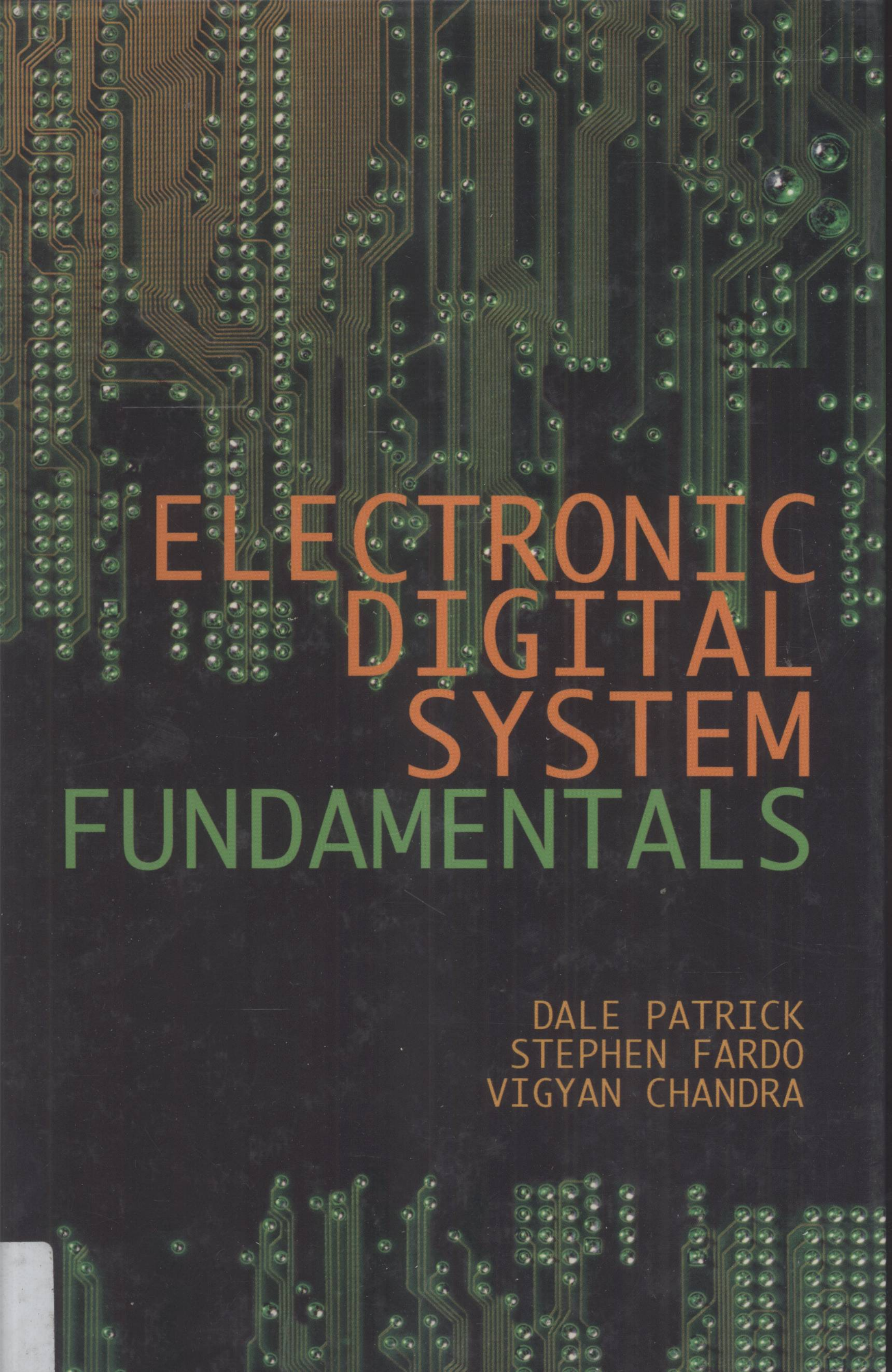


ELECTRONIC DIGITAL SYSTEM FUNDAMENTALS

DALE PATRICK
STEPHEN FARDO
VIGYAN CHANDRA

Electronic Digital System Fundamentals

Dale Patrick
Stephen Fardo
Vigyan 'Vigs' Chandra

THE FAIRMONT PRESS, INC.

