APECE-302: Radio & Television Engineering

Applied Physics, Electronics & Communication Engineering

LEC PPT # 03
Modulation Techniques
(Part 1)

University of Dhaka | APECE DU

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Contents

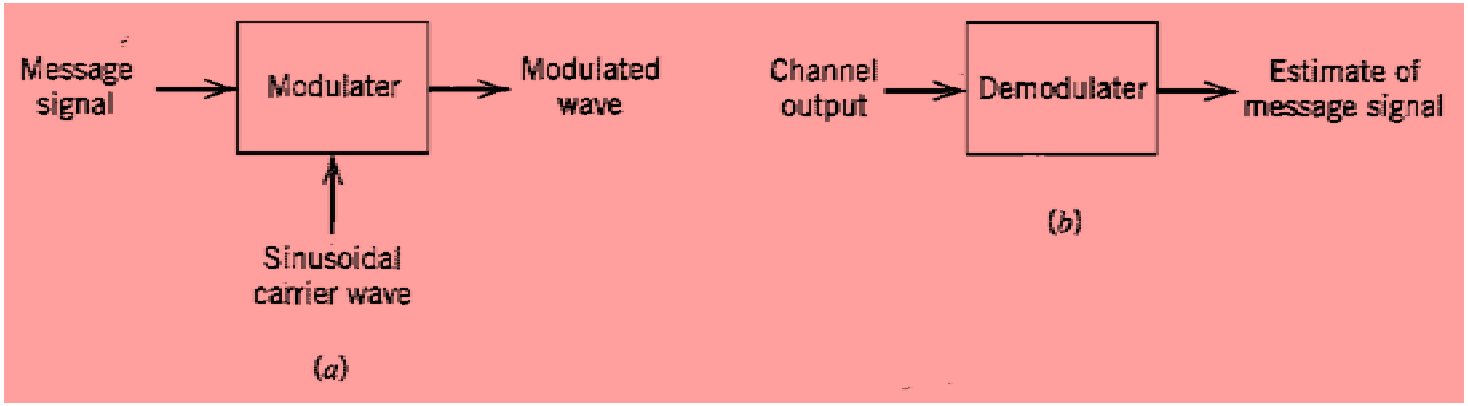
- Introduction to Modulation
  - What, why and how!
- Analog Modulation/Demodulation: AM, FM, and PM
  - DSBSC, SSB, VSB
- Superheterodyne Receiver
- Digital Modulation/Demodulation: ASK/PSK/FSK/QAM/MSK/M-Ary
- Spread Spectrum Modulation: FHSS, DSSS

Introduction

- Information-bearing signals from Tx to Rx
  - Baseband signals
  - Modulating and modulated signal
  - Demodulation

- Reasons
  - Spectrum management
  - Different Stations locating
  - Antenna Height

Introduction

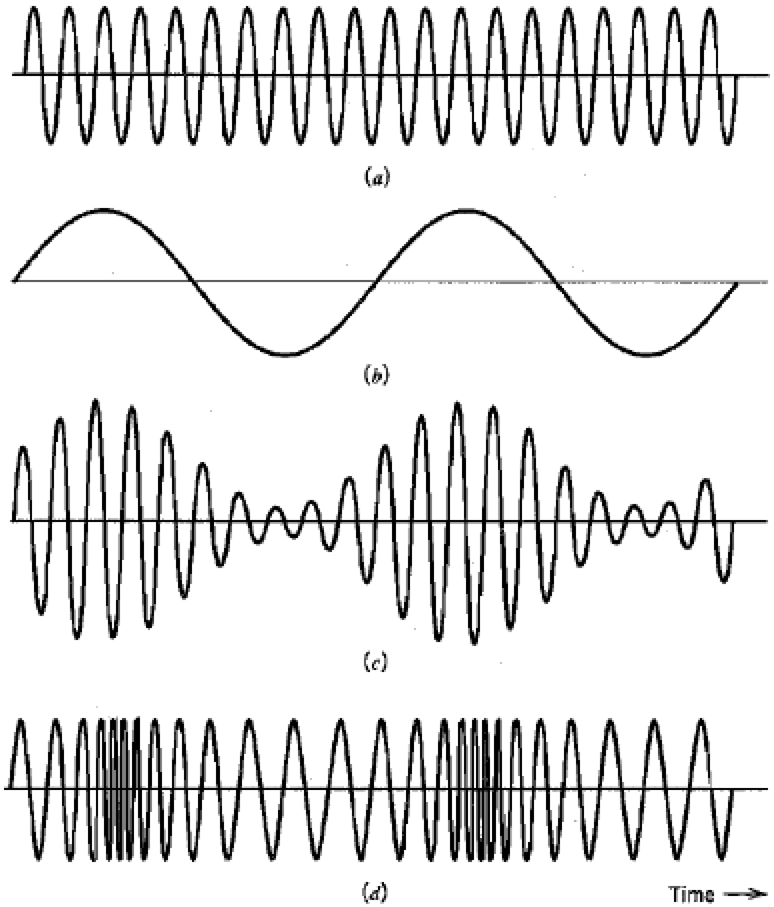


Introduction

- Continuous Modulation: Amplitude and Angle
- Example: Amplitude and frequency modulation at RHS

AM

FM

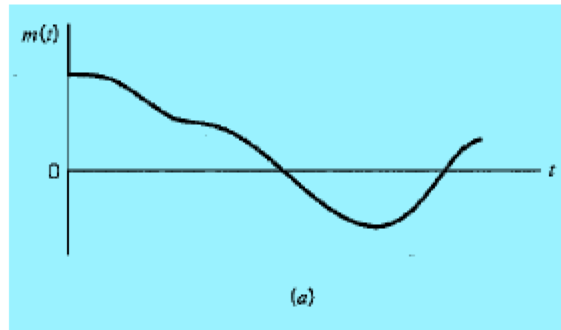


Amplitude Modulation

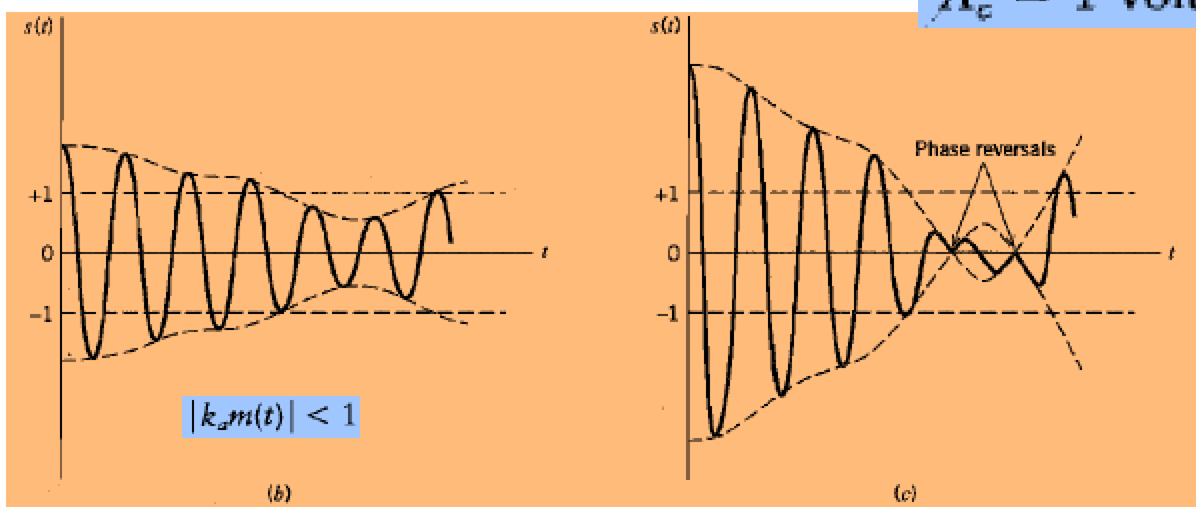
$$c(t) = A_c \cos(2\pi f_c t)$$

$$s(t) = A_c[1 + k_a m(t)] \cos(2\pi f_c t)$$

Amplitude sensitivity; ?unit



$A_c = 1$ volt.



