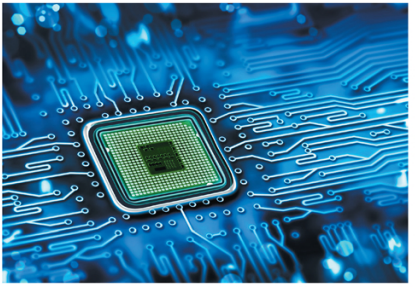
twelfth edition



digital systems

principles and applications

NEAL S. WIDMER
GREGORY L. MOSS
RONALD J. TOCCI

TWELFT

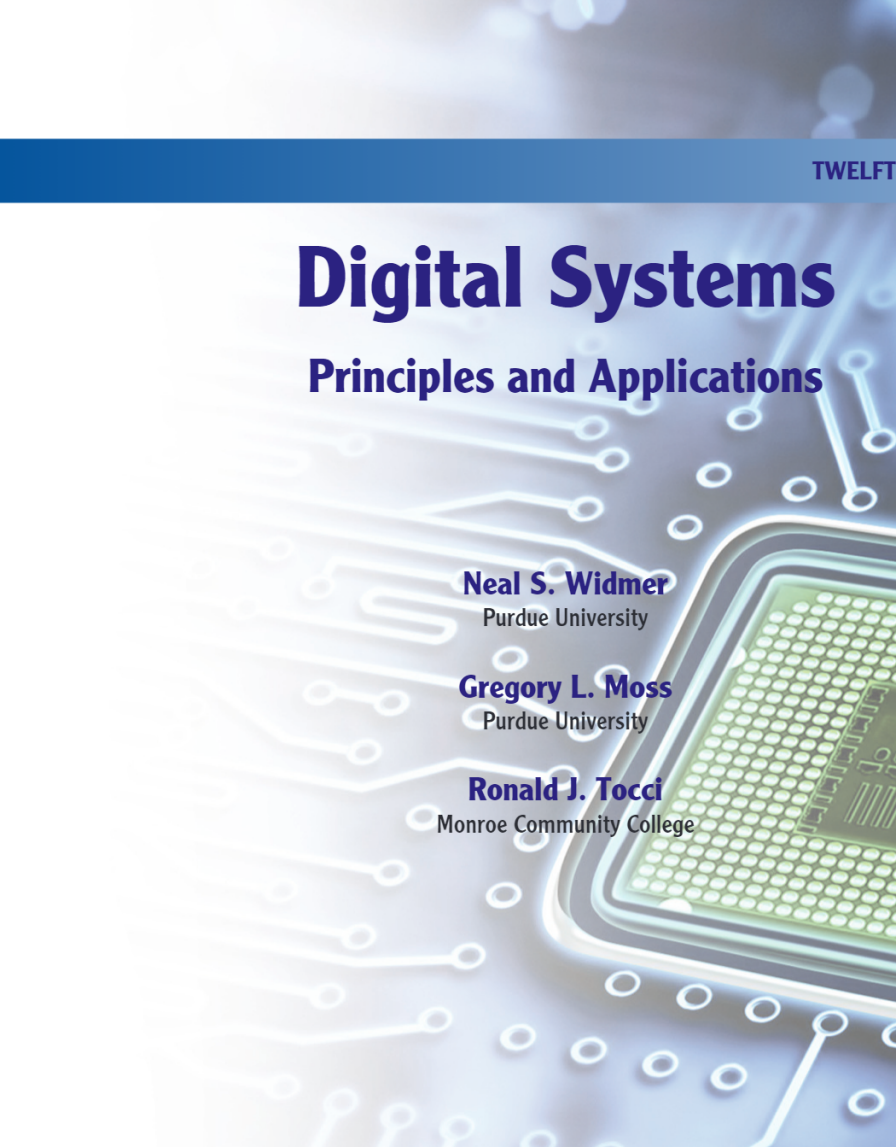
Digital Systems

Principles and Applications

Neal S. Widmer
Purdue University

Gregory L. Moss
Purdue University

Ronald J. Tocci
Monroe Community College



Editor-in-Chief: Andrew Gilfillan
Product Manager: Anthony Webster
Program Manager: Holly Shufeldt
Project Manager: Rex Davidson
Editorial Assistant: Nancy Kesterson
Team Lead Project Manager: Bryan Pirrmann
Team Lead Program Manager: Laura Weaver
Director of Marketing: David Gesell
Senior Product Marketing Manager: Darcy Betts
Field Marketing Manager: Thomas Hayward
Procurement Specialist: Deidra M. Skahill
Creative Director: Andrea Nix
Art Director: Diane Y. Ernsberger
Cover Designer: Cenveo
Full-Service Project Management: Philip Alexander/Integra Software Services, Pvt, Ltd.
Printer/Binder: R.R. Donnelley

