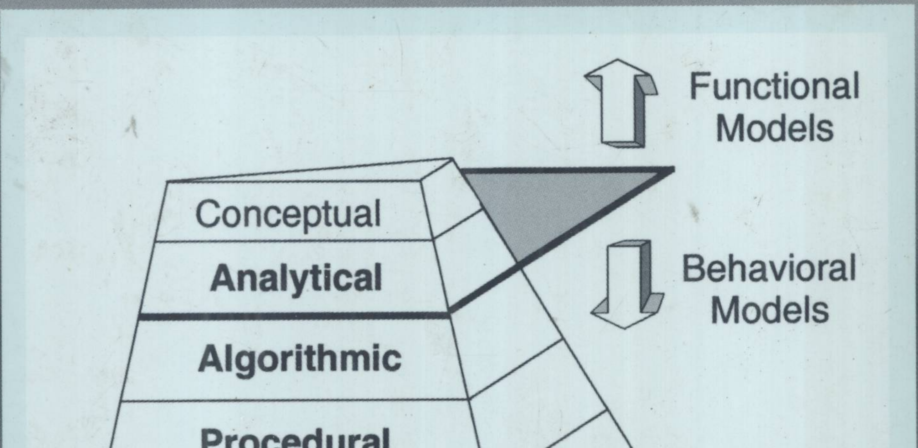
MODEL ENGINEERING IN MIXED-SIGNAL CIRCUIT DESIGN

A Guide to Generating Accurate Behavioral Models in VHDL-AMS

Sorin A. Huss



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by

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To Monika and to our children Britta, Martin, and Michael. Thank you for your patience!

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Sorin A. Huss
Darmstadt, August 2001

Foreword

Model engineering is an important activity within the design flow of integrated circuits and signal processing systems. This activity is not new at all in computer engineering, however, and takes a central role in practice. Model engineering of digital systems is based on agreed concepts of abstraction hierarchies for design object representations as well as the expressive power of hardware description languages (HDL). Since their gradual introduction over time HDL have proved to form the foundation of design methodologies and related design flows. Design automation tools for simulation, synthesis, test generation, and, last but not least, for formal proof purposes rely heavily on standardized digital HDL such as Verilog and VHDL.

In contrast to purely digital systems there is an increasing need to design and implement integrated systems which exploit more and more mixed-signal functional blocks such as A/D and D/A converters or phase locked loops. Even purely analog blocks celebrate their resurrection in integrated systems design because of their unique efficiency when is comes to power consumption requirements, for example, or complexity limitations. Examples of such analog signal processing functions are filtering or sensor signal conditioning. In general, analog and mixed-signal processing is indispensable when interfacing the real world (i.e., analog signals) to computers (i.e., digital data processing). Validation of integrated systems, an activity to be executed during the whole design flow, requires a single HDL for model representation in order to handle both partitions of the system model and especially their interaction efficiently.

Therefore, abstract descriptions of analog and mixed-signal systems and components are a new trend in model engineering. Again, modeling of such design objects is not as new as it might seem from the term of 'behavioral' modeling, an almost ubiquitous buzz word nowadays. Structural descriptions from basic components such as transistors and somewhat more abstract representations of analog circuits denoted as macro models have been used in practice for decades by analog circuit designers for analysis purposes exploiting

SPICE-like simulators. The intrinsic behavior of such models is transparent to most design engineers because it is well hidden within predefined component libraries. The availability of HDL for analog and especially for mixed-signal application domains has considerably changed this situation. Now, a modeler is enabled to express directly the behavior of parts of the integrated system without being limited to low-level model primitives such as transistor instances or controlled voltage sources. However, new questions arise, which are quite similar to those in the early days of modeling in the digital domain. These questions address abstraction level hierarchies, modeling concepts and related methods, model calibration and representation (i.e., the whole range of model engineering in mixed-signal systems).

The purpose of this book, therefore, is to combine the main issues of hardware description, characterization methods for the extraction of model parameters, and modeling methodologies for accurate high-level models of mixed-signal components and functional blocks. The work presented here emphasizes — for the first time — an engineering view on model generation and handling, thus providing a unique guide both for practitioners and students of electrical and computer engineering at graduate level. Chapter 1 presents an introduction to the model flow within integrated systems design, to generic model classes as well as to fundamental modeling concepts and representation languages. Chapter 2 is dedicated to the specification of behavior for analog and digital components. Abstraction hierarchies for these components are presented and discussed with respect to mixed-signal applications. Chapter 3 is intended to present a compact introduction to the basic concepts and to the expressivity of the HDL covered by the new IEEE standard 1076.1, also known as VHDL-AMS. Chapter 4 addresses circuit property extraction (i.e., characterization issues of analog building blocks). A new modeling methodology for mixed-signal circuits is proposed in Chapter 5. Finally, Chapter 6 presents results of the outlined model engineering methods for circuit examples of different complexity and operation domains. Several conclusions are summarized at the end of Chapter 6.

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Chapter 1

INTRODUCTION

Analog and mixed-signal integrated circuits (IC) design represents a major challenge for the design of complex information processing systems, especially when it comes to efficient top-down design flows. The generic architecture of mixed analog-digital systems being integrated into one IC, which is known as the *System-on-a-Chip (SoC)* style, consists of DSP cores and microcontrollers surrounded by A/D and D/A converters, which interface the internal bulk of digital processing to the analog sources and sinks of external information. In the signal processing and integrated circuits community it is widely agreed upon that analog and mixed-signal design expertise will increasingly be exploited for an implementation of powerful and at the same time cost-effective products in the areas of communication, consumer and automotive applications. When it comes to discussions on appropriate design flows for such products then two major problem regions may be identified. First, the design tools applied for design tasks in the analog and in the digital domain have to "talk to each other". An explicit need for such a tool communication is present especially in converter design. Secondly, top-down design — a proven adequate design methodology at least for digital systems — has to be adopted to the mixed-signal domain. However, good model-building concepts and efficient tools are essential for a painless transfer of abstract top-down methodologies to engineering practice. In addition, appropriate calibration methods are a precondition to ensure that high-level behavioral models do not diverge from lower-level, detailed models. In this chapter, therefore, we first will be discussing some basic issues related to model flows, modeling concepts, and model representation languages, which are the main means to making models executable (i.e., to get them to work).