Conditions for AM

The amplitude of $k_a m(t)$ is always less than unity, that is,

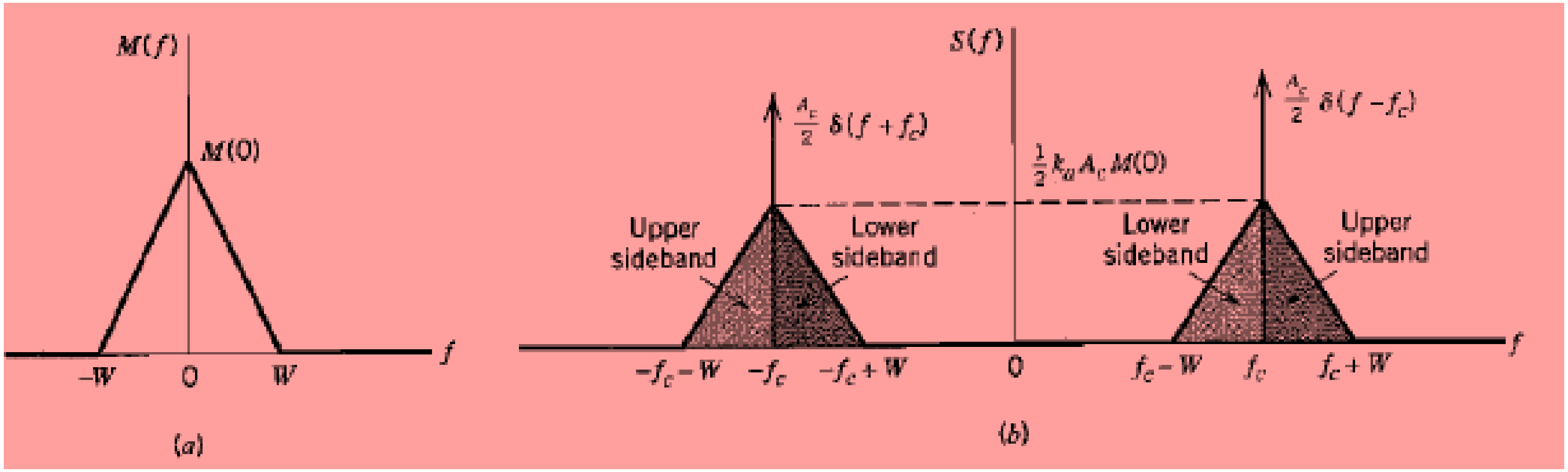
$$|k_a m(t)| < 1 \quad \text{for all } t$$

The carrier frequency f_c is much greater than the highest frequency component W of the message signal $m(t)$, that is

$$f_c \gg W \tag{2.4}$$

Spectrum Analysis in AM

$$S(f) = \frac{A_c}{2}[\delta(f - f_c) + \delta(f + f_c)] + \frac{k_a A_c}{2}[M(f - f_c) + M(f + f_c)]$$

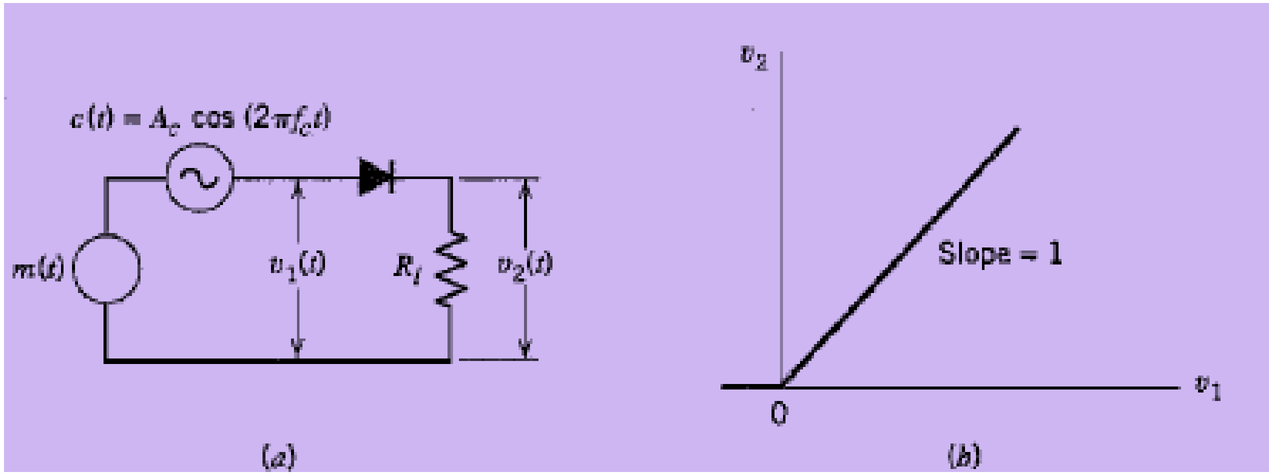


Spectrum Analysis of AM

- ❑ Realization of negative frequency!
- ❑ Must not be overlapped in LSB and USB
- ❑ Tx BW is twice the message BW

Virtues and Limitations of AM

- Oldest method and simplicity of implementation



Virtues and Limitations of AM

- ❑ Wasteful of power
- ❑ Wasteful of BW
- ❑ Overcome: DSB-SC, SSB w. system complexity
- ❑ ?Trade-off>>Linear modulation!

Single-tone Modulation

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

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

Modulation Factor

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

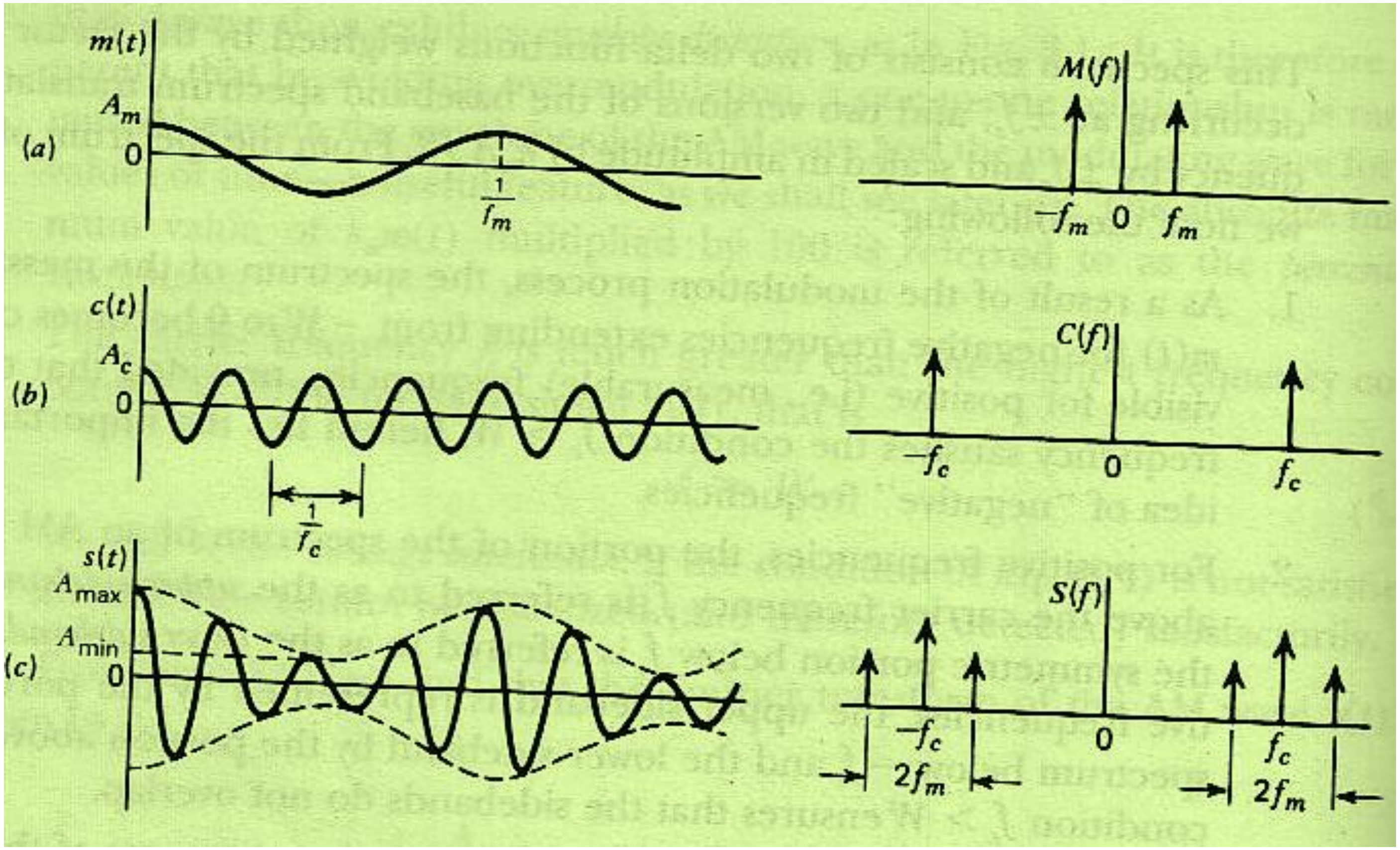
$$s(t) = A_c \cos(2\pi f_c t) + \tfrac{1}{2}\mu A_c \cos[2\pi(f_c + f_m)t] + \tfrac{1}{2}\mu A_c \cos[2\pi(f_c - f_m)t]$$

