Signals and Systems

#12: Communication systems

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Some of the images in this presentation are from "Signals and Systems", A. V. Oppenheim, A. S. Wilsky, and S. H. Nawab, 2nd ed. Pearson.

Outline

- ...
- #09 First-order systems
- #10 Second-order systems
- #11 Sampling and reconstruction
- **#12 Communication systems**
- #13 Laplace transform

Modulation, demodulation, and multiplexing

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

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Demodulation:
extracting the information-bearing signal

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embedding an information-bearing signal into a second signal

Demodulation:
extracting the information-bearing signal

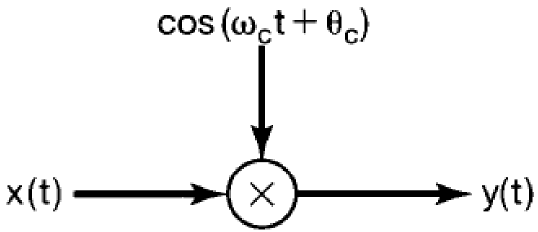
Multiplexing:
simultaneously transmitting multiple signals with overlapping spectra

Sinusoidal amplitude modulation

Information-bearing signal: $x(t)$

Carrier signal: $c(t) = \cos(\omega_c t + \theta_c)$ ω_c carrier frequency

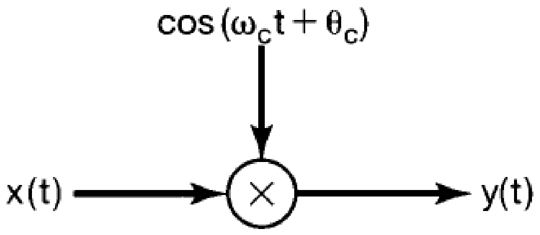
Modulated signal: $y(t) = x(t) \cdot c(t)$



Information-bearing signal: $x(t) \stackrel{\mathcal{F}}{\longleftrightarrow} X(j\omega)$

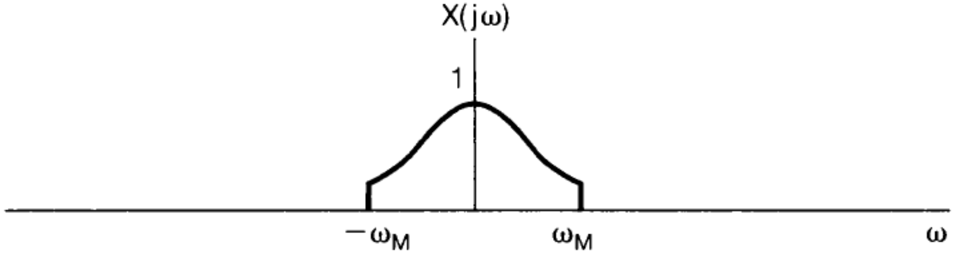
Carrier signal: $c(t) = \cos(\omega_c t + \theta_c) \stackrel{\mathcal{F}}{\longleftrightarrow} C(j\omega)$

Modulated signal: $y(t) = x(t) \cdot c(t) \stackrel{\mathcal{F}}{\longleftrightarrow} \frac{1}{2\pi} X(j\omega) * C(j\omega)$



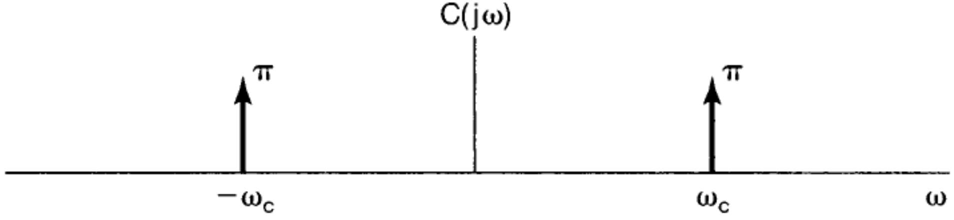
Information-bearing signal:

