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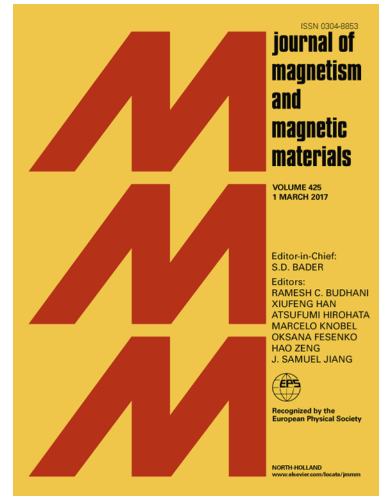

Magnetic metamaterials: Coupling and permeability

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Magnetic metamaterials: Coupling and permeability

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Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia

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Abstract

Magnetic metamaterials made of non-magnetic resonators – metaatoms – are an essential part of metamaterial world reacting to the ac magnetic field and being able to demonstrate negative permeability. We describe local permeability distribution in the vicinity of the resonant frequency where effective medium theory is not applicable because of metasurfaces' finite sizes and the excitation of magnetoinductive (MI) waves. We show that inter-element coupling significantly affects not only MI waves passband but the local permeability distribution.

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Keywords: metamaterials, magnetic metamaterials, metasurface, negative permeability, magnetoinductive waves, coupling

1. Introduction

Metamaterials admittedly became a fruitful field of modern physics due to their originally predicted unusual properties that are impossible to observe in nature materials, such as negative refractive index [1, 2]. The first metamaterial with negative refractive index was experimentally confirmed and that was the beginning of the metamaterial age [3]. Magnetic metamaterials are materials where negative permeability can be obtained in certain frequency range. As a rule they consist of non-magnetic resonant elements of various shapes [4, 5].

The first attempt to obtain the metamaterial's effective magnetic permeability was made by Pendry et.al [6]. The effective magnetic permeability μ_{eff} of the resonant elements system was calculated on the assumption that external magnetic field induced currents in resonant elements. The magnetic field produced by the currents considered being equivalent to a magnetic dipole field, and in the vicinity of resonance frequency but above it when currents were strong enough such magnetic metamaterial could exhibit negative permeability. The expression for μ_{eff} was derived taking into account many structures parameters such as sizes of elements, fill factor (the ratio of metaatom's volume to the volume of the unit cell) and distance between layers of metaatoms. In their work metamaterials were defined as additive systems. But soon it was found that in systems of closely-packed split ring resonators (SRR) in the vicinity of the resonant frequency inter-element interaction (or coupling) gave birth to MI waves which in essence were the waves of currents [7, 8]. The existence of MI waves has been repeatedly proven in different frequency ranges [9] and they are already used in various devices [10-13]. The