A broadband carpet cloak realized by dielectric cylinders

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Abstract

In this paper, a carpet cloak made from nonmagnectic dielectric cylinders is designed, simulated and tested experimentally. By manipulating the periodicity of the dielectric cylinders, it is possible to achieve the required dielectric map and therefor the propagate direction of the electromagnetic waves. The cloak is tested with open-end waveguide from 7 to 9 GHz . Open end waveguide is feeded as excitation to demonstrate that it can work with all incident angle. The experiment results are in good agreement with the simulation results.

1. Introduction

Optical transformation together with metamaterials has enabled precise control of the electromagnetic waves with the spatially tailored properties [1, 2]. Based on these two ideas, the invisible cloak has been realized and attracted increasing attention in the past few years. Although an experimental verification was carried out at microwave frequencies [3], earlier designs of free-space cloaks suffered from inherent limitations of metamaterials such as high loss and narrow bandwidth. Li et al. proposed a so-called ground-plane cloak design [4], which makes broadband cloaking feasible. The idea has been experimentally verified at both microwave and optical frequencies [5, 6, 7, 8, 9]. However, these designs require high index background materials and contain a very large number of metamaterial cells. Subsequently, the idea of the quasi-cloak, which consists of a few carefully designed all-dielectric blocks was presented in [10]. The quasi-cloak completely removes the constrains of metamaterials without significantly sacrificing its performance. Thus it enables certain practical applications from microwave to optical frequency band.

There are a variety of methods to construct the quasi-cloak. For example, in the printed circuit board (PCB) method, I-shaped metal structures are used on PCBs with F4B substrates [8]. Utilizing electron beam lithography, arrays of silicon nanorods can be fabricated to achieve gradient indices [11]. Cylindrical metallic post surface-wave structures and holey plate structures have also been utilized in the design of gradient index lenses, such as the Luneburg Lens [12, 13].

Here in this paper, we design a simplified ground plane carpet cloak from such dielectric cylinders and demonstrate it through both simulation and experiment with the excitation of quasi-point source. The proposed device operates as a ground-plane cloak when placed on top of a ground plane, and in addition it can be modified into a directional free-space cloak which significantly reduces the scattering from the impinging wave at all angles. Since those designs do not require to be embedded in background media, they remain compact and simple to build.

ISBN 978-952-67611-0-7

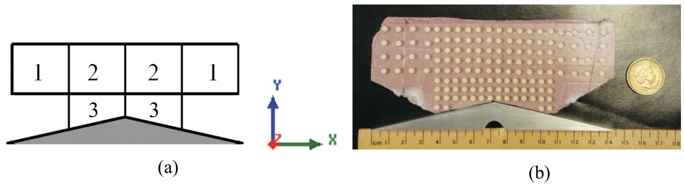

Fig. 1: (a) the scheme of the carpet cloak (b) A photograph of the carpet cloak made up of DDM.

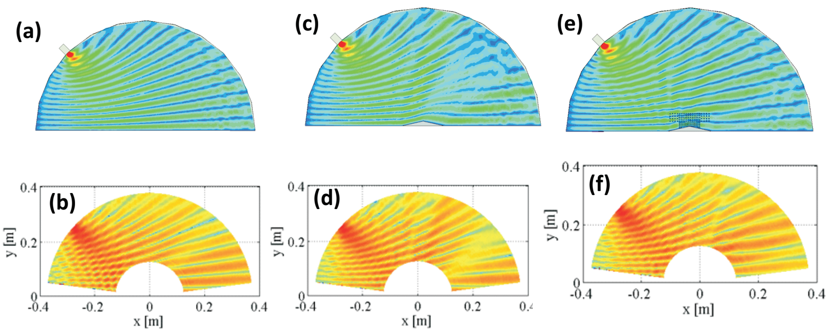

Fig. 2: (a) simulated field distribution of ground plane (b) measured field distribution of ground plane (c) simulated field distribution of ground plane with the bump (d) measured field distribution of ground plane with the bump (e) simulated field distribution of the cloak (e) measured field distribution of the cloak

2. dielectric cloak

Based on the simplified ground-plane cloaking design [10], a carpet cloak is designed to reduce the scattering from a triangular-shaped object with its base placed on a perfectly conducting metallic plane. The object has a height of 16 mm, base of 144 mm and thickness of 15 mm. The device extends 137 mm by 60 mm around the object and consists of six different sections. The block with the ID [1, 2, 3] have the different refractive index: [1.08, 1.14, 1.21] respectively as shown schematically in Fig. 1(a). Here, the block with the refractive index value 1.01 is used to mimic with air. In order to obtain these values, three layers of dielectric cylinders with the hight of 2.2 mm, radius of 1.5 mm and permittivity of 36 and different periods are placed around the device. The periods in x and y dierection of the cylinders are the same and chosen to be [8, 6, 5] mm such that the corresponding effective refractive index values are obtained. The period in z direction is fixed to 5 mm with the aid of form. Some cylinders have been omitted to fit the structure around the object.

In the experiment, the cylinders are mounted on a thin layer of foam with the thickness of 1 mm and a refractive index close to 1 as shown in as shown in Fig. 1(b). Three layers of such a structure are topped up with the total thickness of 15mm. There is also a metallic triangular-shaped object in Fig. 1(b) which is the object we try to cover in the experiment.

Both simulation and experiment are carried out to test the performance of the cloak and the results are shown in Fig. 2. An X-band waveguide with the width of 22.86 mm is incident at 45 degree from the left side of the plane as the excitation source. Since the aperture of the waveguide is very small compare to the mapping field and far from the target, it can be viewed as a point source. Fig. 2 shows the field distribution of these two methods at 8 GHz. In Fig. 2(a), the simulated electric field distribution is shown with the aid of the Finite element method simulation (Ansoft HFSS), while Fig. 2(b) is the measured result. It is seen that above the the ground plane, the field is evenly distributed in a quasi-standing wave manner. In Fig. 2(c) and (d), with the presence of the triangular-shaped bump, there is a strong shadow in the reflected region. In Fig. 2(e) and (f), the strong shadow caused by the bump disappeared and the field

ISBN 978-952-67611-0-7

distribution is restored to almost the same as in Fig. 2(a) and (b), which proves the efficiency of the cloak to all angle. In all these three setups, the measured results are in good agreement with the simulation results. More measured field distributions at 7 GHz and 9 GHz have also been tested and shown that there are no shadow, demonstrating that the cloak still functions at these two frequencies.

3. Conclusion

A carpet cloak is designed and tested with dielectric cylinders from 7 GHz to 9 GHz. The simulation and measurement results are in good agreement. With the excitation of an open-end waveguide, the carpet cloak can successfully reduce the scattering field from al angles of incidence. The cloak should also work at lower frequencies.

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