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AMPLITUDE MODULATION - I

Why not direct 'Baseband' transmission?

Baseband – LP

Channel – BP

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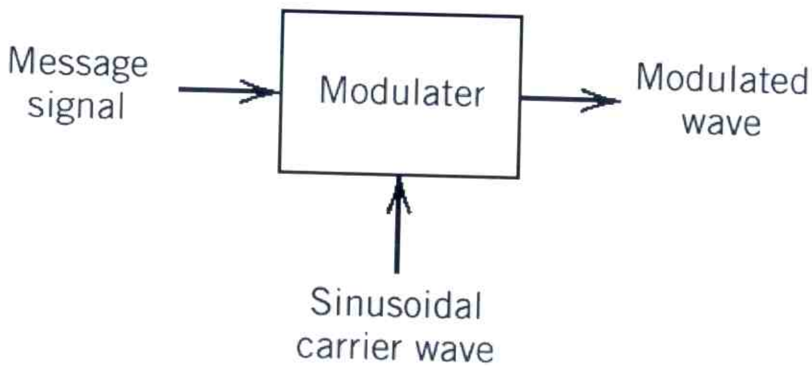
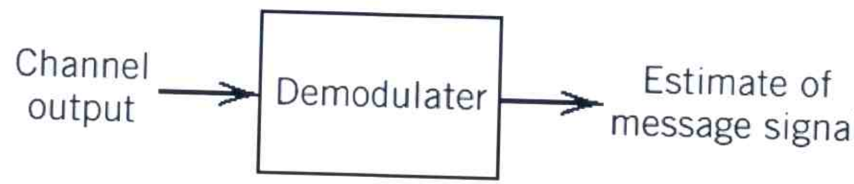
Components of a continuous-wave modulation system: (*a*) transmitter, and (*b*) receiver

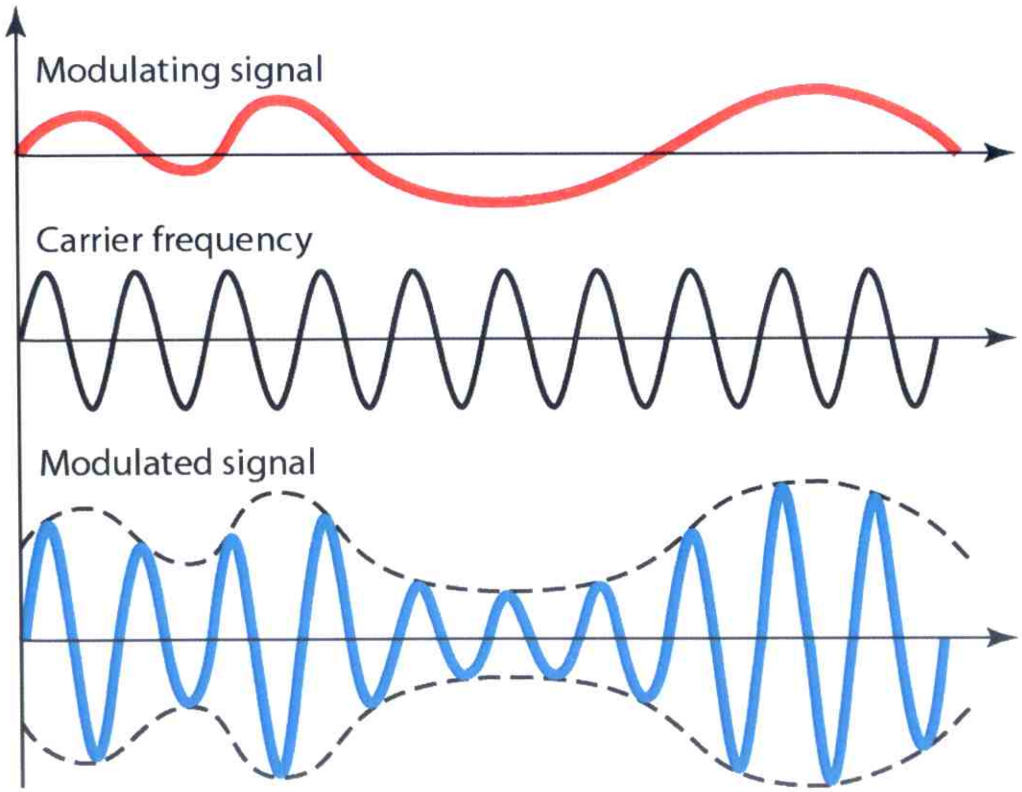


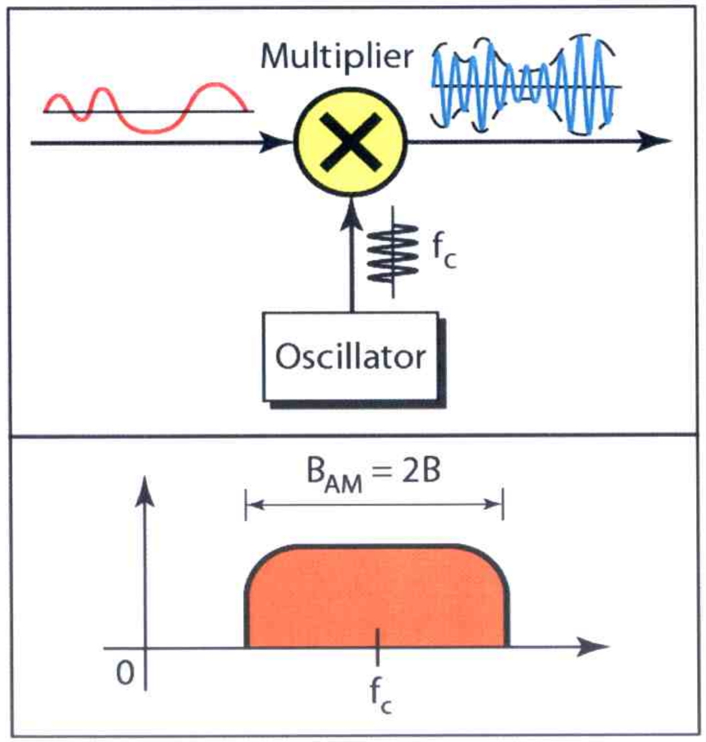
(*a*)



