

Nonreciprocal Concentric Metasurface Cloak

Mojtaba Dehmollaian⁽¹⁾, Guillaume Lavigne⁽¹⁾, and Christophe Caloz⁽²⁾

⁽¹⁾ Polytechnique Montréal, Montréal, Québec, H3T 1J4, Canada

⁽²⁾ ESAT-WAVECORE-META Research Center, KU Leuven, Leuven, 3001, Belgium

Abstract—We introduce here a nonreciprocal (NR) cloak, based on multiple circular concentric metasurfaces, where the curved metasurfaces bend the electromagnetic energy around a cloaked region similar to a conventional reciprocal cloak. On the other hand, we replace one of the reciprocal metasurfaces by a proper nonreciprocal one such that a source placed inside the cloaked region can effectively send signals to the outside. The simulation results confirm the perfect cloak performance and capability of the NR cloak as a transmitter.

I. INTRODUCTION

Cloaking is a powerful concept in electromagnetics [1]. An invisibility¹ cloak is a metamaterial shell that is designed so as to suppresses the scattering cross section of an object surrounded by it, hence making it invisible, ideally for all angles of incidence and observation [1]–[3]. Such invisibility may find wide applications, including warfare stealth, electromagnetic compatibility and noninvasive sensing [3].

Most of the cloaking structures reported to date have been fully reciprocal. An exception is the cloak reported in [4], which is circularly asymmetric, nonreciprocal system that operates as a conventional cloak in one direction and as a reflector in the opposite direction.

Here, we present a different type of NR cloak. This cloak is based on the concentric array of bianisotropic metasurfaces [6] reported in [5], whose inner-most metasurface has been made nonreciprocal [7]. Preserving the circular symmetry of the conventional cloak, this device maintains the all-angle invisibility of the object placed in its center, but allows a source accompanying the object to radiate through the structure and hence to send information to the outside world.

II. OPERATION PRINCIPLE AND METASURFACE STRUCTURE

Figure 1 presents the proposed nonreciprocal metasurface cloak. Figure 1(a) depicts the operation principle of the device. The object inside the cloak (A) is invisible to

an external observer (B), but the same object can transmit a signal to an external receiver (C), possibly with a specified radiation pattern, thanks to nonreciprocity and proper phase gradient.

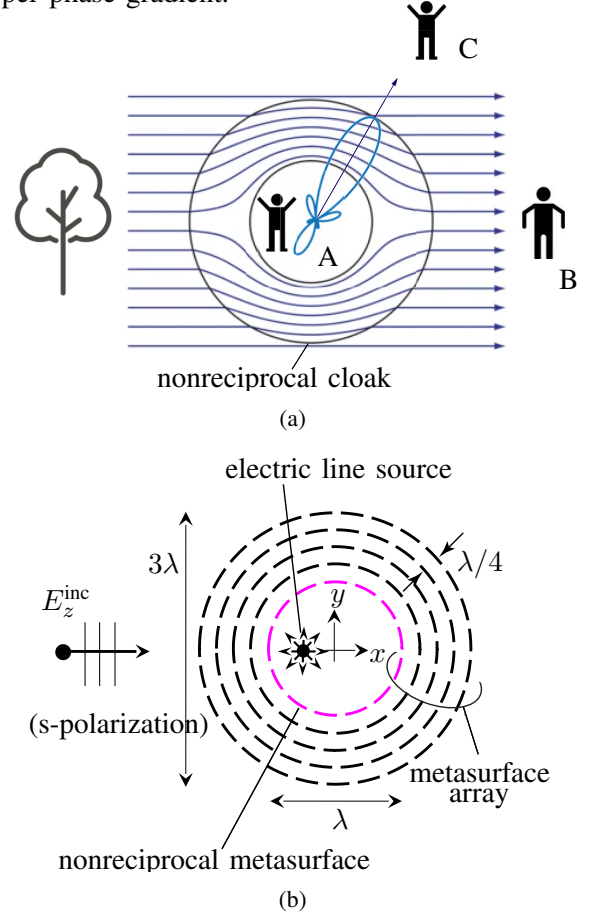


Fig. 1: Proposed cloak. (a) Operation principle. (b) Concentric metasurface structure.