CRC Press
Taylor & Francis Group

Library of Congress Cataloging-in-Publication Data

Patrick, Dale R.
Electronic digital system fundamentals / Dale Patrick, Stephen Fardo, Vigyan 'Vigs' Chandra.
p. cm.
Includes index.
ISBN 0-88173-540-X (alk. paper) -- ISBN 0-88173-541-8 (electronic) -- ISBN 1-4200-6774-5 (Taylor & Francis distribution : alk. paper)
1. Digital electronics. I. Fardo, Stephen W. II. Chandra, Vigyan, 1968- III. Title.

TK7868.D5P378 2008
621.381--dc22

2007032778

Electronic digital system fundamentals / Dale Patrick, Stephen Fardo, Vigyan 'Vigs' Chandra.

Published by The Fairmont Press, Inc.
700 Indian Trail
Lilburn, GA 30047
tel: 770-925-9388; fax: 770-381-9865
http://www.fairmontpress.com

Distributed by Taylor & Francis Ltd.
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487, USA
E-mail: orders@crcpress.com

Distributed by Taylor & Francis Ltd.
23-25 Blades Court
Deodar Road
London SW15 2NU, UK
E-mail: uk.tandf@thomsonpublishingservices.co.uk

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

0-88173-540-X (The Fairmont Press, Inc.)
1-4200-6774-5 (Taylor & Francis Ltd.)

Electronic
Digital System Fundamentals

Preface

Electronic Digital Systems Fundamentals is an introductory text that provides coverage of the various topics in the field of digital electronics. The key concepts presented in this book are discussed using a simplified approach that greatly enhances learning. The use of mathematics is kept to the very minimum and is discussed clearly through applications and illustrations.

Each chapter is organized in a step-by-step progression of concepts and theory. The chapters begin with an introduction, discuss important concepts with the help of numerous illustrations, as well as examples, and conclude with summaries.

The overall learning objectives of this book include:

- Describe the characteristics of a digital electronic system.
- Explain the operation of digital electronic gate circuits.
- Demonstrate how gate functions are achieved.
- Use binary, octal, and hexadecimal counting systems.
- Use Boolean algebra to define different logic operations.
- Change a logic diagram into a Boolean expression and a Boolean expression into a logic diagram.
- Explain how discrete components are utilized in the construction of digital integrated circuits.
- Discuss how counting, decoding, multiplexing, demultiplexing, and clocks function with logic devices.
- Change a truth table into a logic expression and a logic expression into a truth table.
- Identify some of the common functions of digital memory.
- Explain how arithmetic operations are achieved with digital circuitry.

Appendices are also included that contain information regarding circuit symbols, data sheets and electrical safety.

The authors hope that you will find Electronic Digital System Fundamentals easy to understand and that you are successful in your pursuit of knowledge in this exciting technical area.

Dale R. Patrick,
Stephen W. Fardo,
Vigyan 'Vigs' Chandra
Richmond, Kentucky

Table of Contents

Chapters

Appendices

Chapter 1

Introduction to Digital Systems

Chapter 1 provides an overview of electronic digital systems. The concepts discussed in this chapter are important for developing an understanding of electronic digital systems. Digital electronics is undoubtedly the fastest growing area in the field of electronics today. Personal computers, cameras, cell phones, calculators, watches, clocks, video games, test instruments and home appliances are only a few of the applications of digital systems. Digital systems play an essential role in our daily lives and new applications are emerging at a rapid pace.

