

# DIGITAL ELECTRONICS:

FUNDAMENTALS, APPLICATIONS,  
AND EXPERIMENTS

Howard M. Berlin



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## **FUNDAMENTALS, APPLICATIONS, AND EXPERIMENTS**

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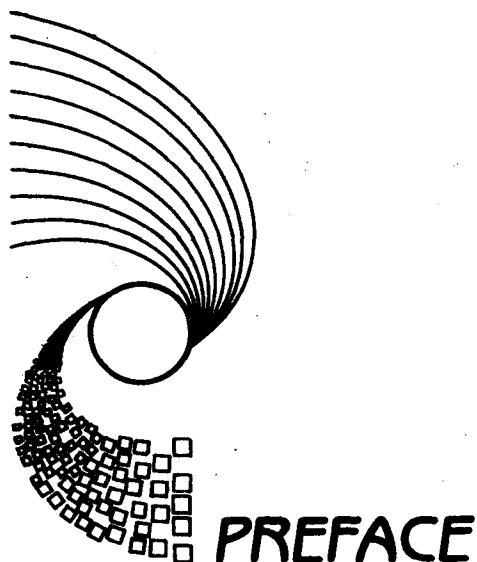
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In today's world, it is virtually impossible not to come into daily contact with some product that uses digital technology. From microwave ovens, digital time clocks and watches, CB radios, and laboratory instruments to video games, all use, at least in part, digital integrated circuits. In fact, without the great strides made in this area over the years, the home personal computer could not be a reality and I would still be writing this book without a word processor.

Because of the widespread importance placed on digital devices today, it is now necessary for students in electronic technology programs to possess a firm understanding of the basics of how digital devices operate and how they are combined to create entire systems.

This book is different from most in that it integrates a variety of laboratory experiments along with the basic text material in a single bound volume. In nine chapters, all the basic elements of digital logic are discussed: gates, flip-flops, multivibrators, shift registers, counters, code converters, multiplexers, demultiplexers, digital displays, and memories. As the majority of digital circuits use either TTL or CMOS devices, the interfacing requirements necessary to connect CMOS and TTL devices together are also presented. The tenth chapter discusses several specialized devices that can replace as much as 50 or so discrete logic devices by usually one or two comparatively low cost packages. In most cases it is not necessary to reinvent the wheel, but rather to be aware of what devices, when available, can do the job more economically and efficiently.

Three appendixes are included as useful reference aids for the reader. Appendix A lists those TTL and CMOS devices that are functionally equivalent, assisting the user to easily convert circuits from one logic family to the other. Appendix B gives the pin diagrams of 124 of the most commonly used TTL and CMOS devices. Finally, Appendix C lists the parts and equipment needed to perform all the experiments presented in this book.

Traditionalists may take issue with the fact that a discussion of sacred topics like Boolean algebra, Venn and Veitch diagrams, and optimization techniques such as Karnaugh mapping have been *intentionally* omitted from this book. However, most gate packages cost on the order of 20 to 30 cents apiece and generally contain four individual gates, so optimization techniques are often not worth the effort. In addition, specific exercises at the end of each chapter are not included. We find that when a popular text is repeatedly used over a period of time, answers to these questions are readily available from students who have previously taken the course, even at a two-year institution. For this reason, the course instructor is free to develop and vary exercises to suit the needs of the course, just as examination questions are periodically changed.

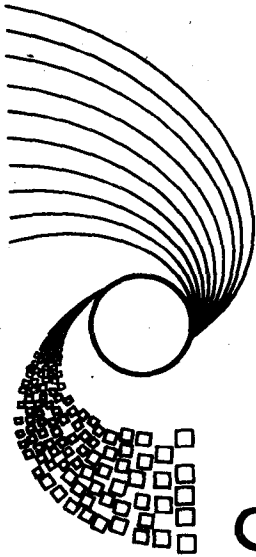
Generally, most graduates of two-year technology programs are *troubleshooting* digital circuits rather than actively *designing* them. On the other hand, when those technology graduates have the occasion to design digital circuits, they are generally "one-of-a-kind" circuits or those whose complexity does not warrant the added effort of mapping, optimization, and so on. Consequently, a major emphasis in this book has been placed on discussing the operation of a variety of TTL and CMOS digital integrated-circuit devices designed to accomplish a specific task rather than presenting drawn out explanations of all the ways discrete gates and flip-flops are used to build these same higher-order logic elements, such as digital counters. Since we cannot physically "look" inside digital integrated-circuit packages, it is perhaps more constructive to discuss how the output of a given device responds to various input signals.