Figure 1(b) shows the structure of the cloak. It is the same structure as the reciprocal metasurface cloak reported in [5], namely an array of concentric metasurfaces separated by a quarter-wavelength distance, except that the inner-most metasurface has been replaced by a nonreciprocal metasurface. The cloaking operation for waves incident on the cloak from the outside region is based on two mechanisms: 1) the suppression of the

¹Other types of cloaks include illusion cloaks.

multiple reflection by 2D Fabry-Perot resonance cancellation and 2) the optimized guidance of the wave across the semi-porous metasurface waveguides. The innermost metasurface is a circular spatial isolator structure that passes light from its center and blocks it, by way of total reflection, in the opposite direction.

In the following results, we assume a two-dimensional problem, with the incident wave being s-polarized and the source inside the cloak being a Dirac line source. The results can be naturally easily generalized to the other polarization and more complex source configurations.

III. DESIGN AND RESULTS

As illustrated in Fig. 1(b), we use an array of 5 concentric metasurfaces. All of them are omega-type bianisotropic [9] structures with appropriate tangential susceptibilities for diffraction-free, lossless and gainless transmission [6]. The reciprocity of the innermost metasurface is broken heteroanisotropically via $\chi_{em}^{zy} \neq -\chi_{me}^{yz}$, as in the flat nonreciprocal metasurface reported in [7].

We model the structure in an exact electromagnetic manner using a combination of Mode Matching (MM) and Generalized Sheet Transition Conditions (GSTCs) [8]. The electromagnetic field in the 6 regions of the structure are expanded over cylindrical Bessel functions in the radial direction and sinusoidal functions in the azimuthal direction, and the GSTCs are applied at the 5 interfaces between these regions.

The synthesis of the structure, i.e., the determination of the susceptibilities of the different metasurface layers required to accomplish the desired operation (see Fig. 1(a)), is performed by iterative minimization of the total scattering cross section for outside illumination with the constraint in the innermost metasurface of total reflection from the outside and total transmission from the inside.

Figure 2 show preliminary results, which demonstrate that the structure operates as expected, i.e., as a perfect cloak for outside illumination (normalized scattered power of 10^{-2}), and as a perfect transmitter for illumination from the inside.

Note that the structure, being composed of uniform metasurfaces, is circularly symmetric, which provides all-angle invisibility for external illumination, and omnidirectional transmission for internal illumination.

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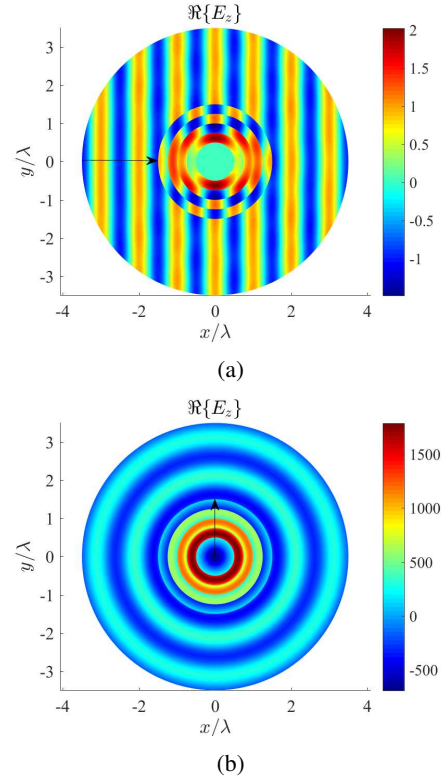


Fig. 2: Analytical results for the nonreciprocal cloak in Fig. 1. (a) Conventional cloak operation for illumination from the outside. (b) Transmission (here omnidirectional) for illumination from the inside.

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