2020-02603 - PhD Position F/M Dispersive electromagnetic media: mathematical and numerical analysis

Type de contrat : CDI
Niveau de diplôme exigé : Bac + 5 ou équivalent
 Fonction : Doctorant

A propos du centre ou de la direction fonctionnelle

Located at the heart of the main national research and higher education cluster, member of the Université Paris Saclay, a major actor in the French Investments for the Future Programme (Idex, LabEx, IRT, Equipe) and partner of the main establishments present on the plateau, the centre is particularly active in three major areas: data and knowledge, security, safety and reliability, modelling, simulation and optimisation (with priority given to energy).

The 480 researchers and engineers from Inria and its partners who work in the research centre's 28 teams, the 60 research support staff members, the high-level equipment at their disposal (image walls, high-performance computing clusters, sensor networks), and the privileged relationships with prestigious industrial partners, all make Inria Saclay Île-de-France a key research centre in the local landscape and one that is oriented towards Europe and the world.

Contexte et atouts du poste

The dispersion phenomenon is ubiquitous in electromagnetism: the light velocity generally depends on the frequency of the wave, which can be seen as an effect of inertia at the microscopic level. Despite its omnipresence, this frequency dispersion has raised numerous theoretical issues and generated intense discussions – even conflicts – especially since the introduction of metamaterials and negative index materials for which the electric permittivity and magnetic permeability become simultaneously negative in some frequency range. This follows in particular the keen interest for spoof SPPs (surface plasmon polaritons) [32], and more recently plasmonic structures like corners with negative permittivity [1, 11]. In this effervescence, apparent contradictions have been pointed in physics literature about the causality principle and the notion of electromagnetic energy. These contradictions are particularly associated with an unarguable physical fact: the theoretical modelling of frequency dispersion, precisely in the range of frequency where the optical properties offered by metamaterials occur. However, most of mathematical studies in this context concerned the frequency domain and not the time-dependent equations. Therefore, it is insufficient to describe “the whole physics” of these materials since the frequencies are “correlated” by dispersion that must be taken into account rigorously. The present PhD thesis aims to fill this gap and to gather mathematical and numerical tools to predict a “frequency-to-time” approach for electromagnetic wave propagation in metamaterials, paying special attention to materials with negative permittivity or permeability. Thus, the aim of this PhD thesis is to go as deeply as possible in the analysis of dispersive systems to predict in particular their time-dependent behaviour. The approach we will develop in this thesis is based on a first mathematical tool that comes from complex analysis and more precisely the theory of Herglotz functions, i.e. analytic functions of the upper-half plane with negative imaginary part, which precisely define the permittivity and permeability of causal and passive linear media as functions of the frequency [4, 8]. Indeed, for dispersive electromagnetic systems, an important progress was made by A. Tip, A. Figotin, J. Schenker and B. Gralak [8, 10, 9, 14] and developed by M. Cassier, C. Hazard, P. Joly and M. Kachanovska in [5, 6]. Using Herglotz functions properties in the frequency domain (in particular their representation theorem), they rewrote the dissipative and dispersive time-dependent Maxwell's equations as a conservative system. In the time-domain, it corresponds to the introduction of additional variables (to the electrical and magnetic fields), so that the Maxwell's equations take the classical form of a conservative and non-dispersive Schrödinger operator which involves a self-adjoint Hamiltonian. In other words, the great interest of this technique is to rewrite a non-self-adjoint and a non-local operator in time as a self-adjoint and time-independent operator that one can study via the spectral theorem. The possible consequences of this idea on the analysis of the initial problem have not been enough explored. This thesis intends to fill in this gap.

