Homework & Tutorial

Homework: 8.4, 8.25, 8.29

Tutorial: 8.34, 8.35, 8.38

Chapter 8: Communication Systems

Department of Electrical & Electronic Engineering

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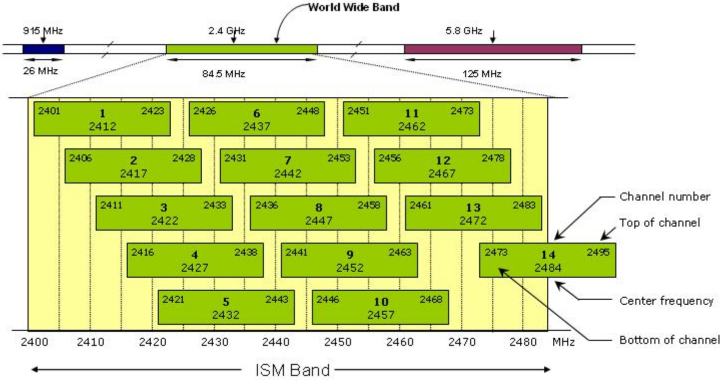
Why Modulation?

- Modulation: Embed an information-bearing signal into a second signal.

$$\text{E.g.}, y(t) = x(t) cos \omega t$$

- Example 1: Voice range ∼ [200Hz, 4kHz], microwave link ∼ [300MHz, 300GHz]
- Example 2: Wifi in industrial, scientific and medical (ISM) radio bands



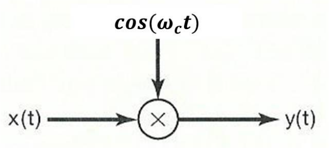
Amplitude Modulation

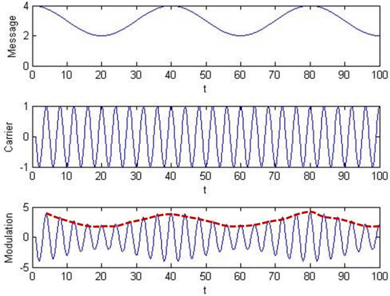
- General form

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

- $x(t)$: modulating signal with information
- $c(t)$: carrier signal
- Complex exponential carrier: $c(t) = e^{j\omega_c t + \theta_c}$
- Sinusoidal carrier: $c(t) = cos(\omega_c t + \theta_c)$

AM with a Sinusoidal Carrier

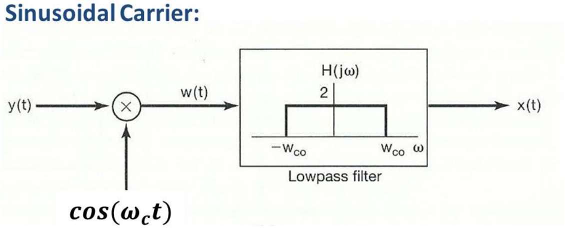




- Time & frequence domain expression

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

Synchronous Demodulation



- Requirement: oscillators at the transmitters and receivers should be synchronized
- What happen if it's not in phase?
- What happen if frequency offset exists?

Phase Error

The carrier phase of the receiver may not synchronize with the transmitter at the very beginning.

$$
\begin{aligned}
w(t) &= x(t)cos(\omega_c t)cos(\omega_c t + \Delta) \\
&= \frac{1}{2}x(t)\left[cos(2\omega_c t + \Delta) + cos(\Delta)\right]
\end{aligned}
$$

After lowpass filter

$$\widehat{x}(t) = x(t)cos(\Delta)$$

Frequency Offset

The carrier frequency at the receiver may not synchronize with the transmitter.

$$
\begin{aligned}
w(t) &= x(t)cos(\omega_c t)cos(\omega_c t + \Delta t) \\
&= \frac{1}{2}x(t)\left[cos(2\omega_c t + \Delta t) + cos(\Delta t)\right]
\end{aligned}
$$

