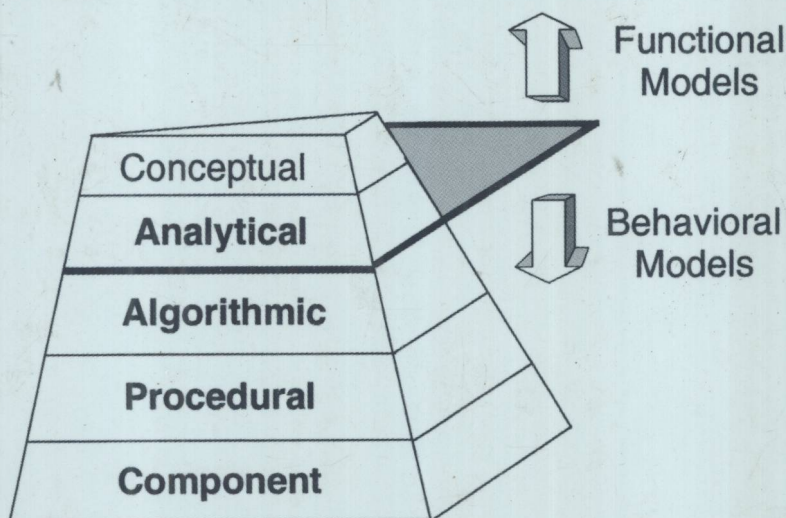


MODEL ENGINEERING IN MIXED-SIGNAL CIRCUIT DESIGN

**A Guide to Generating Accurate
Behavioral Models in VHDL-AMS**

Sorin A. Huss



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by

Sorin A. Huss

Darmstadt University of Technology



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J.A. Cherry, W. M. Snelgrove

*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 it 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.

Contents

List of Figures	ix
List of Tables	xiii
Acknowledgments	xv
Foreword	xvii
1. INTRODUCTION	1
1.1 Model flow in Mixed-Signal Design	2
1.2 Model classes	5
1.3 Modeling languages	8
2. SPECIFICATION OF BEHAVIOR	17
2.1 Analog Components	17
2.2 Digital Modules	23
2.3 Mixed-signal Systems	24
3. MODEL REPRESENTATION	33
3.1 Fundamentals of VHDL	33
3.1.1 Behavior	34
3.1.2 Data flow	35
3.1.3 Structure	36
3.1.4 Relations of models	36
3.2 Introduction to VHDL-AMS	36
3.2.1 Design objects	38
3.2.2 Extensions to VHDL	39
3.2.2.1 Quantities and Terminals	40
3.2.2.2 Conservation Laws	41
3.2.2.3 Representation of Behavior	46
3.2.2.4 Model Flow Using VHDL-AMS	49
3.2.2.5 Multi-Nature Systems	51

3.3	Mixed-Signal, Multi-Nature Modeling Example	54
3.3.1	Partitioning the System	54
3.3.2	Models of VDC functional units	56
3.3.2.1	Testbench	56
3.3.2.2	Environmental Model	57
3.3.2.3	Temperature Sensor	58
3.3.2.4	Analog/Digital Converter	58
3.3.2.5	Digital Block	61
3.3.3	Simulation Results	63
4.	CHARACTERIZATION OF CIRCUIT PROPERTIES	69
4.1	Role and Principles of Circuit Property Extraction	69
4.2	Requirements of Simulation-based Characterization	74
4.3	Visually specified Characterization Plans	78
4.4	Architecture of the ViCE System	83
5.	ADVANCED MODELING METHODOLOGY	89
5.1	Motivation	89
5.2	Classification of Modeling Approaches	90
5.3	The DEV&DESS Model	94
5.4	Basic Methodology and Model Architecture	97
5.5	Model Calibration	108
5.6	Case Study: A Linear Dynamic System	116
6.	APPLICATION EXAMPLES	125
6.1	Overview	125
6.2	Active Filter Circuit in Bipolar Technology	126
6.3	A/D Converter in CMOS Technology	137
6.4	Conclusions	155
	References	157

List of Figures

1.1	'Black box' model of a design process	2
1.2	Design flow for systems design	3
1.3	Model generation and validation	4
1.4	Time- and value-continuous signal waveform	6
1.5	Event discrete signal waveform	7
1.6	Time-discrete signal waveform	8
1.7	Causal model	9
1.8	Acausal model	10
1.9	Linear network	11
1.10	Block diagram of the linear network	12
1.11	Ideal electrical capacitor models	13
1.12	AND gate models	14
2.1	Macro level model of an operational amplifier	20
2.2	Schematic of a nonlinear CMOS circuit	21
2.3	Results of transient simulation	22
2.4	Specification of component behavior	23
2.5	Internal communication within a mixed-signal system	26
2.6	Time scales in mixed-signal systems	26
2.7	D/A conversion models	27
2.8	Abstraction hierarchy for mixed-signal systems	29
2.9	Interrelationship of model and simulator	31
3.1	Entity declaration of LFSR	34
3.2	Block and black box schematic of LFSR	34
3.3	Behavioral model of LFSR	35
3.4	Data flow model of LFSR	35

