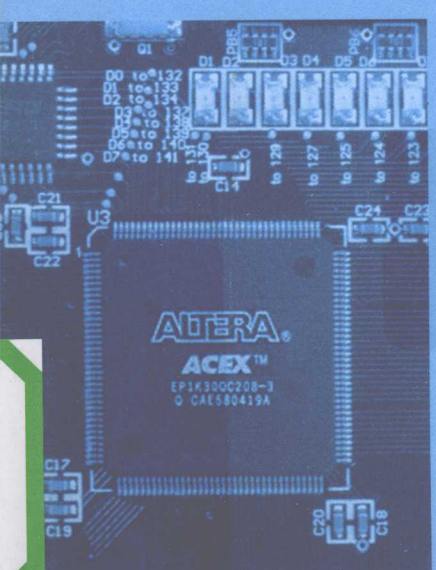
VHDL与数字电路设计

VHDL
and
Digital Circuit Design

■ 王　俭 刘传洋 谷慧娟　编著




```
LIBRARY IEEE;
USE IEEE.STD_LOGIC_1164.ALL;
ENTITY prio_encoder IS
PORT(s0,s1,s2,s3:IN STD_LOGIC;
                    'ECTOR(1 DOWNTO 0));

                    )F prio_encoder IS
BEGIN
   F<="11" WHEN s3 ='1' ELSE
      "10" WHEN s2 ='1' ELSE
      "01" WHEN s1 ='1' ELSE
      "00" WHEN s0 ='1' ELSE
      "XX";
END behavior;
```

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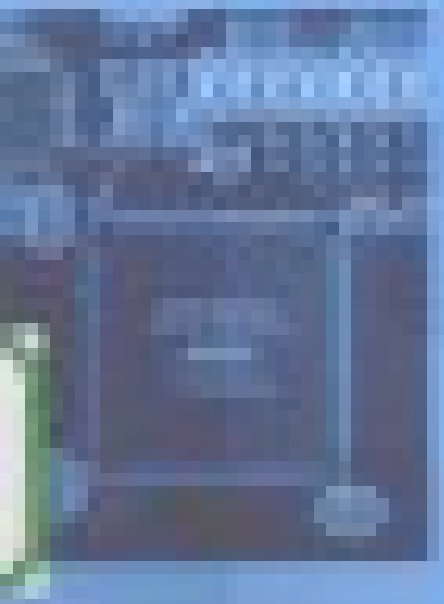

VHDL and Digital Circuit Design

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内容提要

本教材系统介绍涉及数字系统设计的多方面原理、技术及应用。主要内容有数字系统的基本设计思想、设计方法和设计步骤，VHDL 硬件描述语言，PLD 的结构、原理与分类，数字系统设计开发软件平台 Quartus Ⅱ及其使用，常用数字电路的设计方案等；涵盖现代数字系统设计完整过程的三个支撑方面：硬件描述语言、器件、软件开发平台。

本教材可作为普通本科和高职高专的电子、通信、控制类专业学生的专业基础课教材，尤其适合双语教学中的学生使用，同时也可作为从事电子系统开发设计的技术人员的参考书。

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VHDL and Digital Circuit Design

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前言

随着半导体技术和专用集成电路(ASIC)设计技术的快速发展,可编程逻辑器件(PLD)技术日趋成熟、计算机辅助设计(CAD)技术和硬件描述语言(HDL)的日益完善,数字系统的设计可以直接面向用户的需求,根据系统的行为和功能要求,自上而下地完成电路在不同抽象层次下的描述、综合、优化、仿真与验证,直至具体电路的生成实现。在现代数字系统设计方式下,设计人员的主要任务已成为:把由文字说明的系统功能转化为逻辑描述(即算法),进而采用一定的描述工具(如 VHDL 语言等)建立系统描述模型,采用相应的软件开发平台设计并仿真数字系统,最后选择适当的 PLD 器件加以实现。

