Please use the following format for <u>the title of the file</u> so as to ease the management of the web site.

ECXX_LABYY_ NOMChercheur_ Numer
ECXX = ECLi, ECL, ECM, ECN, CS
LABYY = acronyme du laboratoire
NOMChercheur = nom du chercheur émetteur du sujet
Numer = numéro de la proposition (01, 02, ….) pour le chercheur

PhD Proposal 2017

School: CentraleSupélec (CS)	
Laboratory: Laboratoire des Signaux et Systèmes (L2S)	**Web site:** http://www.l2s.centralesupelec.fr
Team: Signaux et Statistiques	**Head of the team:** Pascal Bondon
Supervisor: Dominique Lesselier, Directeur de recherche CNRS	**Email:** dominique.lesselier@l2s.centralesupelec.fr
Collaboration with other partner during this PhD: **In France:** with GeePs - Group of electrical engineering, Paris (CNRS-CentraleSupélec - Univ Paris-Sud - Univ Pierre et Marie Curie)	**In China:** to be defined further, at later stage, see text

Title: Resonant micro-structured 3-dimensional antenna systems – from mathematical analysis to laboratory-controlled experimentation.
Scientific field: Electrical, Electronic and Telecommunication Engineering
Key words: Modeling and simulation of signals and systems, micro-structured antenna systems, mathematical, numerical and experimental analyses, pseudo-cavity resonances, time reversal, super-resolution/localization

Details for the subject:

Background. To improve wireless performance is an issue which is the focus of much attention nowadays, Within that context, at least in a loose sense since the proposed work is set quite upstream with respect to practical challenges, so-called micro-structured systems of wire antennas the inter-element distance of which being much smaller than the electromagnetic wavelengths both/either in transmission and/or reception are to be studied.

Context. How to prove and characterize the effective super-resolution or, much better said, the super-localization of a particular radiating element of a micro-structure as sketched above is the main goal of the investigation. The idea behind it is that one should reach a better resolution with respect to the wavelengths of the radiation from a far-field observation followed by some proper back-propagation onto the relevant domain within which the sources and per extension the whole structure are located (with no or little information on the radiating element, nature and localization as well). This is linked with time-reversal concepts already considered in (scalar) acoustics and further explained in the applied mathematics community via the example of 2-D Helmholtz resonators, while, in parallel, again in a similar 2-D scalar situation, resolution enhancement involving homogenization can be exhibited.

Yet, results in the vector-wave 3-D situation of our interest are preliminary, and to the best of our knowledge absent from the academic literature. So, significant challenges must be overcome, requiring extensive expertise and sustained effort: (i) in computational fashion — we are interested in partially periodic structures of limited extent, open or partially open (above a metal plate), in particular with facing vector wave field equations so as to get, in best circumstances, Green dyads in complex pseudo-cavity regime; (ii) in more practical terms — we must take into account the realization constraints of set-ups, the need of wideband measurements or transient measurement systems, and correspondingly geometrical and electrical uncertainties that theories as built may not account for in the proper way. (iii) in terms of explanation/understanding of observed results — which remain quite controversial in the communities of antennas and inversion, e.g., the notion of coding far fields by resonances of pseudo-cavities as set forth by applied mathematicians.

Success of above endeavors relies in particular on availability of electromagnetic 3-D modeling tools of such micro-structured structures at emission/reception. Commercial codes (say, CST Microwave Studio, HFSS, etc.) can be employed to simulate but they are subject to heavy implementation and this one must be very neat. Yet the observed resonances, tracked to the behavior of dyads Green characteristics of impulse responses of structures under analysis, impose to take into account relevant power feeds and/or realized set-ups. Also, the asymptotic analysis of these dyads, mainly for explaining super-resolution, remains an open issue, noticing that full transient data might end up in time-harmonic frequency-diverse data, and carefully tailored back-propagation algorithms might substitute to traditional TR mirrors.

We in some way need to extend the analysis of scalar 2-D acoustic cases (the Helmholtz resonators aforementioned) to vector 3-D cases of interest, at least to provide a satisfactory interpretation even at the price of model simplification. We also aim at revisiting theories of singularities analysis originally developed for characterizations of remote targets. Overall we have to consider what is meant by super-resolution/localization, since information is carried by evanescent waves collected in near-field yet also transported into mode-structured far-field easier to measure, spatial/temporal focusing in such a multi-path environment being expected.

