tery is fresh, the internal resistance is low (around a few tenths of a volt), but as the battery is drained, the resistance increases (conducting electrons become fewer in number as the chemical reactants run out). The following circuit shows a more realistic representation of a battery that has a load attached to it.

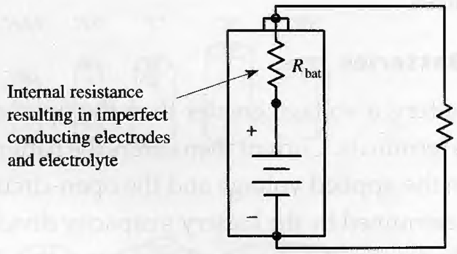


FIGURE 3.29

Using this new representation of the battery, notice that when a load resistor is attached to it, you get a circuit containing an ideal battery connected to two resistors in series (internal-resistance resistor and load resistor). In effect, the internal-resistance resistor will provide an additional voltage drop within the circuit. The actual supplied voltage "felt" by the load resistor will then be smaller than what is labeled on the battery's case. In reality, it is not important to know the exact value of the internal resistance for a battery. Instead, a battery is placed in a circuit, and the voltage across the battery is measured with a voltmeter. (You cannot remove the battery from the circuit and then measure it; the reading will be tainted by the internal resistance of the meter.) Measuring the voltage across a battery when a load is attached to it gives the true voltage that will be "felt" by the load.

Take note, internal resistance may limit a battery's ability to deliver high currents needed for pulse applications, as in photoflashes and radio signaling. A reliable battery designed for pulsing applications is a silver oxide battery.

3.3 Switches

A *switch* is a mechanical device that interrupts or diverts electric current flow within a circuit.

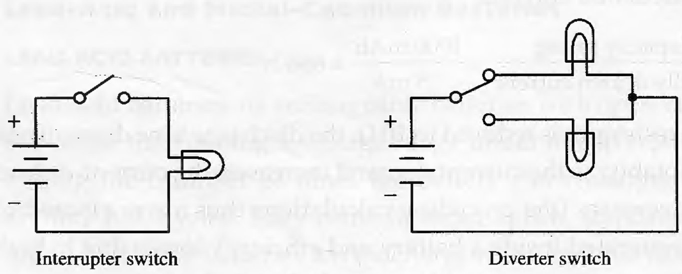


FIGURE 3.30

3.3.1 How a Switch Works

Two slider-type switches are shown in Fig. 3.31. The switch in Fig. 3.31*a* acts as an interrupter, whereas the switch in Fig. 3.31*b* acts as a diverter.

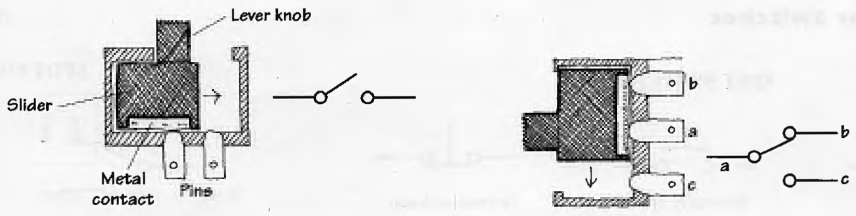


FIGURE 3.31 (*a*) When the lever is pushed to the right, the metal strip bridges the gap between the two contacts of the switch, thus allowing current to flow. When the lever is pushed to the left, the bridge is broken, and current will not flow. (*b*) When the lever is pushed upward, a conductive bridge is made between contacts *a* and *b*. When the lever is pushed downward, the conductive bridge is relocated to a position where current can flow between contact *a* and *c*.

Other kinds of switches, such as push-button switches, rocker switches, magnetic-reed switches, etc., work a bit differently than slider switches. For example, a magnetic-reed switch uses two thin pieces of leaflike metal contacts that can be forced together by a magnetic field. This switch, as well as a number of other unique switches, will be discussed later on in this section.

