All of the foregoing expressions come from simple trigonometric expansions.

Clearly, in both DSB and SSB, a frequency drift that's not small compared to W will substantially alter the detected tone. The effect is more severe in DSB since a *pair* of tones, $f_m + f'$ and $f_m - f'$, is produced. If $f' \ll f_m$, this sounds like warbling or the beat note heard when two musical instruments play in unison but slightly out of tune. While only one tone is produced with SSB, this too can be disturbing, particularly for music transmission. To illustrate, the major triad chord consists of three notes whose frequencies are related as the integers 4, 5, and 6. Frequency error in detection shifts each note by the same absolute amount, destroying the harmonic relationship and giving the music an East Asian flavor. (Note that the effect is *not* like playing recorded music at the wrong speed, which preserves the frequency ratios.) For voice transmission, subjective listener tests have shown that frequency drifts of less than ± 10 Hz are tolerable, otherwise, everyone sounds rather like Donald Duck.

As to phase drift, again DSB is more sensitive, for if $\phi' = \pm 90°$ (LO and carrier in quadrature), the detected signal vanishes entirely. With slowly varying ϕ', we get an apparent **fading** effect. Phase drift in SSB appears as **delay distortion,** the extreme case being when $\phi' = \pm 90°$ and the demodulated signal becomes $\hat{x}(t)$. However, as was remarked before, the human ear can tolerate sizeable delay distortion, so phase drift is not so serious in voice-signal SSB systems.

To summarize,

Phase and frequency synchronization requirements are rather modest for voice transmission via SSB. But in data, facsimile, and video systems with suppressed carrier, careful synchronization is a necessity. Consequently, television broadcasting employs VSB + C rather than suppressed-carrier VSB.

Envelope Detection

Very little was said earlier in Sect. 4.5 about synchronous demodulation of AM for the simple reason that it's almost never used. True, synchronous detectors work for AM, but so does an **envelope detector,** which is much simpler. Because the envelope of an AM wave has the same shape as the message, independent of carrier frequency and phase, demodulation can be accomplished by extracting the envelope with no worries about synchronization.

A simplified envelope detector and its waveforms are shown in Fig. 4.5–6, where the diode is assumed to be piecewise-linear. In absence of further circuitry, the voltage v would be just the half-rectified version of the input v_{in}. But R_1C_1 acts as a lowpass filter, responding only to variations in the peaks of v_{in} provided that

$$W \ll \frac{1}{R_1C_1} \ll f_c \tag{6}$$

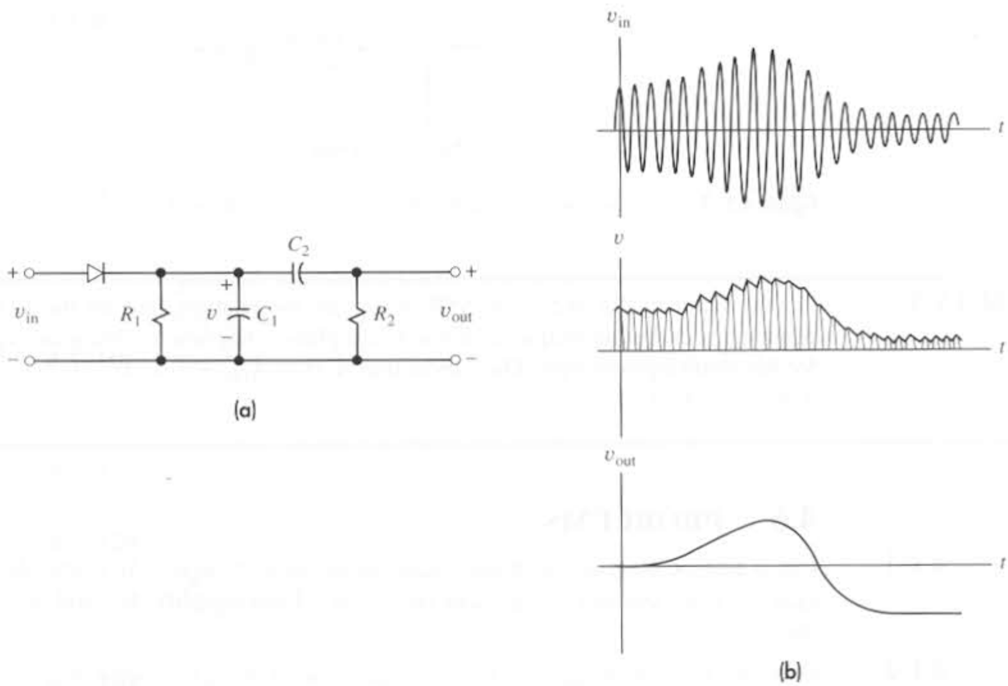

Figure 4.5–6 Envelope detection (*a*) Circuit; (*b*) waveforms.

Thus, as noted earlier, we need $f_c \gg W$ so the envelope is clearly defined. Under these conditions, C_1 discharges only slightly between carrier peaks, and v approximates the envelope of v_{in}. More sophisticated filtering produces further improvement if needed. Finally, R_2C_2 acts as a dc block to remove the bias of the unmodulated carrier component. Since the dc block distorts low-frequency message components, conventional envelope detectors are inadequate for signals with important low-frequency content.

The voltage v may also be filtered to remove the *envelope* variations and produce a dc voltage proportional to the carrier amplitude. This voltage in turn is fed back to earlier stages of the receiver for **automatic volume control** (AVC) to compensate for fading. Despite the nonlinear element, Fig. 4.5–6 is termed a **linear envelope detector;** the output is linearly proportional to the input envelope. Power-law diodes can also be used, but then v will include terms of the form v_{in}^2, v_{in}^3, and so on, and there may be appreciable second-harmonic distortion unless $\mu \ll 1$.

Some DSB and SSB demodulators employ the method of **envelope reconstruction** diagrammed in Fig. 4.5–7. The addition of a large, locally generated carrier to the incoming signal reconstructs the envelope for recovery by an envelope detector. This method eliminates signal multiplication but does not get around the synchronization problem, for the local carrier must be as well synchronized as the LO in a product demodulator.