(*b*)

Amplitude modulation





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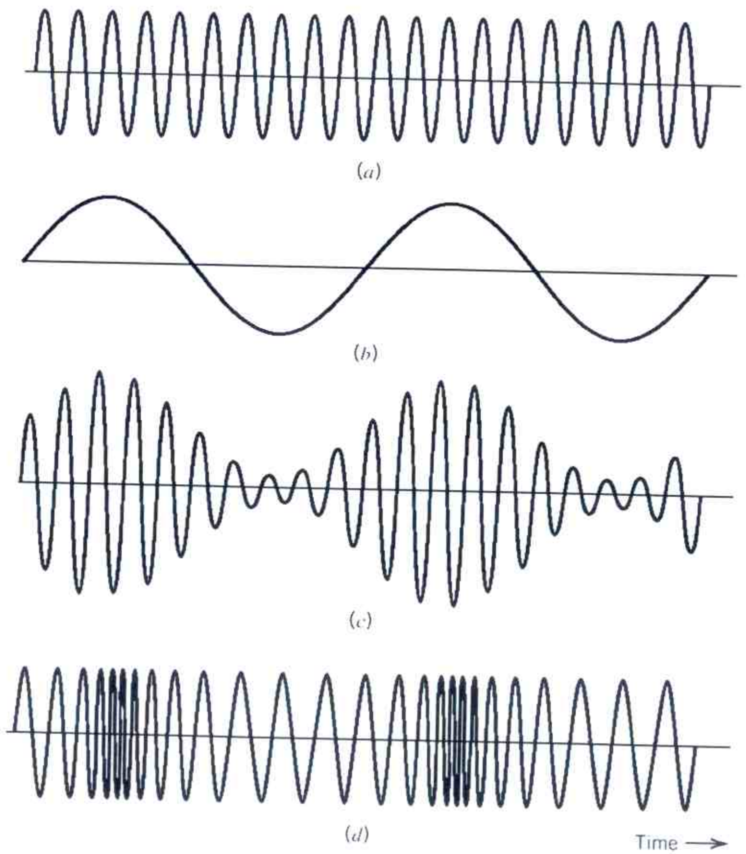
AM and FM signals produced by a single tone. (*a*) Carrier wave. (*b*) Sinusoidal modulating signal. (*c*) Amplitude-modulated signal. (*d*) Frequency-modulated signal.



$$c(t) = A_c \cos 2\pi f_c t$$

$m(t) \rightarrow$ message signal

$$s(t) = \underbrace{A_c\left(1 + \mu m(t)\right)}\underline{\cos 2\pi f_c t}$$

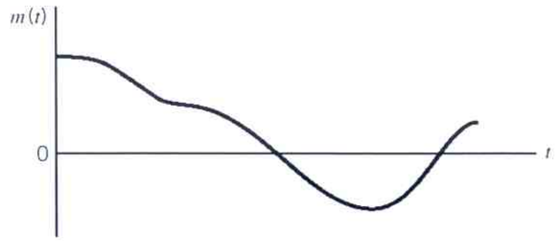
$|m(t)| < 1$ $\quad \mu < 1$ modulation

$\mu > 1$ overmodulation

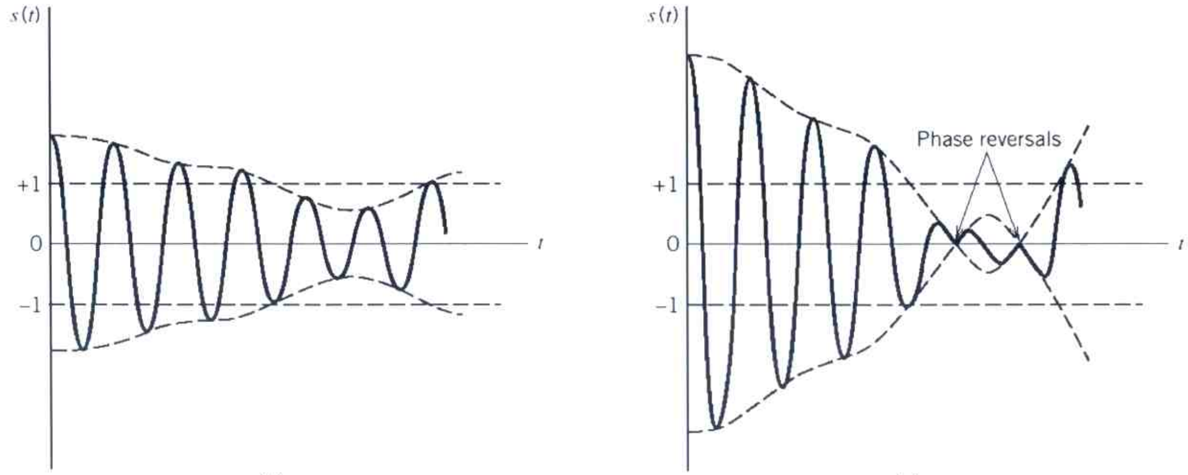
$\mu \rightarrow$ modulation index

% modulation $\equiv 100 \times \mu$

AM waveforms (a) Message; (b) AM wave with $\mu < 1$; (c) AM wave with $\mu > 1$



(a)



