Investigation on Carpet Cloaking and Illusion Using Metasurface

Aritomo Wada, Yuki Fujimoto, Hiroyuki Deguchi, and Mikio Tsuji
Graduate School of Science and Engineering, Doshisha University
1-3 Tatara Miyakodani,Kyotanabe,Kyoto,610-0321 Japan

***Abstract* - This paper proposes an approach to design the carpet cloak by using reflecting elements. Using such a technique, it is possible to realize invisibility by thinner cloaks. Furthermore, an illusion cloaking using the metasurface is investigated numerically and experimentally.**

***Index Terms* — Metasurface, Carpet Cloaking, Illusion Cloaking.**

1. Introduction

Carpet cloaking is a technology which can make an object on a ground plane electromagnetically invisible[1]. Illusion cloaking which is also classified as a cloaking, is a technique that controls the scattering wave from the ground plane as if an object exists[2]. In 2006, Pendry[3] proposed an approach to design the invisible cloak by using the technique called transformation optics. Such a technique, makes it possible to realize invisibility by the cloak consisting of medium with proper permittivity and permeability. However, this way causes difficulty of the fabrication because the constitutive parameter becomes usually high anisotropic[4][5]. More recently, a cloaking technology using metasurfaces has been marked to overcome this disadvantage of transformation optics[6]. By controlling the wave propagation through reflecting elements, it is possible to restore the reflection phase front. In this paper, we propose a carpet cloak and an illusion cloak using metasurfaces which are constructed by resonant elements on a dielectric substrate. A cloaking device using the metasurface has very thin thickness, so they are especially suitable for cloaking. We verify the operation of these cloaks through numerical calculations. Furthermore, usefulness of the proposed illusion cloak is also investigated experimentally.

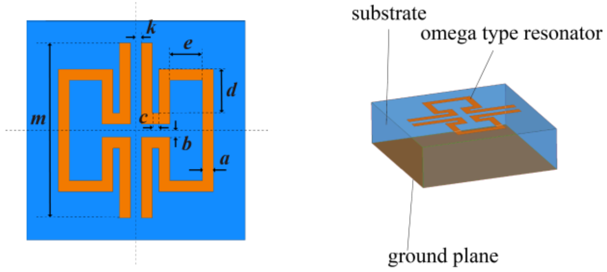
2. Design Method

We design a resonant element made of strip conductors at the frequency 10GHz, as indicated in Fig. 1. The parameter values are shown below;

a=0.5, *b*=0.3, *c*=0.3, *k*=0.25, *l*=10, *h*=5

d, e, m=variable value (unit : mm)

Figure 2 shows the reflection-phase property, and we can see that the reflection phase is varied over the range of 360 degrees.



(a) Front view of reflecting element. (b) Side view of reflecting element.

Fig. 1. Structural drawing of reflecting element.

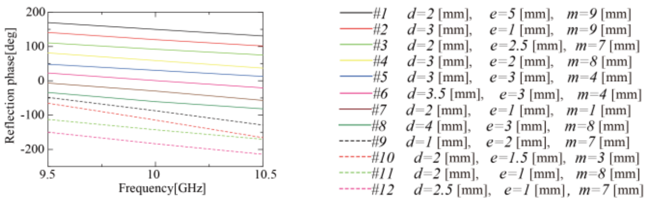


Fig. 2. Reflection phase property.

Figure 3(a) shows the design example of a carpet cloak. To reshape the reflection phase front as if the incident wave were reflected by the ground plane, the required reflection phase of the reflecting element at an arbitrary point on the bump φ_{mc} is given by

$$\varphi_{mc}(x) = \pi - 2k_0 y(x) \qquad (1)$$

where k_0 is the wavenumber in the free space and $y(x)$ is the height at that point from the ground plane. By providing the reflection phase, determined by (1), we can cloak a bump on the ground plane.

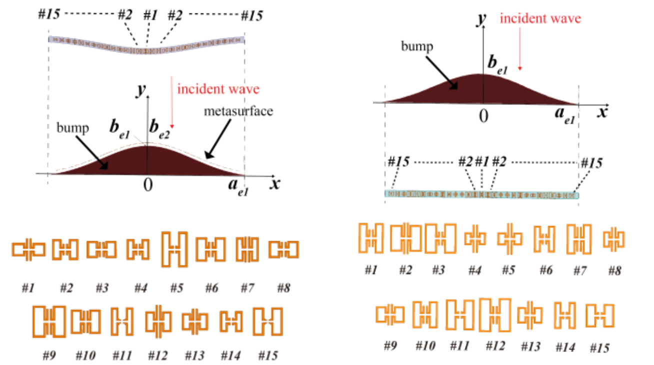
Figure 3(b) shows the design example of an illusion cloak, which is installed on the ground plane. To produce the wavefront distorted by a bump, the required reflection phase at each point on the ground plane φ_{mi} is given by

