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Design of metasurface polarization converter from linearly polarized signal to circularly polarized signal

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ABSTRACT

In this study, we both numerically and experimentally present a metasurface (MS) polarization converter to transform linearly polarized signal into circularly polarized one. The unit cell consists of two rectangular metallic patches placed at the crossed corners of rectangularly arranged inclusions. The results of a full-wave Electromagnetic (EM) simulator are compared to those of free space measurement using two horn antenna at microwave frequency regime. For a linearly polarized antenna, the s-parameters are obtained for both co-polarized and cross-polarized responses. The polarization quality referred to as axial ratio (AR) is expressed by the ratio of these two responses. It is found that, strong polarization conversion activity is obtained with the proposed MS at the frequency of about 3 GHz. As a result, we can generate polarization converter with a wide bandwidth, of interest for microwave filtering, coating, and especially polarization conversion devices.

1. Introduction

Metamaterials (MTM) are artificial materials engineered to produce properties that do not occur naturally. It is composed of a set of small scatterers or apertures in a periodical array throughout a region of space, thus obtaining some desirable bulk electromagnetic behavior become possible. The research towards metamaterial started when Veselago first described the conditions for a negative index metamaterial. He dreamed about a conceptual material in which dielectric permittivity and magnetic permeability are both simultaneously negative [1]. The concept of negative permittivity and negative permeability came to true by Pendry's studies in 1999, although it was introduced forty years ago by the general consideration of the electromagnetic properties of the materials with simultaneously negative values of the dielectric permittivity (ε) and magnetic permeability (μ). Pendry et al. presented their studies in 1996 [2] on the artificial metallic construction which shows negative permittivity and in 1999 [3] on the split rings which show the negative permeability. In 2000, Smith et al. realized the construction of first double negative (DNG) material using the combination of the split rings and wires [4]. Some experimental studies were carried out by Smith et al. to ascertain that the proposed structure show the characteristics of

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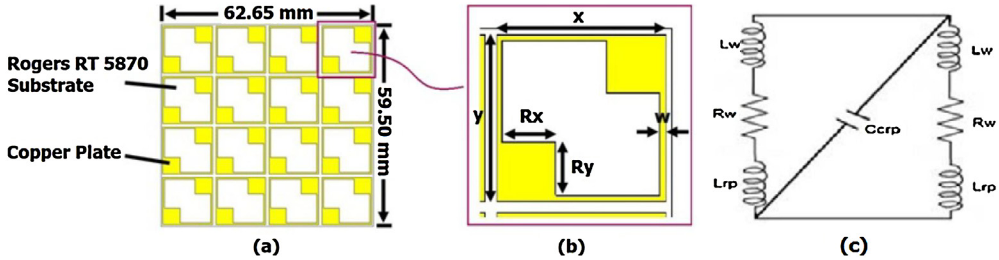

Fig. 1. (a) Linear to circular polarization converter MS, (b) unit cell dimensions of MS, (c) equivalent circuit diagram of MS.

DNG material at microwave frequencies. In 2001, Shelby et al. performed the first experimental investigation of negative refraction on DNG materials at microwave frequencies [5]. In recent years, there has been growing interest in metamaterials where the number of research papers published in this area has grown exponentially.

Electromagnetic metasurfaces (MS) [6–9] are artificial sheet material with sub-wavelength thickness, and therefore it is known as a two-dimensional form of a metamaterial [10–14]. MS allow us to control the behaviors of electromagnetic waves through the specific boundary conditions, rather than the constitutive parameters in three dimensional (3D) space. Metasurfaces have found great potential applications in both microwave and optical frequencies such as electromagnetic absorbers, polarization converters and spectrum filters etc. Due to low profile and low loss properties, metasurfaces have great advantages, and therefore, for many applications, they also fit well in many application areas of metamaterials [15–22]

The goal of this study is to provide a polarization converter to convert linearly polarized signal to circularly polarized one. The axial ratio (AR) is calculated by the ratio of cross-polar response to co-polar response of the antennas, because it is the main parameter in designing a polarization converter. The frequency of 3 GHz is nearly in the middle of the bandwidth, so it is taken as optimal working frequency which is located in the S band. Since it is known that many types of radars and satellites systems are operated in this frequency band. Weather radars operating in S band is affected by bad weather conditions and due to this bad weather conditions it is difficult to operate with linearly polarized waves. Rain and snow cause a microcosm of conditions such as reflectivity, absorption, phasing, multi-path and line of sight. This can be serious if linearly polarized antennas are employed. On the other hand, Multi-path is caused when the primary signal and the reflected signal reach a receiver at nearly the same time. This creates an out of phase problem which results in dead-spots. Furthermore, the polarization of a linearly polarized wave may be rotated as the signal passes through any anomalies such as Faraday rotation in the ionosphere at lower frequencies. Circular polarization will keep the signal constant regardless of these anomalies [23,24]. Situations such as it is not possible to ascertain the polarization of an incoming wave due to multi-path or reflection, it is more reliable to use circular polarization than linear polarization.

In this study, we numerically and experimentally designed a MS polarization converter to convert linearly polarized signal to circularly polarized one. The proposed structure has the following advantages: (i) it provides a perfect AR with a bandwidth of about 200 MHz in S band frequency regime. This bandwidth is considered to be sufficiently large according to the current polarization converters in literature; (ii) it has a simple geometry consisting of two square metallic patches placed at the crossed corner of a rectangle; (iii) it can be easily fabricated using Roger RT5870 dielectric and copper type metal. These materials are cheap, accessible and exhibit low losses; (iv) it can be effectively used in S-band applications such as weather radar, surface ship radar, communications satellites, space shuttle and so on.

2. Design of the proposed metasurface

The proposed MS composed of two rectangular metallic patches are placed at the crossed corners of periodically arranged rectangular patches. The aim of such a designed structure is to realize a conversion in rotation direction of polarization of the incident EM wave. The structure is constructed by using 4×4 layout arranged with 16 unit cells. The proposed structure is shown in Fig.1(a), the shaded (yellow) area represents metal plate designed by using copper with a conductivity of 5.80001 $\times$ 107 S/m and unshaded (white) area represents flame-Roger RT5870 type substrate with a thickness, loss tangent, and relative permittivity of 1.6 mm, 0.012, and 2.33, respectively. The unit cell of periodic MS is shown in Fig.1(b) with a thickness of strip line connecting metallic patches (w = 0.48 mm), width (x = 14.68 mm), length (y = 13.90 mm), and dimensions of each metallic patch (Rx = 4.90 mm, Ry = 4.64 mm). Beside this, the electrical equivalent circuit representation of the unit cell is extracted as shown in Fig.1c. Since E field component of signal is on vertical direction, only left and right side wires shows inductive effect (Lw) and rectangular patches provide higher inductance (L_{rp}) with respect to L_w. The capacitive effect arises from two crossed rectangular metallic patches (C_{crp}).

3. Numerical results

The results of the proposed structure are obtained numerically with a commercial 3D full-wave EM solver based on finite integration technique. The periodic boundary conditions with Floquet ports are used in the simulation. First, we examine the