大学计算机教育丛书（影印版）

DIGITAL LOGIC CIRCUIT ANALYSIS & DESIGN

数字逻辑电路分析与设计

Victor P. Nelson
H. Troy Nagle
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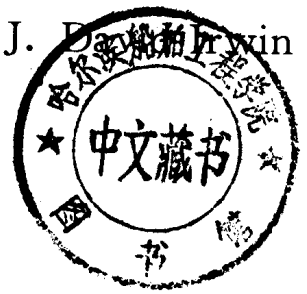

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出版前言

我们的大学生、研究生毕业后，面临的将是一个国际化的信息时代。他们将需要随时查阅大量的外文资料；会有更多的机会参加国际性学术交流活动；接待外国学者；走上国际会议的讲坛。作为科技工作者，他们不仅应有与国外同行进行口头和书面交流的能力，更为重要的是，他们必须具备极强的查阅外文资料获取信息的能力。有鉴于此，在国家教委所颁布的“大学英语教学大纲”中有一条规定：专业阅读应作为必修课程开设。同时，在大纲中还规定了这门课程的学时和教学要求。有些高校除开设“专业阅读”课之外，还在某些专业课拟进行英语授课。但教、学双方都苦于没有一定数量的合适的英文原版教材作为教学参考书。为满足这方面的需要，我们挑选了 7 本计算机科学方面最新版本的教材，进行影印出版。首批影印出版的 6 本书受到广大读者的热情欢迎，我们深受鼓舞，今后还将陆续推出新书。希望读者继续给予大力支持。Prentice Hall 公司和清华大学出版社这次合作将国际先进水平的教材引入我国高等学校，为师生们提供了教学用书，相信会对高校教材改革产生积极的影响。

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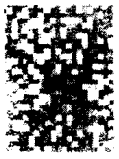

Preface

The Need for This Book

This text has been developed from a previous work, *An Introduction to Computer Logic* (1974) by Nagle, Carroll, and Irwin, which was a widely adopted text on the fundamentals of combinational and sequential logic circuit analysis and synthesis. The original book was praised for its clarity and teaching effectiveness, and despite rapid changes in the field in the late 70's and early 80's, the book continued to enjoy wide use many years after its original publication date, underscoring the interesting fact that during most of the period since the publication of that book, the mainstream educational approach to introductory-level courses in digital design evolved quite slowly, even while major technological changes were rapidly being adopted in industry.

How things have changed! Recently, the astronomical proliferation of digital circuit applications and phenomenal increases in digital circuit complexity have prompted significant changes in the methods and tools used in digital design. Very Large Scale Integrated (VLSI) circuit chips now routinely contain millions of transistors; computer-aided design (CAD) methods, standard cells, programmable logic devices, and gate arrays have made possible rapid turnaround from concept to finished circuit, supported by increased emphasis on hierarchical, modular designs utilizing libraries of standard cells and other predesigned circuit modules. We have developed a text which supports those changes, but we have also worked carefully to preserve the strong coverage of theory and fundamentals.

An effective digital design engineer requires a solid background in fundamental theory coupled with knowledge of practical real-world design principles. This text contains both. It retains its predecessor's strong coverage of fundamental theory. To address practical design issues, over half of the text is new material that reflects the many changes that have occurred in recent years, including modular design, CAD methods, and the use of programmable logic, as well as such practical issues as device timing characteristics and standard logic symbols.

Intended Audience

This book is intended for sophomore, junior, and senior-level courses in digital logic circuits and digital systems for engineers and scientists who may be involved with the design of VLSI circuits, printed circuit boards, multi-chip modules, and computer circuits.

No particular background in electronic circuits or computer systems is assumed or required, and thus the text is suitable for a first course in digital systems. However, the book contains sufficient advanced material and depth to support the needs of more advanced students. This text has been designed to allow each instructor the flexibility to select topics according to the needs of his or her specific course.

This text is also suitable for the reader who wishes to use the self-study approach to learn digital design, and is useful as a reference for practicing engineers.

Significant Features

This book is a unique work representing the combined efforts of the four authors at three universities. In addition to extensive publisher-sponsored reviewing, the manuscript was used in courses at all three schools during its development, with feedback from students and instructors incorporated into the book.

Noteworthy features include:

- Solid coverage of fundamental concepts and theory coupled with practical real-world design methods
- A strong emphasis on developing and using systematic problem solving and design methodologies, abundantly supported by over 250 numbered, worked examples
- Heavy emphasis on visualization, supported by over 600 two-color illustrations
- Numerous problems with a wide range of difficulty levels at the ends of the chapters
- CAD issues integrated in-depth throughout the text without relying heavily on CAD products from specific vendors
- Coverage of hierarchical modular design and standard digital circuit modules
- A chapter containing comprehensive design projects
- Two chapters describing programmable logic devices and their applications in implementing digital circuits
- An in-depth introduction to testing and design for testability
- Support of both breadboarding labs and CAD-based modeling and simulation labs
- An Instructors' Manual with fully worked solutions to each problem

Coverage of Computer-Aided Design

Most modern digital circuit design projects require the use of computer-aided design methods and tools. For this reason, CAD is covered throughout the text at the end of each chapter, allowing CAD methods to be applied to the basic fundamental concepts and design principles presented in that chapter.

