

Reihe 20

Rechnerunter-
stützte Verfahren

Nr. 474

Dipl.-Ing. Andreas Krinke,
Dresden

Constraint Propagation for Analog and Mixed-Signal Integrated Circuit Design



Technische Universität Dresden
Institut für Feinwerktechnik
und Elektronik-Design
Institutsdirektor Prof. Dr.-Ing. habil. Jens Lienig

ifte

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Constraint Propagation for Analog and Mixed-Signal Integrated Circuit Design

Dipl.-Ing.

Andreas Krinke

von der Fakultät Elektrotechnik und Informationstechnik der
Technischen Universität Dresden

zur Erlangung des akademischen Grades

Doktoringenieur

(Dr.-Ing.)

genehmigte Dissertation

Vorsitzender: Prof. Dr.-Ing. habil. Christian Georg Mayr

Gutachter: Prof. Dr.-Ing. habil. Jens Lienig, Prof. Dr.-Ing. Jürgen Scheible

Tag der Einreichung: 3.6.2019

Tag der Verteidigung: 23.8.2019

Fortschritt-Berichte VDI

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Constraint Propagation for Analog and Mixed-Signal Integrated Circuit Design

Fortschr.-Ber. VDI Reihe 20 Nr. 474. Düsseldorf: VDI Verlag 2020.

160 Seiten, 46 Bilder, 2 Tabellen.

ISBN 978-3-18-347420-2, ISSN 0178-9473,

€ 57,00/VDI-Mitgliederpreis € 51,30.

Für die Dokumentation: Entwurfsautomatisierung – Analog- und Mixed-Signal-Entwurf – Systementwurf – Schaltungsentwurf – Layoutentwurf – Ausbreitung von Randbedingungen – Integrierte Schaltungen – Electronic Design Automation – Analog and Mixed-Signal Design – System Design – Circuit Design – Layout Design – Constraint Propagation – Integrated Circuits

While the design of digital integrated circuits (ICs) is largely automated, the design of analog/mixed-signal (AMS) ICs is still dominated by manual tasks. One of the biggest obstacles to further automation is the large number of constraints that have to be taken into account during AMS IC design. They are derived both from the specification and during the actual design process and must be fulfilled before production of the IC can begin. The aim of this work is to present our findings regarding the formalization of constraints and their propagation within the design hierarchy in order to make them visible and verifiable in all relevant cells. Constraints are integrated into the AMS IC design process so that they can be considered at all stages of the design. Our research enables the integration and consideration of constraints in all types of design tools—not only for AMS IC design, but after generalization for any design process.

Bibliographische Information der Deutschen Bibliothek

Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliographie; detaillierte bibliographische Daten sind im Internet unter www.dnb.de abrufbar.

Bibliographic information published by the Deutsche Bibliothek

(German National Library)

The Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliographie (German National Bibliography); detailed bibliographic data is available via Internet at www.dnb.de.

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Als Manuskript gedruckt. Printed in Germany.

ISSN 0178-9473

ISBN 978-3-18-347420-2

To make knowledge productive, we will have to learn to see both forest and tree.

We will have to learn to connect.

Peter F. Drucker

Acknowledgments

This dissertation is the result of my work at the Institute of Electromechanical and Electronic Design (IFTE), especially in the context of the publicly funded projects RESCAR 2.0 and autoSWIFT together with Robert Bosch GmbH. However, arriving at this point to write these lines would never have been possible without the ideas and assistance of numerous people.

First and foremost, I would like to thank my wife Monic, who is at least as much involved in this work as I am, albeit not scientifically, but through her constant love, encouragement and support. Monic, I dedicate this work to you.

I sincerely thank my advisor, Professor Jens Lienig, for the opportunity to work in this rewarding field, for his competent and effective mentoring, and, finally, for his patience, which, surprisingly, did not seem to diminish over time.