DIGITAL AND ANALOG ELECTRONICS SYSTEMS

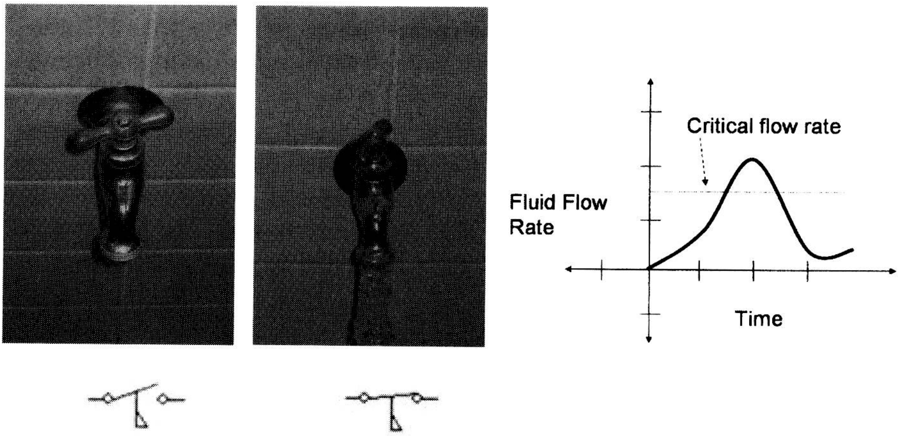
Electronics is further divided into two main categories: analog and digital. Analog electronics deals with the analog systems, in which signals are free to take any possible numerical value. Digital electronics deals with digital or discrete systems, which has signals that take on only a limited range of values. Practical systems are often hybrids having both analog and discrete components.

Analog as in the term 'analogous', is used to represent the variation of an electrical quantity when a corresponding physical phenomenon varies. For example, when the flow of fluid through a pipe increases, an analog meter monitoring the flow may generate a larger voltage (or other electric quantity), which can then be displayed on a scale calibrated to indicate flow rate. Most quantities in nature are inherently analog—temperature, pressure, flow, light intensity change, loudness of sound, current flow in a circuit, or voltage variations.

Digital signals are characterized by discrete variations or jumps in their values. They are useful in producing information about a system. For example, in the case of a sensor monitoring the flow rate in a water canal, it might be sufficient to know whether the flow has reached a critical level, rather than monitoring every possible value of the flow. All values below this critical flow value could be regarded as part of the normal functioning of the system. Hence, when the critical flow value is passed the sensor could trip (switch on), and for normal flow values it would remain off. It can be seen right away that only the values of interest are being used (non-critical flow, critical flow). These in turn can be represented by two conditions of a flow switch—open when the flow is non-critical, and closed when the flow has reached critical.

Figures 1-1(a) and (b) show two conditions of fluid flow through a water pipe, and the corresponding digital flow switch conditions measured by a sensor. Compare it with the graph given for the real-time analog fluid flow rate in the pipe given in (c).

If the switch is connected to a voltage source, then with the flow switch open, no voltage would appear across the buzzer, and the voltage would be 0V. On the other hand when the flow switch is closed, the supply voltage (5V) would appear on the other side of the buzzer. Any digital system receiving a 5V signal would know right away that the flow has reached critical level. Otherwise the system is functioning at a non-critical level (normal flow or even no flow). The process of digitizing the analog signal is shown in Figure 1-2. This might require scaling of the voltage received from the sensor before being applied to a digital circuit. This is because digital circuits require voltage in certain range, 0-5V, before they can



(a) (b) (c)

Figure 1-1. Monitoring fluid-flow in a pipe

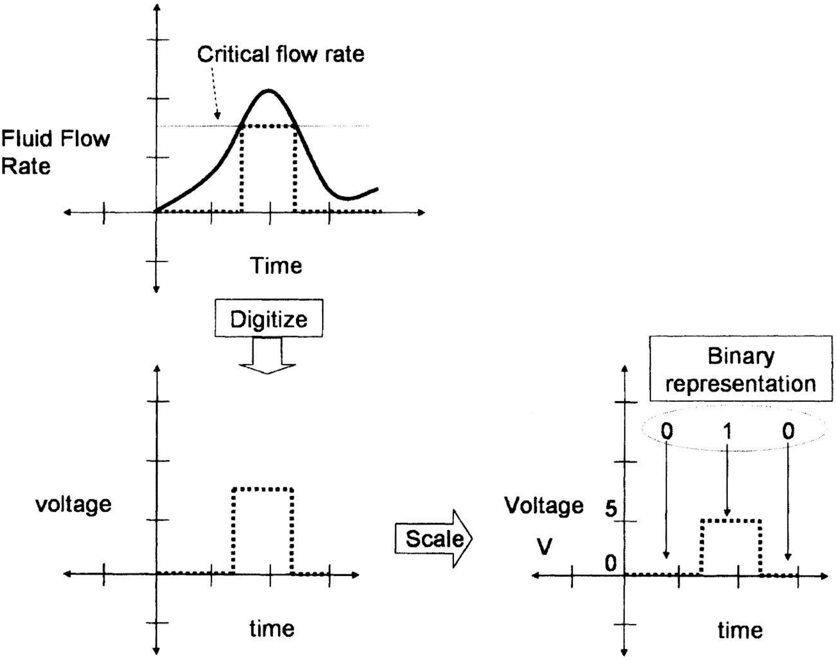


Figure 1-2. Converting an analog signal into a digital signal

function properly.

