Experimental characterization method for metamaterials using an asymmetrical strip transmission line

S. Gómez[1], P. Quéffélec[2], A. Chevalier[3]

[1]LabSTICC UMR 3192, UEB, Université de Bretagne Occidentale
6 av. Le Gorgeu, 29238 Brest Cedex 3, France
Fax: +(33)-2-98-01-63-95; email: sandra.gomez@univ-brest.fr
[2]email: patrick.queffelec@univ-brest.fr
[3]email: alexis.chevalier@univ-brest.fr

Abstract

An experimental technique for measuring the effective permeability and permittivity of metamaterials in the centimetric frequency band is presented. The cell consists in an asymmetrical stripline which satisfies certain conditions imposed by the particular properties of this type of materials. The minimal size of the sample that produces a representative result is determined using electromagnetic simulations and the influence of the metallic parts of the measurement cell over the retrieved properties of the sample is analyzed. Preliminary experimental and simulated results are shown.

1. Introduction

Electromagnetic properties of metamaterials, which are anisotropic, dispersive and heterogeneous media, impose certain conditions when conceiving characterization methods for measuring their effective permittivity ε_{eff} and permeability μ_{eff}. The anisotropy implies that the excitation must be homogeneous in direction and should be oriented in a specific way. To deal with the dispersion of the electromagnetic properties a broadband method is necessary. Finally, a constant magnitude of the excitation all over the unit cells and an Elementary Representative Volume (ERV) of the sample is required due to its heterogeneous character.

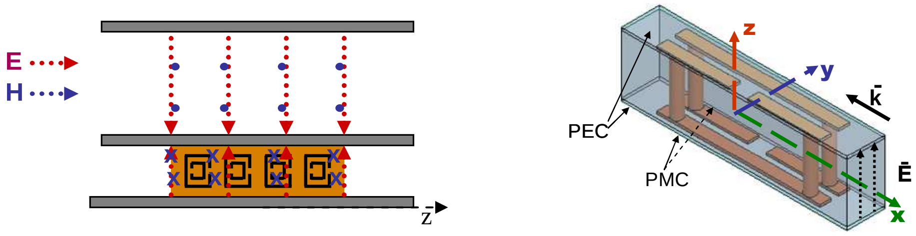
The existing experimental methods used for measuring the electromagnetic properties of metamaterials ε_{eff} and μ_{eff} do not satisfy completely all the previous specifications. The methods based on resonant cavities are not well adapted for dispersive materials. The transmission line based methods (like waveguide or microstrip) do not present the uniform field distribution required for exciting all the volume of the sample. The coaxial lines are not well adapted to the particular geometry of metamaterials. Finally, free space methods could be the most appropriated, but they are not recommended for frequencies below 10 GHz because large samples are required [1].

This work introduces a new experimental characterization method well-suited for metamaterials. It is based on a stripline measurement cell. We will show that all the conditions required for the electromagnetic characterization of metamaterials are taken into account. After presenting the preliminary experimental results, the possible influence of the metallic parts of the measurement cell over the behaviour of the material is analyzed. Finally, the size of the cell is defined by finding the minimum volume of the sample that should be used in order to guarantee the representative character of the found parameters.

2. Stripline method

The measurement cell consists in an asymetrical stripline initially developed in our laboratory for the characterization of magnetic materials. This technique allows "*in situ*" measurements because the field pattern is close to the one used in most planar metamaterials applications. As shown in Fig. 1a, the sample is placed in the region between the central conductor and the ground plane where the higher electromagnetic energy concentration is present. The field's propagation mode could be consider quasi-TEM and below the central conductor the electromagnetic field's distributions satisfies the requirements for metamaterials characterization: the electric field is parallel to the metallic inclusions, the magnetic field is perpendicular to them and the magnitude is constant all over the volume of the material.

The S parameters of the cell loaded by the sample are measured using a Vectorial Network Analyzer and the effective permittivity ε_{eff} and permeability μ_{eff} are obtained using an electromagnetic analysis of the structure. Two different theoretical approaches based on the quasi-static approximation (Variational [2] and Transmission line [3] methods) are used for extracting the parameters of the material. The unit cell of the measured metamaterial is shown in Fig. 1b. Fig. 2 shows the experimental results (real part of the permittivity and permeability spectra) comparing the two approaches with an electromagnetic simulation implemented in HFSS.



a) b)

Fig 1: a) Electromagnetic field pattern of the measurement cell. b) Unit cell of metamaterial

