4.10. Limiters

- ✧ **Limiter** is a nonlinear circuit with an output saturation characteristic
- ✧ It rejects envelope variations but preserves the phase variations.

$$v_{in}(t) = \mathrm{R}(t)\cos\left[w_c t + \theta(t)\right]$$

$$\Downarrow$$

$$v_{out}(t) = KV_L \cos\left[w_c t + \theta(t)\right]$$

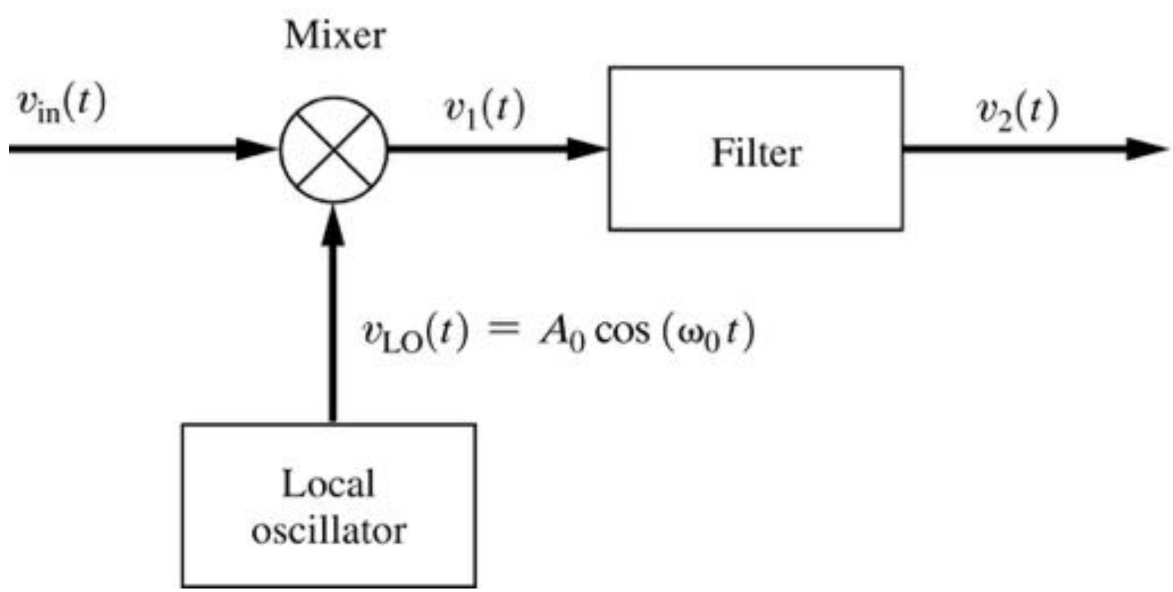
Where K is the level of the fundamental component of the square wave, $4/\pi$, multiplied by the gain of the output (bandpass) filter. V_L is output limits.

4.11. Mixers, Up Converters, Down Converters

- **Ideal mixer** is a mathematical multiplier of two input signals. One of the signals is sinusoidal generated by a local oscillator. Mixing results in frequency translation.

- Mixers are used to obtain frequency translation of the input signal.

where $V_{in}(t)$ is bandpass signal: $v_{in}(t) = \mathrm{Re}\left\{ g_{in}(t) e^{j w_c t} \right\}$



4.11. Mixers, Up Converters, Down Converters

Bandpass Input Signal

$$v_{in}(t) = \mathrm{Re}\left\{ g_{in}(t) e^{j\omega_c t} \right\}$$

Mixer Output

$$v_1(t) = \left[A_0 \,\mathrm{Re}\left\{ g_{in}(t) e^{j\omega_c t} \right\} \right] \cos \omega_0 t$$

$$= \frac{A_0}{4} \left[g_{in}(t) e^{j\omega_c t} + g_{in}^*(t) e^{-j\omega_c t} \right] \left(e^{j\omega_c t} + e^{-j\omega_c t} \right)$$

$$= \frac{A_0}{4} \left[g_{in}(t) e^{j(\omega_c + \omega_0)t} + g_{in}^*(t) e^{-j(\omega_c + \omega_0)t} + g_{in}(t) e^{j(\omega_c - \omega_0)t} + g_{in}^*(t) e^{-j(\omega_c - \omega_0)t} \right]$$

$$\mathrm{Re}\{\cdot\} = \frac{1}{2}\{\cdot\} + \frac{1}{2}\{\cdot\}^*$$

$$v_1(t) = \frac{A_0}{2} \mathrm{Re}\left\{ g_{in}(t) e^{j(\omega_c + \omega_0)t} \right\} + \frac{A_0}{2} \mathrm{Re}\left\{ g_{in}(t) e^{j(\omega_c - \omega_0)t} \right\}$$

