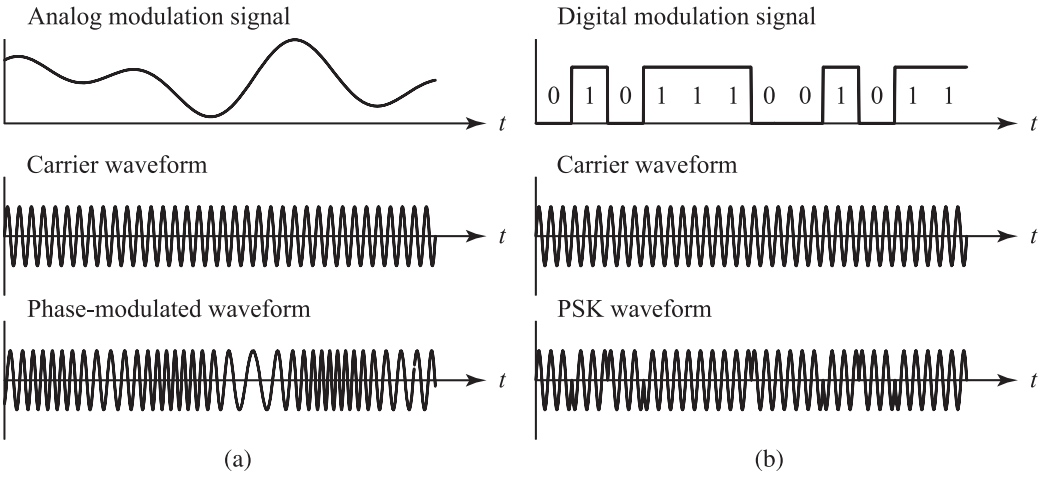

Figure 10.1 (a) Analog phase modulation with an analog signal. (b) Digital phase modulation using two discrete phases separated by π for BPSK. The field magnitude and the carrier frequency stay constant while the phase varies with time.

level. In *binary PSK* (BPSK), two discrete phases separated by π, such as $\{0, \pi\}$ or $\{\pi/2, 3\pi/2\}$, are used to respectively represent the two binary bits of 0 and 1, as shown in Fig. 10.1(b). In *quadrature PSK* (QPSK), four discrete phases that are equally spaced at an interval of $\pi/2$, such as $\{0, \pi/2,\ \pi,\ 3\pi/2\}$ or $\{\pi/4, 3\pi/4, 5\pi/4, 7\pi/4\}$, are used to represent the four possible two-bit combinations of $\{00, 01, 10, 11\}$ by encoding two bits with each phase.

Optical phase modulation is normally accomplished through refractive modulation. By modulating the refractive index of a material through which an optical wave propagates, the phase of the wave can be modulated. The physical mechanisms that can be used for this purpose are discussed in Section 10.4.

10.2.2 Frequency Modulation

A frequency-modulated optical field has a time-varying frequency of $\omega(t)$ that carries the encoded information:

$$\mathbf{E}(0,t) = \hat{e}|\mathcal{E}| \exp\left[\mathrm{i}\varphi_{\mathcal{E}} - \mathrm{i}\omega(t)t\right], \tag{10.6}$$

where $\hat{e}$, $|\mathcal{E}|$, and $\varphi_{\mathcal{E}}$ do not vary with time. In analog frequency modulation, $\omega(t)$ varies continuously with time; in digital frequency modulation, i.e., FSK, $\omega(t)$ shifts abruptly from one frequency to another. In *binary FSK* (BFSK), two different frequencies are used to represent the two binary bits of 0 and 1 for a digital signal. More than two frequencies can be used to digitize a signal in multiple symbols; for example, in *quadrature FSK* (QFSK), four frequencies are used to represent the four possible two-bit combinations of $\{00, 01, 10, 11\}$ by encoding two bits with each frequency.

Figures 10.2(a) and (b) show the temporal characteristics of the optical field under analog frequency modulation and BFSK, respectively. The magnitude of the carrier field stays constant