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Pseudo-Bianisotropic Coupling Through Coherent Illumination

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Abstract – One of the main advantages of bianisotropic metasurfaces is their capability to produce asymmetric scattering depending from which side they are illuminated. For most applications, these metasurfaces are expected to be illuminated with a single source at a time. However, in applications with simultaneous illumination by two or more sources, bianisotropic effects can be replicated by exploiting coherent illumination. In this talk, we discuss how asymmetric scattering can be realized for a planar 180° hybrid junction using bianisotropic metasurfaces with omega response and non-bianisotropic metasurfaces under coherent illumination.

I. INTRODUCTION

The attractiveness of bianisotropic media and metasurfaces stems from their capability to produce cross-polarized (chiral) or asymmetric scattering (omega) response [1–4]. In terms of design, bianisotropic metasurface scattering is established for a single illumination source. This approach is enough to design metasurfaces with asymmetric response under illuminations of their two sides. Indeed, for any linear metasurface, the performance will be as expected whether it is illuminated from only one side or simultaneously from both sides. However, interestingly, as we will discuss here, some asymmetric response can be achieved using simpler non-bianisotropic metasurfaces using coherent illumination by two sources.

In this talk, we discuss the concept of emulating bianisotropic omega-response using coherent illumination. More precisely, how the asymmetric reflection of a bianisotropic metasurface designed as a planar 180° hybrid junction [5] can be replicated using only metasurfaces with electric response illuminated with two coherent sources.

Fig. 1: A $\Delta \Sigma$ metasurface combines two incident waves to produce two outgoing waves whose amplitudes are proportional to the sum and difference of the incident waves amplitudes. This device can be implemented as (a) a single bianisotropic metasurface, (b) by two parallel metasurfaces with only electric response separated a quarter of the operational wavelength, or (c) as a single metasurface with only electric response and matching phases of the two coherent incident sources.
II. COHERENT PSEUDO-BIANISTROPY

A 180° hybrid junction is a 4-port device that combines two input waves and outputs waves proportional to their sum and their difference [5]. A two-port implementation of this concept can be envisaged using asymmetric transmission or reflection. The latter case is preferred as it can be realized as a lossless reciprocal device. A plane-wave implementation, as the one shown in Fig. 1(a), functions for two input sources, one per side of the interface,

\[
\begin{align*}
E_{i,F} &= E_F e^{-jk_0 z} a_x, \\
E_{i,B} &= E_B e^{jk_0 z} a_x,
\end{align*}
\]

resulting in two outcoming waves. The amplitudes are proportional to the sum and difference of the amplitudes of the two illuminating waves:

\[
\begin{align*}
E_\Sigma &= E_{R,F} + E_{T,B} = \alpha (E_F + E_B) e^{jk_0 z} a_x, \\
E_\Delta &= E_{R,B} + E_{T,F} = \alpha (E_F - E_B) e^{-jk_0 z} a_x.
\end{align*}
\]

Here, \(\alpha\) is a scaling factor. The bianisotropic implementation of such device, namely a Delta-Sigma (\(\Delta \Sigma\)) bianisotropic metasurface, can be described by the generalized impedance conditions

\[
\begin{align*}
\mathbf{n} \times (\mathbf{E}_R - \mathbf{E}_L) &= Z_{nn} \frac{\mathbf{H}_R + \mathbf{H}_L}{2} + \gamma_{em} \mathbf{n} \times \left[ \frac{\mathbf{E}_R + \mathbf{E}_L}{2} \right], \\
\mathbf{n} \times (\mathbf{H}_R - \mathbf{H}_L) &= -Y_{ee} \frac{\mathbf{E}_R + \mathbf{E}_L}{2} - \chi_{me} \mathbf{n} \times \left[ \frac{\mathbf{H}_R + \mathbf{H}_L}{2} \right],
\end{align*}
\]

where \(Y_{ee}\) is the sheet electric admittance, \(Z_{nn}\) the sheet magnetic impedance, and \(\gamma_{em}\) and \(\chi_{me}\) are the magnetoelectric coupling parameters [6]. \(E_R (H_R)\) is the net tangential electric (magnetic) field at the right side of the interface, while \(E_L (H_L)\) is the corresponding net tangential electric (magnetic) field at the left side. For the metasurface equivalent \(\Gamma\)-model shown in Fig. 1(a), these parameters read

\[
Y_{ee} = \frac{4}{4Z_{C,B} + Z_{R,B}}, \quad \gamma_{em} = \chi_{me} = \frac{2Z_{R,B}}{4Z_{C,B} + Z_{R,B}}, \quad Z_{nn} = \frac{4Z_{C,B}Z_{R,B}}{4Z_{C,B} + Z_{R,B}}.
\]