$f_u = f_c + f_0$ — UPCONVERSION — BANDPASS FILTER

$f_d = f_c - f_0$ — DOWNCONVERSION — BASEBAND OR BANDPASS FILTER

4.11. Mixers, Up Converters, Down Converters

$$v_1(t) = \frac{A_0}{2}\mathrm{Re}\left\{g_{in}(t)e^{j(\omega_c+\omega_0)t}\right\} + \frac{A_0}{2}\mathrm{Re}\left\{g_{in}(t)e^{j(\omega_c-\omega_0)t}\right\}$$

Up-conversion

Down-conversion

$$f_u = f_c + f_0$$

$$f_d = f_c - f_0$$

Bandpass Filter

Baseband/bandpass Filter (f_c-f_0)

4.11. Mixers, Up Converters, Down Converters

- If $(f_c - f_0) = 0$ ➔ Low Pass Filter gives baseband spectrum
- If $(f_c - f_0) > 0$ ➔ Bandpass filter ➔ Modulation is preserved

Filter Output: $$v_2(t) = \mathrm{Re}\left\{g_2(t)e^{j(\omega_c - \omega_0)t}\right\} = \frac{A_0}{2}\mathrm{Re}\left\{g_{in}(t)e^{j(\omega_c - \omega_0)t}\right\}$$

- If $f_c > f_0$ ➔ modulation on the mixer input is preserved
- If $f_c < f_0$ ➔ $$v_1(t) = \frac{A_0}{2}\mathrm{Re}\left\{g_{in}(t)e^{j(\omega_c + \omega_0)t}\right\} + \frac{A_0}{2}\mathrm{Re}\left\{g_{in}^{*}(t)e^{j(\omega_0 - \omega_c)t}\right\}$$

'ω' needs to be positive

4.11. Mixers, Up Converters, Down Converters

- Complex envelope of an ***Up Converter***:

$$g_2(t) = \frac{A_0}{2} g_{in}(t); \quad f_u = f_c + f_0 > 0$$

- Amplitude is scaled by $A_0/2$

- Complex envelope of a ***Down Converter***:

$f_d = f_c - f_0 > 0$ i.e., $f_0 < f_c$ ➔ down conversion with *low-side injection*

$$g_2(t) = \frac{A_0}{2} g_{in}(t)$$

- Amplitude is scaled by $A_0/2$

$f_d = f_0 - f_c > 0$ i.e., $f_0 > f_c$ ➔ down conversion with *high-side injection*

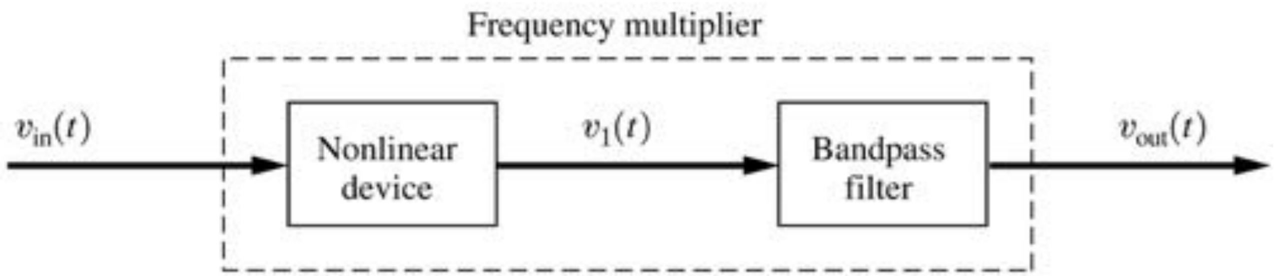
$$g_2 = \frac{A_0}{2} g_{in}^{*}(t)$$

- Amplitude is scaled by $A_0/2$

- Sidebands are reversed from those on the input

4.12. Frequency Multipliers

➢***Frequency Multipliers*** **consists of a nonlinear device together with a tuned circuit. The frequency of the output is n times the frequency of the input.**



