CHAPTER 5

IC Specifications and Simple Interfacing

Learning Outcomes

This chapter will help you to:

5-1 *Determine* logic levels using TTL and CMOS voltage profile diagrams.

5-2 *Use* selected TTL and CMOS IC specifications such as input and output voltages and noise margin.

5-3 *Understand* other IC specifications including drive capability, fan-in, fan-out, propagation delay, and power consumption.

5-4 *List* several safety precautions for handling and designing with CMOS ICs.

5-5 *Recognize* several simple switch interface and debouncing circuits using both TTL and CMOS ICs.

5-6 *Analyze* interfacing circuits for LEDs and incandescent lamps using both TTL and CMOS ICs.

5-7 *Explain* the basics of current sourcing and current sinking when using TTL ICs.

5-8 *Draw* TTL-to-CMOS and CMOS-to-TTL interface circuits.

5-9 *Describe* the operation of interface circuits for buzzers, relays, motors, and solenoids using both TTL and CMOS ICs.

5-10 *Analyze* interfacing circuits featuring an optoisolator.

5-11 *Describe* a servo motor, and *summarize* how it is controlled using pulse-width modulation (PWM).

5-12 *List* the primary characteristics and features of a stepper motor. *Describe* the operation of stepper motor drive circuits.

5-13 *Characterize* the operation of a Hall-effect sensor and its application in a device such as a Hall-effect switch.

5-14 *Demonstrate* the interfacing of an open-collector Hall-effect switch with TTL and CMOS ICs as well as LEDs.

5-15 *Troubleshoot* a simple logic circuit.

5-16 *Demonstrate* interfacing a servo motor to a BASIC Stamp 2 Microcontroller Module. *Explain* the actions of the servo motor when controlled by the microcontroller module.

Logic families: TTL and CMOS

The driving force behind the increased use of digital circuits has been the availability of a variety of *logic families*. Integrated circuits within a logic family are designed to *interface* easily with one another. For instance, in the TTL logic family you may connect an output directly into the input of several other TTL inputs with no extra parts. The designer can have confidence that ICs from the same logic family will interface properly. Interfacing *between* logic families and between digital ICs and the outside world is a bit more complicated.

Interfacing

Interfacing can be defined as the design of the interconnections between circuits that shift the levels of voltage and current to make them compatible. A fundamental knowledge of simple interfacing techniques is required of technicians and engineers who work with digital circuits. Most logic circuits are of no value if they are not interfaced with "real-world" devices.

5-1 Logic Levels and Noise Margin

In any field of electronics most technicians and engineers start investigating a new device in terms of voltage, current, and resistance or impedance. In this section just the *voltage characteristics* of both TTL and CMOS ICs will be studied.

Logic Levels: TTL

How is a logical 0 (LOW) or logical 1 (HIGH) defined? Figure 5-1 shows an inverter (such as the 7404 IC) from the bipolar TTL logic family. Manufacturers specify that for correct operation, a LOW *input* must range from GND to 0.8 V. Also, a HIGH *input* must be in the range from 2.0 to 5.5 V. The unshaded section from

TTL voltage profile

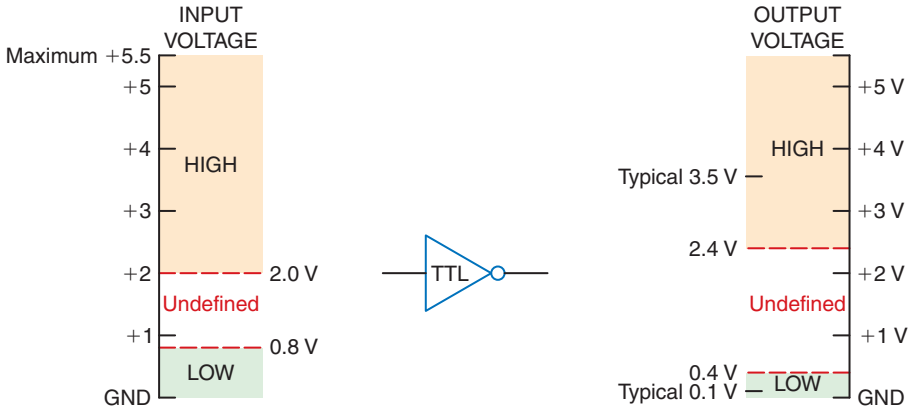


Fig. 5-1 Defining TTL input and output voltage levels.

0.8 to 2.0 V on the input side is the undefined area, or indeterminate region. Therefore, an input of 3.2 is a HIGH input. An input of 0.5 V is considered a LOW input. An input of 1.6 V is in the undefined region and should be avoided. Inputs in the undefined region yield unpredictable results at the output.

Expected outputs from the TTL inverter are shown on the right in Fig. 5-1. A typical LOW output is about 0.1 V. A typical HIGH output might be about 3.5 V. However, a HIGH output could be as low as 2.4 V according to the voltage profile diagram in Fig. 5-1. The HIGH output depends on the resistance value of the load placed at the output. The greater the load current, the lower the HIGH output voltage. The unshaded section on the output voltage side in Fig. 5-1 is the undefined region. Suspect trouble if the output voltage is in the undefined region (0.4 to 2.4 V).

The voltages given for LOW and HIGH logic levels in Fig. 5-1 are for a TTL device. These voltages are different for other logic families.

Internet Connection

Find data sheets for ICs at www.onsemi.com or www.ti.com.

Logic Levels: CMOS

The 4000 and 74C00 series CMOS logic families of ICs operate on a wide range of power supply voltages (from +3 to +15 V). The definition of a HIGH and LOW logic level for a typical CMOS inverter is illustrated in Fig. 5-2(*a*). A 10-V power supply is being used in this voltage profile diagram.

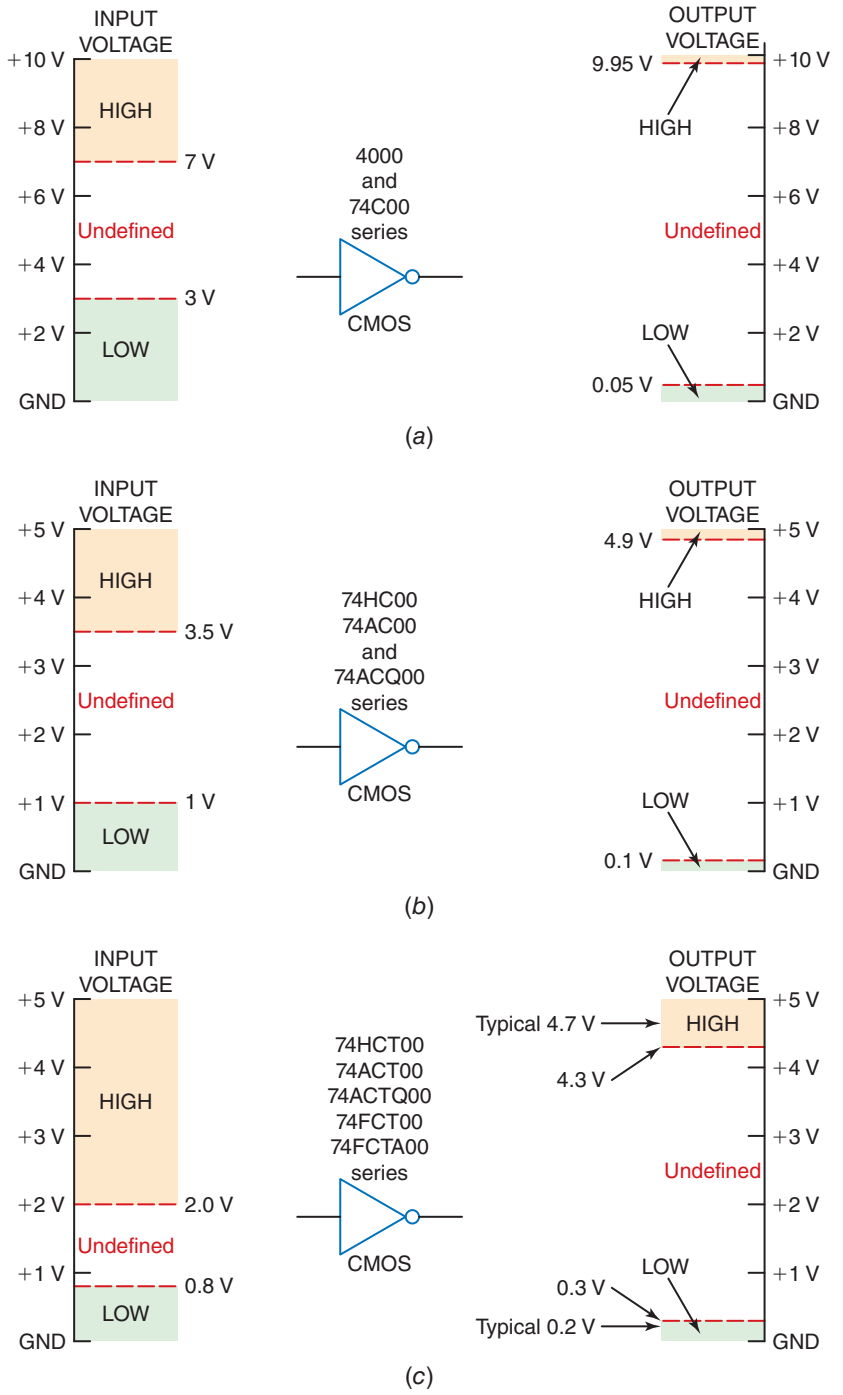
The CMOS inverter shown in Fig. 5-2(*a*) will respond to any input voltage within 70–100 percent of V_{DD} (+10 V in this example) as a HIGH. Likewise, any voltage within 0 to 30 percent of V_{DD} is regarded as a LOW input to ICs in the 4000 and 74C00 series.

Typical output voltages for CMOS ICs are shown in Fig. 5-2(*a*). Output voltages are normally almost at the *voltage rails* of the power supply. In this example, a HIGH output would be about +10 V, while a LOW output would be about 0 V or GND.

The 74HC00 series and the newer 74AC00 and 74ACQ00 series operate on a lower voltage power supply (from +2 to +6 V) than the older 4000 and 74C00 series CMOS ICs. The input and output voltage characteristics are summarized in the voltage profile diagram in Fig. 5-2(*b*). The definition of HIGH and LOW for both input and output on the 74HC00, 74AC00, and 74ACQ00 series is approximately the same as for the 4000 and 74C00 series CMOS ICs. This can be seen in a comparison of the two voltage profiles in Fig. 5-2(*a*) and (*b*).

The 74HCT00 series and newer 74ACT00, 74ACTQ00, 74FCT00, and 74FCTA00 series of CMOS ICs are designed to operate on a 5-V power supply like TTL ICs. The function of the 74HCT00, 74ACT00, 74ACTQ00, 74FCT00, and 74FCTA00 series of ICs is to interface between TTL and CMOS devices. These CMOS ICs with a "T" designator can serve as direct replacements for many TTL ICs.

A voltage profile diagram for the 74HCT00, 74ACT00, 74ACTQ00, 74FCT00, and 74FCTA00 series CMOS ICs is drawn in Fig. 5-2(*c*). Notice that the definition of LOW and HIGH at the *input* is the same for these "T" CMOS ICs as it is for regular bipolar TTL ICs. This can be seen in a comparison of the input side of the voltage profiles of TTL and the "T" CMOS ICs [see Figs. 5-1 and 5-2(*c*)]. The output voltage profiles for all the CMOS ICs are



4000 and 74C00 series CMOS voltage profile

74HC00 and 74AC00 series CMOS voltage profile

"T" series CMOS profile

Fig. 5-2 Defining CMOS input and output voltage levels. (*a*) 4000 and 74C00 series voltage profile. (*b*) 74HC00, 74AC00, and 74ACQ00 series voltage profile. (*c*) 74HCT00, 74ACT00, 74ACTQ00, 74FCT00, 74FCTA00 series voltage profile.

similar. In summary, the "T" series CMOS ICs have typical TTL input voltage characteristics with CMOS outputs.

Logic Levels: Low-Voltage CMOS

As digital circuits become smaller it is useful to use power supply voltages that are lower than the common +5 V. The definition of HIGH and LOW logic levels for a typical *low-voltage CMOS* IC is detailed in Fig. 5-3.

Low-Voltage CMOS

Two modern low-voltage CMOS families are the 74ALVC00 series (advanced low-voltage CMOS) and the 74LVX00 series (low-voltage CMOS with 5-V tolerant inputs). The 74LVX00

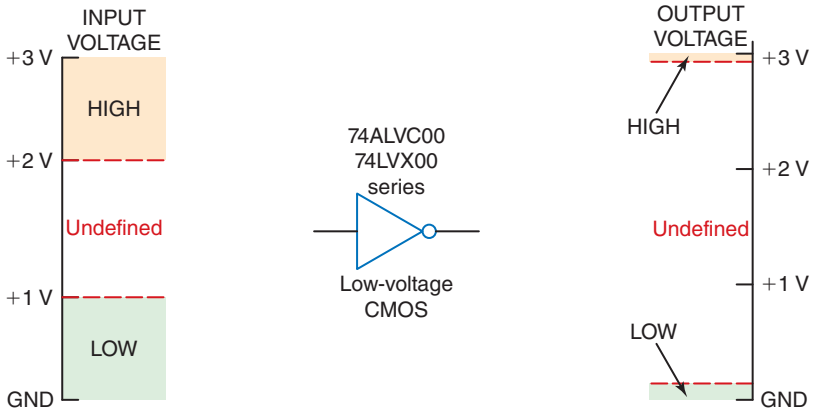


Fig. 5-3 Defining low-voltage CMOS input and output voltage levels.

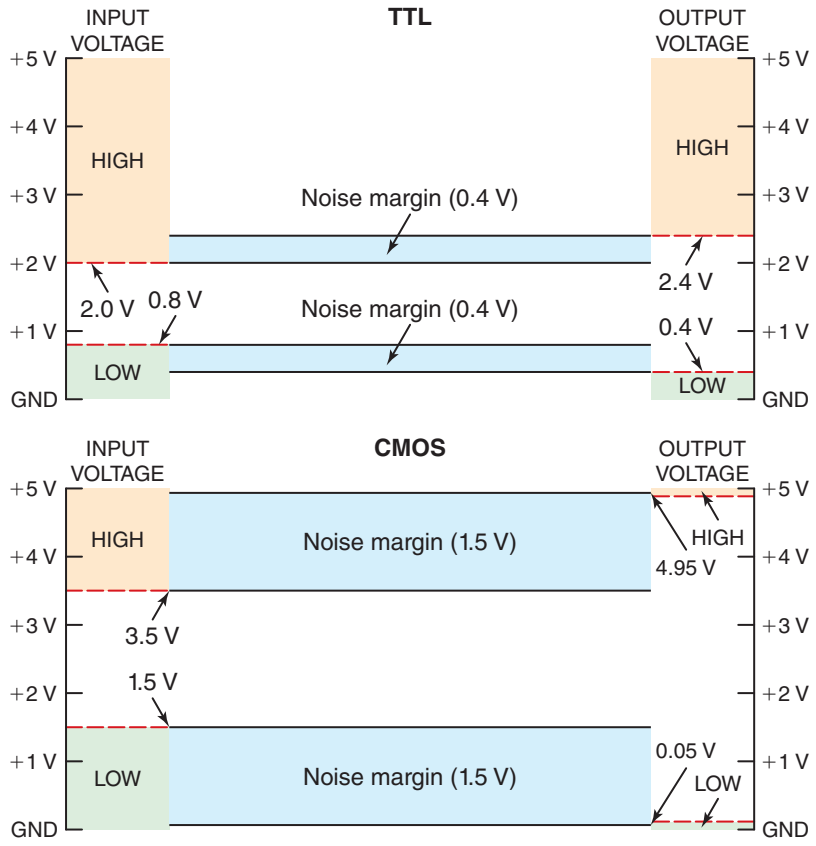


Fig. 5-4 Defining and comparing TTL and CMOS noise margins.

Comparing TTL and CMOS noise margins

ICs can tolerate higher input voltage than suggested in Fig. 5-3 without harm.

As detailed in the voltage profile diagram in Fig. 5-3, input voltages above +2 V are considered HIGH, while input voltages below +0.8 V are in the LOW range. The output voltages from these low-voltage CMOS ICs would be near the voltage rails of +3 V and GND.

Advantages of CMOS

Noise immunity

Noise margin

Many low-voltage CMOS ICs can operate on supply voltages as low as about +1.7 V. The voltage profile would look about like that in Fig. 5-3, but the scaling on the left edge of the profile would be different.

Noise Margin

The most often cited *advantages of CMOS* are its low power requirements and good noise immunity. *Noise immunity* is a circuit's insensitivity or resistance to undesired voltages or noise. It is also called *noise margin* in digital circuits.

The noise margins for typical TTL and CMOS families are compared in Fig. 5-4. The

noise margin is much better for the CMOS than for the TTL family. You may introduce almost 1.5 V of unwanted noise into the CMOS input before getting unpredictable results.

Noise in a digital system is *unwanted voltages* induced in the connecting wires and printed circuit board traces that might affect the input logic levels, thereby causing faulty output indications.

Consider the diagram in Fig. 5-5. The LOW, HIGH, and undefined regions are defined for TTL inputs. If the actual input voltage is 0.2 V, then the margin of safety between it and the undefined region is 0.6 V (0.8 − 0.2 = 0.6 V). This is the *noise margin*. In other words, it would take more than +0.6 V added to the LOW voltage (0.2 V in this example) to move the input into the undefined region.

In actual practice, the noise margin is even greater because the voltage must increase to the *switching threshold,* which is shown as 1.2 V in Fig. 5-5. With the actual LOW input at +0.2 V and the switching threshold at about +1.2 V, the actual noise margin is 1 V (1.2 − 0.2 = 1 V).

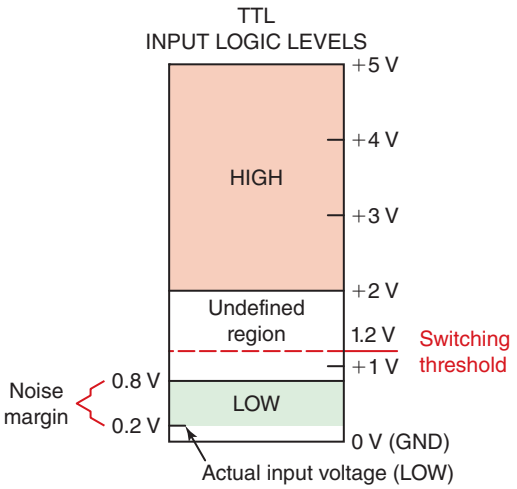


Fig. 5-5 TTL input logic levels showing noise margin.

Noise

The switching threshold is *not* an absolute voltage. It does occur within the undefined region but varies widely because of manufacturer, temperature, and the quality of the components. However, the logic levels are guaranteed by the manufacturer.

Switching threshold

Self-Test

Supply the missing word in each statement.

1. The design of interconnections between two circuits to make them compatible is called _____.
2. An input of +3.1 V to a TTL IC would be considered _____ (HIGH, LOW, undefined).
3. An input of +0.5 V to a TTL IC would be considered _____ (HIGH, LOW, undefined).
4. An output of +2.0 V from a TTL IC would be considered _____ (HIGH, LOW, undefined).
5. An input of +6 V (10-V power supply) to a 4000 series CMOS IC would be considered _____ (HIGH, LOW, undefined).
6. A typical HIGH output (10-V power supply) from a CMOS IC would be about _____ V.
7. An input of +4 V (5-V power supply) to a 74HCT00 series CMOS IC would be considered _____ (HIGH, LOW, undefined).
8. The _____ (CMOS, TTL) family of ICs has better noise immunity.
9. The switching threshold of a digital IC is the *input* voltage at which the output logic level switches from HIGH to LOW or LOW to HIGH. (T or F)
10. The 74FCT00 series of _____ (CMOS, TTL) ICs has an input voltage profile that looks like that of a TTL IC.
11. Refer to Fig. 5-3. The 74ALVC00 series ICs would be referred to as _____ (high-impedance, low-voltage) CMOS chips because it can operate on a +3-V power source.
12. Refer to Fig. 5-3. An input of +2.5 V to a 74ALVC00 series IC would be considered a(n) _____ (HIGH, LOW, undefined) logic level.

Fan-out

5-2 Other Digital IC Specifications

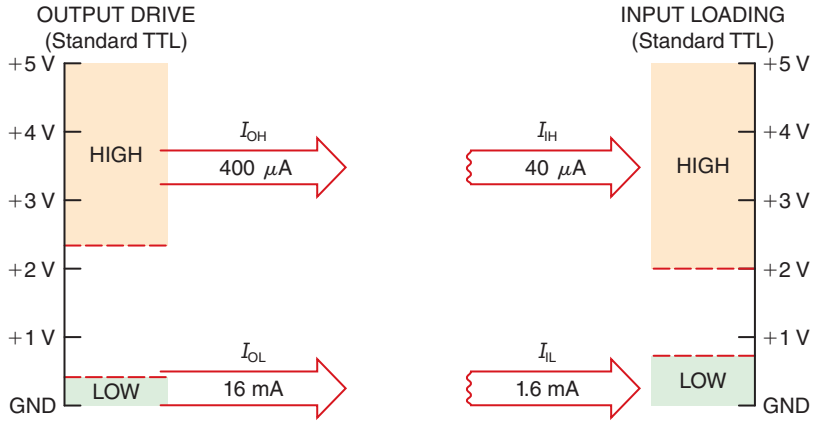
Digital logic voltage levels and noise margins were studied in the last section. In this section, other important specifications of digital ICs will be introduced. These include drive capabilities, fan-out and fan-in, propagation delay, and power dissipation.

Drive Capabilities

Drive capabilities

A bipolar transistor has its maximum wattage and collector current ratings. These ratings determine its *drive capabilities*. One indication of output drive capability of a digital IC is called its fan-out. The *fan-out* of a digital IC is the number of "standard" inputs that can be driven by the gate's output. If the fan-out for standard TTL gates is 10, this means that the output of a single gate can drive up to 10 inputs of the gates *in the same subfamily*. A typical fan-out value for standard TTL ICs is 10. The fan-out for low-power Schottky TTL (LS-TTL) is 20 and for the 4000 series CMOS it is considered to be about 50.

Another way to look at the current characteristics of gates is to examine their output drive and input loading parameters. The diagram in Fig. 5-6(*a*) is a simplified view of the output



(*a*)

	Device Family	Output Drive*	Input Loading
TTL	Standard TTL	I_{OH} = 400 μA I_{OL} = 16 mA	I_{IH} = 40 μA I_{IL} = 1.6 mA
TTL	Low-Power Schottky	I_{OH} = 400 μA I_{OL} = 8 mA	I_{IH} = 20 μA I_{IL} = 400 μA
TTL	Advanced Low-Power Schottky	I_{OH} = 400 μA I_{OL} = 8 mA	I_{IH} = 20 μA I_{IL} = 100 μA
TTL	FAST Fairchild Advanced Schottky TTL	I_{OH} = 1 mA I_{OL} = 20 mA	I_{IH} = 20 μA I_{IL} = 0.6 mA
CMOS	4000 Series	I_{OH} = 400 μA I_{OL} = 400 μA	I_{in} = 1 μA
CMOS	74HC00 Series	I_{OH} = 4 mA I_{OL} = 4 mA	I_{in} = 1 μA
CMOS	FACT Fairchild Advanced CMOS Technology Series (AC/ACT/ACQ/ACTQ)	I_{OH} = 24 mA I_{OL} = 24 mA	I_{in} = 1 μA
CMOS	FACT Fairchild Advanced CMOS Technology Series (FCT/FCTA)	I_{OH} = 15 mA I_{OL} = 64 mA	I_{in} = 1 μA

*Buffers and drivers may have more output drive.

(*b*)

Fig. 5-6 (*a*) Standard TTL voltage and current profiles. (*b*) Output drive and input loading characteristics for selected TTL and CMOS logic families.

drive capabilities and input load characteristics of a standard TTL gate. A standard TTL gate is capable of handling 16 mA when the output is LOW (I_{OL}) and 400 µA when the output is HIGH (I_{OH}). This seems like a mismatch until you examine the input loading profile for a standard TTL gate. The input loading (worst-case conditions) is only 40 µA with the input HIGH (I_{IH}) and 1.6 mA when the input is LOW (I_{IL}). This means that the output of a standard TTL gate can drive 10 inputs (16 mA/1.6 mA = 10). Remember, these are *worst-case conditions,* and in actual bench tests under static conditions these input load currents are much less than specified.

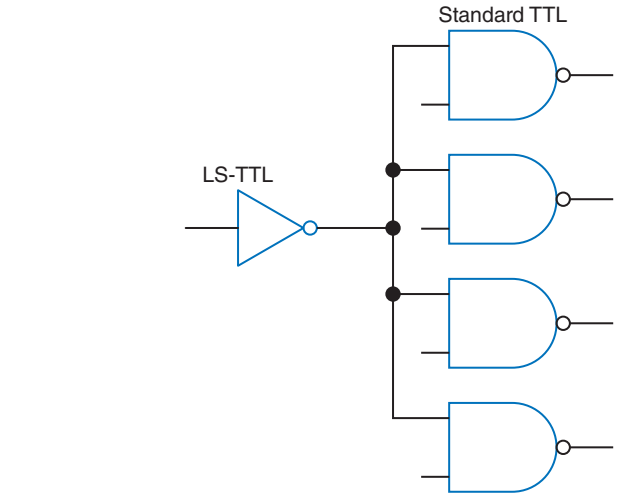
A summary of the *output drive* and *input loading* characteristics of several families of digital ICs is detailed in Fig. 5-6(*b*). Look over this chart of very useful information. You will need these data later when interfacing TTL and CMOS ICs.

Notice the outstanding output drive capabilities of the FACT series of CMOS ICs [see Fig. 5-6(*b*)]. The superior drive capabilities, low power consumption, excellent speed, and great noise immunity make the FACT series of CMOS ICs one of the preferred logic families for new designs. The newer FAST TTL logic series also has many desirable characteristics that make it suitable for new designs.

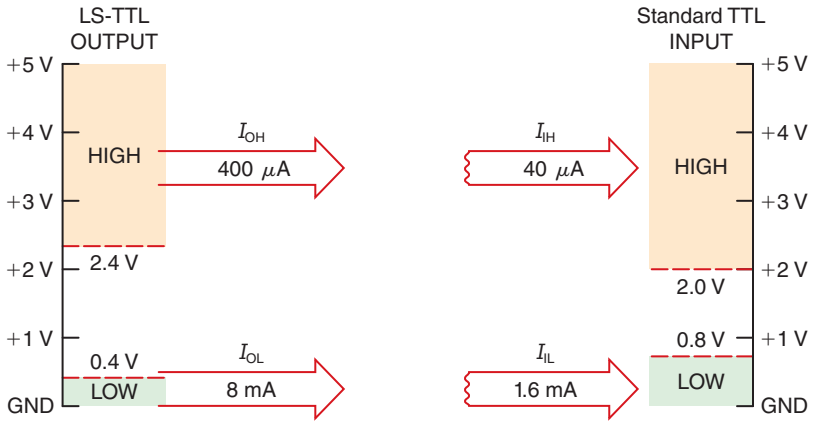
Fan-in

The load represented by a single gate is called the *fan-in* of that family of ICs. The input loading column in Fig. 5-6(*b*) can be thought of as the fan-in of these IC families. Notice that the fan-in or input loading characteristics are different for each family of ICs.

Suppose you are given the interfacing problem in Fig. 5-7(*a*). You are asked if the 74LS04



(*a*)



(*b*)

Fig. 5-7 Interfacing LS-TTL to standard TTL problem. (*a*) Logic diagram of interfacing problem. (*b*) Voltage and current profiles for visualizing the solution to the problem.

Internet Connection

Visit www.ti.com.

inverter has enough fan-out to drive the four standard TTL NAND gates on the right.

Propagation delay

The voltage and current profiles for LS-TTL and standard TTL gates are sketched in Fig. 5-7(*b*). The voltage characteristics of all TTL families are compatible. The LS-TTL gate can drive 10 standard TTL gates when its output is HIGH (400 μA/40 μA = 10). However, the LS-TTL gate can drive only five standard TTL gates when it is LOW (8 mA/1.6 mA = 5). We could say that the fan-out of LS-TTL gates is only 5 when driving standard TTL gates. It is true that the LS-TTL inverter can drive four standard TTL inputs in Fig. 5-7(*a*).