(b) (c)

$$m(t) \longleftrightarrow M(f)$$

$$s(t) \longleftrightarrow S(f)$$

$$s(t) = A_c\,(1 + \mu m(t)) \cos 2\pi f_c t$$

$$= A_c \cos 2\pi f_c t + \mu A_c\, m(t) \cos 2\pi f_c t$$

$$s(t) \leftrightarrow S(f) = \frac{A_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right] + \frac{\mu A_c}{2}\left[M(f - f_c) + M(f + f_c)\right]$$

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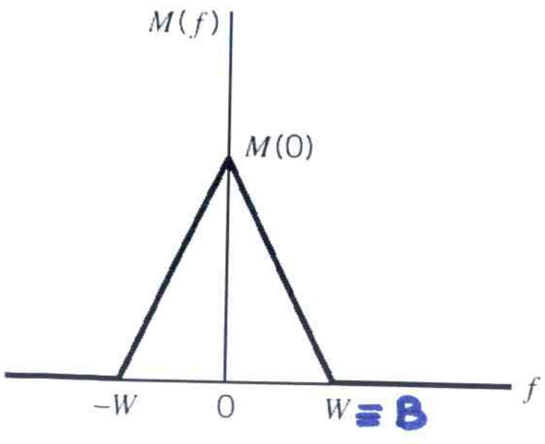
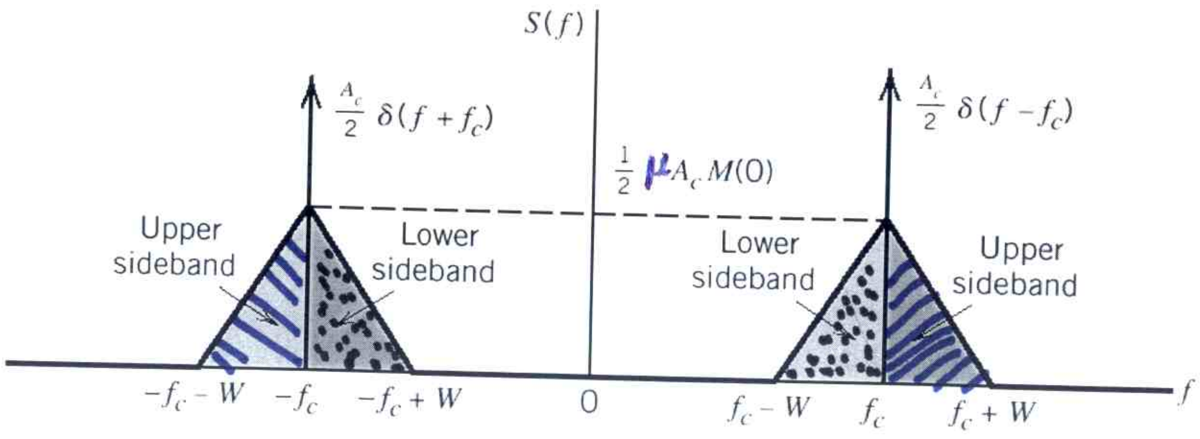
(*a*) Spectrum of baseband signal. (*b*) Spectrum of AM wave



(*a*)



(*b*)

AMPLITUDE MODULATION - II

$$s(t) = A_c\left(1 + \mu m(t)\right)\cos 2\pi f_c t$$

540 kHz – 1600 kHz

10 kHz

535 kHz – 1605 kHz

107 channels

Example: Single-Tone Modulation

$$m(t) = A_m \cos 2\pi f_m t$$

$$c(t) = A_c \cos 2\pi f_c t$$

$$s(t) = A_c \left(1 + \mu \cos 2\pi f_m t\right) \cos 2\pi f_c t$$

$$\mu \triangleq \frac{A_m}{A_c} \qquad |\mu| < 1$$

Envelope of $s(t)$: $A_c\left[1 + \mu \cos 2\pi f_m t\right]$

$$\frac{A_{max}}{A_{min}} = \frac{A_c(1+\mu)}{A_c(1-\mu)} \Rightarrow \mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

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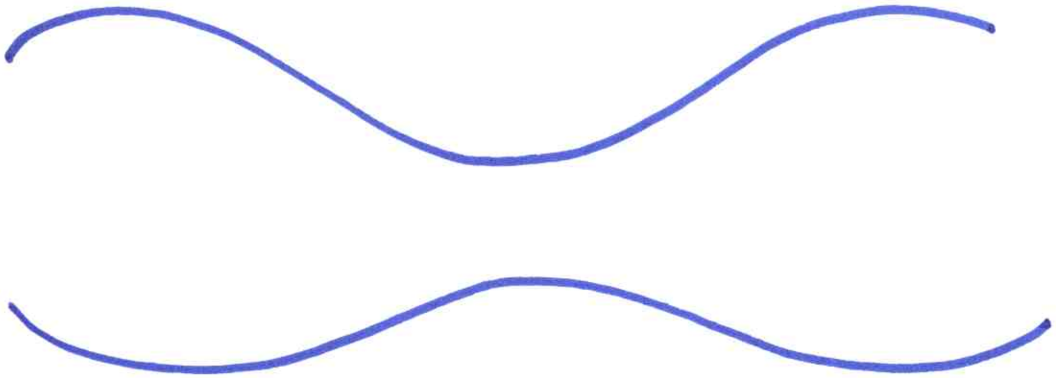
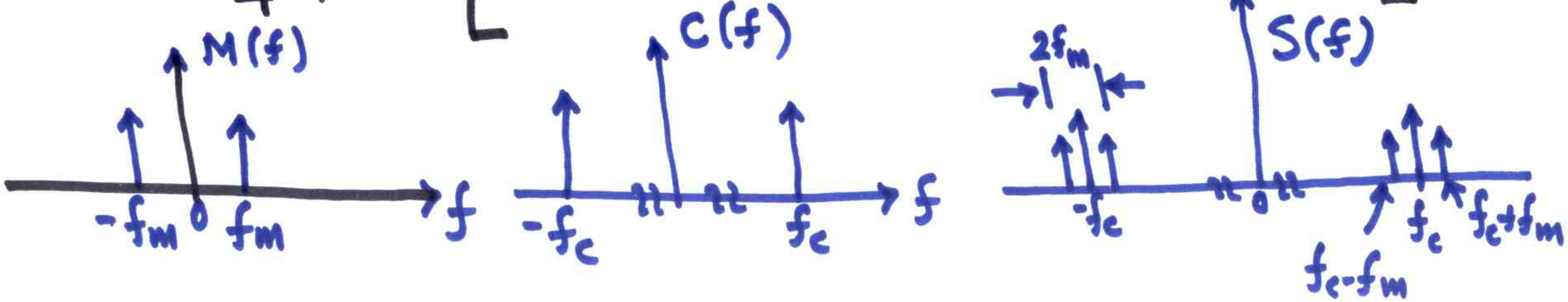


