Computer Networks and Internets

SIXTH EDITION

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Computer Networks and Internets

10.3 Analog Modulation Schemes

We use the term *modulation* to refer to changes made in a carrier according to the information being sent. Conceptually, modulation takes two inputs, a carrier and a signal, and generates a modulated carrier as output, as Figure 10.1 illustrates.

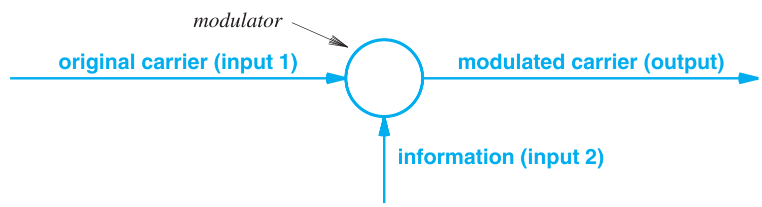

Figure 10.1 The concept of modulation with two inputs.

In essence, a sender must change one of the fundamental characteristics of the wave. Thus, there are three primary techniques that modulate an electromagnetic carrier according to a signal:

- Amplitude modulation
- Frequency modulation
- Phase shift modulation

The first two methods of modulation are the most familiar and have been used extensively. Indeed, they did not originate with computer networks — they were devised and used for broadcast radio, and are also used for broadcast television.

10.4 Amplitude Modulation

A technique known as *amplitude modulation* varies the amplitude of a carrier in proportion to the information being sent (i.e., according to a signal). The carrier continues oscillating at a fixed frequency, but the amplitude of the wave varies. Figure 10.2 illustrates an unmodulated carrier wave, an analog information signal, and the resulting amplitude modulated carrier.

Amplitude modulation is easy to understand because only the amplitude (i.e., magnitude) of the sine wave is modified. Furthermore, a time-domain graph of a modulated carrier has a shape similar to the signal that was used. For example, if one imagines an *envelope* consisting of a curve that connects the peaks of the sine wave in Figure 10.2(c), the resulting curve has the same shape as the information signal in Figure 10.2(b).

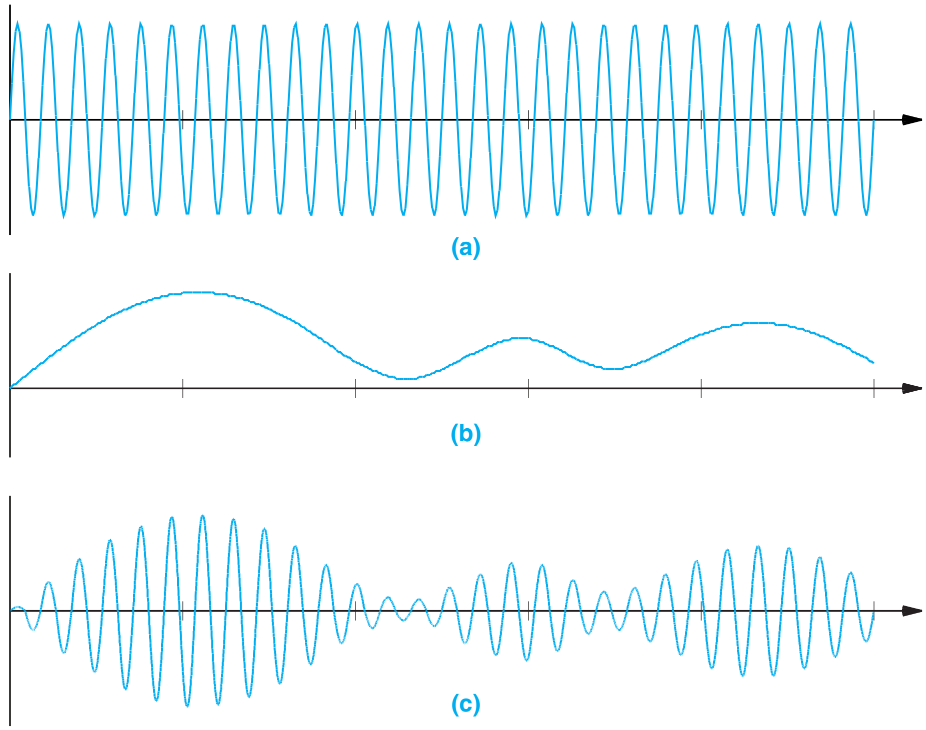

Figure 10.2 Illustration of (a) an unmodulated carrier wave, (b) an analog information signal, and (c) an amplitude modulated carrier.

10.5 Frequency Modulation

An alternative to amplitude modulation is known as *frequency modulation*. When frequency modulation is employed, the amplitude of the carrier remains fixed, but the frequency changes according to the signal: when the signal is stronger, the carrier frequency increases slightly, and when the signal is weaker, the carrier frequency decreases slightly. Figure 10.3 illustrates a carrier wave modulated with frequency modulation according to the signal in Figure 10.2(b).