3.5	Structural model of LFSR	36
3.6	Testbench of LFSR	37
3.7	Combination of signal classes	39
3.8	Connecting functional and behavioral class models	39
3.9	Extension to IEEE Standard 1076-1993	40
3.10	Classification of quantities	41
3.11	Simple example for across and through quantities	42
3.12	Definition of nature Electrical and some branch quantities	42
3.13	Nonconservative block	43
3.14	Mixed causal/acausal block model	44
3.15	Simple analog circuit	45
3.16	Coding of component behavior model	46
3.17	Code of RC circuit	47
3.18	Generic model code of a D/A converter	48
3.19	Flow of model instances in systems design	49
3.20	Generic harmonic oscillator	50
3.21	Entity declarations for implementation variants	50
3.22	Pin compatibility of functional and behavioral models	51
3.23	Subset of a multi-nature package	52
3.24	Structural multi-nature model of a diode	53
3.25	Multi-nature model of a diode	53
3.26	Composition of the depth gauge	55
3.27	Code of vdc_testbench	56
3.28	Entity declaration of vdc_sources	58
3.29	Architecture declaration of LakeDive	59
3.30	Equivalent circuit for a temperature sensor	60
3.31	Model of temperature sensor	61
3.32	Model of vdc_ADC converter	62
3.33	Entity declaration of vdc_dsp	63
3.34	Architecture declaration of vdc_dsp	64
3.35	Model of aberation monitor vdc_tester	66
3.36	Results of system simulation	67
4.1	Output waveforms of an inverter resulting from fanout load conditions	71
4.2	Role of functional block characterization	73
4.3	Part of a characterization plan coded for SimPilot	76
4.4	Characterization on top of procedural simulation	77

4.5	Extraction of slew rate values coded in CLANG	77
4.6	Access windows to the ViCE system	79
4.7	Representation of a graph vertex as a glyph	80
4.8	Visually represented characterization plan for slew rate extraction	81
4.9	Overview of ViCE	84
4.10	Loop parallelization	85
4.11	Generic communication of scheduler and server programs within xpViCE	86
4.12	Outline of graph mapping	87
4.13	User interface of xpViCE	87
5.1	Block schematic of a successive approximation A/D converter	90
5.2	Behavioral generic VHDL-AMS model of an A/D converter	91
5.3	Information flows for model generation	95
5.4	DEV&DESS model architecture	96
5.5	Output signal values at discrete points in time	98
5.6	Response of a dynamic system to an input variable change	98
5.7	External and internal event queues	99
5.8	Generic VHDL-AMS model code for a 1 bit D/A converter	100
5.9	Simulation of mixed-signal circuits	100
5.10	Step response of a dynamic system	103
5.11	Integration steps prior to external event processing	104
5.12	Effect of adjacent events	105
5.13	Generic architecture of a behavioral algorithmic level model	107
5.14	Model generation methodology	109
5.15	Model calibration by means of the methods library	111
5.16	Comparison of reference and model behavior by different error norms	113
5.17	Geometrical interpretation of distances	113
5.18	Layers of methods library	115
5.19	Pseudo-code of interval segmentation for linear approximation	115
5.20	Linear dynamic system of 2. order	116
5.21	DESS model of the linear dynamic system	116
5.22	Passive RC circuit	117
5.23	Behavioral model of RC circuit	118
5.24	Calibrated parameter function $Dctf$	119
5.25	Calibrated parameter function $SlewRate$	119

5.26	Calibrated parameter function TDly	120
5.27	Functional block model of the linear dynamic system	122
5.28	Simulation results gained from executing the functional block model	123
6.1	Schematic of a biquad filter	127
6.2	Schematic of the operational amplifier MOPA1	127
6.3	Testbench adapter tool	129
6.4	Subset of a visually specified characterization plan	130
6.5	Calibration of the DC transfer function	131
6.6	Calibration of slewing behavior	132
6.7	Comparison of dynamic behavior of opamp models	133
6.8	Output resistance as a function of the load condition	134
6.9	Comparison of the DC behavior of models at identical output load conditions	135
6.10	Comparison of the time domain response of different filter models	136
6.11	Context and generic architecture of the A/D converter	138
6.12	Conversion algorithm of a stage	139
6.13	Circuit schematic of a converter stage	140
6.14	DC transfer curve of the converter stage	141
6.15	Partitioned converter stage	141
6.16	DC transfer curves of the ConvSubStage block	142
6.17	Comparison of the time domain responses of different subblock models	143
6.18	Comparison of time domain responses of different converter stage models	144
6.19	Simulation results for mixed-level model of the A/D converter	145
6.20	Calibrated generic model of the A/D converter	146
6.21	Comparison of switching time points for the LSB of the A/D converter	147
6.22	Top level model of the A/D converter	149
6.23	Model of the converter stage	150
6.24	Behavioral model of ConvSubStage	151

List of Tables

2.1	Abstraction hierarchy for analog components and blocks	18
2.2	Abstraction hierarchy for digital modules and systems	25
2.3	Different implementation styles of a filter block	29
3.1	Values of mode subject to PortAttribute	43
4.1	Coverage of requirements of characterization plans	78
4.2	Available control operators	82
5.1	Classes of modeling approaches	92
5.2	Fundamental parameter functions of block models	107
6.1	Testbenches for opamp property extraction	128
6.2	Segments and calibrated regression of the method DCtf	131
6.3	Comparison of requirements in terms of simulation resources	137
6.4	Comparison of simulation times for different models of the A/D converter.	144

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).