Propagation Delay

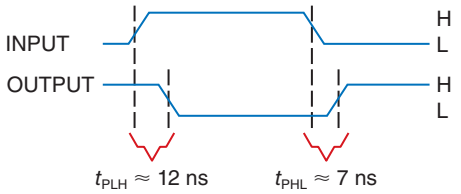
Speed, or quickness of response to a change at the inputs, is an important consideration in high-speed applications of digital ICs. Consider the waveforms in Fig. 5-8(*a*). The top waveform shows the input to an inverter going from LOW to HIGH and then from HIGH to LOW. The bottom waveform shows the output response to the changes at the input. The slight delay between the time the input changes and the time the output changes is called the *propagation delay* of the inverter. Propagation delay is measured in seconds. The propagation delay for the LOW-to-HIGH transition of the input to the inverter is different from the HIGH-to-LOW delay. Propagation delays are shown in Fig. 5-8(*a*) for a standard TTL 7404 inverter IC.

The typical propagation delay for a standard TTL inverter (such as the 7404 IC) is about 12 ns for the LOW-to-HIGH change while only 7 ns for the HIGH-to-LOW transition of the input.

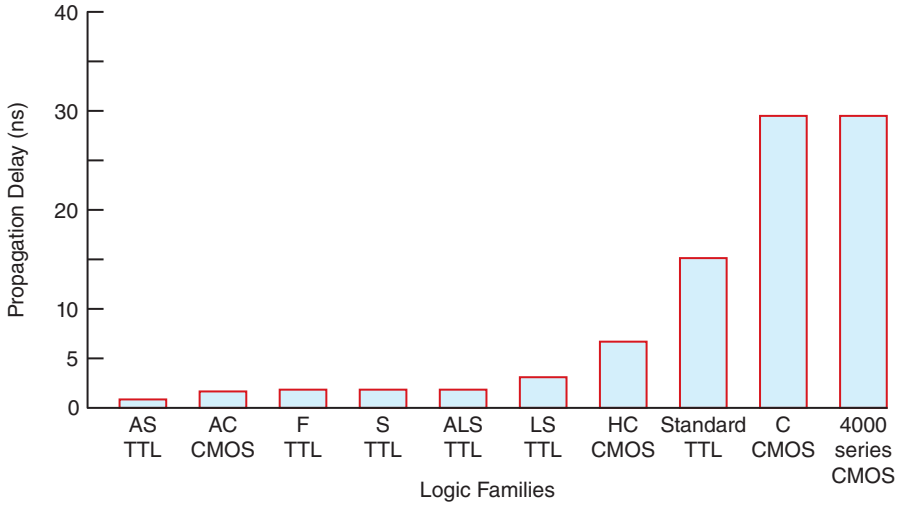
Representative minimum propagation delays are summarized on the graph in Fig. 5-8(*b*). The lower the propagation delay specification for an IC, the higher the speed. Notice that the AS-TTL (advanced Schottky TTL) and AC-CMOS are the fastest with minimum propagation delays of about 1 ns for a simple inverter. The

Internet Connection

Visit www.fairchildsemiconductor.com.



(*a*)



(*b*)

Propagation delays

Fig. 5-8 (*a*) Waveforms showing propagation delays for a standard TTL inverter. (*b*) Graph of propagation delays for selected TTL and CMOS families.

older 4000 and 74C00 series CMOS families are the slowest families (highest propagation delays). Some 4000 series ICs have propagation delays of over 100 ns. In the past, TTL ICs were considered faster than those manufactured using the CMOS technology. Currently, however, the FACT CMOS series rival the best TTL ICs in low propagation delays (high speed). For extremely high-speed operation, the *ECL (emitter-coupled logic)* and the developing gallium arsenide families are required.

Power Dissipation

Generally, as propagation delays decrease (increased speed), the power consumption and related heat generation increase. Historically, a standard TTL IC might have a propagation delay of about 10 ns compared with a propagation delay of about 30 to 50 ns for a 4000 series CMOS IC. The 4000 CMOS IC, however, would consume only 0.001 mW, while the standard TTL gate might consume 10 mW of power. The power dissipation of CMOS increases with frequency. So at 100 kHz, the 4000 series gate may consume 0.1 mW of power.

The speed versus power graph in Fig. 5-9 compares several of the TTL and CMOS families. The vertical axis on the graph represents the propagation delay (speed) in nanoseconds, while the horizontal axis depicts the power consumption (in milliwatts) of each gate. Families with the most desirable combination of both speed and power are those near the lower left corner of the graph. A few years ago many designers suggested that the ALS (advanced low-power Schottky TTL) family was the best compromise between speed and power dissipation. With the introduction of new families, it appears that the FACT (Fairchild advanced CMOS technology) series is now one of the best compromise logic families. Both the ALS and the FAST (Fairchild advanced Schottky TTL) families are also excellent choices.

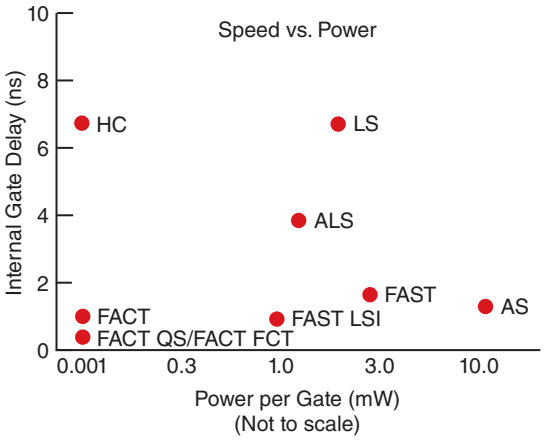


Fig. 5-9 Speed versus power for selected TTL and CMOS families. (Courtesy of National Semiconductor Corporation.)

FACT series CMOS ICs

Emitter-coupled logic (ECL)

Power dissipation

Speed versus power chart

Self-Test

Supply the missing word in each statement.

13. The number of "standard" input loads that can be driven by an IC is called its _____ (fan-in, fan-out).
14. The _____ (4000 series CMOS, FAST TTL series) gates have more output drive capabilities.
15. Refer to Fig. 5-6(*b*). The calculated fan-out when interfacing LS-TTL to LS-TTL is _____.
16. The 4000 series CMOS gates have very low power dissipation, good noise immunity, and _____ (long, short) propagation delays.
17. Refer to Fig. 5-8(*b*). The fastest CMOS subfamily is _____.
18. All TTL subfamilies have _____ (different, the same) voltage and different output drive and input loading characteristics.

Internet Connection

IC manufacturers refer to RoHS. RoHS stands for what?

5-3 MOS and CMOS ICs

MOS ICs

Cautions when using CMOS

Conductive foam

The enhancement type of metal-oxide semiconductor field-effect transistor (MOSFET) forms the primary component in MOS ICs. Because of their simplicity, MOS devices use less space on a silicon chip. Therefore, more functions per chip are typical in MOS devices than in bipolar ICs (such as TTL). Metal-oxide semiconductor technology is widely used in large-scale integration (LSI) and very large-scale integration (VLSI) devices because of this packing density on the chip. Microprocessors, memory, and clock chips are typically fabricated using MOS technology. Metal-oxide semiconductor circuits are typically of either the PMOS (P-channel MOS) or the newer, faster NMOS (N-channel MOS) type. Metal-oxide semiconductor chips are smaller, consume less power, and have a better noise margin and higher fan-out than bipolar ICs. The main disadvantage of MOS devices is their relative lack of speed.

PMOS
NMOS

CMOS ICs

Complementary symmetry metal-oxide semiconductor ICs

Complementary symmetry metal-oxide semiconductor (CMOS) devices use both P-channel and N-channel MOS devices connected end to end. Complementary symmetry metal-oxide semiconductor ICs are noted for their *exceptionally low power consumption*. The CMOS family of ICs also has the advantages of low cost, simplicity of design, low heat dissipation, good fan-out, wide logic swings, and good noise-margin performance. Most CMOS families of digital ICs operate on a wide range of voltages. Some low-voltage CMOS ICs operate on power supplies as low as +1.7 V.

Historically, the main disadvantage of many CMOS ICs was that they were slower than bipolar digital ICs such as TTL devices. In more recent times, CMOS families such as 74AC00 and 74ALVC00 series feature very low propagation delays (perhaps 2 to 5 ns) for use in high-speed digital circuits. For comparison, older 7400 series logic circuits may have propagation delays of about 6 ns. Extra care must be taken when handling CMOS ICs because they must be protected from static discharges. A static charge or transient voltage in a circuit can damage the very thin silicon dioxide layers inside the CMOS chip. The silicon dioxide layer acts like the dielectric in a capacitor and can be punctured by static discharge and transient voltages.

CMOS structure

If you do work with CMOS ICs, manufacturers suggest preventing damage from static discharge and transient voltages by:

1. Storing CMOS ICs in special *conductive foam* or static shielding bags or containers
2. Using battery-powered soldering irons when working on CMOS chips or grounding the tips of ac-operated units
3. Changing connections or removing CMOS ICs only when the power is enturned off
4. Ensuring that input signals do not exceed power supply voltages
5. Always turning off input signals before circuit power is turned off
6. Connecting *all unused input leads* to either the positive supply voltage or GND, whichever is appropriate (only unused CMOS *outputs* may be left unconnected)

FACT CMOS ICs are much more tolerant of static discharge.

The extremely low power consumption of CMOS ICs makes them ideal for battery-operated portable devices. Complementary symmetry metal-oxide semiconductor ICs are widely used in a variety of portable devices.

A typical CMOS device is shown in Fig. 5-10. The top half is a P-channel MOSFET, while the bottom half is an N-channel MOSFET. Both are enhancement-mode MOSFETs. When the input voltage (V_{in}) is LOW, the top MOSFET is on and the bottom unit is off. The output voltage (V_{out}) is then HIGH. However, if V_{in} is HIGH, the bottom device is on and the top MOSFET is off. Therefore, V_{out} is LOW. The device in Fig. 5-10 acts as an inverter.

Notice in Fig. 5-10 that the V_{DD} of the CMOS unit goes to the positive supply voltage. The V_{DD} lead is labeled V_{CC} (as in TTL) by many manufacturers.

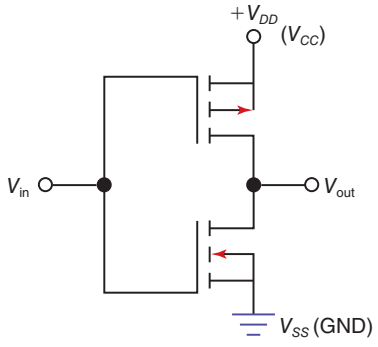


Fig. 5-10 CMOS structure using P-channel and N-channel MOSFETs in series.

The "*D*" in V_{DD} stands for the *drain* supply in MOSFET. The V_{SS} lead of the CMOS unit is connected to the negative of the power supply. This connection is called GND (as in TTL) by some manufacturers. The "*S*" in V_{SS} stands for *source* supply in a MOSFET. CMOS ICs typically operate on 3-, 5-, 6-, 9-, or 12-V power supplies.

The CMOS technology is used in making several families of digital ICs. The most popular are the 4000, 74C00, 74HC00, 74ALVC00, and FACT series ICs. The *4000 series* is the oldest. This family has all the customary logic functions plus a few devices that have no equivalent in TTL families. For instance, in CMOS it is possible to produce *transmission gates* or *bilateral switches*. These gates can conduct or allow a signal to pass in either direction like relay contacts.

The 74C00 series is an older CMOS logic family that is the pin-for-pin, function-for-function equivalent of the 7400 series of TTL ICs. As an example, a 7400 TTL IC is designated as a quadruple ("quad") two-input NAND gate as is the 74C00 CMOS ICs.

The 74HC00 series CMOS logic family is designed to replace the 74C00 series and many 4000 series ICs. It has pin-for-pin, function-for-function equivalents for both 7400 and 4000 series ICs. It is a high-speed CMOS family with good drive capabilities. It operates on a 2- to 6-V power supply.

The FACT (Fairchild advanced CMOS technology) logic IC series includes the 74AC00, 74ACQ00, 74ACT00, 74ACTQ00, 74FCT00, and 74FCTA00 subfamilies. The FACT family provides pin-for-pin, function-for-function equivalents for 7400 TTL ICs. The FACT series was designed to outperform existing CMOS and most bipolar logic families. It features low power consumption even at modest frequencies (0.1 mW/gate at 1 MHz). Power consumption does however increase at higher frequencies (>50 mW at 40 MHz). It has outstanding noise immunity, with the "Q" devices having patented noise-suppression circuitry. The "T" devices have TTL voltage level inputs. The propagation delays for the FACT series are outstanding [see Fig. 5-8(*b*)]. FACT ICs show excellent resistance to static electricity. The series is also radiation-tolerant making it good in space, medical, and military applications. The output drive capabilities of the FACT family are outstanding [see Fig. 5-6(*b*)].

Extremely compact digital devices may use lower-voltage power sources where V_{CC} = 3.3 V, V_{CC} = 2.5 V, or V_{CC} = 1.8 V. The 74ALVC00 series of CMOS ICs may be used because of its low power consumption, 3.6-V tolerant inputs/outputs, TTL direct interface, static protection, and very high speeds (low propagation delays, about 2 to 3 ns).

FACT series CMOS ICs

4000 series

Transmission gates

Bilateral switches

74C00 series

74HC00 series

Self-Test

Supply the missing word in each statement.

19. Large-scale integration (LSI) and very large-scale integration (VLSI) devices make extensive use of _____ (bipolar, MOS) technology.
20. The letters CMOS stand for _____.
21. The most important advantage of using CMOS is its _____.
22. The V_{SS} pin on a CMOS IC is connected to _____ (positive, GND) of the power supply.
23. The V_{DD} pin on a CMOS IC is connected to _____ (positive, GND) of the power supply.
24. The _____ (FACT, 4000) series of CMOS ICs are a good choice for new designs because of their low power consumption, good noise immunity, excellent drive capabilities, and outstanding speed.
25. The 74FCT00 would have the same logic function and pinout as the 7400 quad two-input NAND gate IC. (T or F)
26. The 74ALVC00 series of ICs use _____ (CMOS, TTL) technology in their manufacture.
27. Older series of CMOS ICs (such as the 4000 series) were _____ (not, very) sensitive to static electricity.
28. Older series of CMOS ICs (such as the 4000 series) featured low power consumption but were lacking because of high propagation delays. (T or F)

Internet Connection

Explore BiCMOS or BiMOS technology at en.wikipedia.org.

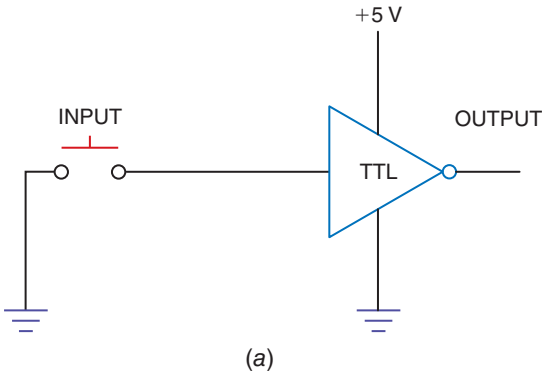
5-4 Interfacing TTL and CMOS with Switches

One of the most common means of entering information into a digital system is the use of switches or a keyboard. Examples might be the switches on a digital clock, the keys on a calculator, or the keyboard on a microcomputer. This section will detail several methods of using a switch to enter data into either TTL or CMOS digital circuits.

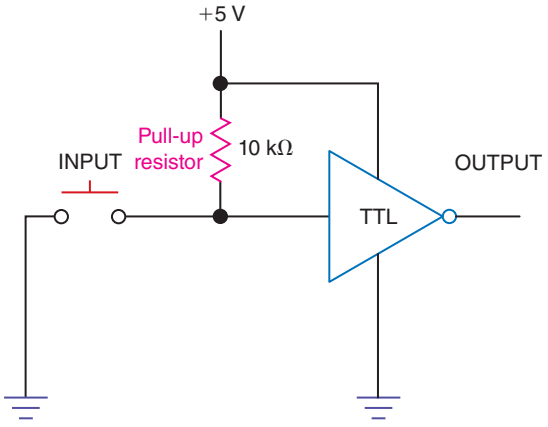
Three simple switch interface circuits are depicted in Fig. 5-11. Pressing the push-button switch in Fig. 5-11(*a*) will drop the input of the TTL inverter to ground level or LOW. Releasing the push-button switch in Fig. 5-11(*a*) opens the switch. The input to the TTL inverter now is allowed to "float." In TTL, inputs usually float at a HIGH logic level.

Floating inputs on TTL are not dependable. Figure 5-11(*b*) is a slight refinement of the switch input circuit in Fig. 5-11(*a*). The 10-kΩ resistor has been added to make sure the input to the TTL inverter goes HIGH when the switch is open. The 10-kΩ resistor is called a *pull-up resistor*. Its purpose is to pull the input voltage up to +5 V when the input switch is open. Both circuits in Fig. 5-11(*a*) and (*b*) illustrate active

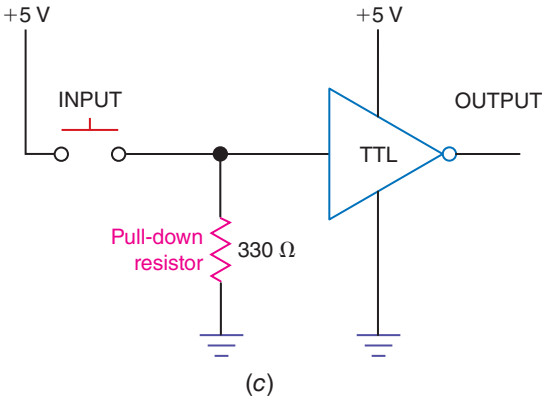
Pull-up resistor



(*a*)



(*b*)

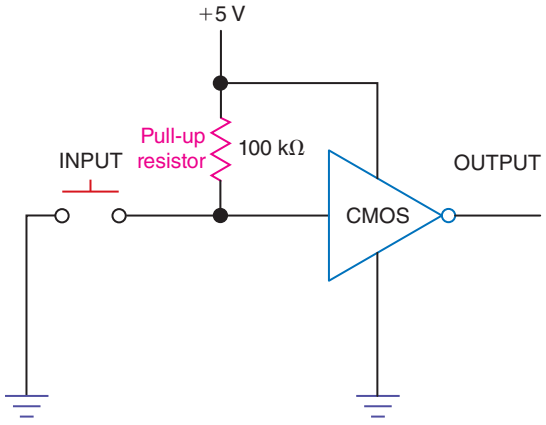


(*c*)

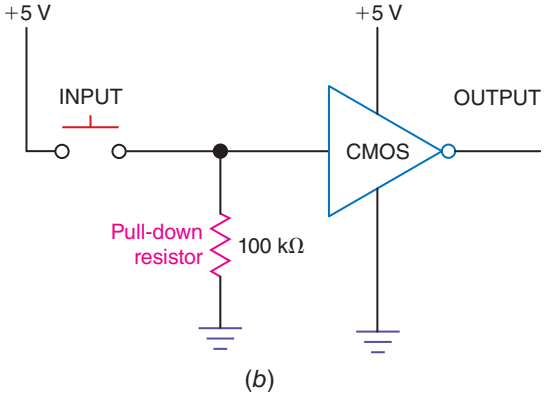
Switch-to-TTL interfaces

Switch-to-CMOS interfaces

Fig. 5-11 Switch-to-TTL interfaces. (*a*) Simple active LOW switch interface. (*b*) Active LOW switch interface using pull-up resistor. (*c*) Active HIGH switch interface using pull-down resistor.



(*a*)



(*b*)

Fig. 5-12 Switch-to-CMOS interfaces. (*a*) Active LOW switch interface with pull-up resistor. (*b*) Active HIGH switch interface with pull-down resistor.

LOW switches. They are called active LOW switches because the inputs go LOW only when the switch is activated.

An active HIGH input switch is sketched in Fig. 5-11(*c*). When the input switch is activated, the +5 V is connected directly to the input of the TTL inverter. When the switch is released (opened), the input is pulled LOW by the *pull-down resistor*. The value of the pull-down resistor is relatively low because the input current required by a standard TTL gate may be as high as 1.6 mA [see Fig. 5-6(*b*)].

Two switch-to-CMOS interface circuits are drawn in Fig. 5-12. An active LOW input switch is drawn in Fig. 5-12(*a*). The 100-kΩ pull-up resistor pulls the voltage to +5 V when the input switch is open. Figure 5-12(*b*) illustrates an active HIGH switch feeding a CMOS inverter. The 100-kΩ pull-down resistor makes sure the input to the CMOS inverter is near ground when the input switch is open. The resistance value of the pull-up and pull-down resistors is much greater than those in TTL interface circuits. This is because the input loading currents are much greater in TTL than in CMOS. The CMOS inverter illustrated in Fig. 5-12 could be from the 4000, 74C00, 74HC00, or the FACT series of CMOS ICs.

Pull-down resistor

Switch Debouncing

The switch interface circuits in Figs. 5-11 and 5-12 work well for some applications. However, none of the switches in Figs. 5-11 and 5-12 were *debounced*. The lack of a debouncing circuit can be demonstrated by operating the counter shown in Fig. 5-13(*a*). Each press of the input switch should cause the decade (0–9) counter to increase by 1. However, in practice each press of the switch increases the count by 1, 2, 3, or sometimes more. This means that several pulses are being fed into the clock (CLK) input

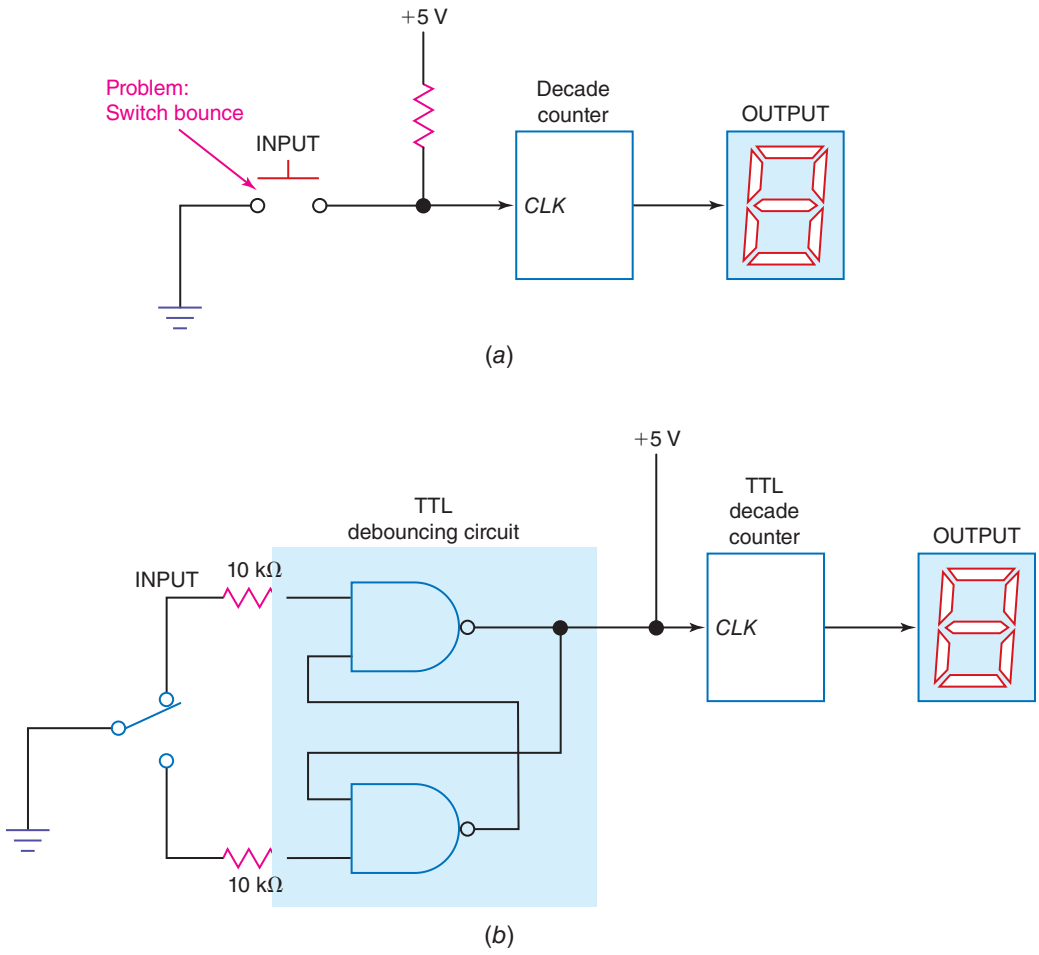


Fig. 5-13 (*a*) Block diagram of switch interfaced to a decimal counter system. (*b*) Adding a debouncing circuit to make the decimal counter work properly.

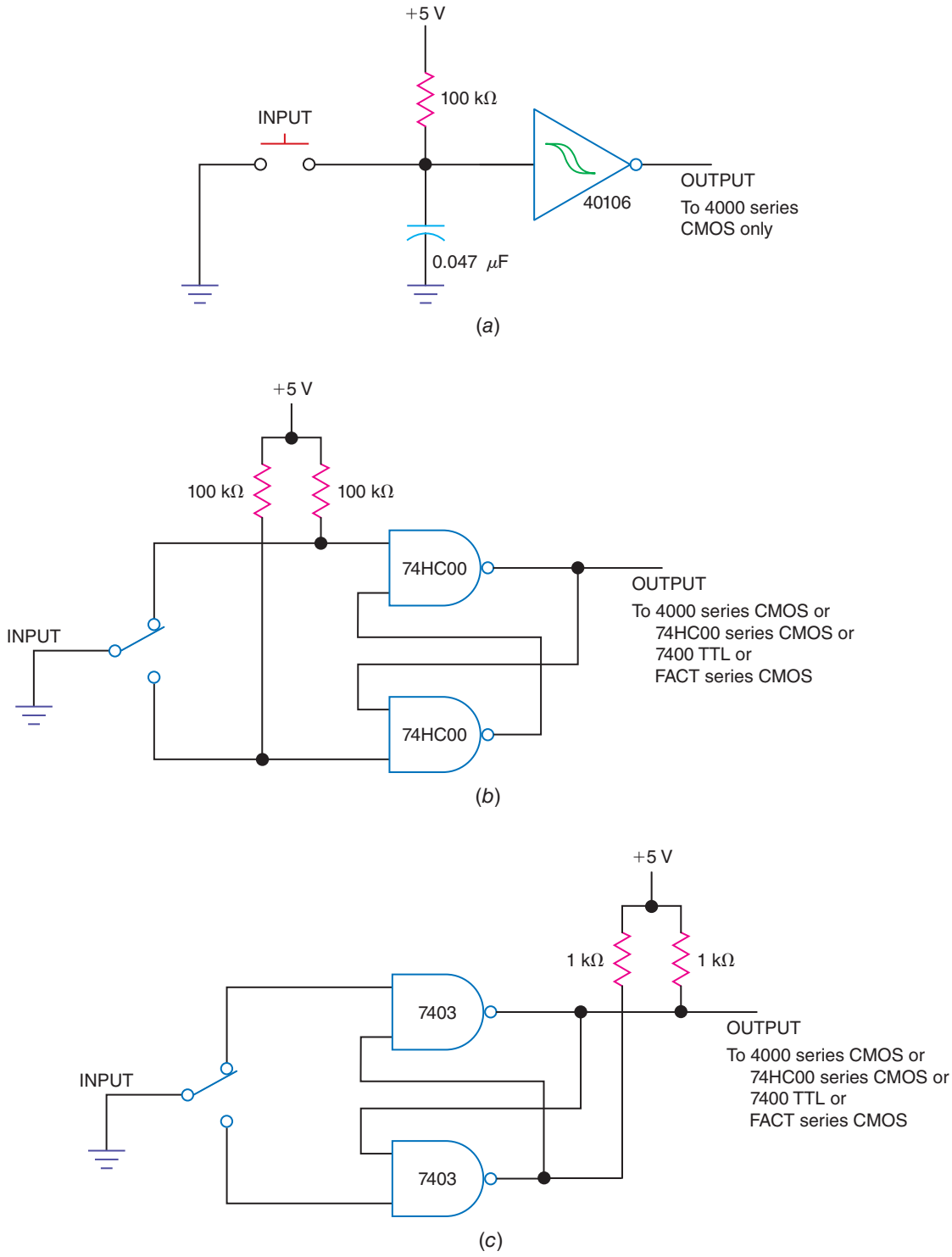
RS flip-flop or latch

Switch debouncing circuit

of the counter each time the switch is pressed. This is caused by switch bounce.