Library of Congress Cataloging-in-Publication Data

Names: Tocci, Ronald J., author. | Widmer, Neal S., author. | Moss, Gregory L., author.
Title: Digital systems: principles and applications/Neal S. Widmer, Purdue University, Ronald J. Tocci, Monroe Community College, Gregory L. Moss, Purdue University.
Description: Twelfth edition. | Upper Saddle River [New Jersey]: Pearson, [2017] | Tocci's name appears first in earlier editions.
Identifiers: LCCN 2016007313 | ISBN 9780134220130
Subjects: LCSH: Digital electronics.
Classification: LCC TK7868.D5 T62 2017 | DDC 621.381—dc23 LC record available at http://lccn.loc.gov/2016007313

PREFACE

This book is a comprehensive study of the principles and techniqu
digital systems. It teaches the fundamental principles of digital
covers thoroughly both traditional and modern methods of app
design and development techniques, including how to manag
level project. The book is intended for use in two- and four-year
technology, engineering, and computer science. It can also be u
School STEM education courses in these topical areas. Although a
in basic electronics is helpful, most of the material requires n
training. Portions of the text that use electronics concepts can
without adversely affecting the comprehension of the logic princ

What's New in This Edition?

The following list summarizes the improvements in the twelf
Digital Systems. Details can be found in the section titled "Speci
on page ix.

- Every *section* of every chapter now has a short list of expect
for that section.
- Chapter 1 has been revised extensively in response to feedbac
- New material on troubleshooting prototype circuits usin
fault isolation techniques applied to digital logic circuits has
to Section 4-13.
- Quadrature Shaft Encoders used to obtain absolute shaft p
as a real example of flip-flop applications, and timing limita

General Features

In industry today, getting a product to market very quickly is importa
use of modern design tools, CPLDs, and FPGAs allows engineers to p
from concept to functional silicon very quickly. Microcontrollers hav
over many applications that once were implemented by digital circu
DSP has been used to replace many analog circuits. It is amazing tha
controllers, DSP, and all the necessary glue logic can now be consolidat
a single FPGA using a hardware description language with advanced d
ment tools. Today's students must be exposed to these modern tools, ev
introductory course. It is every educator's responsibility to find the bes
prepare graduates for the work they will encounter in their profession

The standard SSI and MSI parts that have served as "bricks a
tar" in the building of digital systems for over 40 years are now o
and becoming less available. Many of the techniques that have been
over that time have focused on optimizing circuits that are built fro
outmoded devices. The topics that are uniquely suited to applying
technology *but do not contribute to an understanding of the new techno*
being de-emphasized. From an educational standpoint, however, thes
ICs do offer a way to study simple digital circuits, and the wiring of
using breadboards is a valuable pedagogic exercise. They help to
concepts such as binary inputs and outputs, physical device operati
practical limitations, using a very simple platform. Consequently, w
chosen to continue to introduce the conceptual descriptions of digital
and to offer examples using conventional standard logic parts. For
tors who continue to teach the fundamentals using SSI and MSI circu
edition retains those qualities that have made the text so widely a
in the past. Many hardware design tools even provide an easy-to-use
entry technique that will employ the functionality of conventional s
parts with the flexibility of programmable logic devices. A digital des
be described using a schematic drawing with pre-created building
that are equivalent to conventional standard parts, which can be co
and then programmed directly into a target PLD with the added ca
of easily simulating the design within the same development tool.

We believe that graduates will actually apply the concepts prese
this book using higher-level description methods and more complex p
mable devices. The major shift in the field is a greater need to und
the description methods, rather than focusing on the architecture of a
device. Software tools have evolved to the point where there is little n
concern about the inner workings of the hardware but much more
focus on what goes in, what comes out, and how the designer can descri
the device is supposed to do. We also believe that graduates will be i
with projects using state-of-the-art design tools and hardware solution

This book offers a strategic advantage for teaching the vital topic
ware description languages to beginners in the digital field. VHDL i
putedly an industry standard language at this time, but it is also very d
and has a steep learning curve. Beginning students are often discour
the rigorous requirements of various data types, and they struggle with

Altera's software development system is Quartus II. The ma
text does not attempt to teach a particular hardware platform o
of using a software development system. We have chosen to sh
tool can do, rather than train the reader how to use it.

Many laboratory hardware options are available to users
Complete development boards are available that offer the nor
inputs and outputs like logic switches, pushbuttons, clock signal
7-segment displays. Many boards also offer standard connecto
ily available computer hardware, such as a standard keyboar
mouse, VGA video monitor, COM ports, audio in/out jacks, plu
general-purpose I/O ribbon connectors that allow connection t
peripheral hardware.

