Linear-to-circular polarization transformer based on the employment of electrically small antennas

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Abstract

In this contribution, we propose the use of electrically small antennas for the design of a new setup to increase power transmission through a sub-wavelength aperture. A linear-to-circular polarization transformer based on this concept is also presented. We show that the proposed structure placed at the end of an open-ended circular waveguide is able to change its linear polarization to a circular one. The overall structure is designed to efficiently radiate a circular polarized field at the GPS L1 frequencies (around 1575.42 MHz) with a realized gain greater than 5 dBi.

1. Introduction

According to the Bethe's theory [1], an electromagnetic wave cannot propagate through an electrically small aperture made in an opaque screen. In fact, the transmission efficiency of a circular hole of radius $a << \lambda$ decreases as the fourth power of the hole radius and, therefore, the transmission is typically very weak. Nevertheless, after the attractive work by Ebbesen et al. [2], several approaches to efficiently extract power from a sub-wavelength aperture have been proposed at both microwave [3]-[5] and optical frequencies [6]-[7]. Some of these, are based on the employment of electrically small resonators, which allow increasing transmission without significantly increasing the size of the overall structure. Moreover, by connecting together two identical resonators placed at the two faces of a sub-wavelength aperture, the transmitted power can be further increased [5]. However, these setups consist of resonators that can be effectively excited by a single polarization only and, then, they cannot transmit the other polarization beyond the screen.

In this contribution, we show that new setup based on the circular-polarized electrically small antennas proposed in [8], can be used to change the polarization of a field propagating in a circular waveguide from linear to circular. The proposed setup, can be considered as a linear-to-circular polarization transformer and can be used to adapt existing radiation systems to work in different environments and operate for different services.

2. Geometry and design principles of the proposed structure

In the structure proposed in [5], two split-ring resonators (SRR) are placed at the two faces of a sub-wavelength aperture and their external gaps are connected together through a pair of metallic strips. The SRR at the entrance face is able to receive an electromagnetic field with the proper polarization (i.e. with the magnetic field orthogonal to the SRR plane). Conversely, the SRR at the exit face radiates an electromagnetic field with the same polarization of the incident one. The two SRRs can be, thus, considered as electrically small resonating antennas.

The previous consideration opens the way for new configurations based on efficient electrically small antennas (ESA). In fact, replacing the SRRs with two efficient ESAs, power transmission can be further increased. Moreover, using ESAs with orthogonal linear polarizations or circular polarization, we may design enhanced transmission setups with different polarization properties.

To this end, we may think of using one of the metamaterial-inspired ESAs proposed in [8]. In particular, as shown in Fig. 1, two identical circular polarized (CP) ESAs can be placed at the two faces of a sub-wavelength circular hole made in a metallic screen. As widely documented in [8], the individual radiating elements consist of two orthogonal protractor open loops with slightly different dimensions in order to provide the required $\pi / 2$ phase shift and to achieve the circular polarization. In the original configuration, the two protractor elements are fed by the coupling to two driven monopoles connected to a coaxial cable. In our configuration, the two radiating elements are connected together by removing the coaxial cable and extending the two driven monopoles across the aperture.

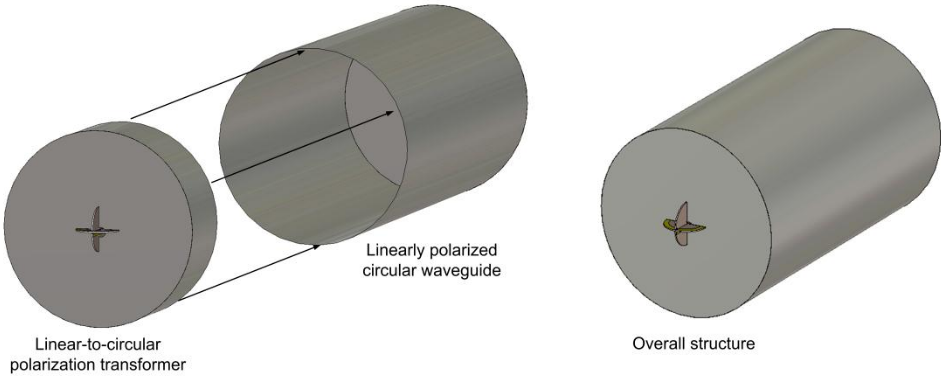

Figure 1: Schematic drawings of a linearly polarized circular waveguide, of the proposed polarization transformer, and of the overall structure.

As shown in Fig. 1, this structure is, then, used to cover an open-ended circular waveguide, in order to validate its effectiveness in transforming the polarization of the incident electromagnetic field. The obtained results are shown in the next section.

