chapter 2

Wireless Data Transmission

After reading this chapter and completing the exercises, you will be able to:

- Discuss the two types of wireless transmission
- Explain the properties of a wave, such as amplitude, wavelength, frequency, and phase
- Describe the basic concepts and techniques related to the transmission of data by radio waves

Consider the wireless cellular telephone that may now be in your pocket or sitting on your desk. If you were to take that telephone apart, you would find an array of pieces: chips, a microphone, a speaker, resistors, capacitors, and other parts. Yet much more than that mobile cordless telephone is needed to complete a call. Some of the other elements involved are the cellular towers, the equipment that manages your call as you move from one cell to another, and all the equipment at the telephone company's central office that directs your call to the correct recipient. Moreover, if you're calling someone overseas, additional equipment, such as satellites or underwater cables, may be used to complete the international connection.

Trying to make sense of a modern communications system is truly mind-boggling because of the sheer number of components that are involved. How can we begin to understand how it all works?

One approach is the bottom-up method, which looks first at the individual elements or components that make up a system, then ties them all together to show how the system works. This chapter uses the bottom-up approach to set the foundation for our exploration of wireless communications and networks. You will apply the concepts covered in this chapter to more specific technologies discussed in later chapters. If you are studying or working in the IT field, you already know how data is represented inside a computer or digital device. In this chapter, you will learn how the various types of wireless signals are used to transmit data. Finally, we'll delve a little deeper into how data is transmitted using radio waves.

To keep things simple, we will use the **American Standard Code for Information Interchange** (or **ASCII** code), which uses only eight bits to represent all the letters of the alphabet, all the numerals, and several symbols. In this book's Appendix, you will find a complete ASCII table showing the hexadecimal value for all the characters and symbols.

Recall that all numbers—such as street-address numbers or any other numbers that are not intended to be used by the computer in calculations—are stored as text (i.e., as character data, without numerical value). In this case, the number is stored in ASCII code. For example, the decimal value 47 is normally stored as its binary equivalent (00101111) in the computer memory. When using ASCII code, the decimal number 4 is stored as hexadecimal 34 (0x34), which uses one byte (00110100 in binary); and the number 7 is stored in another byte in the computer memory using the ASCII code 0x37 (00110111 in binary). See Table 2-1.

First byte	Hexadecimal	3				4			
	Binary	0	0	1	1	0	1	0	0
Second byte	Hexadecimal	3				7			
	Binary	0	0	1	1	0	1	1	1

Table 2-1 ASCII code for 47 as stored in computer memory

One of the limitations of ASCII is that there are not enough codes for all the symbols used by foreign languages. Another coding scheme, called Unicode, is therefore used today. Unicode can represent 65,535 different characters because it uses 16 bits, or two bytes, instead of eight bits, or a single byte, to represent each character. In addition, when one bit out of every byte is used for error control (parity), the ASCII code can only represent 128 different characters.

Wireless Signals

Wired communications uses either copper wires or fiber-optic cables to send and receive data. Wireless transmissions, of course, do not use these or any other visible media. Instead, data signals travel on electromagnetic waves. All forms of electromagnetic energy—gamma rays, radio waves, even light—travel through space in the form of waves. The light from a flashlight or the heat from a fire also moves through space as waves. These waves, known as electromagnetic waves, don't require any special medium (such as air) or any type of conductor (such as a copper wire or optical fiber). Instead, they travel freely through space at the speed of light: 186,000 miles per second (300,000 kilometers per second).

Practically everything in the universe emits or absorbs electromagnetic radiation. Figure 2-1 illustrates the electromagnetic spectrum, which lets you compare each of the properties of electromagnetic radiation—such as the lengh of an electromagnetic wave—with the sizes of some common objects and items. The middle portion of the figure shows the commonly used names for these waves, and the bottom portion shows the range of frequencies—that is, how many waves occur in one second—along with where these waves usually originate. For example, in the visible light emitted by a light bulb, the number of waves that occur in one second is higher than 10^{13}, and each wave is about the size of a bacteria—that is, 0.000001 meters (3.281×10^{-6} feet). In this chapter, you will learn about each of these wave properties and the significance it has in wireless data communications.

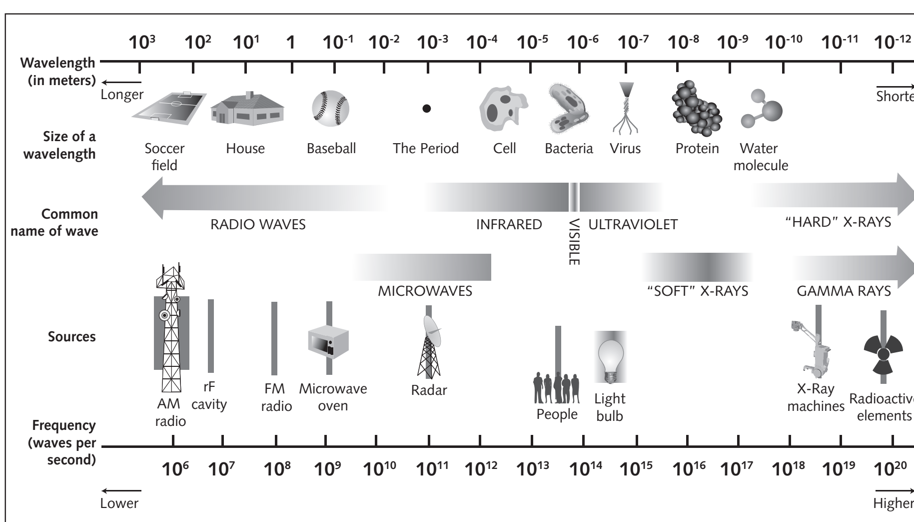

Figure 2-1 Electromagnetic spectrum

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Many people, when asked what type of medium is used to send and receive wireless transmissions, answer "airwaves." If this were the case, radio signals would not propagate in space, where there is no air. Wireless transmissions use electromagnetic (EM) waves as the medium, not air or empty space.

Infrared Light

There are two basic types of waves by which wireless data are sent and received: infrared light and radio waves. For centuries, flashes of light have been used to transmit information. Bonfires set on top of hills were once used to relay messages. Ocean vessels sent signals from ship to ship or from ship to shore using light. In 1880, Alexander Graham Bell demonstrated an invention called the photophone, which used light waves to transmit voice information. Transmitting modern computer or network data using light follows the same basic principle.

Because computers and data communication equipment use binary code, it is easy to transmit information with light. Just as binary code uses only two digits (0 and 1), light has only two properties (off and on). Sending a 1 in binary code could result in a light quickly flashing on; sending a 0 could result in the light remaining off. For example, the letter "A" (ASCII 0x41 or 01000001) could be transmitted by light as *off-on-off-off-off-off-off-on*. This concept is illustrated in Figure 2-2.

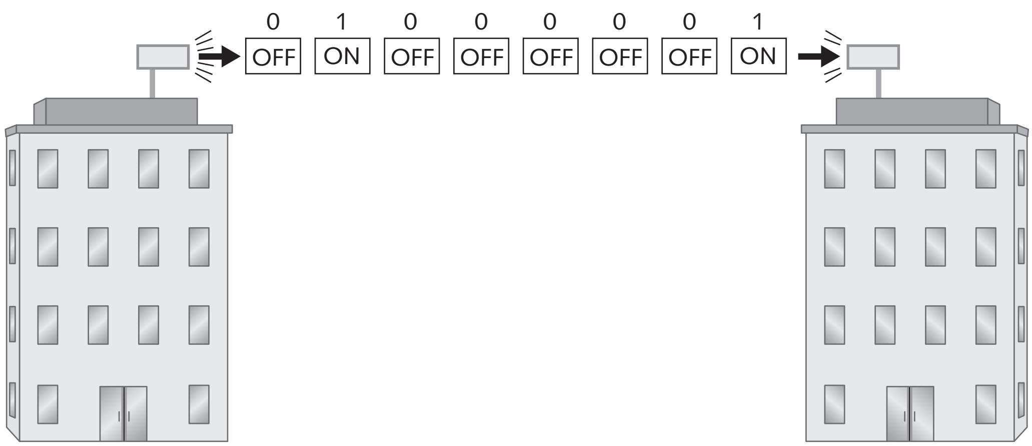

Figure 2-2 Transmitting a message using visible light

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What type of light should be used to transmit these signals? Transmitting data using visible light flashes, such as a strobe light, would be very unreliable because other lights could be mistaken for the transmission signal or another bright light could wash out the light flashes. In addition, visible light (and even some frequencies that are invisible to the human eye) can be blocked by various obstacles—fog, heavy rain, etc.—and is therefore not a reliable medium for data transmissions.

However, visible light is only one type of light. All the different types of light that travel from the Sun to the Earth make up the **light spectrum**, and visible light is just a small part of that entire spectrum. Some of the other forms of energy within the light spectrum, such as X-rays, ultraviolet rays, and microwaves, are also invisible to the human eye. **Infrared light**, some of which is invisible, has many of the characteristics that visible light has because it is adjacent to visible light on the light spectrum. Yet, it is a much better medium for data transmission because it is less susceptible to interference from other sources of visible light.

Each wavelength within the spectrum of visible light represents a particular color. This is because the differing wavelengths of light waves bend at a different angle when passed through a prism, which in turn produces different colors. The colors that visible light produces are red (R), orange (O), yellow (Y), green (G), blue (B), indigo (I), and violet (V). Visible light is sometimes referred to as ROYGBIV.

Infrared wireless systems require that each device have two components: an **emitter**, which transmits a signal, and a **detector**, which receives the signal. (These two components are almost always combined into one device.) An emitter is usually a laser diode or a light-emitting diode (LED). Infrared wireless systems send data by the intensity of the light wave instead of whether the light signal is on or off. To transmit a 1, the emitter increases the intensity of the electrical current and, consequently, the intensity of the infrared light, which indicates a pulse to the receiver. The detector senses the higher-intensity pulse of light and produces a proportional electrical current (see Figure 2-3).

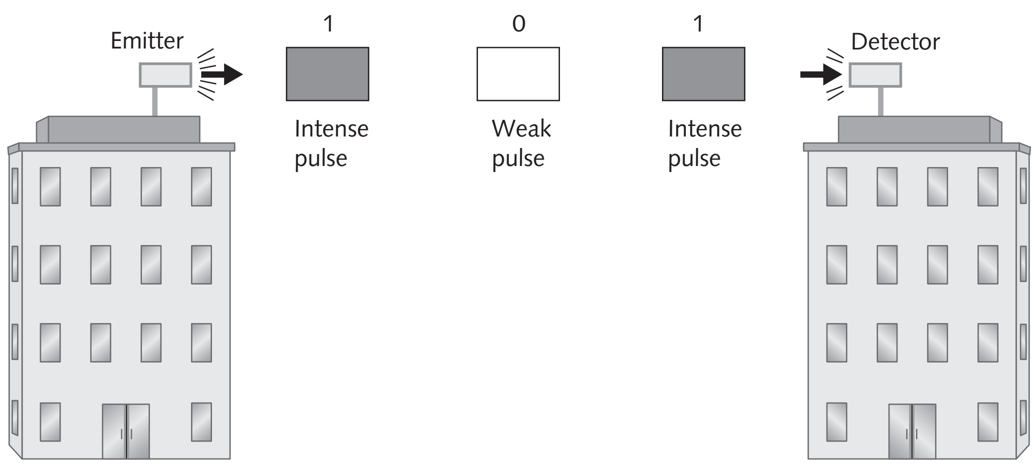

Figure 2-3 Light pulses

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Infrared wireless transmission can be either directed or diffused. A **directed transmission** requires that the emitter and detector be directly aimed at one another (called the **line-of-sight** principle), as shown in Figure 2-4. The emitter sends a narrowly focused beam of infrared light. The detector has a small receiving or viewing area. A television remote control, for example, uses directed transmission, and this is the reason that most of us point the remote at the TV or other remote-controlled devices.

Although TV remote controls generally use directed transmission, with a fresh set of batteries you should be able to point the remote at a white wall directly across from the TV set and use it to change channels, increase the volume, and so on—as long as nothing else is blocking the path of the invisible infrared light.

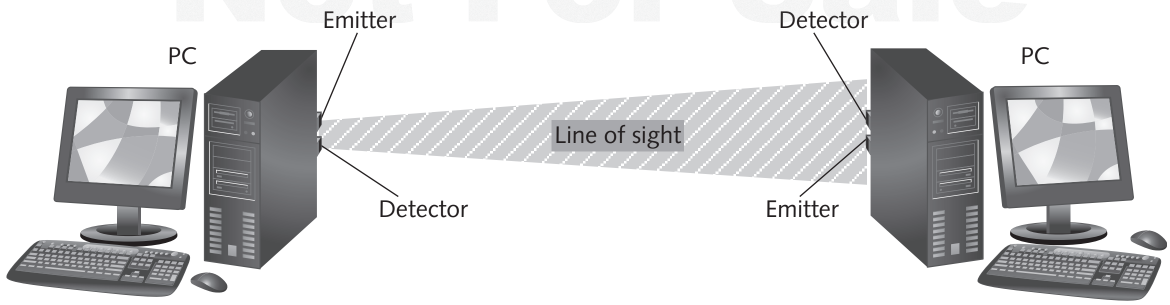

Figure 2-4 Directed infrared transmission

A **diffused transmission** relies on reflected light. With diffused transmissions, the emitters have a wide-focused beam instead of a narrow beam. For example, the emitter might be pointed at the ceiling of a room and use it as a reflection point. When the emitter transmits an infrared signal, the signal bounces off the ceiling and fills the room with the signal. The detectors are pointed at the same reflection point and can detect the reflected signal, as shown in Figure 2-5.