现代数字系统设计的关键已经变为设计平台的选择与搭建。设计包括硬件平台和软件平台,硬件平台包括硬件实现方式如 ASIC 模式和 PLD 模式;而软件平台包括电路描述/编辑环境、综合工具、仿真与验证工具、单元库与 IP 等等,通常软件平台是和硬件平台相对应的。

在 PLD 技术日趋成熟的今天,PLD 内部资源不断增加、成本不断降低、开发设计的标准化程度不断提高,其应用场合也逐渐由高端、专用领域发展到涉及电子信息技术的所有领域。

硬件描述语言的发展已有几十年的历史,并已成功地应用到了数字系统的仿真、验证和设计综合等方面,对系统设计迈向电子设计自动化(EDA)阶段起到了极大的推动作用,尤其是 20 世纪 80 年代后期由美国国防部开发的 VHDL 语言,具有标准性好的特点,可以面向不同层次的设计,因而被 IEEE 标准化(1987 年定为 IEEE Standard 1076—1987 标准,1993 年修订为 ANSI/IEEE Standard 1076—1993 标准)。目前所有的 EDA 工具均支持 VHDL 语言。

编写本教材的主要目的之一是引导读者在掌握数字电路基本原理和分析设计方法的基础上，从传统的功能电路设计转向系统设计，从通用集成电路的应用转向可编程逻辑器件的应用，从单纯硬件设计转向硬件软件高度渗透的设计，从而提高读者的数字系统逻辑设计和工程设计能力。

编写本教材的另一个主要目的是，将专业基础及专业课程的教学与工程技术英语的学习及应用紧密结合起来，将教育部提倡的双语教学要求更好地落到实处，切实对双语教学效果的提高做一些探索和尝试。

本教材系统介绍了涉及数字系统设计的多方面原理和技术及应用。其中：

第 1 章(Developing Digital System)介绍以 74 系列集成电路芯片为基础的数字电路设计和以 PLD 器件为基础、以 CAD 软件平台为工具、以 HDL 语言为手段的数字系统设计的异同和优劣，作为引领学生从传统数字电路设计转入现代数字系统设计的入门部分的内容。

第 2 章(Programmable Logic Devices)对各种 PLD 器件的原理、结构等作一般深度的介绍，结合典型结构述明基本工作原理即可，作为学生的硬件基础。

第 3 章(VHDL—A Programing Language)介绍 VHDL 语言的语法，涉及内容以能够完成实际的应用性设计为目标，作为学生的软件基础。

第 4 章(Using VHDL for Describing Logic Circuits)以举例为主要形式，介绍 VHDL 语言实现一般数字系统的方法、实现各种常用数字部件及电路的方法和代码。

第 5 章(VHDL Design Using Quartus Ⅱ)结合软件平台 Quartus Ⅱ详细介绍数字系统的设计实现步骤，强调可操作性。

第 6 章(Experiments)结合全书已学内容，介绍体现层次化设计思想的实用性设计大作业。

在每章最后配有一定数量的习题(Problems)，目的是帮助学生整理和巩固所学内容。

词汇表(Glossary)对全书的生词和词组予以注释。

参考文献(References)列出本教材编写所参考的若干书刊以及其他一些可供读者参考的书刊。

附录(Appendix)提供相关世界知名生产厂商、技术研发公司、学校的网站，可供教师和学生查阅、参考。

总体而言，本教材有以下特点：

(1) 注重技术实用性。理论部分简明扼要并重点突出，实际应用部分采用大量实例，由简到繁，循序渐进，最后提供由实用案例组装而成的大作业，达到教学与产品设计开发接轨的要求。

（2）努力提高双语教学的实际效果。本书作为英语双语教材，吸收借鉴了外文相关教材的长处和优点，同时兼顾了国内普通本科院校学生的实际英文水平。全书采用简单的句子结构、日常的普通词汇和常用的专业词汇，便于学生自学和教师授课。对足够多生词和词组予以注释，减轻学生阅读英文的心理负担。本书对学生英语水平的要求略低于大学英语四级水平。