A lossless \(\Delta \Sigma\) metasurface with \(\alpha = \pm j1/\sqrt{2}\) is obtained using parallel (\(Z_C\)) and shunt impedances (\(Z_R\)) of

\[
Z_{C,B} = \alpha \eta_0, \quad Z_{R,B} = \frac{\eta_0}{\alpha}.
\]

Next, we show that this \(\Delta \Sigma\) bianisotropic metasurface can be converted into two parallel nonbianisotropic metasurfaces by modelling its electric and magnetic response by equivalent circuit elements \(Z_{C,B}\) and \(Z_{R,B}\), respectively. Then, using a quarter-wave transformer [5], we can convert \(Z_{R,B}\) into an metasurface with electric response leading to

\[
Z_{R,A} = \frac{\eta_0}{Z_{R,B}} = \alpha \eta_0 = Z_{C,A}.
\]

The corresponding device is shown in Fig. 1(b), similarly as done in [7], with surface impedances \(Z_{C,B} = \alpha \eta_0\) separated by a distance \(d = \lambda_0/4\), where \(\lambda_0\) is the operational wavelength. The metasurface pair, unlike the \(\Delta \Sigma\) bianisotropic metasurface, exploits the additional phase difference introduced by its large size, offering the same performance defined by Eqs. (2) for waves whose phases are counted from the reference plane at the left metasurface. Interestingly, this metasurface pair is geometrically symmetric, since both sheets have the same sheet impedance. The required asymmetry for the hybrid operation is ensured by an additional phase shift over the device thickness when the reference plane is defined asymmetrically. In the absolute terms, phases of all input and output waves are counted from the same plane: the metasurface located at \(z = 0\) in Fig. 1(b). Thus, from the point of view of each individual source, the “forward” wave (propagating in the +z direction) has its reference plane at the first metasurface that the wave illuminates. However, the reference plane for the “backward” wave (propagating in the −z direction) is located at the last metasurface that the wave reaches. As a result, the reflected wave \(E_{R,B}\) is defined with an additional phase of \(\phi_{R,B} = 2k_0 d = \pi\) with respect to the incident backward wave.
Moreover, it is possible to emulate this bianisotropic response of the asymmetric metasurface of Fig. 1(a) illuminating a single electrically polarizable sheet by two coherent sources, as illustrated in Fig. 1(c). We call this device $\Delta \Sigma$ coherent metasurface. The metasurface is designed with only electric response in mind [described as $Y_{ee} = 1/Z_C$ and $Z_{nn} = \gamma_m = \chi_{me} = 0$ in Eq. (3)], that can replicate the behaviour of a $\Delta \Sigma$ bianisotropic metasurface by using sources with matching phase $\phi$ in the form

$E_{I,P} = E_Fe^{j\phi}e^{-jk_{0}az}a_x,$  

$E_{I,B} = E_Be^{-j\phi}e^{jk_{0}az}a_x.$  

(7a)

(7b)

Using a modified definition of summation and subtraction from Eqs. (2), with independent scaling factors $\alpha_{\Sigma}$ and $\alpha_{\Delta}$, respectively, the combination of phase and surface impedance that fulfill the boundary conditions of Eq. (3) read

$\phi[n] = \pi \left( \frac{1 + 2n}{4} \right), \quad Z_C[n] = -\frac{j\eta_0}{2\tan(\phi[n])},$  

(8)

where $n$ is an integer value. The corresponding complex scalars for sum and difference, respectively, read

$\alpha_{\Sigma} = -j\sin(\phi[n]), \quad \alpha_{\Delta} = \cos(\phi[n]).$  

(9)

The simulation results shown in Fig. 1 reveal that these three possible architectures can produce the desired scattering using either actual bianisotropy or coherent pseudo-bianisotropy under this specific illumination.

III. Conclusions

In this talk, we have discussed how asymmetric reflection can be emulated using coherent illumination. We presented different implementations of a $180^\circ$ hybrid junction as $\Delta \Sigma$ metasurfaces. The first implementation is based on a metasurface with omega response ($\Delta \Sigma$ bianisotropic metasurface). Using conventional transmission-line techniques, a $\Delta \Sigma$ metasurface pair is a version of the bianisotropic design that exploits the presence of two illuminating sources as a combined coherent source. Finally, we have shown that omega coupling in bianisotropic metasurfaces can be emulated using the introduced concept of $\Delta \Sigma$ coherent metasurface, that exploits coherent illumination to replicate asymmetric reflection using a single metasurface with purely electric response.

REFERENCES


