# 8.0 Communication Systems

- Modulation: embedding an information-bearing signal into a second signal

  e.g. $x(t)$ : information-bearing signal

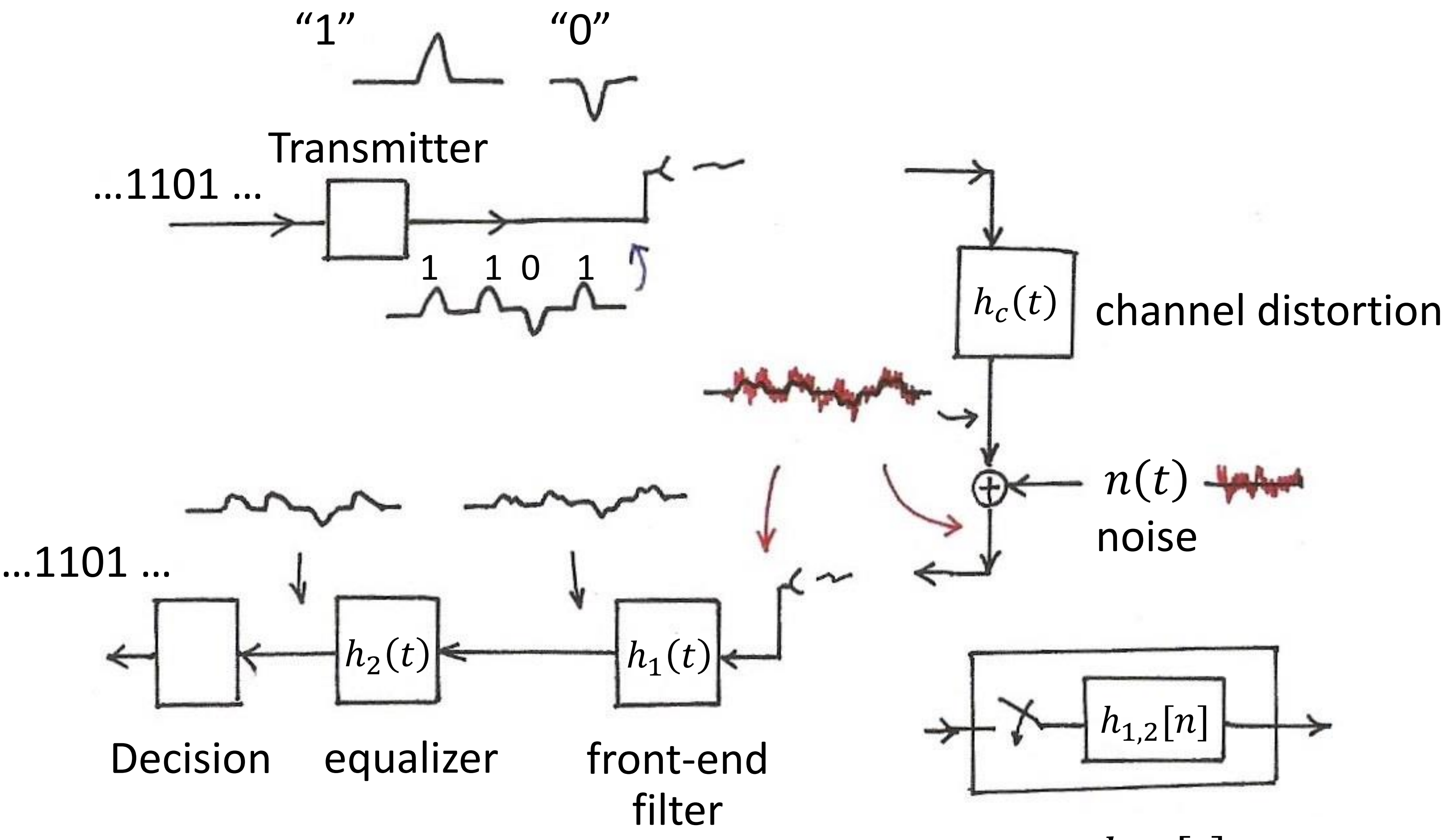
  $c(t)$ : carrier signal

  $y(t) = x(t)c(t)$ : modulated signal

  – purposes :
    - locate the signal on the right band of the spectrum
    - multiplexing : simultaneous transmission of more than one signals over the same channel
    - resistance to noise and disturbance

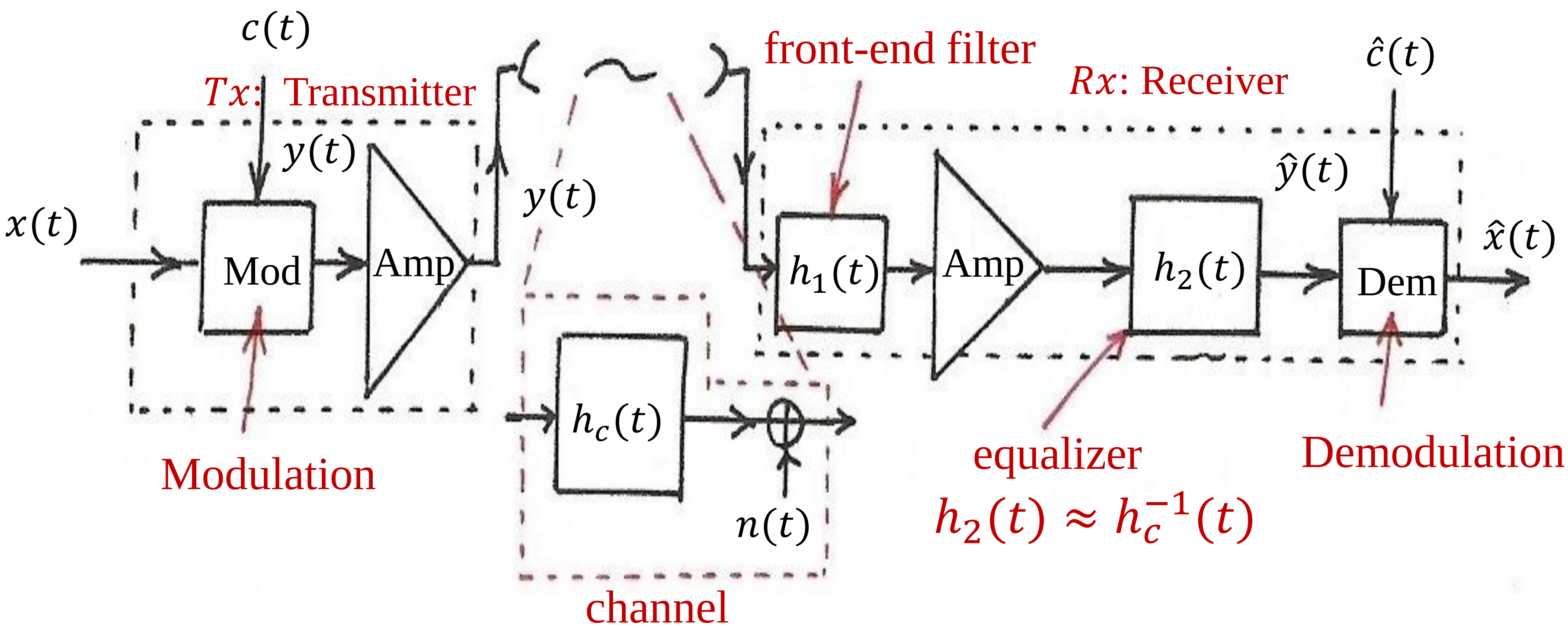
  – demodulation : extracting the information-bearing signal from the modulated signal

# Data Transmission (p.111 of 2.0)




$$h_2[t] \approx h_c^{-1}[t]$$

# Communication




# Modulation Property

$$\underbrace{\boxed{e^{j\omega_0 t}}}_{c(t)} \cdot x(t) \overset{F}{\leftrightarrow} X(j(\omega - \omega_0))$$

# *8.1 Amplitude Modulation (AM) and Frequency-Division Multiplexing (FDM)*

## Complex Exponential Carrier

- Modulation

$$c(t) = e^{j(\omega_c t + \theta_c)}, \ \omega_c : \text{carrier frequency}$$

$$x(t) : \text{information-bearing signal}$$

$$y(t) = x(t) e^{j(\omega_c t + \theta_c)}$$

$$C(j\omega) = 2\pi\delta(\omega - \omega_c), \quad \theta_c = 0$$

$$Y(j\omega) = X(j\omega - j\omega_c)$$

- Demodulation

$$z(t) = y(t) e^{-j(\omega_c t + \theta_c)} = x(t)$$

*See Fig. 8.1, p.584 of text*

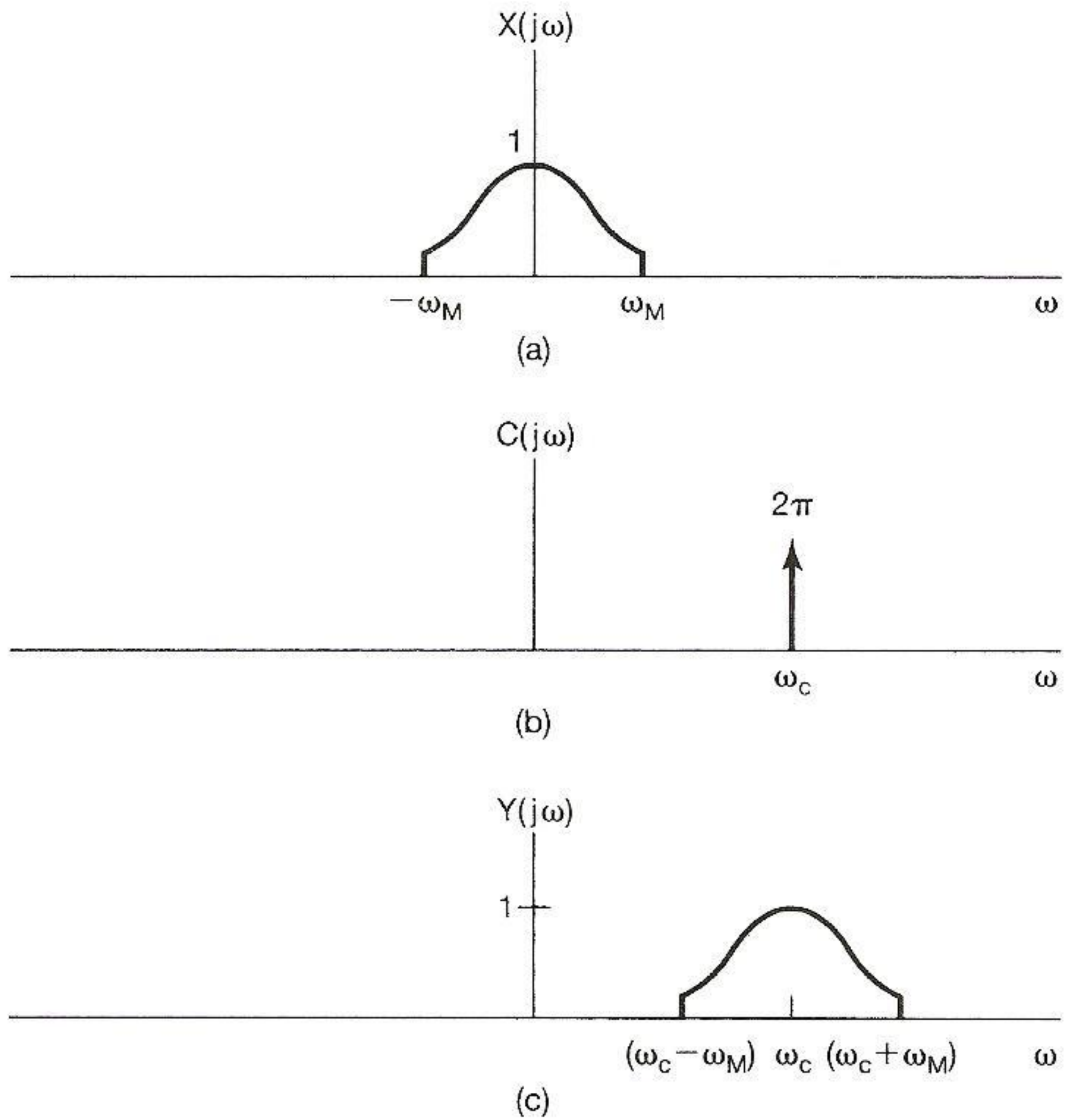



**Figure 8.1** Effect in the frequency domain of amplitude modulation with a complex exponential carrier: (a) spectrum of modulating signal $x(t)$; (b) spectrum of carrier $c(t) = e^{j\omega_c t}$; (c) spectrum of amplitude-modulated signal $y(t) = x(t)e^{j\omega_c t}$.

# Sinusoidal Carrier

- Modulation

$$c(t) = \cos(\omega_c t + \theta_c)$$

$$y(t) = x(t)\cos(\omega_c t + \theta_c)$$

$$C(j\omega) = \pi[\delta(\omega - \omega_c) + \delta(\omega + \omega_c)], \ \theta_c = 0$$

$$Y(j\omega) = \frac{1}{2}[X(j\omega - j\omega_c) + X(j\omega + j\omega_c)]$$

*See Fig. 8.4, p.586 of text*

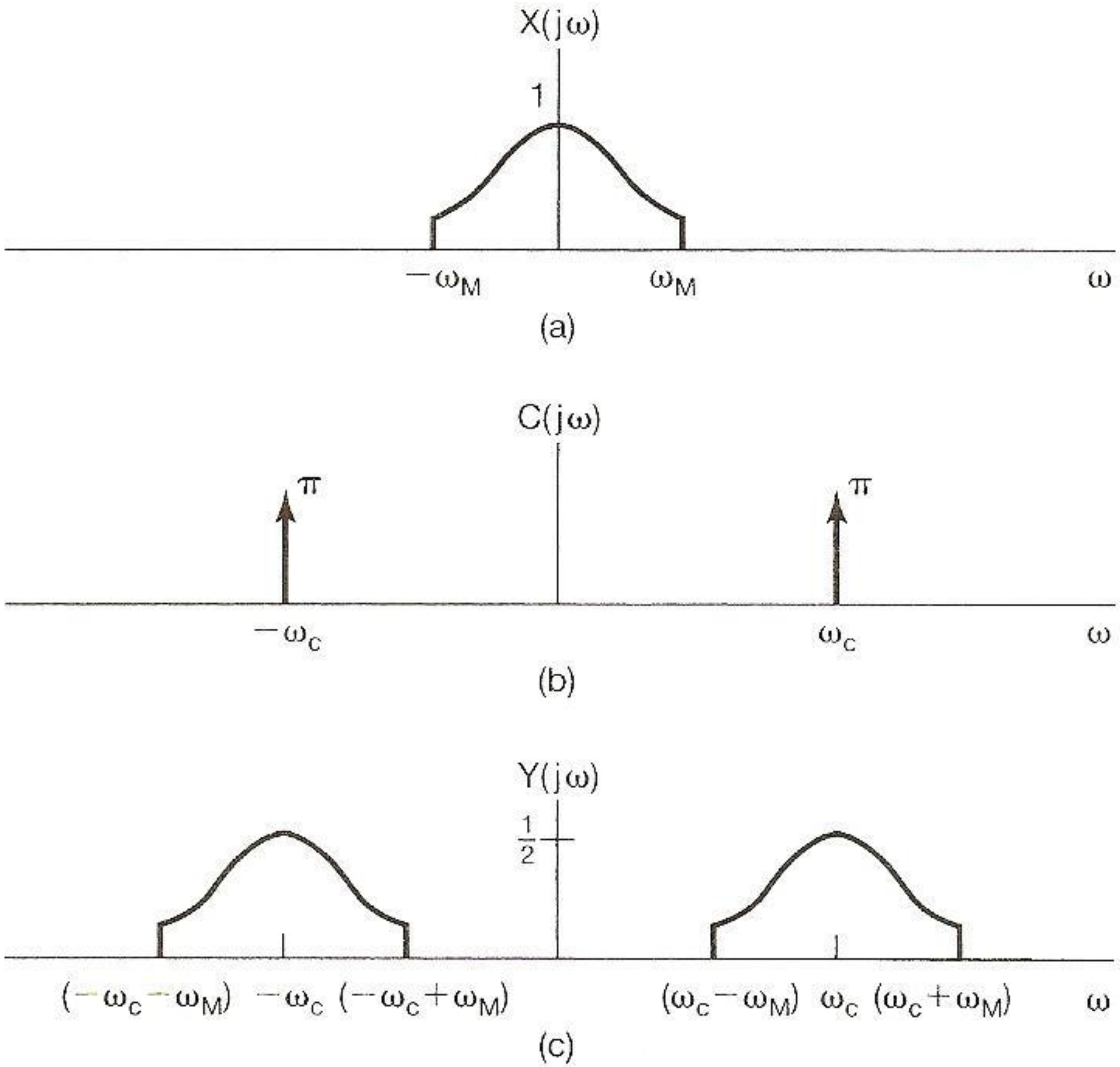



**Figure 8.4** Effect in the frequency domain of amplitude modulation with a sinusoidal carrier: (a) spectrum of modulating signal $x(t)$; (b) spectrum of carrier $c(t) = \cos\omega_c t$; (c) spectrum of amplitude-modulated signal.

# Sinusoidal Carrier

- Demodulation
  - Synchronous demodulation (detection)

$$z(t) = y(t)\cos(\omega_c t + \theta_c)$$

$$z(t) = x(t)\cos^2 \omega_c t\,,\ \theta_c = 0$$

$$= \frac{1}{2}x(t)[1 + \cos 2\omega_c t]$$

*See Fig. 8.6, 8.8, p.588, 589 of text*

A lowpass filter gives $x(t)$

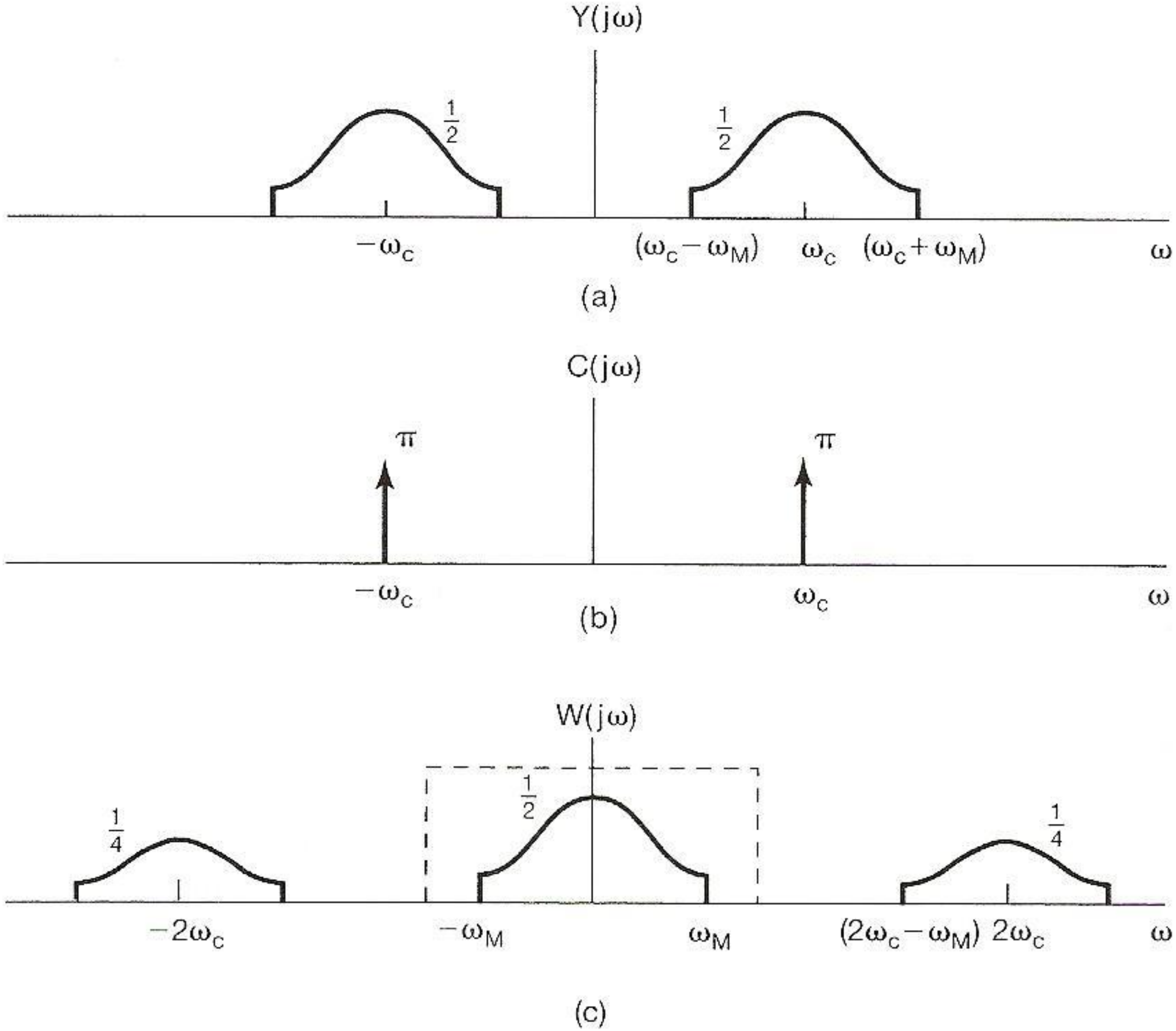



**Figure 8.6** Demodulation of an amplitude-modulated signal with a sinusoidal carrier: (a) spectrum of modulated signal; (b) spectrum of carrier signal; (c) spectrum of modulated signal multiplied by the carrier. The dashed line indicates the frequency response of a lowpass filter used to extract the demodulated signal.

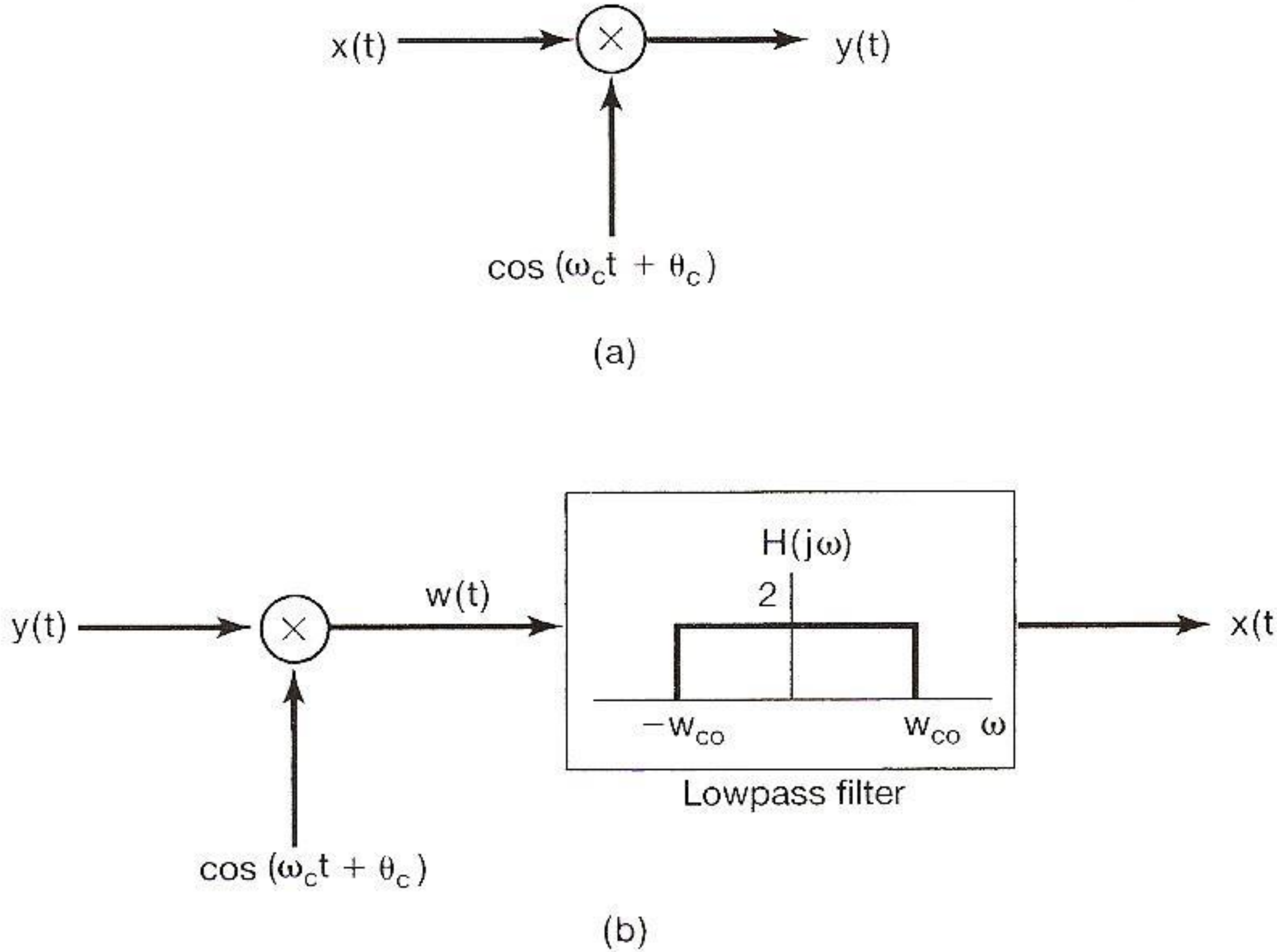



**Figure 8.8** Amplitude modulation and demodulation with a sinusoidal carrier: (a) modulation system; (b) demodulation system. The lowpass filter cutoff frequency $w_{co}$ is greater than $\omega_M$ and less than $2\omega_c - \omega_M$.

# Sinusoidal Carrier

- Demodulation
  - Synchronous demodulation (detection)

    If the demodulating carrier is not in phase with the carrier

$$z(t) = x(t)\cos(\omega_c t + \theta_c)\cos(\omega_c t + \phi_c)$$

$$= \frac{1}{2}x(t)[\cos(\theta_c - \phi_c) + \cos(2\omega_c t + \theta_c + \phi_c)]$$

output signal reduced by $\cos(\theta_c - \phi_c)$
synchronization required.
phase-locked loops.

