An Invisibility Cloak Design at Microwave Frequency Using Commonly Used Materials

Ruey-Bing (Raybeam) Hwang and Fang-Yao Kuo
Department of Electrical and Computer Engineering
National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu, 30010, Taiwan
Email: raybeam@mail.nctu.edu.tw

***Abstract*—In this work, we present a novel cloaking structure designed at microwave frequency. Different from the cloaking structures in need of effectively negative refractive index medium, such a structure is composed of a regular dielectric medium and metallic cylinders array. From the numerical simulation, we may observe that the cloaking outside a metallic cylinder can mold the propagation of energy flow, reducing the backward scattering of the incident wave.**

I. Background Information

In the past, a cloak causing an object to be invisible only exists in science fiction. However, the invisibility cloaks were successfully implemented in microwave and optics recently due to the development of metamaterial having extraordinary effectively permeability and permittivity, and the theory of transformation optics [1], [2]. In this research, we developed a novel cloaking structure consisting of three concentric layers with positive refractive index mediums. Specifically, each of the desired refractive index corresponding to individual layer can be synthesized by using metallic cylinders array immersed in a traditionally used dielectric medium. Such an effective dielectrics was successfully applied in designing a near-zero refractive index medium and a spatial power divider application [4]. Moreover, the plasma medium permittivity model for a metallic rods array has been developed [3]. In the numerical simulation, we observe that the incident plane wave, which is launched by a open-ended waveguide installed with a dielectric lens, will be detoured and is flowing around the metallic column (the object to be cloaked); thus, the backward scattering will be further reduced.

II. Summary of Research Findings

Figure 1 shows the scattering parameters, including the reflection and transmission coefficients in dB, of the transmitting and receiving antennas in a distance d. Between the two antennas is a metallic cylinder, made of perfect electric conductor, with radius equal to λ at 8.2 GHz. The two antennas are made of open-ended waveguide (WR90) installed with dielectric lens for focusing its beam pattern and for improving the impedance match. From this figure, we observe that a strong reflection takes place at the frequency around 8.2GHz. It may be conjectured that at this frequency the metallic cylinder blocks the propagation of wave launched by the transmitting antenna.

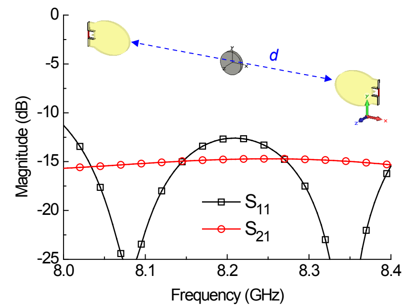

Fig. 1. Propagation loss in the presence of a metallic circular cylinder

Returning to Fig. 1, we draw the contour map of Poynting power at 8.2GHz in the structure under consideration, with the figure shown in Fig. 2. From this figure, it is obvious to see that the metallic cylinder blocks the incident wave, causing a strong backward scattering. Moreover, the shadow region behind the metallic cylinder is apparent.

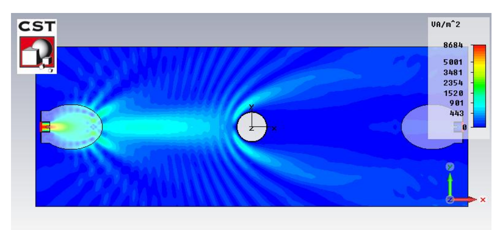

Fig. 2. Contour map of Poynting power at 8.2GHz in the whole structure; without cloak

An interesting cloak design consisting of multiple concentric dielectric layers was reported [2]. Based on their research results, the inner layer guides the rays along the forward direction with a large deflection angle and prevents the occurrence of backward scattering; a diverging lens with the refractive index less than unity was employed. The outer layer was designed based on the theory of Luneburg lens with the refractive index of the medium is radius dependent; it is termed as the converging lens. Combining these two lenses, the cloak is designed to achieve the low-scattering and smooth power-flow. However, the radius-dependent refractive index medium does not exist in nature. Although the multiple uniform dielectric layers with piecewise constant refractive index can be employed, the diverging lens with refractive index less than unity can not be found. In this research, the synthetic dielectrics, made of metallic cylinders array immersed in a commonly used dielectric medium, are developed. The effective refractive index is obtained from the dispersion- and phase-relation of the synthetic dielectric medium, which can be regarded as a periodic medium of infinite in extent. Significantly, the frequency- and angular-dependent effective refractive index of the synthetic dielectric can be determined by the mode-matching approach [7].

