# Digital Design Principles and Practice

*By John F. Wakerly*



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This is a modern revision of the classic digital design textbook. The book teaches the basic tools for the design of digital circuits in a clear, easily accessible manner. New to This Edition: *Nine sections on Verilog Hardware Description Language (HDL) inserted in discrete sections, allowing the material to be covered or skipped as desired. The Verilog HDL presentation is at a suitable level for beginning students who are learning digital circuits for the first time. *Reorganized material on combinational circuits is now covered in a single chapter. *The emphasis in the sequential circuits chapters is now on design with D flip-flops instead of JK and SR flip-flops. *The material on memory and programmable logic is now consolidated in one chapter. *Chapter 8 consists mostly of new material and now covers digital design in the Register Transfer Level (P) FL), preparing the reader for more advanced design projects and further Verilog HDL studies. *A new section in Chapter 11 supplements the laboratory experiments with HDL experiments. These unable the reader to check the circuits designed in the laboratory by means of hardware components and/or by HDL simulation.* Text accompanied by Verilog simulator software-SynaptiCAD's VeriLogger Pro evaluation version, a Verilog simulation environment that combines all of the features of a traditional Verilog simulator with a powerful graphical test vector generator. Fast model testing in VeriLogger Pro allows the reader to perform bottom-up testing of every model in a design. All of the HDL examples in the book can be found on the CD-ROM. *A Companion Website includes resources for instructors and students such as transparency masters of all figures in the book, all HDL code examples from the book, a Verilog tutorial, tutorials on using the VeriLogger Pro software, and more. It can be found at http://www.prenhall.com/mano

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## Editorial Review

From the Publisher
This popular introduction to digital design presents the basic tools for the design of digital circuits, and provides procedures suitable for a variety of digital design applications.

From the Back Cover

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- **Reorganized material on combinational circuits** is now covered in a single chapter.
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- **A Companion Website** includes resources for instructors and students such as transparency masters of all figures in the book, all HDL code examples from the book, a Verilog tutorial, tutorials on using the VeriLogger Pro software, and more. It can be found at **http://www.prenhall.com/mano**



Digital design is concerned with the design of digital electronic circuits. Digital circuits are employed in the design and construction of systems such as digital computers, data communication, digital recording, and many other applications that require digital hardware. This book presents the basic tools for the design of digital circuits and provides the fundamental concepts used in the design of digital systems. It is suitable for use as a textbook in an introductory course in an electrical engineering, computer engineering, or computer science curriculum.

Many of the features in this third edition remain the same as those of the previous editions except for rearrangement of the material or changes in emphasis due to changes in the technology. Combinational circuits are covered in one chapter instead of two, as in the previous edition. The sequential circuit chapter emphasizes design with *D* flip-flops instead of *JK* and *SR* flip-flops. The material on memory and programmable logic are combined in one chapter. Chapter 8 has been revised to include register transfer level (RTL) design procedures.

The main revision in the third edition is the inclusion of sections on Verilog Hardware Description Language (HDL). The HDL material is inserted in separate sections so it can be covered or skipped as desired. The presentation is at a suitable level for beginning students that are learning digital circuits and a hardware description language at the same time.

- Digital circuits are introduced in Chapters 1 through 3 with an introduction to Verilog HDL in Section 3-9.
- Further discussion of HDL occurs in Section 4-11 following the study of combinational circuits.
- Sequential circuits are covered in Chapters 5 and 6 with corresponding HDL examples in Sections 5-5 and 6-6.
- The HDL description of memory is presented in Section 7-2.
- The RTL symbols used in Verilog HDL are introduced in Sections 8-2.
- Examples of HDL descriptions in the RTL and structural levels are provided in Section# 8-5 and 8-8.
- Section 10-10 covers switch-level modeling corresponding to CMOS circuits.
- Section 11-19 supplements the hardware experiments of Chapter 11 with HDL experiments. Now the circuits designed in the laboratory can be checked by means of hardware components and/or by HDL simulation.

The CD-ROM in the back of the book contains the Verilog HDL source code files for the examples in the book and two simulators provided by SynaptiCAD. The first simulator is VeriLogger Pro, a traditional Verilog simulator that can be used to simulate the HDL examples in the book and to verify the solutions of HDL problems. The second is a new type of simulation technology, called an Interactive Simulator. This simulator allows engineers to simulate and analyze design ideas before a complete simulation model or schematic is available. This technology is particularly useful for students, because they can quickly enter Boolean and D flip-flop or latch input equations to check equivalency or to experiment with flip-flops and latch designs. Tutorials are available as HTML files in the CD-ROM Flash display and as MS Word files in the SynaptiCAD installed directory under Book Tutorials.

Additional resources are available in a companion Website at **http://www.prenhall.com/mano**. It includes all the Verilog HDL examples from the book for downloading, all of the figures and tables in the book in PDF format, tutorials on the use of the Verilog software in the CD-ROM, and more.

