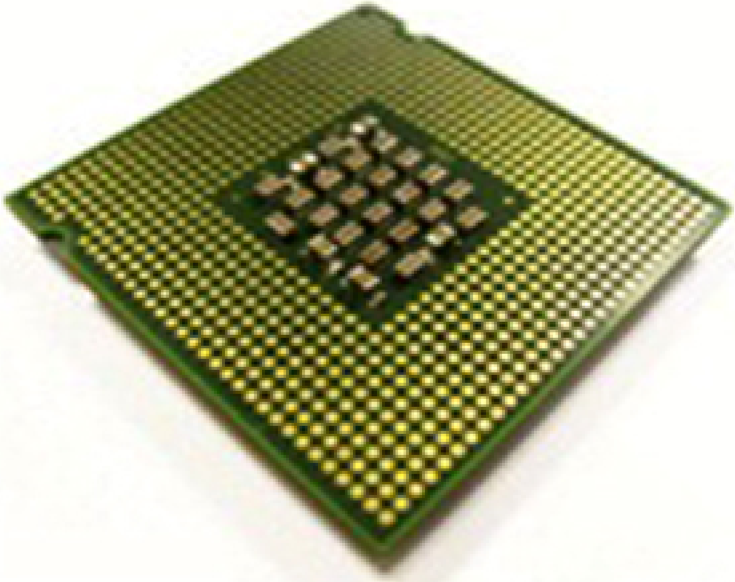

VLSI DESIGN

THEORY AND PRACTICE

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THEORY AND PRACTICE

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Contents

This Book on VLSI Design is dedicated to
To My Dear Brothers
Er. Tarun Mittar Sachdeva & Er. Abhey Vij

—Er. Vikrant Vij

Preface

One must learn by doing the thing; for though you think you know it
You have no certainty, until you try.

— Sophocles, Trachiniae

Digital electronic designs continue to evolve toward more complex, higher pin count components operating at higher clock frequencies.

The Genesis

Since the invention of integrated circuits thirty years ago, manufacturing of electronic systems has taken rapid strides in improvement in speed, size, and cost. For today's integrated circuit chips, switching time is on the order of nanoseconds, minimum feature size is on the order of sub-microns, transistor count is on the order of millions, and cost is on the order of a few dollars. In fact, it was estimated that the performance/cost ratio of integrated circuit chips has been increasing at the rate of one thousand-fold every ten years, so here is a book that we have written to meet the needs of both senior and junior students' and written with a student-oriented approach, based upon years of our teaching.

The VLSI Design provides in a single volume a comprehensive reference work covering the broad spectrum of VLSI technology. The goal is to provide the most up-to-date information in integrated circuits (IC) technology, devices and their models, circuit simulations, microprocessor and ASIC, test and testability, design automation, VLSI signal processing, and design languages and tools. The book is not an all-encompassing digest of everything taught within an engineering curriculum on VLSI technology. Rather, it is the engineer's first choice in looking for a solution.

The question arises that is there any justification of adding one more book to the already large stock of books on the subject. Perhaps there is. This is the only book in which subject matter is dealt from elementary to the advance level in a unique manner which will certainly fascinate the readers.

The book is reader friendly, thought provoking and stimulating. The style which will make students feel as if they are attending a classroom ; is lucid and unadulterated. Understandably, language used is such that an average student can follow. What strands out is the strark simplicity, with which ideas and concepts have been portrayed.

Organisation of this Book

Chapter I is Introduction to VLSI design highlighting evolution of VLSI, applications of VLSI, Design metrics of VLSI design, VLSI design flow, Physical design cycle and basics of CMOS Logic.

Chapter II is Basic of MOSFET Theory MOSFET Characteristics, VLSI Design Structure, MOSFET Circuit Model, Data Acquisition.

Chapter III is CMOS Processing Techniques Photolithography, Self-Aligned MOSFET, CMOS Process Flow, CMOS Inverter Analysis and Design, Static Logic Gates, Dynamic Logic Families.

Chapter IV is CMOS Combinational Design Design Considerations, Design Techniques to reduce Switching activity, How to build even better load, Single ended versus Differential.

Chapter V is CMOS Sequential Design Classification of Memory Elements, Dynamic Latches and Registers, Alternative Register Style, Pipeline approach to optimize Sequential Circuit.

Chapter VI is ASIC Design Fundamentals Introduction to ASIC Design Fundamentals, Physical Compiler Flow, Basic Concepts, Compiler Directives, Technology Libraries, Delay Calculations, Clocking Issues.

Chapter VII is FPGA based VLSI Design FPGA Programming technologies, FPGA Architecture, Migrating ASICS to FPGA's, Schematic and HDL based design flow, FPGA selection criteria.

Chapter VIII is FPGA's and Signal Processing Systems DSP Functionality Characteristics, Key issues in FPGA implementation, Parallel Machines, FPGA implementation of signal processing systems.

Chapter IX is FPGA Design Security Software Security Challenges and Techniques, Hardware Security Challenges, FPGA Updates and Programmability, Memory Protection on FPGAs, Higher-Level Specification Language, System Architecture, and Evaluation.

Chapter X is Fundamentals of Verilog HDL Correspondence to Digital Hardware, Design Flow with Verilog, Data Types and Operators, Structural Description in Verilog, Semantic Model for Verilog HDL, Test Benches and Test Management.

Chapter XI is Fundamentals of VHDL VHDL Design Flow, VHDL Terms, Fundamental VHDL Units, Lexical elements in VHDL, Data Types, Operators and Attributes, Concurrent and Sequential statements, Architecture description, Structural description, Behavioral description, RTL Description.

