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High gain terahertz antenna based on modified holographic artificial impedance surface

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ABSTRACT

This paper proposes the design of a holographic artificial impedance surface antenna, which is capable of beam forming at a desired direction with improved gain for terahertz communications applications. By modifying the design method of artificial impedance surface, two parts of artificial impedance surface with out of phase impedance modulation function are obtained. Combining the two parts of artificial impedance surface together, the split in the main lobe direction of the radiation pattern can be cancelled. Then, an improved gain at the desired direction can be achieved. The design procedure of the surface, with simulation results, is presented.

1. Introduction

Nowadays, the ever increasing demand for spectrum resource leads to exploit higher frequency. Terahertz (THz) spectrum has attracted much attention due to its potential applications in various fields, ranging from high speed communications, detection, to medical imaging etc [1–9]. THz spectrum, typically defined within the frequency range of 0.1 to 10 THz, is between microwave and infrared regions [10–14]. As the rapid development of THz technology, the requirements for high performance THz communications are increased significantly. As it’s well known that antenna plays an important role in the development of THz communications systems [15–28]. Over the past few years, lots of work has been made in realizing THz antennas to enhance the bandwidth [23], obtain high conductivity and good transparency [24], enhance THz pulse emission [25] and detect microorganisms such as yeast cells [26]. Although these antennas exhibit good performances for applications, they are limited for THz communications applications. Thus, there are still challenges in designing THz antennas with high gain, low profile, and a radiation pattern in a desired direction especially deviating from normal radiations. A possible solution is the use of reflection antennas, but one of main problems is bulky volume. To circumvent this problem, a compact and low profile THz antenna based on complementary ring resonator was proposed [27]. The achieved gain was not high. In addition, this antenna was hard to realize a desired radiation characteristic. Holographic antennas are excellent candidates for this purpose because of its high gain, low profile, and easy to realize a desired radiation pattern [28–32]. More recently, a holographic antenna was proposed for THz communications applications in [32]. This antenna exhibits high gain, low profile and easy to realize a desired radiation pattern. But there is a split in the main lobe direction of radiation pattern and the main radiation direction is shifted slightly.

In this paper, a holographic artificial impedance surface antenna with improved gain is proposed based on modifying the design method of artificial impedance surface. By combing two parts of holographic artificial impedance surfaces with impedance modulation function out of phase together, the split in the main lobe direction of radiation pattern is eliminated. The gain at the desired

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radiation direction is improved and the shift problem of main radiation direction is also solved. To verify our proposal, an antenna radiates at 30° from the Z axis in the X–Z plane at 1 THz is finally designed to exhibit high gain at the desired radiation direction.

2. Modified holographic artificial impedance surface

The design and construction of holographic artificial impedance surface for THz communications applications were investigated in Ref. [32]. As discussed in [32], the holographic artificial impedance surface is constructed based on a square lattice of sub wavelength metal patch on a grounded dielectric slab and the surface is positioned in the X–Y plane. The square metal patches are distributed on a grounded dielectric slab corresponding to surface impedance distribution obtained by using the holographic technique. The surface impedance variation versus metal patch dimension is obtained by using the eigen mode solver of HFSS and then the impedance versus the metal patch size can be curve fitting. Thus, the surface impedance modulation function can be described by

$$Z_{surf}(x, y) = j[X_s + M\,\mathrm{Re}(\Psi_{rad}\Psi_{ref}^{*})]. \tag{1}$$

Where X_s is the average value of surface impedance, M is the real modulation depth, Ψ_{rad} is an object wave, and Ψ_{ref} is a reference wave. Assuming that a monopole antenna is located at the focus of the ellipses of the holographic pattern to generate the reference wave and the desired radiation pattern is a pencil beam radiates at 30°off the normal plane. The surface impedance modulation function can be re-given by

$$Z_{surf}(x, y) = j[X_s + M\cos(k_t r - kx\sin 30^{\circ})]. \tag{2}$$

Where k_t is the propagation constant along the surface, k is the free space propagation constant, r is the distance from the source to field point, and x is the distance from the source to focal point at the X-axis. The holographic artificial impedance surface can be constructed based on Eq. (2), as shown in Fig. 1. It can be seen that the holographic pattern looks like a set of concentric ellipses and it is bilateral symmetry.

The main problem of the above holographic artificial impedance surface antenna is the split in the main lobe direction of radiation pattern, which makes the main radiation split into two separate parts. Hence the gain at the desired direction is decreased. This is because a monopole antenna placed at the focus of the ellipses of the holographic pattern excites two waves on the two different sides which possess opposite group velocity. Since the holographic surface is symmetric, it can be deduced from this pattern that one half of the surface i.e. $\varphi < 90^{\circ}$ and $\varphi > 270^{\circ}$ radiates forward traveling waves, while the other half i.e. $90^{\circ} < \varphi < 270^{\circ}$ radiates backward traveling waves, as shown in Fig. 2. The beam formation of the holographic antenna is contributed by both of the forward and backward traveling waves. When the surface doesn't operate at the phase matching frequency, the forward and backward traveling waves don't have the same phase, which lead to the appearance of a split in the main lobe direction of radiation pattern. And the phase difference between the forward and backward traveling waves is 180°.

In order to solve this problem, the impedance modulation function is modified to make the forward and backward traveling waves have the same phase. Based on the above analysis, the modified modulation function of the holographic artificial impedance surface is expressed as:

$$\begin{array}{ll} Z_{surf}(x, y) = j[X_s + M\cos(k_t r - kx\sin\theta_L)] & x < 0 \\ Z_{surf}(x, y) = j[X_s + M\cos(k_t r - kx\sin\theta_L + \pi)] & x \geq 0 \end{array}. \tag{3}$$

Where θ_L is the desired radiation direction. As an example, a holographic artificial impedance surface antenna radiates toward $\theta_L = 30^{\circ}$ at 1 THz based on Eq. (3) is designed and analyzed. In order to compare with the previous holographic antenna [32], the substrate used here also has a relative dielectric constant of 2.2 and a thickness of 18.84 u m and the length of the lattice is also

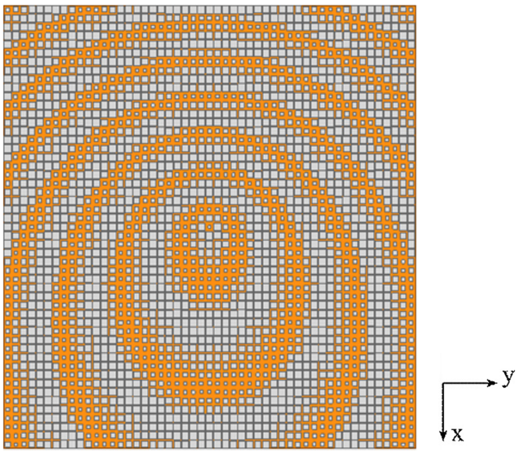

Fig. 1. The layout of the holographic artificial impedance surface.