# Electromagnetic pulses in ultra-dispersive nano-structured media: a theoretical and numerical approach

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The study of the interaction between electromagnetic pulses with dispersive and possible passive materials has a long tradition that can be traced, at least, to the works of Sommerfeld and Brillouin. As time has passed many scientist have contribute to a better understanding of this kind of phenomena. However some well established concepts need to be revisited and some questions remain open. **The aim of this thesis is then, to tackle in a very systematic way, some of the most representative problems in this area**:

**I)** Having as starting point tabulated experimental data for the electrical permmittivity, we have developed a mathematical procedure that allows to find analytical models that in the frequency domain fulfills two fundamental physical properties: reality in time domain and causality. Even more, well know models such as: Drude and/or Drude-Lorentz model, Debye model, or a combination of these elementary resonances, can be seen as particular cases of it.

**II)** Our second task is to determine the velocity of an electromagnetic pulse that propagates in a highly dispersive medium. In order to tackle this problem, we divide the exposition of our ideas as follows: First, we make a brief discussion about the usual concepts of group velocity when dealing with transparent and mild dispersion materials. In order to give a more general notion of what is the propagation velocity for a wave packet, we use the concept of centrovelocity, and show how under certain assumptions it is possible to see the well known definition of group velocity as a particular case of the centrovelocity. With these ideas in mind, we are in position to analyze the case of an EM pulse that illuminates normally a homogeneous temporally dispersive absorbing slab embedded in vacuum. This simple setup allows us two study very important concepts in wave propagation: The very definition of energy for a leaky dispersive material and the propagation velocity of an electromagnetic wave in this kind of material.

**III)** Nanophotonic devices based on silicon or noble metals are countless examples of open resonators. Finding the resonant frequencies and consequently the resonant modes is a well known problem in physics, when the fields are not strictly confined and can leak to the whole universe we can say that we are dealing with Quasi Normal Modes (QNMs). In this thesis we give a brief and straightforward way of deriving the QNMs of a Fabry-Perot cavity. The problem of the determining the right branch cut of the complex logarithm is studied and more important it is shown its importance when obtaining the complex resonant eigenfrequencies of the cavity. We deal with the issue of expressing EM fields in terms of a QNMs expansion. This is done by proposing a QNMs normalization by using Perfectly Matched Layers, and obtaining their biorthogonal vectors.

**IV)** Finally, the problem of describing the electromagnetic field generated by an oscillating charge and its interaction with some dispersive 3D-object is also studied. In order to handle this issue smoothly, we have divided our procedure in two main parts: The first one deals with the pure description of an EM field generated by arbitrary charge density ρ and corresponding current density j. Next, one arrives to the well known results of the Liénard-Wiechert fields which despite to be a closed expression are less explicit than they appear to be. To overcome this difficulty, we propose polyharmonic representation of the electric and magnetic fields in the sense of distributions. These results have been compared with the well know formula of far field power. Second part is related to the interaction of this polyharmonic EM field and a dispersive object (a sphere). This problem is handled via the diffracted field formulation and solved numerically by using Finite Elements Method solver GetDP.