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Cylindrical Resonators Partially Filled with a DNG Metamaterial Sector

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Abstract **– A metallic cylindrical resonator partially filled with double-negative (DNG) metamaterial with sector shape is analyzed in the frequency domain. The remaining part of the resonator is filled by a double-positive (DPS) medium. The structure results in a cylindrical resonator of finite length with a metamaterial wedge whose edge is on the cylinder axis.**

A line source excitation located in the DPS region is applied to investigate the properties of the structure by exciting the compatible modes of the structure. An exact analytical solution is obtained.

1 INTRODUCTION

The use of double-negative (DNG) metamaterial for resonators was introduced by Engheta [1], [2], who proposed a one-dimensional resonator containing double-negative (DNG) metamaterial in part of its volume. The lossless DPS material is characterized by a positive permittivity ε and a positive permeability μ, or equivalently by a propagation constant k = ω√(εμ) and an intrinsic impedance Z = √(μ/ε), while the DNG metamaterial is assumed to be a linear, homogeneous, lossless and isotropic material characterized by a real negative permittivity -ε and a real negative permittivity -μ, or equivalently by a real negative wavenumber – k and a real positive intrinsic impedance. Thus, the DPS and DNG regions are anti-isorefractive to each other.

The use of DNG in three-dimensional cavity resonators was previously investigated by Couture et al. [3,4] and by Uslenghi [5,6]. A review of these structures was presented in [7].

The main property of this kind of resonators is that they can operate independently of frequency if they behave as postulated; however, since passive DNG materials are dispersive, broadbanding may be achievable only by the use of active (non-Foster) metamaterials.

The novel resonator introduced herein is a metallic circular cylindrical resonators of radius *a* with finite length *d,* sectorally filled with DNG metamaterial.

The cross section is characterized by the presence of a DNG wedge whose edge coincides with the axis of the resonator and whose aperture angle is 2α (classical penetrable wedge are studied in [8-10]). A DPS material fills the remaining volume of the resonator.

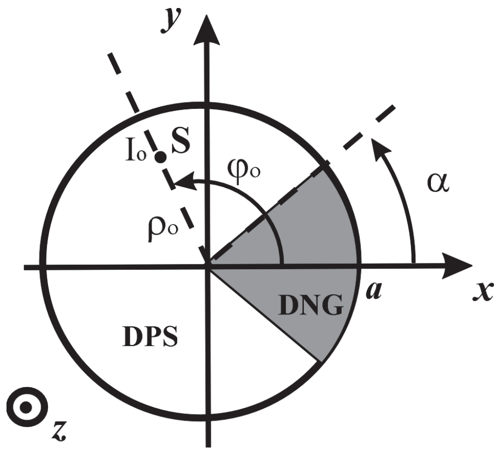

Figure 1: Cross section of the resonator.

We study the structure in the frequency domain with time-dependence factor *exp(+jωt)* omitted throughout.

The cross section of the resonator is shown in Fig. 1, which also shows a line source excitation S at (ρ_o, φ_o):

$$\mathbf{J} = I_o \delta(\boldsymbol{\rho} - \boldsymbol{\rho}_o)\hat{z} = I_o \frac{1}{\rho_o}\delta(\rho - \rho_o)\delta(\varphi - \varphi_o)\hat{z} \quad (1)$$

The case $\alpha<\pi/2$ has been studied in [11]-[12], and some numerical results will be shown at the conference.

The case $\alpha=\pi/2$ is currently under study since it shows some mathematical difficulties.

2 RESONANCE CONDITION

The electric field inside the resonator is assumed to be of the form:

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$$\mathbf{E}^{\pm} = \hat{z} J_{\nu}(\pm k\rho)[A_{\nu}^{\pm} \sin(\nu\varphi) + B_{\nu}^{\pm} \cos(\nu\varphi)] \quad (2)$$

where the upper (lower) sign applies to the DPS (DNG) sub-volume. Consequently, the magnetic field components are

$$\begin{aligned} H_{\rho}^{\pm}(\rho,\varphi) &= \frac{\pm j\nu}{\omega\mu\rho} J_{\nu}(\pm k\rho)[A_{\nu}^{\pm}\cos(\nu\varphi) - B_{\nu}^{\pm}\sin(\nu\varphi)] \\ H_{\varphi}^{\pm}(\rho,\varphi) &= \frac{\mp j}{\omega\mu}\frac{\partial}{\partial\rho}[J_{\nu}(\pm k\rho)][A_{\nu}^{\pm}\sin(\nu\varphi) + B_{\nu}^{\pm}\cos(\nu\varphi)] \\ H_{z}^{\pm}(\rho,\varphi) &= 0 \end{aligned} \quad (3)$$

The imposition of the boundary conditions yields an algebraic system of homogenous equations. Nonzero fields are obtained when:

$$\sin((\pi - 2\alpha)\nu) = 0 \quad (4)$$

Whenever $\alpha \neq \pi/2$, the possible values of the separation constant ν form a discrete set:

$$\nu_m = \frac{m\pi}{\pi - 2\alpha}, \quad (m = 0, \pm 1, \pm 2, ...) \quad (5)$$

The resonator frequencies are obtained by imposing the boundary condition on the metallic walls of the resonator, yielding:

$$J_{\nu_m}(ka) = 0 \quad (6)$$

However, if $\alpha = \pi/2$, then the resonance condition (4) is identically satisfied, and the boundary condition on the PEC walls yields the allowed values of ν for any preassigned frequency; in this case, the possible values of the separation constant ν form a continuous set.

4 PROPOSED SOLUTION

For $\alpha \neq \pi/2$ the solution of the problem can be found by employing the resolvent technique [13]. This technique requires the evaluation of the one dimensional characteristic Green function in the azimuthal direction. In order to reduce this problem to the solution of a Sturm-Liouville (SL) problem on a finite interval, we need to consider the azimuthal periodicity of the field E_z. Because of the presence of the DNG sector, we cannot resort to the expedient used in [13] for the case of a resonator filled with a homogeneous DPS medium. We propose to decompose the problem into two symmetries and to define azimuthal non-uniform transmission lines to model the problem.

For $\alpha = \pi/2$ the solution of the problem cannot be found by employing the technique proposed for $\alpha \neq \pi/2$, since the characteristic Green's function cannot be defined in this case.

We propose to use a heuristic approach based on the introduction of an image source S_1 at $(\rho_o, \pi\text{-}\varphi_o)$ with current $(-I_o)$. The solution can be found by using the procedure employed in [14], where an efficient evaluation of the dyadic Green function is performed.

The detailed analytical procedure and related numerical aspects will be presented.

3 CONCLUSION

A metallic cylindrical resonator containing two lossless media anti-isorefractive to each other and separated by the faces of a wedge whose edge is located on the resonator axis has been studied, with a line source excitation parallel to the cylinder axis.

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