- Homework: 8.4, 8.25, 8.29
- Tutorial: 8.34, 8.35, 8.38

review: $H_D(e^{j\omega}) \longrightarrow H_D(e^{j\omega T}) \longrightarrow \tilde{H}_D(e^{j\omega T}) = H_c(j\omega)$

Final Exam $\longrightarrow$ No cheating paper

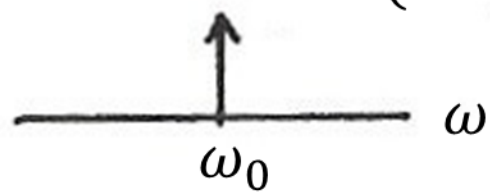
已阅

Chapter 8
Communication Systems

(通信系统)

Review

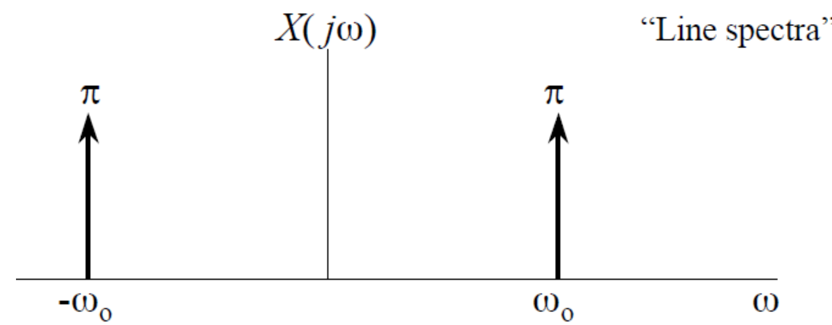
$$e^{j\omega_0 t} \overset{F}{\longleftrightarrow} 2\pi\delta(\omega-\omega_0)$$



$$x(t) = \cos\omega_0 t = \frac{1}{2}e^{j\omega_0 t} + \frac{1}{2}e^{-j\omega_0 t}$$

$$\Updownarrow$$

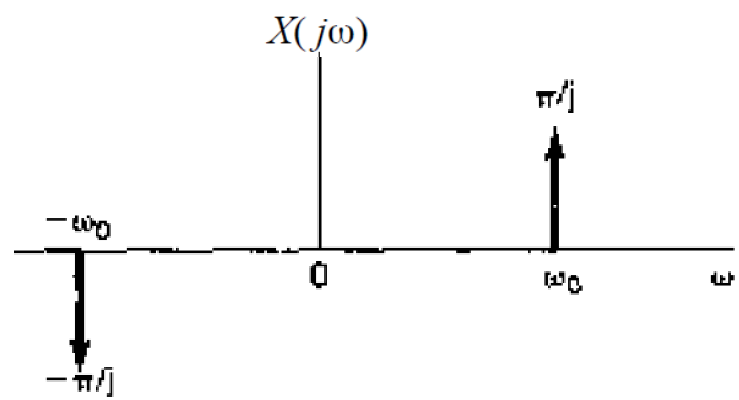
$$X(j\omega) = \pi\delta(\omega-\omega_0) + \pi\delta(\omega+\omega_0)$$



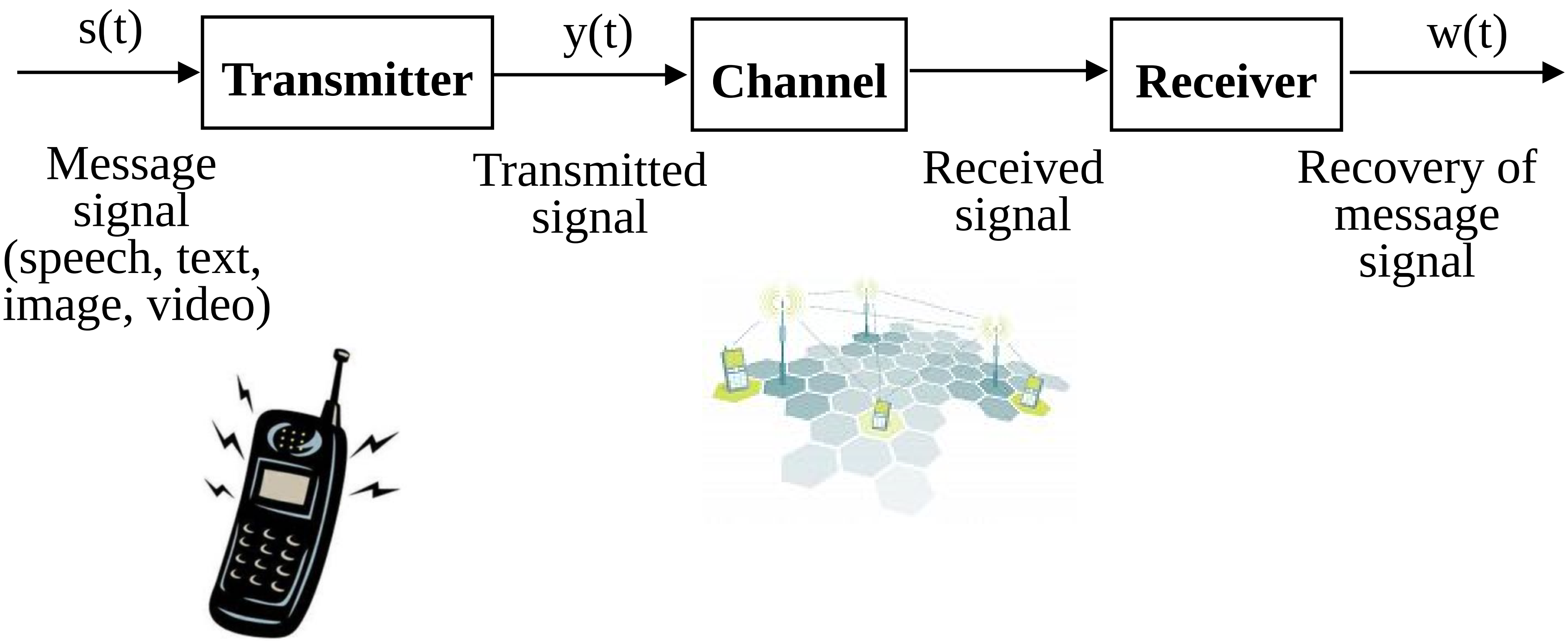
$$x(t) = \sin(\omega_0 t) = \frac{1}{2j}e^{j\omega_0 t} - \frac{1}{2j}e^{-j\omega_0 t}$$

$$\Updownarrow$$

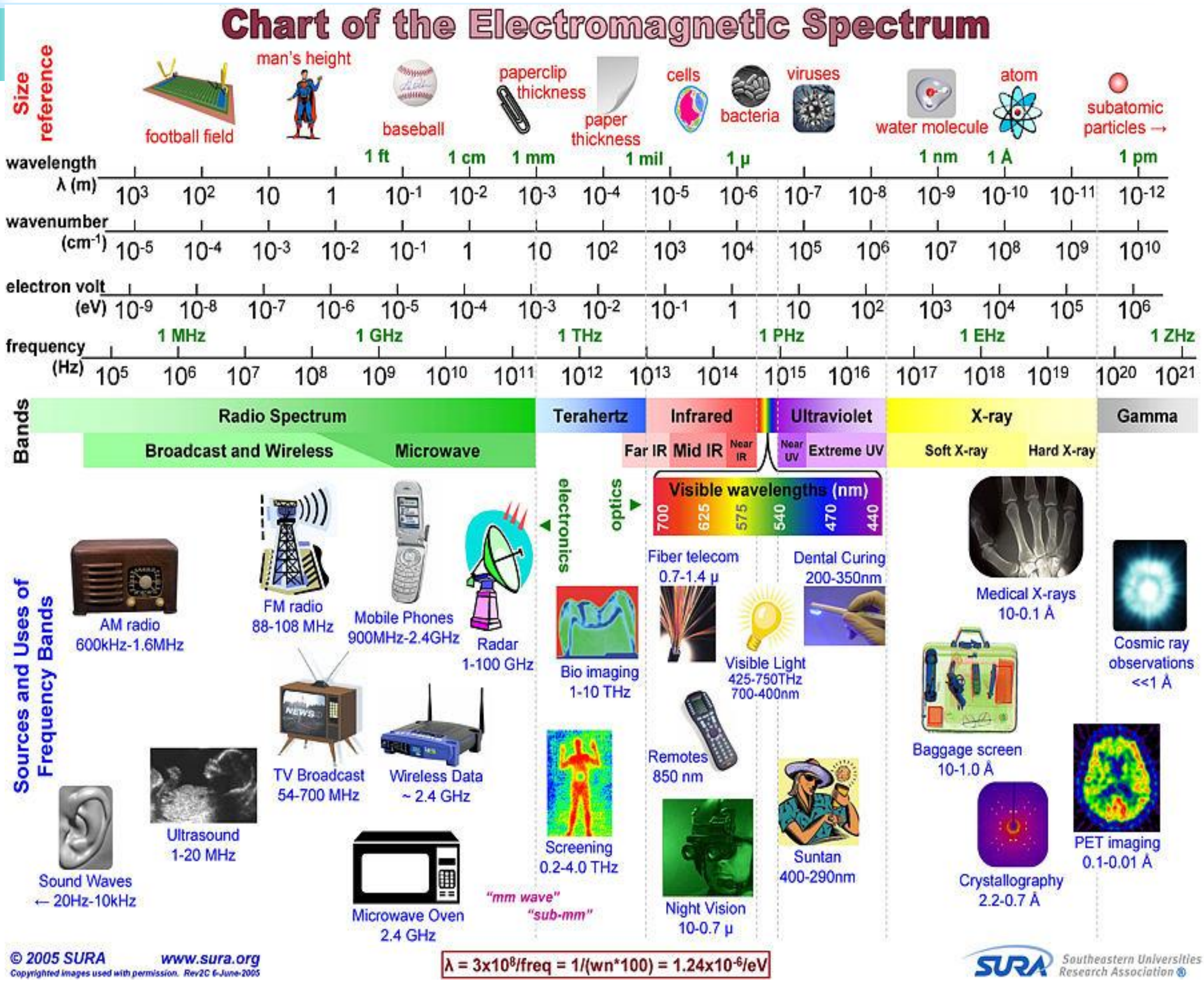
$$X(j\omega) = \frac{\pi}{j}\delta(\omega-\omega_0) - \frac{\pi}{j}\delta(\omega+\omega_0)$$



