Functional Metamaterial Devices for Manipulation of Waves in Microwave Region based on Transformation Optics

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***Abstract* – As an effective approach for manipulating propagation of waves, transformation optics has inspired many novel applications during past decades. In this paper, our recent efforts in metamaterial devices for manipulation of waves in microwave region are reviewed with emphasis on (1) multifunctional device with three different kinds of electromagnetic properties, (2) homogeneous illusion device exhibiting transformed and shifted scattering effect and (3) wave bending devices with homogeneous complementary material. Our designs possess potential applications in fields of electromagnetic engineering.**

***Index Terms* — Transformation optics, Illusion device, Matematerial device, Wave bending.**

1. Introduction

Transformation optics has attracted great attentions of scientists in optics and magnetic since it was proposed in 2006. Based on theory of optical transformation, novel applications in manipulation of waves were proposed and analyzed in theory, such as cloaks, illusion devices and so on [1-7].

In this paper, we briefly review our recent work on metamaterial devices for manipulation of waves based on transformation optics. Both space transformantion and related applications will be focused on. Multifunctional device with three different kinds of electromagnetic properties, homogeneous illlusion device exhibting transformed and shifted scattering effect and wave bending device with homgeneous complementary material will be introduced. Metamaterial device we proposed could possess potentional applications in electromagnetic engineering fields with unique properties.

2. Multifunctional Device with Three Different kinds of Electromagnetic Properties

A multifunctional device with invisible, transparent and illusion electromagnetic properties is proposed. The space transformation principle is shown in Fig.1. Region I is folded to region II, and region III is stregthed to region I, II and III. The basic features exhibited are: first, this device can be used as a complementary cloak, as shown in Fig.2a) and b). Scattering fields of the circular object in Fig.2 a) is cancelled by corresponding anti-object, as shown in Fig.2b). Second, this device can be used as transparent device, as shown in Fig.2c)and d). It can be seen that the field distribution of the device is same as that of a horn antenn in free space. Moreover, this device can also be used as illusion device, as shown in Fig.2 e) and f). It has been shown that the scattering field of circular and triangle object in the device is same as that of triangle object in the free space, that is, the circular object is visually trasformed to the triangle object by the coated device.

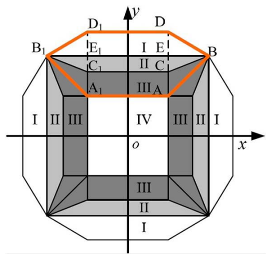

Fig. 1. Space transformation of multifunctional device with three particular electromagnetic properties

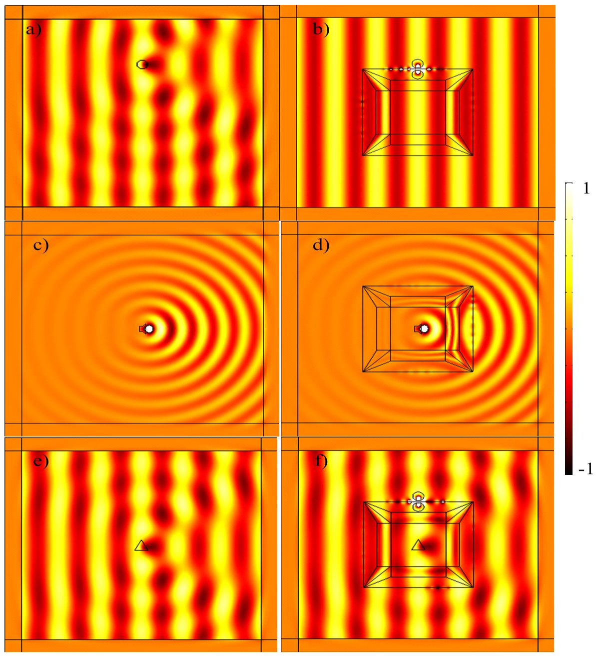

Fig. 2. Electrical field distributions of a) circular object in free space b) circular object in the device c) horn antenna in free space d) horn antenna in the device e) triangle object in free space f) triangle and circular object in the device