$$x(t) \overset{\mathcal{F}}{\longleftrightarrow} X(j\omega)$$



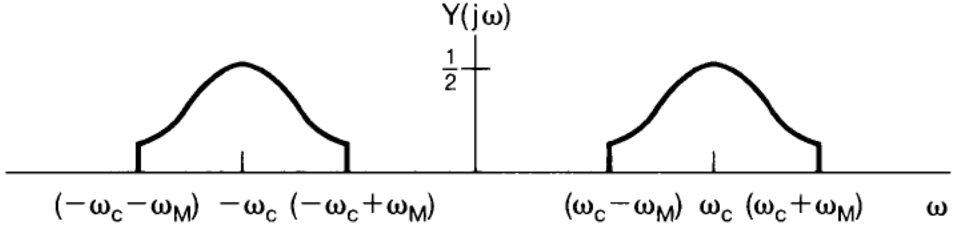
Carrier signal:

$$c(t) = \cos(\omega_c\, t) \qquad (\text{for } \theta_c = 0)$$
$$C(j\omega) = \pi\left[\delta(\omega - \omega_c) + \delta(\omega + \omega_c)\right]$$



Modulated signal:

$$y(t) = x(t) \cdot \cos(\omega_c\, t)$$
$$Y(j\omega) = \frac{1}{2}\left[X(j(\omega - \omega_c)) + X(j(\omega + \omega_c))\right]$$



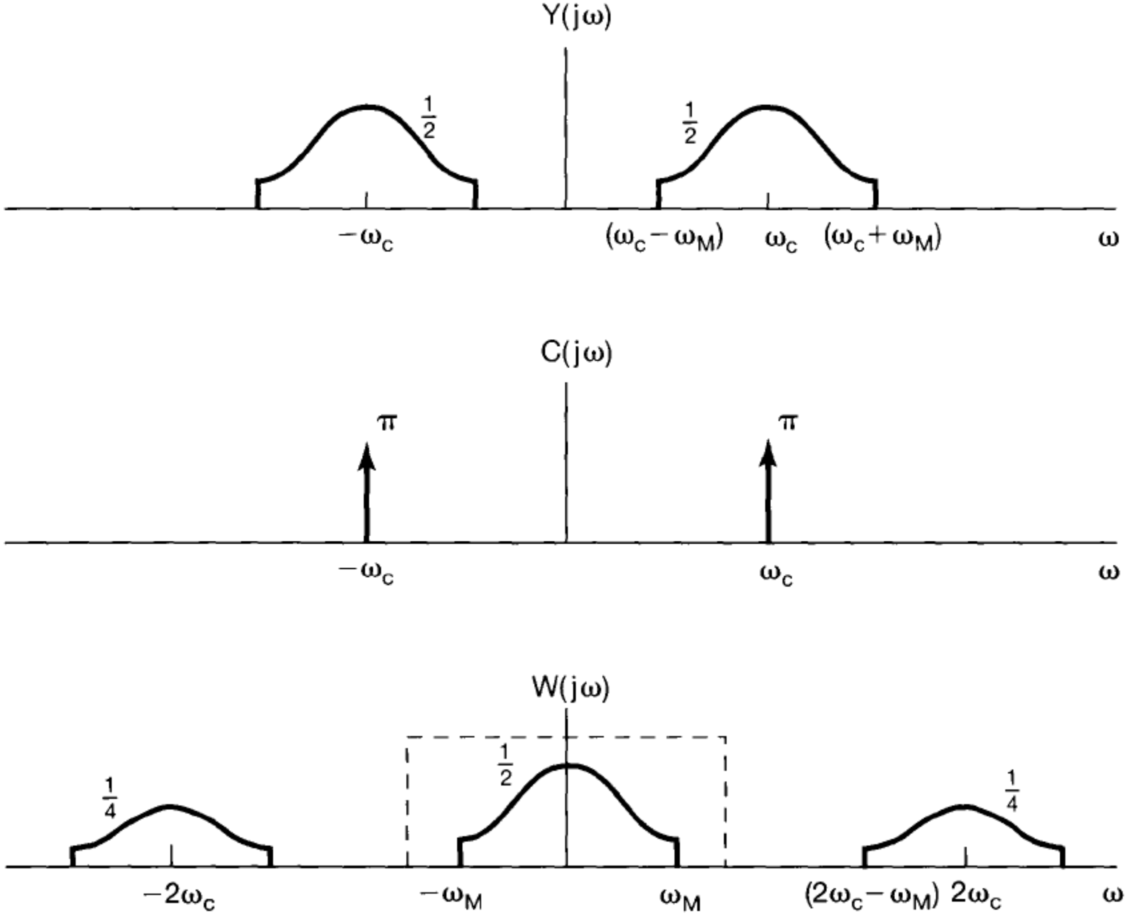
$x(t)$ recoverable if $\omega_c > \omega_M$

