Experimental verification of the all-dielectric innovative cloak

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***Abstract*—We experimentally characterize the innovative cloak, which enables arbitrary multi-objects hidden with movements and visions by the dielectric metamaterials. The field distribution of the cloak is demonstrated through the FITD simulation method and then is mapped through the microwave probe attached to the vector network analyzer. The two results are consistent with each other.**

Keywords—the innovative cloak, microwave mapping, dielectric metamaterials

I. INTRODUCTION

The methodology of creating an invisible cloak from coordinate transformation proposed by Pendry *et al.* [1-3] bursts into a research blossom in recent years. So far, the first experimental demonstration [4] of the internal cloak proposed by Smith *et al.* is achieved by arranging spatially varied split ring resonators (SRRs) to tailor the corresponding constitutive parameters of the internal cloak. Also, the external cloak is realized in the experiment by utilizing inductor-capacitor (L-C) network medium based on the transmission-line theory. Here, we dedicated to experimentally demonstrate an innovative cloak [5], which combines the features of the internal cloak and external cloak to enable arbitrary multi-objects hidden with visions and movements according to the theoretical analysis and the numerical simulation proposed in [5]. However, limited by the Ohmic losses for the conventional metallic SRRs and relative low working frequencies for L-C network medium [6], we would like to utilize the unprecedented dielectric metamaterials [7], which possess profound electric and magnetic responses simultaneously to depress losses and also provide an extra freedom for the anisotropic behavior of the constitutive parameters. Moreover, by carefully detuning the dimensions of the dielectric metamaterials, we can approach different positive/negative electric/magnetic responses, which are difficult for the conventional SRRs and are quite critical for the design of the innovative cloak.

II. NUMERICAL SIMULATION OF THE STRATIFIED CLOAK

To realize the innovative cloak in the experimental measurement setup, due to the finite volume of the metamaterials we might utilized, it is impossible to develop a metamaterial with spatially continuous varied constitutive parameters within the cloak. Thus, we might first stratify the internal-cloak-like and complementary area of the cloak into several different layers, which possess constant anisotropic constitutive parameters within each layer as a reduced cloak. Also, there are many constraints to be considered in the experiments to demonstrate the idea of the innovative cloak such as the operating frequency and the occupied spacing of the utilized metamaterials. Hence, to obtain the proper parameters of the reduced cloak, different numbers of the layers (12 and 15 layers), divided angles within each layer (15, 30 and 45-degree) and the incident wavelength (0.8, 1 and 1.2 unit) are simulated and testified via the FEM simulation to check the concealment ability of the reduced cloak under different condition.

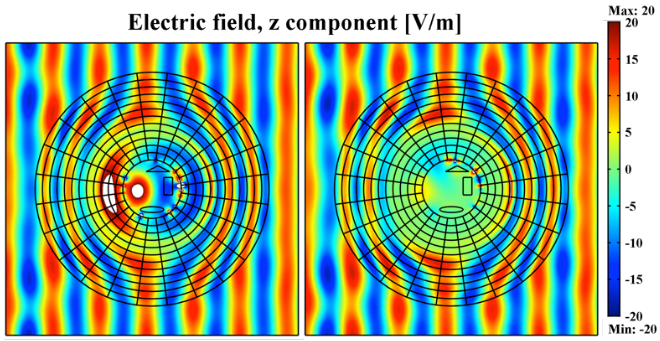

Fig. 1. The snapshots of the electric field of the reduced cloak with 12 stratified layers, 15-degree divided angle and 0.8 unit incident wavelength. Before (a) and after (b) the hidden objects are put inside the cloaked region.

Figure 1 shows the most promising parameters set of the reduced cloak with 12 layers including 4 layers for the complementary area and 8 for the internal-cloak-like area, 15-degree divided angle and 0.8 unit incident wavelength, which shows little scattering field compared to the one of the ideal innovative cloak. Also, the comparison between Fig. 1(a) and 1(b) represents identical scattering field outside the cloak when the hidden objects including of a rectangular metal with $\varepsilon=-5$ and $\sigma=3\times10^8$, a triangular lossy material with $\varepsilon=10+5i$ and $\mu=2+i$ and a elliptical negative index material with $\varepsilon=-5$ and $\mu=-2$ are put inside the cloaked region in Fig. 1(b). Noticed here, although much larger numbers of the layers and lower incident frequency might result in better performance of the reduced cloak due to that under these conditions the metamaterials could be approaching to the spatially continuous constitutive parameters of the ideal innovative cloak, however, it is impractical to increase these two factors unlimitedly because we should consider the corresponding resonant frequency of the dielectric metamaterials with the certain thickness of the layer.

