Time Domain Simulation of Surface Plasmons in Ultra-Compact Optical Devices

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Abstract — **An extended equivalent circuit (EEC) finite-difference time-domain (FDTD) scheme is presented. This technique exhibits high versatility, improved efficiency for the case of non-uniform meshes, and unconditional stability based on novel criteria for dispersive media. In the special case of plasmonic metals Drude- and combined Drude/Lorentz-type of dispersion models can be applied to accurately approximate their frequency dependent permittivities in time domain simulations. With the help of the EEC FDTD technique an ultra-compact power splitter is analyzed at optical frequencies. The functionality of this device is based on the frequency selective coupling of two surface plasmons.**

The equivalent circuit (EC) FDTD scheme [1] is deduced from the *computational cell* shown in Fig. 1, which is the *lumped-element circuit representation of the electromagnetic Yee cell*. This cell is obtained by spatially discretizing Maxwell's equations in their integral form and mapping them to Kirchoff's laws (Faraday → voltage law, Ampere → current law) with properly defined currents and voltages. In general the EC FDTD scheme is a compact and efficient alternative representation of the conventional FDTD scheme and can be used in this initial form for the simulation of non-dispersive materials. The initial EC has been extended in order to simulate dispersive media [2] – hence the term EEC FDTD. Here the special case of plasmonic noble metals with frequency dependent permittivity is considered. In the framework of this application the EEC FDTD turned out to be advantageous for the following reasons:

First, the EEC FDTD scheme is *highly versatile*. Since its updated quantities are the voltages and currents, instead of the electric and magnetic field components, in the computational cell, the EEC FDTD allows *straightforward integration of electronic components* (inductors, capacitors, resistors, diodes, transistors, etc.) within the leap-frog algorithm. Moreover, the EEC FDTD scheme *can be directly applied to analyze dispersive media* by insertion of additional LC elements in the computational cell [2]. All types of dispersive media where an EC can be derived, including Drude, Lorentz and Debye media, can be simulated with the EEC FDTD scheme.

Second, in the case of non-uniform meshes, and in particular meshes with abrupt variation in the sizes of neighboring cells (e.g. for thin metal films with nanoscopic features), the EEC FDTD scheme exhibits a *larger maximum time step* (factor of 2 up to 10) *than that of the commonly used Courant-Friedrichs-Lewy (CFL) criterion* [3], allowing thereby faster computation. For the appropriate resolution of highly concentrated surface plasmons these strongly non-uniform meshes are mandatory to maintain the accuracy. While the CFL criterion, which is based on non-dispersive media assumption, does not guarantee stability for dispersive media, the EEC FDTD scheme has recently proven to provide *unconditional stability* both for non-dispersive and dispersive media (with different criteria), which represents an essential advantage for many media, such as for instance noble metals at optical frequencies. Two different approaches have been used to derive novel stability criteria for the EEC FDTD; one based on a Liapunov energy function [3] and the other one based on an eigenvalue approach where the maximal eigenfrequency of the EC of the mesh limits the time step. These criteria may be applied for all types of dispersive media where an EC can be derived, including Drude and Lorentz media.

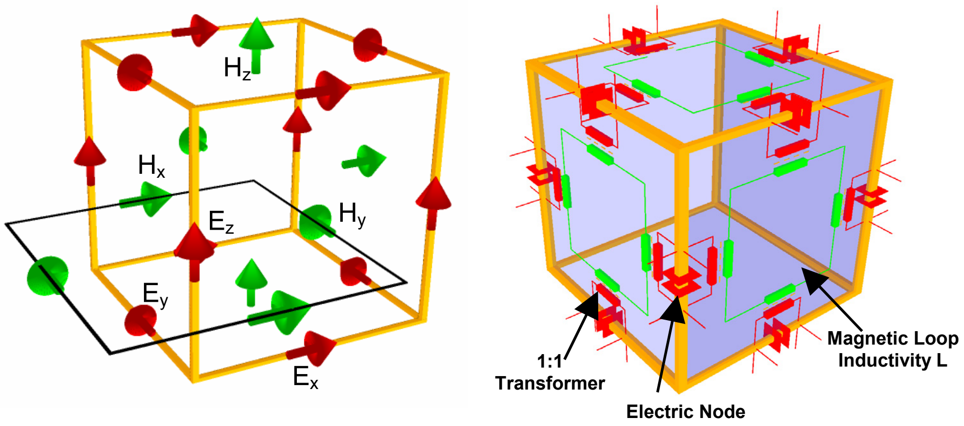

Fig. 1: Yee cell (left) and equivalent circuit (EC) based FDTD computational cell (right) for the simulation of non-dispersive media.

References

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