Digital Integrated Circuit Design

From VLSI Architectures to CMOS Fabrication

- A top-down guide to the design of digital integrated circuits.
- Reflects industry design methods, moving from VLSI architecture design to CMOS fabrication.
- Practical hints and tips, case studies, and checklists provide a how and when guide to design.
- Key concepts and theory are explained when needed to provide the student with an insightful, practical guide.
- Homework problems test the student's understanding.
- Lecture slides help instructors deliver this course.

This unique guide to designing digital VLSI circuits takes a top-down approach, reflecting the nature of the design process in industry. Starting with architecture design, the book explains the why and how of digital design, using the physics that designers need to know, and no more.

Covering system and component aspects, design verification, VHDL modelling, clocking, signal integrity, layout, electrical overstress, field-programmable logic, economic issues, and more, the scope of the book is singularly comprehensive.

With a focus on CMOS technology, numerous examples — VHDL code, architectural concepts, and failure reports — practical guidelines, and design checklists, this engaging textbook for senior undergraduate and graduate courses on digital ICs will prepare students for the realities of chip design.

Practitioners will also find the book valuable for its insights and its practical approach.

Instructor-only solutions and lecture slides are available at www.cambridge.org/9780521882675.

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CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org

First published 2008

Printed in Malaysia

A catalog record for this publication is available from the British Library

ISBN 978-0-521-88267-5 hardback

Contents

Preface

Why this book?

Designing integrated electronics has become a multidisciplinary enterprise that involves solving problems from fields as disparate as

- Hardware architecture
- Software engineering
- Marketing and investment
- Solid-state physics
- Systems engineering
- Circuit design
- Discrete mathematics
- Electronic design automation
- Layout design
- Hardware test equipment and measurement techniques

Covering all these subjects is clearly beyond the scope of this text and also beyond the author's proficiency. Yet, I have made an attempt to collect material from the above fields that I have found to be relevant for deciding whether or not to develop digital Very Large Scale Integration (VLSI) circuits, for making major design decisions, and for carrying out the actual engineering work.

The present volume has been written with two audiences in mind. As a textbook, it wants to introduce engineering students to the beauty and the challenges of digital VLSI design while preventing them from repeating mistakes that others have made before. Practising electronics engineers should find it appealing as a reference book because of its comprehensiveness and the many tables, checklists, diagrams, and case studies intended to help them not to overlook important action items and alternative options when planning to develop their own hardware components.

What sets this book apart from others in the field is its top-down approach. Beginning with hardware architectures, rather than with solid-state physics, naturally follows the normal VLSI design flow and makes the material more accessible to readers with a background in systems engineering, information technology, digital signal processing, or management.

Highlights

- Most aspects of digital VLSI design covered
- Top-down approach from algorithmic considerations to wafer processing
- Systematic overview on architecture optimization techniques
- Scalable concepts for simulation testbenches including code examples
- Emphasis on synchronous design and HDL code portability
- Comprehensive discussion of clocking disciplines
- Key concepts behind HDLs without too many syntactical details
- A clear focus on the predominant CMOS technology and static circuit style
- Just as much semiconductor physics as digital VLSI designers really need to know
- Models of industrial cooperation

- What to watch out for when purchasing virtual components
- Cost and marketing issues of ASICs
- Avenues to low-volume fabrication
- Largely self-contained (required previous knowledge summarized in two appendices)
- Emphasis on knowledge likely to remain useful in the years to come
- Many illustrations that facilitate recognizing a problem and the options available
- Checklists, hints, and warnings for various situations
- A concept proven in classroom teaching and actual design projects

A note to instructors

Over the past decade, the capabilities of field-programmable logic devices, such as FPGAs and CPLDs, have grown to a point where they have become invaluable ingredients of many electronic products, especially of those designed and marketed by small and medium-sized enterprises. Beginning with the higher levels of abstraction enables instructors to focus on those topics that are equally relevant irrespective of whether a design eventually gets implemented as a mask-programmed custom chip or from components that are just configured electrically. This material is collected in chapters 1 to 5 of the book and best taught as part of the Bachelor degree for maximum dissemination. No prior introduction to semiconductors is required. For audiences with little exposure to digital logic and finite state machines, the material can always be complemented with appendices A and B.

Learning how to design mask-programmed VLSI chips is then open to Master students who elect to specialize in the field. Designing electronic circuits down to that level of detail involves many decisions related to electrical, physical, and technological issues. An abstraction to purely logical models is no longer valid since side effects may cause an improperly designed circuit to behave differently than anticipated from digital simulations. How to cope with clock skew, metastability, layout parasitics, ground bounce, crosstalk, leakage, heat, electromigration, latch-up, electrostatic discharge, and process variability in fact makes up much of the material from chapter 6 onwards.