3.3.2 Describing a Switch

A switch is characterized by its number of *poles* and by its number of *throws*. A pole represents, say, contact *a* in Fig. 3.31*b*. A throw, on the other hand, represents the particular contact-to-contact connection, say, the connection between contacts *a* and contact *b* or the connection between contact *a* and contact *c* in Fig. 3.31*b*. In terms of describing a switch, the following format is used: (number of poles) "*P*" and (number of throws) "*T*." The letter *P* symbolizes "pole," and the letter *T* symbolizes "throw." When specifying the number of poles and the number of throws, a convention must be followed: When the number of poles or number of throws equals 1, the letter *S*, which stands for "single," is used. When the number of poles or number of throws equals 2, the letter *D*, which stands for "double," is used. When the number of poles or number of throws exceeds 2, integers such as 3, 4, or 5 are used. Here are a few examples: SPST, SPDT, DPST, DPDT, DP3T, and 3P6T. The switch shown in Fig. 3.31*a* represents a single-pole single-throw switch (SPST), whereas the switch in Fig. 3.31*b* represents a single-pole double-throw switch (SPDT).

Two important features to note about switches include whether a switch has momentary contact action and whether the switch has a center-off position. Momentary-contact switches, which include mainly pushbutton switches, are used when it is necessary to only briefly open or close a connection. Momentary-contact switches come in either normally closed (NC) or normally open (NO) forms. A normally closed pushbutton switch acts as a closed circuit (passes current) when left untouched. A normally open pushbutton switch acts as an open circuit (broken circuit) when left untouched. Center-off position switches, which are seen in diverter switches, have an additional "off" position located between the two "on" positions. It is important to note that not all switches have center-off or momentary-contact features—these features must be specified.

Symbols for Switches

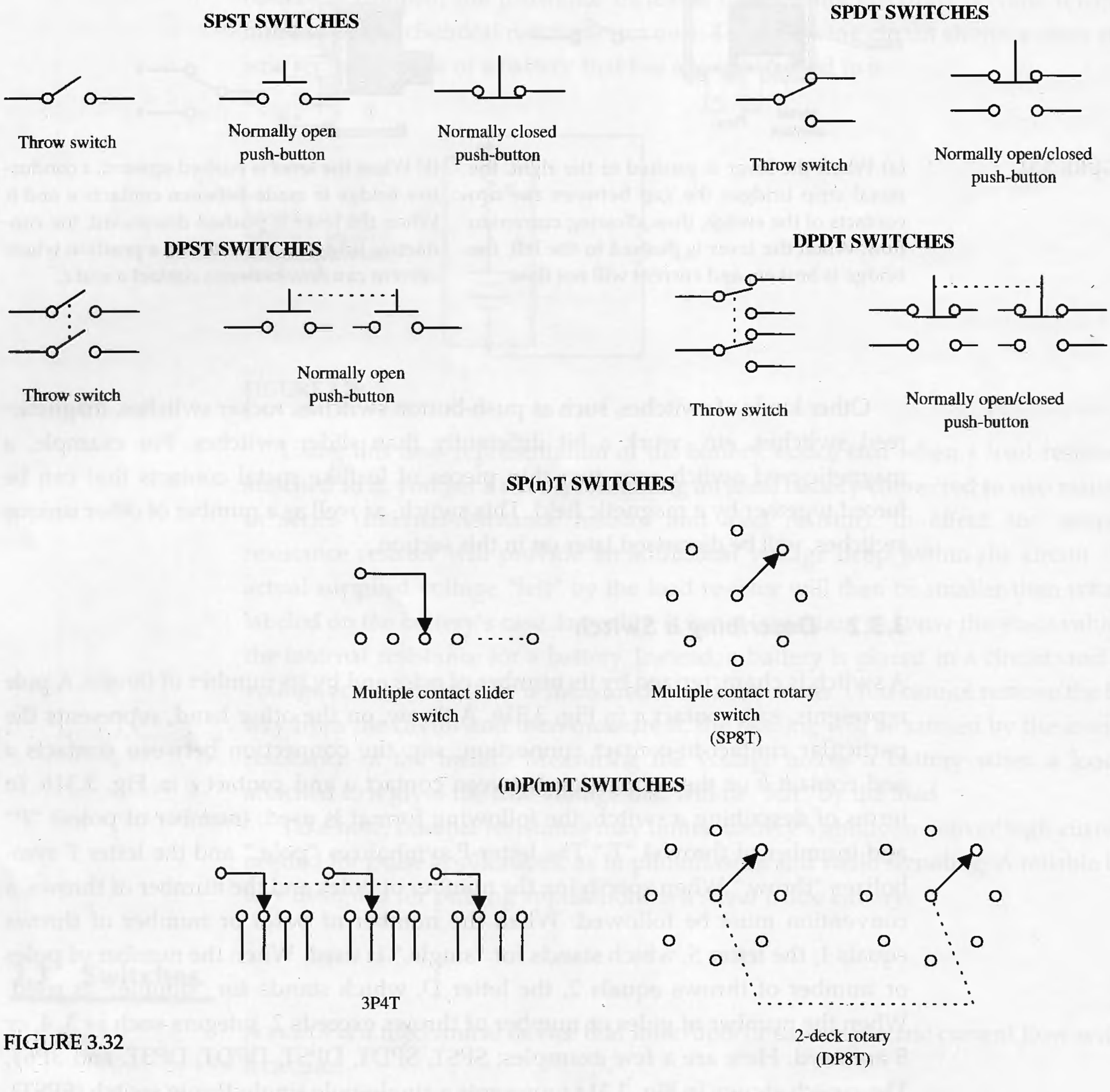
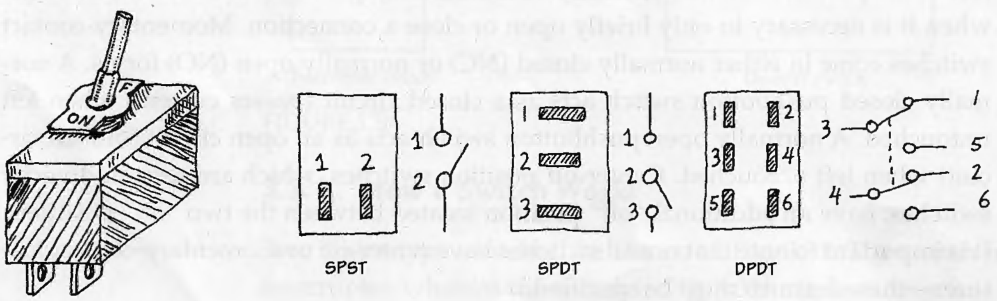