Communication Systems



Channel (media) Example

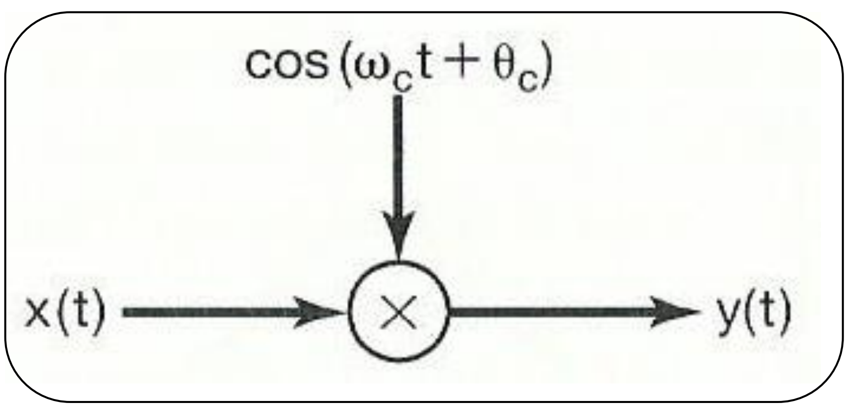


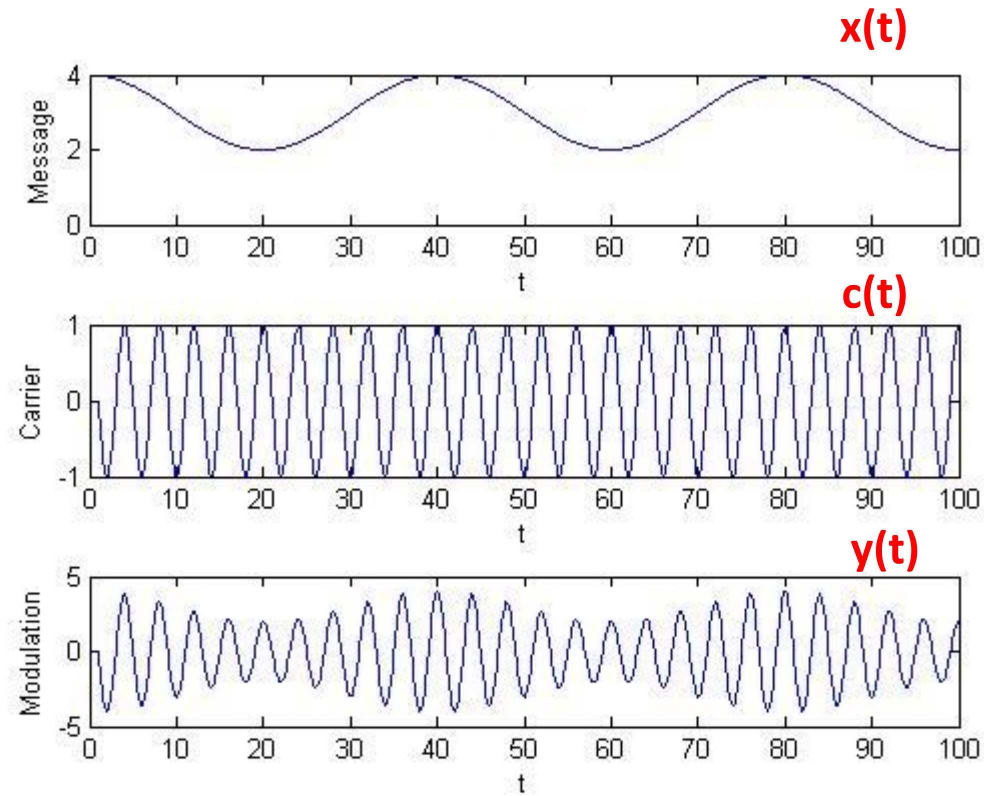
Amplitude modulation调幅

- <u>Modulation</u>: the general process to embed an information-bearing signal into a second signal.

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

x(t): **m**odulating (or message) signal
c(t): **c**arrier signal载波信号
y(t): modulated signal





Amplitude modulation with a complex exponential carrier

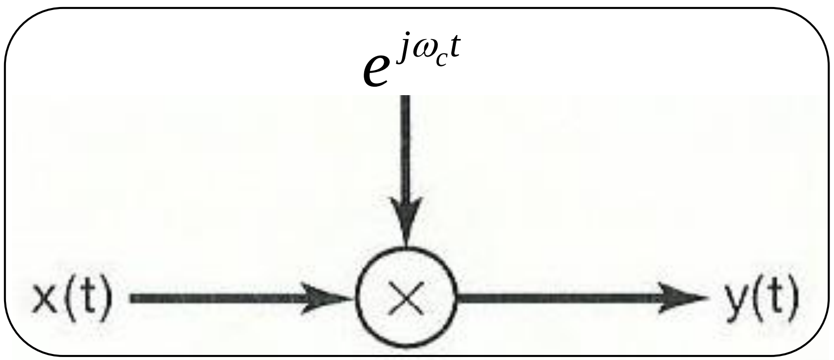
ω_M : the highest frequency in x(t)