Again, the top-down organization of the book leaves much freedom as to where to end a class. A shorter course might skip chapter 8 as well as all material on detailed layout design that begins with section 11.5 on the grounds that only few digital designers continue to address device-level issues today. A similar argument also applies to the CMOS semiconductor technology introduced in chapter 14. Chapter 13, on the other hand, should not be dropped because, by definition, there are no engineering projects without economic issues playing a decisive role.

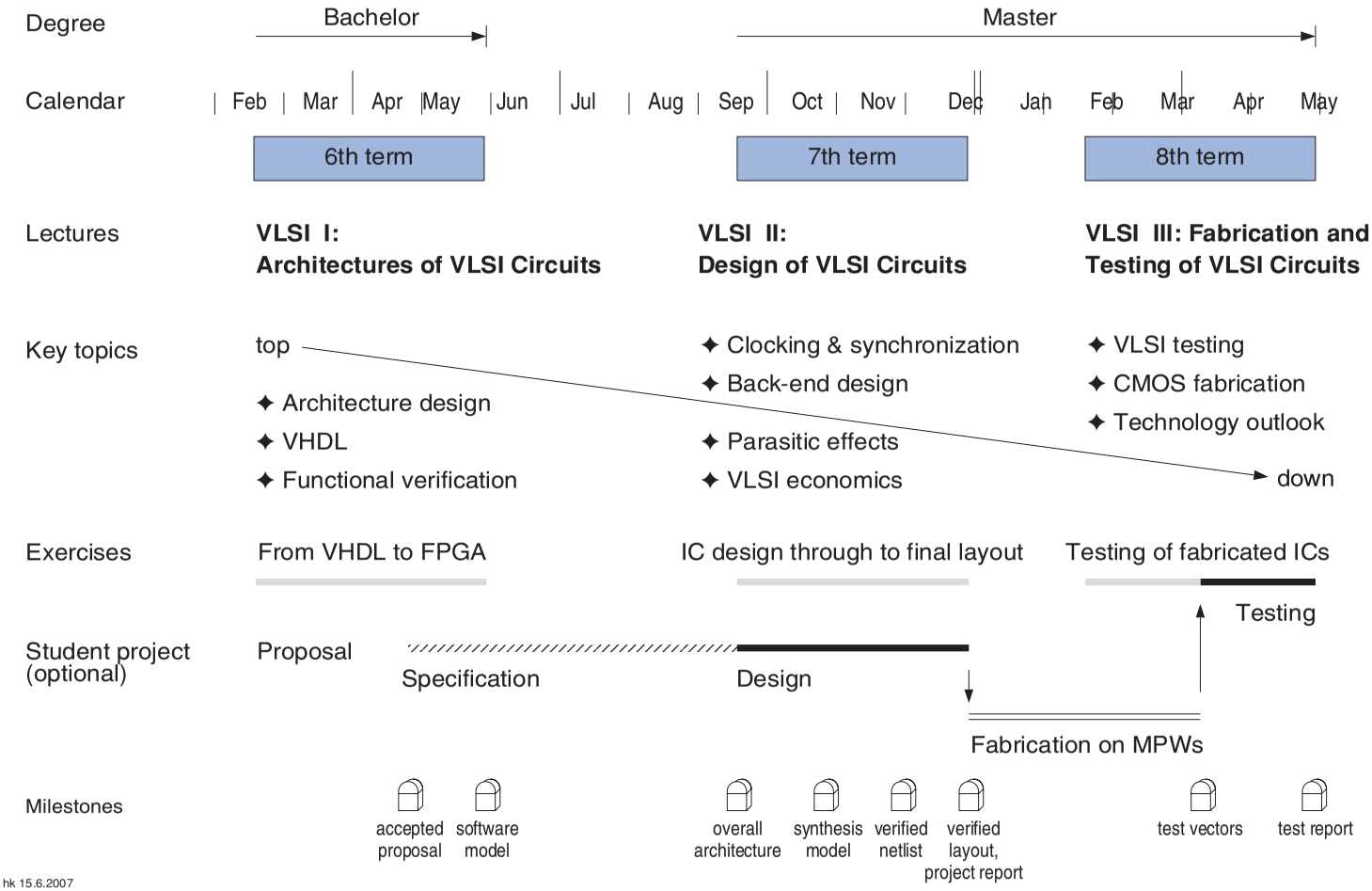
For those primarily interested in the business aspects of microelectronics, it is even possible to put together a quick introductory tour from chapters 1, 13, and 15 leaving out all the technicalities associated with actual chip design.