$$\cos(2\pi f_c t + \phi)$$

$$s(t) = A_c \cos 2\pi f_c t + \frac{1}{2}\mu A_c \cos\{2\pi (f_m + f_c)t\} + \frac{1}{2}\mu A_c \cos\{2\pi (f_c - f_m)t\}$$

$$\updownarrow$$

$$S(f) = \frac{1}{2} A_c \left[\delta(f - f_c) + \delta(f + f_c)\right] + \frac{1}{4}\mu A_c \left[\delta(f - f_c - f_m) + \delta(f + f_c + f_m)\right] + \frac{1}{4}\mu A_c \left[\delta(f - f_c + f_m) + \delta(f + f_c - f_m)\right]$$



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Carrier Power = $\frac{1}{2} A_c^2$

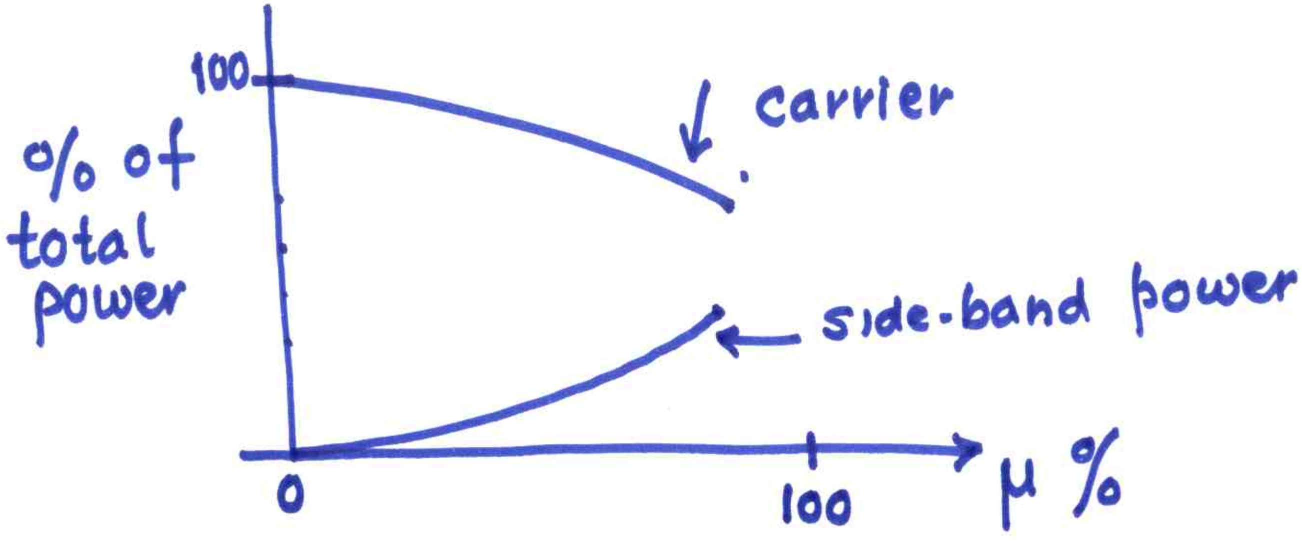
Upper-side-frequency power = $\frac{1}{8} \mu^2 A_c^2$

Lower-side-frequency power = $\frac{1}{8} \mu^2 A_c^2$

$P_{sb} = \frac{1}{8} \mu^2 A_c^2$

Total power in the side-bands = $\frac{1}{4} \mu^2 A_c^2$

$$\frac{\text{total sideband power}}{\text{Total power}} = \frac{\mu^2}{2+\mu^2}$$



$\mu = 20\%$

$$s(t) = A_c\,(1 + \mu\, m(t))\cos 2\pi f_c t$$

$\hookrightarrow$ total-power $\equiv s_T \equiv S_T$

$$S_T = \langle s^2(t) \rangle$$

$$= \frac{1}{2} A_c^2 \langle 1 + 2\mu m(t) + \mu^2 m^2(t) \rangle + \frac{1}{2} A_c^2 \cancelto{0}{\langle [1 + \mu m(t)]^2 \cos 4\pi f_c t \rangle}$$

$$\langle m(t) \rangle = 0$$

$$S_T = \frac{1}{2} A_c^2 \left(1 + \mu^2 \langle m^2(t) \rangle\right)$$

$\langle m^2(t) \rangle \equiv S_m$ $\qquad$ $S_T = \frac{1}{2} A_c^2 (1 + \mu^2 S_m)$

