Radiating Systems Based on Metameterials

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***Abstract*-The concept of metamaterial provides the possibility to obtain electromagnetic properties, at certain frequencies, that are difficult or impossible to achieve with conventional materials. The aim of this research line is to study the viability of appliying metamaterials in radiating systems in order to obtain structures with improved behaviour such as frequency selective surfaces (FSS) or artificial magnetic conductors (AMC).**

I. Description of the Group

The Antenna and Microwave Systems Group (AMS), which was created in 2002, is part of the Wireless Communications Group of the Telecommunication and Engineering System department (TES) in the Universidad Autónoma de Barcelona (UAB). In spite of its youth it is important to stress that members of AMS come from two centers with a wide experience in the fields of simulation, design and measurements of antennas and microwave devices: the Universidad Politécnica de Cataluña (UPC, Spain) and the University of Sheffield (United Kingdom). Nowadays the AMS group is composed of 5 doctors (one of whom holds a postdoctoral Juan de la Cierva grant) and 1 PhD student.

Besides the activities that will be described in this document the AMS group is involved in a technology transfer project related with the miniaturization of RFID for e-security and e-assitance applications (FIT-350300-2005-44). It is also collaborating with the the Instituto de Microelectrónica de Barcelona (CNM-IMB-CSIC), sited on campus at UAB, in the application of Thin-Film Bulk Acoustic Resonators (FBAR) to devices forming part of RF front-ends.

The group participates in the activities carried out in the european networks of excellence in antennas (ACE) and metamaterials (METAMORPHOSE) and it is member of the respective spanish networks (REsA and REME).

Finally it will also be mentioned that the Wireless Communications group has been recently honoured as Emerging Research Group by the Generalitat de Catalunya.

The following activities described in this document are related to metamaterials and are being carried on in collaboration with Universidad Pública de Navarra and UPC. This work is being supported by the Spanish Comisión Interministerial del Ministerio de Ciencia y Tecnología (CICYT) and FEDER funds through grant TIC 2003-09317-C03-02.

II. Development of Numerical Tools for Simulation

One of the objectives of our work is to develope software with the capability of analyse efficiently metamaterial structures (which are periodic but finite) and extract their constitutive parameters (permeability and permitivity).

A. Tools for time domain analysis

The characterisation of metamaterials is being carried out with a view to modelling a complete two-port measurement system using the Finite Difference Time Domain method (FDTD). The modelled system consists of two coaxial-to-waveguide transitions connected to a section of rectangular waveguide in which the sample is placed (Fig.1). Numerical directional couplers in the coaxial cable facilitate the separation of forward and reverse waves. In separate simulations that excite each port in turn, the forward and reverse travelling waves at each port are calculated in time and transformed to the frequency domain to yield all four S-parameters. After that a complete TRL (transmission-line-reflect) calibration of the system is performed over a wide range of frequencies and the constitutive parameters are extracted.

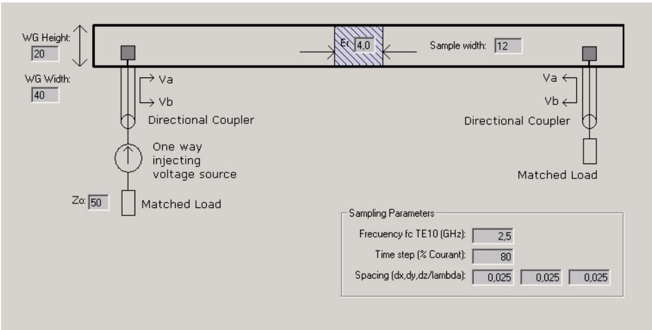

Figure 1. Simulation scheme for a measurement on waveguide using TLR calibration

B. Tools for frequency domain analysis

In the design radiating systems based on metamaterial structures simulation tools are essential to reduce the cost and effort of experimentation. However the full-wave methods usually utilized, such us the Method of Moments (MoM), lead to a full equation system with N unknowns which iterative resolution requires O(iterations x N^2) operations and O(N^2)

memory to store the matrix. This means that the computational requirements will increase rapidly with the electrical size of the problem. This is the case of metamaterials where, even though the basic cell is electrically small, a large number of cells are repeated to synthesize a continuous material.

In order to overcome this problem, the MLFMA (multilevel fast multipole algorithm) and the MLMDA (multilevel matrix decomposition algorithm) are two interesting options due to their low computational requirements (O(*NlogN*) memory, O($Nlog^2N$) operations) and flexibility to deal with arbitrary shapes. Meanwhile the MLFMA is known as the most efficient for 3-D structures in free space, the MLMDA has shown to be comparable to MLFMA for planar objects with a single level of metallization (2-D). Another advantage of MLMDA is that it can be also used with other Green functions than free space.

Recently, our group, in collaboration with the UPC Antenna Lab., has proposed a new implementation of the MLMDA for arbitrary 3D objects that makes it comparable in computation time with MLFMA. This makes MLMDA a very suitable tool for the analysis of objects with a large number of unknowns as it is the case of metamaterials (Fig. 2) or finite arrays (Fig. 3).

