the elevation angle (θ) for an angular range equal to the half-power beamwidth of the spiral, in the two resonant bands (see Fig. 4), it can be deduced that the good angular stability of the artificial magnetic screen results in a good angular stability of the antenna polarization properties. If we compare the obtained results with the ones attainable by using rectangular cells, e.g. [6], we can notice that the herein proposed technique allows obtaining both a better AR for normal incidence and a wider angular stability. Direct consequence of this feature is a low level of the X-polar component for a quite wide angular range, as shown in Figures 6 and 7, respectively. Moreover, the AR stability versus azimuth angle φ (see Fig. 5) provides for a good symmetry of the radiation patterns, being these latter almost the same at each φ cut.

In Figures 6 and 7, an example of the normalized radiation patterns for the two bands in the E plane is given.

Finally, the antenna return loss is shown in Figure 8. Antenna matching is reached in the two working bands by

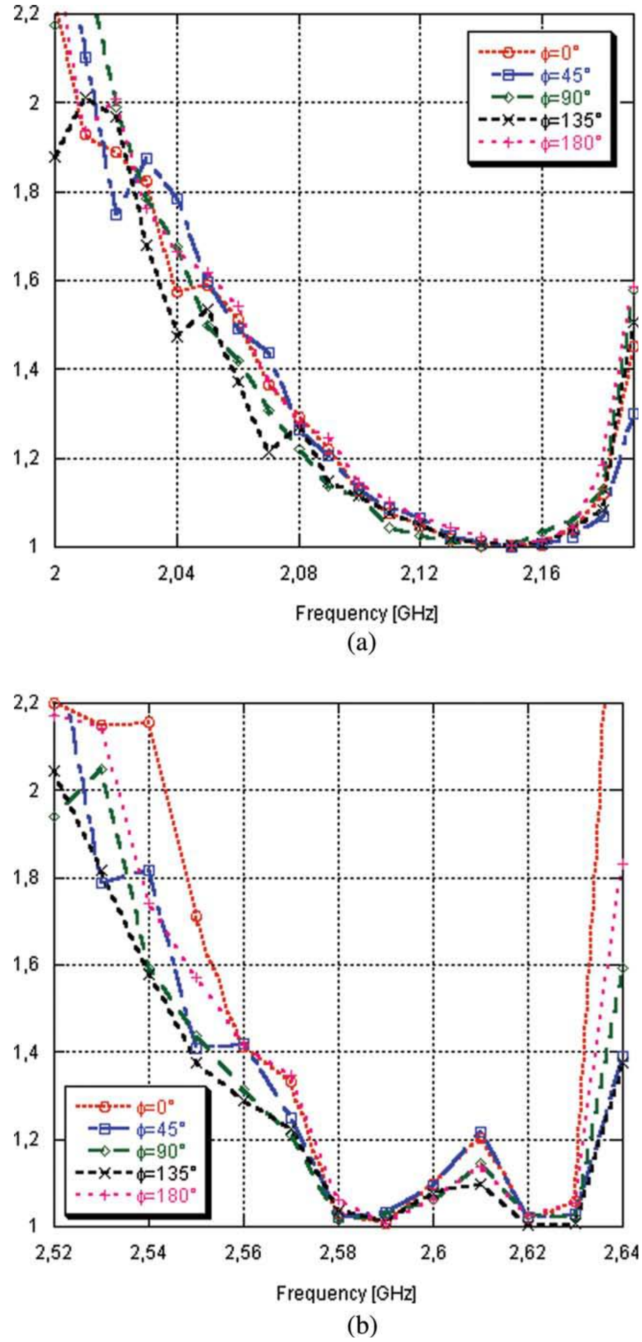


Figure 5 (a) Axial ratio of the spiral closed to the AMC screen vs. azimuth angle for $\theta = 0°$, in the first AMC band. (b) Axial ratio of the spiral closed to the AMC screen vs. azimuth angle for $\theta = 0°$, in the second AMC band. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