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$$S_T = \frac{1}{2} A_c^2 \left(1 + \mu^2 S_m\right)$$

$$= P_c + 2 P_{sb}$$

$$P_c = \frac{1}{2} A_c^2$$

$$P_{sb} = \frac{1}{4} \mu^2 A_c^2 S_m = \frac{1}{2} \mu^2 S_m P_c$$

$$P_c = S_T - 2 P_{sb} \geq \frac{1}{2} S_T \; ; \; P_{sb} \leq \frac{1}{4} S_T$$

Modulation efficiency $\triangleq \dfrac{\mu^2 S_m}{1 + \mu^2 S_m}$

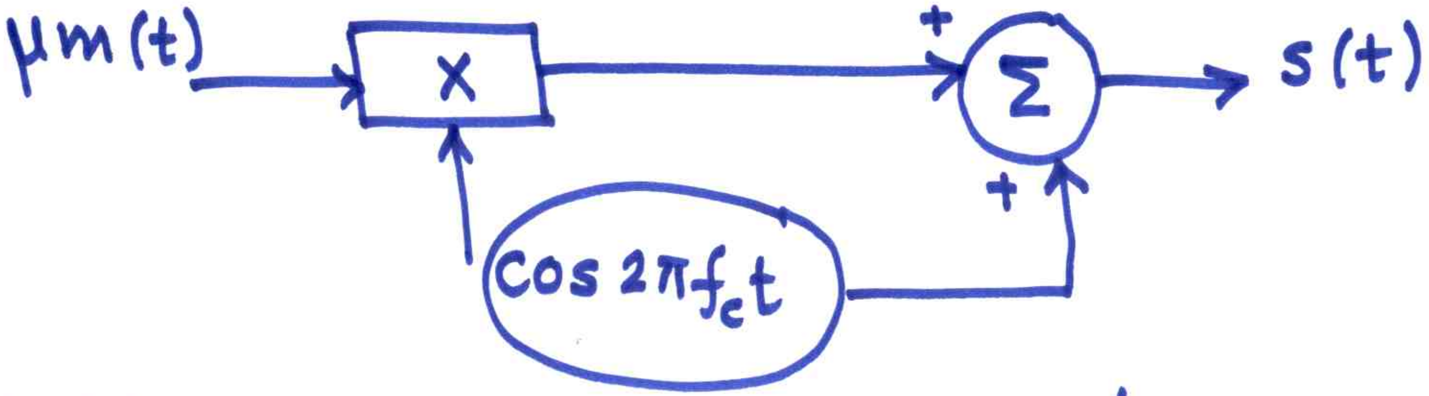
→ POWER

→ BW

$$s(t) = A_c\left(1+\mu m(t)\right)\cos 2\pi f_c t$$

Generation of AM

(i) Multiplier - Analog



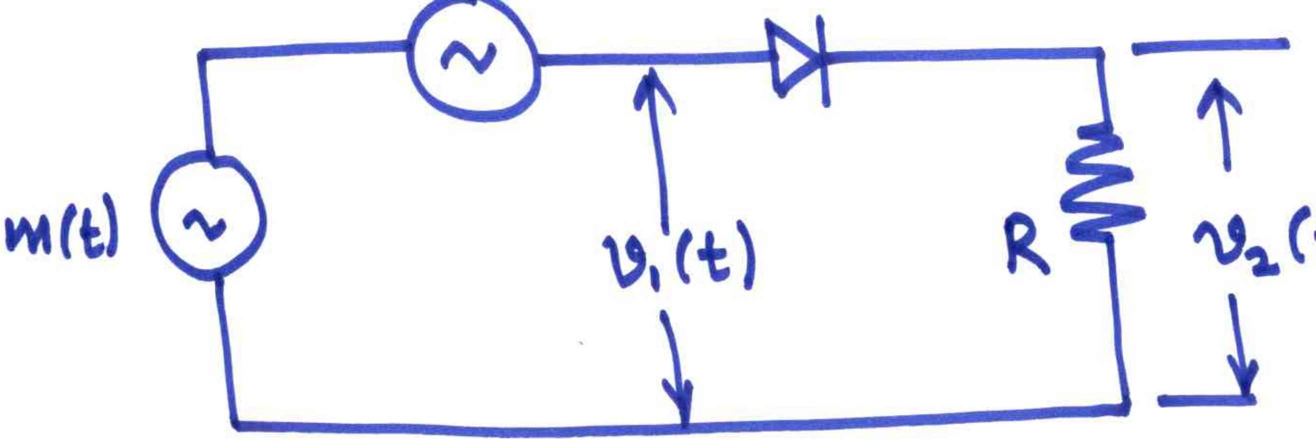
(ii) Non-linear device : diode / transistor

$$x \rightarrow \boxed{\text{NLD}} \rightarrow y = \alpha_0 + \alpha_1 x + \alpha_2 x^2$$

