Multilevel Modified Nodal/Multiport State-space Approach for Frequency-domain Simulation of Large-scale Nonlinear RF and Microwave Circuits

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A multilevel approach for frequency-domain simulation of large-scale nonlinear RF and microwave circuits, including the presence of noise and thermal effects, is presented. In this approach, the circuit to be simulated is firstly decomposed into hierarchically interconnected supernetworks represented by a nodal equation [1]. Then, for each supernetwork we apply a piecewise network decomposition that separates it into linear and nonlinear subnetworks [2]. The nonlinear subnetwork encompasses all nonlinear devices (e.g., FETs and HBTs) in the supernetwork and it is formulated by an extended multiport state-space analysis (MSSA) [3]. While the embedding linear subnetwork is formulated using the classical modified nodal analysis (MNA) [4].

The advantages of using the extended MSSA instead of MNA for formulating the nonlinear subtnetwork is twofold: (i) it uses one single variable to represent a nonlinear function controlling voltage and, (ii) it naturally separates the nonlinear (controlled sources) equations from the other set of linear equations, namely differential (lumped memory elements), difference (distributed and delay elements) and additional (controlled sources) equations. Nevertheless, the MNA is a very powerful technique for formulating the linear subnetwork. It is well conditioned and structured and, it can be efficiently solved via LU factorization combined with sparse matrix computations. The MSSA uses a simple table-based methodology in order to generate the nonlinear subnetwork equations. It worth pointing out, that a very small matrix inversion is required for eliminating the linear (differential, difference and additional) equations and associated linear state-variables.

Our state-space approach is more efficient than the widely used parametric state-space approach [5], since the later approach may lead to a non-square system of equations and may involve high-order derivatives of nonlinear state-variables. These high-order derivatives leads to cumbersome expressions for the computation of nonlinear functions sensitivities with respect to the state-variables.

Finally, we describe the application of the above theory to the following RF and microwave circuit problems: nonlinear steady-state analysis via harmonic balance [5], large-signal conversion signal and noise analysis, and small-signal multiport hybrid signal and noise correlation matrix analysis [6]. New formulae for conversion from multiport hybrid parameters to multiport scattering parameter representation, and vice-versa, are included. Finally, we present frequency-domain simulation results for GaAs MESFET microwave power amplifier and InP HBT millimeter-wave downconverter. These results, obtained by our in-house software, validate the theory presented herein.

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