（3）所介绍的数字系统设计开发软件平台 Quartus Ⅱ，是最新的一种实用型开发设计软件。本书对其使用的介绍完全按照实用设计步骤进行，配以详细的截屏图，便于学生操作和掌握。

王俭（苏州科技大学）编写了第 1、3、4 章，刘传洋（苏州科技大学）编写了第 2、5 章，谷慧娟（苏州高博软件技术职业学院）编写了第 6 章以及习题、词汇表和附录。全书由王俭总体规划和统编。

本教材可作为普通本科和高职高专的电子、通信、控制类专业学生的专业基础课教材，尤其适合双语教学使用。

本教材在编写过程中参考了诸多国外专家学者的著作和研究成果，在此向他们表示衷心的感谢。本教材在成书前曾作为讲义试用数年，期间许多学生提出了不少建议，在此也表示感谢。同时在本书的编写、出版过程中也得到了苏州科技大学电子与信息工程学院和教务处的有关领导大力关心和支持，在此表示深深的谢意。

由于作者水平有限，错误和不当之处在所难免，敬请各位读者不吝指教。

作　者

2009 年 10 月 10 日于苏州

CONTENTS

Chapter 1

Developing Digital System

1.1 Digital Systems and Analog Systems

In our lives, we can see many digital devices and analog devices. For example, a clock may be a digital device or an analog device. TV sets were analog devices, whereas they are digital devices now. Today, cameras, media players and computers are digital devices.

A digital device stores, processes and represents information in discrete forms. An analog device deals with information in continuous forms.

A digital device has a digital circuit in itself. Usually, we call a digital device the digital circuit, or the digital system.

In this book, we will study how to design digital circuits.

1.2 Two Methods of Digital Circuit Design

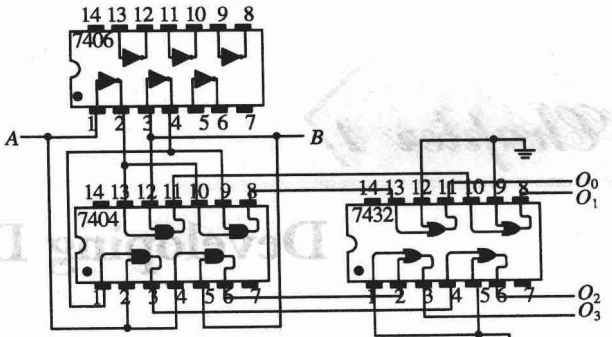
There are two methods to construct a digital circuit. One is the traditional method and the other is the modern method. The traditional method uses standard logic chips, and the modern method uses a programmable logic device (PLD). Let us compare the two methods.

1.2.1 Traditional Method—Using Standard Logic Devices

Fig. 1-1a is a logic function. Fig. 1-1b is a logic circuit which has this logic function.

Inputs		Outputs			
A	B	O_3	O_2	O_1	O_0
0	0	0	0	0	1
0	1	0	0	1	0
1	0	0	1	0	0
1	1	1	0	0	0

(a) Truth table.



(b) Logic circuit.

Figure 1-1 Constructing a circuit using standard logic devices.

The circuit has two inputs, A and B, and four outputs, O_0, O_1, O_2 and O_3. At any time, only one output is high and the rest outputs are low. First, we write the logic expressions for the logic function. Second, we use K-map to achieve the simplest sum-of-product form. Third, we select three integrated circuit (IC) chips such as 7404, 7406 and 7432. Fourth, we construct this circuit on a printed circuit board (PCB).

This is the traditional method of constructing digtal circuits. It has some disadvantages, for example:

1) More than one logic IC chips may be used.

2) Wire laying is time-consuming.

3) Wrong and bad wire laying may happen.

4) Modifying a circuit will be very difficult.

1.2.2 Modern Method—Using Programmable Logic Devices

By using a PLD, a computer-aided design (CAD) tool, and a computer language, we can easily construct a logic circuit.

The first step is describing the logic function. We use a computer language to write computer programs. The computer language is a hardware description language (HDL).