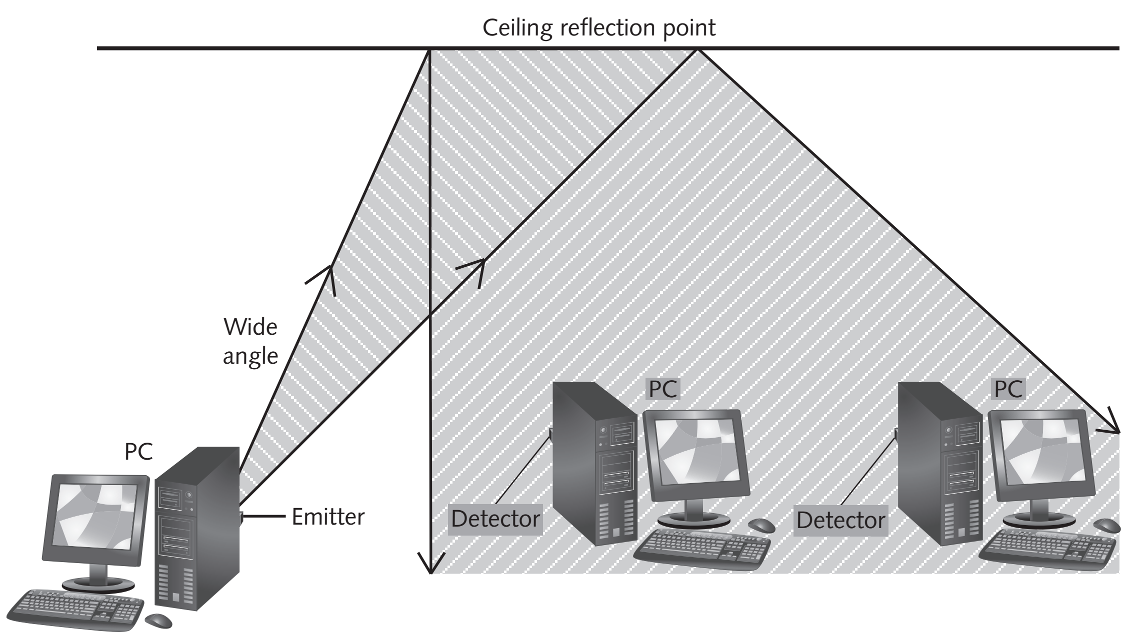

Figure 2-5 Diffused infrared transmission

Infrared wireless systems have several advantages. Infrared light neither interferes with other types of communications signals (such as radio signals) nor is it affected by other signals, except light. In addition, because infrared light does not penetrate walls, the signals are kept inside a room. This makes it impossible for someone elsewhere to listen in on the transmitted signal.

However, there are several serious limitations to infrared wireless systems. The first limitation involves the lack of mobility. Directed infrared wireless systems use a line-of-sight principle, which makes it challenging for mobile users because the alignment between the emitter and the detector would have to be continually adjusted. The second limitation is the range of coverage. Directed infrared systems, which require line of sight, cannot be placed in an environment where there is the possibility that anything could get in the way of the infrared beam (think of someone standing in front of your remote control while you are trying to change TV channels). This means that devices using infrared transmissions must be placed close enough to one another to eliminate the possibility of something moving between them. Due to the angle of deflection, diffused infrared can cover a range of only 50 feet (15 meters). And because diffused infrared requires a reflection point, it can only be used indoors. These restrictions limit the range of coverage.

Another significant limitation of an infrared system is the speed of transmission. Diffused infrared can send data at maximum speeds of only 4 Mbps. This is because the wide angle of the beam loses energy as it reflects. The loss of energy results in a weakening signal. The weak signal cannot be transmitted over long distances, nor does it have sufficient energy to maintain a high transmission speed, resulting in a lower data rate.

Because of these limitations, infrared wireless systems are generally used in specialized applications, such as data transfers between notebook computers, digital cameras, handheld data collection devices, PDAs, electronic books, and other similar mobile devices. In the past, laptop computers were almost always equipped with infrared interfaces; sadly, this is no longer true. If you still need an infrared interface today, you must purchase one that plugs into a USB port on the computer. Figure 2-6 shows an example of such a device.

Figure 2-6 USB infrared adapter with extension cable

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Some specialized wireless local area networks are based on the infrared method of transmitting data signals. These are used in situations where radio signals would interfere with other equipment, such as in hospital operating rooms, or when security is a concern, such as in some government and military installations.

Like other types of electromagnetic waves (such as visible light and heat), infrared light has limitations. Light waves, for example, cannot penetrate through most materials like wood or concrete, and heat rays are absorbed by most objects, including human skin (we feel infrared waves as heat). Solid objects and even dust and humidity (water molecules in the atmosphere) can limit the distance that light and infrared waves can travel. See Figure 2-7.

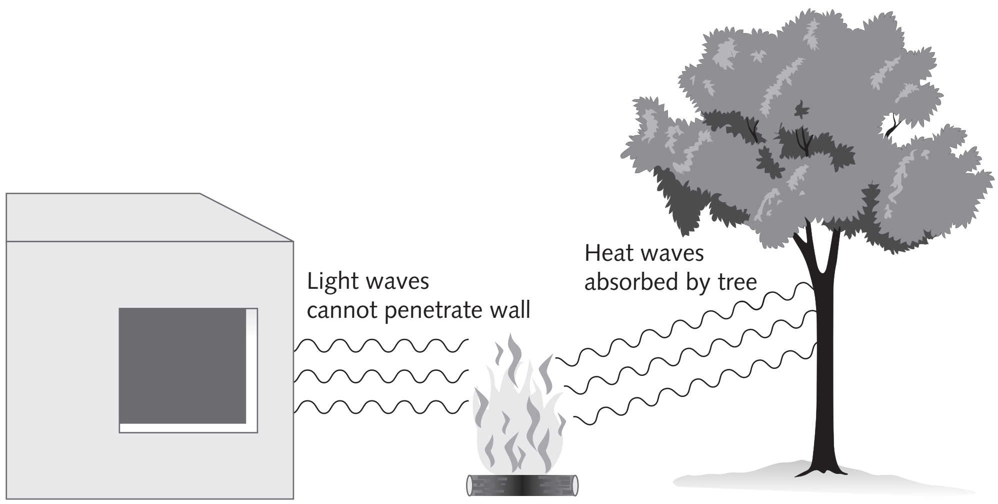

Figure 2-7 Limitations of light and heat waves

Is there a wave in the electromagnetic spectrum that does not have the distance limitations of light or infrared? The answer is yes: radio waves.

Radio Waves

The second means of transmitting a wireless signal is by using radio transmission. Radio waves provide the most common and effective means of wireless communications today. To understand the basic properties of radio waves, imagine that you are watering your lawn with a garden hose. As you move your hand up and down, the water creates what look like waves that are also moving up and down, as shown in Figure 2-8.

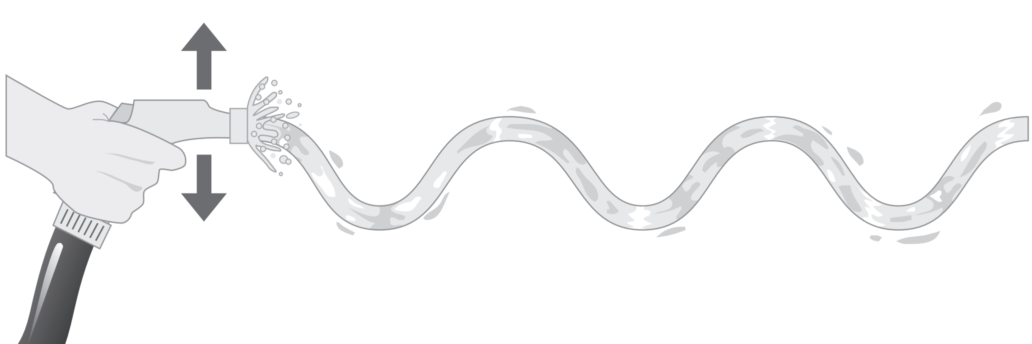

Figure 2-8 Simulating a radio wave using a garden hose

The waves created by the garden hose have a shape that is similar to that of electromagnetic waves. Recall that energy travels through space or air in electromagnetic waves. Infrared light, visible light from a flashlight, and heat from a fire also move through empty space or through the air in the atmosphere as electromagnetic waves.

Another type of electromagnetic wave that travels in this fashion is called a **radio wave** (**radiotelephony**). When an electric current passes through a wire, it creates a magnetic field in the space around the wire. As this magnetic field radiates, it creates radio waves. Because radio waves, like light and heat waves, are electromagnetic waves, they move outward, usually in all directions.

Radio waves are free from some of the limitations that affect light and heat. Unlike heat waves, radio waves can travel great distances. Radio waves can also penetrate most solid objects (with the exception of metallic ones), whereas light waves cannot penetrate anything opaque or solid. Visible light waves and heat waves can be seen and felt, but radio waves are invisible. These characteristics are illustrated in Figure 2-9. Because of these characteristics, radio waves are an excellent means to transmit data without wires.

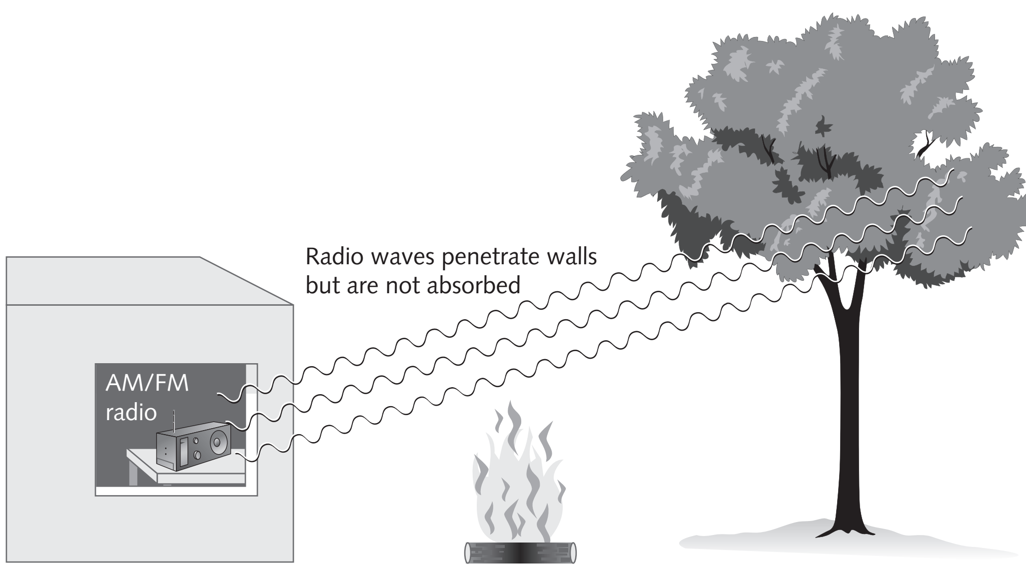

Figure 2-9 Radio waves can penetrate most solid objects

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How Radio Data Is Transmitted

Radio waves can be used to transmit data over long distances without the need for wires. The method by which these waves transport data involves several concepts. We will start by discussing the ways that analog and digital data are transmitted over radio waves.

Analog and Digital

When you create waves using a garden hose, the waves are continuous as long as the water is turned on and you keep moving your hand up and down. These waves represent an analog signal. An **analog signal** is one in which the intensity of the waves (**voltage** or **amplitude**) varies and is broadcast continuously—in other words, the signal has no breaks in it. Figure 2-10 illustrates an analog signal. Audio, video, voice, and even light are all examples of analog signals. An audio signal that contains a tone or a song is continuously flowing and doesn't start and stop until the tone or song is over.

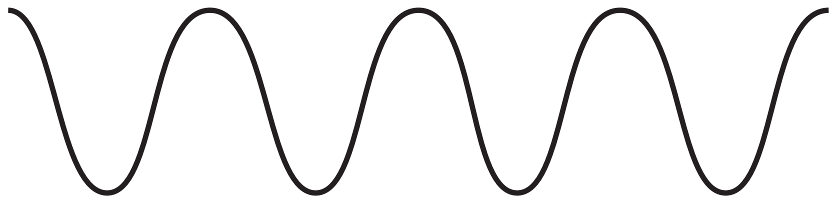

Figure 2-10 Analog signal

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Now, suppose that instead of moving the hose up and down, you were to hold it steady, place your thumb over the end of the garden hose for a second and then remove it. Water would stop flowing while your thumb was over the hose and then start flowing again when you removed your thumb. This on-off activity, shown in Figure 2-11, is similar to a digital signal. A **digital signal** consists of discrete or separate pulses, as opposed to an analog signal, which is continuous. A digital signal has numerous starts and stops throughout the signal stream—Morse code, for example, with its series of dots and dashes. Figure 2-12 illustrates a digital signal.

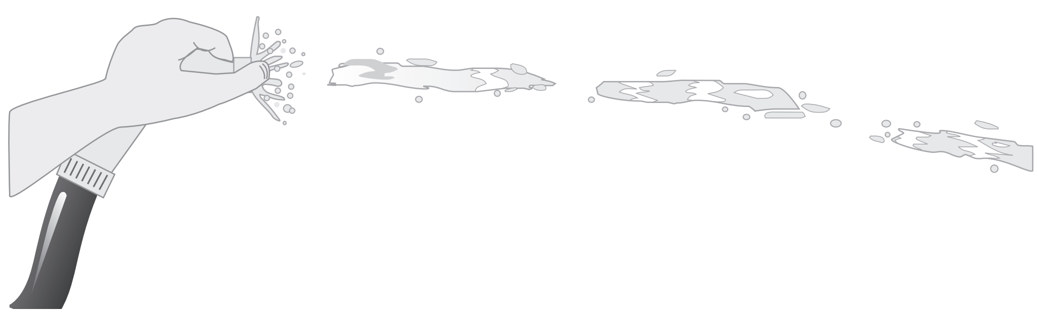

Figure 2-11 Simulating a digital signal with a garden hose

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Figure 2-12 Digital signal

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Computers operate using digital signals. If analog data, such as a video image or an audio sound, needs to be stored on the computer, it must be converted into a digital format before it can be stored and processed or interpreted by a computer.

Various techniques are used to convert the different types of analog data to digital data. For CD-quality stereophonic music (2-channels), the analog signal is measured (sampled) at the rate of 44,100 times per second; each sample is then stored in a digital format, using a minimum of 16 bits per sample. Using a number of other techniques, computers also compress digitized signals to minimize the total amount of storage space or the amount of data that needs to be transmitted.

To transmit a digital signal over an analog medium, as when two computers communicate over an analog telephone line or TV cable, a device known as a **modem** (**MOdulator/DEModulator**) is used. A modem takes the distinct digital signals from a computer and encodes them into a continuous analog signal for transmission over analog phone lines. The process of encoding the digital signals (bits) onto an analog wave is called **modulation.** The modem at the other end of the connection then reverses the process by receiving an analog signal, decoding it, and converting it back into a digital signal.

Frequency and Wavelength

Now, think about holding a garden hose and slowly moving your hand up and down. You will create long waves, as shown in Figure 2-13. If you rapidly move your hand up and down, the waves become shorter, as shown in Figure 2-14. Depending on how fast you move your hand up and down, the peaks of the waves will be closer together or farther apart. This illustrates another property of waves, called the **wavelength**. The wavelength is the distance between any point in one wave **cycle** and the same point in the next wave cycle.