A *switch debouncing circuit* has been added to the counting circuit in Fig. 5-13(*b*). The decade counter will now count each HIGH-LOW cycle of the input switch. The cross-coupled NAND gates in the debouncing circuit are sometimes called an RS *flip-flop or latch*. Flip-flops will be studied later in greater detail.

Several other switch debouncing circuits are illustrated in Fig. 5-14. The simple debouncing circuit drawn in Fig. 5-14(*a*) will work only on



Switch debouncing circuits

Fig. 5-14 Switch debouncing circuits. (*a*) A 4000 series switch debouncing circuit. (*b*) General-purpose switch debouncing circuit that will drive CMOS or TTL inputs. (*c*) Another general-purpose switch debouncing circuit that will drive CMOS or TTL inputs.

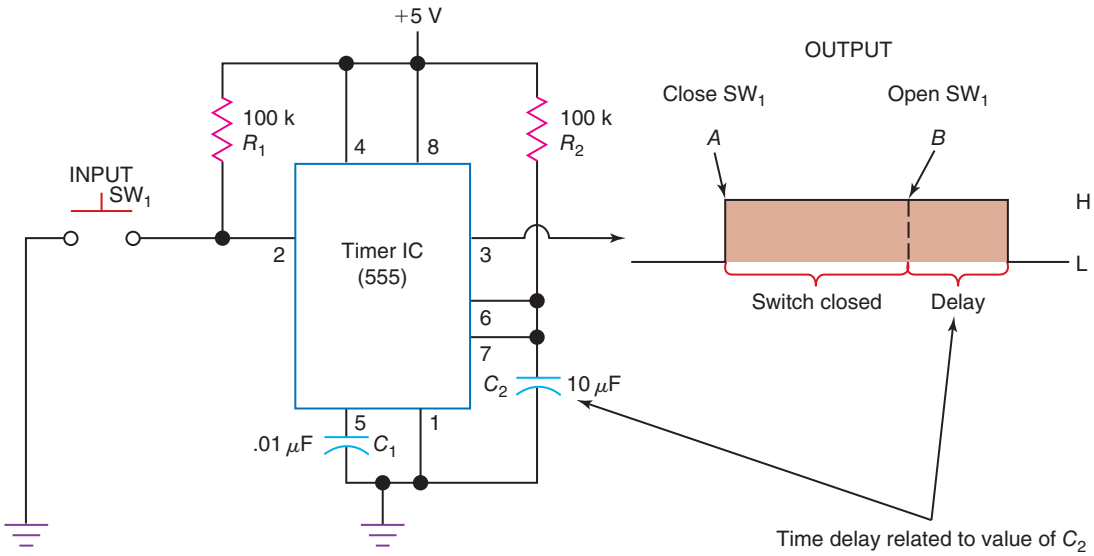


Fig. 5-15 Switch debouncing circuit using the 555 timer IC.

the slower 4000 series CMOS IC. The 40106 CMOS IC is a special inverter. The 40106 is a *Schmitt trigger inverter*, which means it has a "snap action" when changing to either HIGH or LOW. A Schmitt trigger can also change a slow-rising signal (such as a sine wave) into a square wave.

The switch debouncing circuit in Fig. 5-14(*b*) will drive 4000, 74HC00, or FACT series CMOS or TTL ICs. Another general-purpose switch debouncing circuit is illustrated in Fig. 5-14(*c*). This debouncing circuit can drive either CMOS or TTL inputs. The 7403 is an *open-collector* NAND TTL IC and needs pull-up resistors as shown in Fig. 5-14(*c*). The external pull-up resistors make it possible to have an output voltage of just about +5 V for a HIGH. Open-collector TTL gates with external pull-up resistors are useful when driving CMOS with TTL.

Schmitt trigger inverter

Another switch debouncing circuit using the versatile 555 timer IC is sketched in Fig. 5-15. When push-button switch SW_1 is closed (see point *A* on output waveform), the output toggles from LOW to HIGH. Later when input switch SW_1 is opened (see point *B* on waveform), the output of the 555 IC remains HIGH for a delay period. After the delay period (about 1 second for this circuit) the output toggles from HIGH to LOW.

The delay period can be adjusted for the switch debouncing circuit shown in Fig. 5-15. One method of adjusting the time delay is to change the capacitance value of C_2. Decreasing the value of C_2 will decrease the delay time at the output of the 555 IC. Increasing the capacitance value of C_2 will increase the delay time.

Open-collector TTL output

Self-Test

Answer the following questions.

29. Refer to Fig. 5-11(*a*). The input to the TTL inverter goes _____ (HIGH, LOW) when the switch is pressed (closed) but _____ (floats HIGH, goes LOW) when the input push button is open.
30. Refer to Fig. 5-11(*b*). The 10-kΩ resistor, which ensures the input of the TTL inverter, will go HIGH when the switch that is open is called a _____ (filter, pull-up) resistor.
31. Refer to Fig. 5-13(*b*). The cross-coupled NAND gates that function as a debouncing circuit are sometimes called a(n) _____ or latch.
32. Refer to Fig. 5-11(*c*). Pressing the switch causes the input of the inverter to go _____ (HIGH, LOW) while the output goes _____ (HIGH, LOW).

Internet Connection

Go to www.elmelectronics.com for custom debouncing ICs.

33. Refer to Fig. 5-12. The inverters and associated resistors form switch debouncing circuits. (T or F)
34. Refer to Fig. 5-13(*a*). This decade counter circuit lacks what circuit?
35. Refer to Fig. 5-14(*c*). The 7403 is a TTL inverter with a(n) _____ output.
    a. Open collector
    b. Totem pole
    c. Tri state
36. Refer to Fig. 5-15. Pressing (closing) input switch SW_1 caused the output of the 555 IC to toggle from _____ (HIGH to LOW, LOW to HIGH).
37. Refer to Fig. 5-15. Releasing (opening) input switch SW_1 (see point *B* on output waveform) causes the output of the 555 IC to _____.
    a. Immediately toggle from HIGH to LOW
    b. Toggle from LOW to HIGH after a delay time of about 1 millisecond
    c. Toggle from HIGH to LOW after a delay time of about 1 second
38. Refer to Fig. 5-15. The time delay at the output of the 555 IC can be decreased by _____ (decreasing, increasing) the capacitance value of C_2.

5-5 Interfacing TTL and CMOS with LEDs

Light-emitting diode (LED)

Many of the lab experiments you will perform using digital ICs require an output indicator. The *LED (light-emitting diode)* is perfect for this job because it operates at low currents and voltages. The maximum current required by many LEDs is about 20 to 30 mA with about 2 V applied. An LED will light dimly on only 1.7 to 1.8 V and 2 mA.

CMOS-To-LED Interfacing

Interfacing 4000 series CMOS devices with simple LED indicator lamps is easy. Figure 5-16(*a–f*) shows six examples of CMOS ICs driving LED indicators. Figure 5-16(*a*) and (*b*) show the CMOS supply voltage at +5 V. At this low voltage, no limiting resistors are needed in series with the LEDs. In Fig. 5-16(*a*), when the output of the CMOS inverter goes HIGH, the LED output indicator lights. The opposite is true in Fig. 5-16(*b*): when the CMOS output goes LOW, the LED indicator lights.

Current sourcing

Figure 5-16(*c*) and (*d*) show the 4000 series CMOS ICs being operated on a higher supply voltage (+10 to +15 V). Because of the higher voltage, a 1-kΩ limiting resistor is placed in series with the LED output indicator lights. When the output of the CMOS inverter in Fig. 5-16(*c*) goes HIGH, the LED output indicator lights. In Fig. 5-16(*d*), however, the LED indicator is activated by a LOW at the CMOS output.

Figure 5-16(*e*) and (*f*) show CMOS buffers being used to drive LED indicators. The circuits may operate on voltages from +5 to +15 V. Figure 5-16(*e*) shows the use of an inverting CMOS buffer (like the 4049 IC), while Fig. 5-16(*f*) uses the noninverting buffer (like the 4050 IC). In both cases, a 1-kΩ limiting resistor must be used in series with the LED output indicator.

TTL-To-LED Interfacing

Standard TTL gates are sometimes used to drive LEDs directly. Two examples are illustrated in Fig. 5-16(*g*) and (*h*). When the output of the inverter in Fig. 5-16(*g*) goes HIGH, current will flow through the LED causing it to light. The indicator light in Fig. 5-16(*h*) only lights when the output of the 7404 inverter goes LOW. The circuits in Fig. 5-16 are not recommended for critical uses because they can exceed the output current ratings of the ICs. However, the circuits in Fig. 5-16 have been tested and work properly as simple output indicators.

Current Sourcing and Current Sinking

When reading technical literature or listening to technical discussions, you may encounter terms such as *current sourcing* and *current sinking*. The idea behind these terms is illustrated in Fig. 5-17 using TTL ICs to drive LEDs.

In Fig. 5-17(*a*) the output of the TTL AND gate is HIGH. This HIGH at the output of the AND gate lights the LED. In this example, we

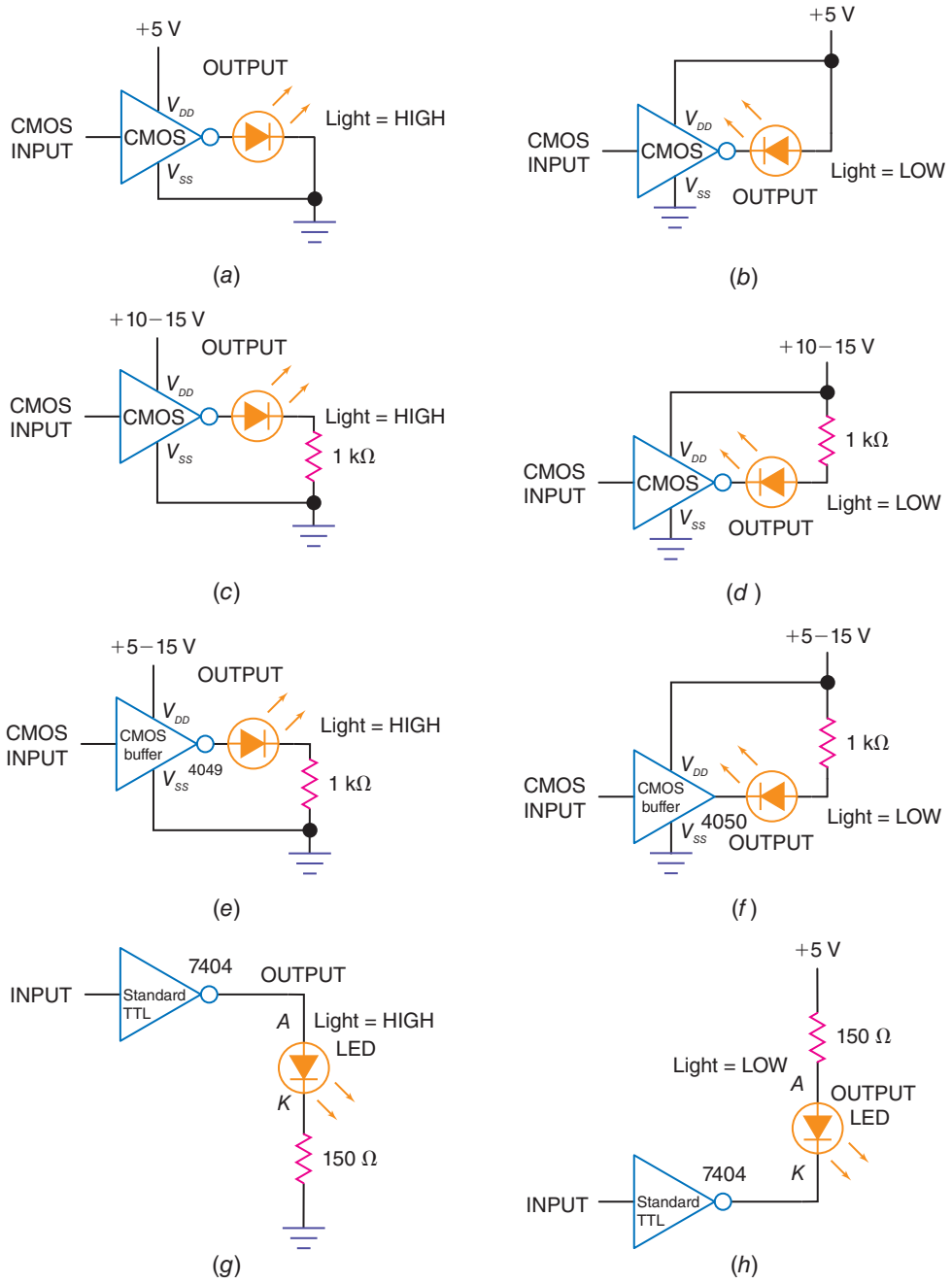


Fig. 5-16 Simple CMOS- and TTL-to-LED interfacing. (*a*) CMOS active HIGH. (*b*) CMOS active LOW. (*c*) CMOS active HIGH, supply voltage = 10 to 15 V. (*d*) CMOS active LOW, supply voltage = 10 to 15 V. (*e*) CMOS inverting buffer to LED interfacing. (*f*) CMOS noninverting buffer to LED interfacing. (*g*) TTL active HIGH. (*h*) TTL active LOW.

Simple CMOS-to-LED interfacing

Simple TTL-to-LED interfacing

talk of the IC as being the source of current (conventional current *flow* from + to −). The *sourcing current* is sketched on the schematic diagram in Fig. 5-17(*a*). The source current appears to "flow from the IC" through the external circuit (LED and limiting resistor) to ground.

In Fig. 5-17(*b*) the output of the TTL NAND gate is LOW. This LOW at the output of the NAND gate lights the LED. In this example, we refer to the IC as sinking the current. The *sinking current* is sketched on the schematic diagram in Fig. 5-17(*b*). The sinking current appears to start with +5 V above the external circuit (limiting resistor and LED) and "sink to ground" through the external circuit (limiting resistor and LED) and the output pin of the NAND IC.

Conventional current flow

Current sinking

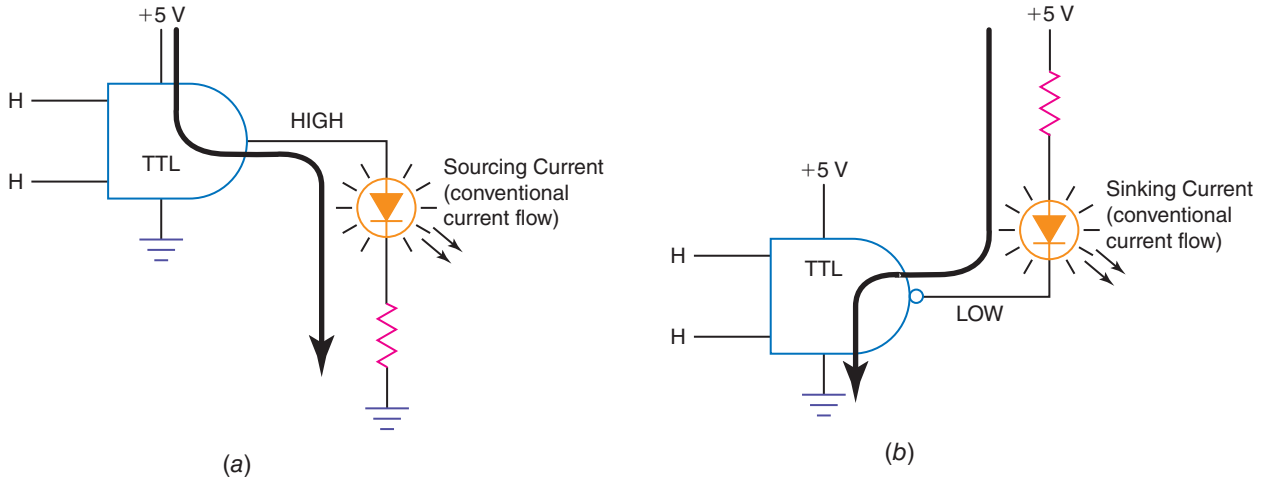
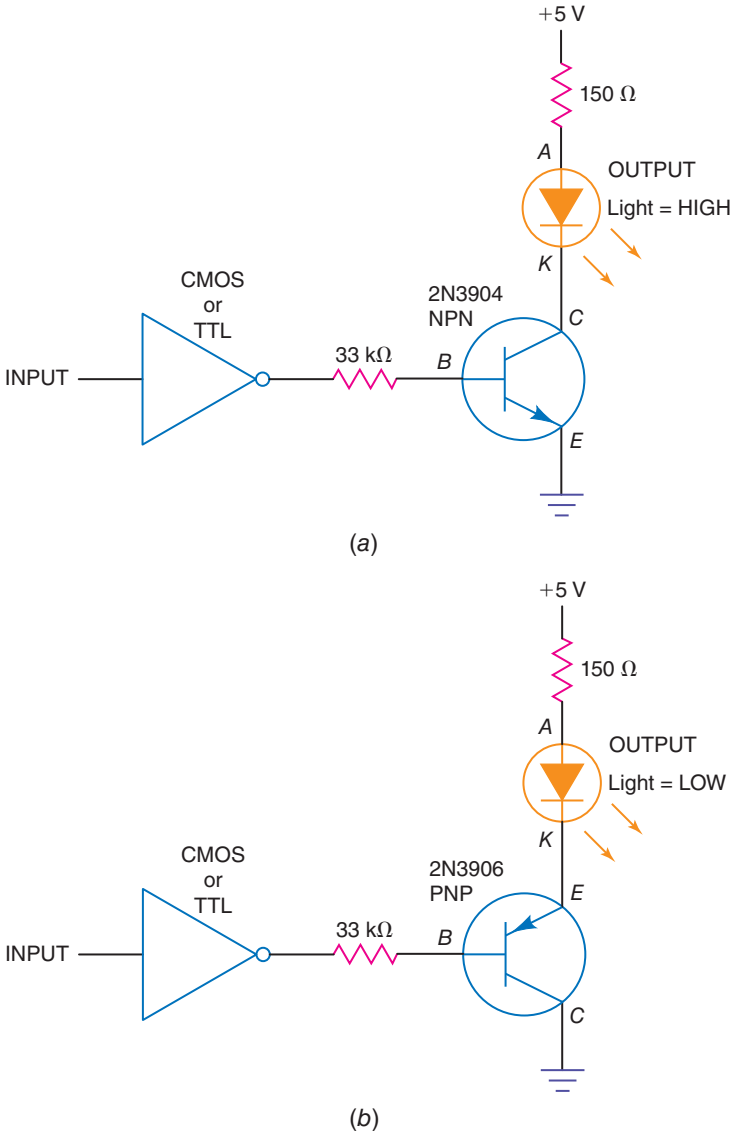


Fig. 5-17 (*a*) Current sourcing. (*b*) Current sinking.



Interfacing to LEDs using a transistor drive circuit

Fig. 5-18 Interfacing to LEDs using a transistor driver circuit. (*a*) Active-HIGH output using a NPN transistor driver. (*b*) Active-LOW output using a PNP transistor driver (simplified logic probe).

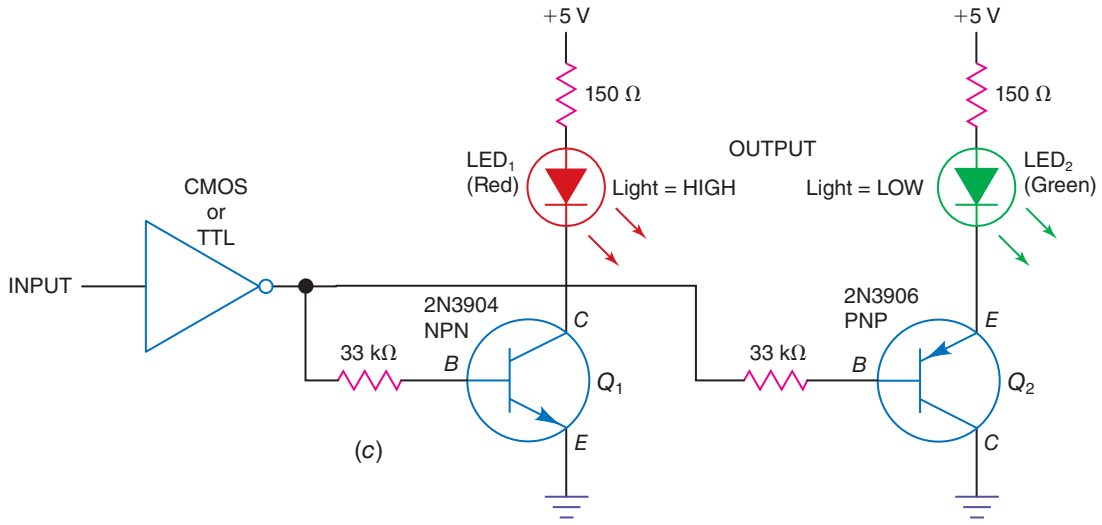


Fig. 5-18 (cont.) Interfacing to LEDs using a transistor driver circuit. (*c*) HIGH-LOW indicator circuit (simplified logic probe).

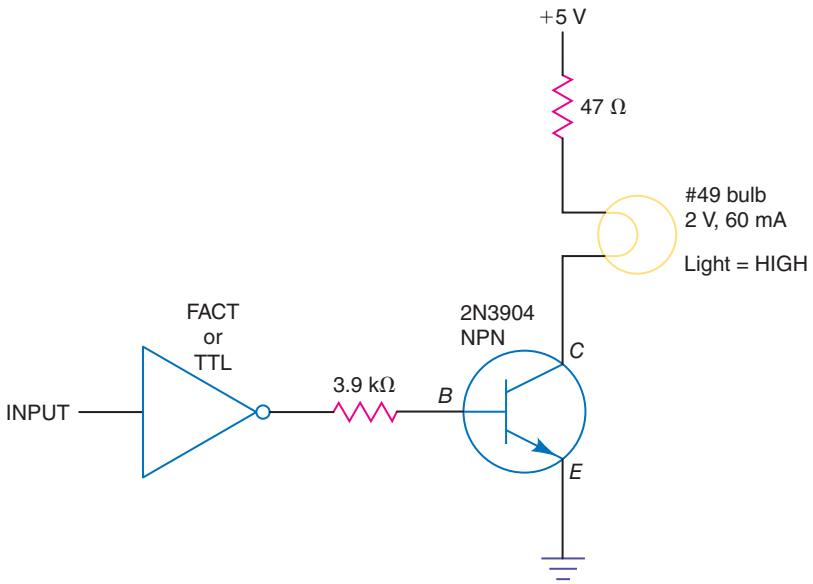


Fig. 5-19 Interfacing to an incandescent lamp using a transistor driver circuit.

Interfacing to an incandescent lamp

Improved LED Output Indicators

Three improved LED output indicator designs are diagrammed in Fig. 5-18. Each of the circuits uses transistor drivers and can be used with either CMOS or TTL. The LED in Fig. 5-18(*a*) lights when the output of the inverter goes HIGH. The LED in Fig. 5-18(*b*) lights when the output of the inverter goes LOW. Notice that the indicator in Fig. 5-18(*b*) uses a PNP instead of an NPN transistor.

The LED indicator circuits in Fig. 5-18(*a*) and (*b*) are combined in Fig. 5-18(*c*). The red light (LED_1) will light when the inverter's output is HIGH. During this time LED_2 will be off. When the output of the inverter goes LOW, transistor Q_1 turns off while Q_2 turns on. The green light (LED_2) lights when the output of the inverter is LOW.

Transistor driver circuit

The circuit in Fig. 5-18(*c*) is a very basic logic probe. However, its accuracy is less than most logic probes.

The indicator light shown in Fig. 5-19, uses an incandescent lamp. When the output of the inverter goes HIGH, the transistor is turned on and the lamp lights. When the inverter's output is LOW, the lamp does not light.

Self-Test

Supply the missing word(s) in each statment.

39. Refer to Fig. 5-16(*a–f*). The _____ (4000, FAST) series CMOS ICs are being used to drive the LEDs in these circuits.
40. Refer to Fig. 5-16(*h*). When the output of the inverter goes HIGH, the LED _____ (goes out, lights).
41. Refer to Fig. 5-18(*a*). When the output of the inverter goes LOW, the transistor is turned _____ (off, on) and the LED _____(does not light, lights).
42. Refer to Fig. 5-18(*c*). When the output of the inverter goes HIGH, transistor _____ (Q_1, Q_2) is turned on and the _____ (green, red) LED lights.
43. Refer to Fig. 5-20. The TTL decoder IC has _____ (active HIGH, active LOW) outputs.
44. Refer to Fig. 5-20. The TTL decoder IC is said to be _____ (sinking current, sourcing current) as it lights segment *a* of the LED display.
45. Refer to Fig. 5-20. Segment *d* on the display is not glowing because it takes a _____ (HIGH, LOW) logic level at output *d* of the IC to light the LED.

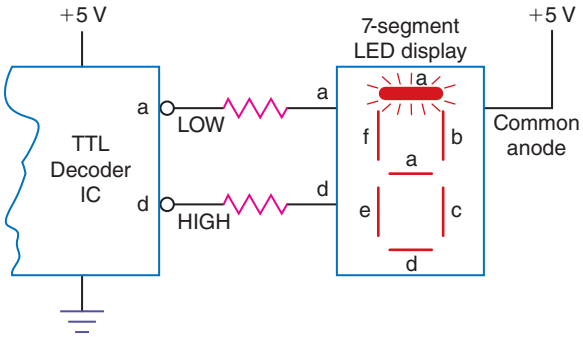


Fig. 5-20 TTL decoder IC driving common-anode seven-segment LED display.

Interfacing TTL and CMOS ICs

5-6 Interfacing TTL and CMOS ICs

CMOS and TTL logic levels (voltages) are defined differently. These differences are illustrated in the voltage profiles for TTL and CMOS shown in Fig. 5-21(*a*). Because of the differences in voltage levels, CMOS and TTL ICs usually cannot simply be connected together. Just as important, current requirements for CMOS and TTL ICs are different.

TTL-CMOS interfacing

CMOS-to-TTL interfacing

Look at the voltage and current profile in Fig. 5-21(*a*). Note that the output drive currents for the standard TTL are more than adequate to drive CMOS inputs. However, the voltage profiles do not match. The LOW outputs from the TTL are compatible because they fit within the wider LOW input band on the CMOS IC. There is a range of possible HIGH outputs from the TTL IC (2.4 to 3.5 V) that do not fit within the HIGH range of the CMOS IC. This incompatibility could cause problems. These problems can be solved by using a *pull-up resistor* between gates to pull the HIGH output of the standard TTL up closer to +5 V. A completed circuit for interfacing standard TTL to CMOS is shown in Fig. 5-21(*b*). Note the use of the 1-kΩ pull-up resistor. This circuit works for driving either 4000 series, 74HC00, or FACT series CMOS ICs.

Pull-up resistor

Several other examples of TTL-to-CMOS and CMOS-to-TTL interfacing using a common 5-V power supply are detailed in Fig. 5-22. Figure 5-22(*a*) shows the popular LS-TTL driving any CMOS gate. Notice the use of a 2.2-kΩ pull-up resistor. The pull-up resistor is being used to pull the TTL HIGH up near +5 V so that it will be compatible with the input voltage characteristics of CMOS ICs.

In Fig. 5-22(*b*), a CMOS inverter (any series) is driving an LS-TTL inverter *directly*. Complementary symmetry metal-oxide semiconductor ICs can drive LS-TTL and ALS-TTL (advanced low-power Schottky) inputs: most CMOS ICs cannot drive standard TTL inputs without special interfacing.