FIGURE 3.32

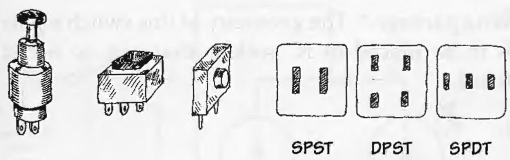
3.3.3 Kinds of Switches

FIGURE 3.33

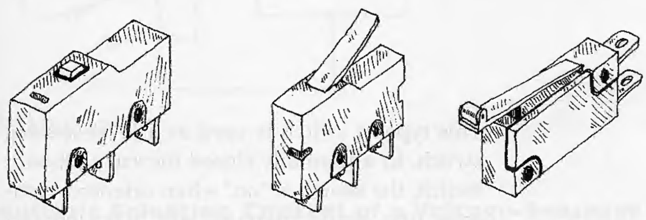
Toggle Switch



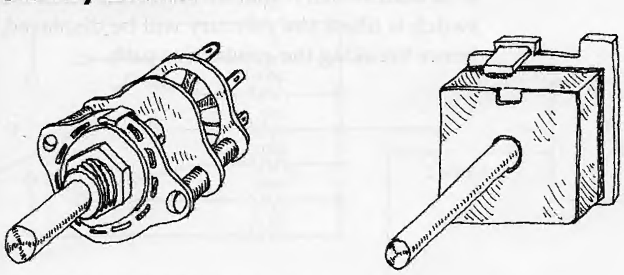
Pushbutton Switch



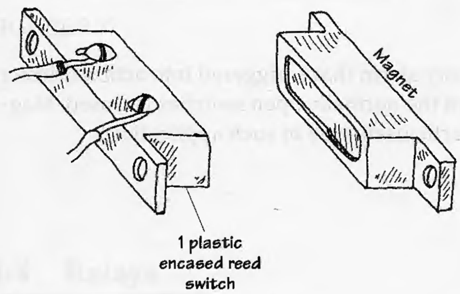
Snap Switch



Rotary Switch

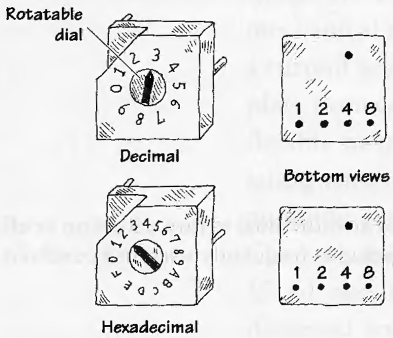


Magnetic Reed Switch



A reed switch consists of two closely spaced leaflike contacts that are enclosed in an air-tight container. When a magnetic field is brought nearby, the two contacts will come together (if it is a normally open reed switch) or will push apart (if it is a normally closed reed switch).

Binary-Coded Switches



These switches are used to encode digital information. A mechanism inside the switch will "make" or "break" connections between the switch pairs according to the position of the dial on the face of the switch. These switches come in either true binary/hexadecimal and complementary binary/hexadecimal forms. The charts below show how these switches work:

True Binary/Hexadecimal

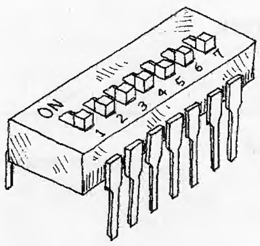
Type		Position	Code 1	Code 2	Code 4	Code 8
Hexadecimal	Decimal	0				
		1	•			
		2		•		
		3	•	•		
		4			•	
		5	•		•	
		6		•	•	
		7	•	•	•	
		8				•
		9	•			•
		A		•		•
		B	•	•		•
		C			•	•
		D	•		•	•
		E		•	•	•
		F	•	•	•	•

Complimentary-Binary/Hexadecimal

Type		Position	Code 1	Code 2	Code 4	Code 8
Hexadecimal	Decimal	0	•	•	•	•
		1		•	•	•
		2	•		•	•
		3			•	•
		4	•	•		•
		5		•		•
		6	•			•
		7				•
		8	•	•	•	
		9		•	•	
		A	•		•	
		B			•	
		C	•	•		
		D		•		
		E	•			
		F				

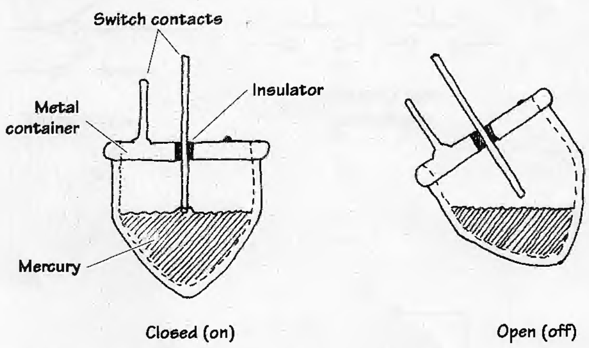
FIGURE 3.33 (*Continued*)

DIP Switch



DIP stands for "dual-inline package." The geometry of this switch's pinouts allows the switch to be placed in IC sockets that can be wired directly into a circuit board.

Mercury Tilt-Over

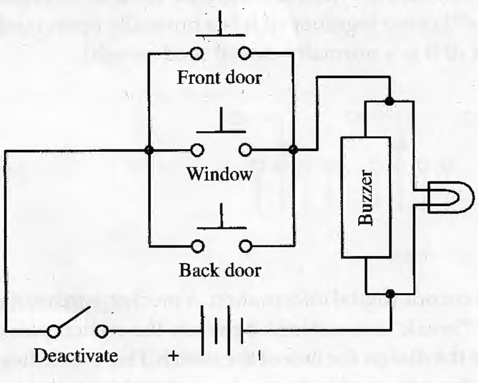


This type of switch is used as a level-sensing switch. In a normally closed mercury tilt-over switch, the switch is "on" when oriented vertically (the liquid mercury will make contact with both switch contacts). However, when the switch is tilted, the mercury will be displaced, hence breaking the conductive path.