Single-tone Modulation

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

$$\begin{aligned} S(f) = {} & \tfrac{1}{2}A_c[\delta(f - f_c) + \delta(f + f_c)] \\ & + \tfrac{1}{4}\mu A_c[\delta(f - f_c - f_m) + \delta(f + f_c + f_m)] \\ & + \tfrac{1}{4}\mu A_c[\delta(f - f_c + f_m) + \delta(f + f_c - f_m)] \end{aligned}$$

Single-tone Modulation

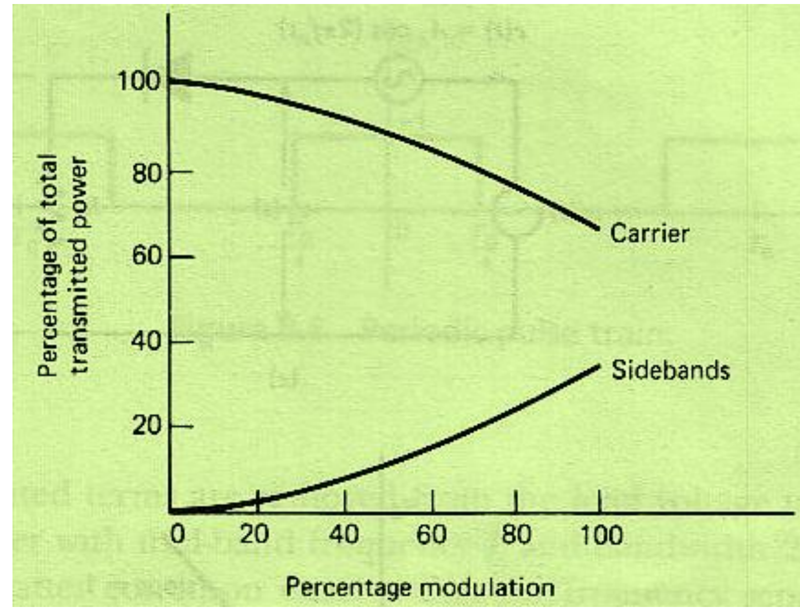


Single-tone Modulation

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

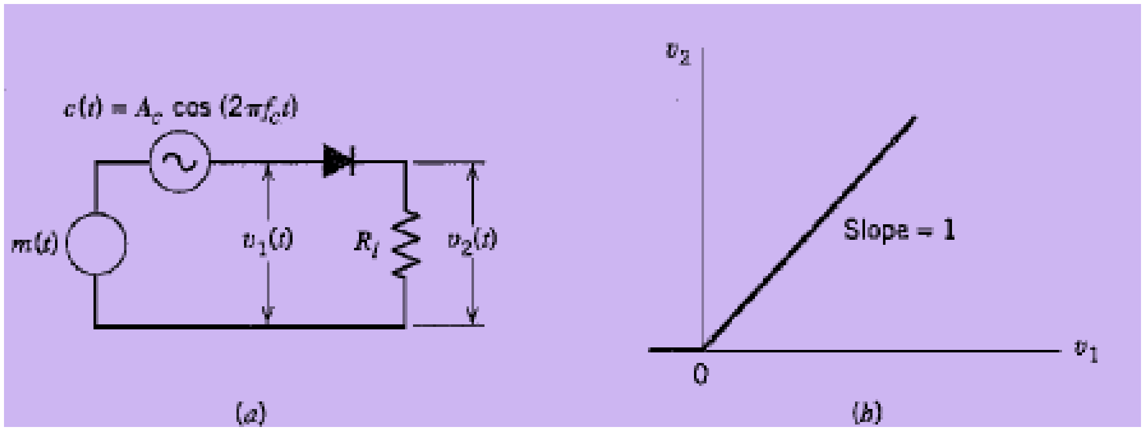
Upper side–frequency power $= \frac{1}{8}\mu^2 A_c^2$

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



- ??>> Ratio of total side-band power to the total power in the modulated wave
  - ??For 100% modulation

Switching Modulator



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

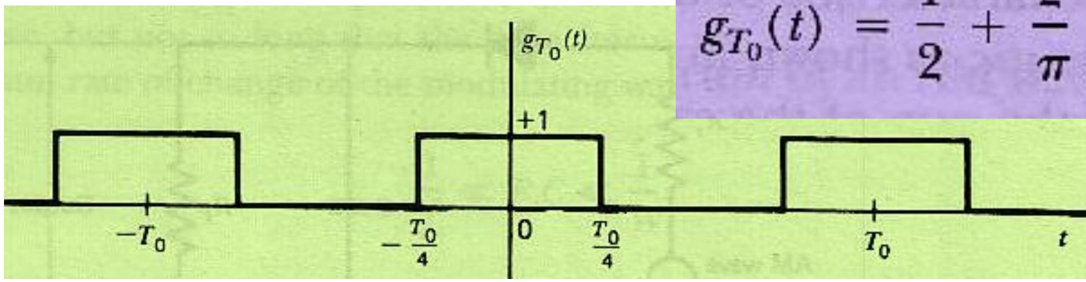
where $|m(t)| << A_c$, the resulting load voltage $v_2(t)$ is

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

Switching Modulator

$$v_2(t) \simeq [A_c \cos(2\pi f_c t) + m(t)]\, g_{T_0}(t)$$

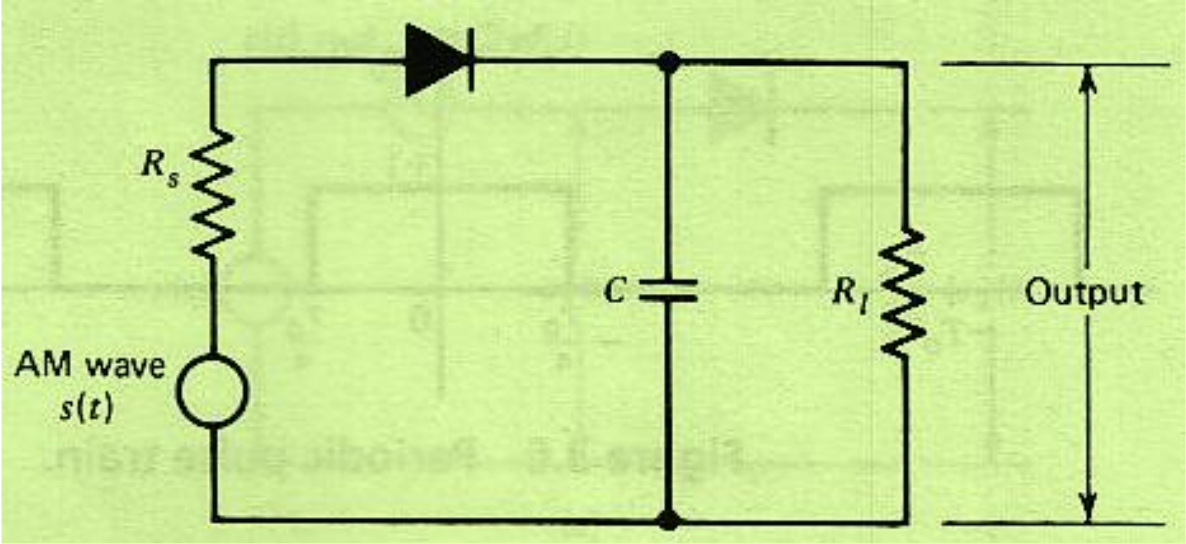
$$g_{T_0}(t) = \frac{1}{2} + \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos[2\pi f_c t(2n-1)]$$