# Sinusoidal Carrier

- Demodulation
  - Asynchronous demodulation (envelope detection)

    envelope (the smooth curve connecting the peaks) carries the information, can be extracted in some other ways

$$y(t) = [A + x(t)]\cos(\omega_c t + \phi_c)$$

$A + x(t)$: always positive

*See Fig. 8.10, 8.11, p.591, 592 of text*

the carrier component consumes energy but carries no information

*See Fig. 8.14, p.593 of text*

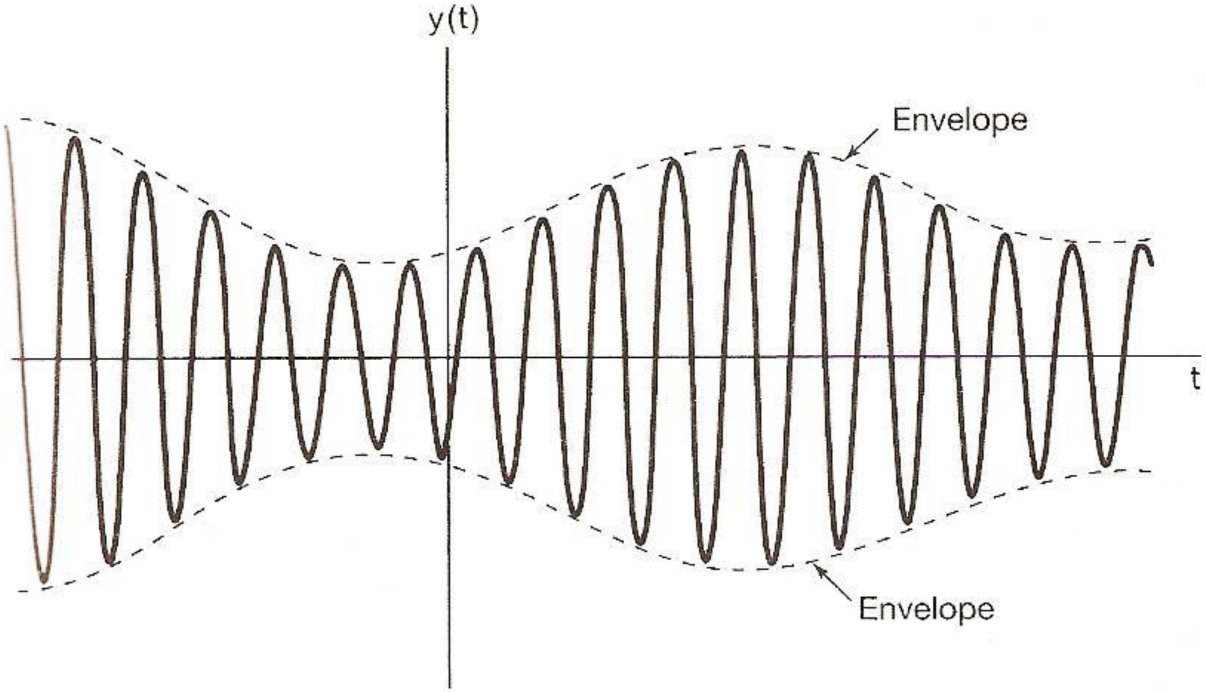
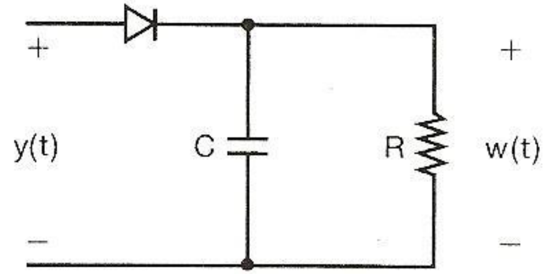
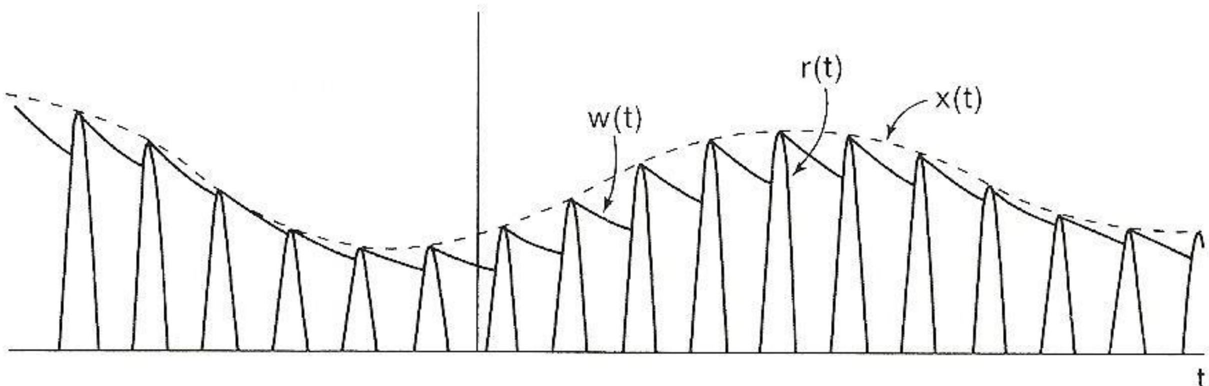



**Figure 8.10** Amplitude-modulated signal for which the modulating signal is positive. The dashed curve represents the envelope of the modulated signal.




(a)




(b)

**Figure 8.11** Demodulation by envelope detection: (a) circuit for envelope detection using half-wave rectification; (b) waveforms associated with the envelope detector in (a): $r(t)$ is the half-wave rectified signal, $x(t)$ is the true envelope, and $w(t)$ is the envelope obtained from the circuit in (a). The relationship between $x(t)$ and $w(t)$ has been exaggerated in (b) for purposes of illustration. In a practical asynchronous demodulation system, $w(t)$ would typically be a much closer approximation to $x(t)$ than depicted here.

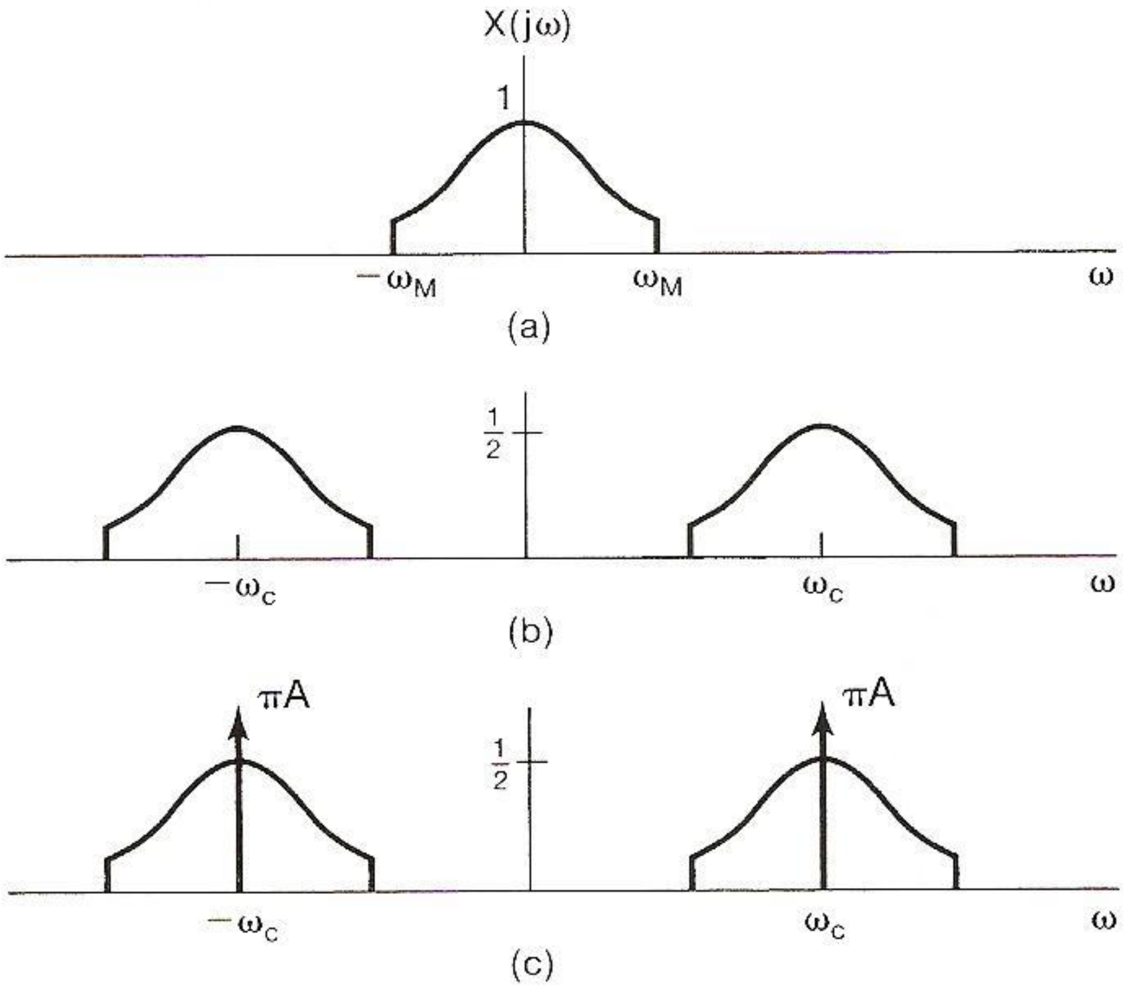



**Figure 8.14** Comparison of spectra for synchronous and asynchronous sinusoidal amplitude modulation systems: (a) spectrum of modulating signal; (b) spectrum of $x(t)\cos\omega_c t$ representing modulated signal in a synchronous system; (c) spectrum of $[x(t) + A]\cos\omega_c t$ representing modulated signal in an asynchronous system.

# Sinusoidal Carrier

- Double-sideband (DSB)/Single-sideband (SSB)

  double-sideband modulation uses twice the bandwidth

  DSB/WC (with carrier) , DSB/SC (suppressed carrier), upper-sideband, lower-sideband

  *See Figs. 8.19, 8.20, 8.21, 8.22, p.598-601 of text*

  – a $90^\circ$ phase-shift network can be used

$$H(j\omega) = \begin{cases} -j, & \omega > 0 \\ j, & \omega < 0 \end{cases}$$

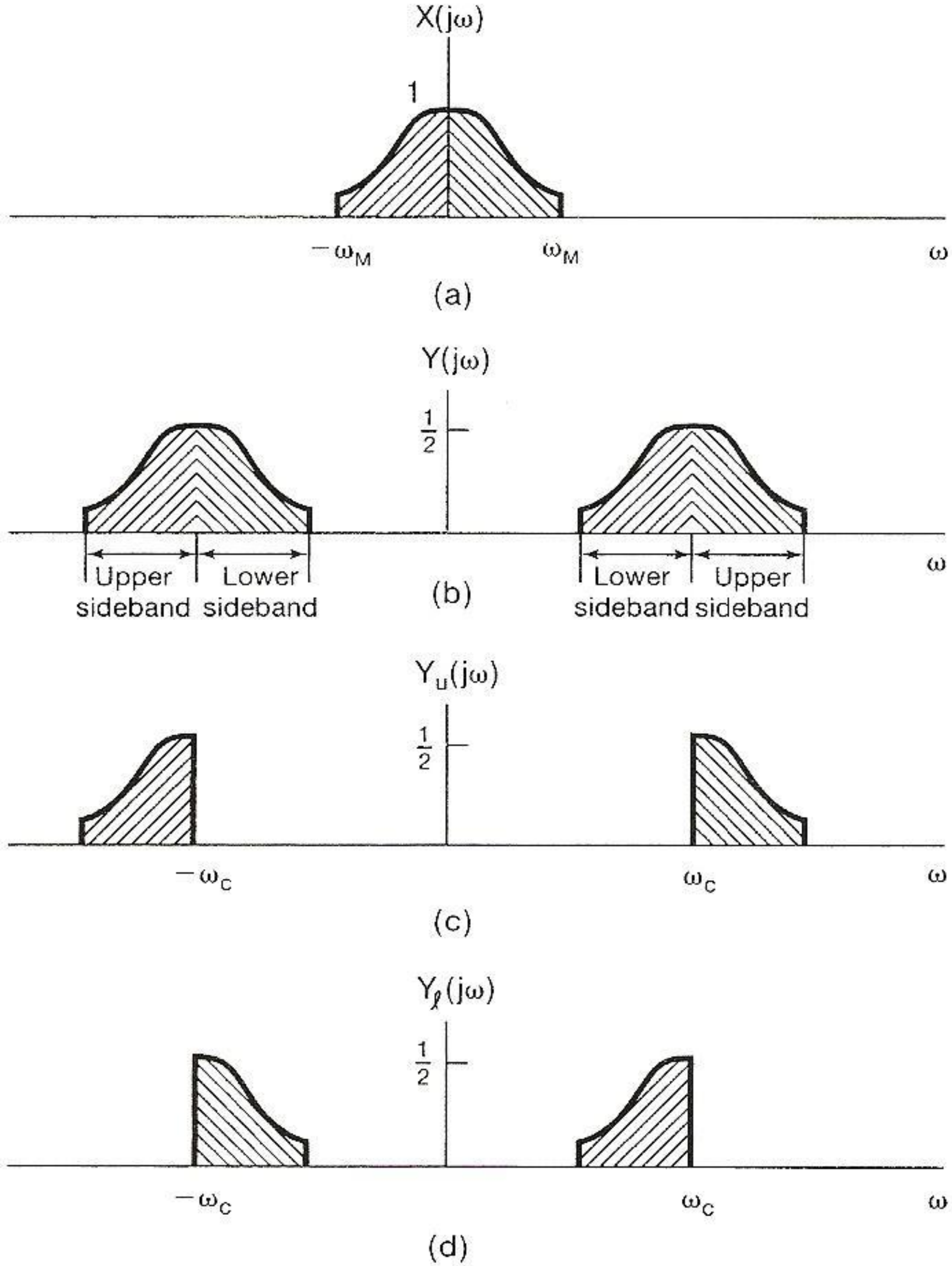



**Figure 8.19** Double- and single-sideband modulation: (a) spectrum of modulating signal; (b) spectrum after modulation with a sinusoidal carrier; (c) spectrum with only the upper sidebands; (d) spectrum with only the lower sidebands.

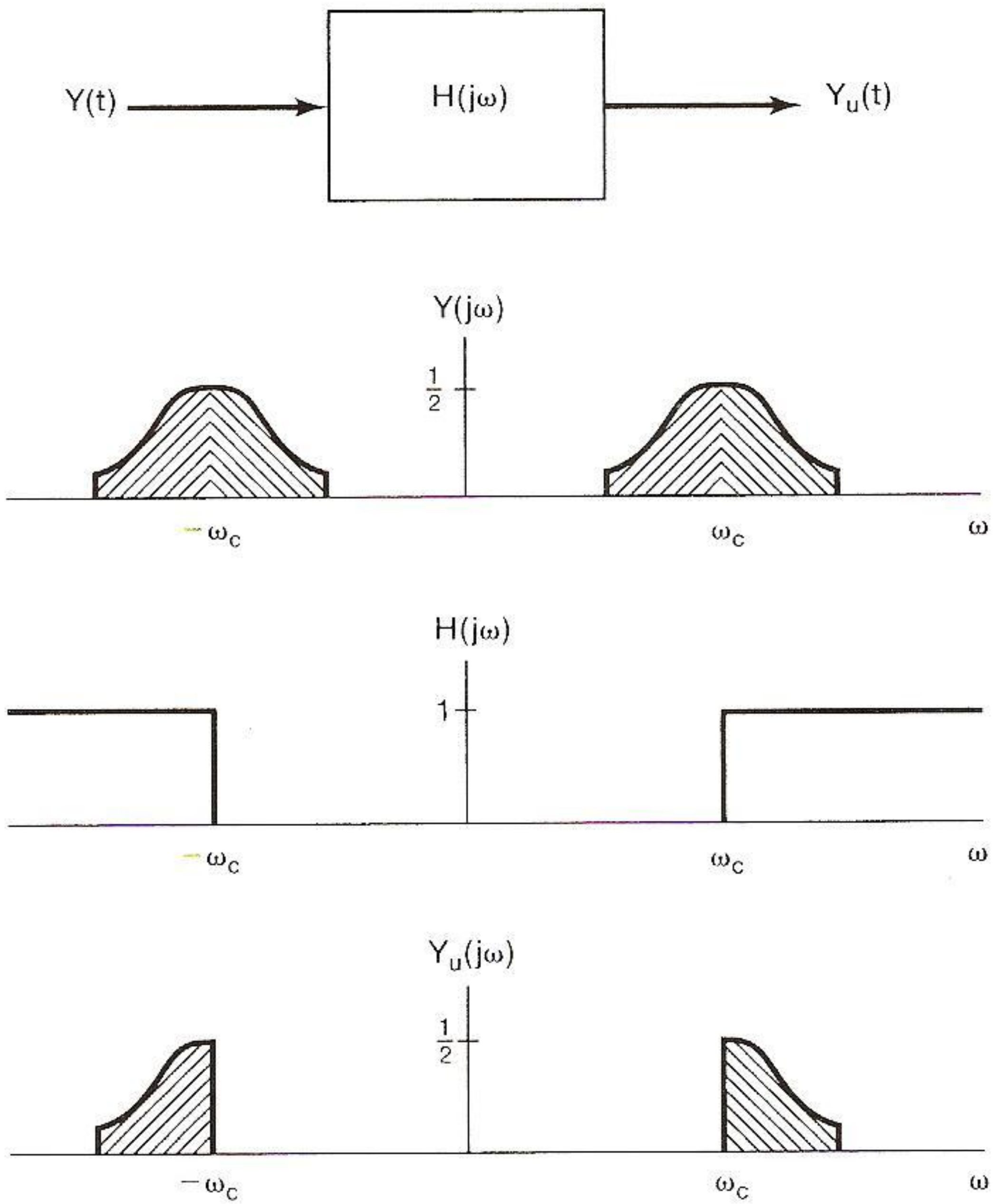
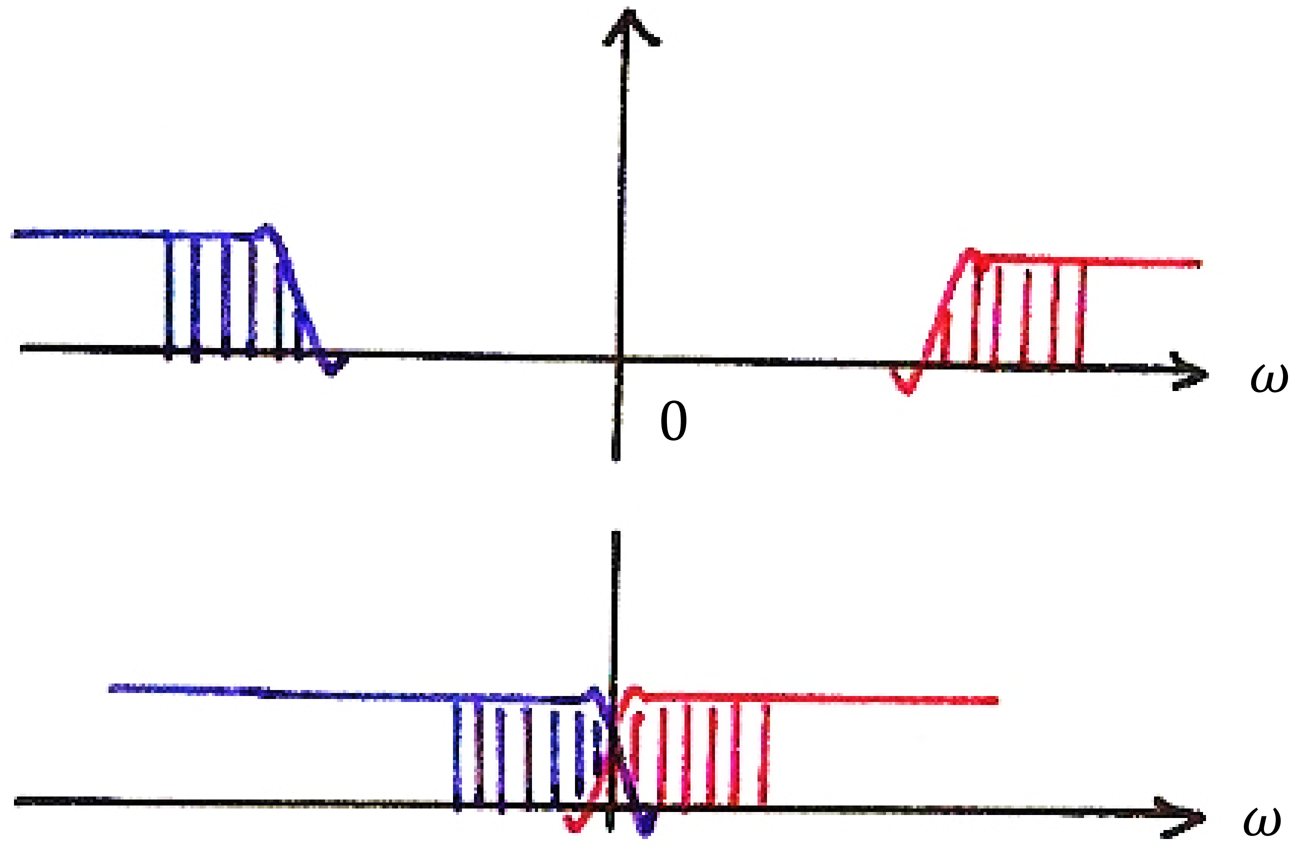



**Figure 8.20** System for retaining the upper sidebands using ideal high-pass filtering.

# Vestigial Sideband



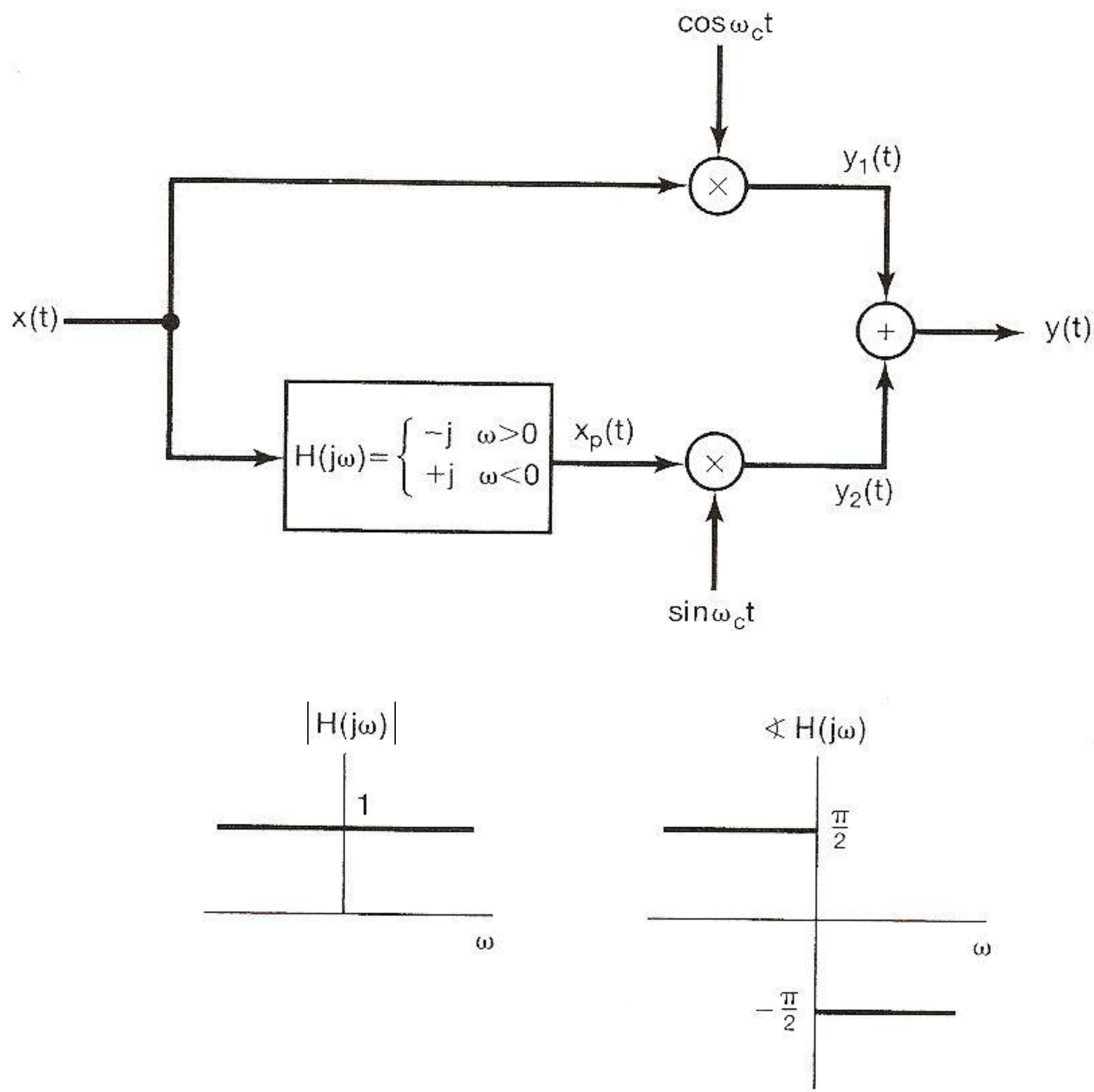
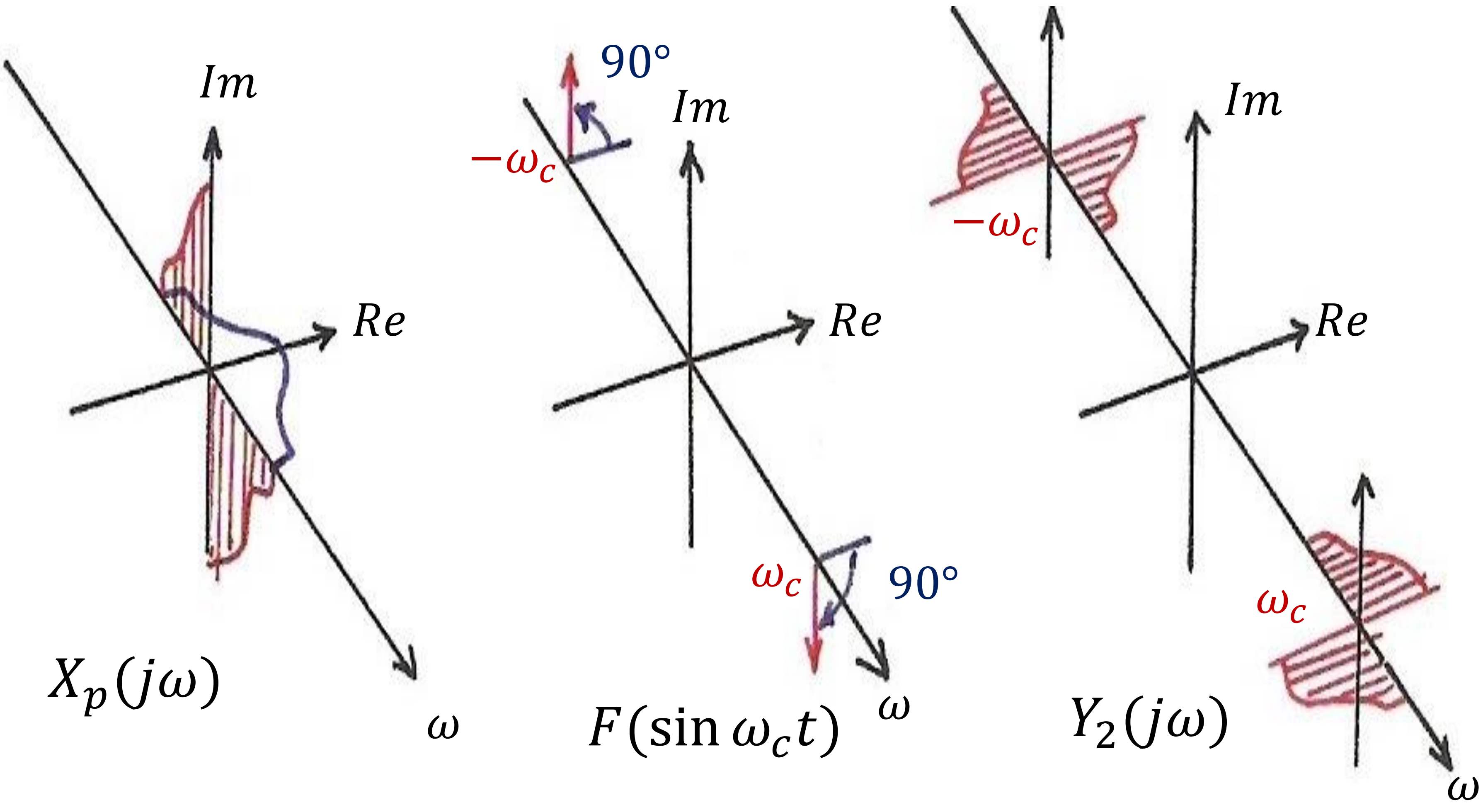



**Figure 8.21** System for single-sideband amplitude modulation, using a 90° phase-shift network, in which only the lower sidebands are retained.