Digital electronics is considered to be a counting operation. A digital watch tells time by counting generated pulses. The resulting count is then displayed by numbers representing hours, minutes, and seconds. A computer also has an electronic clock that generates pulses. These pulses are counted and in many cases manipulated to perform a control function. Digital circuits can store signal data, retrieve them when needed, and make operational decisions.

ADVANTAGES OF DIGITAL SYSTEMS

- Storage space in digital devices can be increased or decreased based on the application. While hard disks used inside computer systems can store enormous quantities of data in various electronic formats, other mobile devices such as cell phones are limited in their storage.

- The accuracy of digital devices can also be increased based on the precision needed in an application.
- Digital devices are less susceptible to electrical interference, temperature and humidity variations as compared to analog devices, since they uses discrete values corresponding to different values, not a continuous range of values.
- Digital devices can be mass manufactured, and with the increase in fabrication technologies, the number of defects in manufactured integrated circuits (ICs) has reduced considerably.
- The design of digital systems is easier as compared to analog systems. This is in part because progressively larger digital systems can be built using the same principles which apply to much smaller digital systems.
- There are several different types of programmable digital devices. This makes it possible to change the functionality of a device.

DISADVANTAGES OF DIGITAL SYSTEMS

- The world around us is analog in general. For example it has continuous variations in temperature, pressure, flow, pressure, sound and light intensity. For a digital system to process this type of information, some accuracy will be sacrificed and delays due to conversion and processing times will be introduced.
- Digital devices use components such as transistors which exhibit analog behavior and it is important to ensure that theses properties do not dominate in the digital circuit.

DIGITAL SYSTEM OPERATIONAL STATES

Digital systems require a precise definition of operational states or conditions in order to be useful. In practice, binary signals can be processed very easily through electronic circuitry because they can be represented by two stable states of operation. These states can be easily defined as on or off, 1 or 0, up or down, voltage or no voltage, right or left, or any of the other two-condition designations. There must be no in-between step or condition. These states must be decidedly different and easily distinguished.

The symbols used to define the operational state of a binary system are very important. In positive binary logic, such things as voltage, on, true, or a letter designation such as 'A' are used to denote the 1 operational state. No voltage, off, false, or the letter $\bar{A}$ are commonly used to denote the alternate, or 0, condition. An operating system can be set to either state, where it will remain until something causes it to change conditions.

Any device that can be set in one of two operational states or conditions by an outside signal is said to be bistable. Switches, relays, transistors, diodes, and ICs are commonly used examples. In a strict sense, a bistable device has the capability of storing one binary digit or bit of information. By employing a number of these devices, it is possible to build an electronic circuit that will make decisions based on the applied input signals. The output of such a circuit is, therefore, a decision based on the operational conditions of the input. Since this application of a bistable device makes logical decisions, it is commonly called a binary logic circuit, or simply a logic circuit.

There are two basic types of logic circuits in a digital system. One type of logic circuit is designed to make decisions. It has data applied to its input and produces an output that coincides with a prescribed combination of rules. Electronic decisions are made with logic gates. Memory is the other type of logic circuit. Memory circuits store binary data. These data can be stored and retrieved from memory when the need arises. Special ICs are used to achieve the memory function of a digital system. Memory is a primary function of a digital system. Performance is largely dependent on the capacity of a system's memory.

BINARY LOGIC LEVELS

The term 'binary' is derived from the term 'bi' meaning two. *A* binary number system thus has two numbers, and since all non-negative numbers in any number system begin at '0', this is the first number. The second number is '1'.

Almost all modern day computer systems and electronic devices use circuits which accept inputs which can have exactly two states. These devices process information and generate outputs each of which can have exactly two states as well. The two states correspond to two voltage ranges or levels designated as 'low' and 'high'.

