# DIGITAL AND MICROPROCESSOR TECHNOLOGY

Patrick O'Connor

# Digital and Microprocessor Technology

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## part III

## MICROPROCESSORS AND MICROCOMPUTERS

# Preface

This book is based loosely on a series of lectures given at the DeVry Institute of Technology to three classes:

T-3 Digital Systems I: 16-week beginning digital electronics course for technicians

T-4 Digital Systems II: 16-week intermediate digital systems course

T-5 Digital Systems III: 15-week final digital interface/microprocessor course

These courses are taken in the students' final three trimesters at DeVry.

Since the goal of the technician program is not to produce designers, but individuals competent enough in the basic principles to service existing equipment, the emphasis in these courses is threefold:

1. To present the vocabulary, so that the student can comprehend and use the "buzzwords" of the field with a real understanding of the underlying concepts which these words embody.
2. To explain the principles of operation of components used in existing circuits and systems.
3. To describe safe handling procedures and failure modes for the logic devices likely to be encountered in the field.

The reader should not need to begin at a reading or math level much beyond high school. The average technician student in these courses has a high school diploma or G.E.D., but is unlikely to have any junior-college courses or a mathematical background much past basic algebra. Any mathematical manipulations presented here will be no more complicated than freshman high school algebra, although "logic" algebra may be different from "arithmetic" algebra in nature.

A familiarity with basic electricity and transistor operation will be helpful, but not indispensable, to understanding the ideas presented here. Although the students at DeVry begin digital with a background of a year's basic electronics courses, the same students could start the course from "ground zero" without any real problems.

*Patrick O'Connor*
*Chicago, Illinois*

# Part I

# ASYNCHRONOUS CIRCUITS

# 1

# Switch Circuits and Logic

All digital logic circuits are switching circuits. Whatever else they may contain, each circuit begins with a circuit component that does the same job as a switch or pushbutton. At the beginning, we are going to look at circuits made out of pushbuttons, and later, we'll find out what types of switches are really used in logic circuits.

Let's begin with some basic ideas.

## 1.1 LOGIC STATES 1 AND 0

There are several schematic symbols for switches. The one you're probably most familiar with looks like that shown in Figure 1-1.

Since there's not much point to having a switch unless there's something to switch on and off, we included a light at one end of the circuit and a power supply (*V*+) at the other. The first piece of information that's new in this picture is the way we indicate whether the light is off or on. A light that's ON is marked with a 1 or with the word TRUE. When the light is OFF, we've marked it with a 0 or the word FALSE. The use of the words TRUE and FALSE makes sense if you remember that the thing at the end of the wire is called a light bulb. When the bulb is operating normally, it's lighted. That's the TRUE condition for an operating light bulb. (Otherwise, we'd have to call it a *dark* bulb!) When the bulb is not operating normally, we indicate that with the word FALSE. Remember that anything, when it's operating normally, is TRUE, and when it's not operating normally, it's FALSE.

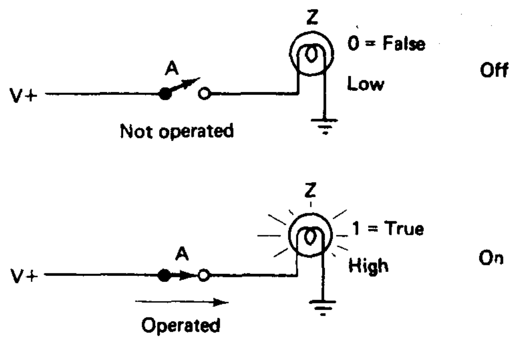

**Figure 1-1** Output 1 and 0 conditions.

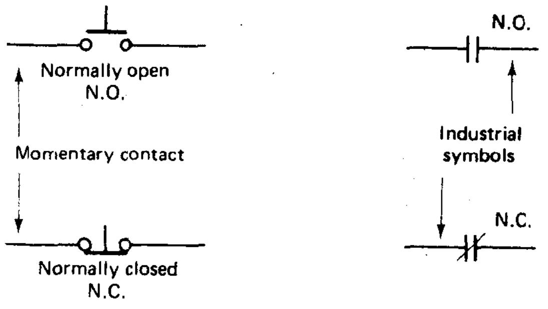

**Figure 1-2** Momentary-contact switch symbols.

The numbers 1 and 0 are another way to indicate TRUE and FALSE. For the light that is lighted, a 1 indicates that there's something there. For the light that's not lighted, the 0 indicates that there's nothing there. On the diagram, there's a third way of indicating what's happening to the light bulb. The word "LOW" by the bulb that's OFF and "HIGH" by the bulb that's ON indicates what *voltage* is applied. A LOW voltage (in this case, nothing) is applied to the bulb when the switch is open. The HIGH voltage is the voltage of the power supply, connected to the light bulb when the switch is closed.

Now that we've seen the meaning of FALSE, LOW, and 0 and TRUE, HIGH, and 1, let's look at another type of switch (Figure 1-2).