# Phase Shift Network



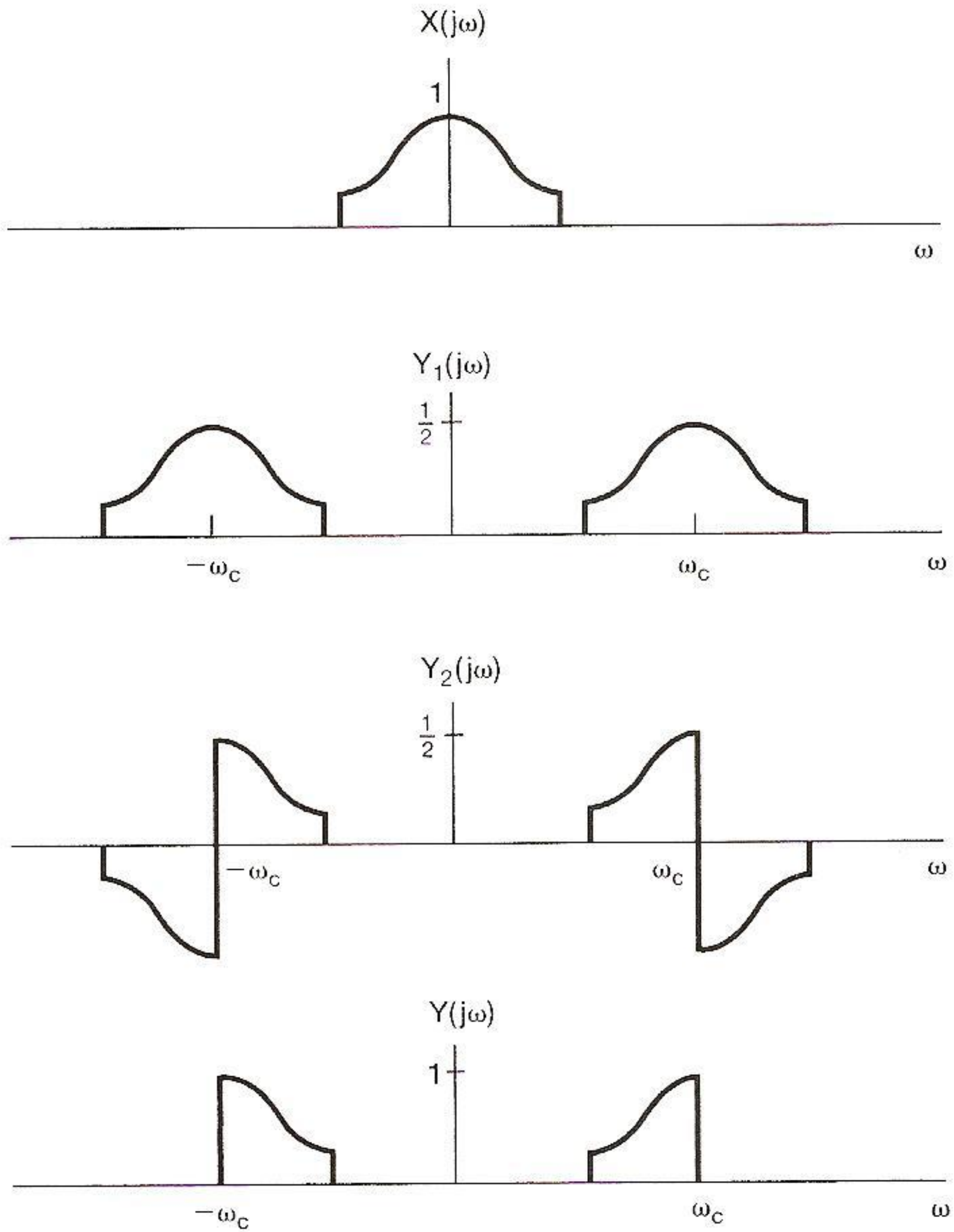



**Figure 8.22** Spectra associated with the single-sideband system of Figure 8.21.

# Frequency-Division Multiplexing (FDM)

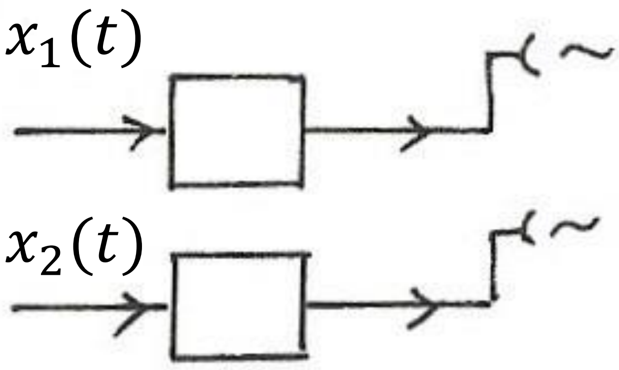
each signal allocated with a frequency slot. Many signals transmitted simultaneously over a single wideband channel using a single set of transmission facilities

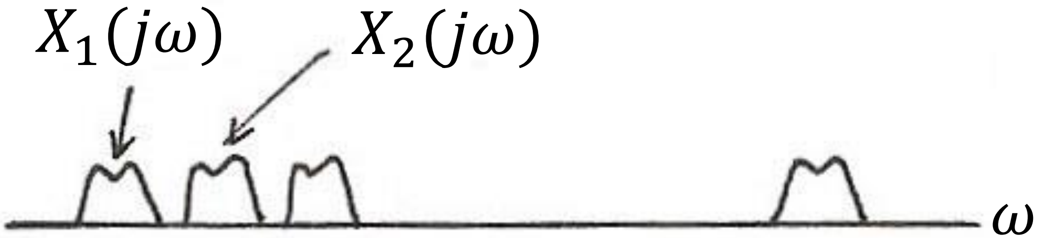
*See Figs. 8.15, 8.16, 8.17, p.594-596 of text*
*See Fig. 4.27, p.326 of text*

Signals mixed in time domain but separated in frequency domain.

# Frequency Division Multiplexing

(p.67 of 4.0)



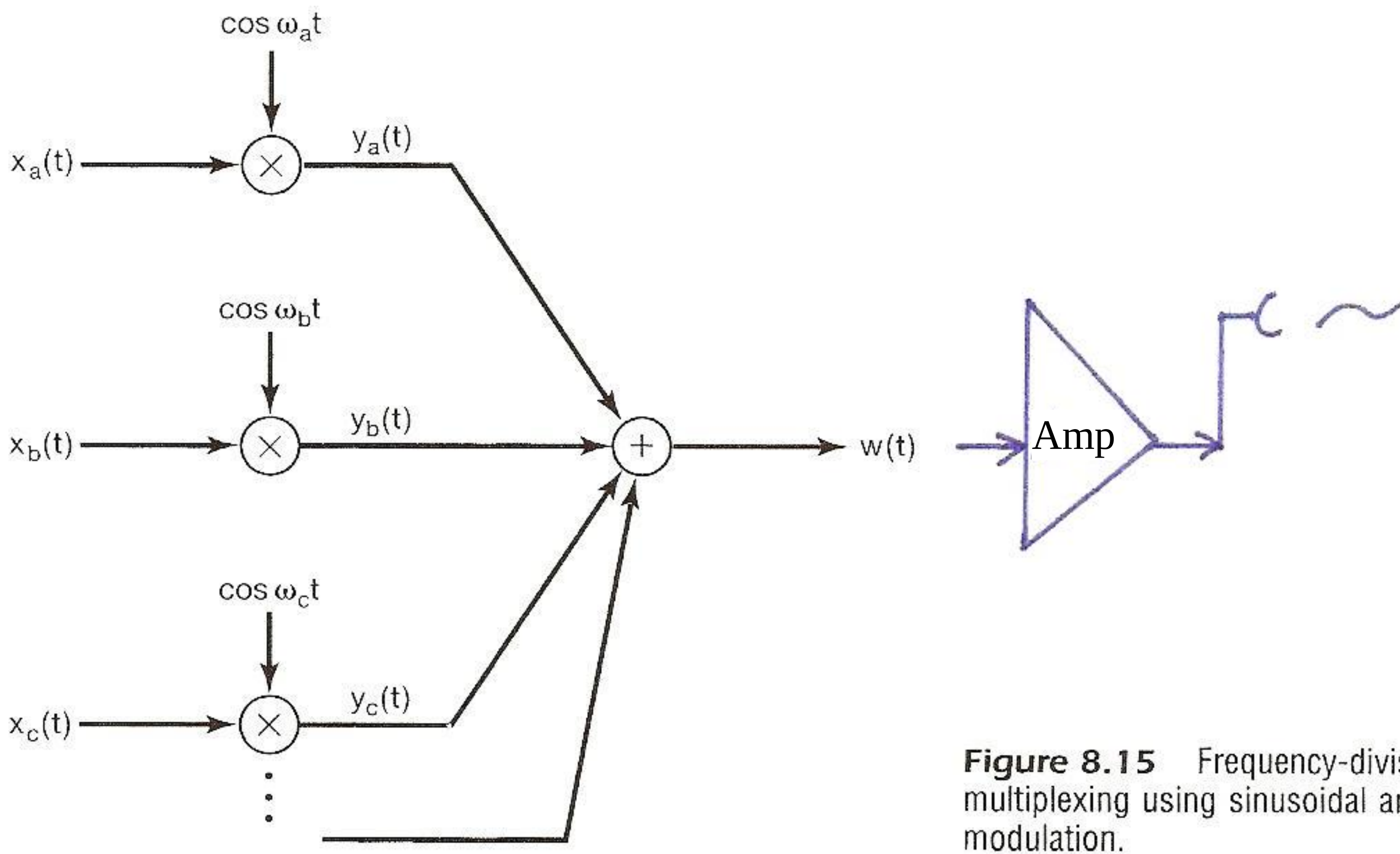



**Figure 8.15** Frequency-division multiplexing using sinusoidal amplitude modulation.

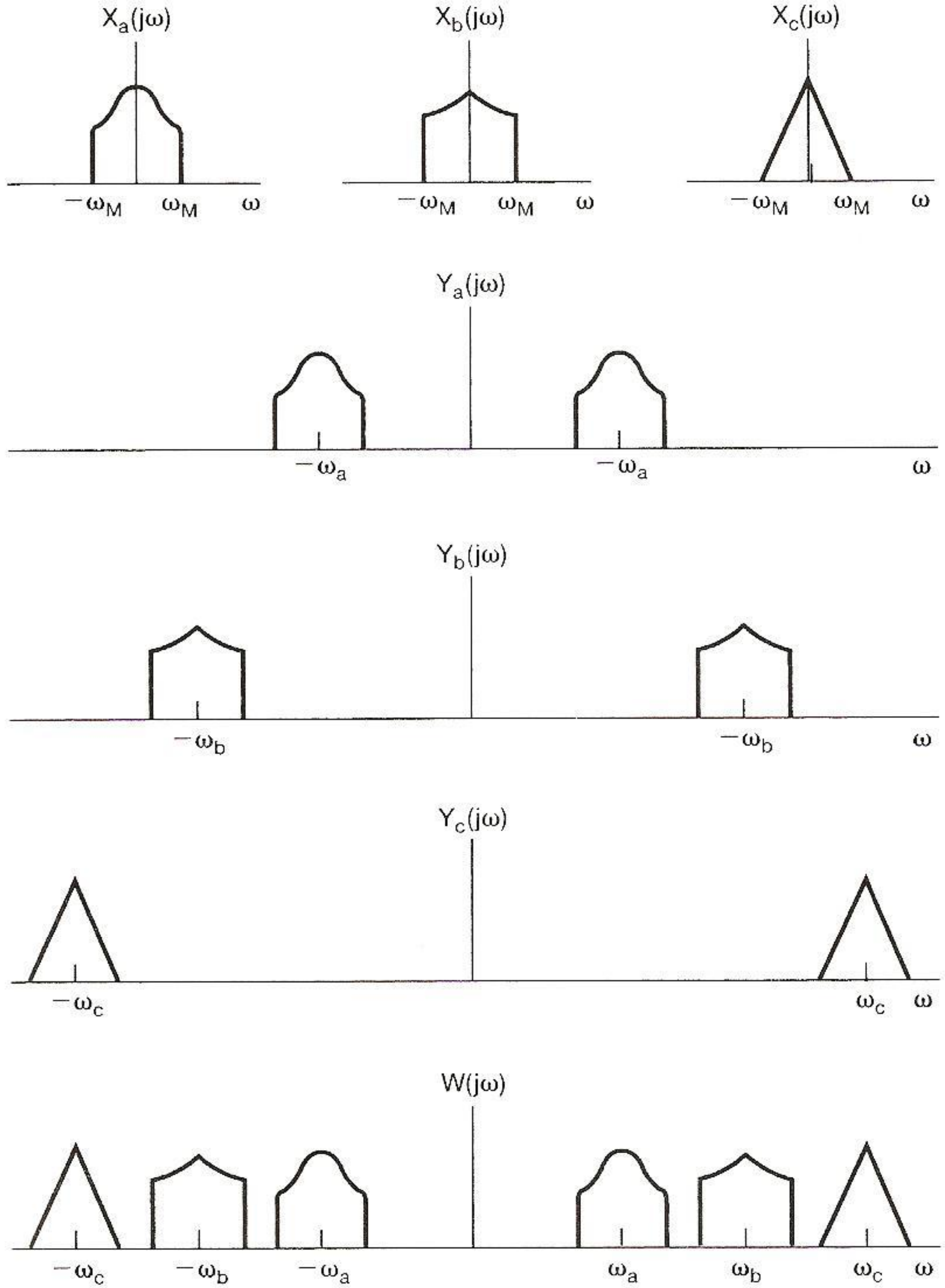



**Figure 8.16** Spectra associated with the frequency-division multiplexing system of Figure 8.15.

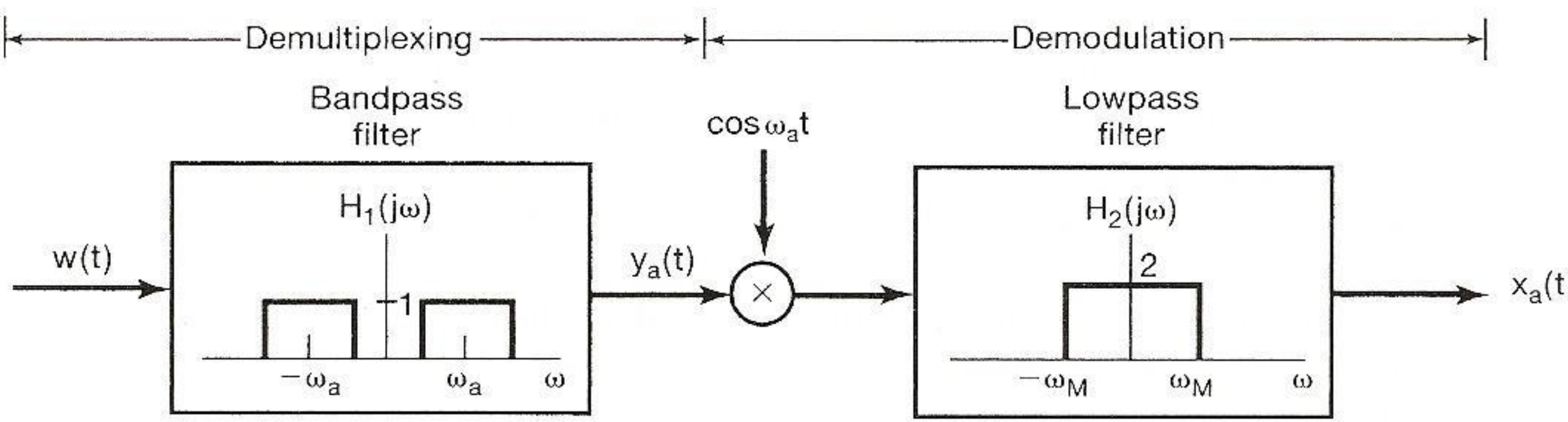
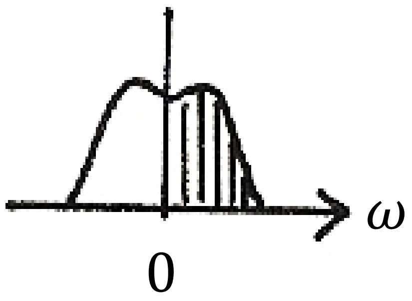
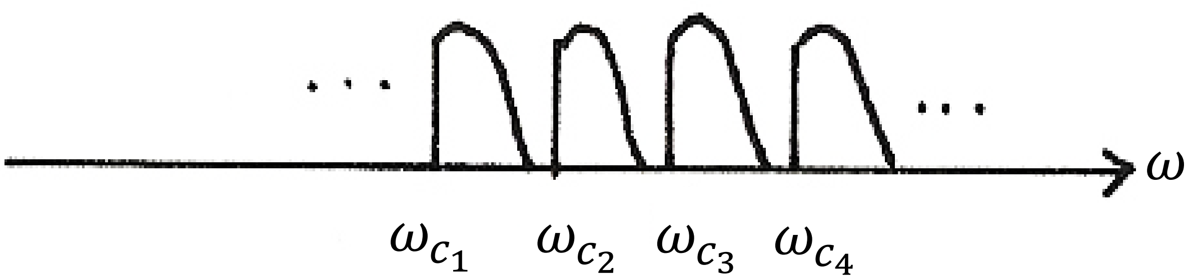



**Figure 8.17** Demultiplexing and demodulation for a frequency-division multiplexed signal.

# FDM with SSB



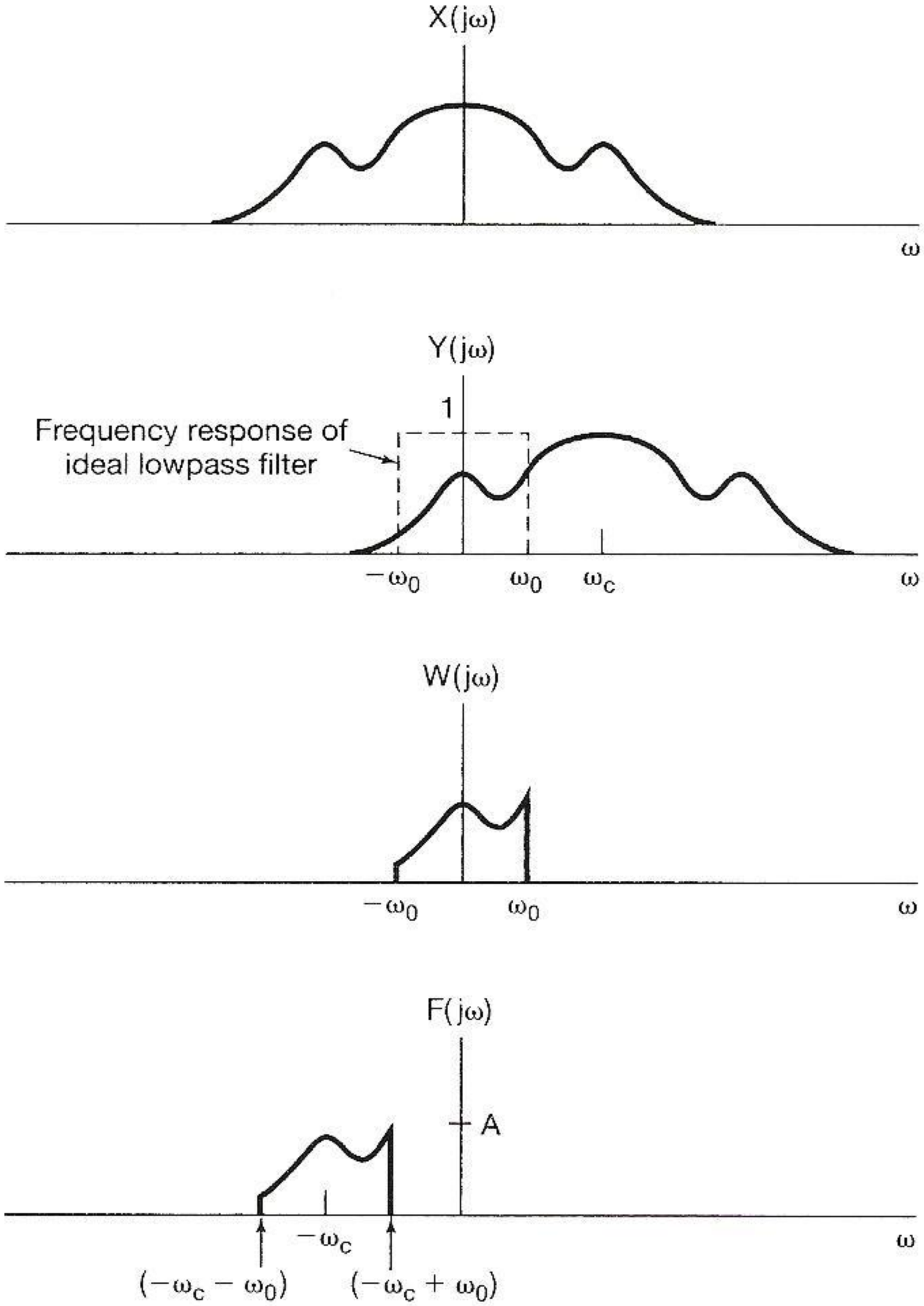



**Figure 4.27** Spectra of the signals in the system of Figure 4.26.

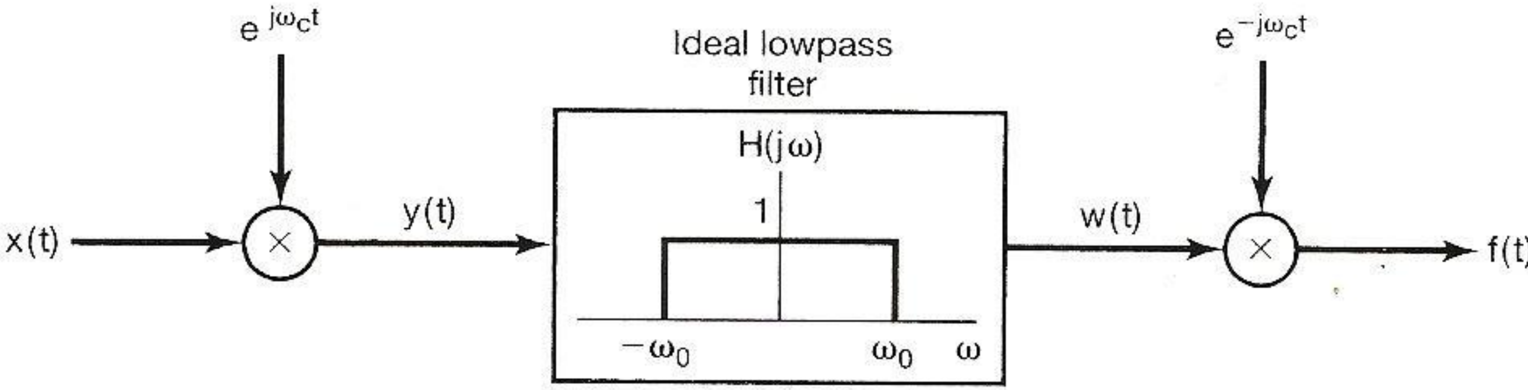



**Figure 4.26** Implementation of a bandpass filter using amplitude modulation with a complex exponential carrier.

# 8.2 Pulse Modulation and Time-Division Multiplexing

- Amplitude Modulation with a pulse train carrier

*See Figs. 8.23, 8.24, p.602, 603 of text*

$$y(t) = x(t)c(t)$$

$$C(j\omega) = 2\pi \sum_{k=-\infty}^{\infty} a_k \delta(\omega - k\omega_c), \quad \omega_c = \frac{2\pi}{T}$$

$$a_k = \frac{\sin(k\omega_c \Delta/2)}{\pi k}$$

$$Y(j\omega) = \sum_{k=-\infty}^{\infty} a_k X(j(\omega - k\omega_c))$$

A lowpass filter gives $x(t)$ if sampling theorem is satisfied, $\omega_c > 2\,\omega_M$