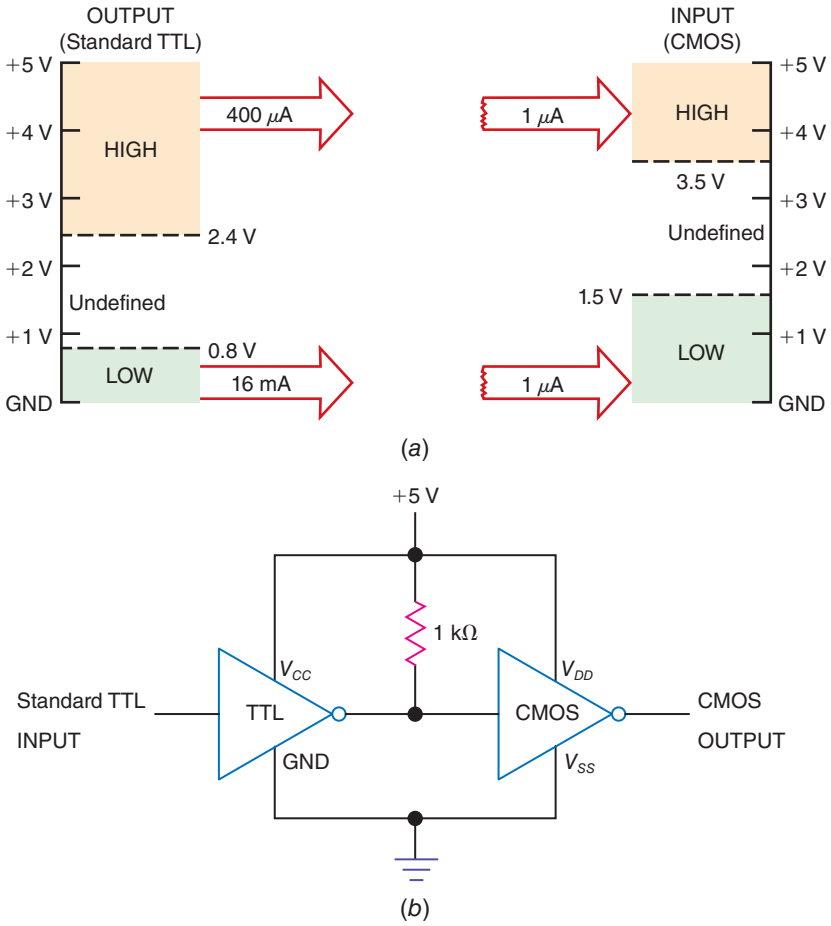


Fig. 5-21 TTL-to-CMOS interfacing. (*a*) TTL output and CMOS input profiles for visualizing compatibility. (*b*) TTL-to-CMOS interfacing using a pull-up resistor.

TTL-to-CMOS interfacing

Manufacturers have made interfacing easier by designing special buffers and other interface chips for designers. One example is the use of the 4050 noninverting buffer in Fig. 5-22(*c*). The 4050 buffer allows the CMOS inverter to have enough drive current to operate up to two standard TTL inputs.

The problem of voltage incompatibility from TTL (or NMOS) to CMOS was solved in Fig. 5-21 using a pull-up resistor. Another method of solving this problem is illustrated in Fig. 5-22(*d*). The 74HCT00 series of CMOS ICs is specifically designed as a convenient interface between TTL (or NMOS) and CMOS. Such an interface is implemented in Fig. 5-22(*d*) using the 74HCT34 noninverting IC.

The *74HCT00 series of CMOS ICs* is widely used when interfacing between NMOS devices and CMOS. The NMOS output characteristics are almost the same as for LS-TTL.

FACT series of CMOS ICs

The modern *FACT series of CMOS ICs* has excellent output drive capabilities. For this reason FACT series chips can drive TTL, CMOS, NMOS, or PMOS ICs directly as illustrated in Fig. 5-23(*a*). The output voltage characteristics of TTL do not match the input voltage profile of 74HC00, 74AC00, and 74ACQ00 series CMOS ICs. For this reason, a pull-up resistor is used in Fig. 5-23(*b*) to make sure the HIGH output voltage of the TTL gate is pulled up near the +5-V rail of the power supply. Manufacturers produce "T"-type CMOS gates that have the input voltage profile of a TTL IC. TTL gates can directly drive any 74HCT00, 74ACT00, 74FCT00, 74FCTA00, or 74ACTQ00 series CMOS IC, as summarized in Fig. 5-23(*c*).

74HCT00 series of CMOS ICs

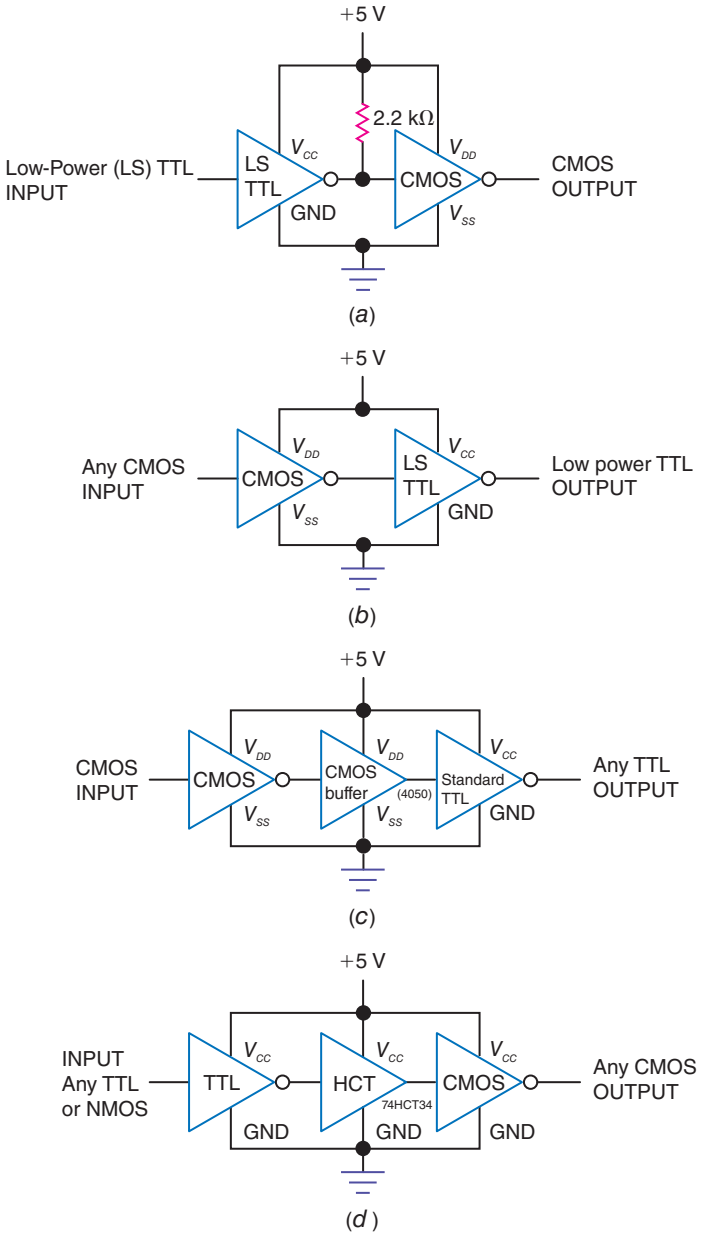


Fig. 5-22 Interfacing TTL and CMOS when both use a common +5-V power supply. (*a*) Low-power Schottky TTL to CMOS interfacing using a pull-up resistor. (*b*) CMOS to low-power Schottky TTL interfacing. (*c*) CMOS to standard TTL interfacing using a CMOS buffer IC. (*d*) TTL to CMOS interfacing using a 74HCT00 series IC.

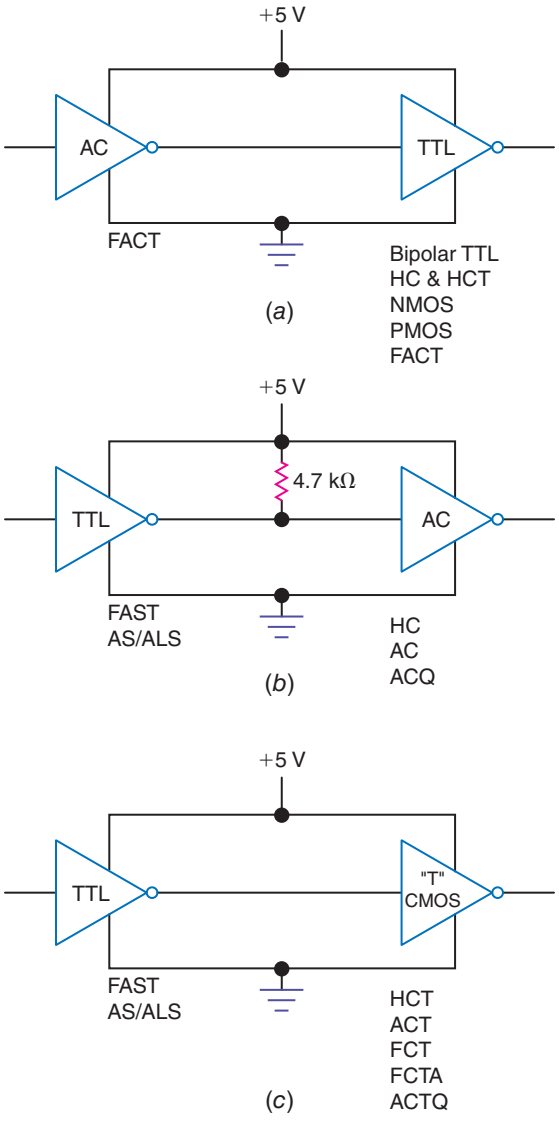


Fig. 5-23 Interfacing FACT with other families. (*a*) FACT driving most other TTL and CMOS families. (*b*) TTL-to-FACT interfacing using a pull-up resistor. (*c*) TTL-to-"T" CMOS ICs.

Interfacing CMOS devices with TTL devices takes some added components when each operates on a *different voltage power supply*. Figure 5-24 shows three examples of TTL-to-CMOS and CMOS-to-TTL interfacing. Figure 5-24(*a*) shows the TTL inverter driving a general-purpose NPN transistor. The transistor and associated resistors translate the lower-voltage TTL outputs to the higher-voltage inputs needed to operate the CMOS inverter.

CMOS buffer

The CMOS output has a voltage swing from about 0 to almost +10 V. Figure 5-24(*b*) shows an open-collector TTL buffer and a 10-kΩ pull-up resistor being used to translate the lower TTL to the higher CMOS voltages. The 7406 and 7416 TTL ICs are two inverting, open-collector (OC) buffers.

Interfacing between a higher-voltage CMOS inverter and a lower-voltage TTL inverter is shown in Fig. 5-24(*c*). The 4049 *CMOS buffer* is used between the higher-voltage CMOS inverter and the lower-voltage TTL IC. Note that the CMOS buffer is powered by the lower-voltage (+5 V) power supply in Fig. 5-24(*c*).

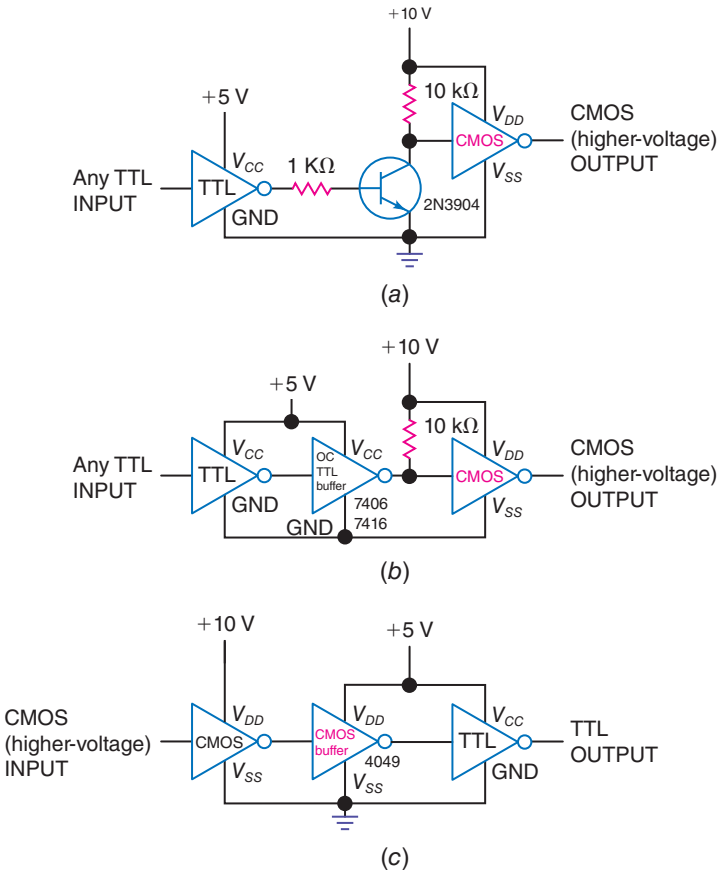


Fig. 5-24 Interfacing TTL and CMOS when each use a different power supply voltage. (*a*) TTL-to-CMOS interfacing using a driver transistor. (*b*) TTL-to-CMOS interfacing using an open collector TTL buffer IC. (*c*) CMOS-to-TTL interfacing using a CMOS buffer IC.

Looking at the voltage and current profiles [such as in Fig. 5-21(*a*)] is a good starting point when learning about or designing an interface. Manufacturers' manuals are also very helpful.

Several techniques are used to interface between different logic families. These include the use of pull-up resistors and special interface ICs. Sometimes no extra parts are needed.

Self-Test

Supply the missing word in each statement.

46. Refer to Fig. 5-21(*a*). According to this profile of TTL output and CMOS input characteristics, the logic devices _____ (are, are not) voltage compatible.
47. Refer to Fig. 5-22(*a*). The 2.2-kΩ resistor in this circuit is called a _____ resistor.
48. Refer to Fig. 5-22(*c*). The 4050 buffer is a special interface IC that solves the _____ (current drive, voltage) incompatibility between the logic families.
49. Refer to Fig. 5-24(*a*). The _____ (NMOS IC, transistor) translates the TTL logic levels to the higher-voltage CMOS logic levels.

5-7 Interfacing with Buzzers, Relays, Motors, and Solenoids

The objective of many electromechanical systems is to control a simple output device. This device might be as simple as a light, buzzer, relay, electric motor, stepper motor, or solenoid. Interfacing to LEDs and lamps has been explored. Simple interfacing between logic elements and buzzers, relays, motors, and solenoids will be investigated in this section.

Interfacing with Buzzers

Piezo buzzer

The *piezo buzzer* is a modern signaling device drawing much less current than older buzzers and bells. The circuit in Fig. 5-25 shows the interfacing necessary to drive a piezo buzzer with digital logic elements. A standard TTL or FACT CMOS inverter is shown driving a piezo buzzer *directly*. The standard TTL output can sink up to 16 mA while a FACT output has 24 mA of drive current. The piezo buzzer draws about 3 to 5 mA when sounding. Notice that the piezo buzzer has polarity markings. The diode across the buzzer is to suppress any transient voltages that might be induced in the system by the buzzer.

Many logic families do not have the current capacity to drive a buzzer directly. A transistor has been added to the output of the inverter in Fig. 5-25(*b*) to drive the piezo buzzer. When the output of the inverter goes HIGH, the NPN transistor is turned on and the buzzer sounds. A LOW at the output of the inverter turns the transistor off, switching the buzzer off. The diode protects against transient voltages. The interface circuit sketched in Fig. 5-25(*b*) will work for both TTL and CMOS.

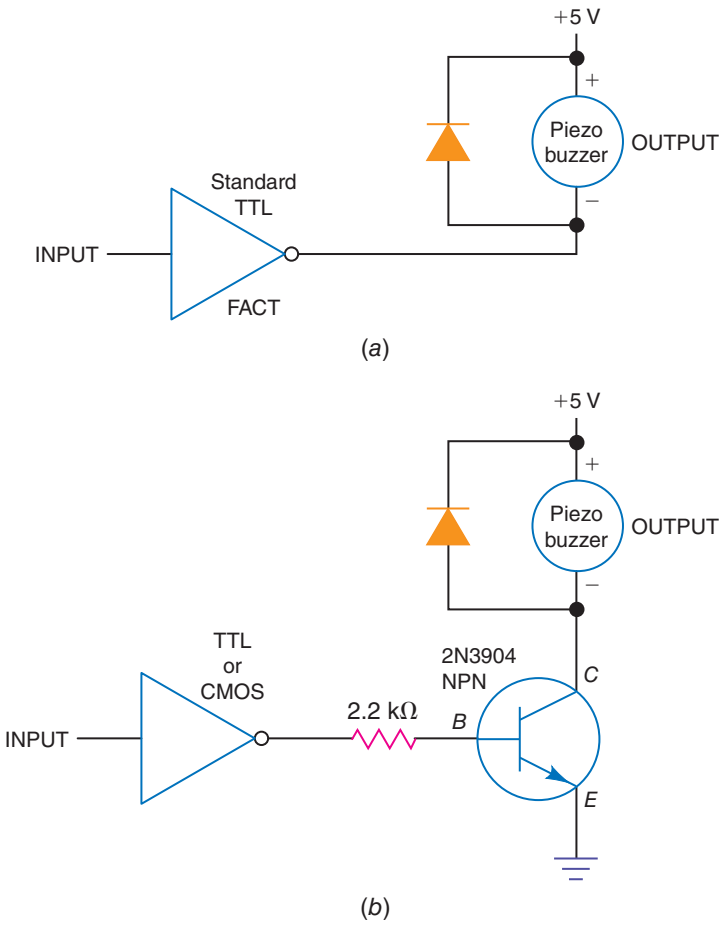


Fig. 5-25 Logic device to buzzer interfacing. (*a*) Standard TTL or FACT CMOS inverter driving a piezo buzzer directly. (*b*) TTL or CMOS interfaced with buzzer using a transistor driver.

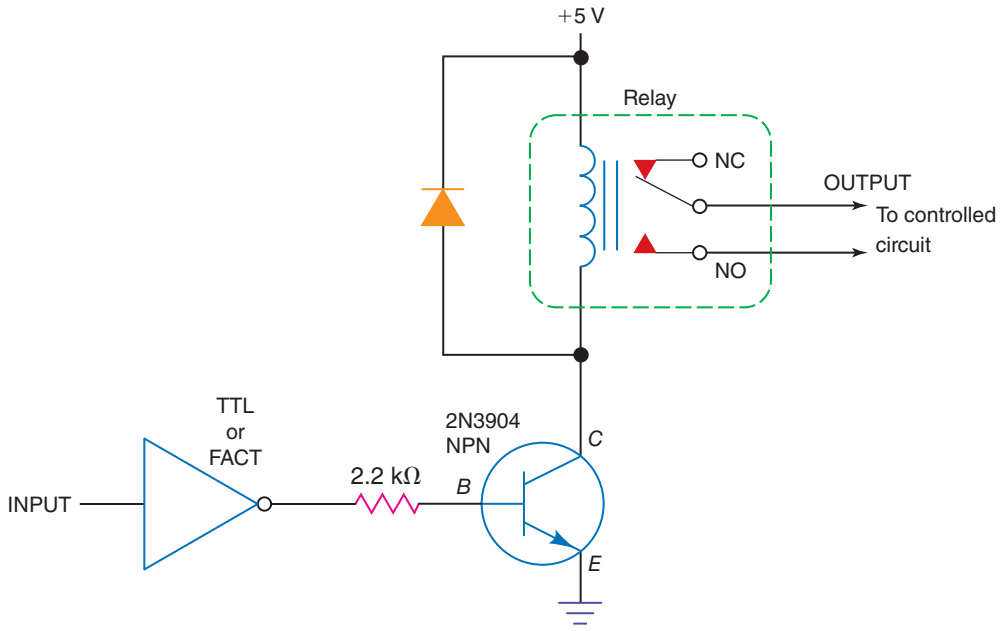


Fig. 5-26 TTL or CMOS interfaced with a relay using a transistor driver circuit.

Interfacing Using Relays

A *relay* is an excellent method of isolating a logic device from a high-voltage circuit. Figure 5-26 shows how a TTL or CMOS inverter could be interfaced with a relay. When the output of the inverter goes HIGH, the transistor is turned on and the relay is activated. When activated, the normally open (NO) contacts of the relay close as the armature clicks downward. When the output of the inverter in Fig. 5-26 goes LOW, the transistor stops conducting and the relay is deactivated. The armature springs upward to its normally closed (NC) position. The *clamp diode* across the relay coil prevents voltage spikes which might be induced in the system.

The circuit in Fig. 5-27(*a*) uses a relay to isolate an electric motor from the logic devices. Notice that the logic circuit and dc motor have separate power supplies. When the output of the inverter goes HIGH, the transistor is turned on and the NO contacts of the relay snap closed. The dc motor operates. When the output of the inverter goes LOW, the transistor stops conducting and the relay contacts spring back to their NC position. This turns off the motor.

Relay

The electric motor in Fig. 5-27(*a*) produces rotary motion. A solenoid is an electric device that can produce linear motion. A solenoid is being driven by a logic gate in Fig. 5-27(*b*). Note the separate power supplies. This circuit works the same as the motor interface circuit in Fig. 5-27(*a*).

Clamp diode

In summary, voltage and current characteristics of most buzzers, relays, electric motors, and solenoids are radically different from those of logic circuits. Most of these electric devices need special interfacing circuits to drive and isolate the devices from the logic circuits.

Logic device to relay interface

Self-Test

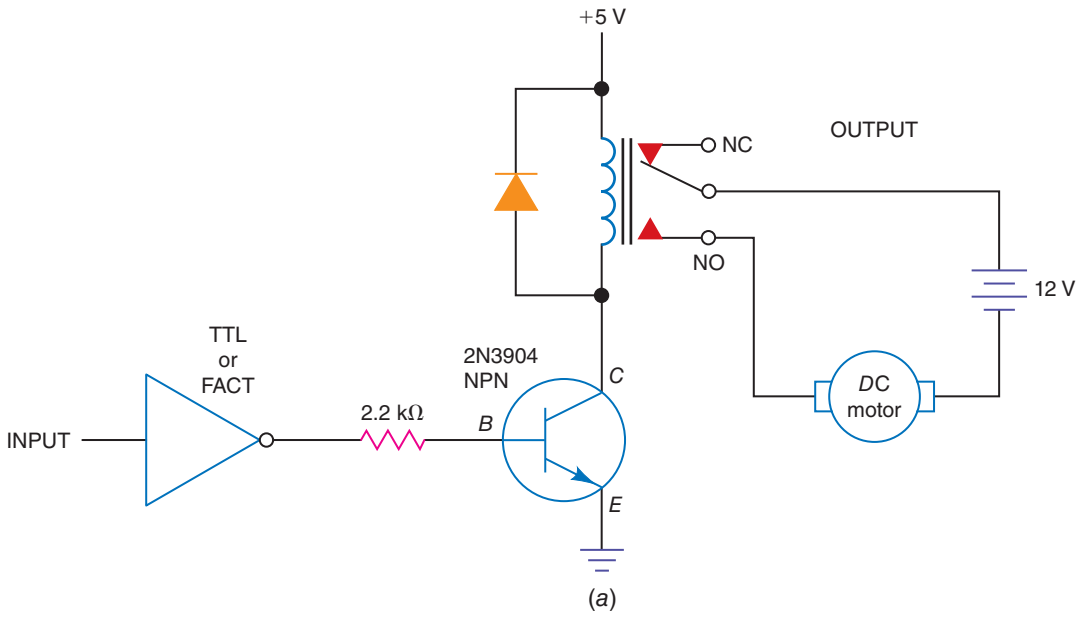
Supply the missing word(s) in each statement.

50. Refer to Fig. 5-25(*a*). If the piezo buzzer draws only 6 mA, it _____ (is, is not) possible for a 4000 series CMOS IC to drive the buzzer directly [see Fig. 5-6(*b*) for 4000 series data].
51. Refer to Fig. 5-25(*b*). When the input to the inverter goes LOW, the transistor turns _____ (off, on) and the buzzer _____ (does not sound, sounds).
52. Refer to Fig. 5-26. The purpose of the diode across the coil of the relay is to

suppress _____ (sound, transient voltages) induced in the circuit.

53. Refer to Fig. 5-27(*a*). The dc motor will run only when a _____ (HIGH, LOW) appears at the output of the inverter.
54. If an electric motor produces rotary motion then a solenoid produces _____ (linear, circular) motion.
55. The main purpose of the relay in Fig. 5-27 is to _____ (combine, isolate) the logic circuitry from the higher-voltage/current motor or solenoid.
56. Refer to Fig. 5-27(*a*). If the input to the inverter is LOW, its output goes HIGH which _____ (turns on, turns off) the NPN transistor.
57. Refer to Fig. 5-27(*a*). When the transistor is turned on, current flows through the coil of the relay and the armature snaps from the _____ (NC to the NO, NO to the NC) position which activates the motor circuit.

Logic device to motor interfacing



Logic device to solenoid interfacing

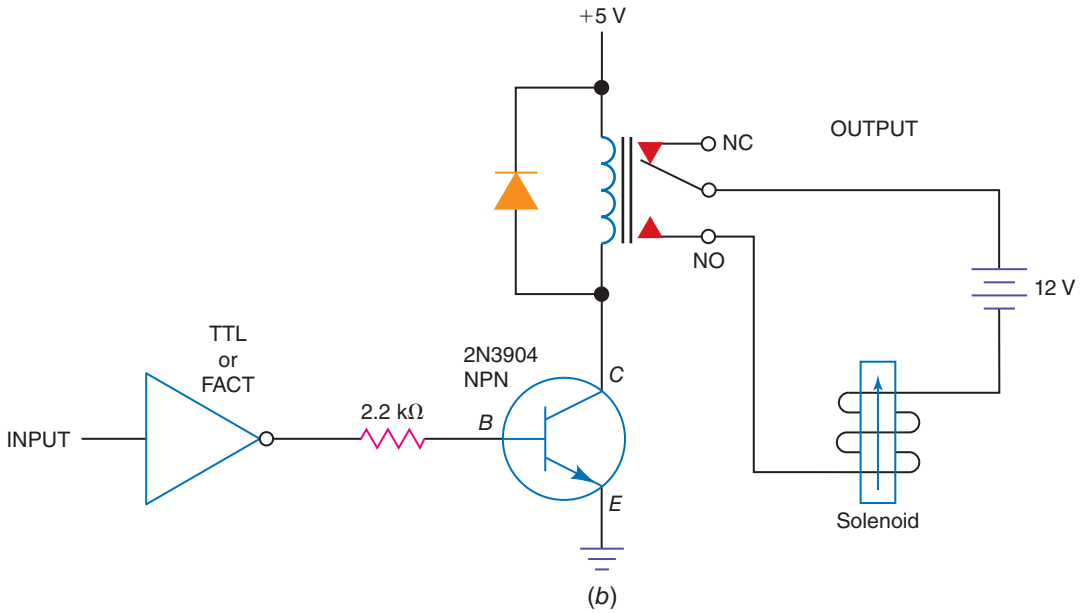


Fig. 5-27 Using a relay to isolate higher voltage/current circuits from digital circuits. (*a*) Interfacing TTL or CMOS with an electric motor. (*b*) Interfacing TTL or CMOS with a solenoid.

5-8 Optoisolators

The relay featured in Fig. 5-27 isolated the lower-voltage digital circuitry from the high-voltage/current devices such as a solenoid and electric motor. *Electromechanical relays* are relatively large and expensive but are a widely used method of control and isolation. Electromechanical relays can cause unwanted voltage spikes and noise due to the coil windings and opening and closing of contact points. A useful alternative to an electromagnetic relay when interfacing with digital circuits is the *optoisolator* or *optocoupler*. One close relative of the optoisolator is the *solid-state relay*.

One economical optoisolator is featured in Fig. 5-28. The *4N25 optoisolator* consists of a *gallium arsenide infrared-emitting diode* optically coupled to a silicon *phototransistor detector* enclosed in a six-pin dual in-line package (DIP). Figure 5-28(*a*) details the pin diagram for the 4N25 optoisolator with the names of the pins. On the input side, the LED is typically activated with a current of about 10 to 30 mA. When the input LED is activated, the light activates (turns on) the phototransistor. With no current through the LED the output phototransistor of the optoisolator is turned off (high resistance from emitter to collector).

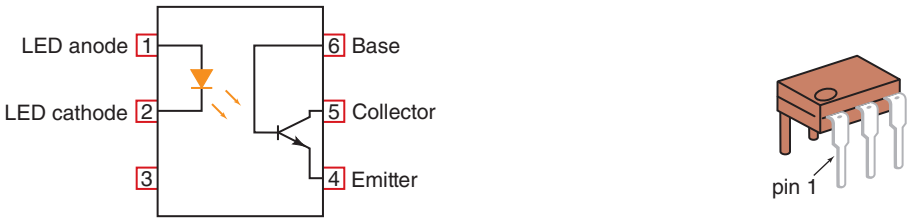
A simple test circuit using the 4N25 optoisolator is shown in Fig. 5-28(*b*). The digital signal from the output of a TTL or FACT inverter directly drives the infrared-emitting diode. The circuit is designed so the LED is activated when the output of the inverter goes LOW, which allows the inverter to sink the 10 to 20 mA LED current to ground. When the LED is activated, infrared light shines (inside the package) activating the phototransistor. The transistor is turned on (low resistance from emitter to collector) dropping the voltage at the collector (OUTPUT) to near 0 V. If the output of the inverter goes HIGH, the LED does not light and the NPN phototransistor turns off (high resistance from emitter to collector). The output (at the collector) is pulled to about +12 V (HIGH) by the 10-kΩ pull-up resistor. In this example, notice that the input side of the circuit operates on +5 V while the output side in this example uses a separate +12-V power supply. In summary, the input and output sides of the circuit are isolated from one another.

