

Computer-Aided Optimization of Nonlinear Microwave Circuits With the Aid of Electromagnetic Simulation

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Invited Paper

Abstract—This paper discusses some modern trends in nonlinear (NL) microwave circuit optimization based on electromagnetic (EM) simulation. In order to keep the CPU time required for a typical design within acceptable limits, the number of expensive EM analyses must be kept under tight control. This may be obtained by resorting to a systematic implementation of some modern algorithmic concepts such as space mapping, domain partitioning, and neural-network modeling of the passive subnetwork and/or of its most critical parts. Although these techniques are well established for linear microwave circuit design coupled with EM analysis, their extension to the NL case is not trivial, and deserves a specialized treatment. Several examples are presented in order to give a feeling of the state-of-the-art of NL/EM optimization.

Index Terms—Electromagnetic (EM) analysis, harmonic balance (HB), nonlinear (NL) microwave circuits, optimization.

I. INTRODUCTION

IN MANY practical applications of microwave circuits, the circuit topology and/or the frequency range of operation may be such that a meaningful simulation of the linear part of the network can only be obtained by a layout-oriented electromagnetic (EM) analysis based on the numerical solution of Maxwell's equations. Circuit design by numerical optimization then becomes a real challenge. The case of purely linear circuits has been addressed in several technical papers (including a number in this *TRANSACTIONS*), and some guidelines to its solution are now relatively well established [1]–[7], although this matter cannot be considered as a settled one, as it is still the subject of intensive research. In principle, the same methods should be applicable to nonlinear (NL) circuits, as well, but, in practice, the inherently higher numerical difficulty of the NL design problem may lead to less satisfactory results. The

main reasons for this are rather obvious. Nonlinearity implies the need for iterative procedures in the circuit analysis step and, thus, for nested loops in the optimization process, which unavoidably degrades numerical performance. In addition, nonlinearity also implies the presence of signal flow at higher order intermodulation (IM) products of the forcing signals, which, in the following, will be synthetically referred to as “harmonics.” Harmonics may be small or even negligible at the circuit ports (usually due to filtering), but are normally important inside the circuit and have a major influence on several key performance aspects such as efficiency, linearity, and the like. In turn, handling harmonics requires both the active devices and passive subnetwork to be accurately characterized over much broader frequency bands than is normally required for linear applications so that even the modeling step becomes more critical and expensive. Probably due to this, only limited attention has been devoted in the literature to NL/EM optimization, the main emphasis still being focused on the linear problem. Nevertheless, a few fundamental trends may be inferred from the available work on both linear and NL applications. The purpose of this paper is to highlight some of the techniques that currently appear promising in view of the development of systematic general-purpose NL/EM optimization capabilities.

NL/EM co-simulation has been demonstrated by several authors, both in the time [8]–[13] and frequency domains [14]–[16]. In principle, time-domain approaches such as the finite difference time domain (FDTD) are very attractive for this kind of application because they allow the semiconductor equations to be integrated with the numerical solution of Maxwell's equations [8]–[13]. On the other hand, this requires an NL iteration (solution of the device equations) to be carried out at each time step, which would lead to three nested loops in the optimization case. For this reason, the most suitable approach to NL/EM optimization seems to be the decomposition of the circuit into a linear multiport subnetwork to be analyzed by EM methods and a set of active devices to be described by computer-aided design (CAD)-oriented NL models. NL analysis aspects are then handled by the piecewise harmonic-balance (HB) technique. The device models normally include the parasitic effects introduced by the finger metallizations, while the electrode pads may be incorporated in

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Nonlinear Active Microwave Circuits Studies In Electrical And Electronic Engineering Volume 29

H Kauffman



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Nonlinear Active Microwave Circuits T. Berceci, 1987 This book presents analysis and design methods of microwave nonlinear active circuits Nonlinear models are established for each individual device thus introducing a set of nonlinear building blocks This allows not only qualitative but also quantitative investigations The relationships thereby obtained can be used for design purposes and they are also a help in understanding the circuit operation and for the detailed investigation of oscillators amplifiers mixers frequency multipliers and dividers The book concentrates on problems arising from the active nonlinear elements and it is mostly nonlinear transmission properties that are investigated Normalized quantities are applied in order to obtain results that can be used generally for a wide range of applications Equations are derived for many important circuit characteristics such as bandwidth gain amplitude and phase response group delay time AM compression AM to PM conversion noise figure AM noise FM noise output power added power efficiency matching optimum adjustment stability dynamic properties The results are directly applicable in the design procedure of circuits **Digital Control of Electric Drives** R. Koziol, J. Sawicki, L. Szklarski, 2013-10-22 The electromechanical systems employed in different branches of industry are utilized most often as drives of working machines which must be fed with electric energy in a continuous periodic or even discrete way Some of these machines operate at constant speed others require wide and varying energy control In many designs the synchronous cooperation of several electric drives is required in addition to the desired dynamic properties For these reasons the control of the cooperation and dynamics of electromechanical systems requires the use of computers This book adopts an unusual approach to the subject in that it treats the electric drive system on the one hand as an element of a control system and on the other as an element of a complex automatic system These two trends in the development of the automatic control of electric drives have resulted in a volume that provides a thorough overview on the variety of different approaches to the design of control systems **Microwave Measurement by Comparison Methods** Ivan Kneppo, 1988 This book is devoted to the problems of measuring electrical parameters of microwave devices circuits and systems by comparing the measured values of a quantity with known values of the quantity as represented by a reference microwave standard The author has tried to cover quite a wide group of microwave measuring techniques in the study since up to now comparison measurements have appeared only in periodicals handbooks of microwave measuring techniques or in various manuals describing the standard measuring procedures This broad based approach offers the possibility of abstracting the principles which are common to all partial comparison techniques and their modifications as well as deriving the general rules for the optimum design set up and use of corresponding measurement networks **Symbolic Network Analysis** Pen-Min Lin, 1991 The value of symbolic network analysis is now well recognized In industry it has been used as an aid in the design of small linear networks In academic institutions it has been found useful as an instructional aid The purpose of this book is to present in a single volume a unified treatment of all symbolic analysis methods using a consistent

set of notation and based on the same theoretical background network topology combinatorial analysis and numerical analysis The emphasis is on those methods which have been implemented and for which there are source codes available The work will be of interest to all those who have the usual college level training in circuit theory **Books in Series** ,1985 Vols for 1980 issued in three parts Series Authors and Titles *Analogue Optical Fibre Communications* Brett Wilson,Zabih Ghassemlooy,Izzat Darwazeh,1995 This book covers issues involved in improving the present range of systems and technology of optical fibre based telecommunications services operating with analogue sourced signals **Subject Guide to Books in Print** ,1993 *Scientific and Technical Books and Serials in Print* ,1989 **IEICE Transactions on Electronics** ,2003 **Nonlinear Active Microwave Circuits** T. Berceci,1987

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