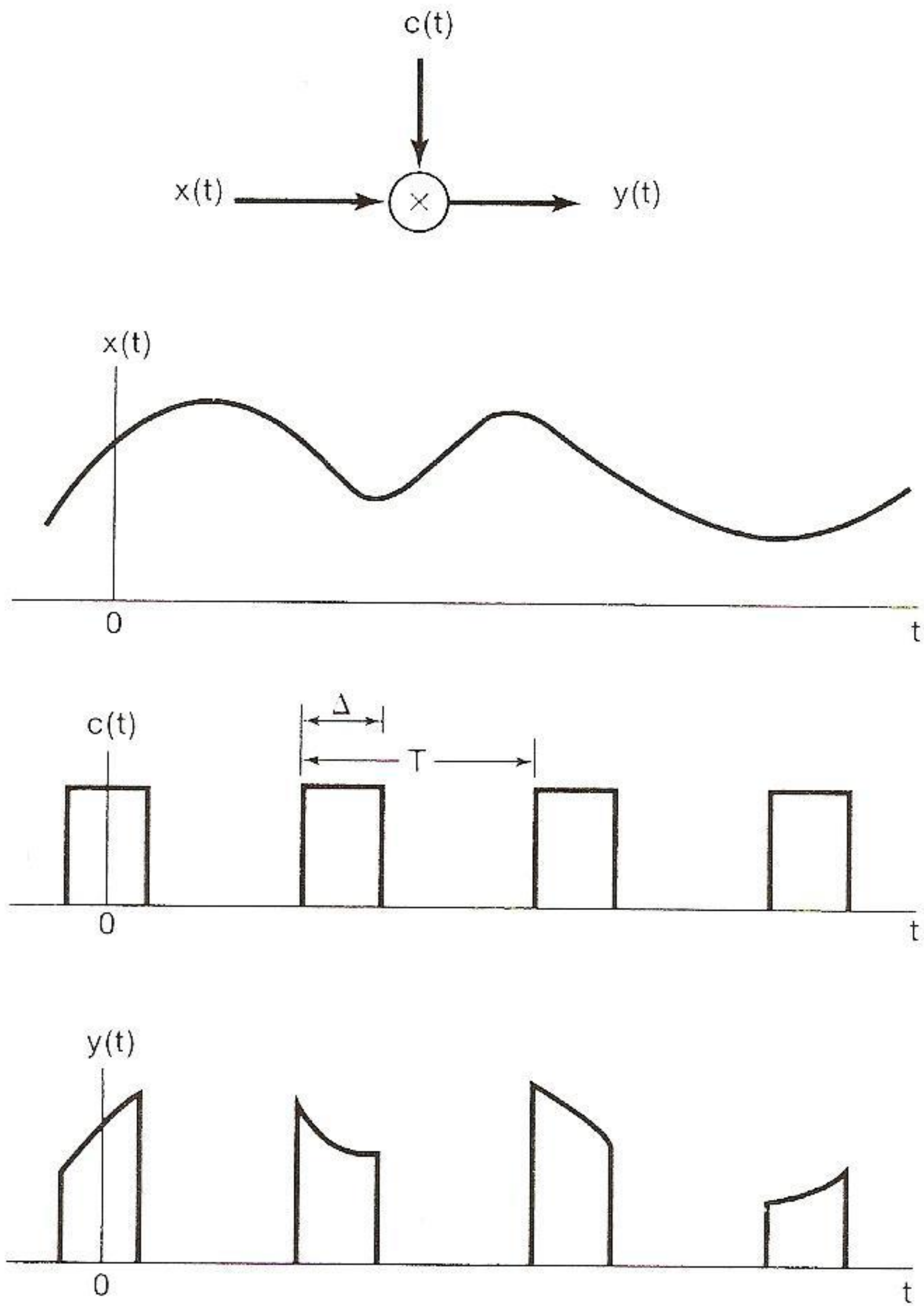
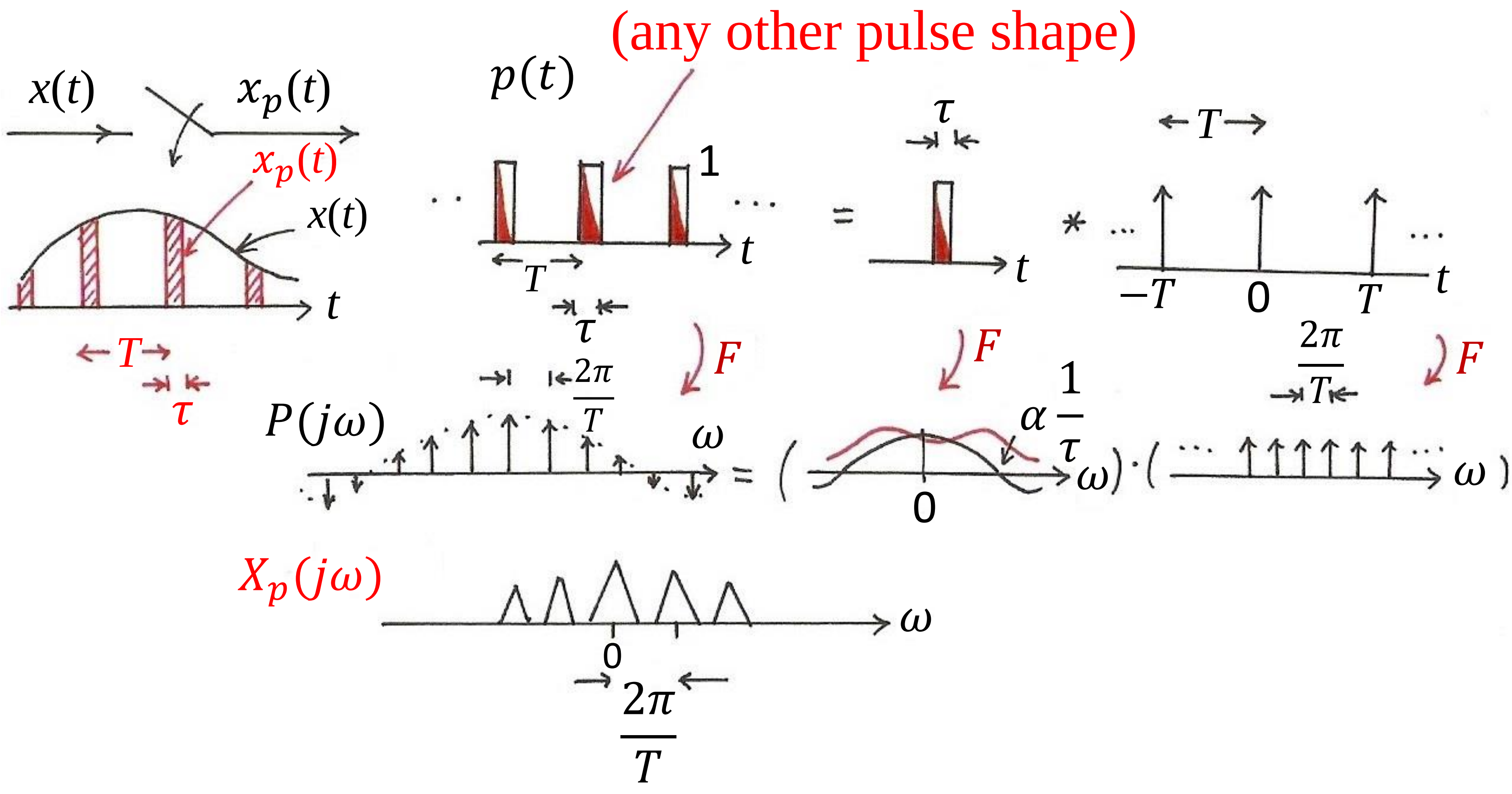



**Figure 8.23** Amplitude modulation of a pulse train.

# **Practical** Sampling (p.19 of 7.0)



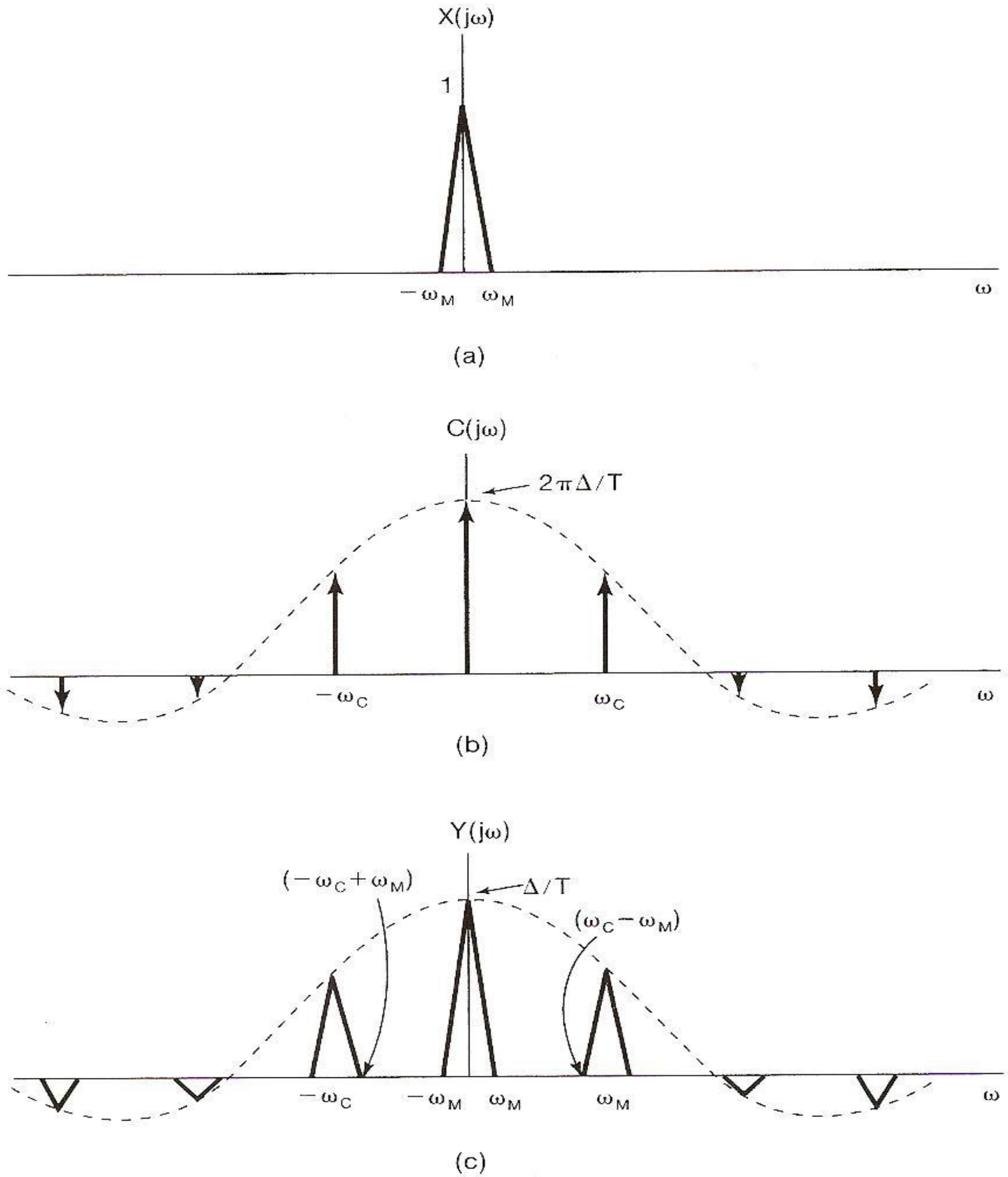



**Figure 8.24** Spectra associated with amplitude modulation of a pulse train: (a) spectrum of a bandlimited-signal $x(t)$; (b) spectrum of the pulse carrier signal $c(t)$ in Figure 8.23; (c) spectrum of the modulated pulse train $y(t)$.

- Amplitude Modulation with a pulse train carrier
  - This remains true as long as $c(t)$ is periodic, represented by a sequence $a_k$. Sinusoidal AM is a special case here. Impulse train sampling is the case $\Delta \rightarrow 0$.

- Pulse-Amplitude Modulation
  - pulse amplitudes corresponds to the sample values

    example : rectangular pulses (sample-and-hold)

    *See Fig. 8.26, p.606 of text*

    Sampling theorem applies.

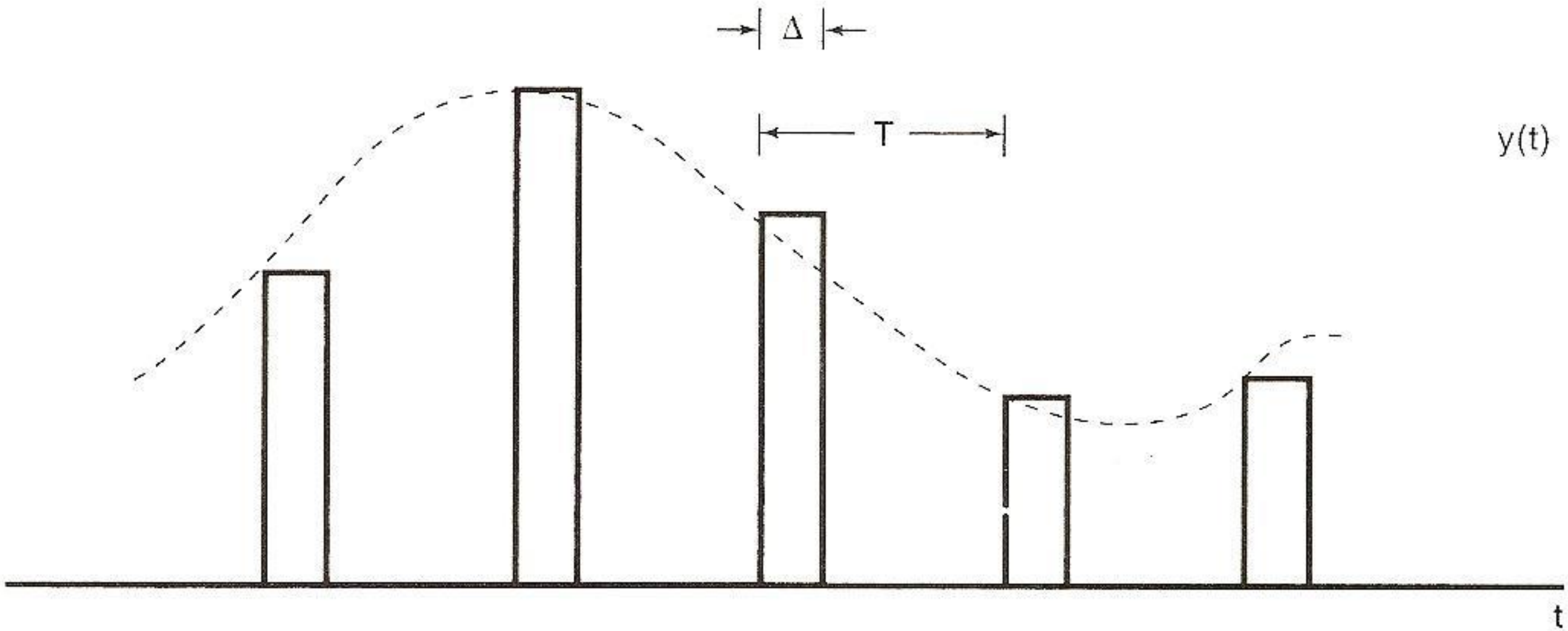
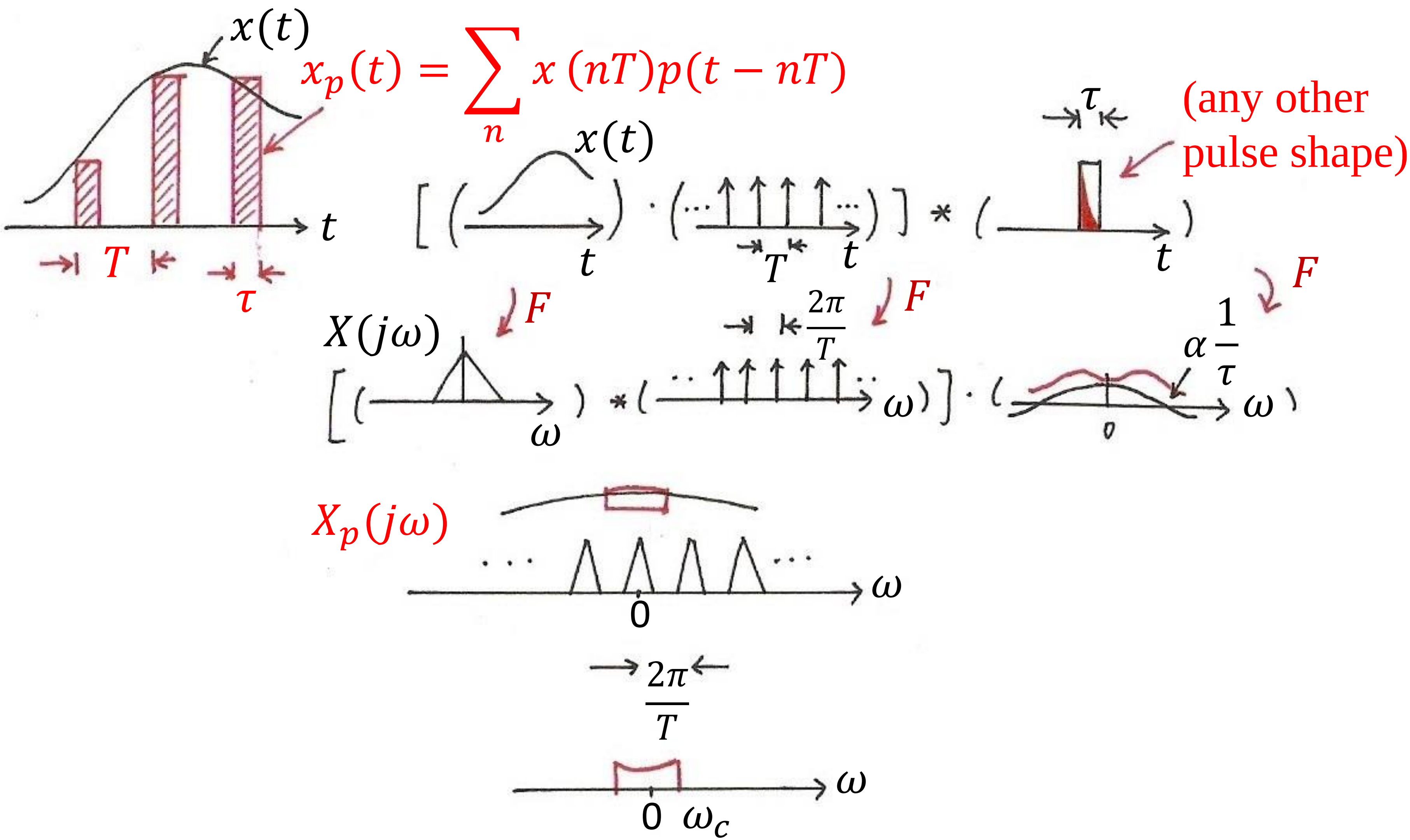



**Figure 8.26** Transmitted waveform for a single PAM channel. The dotted curve represents the signal $x(t)$.

# Practical Sampling (p.20 of 7.0)



- Time-Division Multiplexing (TDM)

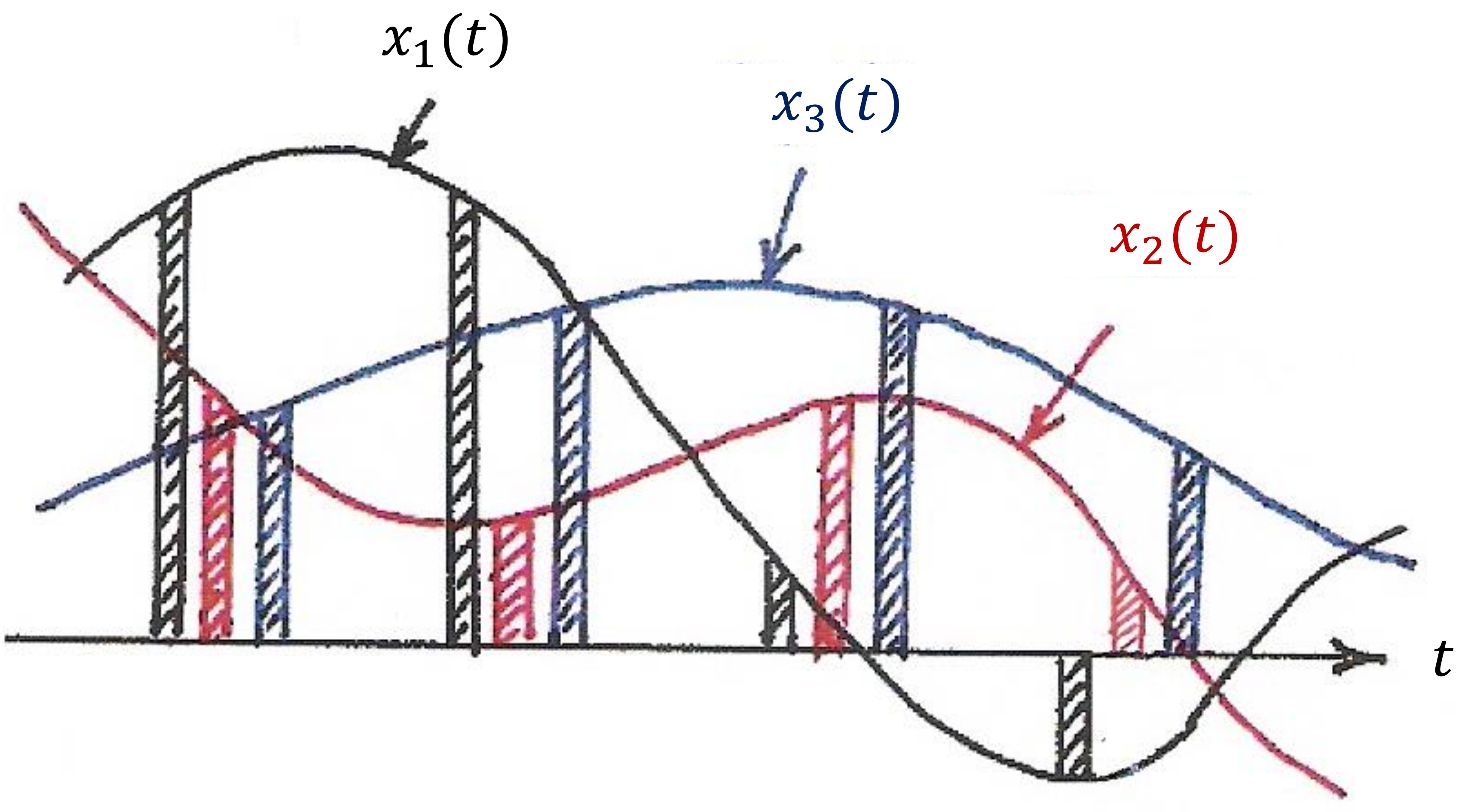
  Each signal allocated with a time slot in a period *T*.

  Many signals transmitted simultaneously over a single channel using a single set of facilities

  *See Figs. 8.25, 8.27, p.605, 606 of text*

  Signals mixed in frequency domain but separated in time domain.

# Time Division Multiplexing (TDM)



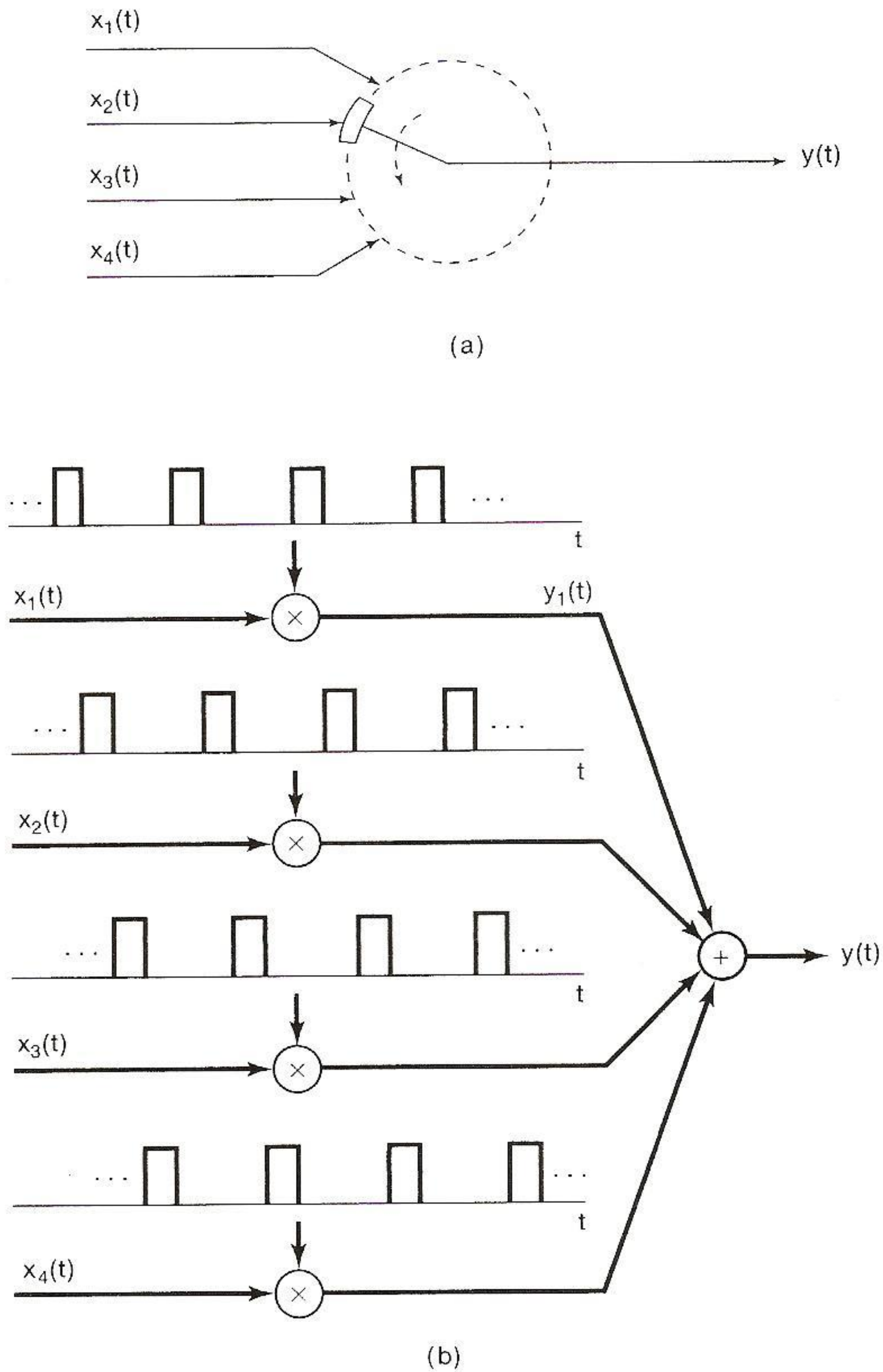



**Figure 8.25** Time-division multiplexing.

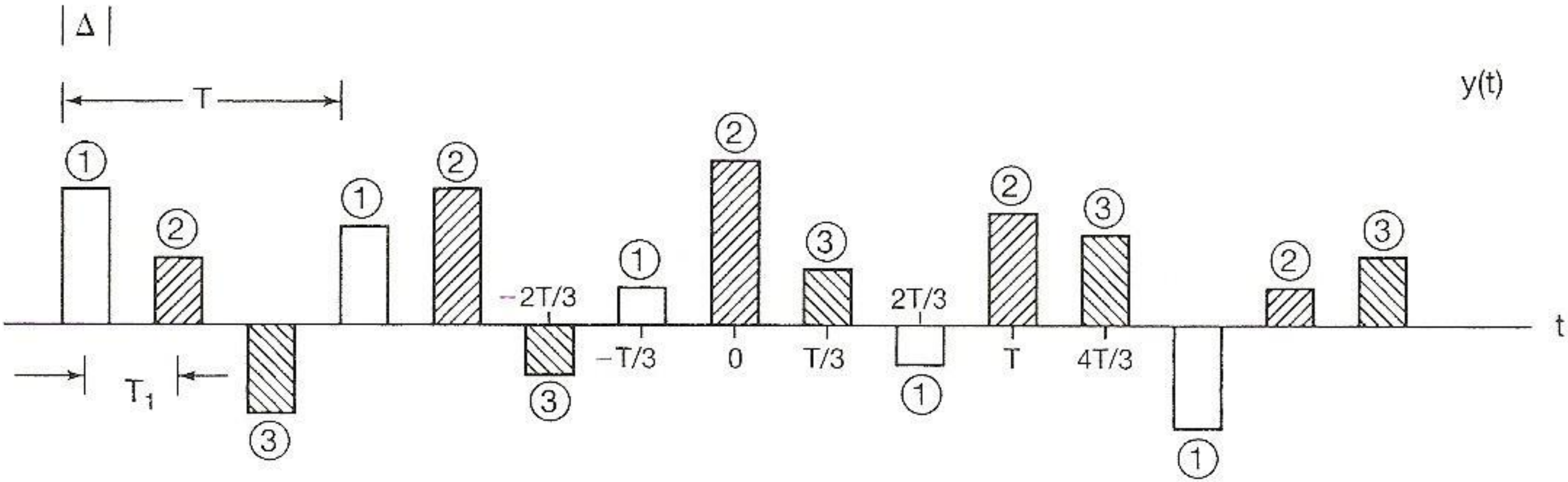



**Figure 8.27** Transmitted waveform with three time-multiplexed PAM channels. The pulses associated with each channel are distinguished by shading, as well as by the channel number above each pulse. Here, the intersymbol spacing is $T_1 = T/3$.

