Efficient Numerical Electromagnetic Methods for Radiation, Scattering and Propagation Applications

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***Abstract* — This document describes the research activities performed in the areas of antennas, scattering and wave propagation by several research groups belonging to different Universities located in Eastern Spain. These groups are working in the practical applications of efficient numerical electromagnetic methods within the frame of several research projects funded by private and public Spanish and European institutions. The main results obtained by these groups related to such topics, i.e. analysis algorithms, CAD tools, validation prototypes, as well as most relevant publications in technical conferences, journals and books, will be thoroughly described in this summary.**

***Index Terms* — Electromagnetic analysis, integral equations, mode-matching methods, antennas, scattering, circuits, frequency selective surfaces, beam-forming networks, materials technology.**

I. Introduction

Modern microwave and millimeter-wave systems are typically composed of radiating elements and related passive circuitry. Some of these systems are developed for supporting practical scattering and propagation applications. Their accurate design, in reasonable computation times, do typically require useful Computer-Aided Design (CAD) tools based on fast and rigorous analysis methods. For such purposes, several numerical electromagnetic methods are increasingly becoming more popular, such as the Integral Equation (IE) technique, the well-known Method of Moments (MoM) and modal analysis techniques such as Mode-Matching (MM).

In this paper, we will describe the most recent advances in these research lines developed closely together by several Spanish Universities, i.e. Technical University of Cartagena, Technical University of Valencia, University Miguel Hernández of Elche, University of Valencia, University of Castilla La Mancha and University of Alicante. The research groups at such Universities strongly co-operate together since many years ago, thanks to several research projects funded either by public (Spanish and European) and/or private institutions. Their common activities were started once some members came back from several research stages developed at ESTEC/ESA (1991-96) funded by the Spanish Government (Spanish Trainee Young Graduate Programme). Later on, they have continuously improved their knowledge in the area by staying at some world-wide reference centers, such as the École Polytechnique Fédérale of Lausanne (Switzerland), the Joint Research Center of European Commission (Ispra, Italy), and the Universities of Pavia (Italy) and Waterloo (Canada).

This summary is organized as follows: section II overviews the research activity developed in the area of radiating systems, section III briefly outlines the results obtained for scattering applications, the achievements in frequency-selective surfaces and beam-forming networks are covered in sections IV and V, and recent results in the area of new and emerging materials are presented in section VI. The References section includes a list of the most relevant publications of the groups in this area.

II. Overview of Radiation Applications

A. Wire Antennas

An efficient IE technique has been proposed for the analysis of wire antennas used in HF, VHF and UHF communication systems. Novel ideas in the rigorous treatment of the thick wire antenna kernel, and related singularities, have allowed the efficient analysis of complex antenna elements [1].

At Technical University of Cartagena, these algorithms have been used for the design and characterization of wire antennas used in the communication systems on board of submarines. A novel CAD tool (PERAL) for the analysis and design of this type of antennas (see Fig. 1) has been developed in collaboration with the Spanish company IZAR, Combat Systems (Spain) (research contract UPCT-Ref. 349/02TIC).

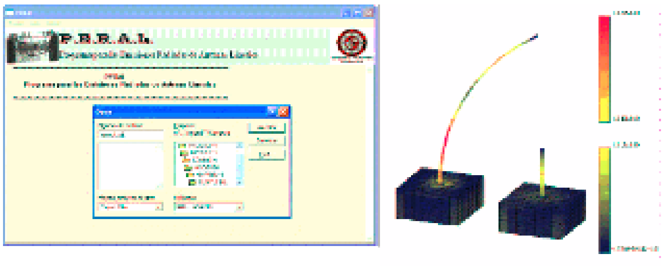

Fig. 1. Software PERAL for the design of wire antennas mounted on board of submarines.

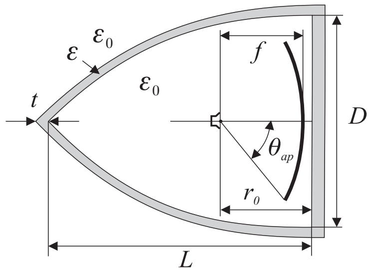

Fig. 3. Dielectric 2-D radome with a complex source excitation and a parabolic metallic reflector.

B. Leaky-Wave Antennas

New leaky-wave antennas have been proposed in hybrid waveguide-printed technology. The main advantage of such novel structures is that radiation characteristics of the antenna can be easily controlled with a printed circuit (slot or strip) placed inside the waveguide. In this way different pointing angles, side-lobe levels and beam widths can be synthesized, just by using different inexpensive printed circuits [2]. In addition, backward to forward scanning capabilities have been added using printed periodic metallization.

The Technical University of Cartagena is currently collaborating with the Wireless Communications Research Group at University of Loughborough (England), where several prototypes have already been manufactured and successfully tested (see Fig.2).