$$\frac{A_c}{2}\left[1 + \frac{4}{\pi A_c} m(t)\right] \cos(2\pi f_c t)$$

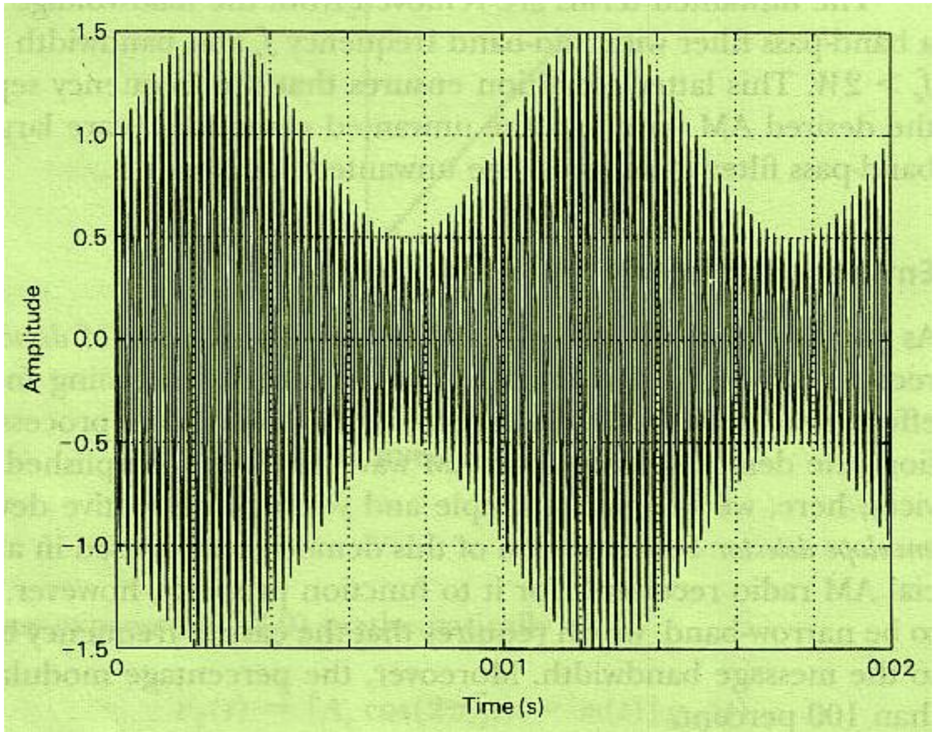
Unwanted components, the spectrum of which contains delta functions at $0, \pm 2f_c, \pm 4f_c$, and so on, and which occupy frequency intervals of width $2W$ centered at $0, \pm 3f_c, \pm 5f_c$, and so on, where W is the message bandwidth.