(a) Block Diagram of a Frequency Multiplier

$$v_{in}(t) = R(t)\cos(\omega_c t + \theta(t))$$

$$v_1(t) = K_n v^n in(t)$$

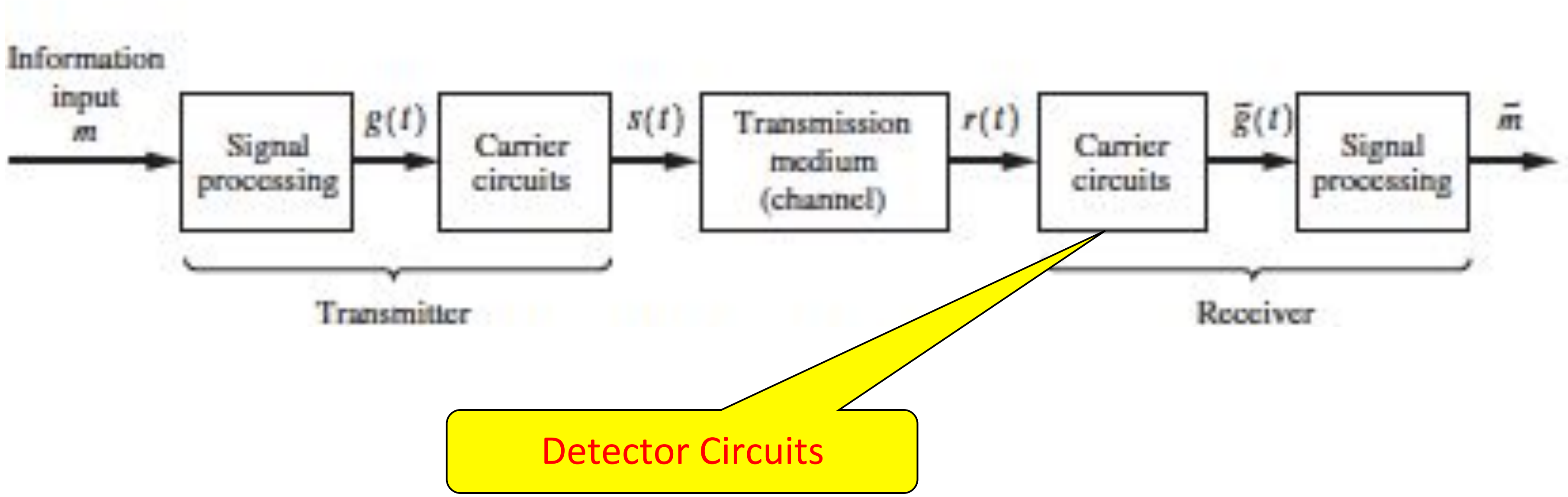
$$= K_n R^n(t)\cos^n(\omega_c t + \theta(t))$$

