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Journal of the European Ceramic Society 26 (2006) 2199–2203
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# CAD of one-layer frequency selected surfaces with metamaterials properties

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Available online 11 November 2005

**Abstract**

In this study, we present CAD of (a) double slit tetragonal resonators and (b) microstrips (wires) resonators periodically expanded on the top surface of a substrate made from a dielectric, using the finite difference time domain (FDTD) method. From the calculated complex $S^{*}$-parameters, we found the effective complex magnetic and dielectric constants of all the structures, when an electromagnetic wave incidents vertically to the top surface of substrate and at two different polarizations of electric field relative to the geometry of resonators. Our calculation shows the existence of positive or negative internal constants and optical bandgaps at different frequency areas between 0 and 60 GHz. Also, in this study, we present a correlation between *S*-parameters and the sign of the calculated internal effective constants.


*Keywords:* Composites; Dielectric properties; Magnetic properties; Substrates

## 1. Introduction

Veselago in 1968, reported for first time the existence of very interesting electromagnetic (EM) properties,[1] i.e. negative refractive index (NRI), reversed Cerencov-Vasilov effect, reversed Doppler effect, 'perfect' lens phenomena, etc. to materials with negative magnetic permeability ($\mu < 0$) and dielectric permittivity ($\varepsilon < 0$). Veselago named them left-handed materials (LHM) because in these materials the vectors $\vec{E}$, $\vec{H}$ and $\vec{k}$ form a left-handed triplet, when EM wave propagates through them. The interest in Veselago's work renewed when Pendry et al. in 1999 proposed an artificial material, made from double slit-ring resonators (SRR) with periodic structure along *x*, *y* and *z*-axis.[2] This structure showed a frequency area of magnetic permeability, which was not expected as the structure did not include magnetic materials. In this study, no correlation of internal constants with possible optical bandgaps was presented. In 2000, Smith et al. developed a structure of double SRR (responsible for $\mu < 0$) and Wires (responsible for $\varepsilon < 0$) located in alternating layers.[3] This extension of properties of artificial materials by engineering created a new family of materials named "metamaterials". After these initial publications many metamaterials with NRI properties, sometimes called double negative metamaterials (DNG), have been published.[4] The main characteristic of all of them is a common pass band frequency in which both magnetic permeability and dielectric permittivity are negative.

In this study, we treat the two "traditional" periodic structures which are responsible for the negative internal constants[4] (double SRR and Wires-microstrips) on the top of a dielectric substrate. The substrate, we used in our analysis is a composite forsterite-based material, which shows good characteristics, like real relative dielectric constant $\varepsilon' = 11$, loss tangent $\tan\delta = 0.00008$, real relative magnetic constant $\mu' = 1$ and thermal coefficient $\tau_f = 0$.[5] We also assumed that the periodic structures designed on the top of the substrates were made from perfect electron conductor (PEC).

Purpose of this study is to calculate the frequency change of some metamaterials properties, i.e. the change of sign of internal constants and/or the existence of optical bandgaps, in the case of no periodicity (only one layer of periodic structure made by PEC) along the axis of incidence of EM wave (*z*-axis). We studied this change in two cases of polarization of the electric field and supposing vertical incidence of EM wave on the surface of the two previous mentioned periodic structures. The results of this study can be important to metamaterials applications as one layer of periodic structures, located on top of single substrates, can be more easily fabricated than multi-layered ones.

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doi:10.1016/j.jeurceramsoc.2005.09.084

## 2. Theoretical background

In this study, we made calculation of internal constants of metamaterials by using the Nicolson–Ross method.[6] According to this method, the relative complex internal constants $\varepsilon$ (with $\varepsilon \equiv \varepsilon' + j\varepsilon''$) and $\mu$ (with $\mu \equiv \mu' + j\mu''$) for a slab material at frequency $f$ can be calculated from its thickness $d$ and the complex $S^*$-parameters at that frequency. Their values are given by the formulas:

$$\varepsilon = \sqrt{c_2/c_1} \text{ and } \mu = \sqrt{c_1 c_2} \tag{1}$$

where,

$$c_1 = \left(\frac{1+\Gamma}{1-\Gamma}\right)^2 \text{ and } c_2 = -\left(\frac{c}{2\pi f d}\ln(1/z)\right)^2 \tag{2}$$

$$z = \frac{V_1 - \Gamma}{1 - V_1\Gamma} \tag{3}$$

$$\Gamma = x \pm \sqrt{x^2 - 1} \tag{4}$$

with the sign selected in order to have $|\Gamma| \leq 1$

$$x = \frac{1 - V_1 V_2}{V_1 - V_2} \tag{5}$$

and

$$V_1 = S^*_{21} + S^*_{11} \text{ and } V_2 = S^*_{21} - S^*_{21} \tag{6}$$

In our case, we supposed that internal constants are the effective constants of metamaterial and a FORTRAN software has been written for the calculation. The used complex $S^*$-parameters, which we need in our calculation, were found from EM simulations using FDTD method and appropriate software.

