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PLANAR DB BOUNDARY PLACED IN A CHIRAL AND CHIRAL NIHILITY METAMATERIAL

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Abstract—Reflection from a planar DB interface placed in chiral and chiral nihility medium is studied. No difference between the two cases, regarding reflection chracteristics, is noted. No reflected backward wave is produced for DB interface placed in chiral nihility metamaterial. In this regard, DB interface may be considered as first known perfect reflector interface which yields non zero power when placed in chiral nihility medium.

1. INTRODUCTION

Chiral medium is a well-known metamaterial for its characteristics to possess the phenomenon of optical activity and circular dichroism [1–4]. After the introduction of nihility concept by Lakhtakia [5], Tretyakov et al. incorporated the nihility conditions to chiral medium and proposed another metamaterial termed as chiral nihility metamaterial [6, 7]. The nihility concept for ordinary media itself has also gained attention of many researchers [8, 9]. It is of worth noting that chiral nihility is taken as a limiting case of the chiral medium. Chiral nihility has made its mark as a metamaterial which can support negative reflection and refraction [10–18]. That is, a perfect electric conductor (PEC) interface placed in chiral nihility metamaterial produces backward wave as reflected wave [10]. It is known that, PEC interface placed in chiral medium produces two reflected forward waves whereas in chiral nihility medium it produces only backward wave as reflected wave. So, there is difference regarding reflection behavior for the two cases. In chiral nihility case, reflected electric field cancels the incident electric field and results in null power propagation in chiral

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nihility medium. Excitation of a grounded chiral nihility layer, means a layer backed by PEC/PEMC interface, due to plane wave produces both negative reflection and refraction in grounded chiral nihility layer [11–13, 19–23]. The result, concluded in PEC case, regarding total power remains valid if PEC interface is replaced with perfect electromagnetic conductor (PEMC) [20]. That is, time average power of incident wave cancels the time average power of reflected backward wave. Furthermore, both reflected and refracted backward waves exist in geometry containing chiral nihility-chiral nihility interface. The contribution already published in technical literature, leads to conclusion, that only a backward reflected wave is produced when perfect reflector, e.g., PEC, PMC, fractional dual interface and PEMC, placed in chiral nihility metamaterial is excited by plane wave. In all cases, either electric field or magnetic field or the time average power do not exist in chiral nihility medium.

Before the advent of idea 'DB boundary' proposed by Lindel et al. [24], all the known interfaces dealt with tangential components of electric and magnetic fields. But the DB boundary proposed by Lindell is analyzed on the basis of normal components of flux densities $\mathbf{D}$ and $\mathbf{B}$ [24–28]. The boundary conditions for DB interface may be written as [24]

$$\begin{aligned}\hat{\mathbf{n}} \cdot \mathbf{D} &= 0\\ \hat{\mathbf{n}} \cdot \mathbf{B} &= 0\end{aligned}$$

where $\hat{\mathbf{n}}$ is normal vector to the surface. For TE excitation, DB interface behaves like a PEC and for TM excitation, DB interface behaves like PMC.

In the present communication, reflection from a DB planar boundary which is placed in a chiral and chiral nihility metamaterial is encountered. Purpose of the discussion to introduce DB boundary interface as a perfect reflector which can yield non zero power when it is attached to chiral nihility medium.

2. PLANAR DB BOUNDARY PLACED IN A CHIRAL METAMATERIAL

Consider a planar DB boundary located at $z = 0$, as shown in Fig. 1. The half space $z < 0$ is occupied by a lossless, homogeneous, and isotropic chiral medium. Unit normal to the interface is $\hat{\mathbf{n}} = \hat{\mathbf{z}}$. The chiral medium is described by the constitutive parameters (ϵ, μ, κ) having following constitutive relations [1]

$$\begin{aligned}\mathbf{D} &= \epsilon\mathbf{E} + i\kappa\mathbf{H}\\ \mathbf{B} &= \mu\mathbf{H} - i\kappa\mathbf{E}\end{aligned}$$

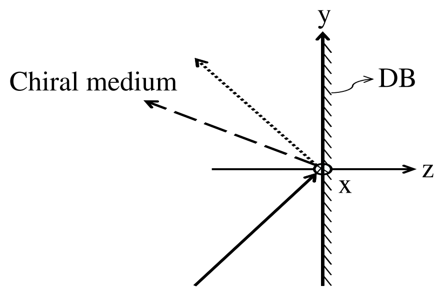

Figure 1. Reflection from a DB boundary placed in chiral medium: Incident LCP (solid lines), Reflected LCP (dotted line), Reflected RCP (dashed line).

The DB planar boundary has been excited by an oblique incident and left circularly polarized (LCP) uniform plane wave from chiral side. Reflected fields from DB boundary may be written as a linear combination of two circularly polarized plane waves as [10]

$$\mathbf{E}_{inc} = \left(\hat{x} - \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y + ik_z^+ z) \tag{1a}$$

$$\begin{aligned}\mathbf{E}_{ref} = {} & A\left(\hat{x} + \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y - ik_z^+ z) \\ & + B\left(\hat{x} - \frac{ik_z^-}{k^-}\hat{y} - \frac{ik_y}{k^-}\hat{z}\right)\exp(ik_y y - ik_z^- z)\end{aligned} \tag{1b}$$

$$\mathbf{H}_{inc} = \frac{i}{\eta}\left(\hat{x} - \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y + ik_z^+ z) \tag{1c}$$

$$\begin{aligned}\mathbf{H}_{ref} = {} & \frac{i}{\eta}\left[A\left(\hat{x} + \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y - ik_z^+ z)\right. \\ & \left. - B\left(\hat{x} - \frac{ik_z^-}{k^-}\hat{y} - \frac{ik_y}{k^-}\hat{z}\right)\exp(ik_y y - ik_z^- z)\right]\end{aligned} \tag{1d}$$

$$\eta = \sqrt{\frac{\mu}{\epsilon}}$$

where $k^{\pm}$ are two wavenumbers for chiral medium and can be illustrated as

$$k^{\pm} = \omega\left(\sqrt{\mu\epsilon} \pm \kappa\right)$$

Coefficients A and B are unknowns, which can be determined by applying DB boundary conditions. Application of the following DB