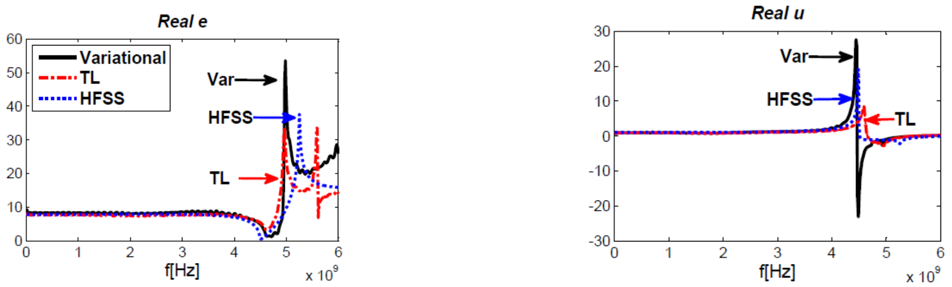


Fig 2. Retrieved permittivity and permeability

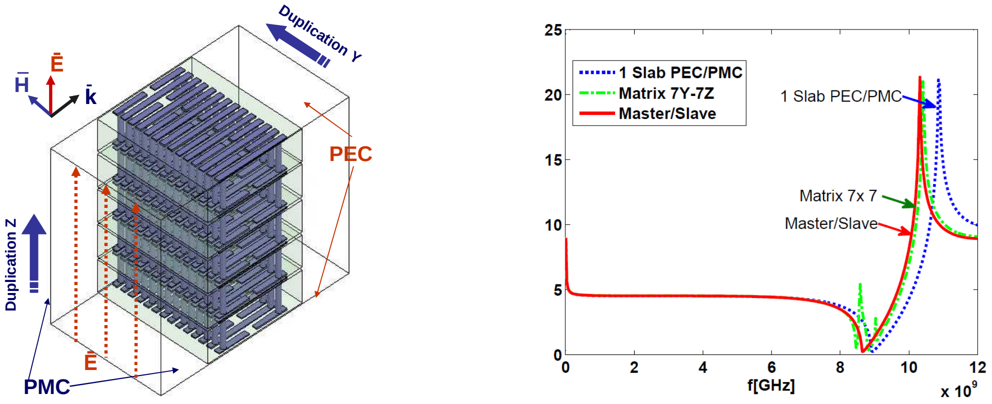
3. Minimal size of the samples

The previous technique satisfies two basic conditions imposed by the particular nature of metamaterials. The excitation is homogeneous all over the volume of the sample and a broadband analysis is done. There are two aspects left to be considered: the difference between characterizing one or more unit cells and the influence of the measurement cell over the final response of the material. To deal with this, electromagnetic simulations of metamaterials were performed and the effective parameters were extracted using the NRW procedure [4]. First, the number of inclusion was progressively increased following the direction of electric and magnetic field's propagation independently. For a few number of inclusions, the obtained parameters were different but as the number of cells was increased a convergence in the results was observed.

In second place, simulations increasing the number of unit cells in both directions at the same time were made, representing a 3D structure (Fig. 2a) which was expanded in E and H directions. The obtained result was different from all the previous ones, which means that in order to obtain a representative response of the material it is necessary to take into account the coupling effects between inclusions set in different directions. In general, we have found that the asymptotic behaviour is found when more than seven unit cells in each direction are considered. This number of cells defines the minimal size of the sample that must be used in the stripline method.

The final step of this analysis was to simulate the behaviour of an infinite sample, using the Floquet's theorem and Master/Slave option in HFSS. As expected, the result of simulating one unit cell over these conditions and multiple unit cells with electric and magnetic walls were the same (Fig. 2b). That confirms the fact that in order to obtain the representative parameters of a metamaterial using our stripline cell, it is necessary to have a sample with a minimum number of inclusions.

The influence of the metallic walls of the measurement cell over the material's behaviour was also extracted from this analysis. The consequence of having metallic inclusions interacting with the electric walls is a modification of the local electromagnetic field distribution that affects the final response. This interaction can not be easily modelled or ignored but we found that increasing the number of unit cells minimizes the relative uncertainty on the measured data due to this error source.



a) **b)**

Fig 2: a) Convergence study. b) Simulation results showing the difference between one and many unit cells

To obtain the asymptotic response of a metamaterial, it is necessary to develop an improved measurement cell well-suited to the new size of the sample. Due to the enlargement of the transversal section of this cell, a modal analysis that takes into account higher propagation modes will be required.

4. Conclusion

The stripline technique used for measuring the electromagnetic properties of metamaterials satisfies all the founded conditions imposed by this type of anisotropic, heterogeneous and dispersive media. However it is necessary to take into account certain considerations for obtaining the effective parameters that represent the behaviour of an "infinite" structure. Respecting the Elementary Representative Volume of the sample is necessary for guarantying the convergence of the retrieved electromagnetic parameters and also for decreasing the uncertainies due to the effect of the metallic parts of the measurement cell over the sample.

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