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output is larger than that of the input signal. In general, the bandpass input signal is represented by

$$v_{in}(t) = R(t) \cos[\omega_c t + \theta(t)] \quad (4-67)$$

The transfer function of the nonlinear device may be expanded in a Taylor's series, so that the n th order output term is

$$v_1(t) = K_n v_{in}^n(t) = K_n R^n(t) \cos^n[\omega_c t + \theta(t)]$$

or[†]

$$v_1(t) = CR^n(t) \cos[n\omega_c t + n\theta(t)] + \text{other terms} \quad (4-68)$$

This illustrates that the input *amplitude* variation $R(t)$ *appears distorted* on the output signal since the envelope on the output is $R^n(t)$. The waveshape of the *angle* variation, $\theta(t)$, is *not distorted* by the frequency multiplier, but the frequency multiplier does increase the magnitude of the angle variation by a factor of n . Thus frequency multiplier circuits are not used on signals where the AM is to be preserved; but as we will see, the frequency multiplier is very useful in PM and FM problems since it effectively "amplifies" the angle variation waveform, $\theta(t)$. The $n = 2$ multiplier is called a *doubler stage*, and the $n = 3$ frequency multiplier is said to be a *tripler stage*.

The frequency multiplier should not be confused with a mixer. The frequency multiplier acts as a nonlinear device. The mixer circuit (which uses a mathematical multiplier operation) acts as a linear circuit with time-varying gain (due to the LO signal). The bandwidth of the signal at the output of a frequency multiplier is larger than that of the input signal, and it appears in a frequency band located at the n th harmonic of the input. The bandwidth of a signal at the output of a mixer is the same as that of the input, but the input spectrum has been translated either up or down depending on the LO frequency and the bandpass of the output filter. Of course, it is realized that a frequency multiplier is essentially a nonlinear amplifier followed by a bandpass filter that is designed to pass the n th harmonic.

Envelope Detector

An *ideal envelope detector* is a circuit that produces a waveform at its output that is proportional to the real envelope of its input. From (4-1b) the bandpass input may be represented by $R(t) \cos[\omega_c t + \theta(t)]$, where $R(t) \geq 0$; then the output of the ideal envelope detector is

$$v_{out}(t) = KR(t) \quad (4-69)$$

where K is the proportionality constant.

A simple diode detector circuit that approximates an ideal envelope detector is shown in Fig. 4-14a. The diode current occurs in pulses proportional to the positive part of the input waveform. The current pulses charge the capacitor to

[†] m th-order output terms, where $m > n$, may also contribute to the n th harmonic output provided that K_m is sufficiently large with respect to K_n . This is illustrated by (A-18), where $m = 4$ and $n = 2$.

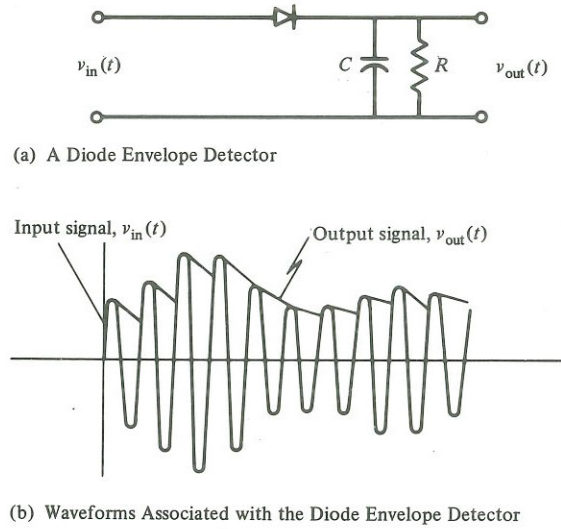


FIGURE 4-14 Envelope detector.

produce the output voltage waveform, as illustrated in Fig. 4-14b. The RC time constant is chosen so that the output signal will follow the real envelope, $R(t)$, of the input signal. Consequently, the cutoff frequency of the low-pass filter needs to be much smaller than the carrier frequency f_c and much larger than the bandwidth of the (detected) modulation waveform, B . That is,

$$B \ll \frac{1}{2\pi RC} \ll f_c \quad (4-70)$$

where RC is the time constant of the filter.

Product Detector

A *product detector* (Fig. 4-15) is a mixer circuit that down-converts the input (bandpass signal plus noise) to baseband. The output of the multiplier is

$$\begin{aligned} v_1(t) &= R(t) \cos[\omega_c t + \theta(t)] A_0 \cos(\omega_c t + \theta_0) \\ &= \frac{1}{2} A_0 R(t) \cos[\theta(t) - \theta_0] + \frac{1}{2} A_0 R(t) \cos[2\omega_c t + \theta(t) + \theta_0] \end{aligned}$$

where the frequency of the oscillator is f_c and the phase is θ_0 . The low-pass filter passes only the down-conversion term, so that the output is

$$v_{\text{out}}(t) = \frac{1}{2} A_0 R(t) \cos[\theta(t) - \theta_0] = \frac{1}{2} A_0 \text{Re}\{g(t)e^{-j\theta_0}\} \quad (4-71)$$

where the complex envelope of the input is denoted by

$$g(t) = R(t)e^{j\theta(t)} = x(t) + jy(t)$$

and $x(t)$ and $y(t)$ are the quadrature components [see (4-2)]. Since the frequency of the oscillator is the same as the carrier frequency of the incoming signal, the

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