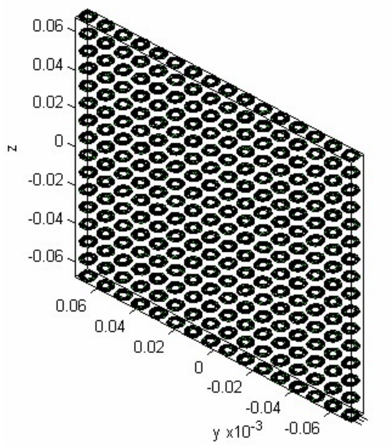

Figure 2. Articial Magnetic Conductor: 4096 unknowns using symmetries. Computer: AMD Opteron 64 1800 dual, 8 GB RAM (Matlab-Linux) Computation time: 1 minute.

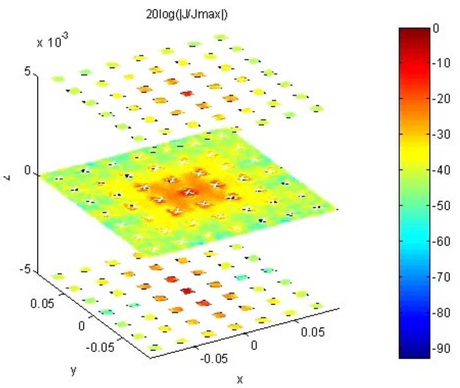

Figure 3. Current distribution for a radiating structure in free space: 16088 unknowns. Computer: AMD Opteron 64 1800 dual, 8 GB RAM (Matlab-Linux) Computation time: 4 minutes.

III. Analysis and Design of Radiating Systems Based on Metamaterials

Mainly two factors have to be taken into account in the design of metamaterial structures: the geometry of the unit cell and its periodicity. The previously developed tools are very useful to deal efficiently with the analysis and design of these structures.

A. *Unit cell*

Several geometries of unit cell are being investigated in order to reduce its size and provide more compactness to the metamaterial. This is the case of the magnetic cylindrical unit cell of Fig. 4. The FDTD simulation of Fig. 5 shows as this structure behaves as magnetic wall (S_{11} = +1) around 2.2 GHz. With such a small size of resonator it may be possible to mix resonators of slightly different resonant frequencies in an attempt to increase bandwidth or to be able to cover multiple bands simultaneously.

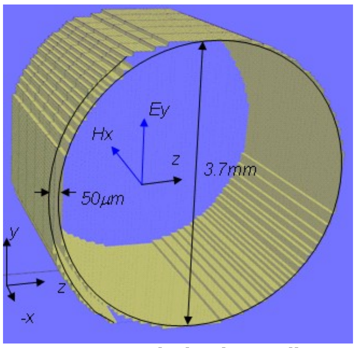

Figure 4. Magnetic cylindrical unit cell parameters

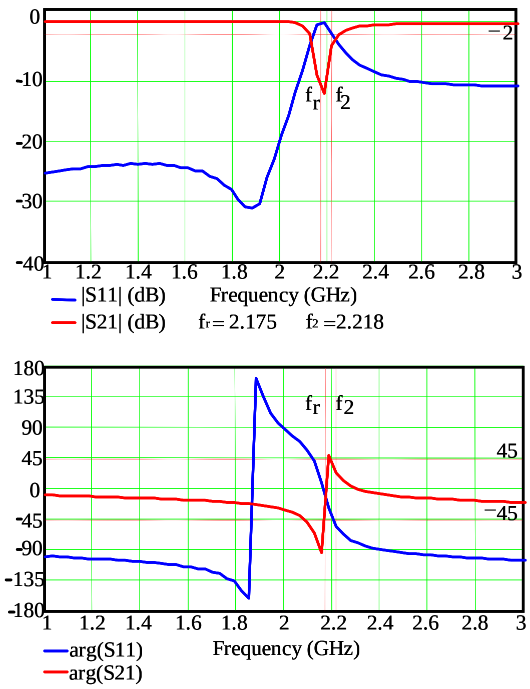

Figure 5. FDTD simulated S-parameters of an infinitely periodic array of cylindrical magnetic resonators of Fig. 4

B. *Artificial Magnetic Reflector*

After validating the MLMDA with several known structures, it has been used in the analysis of a finite artificial magnetic reflector based on split ring resonators (SRR). Fig. 6 shows the parameters of the geometry under study whilst Fig. 7 and Fig. 8 show the radiation patterns obtained for two different configurations. It can be seen as, at certain frequencies, there is a good agreement between the simulations and the theoric results obtained by applying image theory. Another interesting point is that, when the SRR's separation decreases, the frequencies of interest lower.

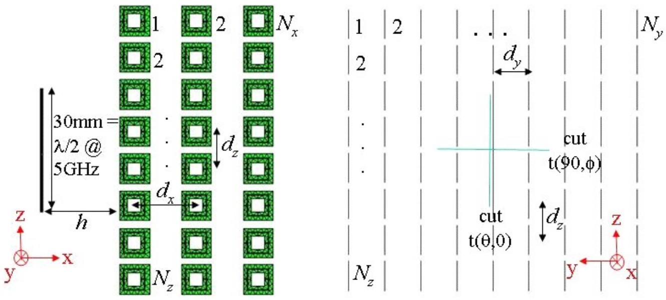

Figure 6. Geomery parameters for an artificial magnetic refrector based on split ring resonators.