Our approach to HDL and PLDs gives instructors several op

1. The HDL material can be skipped entirely without affec
tinuity of the text.
2. HDL can be taught as a separate topic by skipping the
tially and then going back to the last sections of Chapt
7, and 9 and then covering Chapter 10.
3. HDL and the use of PLDs can be covered as the cour
chapter by chapter—and woven into the fabric of the
experience.

Among all specific hardware description languages, VHDL i
industry standard and is most likely to be used by graduates in t
We have always felt that it is a bold proposition, however, to try to
in an introductory course. The nature of the syntax, the subtle d
object types, and the higher levels of abstraction can pose obstacle
ner. For this reason, we have included Altera's AHDL as the re
introductory language for freshman and sophomore courses. W
included VHDL as the recommended language for more advanc
introductory courses offered to more mature students. We do not
trying to cover both languages in the same course. Sections of
cover the specifics of a language are clearly designated with a co
margin. The HDL code figures are set in a color to match the col
explanation. The reader can focus only on the language of his or he
skip the other. Obviously, we have attempted to appeal to the dive
of our market, but we believe we have created a book that can be
tiple courses and will serve as an excellent reference after gradua

Chapter Organization

Many instructors opt to not use the chapters of a textbook in the
which they are presented. This book was written so that, for th
each chapter builds on previous material, but it is possible to al
ter sequence somewhat. The first part of Chapter 6 (arithmetic
can be covered right after Chapter 2 (number systems), altho

FIGURE P1 Letters denote categories of problems, and asterisks indicate that corresponding solutions are provided at the end of the text.

PROBLEMS

SECTION 9-1

B 9-1. Refer to Figure 9-3. Determine the levels at each decoder out
the following sets of input conditions.
(a)*All inputs LOW
(b)*All inputs LOW except E_3 = HIGH
(c) All inputs HIGH except $\overline{E}_1 = \overline{E}_2$ = LOW
(d) All inputs HIGH

B 9-2.* What is the number of inputs and outputs of a decoder that a
64 different input combinations?

* Answers to problems marked with an asterisk can be found in the back of the text.

in each chapter that deal with troubleshooting, PLDs, HDLs, or mi
puter applications can be deferred to an advanced course.

PROBLEM SETS This edition includes six categories of problem
(B), challenging (C), troubleshooting (T), new (N), design (D), and H
Undesignated problems are considered to be of intermediate di
between basic and challenging. Problems for which solutions are
in the back of the text or on the website (http://www.pearsonhigher
careersresources/) are marked with an asterisk (see Figure P1).

PROJECT MANAGEMENT AND SYSTEM-LEVEL DESIGN Sever
world examples are included in Chapter 10 to describe the techniqu
to manage projects. These applications are generally familiar to m
dents studying electronics, and the primary example of a digital
familiar to everyone. Many texts talk about top-down design, but t
demonstrates the key features of this approach and how to use the
tools to accomplish it.

SIMULATION FILES This edition also includes simulation files t
be loaded into Multisim®. The circuit schematics of many of the
throughout the text have been captured as input files for this popu
ulation tool. Each file has some way of demonstrating the operatio
circuit or reinforcing a concept. In many cases, instruments are a
to the circuit and input sequences are applied to demonstrate the
presented in one of the figures of the text. These circuits can then
ified as desired to expand on topics or create assignments and tuto
students. All figures in the text that have a corresponding simulatio
the website are identified by the icon shown in Figure P2.

Specific Changes

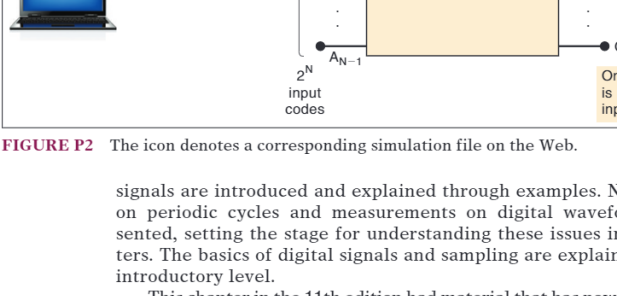


FIGURE 9-1 General decoder diagram.

FIGURE P2 The icon denotes a corresponding simulation file on the Web.

signals are introduced and explained through examples. N
on periodic cycles and measurements on digital wavefo
sented, setting the stage for understanding these issues in
ters. The basics of digital signals and sampling are explain
introductory level.