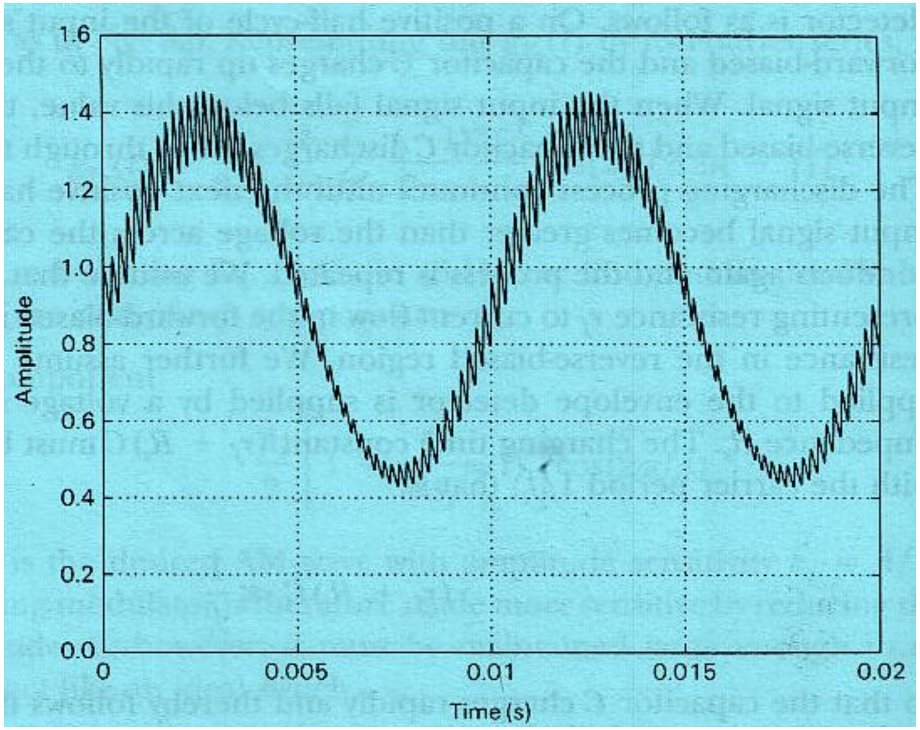
Envelope Detector



$$(r_f + R_s)C \ll \frac{1}{f_c}$$

Envelope Detector



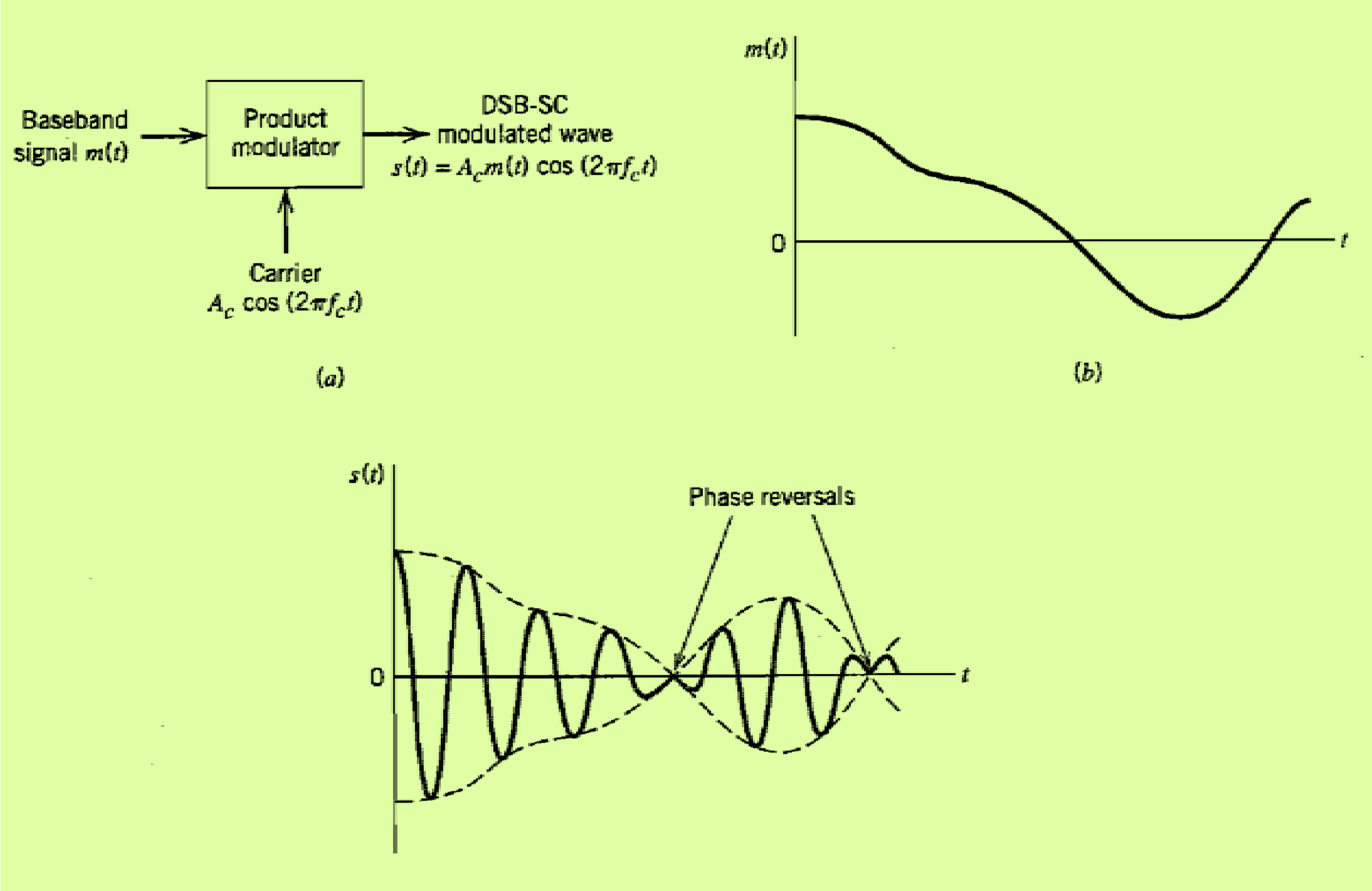


$$\frac{1}{f_c} \ll R_l C \ll \frac{1}{W}$$

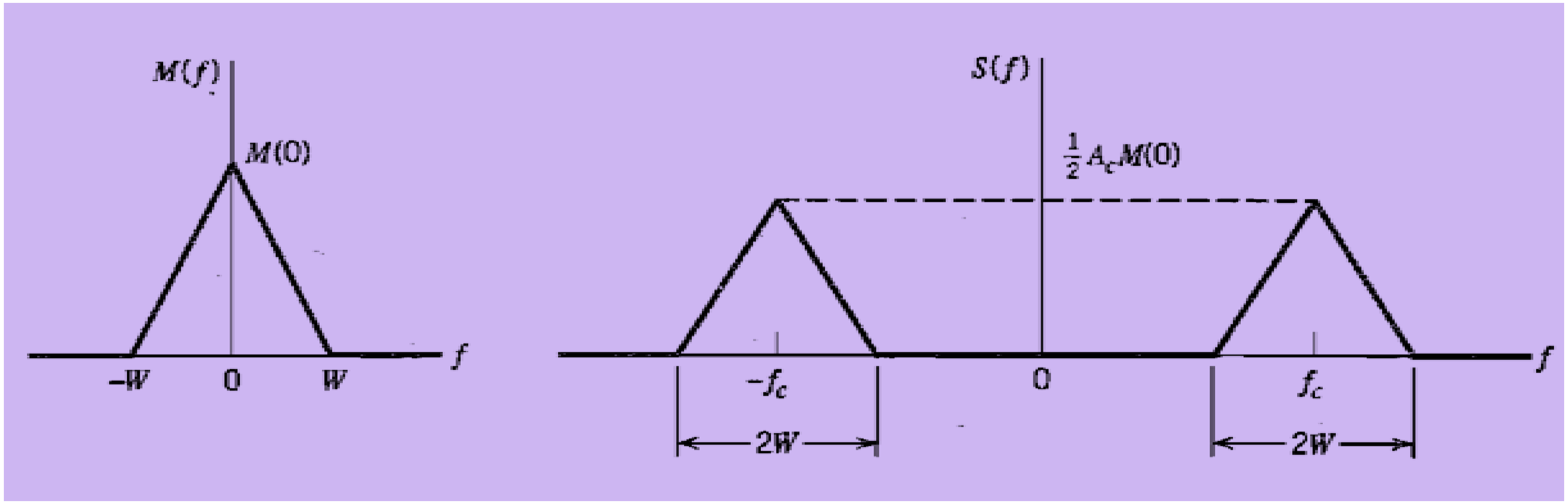
Envelope Detector

Source resistance	$R_s = 75\ \Omega$
Forward resistance	$r_f = 25\ \Omega$
Load resistance	$R_l = 10\ k\Omega$
Capacitance	$C = 0.01\ \mu F$
Message bandwidth	$W = 1\ kHz$
Carrier frequency	$f_c = 20\ kHz$

DSB-SC Modulation

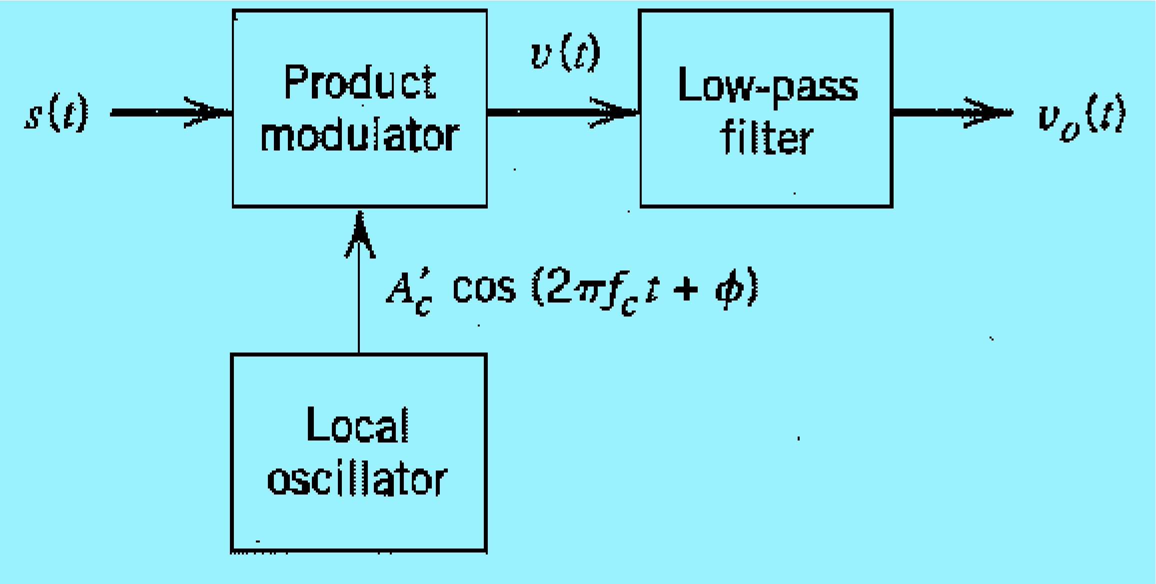


DSB-SC Modulation



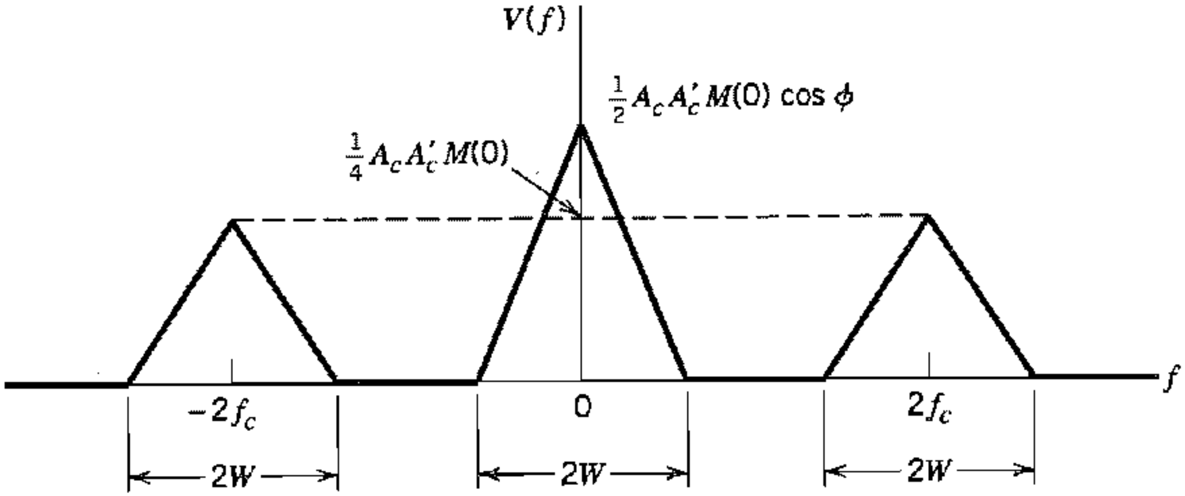
$$S(f) = \frac{1}{2} A_c [M(f - f_c) + M(f + f_c)]$$

Coherent Detection



$$
\begin{aligned}
v(t) &= A_c' \cos(2\pi f_c t + \phi) s(t) \\
&= A_c A_c' \cos(2\pi f_c t) \cos(2\pi f_c t + \phi) m(t) \\
&= \frac{1}{2} A_c A_c' \cos(4\pi f_c t + \phi) m(t) + \frac{1}{2} A_c A_c' \cos\phi \, m(t)
\end{aligned}
$$

Coherent Detection



- Cut-off frequency > W but less than $2f_c$-W

$$v_o(t) = \frac{1}{2} A_c A_c' \cos\phi \, m(t)$$

- Quadrature null effect of coherent detector? >> perfect Synch.