As the figure shows, frequency modulation is more difficult to visualize because slight changes in frequency are not as clearly visible. However, one can notice that the modulated wave has higher frequencies when the signal used for modulation is stronger.

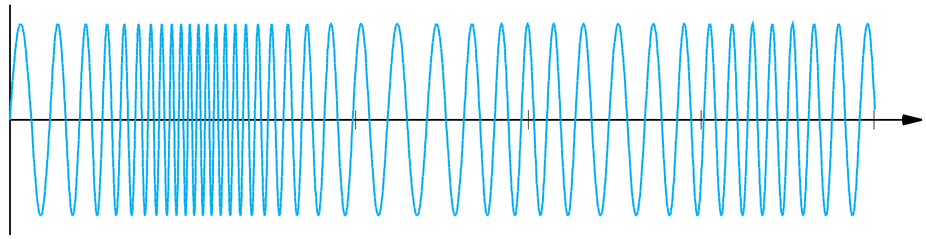

Figure 10.3 Illustration of a carrier wave with frequency modulation according to the signal in Figure 10.2(b).

10.6 Phase Shift Modulation

The third property of a sine wave is its *phase*, the offset from a reference time at which the sine wave begins. It is possible to use changes in phase to represent a signal. We use the term *phase shift* to characterize such changes.

Although modulating phase is possible in theory, the technique is seldom used with an analog signal. To understand why, observe that if phase changes after cycle *k*, the next sine wave will start slightly later than the time at which cycle *k* completes. A slight delay resembles a change in frequency. Thus, for analog input, phase shift modulation can be thought of as a special form of frequency modulation. We will see, however, that phase shifts are important when a digital signal is used to modulate a carrier.

10.7 Amplitude Modulation And Shannon's Theorem

The illustration in Figure 10.2(c) shows the amplitude varying from a maximum to almost zero. Although it is easy for a human to understand, the figure is slightly misleading: in practice, modulation only changes the amplitude of a carrier slightly, depending on a constant known as the *modulation index*.

To understand why practical systems do not allow for a modulated signal to approach zero, consider Shannon's Theorem. Assuming the amount of noise is constant, the signal-to-noise ratio will approach zero as the signal approaches zero. Thus, keeping the carrier wave near maximum ensures that the signal-to-noise ratio remains as large as possible, which permits the transfer of more bits per second.

10.8 Modulation, Digital Input, And Shift Keying

The description of modulation above shows how an analog information signal is used to modulate a carrier. The question arises: how can digital input be used? The answer lies in straightforward modifications of the modulation schemes described above: instead of modulation that is proportional to a continuous signal, digital schemes use discrete values. Furthermore, to distinguish between analog and digital modulation, we use the term *shift keying* rather than modulation.

In essence, shift keying operates similar to analog modulation. Instead of a continuum of possible values, digital shift keying has a fixed set. For example, amplitude modulation allows the amplitude of a carrier to vary by arbitrarily small amounts in response to a change in the signal being used. In contrast, amplitude shift keying uses a fixed set of possible amplitudes. In the simplest case, a full amplitude can correspond to a logical 1 and a significantly smaller amplitude can correspond to a logical 0. Similarly, frequency shift keying uses two basic frequencies. Figure 10.4 illustrates a carrier wave, a digital input signal, and the resulting waveforms for *Amplitude Shift Keying* (*ASK*) and *Frequency Shift Keying* (*FSK*).

10.9 Phase Shift Keying

Although amplitude and frequency changes work well for audio, both require at least one cycle of a carrier wave to send a single bit unless a special encoding scheme is used (e.g., unless positive and negative parts of the signal are changed independently). The Nyquist Theorem described in Chapter 6 suggests that the number of bits sent per unit time can be increased if the encoding scheme permits multiple bits to be encoded in a single cycle of the carrier. Thus, data communications systems often use techniques that can send more bits. In particular, *phase shift keying* changes the phase of the carrier wave abruptly to encode data. Each such change is called a *phase shift*. After a phase shift, the carrier continues to oscillate, but it immediately jumps to a new point in the sine wave cycle. Figure 10.5 illustrates how a phase shift affects a sine wave.