Principales activités

In this PhD thesis, one wants in particular to make the connection between time-dependent and harmonic regime in the context of transmission problems between standard dielectrics and dispersive negative materials. More precisely, the aim is to study the large time behaviour of solutions associated to time-harmonic excitations which is switched on at an initial time and answer the following motivating question: do these solutions converge to a stationary regime for large times? This property is referred to as the limiting amplitude principle (LAP) [7] in scattering theory and is fundamental to justify “the physical relevance” of the harmonic regime. Then, when the LAP applies, a second question on the transient regime and in particular on the convergence rate of the time-dependent solution towards the harmonic regime should be investigated. This second point had been addressed in a non-dispersive acoustic half wave guided in [16]. We want to adapt their method to dispersive systems with separable variables in two and three dimensions since it is strategic for applications for instance in cloaking, stealth technology or lensing. In this setting, the first objective of this thesis is to extend the existing mathematical results on LAP on electromagnetic open dispersive structures. More precisely, in [3, 5], we dealt with the case of a two-layered medium composed of a dielectric and a particular metamaterial (Drude model) separated by a plane interface. In this context, we reformulated the time-dependent Maxwell's equations as a conservative Schrödinger equation and performed its complete spectral analysis. Thanks to this study, we showed finally that the limiting amplitude principle holds except for a particular frequency characterised by a ratio of permittivities and permeabilities equal to -1 across the interface. This frequency is a resonance of the system and the response to this excitation blows up linearly in time. Thus, in this case, the signature of the transient regime never vanishes since there are no associated stationary regime. We underline that such a resonance phenomenon does not exist between two dielectrics [19] and is due to the presence of a negative dispersive material modelled by Drude constitutive laws. Thus, our aim in this PhD thesis will be to extend this study to other structures with separable geometry intensively studied in physics. We want to deal first with the case of the perfect flat lens [18] which consists of a stratified media made a slab of negative material inserted in a dielectric. Then, as a second configuration, we will consider the case of the cylindrical lens [12] which consists of a three layered media in a “cylindrical geometry”. The third situation that we want to explore is

Informations générales

- Thème/Domaine : Schémas et simulations numériques
- Ville : Palaiseau
- Centre Inria : CRI Saclay - Île-de-France
- Date de prise de fonction souhaitée : 2020-10-01
- Durée de contrat : 3 ans
- Date limite pour postuler : 2020-05-20

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A propos d'Inria

Inria est l'institut national de recherche dédié aux sciences et technologies du numérique. Il emploie 2600 personnes. Ses 200 équipes-projets agiles, en général communes avec des partenaires académiques, impliquent plus de 3500 scientifiques pour relever les défis du numérique, souvent à l'interface d'autres disciplines. L'institut fait appel à de nombreux talents dans plus d’une quarantaine de métiers différents. 900 personnels d'appui à la recherche et à l'innovation contribuent à faire émerger et grandir des projets scientifiques ou entrepreneuriaux qui impacter le monde. Inria travaille avec de nombreuses entreprises et a accompagné la création de plus de 180 start-up. L’institut s’efforce ainsi de répondre aux enjeux de la transformation numérique de la science, de la société et de l’économie.

Consignes pour postuler

Sécurité défense :
Ce poste est susceptible d'être affecté dans une zone à régime restrictif (ZRR), telle que définie dans le décret n°2011-1425 relatif à la protection du potentiel scientifique et technique de la nation (PPST). L'autorisation d'accès à une zone est délivrée par le chef d'établissement, après avis ministériel favorable, tel que défini dans l'arrêté du 03 juillet 2012, relatif à la PPST. Un avis ministériel défavorable pour un poste affecté dans une ZRR aurait pour conséquence l'annulation du recrutement.

Politique de recrutement :
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challenging. In the harmonic regime, if the interfaces delimiting the dispersive negative medium is not smooth and presents corners, in a given critical frequency range (which depends on the corner), energy can accumulate near the corner, so that the energy seems to leak at the corner, which is the black-hole effect [1, 10]. This leakage of energy is analogous to the leakage due to radiating waves in unbounded propagative media. What this the time-dependent interpretation of this phenomenon with a limiting amplitude principle result for frequencies contained in the critical interval? All these investigations will be performed alongside with numerical simulations on these open devices which involve negative materials that raises tricky issues, in particular for designing new PMLs, operating in these negative materials [2]. Finally, another challenging question that we want to investigate is the stability of resonance phenomena (which exist at least for the case of the plane interface in a bi-layered medium) by local perturbations of the interface in separable geometries. To do this aim, a perturbation 4 analysis will be investigated on the twolayered medium, the perfect flat lens and the cylindrical lens where the spectral decomposition can be derived explicitly (see [5] for such a spectral decomposition in the case of a bi-layered medium). Furthermore, numerical simulations should be realized in such situations to guess or confirm numerically such theoretical results.

Compétences
We are looking for a candidate with a strong background in partial differential equations. A good knowledge in complex analysis, spectral theory, functional analysis and programming skills are desirable but not mandatory.

Avantages
- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of teleworking (after 6 months of employment) and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Rémunération
Monthly gross salary: 1,982 euros (1st and 2nd year), 2,085 euros (3rd year)