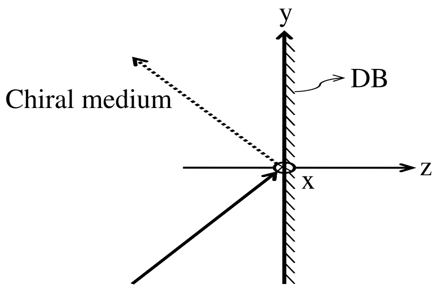

Figure 2. Reflection from a DB boundary placed in chiral medium. Only Co-polarized reflected wave exists.

boundary conditions

$$\hat{\mathbf{n}} \cdot (\mathbf{D}_{inc} + \mathbf{D}_{ref}) = 0 \tag{2a}$$

$$\hat{\mathbf{n}} \cdot (\mathbf{B}_{inc} + \mathbf{B}_{ref}) = 0 \tag{2b}$$

at $z = 0$ yield following results for unknown coefficients

$$A = -1, \qquad B = 0$$

Derived result reveals the fact that if an oblique incident LCP plane wave hits a DB boundary placed in chiral medium, then only LCP plane wave reflects making same angle with the normal as that of incident wave as shown in Fig. 2.

3. PLANAR DB BOUNDARY PLACED IN CHIRAL NIHILITY METAMATERIAL

Chiral nihility states that $\epsilon \to 0$, $\mu \to 0$, and $\kappa \neq 0$. This leads to following constitutive relations [6]

$$\mathbf{D} = i\kappa\mathbf{H}, \qquad \mathbf{B} = -i\kappa\mathbf{E}$$

Two corresponding wavenumbers are

$$k^{\pm} = \pm\omega\kappa$$

and relation between normal components of wave vectors

$$k_z^{+} = -k_z^{-}$$

Using these conditions in (1), resulting field expressions in terms of unknowns for chiral nihility medium are given below [10] and relevant

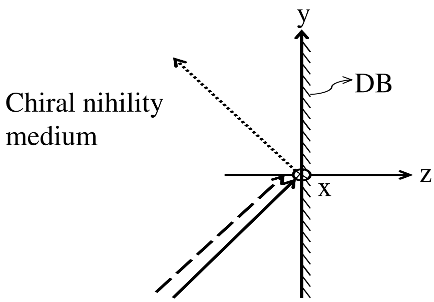

Figure 3. Reflection from a DB boundary placed in chiral nihility medium (wave vector representation): Forward reflected wave (dotted line), Backward wave reflected (dashed line).

geometry is presented in Fig. 3.

$$\mathbf{E}_{inc} = \left(\hat{x} - \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y + ik_z^+ z) \tag{3a}$$

$$\begin{aligned}\mathbf{E}_{ref} &= A\left(\hat{x} + \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y - ik_z^+ z) \\ &\quad + B\left(\hat{x} - \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y + ik_z^+ z)\end{aligned} \tag{3b}$$

$$\mathbf{H}_{inc} = \frac{i}{\eta}\left(\hat{x} - \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y + ik_z^+ z) \tag{3c}$$

$$\begin{aligned}\mathbf{H}_{ref} &= \frac{i}{\eta}\left[A\left(\hat{x} + \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y - ik_z^+ z)\right. \\ &\quad \left. - B\left(\hat{x} - \frac{ik_z^+}{k^+}\hat{y} + \frac{ik_y}{k^+}\hat{z}\right)\exp(ik_y y + ik_z^+ z)\right]\end{aligned} \tag{3d}$$

Second term in expression for reflected electric and magnetic field corresponds to negative reflection. Unknown coefficients can be determined by using the DB boundary conditions (2) at $z = 0$. Application of boundary conditions that normal components of total electric and magnetic fields are zero at $z = 0$, yields the following

$$A = -1, \qquad B = 0$$

Only one reflected wave is produced and it is of same polarization as the incident wave, Fig. 4 describes the situation. Angle of reflected wave with the normal is same as the incident wave.

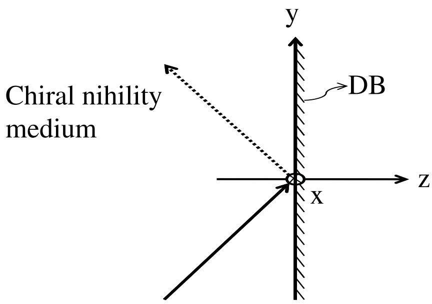

Figure 4. Reflection from a DB boundary placed in chiral nihility medium. No reflected backward wave exists.

4. CONCLUSIONS

Stunning result has broken the ice of phenomenon of negative reflection in chiral nihility medium when perfect reflector placed in chiral nihility medium is excited by plane wave. That is, in this case phenomena of negative reflection is not produced in chiral nihility metamaterial. No difference between reflection characteristics for DB interface placed in chiral and chiral nihility metamaterial is observed. Moreover, DB interface in the presence of chiral and chiral nihility medium behaves like perfect reflector interface in the presence of ordinary dielectric.

DB interface has been introduced as first known perfect reflector which deviates from the previously drawn conclusions about behavior of perfect reflectors placed in chiral nihility medium. That is, DB interface yields nonzero power when placed in chiral nihility medium when excited by electromagnetic fields whereas all already considered, in published literature, perfect reflector yield zero power in such configurations.

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