Sensitivity Analysis of Electromagnetic Structures in a Single FDTD Simulation

Costas D. Sarris and Hans-Dieter Lang
The Edward S. Rogers Sr. Dept. of Electrical & Comp. Engineering
University of Toronto, Toronto, ON, Canada

The complex-step derivative approximation (CSDA) is a finite-difference-free method to approximate derivatives of analytic functions. For a function of one variable, CSDA assumes the form: $f'(x) \approx Im\{f(x+jh)\}/h$. Recent studies in computational fluid dynamics have demonstrated the efficiency of CSDA as a tool for multi-parametric sensitivity analysis (J. R. R. A. Martins, P. Sturdza, J. J. Alonso, ACM Trans. on Math. Software, vol. 29, no. 3, Sept. 2003, pp. 245–262). From a computational electromagnetics perspective, CSDA can be easily coupled with numerical methods in the frequency and the time-domain. This work focuses on embedding CSDA within the Finite-Difference Time-Domain (FDTD) technique.

The resulting CSDA-FDTD scheme is a broadband sensitivity analysis technique that requires a single FDTD simulation in total (i.e. both for the output of interest and its sensitivity). Compared to existing alternatives, such as the Adjoint Variable Method (N. K. Nikolova, J. W. Bandler, and M. H. Bakr, IEEE Trans. Microwave Theory Tech., vol. 52, 2004, pp. 403–419), the proposed method includes no matrix assembly and operations; the post-processing involved is limited to the computation of the CSDA. Most importantly, CSDA can be accurately calculated for $h \to 0$. Contrary to finite-difference approximations, CSDA is not limited by subtractive cancellation errors. Therefore, the simulation that is required for the sensitivity analysis also provides the output of interest with a negligibly small error due to the introduction of the complex perturbation jh.

The technique can be easily applied to sensitivity analysis with respect to material parameters. However, sensitivity analysis with respect to geometric tolerances requires a mapping of those to material tolerances. On the other hand, the method can be extended to both multi-parametric and high-order sensitivity studies. Therefore, it is a computational tool of significant potential for numerical electromagnetics. While this work is focused on FDTD, applicatons of CSDA to frequency-domain numerical methods will also be discussed.