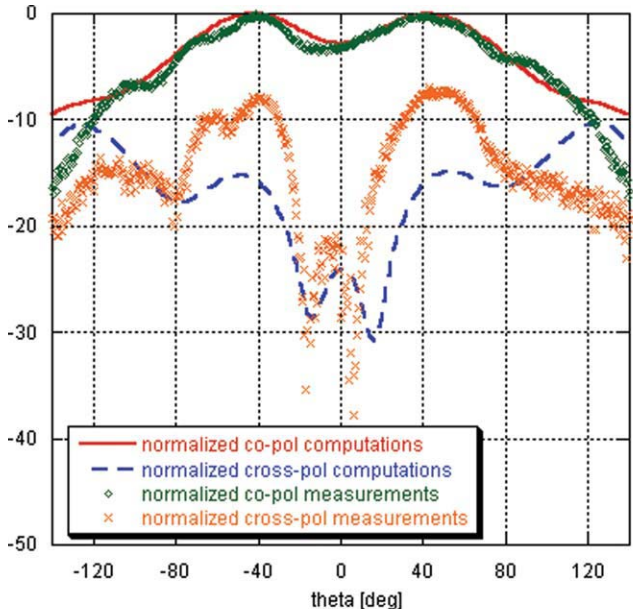


Figure 6 Measured and computed radiation pattern (a) at 2.16 GHz in E plane ($\varphi = 0°$). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

exploiting a matching network similar to the one presented in [2].

4. FURTHER MINIATURIZATION OF THE STRUCTURE

In this paragraph, we show the performance of the antenna characterized by a small number of unit cells in the AMC screen. It has been assessed that minimum dimension of the AMC screen that guarantees appropriate performance is 1.16 $\lambda_0 \times 1.16\ \lambda_0$. In Figure 9, a comparison between the XPD obtained for the two different sized configurations is given. The enhancement in XPD

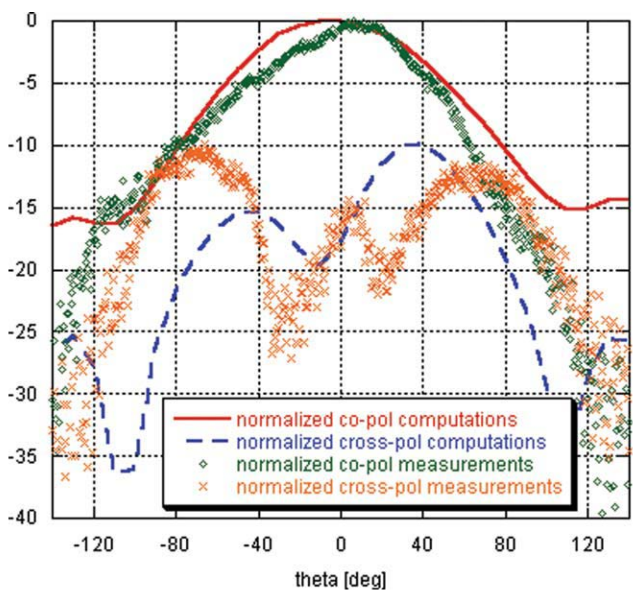


Figure 7 Measured and computed radiation pattern (a) at 2.62 GHz in E plane ($\varphi = 0°$). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

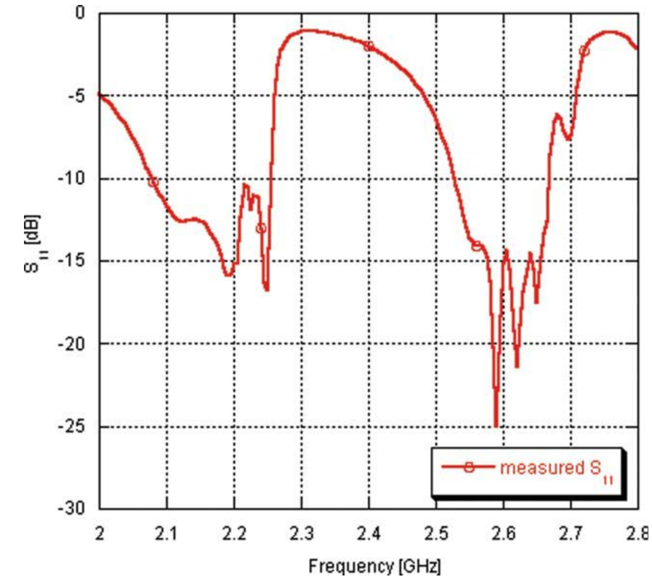


Figure 8 Measured return loss of the spiral backed by the AMC. The antenna has been matched by using an ad hoc matching network. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

can be considered acceptable even by using the small sized screen.

