PRINCIPLES OF MODERN DIGITAL DESIGN

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To Mrs. Mithilesh Tiwari and Miss Shakuntala Tiwari for their love

"*Full many a gem of purest ray serene,*
The dark unfathomed caves of ocean bear:
Full many a flower is born to blush unseen,
And waste its sweetness on the desert air."

Thomas Gray

CONTENTS

PREFACE

This book covers all major topics needed in a modern digital design course. A number of good textbooks in digital design are currently available. Some of these introduce VHDL before students get a good grasp of the fundamentals of digital design. VHDL is a language that is used to describe the function of digital circuits/systems. In the author's opinion, students benefit more from VHDL only when they can appreciate the advantages of using it in digital design. In this book, VHDL is introduced only after a thorough coverage of combinational circuit design and a discussion of the fundamental concepts of sequential circuits.

The complexity of modern digital systems is such that they have to be designed using computer-aided design (CAD) synthesis and minimization tools. The techniques used in some of the CAD tools, for example computer-aided minimization, multilevel logic design, and state assignment are inadequately covered or not covered at all in current undergraduate text books. In this book, the basic concepts of some of these important techniques are introduced in appropriate chapters. The material has been discussed in a tutorial form, although the nature of certain topics makes an abstract discussion unavoidable. The objective is not to achieve understanding at the expense of avoiding necessary theory, but to clarify the theory with illustrative examples in order to establish the theoretical basis for practical implementations.

The book is subdivided into ten chapters.

Chapter 1 provides coverage of number representations and considers various number formats. It also discusses binary arithmetic operations such as addition, subtraction, multiplication, and division.

Chapter 2 provides a comprehensive coverage of a miscellany of basic topics in discrete mathematics required for understanding material presented in later chapters. Also, the operations of various gates used to construct logic circuits are discussed.

Chapter 3 provides an in-depth coverage of combinational logic circuit analysis, minimization, and design techniques. The representation of Boolean functions using cubes is explained and the concept of tautology is discussed. The principles of heuristic minimization, different types of don't cares and multilevel logic synthesis is explained with many examples. A detailed coverage of all types of arithmetic circuits including BCD addition/subtraction algorithms and carry-save addition techniques is provided. Multiplication and division are thoroughly discussed. Combinational logic implementation using Programmable Logic Devices (PLDs) is also covered.

Chapter 4 presents the basic concepts of sequential circuits. The operation of memory elements is analyzed. The use of state diagrams and state tables to represent the behavior of sequential circuits is discussed. Also, the distinction between synchronous and asynchronous operation of sequential circuits is clarified.

It is quite routine in the electronics industry to use a hardware description language such as VHDL to describe the function of digital circuits. Chapter 5 introduces the language in sufficient detail so that readers can write VHDL code for representing digital circuits.

Several examples are given to clarify different ways of representing digital circuit using VHDL. This chapter is not meant to be an exhaustive guide to VHDL; a number of excellent books that deal exclusively with VHDL have been published in recent years.

Chapter 6 builds on the previous chapter and focuses on VHDL code for computer-aided synthesis of combinational logic circuits. Certain features of the VHDL that result in more efficient code for combinational logic circuits are presented. All these are illustrated with complete VHDL codes that have been compiled and synthesized using Altera Corporation's Quartus II software package.

Chapter 7 provides a clear picture of how sequential circuits are designed using fundamental building blocks (e.g., latches and flip-flops) rather than presenting a rigorous mathematical structure of such circuits. Algorithms that are used in some of the currently popular computer-aided state assignment techniques are discussed. A good coverage of partition algebra for deriving state assignment has been included. A detailed discussion of sequential circuit implementation using PLDs is also presented.

Chapter 8 provides comprehensive coverage of counters. Counters are important in many digital applications. Several design examples and illustrations are provided to clarify the design of various types of counters.

Chapter 9 presents VHDL coding of sequential circuits. The coding style for sequential circuits is different from that of combinational circuits. Combinational circuits are usually coded using *concurrent* VHDL statements whereas sequential circuits use mainly *sequential* VHDL statements. Many examples of VHDL coding of sequential circuits are included; these codes have been compiled and synthesized using Quartus II.

Chapter 10 covers design principles for traditional fundamental mode non-synchronous sequential circuits. The concepts of race and hazard are clarified with examples, and state assignment techniques to avoid these are also discussed.

All modern digital systems are implemented using CMOS technology. A short introduction to CMOS logic is provided in Appendix A.

A Quartus II CD ROM from Altera Corporation is included in the book. All the examples in the book have been compiled and synthesized using this state-of-the-art and user-friendly software package.

This book is primarily intended as a college text for a two-semester course in logic design for students in electrical/computer engineering and computer science degree programs, or in electrical/computer technology. It does not require any previous knowledge of electronics; only some general mathematical ability is assumed.

In the first (introductory) course the following sequence of chapters may be covered: Chapter 1, Chapter 2, Chapter 3 (3.1 to 3.4, 3.8, 3.12 to 3.14), Chapter 4, Chapter 7 (Sections 7.1–7.5), Chapter 8.

In the second (more advanced) course the suggested sequence of chapters is: Chapter 3 (Sections 3.5 to 3.7, 3.9 to 3.11), Chapter 5, Chapter 6, Chapter 7 (Section 7.6), Chapter 9 and Chapter 10.

Although the book is meant to be used for a two-semester course sequence, certain sections can be omitted to fit the material in a typical one-semester course. Individual instructors may select chapters at their discretion to suit the needs of a particular digital design course they are teaching.

This book should also be extremely useful for practicing engineers who took logic design courses five or more years ago, to update their knowledge. Electrical engineers who are not logic designers by training but wish to become one, can use this book for self-study.

I am grateful to Dr. Karen Panetta of the Department of Electrical and Computer Engineering, Tufts University for her constructive review and suggestions, and for permitting me to use problems from her laboratory curriculum in VHDL.

I would also like to thank my former students in several universities who took digital design courses I taught over the years. I made references to class projects of some of them in appropriate sections of the book.

I am greatly indebted to my wife, Meena, for her patience. She has been a constant source of support throughout the writing of the book. Finally I would like to thank my children Nupur and Kunal for their quiet encouragement and for being who they are.

PARAG K. LALA