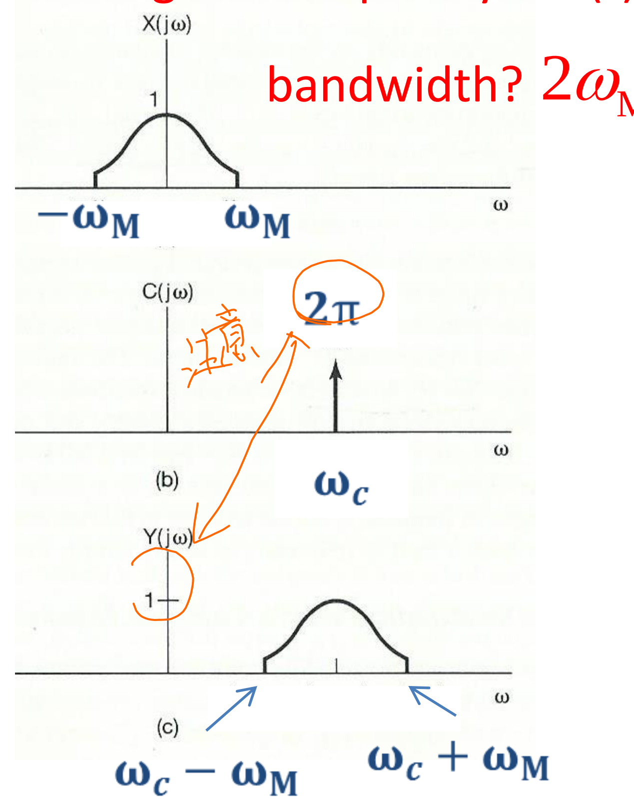
$$c(t) = e^{j(\omega_c t + \theta_c)}$$

ω_c : carrier frequency

First, we suppose $\theta_c = 0$

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

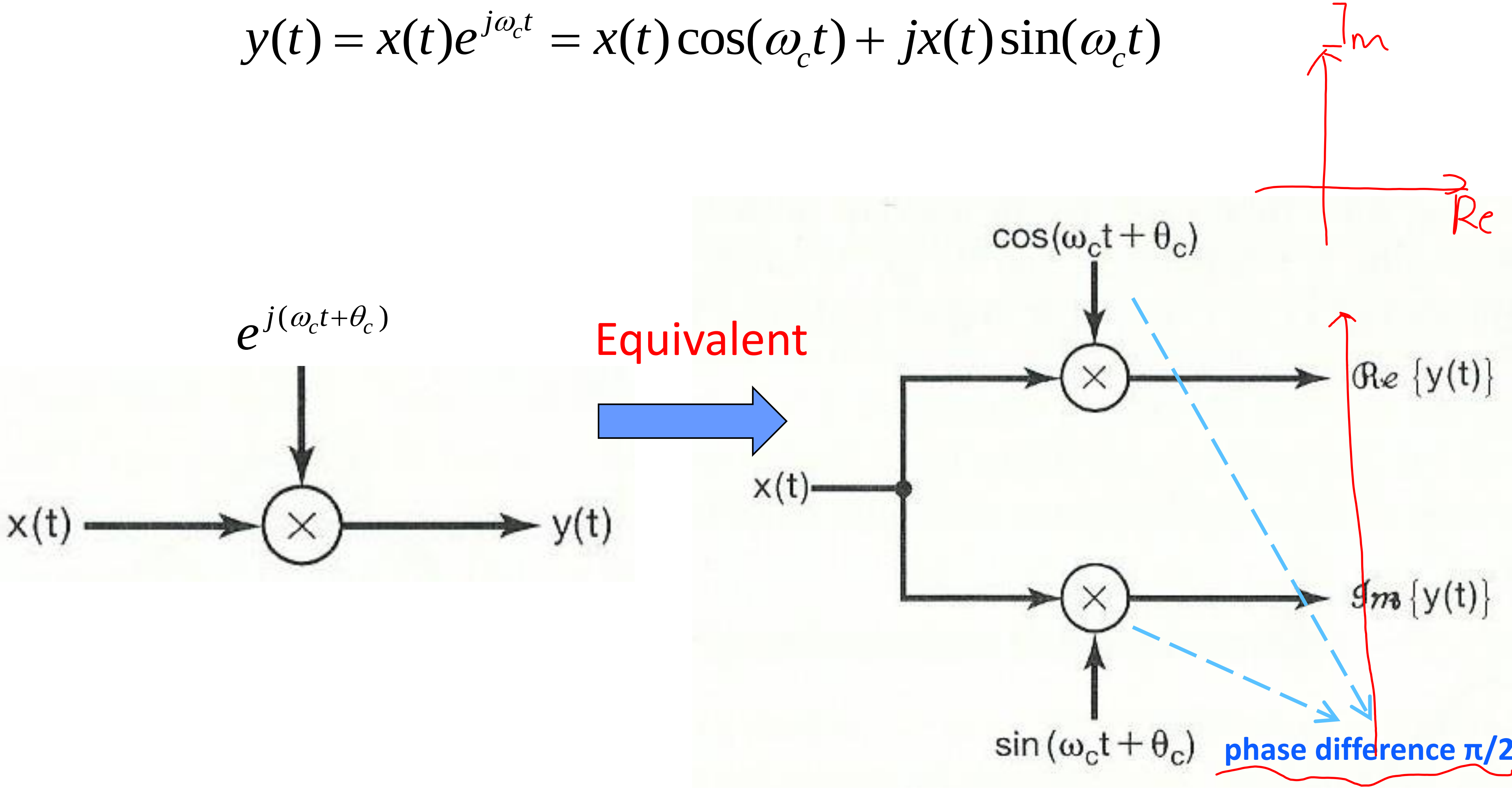




- The spectrum of the modulated output y(t) is that of modulating input x(t), shifted in frequency by amount of carrier frequency ω_c.
- How to recover the modulating input x(t) from modulated signal y(t)?

Amplitude modulation with a complex exponential carrier (cont.)

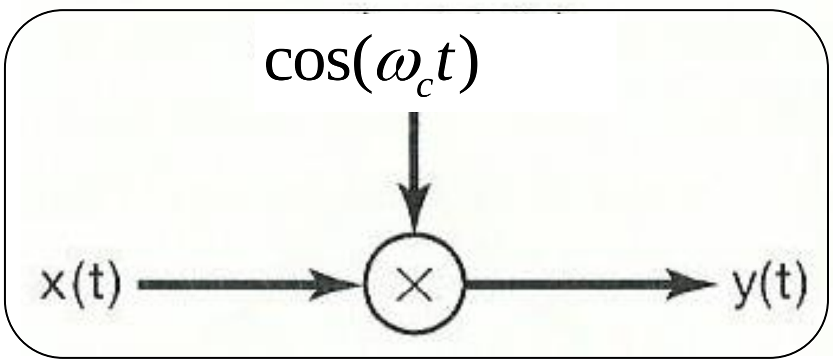
$$y(t) = x(t)e^{j\omega_c t} = x(t)\cos(\omega_c t) + jx(t)\sin(\omega_c t)$$

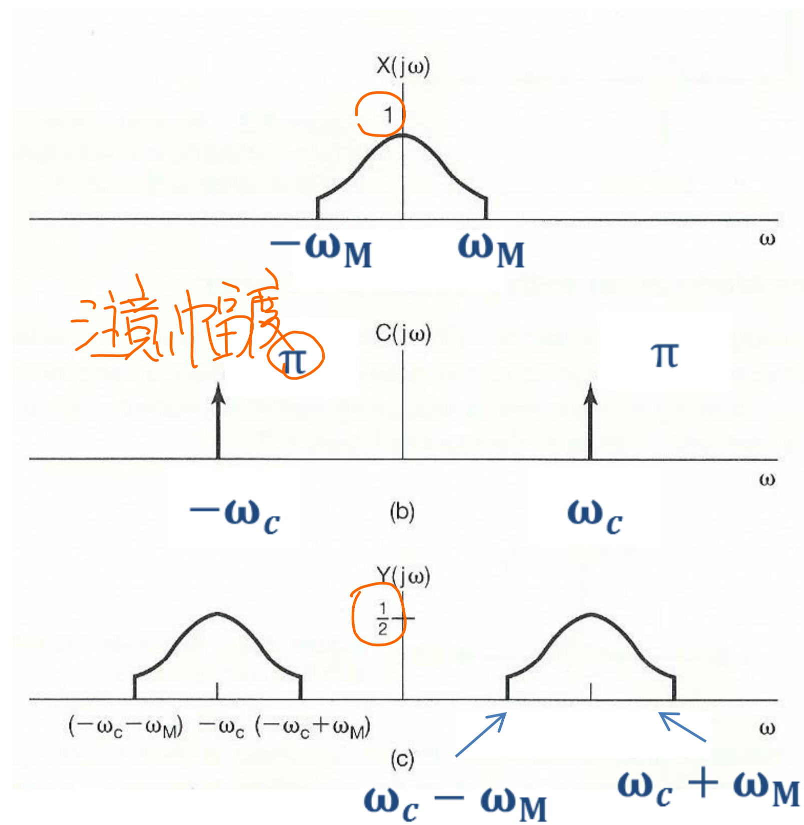


Amplitude modulation with a sinusoidal carrier

First, we suppose $\theta_c = 0$

$$y(t) = x(t)c(t) = x(t)\cos(\omega_c t)$$





What is required if x(t) is recoverable from y(t)?

Condition: $\omega_c > \omega_M$

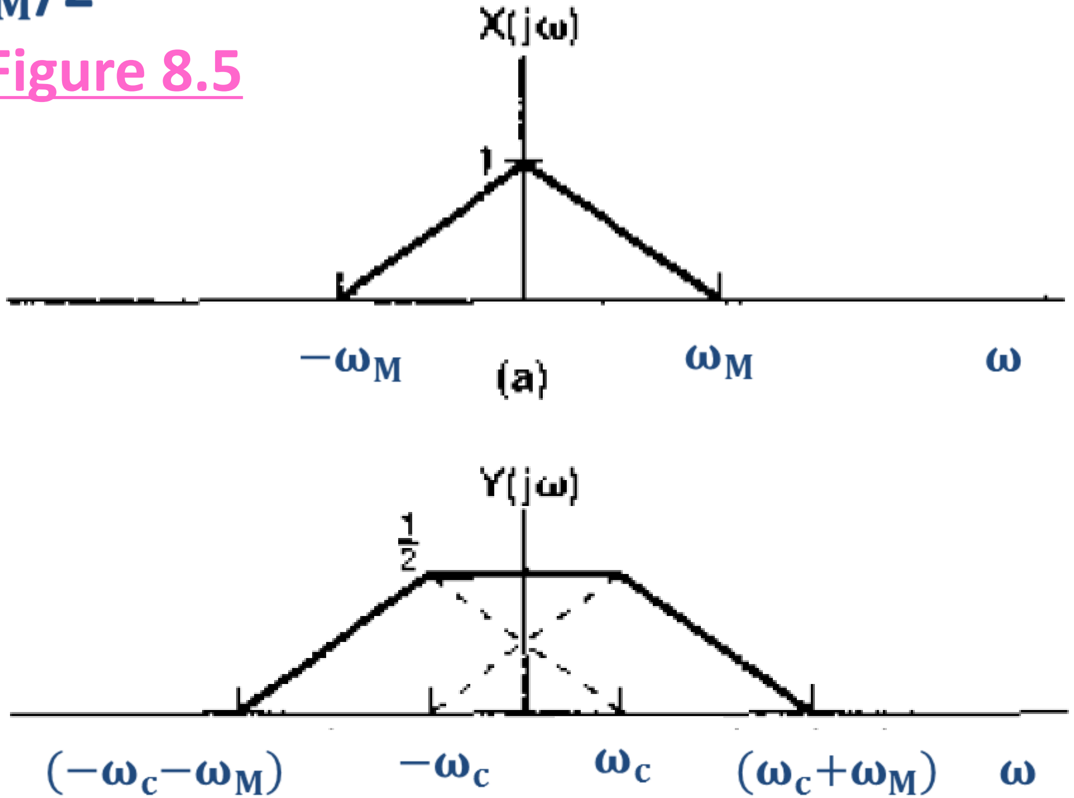
Amplitude modulation with a sinusoidal carrier (cont.)

What happens if $\omega_c < \omega_M$?