In Fig. 5-28(*b*), when pin 2 of the optoisolator goes LOW, the output at the collector of the transistor goes LOW. The grounds of the separate power supplies should not be connected to complete the isolation between the low- and high-voltage sides of the optoisolator.

Optoisolator

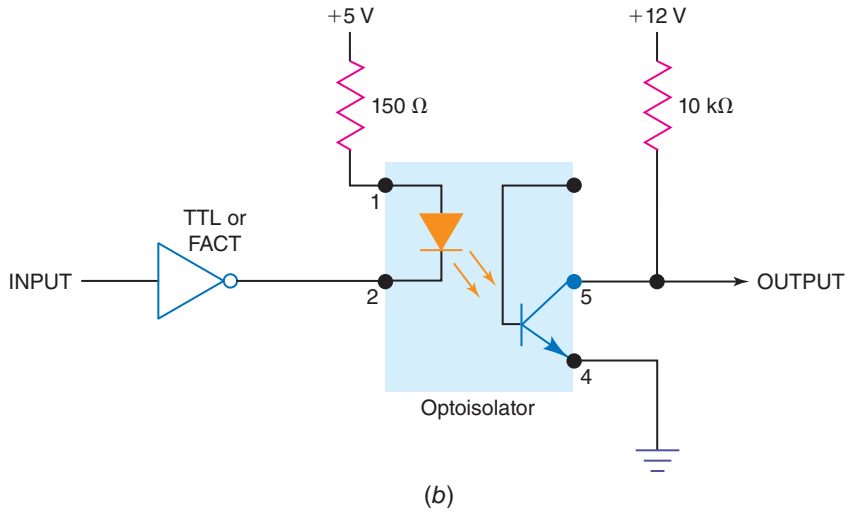
A simple application of the optoisolator being used to interface between TTL circuitry and a piezo buzzer is diagrammed in Fig. 5-28(*c*). In this example the pull-up resistor is removed because we are using the NPN phototransistor in the optoisolator to sink the 2 to 4 mA of current when the transistor is activated. A LOW at the output of the inverter (pin 2 of optoisolator) activates the LED, which in turn activates the phototransistor.

To control heavier loads using the optoisolator, we could attach a power transistor to the output as is done in Fig. 5-28(*d*). In this example, if the LED is activated, it activates the phototransistor. The output of the optoisolator (pin 5) drops LOW, which turns off the power transistor. The emitter-to-collector resistance of the power transistor is high, turning off the dc motor. When the output of the TTL inverter goes HIGH, it turns off the LED and the phototransistor in the optoisolator. The voltage at output pin 5 goes positive, which turns on the power transistor and operates the dc motor.

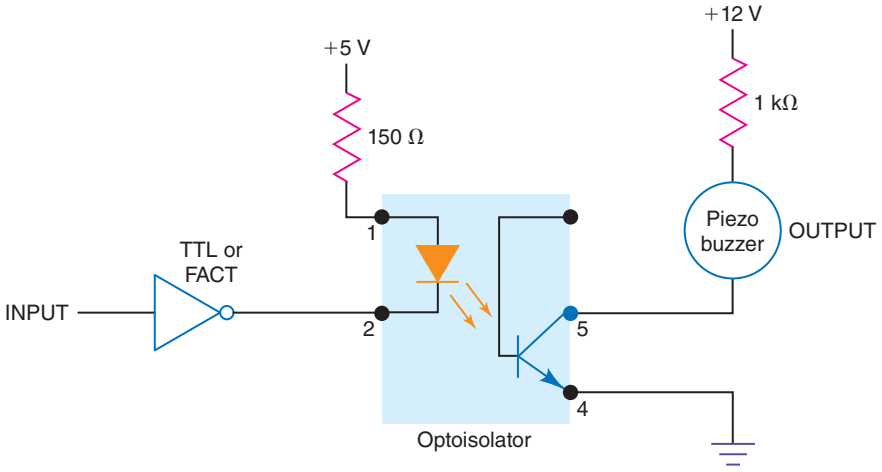


(*a*)

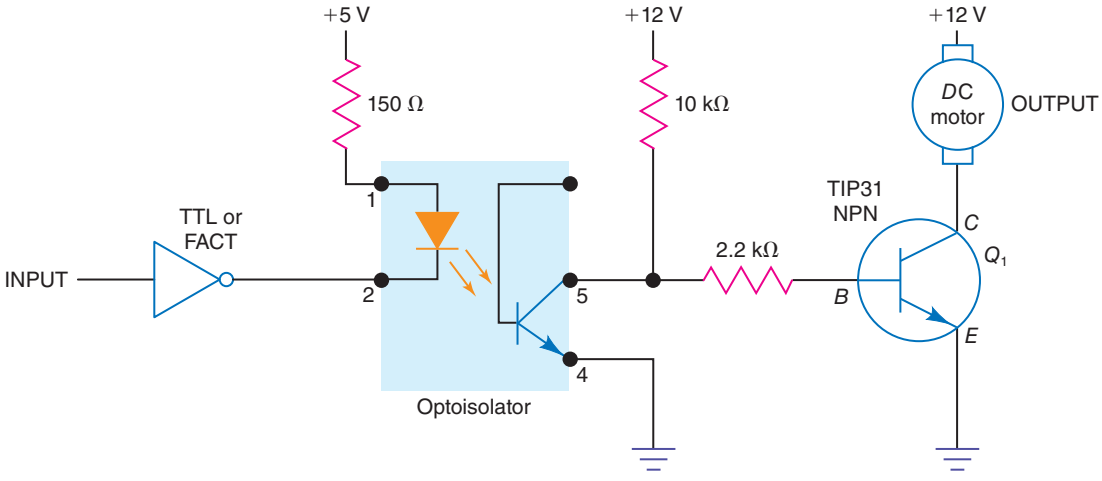
Fig. 5-28 (*a*) The 4N25 optoisolator pin out and six-pin DIP.



(*b*)



(*c*)



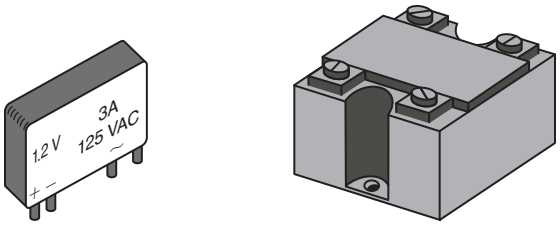
(*d*)

Fig. 5-28 (cont.) (*b*) Basic optoisolator circuit separates 5-V and 12-V circuits. (*c*) Optoisolator driving piezo buzzer. (*d*) Optoisolator isolating low-voltage digital circuit from high-voltage/current motor circuit.

If the power transistor (or other power-handling device such as a triac) in Fig. 5-28(*d*) were housed in the isolation unit, the entire device is sometimes a *solid-state relay*. Solid-state relays can be purchased to handle a variety of outputs included in either ac or dc loads. The output circuitry in a solid-state relay may be more complicated than that shown in Fig. 5-28(*d*).

Several examples of solid-state relay packages are shown in Fig. 5-29. The unit in Fig. 5-29(*a*) is a smaller PC-mounted unit. The larger bolted-on solid-state relay has screw terminals and can handle greater ac currents and voltages.

In summary, it is common to isolate digital circuitry from some devices because of high operating voltages and currents or because of dangerous feedback in the form of voltage spikes and noise. Traditionally, electromagnetic relays have been used for isolation, but optoisolators and solid-state relays are an inexpensive and effective alternative when interfacing with digital circuits. A typical optoisolator, shown in Fig. 5-28(*a*), contains an infrared-emitting diode that activates a phototransistor. If you are building an interface project using the parallel port from an IBM-compatible PC, you will want to use optoisolators between your circuits and the computer. The PC parallel-port outputs and inputs operate with TTL level signals. Good isolation protects your computer from voltage spikes and noise.



Solid-state relay

Fig. 5-29 (*a*) Solid-state relay—small PC-mounted package. (*b*) Solid-state relay—heavy-duty package.

Self-Test

Supply the missing word(s) in each statement.

58. Refer to Fig. 5-27(*a*). The _____ (relay, transistor) isolates the digital circuitry from the higher-voltage and noisy dc motor circuit.
59. The 4N25 optoisolator device contains an infrared-emitting diode optically coupled to a _____ (phototransistor, triac) detector enclosed in a six-pin DIP.
60. Refer to Fig. 5-28(*b*). If the output of the TTL inverter goes LOW, the infrared LED _____ (does not light, lights), which _____ (activates, deactivates) the phototransistor and the voltage at pin 5 (output) goes _____ (HIGH, LOW).
61. Refer to Fig. 5-28(*b*). The 10-kΩ resistor connecting the collector of the phototransistor to +12 V is called a(n) _____ resistor.
62. Refer to Fig. 5-28(*c*). If the output of the TTL inverter goes HIGH, the LED _____ (does not light, lights), which _____ (activates, deactivates) the phototransistor and the voltage at pin 5 (output) goes (HIGH, LOW) and the buzzer _____ (does not sound, sounds).
63. Refer to Fig. 5-28(*d*). If the output of the TTL inverter goes HIGH, the LED does not light, which deactivates (turns off) the phototransistor and the voltage at pin 5 (output) goes more positive. This positive-going voltage at the base of the power transistor _____ (turns on, turns off) Q_1 and the dc motor _____ (does not run, runs).
64. The _____ (electromagnetic, solid-state) relay is a close relative of an optoisolator.
65. Refer to Fig. 5-28(*c*). If the *input* to the inverter is HIGH then the piezo buzzer _____ (will not sound, will sound).

5-9 Interfacing with Servo and Stepper Motors

The dc motor mentioned previously in this chapter is a device that rotates continuously when power is applied. The control over the dc motor is limited to ON-OFF, or if you reverse the direction of current flow through the motor the direction of rotation reverses. A simple dc motor does not facilitate good speed control, and it will not rotate a given number of degrees to stop for angular positioning. Where precision positioning or exacting speed are required, a regular dc motor does not do the job.

Servo Motor

Both the servo and the stepper motor can rotate to a given position and stop and also reverse direction. The word "servo" is short for *servo motor*. "Servo" is a general term for a motor in which either the angular position or speed can be controlled precisely by a servo loop which uses feedback from the output back to input for control. The most common servos are the inexpensive units used in model aircraft, model cars, and some educational robot kits. These servos are geared-down dc motors with built-in electronics that respond to different pulse widths. These servos use feedback to ensure the device rotates to and stays at the current angular position. These servos are popular in remote-control models and toys. They commonly have three wires (one wire for input and two wires for power) and are not commonly used for continuous rotation.

Internet Connection

Find more information on how servo motors work.

The position of a hobby servo's output shaft is determined by the width or duration of the control pulse. The width of the control pulse commonly varies from about 1 to 2 ms. The concept of controlling the hobby servo motor using a control pulse is sketched in Fig. 5-30. The *pulse generator* emits a constant frequency of about 50 Hz. The *pulse width* (or *pulse duration*) can be changed by the operator using an input device such as a potentiometer or joystick. The internally geared motor and feedback-and-control circuitry inside the servo motor responds to the continuous stream of pulses by rotating to a new angular position. As an example, if the pulse width is 1.5 ms, the shaft moves to the middle of its range as illustrated in Fig. 5-30(*a*). If the pulse width decreases to 1 ms, the output shaft takes a new position rotating about 90° clockwise as shown in Fig. 5-30(*b*). Finally if the pulse width increases to 2 ms as in Fig. 5-30(*c*), the output shaft moves counterclockwise to its new position.

The changing of the pulse duration is called *pulse-width modulation* (PWM). In the example shown in Fig. 5-30, the pulse generator outputs a constant frequency of 50 Hz but the pulse width can be adjusted.

A sketch of the internal functions of a servo motor is shown in Fig. 5-30(*d*). The servo contains a dc motor and speed-reducing gear. The last gear drives the output shaft and is also connected to a potentiometer. The potentiometer senses the angular position of the output. The varying resistance of the potentiometer is fed back to the control circuitry and repeatedly *compares* the pulse width of the external (input) pulse with an internally generated pulse from a one-shot inside the control circuit. The internal pulse width is varied based on the feedback from the potentiometer.

For the servo motor in Fig. 5-30 suppose the *external pulse width is 1.5-ms* and the internal pulse width is 1.0-ms. After comparing the pulses, the control circuitry would start to rotate the output shaft in a CCW direction. After each external pulse (50 times per second) the control circuitry would make a small CCW shaft adjustment until the external and internal pulse widths are both 1.5-ms. At this point the shaft would stop in the position shown in Fig. 5-30(*a*).

Next for the servo motor in Fig. 5-30 suppose the *external pulse width changes to 1 ms* and the internal pulse width, based on the feedback from the potentiometer, is at 1.5 ms. After comparing the pulses, the control circuitry would start to rotate the output shaft in a CW direction. After each external pulse (50 times per second) the control circuitry would make a small CW shaft adjustment until the external and internal pulse width are both 1.0 ms. At this point the shaft would stop in the position shown in Fig. 5-30(*b*).

When both external and internal pulse widths are equal for the servo motor in Fig. 5-30, the control circuitry stops the dc motor. For instance, if both the external and internal pulse widths are 2.0 ms, then the output shaft would freeze in the position shown in Fig. 5-30(*c*).

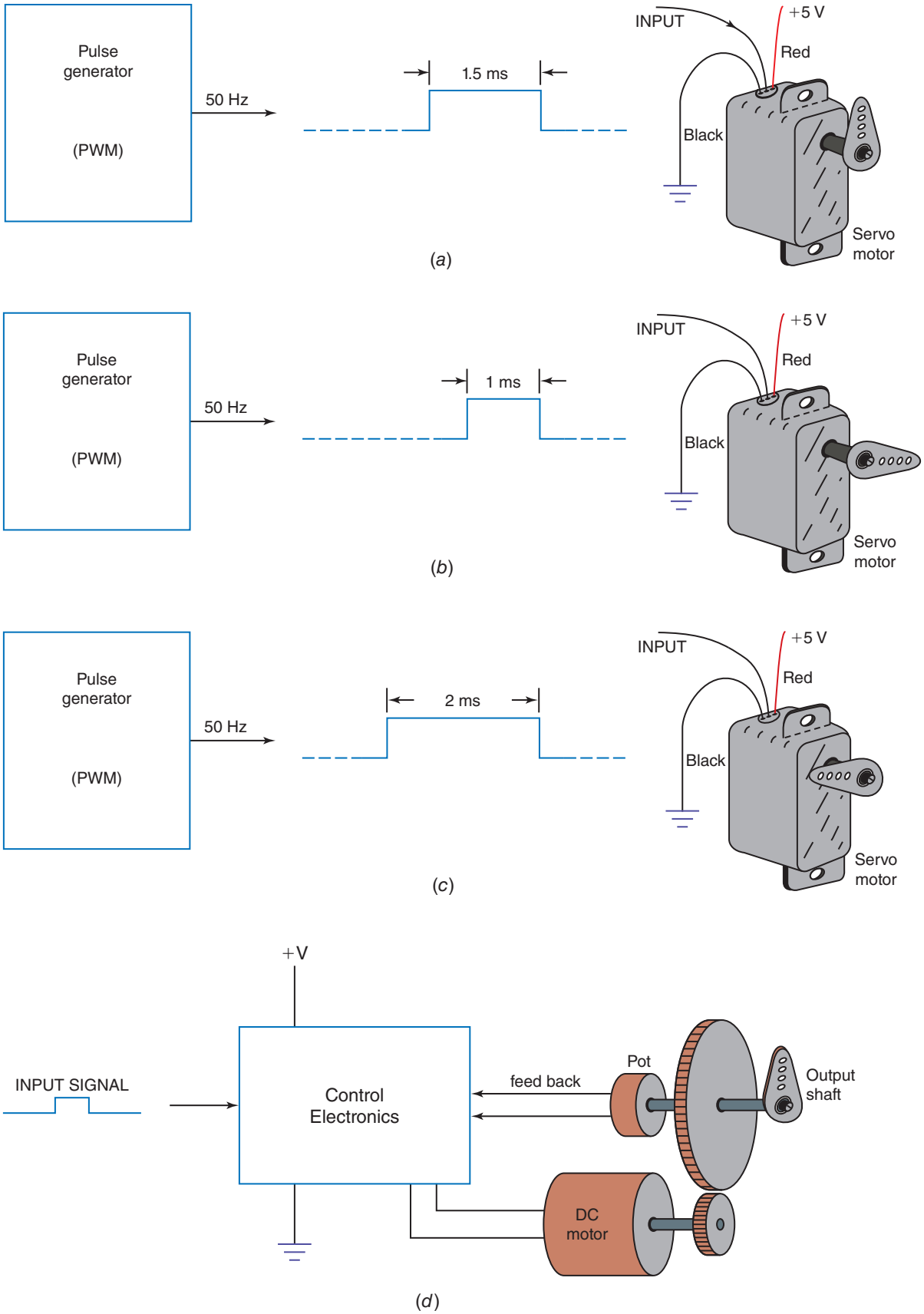


Fig. 5-30 Controlling the angular position of a hobby servo motor using pulse-width modulation (PWM). (*Note:* Some hobby servos rotate in the opposite direction as the pulse width increases.)

Some hobby servo motors may have opposite rotational characteristics from the unit featured in Fig. 5-30. Some servos are internally wired so that a narrow pulse (1 ms) would cause full CCW rotation instead of CW rotation shown in Fig. 5-30(*b*). Likewise, a wide pulse (2 ms) would cause full CW rotation. This is opposite that pictured in Fig. 5-30(*c*).

Stepper Motor

The *stepper motor* can rotate a *fixed angle* with each input pulse. A common four-wire stepper motor is sketched in Fig. 5-31(*a*). From the label you can see some of the important characteristics of the stepper motor. This stepper motor is designed to operate on 5-V dc. Each of the two coils (L_1 and L_2) has a resistance of 20 Ω. Using Ohm's law we calculate that the dc current through each coil is 0.25 A or 250 mA ($I = V/R$, substituting $I = 5/20$, then $I = 0.25$ A). The 2 ph means this is a *two-phase* or *bipolar* (as opposed to unipolar) stepper motor. *Bipolar stepper motors* typically have four wires coming from the case as is shown in Fig. 5-31(*a*). Unipolar stepper motors can have five to eight wires coming from the unit. The label on the stepper motor in Fig. 5-31(*a*) indicates that each step of the motor is 18° (meaning each input pulse rotates the shaft of the stepper motor an angle of 18°).

Control sequence for stepper motor

Bipolar stepper motor

Other important characteristics that might be given in a catalog or manufacturer's data sheet are physical size, inductance of coils, holding torque, and detent torque of motor. A schematic of the stepper motor's coils would probably be included. Notice that there are two coils in the schematic diagram of this stepper motor. A control sequence is also usually given for a stepper motor.

A simplified exploded view of a stepper motor is drawn in Fig. 5-31(*c*). Of interest is the *permanent magnet rotor* attached to the output shaft. Some stepper motors have a gearlike soft-iron rotor with the number of poles unequal to the number of poles in the stator. These are referred to as *variable reluctance stepper motors*. There are two stators as shown in Fig. 5-31(*c*). A series of poles are visible on both stator 1 and 2. The number of poles on a single stator are the number of steps required to complete one revolution of the stepper motor. For instance, if a stepper motor has a single step angle of 18°, you can calculate the number of steps in a revolution as

Variable reluctance stepper motor

Degs. in circle/single-step angle = steps per revolution

360°/18° = 20 steps per revolution

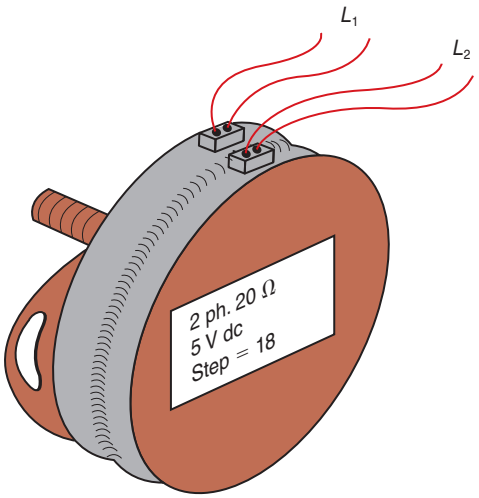
In this example, each stator has 20 visible poles. Notice that the poles of stator 1 and 2 are not aligned but are one-half the single-step angle, or 9° different. Common stepper motors are available in step angles of 0.9°, 1.8°, 3.6°, 7.5°, 15°, and 18°.

Stepper Motor Control Sequence

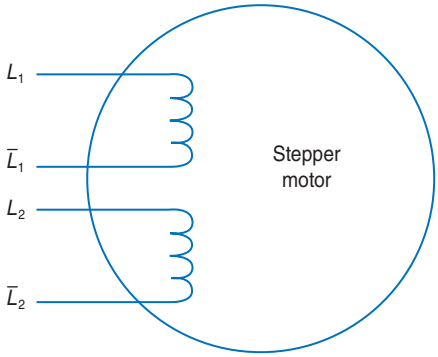
The *stepper motor* responds to a standard control sequence. That control sequence for a sample bipolar stepper motor is charted in Fig. 5-32(*a*). Step 1 on the chart shows coil lead L_1 at about +5 V, while the other end of the coil ($\overline{L}_1$) is grounded. Likewise, step 1 also shows coil lead L_2 at about +5 V while the other end of the coil ($\overline{L}_2$) is grounded. In step 2, note that the polarity of coil $L_1/\overline{L}_1$ is reversed while $L_2/\overline{L}_2$ stays the same, causing a clockwise (CW) rotation of one step (18° for the sample stepper motor). In step 3, only the polarity of coil $L_2/\overline{L}_2$ is reversed, causing a second CW rotation of one step. In step 4, only the polarity of coil $L_1/\overline{L}_1$ is reversed, which causes a third CW rotation of a single step. In step 1, only the polarity of $L_2/\overline{L}_2$ has been reversed, causing a fourth CW rotation of a single step. Continuing the sequence of steps 2, 3, 4, 1, 2, 3, and so on would cause the stepper motor to continue rotating in a CW direction 18° at each step.

To reverse the stepper motor's direction of rotation, move upward on the control sequence chart in Fig. 5-32(*a*). Suppose we are at step 2 at the bottom of the chart. Moving upward to step 1, the polarity of only coil $L_1/\overline{L}_1$ changes and the motor rotates one step counterclockwise (CCW). Moving upward again to step 4, the polarity of only coil $L_2/\overline{L}_2$ changes and the motor rotates a second step CCW. In step 3, the polarity of only coil $L_1/\overline{L}_1$ changes as the motor rotates a third step CCW. CCW rotation continues as long as the sequence 2, 1, 4, 3, 2, 1, 4, 3, and so forth from the control sequence is followed.

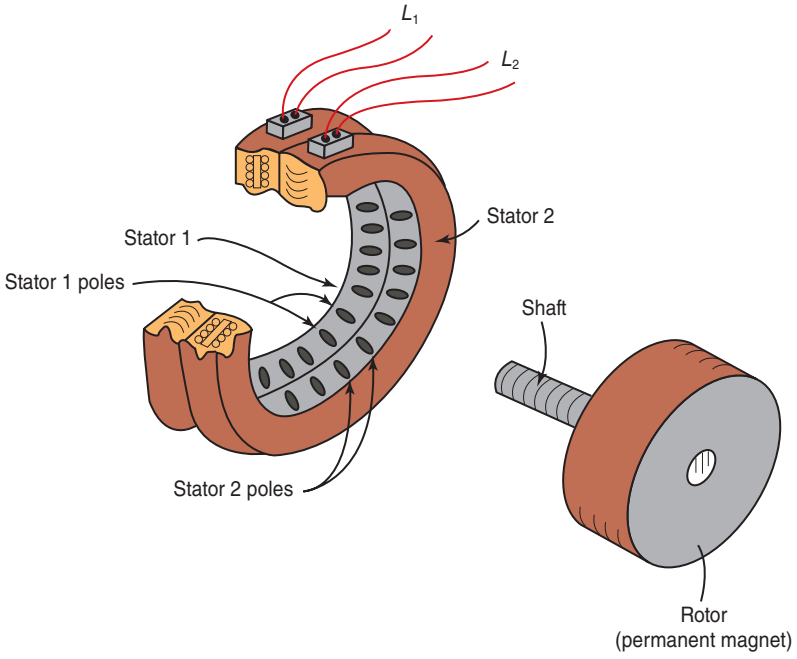
In summary, CW rotation occurs when you progress downward on the control sequence



(*a*)



(*b*)



(*c*)

Fig. 5-31 (*a*) Typical four-wire stepper motor. (*b*) Schematic of four-wire bipolar stepper motor. (*c*) Simple exploded view of typical permanent magnet type stepper motor.

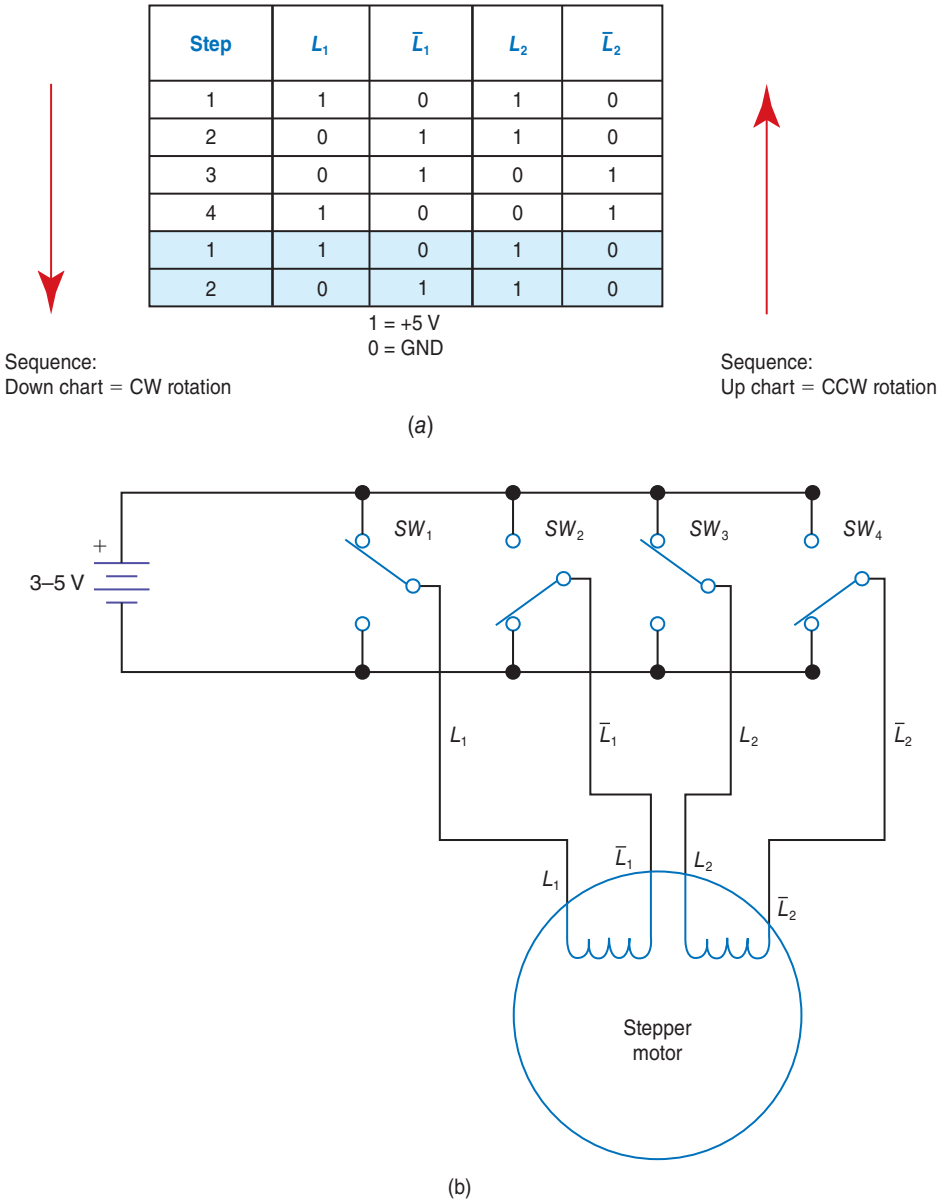


Fig. 5-32 (*a*) Bipolar control sequence chart. (*b*) Test circuit for hand checking a four-wire bipolar stepper motor.

chart in Fig. 5-32(*a*). Counterclockwise rotation occurs when you stop at any step on the chart in Fig. 5-32(*a*) and then progress upward. The stepper motor is excellent at exact angular positioning, which is important in computer disk drives and printers, robotics and all types of automated machinery, and NC machine tools. The stepper motor can also be used for continuous rotation applications where the exact speed of rotation is important. Continuous rotation of a stepper motor can be accomplished by sequencing through the control sequence quickly. For instance, suppose you want the motor from Fig. 5-31(*a*) to rotate at 600 rpm. This means that the motor rotates 10 revolutions per second (600 rpm/60 s = 10 rev/s). You would have to send the code from the control sequence in Fig. 5-32(*a*) to the stepper motor at a frequency of 200 Hz (10 rev/s × 20 steps per rev = 200 Hz).