- Intersymbol interference

  pulses distorted during transmission and causing interference to adjacent symbols

  *See Figs. 8.28, 607 of text*

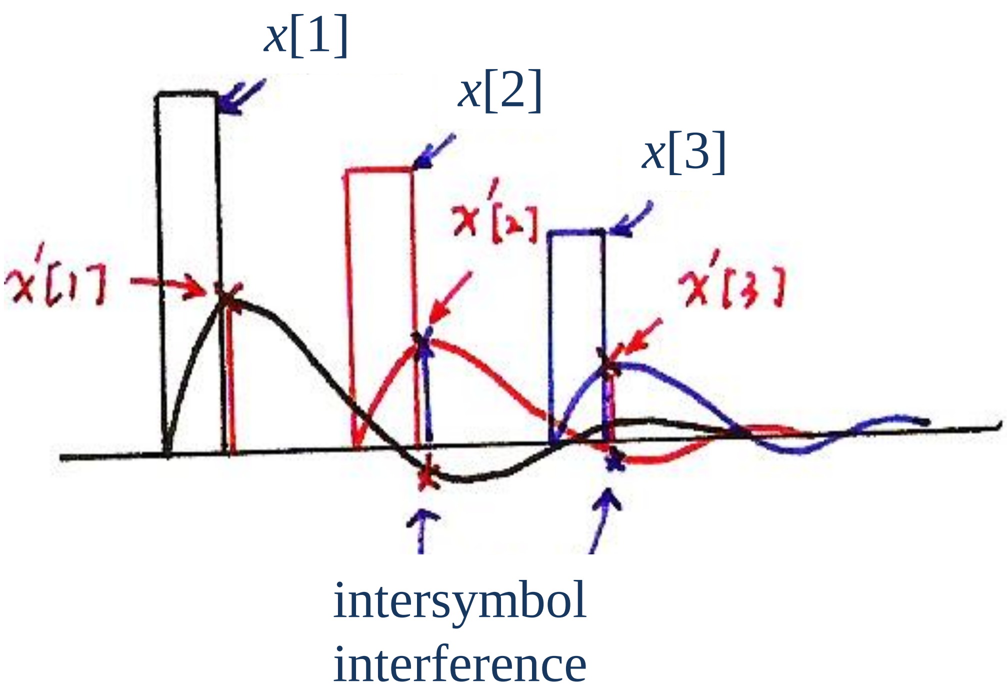
  Pulses with zero intersymbol interference

  $$p(t) = 0, \quad t = \pm T_1, \pm 2T_1, \pm 3T_1, ......$$

  $$(1) \quad p(t) = \frac{T_1 \sin(\pi t / T_1)}{\pi t}$$

  *See Figs. 8.30, 609 of text*

# Intersymbol Interference




It is the sample values rather than pulse shapes to be transmitted

Distortionless transmission via distorted channels

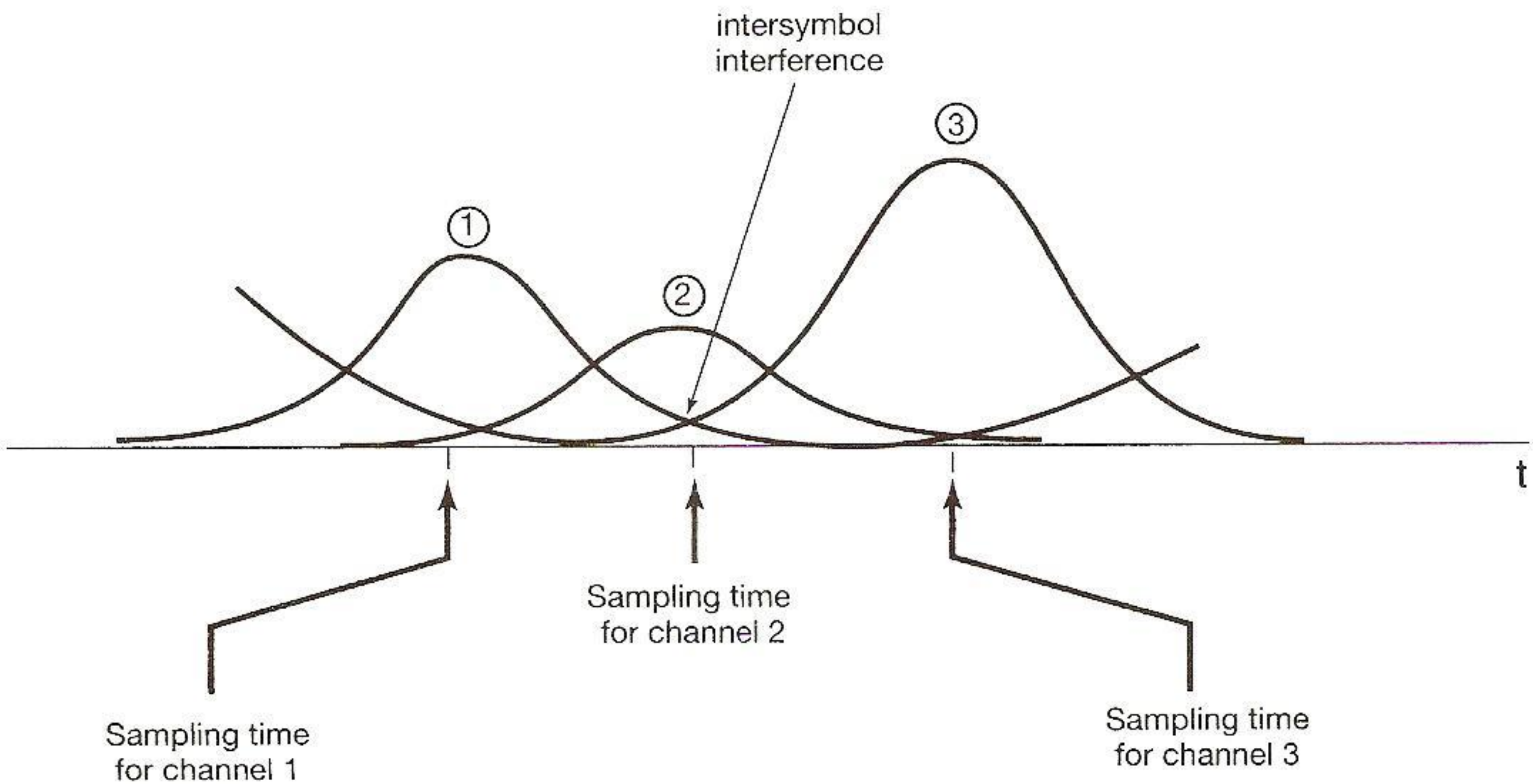



**Figure 8.28** Intersymbol interference.

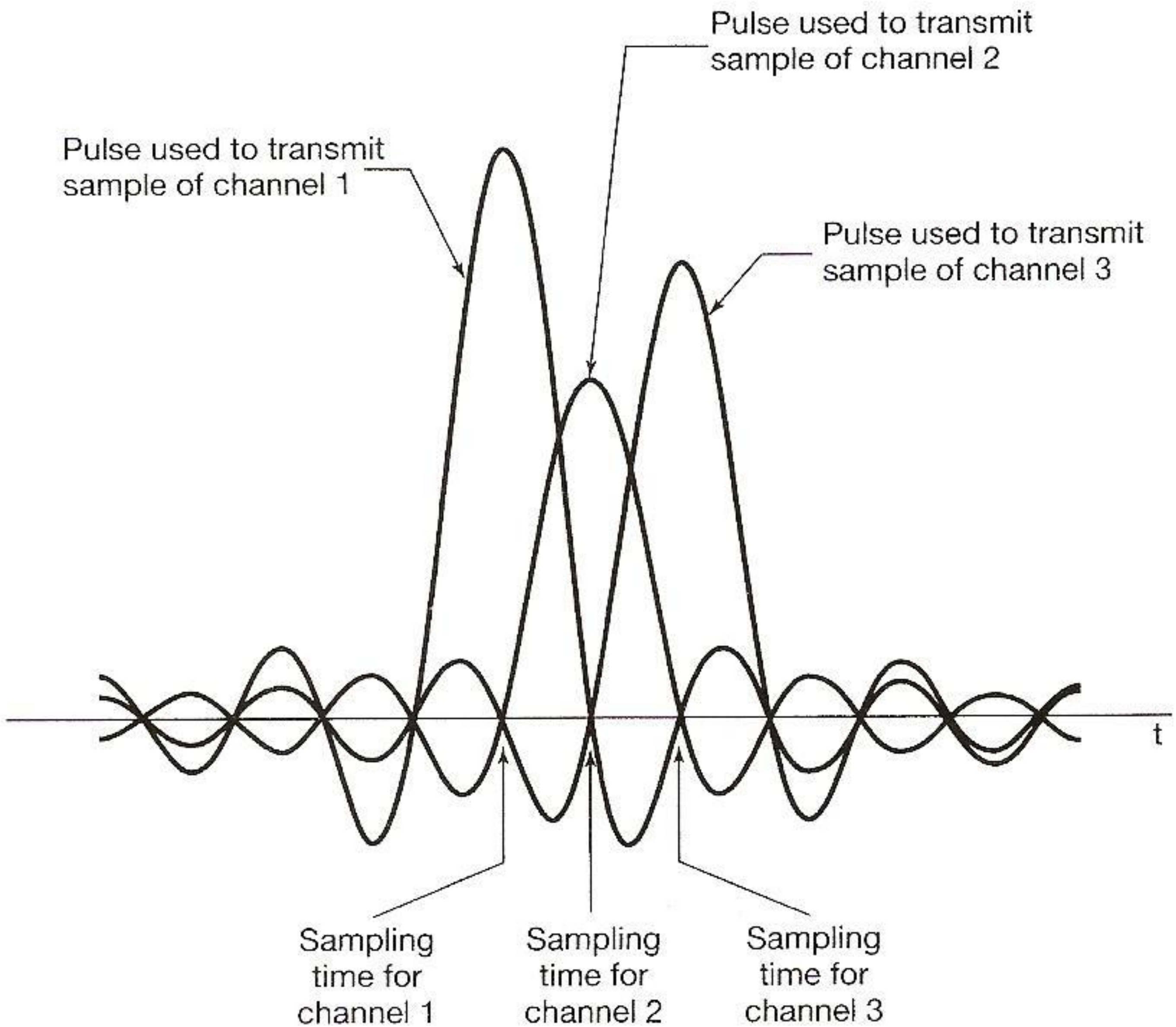



**Figure 8.30** Absence of intersymbol interference when sinc pulses with correctly chosen zero-crossings are used.

- Intersymbol interference

Pulses with zero intersymbol interference

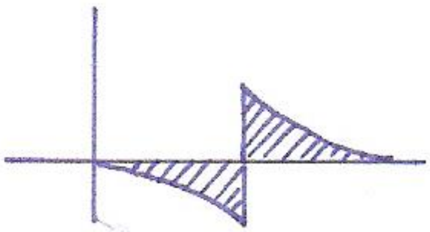
$$p(t) = 0, \quad t = \pm T_1, \pm 2T_1, \pm 3T_1, \ldots\ldots$$

(2) $$P(j\omega) = \begin{cases} 1 + P_1(j\omega), & |\omega| < \dfrac{\pi}{T_1} \\ P_1(j\omega) \quad , & \dfrac{\pi}{T_1} < |\omega| \le \dfrac{2\pi}{T_1} \\ 0 \quad , & \text{else} \end{cases}$$

$P_1(jw)$ with odd symmetry about $j\dfrac{\pi}{T_1}$

$$P_1\left(-j\omega + j\frac{\pi}{T_1}\right) = -P_1\left(j\omega + j\frac{\pi}{T_1}\right), \quad 0 \le \omega \le \frac{\pi}{T_1}$$

*See Figs. 8.31, 610 of text*



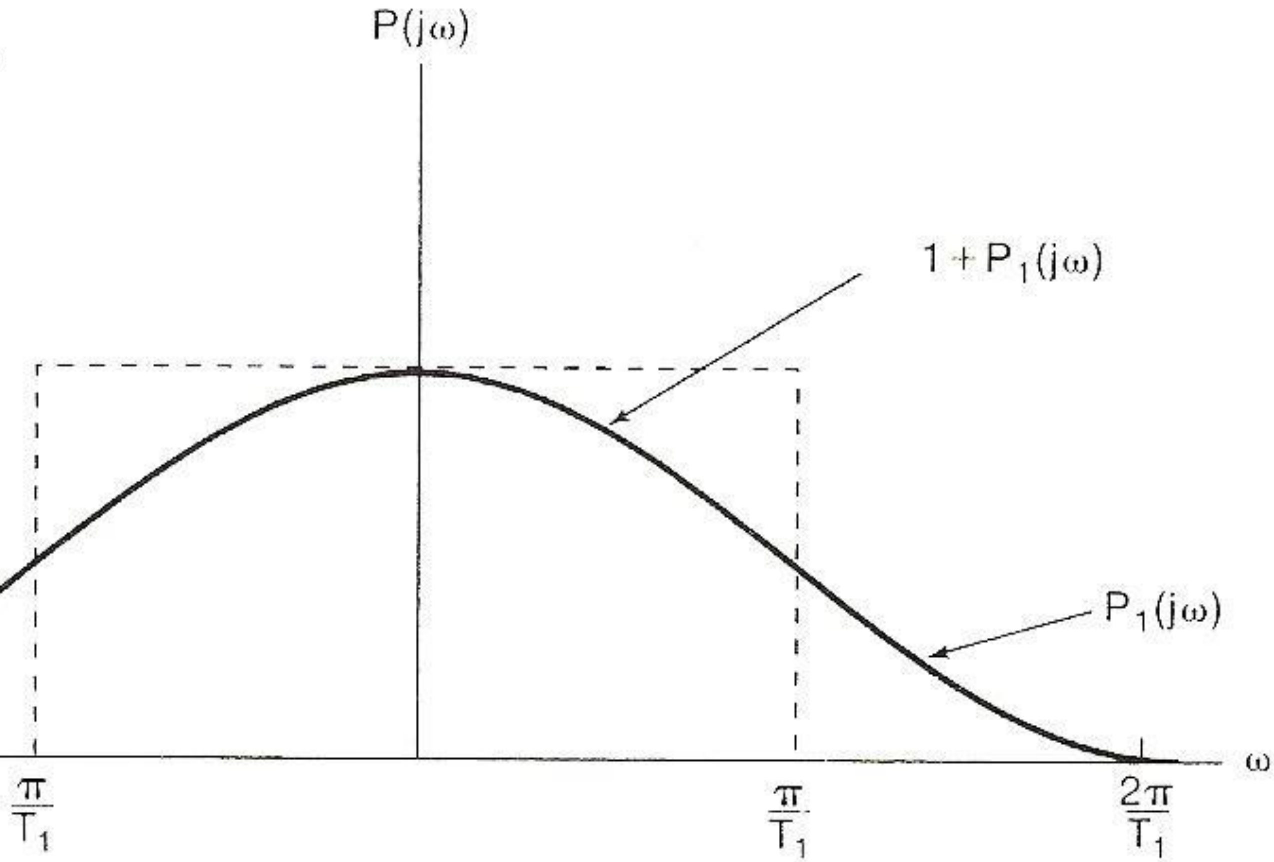
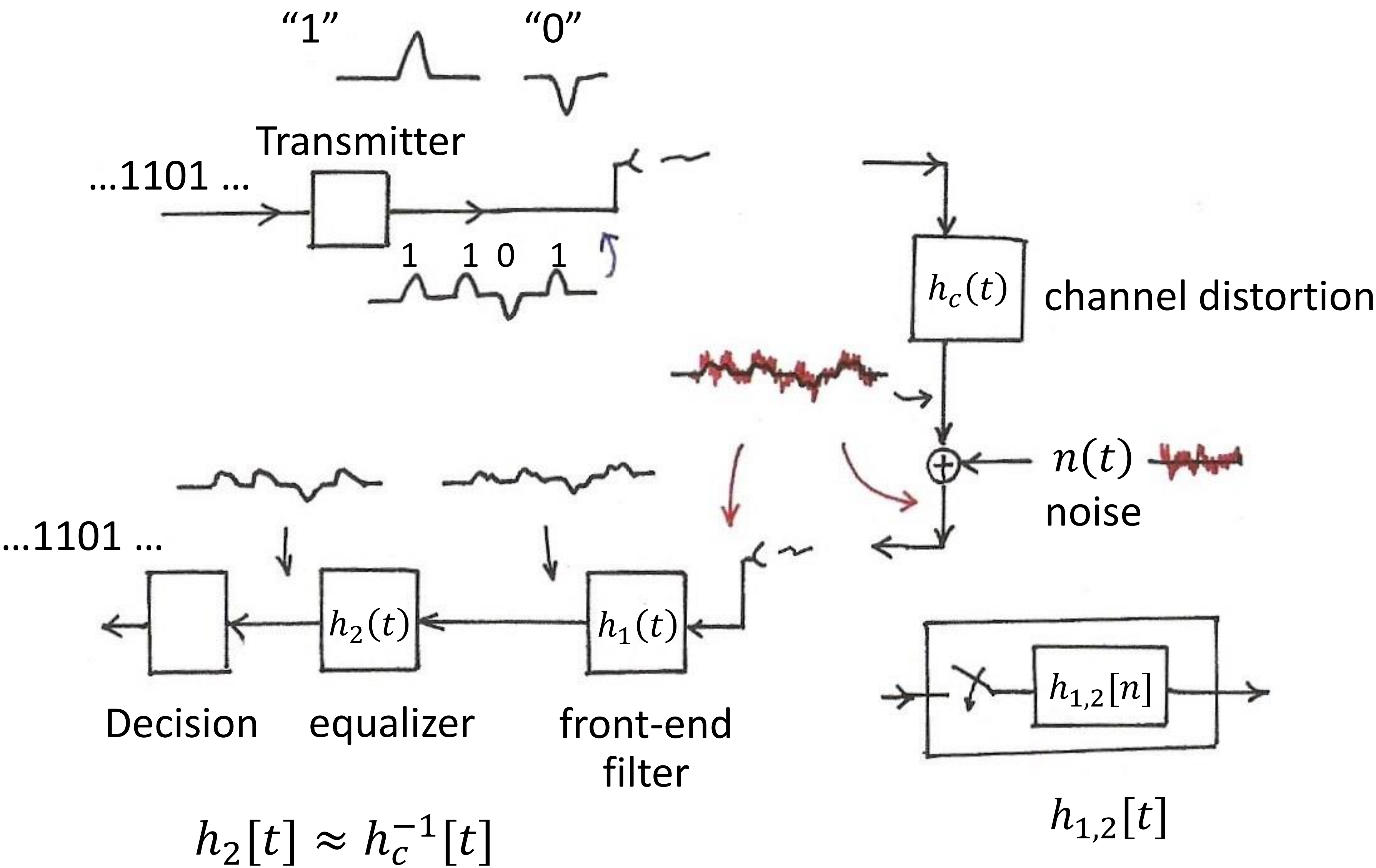



**Figure 8.31** Odd symmetry around $\pi/T_1$ as defined in eq. (8.29).

- Pulse coded modulation (PCM)
  - binary representation of pulse amplitude (sample values) and binary transmission of signals
  - much more easier to distinguish between 1’s and 0’s

# Date Transmission (p.111 of 2.0)



# 8.3 Angle/Frequency Modulation

## Angle Modulation

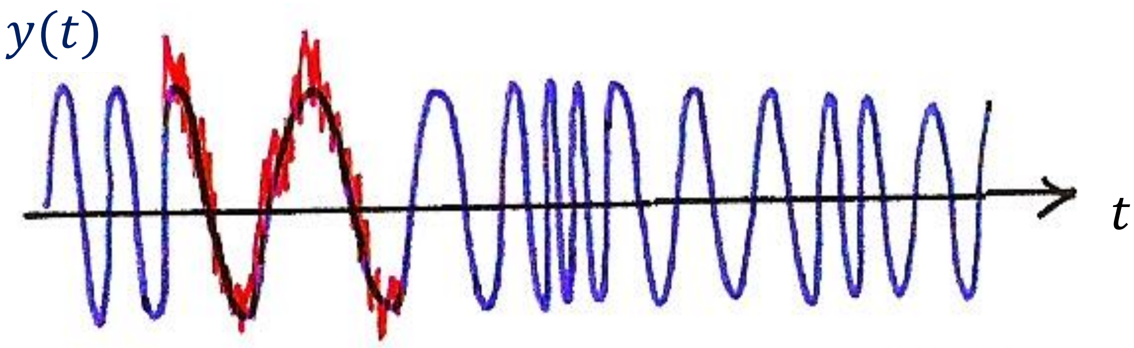
– $y(t) = \cos[\omega_c t + \theta_c(t)] = \cos[\theta(t)]$

$\theta_c(t) = \theta_0 + k_p x(t)$ phase modulation (PM)

$\frac{d\theta(t)}{dt} = \omega_c + k_f x(t)$ frequency modulation (FM)

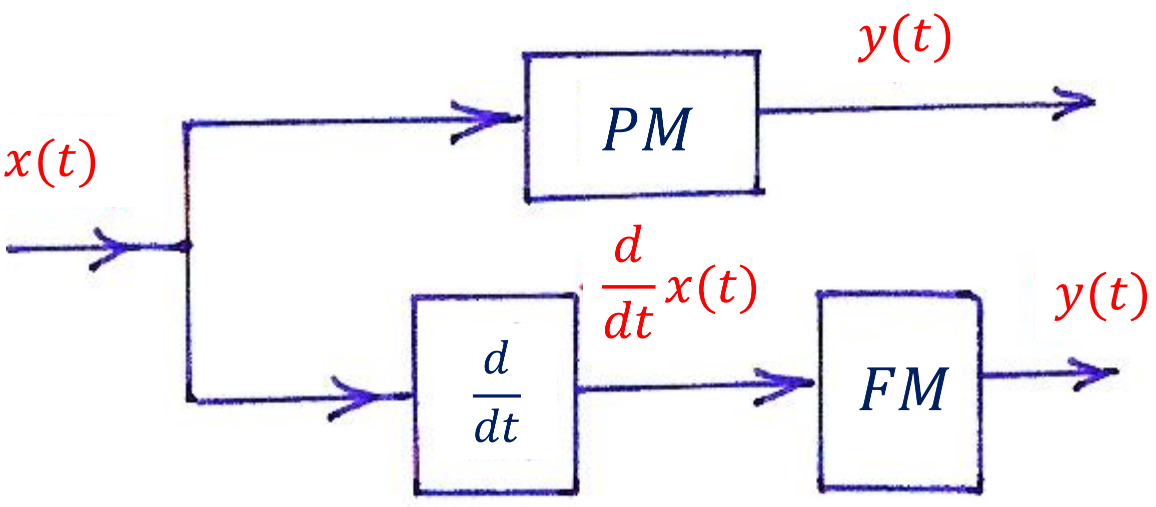
$\frac{d\theta(t)}{dt} = \omega_c + k_p \frac{dx(t)}{dt}$ phase modulation with $x(t)$ corresponds to frequency modulation with $dx(t)/dt$

# Angle Modulation




$$y(t) = A\cos(\omega_0 t + \underline{\theta})$$

$\theta(t)$



# Angle Modulation

– instantaneous frequency

$$\omega_i(t) = \frac{d}{dt}\theta(t)$$

phase modulation $\omega_i(t) = \omega_c + k_p \frac{d}{dt} x(t)$

frequency modulation $\omega_i(t) = \omega_c + k_f x(t)$

Highly nonlinear process *See Figs. 8.32, p.612 of text*

– features

constant envelope: transmitter always operates at peak power

information not carried by amplitudes : amplitude disturbances eliminated to a large extent

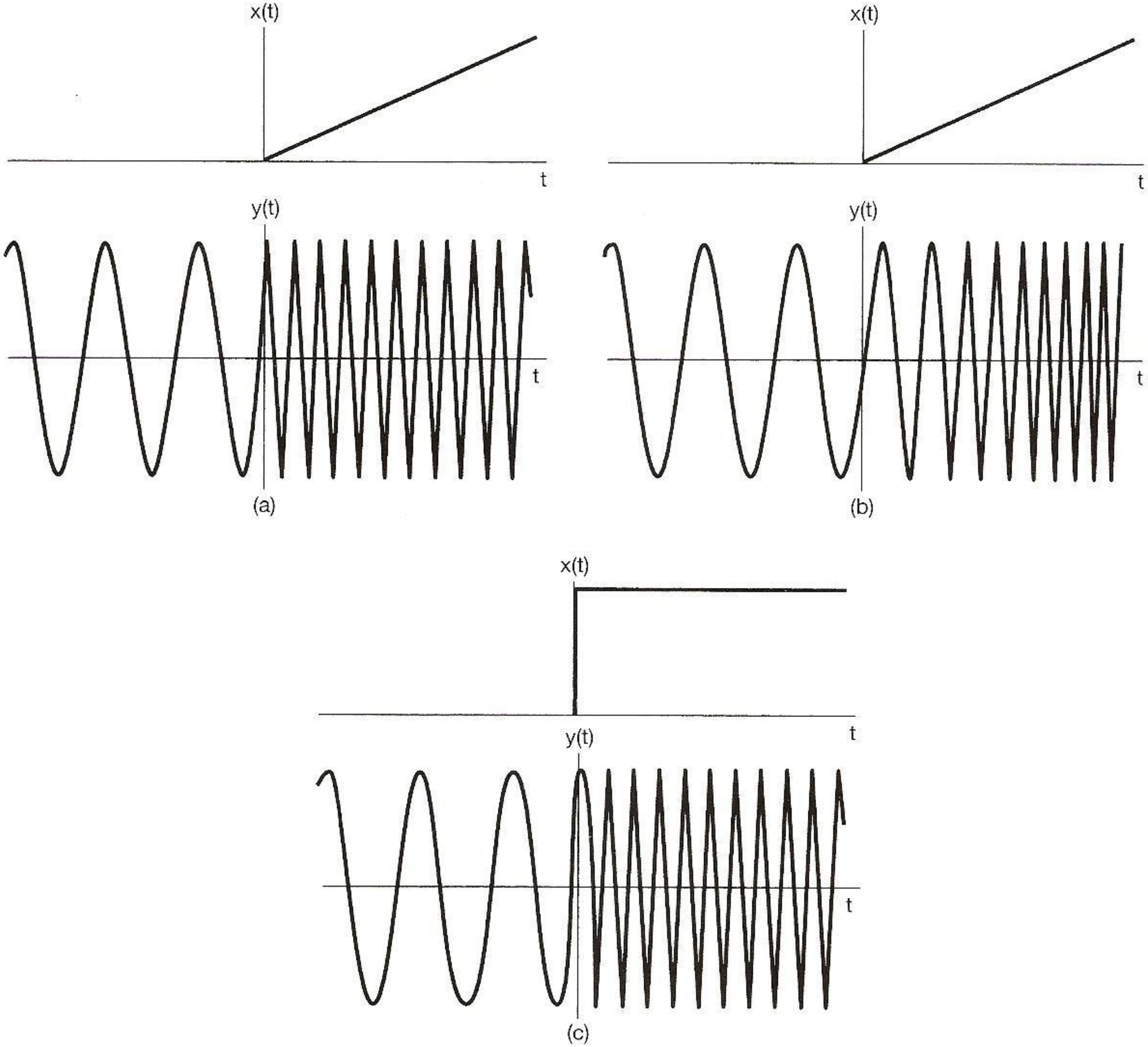
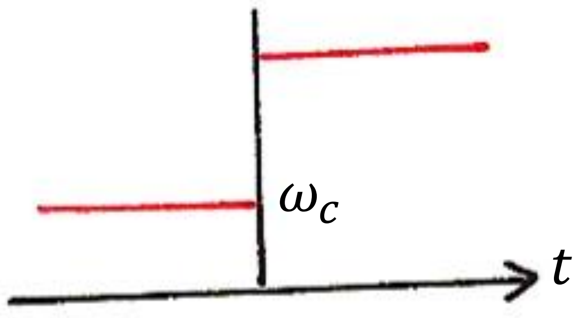


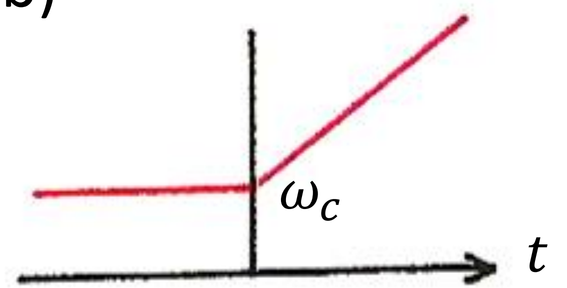

**Figure 8.32** Phase modulation, frequency modulation, and their relationship: (a) phase modulation with a ramp as the modulating signal; (b) frequency modulation with a ramp as the modulating signal; (c) frequency modulation with a step (the derivative of a ramp) as the modulating signal.

