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Wave propagation in structured materials as a platform for effective parameters retrieving

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One of the most convenient ways to describe metamaterial (MM) media is by employing effective parameters (EPs), provided that they can be introduced. Generally, in literature two types of EPs are considered: wave and material parameters[1]. The former EPs may be derived from the refection/transmission spectra at a fixed incident angle. However, for a complete description of MM properties, material EPs should be introduced. Up to now, a large variety of retrieval methods has been suggested. The simplest and most used definitely is the S-parameters method also referred to as the Nicholson-Ross-Weir (NRW) method[1,2]. The majority of the retrieving methods are either simple but give wave (or nonlocal) EPs, or they provide material (local) parameters but at the cost of complexity in realization and sometimes with restricted applicability. The universal procedure of EPs retrieval have not been fully established yet.

In this contribution, we present an overview of our activity in EPs retrieving based on observation of wave propagation phenomena in thick (multilayer) MMs. We put a goal to develop a method which is unambiguous, but at the same time simple and straightforward. The idea is that thick enough MM slab can be considered as a semi-infinite medium. Modelling the one-directional (forward) propagation of the wave inside a metamaterial slab thick enough to avoid transition layers effects and reflection from the rear interface we are able to restore complex refractive index[3]. Getting the input (Bloch) impedance from the reflection at the input interface serves to determine complex wave effective parameters. The method was successfully extended on chiral media with circular polarized eigenwaves[4].

Elaborating the approach we aim to determine both the wave and material EPs in periodic MMs via utilization of the Bloch-mode analysis[5]. The idea is to perform the Bloch mode expansion[6] of the field inside the metamaterial slab when it is illuminated with a plane wave incident from vacuum. Then we determine the effective refractive index from the propagation constant of the dominating (fundamental) Bloch mode. The Bloch and wave impedances are determined by definition as the proportionality coefficient between electric and magnetic fields of the fundamental Bloch mode volume or surface averaged over the unit cell[1]. The ratio of the surface averaged fields provides the value of the Bloch impedance and, respectively, enables the retrieval of wave EPs. The volume averaging provides the wave impedance, which is needed for the retrieval of the materials parameters.

The main advantage of our method is its simple numerical realization. The first part of the method involves the extraction of the dominating (fundamental) Bloch modes from the simulation data of the field distribution in several unit cells. The retrieval procedure is performed within a single computational cycle, after exporting fields directly from Maxwell's equations solver.

In this presentation we analyze the following examples: (1) homogeneous slab under two cases: lossless and Lorentz dispersion in permittivity and permeability; (2) a set of nanospheres with plasmonic resonances; (3) split cubes metamaterial that possesses magnetic resonance and negative permeability; (4) a wire medium with negative permittivity; (5) negative refractive index fishnet structure; and (6) split-cube-in-carcass structure[5]. In the last two cases volume-averaged fields lead to negative real part of the impedance, the fact that signals on violation of the direction of the Poynting vector for outward wave propagation. For deeper understanding we focus on the Bloch modes contributions into the total field structure and in the flux density, which can differ considerably in the resonant part of the spectrum. The analysis of the contributions will be reported at the symposium too.

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