

Transistor Sizing for High Performance and Low Power

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Abstract

Tuning a circuit by adjusting individual transistor sizes offers higher performance and lower power, for circuits with up to hundreds of thousands of transistors, than the best that can be achieved with standard cells. Typically, at the same clock rate, power can be cut in half. At the same power, clock rate can be increased 25%.

1 Introduction

In recent years, the joint optimization of performance and power consumption in VLSI circuits has taken on increased importance, fueled by two market trends. First is the great expansion in portable products that must rely on battery power. Second is the large increase in power consumption of high-end microprocessors, due to increasing clock rates and scale of integration. The product that exemplifies both these trends is the laptop PC, which with current technology suffers from a combination of poor performance, heavy batteries, and limited charge lifetime. An improved delay-vs.-power tradeoff curve is an important asset in today's VLSI markets, and will increase in importance as line widths continue to decrease.

Both the power and maximum clock rate of a sequential circuit can be controlled by varying the sizes (channel widths) of the transistors. The sum of transistor sizes gives a rough estimate of power consumption, but delay depends nonlinearly on transistor sizes: Doubling a transistor's size halves the time for it to drive a load, but slows down its input. The problem can be formalized fairly simply: Given a synchronous circuit with N transistors of sizes x_1, x_2, \dots, x_N , find values for the x_i that jointly minimize the power consumption and the smallest clock period at which the circuit will operate correctly.

TILOS (Timed LOGic Synthesizer, pronounced tee-los) [4] [6], is a program that accepts a transistor-level connectivity file and a performance-specification file, and adjusts transistor sizes and permutes series-connected networks within complex logic gates to meet the user's performance specification while simultaneously minimizing power consumption. This paper relates experiences applying TILOS to various commercial circuits, and the enhancements necessary to accommodate these circuits.

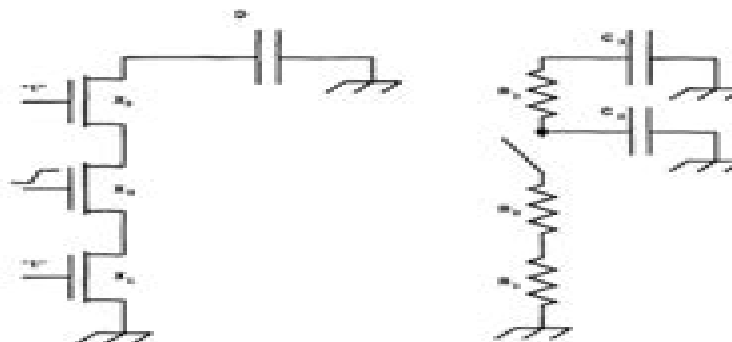


Figure 1: A pulldown network is modeled by an equivalent RC network.

2 Timing Model

TILOS models a transistor as a perfect switch in series with a linear resistor. The gate, source, and drain capacitances are proportional to transistor size X , and the transistor resistance is inversely proportional to X .

Figure 1 illustrates the modeling of a pulldown network by an equivalent RC network. The delay is modeled by Elmore delay [9], which in this case is

$$(R_1 + R_2)C_2 + (R_1 + R_2 + R_3)C_3. \quad (1)$$

Given that each terminal capacitance is proportional to transistor size, and resistance is inversely proportional to transistor size, (1) can be rewritten in terms of the transistor sizes X_1 , X_2 , and X_3 . Each R_i is proportional to $1/X_i$, and each C_i is some constant (for wire capacitance) plus one term for each transistor terminal incident on the node. Each of these terms is proportional to transistor size. (1) can then be rewritten as

$$(A/X_1 + A/X_2) \cdot (B \cdot X_2 + B \cdot X_3 + C) + (A/X_1 + A/X_2 + A/X_3) \cdot (B \cdot X_3 + D) \quad (2)$$