# Fig. 8.32

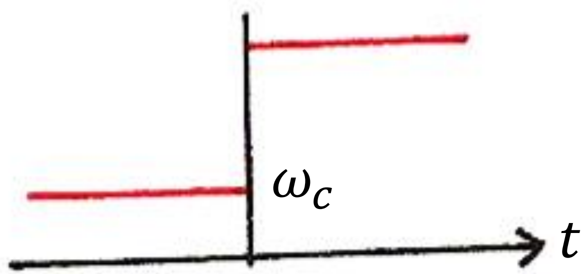
(a)




(b)




(c)




Instantaneous frequency

$$\omega_i(t) = \frac{d}{dt}\theta(t)$$

# Spectrum of FM Signals

- Consider the easiest case

$$x(t) = A\cos\omega_m t$$

$$\omega_i(t) = \omega_c + k_f A\cos\omega_m t = \omega_c + \Delta\omega\cos\omega_m t, \quad \Delta\omega = k_f A$$

$$y(t) = \cos[\omega_c t + (\Delta\omega/\omega_m)\sin\omega_m t]$$

$$\Delta\omega/\omega_m = m, \quad \text{modulaton index}$$

- Narrowband FM, $m << \pi/2$

$$\cos(m\sin\omega_m t) \approx 1$$

$$\sin(m\sin\omega_m t) \approx m\sin\omega_m t$$

$$y(t) \approx \cos\omega_c t - m(\sin\omega_m t)(\sin\omega_c t) \quad \text{narrowband FM}$$

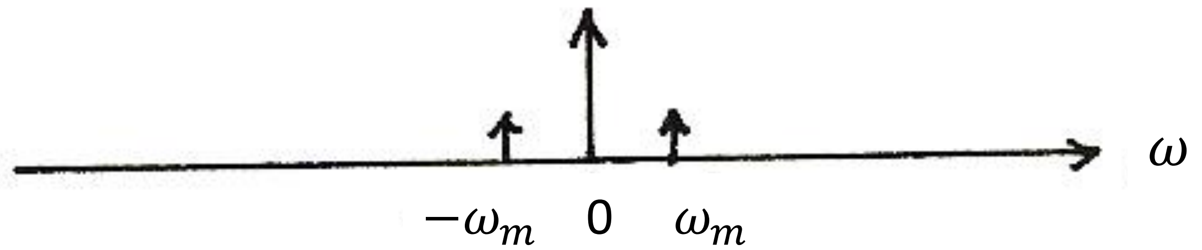
$$y_2(t) = \cos\omega_c t + m(\cos\omega_m t)(\cos\omega_c t) \quad \text{DSB/WC}$$

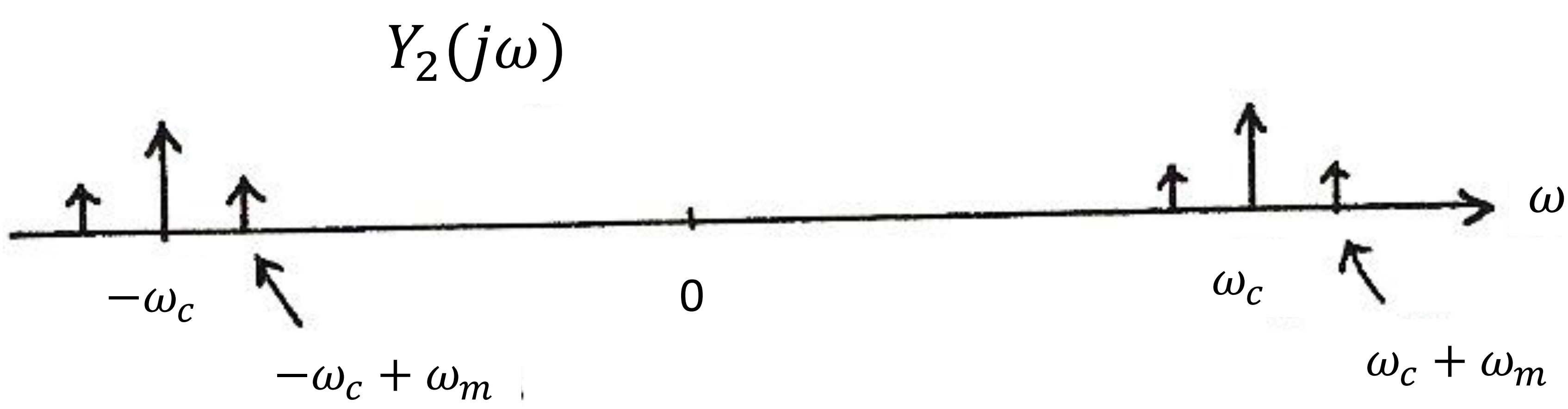
*See Figs. 8.33, 8.34, p.615 of text*

# Narrowband FM vs. DSB/WC

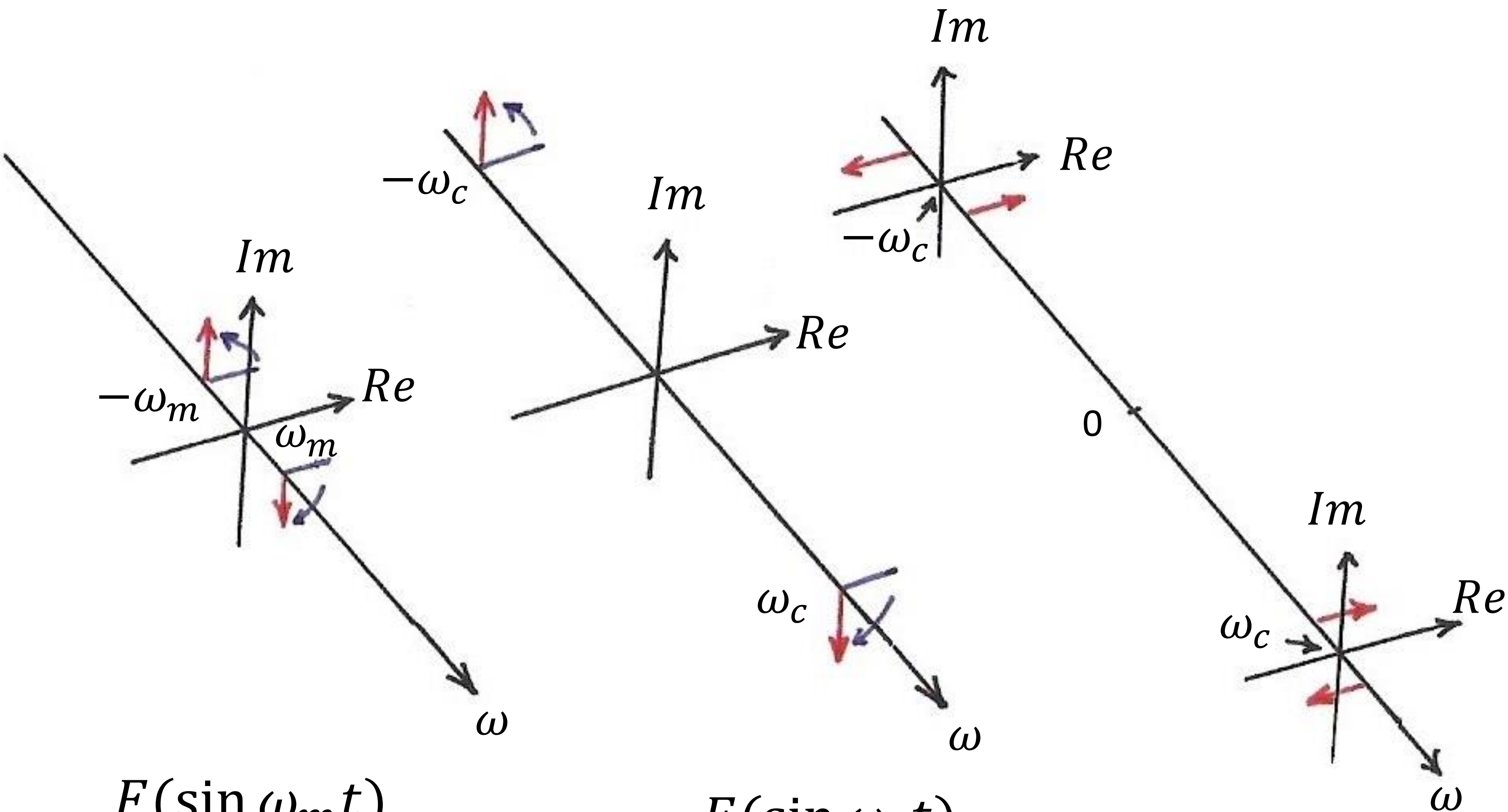
$$y_2(t) = [1 + m\cos\omega_m t]\cos\omega_c t$$

$$= [1 + x(t)]\cos\omega_c t$$



# Narrowband FM




$F(\sin\omega_m t)$

$F(\sin\omega_c t)$

$F[(\sin\omega_m t)(\sin\omega_c t)]$

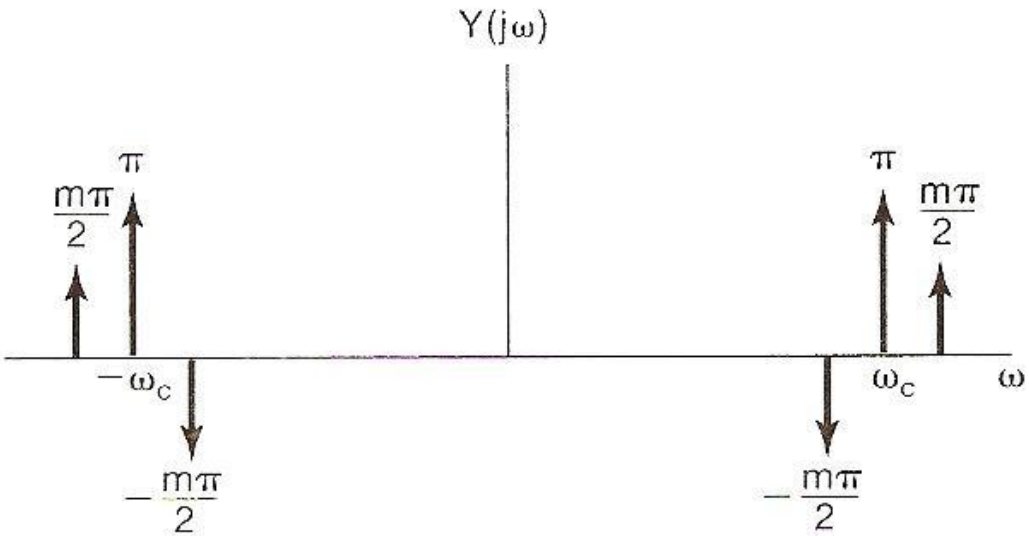



***Figure 8.33*** Approximate spectrum for narrowband FM.

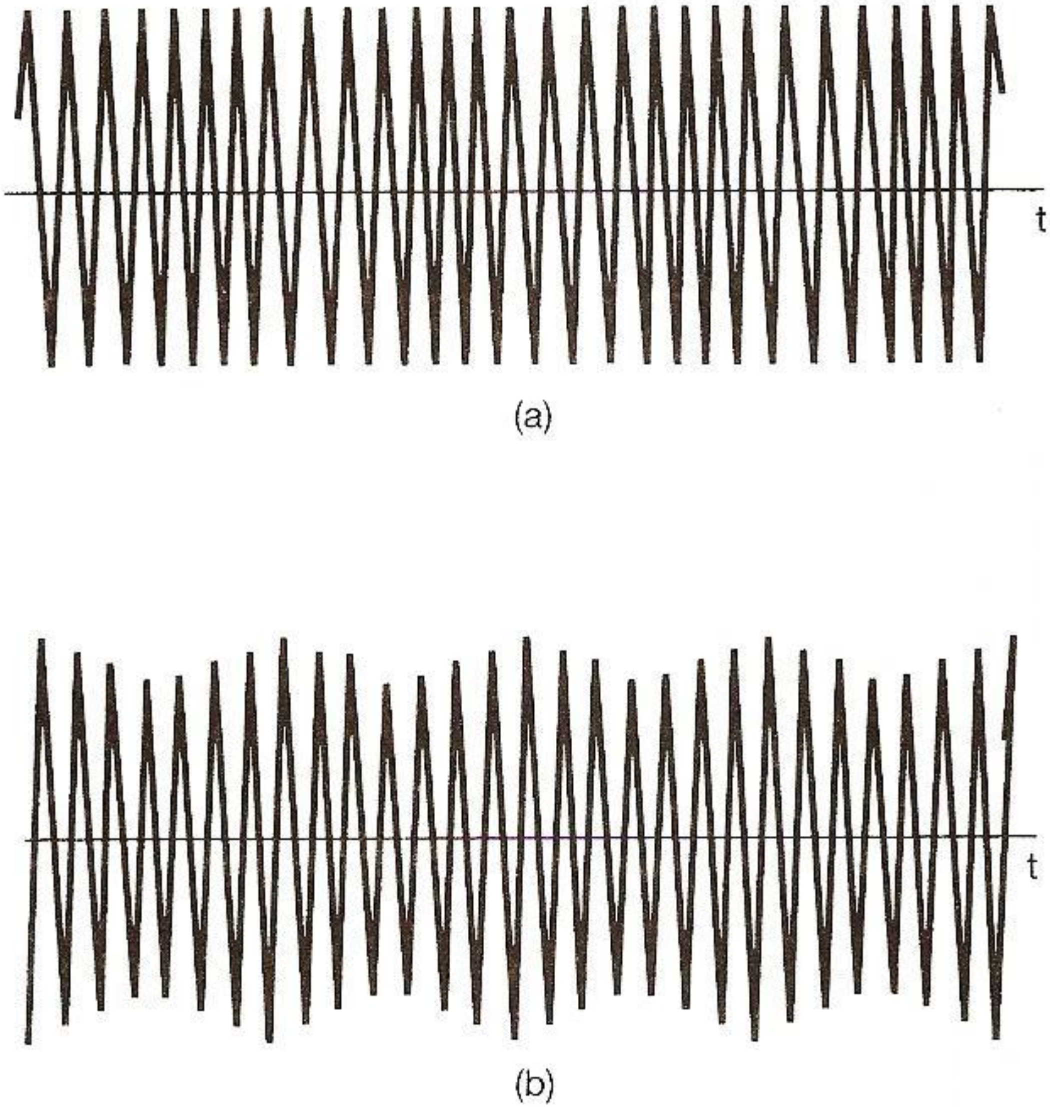



**Figure 8.34** Comparison of narrowband FM and AM-DSB/WC: (a) narrowband FM; (b) AM-DSB/WC.

# Spectrum of FM Signals

- Wideband FM , $m$ not small

$$y(t) = \cos\omega_c t\cos(m\sin\omega_m t) - \sin\omega_c t\sin(m\sin\omega_m t)$$

– $\cos(m\sin\omega_m t)$, $\sin(m\sin\omega_m t)$

periodic with fundamental frequency $\omega_m$

with spectrum of impulses at multiples of $\omega_m$

*See Figs. 8.35, p.616 of text*

n-th harmonics considered negligible, $|\,n\,| > m$

$$B \approx 2m\omega_m = 2\Delta\omega = 2k_f A$$

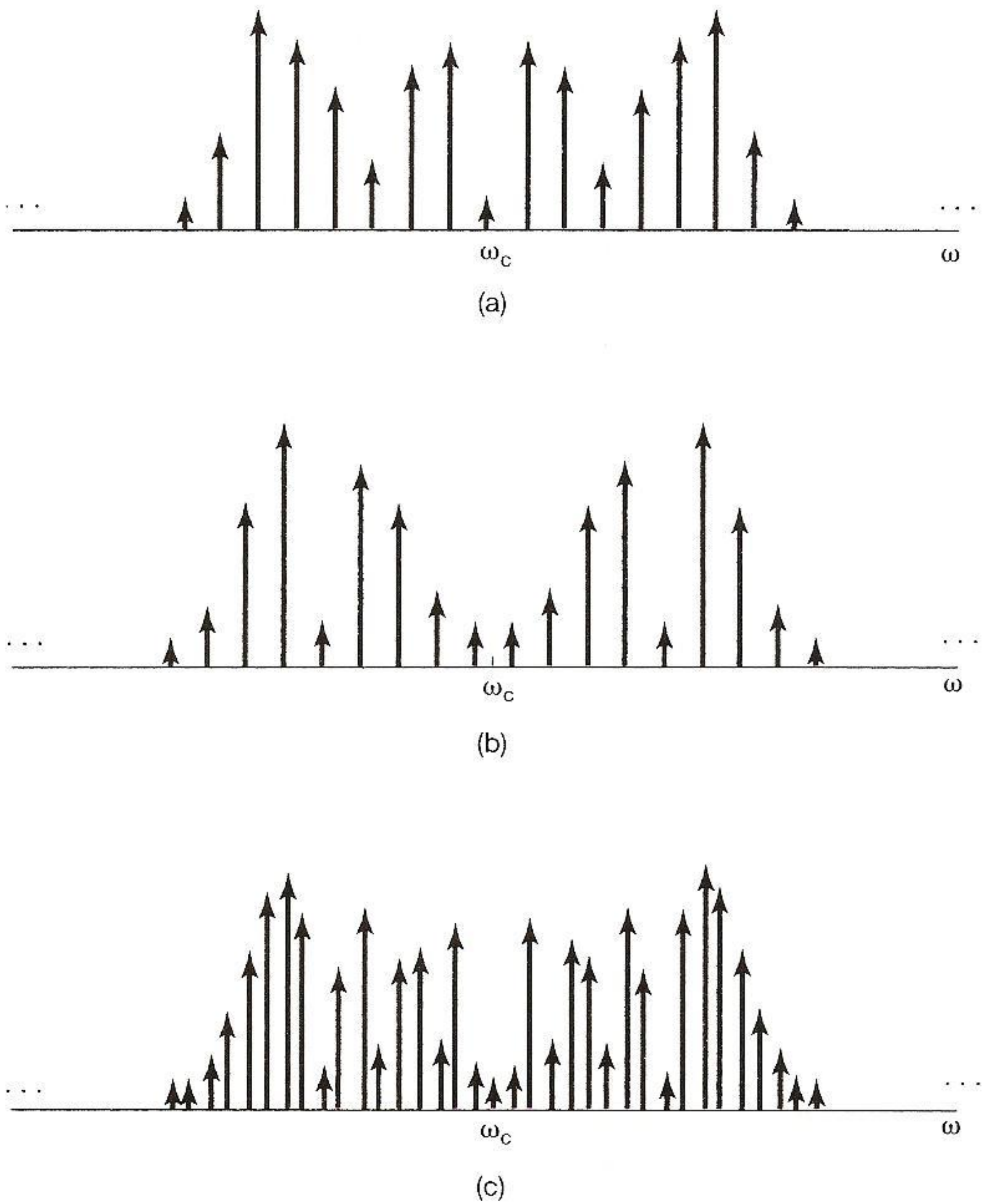



**Figure 8.35** Magnitude of spectrum of wideband frequency modulation with $m = 12$: (a) magnitude of spectrum of $\cos \omega_c t \cos[m \sin \omega_m t]$; (b) magnitude of spectrum of $\sin \omega_c t \sin[m \sin \omega_m t]$; (c) combined spectral magnitude of $\cos[\omega_c t + m \sin \omega_m t]$.

# Spectrum of FM Signals

- Example : periodic square wave signal

$$x(t): \text{periodic square - wave, } k_f = 1,\ \Delta\omega = A$$

$$\omega_i(t) = \omega_c + \Delta\omega \quad \text{or} \quad \omega_c - \Delta\omega$$

$$y(t) = r(t)\cos[(\omega_c + \Delta\omega)t] + r\left(t - \frac{T}{2}\right)\cos[(\omega_c - \Delta\omega)t]$$

*See Figs. 8.36-8.39, p.617, 618 of text*

$$Y(j\omega) = \frac{1}{2}[R(j\omega + j\omega_c + j\Delta\omega) + R(j\omega - j\omega_c - j\Delta\omega)]$$

$$+ \frac{1}{2}[R'(j\omega + j\omega_c - j\Delta\omega) + R'(j\omega - j\omega_c + j\Delta\omega)]$$