Example of an overlapping between the two replications of $X(j\omega)$

$\omega_c = \omega_M/2$

Figure 8.5



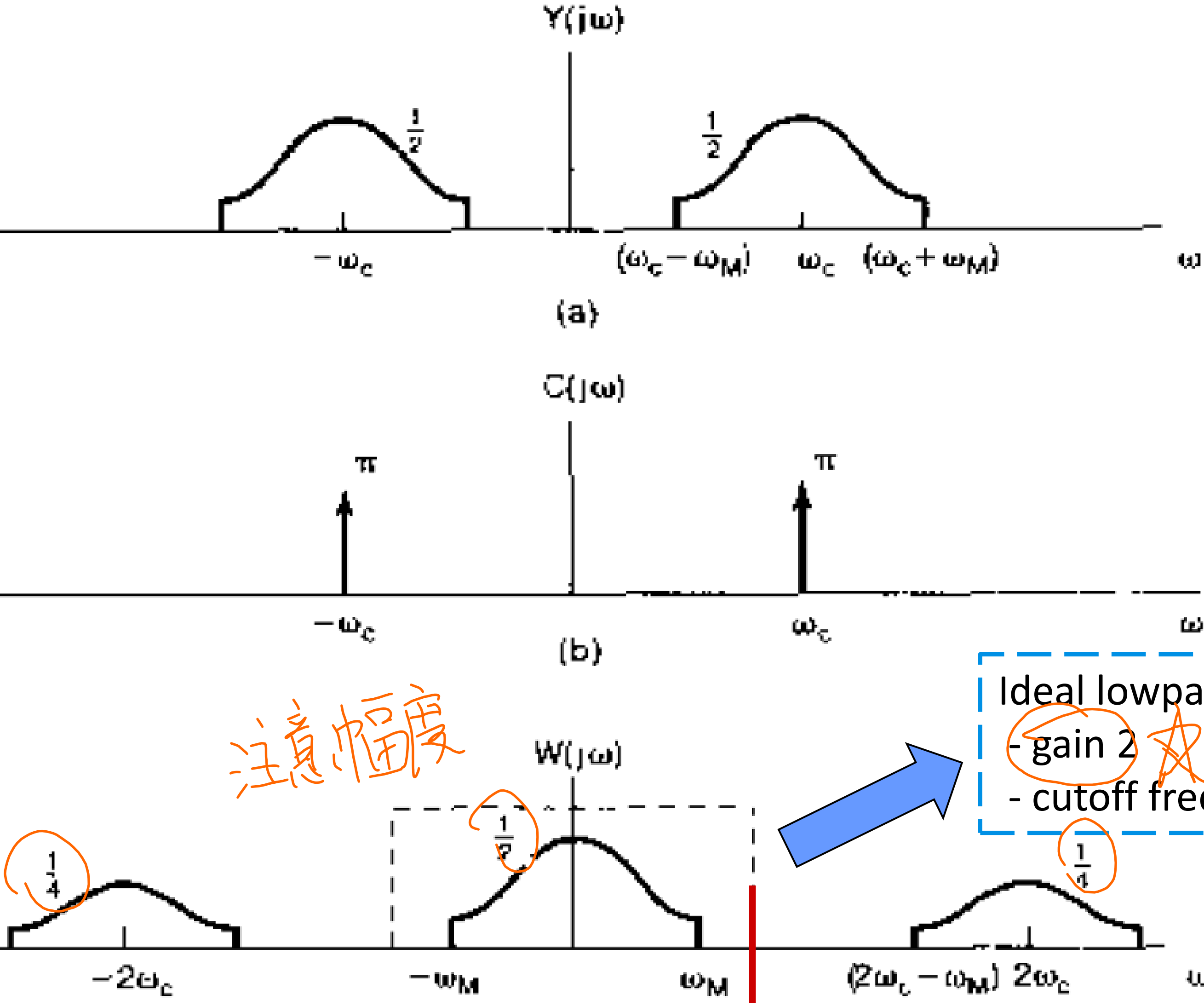
解调

Demodulation for sinusoidal AM

- Purpose: to recover the information-bearing signal x(t) from the modulated signal y(t).
- Two types of AM demodulation:
  - Synchronous demodulation 同步解调, in which transmitter and receiver are synchronized in phase and frequency
  - Asynchronous demodulation 异步解调

Synchronous demodulation

With sinusoidal carrier



注意幅度

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

$$w(t) = y(t)\cos(\omega_c t)$$

$w(t)$: demodulated signal

Ideal lowpass filtering

- gain 2

- cutoff frequency > ω_M and < $2\omega_c - \omega_M$

Synchronous demodulation (cont.)

- Mathematically,

AM modulation → $$y(t) = x(t)\cos(\omega_c t)$$

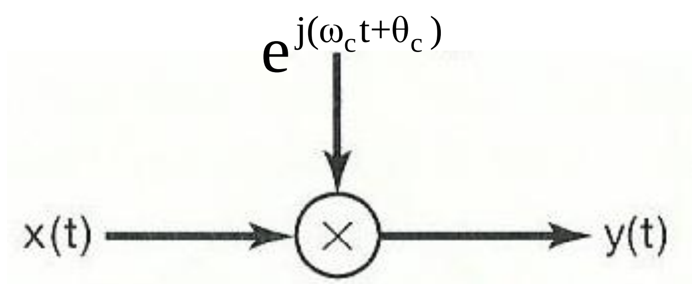
AM demodulation → $$\begin{aligned} w(t) &= y(t)\cos(\omega_c t) = x(t)\cos^2(\omega_c t) \\ &= x(t)[\frac{1}{2} + \frac{1}{2}\cos(2\omega_c t)] \\ &\boxed{= \frac{1}{2}x(t)} + \frac{1}{2}x(t)\cos(2\omega_c t) \end{aligned}$$

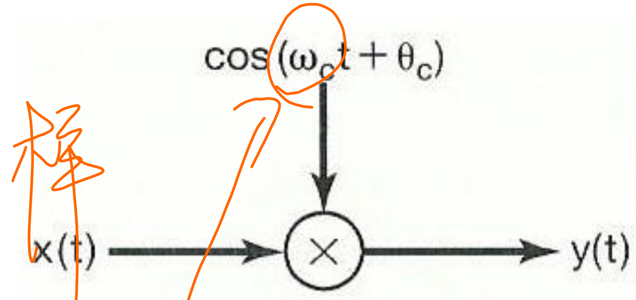
Synchronous demodulation (cont.)

Complex exponential carrier:

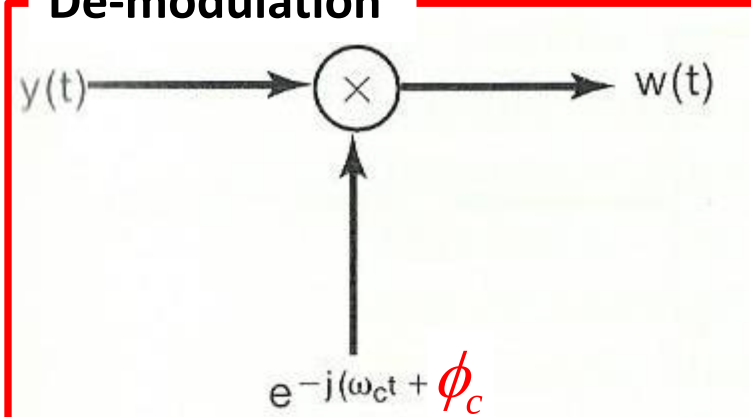
Sinusoidal carrier:

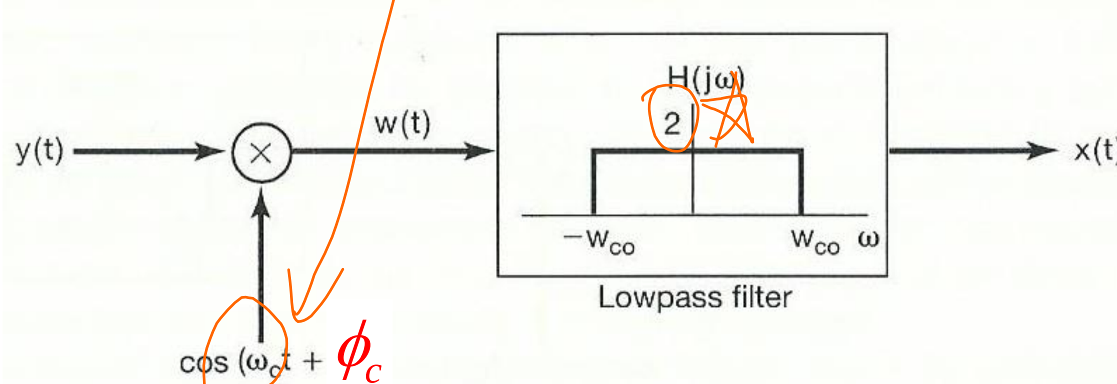
AM modulation





De-modulation





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

$$w(t)=e^{-j(\omega_c t+\phi_c)}y(t)$$

$$=e^{j(\theta_c-\phi_c)}x(t)$$

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

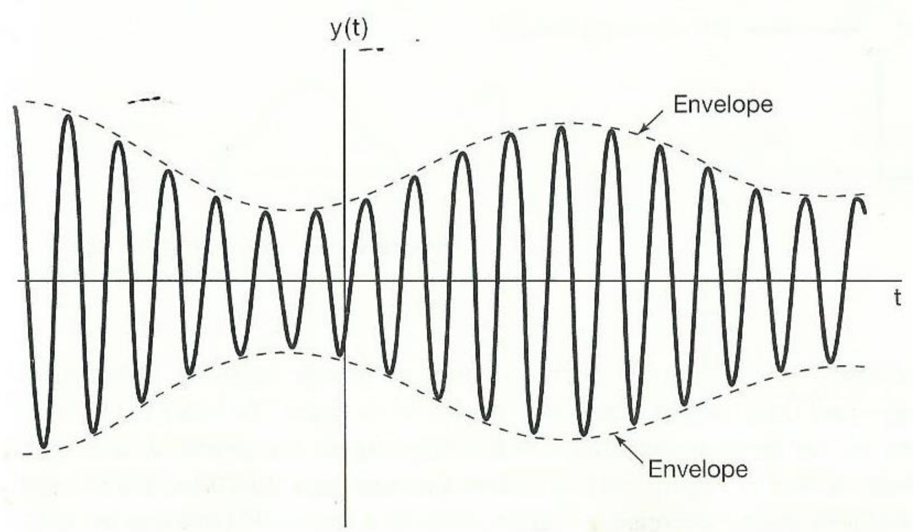
$$=\boxed{\frac{1}{2}\cos(\theta_c-\phi_c)x(t)}+\frac{1}{2}x(t)\cos(2\omega_c t+\theta_c+\phi_c)$$

What is the cost ?

Asynchronous demodulation

- Avoid the need for synchronization between modulator and demodulator.

An example of modulated signal y(t), when x(t) is positive, and $\omega_c > \omega_M$.

