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SIMULATION RESEARCH ON THE ELECTROMAGNETIC PROPERTIES OF THE ELC RESONATOR IN THE MICROWAVE RANGE

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Abstract: The paper concerns modeling and simulation of the interaction of electromagnetic radiation with the metamaterial ELC resonator in the microwave range of 5 GHz to 10 GHz. The simulation was performed using the CST Studio software in the Student version. The result of the simulation is the frequency characteristics of the coefficients of absorption (A), transmission (T) and reflection (R) of the ELC resonator, as well as the values of the real and imaginary parts of electric and magnetic permeability coefficients of that structure. The results obtained suggest that the examined metamaterial structure of the ELC shows strong absorption properties of resonant nature.

Keywords: electromagnetic radiation absorbers, microwave ELC resonator, metamaterials, interaction of electromagnetic radiation with metamaterial structures.

1. INTRODUCTION

Standard electromagnetic radiation absorbers are materials that are widely used in various fields of science. Their practical application includes electromagnetic radiation filters and structures and technological solutions related to the masking of objects and broadly defined electromagnetic compatibility [Chakraborty 2013; Panwar et al. 2015; Singh and Marwaha 2015; Panwar and Lee 2017].

In recent years there has been a growing interest in alternative solutions that use new materials and technological structures with absorption properties. This trend includes non-natural metamaterials that have non-standard electromagnetic properties. Research on metamaterials and their properties shows that they can be used to build single absorbers, but also complex absorption structures. The electromagnetic properties of a metamaterial structure depend on its characteristic dimensions, shape of individual components, material parameters, and frequency of incident radiation. Three types of interaction of electromagnetic radiation with a metamaterial structure can be distinguished: resonant, band, and mixed [Watts, Liu and Padilla 2012].

The purpose of this paper is to examine selected electromagnetic properties of a single planar ELC (Electric LC Circuit) metamaterial resonator designed to operate in the microwave range of 5 GHz to 10 GHz.

2. ELC RESONATOR

A typical electric ELC resonator consists of a thin metal symmetrical loop placed on a dielectric substrate. The resonance frequencies of the structure can be determined from the substitute LC system, in which metal circuits simulate inductance and gaps between them simulate capacitance. The electromagnetic properties of the resonator depend directly on the shape and dimensions of the individual components and on the material parameters of these components. It is expected that the electromagnetic characteristics of the ELC resonator will depend on the frequency. This is due not only to the resonant nature of this electrical circuit, but also to the finite conductivity of the thin metal loop.

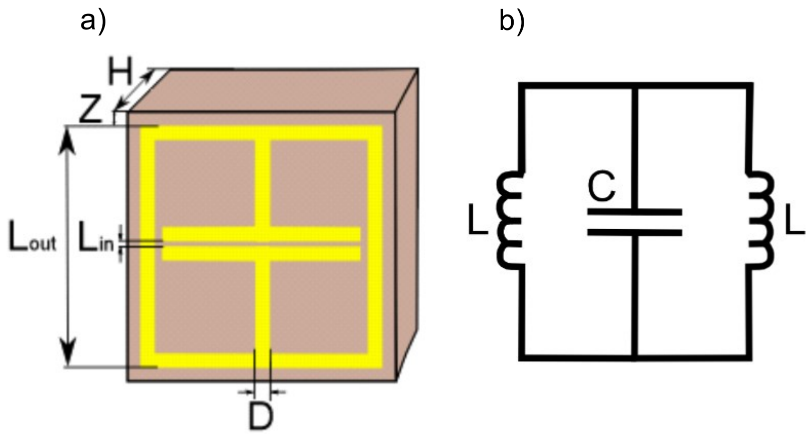

Fig. 1. The geometric diagram (a) of the ELC electric resonator (lighter color) on a dielectric substrate FR-4 (darker color) and (b) the equivalent substitute circuit of the ELC resonator. The dimensions of the ELC resonator – substrate structure are given in Tab. 1

The geometrical diagram of the metamaterial structure of the tested ELC electric resonator is shown in Figure 1. This structure is a thin metal loop formed from a 35 μm thick copper circuit, applied on a perpendicular dielectric FR-4 substrate. The dielectric ε_d^* and magnetic μ_d permeabilities of the FR-4 dielectric material in the 5 GHz to 20 GHz frequency range are equal to ε_d^* = 4,3 - 0,11 and μ_d = 1, respectively [Djordjevic et al. 2001]. The dimensions of the ELC – FR-4 substrate structure are specified in Table 1.