$x = m(t) + \cos 2\pi f_c t$

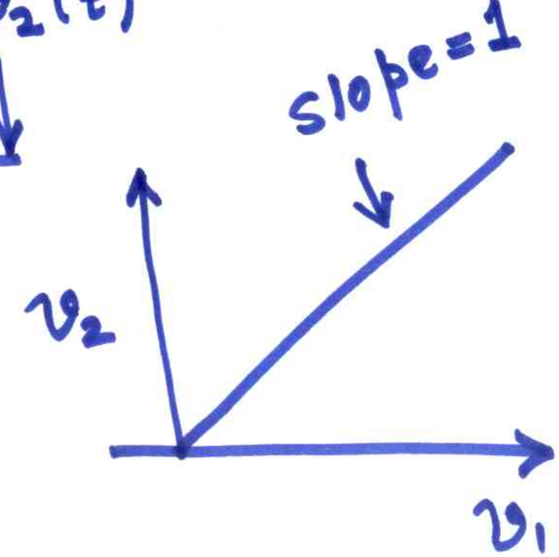
(iii) Switching Modulator

$c(t) = A_c \cos(2\pi f_c t)$



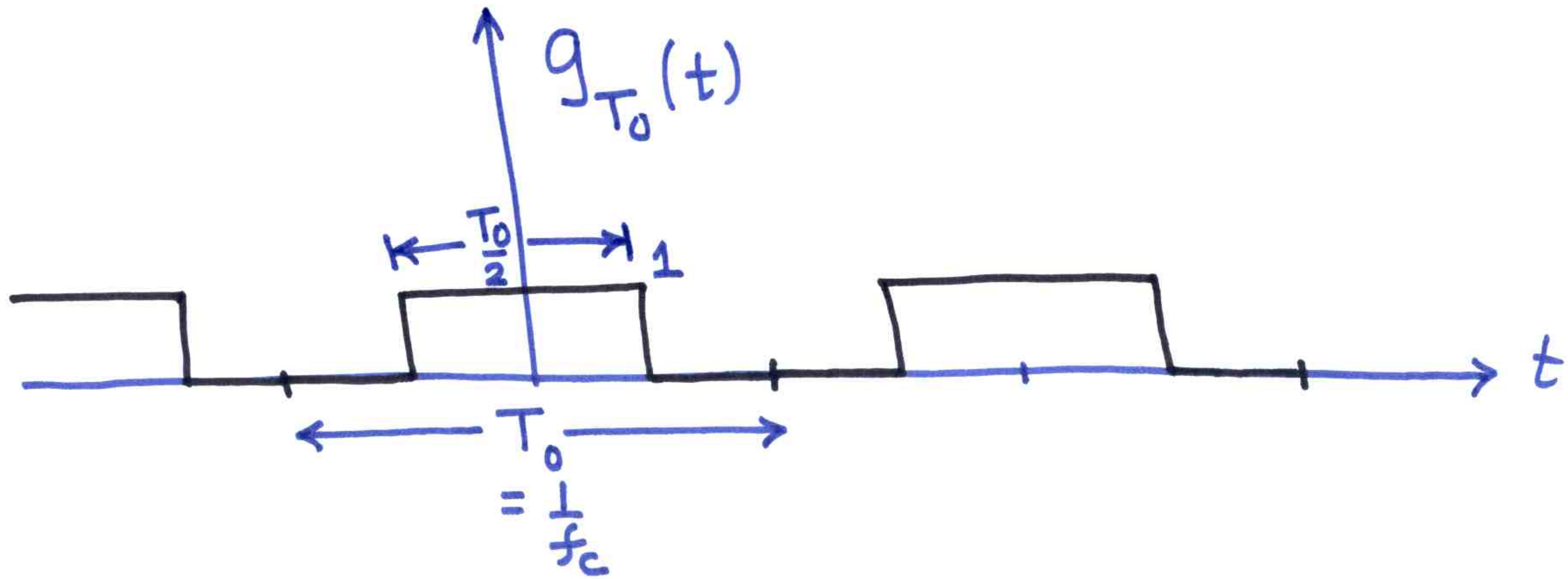
$v_1(t) = A_c \cos 2\pi f_c t + m(t)$

$$v_2(t) \approx \begin{cases} v_1(t), & c(t) > 0 \\ 0, & c(t) < 0 \end{cases}$$



$$v_2(t) \cong \left[A_c \cos 2\pi f_c t + m(t) \right] g_{T_0}(t)$$

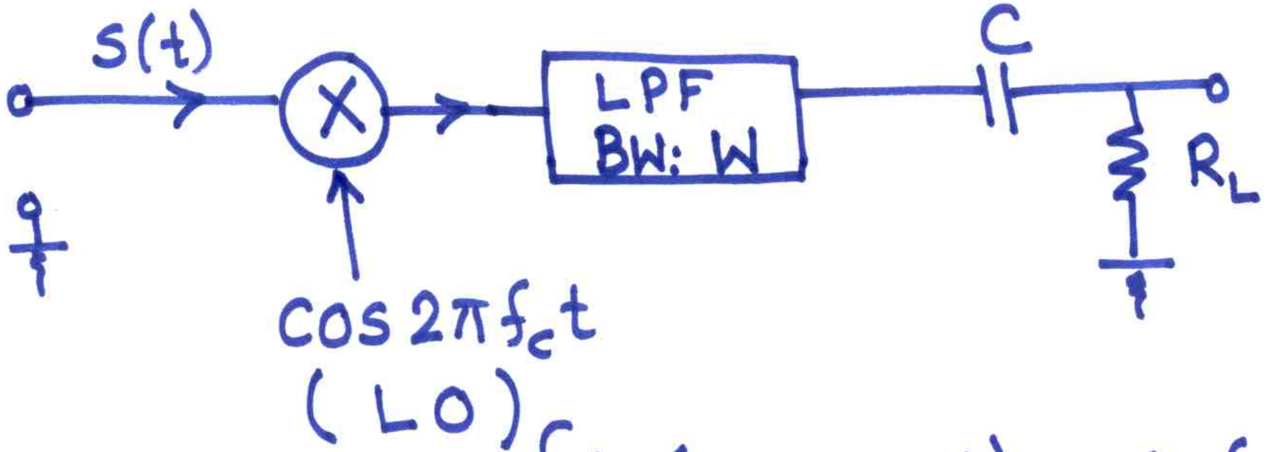
$g_{T_0}(t) \rightarrow$ periodic square wave with period $T_0 = \frac{1}{f_c}$ with 50% duty cycle