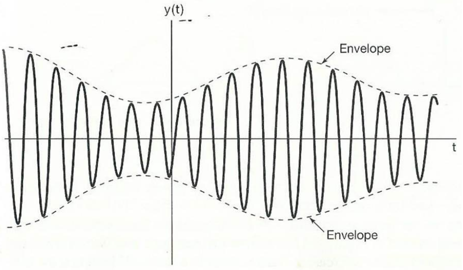
After lowpass filter

$$\widehat{x}(t) = x(t)cos(\Delta t)$$

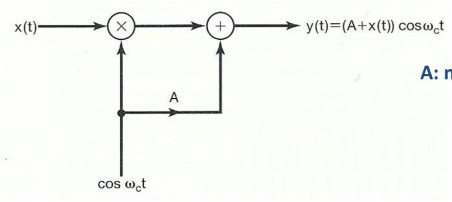
Modulator for Asynchronous Demodulation

- AM signal is like

Envelope of the carrier taking information: (Negative Signal??)

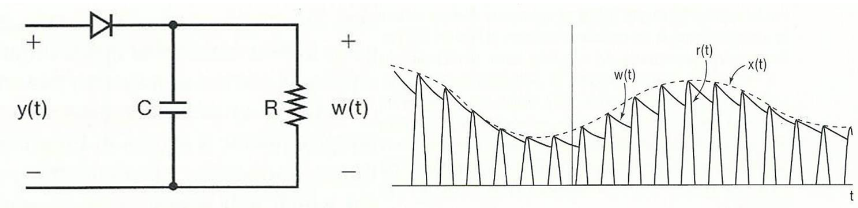


- Modulator structure (Percent Modulation)



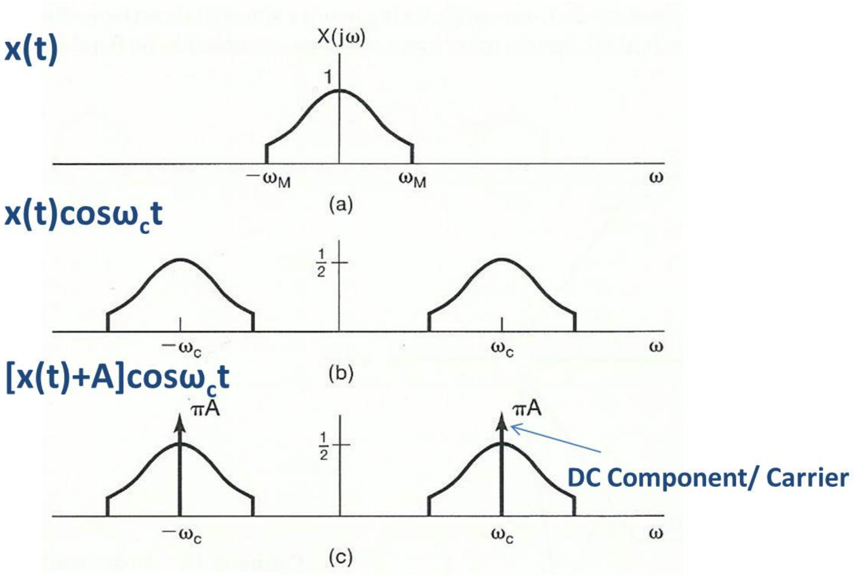
A: make sure A+x(t) is positive

Envelope Detector

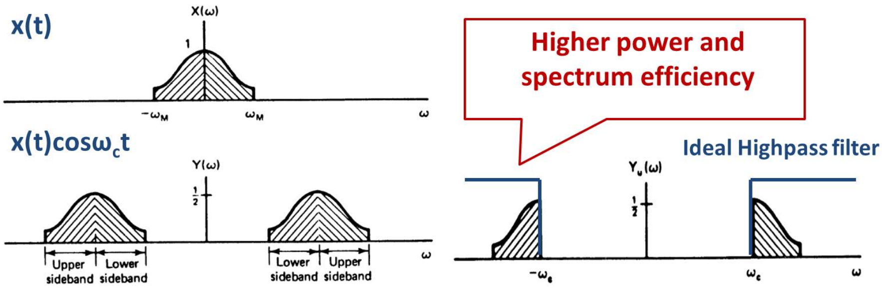


- Requirement: Carrier frequency >> Signal bandwidth
- Larger transmission power v.s. simpler receiver (asynchronous)
  - Public radio broadcasting
- Question
  - How to improve the quality of $w(t)$?

