Circuit Design and Simulation with VHDL

second edition

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Preface

The book presents one of the most comprehensive coverages so far of VHDL and its applications to the design and simulation of real, industry-standard circuits. It does not focus only on the VHDL language, but also on its use in building and testing digital circuits. In other words, besides explaining VHDL in detail, it also shows why, how, and which types of circuits are inferred from the language constructs, and how any of the four simulation categories can be implemented, all demonstrated by means of numerous examples. A rigorous distinction is made between VHDL for synthesis and VHDL for simulation. In both cases, the VHDL codes are always complete, not just partial sketches, and are accompanied by circuit theory, code comments, and simulation results whenever applicable. The book also reviews fundamental concepts of digital electronics and digital design, resulting in a very practical, self-contained approach. A series of modern extended and advanced designs are also presented, covering state machines, memory implementations, serial data communications circuits, video interfaces, and more.

Main Features

- The book focuses on the *use* of VHDL rather than solely on the language itself. In other words, besides explaining VHDL in detail, it also shows why, how, and which types of circuits are inferred from the language constructs.
- The book makes a clear distinction between the parts of VHDL that are for *synthesis* versus those that are for *simulation* (contrary to other books, which usually mix up all VHDL constructs).
- The VHDL codes in all design examples are complete, not just partial sketches. Circuit diagrams, physical synthesis in Field Programmable Gate Arrays (FPGAs), simulation results, and explanatory comments are also included in the designs.
- It teaches all indispensable features of VHDL in a very concise format.
- It is the first text to also include a detailed analysis of circuit simulation with VHDL testbenches in all four categories (nonautomated and fully automated, functional and timing

simulations), accompanied also by related tutorials (like ModelSim), which allow complete end-to-end practical examples to be presented.

- The book also reviews fundamental concepts of digital electronics and digital design, resulting in a very practical, self-contained approach.
- To ease the understanding of the language and its applications, the review and the examples are separated into *combinational* and *sequential* circuits. Further distinction is made between *logical* versus *arithmetic* combinational circuits, as well as between *regular* versus *state-machine-based* sequential circuits.
- The book is divided into three parts, with circuit-level VHDL in part 1 (chapters 1–8), system-level VHDL and simulation in part 2 (chapters 8–10), and finally extended and advanced designs in part 3 (chapters 11–17). In summary, chapters 1–10 teach VHDL, while chapters 11–17 show a series of extended and advanced designs using VHDL.
- Inclusion of new, modern digital circuits, like advanced state machines, serial data communications circuits, and video interfaces, all with theory, complete VHDL codes, simulation, and explanatory comments, makes the lab sections much more productive.
- All examples and exercises are named to ease the identification of the circuit/design under analysis.
- Finally, a series of 15 appendices show tutorials on very important design tools, such as ISE, Quartus II, and ModelSim, plus descriptions of programmable logic devices (CPLDs/FPGAs, in which the designs are implemented), of the DE2 development board, of standard VHDL packages, and more.

Main Differences Relative to the First Edition

The book was updated, extended, and immensely improved. The VHDL language is now covered in chapters 1–10 (including fundamental designs and simulation), while chapters 11–17 present extended and advanced designs. Below is a summary of the main improvements with respect to the first edition, preceded by the total number of examples, exercises, and figures in both editions.

Enumerated design examples: 79 (first edition); 94 (second edition)

Exercises: 96 (first edition); 231 (second edition)

Figures: 145 (first edition); 278 (second edition)

With Respect to the Language

The study of VHDL (chapters 1–10) was updated, extended, and deepened. The syntax was improved, with better coverage and a simplified representation adapted from the Backus-Naur Form. Features of VHDL 2008 were also included. New theoretical details

were included in the descriptions of basically all circuits. Additionally, the number of examples and of exercises grew substantially.

In chapters 2–4, the study of VHDL libraries/packages was extended. Numerous new details, particularly for synthesis, were described and included in the examples and exercises. The description of the code structure, in chapter 2, was modernized, including additional details about the syntax and synthesis packages as well as new introductory design examples.