My special thanks go to Göran Jerke for the valuable and guiding suggestions on the topic of my research, his insights into the industry, his support in pursuing my own ideas, and the lessons he taught me in technical writing—more than once.

I thank Professor Jens Lienig and Dr. Robert Fischbach for the many helpful corrections during the creation of the manuscript. Not only did they read the words, they also questioned the text and thereby revealed weaknesses. Of course I added new mistakes afterwards, so that all still existing errors are my fault.

Professor Jürgen Scheible has agreed to be the second examiner of this dissertation, for which I am very grateful.

My special thanks also go to my current and former colleagues at IFTE Dr. Steve Bigalke, Stefan Drechsel, Dr. Robert Fischbach, Tobias Heimpold, and many others for numerous joint breakfasts, a harmonious work environment, and many con-

structive discussions—both professionally and personally. I am glad that colleagues have become friends.

I would also like to thank Hannes Hahne, my school friend and later colleague at the Dresden University of Technology, for the extensive discussions during our Friday lunches. As it turned out, there are many interesting constraints to consider when planning biogas plants.

Last but not least, I thank my family for their continued love and encouragement. My sister Susanna asked more and more cautiously when this thesis would be finished. Our parents Joachim and Heidemarie have brought me to this point with their care and constant support, for which I am very grateful. I thank my parents-in-law Frank and Sylvia for their willingness to take over childcare, often at short notice. Finally, I thank my two wonderful children Olivia and Arthur for showing me every day what is truly important. They motivate me in their own way, or as Arthur would say: “Dad, when you’re done, you can buy a 3D printer!”

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Abbreviations

ADC	analog-to-digital converter
AMS	analog/mixed-signal
API	application programming interface
CAD	computer-aided design
CAS	computer algebra system
CLP	constraint logic programming
CMOS	complementary metal-oxide-semiconductor
CMP	chemical-mechanical planarization
CPLD	complex programmable logic device
CPU	central processing unit
CSP	constraint satisfaction problem
DAC	digital-to-analog converter
DBMS	database management system
DMA	direct memory access
DSP	digital signal processor
EDA	electronic design automation
ESD	electrostatic discharge
FPGA	field-programmable gate array
GDP	gross domestic product
GP	geometric programming
GPU	graphics processing unit
GSA	Global Semiconductor Alliance
HDL	hardware description language

HTTP	Hypertext Transfer Protocol
I/O	input/output
IC	integrated circuit
ID	identifier
IP	intellectual property
IPC	interprocess communication
JSON	JavaScript Object Notation
LDE	layout-dependent effect
LTE	Long Term Evolution
NoSQL	no (or not only) SQL
PDK	process design kit
RAK	rapid adoption kit
RAM	random-access memory
RDBMS	relational database management system (DBMS)
REST	representational state transfer
RF	radio frequency
RX	receiver
SA	simulated annealing
SOC	system on chip
SQL	structured query language
STI	shallow trench isolation
TX	transmitter
URL	uniform resource locator
VHDL	very high speed integrated circuit hardware de- scription language
VLSI	very large scale integration
WFF	well-formed formula
WPE	well proximity effect

Selected Symbols

\mathbb{B}	Boolean domain
c	Constraint
C, C_i	Cell
C_p	Parent cell
D	Design state
\mathcal{D}	Set of all possible design states
E	Expression tree
F	Set of function symbols
G	Design hierarchy
I_i	Instance
M	Set of all possible constraint members
m_i	Constraint member
N	Net
Ω	Set of all possible values in a constraint function
O_X	Set of all global instances (occurrences) of cell X in the design
P	Set of predicate symbols
p	Predicate
Φ	Higher-order constraint function
φ	Constraint function
φ^*	Transformed constraint function
Ψ	Set of design parameters
ψ	Design parameter