Stepper Motor Interfacing

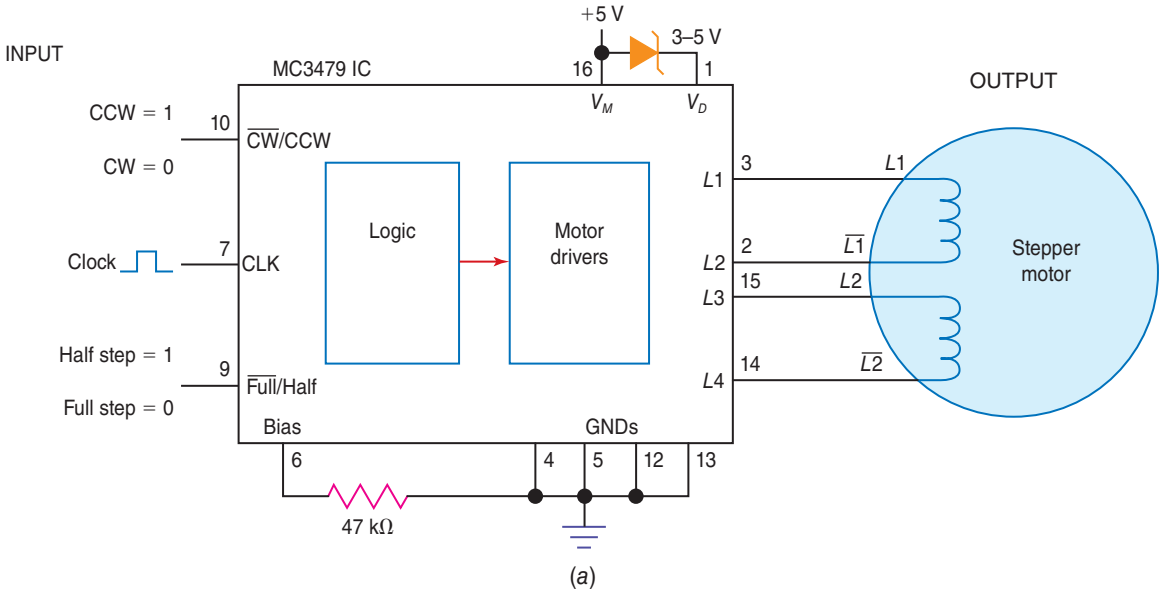
Consider the simple test circuit in Fig. 5-32(*b*) which could be used to check a bipolar stepper motor. The single-pole, double-throw (SPDT) switches are currently set to deliver the voltages defined by step 1 on the control sequence

chart in Fig. 5-32(*a*). As you change the voltage inputs to the coils as specified by step 2, then step 3, and then step 4, and so on, the motor rotates by stepping in a CW direction. If you reverse the order and sequence upward on the control sequence chart in Fig. 5-32(*a*), the motor reverses and rotates by stepping in a CCW direction. The circuit in Fig. 5-32(*b*) is an impractical interface circuit but can be used for hand testing a stepper motor.

A practical bipolar stepper motor interface is based on the *MC3479 stepper motor driver IC* from Motorola. The schematic diagram in Fig. 5-33(*a*) details how you might wire the MC3479 driver IC to a bipolar stepper motor. The MC3479 IC has a logic section that generates the proper control sequence to drive a bipolar stepper motor. The motor driver section has a drive capability of 350 mA per coil. Each step of the motor is triggered by a single positive-going clock pulse entering the CLK input (pin 7) of the IC. One input control sets the direction of rotation of the stepper motor. A logic 0 at the CW/CCW input to the MC3479 allows CW rotation, while a logic 1 input at pin 10 changes to CCW rotation of the stepper motor.

Bipolar stepper motor

The MC3479 IC also has a full/half input (pin 9) which can change the operation of the



(*a*)

Step	L_1	L_2	L_3	L_4
1	1	0	1	0
2	0	1	1	0
3	0	1	0	1
4	1	0	0	1
1	1	0	1	0
2	0	1	1	0

(*b*)

Step	L_1	L_2	L_3	L_4
1	1	0	1	0
2	1	1	1	0
3	0	1	1	0
4	0	1	1	1
5	0	1	0	1
6	1	1	0	1
7	1	0	0	1
8	1	0	1	1
1	1	0	1	0
2	1	1	1	0
3	0	1	1	0
4	0	1	1	1

(*c*)

Fig. 5-33 (*a*) Using the MC3479 stepper motor driver IC to interface with a bipolar stepper motor. (*b*) Control sequence of the MC3479 IC in the full-step mode. (*c*) Control sequence for the MC3479 IC in the half-step mode.

Internet Connection

Find the data sheet for the MC3479 IC at onsemi.com.

IC from stepping by full steps or half steps. In the *full-step mode,* the stepper motor featured in Fig. 5-31 rotates 18° for each clock pulse (each single step). In the *half-step mode,* the stepper motor rotates half of a regular step or only 9° per clock pulse. The *control sequence* used by the MC3479 IC in the full-step mode is shown in chart form in Fig. 5-33(*b*). Note that this is the same control sequence used in Fig. 5-32(*a*). The control sequence used by the MC3479 IC in the half-step mode is detailed in chart form in Fig. 5-33(*c*). These control sequences are standard for bipolar or two-phase stepper motors and are built into the logic block of the *MC3479 stepper motor driver IC*. Specialized ICs such as the MC3479 stepper motor driver are usually the simplest and least expensive method of solving the problem of generating the correct control sequences, allowing for either CW or CCW rotation, and allowing the stepper motor to operate in either the full-step or half-step mode. The motor driver circuitry of the MC3479 is included inside the IC so lower-power stepper motors can be driven directly by the IC as illustrated in Fig. 5-33(*a*).

Unipolar stepper motor

MC 3479 stepper motor driver IC

5804 stepper motor driver IC

Unipolar stepper moter

Unipolar or four-phase stepper motors have five or more leads exiting the motor. Specialized ICs are also available for generating the correct control sequence for these four-phase motors. One such product is the *EDE1200 unipolar stepper motor IC* by E-LAB Engineering. The EDE1200 has many of the same features of the Motorola MC3479 except it does not have the motor drivers inside the IC. External driver transistors or a driver IC must be used in conjunction with the EDE1200 unipolar stepper motor IC. The control sequence for four-phase (unipolar) and two-phase (bipolar) stepper motors is different.

Note the use in Fig. 5-34 of two power supplies (+5 V and +12 V), both connected to the same 5804 IC. The +5-V supply powers the

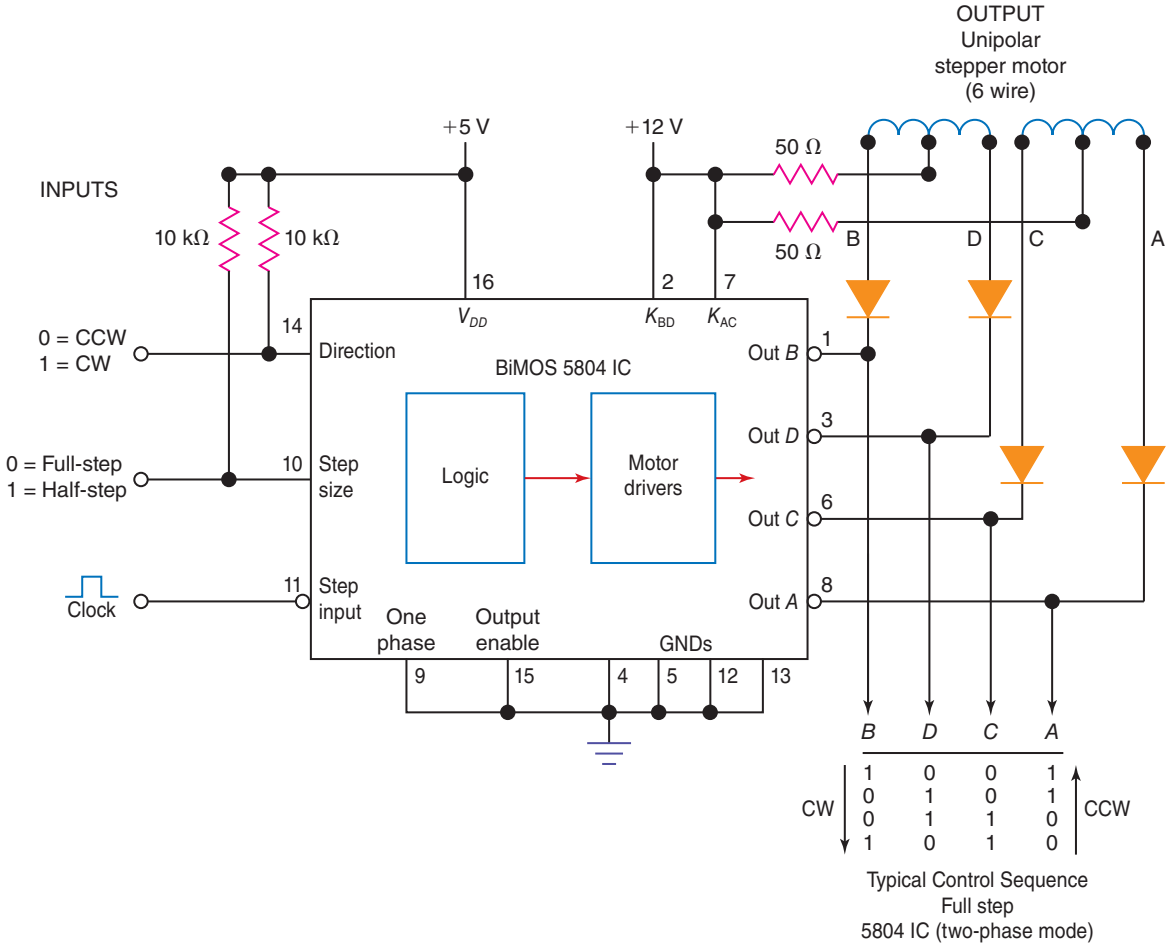


Fig. 5-34 A six-wire unipolar stepper motor is being driven by the BiMOS 5804 stepper motor translator/driver IC in this schematic diagram.

input and logic sections of the 5804 IC. The +12-V supply powers the high current, high-voltage active LOW outputs.

A typical full-step control sequence generated by the 5804 IC's logic section is shown at the lower right in Fig. 5-34. When a 5804 output goes LOW, it sinks the high current from the coils of the stepper motor.

The four Schottky diodes allow normal currents to flow through while protecting the 5804 IC from damaging voltage spikes. Pull-up resistors (two 10 kΩ) are shown at the upper left of Fig. 5-34.

This is a circuit you could construct in the lab.

Summary

In summary, a simple permanent magnet dc motor is good for continuous rotation applications. Servo motors (such as the hobby servo motor) are good for angular positioning of a shaft. Pulse-width modulation (PWM) is a technique used to rotate the servo to an exact angular position. Stepper motors can be used for angular positioning of a shaft or for controlled continuous rotation.

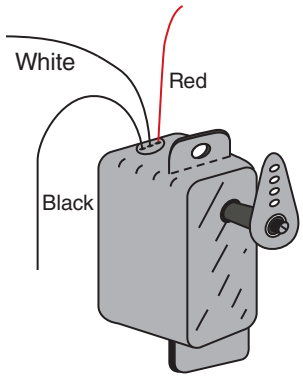


Fig. 5-35 Art for self-test questions 69, 70 and 71.

Self-Test

Answer the following questions.

66. The _____ (dc motor, servo motor) is a good choice for continuous rotation applications not requiring speed control.
67. The _____ (dc motor, stepper motor) is a good choice for applications that require exact angular positioning of a shaft.
68. Both the servo and stepper motors can be used in applications that require exact angular positioning. (T or F)
69. Refer to Fig. 5-35. This device, which might be found in a radio-controlled airplane or car, is called a _____ (servo motor, stepper motor).
70. Refer to Fig. 5-35. The red lead is connected to + of the power supply, the black lead to ground, and the white lead to the servo is the _____ (input, output) lead.
71. Refer to Fig. 5-35. This hobby servo motor is controlled by inputs from a pulse generator using _____ (pulse-amplitude, pulse-width) modulation.
72. The device featured in Fig. 5-31 is a _____ (bipolar, unipolar) stepper motor.
73. The chart in Fig. 5-32(*a*) shows the _____ sequence for a _____ (bipolar, unipolar) stepper motor.
74. Refer to Fig. 5-32(*a*). If we are at step 4 and progress upward on the control sequence chart to step 3, the stepper motor rotates in a _____ (CCW, CW) direction.
75. Refer to Fig. 5-33(*a*). The _____ (logic, motor drive) block inside the MC3479 IC assures that the control sequence for driving a bipolar stepper motor is followed.
76. Refer to Fig. 5-33(*a*). The maximum drive current for each coil available using the MC3479 is _____ (10, 350) mA, which allows it to drive many smaller stepper motors directly.
77. Refer to Fig. 5-33(*a*) and assume input pins 9 and 10 are HIGH. When a clock pulse enters pin 7, the attached stepper motor rotates _____ (CCW, CW) a _____ (full step, half step).

Internet Connection

For information on servo mechanisms and stepper motors see en.wikipedia.org

5-10 Using Hall-Effect Sensors

The *Hall-effect sensor* is often used to solve difficult switching applications. Hall-effect sensors are *magnetically activated* sensors or switches. Hall-effect sensors are immune to environmental contaminants and are suitable for use under severe conditions. Hall-effect sensors operate reliably under oily and dirty, hot or cold, bright or dark, and wet or dry conditions.

Several examples of where Hall-effect sensors and switches might be used in a modern automobile are graphically summarized in Fig. 5-36. Hall-effect sensors and switches are also used in other applications such as ignition systems, security systems, mechanical limit switches, computers, printers, disk drives, keyboards, machine tools, position detectors, and brushless dc motor commutators.

Many of the advances in automotive technology revolve around accurate reliable sensors sending data to the central computer. The central computer gathers the sensor data and controls many functions of the engine and other systems of the automobile. The computer also gathers and stores data from the sensors to be used by the *on-board diagnostics* system (OBD I or the newer OBD II). Only some of the many sensors in an automobile are Hall-effect devices.

Basic Hall-Effect Sensor

The basic Hall-effect sensor is a semiconductor material represented in Fig. 5-37(*a*). A source voltage (bias voltage) will cause a constant bias current to flow through the Hall-effect sensor. As demonstrated in Fig. 5-37(*a*), when a magnetic field is present, a voltage is generated by the Hall-effect sensor. The Hall voltage is proportional to the strength of the magnetic field. As an example, if no magnetic field is present, then the sensor will produce no Hall-effect voltage at the output. As the magnetic field increases, the Hall voltage increases proportionally. In summary, if a biased Hall sensor is placed in a magnetic field, the voltage output

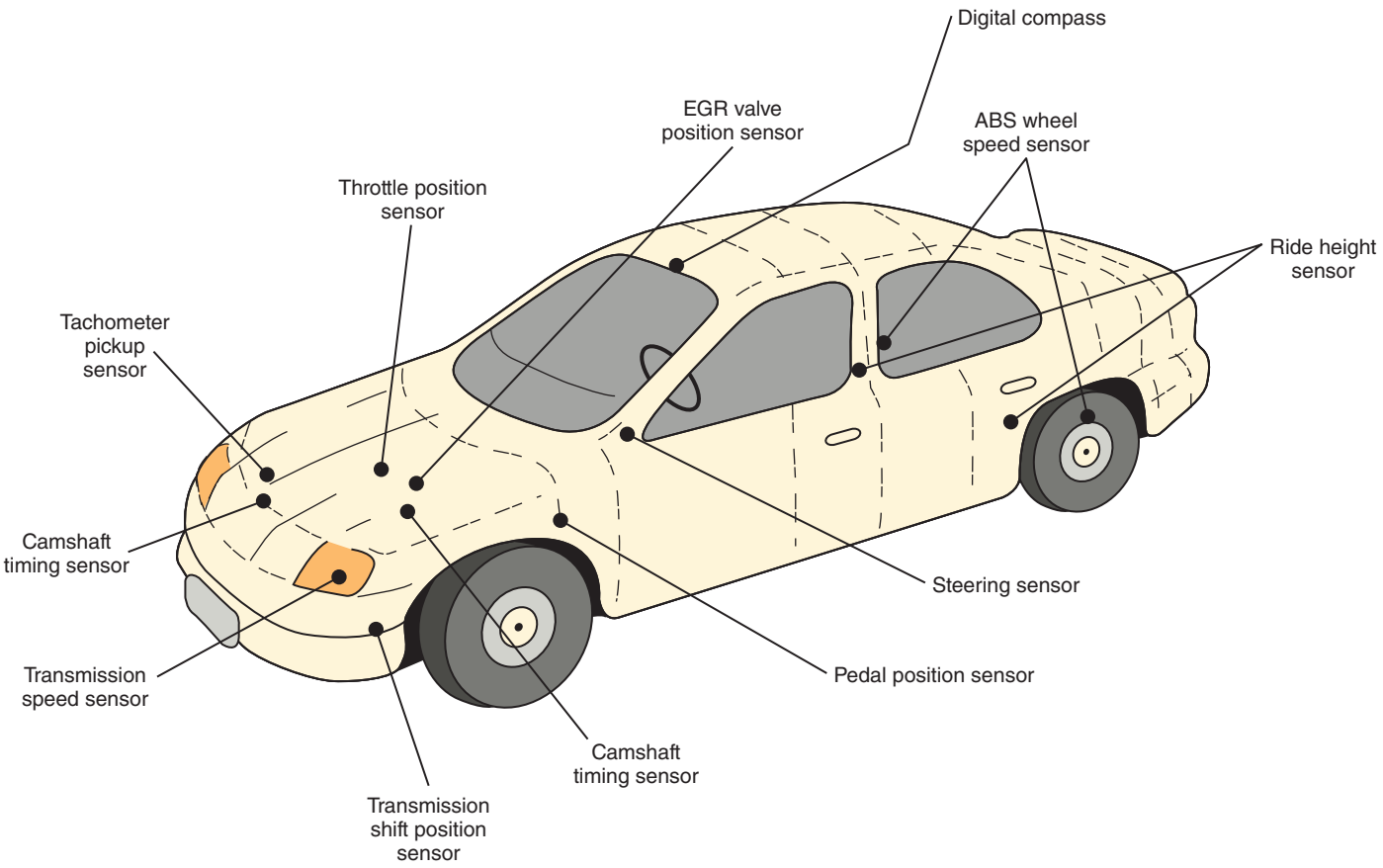
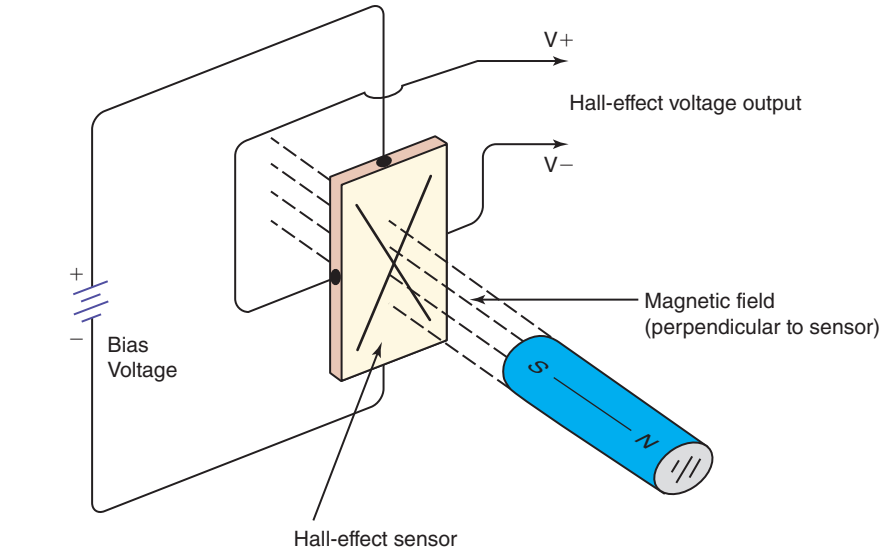
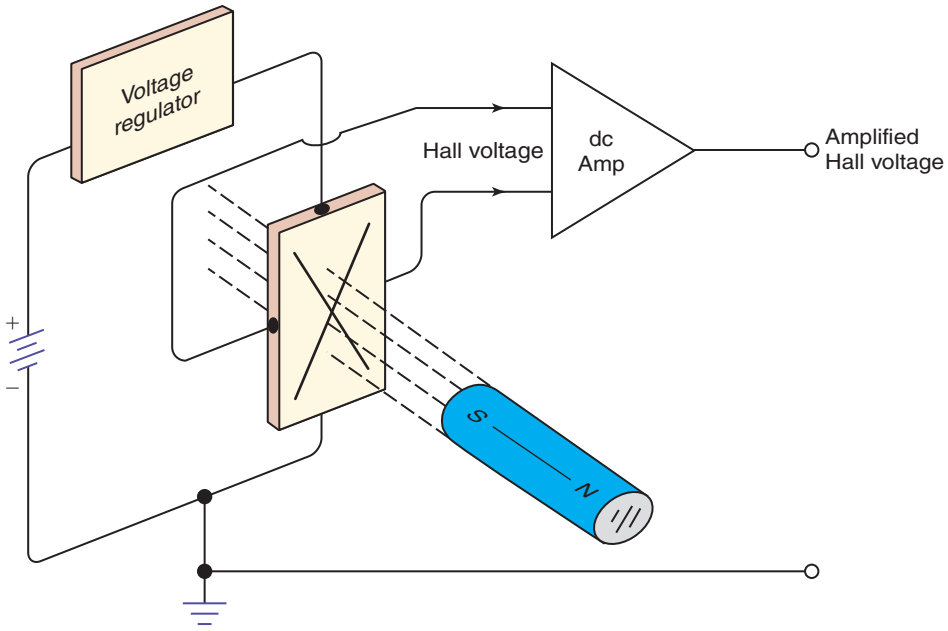


Fig. 5-36 Hall-effect sensors used in a modern automobile.



(*a*)



(*b*)

Fig. 5-37 Hall-effect sensor. (*a*) Sensor produces a small voltage proportional to the strength of the magnetic field. (*b*) Adding a voltage regulator and dc amplifier to produce a more usable Hall-effect sensor.

will be directly proportional to the strength of the magnetic field. The Hall effect was discovered by E. F. Hall in 1879.

The output voltage of the Hall-effect sensor is small and is commonly amplified to be more useful. A Hall-effect sensor with a dc amplifier and voltage regulator is sketched in Fig. 5-37(*b*). The output voltage is linear and proportional to the strength of the magnetic field.

Hall-Effect Switch

Hall-effect devices are produced in rugged IC packages. Some are designed to generate a linear output voltage such as the sensor sketched in Fig. 5-37(*b*). Others are designed to operate as switches. A commercial Hall-effect switch is featured in Fig. 5-38. The Hall-effect switch detailed in Fig. 5-38 is the *3132 bipolar Hall-effect switch* produced by Allegro Microsystems, Inc.

Internet Connection

For more information on Hall-effect sensors and switches, visit www.allegromicro.com.

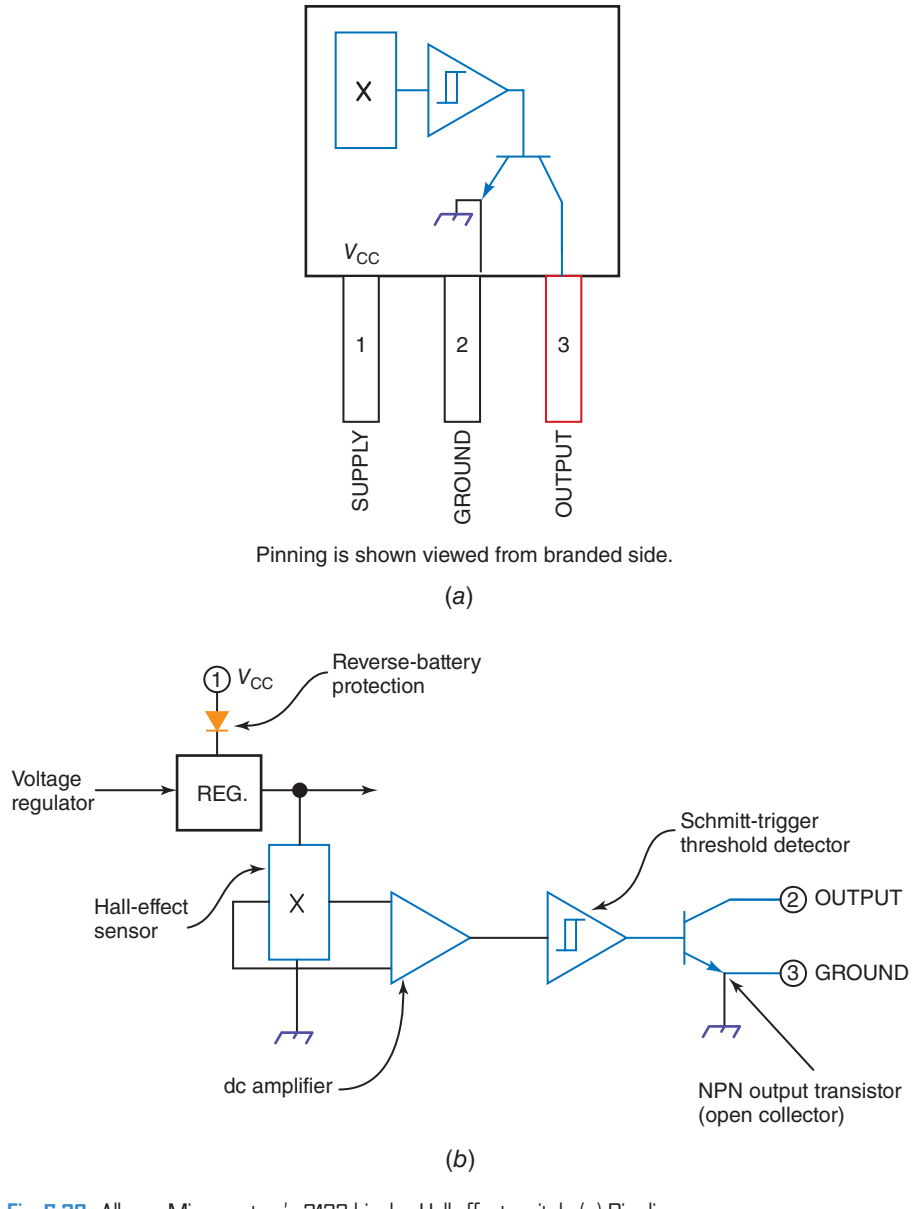
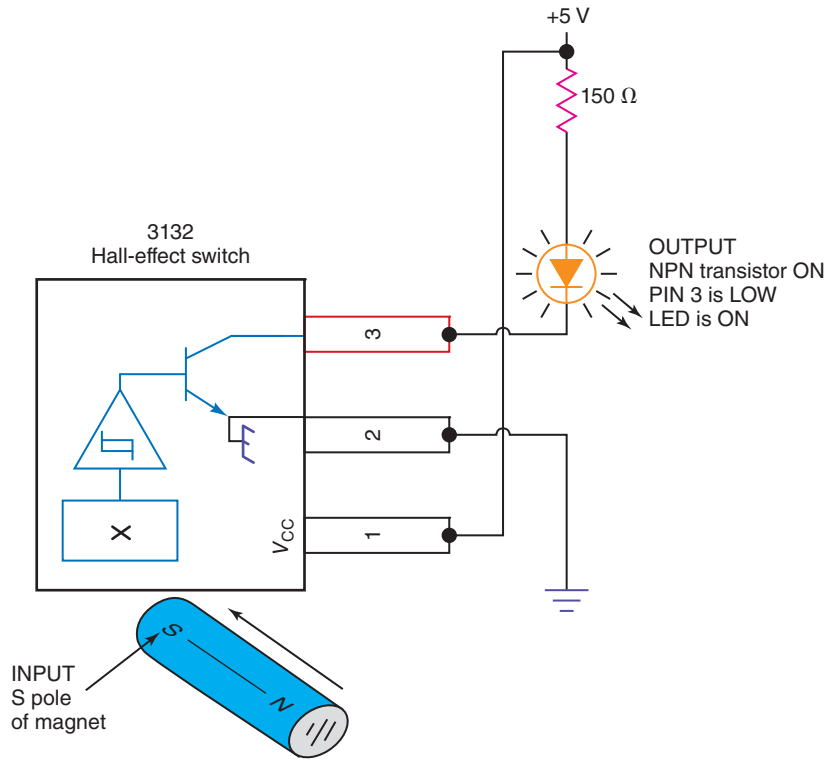


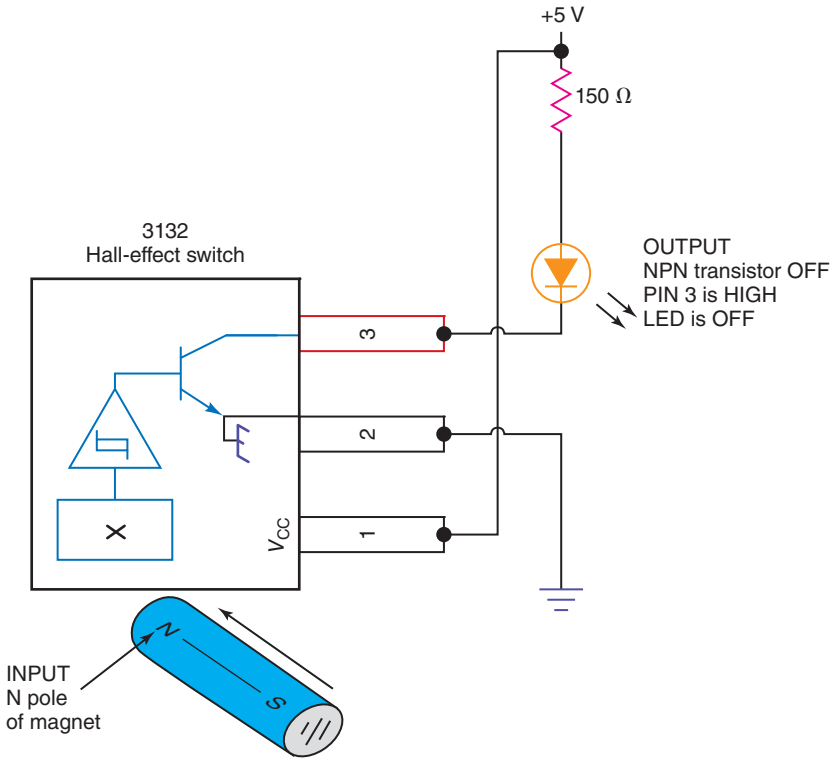
Fig. 5-38 Allegro Microsystem's 3132 bipolar Hall-effect switch. (*a*) Pin diagram. (*b*) Functional block diagram.

