An information-bearing signal must conform to the limitations of its channel. While the bit streams we wish to transmit are inherently discrete-time, all physical media are continuous-time in nature. Hence, we need to represent the bit stream as a continuous-time signal for transmission, a process called **modulation**.

Rather than examine the modulation process in full generality, this chapter specializes to a special class of modulation techniques called **pulse-amplitude modulation (PAM)**. There are two reasons for this restriction. First, PAM is widely used in a variety of applications and is an extremely important technique in its own right. Second, the simplicity of PAM facilitates our development of the basic principles of receiver design. The main results of this chapter will be generalized to arbitrary modulation schemes in Chapter 6.

We start with **baseband PAM**, in which a sequence of time-translates of a basic pulse is amplitude-modulated by a sequence of data symbols. Baseband PAM is commonly used for metallic media, such as wire pairs, where the signal spectrum is allowed to extend down to zero frequency (d.c.). We then extend PAM to **passband transmission** by introducing a sinusoidal carrier signal. Passband PAM is commonly used on media with highly constrained bandwidth, such as radio. It uses two sinusoidal carriers of the same frequency (with a ninety
degree phase difference) which are modulated by the real and imaginary parts of a complex-valued baseband signal. Special cases of passband PAM are the commonly used phase-shift keying (PSK), amplitude and phase modulation (AM-PM) and quadrature amplitude modulation (QAM). By treating these techniques as special cases of passband PAM we avoid the alphabet soup that pervades most comprehensive treatments of digital communications, where every minor variation is given a new acronym and treated as a separate topic.

We then shift our focus to the receiver, where we study the problem of receiver design. In particular, this chapter proposes the minimum-distance strategy for receiver design that has many advantages: it is easy to describe and intuitively reasonable; it leads to many important receiver structures (such as correlators, matched filters, whitened-matched filters, folded spectra, and even the Viterbi algorithm); and it turns out to be optimal under certain constraints on the statistics of the noise. The precise conditions under which the minimum-distance criterion is optimal will be established later, in Chapter 7. For now, we just consider minimizing distance for its own sake. We do not consider the noise statistics until the last section, when we analyze the error-probability performance of PAM with minimum-distance receivers when the noise happens to be white and Gaussian.

The choice of modulation scheme depends on the characteristics of the medium. Many channels can be approximated as either baseband or passband; a baseband channel has the frequency response of a low-pass filter, while a passband channel has the frequency response of a bandpass filter, as sketched below:

A baseband channel calls for a form of PAM called baseband PAM, as described in Section 5.1. A passband channel calls for passband PAM, which is described in Section 5.2.

### 5.1. Baseband PAM

A baseband PAM transmitter sends information by modulating the amplitudes of a series of pulses, so that the transmitted signal is:

\[
s(t) = \sum_{m=-\infty}^{\infty} a_k g(t - kT),
\]

where \(1/T\) is the symbol rate, where \(g(t)\) is the pulse shape, and where the set of amplitudes \(\{a_k\}\) are referred to as symbols. This signal can be interpreted as a sequence of possibly