$$v_1(t) = CR^n(t)\cos(n\omega_c t + n\theta(t)) + other\ terms$$

$$v_{out}(t) = CR^n(t)\cos(n\omega_c t + n\theta(t))$$

4.13. Detector Circuits

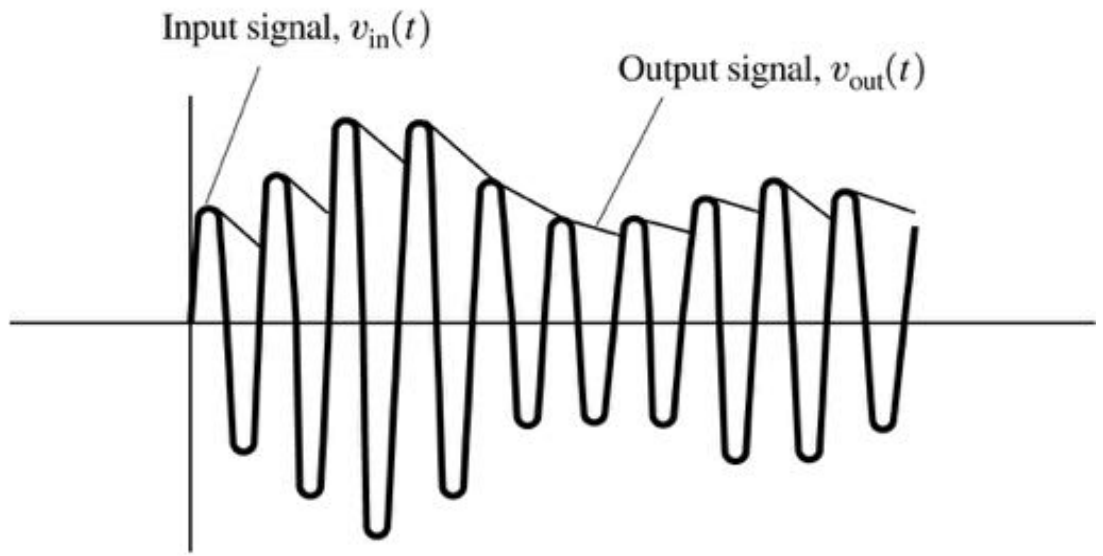
- **Detectors** convert input bandpass waveform into an output baseband waveform.



4.13. Detector Circuits

Envelope Detector

➢ Ideal envelope detector: Waveform at the output is a real envelope $R(t)$ of its input



Bandpass input: $v_{in}(t) = R(t)\cos[\omega_c t + \theta(t)]$ $\quad R(t) \geq 0$

Envelope Detector Output: $v_{out}(t) = KR(t)$

K – Proportionality Constant

4.13. Detector Circuits

Envelope Detector

The envelope detector is typically used to detect the modulation on AM signal. The detected DC is used for **Automatic Gain Control (AGC)**.

In this case, the complex envelope of the input signal

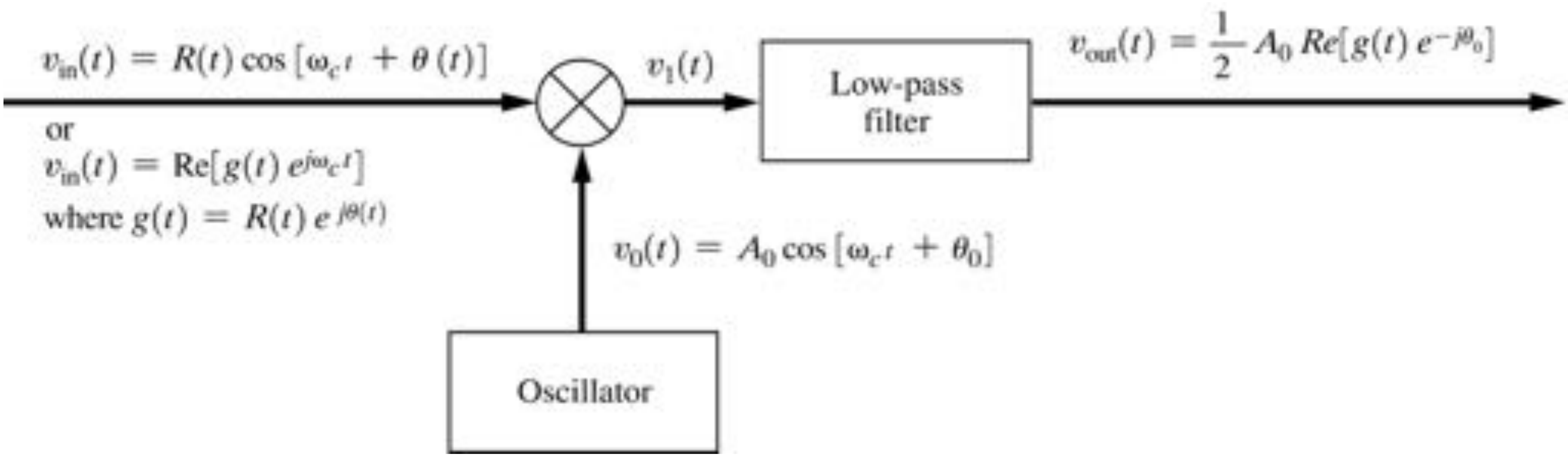
g(t) = Ac[1+m(t)].