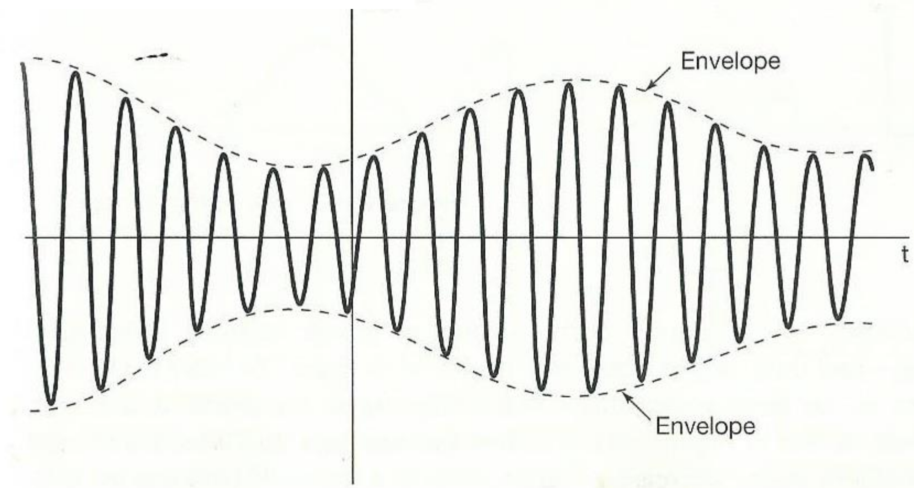


Envelope signal, a smooth curve connecting the peaks, approaches to the modulating signal x(t).

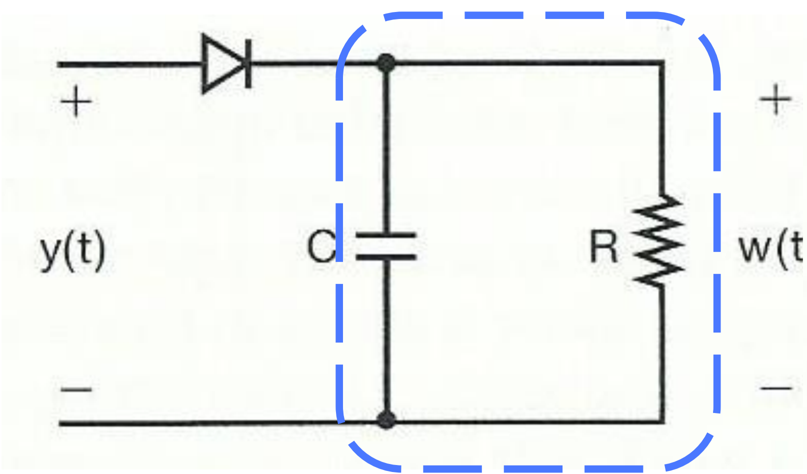
Envelope detector

Full wave or half-wave envelope detector?

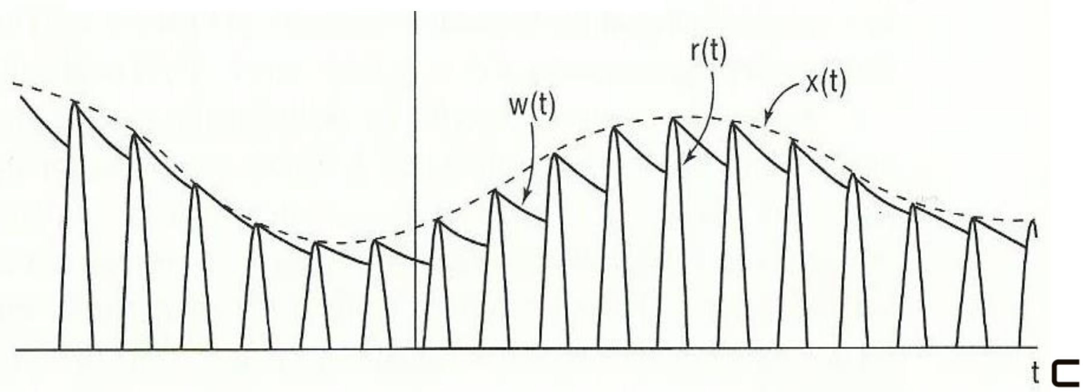
Modulated signal



Lowpass filtering

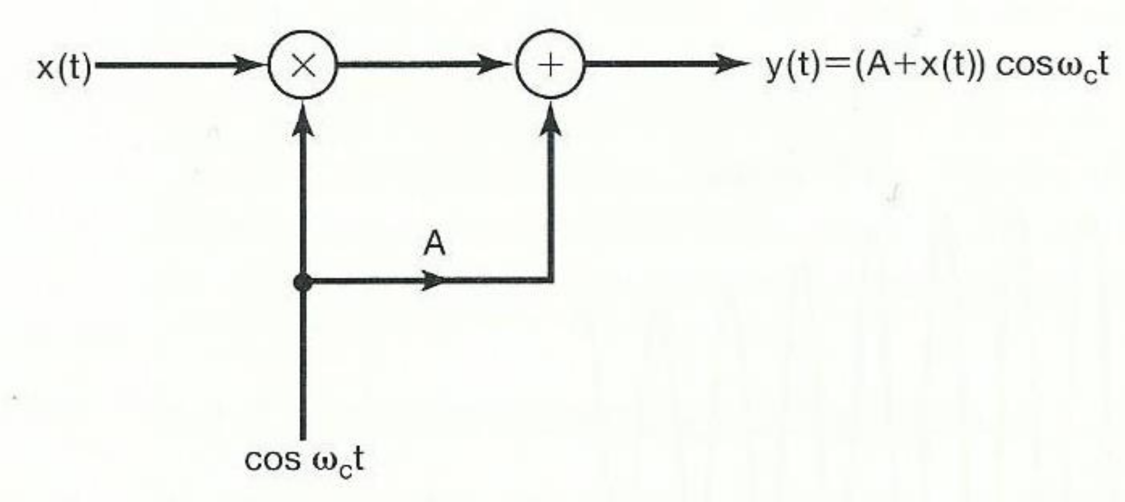


Envelope detector output



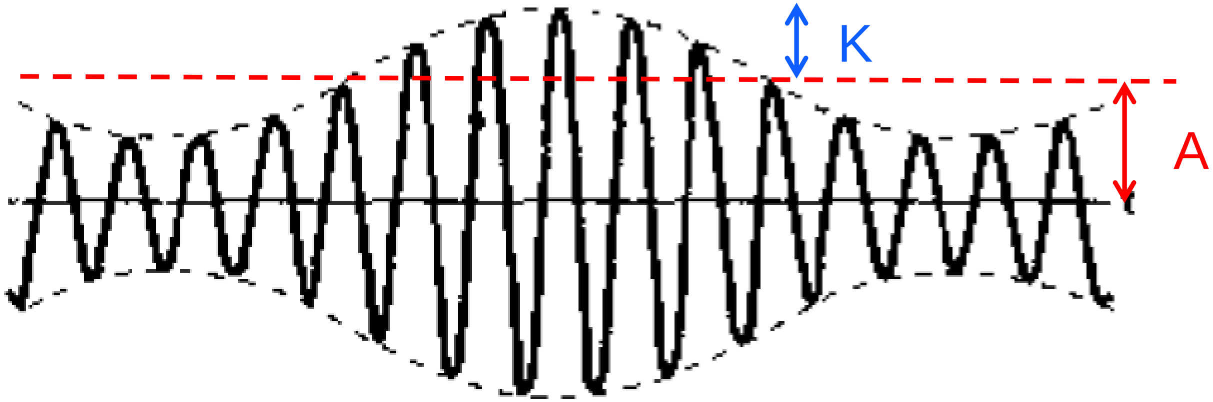
AM in an asynchronous system

- Two important assumptions:
  - ω_c is higher than ω_M
  - x(t) is always positive



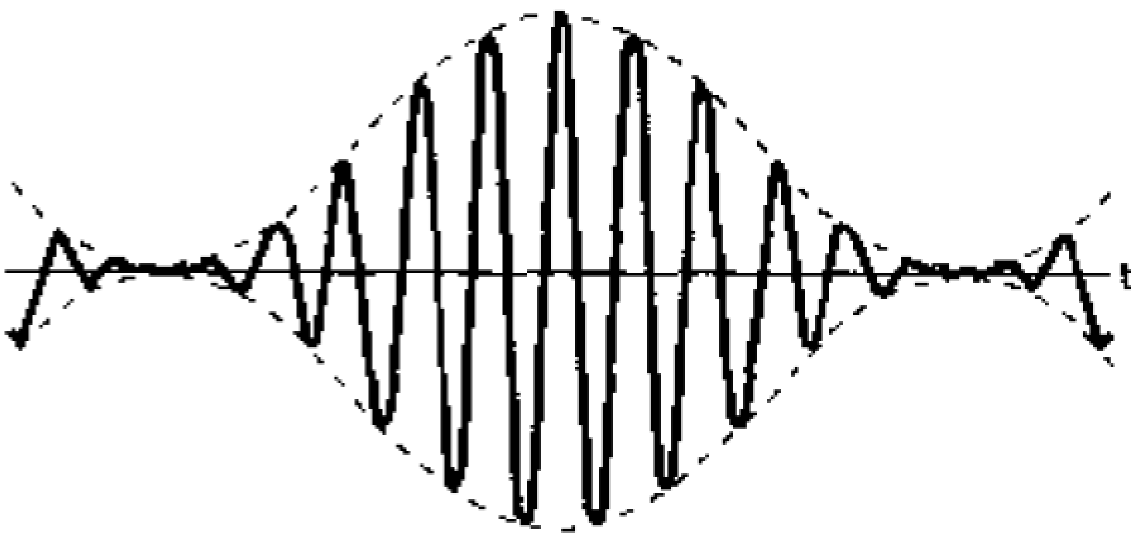
1) Add a constant A to make sure [A+x(t)] is positive.
   Let K be the maximum amplitude of x(t), or $|x(t)| \le K$. We need to have $A > K$.

2) Define K/A as modulation index *m*, which is from 0 to 1.