With the exception of the first introductory chapter, a series of step-by-step experiments designed to reinforce some of the important concepts discussed are given at the end of each chapter. Depending on the student, several experiments can be completed in a two- or three-hour laboratory session. Although there are a total of 27 experiments, this number was intentionally kept to a minimum for a variety of reasons. At Delaware Technical and Community College, the students in either our electronics, process instrumentation, or robotics programs are responsible for providing their own electronics parts, such as

a VOM/DVM, transistors, digital ICs, and resistors, for all laboratory courses in these programs, although other training devices and laboratory instruments are provided. For this reason, the number of components, as well as the total cost of these parts, is kept as low as possible while still affording the students a practical and meaningful learning experience.

This combination text and laboratory workbook is designed to be used by a wide audience. For the electronics student in a two-year technology program, this book can be used in either a one- or two-term introductory course in digital electronics, generally taken during the student's second year after completing course work in basic electricity and analog electronics, but prior to studying microcomputers. This book can also be used by the increasing number of four-year college and university courses in digital electronics, which traditionally are the domain of the electrical engineering departments, but are also now taught by faculty members in other diverse areas such as chemistry and physics where a high degree of theoretical design expertise is not required or desired of their students in such an introductory course. Finally, this book is also well suited for those who like to learn by self-study without requiring an extensive amount of prerequisite background in electricity or electronics other than a knowledge of Ohm's law coupled with the motivation to learn by performing the experiments.

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*Wilmington, Delaware*



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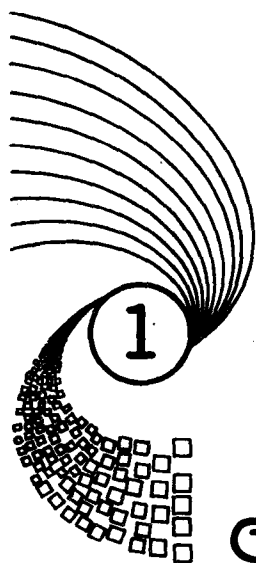
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# GETTING STARTED

## INTRODUCTION

This chapter provides a brief introduction to digital electronics. Before discussing the various types of digital logic elements, we must first consider some ground rules for integrated circuits, logic levels, and binary numbers and what is expected from the experiments found at the end of the following nine chapters.

## OBJECTIVES

*After completing this chapter you will be able to:*

- *Identify logic 0 and logic 1 levels.*
- *Identify the leading and trailing edges of a digital pulse.*
- *Identify the numbered pins on an integrated-circuit device.*
- *List some of the major precautions that must be followed when working with TTL and CMOS devices.*
- *Convert a binary number to its equivalent decimal number.*
- *Understand 4-bit BCD and hexadecimal code systems.*

## LOGIC SIGNALS

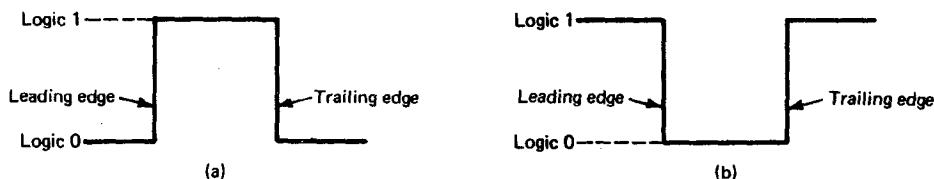
Unlike analog electronics, power supply voltages, as well as signals to and from digital devices, are basically concerned with only two voltage levels. Unless stated otherwise, we will only consider voltage levels that are either at ground (i.e., 0 volts) or at the positive supply voltage that is used to power the digital devices. This convention is termed *positive logic*. When a digital signal is at ground at any point in time, it is said to be at or equal to *logic 0*, or simply 0. On the other hand, if the signal level equals the positive supply voltage, it is said to be at or equal to *logic 1* or 1. Other terms have been used to indicate these 0 and logic 1 levels. They are:

Logic 0: Low, False, or Off

Logic 1: High, True, or On

Although a voltage level of 0 volts (ground) may be referred to as either 0, logic 0, low, false, or off, the practice is to use the correct corresponding term when referring to the logic level that corresponds to the positive supply voltage. For example, if you use the term *logic 0*, then you should also use the term *logic 1* instead of on, high, or true. Consequently, you should describe logic signals in pairs as either 0 and 1, logic 0 and 1, low and high, false and true, or off and on. In the experiments that are included at the end of the chapters, very often an input is designated either as 0 or 1 to indicate that this input should be connected either to logic 0 (ground) or to logic 1 (the positive supply voltage).

Figure 1-1a is the representation of a single digital signal that goes from a logic 0 to a logic 1 and back to a logic 0 state. Such a signal is called a *positive pulse* and is normally at logic 0. On the other hand, a *negative pulse*, shown in Figure 1-1b, is generated when its level goes from a normally logic 1 state to logic 0 and back to logic 1.