The three-lead package in Fig. 5-38(*a*) shows that pins 1 and 2 are for connecting the external power supply (+ to V_{CC} and − to ground). Pin 3 is the output of this bounce-free switch. The pinout in Fig. 5-38(*a*) is correct when viewing the 3132 Hall-effect switch from the printed side (branded side) of the IC package. A functional block diagram of Allegro Microsystem's 3132 Hall-effect switch is drawn in Fig. 5-38(*b*). Notice that the symbol for the Hall-effect sensor is a rectangle with an *X* inside. Added to the sensor are several sections that convert the analog Hall-effect device into a digital switch. The *Schmitt-trigger threshold detector* produces a snap-action bounce-free output needed for digital switching. Its output is either HIGH or LOW. The open-collector output transistor is included so the IC can drive a load up to 25 mA continuously.

The two most important characteristics of a magnetic field are its *strength* and its *polarity* (south or north poles of the magnet). Both of these characteristics are used in the operation of the bipolar 3132 Hall-effect switch. To demonstrate the operation of the bipolar Hall-effect switch, study the circuit in Fig. 5-39(*a*) including the 3132 IC. An output indicator LED with 150-Ω limiting resistor has been added at the output of the IC.



(*a*)



(*b*)

Fig. 5-39 Controlling 3132 Hall-effect switch with opposite poles of a magnet. (*a*) Turning on switch with S pole. (*b*) Turning off switch with N pole.

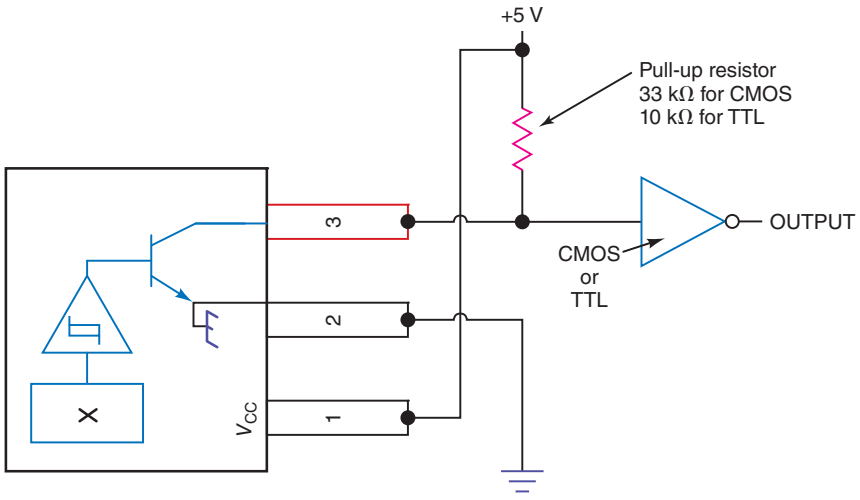


Fig. 5-40 Interfacing Hall-effect switch IC with either TTL or CMOS.

In Fig. 5-39(*a*), the *south pole* of the magnet approaches the branded side (side with printing) of the IC causing the internal NPN transistor to turn on. This causes pin 3 of the IC to drop LOW causing the LED to light.

In Fig. 5-39(*b*), the *north pole* of the magnet approaches the branded side (side with printing) of the IC causing the internal NPN transistor to turn off. This causes pin 3 of the IC to go HIGH, and the LED does not light.

The 3132 Hall-effect switch was *bipolar* because it required a S pole and then a N pole to make it toggle between ON and OFF. Unipolar Hall-effect switches are also available which turn on and off by just increasing (switch on) and decreasing (switch off) the magnetic field strength and not changing polarity. One such unipolar Hall-effect switch is the 3144 by Allegro Microsystems, Inc. The *3144 unipolar Hall-effect switch* is a close relative the 3132 bipolar Hall-effect switch you have already studied. The unipolar 3144 IC shares the same pin-out diagram [Fig. 5-38(*a*)] and functional block diagram [Fig. 5-38(*b*)] as the bipolar 3132 Hall-effect switch. The 3144 Hall-effect switch features a snap-action digital output. The 3144 IC also features an NPN output transistor that will sink 25 mA.

The Hall-effect switch IC drawn in Fig. 5-40 has an NPN driver transistor with an open collector. Interfacing a Hall-effect switch IC with digital ICs (TTL or CMOS) requires the use of a pull-up resistor as shown in Fig. 5-40. Typical values for the pull-up are shown as 33 kΩ for CMOS and 10 kΩ for TTL. The Hall-effect switch shown in Fig. 5-40 could be either the 3132 or 3144 ICs.

Gear-Tooth Sensing

Other common Hall-effect switching devices include gear-tooth sensing ICs. Gear-tooth sensing ICs contain one or more Hall-effect sensors and a built-in permanent magnet. A sketch of typical gear-tooth sensing IC and gear is shown in Fig. 5-41. The south pole of the permanent magnet produces a magnetic field that varies with the position of the gear. When a gear tooth moves

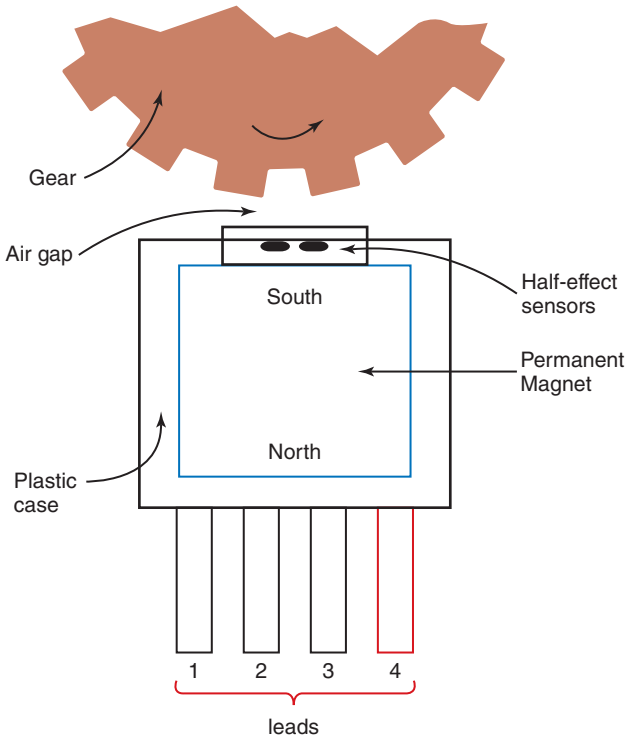


Fig. 5-41 Hall-effect gear-tooth sensor with rotating gear for triggering.

into position to shorten the air gap, the field gets stronger and the Hall-effect sensor switches. Gear-tooth sensors are commonly used in mechanical systems including automobiles to count the position, rotation, and speed of gears.

It is a characteristic of Hall-effect switch ICs to function as a bounce-free switch. This is sometimes difficult with mechanical switches. You will observe that the magnet does not have to touch the surface of the Hall-effect switch to turn it on and off. These are touch-free switches that can operate under severe environmental conditions. Simple Hall-effect switch ICs are small, rugged, and very inexpensive.

Self-Test

Answer the following questions.

78. A Hall-effect sensor is a(n) _____ (magnetically, optically) activated device.
79. Hall-effect devices such a _____ (gear-tooth sensors, thermocouples) and switches are commonly used in automobiles because they are reliable, inexpensive, and can operate under severe conditions.
80. Refer to Fig. 5-42. The semiconductor material shown with the *X* on it is called the _____ (electromagnet, Hall-effect sensor).
81. Refer to Fig. 5-42. Moving the permanent magnet closer to the Hall-effect sensor increases the magnetic field causing the output voltage to _____ (decrease, increase).
82. Refer to Fig. 5-43. The 3132 Hall-effect IC is a _____ (bipolar, unipolar) switch.
83. Refer to Fig. 5-43(*a*). Output transistor of the IC is turned on and the output at pin 3 goes _____ (HIGH, LOW) when the south pole of a magnet approaches the Hall-effect sensor in the 3132 causing the LED to _____ (light, not light).
84. Refer to Fig. 5-43(*b*). Output transistor of the IC is turned _____ (on, off) and the output at pin 3 goes _____ (HIGH, LOW) when the north pole of a magnet approaches the Hall-effect sensor in the 3132 causing the LED to not light.
85. Refer to Fig. 5-38. The snap action causing a digital output (either HIGH or LOW) from the IC is caused by the _____ (dc amplifier, Schmitt-trigger) section of the IC.
86. Hall-effect switches are small, bounce-free, rugged, and _____ (inexpensive, very expensive).
87. The open-collector of the NPN driver transistor used in both the 3132 and 3144 Hall-effect switches requires the use a _____ (pull-up, transition) resistor when sending digital signals to either CMOS or TTL logic devices.

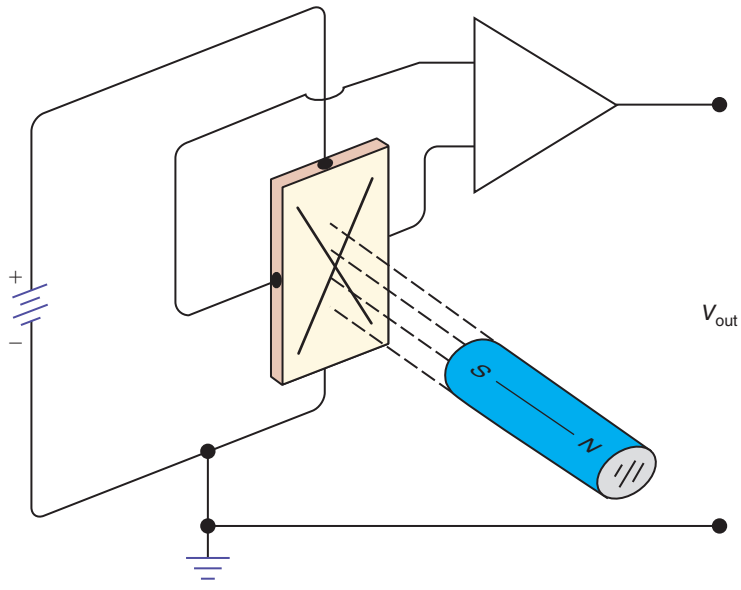
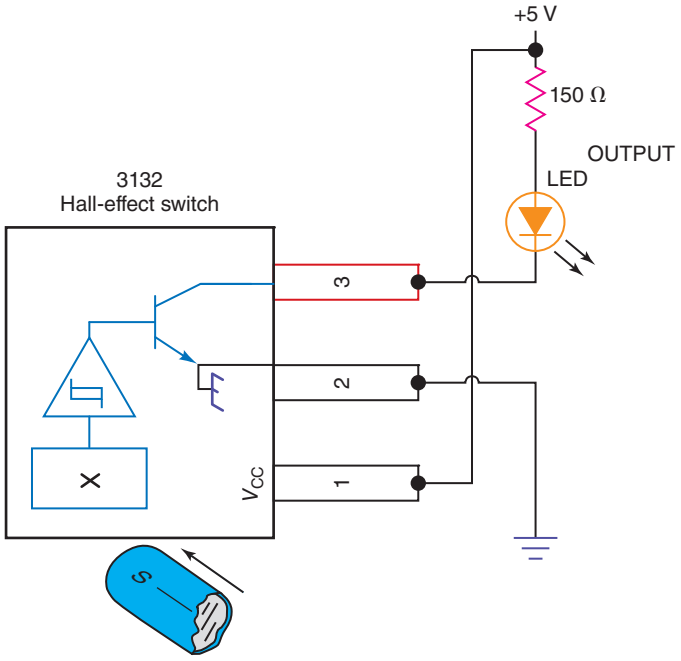
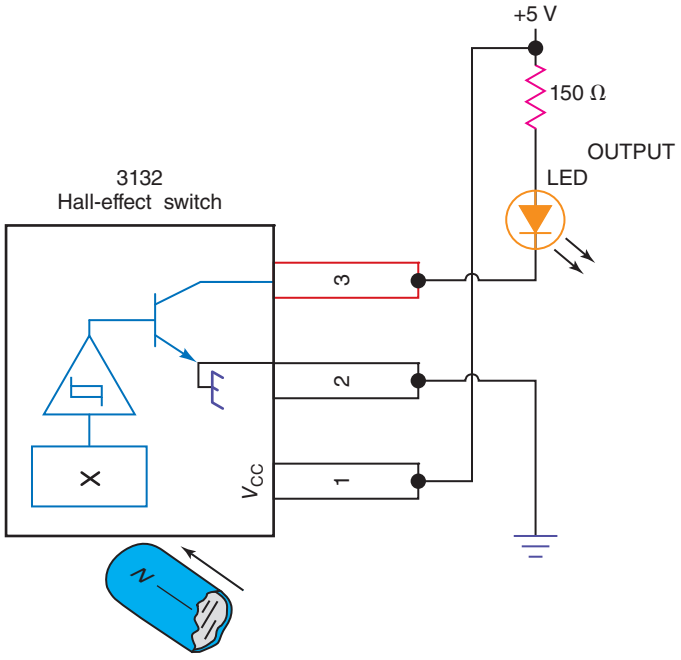


Fig. 5-42 Hall-effect sensor.



(*a*)



(*b*)

Fig. 5-43 Hall-effect switch.

5-11 Troubleshooting Simple Logic Circuits

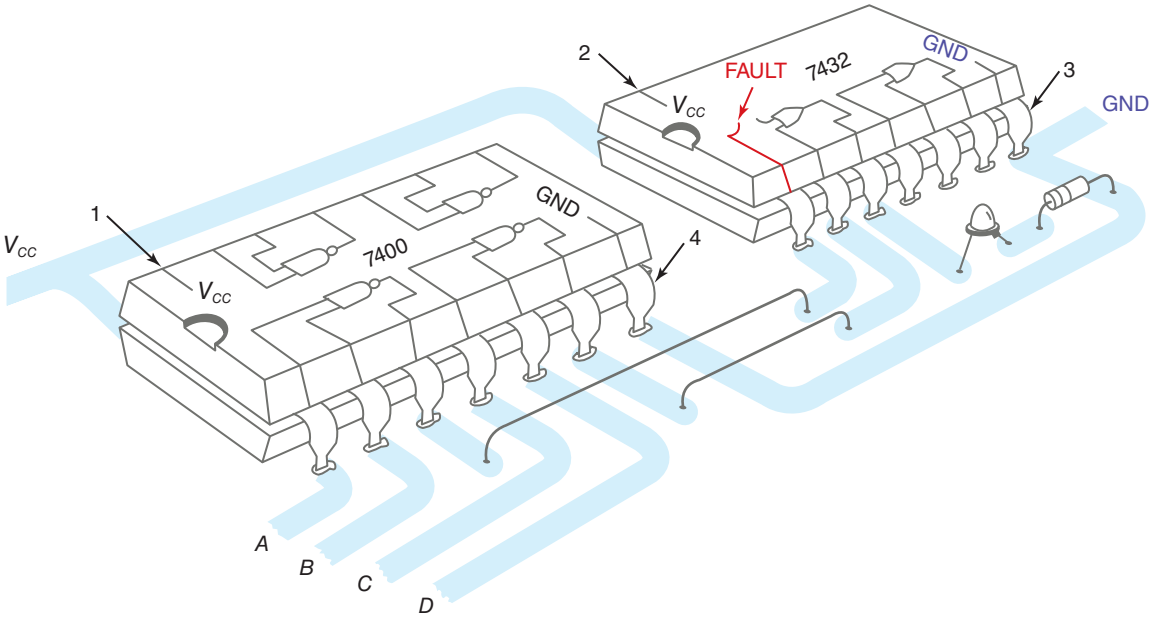
Troubleshooting using a logic probe

One test equipment manufacturer suggests that about three-quarters of all faults in digital circuits occur because of open input or output circuits. Many of these faults can be isolated in a logic circuit using a logic probe.

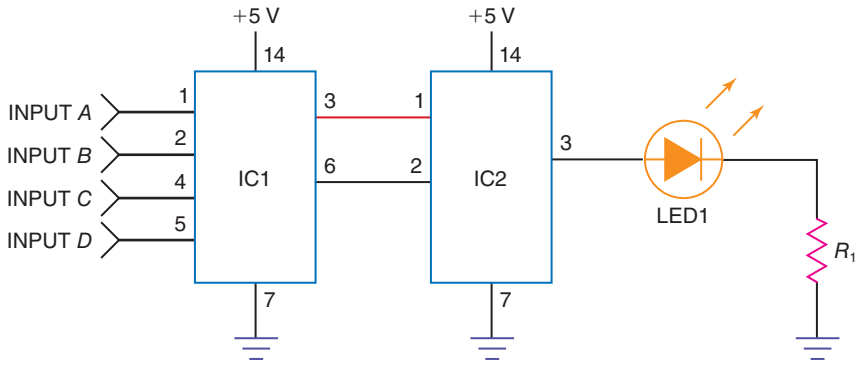
Consider the combinational logic circuit mounted on a printed circuit board in Fig. 5-44(*a*). The equipment manual might include a schematic similar to the one shown in Fig. 5-44(*b*). Look at the circuit and schematic, and determine the logic diagram. From that you can determine the Boolean expression and truth table. You will find that in this example, two NAND gates are feeding an OR gate. This is equivalent to the four-input NAND function.

The fault in the circuit in Fig. 5-44(*a*) is shown as an open circuit in the input to the OR gate. Now let's troubleshoot the circuit to see how we find this fault.

1. Set the logic probe to TTL, and connect the power.



(*a*)



PARTS LIST

IC1	7400 quad 2-input NAND gate
IC2	7432 quad 2-input OR gate
LED1	Red diffused T–1-3/4 light-emitting diode
R_1	1/2 W, 150 Ω, 10% resistor

(*b*)

Fig. 5-44 Troubleshooting problem. (*a*) Testing a faulty circuit mounted on a PC board. (*b*) Schematic diagram of four-input NAND circuit.

2. Test nodes 1 and 2 [see Fig. 5-44(*a*)]. *Result:* Both are HIGH.
3. Test nodes 3 and 4. *Result:* Both are LOW. *Conclusion:* Both ICs have power.
4. Test the four-input NAND circuit's unique state (inputs *A, B, C,* and *D* are all HIGH). Test at pins 1, 2, 4, and 5 of the 7400 IC. *Results:* All inputs are HIGH, but the LED still glows and indicates a HIGH output. *Conclusion:* The unique state of the four-input NAND circuit is faulty.
5. Test the outputs of the NAND gates at pins 3 and 6 of the 7400 IC. *Results:* Both outputs are LOW. *Conclusion:* The NAND gates are working.
6. Test the inputs to the OR gate at pins 1 and 2 of the 7432 IC. *Results:* Both inputs are LOW. *Conclusion:* The OR gate inputs at pins 1 and 2 are correct, but the output is still incorrect. Therefore, the OR gate is faulty, and the 7432 IC needs to be replaced.

Self-Test

Supply the missing word in each statement.

88. Most faults in digital circuits occur because of _____ (open, short) circuits in the inputs and outputs.
89. A simple piece of test equipment, such as a(n) _____, can be used for checking a digital logic circuit for open circuits in the inputs and outputs.
90. Refer to Fig. 5-44. With inputs *A, B, C,* and *D* all HIGH, the output (pin 3 of IC2) should be _____ (HIGH, LOW).

5-12 Interfacing the Servo (BASIC Stamp Module)

Programmable devices are very common in modern digital electronics. This section will explore interfacing of the BASIC Stamp 2 Microcontroller Module with a simple servo.

Review Sec. 5-9 on servo motors. Hobby servo motor operation is summarized in Fig. 5-30. Notice the use of pulse-width modulation (PWM) to control the angular position of the servo motor. In this section, you will program a BASIC Stamp 2 (BS2) Microcontroller Module to act as the *PWM pulse generator* sketched in Fig. 5-30(*a*), (*b*), and (*c*). Notice in Fig. 5-30 that the positive pulse widths are 2 ms for fully CCW rotation, 1 ms for fully CW rotation, or 1.5 ms for centering of the servo's output shaft.

Consider the hobby servo motor connected to the BASIC Stamp 2 module in Fig. 5-45. This is a test circuit to rotate the servo (1) fully CCW, (2) fully CW, and (3) to finally center the output shaft.

The procedure for solving the logic problem with the use of the BASIC Stamp 2 module is detailed below. The steps in wiring and programming the BASIC Stamp 2 module are:

1. Refer to Fig. 5-45. Wire the hobby servo motor to port P14 of the BASIC Stamp 2 module. Note the color coding (red = V_{dd} and black = V_{ss} or GND) of the power wires.
2. Load the PBASIC text editor program (version for the BS2 IC) into the PC. Type your PBASIC program describing the **'Servo Test 1**. A PBASIC program titled **'Servo Test 1** is listed in Fig. 5-46.
3. Attach a serial cable (or USB cable) between the PC and the BASIC Stamp 2 development board (such as the Board of Education by Parallax, Inc.).
4. With the BASIC Stamp 2 module turned on, download your PBASIC program from the PC to BS2 module using the RUN command.
5. Disconnect the serial cable (or USB cable) from the BS2 module.
6. Observe the rotation of the servo output shaft. The PBASIC program stored in EEPROM program memory in the BASIC Stamp 2 module will restart each time the BS2 IC is turned on.

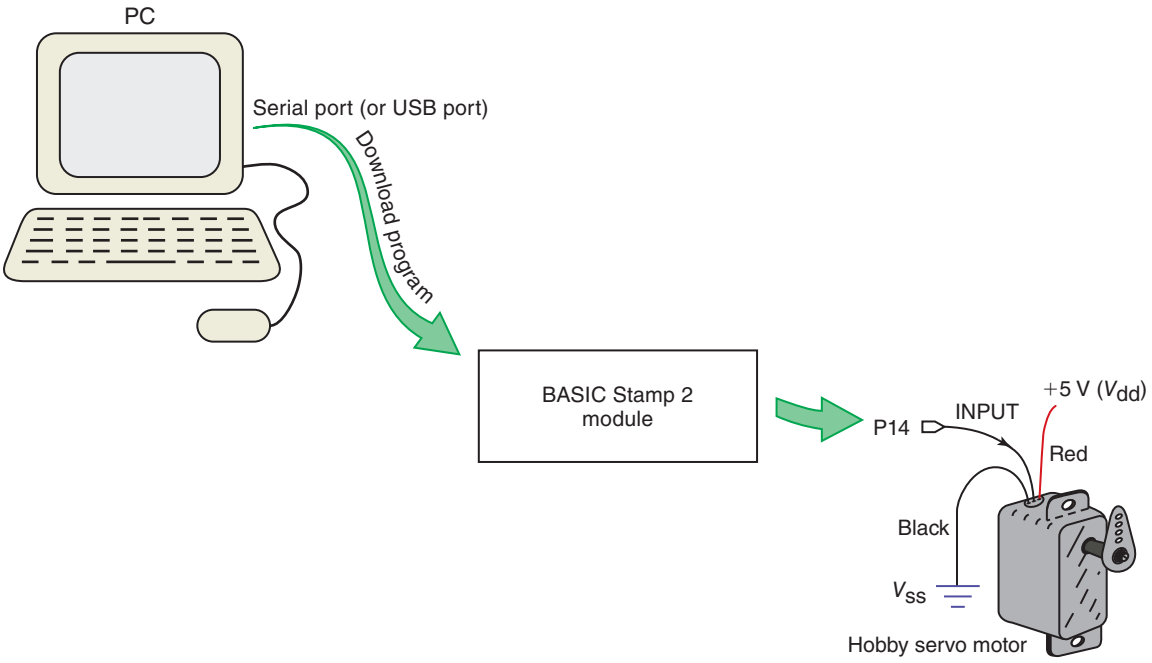


Fig. 5-45 Hobby servo motor connected to a BASIC Stamp 2 module for testing.

PBASIC Program—ServoTest 1

Consider in Fig. 5-46 the PBASIC program titled **'ServoTest 1**. Lines 1 and 2 both begin with an apostrophe (') meaning these are *remark statements*. Remark statements are used to clarify the program and are not executed by the microcontroller. Line 3 is a line of code to *declare a variable* that will be used later in the program As an example, line 3 reads **C VAR Word**. This tells the microcontroller that **C** is

```
'ServoTest 1                    'Title of program (See Fig. 5-45.)          L1
'Test servo in 3 different positions, CCW, CW and centered                  L2

C       VAR Word                'Declare C as variable, 16-bit length       L3

FOR C = 1 TO 75                 'Begin counting loop, C = 1 thru 75         L4
PULSOUT 14, 1000                'Pulse output (HIGH) at pin 14 for 2 ms     L5
PAUSE 20                        'Pause for 20 ms, output LOW                L6
NEXT                            'Back to FOR if C < 75                      L7

FOR C = 1 TO 75                 'Begin counting loop, C = 1 thru 75         L8
PULSOUT 14, 500                 'Pulse output (HIGH) at pin 14 for 1 ms     L9
PAUSE 20                        'Pause for 20 ms, output LOW                L10
NEXT                            'Back to FOR if C < 75                      L11

FOR C = 1 TO 75                 'Begin counting loop, C = 1 thru 75         L12
PULSOUT 14, 750                 'Pulse output (HIGH) at pin 14 for 1.5 ms   L13
PAUSE 20                        'Pause for 20 ms, output LOW                L14
NEXT                            'Back to FOR if C < 75                      L15

END                                                                         L16
```

Fig. 5-46 PBASIC program listing for ServoTest 1.

a variable name that will hold a word length value (16 bits). The 16-bit variable **C** can hold a range of values from 0 to 65535 in decimal.

