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Network Methods in Electromagnetic Field Computation

Prof. Dr. Peter Russer

Institute for High Frequency Engineering
Munich University of Technology
Arcisstrasse 21, Munich D-80333, Germany
russer@tum.de

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Faculty of Electrical Engineering
Czech Technical University in Prague
Technická 2, 166 27 Prague 6
Abstract

With increasing bandwidths and data rates of modern electronic circuits and systems, electromagnetic wave phenomena that in the past were in the domain of the microwave engineer, are now becoming pivotal in the design of analog and digital systems. Design, modeling and optimization of high-speed analog and digital electronic circuits and systems, photonic devices and systems, of antenna, radar, imaging and communications systems, among other applications, require the application of advanced tools in computational electromagnetics.

Compared with a network-oriented design a field-oriented design of circuits and systems requires a tremendously higher computational effort. The availability of steadily increasing computing facilities has not reduced the demand for efficient methods of electromagnetic field computation. This is readily understandable especially in the highly competitive design of broadband and high-speed electronic components. The demands for volume, weight and cost reduction foster a compact and complex design of electromagnetic structures yielding a high computational effort in electromagnetic modeling.

Network-oriented methods applied to electromagnetic field problems may contribute significantly to the problem formulation and solution methodology. Whereas in field theory the three-dimensional geometric structure of the electromagnetic field has to be considered, a network model exhibits a plain topological structure. Network models relate integral quantities like voltage and current, which at lower frequencies, can be defined uniquely by line integrals over electric and magnetic field quantities. An essential point is that network models can also apply to electromagnetic structures at higher frequencies when generalized voltages and currents are introduced by a proper definition of integral field quantities. One particular example of this procedure realized in Method of Moments (MoM) where the coefficients of the expansions of electric and magnetic fields can be considered as generalized voltages and currents and the linear equations relating these quantities as network equations.

In network theory systematic approaches for circuit analysis are based on the separation of the circuit into the connection circuit and the circuit elements. The connection circuit represents the topological structure of the circuit and contains only interconnects, including ideal transformers. Applying a network description electromagnetic structures can be segmented into substructures. These substructures define the circuit elements and the set of boundary surfaces between the substructures define the interconnection network. Canonical Foster equivalent circuits can represent lossless structures in sub-domains. Canonical Cauer networks can describe radiation modes. The lumped element models can be obtained by analytic methods, i.e. via Green's function or mode matching approaches or by numerical methods techniques (Transmission Line Matrix Method or Transverse Wave Formulation) in connection with system identification techniques.

The network approach allows a systematic introduction of hybrid methods. Furthermore, network formulations are well suited for the application of model order reduction methods. Analytic and numerical methods and examples of their application are discussed. Network methods are applicable in connection with the main analytic and numerical methods for electromagnetic field modeling and provide a large variety of tools for efficient modeling of complex electromagnetic structures.