3. Homogeneous Illusion Device Exhibiting Transformed and Shifted Scattering Effect

A kind of homogenous illusion device exhibiting shifted and transformed scattering effect is proposed. The space transformation can be completed by two steps, as shown in Fig. 3. Step 1 is shifting region $A_2B_2D_2C_2$ to identical region $A_1B_1D_1C_1$ while keeping the boundary ABDC unchanged, and Step 2 is transforming region $A_1B_1D_1C_1$ to region $A_3B_3D_3C_3$ while keeping the boundary ABDC unchanged. According to the relationship of $A_3B_3D_3C_3$ and $A_1B_1D_1C_1$, illusion shape of the target could be linearly minified, magnified and reshaped. Fig. 4 a), c) and e) show the electric field distributions of different PECs in shifting device with linearly minified, magnified and reshaped properties respectively. For comparison, the electric field distributions of the equivalent PECs in the above three cases are shown in Fig. 4 b), d) and f) respectively. Compared electric field distributions of practical PEC with that of equivalent PEC, we can see that the field distributions of two PECs are same although they have different size and locate in different location.

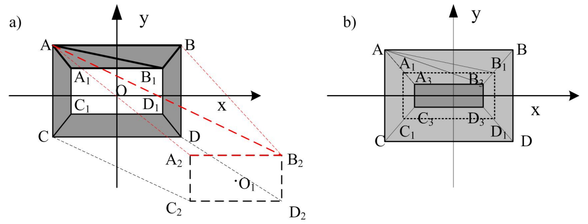

Fig. 3. Space transformation of proposed illusion device a) step 1 b) step 2

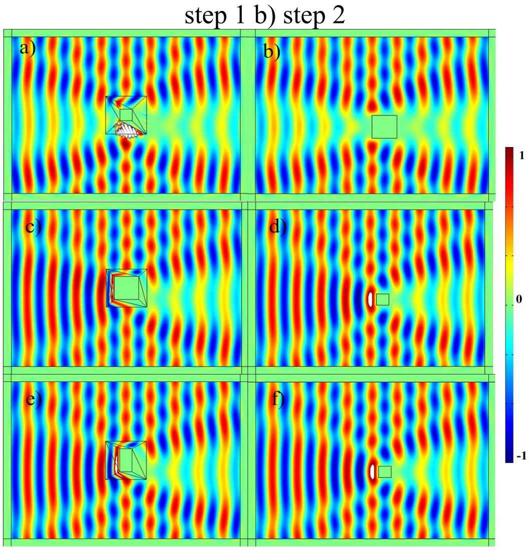

Fig. 4. Electrical field distributions of a) small PEC b) equivalent big PEC c) big PEC d) equivalent small PEC e) rectangle PEC f) equivalent square PEC

4. Wave Bending Devices with homogeneous Complementary Material

We adopt homogeneous complementary material to manipulate the propagation property of waves, and space transformation is that region ADB is folding back onto ACB, as shown in Fig.5. This method of manipulating waves can be used to design a wave refractor, splitter or waveguide bends with different widths and directions, as shown in Fig.6. Fig.6 a) and b) show the wave deflects with a given angle moving through the refractor and splitter. Fig.6 c) and d) show electric field distributions and the time average power outflow of waveguide bend respectively. It is clear that the guiding mode pattern is not distorted and the nearly all the energies are transmitted.

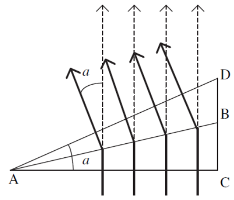

Fig. 5. Space transformation of manipulating wave direction by homogeneous complementary material.

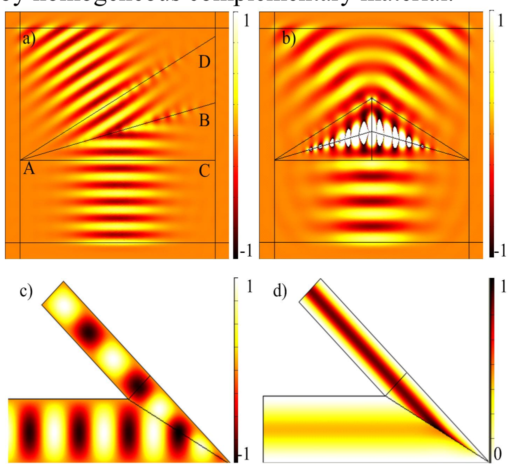

Fig. 6. Electrical field distributions of a) wave refractor b) wave splitter c) waveguide bend and d) time average power outflow of waveguide bend

5. Conclusion

In this paper, three unique metamaterial devices for manipulation of waves based on transformation optics are summarized. The applications discussed here are by no means the only applicability. However, they offer a few new ideas of where optical transformation can be potentially applied, and hopefully opens the door to the development of other new applications.

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