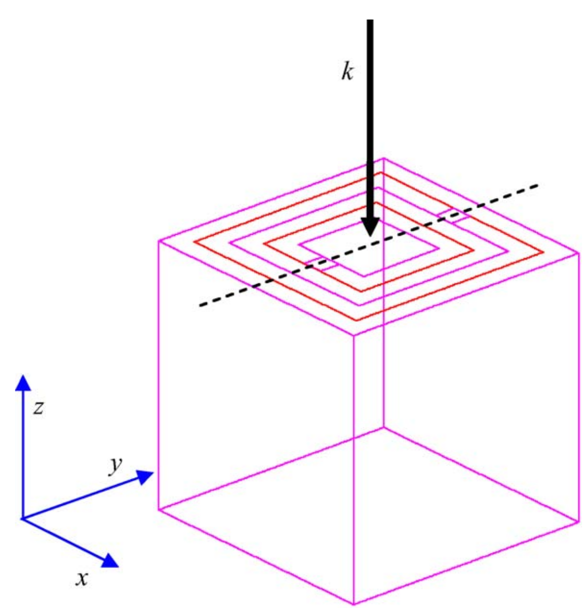


Fig. 1. Double slit tetragonal resonators with unit cell size 1.2 mm × 1.2 mm × 1.2 mm. The size of the tetragonal resonators is 1.0 mm × 1.0 mm for the outer and 0.6 mm × 0.6 mm for the inner one. The size of both tetragonal slits is 0.1 mm × 0.1 mm. Axis of slits is shown.

## 3. EM simulations results and discussion

In Fig. 1, we present the cubic unit cell of a metamaterial expanded in the $xy$-plane without periodicity in $z$-axis (one layer). In Figs. 2 and 3, we present the calculated $S$-parameters

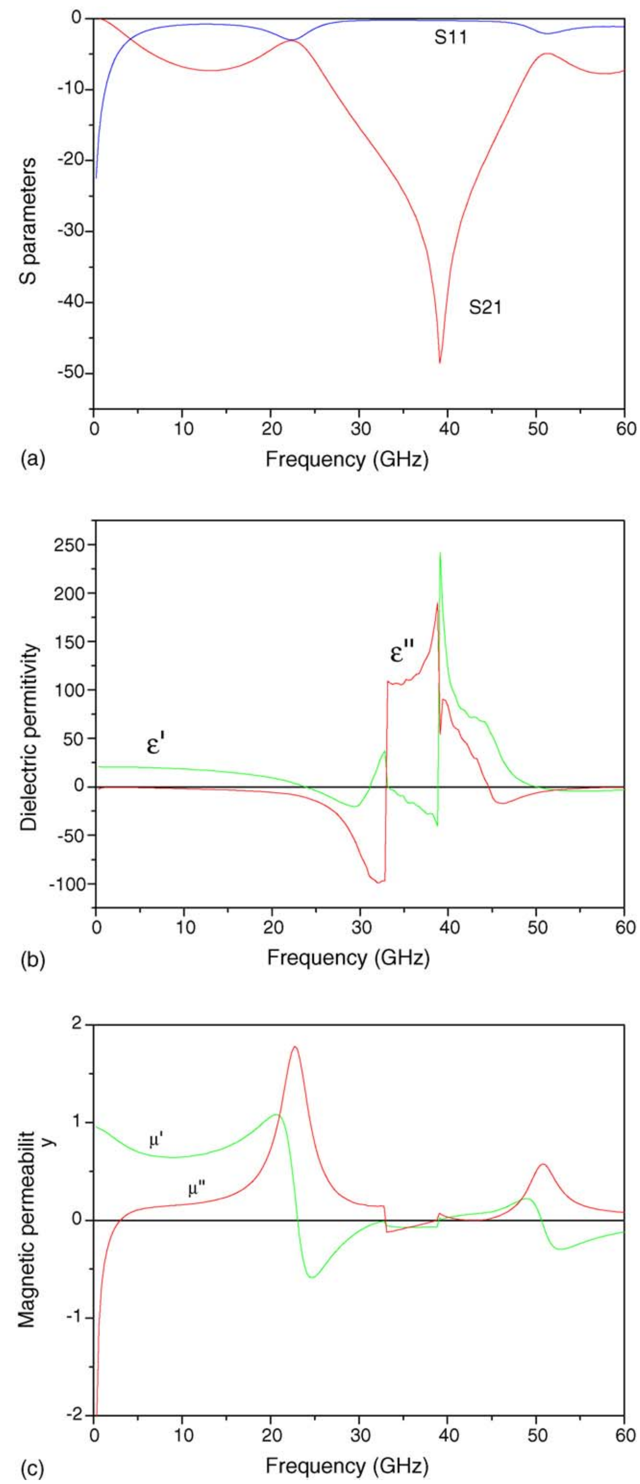


Fig. 2. Double slit tetragonal resonators: (a) calculation of $S$-parameters; (b) calculation of complex dielectric constants; and (c) calculation of complex magnetic constants. The electric field of the incident EM wave is parallel to the slits axis.