Transformation-optics and illusion-optics devices made of microwave metamaterials

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Abstract

In this paper, we review several transformation-optics and illusion-optics devices realized by microwave metamaterials, including three-dimensional (3D) ground-plane cloak, 3D Luneburg lens with flattened focal surface, two-dimensional (2D) shrinking device, and 2D material-convention device. Experiments demonstrate good performances of such devices.

1. Introduction

From the effective medium theory [1,2], periodic structures with sub-wavelength elements can be viewed as homogeneous metamaterials (e.g. left-handed materials, zero-index materials, epsilon-negative medium, mu-negative medium, anisotropic metamaterials, and chiral medium). Some unusual and exciting electromagnetic properties have been found with such homogeneous metamaterials, like the negative refraction [3] and perfect imaging [4]. However, inhomogeneous metamaterials which are composed of non-periodic structures can provide much more freedom to control electromagnetic waves. The transformation optics [5] is a powerful tool to design the inhomogeneous metamaterials by controlling electromagnetic waves as one imagines, which has received great attention in recent years. However, only limited fantastic features predicted by the transformation optics can be realized using the artificial metamaterials. Microwave metamaterials, i.e., metamaterials designed and fabricated in the microwave frequency, have played an important role in the verification to novel phenomena (such as cloaks [6,7]) and real applications, owing to their easy fabrication. In this paper, we will review the transformation-optics and illusion-optics devices composed of inhomogeneous and isotopic or anisotropic microwave metamaterials.

2. Ground-plane cloaks

The ground-plane cloak is one of the most important transformation-optics devices, which was first realized in the microwave frequency [7]. However, the ground-plane cloak has a restriction of large size compared to the cloaked target. To overcome this restriction, we have presented a two-dimensional (2D) compact-sized ground-plane cloak [8], which is realized using the non-resonant metamaterials in the microwave frequency. Experimental results show good invisibility properties in a broad frequency band from 8 GHz to 12 GHz. Based on such a 2D compact-sized cloak, we have designed a three-dimensional (3D) ground-plane cloak by rotating it around the optical axis [9]. Such a design is an approximation to the 3D optical transformation, which has perfect cloaking effect to conceal 3D objects located under a curved conducting plane by imitating the reflection of a flat conducting plane when the incident waves are propagating in planes containing the optical axis. When the incident planes are near the optical axis, the cloak has also very good performance. The 3D cloak is composed of inhomogeneous isotropic dielectric materials, and has been realized by drilling inhomogeneous holes in multiple layered dielectric plates. The 3D cloak has a broadband and low loss in the microwave frequencies. Experimental results demonstrated very good performance of the 3D cloak for different polarized incident waves from 8 GHz to 12 GHz [9].

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3. 3D Flattened Luneburg Lens

We have also used the transformation optics to design new types of lenses. Luneburg lenses have superior performance compared to conventional lenses made of uniform materials with specially designed surfaces, but they are restricted by their spherical focal surfaces. Recently, a novel 2D imaging lens was proposed using the transformation optics based on the Luneburg lens [10], which has a flattened focal surface and is valid to extremely large viewing angles. We have demonstrated the design, realization, and measurement of a 3D Luneburg lens with flattened focal surface using the approximate transformation optics in microwave frequency [11]. The proposed 3D lens has great advantages to the conventional uniform-material lens and the spherical Luneburg lens with no aberration, zero focal distance, a flattened focal surface, and the ability to form images at extremely large angles. The 3D lens was made of multi-layered isotropic dielectric plates by drilling inhomogeneous holes. Experimental results demonstrate excellent performance of the 3D metamaterial lens for different polarizations over a broad frequency band (from 12 to 18 GHz). The 3D Luneburg lens can be directly used as a high-gain antenna to radiate or receive narrow beams in large scanning angles for dual polarizations [11].

4. Illusion-optics devices

For illusion-optics devices, we proposed a class of optical transformation media which can generate multiple virtual objects [12], move a object virtually [13], and change the material makeup of an object virtually [14]. Unlike the published illusion devices which are composed of left-handed materials, all permittivity and permeability components of the proposed illusion media are finite and positive. Hence the presented approach makes it possible to realize the illusion devices using artificial metamaterials. In experiments, we presented a shrinking device [15], which can transform an arbitrary object virtually into a small-size object with different material parameters as one desires. Such an illusion device will confuse the detectors or the viewers, and hence the real size and material parameters of the enclosed object cannot be perceived. We fabricated and measured the shrinking device by using metamaterials, which works at the non-resonant frequency and hence has low loss. The device has been validated by both numerical simulations and experiments on circular and square objects, and good shrinking performance has been demonstrated [15].

As the other example of illusion devices, we propose the concept of radar illusion, which can make the electromagnetic image of a target gathered by radar look like a different target [16]. We have realized the radar illusion device experimentally to change the radar image of a metallic target into a dielectric target with predesigned size and material parameters. Such an illusion device will confuse the radar, and hence the real electromagnetic properties of the metallic target cannot be perceived. We designed and fabricated the radar illusion device using artificial metamaterials in the microwave frequency, and good illusion performances are observed in the experimental results [16].

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