The second step is compiling the HDL program. We use the CAD tool to create a virtual logic circuit. Then, the operation of this virtual circuit is simulated.

The third step is simulating the operation of this virtual circuit. From the result of simulation, we can know if the virtual circuit works well. Of course, the simulation may be unsuccessful. Then, we should do the first step work and/or the second step work again.

The fourth step is downloading the design into a PLD. When downloading

completed, your logic circuit has been constructed in the PLD chip.

The last step is testing the real PLD circuit. We can make the test experiment by using some switches and some LEDs.

In Fig. 1-2, a PLD is used to construct a logic circuit. It has the same logic function as Fig. 1-1.

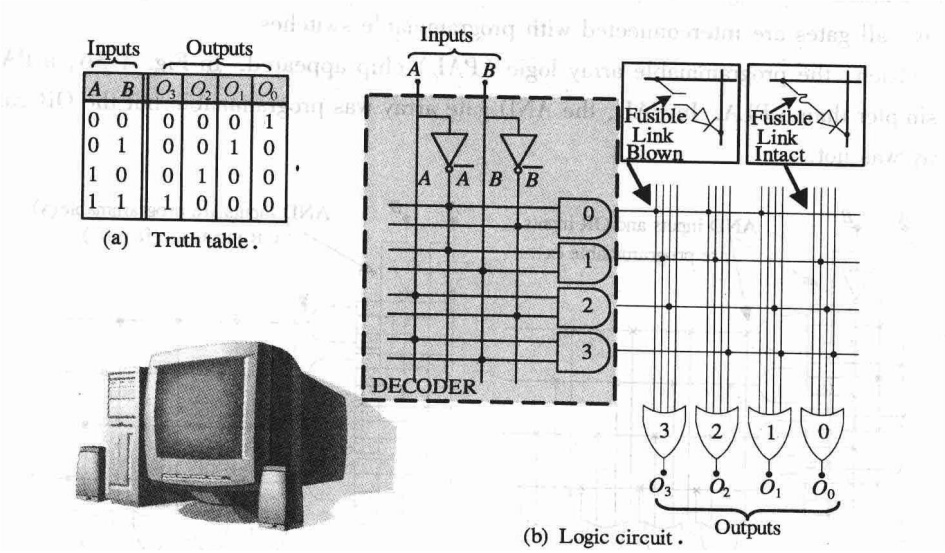


Figure 1-2 Constructing a circuit using Programmable Logic Devices (PLDs).

This is the modern method of constructing logic circuits. It has the following advantages:

1) Only one chip of PLD may be used.
2) Wiring errors can be avoided.
3) Modifying the circuit may be very easy.
4) The PLD can be used many times.
5) All work is time-saving.

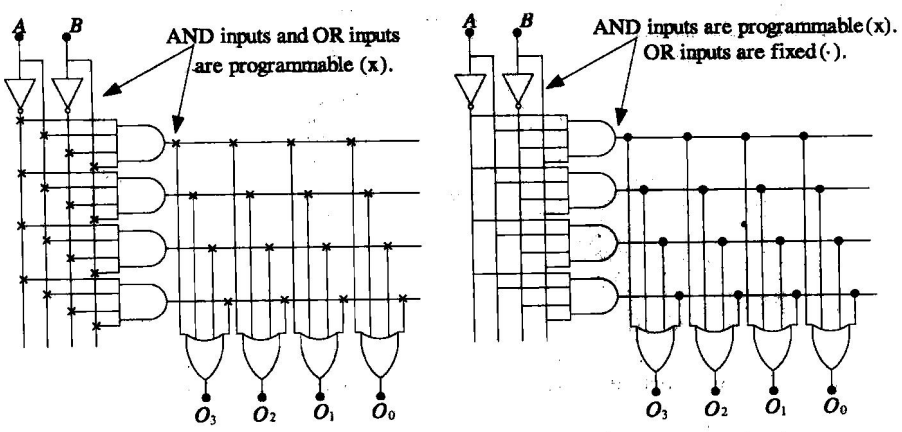
1.3 Introduction of Programmable Logic Devices

As we know, today's digital circuits are integrated circuits (ICs). One kind of these ICs are PLDs. The PLDs are half-made ICs. On a single chip, there are millions of logic gates. A PLD contain the logic elements, interconnection wires, and so on. PLDs can realize logic functions by using all the resources.