Demodulation of AM Signals

(1) Coherent Detection

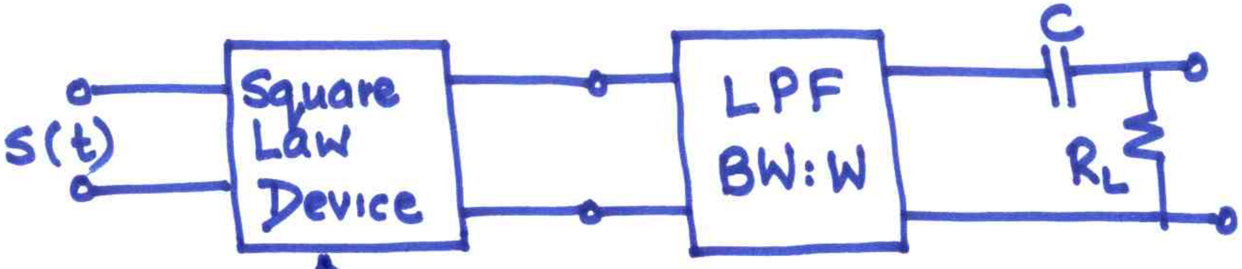
$$s(t) = A_c\left(1+\mu m(t)\right)\cos 2\pi f_c t$$



$$s(t)\cos 2\pi f_c t = \left\{A_c\left(1+\mu m(t)\right)\cos 2\pi f_c t\right\}\cos 2\pi f_c t$$

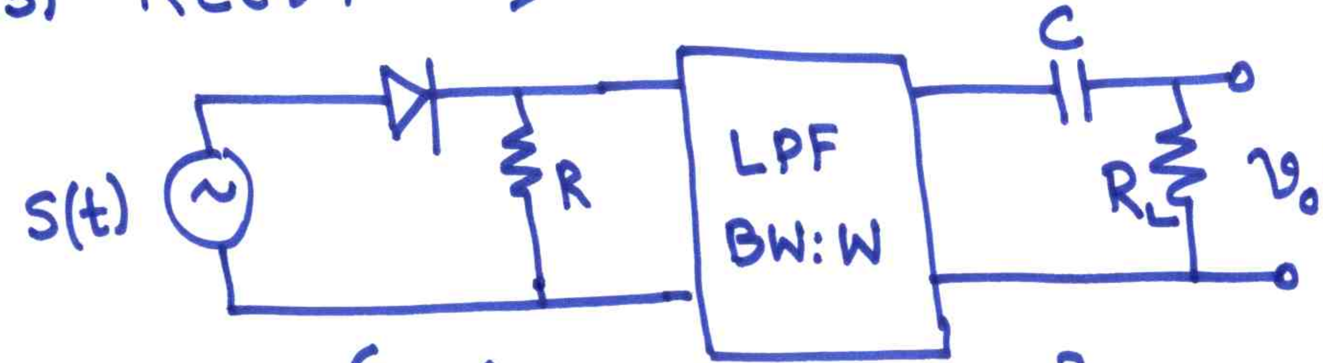
$$= \frac{A_c}{2} + \mu\frac{A_c}{2}m(t) + \frac{A_c}{2}\cos 4\pi f_c t + \mu\frac{A_c}{2}m(t)\cos 4\pi f_c t$$