The coverage of CAD methods and tools was designed to be generic in nature, rather than specific to any particular vendor's tools. This will allow students to apply these concepts to whichever CAD tools may be available, including comprehensive packages running on engineering workstations from such vendors as Mentor Graphics, Cadence, and Viewlogic, and lower-end tools designed for use on personal computers. A number of the latter are available at nominal pricing for students and educators.

The CAD coverage in the chapters is as follows:

Chapter 2 introduces the computer-aided design process as used in the design and analysis of digital logic circuits and systems. Topics covered include design representation with schematic diagrams and hardware description languages, schematic capture, and logic simulation for design verification and timing analysis.

Chapter 3 discusses CAD methods for simplification and optimization of combinational logic circuits. Chapter 4 extends the CAD coverage to support of hierarchical, modular combinational logic circuit designs. Chapter 5 describes CAD tools for designing and modeling circuits to be implemented in programmable logic devices, including hardware description languages.

In the sequential circuit section of the book, Chapter 8 discusses CAD methods used in the design and analysis of sequential logic circuits, including timing analysis and detection of timing constraint violations. Chapter 11 extends this discussion to methods used for modeling sequential logic circuits to be implemented in programmable logic devices.

Laboratory Support

Courses in digital design often utilize laboratory experiments to reinforce concepts presented in class. In some cases, schematic capture or other CAD tools are used to model circuits of varying degrees of complexity, and simulation tools are used to study the operation of these circuits. This text supports both CAD-based and traditional breadboarding laboratories.

The traditional breadboarding lab usually involves the construction of digital circuits with standard TTL small scale integrated (SSI) and medium scale integrated (MSI) circuit modules. Many examples of such modules are covered throughout the book, discussing the design and operation of each module and the design of higher-level circuits using these modules.

In addition to short laboratory exercises, it is often desirable to use comprehensive design projects to have students assimilate the different concepts learned in a course. To illustrate the planning and design steps in such projects, the final chapter of this text presents four case studies based on projects done by students at North Carolina State University and Auburn University.

Chapter Descriptions

The material in this text has been organized into several sections. In each section, fundamental concepts and theory are first developed to provide a solid foundation. Then the theory is applied to the design and analysis of simple circuits, and extended to the design of optimal circuits. Finally, practical design issues and methods are discussed, including the use of modular design methods, computer-aided design techniques, and programmable logic devices. Extensive examples are presented throughout each section to illustrate and reinforce the concepts presented in that section.

Background

Since no particular prerequisites are assumed, the first two chapters present background material that will aid in the understanding of digital circuit design.

Chapter 0 introduces digital circuits and digital computers, including the primary software and hardware components of a computer.

Chapter 1 presents number systems and representation of information, with emphasis on binary codes used to represent numbers and other information in digital computers and other circuits. Arithmetic with binary numbers is also discussed, as a prelude to the design of digital computer circuits that perform such operations.

Combinational Logic Circuits

The analysis and design of combinational logic circuits is the topic of the next section of the book, beginning with fundamentals in chapter 2, and progressing through optimization in Chapter 3, modular design in Chapter 4, and design with programmable logic in Chapter 5.

Chapter 2 begins with a presentation of Boolean and switching algebras, which form the basis of logic circuit design. Digital logic gates are introduced next, followed by coverage of analysis techniques for circuits constructed with basic gates. The synthesis and design of logic circuits from various types of specifications are presented next. The chapter concludes with an introduction to computer-aided design of digital logic circuits.

Chapter 3 presents algorithms and methods for simplifying combinational logic circuits. The use of Karnaugh maps and the tabular Quine-

McCluskey method are presented in detail, and then computer-aided methods for simplification of combinational logic circuits are discussed.

Chapter 4 discusses hierarchical, modular design of digital circuits. The design and use of various modules in such designs are described, including decoders, multiplexers, and arithmetic circuits. CAD tool support of hierarchical, modular design activities is presented to conclude the discussion.

Chapter 5 describes the basic operation of programmable logic devices, and the implementation of combinational logic circuits with programmable arrays. The three basic device architectures, PLA, PROM, and PAL, are described, along with examples of commercially-available modules. CAD tools to support the modeling of combinational logic circuits to be implemented with programmable devices are presented.