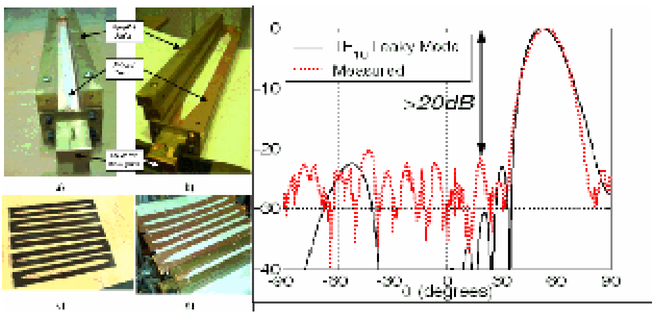

Fig. 2. Novel leaky-wave antenna implemented in hybrid waveguide-printed technology.

III. Overview of Scattering Applications

A. Scattering by Electrically Large Objects

The scattering produced by electrically large objects can be found in many practical applications, such as in the analysis of reflector and horn antennas, the accurate prediction of radar cross-section of complex targets, the solution of radomes, and the analysis and design of passive circuitry. For the accurate and efficient solution of these problems, several techniques based on multi-resolution analysis (wavelets), and Fast-Multipole Method (FMM), are being considered.

At Technical University of Valencia (Mrs. Vidal-Pantaleoni and Dr. Esteban-González), in cooperation, respectively, with Technical University of Cartagena (Mr. Quesada-Pereira) and University of Castilla La Mancha (Mr. Belenguer-Martínez), several methods based on wavelets and FMM have been recently proposed for solving large scattering problems [3], which are being successfully applied to the fast and accurate analysis of cylindrical arbitrarily shaped radomes (see Fig. 3). These activities are being performed in the frame of a coordinated research project (TEC2004-04313-C02) funded by the Spanish Government (2004-07).

These techniques have been extended to 3D problems at Technical University of Cartagena. A volume IE technique, with advanced segmentation schemes, has been implemented for the analysis of finite size microstrip antennas [4]. With such technique, the effects of the finite size dielectric layers on side-lobes and backward radiation is accurately predicted.

B. Application to Passive Circuits

The IEs techniques for solving scattering problems can also be successfully applied to the analysis of passive circuits related to radiation elements. For instance, a hybrid method combining mode-matching and MoM was developed at Technical University of Valencia for coping with arbitrarily shaped inductive geometries in waveguide technology [5]. On the other hand, Technical University of Cartagena has recently proposed the use of neural networks for the efficient analysis of multilayered shielded passive microwave circuits [6], as well as compact transversal filters in microstrip technology with high selectivity. Novel structures composed of open loop resonators, as well as short-circuited cross-shaped resonators, including couplings between the input and output non-resonant nodes, have been recently proposed. Both band-pass and band-stop filters have been recently manufactured and successfully tested (see Fig. 4).

Both above mentioned research groups, in co-operation with University of Valencia (Dr. Gimeno-Martínez) are still working in extending such techniques to more complex geometries. These activities were initiated through common research projects (TIC2000-0591-C03 and ESP2001-4547-PE) funded by Spanish Government in the period 2000-04.

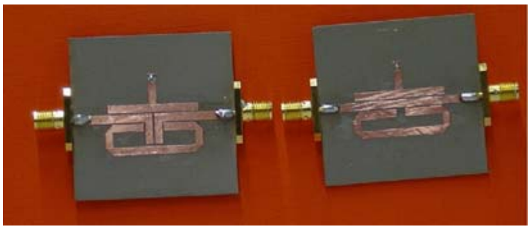

Fig. 4. Novel compact transversal filters in microstrip technology.

IV. Frequency Selective Surfaces

Frequency Selective Surfaces (FSS) are commonly employed in antenna subsystems as frequency filters, polarizers, dichroic mirrors, and so on. In particular, we have studied two kinds of FSSs: polarizer rotator systems and Dielectric FSS (DFSS).

In some antenna applications, the rotation of the polarization plane by some desired angle relative to a fixed feed is usually requested. To proceed, we have proposed a system composed of several parallel linear polarizers, whose axis are oriented in different directions for progressively rotating the polarization plane of an incident linear wave over a broad frequency band. Metallic strip-gratings impressed on a dielectric substrate have been employed. An efficient and accurate CAD tool for the rigorous analysis of such structures was developed at University of Valencia [7]. The oblique incidence of plane waves and more realistic beams (i.e. those radiated by horn antennas) were also studied in detail [8].

DFSSs are planar structures consisting on the cascaded connection of multilayered periodic dielectric layers showing a frequency selective behaviour. As a result, these structures may be used in a wide variety of active and passive devices operating in the microwave and optical frequency bands. At University Miguel Hernández of Elche (Dra. Coves-Soler), and University of Valencia (Dr. Gimeno-Martínez), the study of DFSSs composed by lossy dielectric gratings (see Fig. 5) has been solved by a fast and rigorous full-wave vectorial modal method [9]. A software CAD tool for solving the 3D scattering of multilayered DFSSs structures under plane-wave excitation has been also considered [10].