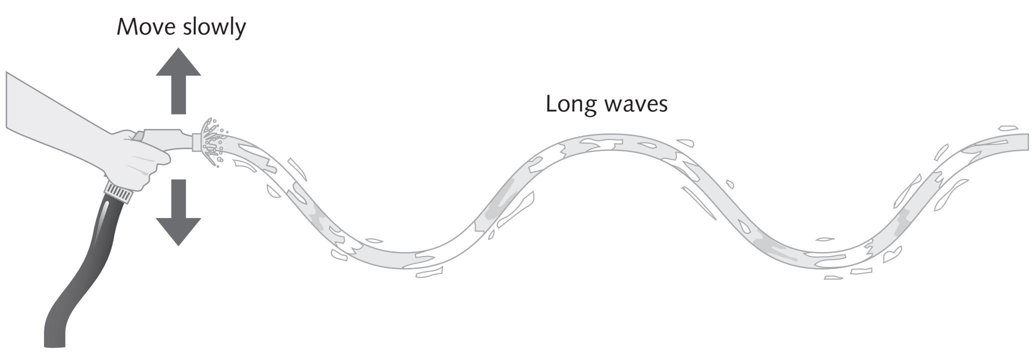

Figure 2-13 Long waves

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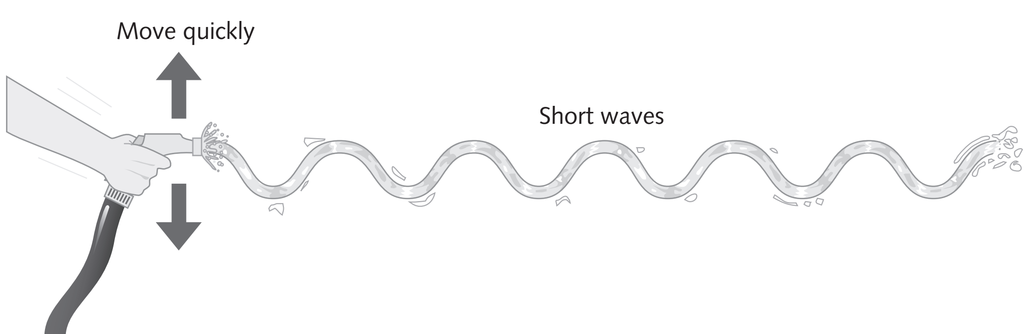

Figure 2-14 Short waves

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The same variations occur with radio waves. The rate at which a radio circuit creates the waves (like moving the garden hose up and down faster or slower) will result in a different number of radio waves being created each second and the peaks becoming either closer or farther apart. This rate is a radio wave's **frequency**. That is, the number of times a cycle (which is composed of one top [positive] and one bottom [negative] peak) occurs within one second equals the frequency of a wave.

The wavelength is inversely proportional to the frequency, which means that when the frequency is high, the wavelength is short or small, and when the frequency is low, the wavelength is long.

Radio transmitters send what is known as a **carrier signal**. This is a **continuous wave (CW)** of constant amplitude (measured in volts) and frequency. This is essentially an up-and-down wave called an **oscillating signal** or a **sine wave**, as illustrated in Figure 2-15. A CW carries no useful information by itself. Only after it is modulated does it contain some kind of information signal, such as music, voice, or data; then, it is correctly called a carrier signal or carrier wave. A receiver is adjusted (or tuned) to the frequency of the carrier, and it ignores all the other frequencies.

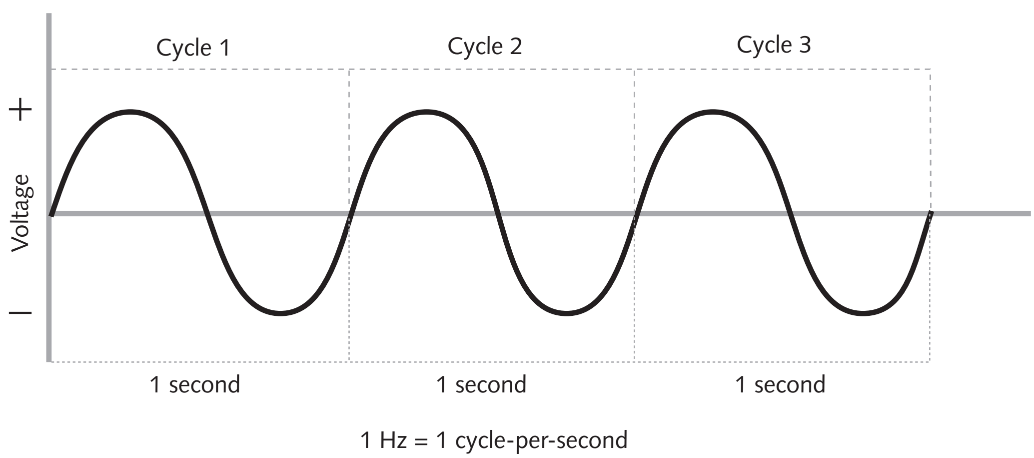

Figure 2-15 Sine wave (analog wave) and frequency

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Notice in Figure 2-15 that the wave starts at zero, moves up to the maximum voltage (+), then down to the minimum voltage (−), and finally returns to its starting point (0) before beginning all over again. Whenever the wave completes its trip up, then down, and returns back to the starting point, it has finished one cycle. Recall that frequency is defined as the number of times a wave completes a cycle in one second.

Figure 2-16 illustrates two different frequencies. Notice that both the lower frequency and the higher frequency alternate to the same maximum and minimum voltage. A change in voltage does not create a change in frequency. Instead, changes in frequency result from how long it takes to reach the maximum, fall back to the minimum, and then return to neutral to complete a cycle.

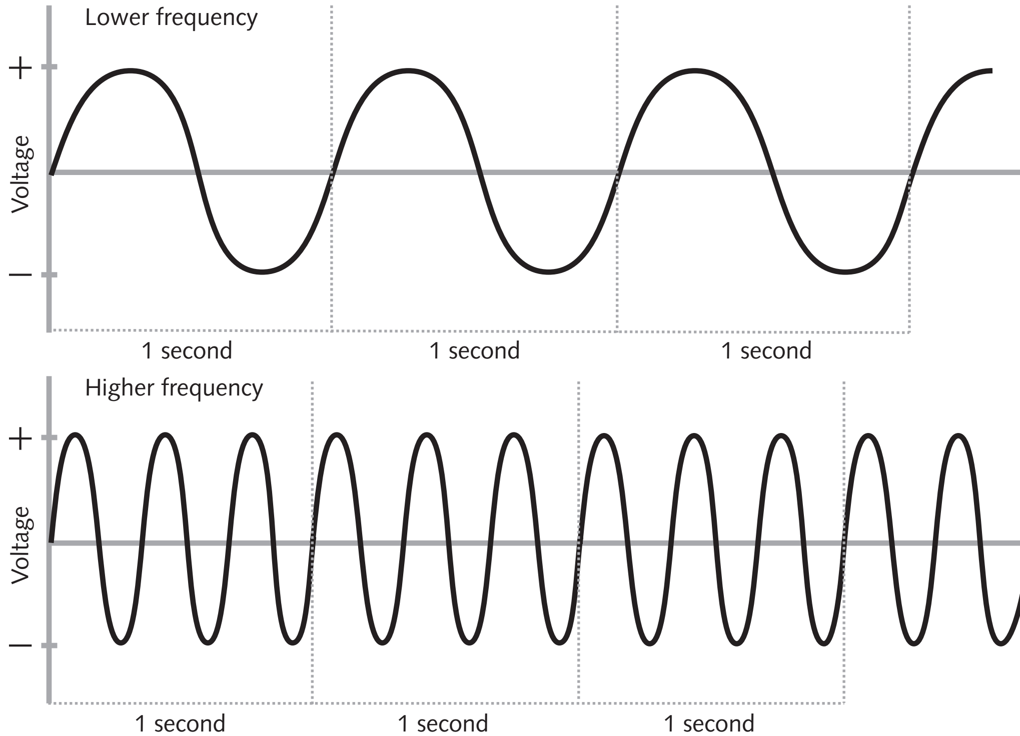

Figure 2-16 Two different frequencies; same amplitude

In electrical terms, the cycle produces what is known as an alternating current (AC) because it flows between negative (−) and positive (+). AC is the type of current that runs to the electrical outlets in a house, and it usually has a frequency of 60 Hz. Direct current (DC) is found in batteries. With DC, the current flows only from one terminal (−) to the other (+) and does not alternate. This lack of fluctuating movement also means that DC cannot be directly transmitted via an analog medium and cannot carry any data.

Although frequencies are measured by counting the number of complete wave cycles that occur in one second, the term **Hertz (Hz)** is used instead of cycles-per-second. A radio wave measured as 710,000 Hz means that its frequency is 710,000 cycles per second. Because of the high number of cycles in radio waves, metric prefixes are used when referring to frequencies. A **Kilohertz (KHz)** is 1,000 Hertz, a **Megahertz (MHz)** is 1,000,000 Hertz, and a **Gigahertz (GHz)** is 1,000,000,000 Hertz. The wave measured as 710,000 Hz is referred to as 710 KHz.

Frequency is an important part of music also. The frequency of the musical note A is 440 Hz, and middle C is 262 Hz. This means that when middle C is played, 262 pockets of higher air pressure pound against your eardrum each second.

Radio waves are usually transmitted and received using an **antenna**. An antenna is a length of copper wire, or similar material, with one end free and the other end connected to a receiver or transmitter. When transmitting, the radio waves created by the electronic circuit of the transmitter are fed to this antenna wire. This sets up an electrical pressure (voltage) along the wire, which will cause a small electrical current to flow into the antenna. Because the current is alternating, it flows back and forth in the antenna at the same frequency as the radio waves. When the electricity moves back and forth in the antenna at the same frequency as the radio waves, it creates both a magnetic field and an electrical field around the antenna. This continuous (analog) combination of magnetism and electrical pressure moves away (propagates) from the antenna the same way that water waves move away from the point of impact when you throw a rock in a pond. The result is an **electromagnetic wave (EM wave)**, as illustrated in Figure 2-17.

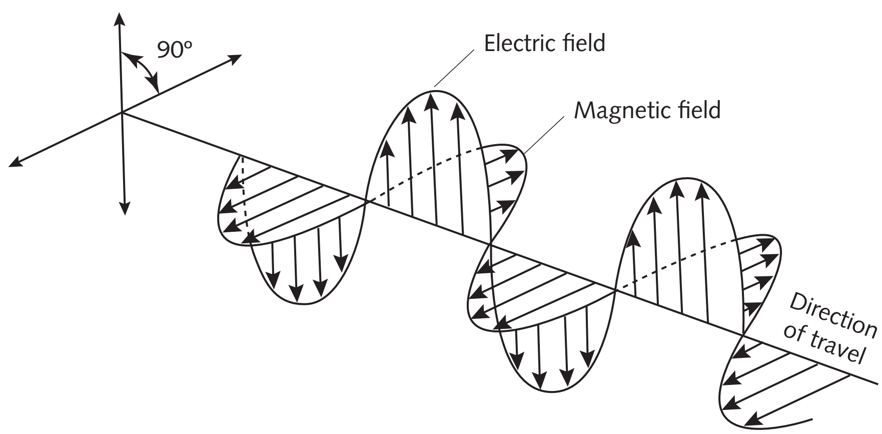

Figure 2-17 Electromagnetic wave consisting of electrical and magnetic fields

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Antennas are also used to pick up transmitted radio signals. A very small amount of electricity moves back and forth in the receiving antenna in response to the radio signal (EM wave) reaching it. This results in a very small amount of current flowing from the antenna into the receiver, as shown in Figure 2-18. In Chapter 3, you will learn what needs to be done to this small current so that the receiver can demodulate it and retrieve the data that was transmitted.

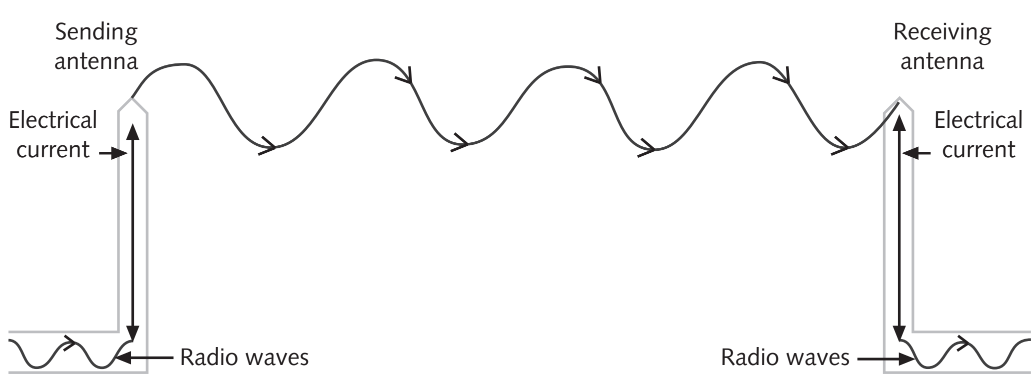

Figure 2-18 Radio antennas transmitting and receiving signals

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Transmission Speed

Several different terms are used when referring to the transmission speed of radio waves. The electromagnetic waves themselves always travel at the speed of light, which is 186,000 miles per second (300,000 kilometers per second). When digital information is transmitted using radio waves, the speed of transmission is usually shown in **bits per second** (**bps**), since the primary concern is how efficiently the data can be moved from one place to another.

Another term used in measuring the speed of radio transmission is *baud rate*. Recall that radio transmissions send out a carrier signal and that this signal can be changed or modulated. A **baud** is a change in that signal, and every time the signal changes, as you will learn later in this chapter, it defines the boundary of a signal unit. **Baud rate**, then, refers to the number of signal units (changes) per second that are required to represent the bits transmitted. The fewer signal units required, the better the system works, since the range of frequencies required for transmitting the signal is smaller.

Sometimes the terms *bps* and *baud rate* are used interchangeably, although they are not synonymous. This confusion originated with early computer modems. The first modems, for example, had speeds of 300, 600, and 1200 baud. These early modems used a simple modulation technique and were capable of transmitting at a maximum of one signal unit per bit transmitted; therefore, their speed in bps was the same as the baud rate, or 300, 600, and 1200 bps. For example, to transmit the letter U (0x55 ASCII or 01010101), it would take eight signal changes, one for each bit. Thus, the number of bits transmitted per signal unit (baud) was 1.

However, with later modems, it became possible to have a change in signal (a baud) represent more than one bit. A signal can be changed in several different ways, as explained later in this textbook; different changes result in different combinations of two bits (there can be up to four), each being assigned to one of four different signal changes. This is illustrated in Table 2-2.

Signal Change (Baud)	Bit Combination Represented
Signal W	00
Signal X	01
Signal Y	10
Signal Z	11

Table 2-2 Bit representation of four signal changes

The letters in Table 2-2 are simply used to differentiate four different types of signal changes. Today's analog modems transmit at a maximum rate of 4,800 baud, which is the maximum number of signal changes per second that a typical phone line can support. However, by using more complex modulation techniques, along with compression of the data, current modems can transmit data at speeds of up to 33,600 bps and receive data at up to 56,200 bps.