## 1.2 SWITCH CIRCUIT REPRESENTATION FOR 1 AND 0 AS INPUTS AND OUTPUTS

The two switches in the picture are called **normally open** (N.O.) and normally closed (N.C.) types. Another name for switches of this type is *momentary contact*, or *pushbuttons.* The N.O. (normally open) pushbutton is open until you push the button, then it closes and completes the connection. The N.C. (normally closed) pushbutton is closed until you push the button and break the connection. We've also included the industrial standard sym-

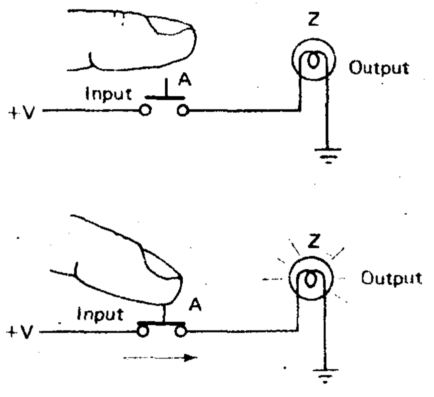

**Figure 1-3** Input 1 and 0 conditions (normally open).

bol for these types of switch contacts, which isn't as easy to recognize, but is easier to draw. The circuit with a momentary-contact pushbutton instead of the switch in Figure 1-1 looks like the one shown in Figure 1-3.

Now, we have a circuit with an input and an output. The **input operation**, A, is whatever you're doing to the pushbutton, and the **output operation**, Z, is whatever the light bulb is doing. How is the pushbutton being operated? Remember the definition we had for 1 and 0; if the pushbutton is pushed, it's being operated, so it's a 1 (TRUE); if the pushbutton is not being pushed, it's a 0 (FALSE). For the input of the pushbutton circuit, a 1 is a pushed pushbutton, and a 0 is one that's been released.

Now, let's look at the output. We already know that a lighted light bulb is a 1, and a dark one is a 0. How does the input affect the output? If what you're doing at A is a 1 (pushing the button), the output at Z is also a 1 (the light is lit). If what you're doing at A is a 0 (not pushing the button), the output at Z (the state of the bulb) is also a 0 (dark). Notice that whatever you do at A, the **logic state** of Z (the 1 or 0) is the same. We could say that "Z is a 1 if A is a 1" and "Z is a 0 if A is a 0," or we could say the same thing with the expression

$$Z = A \qquad \text{(Boolean expression)}$$

The **Boolean expression** is named after George Cayley Boole, who first used this kind of representation to show the relation between a cause and an effect. Actually, Boole did a great deal more, but we'll see that later.

The circuit in Figure 1-3 shows everything you can do with one (N.O.) switch. Let's see how many different ways we can use two switches:

1. We can attach two switches together in a **series** connection.
2. We can use a **parallel** connection.

Figure 1-4 shows both of these.

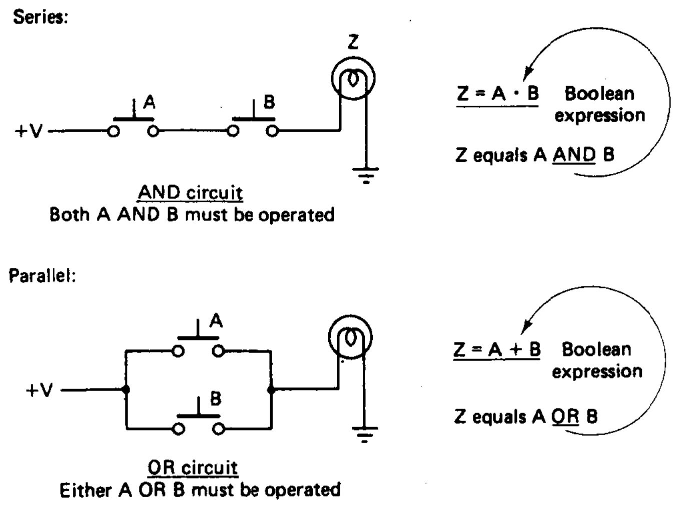
Series:
Z
A
B
+V
AND circuit
Both A AND B must be operated
Z = A · B Boolean expression
Z equals A AND B
Parallel:
A
B
+V
OR circuit
Either A OR B must be operated
Z = A + B Boolean expression
Z equals A OR B

**Figure 1-4** Switch logic (normally open contacts in series and parallel).

## 1.3 SWITCH CIRCUIT REPRESENTATION OF AND LOGIC AS A SERIES CIRCUIT OF NORMALLY OPEN SWITCHES

The *series* circuit in Figure 1-4 is identified as an **AND circuit.** Both switch A AND switch B must be operated before the light will go on. We say that a 1 must be input to A AND B to get a 1 at the output, Z. There is a Boolean expression for this relationship written to the right of the series diagram. We'll find out later just why the "dot" is used to represent the word AND in this expression.