3. Numerical results

The structure in Fig. 1 has been numerically simulated by using the frequency-domain solver of CST Microwave Studio. Matching and radiating properties of a regular open-ended circular waveguide, of the same waveguide closed by a metallic plate having an electrically small circular aperture, and of the structure reported in Fig. 1 have been evaluated. As shown in Fig. 2 (a), the proposed structure is well matched around 1.575 GHz and exhibits a narrower bandwidth compared to the one of a circular open-ended waveguide. Moreover, the proposed structure radiates a left-handed CP field with an overall efficiency greater than 80%. The axial ratio for the main beam direction is shown in Fig. 2 (b), while the realized gain radiation pattern is reported in Fig. 3. All the presented results confirm the effectiveness of the proposed setup to work as an efficient linear-to-circular polarization transformer. The proposed transformer can be considered as a simple add-on to enhance and extend the operation of existing antenna modules to work in different application fields and support different services.

4. Conclusion

We have shown that enhanced transmission setups can be improved by using efficient electrically small antennas. Moreover, starting from this concept and employing a circular polarized metamaterial-inspired protractor antenna, a linear-to-circular polarization transformer has been presented. The proposed structure can be seen as an add-on to change the polarization properties of existing radiation systems. In particular, we have shown that an open-ended linear polarized circular waveguide capped by the proposed polarization transformer, behaves as an efficient CP radiator at the GPS L1 frequency.

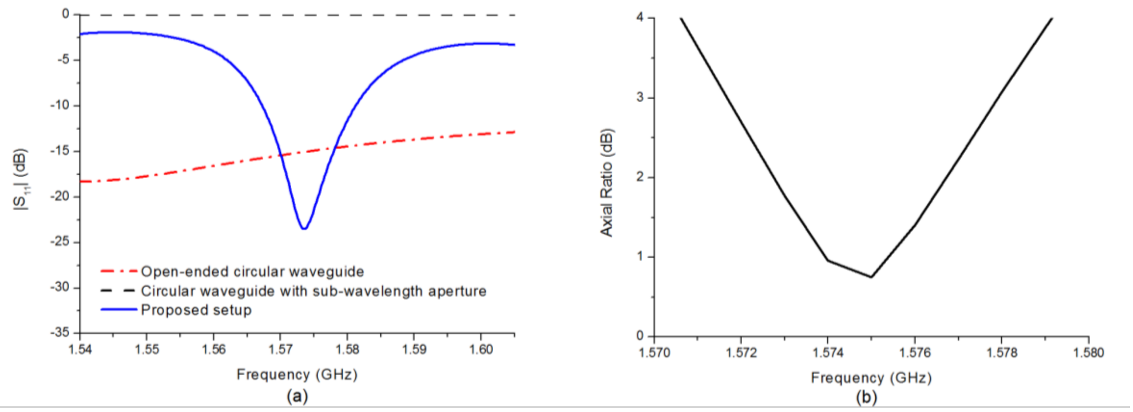

Figure 2: (a) $|S_{11}|$ of an open-ended circular waveguide (dash-dotted line), of a circular waveguide with a sub-wavelength aperture (dashed line), and of the structure shown in Fig. 1 (solid line); (b) Axial ratio for the main beam direction of the circular waveguide capped with the proposed polarization transformer.

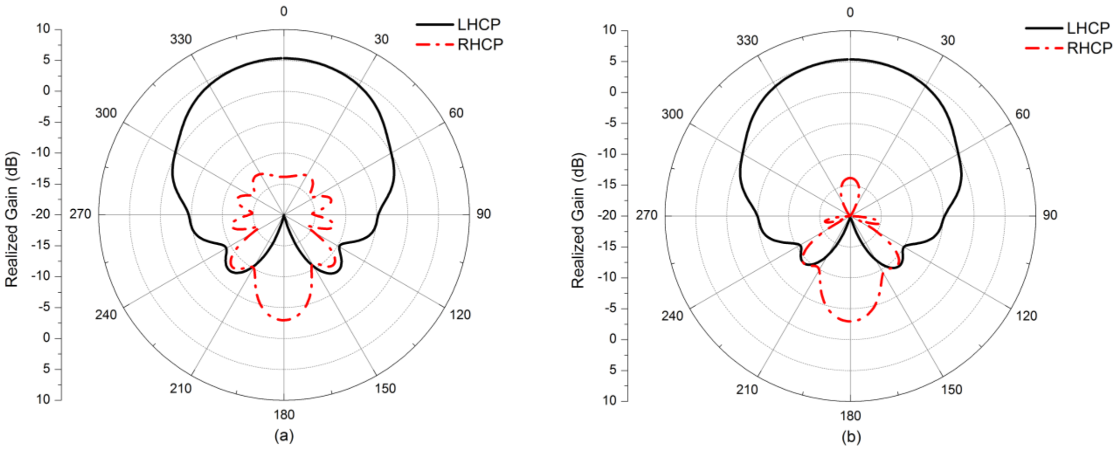

Figure 3: Realized gain radiation patterns at 1.575 GHz of the setup shown in Fig. 1: (a) φ = 0° , (b) φ = 90°.

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