ψ^*	Transformed design parameter
Q	Set of all possible constraint parameter values
q_i	Constraint parameter
S	Set of sorts
s	Shape
Σ	Signature of a many-sort predicative logic
σ	Sort
S_x	Set of electrically connected layout shapes
\mathcal{T}	Constraint type
T, T_i	Terminal
$T^{I_T}, T_i^{I_T}$	Instance terminal of instance I_T
X	Constraint context cell
\mathcal{X}	Set of all cells in the design

Abstract

While the design of digital integrated circuits (ICs) is largely automated, the design of analog/mixed-signal (AMS) ICs is still dominated by manual tasks. One of the biggest obstacles to further automation is the large number of constraints that have to be taken into account during AMS IC design. They are derived both from the specification and during the actual design process and must be fulfilled before production of the IC can begin. Current IC design tools hardly support working with constraints—they are either not formally described and are therefore only available as export knowledge, or they are not visible in all cells in which they must be considered.

This thesis addresses three selected, practically relevant problems of constraint management during AMS IC design: (1) formal description of constraints and their classification, (2) propagation of constraints within the design hierarchy so that they are visible and verifiable in all relevant cells, and (3) influence of constraints on the modeling and storage of design data. By implementing solutions to all three problems, the comprehensive and consistent consideration of constraints in the entire design hierarchy and flow is made possible, thereby overcoming the obstacle described above.

The objective of this work is to formalize constraints and integrate them into the AMS IC design process so that they can be considered at all stages of the design. Experimental investigations show the practical suitability of the methods even for complex circuits. Our findings enable the integration and consideration of constraints in all types of design tools—not only for AMS IC design, but after generalization also for any design process.

Kurzfassung

Der Entwurf digitaler integrierter Schaltungen (ICs) ist weitestgehend automatisiert. Im Gegensatz dazu wird der Entwurf analoger und gemischt analog/digitaler AMS-ICs noch immer von manuellen Arbeiten dominiert. Eines der größten Hindernisse für die weitere Automatisierung ist die große Zahl von Randbedingungen, die beim Analogentwurf berücksichtigt werden müssen. Diese ergeben sich sowohl aus der Spezifikation als auch während des eigentlichen Entwurfs und müssen erfüllt sein, bevor die Herstellung des Schaltkreises beginnen kann. Aktuelle Entwurfswerkzeuge unterstützen die Arbeit mit Randbedingungen kaum – entweder sie sind nicht formal beschrieben und liegen somit nur als Expertenwissen vor, oder sie sind nicht in allen Zellen sichtbar, in denen sie beachtet werden müssen.

In dieser Arbeit werden drei ausgewählte, praktisch relevante Problemstellungen der Verwaltung von Randbedingungen beim Entwurf von AMS-ICs bearbeitet: (1) die formale Beschreibung von Randbedingungen und ihre Klassifikation, (2) die Propagierung von Randbedingungen innerhalb der Entwurfshierarchie, so dass sie in allen relevanten Zellen sicht- und verifizierbar sind, sowie (3) der Einfluss von Randbedingungen auf die Modellierung und Speicherung von Entwurfsdaten. Durch die Implementierung von Lösungen für alle drei Probleme wird die umfassende und konsistente Berücksichtigung von Randbedingungen in der gesamten Entwurfshierarchie und in allen Teilen des Entwurfsprozesses ermöglicht und damit das oben beschriebene Hindernis überwunden.

Das Ziel dieser Arbeit besteht darin, Randbedingungen zu formalisieren und in den Entwurfsprozess von AMS-ICs zu integrieren, so dass sie in allen Phasen des Entwurfs berücksichtigt werden können. Experimentelle Untersuchungen zeigen die Praxistauglichkeit der Methoden auch für komplexe Schaltungen. Die Erkenntnisse

ermöglichen die Integration und Berücksichtigung von Randbedingungen in allen Arten von Entwurfswerkzeugen – nicht nur für den Entwurf von AMS-ICs, sondern nach Verallgemeinerung auch für beliebige Entwurfsprozesse.