Chapter XII is Combinational Design using VHDL Synthesis of Combinational Circuit, Minimization of Combinational Circuit, Different Styles of Modeling, VHDL for Combinational Circuit.

Chapter XIII is Floor Planning and Routing Concepts Problem Formulation of Floor Planning, Floor planning Algorithms Placement Algorithm, Global Routing, Classification of Global Routing Algorithms, Comparison of Different Routing Layers, and Routing Models.

Audience for this Book

The book has been written to position itself within the marketplace midway between a number of texts in this subject area which may be regarded as comprehensive, and almost reference works, and a number of other texts which are rather brief and tend to be merely primers. Reference texts can be too detailed and large for a newcomer to the topic and the primer type of text can lack information and be rather bland for many readers. With this in mind the book is written to appeal to two broad ranges of readers:

1. Students of electronics/Computer engineering undergraduate and postgraduate courses who are studying VLSI and circuit design.
2. For the new engineer embarking on an exciting career in electronics design and control.

Acknowledgements by Author

I wish to express my gratitude to **My loving Grand parents** for their support and blessings throughout my life. I am thankful to **my Parents Er. Harsh Kumar Vij and Mrs. Muktesh Vij** for being with me when I was fighting for my life against cancer.

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—Authors

1 Introduction to VLSI Design

Learning Objectives

After reading this chapter, you will be able to explain:

- Introduction
- Evolution of VLSI Systems
- Applications of VLSI Systems
- Quality Metrics of a VLSI Design
- VLSI Design Flow
- Physical Design Cycle
- Design Styles
- CMOS Logic

1.1 INTRODUCTION

The electronics industry has achieved a phenomenal growth over the last few decades, mainly due to the rapid advances in large scale integration technologies and system design applications. With the advent of very large scale integration (VLSI) designs, the number of applications of integrated circuits (ICs) in high performance computing, controls, telecommunications, image and video processing, and consumer electronics has been rising at a very fast pace. IC technology has evolved in the 1960s from the integration of a few transistors (referred to as *Small Scale Integration* (SSI)) to the integration of millions of transistors in *Very Large Scale Integration* (VLSI) chips currently in use. Early ICs were simple and only had a couple of gates or a flip-flop. Some ICs were simply a single transistor, along with a resistor network, performing a logic function. In a period of four decades there have been four generations of ICs with the number of transistors on a single chip growing from a few to over 20 million. Ever-increasing global communications has opened up a brand new vista for people interested in a career in the information technology and VLSI design including embedded systems. The advent of advanced EDA tools gives one the freedom to innovate and experiment to develop a new product that could be the next breakthrough in all spheres of research and development. In this chapter, we will discuss evolution of VLSI systems, applications etc.

1.2 EVOLUTION OF VLSI SYSTEMS

With the advent of discrete semiconductor devices such as bipolar transistors, uni-junction transistors, field effect transistors, etc., miniaturization started in full swing, replacing bulky systems that used vacuum tubes. During 1950s computers using vacuum tubes occupied an entire floor of a big building. Gradually, attempts were made to integrate several circuits, be it analog or digital, in a single package. These attempts succeeded in producing both analog and digital ICs, as well as mixed signal ICs. Analog ICs offered operational amplifiers, multipliers, modulators/demodulators, etc., while digital ICs integrated AND, OR, XOR gates and so on. Digital ICs are broadly classified according to their circuit complexity measured in terms of the number of logic gates or transistors in a single package. Chips falling under the category of small scale integration (SSI) contain up to 10 independent gates in a single package. The inputs and outputs of these gates are connected directly to the pins in the package with provision for connections to a power supply. With the advances in integration technology, more devices having a complexity of approximately 10 to 100 gates were packed in a single package. They were called medium scale integration (MSI) devices. Decoders, adders, multiplexers, de-multiplexers, encoders, comparators are examples of MSIs. Thereafter, large scale integration (LSI) devices emerged, which integrated between 100 and 1000 gates in a single package. Examples of this category include digital systems such as processors, memory chips, and programmable logic devices. Finally in late 1970s, very large scale integration devices containing thousands of gates within a single package became a reality. Since then, integration has been growing by leaps and bounds crossing 10 million gates in a single package, going into realms of ultra large scale integration (ULSI), system level integration (SLI), and system-on-chip (SOC). FPGAs fall under all the above high-end categories starting from VLSI. The foregoing classifications are summarized in the following.

Category	***Year***	***Density (gates)***
Single transistor	1959	1 device
Logic gate	1960	1
Small scale integration (SSI)	1964	Up to 10
Medium scale integration (MSI)	1967	10 – 100
Large scale integration (LSI)	1972	100 – 1000
Very large scale integration (VLSI)	1978	1000 – 10000
Ultra large scale integration (ULSI)	1989	10000 and above
SLI/SOC	Late 1990s	> 10 million

In the 1960s, Gordon Moore, then with Fairchild Corporation and later cofounder of Intel, predicted that the number of transistors that can be integrated on a single die would grow exponentially with time. This prediction, later called *Moore's law*, has proven to be amazingly visionary. Its validity is best illustrated with the aid of a set of graphs. Figure 1.1 plots the integration density of both logic IC's as a function of time. As can be observed, integration complexity doubles approximately every 1 to 2 years. As a result, memory density has increased by more than a thousand fold since 1970.

Typically used abstraction levels in digital circuit design are, in order of increasing abstraction, the device, circuit, gate, functional module (e.g., adder) and system levels (e.g., processor), as illustrated in Figure 1.2. A semiconductor device is an entity with a very complex behavior. No circuit designer will ever seriously consider the solid-state physics equations governing the behavior of the device when designing a digital gate. Instead he will use a simplified model that