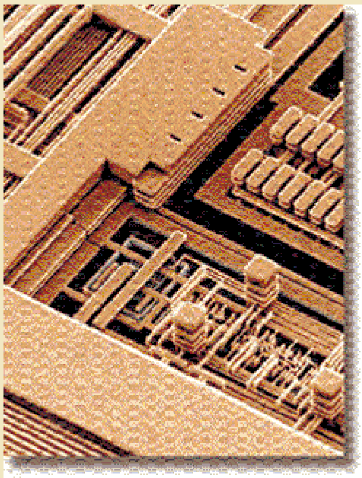
technische universiteit eindhoven

Reduced Order Modelling of Passive Substructures in Electronic Simulation

Ir. P.J. Heres, Prof.Dr. W.H.A. Schilders

Introduction



The continuing trend of higher frequencies and smaller feature sizes force the designer of electronic circuits to take into account electromagnetic effects caused by the interconnect structures. Straightforward coupling of circuit simulators with Maxwell solvers is prohibitive because of the large computational effort associated with this. Also, it seems unneccessary to use a detailed simulation of the electromagnetic effects for current problems. Therefore, one often attempts to capture the main electromagnetic effects into a compact model for the interconnect structure, and couples this to the circuit simulation programme. In this, numerical mathematics plays an important role, since most reduced order modelling techniques are based on Krylov subspace techniques. On the other hand, it is important to use simplifications which can be motivated using arguments from the theory of electromagnetics. Combining these two aspects, the SMURF project attempts to generate reduced order models for electronic interconnect structures.

System formulation

The interconnect can be modelled as a lumped-RLC-model with n ports and therefore can be described by a set of Kirchhoff's Current Laws and branch equations for the current controlled branches:

$$\begin{aligned} \mathbf{C}\dot{\mathbf{x}} &= -\mathbf{G}\mathbf{x} + \mathbf{B}\mathbf{v}_p \\ \mathbf{i}_p &= \mathbf{B}^T\mathbf{x}, \end{aligned} \qquad (1)$$

where $\mathbf{x}$ are the internal node voltages and currents, $\mathbf{v}_p$ is a set of voltages at the ports. This leads to a unique set of currents over the ports $\mathbf{i}_p$.

After Laplace transforming the system to the frequency domain, a transfer function can be formulated. This function gives a direct relation between input $\mathbf{v}_p$ and output $\mathbf{i}_p$ in the frequency domain and is therefore used as a measure of approximation for a reduction technique. For a multiport system as given in (1) the transfer function is a matrix valued function, given by:

$$\mathbf{H}(s) = \mathbf{B}^T(\mathbf{G} + s\mathbf{C})^{-1}\mathbf{B} \qquad (2)$$

Reduced Order Modelling

There are many techniques available in Reduced Order Modelling. The basis of our research is the SVD-Laguerre reduction technique proposed by Knockaert and De Zutter in 1999[a]. In this method a Krylov-space is generated, based on the observation that the transfer function can be expanded into Laguerre functions:

$$\mathbf{H}(s) = \frac{2\alpha}{s+\alpha}\mathbf{L}^T \sum_{n=0}^{\infty} \left((\mathbf{G}+\alpha\mathbf{C})^{-1}(\mathbf{G}-\alpha\mathbf{C})\right)^n (\mathbf{G}+\alpha\mathbf{C})^{-1}\mathbf{B}\left(\frac{s-\alpha}{s+\alpha}\right)^n$$

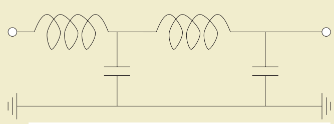
The matrices $(\mathbf{G}+\alpha\mathbf{C})^{-1}(\mathbf{G}-\alpha\mathbf{C})$ and $(\mathbf{G}+\alpha\mathbf{C})^{-1}\mathbf{B}$ are used to generate the Krylov subspace.

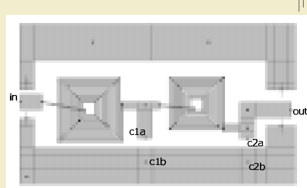
In the first year of the project we modified this algorithm in such a way that more accurate models are obtained. This was achieved by orthogonalizing the columns of the Krylov-space during the process, rather than at the end of the iterative process. In addition, an efficient implementation for multiple input columns was developed.

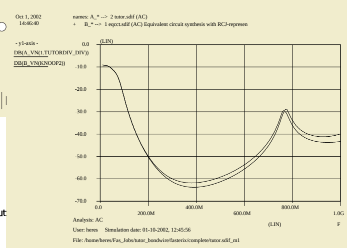
Via the Laguerre expansion we also found a new way to represent the reduced models in form of an electronic circuit, thus enabling a direct coupling with circuit simulations programmes.

Results

The example is a PCB of a lowpass filter, see the first figure below. On the board two spirals are printed which represent the two inductors. The two capacitors are added later, in order to be able to change the characteristics of the filter. We therefore want a circuit, with 6 ports, of which 4 ports are needed to connect 2 capacitors to it later. The printed board and the pins are shown in the second figure.







With the new version of the SVD-Laguerre algorithm this system can be reduced. The example, derived from a layout simulator, originally consisted of an RLC model, of which the MNA formulated matrix has size 465×465. The system is reduced to the size 84×84. After reduction the passivity of the system is preserved and we are still able to connect components at the ports of the reduced model. In the last picture the transfer function of the reduced system is compared with the results of a layout simulator.

Footnotes

[a] Luc Knockaert and Daniel De Zutter, "Passive Reduced Order Multiport Modeling: The Padé-Arnoldi-SVD Connection", *Int. J. Electronics and Communications*, nr. 53, 1999, pp. 254-260.

[b] This work is done by means of a grant of NWO (Dutch Organisation for Scientific Research, file nr. 635.000.010) and in corporation with Philips.

[c] Check www.ecce.tue.nl/SMURF for a detailed project description.