**Fig. 1-1** Pulse wave forms showing leading and trailing edges: (a) positive pulse, (b) negative pulse.

Each pulse is characterized by two edges: a *leading* edge and a *trailing* edge. When referring to positive pulses, the leading edge is the logic 0 to 1 transition, whereas the following logic 1 to 0 transition is the trailing edge. For negative pulses, the situation is reversed.

## ABOUT INTEGRATED CIRCUITS

### *Logic Families*

Digital integrated-circuit devices are manufactured by different methods and are divided into classes called *logic families*. Digital devices that belong to a given logic family generally have similar electrical characteristics such as power supply levels and speed, and are usually different from devices that belong to other logic families. In this section, the TTL and CMOS logic families are briefly discussed. Additional TTL and CMOS family characteristics are discussed in Chapter 8.

#### 1. TTL Devices

Perhaps the most widely used logic family is *transistor-transistor logic*, or TTL, whose basic internal element is the bipolar transistor. As digital technology has evolved, TTL devices have been further divided into TTL subfamilies that exhibit trade-offs between power consumption and speed. However, all TTL logic families have one thing in common; they all operate with a +5-volt (V) power supply. Consequently, logic 0 is ground, while logic 1 is equivalent to a voltage level of +5 V. Generally, the 5-V level may vary by as much as 5%, so TTL devices may operate properly from any supply voltage from +4.75 to +5.25 V.

There are five widely used TTL subfamilies:

- Standard TTL
- High-power TTL
- Low-power TTL
- Schottky TTL
- Low-power Schottky TTL

Of these five, the standard and low-power Schottky TTL devices are the most popular and are discussed in the following sections.

### • Standard TTL

Standard TTL, also called regular TTL or simply TTL, is the oldest, lowest-priced, and most frequently used logic family. Shown in Figure 1-2 is a circuit for a TTL inverter. For the purposes of this book, it is not important to understand how this circuit works, but to realize what is needed to build even the simplest of logic elements: four NPN transistors, two diodes, and four resistors. From this basic arrangement, other, more complicated logic functions are made.

### • Low-Power Schottky TTL

The low-power Schottky TTL family of devices, frequently referred to as LS TTL, as its name implies, is intended for low-power consumption. The equivalent circuit for an LS TTL inverter is the same as shown in Figure 1-2, except that Schottky diodes are used in place of the regular diodes, and the four resistors have higher values than the standard TTL circuit, which in turn reduces the current and therefore the power consumption. However, this reduction in power has a penalty. The time that it takes for logic levels to change, the *switching time*, is increased. Therefore, the advantage gained over standard TTL of lower power consumption entails lower speed.

### • Decoupling Capacitors

As a rule, all TTL devices have the ability to generate large current spikes on the power supply line when their outputs are switching from

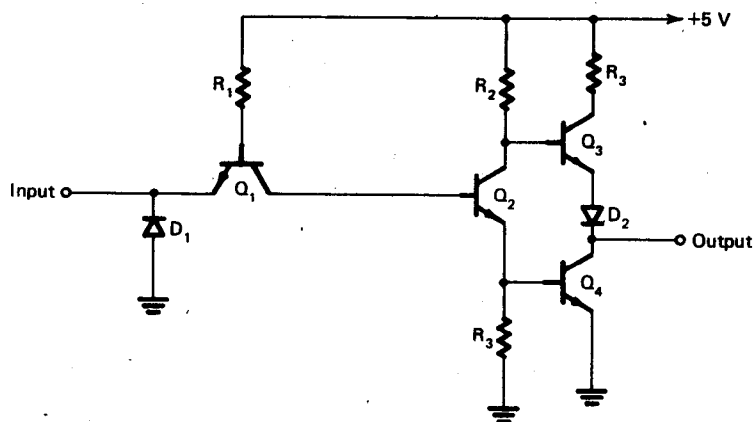


Fig. 1-2 Circuit for a TTL inverter.

one state to the other. To remove these unwanted spikes, which may act as digital signals and can possibly upset various stages, *coupling*, or *despiking*, capacitors are placed as close as possible to the integrated-circuit chip and are connected with the shortest leads possible from the device's positive supply line and ground. These capacitors range typically from 0.01 to 0.1 microfarad ( $\mu\text{F}$ ).

In general, one decoupling capacitor is used for every three or four logic gate packages; otherwise, one capacitor for every two DIP devices other than gates is used. If noise problems persist, more are added.