$$R'(j\omega) = e^{-j\omega T/2}R(j\omega)$$

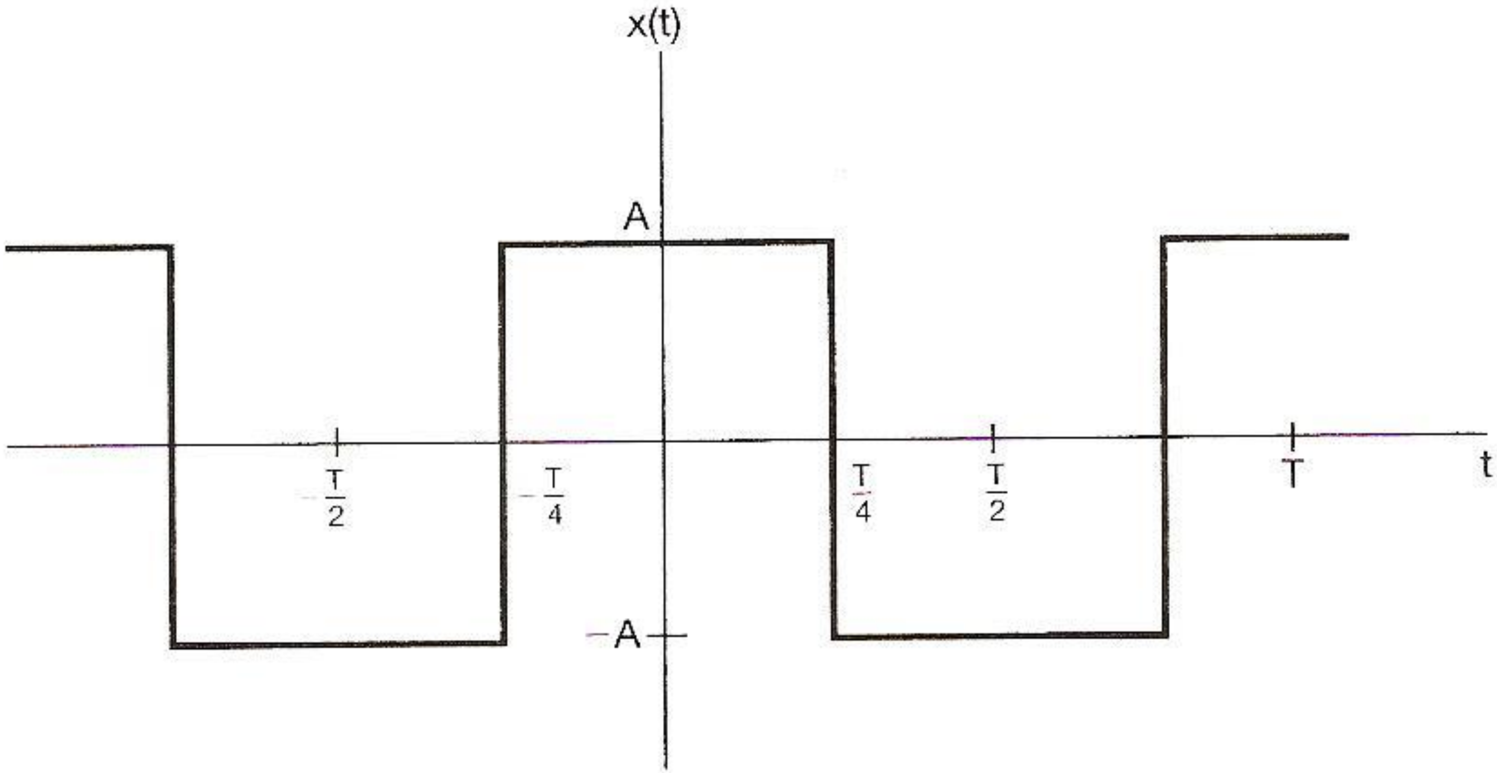



**Figure 8.36** Symmetric periodic square wave.

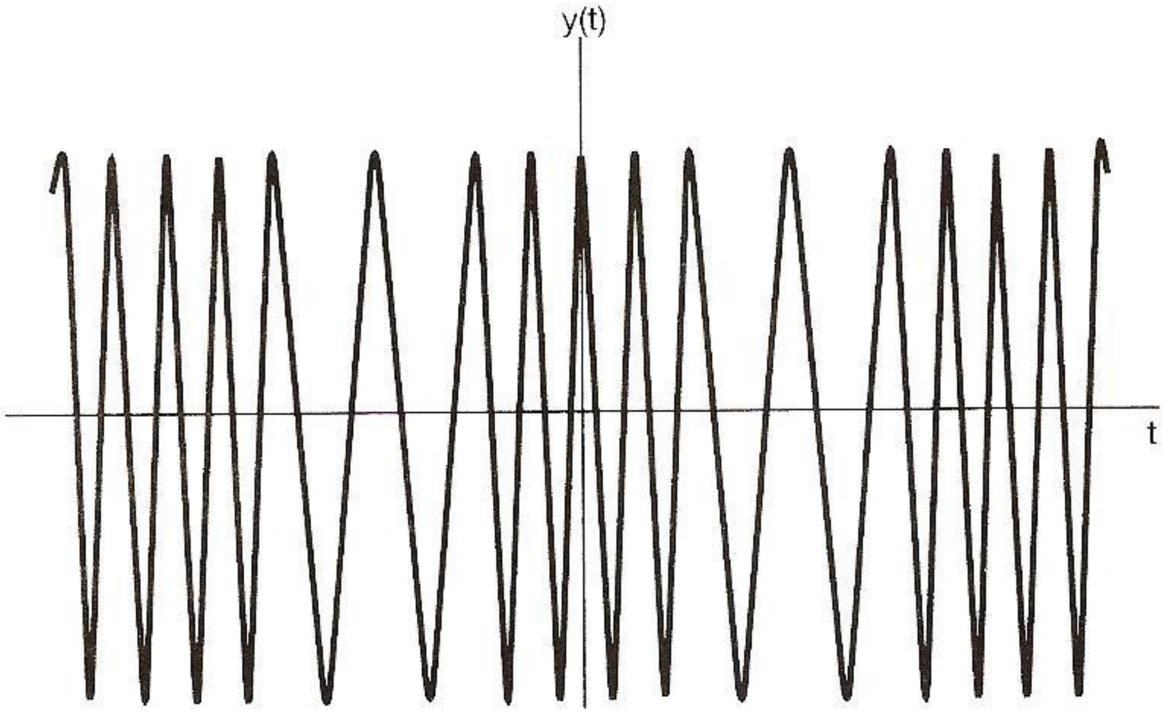



**Figure 8.37** Frequency modulation with a periodic square-wave modulating signal.

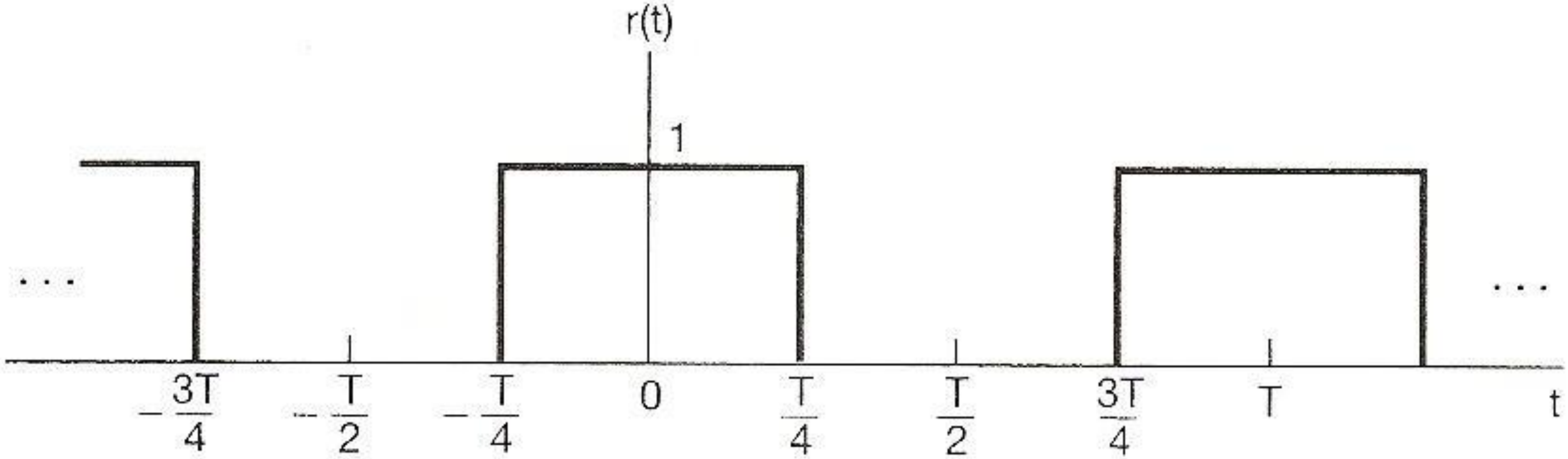



**Figure 8.38** Symmetric square wave $r(t)$ in eq. (8.50).

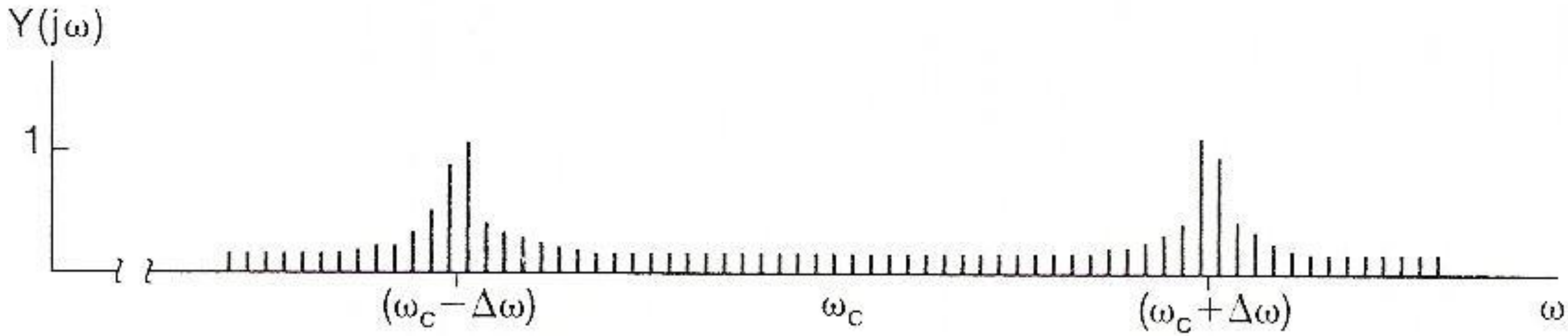



**Figure 8.39** Magnitude of the spectrum for $\omega > 0$ corresponding to frequency modulation with a periodic square-wave modulating signal. Each of the vertical lines in the figure represents an impulse of area proportional to the height of the line.

# 8.4 Discrete-time Modulation

- Complex exponential carrier

$$c[n] = e^{j\omega_c n}$$

$$C\left(e^{j\omega}\right) = \sum_{k=-\infty}^{\infty} 2\pi\delta(\omega - \omega_c + k2\pi)$$

$$y[n] = x[n]c[n]$$

$$Y\left(e^{j\omega}\right) = \frac{1}{2\pi}\int_{2\pi} X\left(e^{j\theta}\right)C\left(e^{j(\omega-\theta)}\right)d\theta$$

*See Figs. 8.41, p.620 of text*

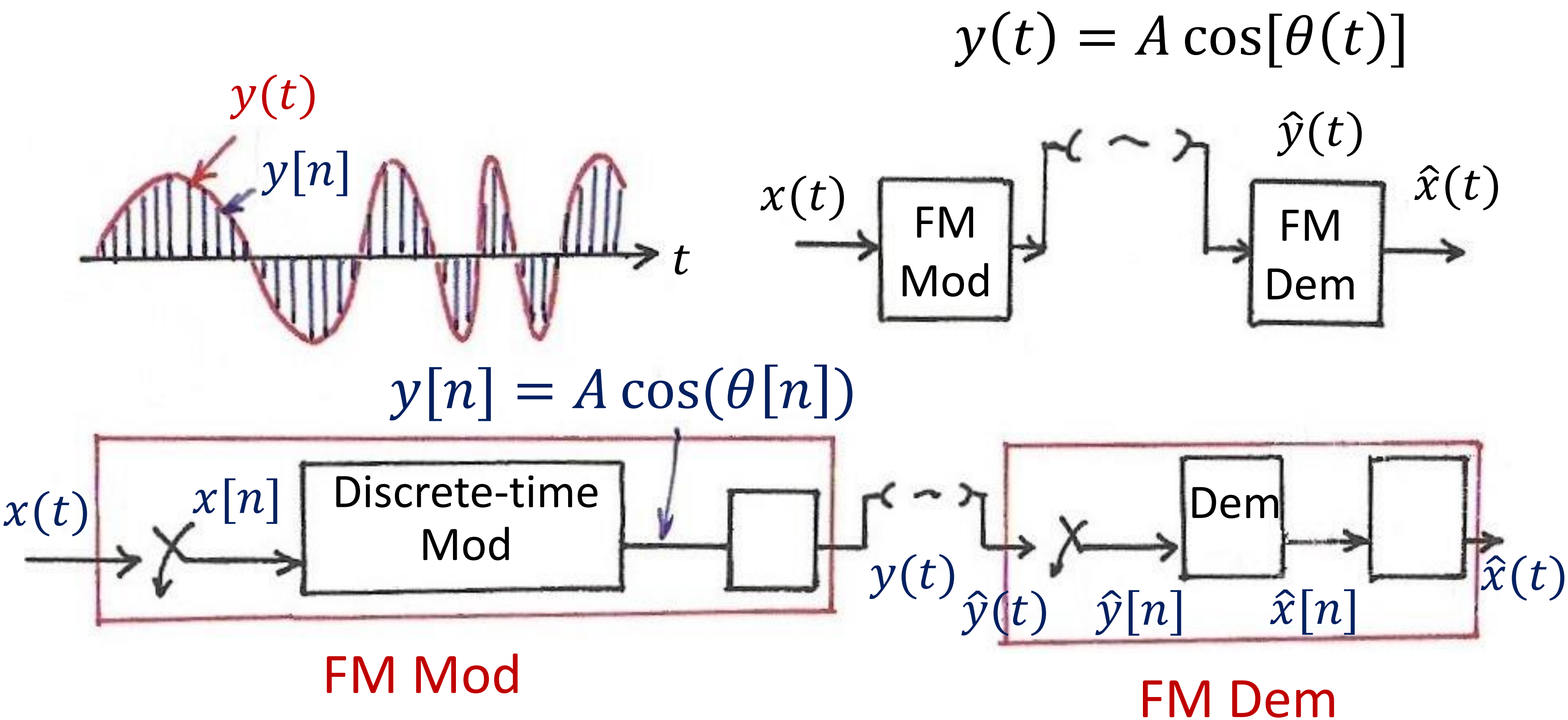
- Sinusoidal carrier

$$c[n] = \cos\omega_c n$$

*See Figs. 8.42, 8.43, p.621, 612 of text*

- Example : Software Defined Radio

# Discrete-time Realization of Continuous-time Modulation



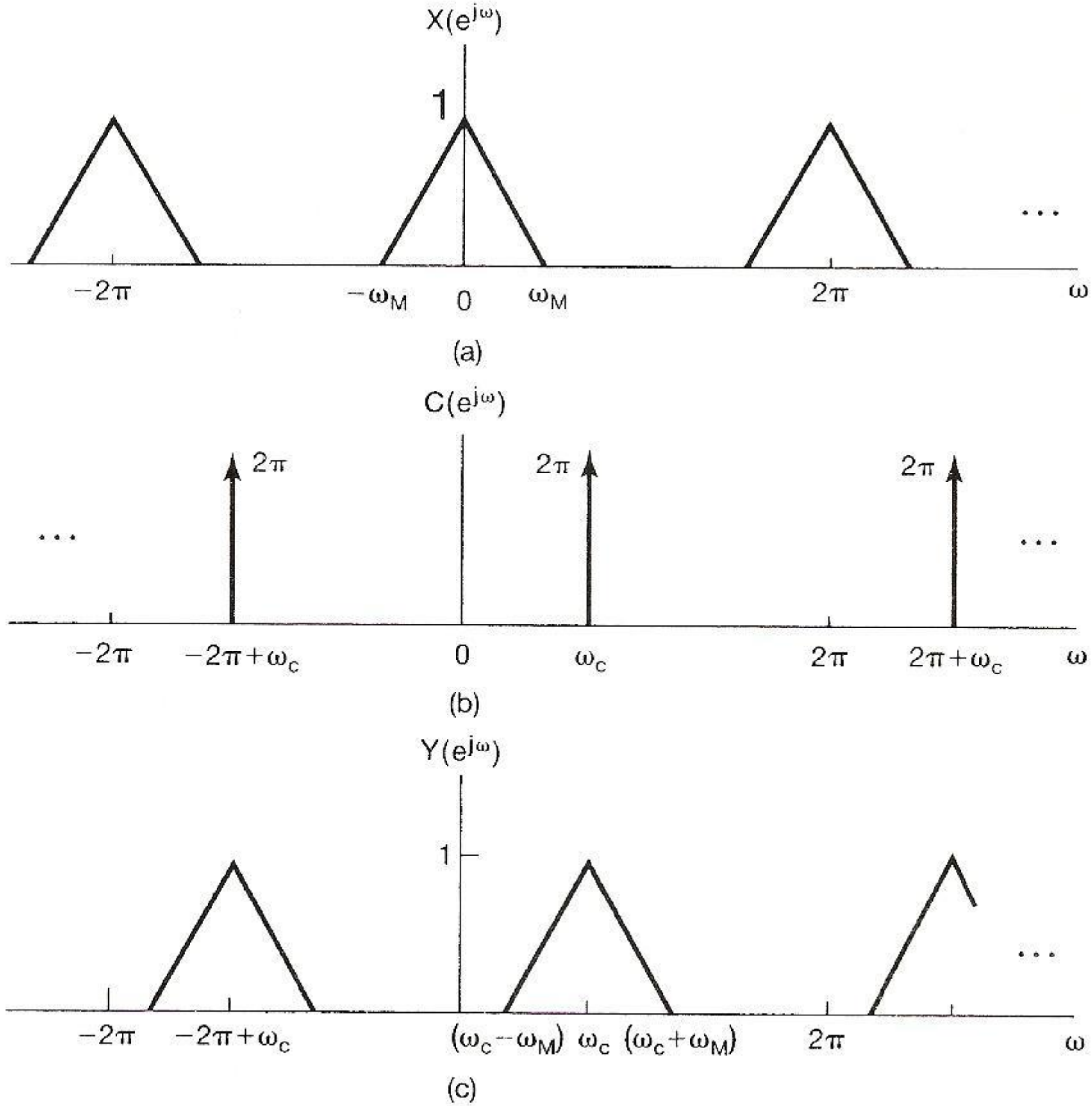



**Figure 8.41** (a) Spectrum of $x[n]$; (b) spectrum of $c[n] = e^{j\omega_c n}$; (c) spectrum of $y[n] = x[n]c[n]$.

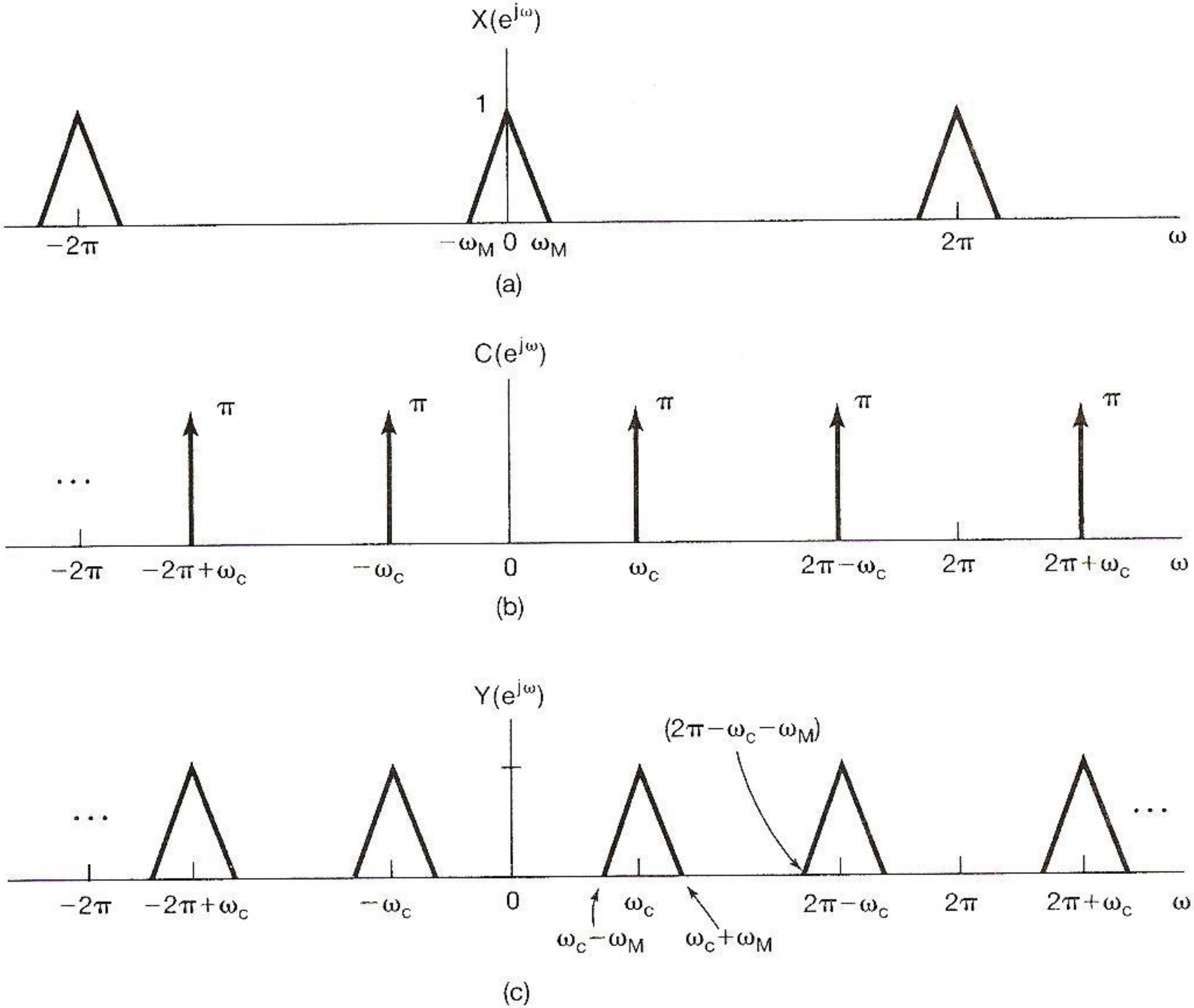



**Figure 8.42** Spectra associated with discrete-time modulation using a sinusoidal carrier: (a) spectrum of a bandlimited-signal $x[n]$; (b) spectrum of a sinusoidal carrier signal $c[n] = \cos \omega_c n$; (c) spectrum of the modulated signal $y[n] = x[n]c[n]$.

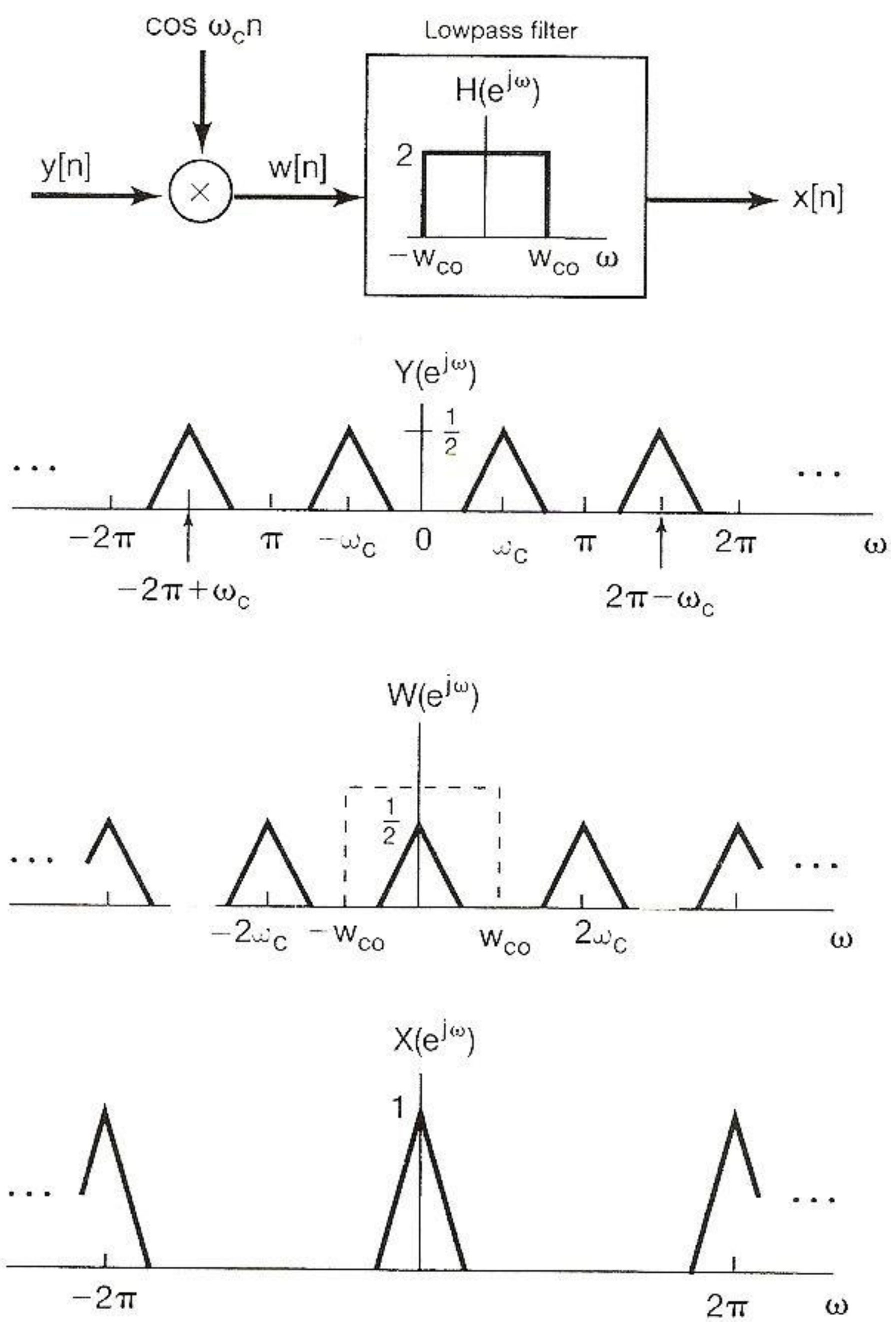
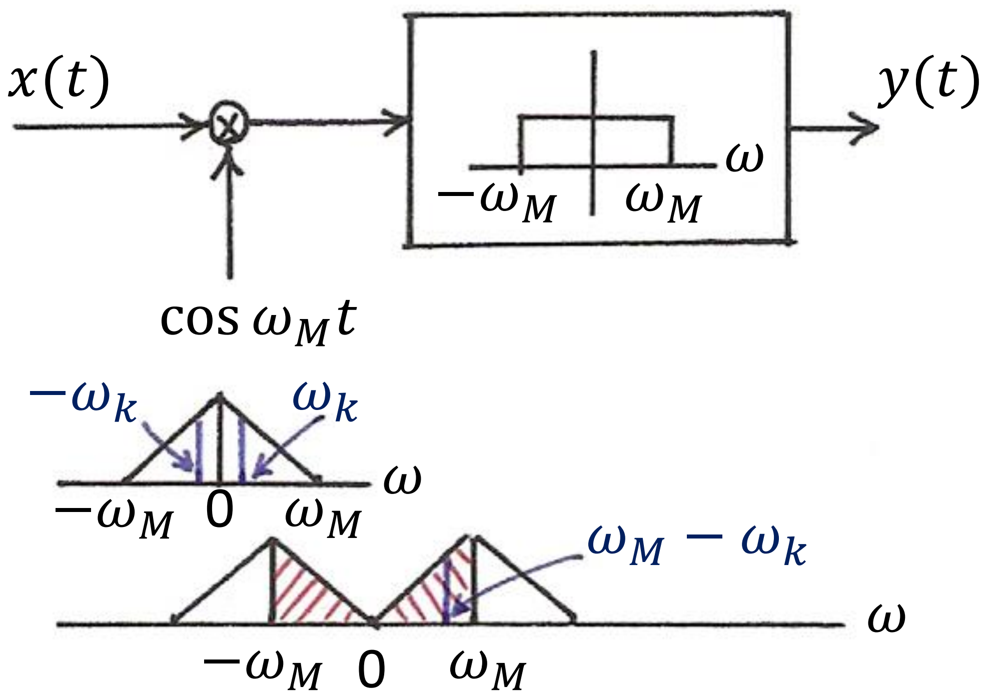



**Figure 8.43** System and associated spectra for discrete-time synchronous demodulation.

# Problems

- **Problem 8.25, p.633 of text**
  - Frequency inverter as a speech scrambler for secure speech communication

$$X(j\omega) = 0,\ |\omega| > \omega_M,\ x(t)\ \text{real}$$




  - Inverse system is itself

# Problems

- **Problem 8.34, p.640 of text**
  - Implementing AM with a nonlinear element (multiplier is difficult to implement)

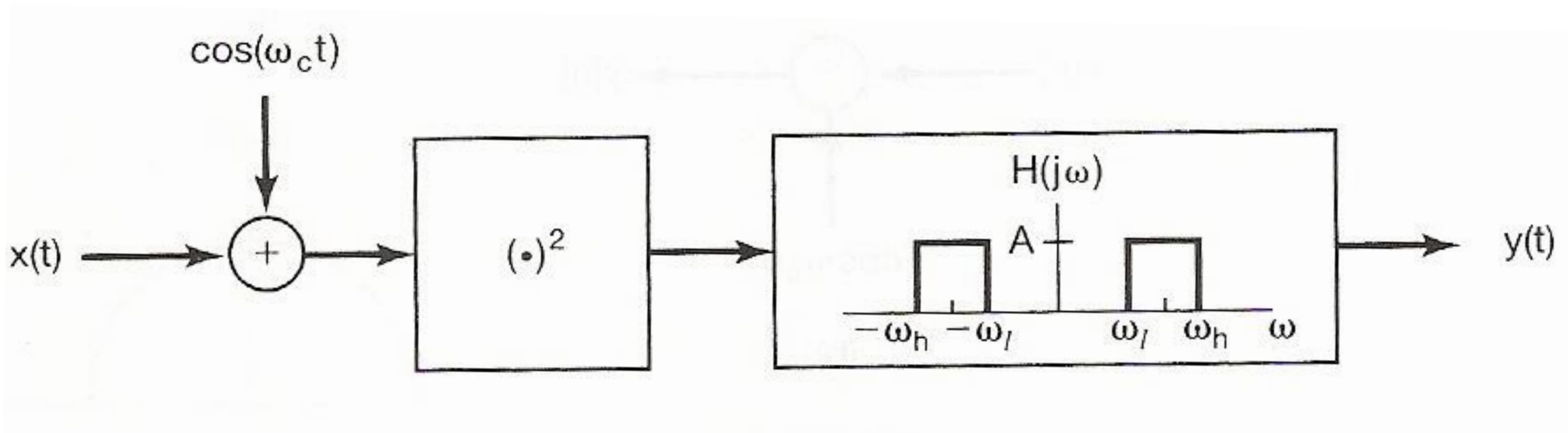



Figure P8.34

$$[x(t) + \cos \omega_c t]^2 = x^2(t) + \cos^2(\omega_c t) + 2x(t)\cos(\omega_c t)$$

