Communication Systems Engineering

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We begin by developing a geometric representation for several different types of pulse modulation signals. Optimum demodulation and detection of these signals is then described. Finally, we evaluate the probability of error as a performance measure for the different types of modulation signals on an AWGN channel. The various modulation methods are compared on the basis of their performance characteristics, their bandwidth requirements, and their implementation complexity.

Initially, we will not impose bandwidth constraints in the design of signals for digital modulation. However, because the channel bandwidth is an important parameter that influences the design of most communication systems, the design of the modulator and demodulator for bandlimited channels is treated in depth in Chapter 8.

7.1 PULSE MODULATION SIGNALS AND THEIR GEOMETRIC REPRESENTATION

In this section, we introduce several types of pulse modulation signals that are used for the transmission of digital information and develop a geometric representation of such signals. The pulse modulation signals considered include (1) pulse amplitude modulated signals, (2) pulse position modulated (orthogonal) signals, (3) biorthogonal signals, (4) simplex signals, and (5) signals generated from binary code sequences. First we describe how the digital information is conveyed with these types of signals.

7.1.1 Pulse Modulation Signals

In *pulse amplitude modulation* (PAM), the information is conveyed by the amplitude of the pulse. For example, in binary PAM, the information bit 1 is represented by a pulse of amplitude A and the information bit 0 is represented by a pulse of amplitude $-A$ as shown in Figure 7.1. Pulses are transmitted at a bit rate $R_b = 1/T_b$ bits per second, where T_b is called the bit interval. Although the pulses are shown as rectangular, in practical systems, the rise time and decay time are nonzero and the pulses are generally smoother. The effect of the pulse shape on the spectral characteristics of the transmitted signal is considered in Chapter 8.

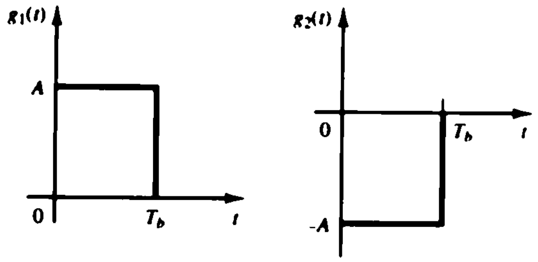

FIGURE 7.1. Example of signals for binary PAM.

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In *pulse position modulation* (PPM), the information is conveyed by the time interval in which the pulse is transmitted. For example, in binary PPM, the bit interval is divided into two time slots of $T_b/2$ seconds each. The information bit 1 is represented by a pulse of amplitude A in the first time slot and the information bit 0 is represented by a pulse of amplitude A in the second time slot, as shown in Figure 7.2. The pulse shape within a time slot need not be rectangular.

Another pulse modulation method for transmitting binary information is called on-off keying (OOK). The transmitted signal for transmitting a 1 is a pulse of duration T_b. If a 0 is to be transmitted, no pulse is transmitted in the signal interval of duration T_b.

The generalization of PAM and PPM to nonbinary (M-ary) pulse transmission is relatively straightforward. Instead of transmitting one bit at a time, the binary information sequence is subdivided into blocks of k bits, called *symbols*, and each block, or symbol, is represented by one of $M = 2^k$ pulse amplitude values for PAM and pulse position values for PPM. Thus, with $k = 2$, we have $M = 4$ pulse amplitude values, or pulse position values. Figure 7.3 illustrates the PAM and PPM signals for $k = 2$, $M = 4$. Note that when the bit rate R_b is fixed, the *symbol interval* is

$$T = \frac{k}{R_b} = kT_b \tag{7.1.1}$$

as shown in Figure 7.4.

It is interesting to characterize the PAM and PPM signals in terms of their basic properties. For example, the M-ary PAM signal waveforms may be expressed as

$$s_m(t) = A_m g_T(t), \quad m = 1, 2, \ldots, M$$

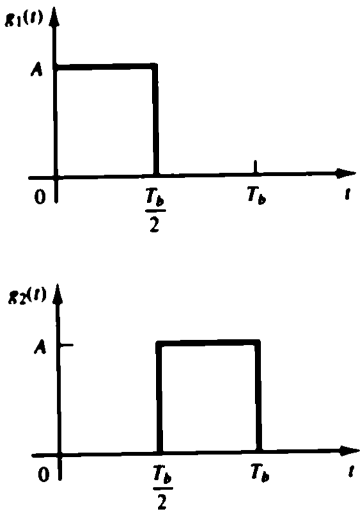

FIGURE 7.2. Example of signals for binary PPM.

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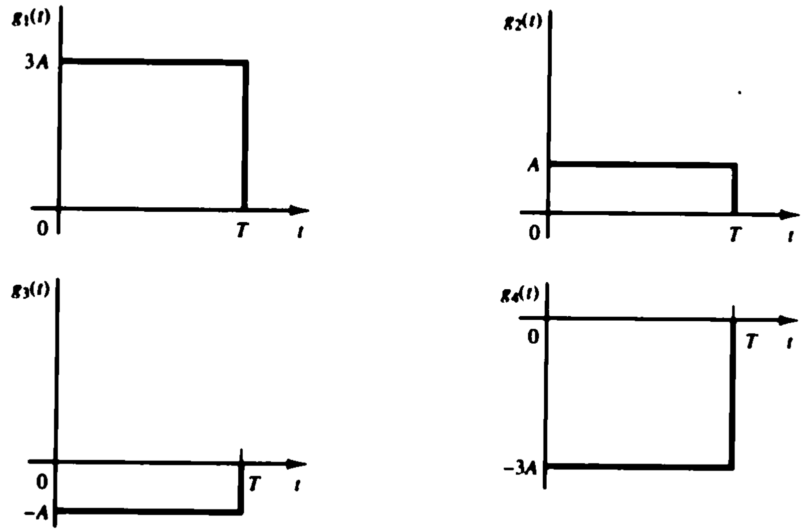
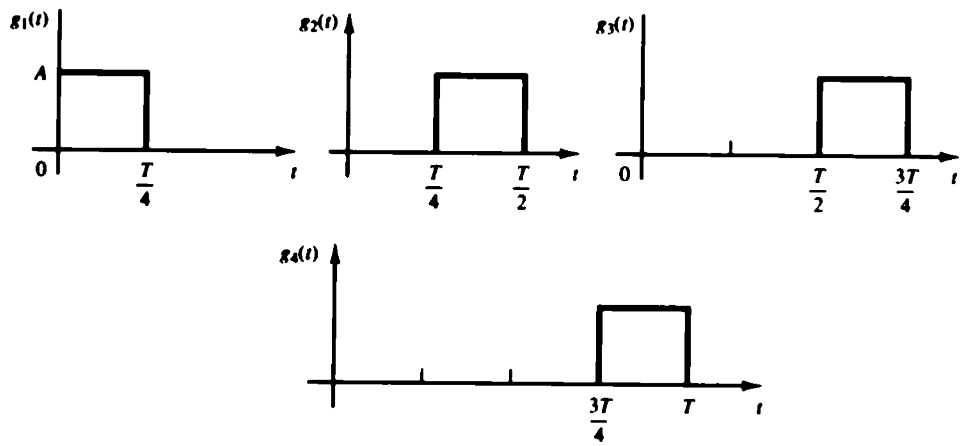


(a) $M = 4$ PAM signals



(b) $M = 4$ PPM signals

FIGURE 7.3. Examples of $M = 4$ PAM and PPM signals.

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