27.3.1

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Proceedings of the IEEE 1987 Custom Integrated Circuits Conference ,1987 Handbook of Thin Film Deposition Krishna Seshan,Dominic Schepis,2018-02-23 Handbook of Thin Film Deposition Fourth Edition is a comprehensive reference focusing on thin film technologies and applications used in the semiconductor industry and the closely related areas of thin film deposition thin film micro properties photovoltaic solar energy applications materials for memory applications and methods for thin film optical processes The book is broken up into three sections scaling equipment and processing and applications In this newly revised edition the handbook will also explore the limits of thin film applications most notably as they relate to applications in manufacturing materials design and reliability Offers a practical survey of thin film technologies aimed at engineers and managers involved in all stages of the process design fabrication quality assurance applications and the limitations faced by those processes Covers core processes and applications in the semiconductor industry and new developments within the photovoltaic and optical thin film industries Features a new chapter discussing Gates Dielectrics Proceedings of the 1984 Custom Integrated Circuits Conference, Genesee Plaza/Holiday Inn, Rochester, NY, May 21-23, 1984 ,1984 Organic and Pervasive Computing -- ARCS 2004 Christian Müller-Schloer,Theo Ungerer,Bernhard Bauer,2004-02-12 Where is system architecture heading The special interest group on Computer and Systems Architecture Fachausschuss Rechner und Systemarchitektur of the German computer and information technology associations GI and ITG a ed this question and discussed it during two Future Workshops in 2002 The result in a nutshell Everything will change but everything else will remain Future systems technologies will build on a mature basis of silicon and IC technology onwell understoodprogramminglanguagesandsoftwareengineering techniques and on well established operating systems and middleware concepts Newer and still exotic but exciting technologies like quantum computing and DNA processing are to be watched closely but they will not be mainstream in the next decade Although there will be considerable progress in these basic technologies is there any major trend which uni es these diverse developments There is a common denominator according to the result of the two ture Workshops which marks a new quality The challenge for future systems technologies lies in the mastering of complexity Rigid and in exible systems built under a strict top down regime have reached the limits of manageable complexity as has become obvious by the recent failure of several large scale projects Nature is the most complex system we know and she has solved the problem somehow We just haven t understood exactly how nature does it But it is clear that systems designed by nature like an anthill or a beehive or a swarm of birds or a city are di erent from today s technical systems that have beendesignedbyengineersandcomputerscientists *The VLSI Handbook* Wai-Kai Chen,2018-10-03 For the new millenium Wai Kai Chen introduced a monumental reference for the design analysis and prediction of VLSI circuits The VLSI Handbook Still a valuable tool for dealing with the most dynamic field in engineering this second edition includes 13 sections comprising nearly 100 chapters focused on the key concepts models and

equations Written by a stellar international panel of expert contributors this handbook is a reliable comprehensive resource for real answers to practical problems It emphasizes fundamental theory underlying professional applications and also reflects key areas of industrial and research focus WHAT S IN THE SECOND EDITION Sections on Low power electronics and design VLSI signal processing Chapters on CMOS fabrication Content addressable memory Compound semiconductor RF circuits High speed circuit design principles SiGe HBT technology Bipolar junction transistor amplifiers Performance modeling and analysis using SystemC Design languages expanded from two chapters to twelve Testing of digital systems Structured for convenient navigation and loaded with practical solutions The VLSI Handbook Second Edition remains the first choice for answers to the problems and challenges faced daily in engineering practice Wireless Technologies Krzysztof Iniewski,2017-12-19 Advanced concepts for wireless technologies present a vision of technology that is embedded in our surroundings and practically invisible From established radio techniques like GSM 802 11 or Bluetooth to more emerging technologies such as Ultra Wide Band and smart dust motes a common denominator for future progress is the underlying integrated circuit technology Wireless Technologies responds to the explosive growth of standard cellular radios and radically different wireless applications by presenting new architectural and circuit solutions engineers can use to solve modern design problems This reference addresses state of the art CMOS design in the context of emerging wireless applications including 3G 4G cellular telephony wireless sensor networks and wireless medical application Written by top international experts specializing in both the IC industry and academia this carefully edited work uncovers new design opportunities in body area networks medical implants satellite communications automobile radar detection and wearable electronics The book is divided into three sections wireless system perspectives chip architecture and implementation issues and devices and technologies used to fabricate wireless integrated circuits Contributors address key issues in the development of future silicon based systems such as scale of integration ultra low power dissipation and the integration of heterogeneous circuit design style and processes onto one substrate Wireless sensor network systems are now being applied in critical applications in commerce healthcare and security This reference which contains 25 practical and scientifically rigorous articles provides the knowledge communications engineers need to design innovative methodologies at the circuit and system level **Metrology and Diagnostic Techniques for Nanoelectronics** Zhiyong Ma,David G. Seiler,2017-03-27 Nanoelectronics is changing the way the world communicates and is transforming our daily lives Continuing Moore s law and miniaturization of low power semiconductor chips with ever increasing functionality have been relentlessly driving R D of new devices materials and process capabilities to meet performance power and cost requirements This book covers up to date advances in research and industry practices in nanometrology critical for continuing technology scaling and product innovation It holistically approaches the subject matter and addresses emerging and important topics in semiconductor R D and manufacturing It is a complete guide for metrology and diagnostic techniques essential for process technology