1.3.1 Early Programmable Logic Devices

The programmable logic array (PLA) is the earliest PLD. In Fig. 1-3a, a PLA chip contains a set of NOT gates, AND gates, and OR gates. On the left is a programmable AND gate array. On the right is a programmable OR gate array. In each array, all gates are interconnected with programmable switches.

Then, the programmable array logic (PAL) chip appeared. In Fig. 1-3b, a PAL is simpler than a PLA. In PAL, the AND gate array was programmable but the OR gate array was not.



(a) Programmable logic array (PLA). (b) Programmable array logic (PAL).

Figure 1-3 Early types of programmable logic devices.

The PLA and PAL could creat any logic function. However, they are small-scaled. To construct a circuit, we had to use more than one chip. PLAs and PALs use fuses at the wire cross-points. Once a fuse was blown, it can not be resumed. So PLAs and PALs are one-time programmable.

1.3.2 Today's Programmable Logic Devices

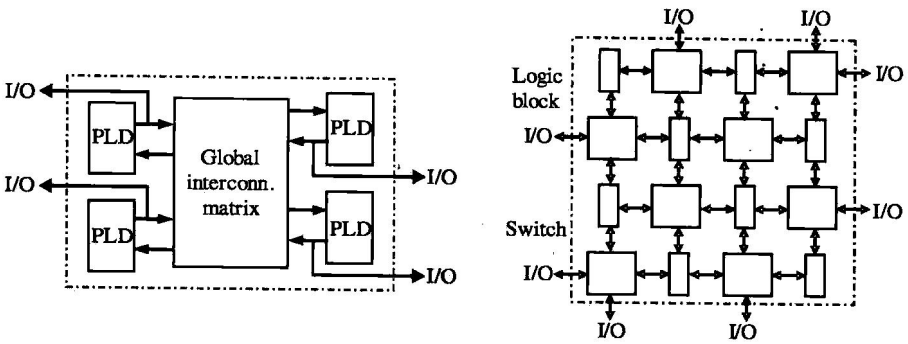
Later, two very large PLD chips were made. One is complex programmable logic device (CPLD) and the other is field-programmable gate array (FPGA). Fig. 1-4 shows the structure of them. They have different structures. A complete digital system can be programmed into a single CPLD or FPGA.

Fig. 1-4a shows the CPLD. It contains several PLD blocks and a global interconnection matrix. To construct a logic circuit in a CPLD, the PLD blocks and the matrix must be programmed. The PLDs perform the logic function. The matrix

determines the connection between PLDs.

Fig. 1-4b shows the FPGA. It has several programmable logic blocks and switches. To construct a logic circuit in an FPGA, both logic blocks and switches should be programmed. Programming the logic blocks can perform logic functions. Programming the switches can connect the logic blocks.

The interconnections in CPLDs are reprogrammable. And the switches in FPGAs are reprogrammable, too. So they can be used again and again.



(a) CPLD (b) FPGA

Figure 1-4 Today's programmable logic device types.

1.4 Computer-aided Design of Logic Circuits on PLD

Today, it is impossible to develop digital circuits without CAD tools. Usually, several CAD tools are packaged into a CAD system. Generally, the developing process contains six steps. Fig. 1-5 shows the six steps.

We explain the six steps one by one:

Step 1: Describing the new circuit. Logic circuits are described in the language, VHDL. By using the CAD system's text editor, this work can be done.

Step 2: Compiling the circuit. The described digital circuit is compiled into logic equation form. And the logic equation form is minimized.

Step 3: Verifying the operation of the circuit. By using the CAD's functional and timing simulator, the compiled circuit is simulated. That is, it is verifying to be correct.