$$\varphi_{mi}(x) = \pi + 2k_0 y(x) \qquad (2)$$

Arranging reflecting elements properly on the ground plane, it is possible to control the electromagnetic wave as if a bump were present. As an example, we consider here a scattering surface which is expressed by

$$y(x) = A(e^{-\frac{x^2}{\sigma^2}} - e^{-\frac{a_{e1}^2}{\sigma^2}})$$

$$a_{e1} = 150,\ b_{e1} = 45,\ b_{e2} = 50 \quad \text{(unit : mm)}$$

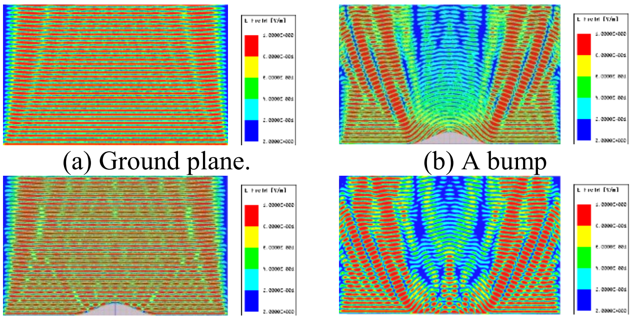


(a) Carpet cloak. (b) Illusion cloak.

Fig. 3. Designed structures of carpet cloak and illusion cloak.

3. Numerical consideration

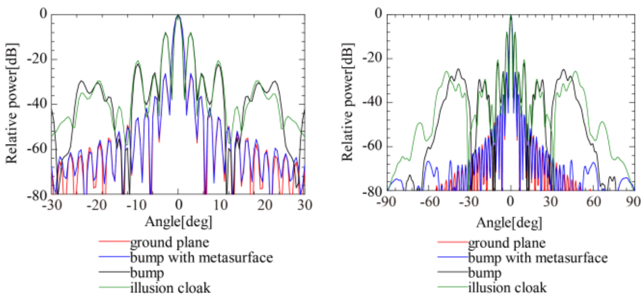
Figure 4 shows amplitude distributions of the scattering wave for the ground plane (4(a)), the bump (4(b)), the bump with the cloak (4(c)), and the illusion cloak of the bump (4(d)). It is clearly seen from comparison of Fig. 4(a)-(c) that the carpet cloak works very well and restores the distortion by the bump. Furthermore, comparison of Fig. 4(b) and (d), the illusion cloak simulates the scattering wave by the bump well. Fig. 5 shows radiation patterns, as another verification of cloaking devices. These numerical calculations are performed by the HFSS (Ansys Inc.).



(a) Ground plane. (b) A bump

(c) A bump with carpet cloak (d) Illusion cloak on ground plane

Fig. 4. Amplitude distributions of scattered fields.

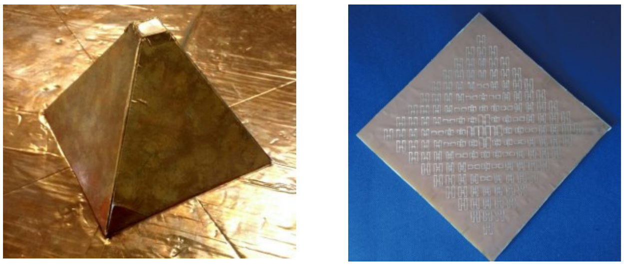


(a) Narrow angle. (b) Wide angle.

Fig. 5. Radiation pattern.

4. Experimental consideration

Figure 6 shows a bump and an illusion cloak fabricated by us. Figure 7 shows measured radiation patterns for the ground plane, the bump, and the illusion cloak. It should be noted that the incident angle is set up to the 20 degrees to avoid the receiving-antenna blockage. The measured results demonstrate that the illusion cloak substantially can simulate the radiation pattern from the scattering object.



(a) Fabricated bump. (b) Fabricated illusion cloak.

Fig. 6. Fabricated a bump and illusion cloak.

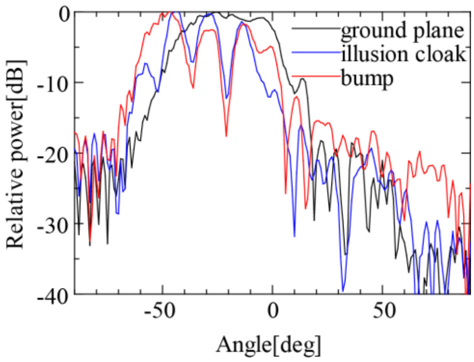


Fig. 7. Radiation pattern at incident angle of 20 degrees.

Conclusion

We have proposed the carpet cloaking and the illusion cloaking by using the reflectarray of resonant elements. Their effectiveness has been verified through numerical discussion. Moreover, effectiveness of the illusion cloaking has been also confirmed experimentally.

Acknowledgment

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