Practical Realization of DB Unit Cell

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Abstract

Recently introduced DB boundary is a hypothetical surface, on which cancellation of normal components of the **D** and **B** field occurs. Such a DB surface behaves either as a low impedance surface or a high impedance surface, depending whether the incident plane wave is TE or TM polarized, respectively. Basic EM properties of an artificial surface based on recently proposed DB unit cell in 8 GHz frequency band are investigated numerically in various waveguide environments. Preliminary experimental results of unit cell scaled down to frequency band of 300 MHz are reported.

1. Introduction

Novel boundary conditions that cause vanishing of the normal components of electric flux density vector (**D**) and magnetic flux density vector (**B**) were recently introduced and named as DB boundary conditions [1]. In order to achieve vanishing of normal components of **D** and **B** vectors, the components of permittivity tensor (ε_n) and permeability tensor ($\boldsymbol{\mu}_n$) in the direction normal to the surface of the material should be equal to zero (Fig. 1):

$$\vec{D}\cdot\hat{n} = \varepsilon_n \cdot \vec{E}\cdot\hat{n} = 0 \quad \Rightarrow \varepsilon_n = 0,$$
$$\vec{B}\cdot\hat{n} = \mu_n \cdot \vec{H}\cdot\hat{n} = 0 \quad \Rightarrow \mu_n = 0. \qquad (1)$$

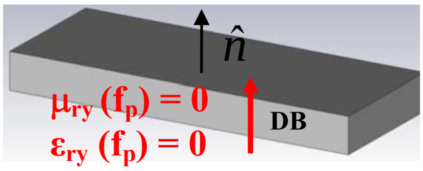

Fig. 1: DB material with zero-permittivity and zero-permeability in direction normal to the surface.

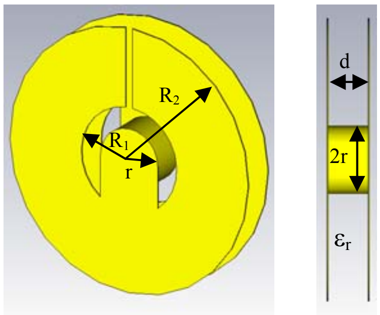

Fig. 2: Simplified composite unit cell that simultaneously behaves as MNZ and ENZ particle. Left: isometric view, Right: side view. r=0,7mm, R_1=1mm, R_2=2,5mm, d=0,7mm, ε_r=2,6.

Knowing the fundamental dispersion constrains of any passive material, it is expected that the DB phenomenon may occur only at one frequency. Several practical realizations of the DB surface, based on passive resonant metamaterial inclusions, have been proposed at University of Zagreb [2,3,4,5]. This paper presents results of numerical analysis performed on a DB slab composed of recently proposed unit cell [3] that operates in 8 GHz band, in various waveguide environments. Due to technological constrains, experimental prototype was designed to operate in frequency band of 300 MHz. The preliminary measurement results are reported.

2. Unit Cell Design and Numerical Investigation in 8 GHz Band

The guiding idea in designing unit cell that should behave as DB particle was to incorporate properties of both capacitively loaded inductance and inductively loaded short dipole into a single composite unit cell. Therefore, the proposed DB unit cell comprises a broadside-coupled split-ring resonator, the lower and upper rings of which are mutually connected with a thin wire (Fig. 2.).
For the TM polarization this inclusion behaves like a simple inductively loaded short dipole. For the TE polarization the particle behaves as an ordinary split-ring resonator, since the inherent symmetry almost completely suppresses the flow of the conduction current trough a perpendicular wire between the rings. In order to verify that proposed structures are good representatives of DB boundary, series of numerical simulations were performed using commercial full-wave solver [7].
In the first series of simulations, the effective permittivity and permeability were extracted, using procedure described in [6]. Results (not shown due lack of space) have confirmed almost perfect matching of plasma frequencies at 8,23 GHz. Furthermore, two slabs, each comprising twenty DB unit cells were formed and used as the side walls of various waveguide structures (Fig. 3a). Depending on the boundary conditions applied in the direction parallel to the slabs, the entire guiding structure should behave either as an ordinary metallic rectangular waveguide or hypothetical PMC waveguide. The distribution of magnetic field inside the guiding structure (Fig. 3b.), while PMC boundary conditions were applied, reveals great similarity to TM_{10} mode. This mode is actually the fundamental mode of hypothetical waveguide made completely of PMC walls. However, the distribution of electric field inside the waveguide (Fig. 3c.), while PEC boundary conditions were applied, is equal to the field pattern inside an ordinary metallic waveguide - TE_{10} mode. Therefore, it is obvious that proposed DB structure indeed shows PMC or PEC behaviour, depending on polarization of incident plane wave.