Sinusoidal amplitude demodulation

Synchronous demodulation:

- multiply $y(t)$ by the carrier

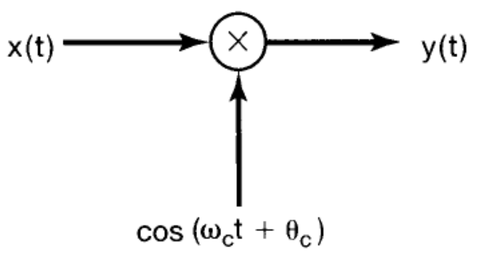
- apply a lowpass filter

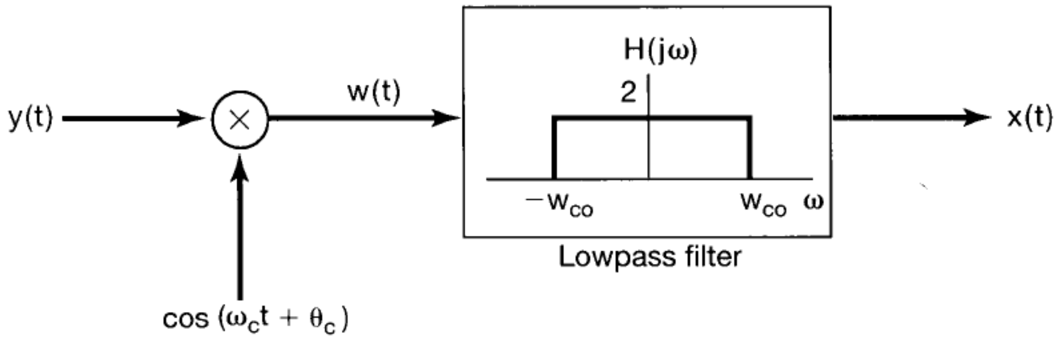


Synchronous demodulation:

- $w(t) = y(t) \cdot \cos(\omega_c t + \theta_c) = x(t) \cdot \cos^2(\omega_c t + \theta_c) = \frac{1}{2}\, x(t) + \frac{1}{2}\, x(t) \cdot \cos(2\,\omega_c t + 2\,\theta_c)$

- apply a lowpass filter





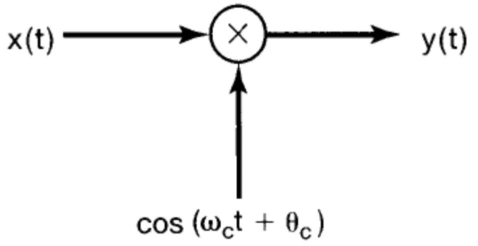
Synchronous demodulation:

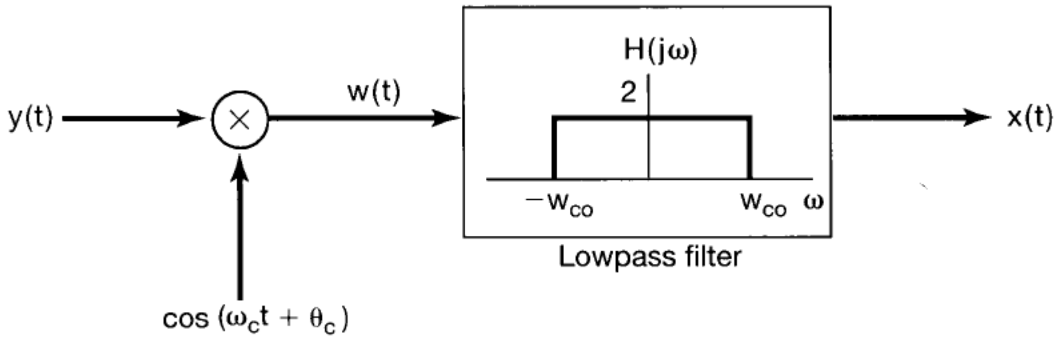
- $w(t) = y(t) \cdot \cos(\omega_c\, t + \theta_c) = x(t) \cdot \cos^2(\omega_c\, t + \theta_c) = \dfrac{1}{2}\, x(t) + \dfrac{1}{2}\, x(t) \cdot \cos(2\, \omega_c\, t + 2\, \theta_c)$

- apply a lowpass filter

original signal kept by lowpass filter

modulated at $2 \times \omega_c$ filtered out





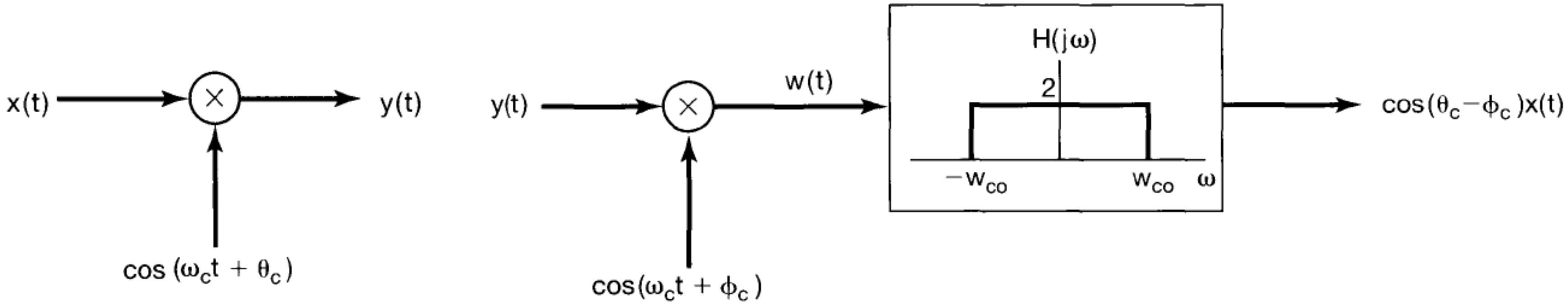
W/o synchronization:

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

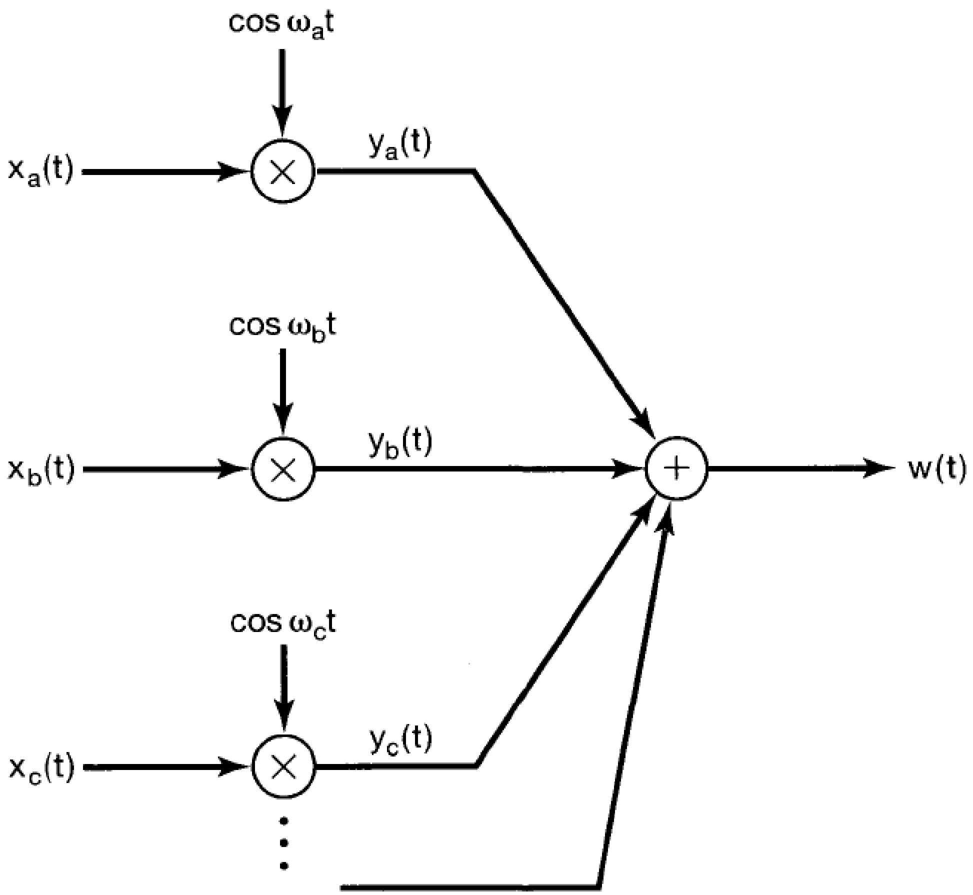
- apply a lowpass filter

original signal
kept by lowpass filter

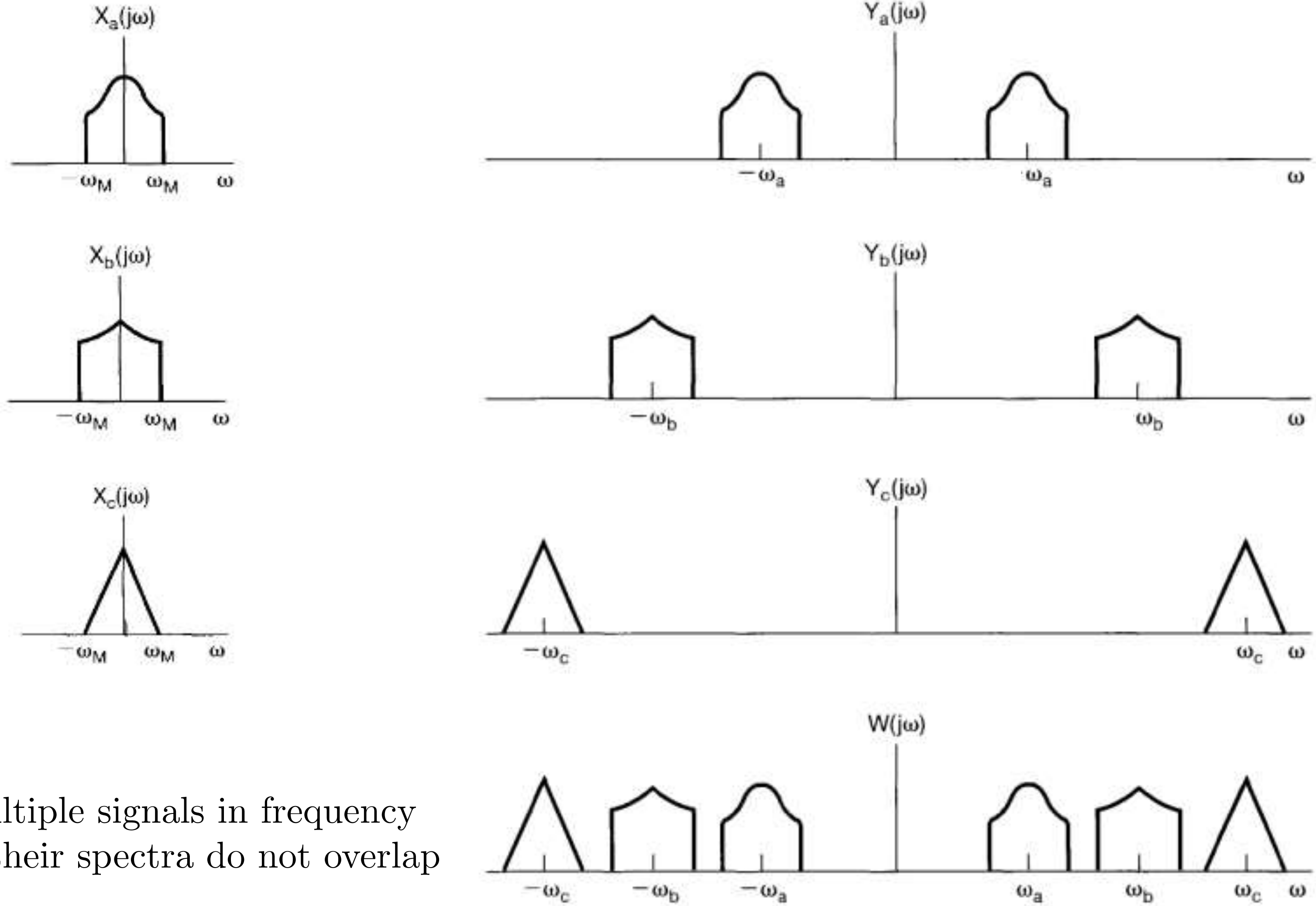
modulated at $2 \times \omega_c$
filtered out