The figure below explains how digital VLSI is being taught by the author and his colleagues at the ETH. Probably the best way of preparing for an engineering career in the electronics and microelectronics industry is to complete a design project where circuits are not just being modeled and simulated on a computer but actually fabricated. Provided they come up with a meaningful project proposal, our students are indeed given this opportunity, typically working in teams of two. Following tapeout at the end of the 7th term, chip fabrication via an external multi-project wafer service takes roughly three months. Circuit samples then get systematically tested by their very developers in their 8th and final term. Needless to say that students accepting this offer feel very motivated and that industry highly values the practical experience of graduates formed in this way.

The technical descriptions and procedures in this book have been developed with the greatest of care; however, they are provided as is, without warranty of any kind. The author and editors of the book make no warranties, expressed or implied, that the equations, programs, and procedures in this book are free of error, or are consistent with any particular standard of merchantability, or will meet your requirements for any particular application. They should not be relied upon for solving a problem whose incorrect solution could result in injury to a person or loss of property.

Syllabus of ETH Zurich in

Digital VLSI Design and Test



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Acknowledgements

This volume collects the insight and the experience that many persons have accumulated over the last couple of years. While I was fortunate enough to compile the text, I am indebted to all those who have been willing to share their expertise with me.

My thanks thus go not only to my superiors at the ETH Zürich, Switzerland, Professors Wolfgang Fichtner, Qiuting Huang, and Rüdiger Vahldieck, but also to many past and present colleagues of mine including Dr. Dölf Aemmer, Professor Helmut Bölcskei, Dr. Heinz Bonnenberg, Dr. Andreas Burg, Felix Bürgin, Professor Mike Ciletti, Dr. Flavio Carbognani, Dr. Andreas Curiger, Stefan Eberli, Dr. Nobert Felber, Dr. Steffen Gappisch, Dr. Ronald Gull, Dr. Simon Häne, Kurt Henggeler, Dr. Lucas Heusler, Peter Lüthi, Dr. Chiara Martelli, Dieter Müller, Stephan Oetiker, Dr. David Perels, Dr. Robert Rogenmoser, Andreas Romer, Dr. Fritz Rothacher, Dr. Thomas Röwer, Dr. Manfred Stadler, Dr. Andreas Stricker, Christoph Studer, Thomas Thaler, Dr. Markus Thalmann, Jürg Treichler, Dr. Thomas Villiger, Dr. Jürgen Wassner, Dr. Marc Wegmüller, Markus Wenk, Dr. Rumi Zahir, and Dr. Reto Zimmermann. Most of these experts have also reviewed parts of my manuscript and helped to improve its quality. Still, the only person to blame for all errors and other shortcomings that have remained in the text is me.

Next, I would like to express my gratitude towards all of the students who have followed the courses on Digital VLSI Design and Testing jointly given by Dr. Nobert Felber and myself. Not only their comments and questions, but also results and data from many of their projects have found their way into this text. André Meyer and Thomas Peter deserve special credit as they have conducted analyses specifically for the book.

Giving students the opportunity to design microchips, to have them fabricated, and to test physical samples is a rather onerous undertaking that would clearly have been impossible without the continuous funding by the ETH Zürich. We are also indebted to Professor Fichtner for always having encouraged us to turn this vision into a reality and to numerous Europractice partners and industrial companies for access to EDA software, design kits, and low-volume manufacturing services.

The staff of the Microelectronics Design Center at the ETH Zürich and various IT support people at the Integrated Systems Laboratory, including Christoph Balmer, Matthias Brändli, Thomas Kuch, and Christoph Wicki, do or did a superb job in setting up and maintaining the EDA infrastructure and the services indispensable for VLSI design in spite of the frequent landslides caused by rapid technological evolution and by unforeseeable business changes. I am particularly grateful to them for occasionally filling all sorts of gaps in my technical knowledge without making me feel too badly about it.

I am further indebted to Dr. Frank Gürkaynak and Professor Yusuf Leblebici of the EPFL in Lausanne, Switzerland, for inciting me to turn my lecture notes into a textbook and for their advice. In a later phase, Dr. Julie Lancashire, Anna Littlewood, and Dawn Preston of Cambridge University Press had to listen to all my silly requests before they managed to get me acquainted with the realitities of printing and publishing. Umesh Vishwakarma of TeX Support is credited for preparing bespoke style files for the book, Christian Benkeser and Yves Saad for contributing the cover graphics.

Finally, I would like to thank all persons and organizations who have taken the time to answer my reprint requests and who have granted me the right to reproduce illustrations of theirs.