Angle Modulation

$$s(t) = A_c \cos[\theta_i(t)]$$

$$f_{\Delta t}(t) = \frac{\theta_i(t + \Delta t) - \theta_i(t)}{2\pi \Delta t}$$

$$\begin{aligned} f_i(t) &= \lim_{\Delta t \to 0} f_{\Delta t}(t) \\ &= \lim_{\Delta t \to 0} \left[\frac{\theta_i(t + \Delta t) - \theta_i(t)}{2\pi \Delta t} \right] \\ &= \frac{1}{2\pi} \frac{d\theta_i(t)}{dt} \end{aligned}$$

UM

$$\theta_i(t) = 2\pi f_c t + \phi_c$$

PM

$$\theta_i(t) = 2\pi f_c t + k_p m(t)$$

$$s(t) = A_c \cos[2\pi f_c t + k_p m(t)]$$

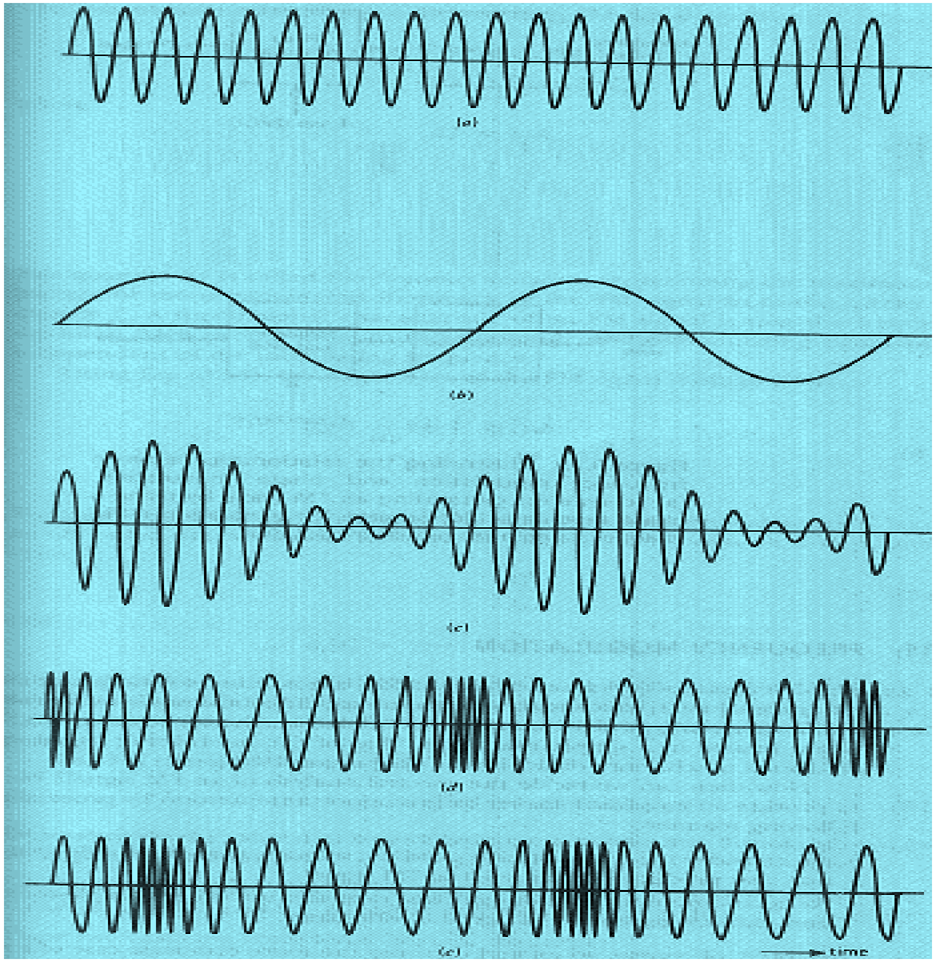
FM

$$f_i(t) = f_c + k_f m(t)$$

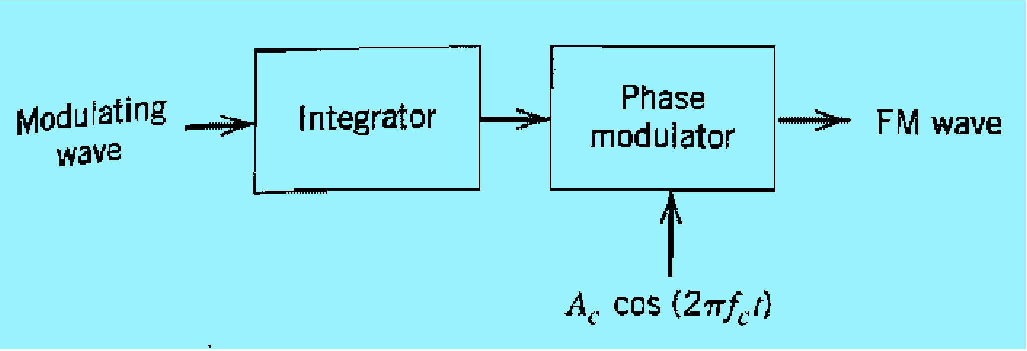
$$\theta_i(t) = 2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau$$

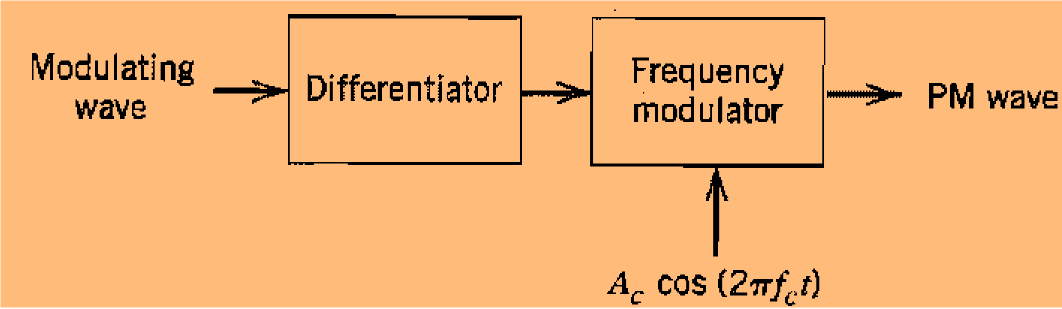
$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau\right]$$

Angle Modulation



Angle Modulation





Frequency Modulation

Spectral Analysis: Difficult compared to simple AM

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

The instantaneous frequency of the resulting FM signal equals

$$f_i(t) = f_c + k_f A_m \cos(2\pi f_m t)$$
$$= f_c + \Delta f \cos(2\pi f_m t)$$

where

$$\Delta f = k_f A_m$$

Frequency deviation

Proportional to amplitude of m(t) and independent of f_m

Frequency Modulation

$$\theta_i(t) = 2\pi \int_0^t f_i(\tau)\, d\tau$$

$$= 2\pi f_c t + \frac{\Delta f}{f_m} \sin(2\pi f_m t)$$

Modulation index

$$\beta = \frac{\Delta f}{f_m}$$

Phase deviation

$$\theta_i(t) = 2\pi f_c t + \beta \sin(2\pi f_m t)$$

$$s(t) = A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$$

NB or WB

Frequency Modulation

NB Frequency Modulation

$$s(t) = A_c \cos(2\pi f_c t) \cos[\beta \sin(2\pi f_m t)] - A_c \sin(2\pi f_c t) \sin[\beta \sin(2\pi f_m t)]$$