FIGURE 3.33 (*Continued*)

3.3.4 *Simple Switch Applications*

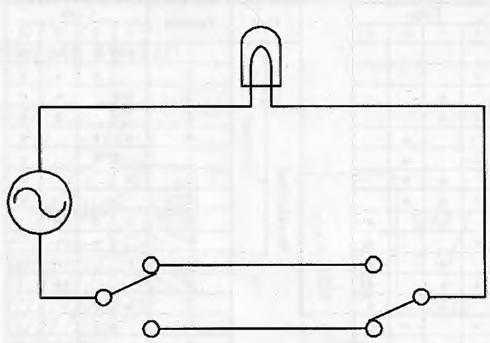
Simple Security Alarm



Here's a simple home security alarm that's triggered into action (buzzer and light go on) when one of the normally open switches is closed. Magnetic reed switches work particularly well in such applications.

FIGURE 3.34

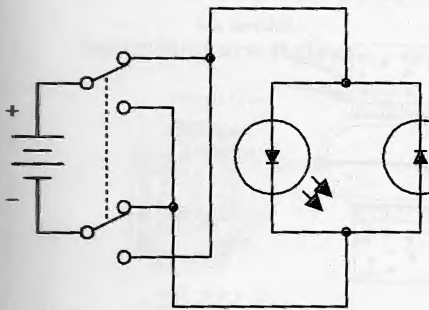
Dual-Location On/Off Switching Network



Here's a switch network that allows an individual to turn a light on or off from either of two locations. This setup is frequently used in household wiring applications.

FIGURE 3.35

Current-Flow Reversal



A DPDT switch, shown here, can be used to reverse the direction of current flow. When the switch is thrown up, current will flow throw the left light-emitting diode (LED). When the switch is thrown down, current will flow throw the right LED. (LEDs only allow current to flow in one direction.)

FIGURE 3.36

Multiple Selection Control of a Voltage-Sensitive Device via a Two-Wire Line

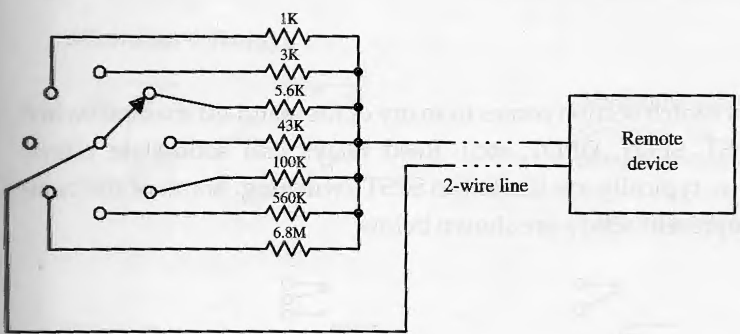


FIGURE 3.37

Say you want to control a remote device by means of a two-wire line. Let's also assume that the remote device has seven different operational settings. One way of controlling the device would be to design the device in such a way that if an individual resistor within the device circuit were to be altered, a new function would be enacted. The resistor may be part of a voltage divider, may be attached in some way to a series of window comparators (see op amps), or may have an analog-to-digital converter interface. After figuring out what valued resistor enacts each new function, choose the appropriate valued resistors and place them together with a rotary switch. Controlling the remote device becomes a simple matter of turning the rotary switch to select the appropriate resistor.

3.4 Relays

Relays are electrically actuated switches. The three basic kinds of relays include mechanical relays, reed relays, and solid-state relays. For a typical mechanical relay, a current sent through a coil magnet acts to pull a flexible, spring-loaded conductive plate from one switch contact to another. Reed relays consist of a pair of reeds (thin, flexible metal strips) that collapse whenever a current is sent through an encapsulating wire coil. A solid-state relay is a device that can be made to switch states by applying external voltages across *n*-type and *p*-type semiconductive junctions (see Chap. 4). In general, mechanical relays are designed for high currents (typically 2 to 15 A) and relatively slow switching (typically 10 to 100 ms). Reed relays are designed for moderate currents (typically 500 mA to 1 A) and moderately fast switching (0.2 to 2 ms). Solid-state relays, on the other hand, come with a wide range of current ratings (a few microamps for low-powered packages up to 100 A for high-power packages) and have extremely fast switching speeds (typically 1 to 100 ns). Some limitations of both reed relays and solid-state relays include limited switching arrangements (type of switch section) and a tendency to become damaged by surges in power.