The following is a brief description of the topics that are covered in each chapter with emphasis on the revisions that were made for the third edition.

**Chapter 1** presents the various binary systems suitable for representing information in digital systems. The binary number system is explained and binary codes are illustrated. Examples are given for addition and subtraction of signed binary numbers and decimal numbers in BCD.

**Chapter 2** introduces the basic postulates of Boolean algebra and shows the correlation between Boolean expressions and their corresponding logic diagrams. All possible logic operations for two variables are investigated and from that, the most useful logic gates used in the design of digital systems are determined. The characteristics of integrated circuit gates are mentioned in this chapter but a more detailed analysis of the electronic circuits of the gates is done in Chapter 10.

**Chapter 3** covers the map method for simplifying Boolean expressions. The map method is also used to simplify digital circuits constructed with AND-OR, NAND, or NOR gates. All other possible two-level gate circuits are considered and their method of implementation is explained. Verilog HDL is introduced together with simple gate-level modeling examples.

**Chapter 4** outlines the formal procedures for the analysis and design of combinational circuits. Some basic components used in the design of digital systems, such as adders and code converters, are introduced as

design examples. Frequently used digital logic functions such as parallel adder and subtractor, decoders, encoders, and multiplexers are explained, and their use in the design of combinational circuits is illustrated. HDL examples are given in the gate-level, dataflow, and behavioral modeling to show the alternative ways available for describing combinational circuits in Verilog HDL. The procedure for writing a simple test bench to provide stimulus to an HDL design is presented.

**Chapter 5** outlines the formal procedures for the analysis and design of clocked synchronous sequential circuits. The gate structure of several types of flip-flops is presented together with a discussion on the difference between level and edge triggering. Specific examples are used to show the derivation of the state table and state diagram when analyzing a sequential circuit. A number of design examples are presented with emphasis on sequential circuits that use D-type flip-flops. Behavioral modeling in Verilog HDL for sequential circuits is explained. HDL Examples are given to illustrate Mealy and Moore models of sequential circuits.

**Chapter 6** deals with various sequential circuits components such as registers, shift registers, and counters. These digital components are the basic building blocks from which more complex digital systems are constructed. HDL descriptions of shift registers and counter are presented.

**Chapter 7** deals with random access memory (RAM) and programmable logic devices. Memory decoding and error correction schemes are discussed. Combinational and sequential programmable devices are presented such as ROM, PAL, CPLD, and FPGA.

**Chapter 8** deals with the register transfer level (RTL) representation of digital systems. The algorithmic state machine (ASM) chart is introduced. A number of examples demonstrate the use of the ASM chart, RTL representation, and HDL description in the design of digital systems. This chapter is the most important chapter in the book as it prepares the student for more advanced design projects.

**Chapter 9** presents formal procedures for the analysis and design of asynchronous sequential circuits. Methods are outlined to show how an asynchronous sequential circuit can be implemented as a combinational circuit with feedback. An alternate implementation is also described that uses SR latches as the storage elements in asynchronous sequential circuits.

**Chapter 10** presents the most common integrated circuit digital logic families. The electronic circuits of the common gate in each family is analyzed using electrical circuit theory. A basic knowledge of electronic circuits is necessary to fully understand the material in this chapter. Examples of Verilog switch-level descriptions demonstrate the ability to simulate circuits constructed with MOS and CMOS transistors.

**Chapter 11** outlines experiments that can be performed in the laboratory with hardware that is readily available commercially. The operation of the integrated circuits used in the experiments is explained by referring to diagrams of similar components introduced in previous chapters. Each experiment is presented informally and the student is expected to produce the circuit diagram and formulate a procedure for checking the operation of the circuit in the laboratory. The last section supplements the experiments with corresponding HDL experiments. Instead of, or in addition to, the hardware construction, the student can use the Verilog HDL software provided on the CD-ROM to simulate and check the design.

**Chapter 12** presents the standard graphic symbols for logic functions recommended by an ANSI/IEEE standard. These graphic symbols have been developed for SSI and MSI components so that the user can recognize each function from the unique graphic symbol assigned. The chapter shows the standard graphic symbols of the integrated circuits used in the laboratory experiments. The various digital components that are represented throughout the book are similar to commercial integrated circuits. However, the text does not mention specific integrated circuits except in Chapters 11 and 12. The practical application of digital design

will be enhanced by doing the suggested experiments in Chapter 11 while studying the theory presented in the text.

Each chapter has a list of references and a set of problems. Answers to selected problems appear in at the end of the book to aid the student and to help the independent reader. A solutions manual is available for the instructor from the publisher.

I would like to thank Charles Kime for introducing me to Verilog. My greatest thanks go to Jack Levine for guiding me and checking the sections, examples, and problem solutions to all Verilog HDL material. Thanks go to Tom Robbins for helping me decide to write the third edition and my editor Eric Frank for his pat...

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