AM Spectrum w/o Carrier

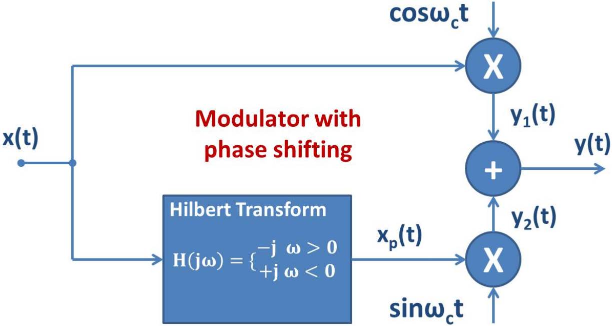


Single-Sideband AM



- Observation: each sideband (lower sideband or upper sideband) contains the complete signal information
- Use ideal highpass/lowpass filter to obtain the upper/lower sideband
- Question: how to do demodulation?
- Advantage: save the spectrum and power

Single-Sideband AM: Another Modulator

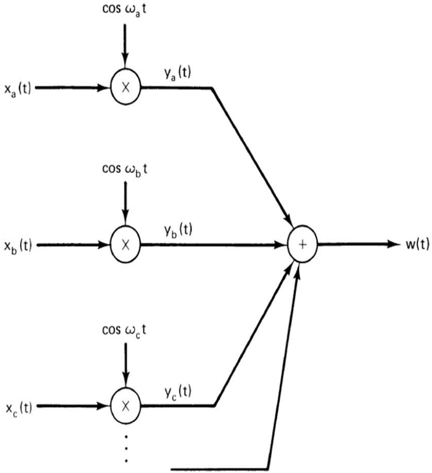


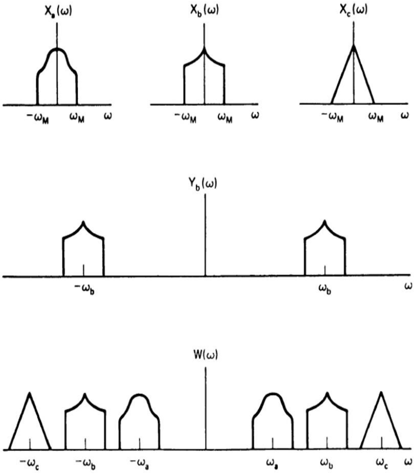
- Questions :
  - What's the output signal?
  - How to filter out the other sideband?

Sinusoidal AM: Summary

- Four types of sinusoidal AM
  - AM-DSB/SC: $y(t) = x(t) cos \omega_c t$
  - AM-DSB/WC: $y(t) = (x(t) + A) cos \omega_c t$
  - AM-SSB/SC: AM-DSB/SC + ideal highpass/lowpass filter
  - AM-SSB/WC: AM-SSB/SC + $A cos \omega_c t$
- Questions:
  - How to compare the transmitter/receiver complexity?
  - How to compare the efficiency?

Frequency-Division Multiplexing (FDM)





Problem 1

Let $x(t)$ be a real-valued signal for which $X(j\omega) = 0$ when $|\omega| > 2000\pi$. Amplitude modulation is performed to produce the signal

$$g(t) = x(t) sin(20000\pi t).$$

Please design a synchronous demodulator for g(t), and specify all the necessary parameters.

