**(a)** Suppose that the pitch period of the speaker is steady except for a small deviation of $\epsilon$ that alternates in sign every pitch period (Figure 3.31a). Show that the glottal pulse train (assume no shaping) can be expressed as

$$p[n] = \sum_{k=-\infty}^{\infty} \delta[n - (2k)P] + \sum_{k=-\infty}^{\infty} \delta[n + \epsilon - (2k + 1)P].$$

Then derive the following expression:

$$|P(\omega)|^2 = 2(1 + \cos[(\epsilon - P)\omega]) \left[ \sum_{k=-\infty}^{\infty} \frac{2\pi}{2P} \delta(\omega - k\frac{2\pi}{2P}) \right]^2$$

where $P(\omega)$ is the Fourier transform of $p[n]$. Plot $|P(\omega)|^2$ for $\epsilon = 0$, for $0 < \epsilon \ll P$, and for $\epsilon = P$. What is the effect of pitch jitter on the short-time speech spectrum? Sketch the effect and assume a short-time rectangular window of length $N_w = 3P$. Argue why the presence of pitch jitter may lead to the appearance of "false resonances" in the speech spectrum. In determining the effect of pitch jitter on the short-time spectrum, use MATLAB, if helpful.

**(b)** Suppose now that the amplitude of the ideal glottal pulses is constant except for a small alternating deviation of $\Delta$, as illustrated in Figure 3.31b. Derive the following expression for $|P(\omega)|^2$:

$$|P(\omega)|^2 = 2(1 + \Delta^2) \left[ 1 + \frac{(1 - \Delta^2)}{(1 + \Delta^2)} \cos(P\omega) \right] \left[ \sum_{k=-\infty}^{\infty} \frac{2\pi}{2P} \delta(\omega - k\frac{2\pi}{2P}) \right]^2.$$

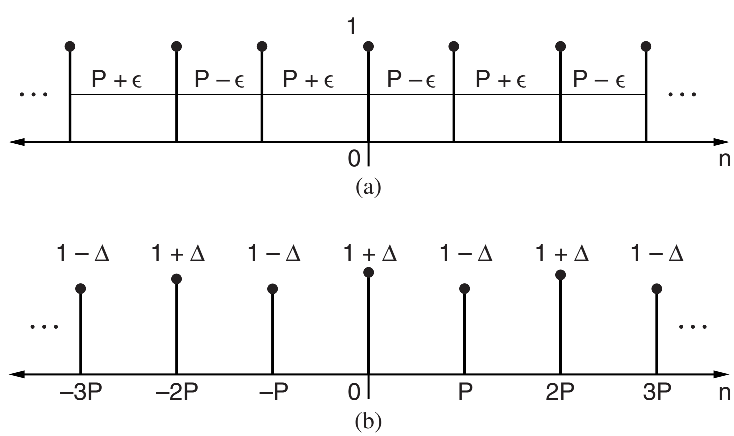


**Figure 3.31** Illustration of (a) pitch and (b) amplitude jitter.