5. DISCUSSION OF RESULTS AND ALTERNATIVE CONFIGURATION OF THE RADIATING ELEMENT

As outlined before, the proposed artificial magnetic surface is able to efficiently convert an elliptic polarization into a circular one if conveniently excited. To show that the spiral represents an optimal source, we have also analyzed the behavior of two

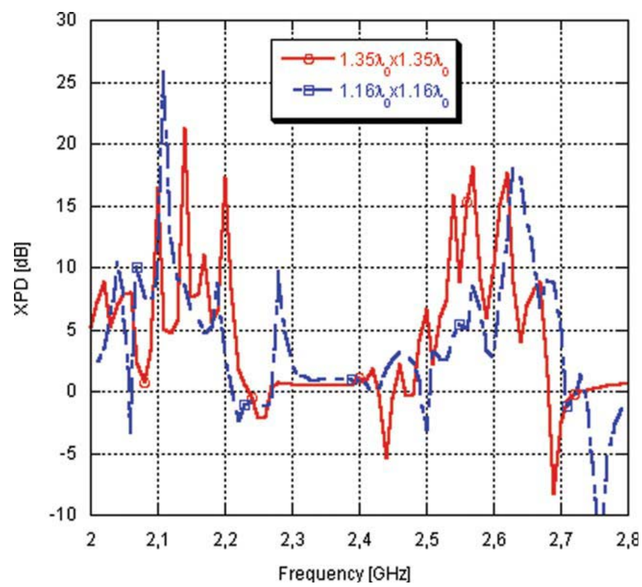
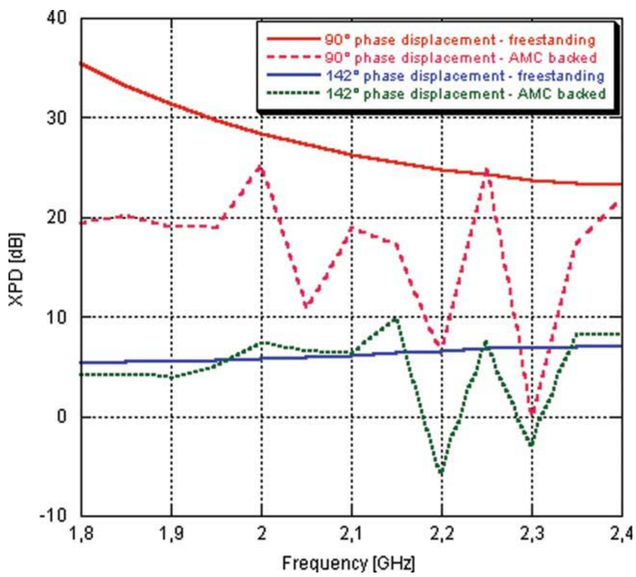


Figure 9 Comparison between the XPD of the antenna backed by the 6 × 6 sized screen (straight line) and the 4 × 4 sized screen (dashed line). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]



+90° phase displacement (perfect CP) and with a +142° phase displacement (EP), in freestanding configuration and in presence of the AMC screen. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

orthogonal dipoles fed with an opportune phase displacement, placed close to the surface.

Our intention is showing that the considered AMC does not enhance the CP properties of a radiating element different from the spiral due to the particular properties of the radiated field. In the first configuration, the dipoles are fed with a +142 degrees phase displacement. The chosen value is equal to the phase displacement between the θ and ϕ electric field components of the freestanding spiral. In this case, an elliptic polarization is radiated by the dipoles. The intention is to underline that again no improvement to the XPD is provided by the AMC. The case of +90 degrees phase displacement has been analyzed as well.

6. DIPOLES DESIGN

As the dipole is not a broadband antenna, we have designed it to resonate in the first AMC band, i.e., around 2.2 GHz.

To make a comparison with the spiral, dipoles have been placed at the same distance (λ_0/18) from the screen. Computations have been performed by using HFSS v.10.

In Figure 10, a plot of the XPD for the two analyzed configurations is given. In particular, we have compared the trend of the XPD in freestanding case with the one in presence of the AMC surface.

We can remark that the AMC does not provide any improvement for the CP properties of the dipoles. In fact, in both cases (+90° and +142° phase displacement), the XPD curve obtained in presence of the artificial magnetic surface oscillates around the maximum value reached in the freestanding configuration. By using the spiral, on the contrary, two noticeable spikes of XPD are visible at the AMC resonances in Figure 3. Moreover, in the same figure, a slight decrease of the XPD is apparent within the frequency regions far from the AMC resonances, owing to the perfect electric conductor (PEC) behavior of the screen, further proving that the circular polarization is given exclusively by the presence of the AMC screen.

7. CONCLUSIONS

An artificial magnetic conductor has been proposed that is able to efficiently convert an elliptic polarization into a circular one if conveniently excited. Indeed, an increase of XPD can be clearly observed at the AMC resonances (see Fig. 3). Moreover, a slight decrease of the XPD is apparent in the frequency regions far from the AMC resonance, owing to the PEC behavior of the surface, further proving that the circular polarization is given exclusively by the presence of the AMC screen.

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