Table 1. ELC structure dimensions

Designation	Value [mm]
H	5
Lin	0.2
Lout	26
D	2
Z	2

3. SIMULATION PROCEDURE

The examined metamaterial structure was designed in the CST (Computer Simulation Technology) Studio software in the Student version. The MW&RF&Optical module was used for the design [www.cst.com].

It should be expected that the properties of the ELC electric resonator tested will strongly depend on the polarity of the electric component E of the incident wave, which conventionally determines the polarity of the wave in relation to the selected element of the structure under test. In these tests, the ELC – FR-4 substrate structure was placed in a virtual propagation path of a flat electromagnetic wave. The polarization of the flat wave was determined in such a way that its electric field vector E was parallel to the paths determining the electric capacity of the structure. The propagation path of the flat wave with appropriate boundary conditions (values of tangential components of the electric field E_t and the magnetic field H_t) is shown in Figure 2.

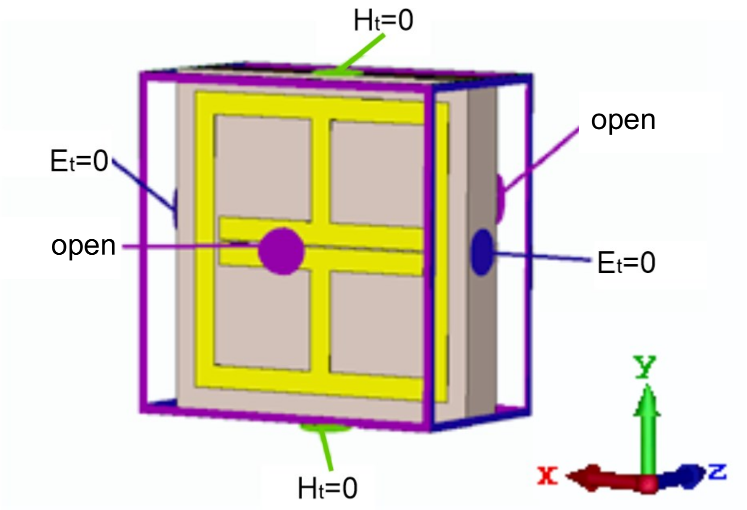

Fig. 2. The propagation path and the boundary conditions for the tangential components of the electric field E_t and the magnetic field H_t. The direction of propagation of the flat wave along the Z-axis

Generally speaking, electromagnetic radiation incident on the ELC – resonator – dielectric substrate structure can be absorbed, reflected, or transmitted. The CST Studio software enables simulation and analysis of these processes by determining the coefficients of the scattering matrix S of the electromagnetic radiation incident on the examined structure [Zhu 2018].

Knowing the values of the scattering matrix coefficients S_{11}, S_{12}, S_{21}, and S_{22} of the structure, one can calculate its coefficients of absorption (A), reflection (R), and transmission (T), and then, using the Nicolson-Ross Weir algorithm, the relative combined electrical $\varepsilon_M{}^* = \varepsilon_M' - j\,\varepsilon_M''$ and magnetic $\mu_M{}^* = \mu_M' - j\,\mu_M''$ permeabilities of the structure [Rothwell et al. 2016]. The values of ε_M' i ε_M'' signify the real part and the imaginary part of electrical permeability, and μ_M' i μ_M'' signifies the real part and the imaginary part of magnetic permeability of the structure.

4. SIMULATION TEST RESULTS

Figures 3, 4 and 5 show the results of the simulation tests. The frequency characteristics of the coefficients of absorption (A), transmission (T), and reflection (R) of the studied structure in the frequency range of 5 GHz to 10 GHz are shown in Figure 3. Figure 3 shows that there are four absorption maximums in the frequency range under consideration for the frequencies of 8.3 GHz, 9 GHz and 9.5 GHz. For these frequencies, the radiation absorption coefficients reached the following values, respectively: A = 0.70, 0.60 and 0.61. Figure 3 also shows that the structure has relatively wide frequency bands with a reflection coefficient greater than 0.5 (for frequencies from approx. 5.75 GHz to 7.7 GHz). The examined structure has also a non-zero transmission coefficient of T > 0.1 for frequencies from approx. 7.7 GHz to 9.4 GHz. The maximum value of the transmission coefficient of the structure was T = 0.2.