Sequential Logic Circuits

Sequential logic circuits, which involve memory, are discussed in the next section of the book. Chapter 6 describes the memory elements used in sequential circuits and Chapter 7 examines the design and operation of a number of standard circuit modules based on these memory elements. Chapter 8 presents the fundamentals of synchronous circuit analysis and design, with Chapter 9 discussing methods for optimizing these circuits. Chapter 10 discusses the unique problems associated with the analysis and design of asynchronous sequential circuits. Finally, Chapter 11 describes the use of programmable logic devices in sequential circuit design.

Chapter 6 begins by introducing sequential logic circuits, including the role played by memory elements in these circuits. The design and operation of the two basic types of memory devices, latches and flip-flops, are then discussed, and the features of a number of commercially-available modules containing such devices are described.

Chapter 7 describes the design and operation of a number of standard sequential logic circuit modules, including registers, shift registers, and counters. For each module type, the basic design and theory of operation are presented, and then the features and use of a number of representative standard TTL modules are described.

Chapter 8 presents fundamentals and techniques for analysis and synthesis of synchronous sequential logic circuits, including timing diagrams, state tables, and flip-flop excitation tables. The chapter concludes with an overview of CAD methods for modeling and simulating the operation of synchronous sequential circuits and for analyzing the unique timing characteristics of such circuits.

Chapter 9 discusses optimization of synchronous sequential logic circuits. Methods are presented for eliminating redundant states to reduce the number of memory elements needed to implement a design, and methods for

optimal assignment of state variables to minimize the number of required combinational logic gates.

Chapter 10 discusses pulse mode and fundamental mode asynchronous sequential circuits. Methods for analysis and synthesis of each type of circuit are presented, including the identification of races in fundamental mode circuits and methods for preventing critical races.

Chapter 11 concludes the sequential circuit section by describing programmable logic devices used to implement synchronous and asynchronous sequential circuits, including registered PALs and PLAs, and flexible macrocell-based devices. Also covered are field programmable gate arrays. The chapter includes an overview of CAD methods for modeling sequential circuits to be synthesized with programmable logic devices.

Testing and Design for Testability

Chapter 12 provides an introduction to faults in digital logic circuits and testing methods, including the process of deriving test sets for logic circuits. Testing of a digital circuit represents a significant cost, especially as circuits grow in size. To facilitate testing and minimize testing cost, design for testability is critical. Therefore, this chapter discusses a number of digital circuit design techniques that can improve testability at the gate and circuit board levels, including the use of built-in testing circuits.

Digital Design Case Studies

Chapter 13 concludes the text by presenting four case studies based on actual comprehensive digital design projects done by students at North Carolina State University and Auburn University: a slot machine game, an automobile keyless entry system, a traffic controller to coordinate two-way traffic on a single-lane road, and a cash register controller.

Suggested Course Outlines

The material in this course may be used in a quarter or semester course, or may be extended to two quarters. A 10-week quarter course might use the following outline.

Chapter 0: General introduction
Chapter 1: Binary number codes and binary arithmetic
Chapter 2: Boolean algebra and switching functions, logic gates, combinational circuit analysis and design
Chapter 3: Minimization—one method (typically K-maps)
Chapter 4: Modular, hierarchical design and standard circuit modules
Chapter 6: Basic operation and design of flip-flops and latches

Chapter 7: Simple sequential shift register and counter modules
Chapter 8: Analysis and synthesis of synchronous sequential circuits

A second 10-week quarter course can spend more time on computer-aided design, programmable logic, asynchronous circuits, and testing.

A 16-week semester course can simply follow the book outline, adding the optimization topics in chapters 3 and 9, coverage of programmable logic devices in chapters 5 and 11, and testing from chapter 12.

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Victor P. Nelson
H. Troy Nagle
Bill D. Carroll
J. David Irwin

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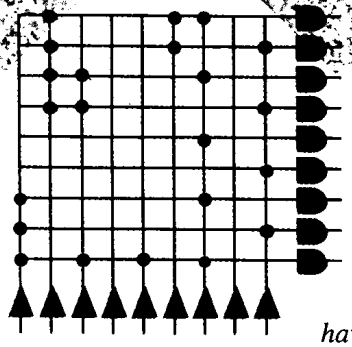

We are living in an age that sociologists have called the computer revolution. Like any true revolution, it is widespread and all-pervasive and will have a lasting impact on society. It is as fundamental to our present economic and social order as was the industrial revolution in the nineteenth century. It will affect the thinking patterns and life-styles of every individual. Whereas the major effect of the industrial revolution was to augment our physical powers, the computer revolution is extending our mental powers.

Computers are composed of electronic, mechanical, and/or optical elements known as the hardware and of programs and data known as the software. This book introduces the subject of computer hardware. In particular, we will study the analysis and design of logic circuits that form the basis for most computer electronic hardware. But first, let's take a closer look at the history and the organization of the digital computer.

Contents