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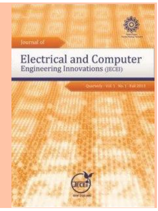


# Electromagnetic Absorber Realization Using Huygens Metasurfaces

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**ABSTRACT**

In this paper, the possible realization of the electromagnetic (EM) absorber as a thin metasurface is considered. The metasurface is based on establishing a passive surface of electric and magnetic currents using the Huygen's principle. So, the absorber is named Huygens Absorber (HA). The metasurface can be designed using split meander lines with spiral rings. In this way, both sides of the substrate must be patterned to obtain electric and magnetic currents. In this paper, it is shown that the currents can be obtained using appropriate cells based on bi-anisotropic media theory. It is shown that to obtain a normal absorber, appropriate omega particles can be used. It is worth noting that the proposed absorber does not need any lossy material to absorb the waves which is a unique and excellent property of this kind of absorber. It is a thin groundless surface which makes it possible to design a double-sided metasurface.

## 1. Introduction

Metamaterial absorbers (MAs), which are formed by periodic or random patterns and dielectric substrates, have attracted attention since they are easy to fabricate and also have good absorbing properties [1]. The first electromagnetic (EM) absorber so-called Salisbury screen was proposed in late 1980s [2]. It consists of a continuous resistive film placed a quarter wavelength above a ground plane. Because of its resonant feature, the Salisbury screen has a limited bandwidth. Later, Jaumann screen and lossy frequency selective surfaces (FSS) were reported as thick broadband absorbers [3-4] and lossy high-impedance surface (HIS) as a thinner one [5-6]. Regardless of the bandwidth, all of the absorbers have one common characteristic, which is loss. Furthermore, most of them need a ground plane and have thick substrates.

Recently, metasurfaces which are two dimensional metamaterials have been introduced and applied in various applications such as absorbers, lenses and refracting surfaces [7-8]. A class of metasurfaces called Huygens metasurface, suggests an active strategy by placing electric and magnetic dipoles and a passive strategy by a combined impedance and admittance surface to manipulate the EM waves. The idea is based on the equivalence principle.

In this paper, we suggest a new strategy to design EM absorbers using Huygens metasurfaces. The design is based on cancellation of reflected and transmitted fields from the interface, using passive Huygens metasurface. The method leads to a thin structure, without the need for a ground plane, and above all, without the need for any lossy materials. Furthermore, two ways to realize a metasurface are proposed: (a) to combine two separate Huygens electric and magnetic current surfaces using split meander lines and spiral rings, and (b) to use omega particles to provide electric and magnetic currents on a single surface.

## 2. Theory

According to the Huygen's principle, the transmitted fields above an imaginary interface can be obtained by placing suitable fictitious electromagnetic sources which satisfy the boundary conditions over the surface. The interface can be created using the electric and magnetic currents which act as a Huygens source to radiate the desired fields. These currents can be synthesized either by an array of electric and magnetic dipoles as an active implementation or by a combined impedance and admittance surface as a passive one.

The electromagnetic absorber prohibits the EM waves from transmitting and reflecting. Basically, most of the absorbers need resistive materials to absorb the EM waves by wasting their energy. Based on Huygen's principle, the passive surface can be designed so as to cancel out the reflected and transmitted fields from the interface without wasting any power. Fig. 1(a) shows an electromagnetic (EM) plane wave incident normally to the interface depicted by dashed lines. Assuming the environment as the free space, if there is no discontinuity at the fictitious interface, the incident field would transmit completely with no change and reflection. By placing an absorbing surface at the boundary, the transmitted field also vanishes just as the reflected field, as illustrated in Fig. 1(b).

Based on the Huygen's principle, appropriate Huygens sources on the interface can be placed such that they radiate electromagnetic fields equal to the incident field but in the opposite direction. This is depicted in Fig. 1(c). In general, assuming the fields at both sides of the boundary are known, the required Huygens sources are obtained using the tangential boundary conditions. Using the summation rule, when the plane wave impinges on the Huygens metasurface, the total EM fields at both sides of the interface vanishes or is absorbed. As can be seen, no lossy material is needed to absorb the fields, as shown in Fig. 1(d).