NOTE

56 Kbps modems are a little different from 33.6 Kbps modems in that one end of the connection must be a digital connection. To achieve 56 Kbps download speed from the ISP, the signal conversion from analog to digital or from digital to analog must only happen at one end of the phone line. Because of this limitation, these modems achieve a high downstream speed (from the ISP side to the modem) of 56 Kbps. The maximum speed from the modem side to the ISP side, or upstream, is 33.6 Kbps.

A signal unit—that is, the change that is made to the signal that represents two bits—is known as a **dibit**. When a signal unit can represent three bits, it is called a **tribit**. If 16 different signal units are used, then four bits per signal unit can be represented (known as a **quadbit**). These characteristics are summarized in Table 2-3.

Name	Number of Signal Changes	Number of Bits Encoded Per Baud
Standard	1	1
Dibit	4	2
Tribit	8	3
Quadbit	16	4

Table 2-3 Signal changes (baud) vs. number of bits represented

Another term used when referring to transmission speed is **bandwidth**. Although this term is often used to refer to the maximum data transmission capacity, this is accurate only when referring to purely digital systems. Strictly speaking, in analog systems, bandwidth is defined as the range of frequencies that can be transmitted by a particular system or medium. In simple terms, bandwidth is the difference between the higher frequency and the lower frequency. Suppose a transmission for a human voice could be sent between 300 Hz and 3,400 Hz. The difference between the two frequencies (3,400 Hz minus 300 Hz) is 3,100 Hz, which happens to be the bandwidth of a human voice that is transmitted during a telephone conversation.

NOTE

Digital Subscriber Line (DSL) modems usually transmit at speeds ranging from a few hundred Kbps to about 25 Mbps on a telephone line, at a distance of up to 2.5 miles (4 kilometers). The usable bandwidth of the pair of copper wires in a modern phone line is about 1 Megahertz. DSL takes advantage of the higher frequencies that can be transmitted on a phone line but that are not used for voice (above 4,000 Hz); it divides these into a large number of separate frequencies and transmits data bits at a few bps over several of them at the same time, resulting in the high data rates described earlier. Full coverage of DSL technology is beyond the scope of this book, but later chapters cover technologies that work in a very similar fashion.

Analog Modulation

Recall that the carrier signal sent in analog radio transmissions is simply a continuous electrical signal. It carries no information and is more correctly referred to as a CW. Only after information is added to it by modulation should it be called a carrier. **Analog modulation** is the representation of analog information by an analog signal. There are three types of modulation that can be applied to an analog signal to enable it to carry information: the height of the signal, the frequency of the signal, and the relative starting point, or **phase**, of the signal. Let's look at each type of modulation separately.

The height, frequency, and relative starting point of a signal (phase) are sometimes called the "three degrees of freedom."

Amplitude Modulation (AM) The height of a wave, known as the **amplitude**, can be measured in volts (electrical pressure). This is illustrated in Figure 2-19 with a typical sine wave. In **amplitude modulation** (AM), the height of the wave is changed in accordance with the height of another analog signal, called the modulating signal. In the case of an AM radio station, the modulating signal is the voice of the announcer or the music, which is also an analog signal. The carrier wave's frequency and phase remain constant.

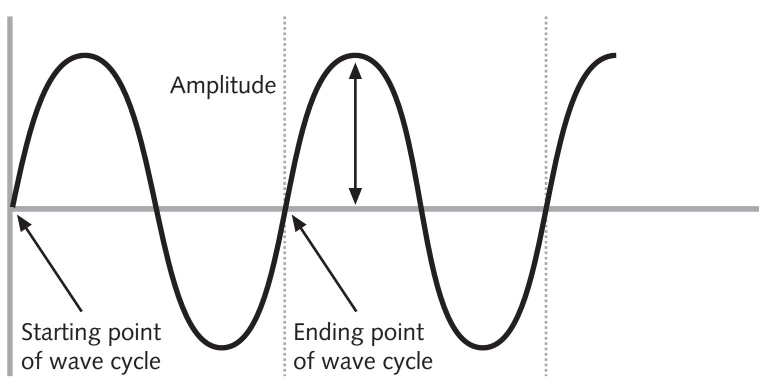

Figure 2-19 Amplitude of a signal

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Amplitude modulation is used by broadcast radio stations. Because pure AM is very susceptible to interference from outside sources, such as lightning, it is not generally used for data transmissions. Figure 2-20 shows a carrier wave and a sine wave being used to modulate the carrier. The bottom portion of the figure shows the carrier wave after it has been modulated.

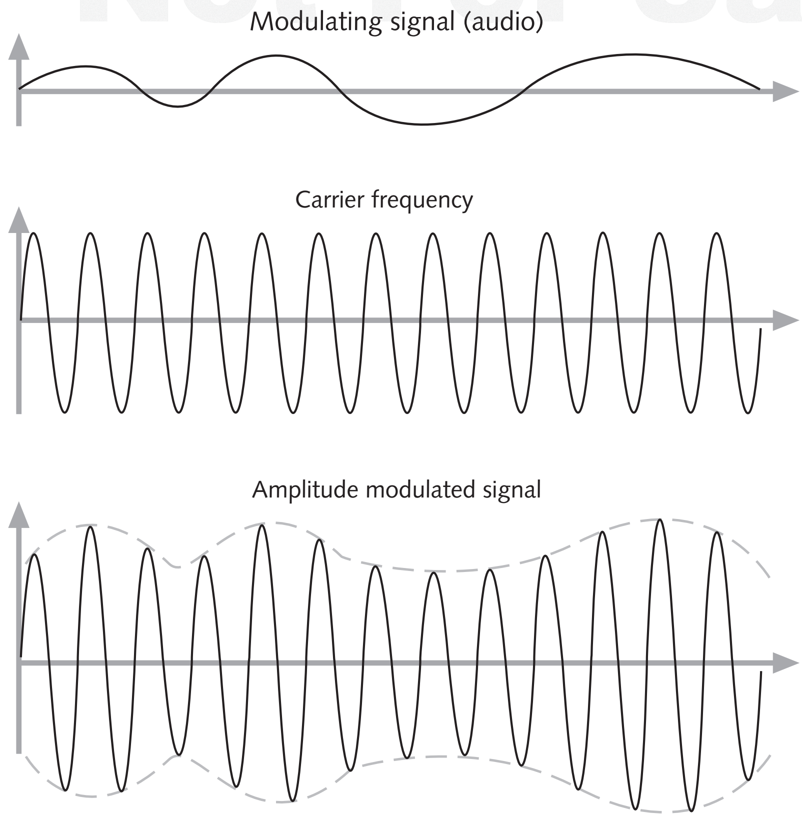

Figure 2-20 Amplitude modulation (AM)

Frequency Modulation (FM) In **frequency modulation** (FM), the number of waves that occur during one second undergoes change based on the amplitude of the modulating signal while the amplitude and the phase of the carrier remain constant. Figure 2-21 illustrates an FM signal and a simple modulating sine wave. The bottom portion of the figure shows the result of modulating the FM carrier in frequency. Note how the frequency changes proportionally, based on the change in amplitude of the input signal, which effectively allows the receiver to reproduce the signal with the correct amplitude (or the volume of the sound). In addition, the rate of change of the modulated signal also follows the rate of change of the input signal, which, in turn, allows the receiver to reproduce the frequency (pitch or tone) at the output.

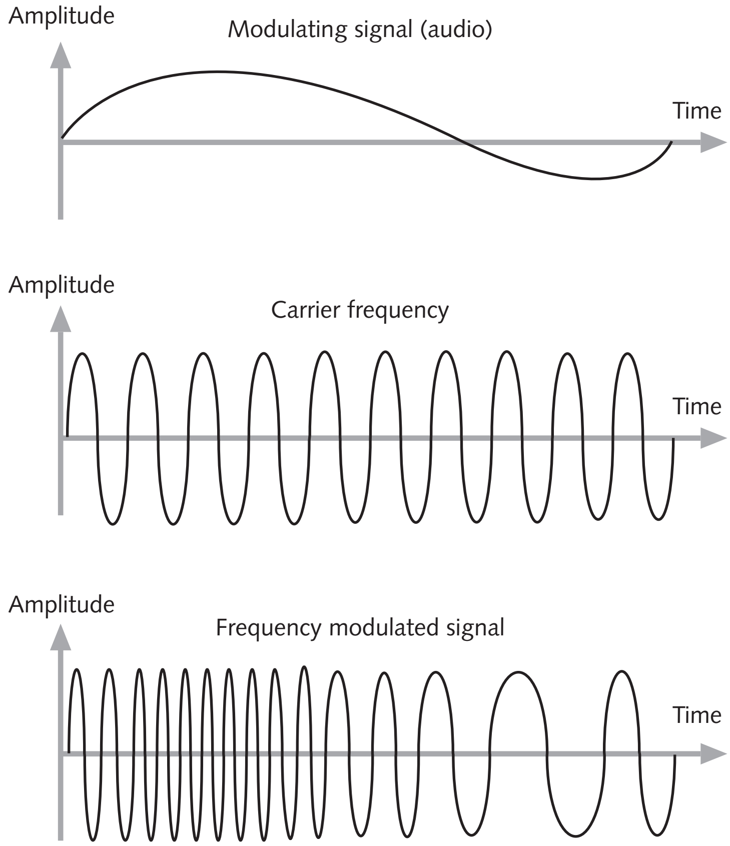

Figure 2-21 Frequency modulation (FM)

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Like amplitude modulation, frequency modulation is often used by broadcast radio stations. However, FM is not as susceptible to interference from outside sources and is most commonly used to broadcast music programs. In addition, an FM carrier has a wider bandwidth, which allows it to carry Hi-Fi as well as stereophonic signals, with two separate sound channels.

In most countries, FM radio stations broadcast between 88 MHz and 108 MHz, whereas AM stations transmit between 535 KHz and 1,700 KHz.

Phase Modulation (PM) In contrast to AM, which changes the height of the wave, and FM, which increases the number of waves per cycle, **phase modulation (PM)** changes the starting point of the cycle, while the amplitude and frequency of the carrier remain constant. Phase modulation is not generally used to represent analog signals.

A signal composed of sine waves has a phase associated with it. This phase is measured in degrees, and one complete wave cycle covers 360 degrees. A phase change is always measured with reference to some other signal. Because it would be very difficult to ensure that the wave cycles of a reference signal in two separate devices—the transmitter and the receiver—remain perfectly synchronized (in phase), PM systems almost always use the previous wave cycle as the reference signal. Figure 2-22 shows an example of four different phase shifts with respect to a reference signal shown at the top of the figure.

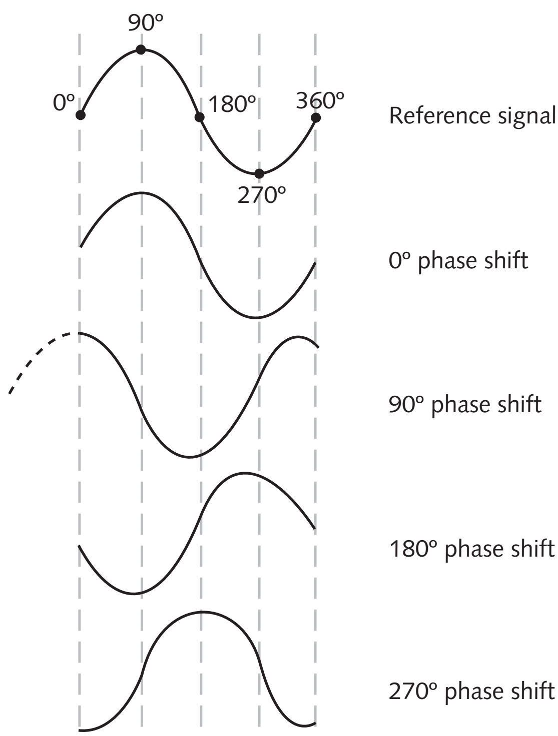

Figure 2-22 Visual representation of phase shift

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Although radio broadcasts use either amplitude modulation (AM) or frequency modulation (FM), television broadcasts actually use AM, FM, and phase modulation (PM). A television video signal uses amplitude modulation, the sound uses frequency modulation, and the color information uses phase modulation.

Digital Modulation

How can digital data be transmitted by an analog carrier signal when the medium used for transmission cannot be used with digital signals? The simple answer is that it can be done by modulating the analog signal or changing it to represent a 1 bit or a 0 bit.

Most modern wireless systems use **digital modulation**, which is the method of encoding a digital signal onto an analog wave for transmission over a medium that does not support digital signals, such as the atmosphere or the vacuum of space. In an analog system, the carrier signal is continuous, and amplitude, frequency, and phase changes also occur continuously because the input or modulating signal is still analog and therefore continuous. However, in a digital system that uses binary signals, the changes are distinct, which results in one of two states: a 1 or a 0, a constant positive or a constant negative voltage, on or off. For a computer to be able to understand these signals, each bit must have a fixed duration to represent a 1 or a 0 (more on digital signals later). Otherwise, the computer would not be able to determine when one bit ends and another one begins.

There are four primary advantages of digital modulation over analog modulation:

- It makes better use of the bandwidth available.
- It requires less power to transmit.
- It performs better when the signal experiences interference from other signals.
- Its error-correcting techniques are more compatible with other digital systems.

With digital modulation, as with analog modulation, there are three basic changes that can be made to the signal to enable it to carry information: the height, the frequency, and the relative starting point (phase) of the signal. However, with the need for faster transmission speeds, more binary signals (or bits) have to be crammed into the same number of wave cycles. The result is that in wireless communications there are now dozens of different types of modulation. For the most sophisticated modulations, it is practically impossible to show a graphic example of what the signals look like. This chapter covers a few basic methods of digital modulation; these methods serve as the basis for more sophisticated modulation techniques.

Binary Signals Recall that with an analog signal the carrier wave alternates between the positive and negative voltage in a continuous cycle—that is, it doesn't stop. A binary signal can alternate between positive and zero volts or between a positive and a negative voltage. Data transmissions are typically sent in bursts of bits, meaning that some bits are transmitted, then the transmission momentarily stops. When there are no bits to be transmitted, no signal is transmitted. In analog systems, even when a radio station is not transmitting any sound, the carrier wave continues to be transmitted; in this case, your radio receiver simply does not detect any modulation of the carrier and therefore does not extract the original signal. Consequently, the receiver does not reproduce any sound even though the continuous carrier signal is still being transmitted.

Three types of binary signaling methods can be used. The **return-to-zero** (**RZ**) technique calls for the signal to rise (the voltage to increase) to represent a 1 bit. A 0 bit is represented by the absence of voltage, or 0 volts. This is illustrated in Figure 2-23. Notice that the voltage is reduced to 0 before the end of the period for transmitting a 1 bit. Also notice that the signal does not quite fill the bit period; this transition of the signal in the middle of a bit period is used to synchronize the transmitter and receiver.

