

# Coupled Electromagnetic Field & Electric Circuit Simulation: Monolithic vs. Co-Simulation Approach

C. Strohm<sup>1</sup> and C. Tischendorf<sup>2</sup>

**Abstract:** We consider coupled dynamical systems, see [1], of the form

$$\frac{d}{dt}u(t) + b(u(t), t) = c_1(x(t)), \quad u(t_0) = u_0, \quad (1)$$

$$f\left(\frac{d}{dt}d(x(t)), x(t), t\right) = c_2(u(t)), \quad x(t_0) = x_0. \quad (2)$$

The ordinary differential equation (1) reflects the spatially discretized electromagnetic field equations, see [2]. The differential-algebraic equation (2) describes the equations of a lumped circuit obtained by the modified nodal analysis, e. g. see [3]. The vector valued time dependent functions  $u$  and  $x$  comprise the electromagnetic field and circuit system variables, respectively. The right hand side functions  $c_1$  and  $c_2$  describe the coupling of both systems. Notice that the systems dimension may easily reach millions of unknowns whereby the dimension of  $u$  is magnitudes higher than of  $x$ .

We discuss the advantages and limits of both, monolithic and co-simulation, approaches. Whereas the monolithic solving of (1) – (2) requires an implicit numerical solving scheme, the co-simulation approach allows (1) to be solved explicitly, e. g. using the Leapfrog integration. Considering the dimension of  $u$  as the bottleneck, an explicit solving scheme is preferred in terms of computation space and time. On the other hand  $c_1$  and  $c_2$  have to fulfill certain criteria in order to guarantee convergence of the co-simulation approach, contrary to the monolithic one.

For an exemplary problem with coupling functions fulfilling the sufficient criteria for the Jacobi iteration scheme derived in [4], numerical results are presented and discussed with respect to the number of iterations, speed, memory and accuracy.

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- [2] Merkel, M., Niyonzima, I., Schöps, S.: ParaExp using Leapfrog as Integrator for High-Frequency Electromagnetic Solutions. arXiv preprint arXiv:1705.08019 (2017)
- [3] Lamour, R., März, R., Tischendorf, C.: Differential-Algebraic Equations: A Projector Based Analysis: A Projector Based Analysis. Springer (2013)
- [4] Pade, J., Tischendorf, C.: A Convergence Criterion for the Gauss-Seidel Waveform Relaxation Applied to Index-2 circuit DAEs. Dept. of Math. HU-Berlin Preprint 2016-21 (2016)

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<sup>1,2</sup> Department of Mathematics, Humboldt-University of Berlin  
Unter den Linden 6, 10099 Berlin, Germany  
[strohmch@math.hu-berlin.de](mailto:strohmch@math.hu-berlin.de), [tischendorf@math.hu-berlin.de](mailto:tischendorf@math.hu-berlin.de)