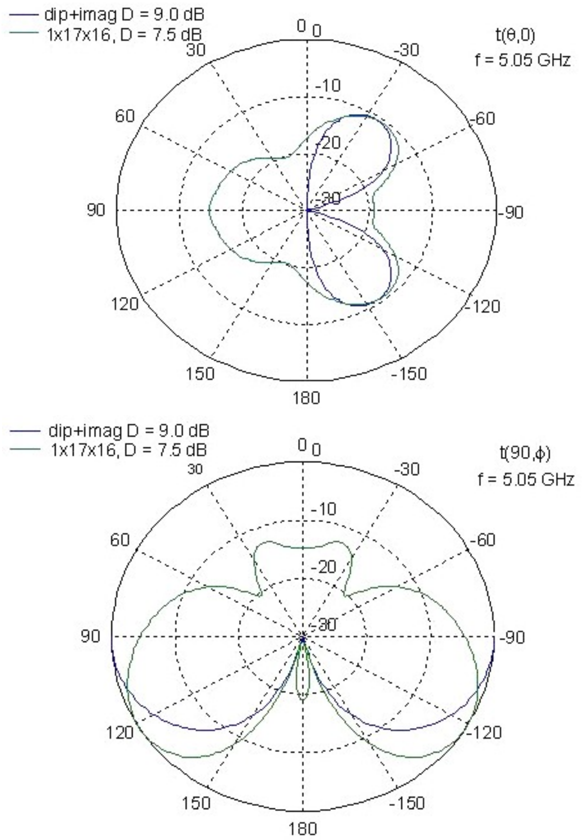

Figure 7. Radiation pattern cuts for the artificial magnetic reflector with h = 15 mm, Nx = 1, Ny = 17, Nz = 16, dx = dy = dz = 9 mm

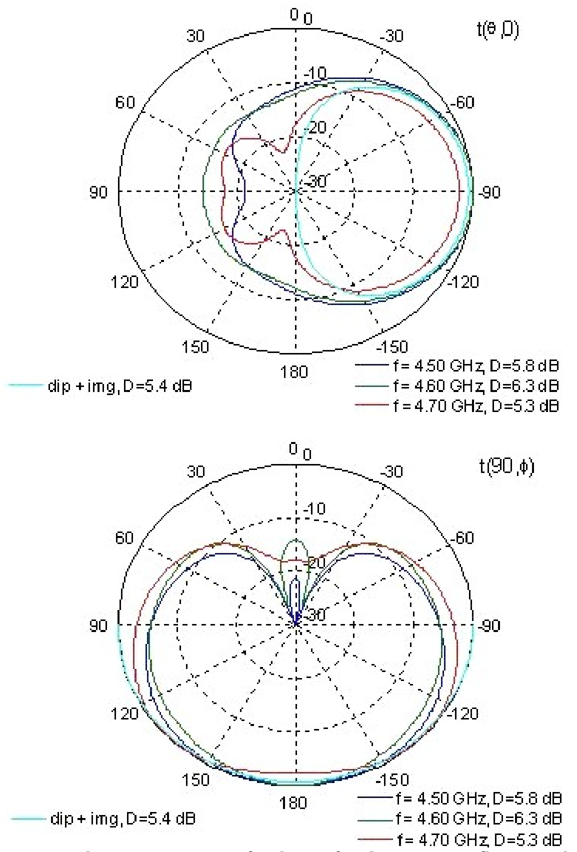

Figure 8. Radiation pattern cuts for the artificial magnetic reflector with h = 3.75 mm, Nx = 1, Ny = 25, Nz = 8,dx = dy = dz = 3 mm

IV. Contracts

The following table shows the actual projects where the group is involved at this moment:

Title	Year	PI
Design of materials with negative permeability and permitivity and their application in antennas. CICYT: TIC 2003-09317-C03-02	2003-06	J. Parrón
Radiofrequency identification system (RFID) in the UHF and microwave bands for E-assistence and E-security FIT-350300-2005-44	2005-06	P. de Paco

Other investigation projects where the members of the group were involved during their stay at UPC are:

Title	Year	PI
Exploring the limits of Fractal Electrodynamics for the future telecommunication tecnologies (FRACTALCOMS) European Comission IST-2001-33055	2002-03	J. M. Rius
Analysis of wideband and multiband antennas through hybrid and parallelizable numerical methods CICYT TIC98-1037	1999-01	J. M. Rius
Advanced structures of antennas and front-ends for UMTS base stations CICYT TIC 2001-2364-C03-01	2002-03	J. Romeu
Radiometers at 30 and 44 GHz for Planck mission CICYT-FEDER	1999-04	Ll. Pradell
Development of a YBCO RF filter operating at low temperature and characterization of superconductor layers for microwave frequencies CICYT MAT99-0984-C03-03	1999-02	J.O'Callaghan

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