Consider a plane wave of $x$ polarization impinging normally to the interface as shown in Fig. 2(a). To absorb the fields, the required Huygens sources are obtained accordingly to provide EM fields as depicted in Fig. 2(b). Applying the boundary conditions, the required Huygens currents are obtained as in Eqs. 1(a-f).

$$\hat{n}\times\left(\vec{E}_2-\vec{E}_1\right)=-\vec{M}_s \tag{1.a}$$

$$\hat{n}\times\left(\vec{H}_2-\vec{H}_1\right)=\vec{J}_s \tag{1.b}$$

$$\hat{z}\times\left(-E_i\hat{x}\right)=-\vec{M}_s \tag{1.c}$$

$$\hat{z}\times\left(-H_i\hat{y}\right)=\vec{J}_s \tag{1.d}$$

$$\vec{M}_s=-E_i\hat{y} \tag{1.e}$$

$$\vec{J}_s=H_i\hat{x} \tag{1.f}$$

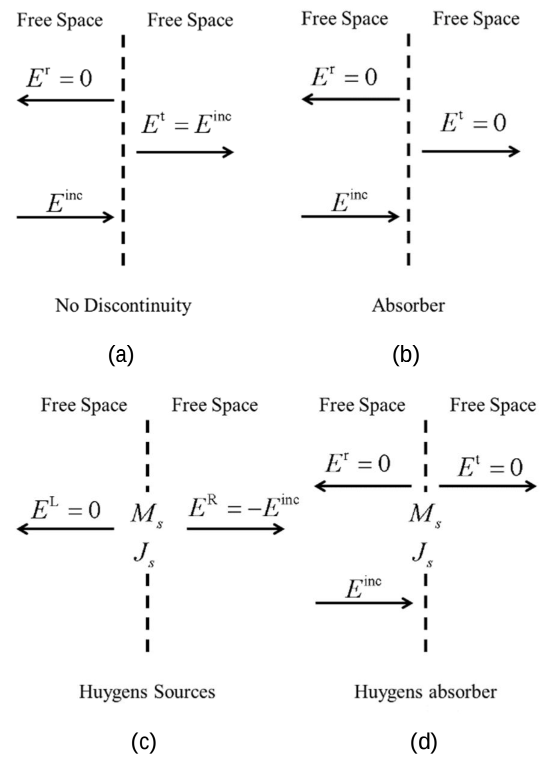


Figure 1: (a) EM plane wave propagating in the free space with no discontinuity, (b) EM plane wave impinging onto the absorber, (c) The required Huygens sources to cancel out the transmitted and reflected waves from the fictitious interface, (d) Huygens absorber.

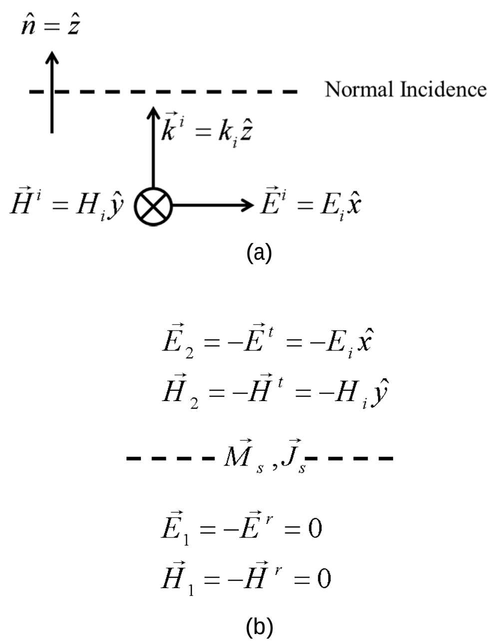


Figure 2: (a) Normal incidence of x polarized EM field, (b) The required Huygens sources to absorb the incident fields.