$$\cos[\beta \sin(2\pi f_m t)] \simeq 1$$

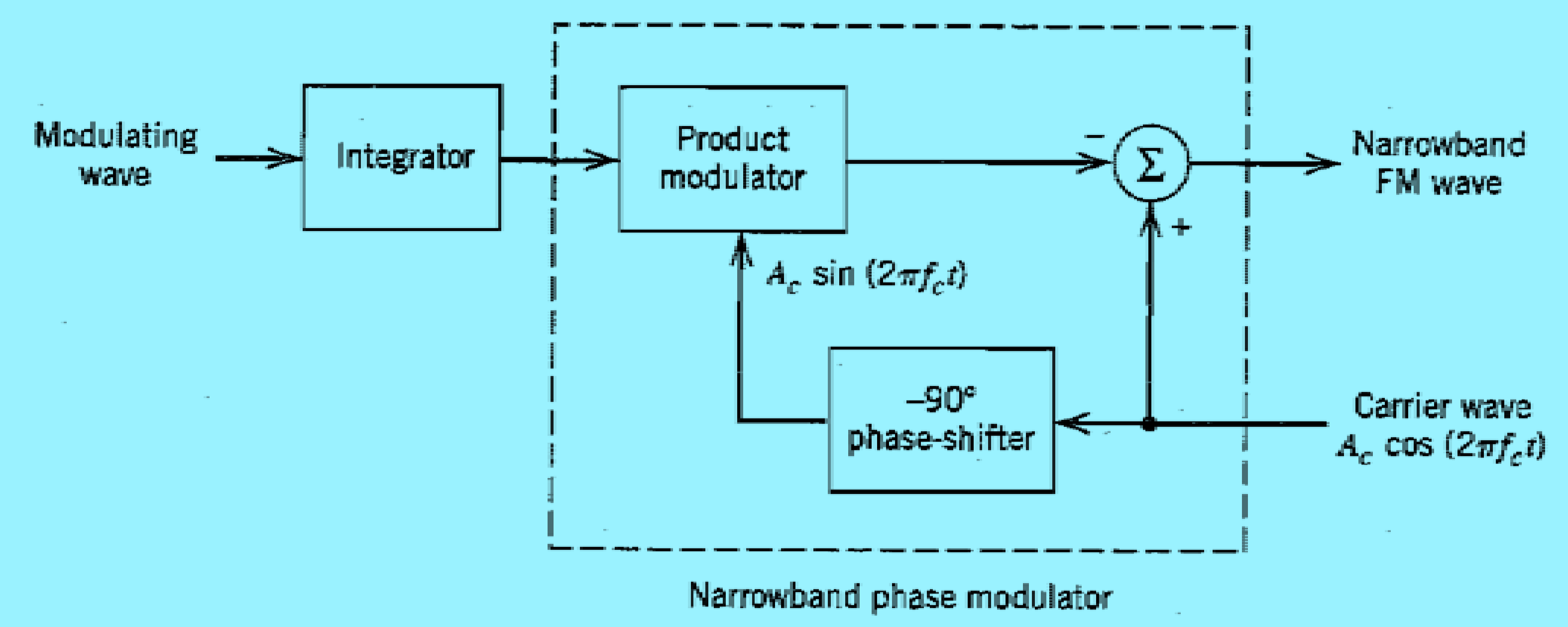
and

$$\sin[\beta \sin(2\pi f_m t)] \simeq \beta \sin(2\pi f_m t)$$

Hence, Equation (2.34) simplifies to

$$s(t) \simeq A_c \cos(2\pi f_c t) - \beta A_c \sin(2\pi f_c t) \sin(2\pi f_m t)$$

Frequency Modulation



1. The envelope contains a *residual* amplitude modulation and, therefore, varies with time.
2. For a sinusoidal modulating wave, the angle $\theta_i(t)$ contains *harmonic distortion* in the form of third- and higher-order harmonics of the modulation frequency f_m.

Modulation index < 0.3 rad

Frequency Modulation

$$s(t) \simeq A_c \cos(2\pi f_c t) + \frac{1}{2}\beta A_c\{\cos[2\pi(f_c + f_m)t] - \cos[2\pi(f_c - f_m)t]\}$$

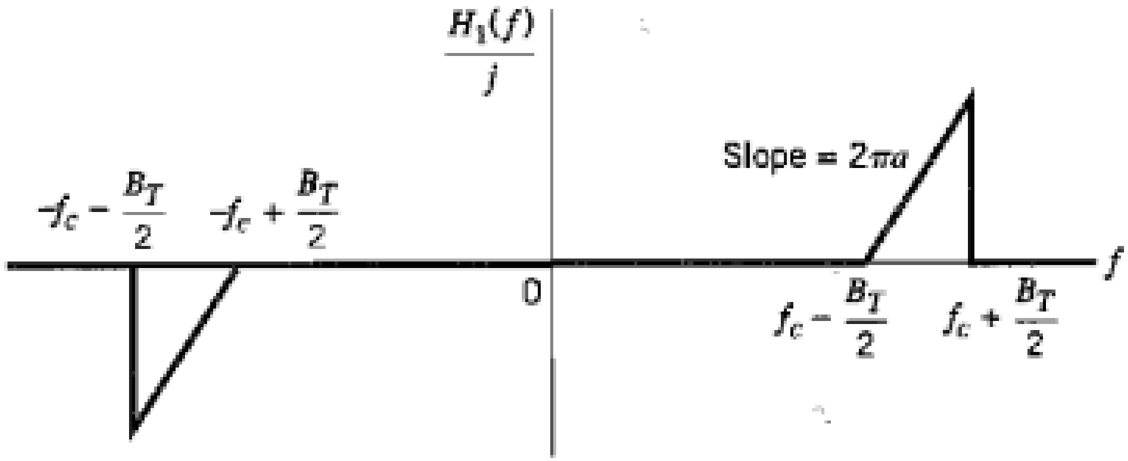
$$s_{AM}(t) = A_c \cos(2\pi f_c t) + \frac{1}{2}\mu A_c\{\cos[2\pi(f_c + f_m)t] + \cos[2\pi(f_c - f_m)t]\}$$

Difference is algebraic sign of LSB is reversed, so the Tx BW is the same as that if AM ($2f_m$)

Demodulation of FM Signals

Using Frequency Discriminator Slope Circuit followed by Envelope detector

$$H_1(f) = \begin{cases} j2\pi a\left(f - f_c + \dfrac{B_T}{2}\right), & f_c - \dfrac{B_T}{2} \le f \le f_c + \dfrac{B_T}{2} \\ j2\pi a\left(f + f_c - \dfrac{B_T}{2}\right), & -f_c - \dfrac{B_T}{2} \le f \le -f_c + \dfrac{B_T}{2} \\ 0, & \text{elsewhere} \end{cases}$$



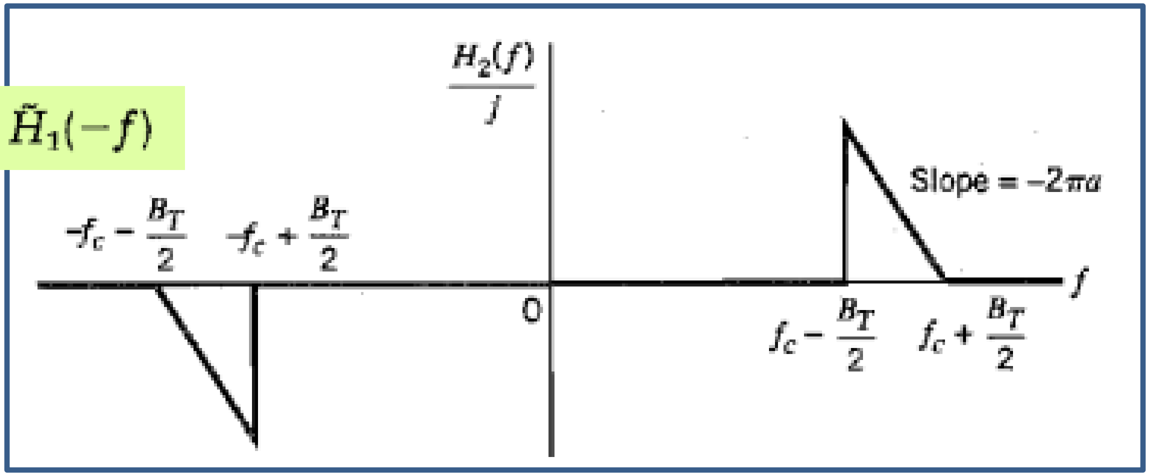
Demodulation of FM Signals

$$s_1(t) = \text{Re}[\tilde{s}_1(t)\exp(j2\pi f_c t)]$$
$$= \pi B_T a A_c\left[1 + \frac{2k_f}{B_T} m(t)\right]\cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\,d\tau + \frac{\pi}{2}\right]$$