V. Microwave Photonics for Beam-Forming Networks

The use of photonic systems for controlling and processing microwave signals is a research activity covered at University of Valencia (Dr. Andrés-Bou), which is focused on three main aims: microwave filters, tuneable delay lines for microwave signals (to be used in beam-forming networks for phased arrays), and mm-wave generation fibre-optics techniques. Some of these fibre-optic components can be used as tuneable delay lines for microwave signals, with a time response shorter than 1 ms [11]. Another activity related to this topic was the design, in the early nineties, of a wide-band Rotman Lens in microstrip technology for a phased-array antenna [12].

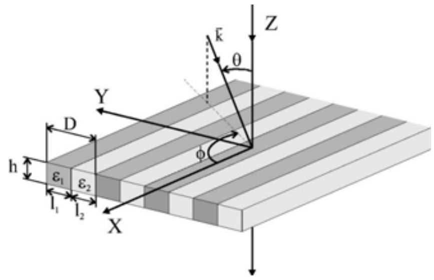

Fig. 5. Dielectric frequency selective surface.

Several spectral and angular reflection filters, based on DFSSs, have been successfully designed for operating at microwave and optical frequencies.

VI. New Materials for Antennas

A. EBG Substrates for Printed Array Antennas

In this area, new strategies for developing innovative planar printed antennas, based on EBG substrates technology, are being investigated in order to meet fundamental requirements for integrated front-ends, such as low cost and profiles, high gain, and easy integration with Tx/Rx modules. In particular, the analysis and design of Planar Circularly Symmetric (PCS) EBG structures, for reducing the undesired surface waves excited by printed antennas on dense dielectric surfaces, are being discussed. Integrated planar antennas with bandwidths up to 20% have been successfully designed and tested [13]. Using this technology, a prototype of 1-D phased array that scans up to 40º with a large bandwidth (15%) has been manufactured (see Fig. 6).

This research activity is the core of the Ph.D thesis work developed by Mrs. Llombart-Juan, which has been mainly developed at the Defense, Security and Safety Institute of the Netherlands Organization for Applied Scientific Research (FEL-TNO) in The Hague (The Netherlands), in co-operation with Technical University of Valencia (Spain). Such joint activity was initially funded by MMCODEF Research Training Network (HPRN-CT-2000-00043) funded by the 5th Framework Program of European Commission, and later on by the AIO Funds of Dutch Ministry of Defense, and by a European Space Agency (ESTEC) Project about Photonic Bandgap Structures (Nr. 17539/03/NL/JA).

B. Applications of Metamaterials

Metamaterials are new artificial structures showing simultaneous negative permittivity and permeability, which are being considered for potential use in new kinds of low-profile antennas and related passive circuitry. 1-D metamaterial-based devices, either in waveguide or planar technology, are being proposed as high performance compact filters and negative phase shifters. 2D or planar surface configurations can exhibit electromagnetic selectivity in certain frequency and angular ranges, thus providing high impedance surfaces which do not support undesired propagating surface waves.

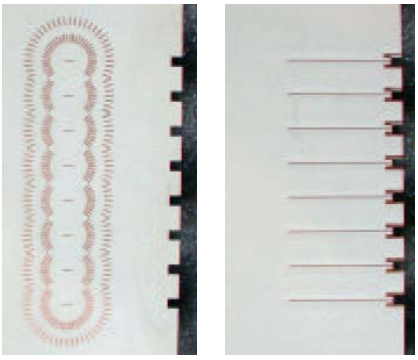

Fig. 6. 1-D scanning array composed of 8 elements with PCS-EBGs Front (left) and back (right) views.

At Technical University of Valencia, Dr. Carbonell-Olivares and Dr. Boria-Esbert are actively working in the area [14]. They are supervising the Ph.D. activity of Mr. Roglá-Madrid in the study of equivalent circuits for 1-D metamaterial-based structures in planar and waveguide technologies for filtering applications (see Fig. 7). Several co-operation activities with ITESO, Guadalajara (Mexico), and with the Institute of Electronics, Microelectronics and Nanotechnology (IEMN) of Technological and Science University of Lille (France), have been recently set up.

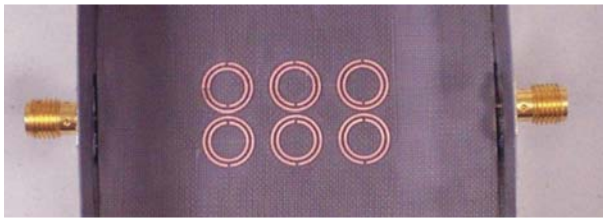

Fig. 7. Prototype of a metamaterial-based planar filter in coplanar waveguide technology using 3 unit cell SRR structure.

VII. Conclusions

This paper has described the research activities performed in the areas of antennas, scattering and wave propagation performed by several research groups belonging to several Universities placed at Eastern Spain. Most relevant results and publications in the last ten years period have been reviewed.

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