## 1.4 SWITCH CIRCUIT REPRESENTATION OF OR LOGIC AS A PARALLEL CIRCUIT OF NORMALLY OPEN SWITCHES

The *parallel* circuit in Figure 1-4 is identified as an **OR circuit.** Either switch A OR switch B (or both) must be operated before the light will go on. We say that a 1 must be input to A OR B to get a 1 at the output, Z. There is a Boolean expression for this relationship written to the right of the parallel diagram. We'll find out later just why the "plus" is used to represent the word OR in the Boolean expression.

## 1.5 SWITCH CIRCUIT REPRESENTATION OF NOT LOGIC AS A SWITCH WITH NORMALLY CLOSED CONTACTS

There's one more thing that can be done using the pushbuttons. Up to now, we've only seen what normally open contacts do. Let's take a look at the

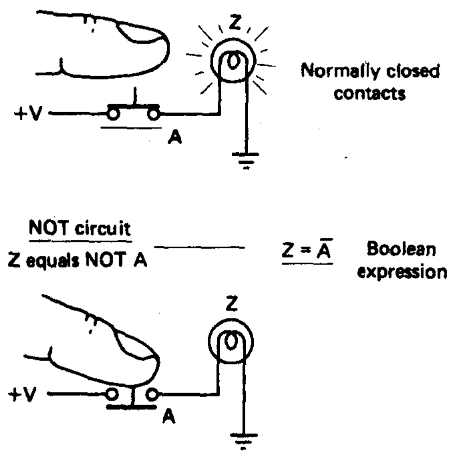

**Figure 1-5** NOT gate (normally closed contacts).

*normally closed* pushbutton. If we attach it like the switch in Figure 1-3, what we get is shown in Figure 1-5.

The input A has a different effect on the light Z than it did before. Because the switch *breaks* the circuit when it is pushed, the light goes out only when the button is pushed. Now, if we recall that a *pushed* pushbutton is a 1, and a *lighted* light bulb is a 1, we can see that a 1 input does NOT produce a 1 output. In fact, the A input and the Z output are exactly the *opposite*. When the switch is a 1 (pushed), the light is a 0 (dark); when the switch is a 0 (released), the light is a 1 (lit). Whatever the A input is, the Z output is NOT. If the switch is ON (pushed), the light is NOT ON. If the switch is OFF (released), the light is NOT OFF. The way this circuit behaves leads us to call it a NOT circuit.

Earlier, we promised that we'd see what the switches used in logic circuits were really like. After all, you can't make a computer (with tens of thousands of switches) out of pushbuttons. First, you'd need tens of thousands of people to push the buttons! And second, to operate at anything like the speed of real computers, the people would need to have awfully fast hands! There ought to be better things for all those people with fast hands to do, so let's look at another solution to the "fast-pushbuttons-without-fingers" problem.

## 1.6 BIPOLAR TRANSISTORS USED AS SWITCHES

Figure 1-6 illustrates the use of a **bipolar transistor** as a switch. Instead of a finger pressing on a button, the thing that operates this "switch" is a current coming in the wire marked *base*. When this happens, another (usually larger) current begins to flow in the wire marked *collector*. You can see that this current is going to light the bulb. Without the base current, there's no col-

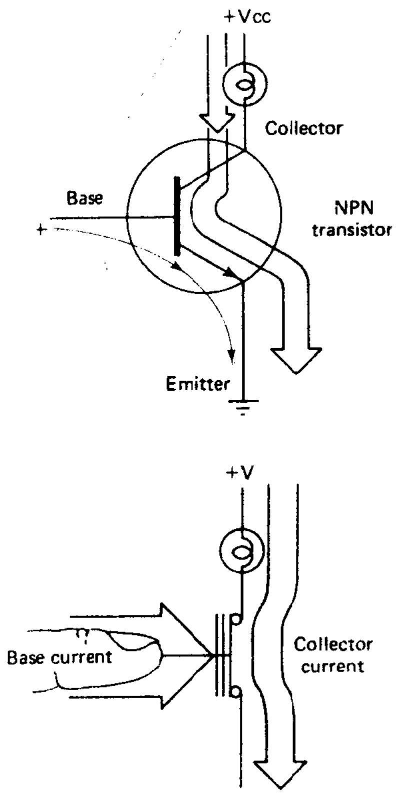

**Figure 1-6** Bipolar transistor used as a switch.

lector current. You can think of the transistor as a pushbutton, like the one shown below the transistor in the diagram. Instead of a push, the button is activated by a current. This means that there'll be no moving parts involved in switching the light on and off. An *NPN transistor* like the one shown needs a positive voltage to make base current flow. Another type of transistor (*PNP*) needs a negative polarity. For our purposes, let's stick with a transistor that is switched on by a positive signal.

Transistors can switch millions of times faster than a pushbutton. Mechanical switches wear out, and fail sometimes because things get caught between the moving parts. The transistor, having no moving parts, is not only faster, but is more reliable than a pushbutton. We'll see types of logic circuitry later that put together bipolar transistors exactly as we put together switches in the AND or OR circuits.

## 1.7 FIELD-EFFECT TRANSISTORS USED AS SWITCHES

Figure 1-7 shows a field-effect transistor (FET) used to replace a pushbutton in the same way as Figure 1-6 used a bipolar transistor. Like bipolar transis-