CMOS VLSI Design

A Circuits and Systems Perspective

Fourth Edition

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To Avril, Melissa, Tamara, Nicky, Jocelyn,
Makayla, Emily, Danika, Dan and Simon
N. W.

To Jennifer, Samuel, and Abraham
D. M. H.

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Chapter 7 **Robustness**

Chapter 8 **Circuit Simulation**

Preface

In the two-and-a-half decades since the first edition of this book was published, CMOS technology has claimed the preeminent position in modern electrical system design. It has enabled the widespread use of wireless communication, the Internet, and personal computers. No other human invention has seen such rapid growth for such a sustained period. The transistor counts and clock frequencies of state-of-the-art chips have grown by orders of magnitude.

	1st Edition	2nd Edition	3rd Edition	4th Edition
Year	1985	1993	2004	2010
Transistor Counts	10^5–10^6	10^6–10^7	10^8–10^9	10^9–10^{10}
Clock Frequencies	10^7	10^8	10^9	10^9
Worldwide Market	$25B	$60B	$170B	$250B

This edition has been heavily revised to reflect the rapid changes in integrated circuit design over the past six years. While the basic principles are largely the same, power consumption and variability have become primary factors for chip design. The book has been reorganized to emphasize the key factors: delay, power, interconnect, and robustness. Other chapters have been reordered to reflect the order in which we teach the material.

How to Use This Book

This book intentionally covers more breadth and depth than any course would cover in a semester. It is accessible for a first undergraduate course in VLSI, yet detailed enough for advanced graduate courses and is useful as a reference to the practicing engineer. You are encouraged to pick and choose topics according to your interest. Chapter 1 previews the entire field, while subsequent chapters elaborate on specific topics. Sections are marked with the "Optional" icon (shown here in the margin) if they are not needed to understand subsequent sections. You may skip them on a first reading and return when they are relevant to you.

We have endeavored to include figures whenever possible ("a picture is worth a thousand words") to trigger your thinking. As you encounter examples throughout the text, we urge you to think about them before reading the solutions. We have also provided extensive references for those who need to delve deeper into topics introduced in this text. We

have emphasized the best practices that are used in industry and warned of pitfalls and fallacies. Our judgments about the merits of circuits may become incorrect as technology and applications change, but we believe it is the responsibility of a writer to attempt to call out the most relevant information.

Supplements

Numerous supplements are available on the Companion Web site for the book, `www.cmosvlsi.com`. Supplements to help students with the course include:

- A lab manual with laboratory exercises involving the design of an 8-bit microprocessor covered in Chapter 1.
- A collection of links to VLSI resources including open-source CAD tools and process parameters.
- A student solutions manual that includes answers to odd-numbered problems.
- Certain sections of the book moved online to shorten the page count. These sections are indicated by the "Web Enhanced" icon (shown here in the margin).

Supplements to help instructors with the course include:

- A sample syllabus.
- Lecture slides for an introductory VLSI course.
- An instructor's manual with solutions.

These materials have been prepared exclusively for professors using the book in a course. Please send email to `computing@aw.com` for information on how to access them.

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Sally Harris has been editing family books since David was an infant on her lap. She read the page proofs with amazing attention to detail and unearthed hundreds of errors.

This book would not have existed without the support of our families. David would particularly like to thank his wife Jennifer and sons Abraham and Samuel for enduring two summers of absence while writing, and to our extended family for their tremendous assistance.

We have become painfully aware of the ease with which mistakes creep into a book. Scores of 3rd edition readers have reported bugs that are now corrected. Despite our best efforts at validation, we are confident that we have introduced a similar number of new errors. Please check the errata sheet at `www.cmosvlsi.com/errata.pdf` to see if the bug has already been reported. Send your reports to `bugs@cmosvlsi.com`.

N. W.
D. M. H.
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