## 3. Required Huygens sources

As can be seen, the incident EM fields in this case are $E_x$ and $H_y$. Thus, the electric and magnetic current cells should provide electric and magnetic currents in x and y directions, respectively. Recently, a method to design Huygens sources with desired electric and magnetic complex currents has been presented in [9]. The design is based on using split meander lines and spiral rings to accommodate complex equivalent electric and magnetic currents for the desired transmitted fields. The same method can be used to obtain the required Huygens sources for the absorber. The method needs a thin substrate with one side patterned by split meander lines directed in the *x* direction and the other side with *y* directed spiral rings. Although the design method reported in [9] is very general and seems to work for any desired metasurface, there are some disadvantages, too. The electric and magnetic currents cells must be designed separately as a two-sheet structure, which makes the structure not easy to be fabricated. Furthermore, the sheets are designed individually and then placed on the sides of a thin substrate that may lead to some mutual coupling effects which are not considered in [9]. Here, we suggest another passive Huygens metasurface which can be applied in the absorber. Small particles of complex shapes formed as the combination of wires and loops in the bi-anisotropic approximation can be characterized by dyadic electric and magnetic polarizabilities, which define the bi-anisotropic relation between the induced electric and magnetic dipole moments $\vec{p},\vec{m}$ and the external electric and magnetic fields $\vec{E},\vec{H}$, as shown below:

$$\begin{aligned}\vec{p} &= \bar{\bar{\alpha}}_{ee}\cdot\vec{E}+\bar{\bar{\alpha}}_{em}\cdot\vec{H}\\ \vec{m} &= \bar{\bar{\alpha}}_{me}\cdot\vec{E}+\bar{\bar{\alpha}}_{mm}\cdot\vec{H}\end{aligned} \tag{2}$$

Here, $\bar{\bar{\alpha}}_{ij}$ is the polarizability dyadic and the sub-indices (*i*,*j*) indicate that the external force is *j*, and that the effect is *i*. For example, $\bar{\bar{\alpha}}_{em}$ designates the electrical polarizability dyadic that the external force is magnetic and the effect is electric.

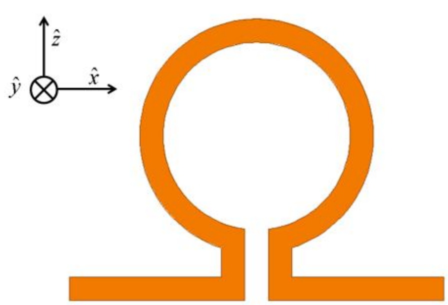


Figure 3: Omega particle.

In these particles both of the induced electric and magnetic currents are related to both electric and magnetic fields [10]. The omega particle is one of the simplest bi-anisotropic particles, as shown in Fig. 3.

Considering the loop normal to the *y*-direction and the arms normal to the *x*-direction, the possible electric and magnetic induced currents on it are as follows:

$$\begin{aligned}&E_x \rightarrow p_x \text{ and } m_y\\ &E_y \rightarrow \text{no effect}\\ &E_z \rightarrow \text{non}-\text{resonant } p_z\\ &H_x \rightarrow \text{no effect}\\ &H_y \rightarrow p_x \text{ and } m_y\\ &H_z \rightarrow \text{no effect}\end{aligned}$$

The exact solution for $\vec{p},\vec{m}$ can be found in [10]. In the special case of normal absorber problem, the incident EM fields are $E_x$ and $H_y$. There is no $E_z$, thus no z directed electric current is induced on the particle. By appropriately designing the cell, it can be used as a Huygens metasurface for the absorber with proper induced EM currents. To obtain the desired complex currents, the arms and the ring of the omega can be modified just like meander lines and spiral. The advantages of the proposed Huygens absorber can be listed as follows:

- The absorber is a plane thin surface
- There is no need for lossy materials
- There is no need for a ground plane. Therefore, it is possible to design a double-sided absorber.
- Using omega cells, problems related to the substrate thickness such as mutual coupling between electric and magnetic cells due to thin substrate and phase delay due to thick substrate are removed.

## 4. Conclusion

The possible realization of EM absorber using passive Huygens metasurface was discussed. For the normal plane wave incidence, it was shown that the metasurface can be designed using split meander lines and spiral rings. Also, it was explained that the Huygens absorber can be formed by omega particles as a unique electromagnetic current source instead of two discrete electric and magnetic current sources.

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