Metamaterial Property Determination Taking Boundary Effects into Account

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Many researchers have studied the properties of metamaterials both theoretically and experimentally. In the latter case, determination of the effective permittivity and permeability is based upon measurements of reflection and transmission from material samples. Up until now, however, none of the experimental work has taken into account the effects of excess polarization and magnetization induced near the surfaces of the metamaterial samples. E. F. Kuester, *et al.* (*IEEE Trans. Ant. Prop.*, 51, 2641-2651, 2003) have introduced the concept of generalized sheet transition conditions (GSTCs) for the averaged electromagnetic fields across a metafilm — a surface distribution of electrically small scatterers constituting a two-dimensional metamaterial. Recent theoretical work has shown that GSTCs can also characterize the effect of boundary-localized fields at the interface between an ordinary material and a metamaterial.

The present work is intended to establish methods to determine the properties of such metamaterials from experimental reflection and transmission data, taking the boundary effects into account using the GSTC model. The incident wave is assumed to propagate normally to the interfaces. Equations relating the measured S-parameters to both the bulk parameters of the metamaterial and to the GSTC (boundary) parameters are derived. The air-to-slab and slab-to-air reflection and transmission coefficients are *not* assumed to be given by the Fresnel formulas in this method. From measurements made on two different sample thicknesses of the same metamaterial, the bulk and boundary parameters are expressed in terms of the measured data. This technique is tested on several configurations. First, we consider a simple configuration where two parallel metafilms separated by an air-filled region (either in a waveguide or in free space) are separated by a sufficient distance to prevent near-field interaction. Next, we show that measurements of conventional materials (where boundary effects are negligible) based on this new method lead to accurate recovery of the bulk parameters. The permittivity and permeability of nylon are calculated from S-parameters extracted experimentally by a VNA and compared to results obtained using the Nicolson-Ross-Weir (NRW) algorithm. Finally, we also attempt to find the effective properties from the measured S-parameters of a metamaterial. Numerically computed S-parameters obtained from HFSS are used as artificial experimental data, and we discuss and compare the results with those from the literature that do not account for boundary effects. It will be shown that the influence of the boundaries can be substantial.