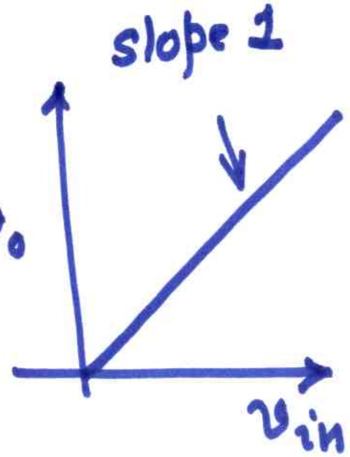
(2) Square-law detector



$$y(t) = \alpha_1 x^2(t) + \alpha_2 x(t)$$

(3) Rectifier Detector



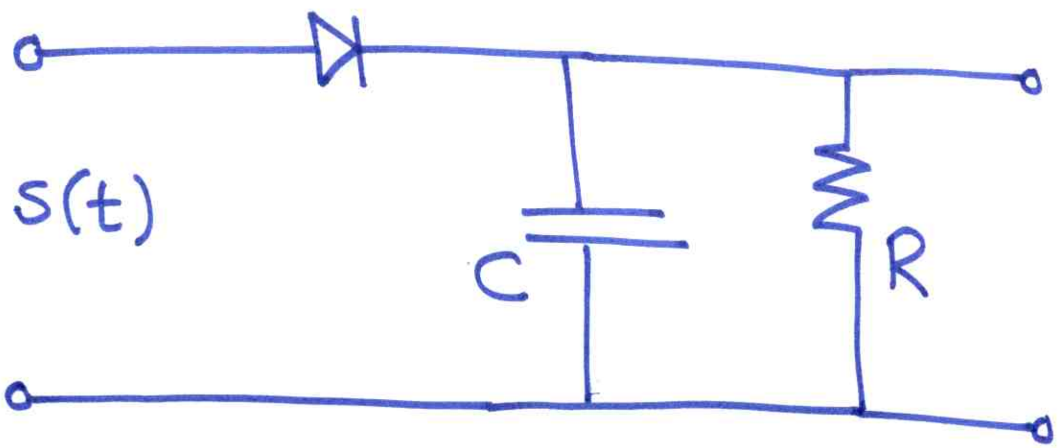


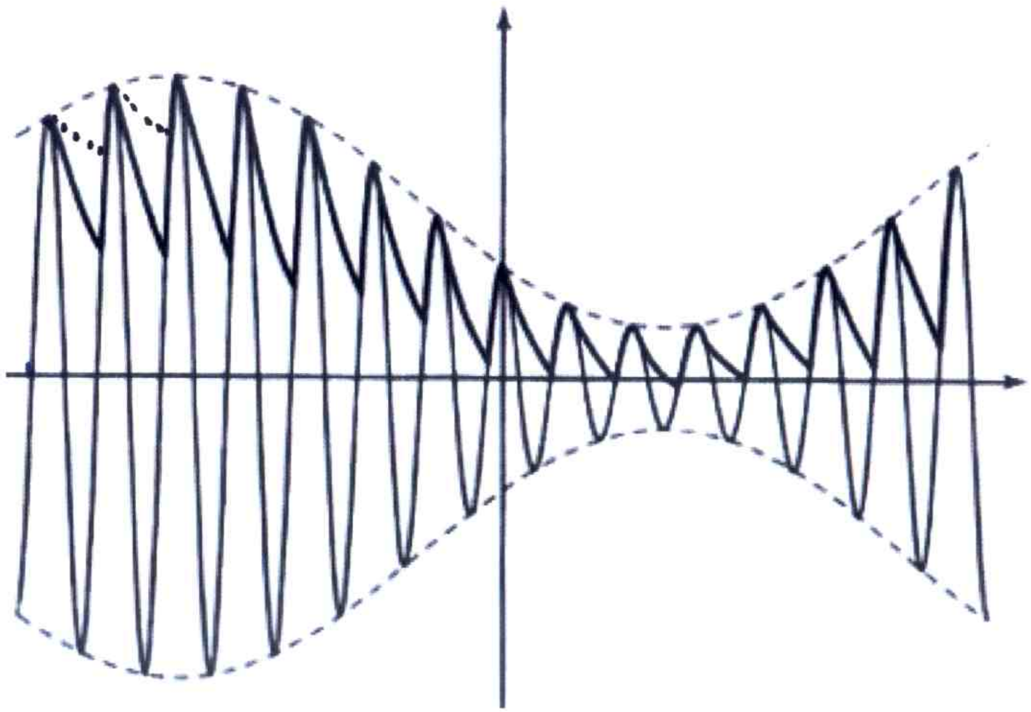
$$v_o(t) = \left\{A_c\left(1 + \mu m(t)\right)\cos 2\pi f_c t\right\} w(t)$$

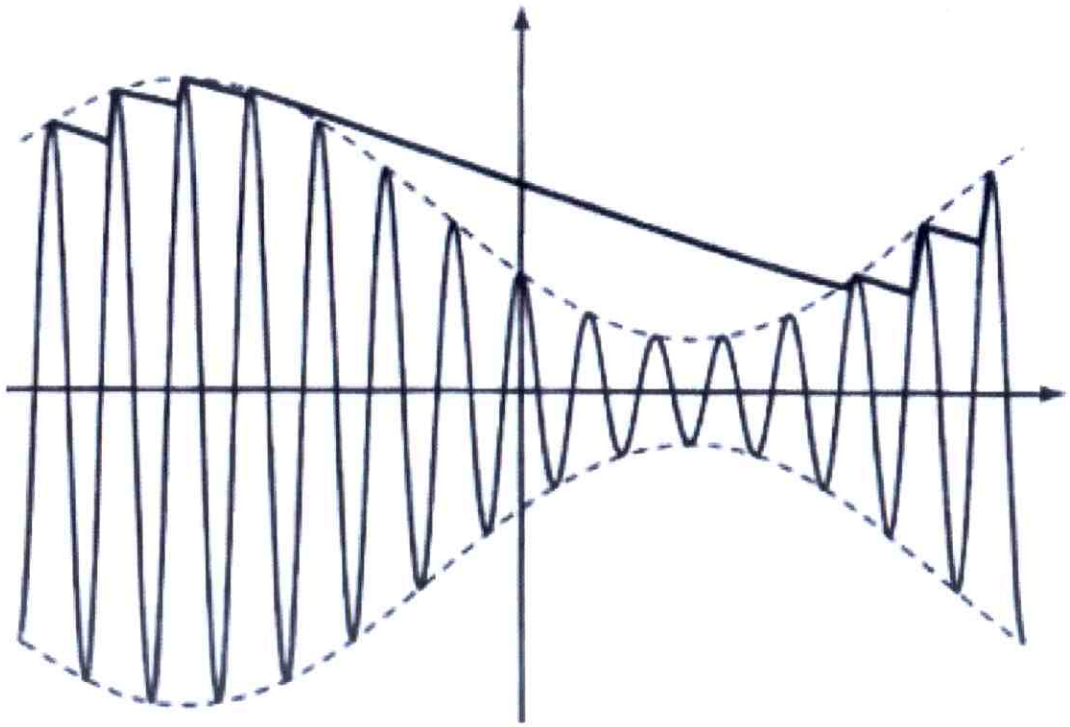
$$w(t) = \frac{1}{2} + \frac{2}{\pi}\left(\cos 2\pi f_c t - \frac{1}{3}\cos 6\pi f_c t + \frac{1}{5}\cos 10\pi f_c t \cdots\right\}$$

$$= \frac{A_c}{\pi}\left[1 + \mu m(t)\right] + \text{other high freq. terms}$$

(4) ENVELOPE DETECTOR







$$\frac{1}{f_c} \ll RC \ll \frac{1}{W}$$

"Diagonal Clipping"