(a)

m=0.5



(b)

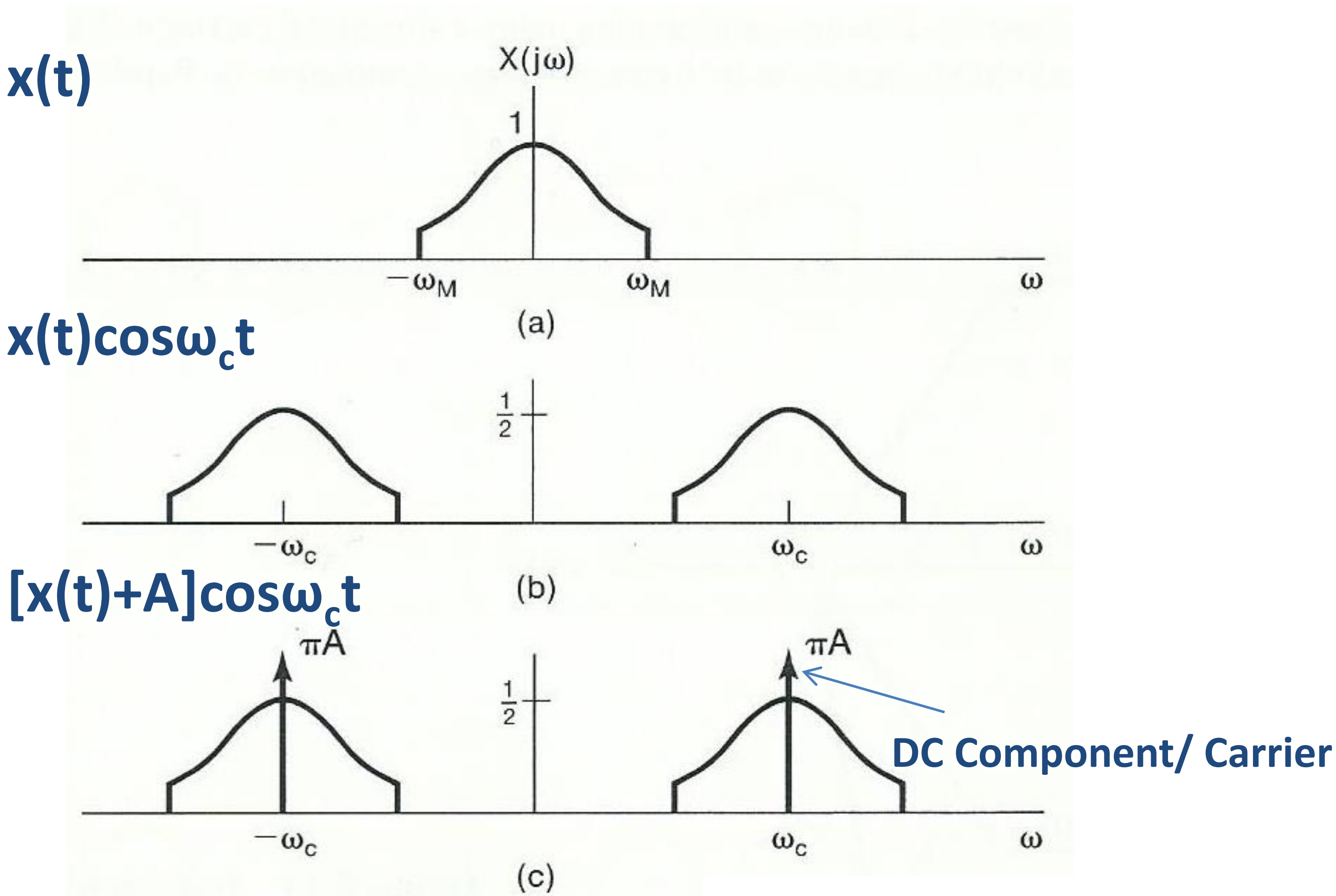
m=1

→ $x(t)=0$

What about m=0?

AM in an asynchronous system (cont.)

Spectrum of modulated signal in an asynchronous system



What is the cost ?

Frequency-division multiplexing (FDM)

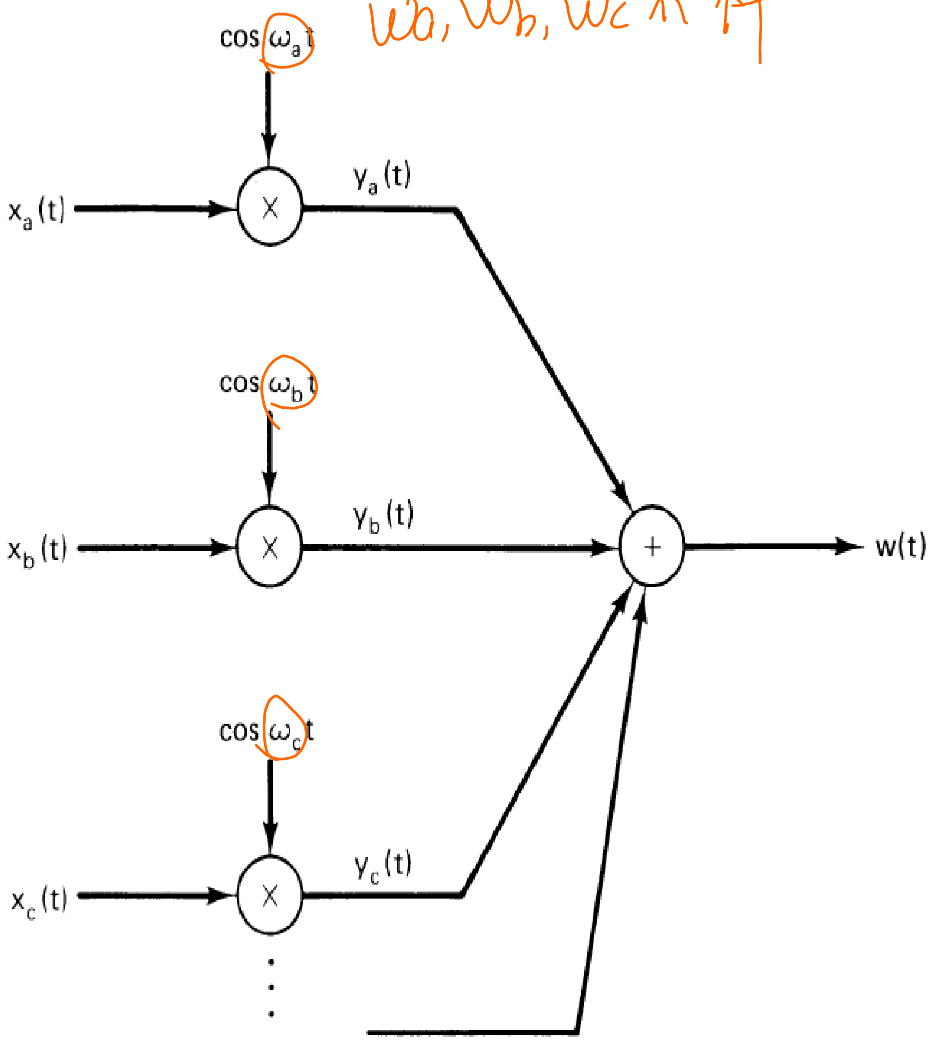
频分复用

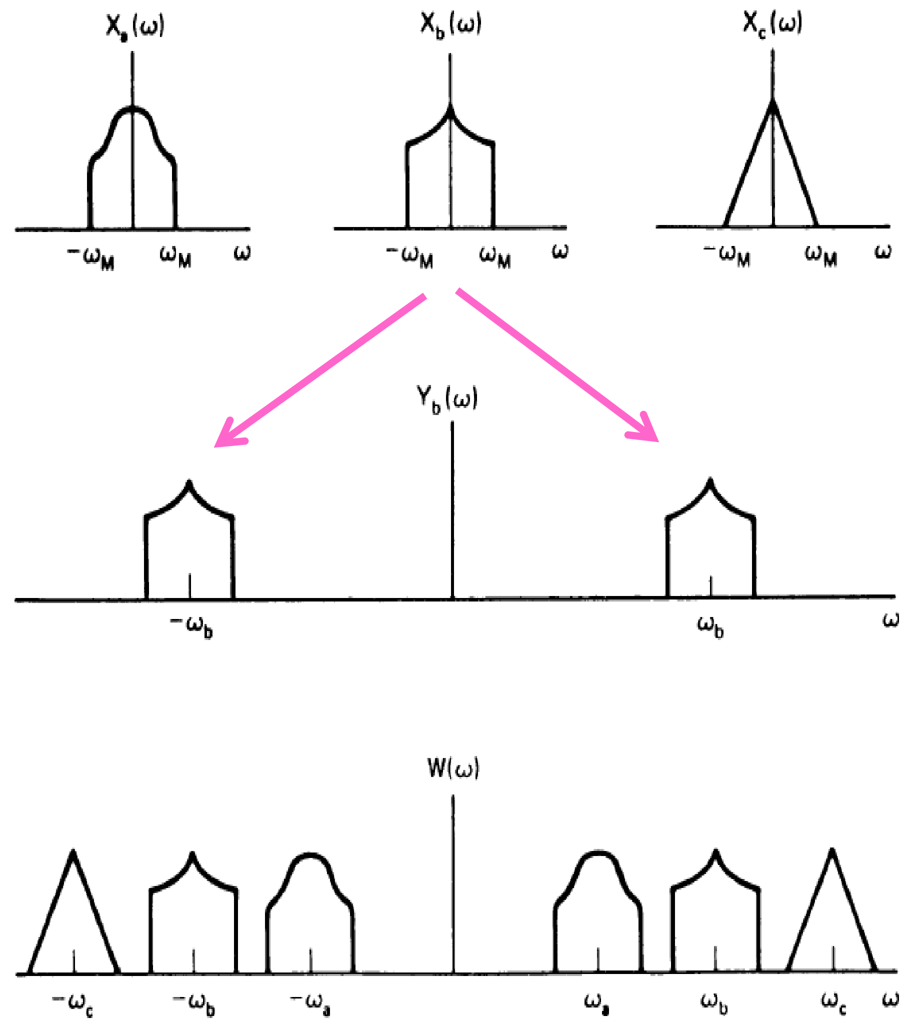
- Systems for transmitting signals provide more bandwidth than is required for one signal.
  - E.g., speech signal → 20 ~ 20 kHz
    microwave channel → 300 MHz ~ 300 GHz
    satellite link → a few hundred MHz ~ 40 GHz
    (more in Fig. 8.18)
- Different modulating signals (e.g., speech), which are overlapping in frequency, can have their spectra shifted (e.g., by sinusoidal AM) without overlapping, so they can be transmitted simultaneously over a single wideband channel.