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Handbook of Signal Processing Systems Shuvra S. Bhattacharyya, Ed F. Deprettere, Rainer Leupers, Jarmo Takala, 2010-09-10 It gives me immense pleasure to introduce this timely handbook to the research development communities in the field of signal processing systems SPS This is the first of its kind and represents state of the arts coverage of research in this field The driving force behind information technologies IT hinges critically upon the major advances in both component integration and system integration The major breakthrough for the former is undoubtedly the invention of IC in the 50 s by Jack S Kilby the Nobel Prize Laureate in Physics 2000 In an integrated circuit all components were made of the same semiconductor material Beginning with the pocket calculator in 1964 there have been many increasingly complex applications followed In fact processing gates and memory storage on a chip have since then grown at an exponential rate following Moore s Law Moore himself admitted that Moore s Law had turned out to be more accurate longer lasting and deeper in impact than he ever imagined With greater device integration various signal processing systems have been realized for many killer IT applications Further breakthroughs in computer sciences and Internet technologies have also catalyzed large scale system integration All these have led to today s IT revolution which has profound impacts on our lifestyle and overall prospect of humanity It is hard to imagine life today without mobiles or Internets The success of SPS requires a well concerted integrated approach from multiple disciplines such as device design and application

Noble and Precious Metals Mohindar Seehra, Alan Bristow, 2018-07-04 The use of copper silver gold and platinum in jewelry as a measure of wealth is well known This book contains 19 chapters written by international authors on other uses and applications of noble and precious metals copper silver gold platinum palladium iridium osmium rhodium ruthenium and rhenium The topics covered include surface enhanced Raman scattering quantum dots synthesis and properties of nanostructures and its applications in the diverse fields such as high tech engineering nanotechnology catalysis and biomedical applications The basis for these applications is their high free electron concentrations combined with high temperature stability and corrosion resistance and methods developed for synthesizing nanostructures Recent developments in all these areas with up to date references are emphasized

Proceedings of the ... Midwest Symposium on Circuits and Systems, 2000 **RF Power Amplifiers for Mobile Communications** Patrick Reynaert, Michiel Steyaert, 2006-11-18 This book tackles both high efficiency and high linearity power amplifier PA design in low voltage CMOS With its emphasis on theory design and implementation the book offers a guide for those actively involved in the design of fully integrated CMOS wireless transceivers Offering mathematical background as well as intuitive insight the book is essential reading for RF design engineers and researchers and is also

suitable as a text book **Proceedings** ,2003 Applied Scanning Probe Methods V Bharat Bhushan,Harald Fuchs,Satoshi Kawata,2006-11-04 The scanning probe microscopy eld has been rapidly expanding It is a demanding task to collect a timely overview of this eld with an emphasis on technical dev opments and industrial applications It became evident while editing Vols I IV that a large number of technical and applicational aspects are present and rapidly veloping worldwide Considering the success of Vols I IV and the fact that further colleagues from leading laboratories were ready to contribute their latest achie ments we decided to expand the series with articles touching elds not covered in the previous volumes The response and support of our colleagues were excellent making it possible to edit another three volumes of the series In contrast to to cal conference proceedings the applied scanning probe methods intend to give an overview of recent developments as a compendium for both practical applications and recent basic research results and novel technical developments with respect to instrumentation and probes The present volumes cover three main areas novel probes and techniques Vol V characterization Vol VI and biomimetics and industrial applications Vol VII Volume V includes an overview of probe and sensor technologies including integrated cantilever concepts electrostatic microscanners low noise methods and improved dynamic force microscopy techniques high resonance dynamic force croscopy and the torsional resonance method modelling of tip cantilever systems scanning probe methods approaches for elasticity and adhesion measurements on the nanometer scale as well as optical applications of scanning probe techniques based on near eld Raman spectroscopy and imaging

