

Coupled circuit/EM simulation for radio frequency circuits

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Summary. In Radio Frequency (RF) circuits one observes on the one hand slowly varying baseband signals and on the other modulated or bandpass signals. The spectra of bandpass signals are centered around a carrier frequency, typically in the GHz range. The baseband are the envelopes of bandpass signals.

Communication engineers are mainly interested in distortions of the baseband signals during transmission. Therefore the method of the Equivalent Complex Baseband (ECB) was developed, which splits the envelope from the carrier waveform. This method circumvents the bottleneck caused by the sampling theorem, what speeds up the run-time significantly.

This technique is however not applicable for nonlinear circuits. Circuits are described by the Modified Nodal Analysis (MNA) and device constitutive equations, resulting in often huge systems of generally nonlinear ordinary differential algebraic equations (DAEs). Standard DAE solvers employing Backward Differentiation Formulas (BDF) are prohibitively slow since the time-steps for numerical integration must be much smaller than the reciprocal of the highest relevant frequency. The Multirate Partial Differential Equation (MPDE) reformulates the system of ordinary DAEs as a system of partial differential equations (PDEs) with mixed boundary/initial value conditions. The baseband and bandpass signals have then appropriate time-steps, circumventing the restriction of the sampling theorem. The solution of the ordinary DAE is obtained along a characteristic curve of the PDE.

The boundary/initial value problem can be solved by standard techniques such as the well known Harmonic Balance (HB) method based on trigonometric basis functions, multistep integration formulas (e.g. BDF methods) etc. On the one hand, trigonometric basis functions are not compact and do not permit local refinements. BDF methods exhibit, on the other hand, a numerical consumption of energy, leading to erroneous results, e.g., for oscillator circuits. In recent research projects spline/wavelet methods with adaptive grids have been developed as an alternative. Due to their compactness B-splines lead to highly sparse systems, making the solution run-time efficient. Moreover Gibb's phenomenon is avoided. Trigonometric B-splines moreover avoid the numerical damping.

In RF circuitry the lumped model assumption is often not valid anymore. Moreover critical devices are to be optimized w.r.t. geometry and even - in the case of semiconductors - doping profile. Therefore, in a current research project the in-house circuit simulator is coupled with a commercial EM field/device simulator. Critical RF devices are sim-

ulated in full 3D, whereas for the remaining circuit lumped device models are employed.

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