Frequency division multiplexing

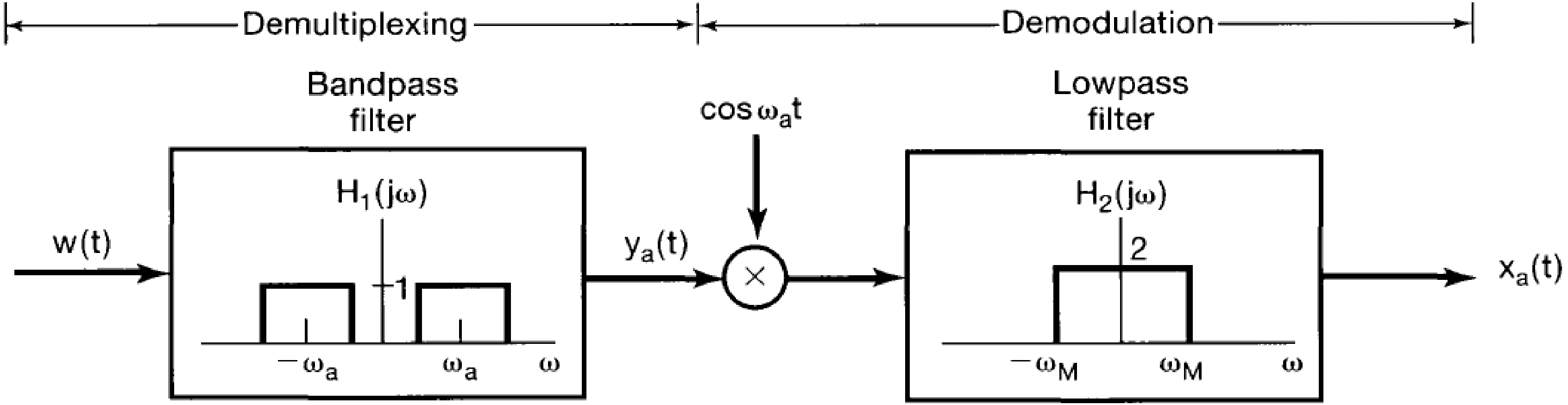


Shift multiple signals in frequency
so that their spectra do not overlap



Shift multiple signals in frequency so that their spectra do not overlap

Example: recover $x_a(t)$



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