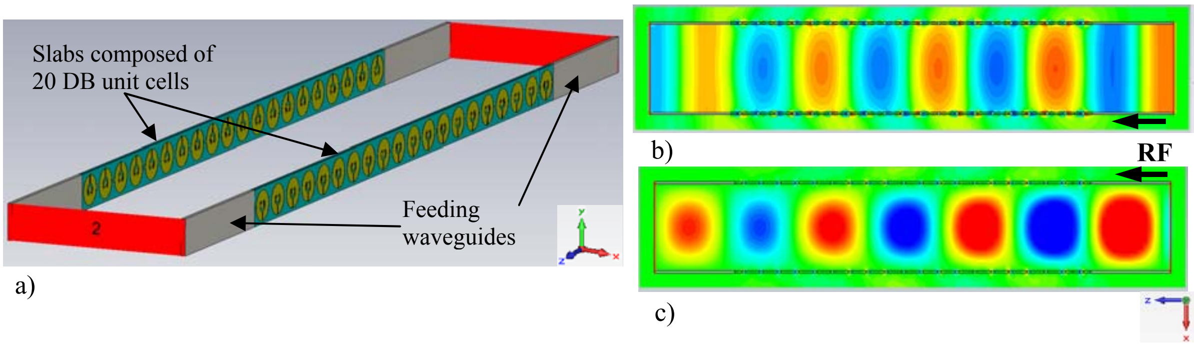

Fig. 3: **a)** Waveguide structure with walls made of DB slabs. **b)** Magnetic field distribution inside the waveguide, while PMC boundary conditions were applied in y-direction. **c)** Electric field distribution inside the waveguide, while PEC boundary conditions were applied in y-direction.

3. Experimental Investigation in 300 MHz Band

Due to technological constrains, scaled experimental prototype was manufactured in frequency band of 300 MHz [8]. Two series of measurements were performed. In the first part, response of DB unit cell on incident magnetic field was observed. The DB unit cell was placed between two loop antennas (Fig. 4.) and the transmission coefficient of the system was measured. Obtained results are depicted in Fig. 5. A very sharp notch in transmission indicates zero-permeability at frequency of 318 MHz. In the second series of experiments, response of DB unit cell on incident electric field was measured. The DB unit cell was placed inside parallel plate capacitor (Fig. 6.) and the effective impedance of the system was calculated (Fig. 7.) from measured reflection coefficient. Analysing the curve of reactance, one may spot zero-capacitance of the system at frequency of 318 MHz, indicating zero-permittivity.

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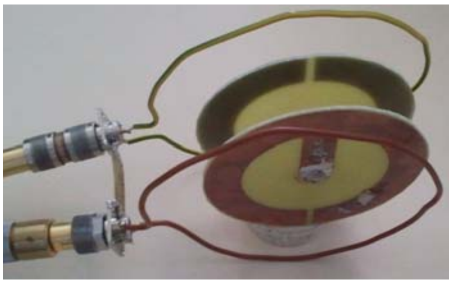

Fig. 4: Scaled DB unit cell placed between two loop antennas.

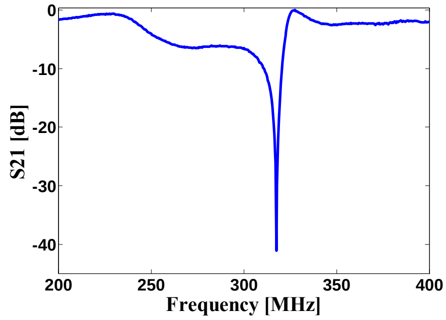

Fig. 5: Measured transmission coefficient reveals zero-permeability at frequency 318 MHz.

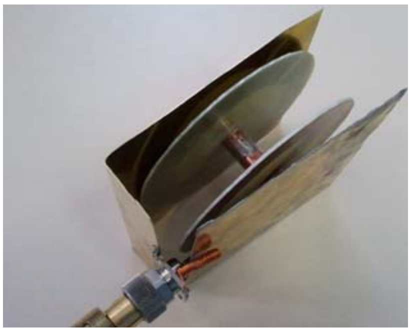

Fig. 6: Scaled DB unit cell placed inside parallel-plate capacitor.

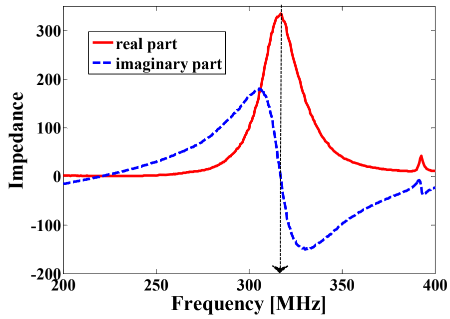

Fig. 7: Setup impedance calculated from measured reflection coefficient. Zero-permittivity is achieved at frequency 318 MHz.

4. Conclusions

Basic properties of a novel concept of boundary condition called DB boundary have been reviewed. Slab made of recently proposed unit cells that operate in frequency band of 8 GHz was analyzed in various waveguide environments and preliminary results show very good agreement with theoretical predictions. Due to technological constrains, experimental prototype was designed to operate in frequency band of 300 MHz. Experimental investigations have confirmed that scaled unit cell has both electric and magnetic responses (the DB behaviour) at frequency of 318 MHz.

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