Problem 2

Suppose

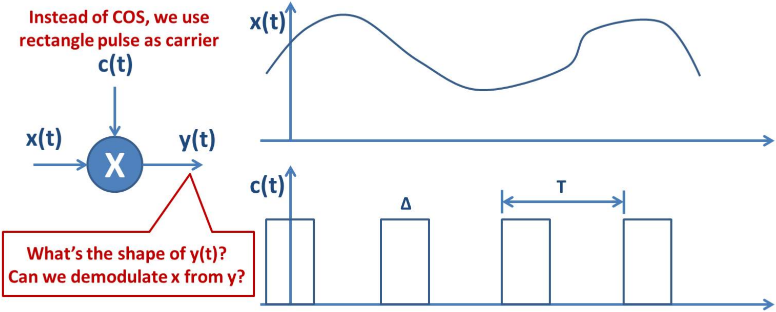
$$x(t) = sin(200\pi t) + 2sin(400\pi t)$$

and

$$g(t) = x(t)sin(400\pi t)$$

If the product $g(t)sin(400\pi t)$ is pass through an ideal lowpass filter with cutoff frequency 400π and passband gain of 2, determine the signal obtained at the output of the lowpass filter.

AM with Pulse-Train Carrier



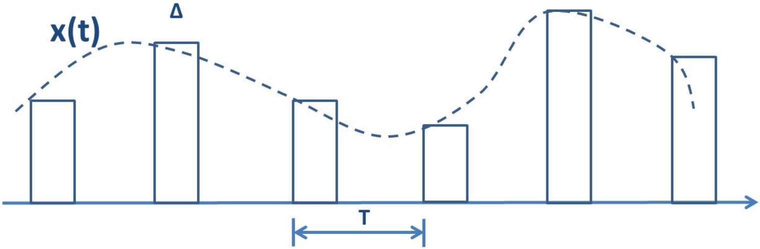
$$C(j\omega) = \sum_{k=-\infty}^{+\infty} \frac{2 sin k\omega_0 \frac{\Delta}{2}}{k} \delta(\omega - k\omega_0) \quad where \quad \omega_0 = 2\pi / T \tag{1}$$

$$
\begin{aligned}
Y(j\omega) &= \frac{1}{2\pi} C(j\omega) * X(j\omega) \\
&= \frac{1}{2\pi} \sum_{k=-\infty}^{+\infty} \frac{2sink\omega_0 \frac{\Delta}{2}}{k} \delta(\omega - k\omega_0) * X(j\omega) \\
&= \sum_{k=-\infty}^{+\infty} \frac{2sink\omega_0 \frac{\Delta}{2}}{k\pi} X(\omega - k\omega_0)
\end{aligned}
$$

Periodic extension with different scaling factors.

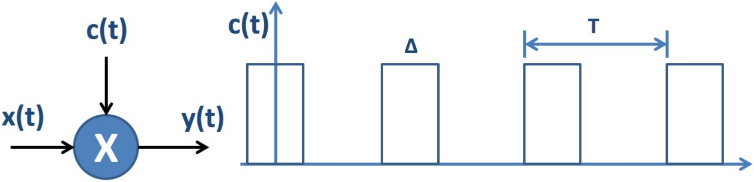
- How can we do demodulation?
- What's the effect of Δ and T on demodulation?
- Can we change the shape of pulse?

Pulse-Amplitude Modulation (PAM)

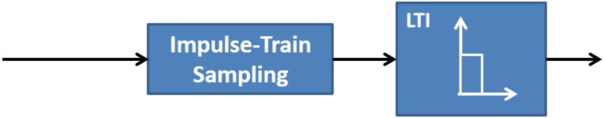


- Pulse-Amplitude Modulation (PAM): sample with period T and hold for duration Δ
- Questions:
  - Without channel distortion, how to demodulate?
  - Can we use pulse with other shape in PAM?

Pulse-Train Carrier vs. PAM



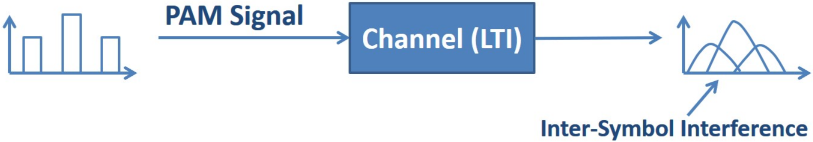
Modulating Signal



What is the difference in time or frequency domain?

Inter-Symbol Interference (ISI)

- Wired communication channels are usually low-pass filters
- E.g., optical fiber, twisted pair
- Rectangular wave will disperse and overlap with each other



- Wireless channel has multipath effect