In chapter 3, the description of data types was updated and immensely expanded. A more rigorous distinction between the several data type families was provided, including several type classifications. A successful technique introduced in the first version, which bases any data type on its number of bits, was again employed and extensively used in the examples. Type conversion and the analysis of unsigned versus signed types were also deepened.

In chapter 4, the description of operators and attributes was updated and expanded. All predefined options are now present in the text. A series of synthesis attributes, to prevent logic or register simplifications or for automated pin assignments, were also included.

The study of concurrent code, in chapter 5, received new examples and new topics, including recommendations for the implementation of signed systems, followed by respective examples. The use of special synthesis attributes, described in chapter 4, was also illustrated. Additionally, the study of sequential code, in chapter 6, was modernized. The examples were reorganized and new examples and new exercises were provided.

In chapter 7, the study of signal versus variable was modernized, with six rules introduced for the proper understanding of their differences. A new topic, which introduces a technique to allow multiple signal assignments, was also included.

Chapter 8's description of packages and components was also updated. New examples and exercises were included, as well as configuration declarations and multiple component instantiations.

The study of functions and procedures, in chapter 9, was reorganized and expanded. Additional details were presented, with more information on overloading and the inclusion of new function implementations.

Contrary to all other chapters, which deal exclusively with synthesis, chapter 10 is completely dedicated to simulation (this did not exist in the previous edition). All four categories of VHDL simulation with testbenches are described, and several practical examples are given. The use of text files, which are very helpful in simulations, is also described. This chapter is a crucial distinguishing feature with respect to the previous edition (in fact, with respect to any other VHDL book).

With Respect to the Extended and Advanced Design Examples

Chapters 11–17 are dedicated exclusively to the presentation of extended and advanced designs, constituting another major addition to the book. Another difference is that these designs are not done without first going through the theory on the involved circuits,

including the analysis of official standards, when applicable. This part of the book replaces chapters 8, 9, and 12 of the previous edition. The main differences are summarized below.

Chapter 11 presents detailed design techniques for finite state machines (FSMs) using VHDL. A new technique for complex, timed machines is introduced in this new edition. Another new topic discusses the state-bypass problem in FSMs. The result is the most comprehensive study of FSM design using VHDL so far.

Chapter 12 is another completely new addition to the book. It presents a series of designs involving basic displays (LEDs, SSDs, and LCDs). Because these devices provide physical (visual) feedback to the students, lab exercises involving them are very motivating. As in all other chapters, each design is preceded by theoretical information on the circuits to be designed.

Chapter 13, also new, shows a study of memory implementations. This is important because basically any modern digital system requires some sort of memory.

Chapter 14 is the longest of the new chapters. It deals with a very modern topic, present in almost all large designs, which consists of serial data communications circuits. Several modern interfaces are described (I^2C, SPI, TMDS, PS2) and subsequently used in actual applications, driving actual ICs.

Chapters 15–17 are also new. All three deal with video circuits, again providing interesting, advanced circuits for lab experiments. Chapter 15 deals with the traditional VGA interface, used to connect computers to analog video monitors. Chapter 16 describes the DVI interface, fully digital and much more complex, used to connect desktop computers to LCD monitors. Finally, chapter 17 deals with the FPD-Link interface, which is a modern video interface for industrial and hand-held applications.

With Respect to the Exercises

The exercise sections were modernized and greatly expanded (there were 96 exercises in the previous edition; there are now 231). A broader coverage is achieved, with numerous interesting exercises for implementation and testing in FPGA boards during the lab sections.

With Respect to the Overall Presentation

The text was fully revised and expanded, with a smoother presentation and the inclusion of many additional details, both theoretical and practical. The same occurred with the figures, with the inclusion of many new ones and the complete reconstruction of those brought over from the first edition.

Audience

The book is mainly intended for the following:

- electrical engineering undergraduate and graduate students,
- computer engineering undergraduate and graduate students,

- computer science undergraduate and graduate students,
- digital design professors and instructors,
- VHDL professors and instructors,
- digital design engineers and practitioners in the industry, and
- digital design consultants and other practitioners at all levels.

Companion Books

The following two references are highly recommended:

- IEEE 2008 for additional details on the VHDL language.
- Pedroni 2008 for theoretical background on digital concepts and digital circuits.