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III. THE ANISOTROPIC DIELECTRIC CUBES BASED CLOAK

Here, encouraging by our experimental verification of the negative identities and slowing light effect, we have chosen the dielectric metamaterials as our building block of the reduced innovative cloak due to the two major reason: the first point is that the dielectric metamaterial can be manipulated to achieve bi-axial constitutive parameters along two orthogonal directions, which would serve as the μ_{xx} and μ_{yy} of the reduced cloak; the other should be that the intrinsic loss of the dielectric metamaterials is drastically suppressed due to the elimination of the losses from Ohmic heating, stemming from the metal utilized in the conventional metallic resonators. Thus, the utilization of the dielectric metamaterials not only maintains the negative identities at higher frequency but also avoids the losses killing the performances of the reduced innovative cloak.

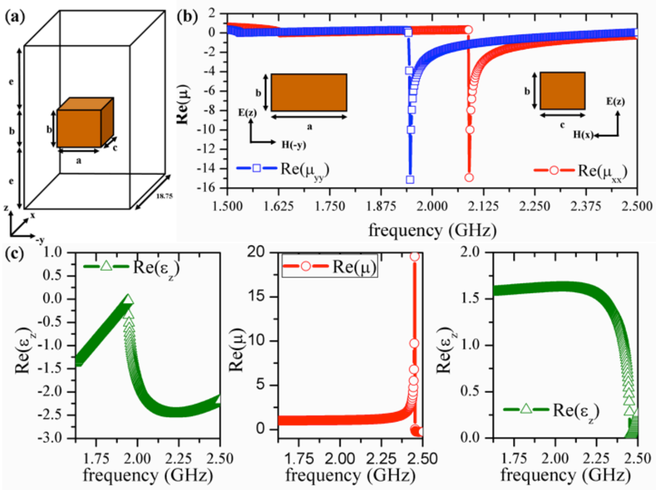

Fig. 2. The extreme constitutive parameters retrieved from the dielectric metamaterials under two different incident conditions.

After the determination of the utilized metamaterials of the reduced innovative cloak, herein, we would like to employ FITD simulation method to examine the scattering parameters (i.e., S11 and S21) of the dielectric metamaterials and retrieve the corresponding constitutive parameters in the aids of our home-made retrieval code based on the effective medium theory. A simple example of the dielectric metamaterials is shown in Fig. 2, illustrating the different extreme values of the dielectric metamaterials for all of ε_z (ranging from 0 to 1.5 for the internal-cloak-like area and 0~-2.5 for the complementary area), μ_{xx} and μ_{yy} (ranging from 0~19 for the internal-cloak-like area and 0~-15.5 for the complementary area). Noticed here, according to the incident wavelength and the spacing of the dielectric metamaterials, the operating frequency here should be 2.5 GHz with the wavelength of 120 mm and the overall radius of the cloak should be 300 mm for 0.8 unit incident wavelength.

IV. EXPERIMENTAL SETUP

Since the working principle of the dielectric metamaterials is realized, the required constitutive parameters of the cloak would be approached by the dielectric metamaterials with varied dimensions. After the simulation and the fabrication of the dielectric metamaterials are finished, we might utilize vector network analyzer (Agilent E8364A) attached with horn antenna (0.6-18 GHz) and a microwave probe to map the entire field distribution within the cloak sandwiched by two metal plates as perfect electric conductor boundary condition in the microwave region. A stepper is also employed to detect different area of the cloak with constant movement. Noticed that the operating frequency is set to 2.5 GHz due to the constraint from the working frequency of the available microwave probe.

V. CONCLUSIONS

The operating frequency can further promote by simply modifying the dimensions of the dielectric metamaterials. Finally, the many features of the innovative cloak would be examined including of the concealment of arbitrary objects, the movement of the objects and illusion optics, on the other hand, “transforming one object to appear as another”.

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