Lines 4–7 produce the full CCW rotation of the servo motor shaft. The FOR-NEXT loop will be executed 75 times (**C = 1 to 75**). The **PULSOUT 14, 1000** code (L5) generates a HIGH pulse at pin 14 for 2 milliseconds (2 μseconds × 1000 = 2000 μs = 2 ms). Pin 14 then drops LOW after the 2-ms positive pulse. The **PAUSE 20** code (L6) allows pin 14 to remain LOW for 20 ms. This first FOR-NEXT loop (L4–7) will cause the hobby servo motor to turn fully CCW.

Lines 8–11 produce the full CW rotation of the servo motor shaft. The FOR-NEXT loop will be executed 75 times (**C = 1 to 75**). The **PULSOUT 14, 500** code (L9) generates a HIGH pulse at pin 14 for 1 millisecond (2 μseconds × 500 = 1000 μs = 1 ms). Pin 14 then drops LOW after the 1-ms positive pulse. The **PAUSE 20** code (L10) allows pin 14 to remain LOW for 20 ms. This second FOR-NEXT loop (L8–11) will cause the hobby servo motor to turn fully CW.

Lines 12–15 cause the servo motor shaft to center itself. The FOR-NEXT loop will be executed 75 times (**C = 1 to 75**). The **PULSOUT 14, 750** code (L13) generates a HIGH pulse at pin 14 for 1.5 milliseconds (2 μseconds × 750 = 1500 μs = 1.5 ms). Pin 14 then drops LOW after the 1.5-ms positive pulse. The **PAUSE 20** code (L14) allows pin 14 to remain LOW for 20 ms. This last FOR-NEXT loop (L12–15) will cause the hobby servo motor shaft to move to the center of its range. The **END** statement (L16) causes the program to stop executing.

The PBASIC program **'ServoTest 1** will run once while the BS2 module is powered. The PBASIC program is held in EEPROM program memory for future use. Turning the BS2 off and then on again will restart the program. Downloading a different PBASIC program to the BASIC Stamp module will erase the old program and start execution of the new listing.

Self-Test

Answer the following questions.

91. The angular position of a hobby servo motor is controlled by a technique called _____ (amplitude, pulse-width) modulation.
92. Refer to Fig. 5-46. Variable *C* may hold only a single bit of data. (T or F)
93. Refer to Fig. 5-46. Each of the three FOR-NEXT loops will be repeated _____ (20, 75) times.
94. Refer to Fig. 5-46. The purpose of the **PAUSE 20** statement is to permit the microcontroller to cool off for 20 minutes. (T or F)
95. Refer to Fig. 5-46. The **PULSOUT 14, 750** output a positive pulse to pin 14 with a time duration of _____ millisecond(s).
96. Refer to Figs. 5-45 and 5-46. What is the effect on the servo's output shaft when the FOR-NEXT loop in lines 12–15 is totally executed (75 times through the loop)?

Chapter 5 Summary and Review

Summary

1. Interfacing is the design of circuitry between devices that shifts voltage and current levels to make them compatible.
2. Interfacing between members of the same logic family is usually as simple as connecting one gate's output to the next logic gate's input, etc.
3. In interfacing between logic families or between logic devices and the "outside world," the voltage and current characteristics are very important factors.
4. Noise margin is the amount of unwanted induced voltage that can be tolerated by a logic family. Complementary symmetry metal-oxide semiconductor ICs have better noise margins than TTL families.
5. The fan-out and fan-in characteristics of a digital IC are determined by its output drive and input loading specifications.
6. Propagation delay (or speed) and power dissipation are important IC family characteristics.
7. The ALS-TTL, FAST (Fairchild advanced Schottky TTL), and FACT (Fairchild advanced CMOS technology) logic families are very popular owing to a combination of low power consumption, high speed, and good drive capabilities. Earlier TTL and CMOS families are still in use.
8. Advanced low-voltage CMOS ICs (such as the 74ALVC00 series) are used in many modern designs. These low-voltage CMOS ICs feature low power consumption, TTL direct interface, static protection, and very high speeds.
9. Many CMOS ICs are sensitive to static electricity and must be stored and handled properly. Other precautions to be observed include turning off an input signal before circuit power and connecting all unused inputs.
10. Simple switches can drive logic circuits using pull-up and pull-down resistors. Switch debouncing is usually accomplished using latch circuits.
11. Driving LEDs and incandescent lamps with logic devices usually requires a driver transistor.
12. Most TTL-to-CMOS and CMOS-to-TTL interfacing requires some additional circuitry. This can take the form of a simple pull-up resistor, special interface IC, or transistor driver.
13. Interfacing digital logic devices with buzzers and relays usually requires a transistor driver circuit. Electric motors and solenoids can be controlled by logic elements using a relay to isolate them from the logic circuit.
14. Optoisolators are also called optocouplers. Solid-state relays are a variation of the optoisolator. Optoisolators are used to electrically isolate digital circuitry from circuits that contain motors or other high-voltage/current devices that might cause voltage spikes and noise.
15. Hobby servo motors are used for angular positioning of an output shaft. A pulse generator employing pulse-width modulation (PWM) is used to drive a these inexpensive servo motors.
16. Hobby servo motors can be driven by programmable devices such as the BASIC Stamp 2 Microcontroller Module.
17. Stepper motors operate on dc and are useful in applications where precise angular positioning or speed of an output shaft is important.
18. Stepper motors are classified as either bipolar (two phase) or unipolar (four phase). Other important characteristics are step angle, voltage, current, coil resistance, and torque.
19. Specialized ICs are useful for interfacing and driving stepper motors. The logic section of the IC generates the correct control sequence to step the motor.
20. A Hall-effect sensor is a magnetically activated device used in Hall-effect switches. Hall-effect switches are classified as either bipolar (need S and N poles of magnet to activate) or unipolar (need S pole or no magnetic field to activate).

Summary...continued

21. External magnetic fields are commonly used to activate a Hall-effect sensor or switch. Gear-tooth sensors have Hall-effect sensors and a permanent magnet encapsulated in the IC. Hall-effect gear-tooth sensors are triggered by ferrous metals (such as steel gear teeth) passing near the IC.
22. Each logic family has its own definition of logical HIGH and LOW. Logic probes test for these levels.

Chapter Review Questions

Answer the following questions.

5-1. Applying 3.1 V to a TTL input is interpreted by the IC as a(n) _____ (HIGH, LOW, undefined) logic level (5-V power source).

5-2. A TTL output of 2.0 V is considered a(n) _____ (HIGH, LOW, undefined) output (5-V power source).

5-3. Applying 2.4 V to a CMOS input (10-V power supply) is interpreted by the IC as a(n) _____ (HIGH, LOW, undefined) logic level.

5-4. Applying 3.0 V to a 74HC00 series CMOS input (5-V power supply) is interpreted by the IC as a(n) _____ (HIGH, LOW, undefined) logic level.

5-5. A "typical" HIGH output voltage for a TTL gate would be about _____ (0.1, 0.8, 3.5) V.

5-6. A "typical" LOW output voltage for a TTL gate would be about _____ (0.1, 0.8, 3.5) V.

5-7. A "typical" HIGH output voltage for a CMOS gate (10-V power supply) would be about _____ V.

5-8. A "typical" LOW output voltage for a CMOS gate (10-V power supply) would be about _____ V.

5-9. Applying 3.0 V to a 74HCT00 series CMOS input (5-V power supply) is interpreted by the IC as a(n) _____ (HIGH, LOW, undefined) logic level.

5-10. Applying 1.0 V to a 74HCT00 series CMOS input (5-V power supply) is interpreted by the IC as a(n) _____ (HIGH, LOW, undefined) logic level.

5-11. The 74ALVC series of logic ICs are modern _____ (CMOS, TTL) chips.

5-12. Applying 2.4 V to a 74ALVC00 series (3-V power supply) input would be interpreted by the IC as a(n) _____ (HIGH, LOW, undefined) logic level.

5-13. Modern logic families such as the 74ALVC00 series feature _____ (high-, low-) voltage operation, low power consumption, good static protection, and very _____ (high, low) propagation delays (for high-speed operation).

5-14. The _____ (CMOS, TTL) logic family has better noise immunity.

5-15. Refer to Fig. 5-4. The noise margin for the TTL family is about _____ V.

5-16. Refer to Fig. 5-4. The noise margin for the CMOS family is about _____ V.

5-17. Refer to Fig. 5-5. The *switching threshold* for TTL is always exactly 1.4 V (T or F).

5-18. The fan-out for standard TTL is said to be _____ (10, 100) when driving other standard TTL gates.

5-19. Refer to Fig. 5-6(*b*). A single ALS-TTL output will drive _____ (5, 50) standard TTL inputs.

5-20. Refer to Fig. 5-6(*b*). A single 74HC00 series CMOS output has the capacity to drive at least _____ (10, 50) LS-TTL inputs.

5-21. Refer to Fig. 5-47. If both family *A* and *B* are TTL, the inverter _____ (can, may not be able to) drive the AND gates.

5-22. Refer to Fig. 5-47. If family *A* is ALS-TTL and family *B* is standard TTL, the inverter _____ (can, may not be able to) drive the AND gates.

5-23. Refer to Fig. 5-47. If both families *A* and *B* are ALS-TTL, the inverter _____ (can, may not be able to) drive the AND gates.

5-24. The _____ (4000, 74AC00) series CMOS ICs have greater output drive capabilities.

5-25. Refer to Fig. 5-8(*b*). The _____ logic family has the lowest propagation delays and is considered the _____ (fastest, slowest).

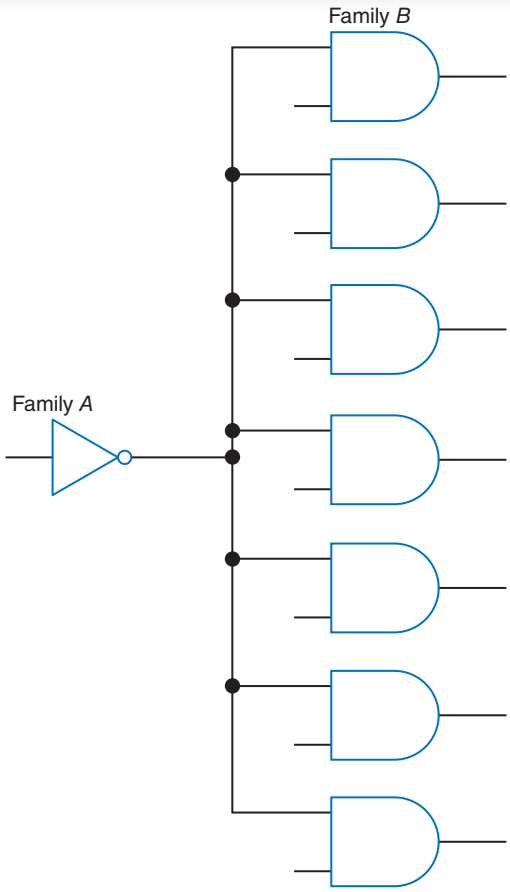


Fig. 5-47 Interfacing problem.

5-26. The 74FCT08 IC would have the same logic function and pin-out as the standard TTL IC with part number _____.

5-27. Generally, _____ (CMOS, TTL) ICs consume the least power.

5-28. List several precautions that should be observed when working with CMOS ICs.

5-29. The V_{DD} pin on a 4000 series CMOS IC is connected to _____ (ground, positive) of the dc power supply.

5-30. Refer to Fig. 5-11(*b*). With the switch open, the inverter's input is _____ (HIGH, LOW) while the output is _____ (HIGH, LOW).

5-31. Refer to Fig. 5-12(*a*). When the switch is open, the _____ resistor causes the input of the CMOS inverter to be pulled HIGH.

5-32. Refer to Fig. 5-48. Component R_1 is called a _____ resistor.

5-33. Refer to Fig. 5-48. Closing SW_1 causes the input to the inverter to go _____ (HIGH, LOW) and the LED _____ (goes out, lights).

5-34. Refer to Fig. 5-48. With SW_1 open, a _____ (HIGH, LOW) appears at the input of the inverter causing the output LED to _____ (go out, light).

5-35. The common switch debouncing circuits in Fig. 5-14(*b*) and (*c*) are called RS flip-flops or _____.

5-36. Refer to Fig. 5-15. Closing input switch SW_1 causes the output of the 555 IC to toggle from _____ (HIGH to LOW, LOW to HIGH).

5-37. Refer to Fig. 5-15. Opening input switch SW_1 causes the output of the 555 IC to toggle from HIGH to LOW _____.

a. immediately
b. after a delay of about 1 second
c. after a delay of about 1 microsecond

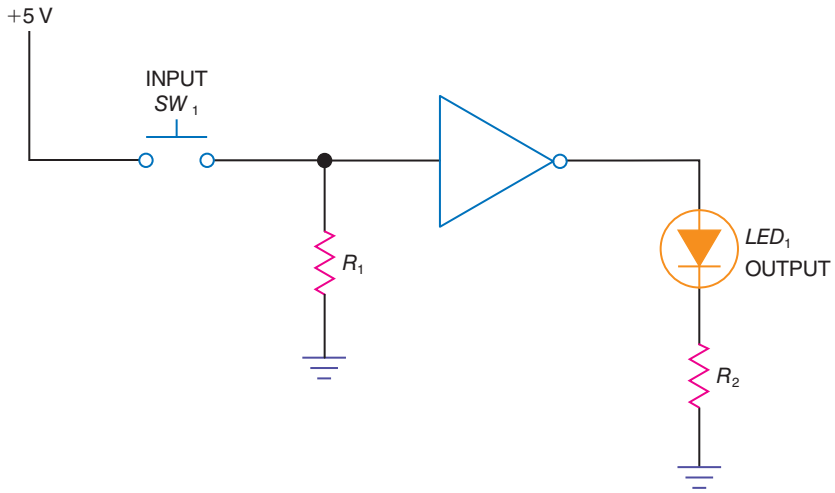


Fig. 5-48 Interfacing problem.

5-38. A TTL output can drive a regular CMOS input with the addition of a(n) _____ resistor.

5-39. Any CMOS gate can drive at least one LS-TTL input. (T or F)

5-40. A 4000 series CMOS output can drive a standard TTL input with the addition of a(n) _____.

5-41. Open-collector TTL gates require the use of _____ resistors at the outputs.

5-42. Refer to Fig. 5-25(*b*). The transistor functions as a(n) _____ (AND gate, driver) in this circuit.

5-43. Refer to Fig. 5-25(*b*). When the input to the inverter goes LOW, its output goes _____ (HIGH, LOW) which _____ (turns off, turns on) the transistor allowing current to flow through the transistor and piezo buzzer to sound the buzzer.

5-44. Refer to Fig. 5-27(*a*). When the input to the inverter goes LOW, its output goes HIGH which _____ (turns off, turns on) the NPN transistor; the coil of the relay is _____ (activated, deactivated), the relay armature clicks downward, and the dc motor _____ (rotates, will not rotate).

5-45. Refer to Fig. 5-27(*b*). When the input to the inverter goes HIGH, its output goes LOW which _____ (turns off, turns on) the NPN transistor; the coil of the relay is _____ (activated, deactivated), the armature of the relay _____ (clicks, will not click) downward, and the solenoid _____ (is, will not be) activated.

5-46. Refer to Fig. 5-28. The 4N25 optoisolator contains a gallium arsenide _____ (infrared-emitting diode, incandescent lamp) optically coupled to a phototransistor output.

5-47. Refer to Fig. 5-28(*b*). If the input to the inverter goes HIGH, its output goes LOW which _____ (activates, deactivates) the LED, the phototransistor is _____ (turned off, turned on), and the output voltage goes _____ (HIGH, LOW).

5-48. Refer to Fig. 5-28(*c*). The piezo buzzer sounds when the input to the inverter goes _____ (HIGH, LOW).

5-49. Refer to Fig. 5-28(*d*). This is an example of good design practice by using an optoisolator to isolate the low-voltage digital circuit from the higher-voltage noisy motor circuit. (T or F)

5-50. Refer to Fig. 5-28(*d*). The dc motor turns on when a _____ (HIGH, LOW) logic level appears at the input of the inverter.

5-51. A solid-state relay is a close relative of the optoisolator. (T or F)

5-52. The electromagnetic device well suited to continuous rotation in either direction is the _____ (dc motor, hobby servo motor).

5-53. Refer to Fig. 5-49. The pulse generator will vary the _____ causing the servo motor to adjust the angular position of the output shaft.
   a. Frequency from about 30 to 100 Hz
   b. Pulse width from about 1 to 2 ms
   c. Pulse amplitude from about 1 to 5 V

5-54. A _____ (dc motor, stepper motor) should be used when the application calls for exact angular positioning of a shaft (as in a robot wrist).

5-55. The stepper motor sketched in Fig. 5-31(*a*) is classified as a unipolar or four-phase unit. (T or F)

5-56. The device featured in Fig. 5-31 is a _____ (permanent magnet, variable reluctance) type stepper motor.

5-57. The step angle for the stepper motor in Fig. 5-31(*a*) is _____ degrees.

5-58. The control sequence shown in Fig. 5-32(*a*) is for a _____ (bipolar, unipolar) stepper motor.

5-59. Refer to Fig. 5-33(*a*). How is the MC3479 IC described by its manufacturer?

5-60. Refer to Fig. 5-33(*a*) and assume pins 9 and 10 of the MC3479 IC are LOW. When a single

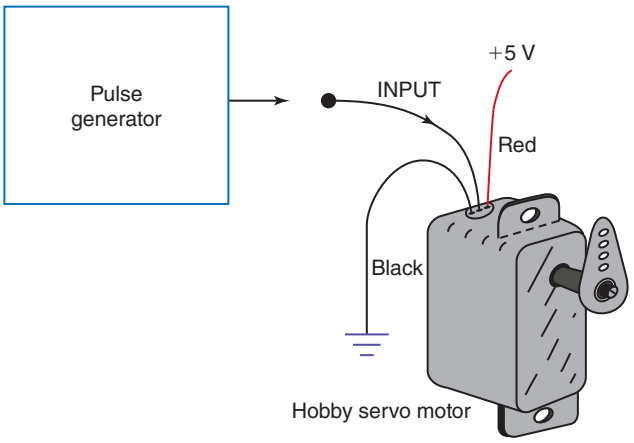


Fig. 5-49 Driving a servo motor.

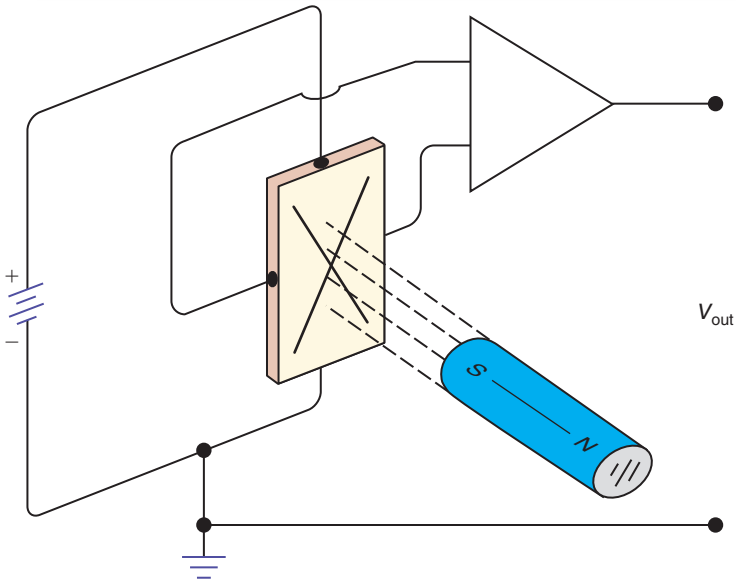


Fig. 5-50 Art for chapter review questions 5-64, 5-65, and 5-69.

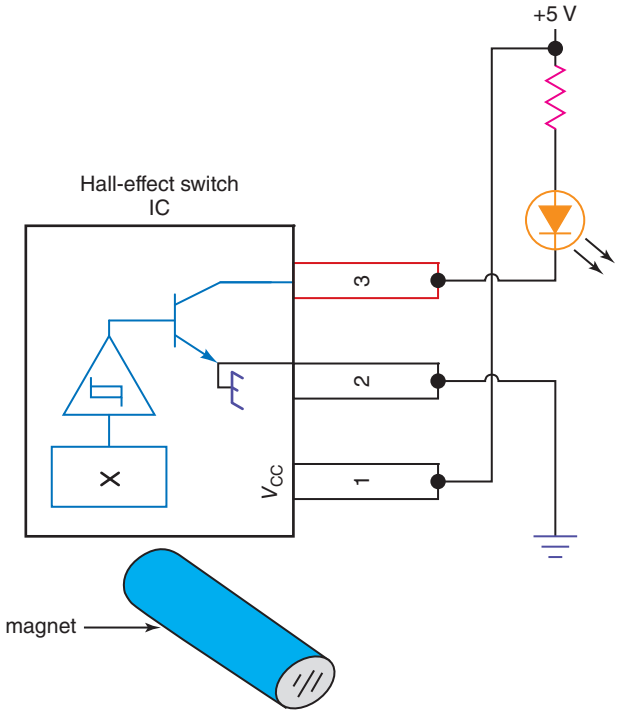


Fig. 5-51 Art for chapter review questions 5-66, 5-67, 5-68, and 5-70.

clock pulse enters the CLK input (pin 7), the stepper motor rotates a _____ (full step, half step) in the _____ (CCW, CW) direction.

5-61. Refer to Fig. 5-33(*a*) and assume pins 9 and 10 of the MC3479 IC are HIGH and the stepper motor has a step angle of 18°. Under these conditions, how many clock pulses must enter the CLK input to cause the stepper motor to rotate one revolution?

5-62. The Hall-effect sensor is a _____ (magnetically, pressure-) activated device.

5-63. Hall-effect devices such as gear-tooth sensors and switches are commonly used in automobiles because they are rugged, reliable, operate under severe conditions, and are inexpensive. (T or F)

5-64. Refer to Fig. 5-50. The sections of this Hall-effect device are the Hall-effect sensor, the bias battery, and a _____ (dc amplifier, multiplexer).

5-65. Refer to Fig. 5-50. Moving the magnet closer to the Hall-effect sensor increases the strength of the magnetic field which causes the output voltage to _____ (decrease, increase).

5-66. Refer to Fig. 5-51. If the Hall-effect IC uses *unipolar switching*, then increasing the magnetic field by moving the south pole of the magnet toward the sensor will turn the switch _____ (off, on), while removing the permanent magnet completely will turn the switch _____ (off, on).

5-67. Refer to Fig. 5-51. If the IC is the bipolar 3132 Hall-effect switch, then the _____ (N, S) pole of the magnet will turn the device on while the _____ (N, S) pole will turn the output transistor off.

5-68. Refer to Fig. 5-51. If the IC is the bipolar 3132 Hall-effect switch, then moving the north pole of the magnet near the sensor will turn _____ (off, on) the switch, the voltage at pin 3 will _____ (drop LOW, raise HIGH), and the LED will _____ (light, not light).

5-69. Refer to Fig. 5-50. The output of this device is _____ (analog, digital) in nature.

5-70. Refer to Fig. 5-51. The output of this IC is _____ (analog, digital) in nature.

5-71. Refer to Fig. 5-45. The BASIC Stamp 2 _____ (Audio-amplifier, Microcontroller) Module substitutes as a PWM generator to rotate the servo motor.

5-72. In Parallax's PBASIC language, the statement **PULSOUT 14, 750** generates 14 negative pulses each 750 µs. (T or F)

Critical Thinking Questions

5-1. How would you define *interfacing*?
5-2. How do you define *noise* in a digital system?
5-3. What is the propagation delay of a logic gate?
5-4. List several advantages of CMOS logic elements.
5-5. Why might a design engineer use the 74ALVC00 series of logic ICs for a new tiny handheld device?
5-6. Refer to Fig. 5-45. If family *A* is standard TTL and family *B* is ACT-CMOS, the inverter _____ (can, may not be able to) drive the AND gates.
5-7. Refer to Fig. 5-18(*c*). Explain the operation of this HIGH-LOW indicator circuit.
5-8. What is the purpose of "T"-type CMOS ICs (HCT, ACT, etc.)?
5-9. What electromechanical device could be used to isolate higher-voltage equipment (such as motors or solenoids) from a logic circuit?
5-10. An electric motor converts electric energy into _____ motion.
5-11. A(n) _____ is an electromechanical device that converts electric energy into linear motion.
5-12. Why is the FACT-CMOS series considered by many engineers to be one of the best logic families for new designs?
5-13. Refer to Fig. 5-26. Explain the circuit action when the inverter input is LOW.
5-14. Refer to Fig. 5-27(*a*). Explain the circuit action when the inverter input is HIGH.
5-15. An optoisolator prevents the transmission of _____ (the signal, unwanted noise) from one electronic system to another that operates on a different voltage.
5-16. Refer to Fig. 5-28(*d*). Explain the circuit action when the inverter input is LOW.
5-17. If the coil resistance of a 12-V stepper motor is 40 Ω, what is the current draw for the coil?
5-18. If a stepper motor is designed with a step angle of 3.6°, how many steps are required for one revolution of the motor?
5-19. Why are Hall-effect devices such as switches and gear-tooth sensors so widely used in modern automobiles?
5-20. Explain what we mean by current sinking.
5-21. What is PWM, and how is it used to drive a hobby servo motor?
5-22. Refer to Fig. 5-33(*c*). What do you notice as you progress down the control sequence for a stepper motor (*Hint:* Direction of current flow through windings)?
5-23. Refer to Fig. 5-38(*b*). What is the purpose of the Schmitt trigger in the Hall-effect switch?
5-24. Refer to Fig. 5-38(*b*). The output of the driver transistor in this IC is the _____ (open-collector, totem-pole) type.
5-25. Describe the difference between the operation of a bipolar and a unipolar Hall-effect switch.
5-26. Design circuits including the following interfaces: switches with TTL ICs; LEDs with TTL and CMOS ICs; TTL and CMOS ICs; and CMOS ICs with buzzers, relays, and motors.
5-27. How would you use an optoisolator to interface between TTL ICs and higher-voltage devices (buzzer and motor)?
5-28. Describe interfacing with a stepper motor.
5-29. How would you apply Hall-effect switches (both bipolar and unipolar) to drive a CMOS counter IC?
5-30. Describe using a pulse-width modulator (PWM) to control a servo motor.
5-31. Design and demonstrate a TTL logic block that controls a stepper motor driver IC and stepper motor.
5-32. Describe driving a servo motor using a microcontroller (BASIC Stamp 2 system).

Answers to Self-Tests

1. interfacing
2. HIGH
3. LOW
4. undefined
5. undefined
6. +10

7. HIGH
8. CMOS
9. T
10. CMOS
11. low-voltage
12. HIGH
13. fan-out
14. FAST TLL series
15. 20 (8 mA/400 μA = 20)
16. long
17. FACT series CMOS
18. the same
19. MOS
20. complementary symmetry metal-oxide semiconductor
21. low power consumption
22. GND
23. positive
24. FACT
25. T
26. CMOS
27. very
28. T
29. LOW, floats HIGH
30. pull-up
31. RS flip-flop
32. HIGH, LOW
33. F
34. switch debouncing circuit
35. open collector
36. LOW to HIGH
37. C
38. decreasing
39. 4000
40. goes out
41. off, does not light
42. Q_1, red
43. active LOW
44. sinking current
45. LOW
46. are not
47. pull-up
48. current drive
49. transistor
50. is not
51. on, sounds
52. transient voltages
53. HIGH
54. linear
55. isolate
56. turns on
57. NC to the NO
58. relay
59. phototransistor
60. lights, activates, LOW
61. pull-up
62. does not light, deactivates, HIGH, does not sound
63. turns on, runs
64. solid-state
65. will sound
66. dc motor
67. stepper motor
68. T
69. servo motor
70. input
71. pulse-width
72. bipolar
73. control, bipolar
74. CCW
75. logic
76. 350
77. CCW, half step
78. magnetically
79. gear-tooth sensors
80. Hall-effect sensor
81. increase
82. bipolar
83. LOW, light
84. OFF, HIGH
85. Schmitt-trigger
86. inexpensive
87. pull-up
88. open
89. logic probe or voltmeter
90. LOW
91. pulse-width
92. F
93. 75
94. F
95. 1.5
96. rotates to the center of its range