$$\begin{aligned} v_{out}(t) &= KR(t) \\ &= K\left|g(t)\right| \\ &= KA_c\left[1+m(t)\right] \\ &= \mathrm{DC} + \mathrm{Message} \end{aligned}$$

4.13. Detector Circuits

Product Detector

Product Detector is a Mixer circuit that down converts input to baseband.



f_c- Freq. of the oscillator

ϑ_0- Phase of the oscillator

4.13. Detector Circuits

Product Detector

Output of the multiplier:

$$v_1(t) = R(t)\cos\left[\omega_c t + \theta(t)\right] A_0 \cos\left(\omega_c t + \theta_0\right)$$

$$= \frac{1}{2} A_0 R(t)\cos\left[\theta(t) - \theta_0\right] + \frac{1}{2} A_0 R(t)\cos\left[2\omega_c t + \theta(t) + \theta_0\right]$$

Low-pass Filter passes down conversion component:

$$v_{out}(t) = \frac{1}{2} A_0 R(t)\cos\left[\theta(t) - \theta_0\right] = \frac{1}{2} A_0 \operatorname{Re}\left\{g(t) e^{-j\theta_0}\right\}$$

Where $g(t)$ is the complex envelope of the input and $x(t)$ & $y(t)$ are the quadrature components of the input:

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

4.13. Detector Circuits

Applications of Product Detector

➢ **INPHASE DETECTOR :**

$$\text{if } \theta_0 = 0: \quad \Rightarrow v_{out}(t) = \frac{1}{2} A_0 x(t)$$

➢ **QUADRATURE PHASE DETECTOR**

$$\text{if } \theta_0 = 90 \quad \Rightarrow v_{out} = \frac{1}{2} A_0 y(t)$$

➢ **ENVELOPE DETECTOR**

$$\text{if } \theta(t) = 0 \quad \Rightarrow v_{out} = \frac{1}{2} A_0 R(t)$$

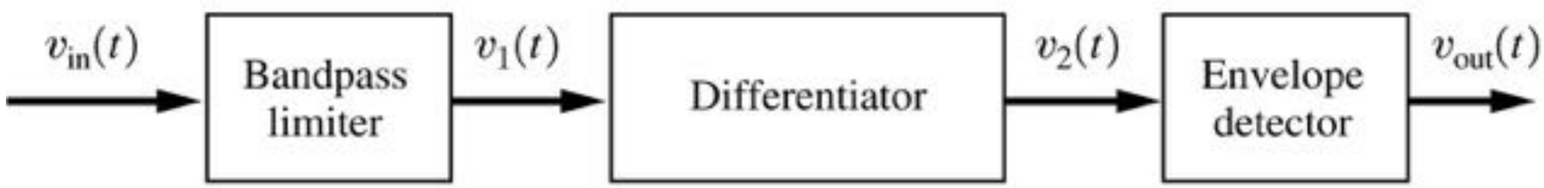
➢ **PHASE DETECTOR** If an angle modulated signal is present at the input and reference phase (ϑ_0) =90°

$$\text{if } \theta_0 = 90^\circ \;\; v_{in}(t) = A_c \cos\left[\omega_c t + \theta(t)\right]$$

4.13. Detector Circuits

Frequency Modulation Detector

- **A ideal FM Detector is a device that produces an output that is proportional to the instantenous frequency of the input.**



4.13. Detector Circuits

Frequency Modulation Detector

Frequency demodulation using slope detection.

$$v_{in}(t) = A(t)\cos[\omega_c t + \theta(t)] \qquad \theta(t) = K_f \int_{-\infty}^{t} m(\tau)d\tau$$

$$v_1(t) = V_L \cos[\omega_c t + \theta(t)] \quad v_2(t) = -V_L \left[\omega_c + \frac{d\theta(t)}{dt}\right]\sin[\omega_c t + \theta(t)]$$

$$v_{out}(t) = \left|-V_L \left[\omega_c + \frac{d\theta(t)}{dt}\right]\right| = V_L \left[\omega_c + \frac{d\theta(t)}{dt}\right] =$$

$$V_L\omega_c + V_L K_f m(t) = \mathrm{DC} + \mathrm{AC}\ (\text{Proportional to } m(t))$$

- The DC output can easily be blocked