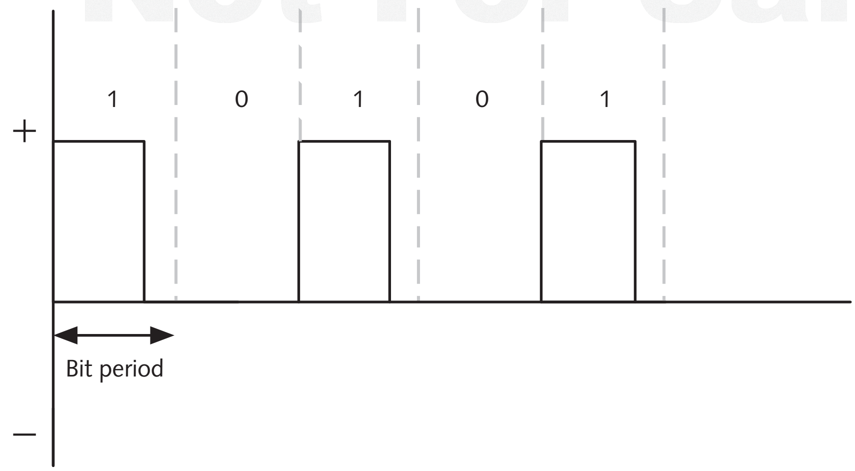

Figure 2-23 Return-to-zero (RZ)

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The second method is known as the **non-return-to-zero** (**NRZ**) technique. With non-return-to-zero, the voltage signal remains positive (high) for the entire length of the bit period. In addition, if the next bit to be transmitted is the same as the previous bit, the signal does not change, remaining high for a 1 and low (0 volts or no voltage) for a 0. This effectively reduces the number of signal transitions (baud) required to transmit the message. As with RZ, there is no voltage when transmitting a 0 bit (see Figure 2-24).

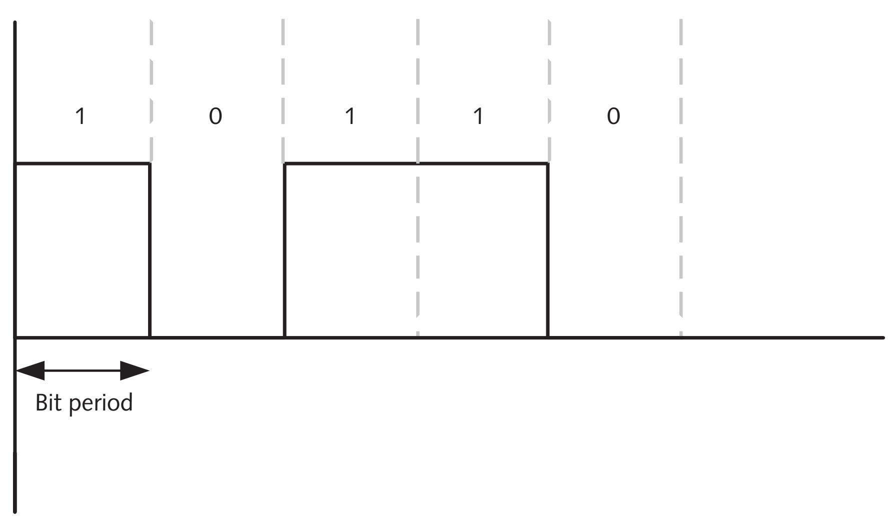

Figure 2-24 Non-return-to-zero (NRZ)

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The final method, **polar non-return-to-zero** (**polar NRZ**), raises the signal (increases the voltage) to represent a 1 bit and drops the signal (reduces the voltage to a negative amount) to represent a 0 bit. This technique is more commonly referred to as **non-return-to-zero-level** (**NRZ-L**) because the signal never returns to the 0 volts level. NRZ-L is illustrated in Figure 2-25.

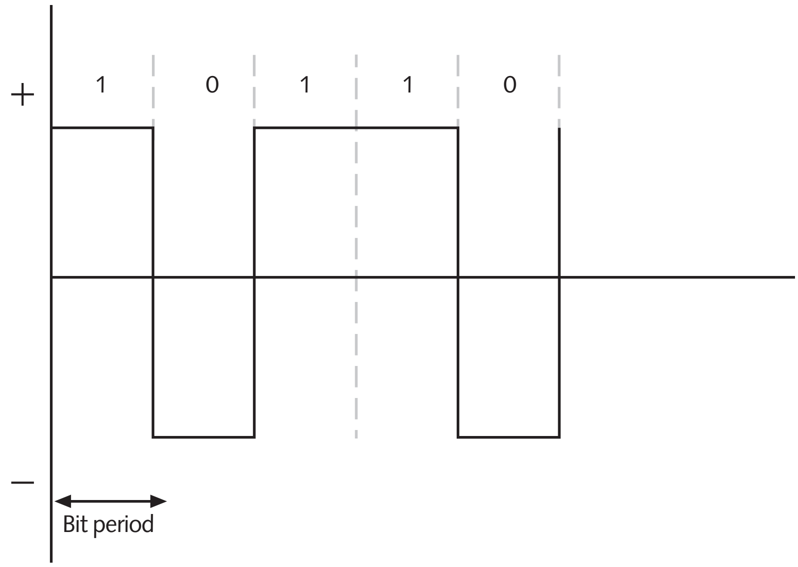

Figure 2-25 Polar non-return-to-zero (non-return-to-zero level or NRZ-L)

The difference between NRZ and polar NRZ is that polar uses two voltage levels (positive and negative).

A variation of NRZ-L is **non-return-to-zero, invert-on-ones** (**NRZ-I**). This is also used to reduce the baud rate required to transmit a digital signal. In NRZ-I, a change in voltage level represents a 1 bit, whereas no change in voltage level indicates that the next bit is a 0. NRZ-I is illustrated in Figure 2-26.

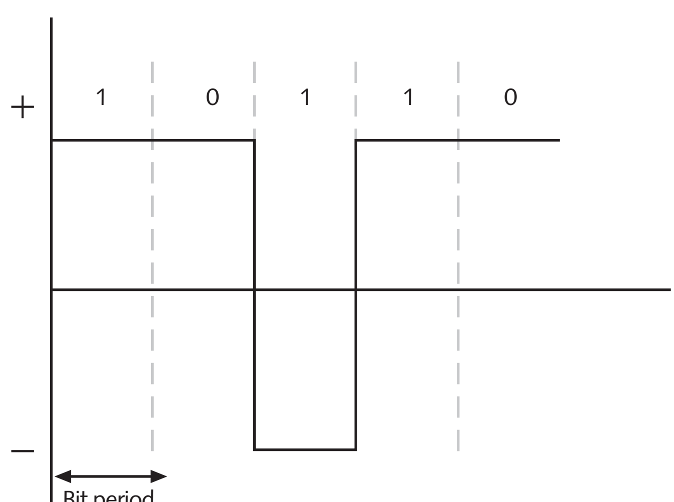

Figure 2-26 Non-return-to-zero, invert-on-ones (NRZ-I)

Why are there so many binary signaling methods? Here are two important reasons:

- Digital electronic circuits tend to average the level of a signal that exhibits a lot of transitions. The result is that the more transitions the signal has, the greater the chance that the circuits will lower the maximum amplitude of the signal, thus making it harder for the receiver to detect the transitions. Using bipolar signals helps but does not eliminate the problem completely.
- Transmitters and receivers have a tendency of getting out of synchronization with each other. If the transmitter sends a long string of 1s or a long string of 0s, the lack of transitions makes it difficult to keep both devices in sync.

Therefore, while trying to minimize the number of transitions, we must also be concerned with having enough of them to ensure good synchronization between the transmitter and the receiver. The methods described above are the most basic ones that are employed when transmitting at lower speeds. Many more sophisticated and complex methods of transmitting digital signals over wires and cables exist, but they are beyond the scope of this book. You will certainly learn about them in later, more advanced courses and books.

Amplitude Shift Keying (ASK) **Amplitude shift keying** (ASK) is a binary modulation technique similar to amplitude modulation in that the height of the carrier signal can be changed to represent a 1 bit or a 0 bit. However, instead of both a 1 bit and a 0 bit having a carrier signal, as with amplitude modulation, ASK usually employs NRZ coding. This means that the presence of a carrier signal represents a 1 bit (positive voltage), whereras the absence of a carrier signal represents a 0 bit (zero voltage). Figure 2-27 illustrates the letter A (ASCII 0x41 or 01000001) being transmitted using ASK.

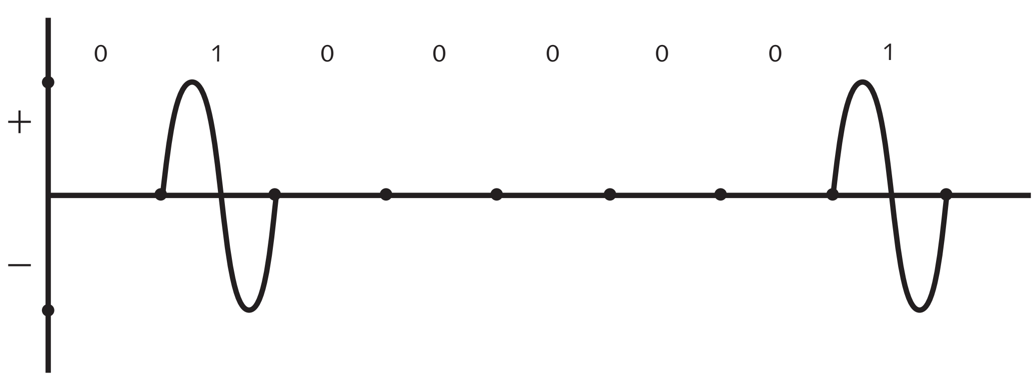

Figure 2-27 Amplitude shift keying (ASK)

The signals for transmission using digital binary modulation are still shown here as sine waves because wireless transmissions use a medium (electromagnetic waves) that can only support analog signals. Note that the direct transmission of purely digital signals (discrete pulses) can only be done using a medium that conducts electricity, such as copper wiring.

Frequency Shift Keying (FSK) Similar to frequency modulation, **frequency shift keying (FSK)** is a binary modulation technique that changes the frequency of the carrier signal. Because it is sending a binary signal, the carrier signal does start and stop as the data transmission stops. As an example, when using FSK, more wave cycles are needed to represent a 1 bit and, respectively, fewer wave cycles are needed to represent a 0 bit. Figure 2-28 illustrates the letter A (ASCII 0x41 or 01000001) being transmitted using FSK. In this example, the number of wave cycles used to represent a 1 bit is double that of the number of wave cycles used to represent a 0 bit.

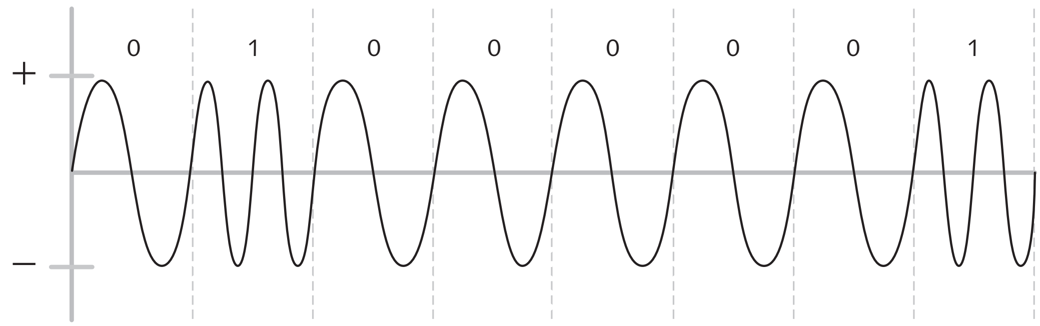

Figure 2-28 Frequency shift keying (FSK)

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Phase Shift Keying (PSK) **Phase shift keying (PSK)** is a binary modulation technique, similar to phase modulation, in which the transmitter varies the starting point of the wave. The difference is that the PSK signal starts and stops because it is a binary signal. Figure 2-29 illustrates the letter A (ASCII 0x41 or 01000001) being transmitted using PSK.

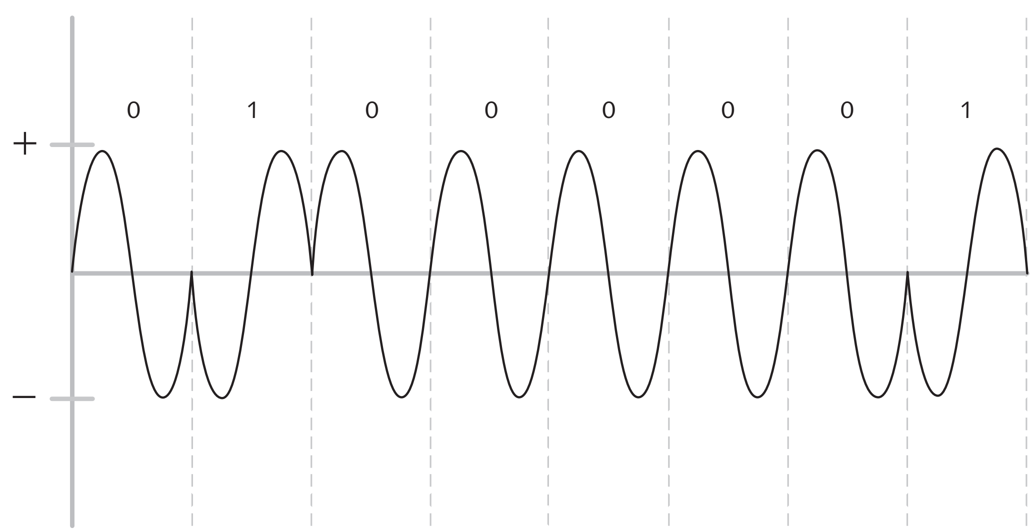

Figure 2-29 Phase shift keying (PSK)

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Notice that whenever a bit being transmitted changes from 1 to 0 (or 0 to 1), the starting point (i.e., the direction of the wave) changes. For example, after the first 0 bit is represented by a "normal" carrier wave cycle, the next bit is a 1 bit. However, instead of this being indicated by another normal carrier wave cycle in which the signal goes into the positive range (goes up on the sine wave), it starts by going into the negative range. The change in starting point (going down instead of up) represents a change in the bit being transmitted (0 to 1).

In the preceding example, the change in the starting point of the wave means that the wave will start moving in the opposite direction—in this case, 180 degrees from the original direction. Note that phase modulation can change the starting point at various points (angles), as shown in Figure 2-30.