同时地

FDM (cont.)

ωa, ωb, ωc 不一样

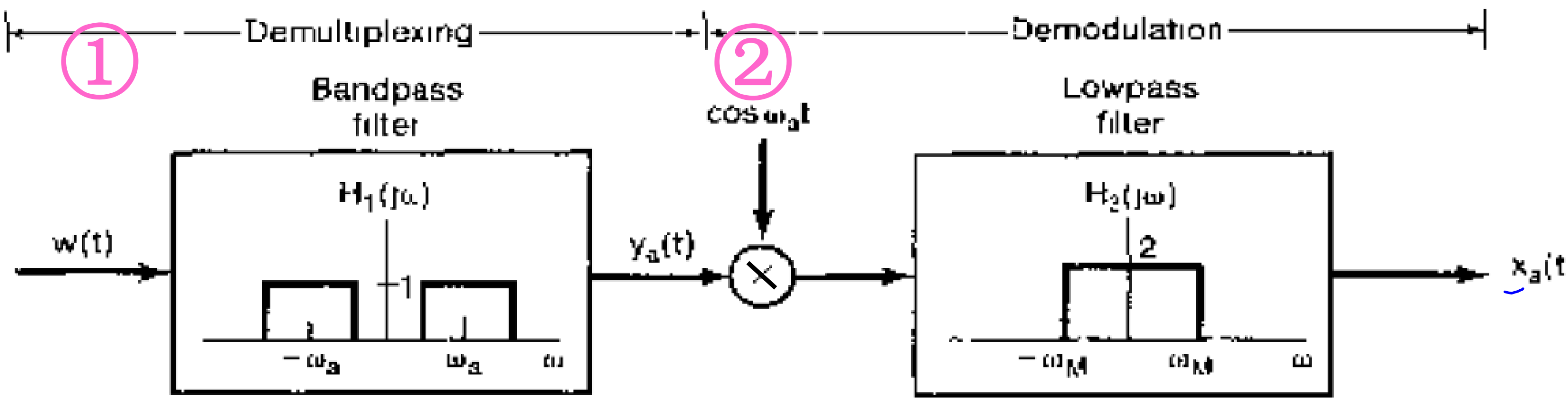


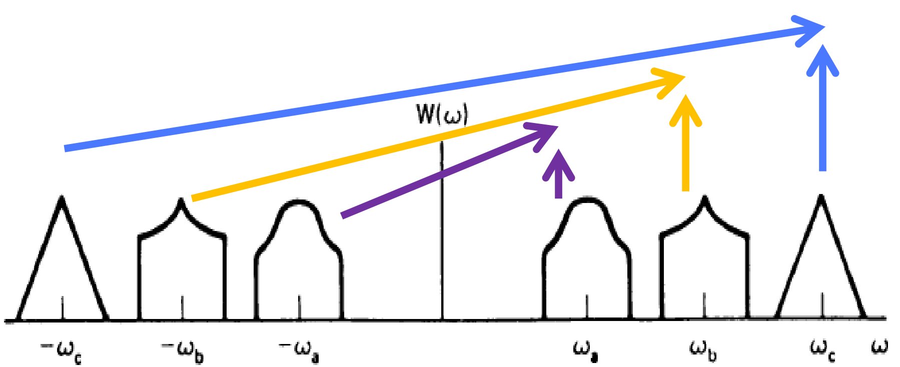


FDM demultiplexing and demodulation

① bandpass filtering to have the modulated signal from one channel

② demodulation to recover the modulating signal



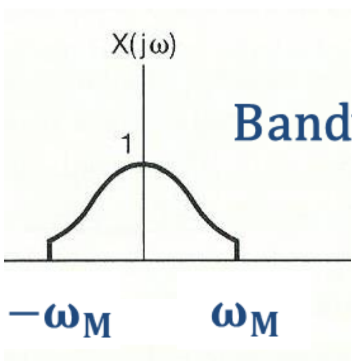


Occupy twice the original bandwidth

→ insufficient use of bandwidth

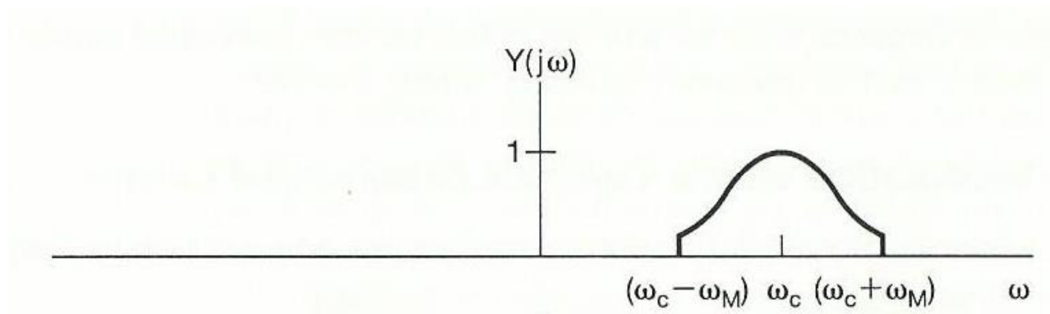
Single-sideband (SSB) sinusoidal AM

Occupied bandwidth:

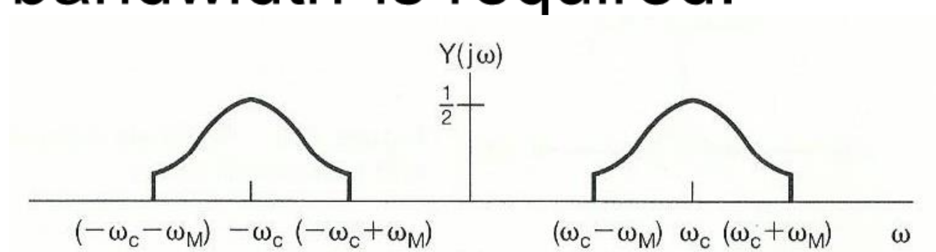


Bandwidth: $2\ \omega_M$

- With exponential carrier, the bandwidth is still $2\ \omega_M$

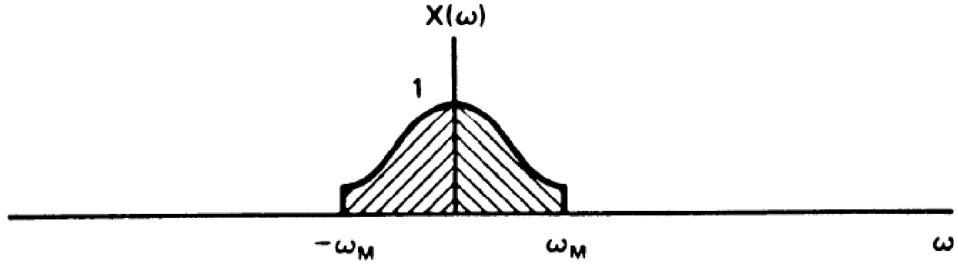


- With sinusoidal carrier, twice bandwidth is required.



SSB sinusoidal AM (cont.)

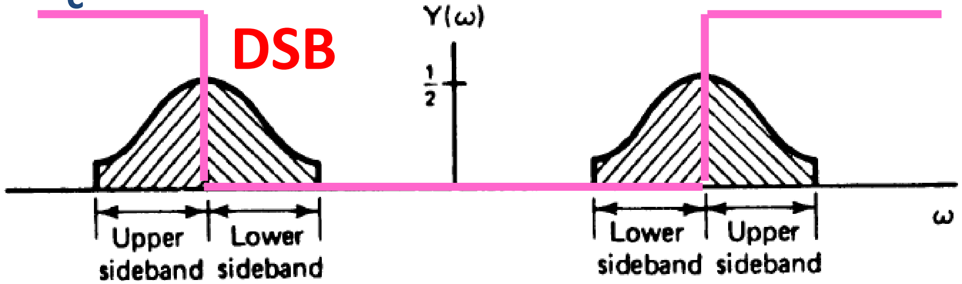
x(t)



$x(t)\cos\omega_c t$

Double-sideband Ideal Highpass filter

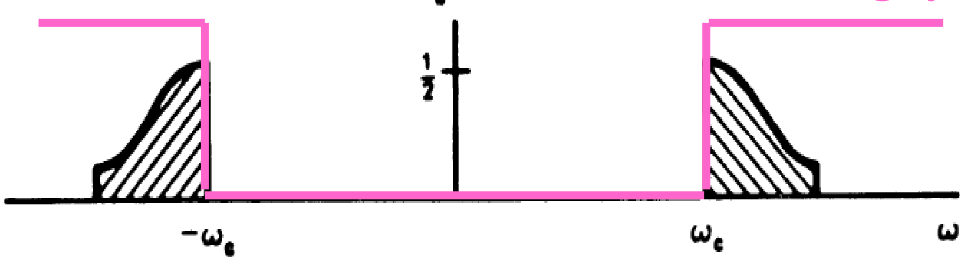
DSB



<u>Observation:</u> x(t) can be recovered if two upper (or lower) sidebands are retained.