↑ ↑

removed by filtering

# Problems

- **Problem 8.39, p.645 of text**
  - Frequency Shift Keying (FSK) for digital transmission

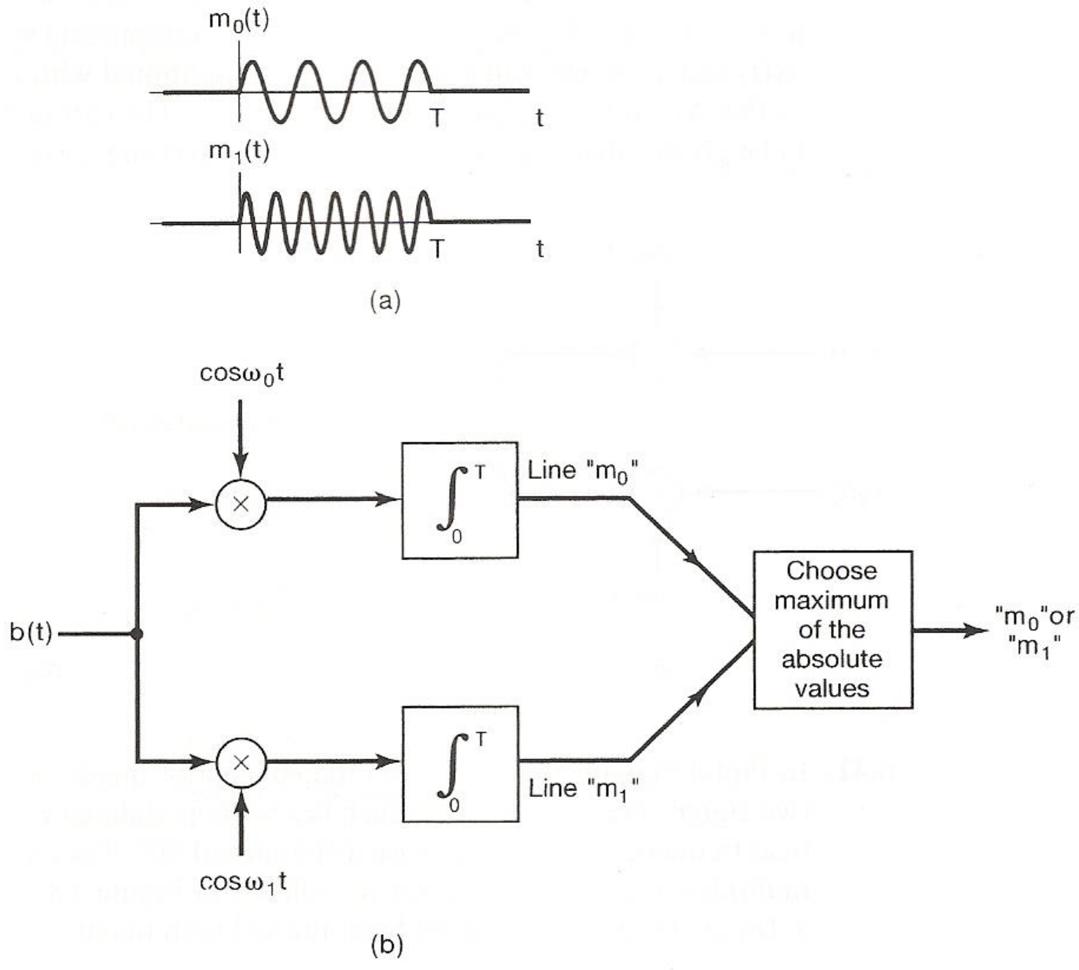
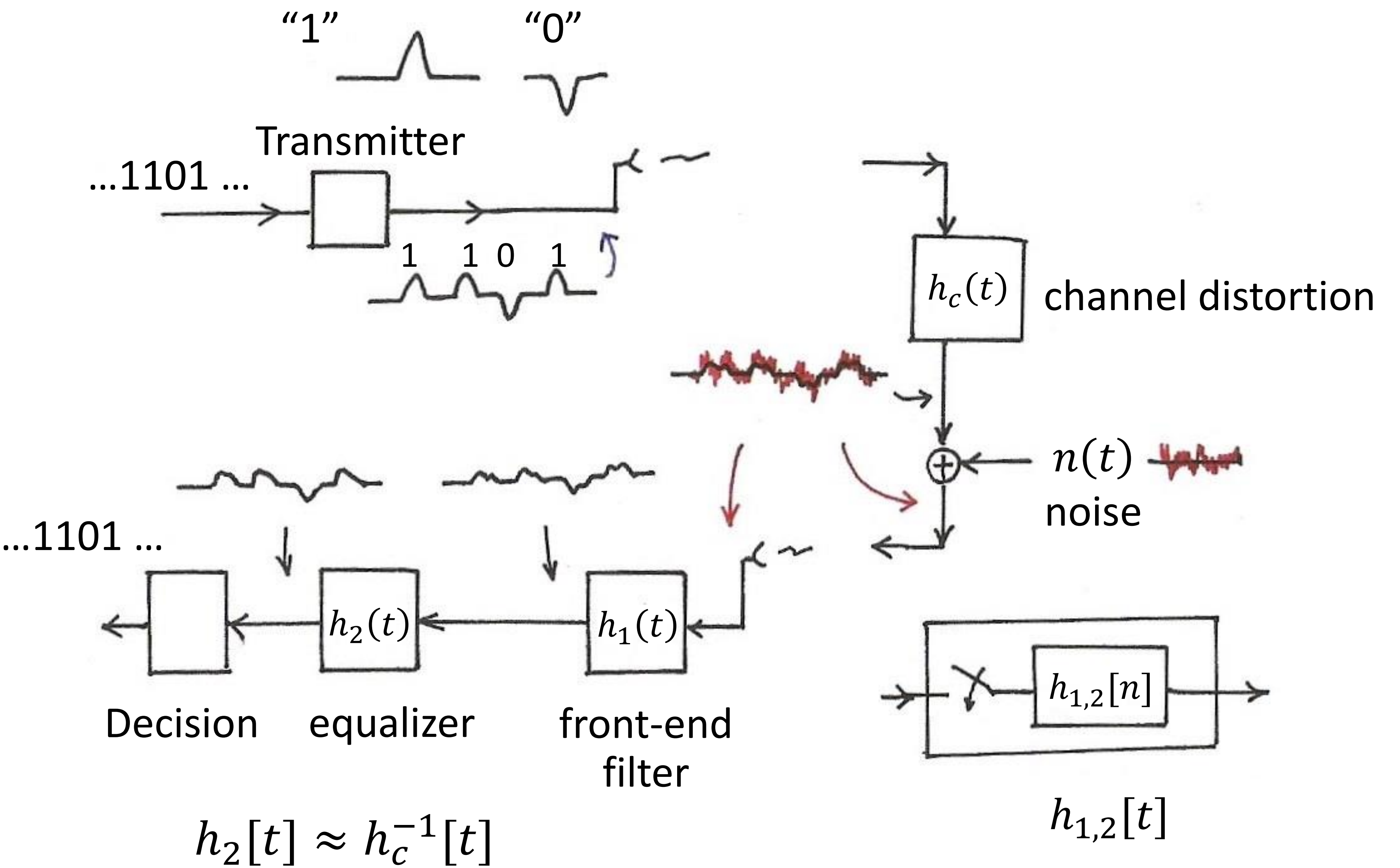



**Figure P8.39**

# Data Transmission (p.111 of 2.0) (p.2 of 8.0)



# Problems

- **Problem 8.39, p.645 of text**

(a) $x_k = 0,$

$$y = |y_0| - |y_1| = \left|\int_0^T \cos^2(\omega_0 t)dt\right| - \left|\int_0^T (\cos\omega_0 t)(\cos\omega_1 t)dt\right|$$

$x_k = 1,$

$$-y = |y_1| - |y_0| = \left|\int_0^T \cos^2(\omega_1 t)dt\right| - \left|\int_0^T (\cos\omega_0 t)(\cos\omega_1 t)dt\right|$$

$y$ or $-y$ maximized when

$$\left|\int_0^T (\cos\omega_0 t)(\cos\omega_1 t)dt\right| = \int_0^T (\cos\omega_0 t)(\cos\omega_1 t)dt = 0$$

"orthogonal" but evaluated in a period of T

(b) $\int_0^T (\cos\omega_0 t)(\cos\omega_1 t)dt = \frac{1}{2}\int_0^T [\cos(\omega_0 + \omega_1)t + \cos(\omega_0 - \omega_1)t]dt = 0$

when T is a common multiple of the periods of both $\cos(\omega_0 + \omega_1)t$ and $\cos(\omega_0 - \omega_1)t$

# Problems

- **Problem 8.40, p.646 of text**
  - Quadrature multiplexing

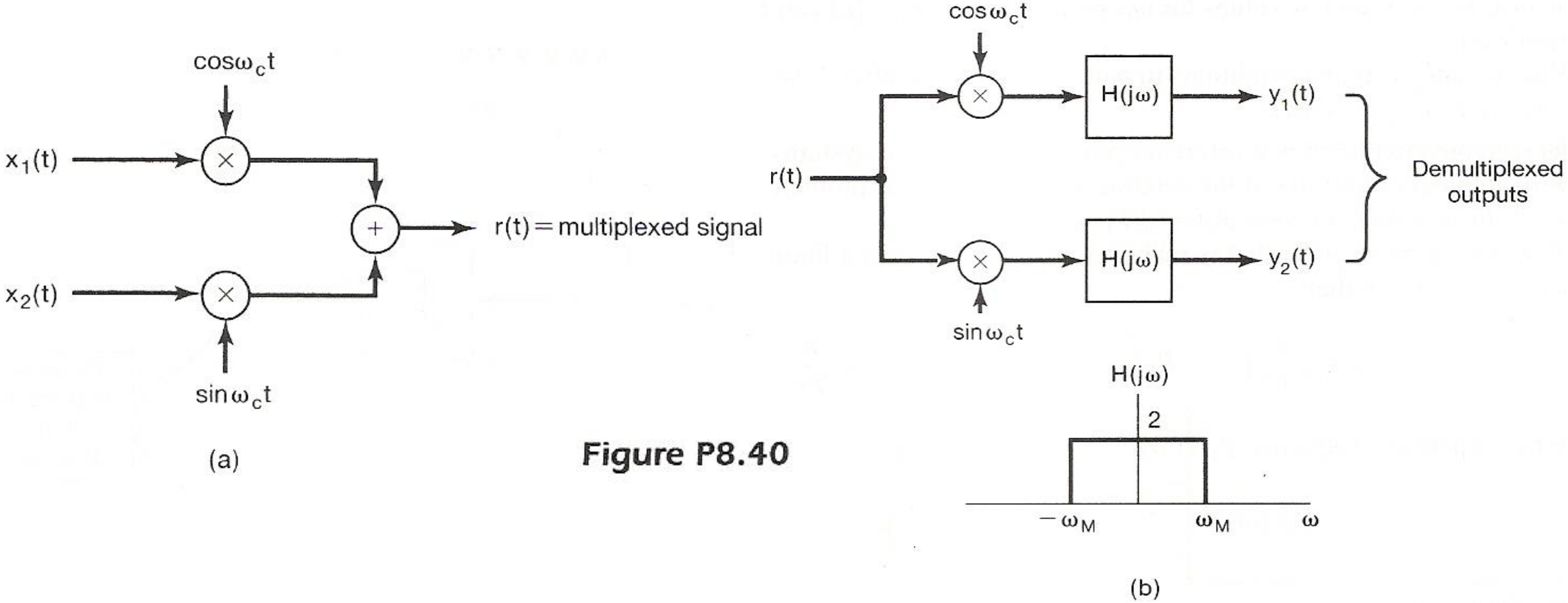



Figure P8.40

# Problems

- **Problem 8.40, p.646 of text**

$$\left[x_1(t)\cos\omega_c t + x_2(t)\sin\omega_c t\right]\cos\omega_c t$$

$$= x_1(t)\underbrace{\cos^2(\omega_c t)}_{\uparrow\ 1,\ \cos(2\omega_c t)} + x_2(t)\underbrace{(\sin\omega_c t)(\cos\omega_c t)}_{\uparrow\ \sin(2\omega_c t)}$$

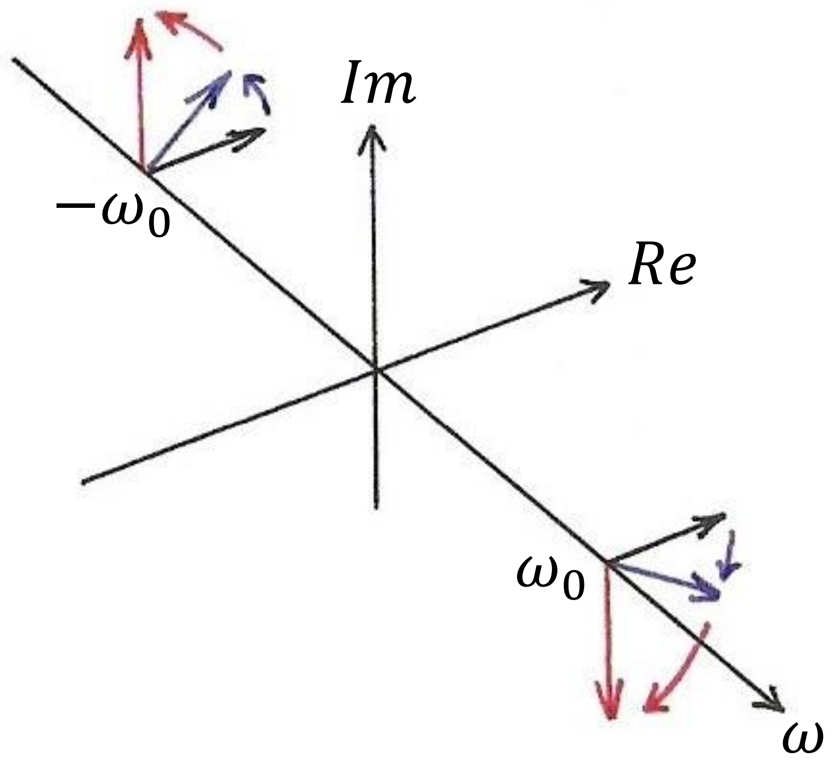
In frequency domain,

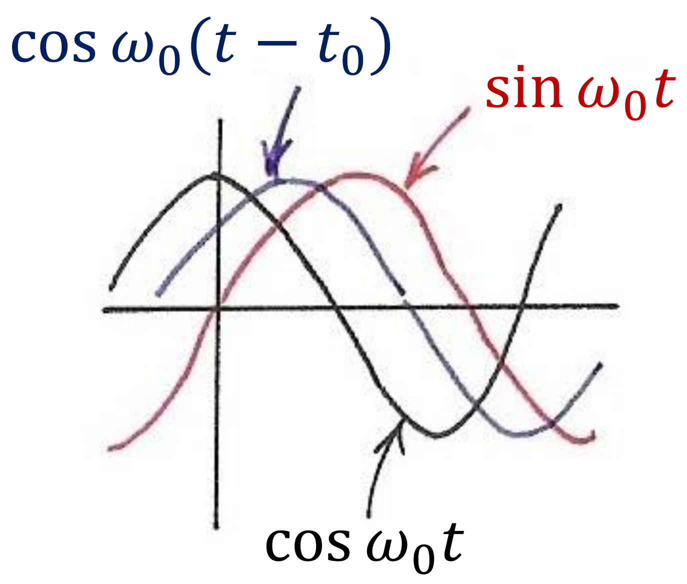
$$\left[X_1\big(j(\omega-\omega_c)\big) + X_1\big(j(\omega+\omega_c)\big)\right] - j\left[X_2\big(j(\omega-\omega_c)\big) - X_2\big(j(\omega+\omega_c)\big)\right]$$

# Sinusoidals (p.25 of 4.0)

$$\cos \omega_0 t \overset{F}{\leftrightarrow} \pi[\delta(\omega - \omega_0) + \delta(\omega + \omega_0)], \quad \tfrac{1}{2}[e^{j\omega_0 t} + e^{-j\omega_0 t}]$$

$$\sin \omega_0 t \overset{F}{\leftrightarrow} \frac{\pi}{j}[\delta(\omega - \omega_0) - \delta(\omega + \omega_0)], \quad \tfrac{1}{2j}[e^{j\omega_0 t} - e^{-j\omega_0 t}]$$

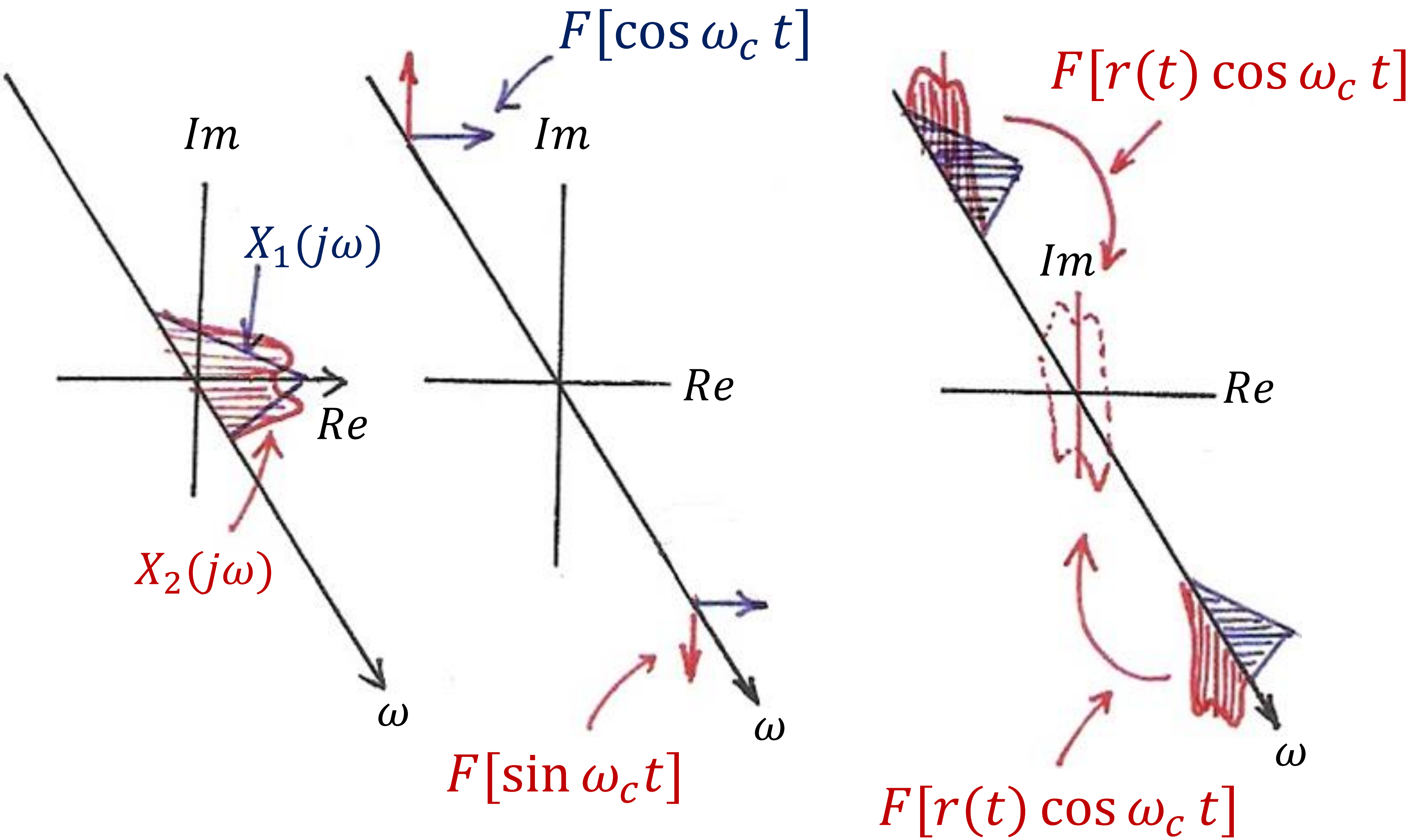



$$x(t - t_0) \leftrightarrow e^{-j\omega_0 t} \cdot X(j\omega)$$

# Problems

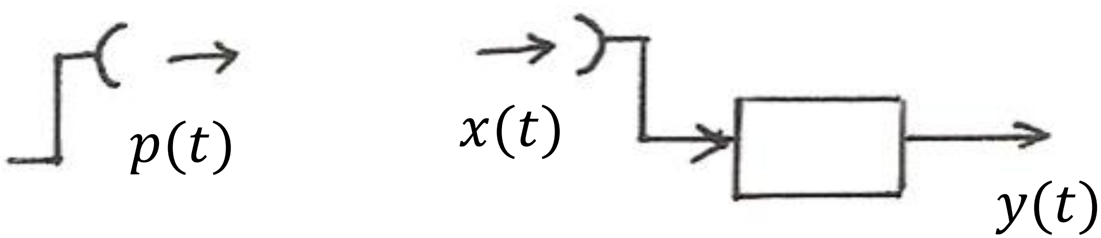
- **Problem 8.40, p.646 of text**

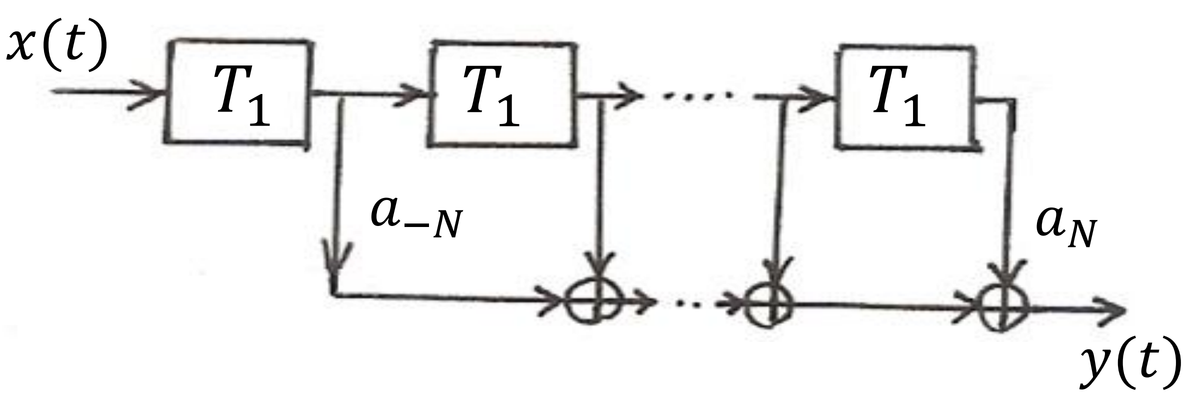


# Problems

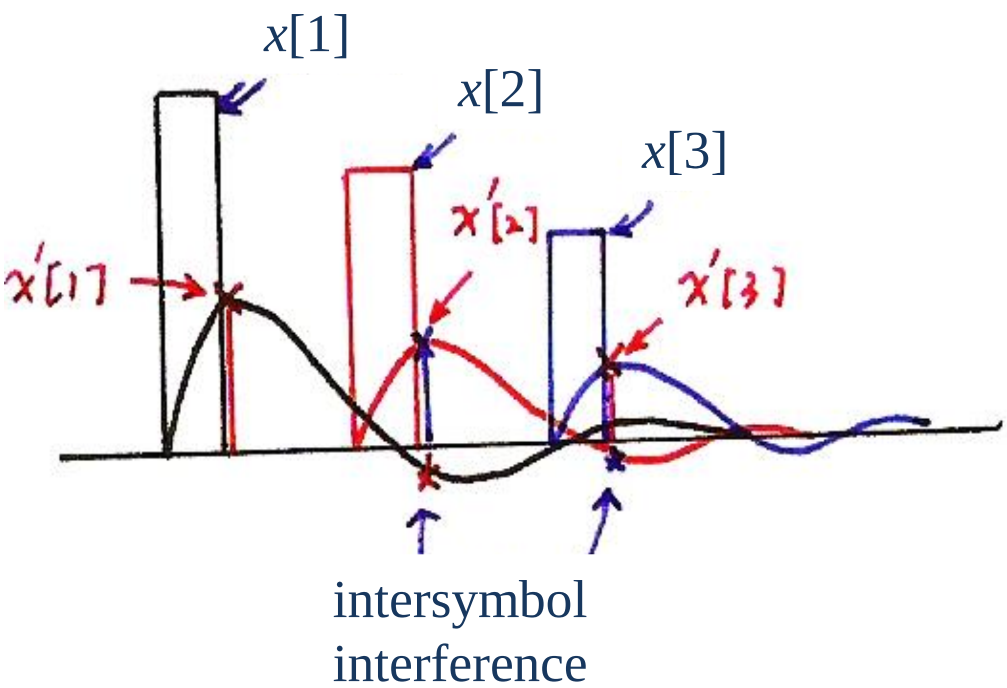
- **Problem 8.44, p.649 of text**
  - Zero-forcing equalizer for pulse transmission

$$y(t) = \sum_{k=-N}^{N} a_k x(t - kT_1)$$



# Intersymbol Interference (p.43 of 8.0)




It is the sample values rather than pulse shapes to be transmitted

Distortionless transmission via distorted channels

# Problems

- **Problem 8.44, p.649 of text**

$$h(t) = \sum_{k=-N}^{N} a_k \delta\left(t - kT_1\right)$$

Requirement: $y(kT_1) = \begin{cases} 1, & \mathrm{k} = 0 \\ 0, & \mathrm{k} = \pm 1,\ \pm 2,\ \pm 3 \cdots \end{cases}$

Example: $N = 1$

$$y(0) = a_1 x(-T_1) + a_0 x(0) + a_{-1} x(T_1) = 1$$
$$y(T_1) = a_1 x(0) + a_0 x(T_1) + a_{-1} x(2T_1) = 0$$
$$y(2T_1) = a_1 x(T_1) + a_0 x(2T_1) + a_{-1} x(3T_1) = 0$$

solve for $a_0, a_1 ...$