Different from the design in [2], only three layers are employed in our cloak design. Figure 3 shows a metallic cylinder and a cloaking structure composed of three concentric layers outside the circular cylinder. Each layer is made of the aforementioned synthetic dielectric. The arrangement of the three layers are described as follows. The outmost layer has the refractive index near the background material (air) for reducing the direct reflection (impedance match). The middle layer has the refractive index greater than one for guiding the rays along this channel. The two outer layers form a converging lens. On the other hand, the inner layer having the refractive index less than unity is served as a diverging lens.

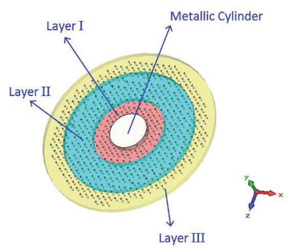

Fig. 3. Invisibility cloak and the metallic column under cloaking

We again carry out the numerical simulation by replacing the metallic circular cylinder in Fig.1 with the structure shown in Fig. 3. Figure 4 shows transmission characteristics in the presence of the metallic block installed with the cloak designed at 8.2GHz. Apparently, the transmission coefficient is considerably enhanced compared with that depicted in Fig 1. We would emphasize that such a cloak is a narrow band device. The frequency-dependent refractive index of the synthetic dielectrics, in fact, affects the cloaking performance significantly.

To understand the physical consequence of the wave process involved in the cloaking structure under development, the contour map of Poynting power at 8.2GHz was drawn and shown in Fig. 5. Since the outmost layer has the refractive index near one, the direct reflection is minimized. The transmitted wave is then guided along the middle layer. As a consequence, we may see the power density is surrounding the circular cylinder and resides in the middle layer. Moreover, because of the inner layer with the refractive index less than one, the wave is forced to be pushed away from this layer (diverging lens). The converging lens based on the Luneburg lens theory enables the presence of a focal point at the other side. The

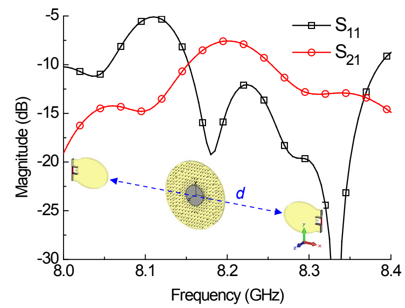

Fig. 4. Propagation loss in the presence of a metallic circular cylinder with the cloak

emission from the focal point completes the microwave link. Significantly, the shadow region disappears in this example.

The research findings of this research contain: (1) the three-layered structure with the refractive indices near one, greater than one, and less than one (from outer to inner) can achieve a cloak design, and (2) the synthetic dielectrics using metal cylinders array immersed in a commonly used dielectric medium have the effective refractive ranging from less than one to greater than one.

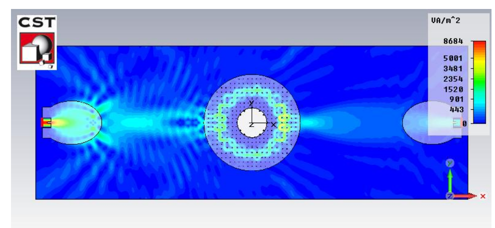

Fig. 5. Contour map of Poynting power at 8.2GHz in the whole structure; with cloak

ACKNOWLEDGEMENT

The author thanks National Science Council, Taiwan for their support in the project under the contract: MOST 103-2221-E-009 -029.

REFERENCES

[1] J. B. Pendry, D. Schurig, and D. R. Smith, “Controlling electromagnetic fields,” *Science*, vol. 312, no. 5781, pp. 1780–1782, 2006.
[2] J. Sun, J. Zhou, and L. Kang, “Homogenous isotropic invisible cloak based on geometrical optics,” *Optics Express*, vol. 16, no. 22, pp. 17 768–17 773, 2008.
[3] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, “Low frequency plasmons in thin-wire structures,” *Journal of Physics*, vol. 10, pp. 4785–4809, 1998.
[4] R.-B. Hwang, H.-W. Liu, and C.-Y. Chin, “A metamaterial-based e-plane horn antenna,” *Progress In Electromagnetics Research*, vol. 93, pp. 275–289, 2009.
[5] “CST studio suite 2012,” http://www.cst.com.
[6] N. Pohl, “A dielectric lens antenna with enhanced aperture efficiency for industrial radar applications,” in *Antennas and Propagation (MECAP), 2010 IEEE Middle East Conference on*, pp. 1–5.
[7] Ruey-Bing (Raybeam) Hwang, *Periodic Structures: Mode-Matching Approach and Applications in Electromagnetic Engineering, 1st ed.*. Wiley-IEEE Press, 2013