Electronic devices normally accept inputs which are in the interval 0V-5V. Some part of this interval is designated as the low level, and another as the high level. In order to ensure that these two ranges do not overlap, they are separated by an intermediate range. This is shown in Figure 1-3.

Since digital devices operate in either the low range or the high range of voltage, it is important that while switching between these levels, the transition be as quick as possible, minimizing the time spent in the intermediate range. The reason is that the behavior of digital devices is unpredictable when their inputs are not in the valid low or high ranges.

BINARY NUMBER SYSTEM

The binary number system, with its use of two numerals, 0 and 1, are referred to as 'low' and 'high' levels, finds numerous applications in digital circuits. As with the decimal number system more than one digit may be used for expressing larger quantities.

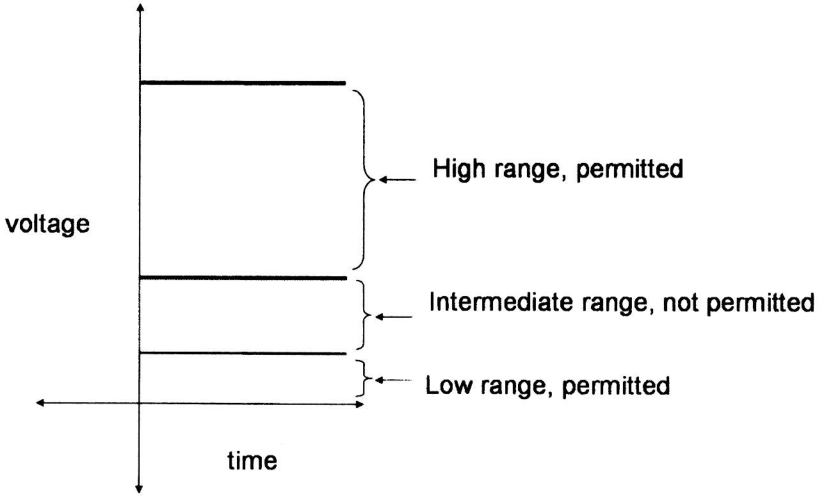


Figure 1-3. Voltage ranges for Low and High sensed by digital devices

BIT

Each binary digit is abbreviated as a 'bit' ('bi' from binary, and the 't' from the digit). Each bit can take on 2 values, 0 or 1. This is shown in Figure 1-4.

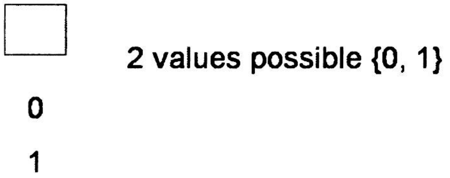


Figure 1-4. Enumerating all possible single-bit values

The bit is used most often for expressing the status of a digital input or output. For example the input of a push-button switch to a digital system may cause a 0V or a 5V to be applied or removed based on the switch connections. Similarly, the output of a digital system driving a buzzer for example, may be at 0V (off) or 5V (on).

When more than one bit it used it can be used to represent larger quantities. With 2 bits for example, each bit is permitted to take on $2 = 2^1 = 2$, with the values 0 or 1, there are a total of $2 \times 2 = 2^2 = 4$ possible values that can be taken. This is shown in Figure 1-5.

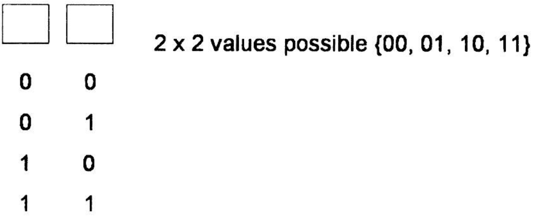


Figure 1-5. Enumerating all possible 2-bit values

DISCRETE AND INTEGRATED CIRCUITS

Discrete circuits are created when electrical components such as resistors, capacitors; and transistors are manufactured separately then connected together forming a circuit either using wires or conducting tracks on printed circuit boards. Discrete circuits take up considerable space and generate heat. They also require wiring with soldered contacts for joining the different circuit components together. For reasonably large size circuits with hundreds of components such as those used in washing machines or VCRs, the need for external wiring including subsequent soldered points creates reliability issues. Miniaturization of circuit components solves some of these issues but the need for external wiring and soldering still exists, and at high frequencies as are present in computers these act as tiny antennas. This causes interference, wherein the signal radiated out by a component or on wires can be picked up by others.