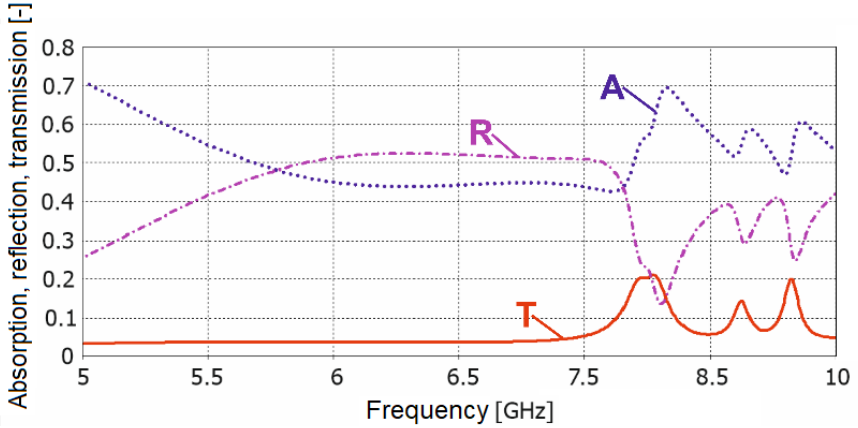

Fig. 3. Coefficients of absorption (A), reflection (R), and transmission (T) of electromagnetic radiation of the studied ELC – FR-4 substrate structure as a function of frequency

In the simulation tests, the real and imaginary parts of the electric and magnetic permeability coefficients were also calculated. Figure 4 shows the real parts of the electric and magnetic permeability coefficients, while Figure 5 shows the imaginary parts of these coefficients.

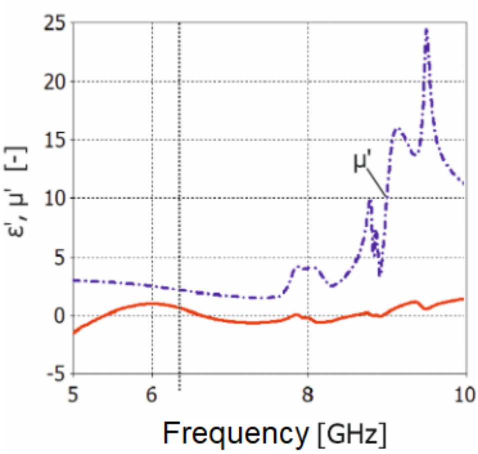

Fig. 4. The frequency characteristics of the determined values of the real part of electric permeability ε' and magnetic permeability μ' of the examined ELC – FR-4 substrate structure

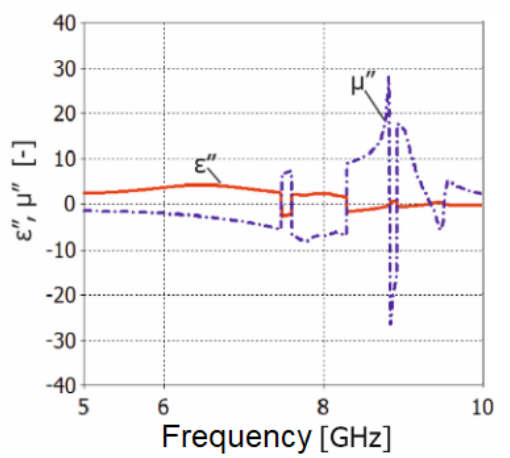

Fig. 5. The frequency characteristics of the determined values of the imaginary part of electric permeability ε" and magnetic permeability μ" of the examined ELC – FR-4 substrate structure

Figures 4 and 5 show that for frequencies with the maximum absorption coefficient, the real parts of the combined magnetic permeability coefficient μ' have positive values, while the imaginary parts μ'' have negative values. On the other hand, both the real ε_M' and the imaginary ε_M'' part of the combined electric permeability coefficient have positive values for all absorption coefficient maximums.

5. CONCLUSIONS

The characteristics of the interaction of electromagnetic radiation with the tested ELC – FR-4 substrate structure determined as a result of numerical simulation in the CST Studio software showed that the tested structure demonstrates absorption-reflective-transmission properties in the range of 5 GHz to 10 GHz.

The absorption properties of the ELC – FR-4 substrate structure are resonant (the absorption coefficient is high for several frequencies), while the reflective and transmission properties of the structure are of band nature.

The simulation tests performed made it possible to determine the numerical values of the coefficients of absorption (A), reflection (R), and transmission (T) for the planar metamaterial structure of the ELC. The absorption coefficient of this structure reached A = 70% at 8.3 GHz. The reflection coefficient values were greater than R = 0.50 for frequency band: 5.75 GHz to 7.7 GHz.

The results of the tests of a small individual ELC resonator – FR-4 substrate structure suggest that such a structure can be used to design and build larger microwave absorbers.

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