$$|\tilde{s}_1(t)| = \pi B_T a A_c\left[1 + \frac{2k_f}{B_T} m(t)\right]$$

$$\left|\frac{2k_f}{B_T} m(t)\right| < 1 \quad \text{for all } t$$

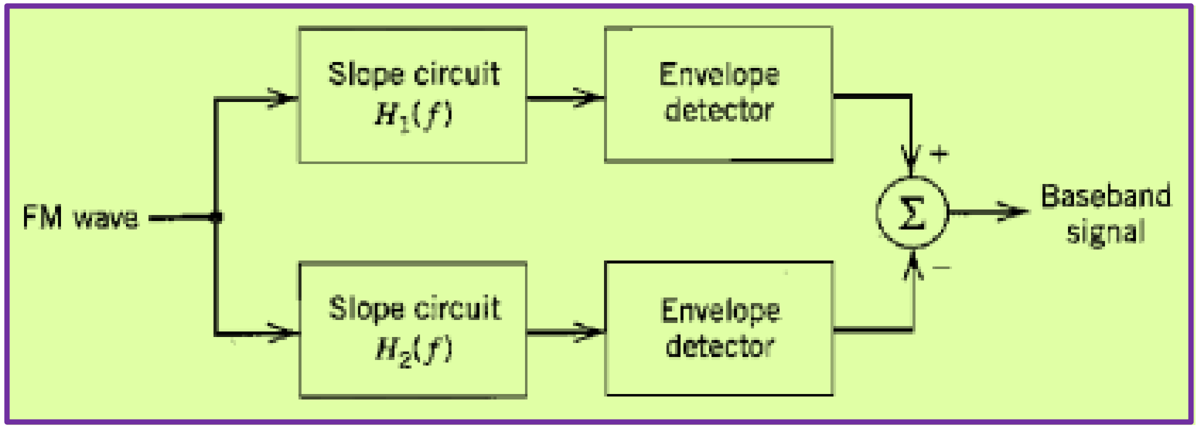
$$\tilde{H}_2(f) = \tilde{H}_1(-f)$$



Demodulation of FM Signals

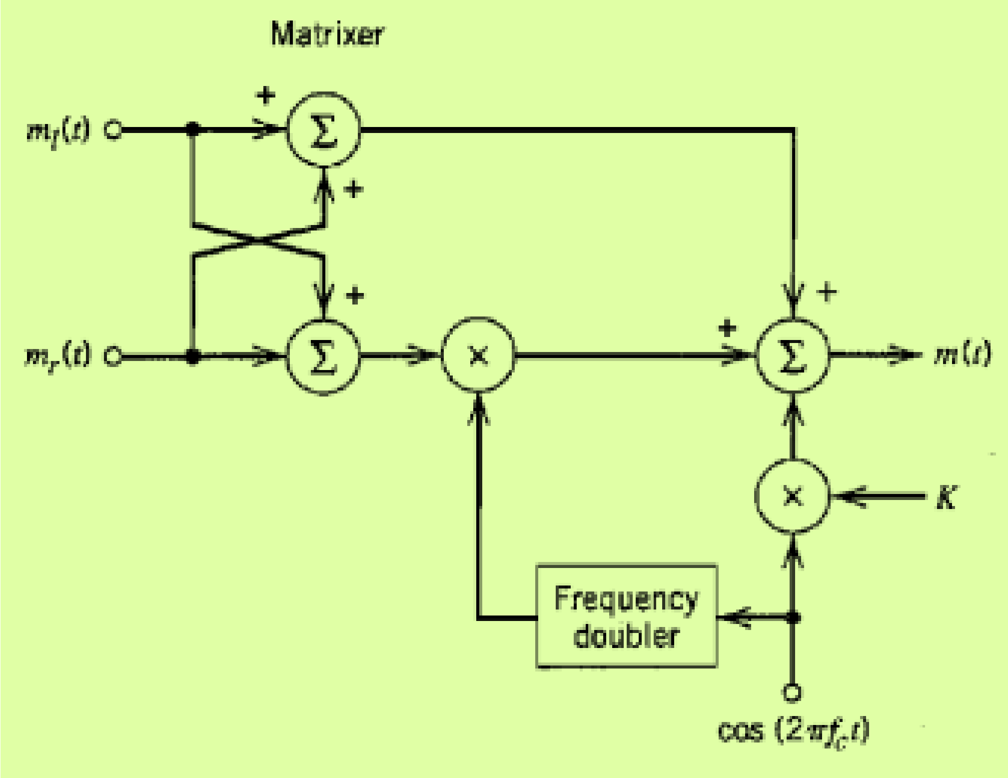
$$|\tilde{s}_2(t)| = \pi B_T a A_c \left[1 - \frac{2k_f}{B_T} m(t)\right]$$

$$s_o(t) = |\tilde{s}_1(t)| - |\tilde{s}_2(t)| = 4\pi k_f a A_c m(t)$$

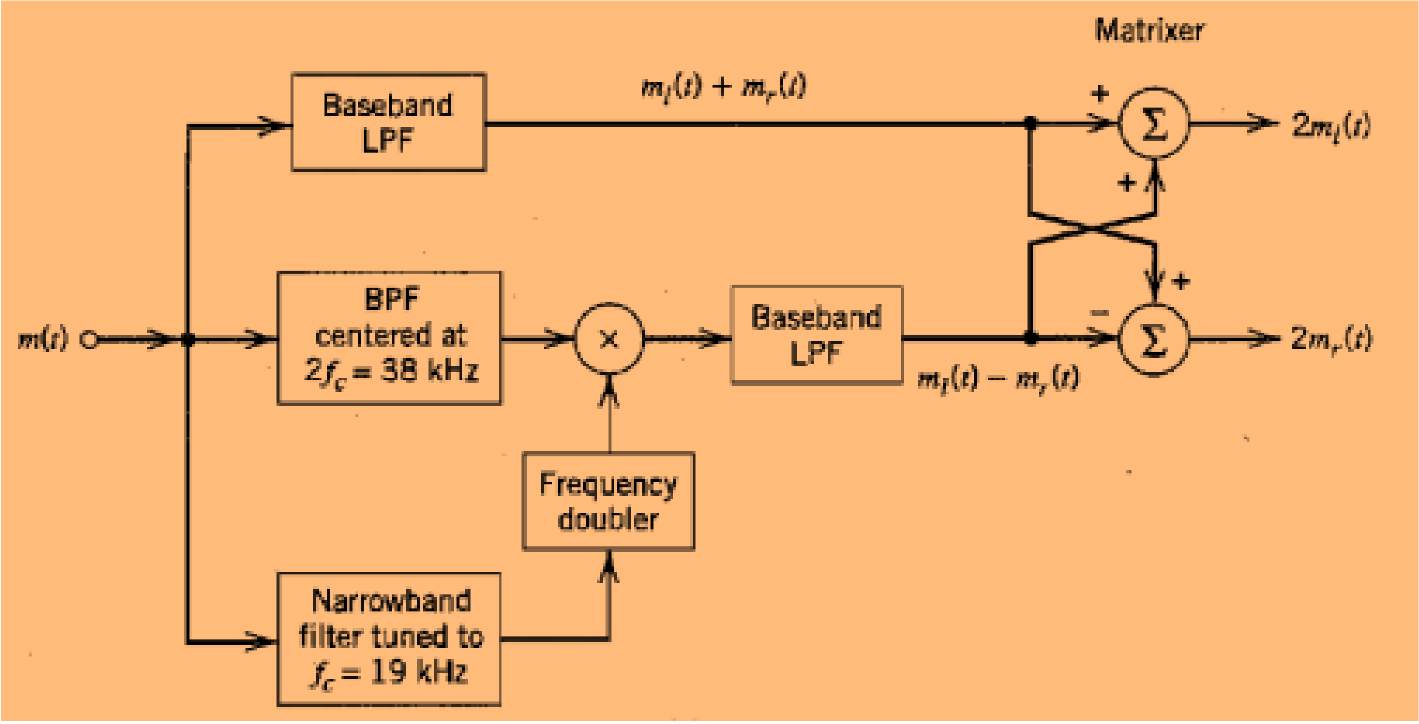


Balanced Frequency Discriminator

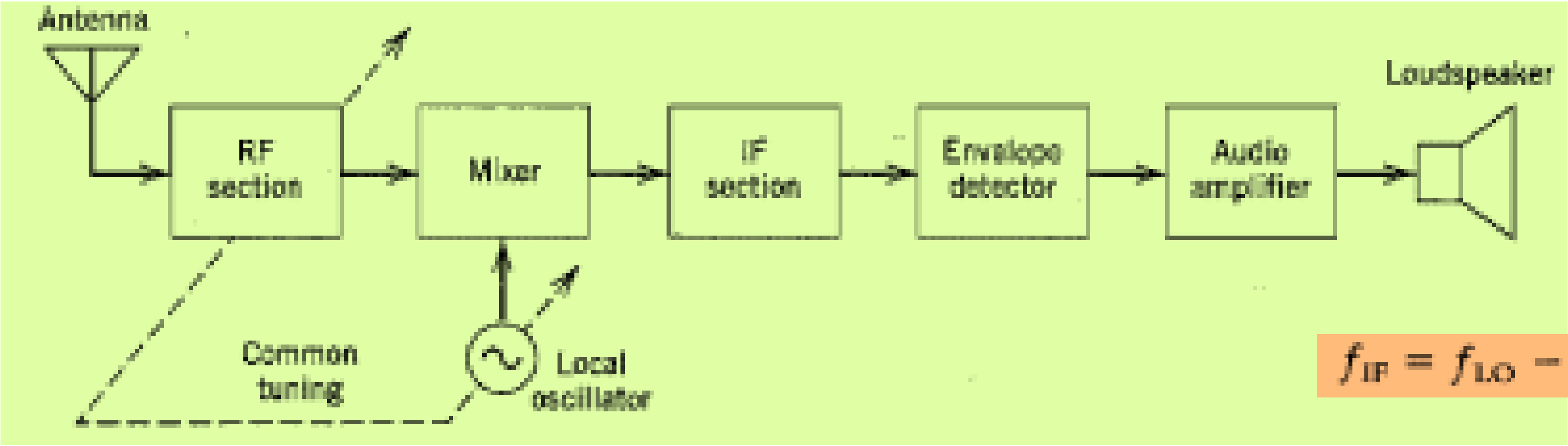
FM Stereo Multiplexing



FM Stereo Multiplexing



Superheterodyne Receiver



$$f_{IF} = f_{LO} - f_{RF}$$

Disadvantage: Image Frequency

Q & A