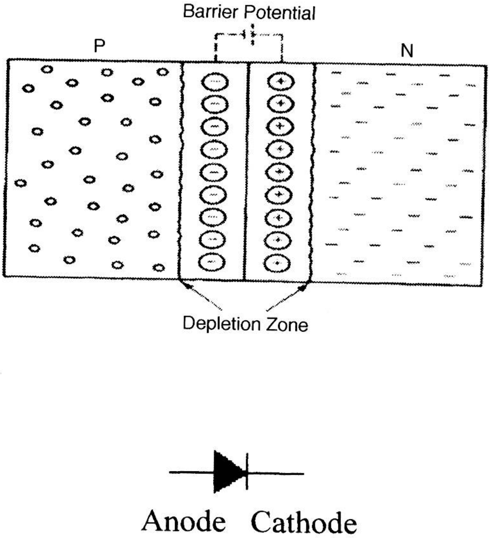
Integrated circuits (ICs) are monolithic device which would incorporate electrical components such as resistors, capacitors, and semi-conductors such as transistors, diodes, are interconnected in a single package. In discrete components there is a need to connect all devices together for creating larger circuits, with the connections being soldered. Handling the hundreds and thousands of components and their associated wiring came to be termed as the 'tyranny of numbers'. The solution to this was first proposed by Robert Noyce and Jack Kirby at approximately the same time and independent of each other. This was done at a time when miniaturization of discrete components was nearing its physical limits and wiring between these minute components was becoming increasing hard to manufacture. ICs made it possible to create all these devices on a slice of semiconductor material, whose electrical conductivity can be manipulated. Owing to mass manufacturing techniques the reliability of ICs is phenomenal. Several million of these devices can be manufactured simultaneously, as in the case of modern day microprocessors, out of the same piece of semi-conductor material such as silicon or germanium. They weigh considerably less, and take up less space, and generate less heat, thus consuming less power. However, if any sub-component of an IC fails the entire device needs to be replaced. Once manufactured the properties of all circuit components is set and cannot be altered. Additionally, only very small capacitors can be manufactured, and in the past it has not been possible to manufacture inductors and transformers on an IC.

Over the years as the complexity of digital devices has expanded phenomenally, the space requirement has shrunk at the same rate. This phenomenon observed by Gordon Moore, which bears the important law after his name stating that the number of electronic devices (transistors) and resistors used on a chip doubles every 18 months.

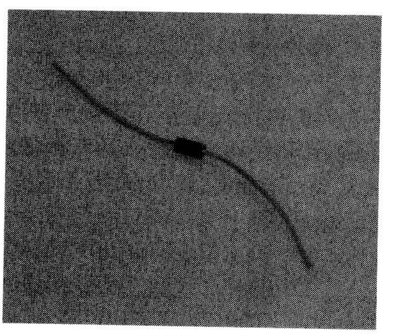
Semiconductors as the name suggests do not function quite like conductors at room temperature. In fact, they have little or no conductivity at room temperature. However, by a process of doping (adding minute quantities of other materials) the conductivity of the material can be substantially enhanced. When the doping process produces an excess of electrons in the semiconductor a 'n' material is said to have been created. On the other hand, when the doping process produces a material with a deficit of electrons in the semiconductor, a 'p' material is said to have been created.

When p and n materials are joined to each other, the structure is called the 'pn junction'. At this junction there is an initial diffusion of excess electrons from the n into the p region which has a deficit of electrons. After awhile the diffusion process stops. The portion of the n region at the junction which lost electrons gains a net positive charge, whereas the portion of the p region at the junction which gains electrons gains a net negative charge. Overall the junction thus develops a minute potential, approximately 0.7V for silicon semiconductors and 0.3V for germanium semiconductors. This is shown Figure 1-6. The symbol and crystal structure of the diode is shown in Figure 1-6 (a), and the photograph of a diode is shown in Figure 1-6 (b). In a diode the p region is designated as the anode and the n region as the cathode.

