The basic practical result of transmission line theory is that, as the speed-distance product of an electrical signal increases, the signal tends to reflect off the ends of wires and bounce back and forth on the wire. When slow signals travel relatively moderate distances, the speed-distance product is not large enough to cause this phenomenon to any noticeable degree. Fast signals traveling over very short distances may also be largely immune to such reflections. However, when RS-422 signals travel over several kilometers, the speed-bandwidth product is great enough to cause previously transmitted data signals to reflect and interfere with subsequent data. This problem can be largely solved by properly *terminating* the receiving end of the transmission line with the line's *characteristic impedance*, Z_O. Typical coaxial and twisted-pair transmission lines have Z_O = 50, 75, or 110 Ω. Briefly put, Z_O is the impedance, or electrical resistance, that would be observed between both conductors of a balanced transmission line of infinite length. Again, there is substantial theory lurking here, but the practical result is that, by placing a resistor equal to Z_O at the far end of the line between both conductors, the transmission line will appear to be continuous and not exhibit reflections. A typical schematic diagram of a terminated RS-422 serial link is shown in Fig. 5.8.

5.6 MODEMS AND BAUD RATE

Information is conveyed by varying the electromagnetic field of a particular medium over time. The rate at which this field (e.g., voltage) changes can be represented by a certain bandwidth that characterizes the information. Transducers such as those that facilitate RS-232/RS-422 serial links place the information that is presented to them essentially unmodified onto the transmission medium. In other words, the bandwidth of the information entering the transducer is equivalent to that leaving the transducer. Such a system operates at *baseband:* the bandwidth inherent to the raw information. Baseband operation is relatively simple and works well for a transmission medium that can carry raw binary signals with minimal degradation (e.g., various types of wire, or fiber optic cable, strung directly from transmitter to receiver). However, there are many desirable communications media that are not well suited to directly carrying bits from one point to another. Two prime examples are free-space and acoustic media such as a telephone.

To launch raw information into the air or over a telephone, the bits must be superimposed upon a *carrier* that is suited to the particular medium. A carrier is a frequency that can be efficiently radiated from a transmitter and detected by a remote receiver. The process of superimposing the bits on the carrier is called *modulation*. The reverse process of detecting the bits already modulated onto the carrier is *demodulation*. For the purposes of this discussion, one of the simplest forms of modulation, binary *amplitude modulation* (AM), is presented as an example. More precisely, this type of AM is called *amplitude shift keying* (ASK). With two states, it is called 2-ASK and is illustrated in Fig. 5.9. Each time a 1 is to be transmitted, the carrier (shown as a sine wave of arbitrary frequency) is turned on with an arbitrary amplitude. Each time a 0 is to be transmitted, the carrier is turned off with an amplitude of zero. If transmitting over free space, the carrier frequency might be anywhere from hundreds of kilohertz to gigahertz. If communicating over a fiber optic cable, the carrier is

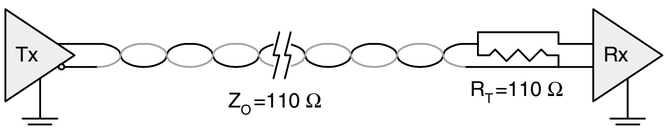

FIGURE 5.8 RS-422 transmission line termination.

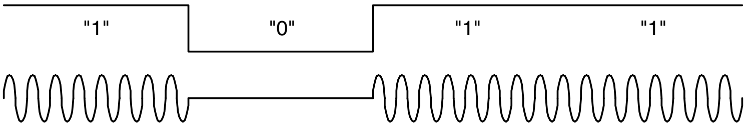

FIGURE 5.9 2-ASK modulation.

light. If an acoustic medium such as a telephone is used to send the data, the carrier is audible in the range of several kilohertz.

Frequency shift keying (FSK), a type of *frequency modulation* (FM) is a scheme that can be used to transmit multiple bits simultaneously without resorting to multiple levels of amplitude by using AM. FSK represents multiple bits by varying the frequency rather than the amplitude of the carrier. This constant amplitude approach is less susceptible to noise. Figure 5.10 shows 4-FSK modulation, in which each of the four frequency steps represents a different two-digit binary value.

A general term for a modulated data unit is a *baud*. If 2-ASK is used, each baud corresponds to one bit. Therefore, the baud rate matches the bit rate. However, the 4-FSK example shows that each baud represents two bits, making the bit rate twice that of the baud rate. This illustrates that baud rate and bit rate are related but not synonymous, despite common misuse in everyday conversation. Engineers who design modulation circuitry care about the baud rate, because it specifies how many unique data units can be transmitted each second. They also try to squeeze as many bits per baud as possible to maximize the overall bit rate of the modulator. Engineers who use modulators as black-box components do not necessarily care about the baud rate; rather, it is the system's bit rate that matters to the end application.

Enter the *modem*. A modem is simply a device that incorporates a modulator and demodulator for a particular transmission medium. The most common everyday meaning of modem is one that enables a computer to transfer bits over an analog telephone line. These modems operate using different modulation schemes depending on their bit rate. Early 300- and 1,200-bps modems operate using FSK and *phase shift keying* (PSK). Later modems, including today's 33.6- and 56-kbps models, operate using variations of *quadrature amplitude modulation* (QAM).

While *modem* often refers to telephone media, it is perfectly correct to use this term when referring to a generic modulator/demodulator circuit that operates on another medium. Digital wireless communication is increasingly common in such applications as portable cellular phones and untethered computer networking. These devices incorporate radio frequency (RF) modems in addition to digital transceivers that frame the data as it travels from one point to another.

5.7 NETWORK TOPOLOGIES

The communications schemes discussed thus far are point-to-point connections—they involve one transmitter and one receiver at either end of a given medium. Many applications require multidrop communications whereby multiple devices exchange data over the same medium. The general term

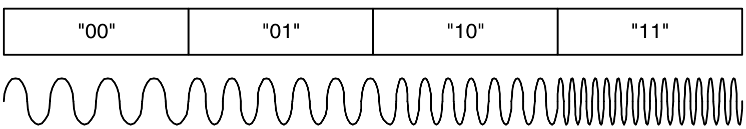

FIGURE 5.10 4-FSK modulation.