This chapter in the 11th edition had material that has now
outdated since its publication. Some of the historic analogies
edition were ineffective. The revisions have replaced or elimi

- **Chapter 2.** The Gray Code is used to introduce the conce
drature encoder: a device that produces a 2-bit Gray Co
capable of discerning the direction and angular rotation of
- **Chapter 3.** New problems at the end of this chapter focus on
common to automobiles.
- **Chapter 4.** The material introducing PLD programming a
ment software has been updated and improved. The sectio
shooting has been expanded to teach structured problem
applies to hardware debugging of traditional prototyped dig
The VHDL material has been enhanced to explain some
very important aspects of data objects in this language. Th
"PROCESS" is also more thoroughly covered improving th
that Chapter 5 builds on.
- **Chapter 5.** High-speed digital systems are easily affected by
tations of the circuitry. New material in this chapter explains
effects caused when setup and hold time requirements are
explaining meta-stability. A teaching example that can be re
the laboratory environment has been added. The focus is
applications of D flip-flops but it is presented in the context
ture shaft encoder that must reliably and repeatedly ke
absolute shaft position as it is rotated back and forth over
Design techniques from Chapter 4 are employed to design a
should meet the system's needs. The initial circuit's mar
mance demonstrates what happens when real-timing constr
taken into account. A way to correct this problem is presente

- **Chapter 9.** The concept of Time Division Multiplexing is added to an example of how many digital signals are able to share a comm pathway. A simple system is presented that can easily be reprod a laboratory exercise.
- **Chapter 10.** No changes were made in Chapter 10.
- **Chapter 11.** No changes were made in Chapter 11.
- **Chapter 12.** The coverage of floating gate MOSFETS, the tech behind flash memory, is enhanced.
- **Chapter 13.** This chapter has been generalized with references t series of CPLDs and FPGAs abbreviated.

Retained Features

This edition retains all of the features that made the previous edi widely accepted. It utilizes a block diagram approach to teach the bas operations without confusing the reader with the details of interna tion. All but the most basic electrical characteristics of the logic withheld until the reader has a firm understanding of logic princi Chapter 8, the reader is introduced to the internal IC circuitry. At tha the reader can interpret a logic block's input and output characteris "fit" it properly into a complete system.

The treatment of each new topic or device typically follows thes the principle of operation is introduced; thoroughly explained ex and applications are presented, often using actual ICs; short revie tions are posed at the end of the section; and finally, in-depth probl available at the end of the chapter. These problems, ranging from to complex, provide instructors with a wide choice of student assig These problems are often intended to reinforce the material without repeating the principles. They require students to demonstrate com sion of the principles by applying them to different situations. This ap also helps students to develop confidence and expand their knowl the material.

The material on PLDs and HDLs is distributed throughout the te examples that emphasize key features in each application. These topics at the end of each chapter, making it easy to relate each topic to the discussion earlier in the chapter or to address the general discussio rately from the PLD/HDL coverage.

The extensive troubleshooting coverage is spread over Cha through 12 and includes presentation of troubleshooting princip techniques, case studies, 17 troubleshooting examples, and 46 *real* t shooting problems. When supplemented with hands-on lab exercis material can help foster the development of good troubleshooting

This edition offers more than 220 worked-out examples, more th review questions, and more than 640 chapter problems/exercises. S these problems are applications that show how the logic devices prese the chapter are used in a typical microcomputer system. Answers to a

Supplements

An extensive complement of teaching and learning tools has
oped to accompany this textbook. Each component provid
function, and each can be used independently or in conjunct
others.

WEB RESOURCES

- **Quartus II Web Version software from Altera.** This develop
software is available from Altera.
- **Design files from the textbook figures.** More than 40 design
language are presented in figures throughout the text. S
load these into the Altera software and test them.
- **Solutions to selected problems: HDL design files.** A few o
chapter problem solutions are available to students. (All
solutions are available to instructors in the *Instructor's Resou*
Solutions for Chapter 7 problems include some large graph
files that are not published in the back of the book but are
the web site.
- **Circuits from the text rendered in Multisim®.** Students c
work interactively with approximately 100 circuits to in
understanding of concepts and prepare for laboratory ac
Multisim circuit files are provided for use by anyone who h
software.

INSTRUCTOR RESOURCES

- ***Online Instructor's Resource Manual.*** This manual conta
out solutions for all end-of-chapter problems in this text
0-13-422021-8)
- ***Online PowerPoint® presentations.*** Figures from the text, i
Lecture Notes for each chapter, are available. (ISBN 0-13-4
- ***Online TestGen.*** A computerized test bank is available.
422016-1)

To access supplementary materials online, instructors nee
an instructor access code. Go to **www.pearsonhighered.com/ir**
can register for an instructor access code. Within 48 hours af
ing, you will receive a confirming e-mail, including an instr
code. Once you have received your code, go to the site and lo
instructions on downloading the materials you wish to use.

Acknowledgments

We are grateful to all those who evaluated the eleventh edit

We are grateful to all those who evaluated the eleventh edi
vided answers to an extensive questionnaire:

Their comments, critiques, and suggestions were given se
eration and were invaluable in determining the final form of
edition.

We also are greatly indebted to Professor Frank Ambro
Community College, for his usual high-quality work on the