The resultant semiconductor component is called a 'diode', which permits current flow in one direction but blocks it in the opposite direction. It can thus be used as a switch. Since it is fabricated using a block of semiconductor material by varying the doping of different regions, it is also a type of integrated circuit or IC. ICs are generally referred to as a 'chip'. When volt-



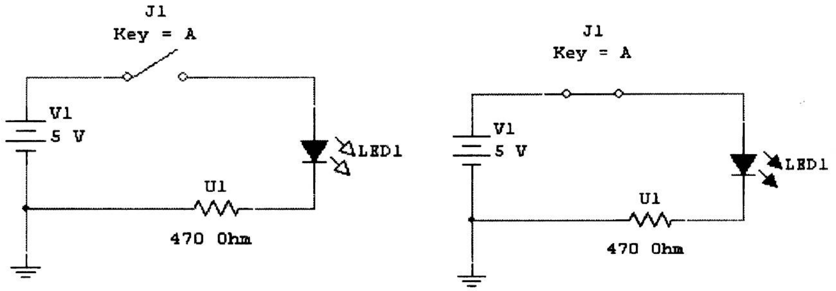
(a)



(b)

Figure 1-6. pn junction

age is applied across the diode such that the anode is connected to the positive and the cathode the negative, electrons can flow across the junction, and current flow established. As the electrons move from the n region to the p region they lose energy, which is dissipated usually in the form of heat. In the case of light emitting diodes or LEDs this energy is dissipated in the form of light as shown in Figure 1-7. A current limiting resistor, usually between 200-1000 Ω should be used in a LED circuit, when used with voltage source (3-6 V). This restricts the current flow to be well within safe operating values for the LED.



Switch 'A' open, LED off
(a)

Switch 'A' close, LED on
(b)

Figure 1-7. Operation of an LED

It is possible to create other electronic components on ICs such as:

- resistors (a heavily doped semiconductor material),
- transistors (a device with 2 pn junctions suitably arranged),
- capacitors (a p and n material separated by an insulator such as silicon di-oxide.

ICs are now used in almost every electronic device today—ranging from calculators, microprocessors, digital phones, personal computers, and cameras. Simple ICs perform specific functions and have a fewer number of pins, whereas complex ICs may offer programming, storage functions and have many pins.

Digital devices are built using two predominant types of technologies—TTL (Transistor Transistor Logic) and CMOS (Complementary Metal Oxide Semiconductor). Both of these have specific ranges for low and high for both the input and the outputs they generate. These transistor technologies themselves are described next.

TTL (TRANSISTOR-TRANSISTOR LOGIC)

TTL gates were first introduced by Texas Instruments or TI in the early 1960s. These devices were meant for educational, industry and experimental use. They were and still are marketed under the 74 _ _ series designation, where the '_ _' were decimal numerals that specify the particular type of operation being performed.

74XX is the common abbreviation used when referring to these devices, where the Xs stand for decimal numerals. It is common practice also to drop the 74 portion and refer to the gate simply by the latter portion which specifies the type of function the device has. For example the 7408 chip implements the AND logic function. It is commonly referred to as the 08 chip. The 74XX series is designed to operate in the temperature range of 0°C to 75°C. TI also manufactured the 54XX series which were meant primarily for military applications and could operate in the range -55°C to 125°C.

Over the years there have been improvements in the speed and power requirements of the TTL devices. With the use of a special type of transistor called the Schottky transistor, there was a great improvement in speed with these devices being called the 74SXX series, with the 'S' standing for the Schottky devices. However, there was an increase in power requirements, and a sub-family called the 74LSXX with the 'L' standing for low- power device. In this text most of the devices used will be of the 74LSXX series, for example the 74LS08 would then be a Low-power Schottky family quad AND gate. Further improvements led to the 74ASXX where the 'A' signifies advanced and the 74ALSXX, where the ALS signifies the advanced low-power Schottky devices.

Usually more than one gate is fabricated on an IC. In Figure 1-8(a) the gate level layout of the 7408 chip is shown, which implements the AND function. It has 4 AND logic gates packaged into one chip, thus being termed as a quad 2-input AND gate. Each AND gate uses 3 pins (2 for input and 1 for the output). The 4 gates of a 7408 needs 3 x 4 = 12 pins. For its operation the chip also needs a source of power, which is designated as VCC and ground, or GND. Thus, the total number of pins this chip has: 12 + 2 = 14. The 7408 IC is packaged as a Dual Inline Pin, or DIP package, and the pins arranged in two rows. This is shown in Figure 1-8(b).