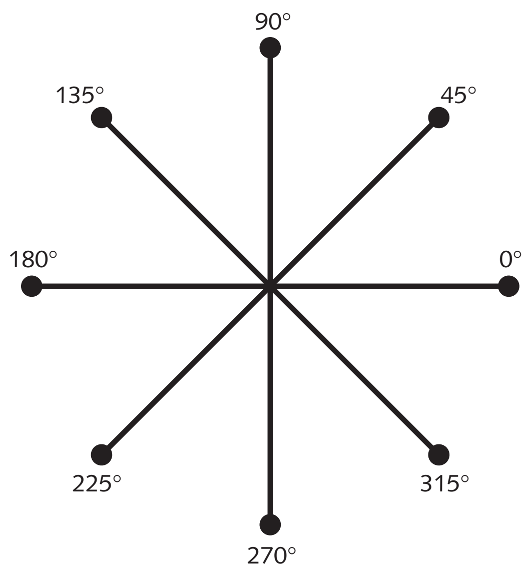

Figure 2-30 Phase modulation angles

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In this case, there are eight possible starting points for a signal (0 degrees, 45 degrees, 90 degrees, 135 degrees, 180 degrees, 225 degrees, 270 degrees, and 335 degrees), with each dot in the figure representing a different starting point. You will recall that to transmit a tribit (3 bits per signal change or baud), eight different signals are needed. Using phase modulation with 45-degree angles can result in eight different signals. However, in wireless communications today, phase modulation is combined with amplitude modulation, which is easier for receivers to detect than very small phase changes and can provide 16 or more different signals.

In Figure 2-31, each dot represents a different signal, for a total of 16 different combinations that can be used to transmit quadbits. This technique of combining amplitude and phase modulation is called **quadrature amplitude modulation** (**QAM**). Due to the potential complexity of the resulting signal, most graphic representations of QAM only show the starting point of each wave with a dot. This representation is called a **constellation diagram.**

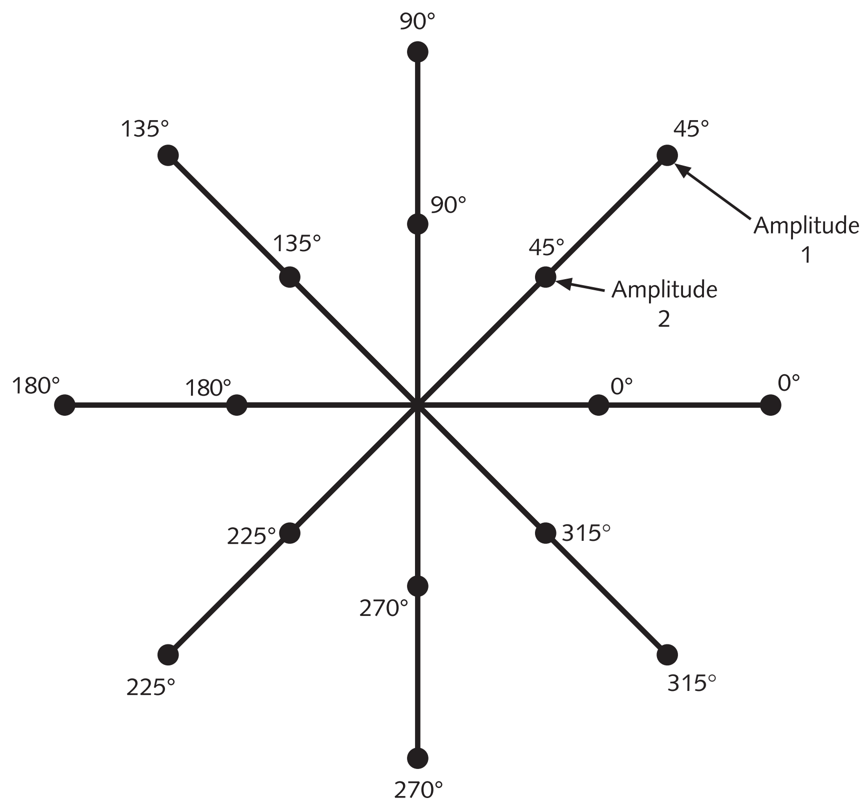

Figure 2-31 Constellation diagram (QAM—quadrature amplitude modulation)

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In the presence of background electromagnetic noise (interference), receivers can detect a phase change much more reliably than a frequency or amplitude change. Noise may be detected as a spike or sudden change in the amplitude of the signal and can also be detected as a change to a higher frequency at a particular point, although the latter happens less frequently. Because the phase of a signal is always referenced to the phase of the last wave cycle that was correctly detected, it is much less likely that noise will occur at the same time in a wave and at an amplitude level that would make the receiver detect it as a phase change; that's because noise is random. These benefits make PSK-based systems more attractive for high-speed wireless communications.

A variation of the PSK modulation technique previously described combines amplitude modulation with PSK. This variation, called **binary phase shift keying (BPSK)**, can be used to transmit dibits (four signal changes equals 2 bits per signal change). Figure 2-32 shows an approximate representation of the resulting waveform of this modulation technique for sending a series of 10 bits. It would be practically impossible to visualize this signal with any kind of electronic instrument, such as an oscilloscope, but simple modulations like this one allow us to demonstrate graphically (as in Figure 2-32) what it would look like.

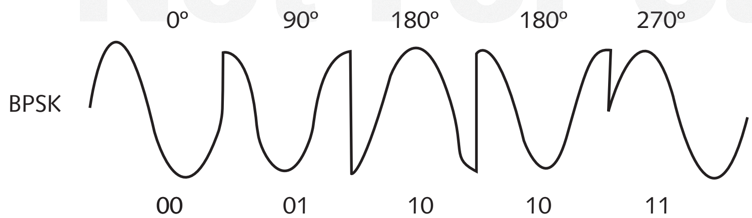

Figure 2-32 Transmitting dibits using BPSK

Spread Spectrum

Radio signal transmissions are, by nature, **narrow-band transmissions**. This means that each signal transmits on one radio frequency or a very narrow range of frequencies. An FM broadcast radio station, for example, might tell its listeners to "tune to 90.3 MHz" because this is the frequency on which it broadcasts. The next-lower frequency that listeners would be able to tune to would be 90.1 MHz; and 90.5 MHz would be the station with the next-higher frequency. This ensures that the station at 90.3 MHz can broadcast roughly between 90.2 and 90.4 MHz without interfering with other stations. The actual bandwidth used by FM stations is less than the difference between 90.2 and 90.4 MHz, allowing for some unused "frequency space" between the highest frequency used by the next-lower station on the FM band, the station you are tuned to, and the next station operating at a higher frequency.

Narrow-band transmissions are vulnerable to outside interference from another signal. Another signal that is transmitted at or near the broadcast frequency—90.3, in this case—can easily render the radio signal inoperable or make it difficult to detect and decode the information contained in the signal.

Broadcast radio stations work effectively with narrow-band transmissions because each station is allowed to transmit on only one frequency in a specific area. Radio stations broadcast using high-powered transmitters and use different frequencies, which are licensed by the Federal Communications Commission (FCC) in the United States. In contrast, most WLAN devices use the same frequency band but transmit at very low power levels. This means that the signals have a short useful range, helping to ensure that minimum interference occurs.

An alternative to narrow-band transmission is **spread spectrum transmission**. Spread spectrum is a technique that takes a narrow band signal and spreads it over a broader portion of the radio frequency band, as shown in Figure 2-33. Spread spectrum transmissions are more resistant to outside interference because any noise is likely to affect only a small portion of the signal instead of the entire signal. As an analogy, although an accident in one lane of an eight-lane freeway is inconvenient, there are still seven other lanes that traffic can use. Likewise, spread spectrum results in less interference and fewer errors. Two common methods used in spread spectrum transmissions are frequency hopping and direct sequence.

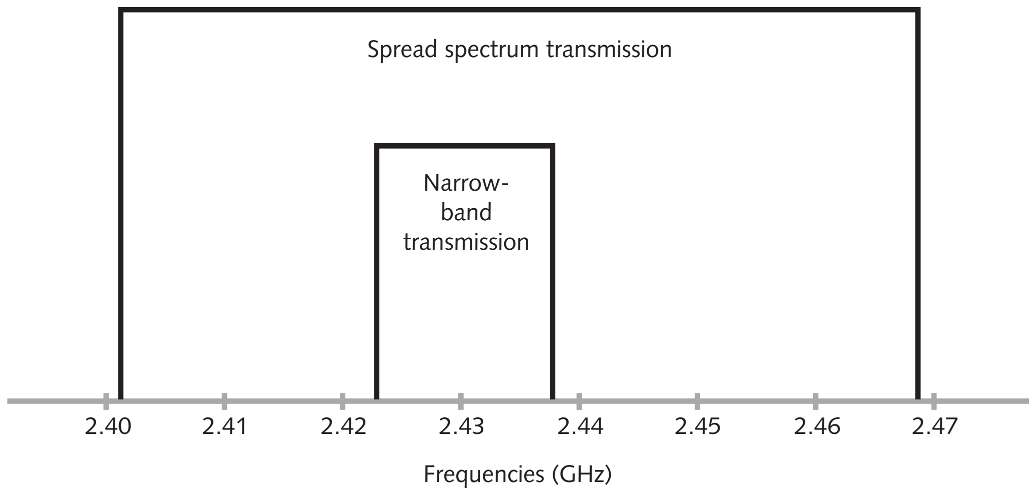

Figure 2-33 Spread spectrum vs. narrow-band transmission

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Frequency Hopping Spread Spectrum (FHSS)

Instead of transmitting on just one frequency, **frequency hopping spread spectrum** (FHSS) uses a range of frequencies and changes the frequency of the carrier several times during the transmission. With FHSS, a short burst of data is transmitted in one frequency, and then another short burst is transmitted at another frequency, and so on until the transmission is completed.

Hedy Lamarr, a well-known film actress during the 1940s, and George Antheil, who had experience synchronizing the sounds of music scores with motion pictures, conceived the idea of frequency hopping spread spectrum during the early part of World War II. Their goal was to keep the Germans from jamming the equipment that guided U.S. torpedoes against German warships. Lamarr and Antheil received a U.S. patent in 1942 for their idea.

Figure 2-34 shows how an FHSS transmission starts by sending a burst of data at the 2.44 GHz frequency for 1 microsecond. Then the transmission switches to the 2.41 GHz frequency and transmits for the next microsecond. During the third microsecond, the transmission takes place at the 2.42 GHz frequency. This continual switching of frequencies takes place until the entire transmission is complete. The sequence of changing frequencies is called the **hopping code**. In the example shown in Figure 2-34, the hopping code is 2.44–2.41–2.42–2.40–2.43. The receiving station must also know the hopping code in order to correctly receive the transmission. The hopping codes are predefined and are usually part of the standard that defines how the radio circuit will be designed and implemented. Hopping codes can change so that multiple radios can each use a different sequence of frequencies within the same area and never interfere with one another, but the transmitter and receiver have to agree beforehand on which sequence to use.

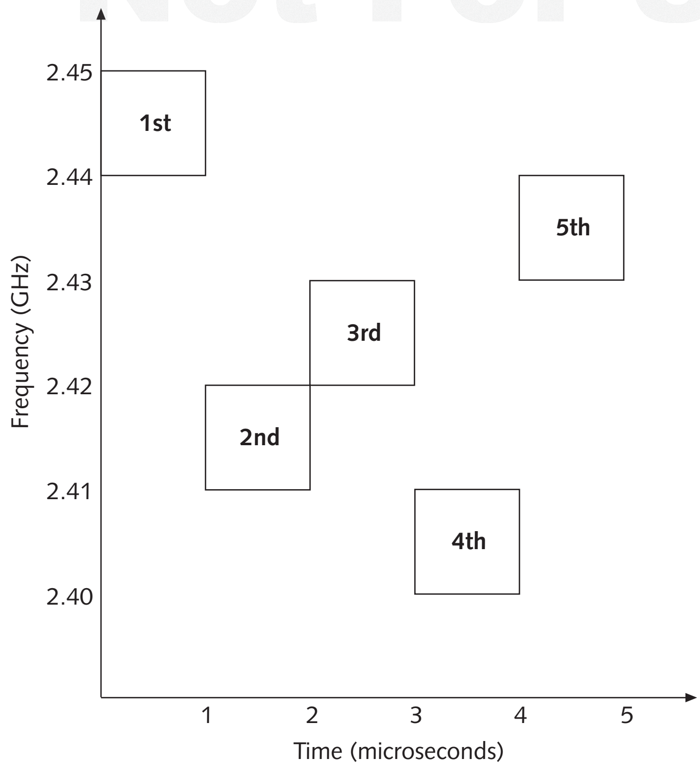

Figure 2-34 Frequency hopping spread spectrum (FHSS) transmission

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If interference is encountered while transmitting with FHSS on a particular frequency, only a small part of the message is lost. Figure 2-35 shows an example in which the second transmission has been affected by interference. Each block of data transmitted in FHSS is only about 400 bytes long, and FHSS systems can detect errors at the lower protocol layers and request retransmission before passing the data to higher protocol layers. Some technologies make use of forward error correction (FEC), a technique that sends redundant data to minimize the need for retransmission of the messages. Error handling and error detection and correction at the lower protocol layers are discussed in later chapters.

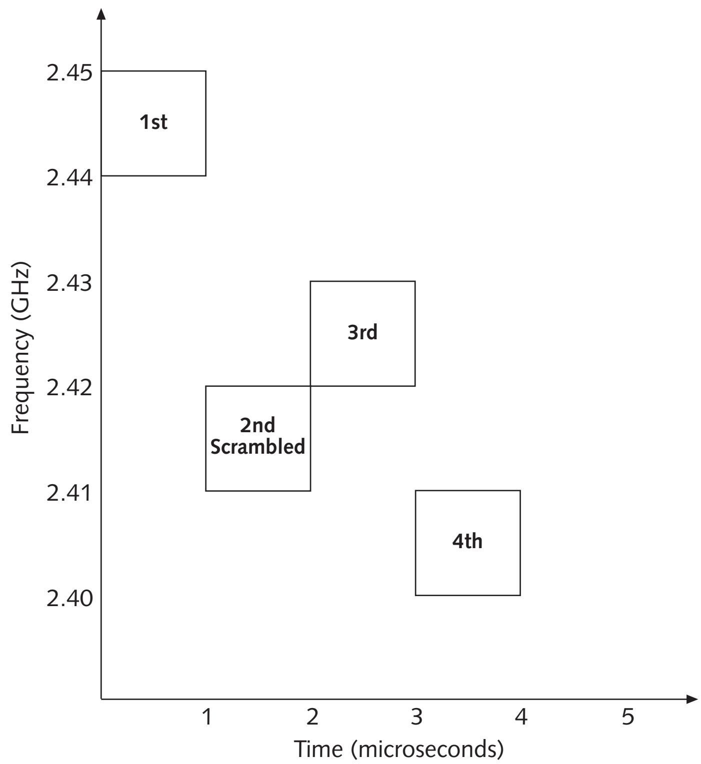

Figure 2-35 FHSS error detection

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Frequency hopping can reduce the impact of interference from other radio signals. An interfering signal will affect the FHSS signal only when both are transmitting at the same frequency and at the same time. Because FHSS transmits short bursts over a wide range of frequencies, the extent of any interference will be very small, the error can be detected through error checking, and the message can be easily retransmitted. In addition, FHSS signals exert minimal interference on other signals. To an unintended receiver, FHSS transmissions appear to be of a very short duration (similar to noise), and unless the receiver knows the exact hopping sequence of frequencies, it is extremely difficult to eavesdrop on the message.

