# Permeability and Permittivity of Metamaterials Determined by the Field Summation Method

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Negative index materials have been recently demonstrated using adequate topologies of metallic inclusions exhibiting both engineered permeability and permittivity [1]. The opportunities associated to these so-called metamaterials, first envisioned 40 years ago, are continuously expanding to new field of applications and extended wavelengths.

The effective parameters $\varepsilon$ and $\mu$ are fundamental quantities in the conception of a metamaterial. As a consequence, it is of foremost importance to be able to enhance our ability to predict these quantities for different inclusion topologies, and retrieve them from experimental results. A method has been proposed [2] to determine the effective parameters of heterogeneous materials, from the knowledge of the fields inside the material. This paper shows that this method can be fruitfully applied to the determination of permeability and permittivity of a metamaterial.

As an example, a composite consisting of resonant permeability inclusions has been considered. The fields in the composite have been determined using HFSS commercial software. The permeability and permittivity have been deduced using this field summation method. Reflexion and transmission coefficients have been computed from these values, and are compared with raw numerical prediction by HFSS. It is evidenced on Fig. 1 that a satisfactory agreement is observed.

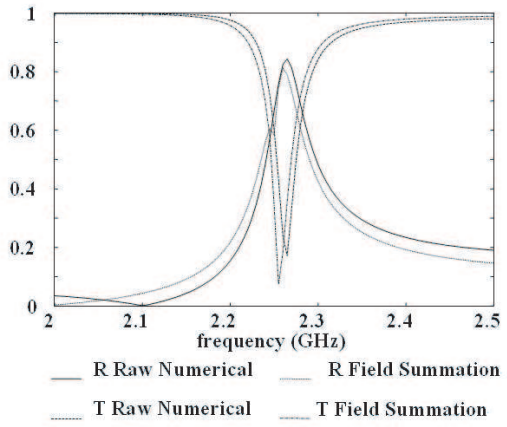


Figure 1: Reflection and transmission coefficient derived from effective parameters obtained by field summation, and compared to raw numerical results, for a composite made of split ring resonators.

Different types of composite materials are considered. In some cases, the field summation method indicates that it is not adequate to describe a metamaterial through an homogenization approach at frequencies close to the resonance. This observation may account for some difficulties in retrieving effective parameters from experimental results, and the scarcity of direct experimental determinations of $\varepsilon$ and $\mu$ on metamaterials.

## REFERENCES

1. Smith, D. R., J. B. Pendry, and M. C. K. Wiltshire, *Science*, Vol. 305, 788, 2004.
2. Acher, O., A. L. Adenot, and F. Duverger, *Phys. Rev. B*, Vol. 62, 13748, 2000.