VLSI Design and Test for Systems Dependability Shojiro Asai,2018-07-20 This book discusses the new roles that the VLSI very large scale integration of semiconductor circuits is taking for the safe secure and dependable design and operation of electronic systems The book consists of three parts Part I as a general introduction to this vital topic describes how electronic systems are designed and tested with particular emphasis on dependability engineering where the simultaneous assessment of the detrimental outcome of failures and cost of their containment is made This section also describes the related research project Dependable VLSI Systems in which the editor and authors of the book were involved for 8 years Part II addresses various threats to the dependability of VLSIs as key systems components including time dependent degradations variations in device characteristics ionizing radiation electromagnetic interference design errors and tampering with discussion of technologies to counter those threats Part III elaborates on the design and test technologies for dependability in such applications as control of robots and vehicles data processing and storage in a cloud environment and heterogeneous wireless telecommunications This book is intended to be used as a reference for engineers who work on the design and testing of VLSI systems with particular attention to dependability It can be used as a textbook in graduate courses as well Readers interested in dependable systems from social and industrial economic perspectives will also benefit from the discussions in this book **Efficient Sensor Interfaces, Advanced Amplifiers and Low Power RF Systems** Kofi A.A. Makinwa,Andrea Baschiroto,Pieter Harpe,2015-08-28 This book is based on the 18 tutorials presented during the 24th

workshop on Advances in Analog Circuit Design Expert designers present readers with information about a variety of topics at the frontier of analog circuit design including low power and energy efficient analog electronics with specific contributions focusing on the design of efficient sensor interfaces and low power RF systems This book serves as a valuable reference to the state of the art for anyone involved in analog circuit research and development *CMOS Analog and Mixed-Signal Circuit Design* Arjuna Marzuki, 2020-05-12

The purpose of this book is to provide a complete working knowledge of the Complementary Metal Oxide Semiconductor CMOS analog and mixed signal circuit design which can be applied for System on Chip SOC or Application Specific Standard Product ASSP development It begins with an introduction to the CMOS analog and mixed signal circuit design with further coverage of basic devices such as the Metal Oxide Semiconductor Field Effect Transistor MOSFET with both long and short channel operations photo devices fitting ratio etc Seven chapters focus on the CMOS analog and mixed signal circuit design of amplifiers low power amplifiers voltage regulator reference data converters dynamic analog circuits color and image sensors and peripheral oscillators and Input Output I O circuits and Integrated Circuit IC layout and packaging Features Provides practical knowledge of CMOS analog and mixed signal circuit design Includes recent research in CMOS color and image sensor technology Discusses sub blocks of typical analog and mixed signal IC products Illustrates several design examples of analog circuits together with layout Describes integrating based CMOS color circuit

IEEE International Reliability Physics Symposium Proceedings International Reliability Physics Symposium, 2004 *IEEE 2000 First International Symposium on Quality Electronic Design*, 2000 **Hardware/Software Co-design for Heterogeneous Multi-core Platforms** Koen Bertels, 2012-02-02 HW SW Co Design for Heterogeneous Multi Core Platforms describes the results and outcome of the FP6 project which focuses on the development of an integrated tool chain targeting a heterogeneous multi core platform comprising of a general purpose processor ARM or powerPC a DSP the diopsis and an FPGA The tool chain takes existing source code and proposes transformations and mappings such that legacy code can easily be ported to a modern multi core platform Downloadable software will be provided for simulation purposes

VLSI-SoC: Forward-Looking Trends in IC and Systems Design Jose L. Ayala, David Atienza Alonso, Ricardo Reis, 2012-02-24 This book contains extended and revised versions of the best papers presented at the 18th IFIP WG 10 5 IEEE International Conference on Very Large Scale Integration VLSI SoC 2010 held in Madrid Spain in September 2010 The 14 papers included in the book were carefully reviewed and selected from the 52 full papers presented at the conference The papers cover a wide variety of excellence in VLSI technology and advanced research They address the current trend toward increasing chip integration and technology process advancements bringing about stimulating new challenges both at the physical and system design levels as well as in the test of these systems

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