Work plan. (The Chinese cursus of the PhD candidate is mostly to impact the 1st year.) WP1 (*months* 1-12) – *Learning about state of art, definition of theoretical/numerical/ experimental steps*: to understand state-of-art at direct modeling/ inversion/imaging level, + gain grasp of existing solution tools/experimental challenges. WP2 (*months* 6-24) – *Modeling, numerical analysis, choice of scenarios*: to develop modeling algorithms of electromagnetic behaviors in situations of interest with changes (geometry, material parameters, feeds, etc.) of structures, while to involve with laboratory-controlled measurements, + to propose imaging relevant to time-reversal "at large". WP3 (*months* 12-36) – *Development and testing*: to build a software demonstrator and test direct modeling and imaging solutions, with confrontation to experimental laboratory-controlled data available. WP4 (*months* 18-36) – *Dissemination*: to disseminate via contributions at symposia & journals. 1^{st} conference contributions to be proposed/given in 2^{nd} year, writing articles started after 24^{th} month, most work last 6 months.

Available expertise & cooperation. The work is to be run within a co-operation between L2S (mathematical analysis, construction of models, numerical simulations, mostly using in-house codes to be developed) and GeePs (numerical simulations as well, mostly using commercial codes, controlled-laboratory experiments on properly down-scaled set-ups in anechoic chambers). In that framework the PhD student will be advised from L2S, within the STIC Paris-Saclay Doctoral School, by D. Lesselier, in view of his broad upstream expertise. A close-knit co-direction is envisaged within the companion EOBE Doctoral School, with M. Serhir, Associate-Professor of CentraleSupélec and working in GeePs, due to his fine knowledge of numerical simulations and experiments in the microwave domain.

The broad expertise of L2S in signal processing, modeling and inversion is proven, as the one of GeePs for whatever concerns the science of antennas. The PhD investigation is to be fruitfully discussed with the Department of Mathematics, ETH Zurich (H. Ammari and team) and Department of Mathematics, Hong Kong University of Science and Technology (H. Zhang), in view of the sophisticated analysis behind it. Linkage could be set up with Chinese partners (it exists already with the Institute of Applied Physics, University of Electronic Science and Technology of China, Chengdu, others can be pursued).

Pre-requisites & skills fostered during PhD. The applicant, beyond a Master degree (in physics, applied mathematics, numerical analysis, electrical/telecommunication engineering, signal and image sciences, ...), should have good skills in electromagnetics at large. Knowledge in antenna design and experiments, applied mathematics and computer science is a +. He/she should be willing to carry out numerical developments to illustrate work at best level. The topic offers opportunity to develop expertise in challenging multi-wave modeling/ numerical methods, and inversion/imaging. Carrying out/disseminating cutting-edge research in academic, multi-disciplinary/national framework is an obvious asset.

References on the topic (6 among possibly many, set per alphabetical order)

[1] Ammari, H. and H. Zhang, "A mathematical theory of super-resolution by using a system of sub-wavelength Helmholtz resonators," *Commun. Mathemat. Phys.* **337**, 379-428, 2015.
[2] Chauveau, J., N. de Beaucoudrey, and J. Saillard, "Resonance behavior of radar targets with aperture: example of an open rectangular cavity," *IEEE Trans. Antennas Propagat*. **58**, 2060-2068, 2010.
[3] Dyab, W., T. K. Sarkar, A. Garca-Lamperez, M. Salazar-Palma, and M. A. Lagunas, "A critical look at the principles of electromagnetic time reversal and its consequences," *IEEE Antennas Propagat. Magaz*. **55**, no. 5, 35 pp, 2013.
[4] Lerosey, G., J. de Rosny, A. Tourin, A. Derode, G. Montaldo, and M. Fink, "Time reversal of electromagnetic waves," *Phys. Rev. Lett.* **92**, 193904(1–3), 2004.
[5] Serhir, M., "Transient UWB antenna near-field and far-field assessment from time domain planar near-field characterization: simulation and measurement investigations," *IEEE Trans. Antennas Propagat.* **63**, 4868-4876, 2015.
[6] H. Tu, S. Xiao, D. Lesselier, and M. Serhir, "Super-resolution characteristics based on time-reversed single-frequency electromagnetic wave," *J. Electromagn. Waves Applic*, 11 pp, doi 10.1080/0920 5071.2016.1210037, 2016.