Fast Techniques for Integrated Circuit Design

Do you want to deepen your understanding of complex systems and design integrated circuits more quickly? Learn how with this step-by-step guide that shows, from first principles, how to employ estimation techniques to analyze and solve complex problems in IC design using a simplified modeling approach. Applications are richly illustrated using real-world examples from across IC design, from simple circuit theory to electromagnetic effects and high-frequency design and systems such as data converters and phase-locked loops. Basic concepts such as inductance and capacitance are related to each other and to other RF phenomena inside a modern chip, enhancing understanding without the need for simulators. Use the easy-to-follow models presented to start designing your own products, from inductors and amplifiers to more complex systems.

Whether you are an early-career professional or researcher, graduate student, or established IC engineer looking to reduce your reliance on commercial software packages, this is essential reading.

Mikael Sahrling is Principal Engineer for ASIC Design at Tektronix Inc. He has over 20 years of experience in analog and mixed-signal circuit design.

"The estimation analysis techniques in this book open up a new and unique approach to gaining a deeper understanding of circuits, thus accelerating the optimization and design of a broad range of circuits, which is a critical skill in the fast paced IC design world where time to market is crucial to success."

Joel King, ***Skyworks Solutions, Inc.***

"Developing engineering solutions benefits greatly from the proverbial back of the envelope analysis. This book does an excellent job of not only providing a great reference to a number of estimating techniques (limitations clearly identified) for a number of key topics. It also resurrects the concept of engineering estimation, to quickly evaluate ideas and drive to useful conclusions without losing context. This art form is dwindling as today's engineers continue to depend on (very capable) computer simulators, slowing the development of intuition and hence innovation."

Claudio Anzil, ***Innophase Inc.***

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MIKAEL SAHRLING
Tektronix Inc.

CAMBRIDGE
UNIVERSITY PRESS

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University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781108498456
DOI: 10.1017/9781108682336

First published 2019

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data
Names: Sahrling, Mikael, 1964– author.
Title: Fast techniques for integrated circuit design / Mikael Sahrling (Tektronix Inc.).
Description: Cambridge, United Kingdom ; New York, NY : Cambridge University Press, 2019. | Includes bibliographical references and index.
Identifiers: LCCN 2019009296 | ISBN 9781108498456 (hardback) | ISBN 1108498450 (hardback)
Subjects: LCSH: Integrated circuits–Design and construction.
Classification: LCC TK7874 .S187 2019 | DDC 621.3815–dc23
LC record available at https://lccn.loc.gov/2019009296

ISBN 978-1-108-49845-6 Hardback

For Nancy and Nicole

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Preface

This book is a result of many years in active design work in the semiconductor industry. I started my career as a theoretical physicist working on dense matter theory and electromagnetic fields in an astrophysical environment. After a few years my interest turned toward integrated circuit design, where there were also electromagnetic fields, and I have been working in this field ever since. It is a rich environment for the study of nature and mathematics and I am thrilled to be a part of it. As a theoretical physicist one always tries to get a handle on experiments and observations by doing simple mathematical modeling, and in my stint as a postdoc in the theoretical physics group at Caltech in the 1990s I was part of an Order of Magnitude Physics, 103c class that took this idea to town. The students were asked to estimate things such as the amount of rubber dumped into the air from cars on LA's freeways and how long a grass straw would grow in a week with a given precipitation and sunlight. The class was taught by Professor Peter Goldreich and Professor Sterl Phinney, and it opened my eyes to the power of estimation. In my career I have always tried to understand things by first estimating the impact of a certain effect and then verifying it. This analysis method has been a great help for me personally and the people I have been lucky enough to tutor. I have also encountered many other engineers and academic professionals who are very good at following these same principles. This book is an attempt to bring this way of thinking about design in general and circuit design in particular to a broader audience. I refer to the analysis method as estimation analysis, but many people use the term hand calculations, which I find to be rather misleading. Simply put, we consider complex problems in a way that do not require exact full solutions. The book will show that this approach can be taken for almost any problem, be it circuit analysis, high frequency phenomena, sampling concepts or jitter, to name a few. The scope of the book is from simple circuit theory, familiar to most engineers, to high frequency theory with a particular focus on integrated circuit applications, to systems such as data converters and phase-locked loops (PLLs). The applications are intentionally fairly broad, to illustrate the power of the techniques. What is different in this book compared with other similar ones is a strict physical approach where all situations are modeled carefully, often from first principles, followed by useful solutions and illustrative relationships after some algebra. Once such a model is established one can use it as a starting point for simulations where the simulator is used to fine-tune the design.

It is assumed that the reader is familiar with basic electromagnetism and circuit theory. There is no need to have any previous exposure to high level systems such as

PLLs and analog-to-digital converters (ADCs). Mathematical maturity corresponding to one year of college-level calculus and vector analysis is also assumed.

The book will start with a short chapter outlining the basic modeling concept, followed by two chapters describing basic circuit analysis where this modeling approach is used. These chapters should be familiar to most readers; the intention is to use the analysis technique in a familiar setting as an illustration. Then, in Chapters 4–6, the modeling concept is applied to high frequency situations, with a focus on integrated circuit applications. Here, we will also take the opportunity to define the concepts of capacitance and inductance in a way that shows their duality. Using the modeling technique, other interesting and much less discussed aspects of high frequency issues are further highlighted. The final chapter of the book describes higher system level applications where the same principles are applied. It covers PLLs and ADCs, their building blocks, and some of their properties. The hope is that this will help practicing electronics engineers reduce the need for simulators, and help them focus on the key problems faster. Each chapter also contains a set of exercises so that the reader can get more familiar with a concept and verify that the main points have been grasped.

The chapters are more or less independent of each other and for a one-semester class one can easily go through all the material. For students interested in electromagnetism and applications Chapters 4–6 should prove useful. For more system-level aspects of the estimation analysis technique Chapter 7 is a must. For a mild general introduction Chapters 2 and 3 on circuit analysis including nonlinear effects are of help.

A project like this cannot be completed without the help of many people. The patience and support of my family, Nancy and Nicole, have been unwavering. My manager, Pirooz Hojabri, and the technical staff at Tektronix have also been great champions of the project. In particular, Vincent Tso and Behdad Youssefi have read and commented on early drafts of the manuscript and Garen Hovakimyan and Patrik Satarzadeh have provided feedback on some of the mathematical derivations. I am very much indebted to them for their support and help. In addition, the helpful comments from the anonymous reviewers at Cambridge University Press helped elevate this book from a mere theoretical exercise to something much more useful for practicing engineers. Finally, I would like to thank the editorial staff at Cambridge University Press for their encouragement and support all through this project. Their sense of style and many helpful comments on the writing improved the book much beyond what I could have achieved alone.