Nonreciprocal Concentric Metasurface Cloak

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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 invisibility\textsuperscript{1} 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.

\textsuperscript{1}Other types of cloaks include illusion cloaks.
multiple reflection by 2D Fabry-Perot resonance cancel-
lation 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 meta-
surface is broken heteroanisotropically via \( \chi_{ym} \neq -\chi_{ym} \),
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 lay-
ers 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 per-
fected cloak for outside illumination (normalized scattered
power of \( 10^{-2} \)), and as a perfect transmitter for illumi-
nation from the inside.

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

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