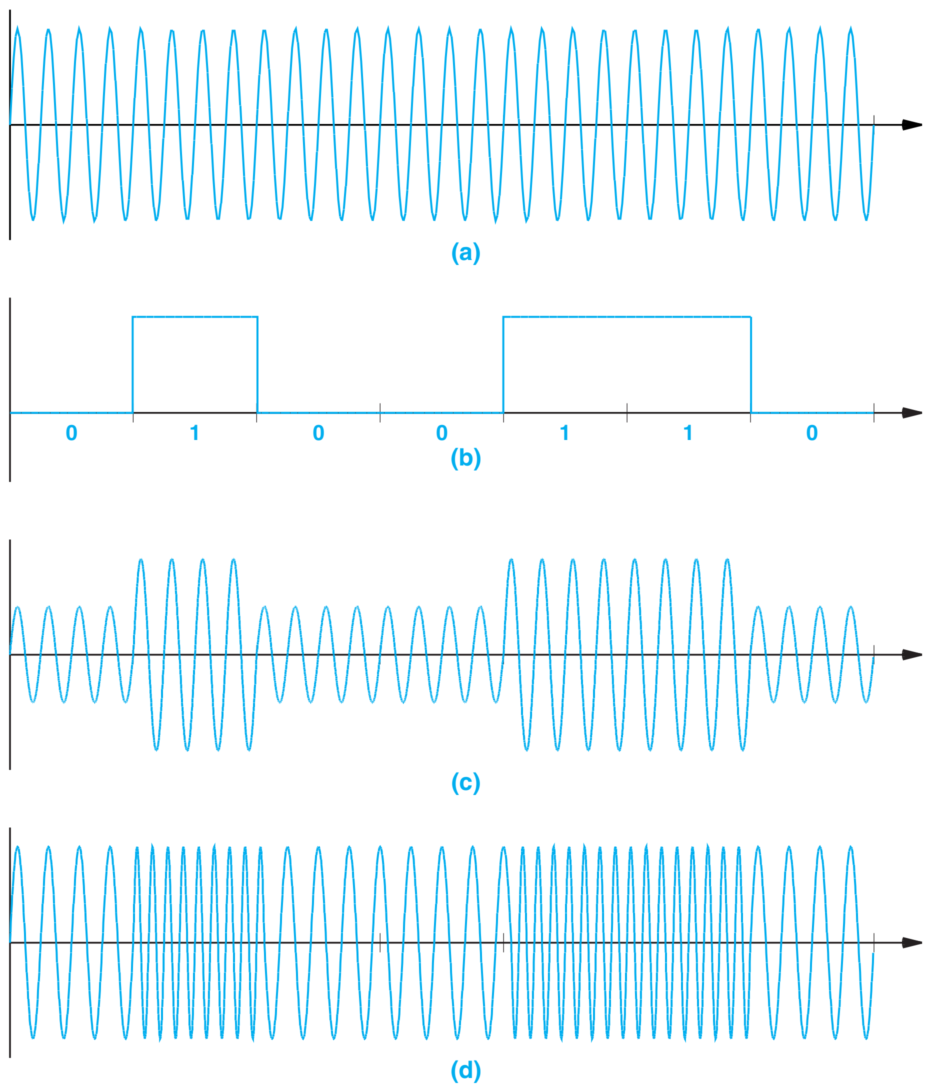

Figure 10.4 Illustration of (a) carrier wave, (b) digital input signal, (c) amplitude shift keying, and (d) frequency shift keying.

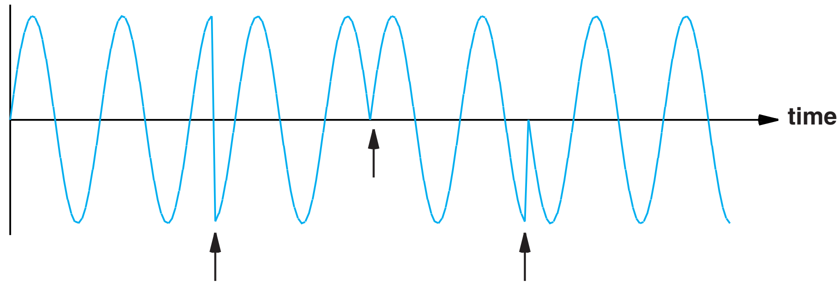

Figure 10.5 An illustration of phase shift modulation with arrows indicating times at which the carrier abruptly jumps to a new point in the sine wave cycle.

A phase shift is measured by the angle of the change. For example, the leftmost shift in Figure 10.5 changes the angle by $\pi/2$ radians or 180°. The second phase change in the figure also corresponds to a 180° shift. The third phase change corresponds to a shift of –90° (which is equivalent to 270°).

10.10 Phase Shift And A Constellation Diagram

How can data be encoded using phase shifts? In the simplest case, a sender and receiver can agree on the number of bits per second, and can use no phase shift to denote a logical 0, and the presence of a phase shift to denote a logical 1. For example, a system might use a 180° phase shift. A *constellation diagram* is used to express the exact assignment of data bits to specific phase changes. Figure 10.6 illustrates the concept.

Hardware can do more than detect the presence of a phase shift — a receiver can measure the amount a carrier shifted during a phase change. Thus, it is possible to devise a communications system that recognizes a set of phase shifts, and use each particular phase shift to represent specific values of data. Usually, systems are designed to use a power of two possible shifts, which means a sender can use bits of data to select among the shifts.