A variety of devices use FHSS. Several of these devices are consumer-oriented products, because FHSS devices are relatively inexpensive to manufacture. Cordless phones, including multi-handset units for small businesses, typically use FHSS. Bluetooth, which is covered in Chapter 5, also uses FHSS.

Direct Sequence Spread Spectrum (DSSS)

The other type of spread spectrum technology is **direct sequence spread spectrum** (DSSS). DSSS uses an expanded redundant code to transmit each data bit and then a modulation technique such as **quadrature phase shift keying** (QPSK). This means that a DSSS signal is effectively modulated twice. The first step before transmission is shown in Figure 2-36. At the top of the figure are two original data bits to be transmitted: a 0 and a 1.

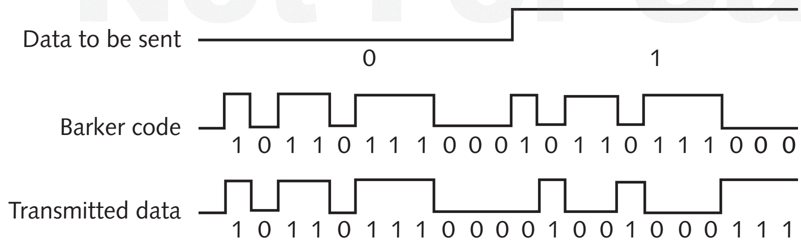

Figure 2-36 Encoding before modulation in a DSSS transmission

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However, instead of simply encoding these two bits over a carrier wave for transmission, the value of each data bit is first added to each individual 1 and 0 in a sequence of binary digits called a Barker code. A **Barker code** (or **chipping code**) is a particular sequence of 1s and 0s that has properties that make it ideal for modulating radio waves as well as for being detected correctly by the receiver. These 1s and 0s are called *chips*- instead of bits to avoid confusing them with the actual data bits. The chipping code is sometimes called a **pseudo-random code** because it is usually derived through a number of mathematical calculations as well as through practical experimentation.

The term *Barker code* is correctly used only when referring to 802.11 transmissions at 1 and 2 Mbps. When referring to most other spreading codes used in DSSS-based systems—such as CDMA cellular phones—the terms *pseudo-random code*, *PN code*, *spreading code*, and *chipping code* may be used interchangeably.

The result of the addition is the actual set of 1s and 0s (the chips) that will be modulated over a carrier wave and transmitted (as seen in the bottom line of Figure 2-36). Let's take another look at how this sequence of chips is created. If a 1 bit is to be transmitted, then a 1 is added to each bit of the chipping code:

Bit to be transmitted: 1	1	1	1	1	1	1	1	1	1	1	1
Add Barker code:	1	0	1	1	0	1	1	1	0	0	0
Resulting signal sent:	0	1	0	0	1	0	0	0	1	1	1

If a 0 data bit is to be transmitted, then a 0 is added to each bit of the chipping code:

Bit to be transmitted: 0	0	0	0	0	0	0	0	0	0	0	0
Add Barker code:	1	0	1	1	0	1	1	1	0	0	0
Resulting signal sent:	1	0	1	1	0	1	1	1	0	0	0

The adding of the chipping code and the specific value to be added are arrived at by the Boolean operation of "exclusive or" (XOR) on a bit-by-bit basis, which is equivalent to a modulo 2 addition. In modulo 2 addition, there is no carryover, which means that 1 + 1 = 0 and a 1 is not carried over to the next digit to the left. Other than that, a modulo 2 addition works exactly like a normal sum of two digits. See "Boolean Operations, XOR (Exclusive Or)" at *www.cplusplus.com/doc/papers/boolean.html*.

Instead of transmitting a single 1 or 0, a DSSS system transmits these combinations of chips. The 11 chips are transmitted at a rate 11 times faster than the data rate; in other words, the data rate does not change. However, the result of transmitting at a higher rate is the spreading of the signal over a much wider frequency band than that of the channel. In the case of 802.11, to continue with the example given earlier, the signal is spread 11 MHz to each side of the center frequency and ends up occupying a total bandwidth of 22 MHz. Figure 2-37 illustrates the results.

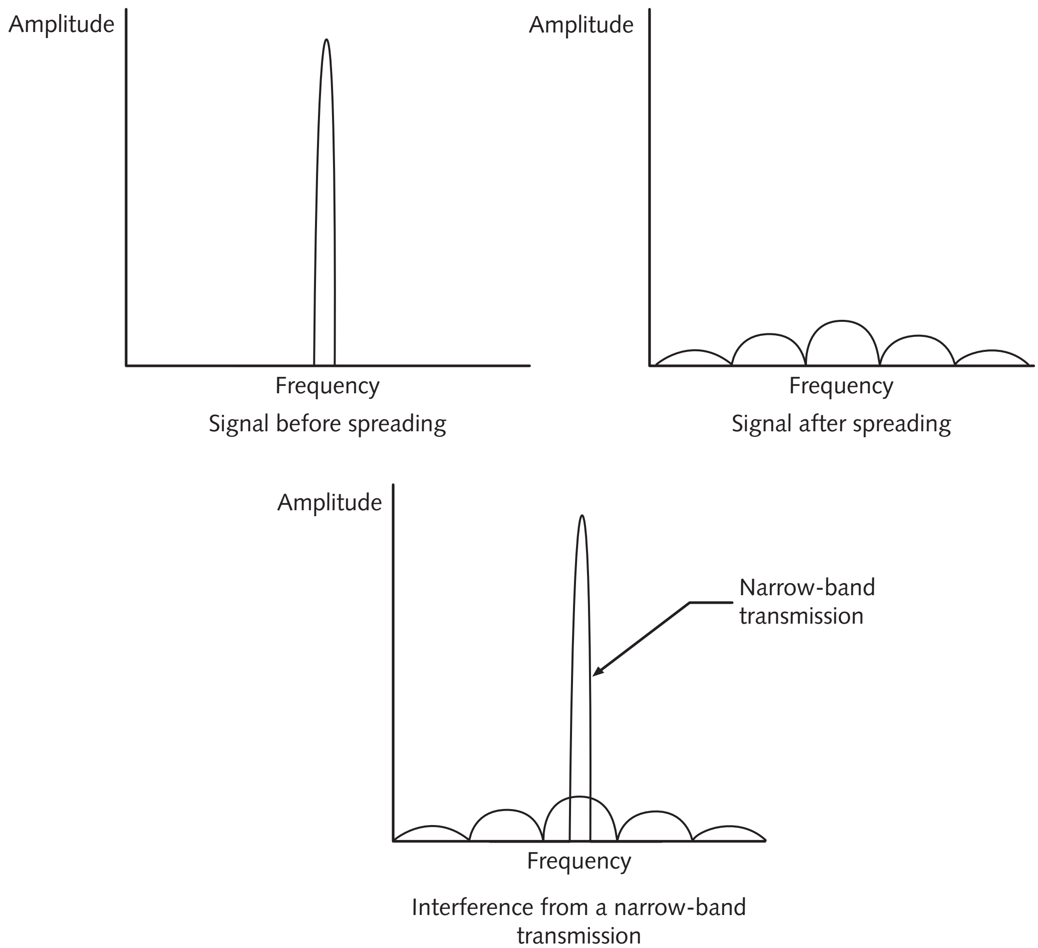

Figure 2-37 Spreading the signal over a wider range of frequencies

This spread signal has three important characteristics:

- The frequency of the signal's digital component (or chipping rate) is much higher than that of the original data.
- A plot of the signal's frequency spectrum looks similar to random noise.
- All the information contained in the original signal (a 0 bit or a 1 bit) is still there.

The most important aspect of this, however, is not the spreading of the signal but the fact that the power level (amplitude), *at any given frequency*, has dropped significantly. In similar fashion to FHSS, a DSSS signal appears to an unintended narrow-band receiver to be low-powered noise, which is one major advantage of this method.

At the receiver, the signal is first demodulated and then de-spread. One of the techniques the receiver uses to detect which bit was transmitted is to count the number of 0 chips. If the pattern of chips received contains six 0s, the value of the data bit is 1. Conversely, if the pattern contains six 1s, the value of the data bit is 0.

Another major advantage of using DSSS with a chipping code is that in conventional narrow-band transmissions, any interference, even if it caused the loss of only one bit, would require the entire message to be re-sent, which takes time. In DSSS, if there is any noise or other type of narrow-band interference that may cause some of the chips to change value, the receiver can employ embedded statistical techniques—mathematical algorithms that are used to recover the original data bit, thus avoiding the need for retransmission.

Devices that use DSSS are typically higher-end products because they are more expensive to manufacture than FHSS systems, but they also have many advantages over FHSS, as previously described. WLANs use DSSS along with products that interconnect networks located in several buildings that comprise a campus setting, such as a school, a large corporation, a manufacturing plant, or a convention center.

FHSS and DSSS are not the only transmission techniques used for spread spectrum transmission. There are other techniques that are even more resistant to interference and to different kinds of phenomena that can cause data loss or reduce the performance of this type of wireless transmission. Some of the techniques are based on variations of DSSS; others are completely different. Later chapters of this book discuss some of the more sophisticated techniques as well as the types of problems that can affect wireless transmissions.

Chapter Summary

- One of the arbitrary coding schemes, which uses the numbers from 0 to 127, is called the American Standard Code for Information Interchange (ASCII). A character that will be stored or transmitted by the computer is first converted to its ASCII equivalent, then that number is stored as a byte in binary.
- Whereas traditional wired communications use copper wires or fiber-optic cables to send and receive data, wireless transmissions do not use a visible medium. Instead, they travel on electromagnetic waves. There are two basic types of waves by which wireless signals are sent and received: infrared light and radio waves.
- Infrared light, which is next to visible light on the light spectrum, has many of the same characteristics as visible light. Infrared wireless transmission can be either directed or diffused. A directed transmission sends a narrowly focused beam of infrared light from the emitter to the detector. A diffused transmission relies on reflected light.
- The second means of transmitting a wireless signal is by using radio transmission. Radio waves provide the most common and effective means of wireless communications today. Radio waves have fewer limitations than light waves.

- Radio transmissions use a carrier signal, which is a continuous wave (CW) of constant amplitude (voltage) and frequency. This signal is essentially an up-and-down wave called an oscillating signal or sine wave. The carrier signal sent by analog radio transmissions is simply a continuous electrical signal that carries no information.
- The carrier signal can undergo three types of modulation (i.e., change) to enable it to carry information: the height of the signal, the frequency of the signal, and the relative starting point. Amplitude modulation (AM) changes the signal height. Frequency modulation (FM) changes the number of wave cycles that occur in one second. Phase modulation (PM) changes the starting point of the cycle.
- In digital modulation, there are also three types of changes that can be made to the carrier to enable it to carry information: the height of the signal, the frequency of the signal, and the relative starting point. Amplitude shift keying (ASK) changes the height of the carrier to represent a 1 bit or a 0 bit. A carrier is transmitted for a 1 bit, and no signal is transmitted for a 0 bit. Frequency shift keying (FSK) is a modulation technique that changes the frequency of the carrier signal. Phase shift keying (PSK) is a modulation technique similar to phase modulation. The difference is that the PSK signal starts and stops because it is a binary signal.
- Radio signals are by nature a narrow-band type of transmission, which means that they transmit on one radio frequency or a very narrow spectrum of frequencies. An alternative to narrow-band transmissions is spread spectrum transmission. Spread spectrum is a technique that takes a narrow signal and spreads it over a broader portion of the radio frequency band.
- Spreading the signal over a wide range of frequencies and reducing the amplitude has the advantage of making the signal look like noise to an unintended narrow-band receiver, reducing the effects of interference.
- One of the most common spread spectrum methods is frequency hopping spread spectrum (FHSS). Instead of sending on just one frequency, frequency hopping uses a range of frequencies and changes frequencies during the transmission. The other method is direct sequence spread spectrum (DSSS). DSSS uses an expanded redundant code to transmit each data bit.

Key Terms

American Standard Code for Information Interchange (ASCII) An arbitrary coding scheme that uses the numbers from 0 to 127 to represent alphanumeric characters and symbols.

amplitude The height of a carrier wave.

amplitude modulation (AM) A technique that changes the height of a carrier wave in response to a change in the height of the input signal.

amplitude shift keying (ASK) A digital modulation technique whereby a 1 bit is represented by the existence of a carrier signal, whereas a 0 bit is represented by the absence of a carrier signal.

analog modulation A method of encoding an analog signal onto a carrier wave.

analog signal A signal in which the intensity (amplitude or voltage) varies continuously and smoothly over a period of time.

antenna A copper wire, rod, or similar device that has one end up in the air and the other end connected to the ground through a receiver.

bandwidth The range of frequencies that can be transmitted.

Barker code (chipping code) A bit pattern used in a DSSS transmission. The term *chipping code* is used because a single radio bit is commonly referred to as a *chip*.

baud A change in a carrier signal.

baud rate The number of times that a carrier signal changes per second.

binary phase shift keying (BPSK) A simple digital modulation technique that uses four phase changes to represent 2 bits per signal change.

bits per second (bps) The number of bits that can be transmitted per second.

carrier signal A signal of a particular frequency that is modulated to contain either analog or digital data.

constellation diagram A graphical representation that makes it easier to visualize signals using complex modulation techniques such as QAM. It is generally used in laboratory and field diagnostic instruments and analyzers to aid in design and troubleshooting of wireless communications devices.

continous wave (CW) An analog or sine wave that is modulated to eventually carry information, becoming a carrier wave.

cycle An oscillating sine wave that completes one full series of movements.

detector A diode that receives a light-based transmission signal.

dibit A signal unit that represents 2 bits.

diffused transmission A light-based transmission that relies on reflected light.

digital modulation A method of encoding a digital signal onto an analog carrier wave for transmission over media that does not support direct digital signal transmission.

digital signal Data that is discrete or separate.

direct sequence spread spectrum (DSSS) A spread spectrum technique that uses an expanded, redundant code to transmit each data bit.

directed transmission A light-based transmission that requires the emitter and detector to be directly aimed at one another.

electromagnetic wave (EM wave) A signal composed of electrical and magnetic forces that in radio transmission usually propagates from an antenna and can be modulated to carry information.

emitter A laser diode or a light-emitting diode that transmits a light-based signal.

frequency A measurement of radio waves that is determined by how frequently a cycle occurs.

frequency hopping spread spectrum (FHSS) A spread spectrum technique that uses a range of frequencies and changes frequencies during the transmission.

frequency modulation (FM) A technique that changes the number of wave cycles in response to a change in the amplitude of the input signal.

frequency shift keying (FSK) A digital modulation technique that changes the frequency of the carrier signal in response to a change in the binary input signal.