## 2. CMOS Devices

Instead of using a bipolar transistor, *complementary metal oxide semiconductor* (CMOS) devices use both p- and n-channel enhancement MOS field-effect transistors (i.e., MOSFETs) as the basic element, as illustrated by the CMOS inverter circuit of Figure 1-3. As a result, this logic family exhibits very low power consumption but is slower than standard TTL devices. However, unlike any of the TTL logic families, the supply and logic levels are not restricted to a fixed voltage, such as 5 V. In fact, supply voltages for CMOS devices can typically range from 3 to 18 V, and, coupled with their low power requirements, make them ideally suited for circuits designed for portable operation using low-cost batteries.

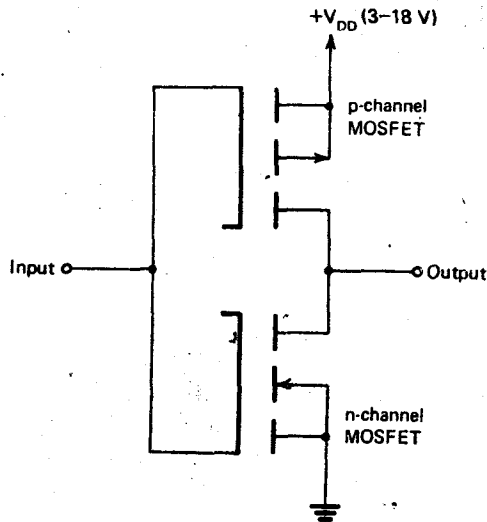


Fig. 1-3 Circuit for a CMOS inverter.

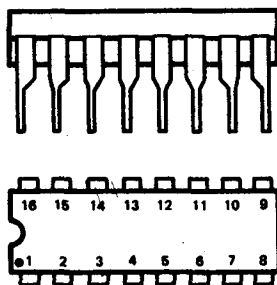


Fig. 1-4 Side and top views of an integrated circuit dual in-line package.

## Package Style

Virtually all the digital integrated-circuit devices that you will encounter are packaged in what is termed a *dual in-line package*, or *DIP* standard. These devices, or chips, as shown in Figure 1-4, generally look like little black or gray "bugs" or centipedes, and, depending on the device, are available with 8, 14, 16, 18, 24, 28, or 40 pins. For example, a 14-pin device has 7 equally spaced pins on each side, and each pin is numbered from 1 to 14 in a *counterclockwise* direction, starting with the pin in the upper-left corner of the chip.

To correctly determine which is the "upper-left corner," each DIP has either a dotlike indentation in one corner or a semicircular cutout at one end, or both. Consequently, one end is somehow different from the other end, which is plain. The end that has the dot or cutout we will call the "top." The pin to the left of the dot or cutout is pin 1. It is very important to be able to identify which is pin 1. From it you must count counterclockwise to find other specific pin numbers. You are almost certain to destroy a device if you connect the power connections backward and apply power or other signals to the wrong pins.

Marked on the top of each device are generally two numbers. One is the device number, while the other number is the date on which the particular device was manufactured. *Standard* TTL devices generally have their serial numbers in the form 74XXX and may have a two-letter prefix, such as DM, MM or SN. As an example, the same TTL device may be marked either as 7492, SN7492, or DM7492. Other letters are used to indicate the TTL logic family. For example, a low-power Schottky TTL version of the 7492 device may be marked as 74LS92, SN74LS92, or DM74LS92. In addition to the basic device number, there may also be a one-letter suffix, usually the letter N, which denotes that the package case is plastic.



The 74 series of TTL devices is generally referred to as the *commercial* version. High-reliability versions designed for use in military systems can operate over a wider temperature range and are marked with a 54 prefix. As an example, the 5492 is the high-reliability counterpart of the 7492 device and is exactly pin for pin the same. CMOS devices may be numbered using either a 4000, 34000, or 74C series code. The 4000 series devices may have a prefix such as CD or MM.

It is very important to identify the device number and not confuse it with the date of manufacture, which is simply a four-digit number that indicates the year and week. For example, as shown in Figure 1-5, a digital integrated-circuit device may have the following markings:

SN7432N

7419

This tells us that the device is a 7432 in a plastic package, and that it was made in 1974 during the 19th week. In most cases the device number is easy to determine. Also, as a general rule, the device number is placed *above* the date of manufacture, and pin 1 is located at the lower-left corner from these numbers.

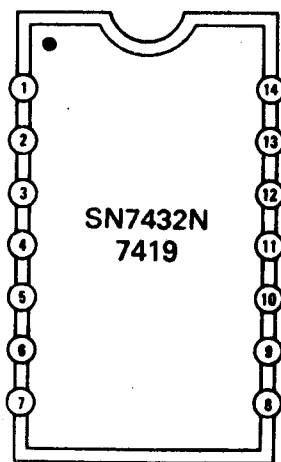


Fig. 1-5 Location of integrated-circuit digital device and date codes.