SSB

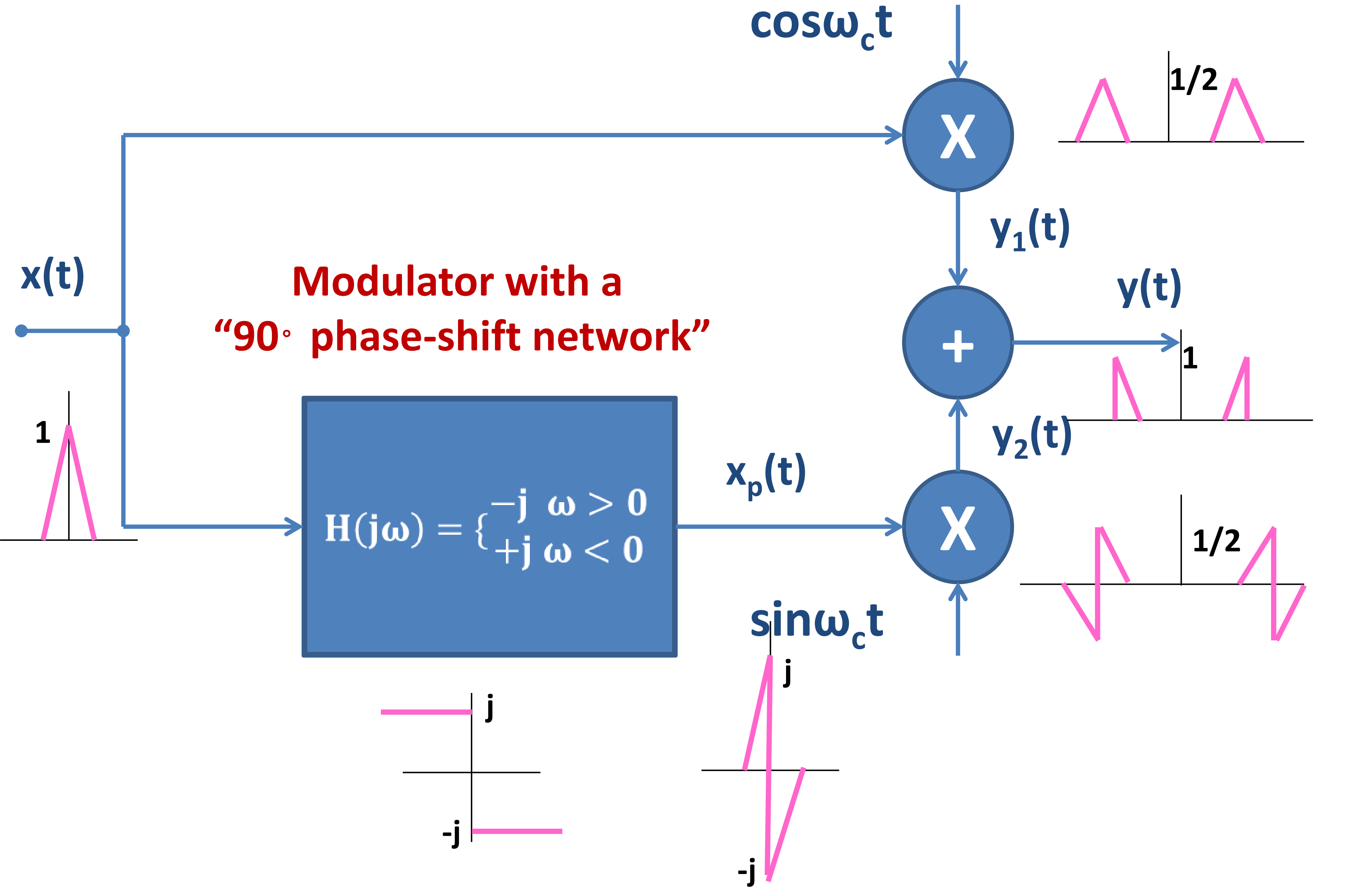
Ideal Highpass filter



Higher power and spectrum efficiency

What is the cost ?

SSB sinusoidal AM (cont.)

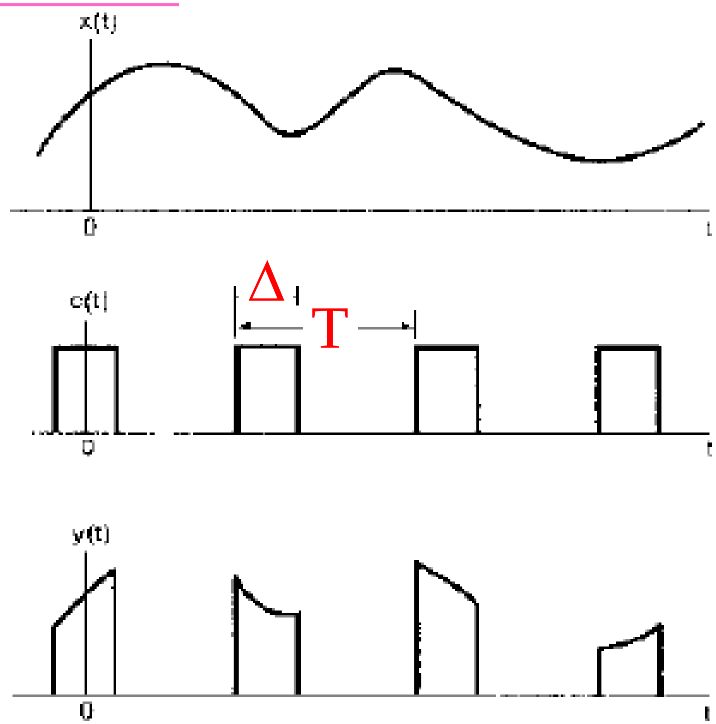


Amplitude modulation with a pulse train

- Carrier signal could be a sinusoidal signal, or a pulse train.

你把c(t)写成CTFS,
再 CTFS → CTFT

Figure 8.23



$$X(j\omega)$$

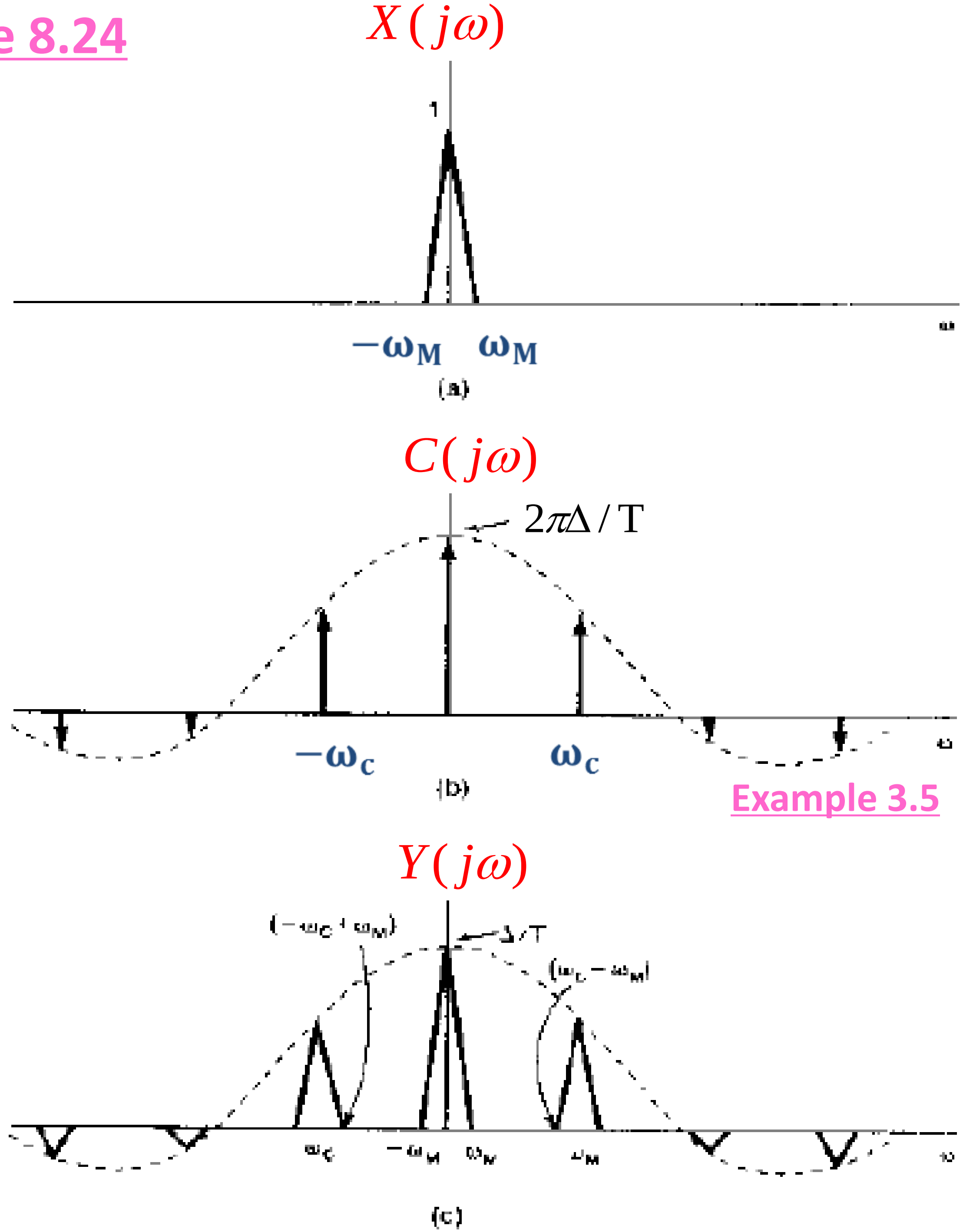
$$C(j\omega)=2\pi\sum_{k=-\infty}^{\infty}a_k\delta(\omega-k\omega_c)$$

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

Read Example 3.5

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

Figure 8.24



Example 3.5

When $\omega_c > 2\omega_M$, $X(j\omega)$ can be recovered by lowpass filtering.

Note: similar to the condition in sampling.

Summary

- Meaning of amplitude modulation
  - with a complex exponential carrier
  - with a sinusoidal carrier
- Demodulation for sinusoidal AM
  - Synchronous demodulation
  - Asynchronous demodulation, and its two important assumptions
- Frequency-division multiplexing (FDM)