Gigahertz (GHz) 1,000,000,000 Hertz.

Hertz (Hz) The number of cycles per second.

hopping code The sequence of changing frequencies used in FHSS.

infrared light Light that is next to visible light on the light spectrum and that has many of the same characteristics as visible light.

Kilohertz (KHz) 1,000 Hertz.

light spectrum All the different types of light that travel from the Sun to the Earth.

line of sight The direct alignment as required in a directed transmission.

Megahertz (MHz) 1,000,000 Hertz.

modem (MOdulator/DEModulator) A device used to convert digital signals into an analog format, and vice versa.

modulation The process of changing a carrier signal.

narrow-band transmissions Transmissions that use one radio frequency or a very narrow portion of the frequency spectrum.

non-return-to-zero (NRZ) A binary signaling technique that increases the voltage to represent a 1 bit but provides no voltage for a 0 bit.

non-return-to-zero, invert-on-ones (NRZ-I) A binary signaling technique that changes the voltage level only when the bit to be represented is a 1.

non-return-to-zero level (NRZ-L) *See* polar non-return-to-zero.

oscillating signal A wave that illustrates the change in a carrier signal.

phase The relative starting point of a wave, in degrees, beginning at zero degrees.

phase modulation (PM) A technique that changes the starting point of a wave cycle in response to a change in the amplitude of the input signal. This technique is not used in analog modulation.

phase shift keying (PSK) A digital modulation technique that changes the starting point of a wave cycle in response to a change in the binary input signal.

polar non-return-to-zero (polar NRZ) A binary signaling technique that increases the voltage to represent a 1 bit but drops to negative voltage to represent a 0 bit.

pseudo-random code A code that is usually derived through a number of mathematical calculations as well as practical experimentation.

quadbit A signal unit that represents 4 bits.

quadrature amplitude modulation (QAM) A combination of phase modulation with amplitude modulation to produce 16 different signals.

quadrature phase shift keying (QPSK) A digital modulation technique that combines quadrature amplitude modulation with phase shift keying.

radio wave (radiotelephony) An electromagnetic wave created when an electric current passes through a wire and creates a magnetic field in the space around the wire.

return-to-zero (RZ) A binary signaling technique that increases the voltage to represent a 1 bit, but the voltage is reduced to 0 before the end of the period for transmitting the 1 bit, and there is no voltage for a 0 bit.

sine wave A wave that illustrates the change in a carrier signal.

spread spectrum transmission A technique that takes a narrow signal and spreads it over a broader portion of the radio frequency band.

tribit A signal unit that represents 3 bits.

voltage Electrical pressure.

wavelength The length of a wave as measured between two positive or negative peaks or between the starting point of one wave and the starting point of the next wave.

Review Questions

1. Which range of the electromagnetic spectrum is less susceptible to interference from sources of visible light?
   a. ultraviolet
   b. gamma light
   c. infrared
   d. yellow light
2. The distance between one positive peak and the next positive peak of a wave is called ______________.
   a. frequency
   b. wavelength
   c. elasticity
   d. intensity
3. Which type of transmission is used when human voice is modulated directly onto a carrier wave?
   a. analog
   b. digital
   c. diffused
   d. directed
4. Why do computers and data transmission equipment use binary?
   a. They are electrical devices, and electricity has only two states.
   b. Base 2 is too difficult to use.
   c. Base 10 was developed before binary.
   d. Binary is the next step beyond quadecimal.
5. Eight binary digits grouped together form which of the following?
   a. byte
   b. bit
   c. binary
   d. 2x quad
6. The American Standard Code for Information Interchange (ASCII) can represent up to 1024 characters. True or False?
7. Letters of the alphabet and symbols are stored using the ASCII code, but not numbers used in calculations. True or False?
8. Infrared light, though invisible, has many of the characteristics of visible light. True or False?

9. Infrared wireless systems require that each device needs to have only one component: either an emitter that transmits a signal or a detector that receives the signal. True or False?

10. Infrared wireless systems send data by the intensity of the light wave instead of whether the light signal is on or off. True or False?

11. Infrared wireless transmission can be either directed or ______.
    a. analog
    b. digital
    c. diffused
    d. detected

12. Radiotelephony or radio travels in waves known as ______ waves.
    a. electromagnetic
    b. analog
    c. magnetic
    d. electrical

13. Unlike a digital signal, a(n) ______ signal is a continuous signal with no "breaks" in it.
    a. magnetic
    b. visible
    c. light
    d. analog

14. Changing a signal to encode data onto it is known as ______.
    a. baud
    b. demodulation
    c. modulation
    d. continuity

15. PSK is an example of ______.
    a. ASCII encoding
    b. unicoding
    c. phase modulation
    d. digital modulation

16. Explain how a radio antenna works when transmitting a signal.

17. Explain the difference between bps and baud rate.

18. Explain the difference between amplitude modulation, frequency modulation, and phase modulation.

19. What is quadrature amplitude modulation (QAM) and how does it work?
20. List and describe the three different types of binary signaling techniques.

Hands-On Projects

Project 2-1

In this project, you will write your name in both hexadecimal and binary.

1. Using the ASCII chart found in the Appendix of this book, look up the hexadecimal ASCII value for each of the letters of your last name. (Note that the ASCII table contains codes for both uppercase and lowercase letters.) Here is what my last name looks like in hexadecimal, with a dash placed between successive letters, to make it easier to read:

   O–l–e–n–e–w–a = 4F–6C–65–6E–65–77–61

2. Convert each hexadecimal value to binary. The easiest way to do this is to break the hexadecimal code for each character into two separate digits. In the case of an uppercase O, this would be 4 and F. Each digit represents four bits out of one byte (also called a nibble).
3. Convert each digit to its binary equivalent in the range 0000 (0x0) to 1111 (0xF). Put the two groups of four bits together into a byte. For the purposes of this project, the most significant bit, which is generally used for parity, will always be a 0.
4. Write your full last name in binary. Again, use a dash between each group of eight bits to make it easier to read. Here is what my last name looks like:

   01001111–01101100–01100101–01101110–01100101–01110111–01100001

You will use these results in the following projects.

Project 2-2

This project helps you develop an appreciation for the topic of modulation and what it takes to transmit data—analog or digital—over the wireless medium. As you know, this book introduces many different wireless technologies that use various modulation techniques. In this project, you perform amplitude modulation.

1. In Figure 2-38, an analog input signal is shown at the top of the grid. To draw a wave that is modulated in amplitude, begin by copying the input signal to the top two rows of the grid shown in Figure 2-38. The goal is to create an “envelope” to guide you and make it easier to draw the carrier wave, showing what it will look like after it is modulated. Use a dashed line to draw the input signal.
2. Complete the envelope by drawing a mirror-image (vertically inverted) version of the input signal in the bottom two rows of the grid. Again, use a dashed line.

3. You are now ready to draw the modulated carrier. Considering a carrier with a frequency of 4 Hz, so that it will be easier to draw and visualize, draw a sine wave with four complete cycles for each second. The wave must fit inside and follow the contour of the envelope you created in the previous two steps. The frequency of the modulated carrier must remain constant at 4 Hz for each one-second interval on the grid. The high and low peaks of the modulated carrier must reach all the way to the upper and lower guides you just drew, the envelope.

4. Check your results with your instructor, or see Figure 2-20 to make sure you got it right.

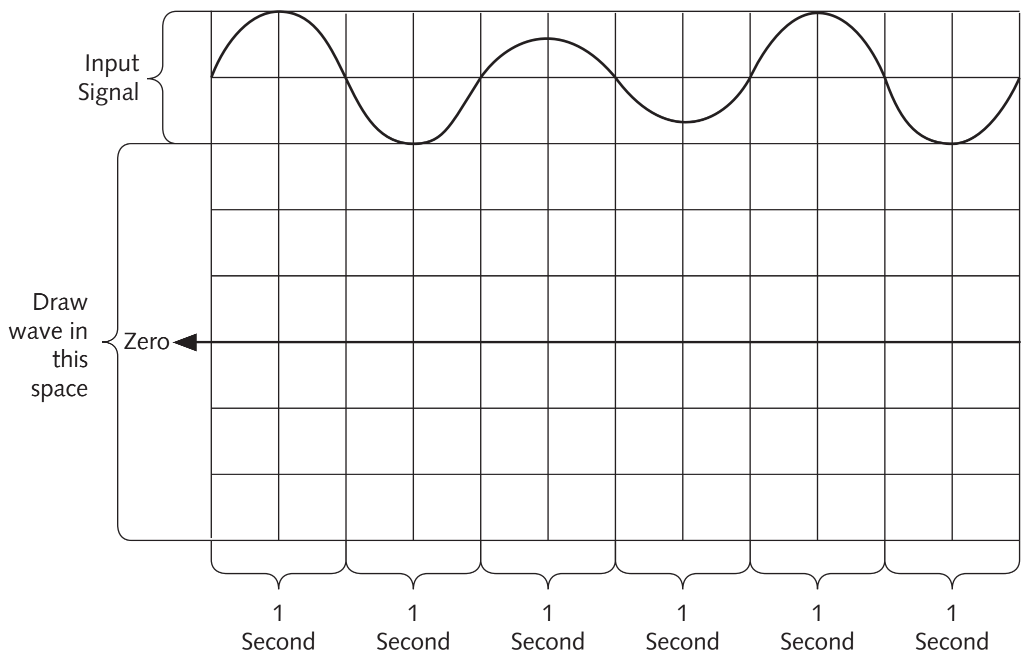

Figure 2-38 Analog modulation grid

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Enter
HANDS-ON PROJECTS

Project 2-3

As you have learned, digital modulation makes it possible to transmit a digital signal using an analog medium such as an electromagnetic wave. In this project, you draw a waveform to show how a digital signal can be encoded onto a carrier using one bit per phase change (PSK).

1. In Figure 2-39, a grid and an analog reference wave are shown without an input signal. Input the binary ASCII code for the first letter of your last name in the spaces provided at the top of the grid.

2. The modulated carrier wave should have the same amplitude as the original carrier. Begin at the 0 level indicated on the left side of the grid and draw a 4 Hz carrier to represent the first bit, a 0.

3. At the end of the first second, continue drawing the carrier but change the phase if the second most significant bit is a 1. If not, continue drawing the carrier at the same phase.

4. Keep drawing the 4 Hz carrier wave, changing phase as required to show a change from a bit with a value of 1 or 0.

5. After you have drawn the carrier wave for all eight bits of the ASCII code, compare your results with Figure 2-39 to make sure it looks correct.

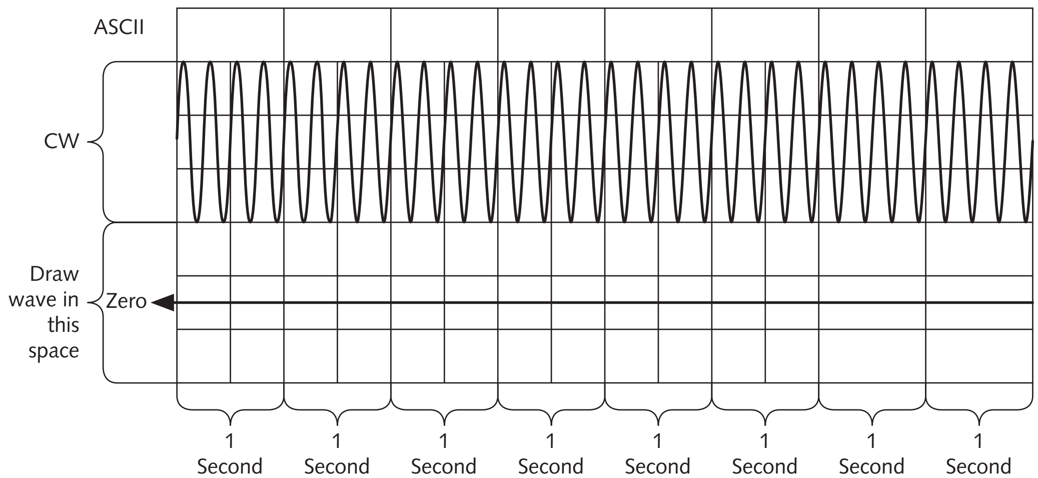

Figure 2-39 Phase shift keying grid

Real World Exercises

The Baypoint Group (TBG), a company of 50 consultants who assist organizations and businesses with issues involving network planning and design, has hired you as a consultant. One of their oldest clients, Woodruff Medical Group, needs your help with the following tasks.

Exercise 2-1

Woodruff Medical has been approached by a vendor who is trying to sell it an infrared WLAN for its office. Because the equipment is proprietary, the cost is quite high, and this is one of their main concerns. Although none of the networking equipment will be placed around sensitive medical equipment, the office manager prefers infrared because he believes that other types of wireless networking equipment could interfere with the medical equipment in another hospital campus building that is located about 125 meters away.

Exercise 2-2

Prepare a PowerPoint presentation outlining how infrared and radio wireless transmissions work. This will be presented to the office manager, who is not technically inclined, and the LAN manager, who has a strong technology background. Be sure to list the advantages and disadvantages of both. The presentation should contain at least 10 slides. You will only have 20 minutes to explain both technologies.

Exercise 2-3

After listening to your presentation, the office manager has several questions. One of the questions involves wireless transmission speeds. The office manager has a "good 56 Kbps baud" dial-up data modem at home and wants to know how its transmission speed compares with that of an infrared and RF WLAN. He also does not understand the difference between *baud* and *bps*, two terms that he has been hearing a lot about lately, but none of the explanations has satisfied him yet. For this, the office manager wants a written report instead of a presentation. Write a one-page summary regarding different transmission speeds. Be sure to include information about the difference between bps, baud, baud rate, and bandwidth. Also, show how bps is not always identical to baud.

Challenge Case Project

A local community college has contacted The Baypoint Group for information about modulation for a networking class, and TBG has passed this request on to you. Form a team of two or three consultants and research AM, FM, PM, ASK, FSK, and PSK. Specifically, pay attention to how they are used, as well as their strengths and weaknesses. Provide your conclusions regarding which of these methods, or combination of methods, is now the dominant player in wireless data transmission and why you think this is the case.