

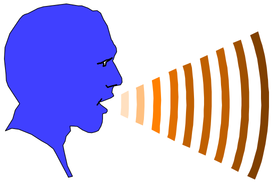


EE3414

Multimedia Communication Systems - I

Modulation for Analog Communication

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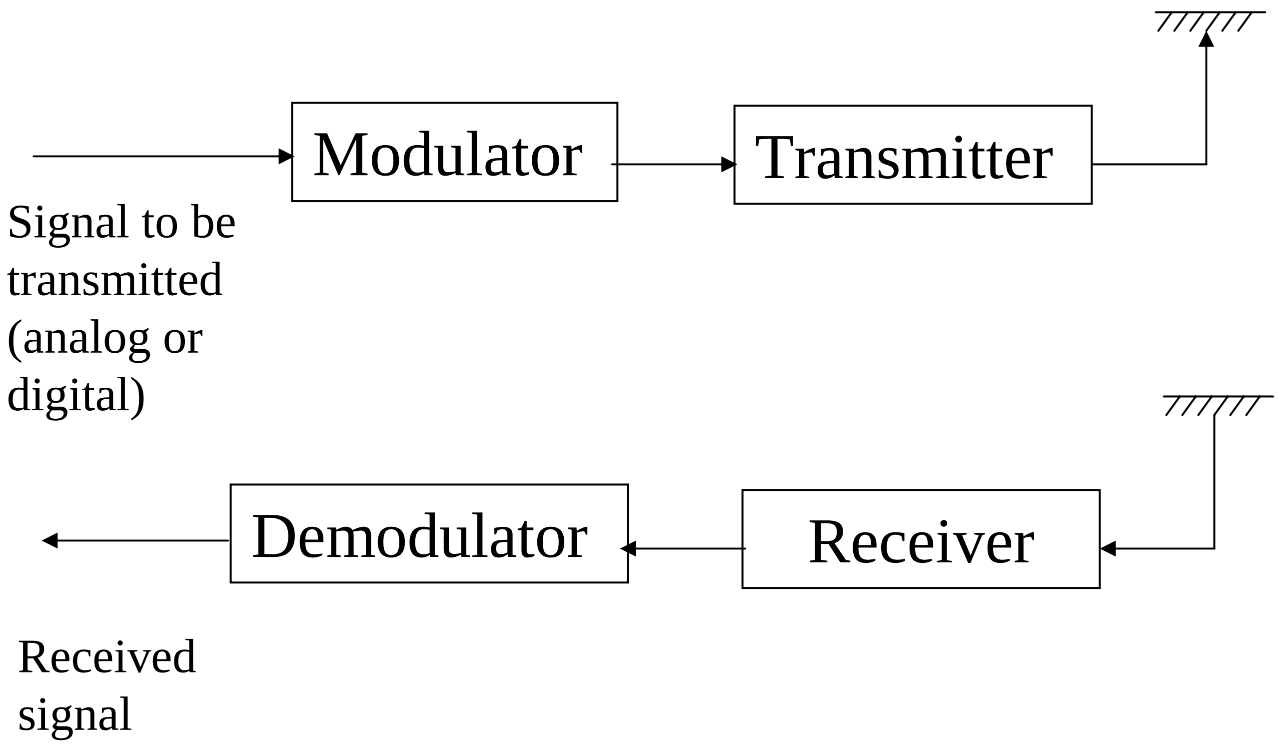
Outline

- Baseband communication: bandwidth requirement
- Modulation of continuous signals
  - Amplitude modulation
  - Quadrature amplitude modulation
  - Other modulation techniques: frequency/phase modulation
- Frequency division multiplexing
- Application of modulation
- Demo of AM and QAM

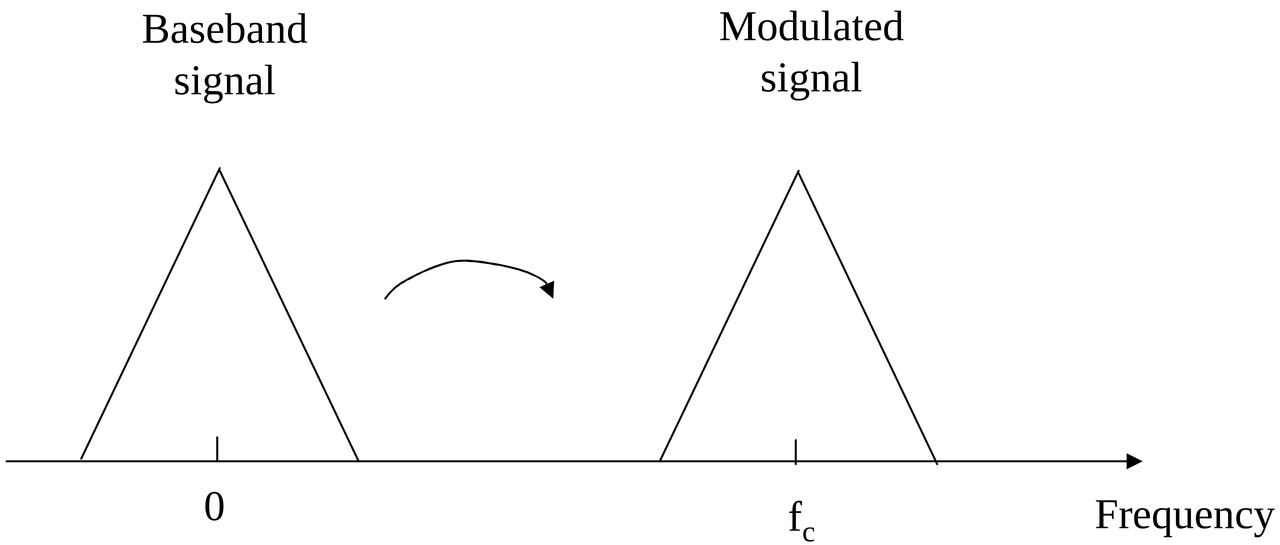
Baseband Communications

- Signal strength attenuates with distance. Needs repeaters to amplify the signals in stages
- Received signal is corrupted by noise
  - $R(t)=A\,S(t)+n(t)$
- Received signal quality depends on channel noise and noise between repeaters accumulate
- To transmit a signal with bandwidth B, we need $>=B$ Hz in channel bandwidth
- If the signal is low-pass (0-B), must the channel operate at 0-B range of frequency?
- How do we send multiple signals over the channel?

A Typical Communication System



Modulation = Frequency Shifting

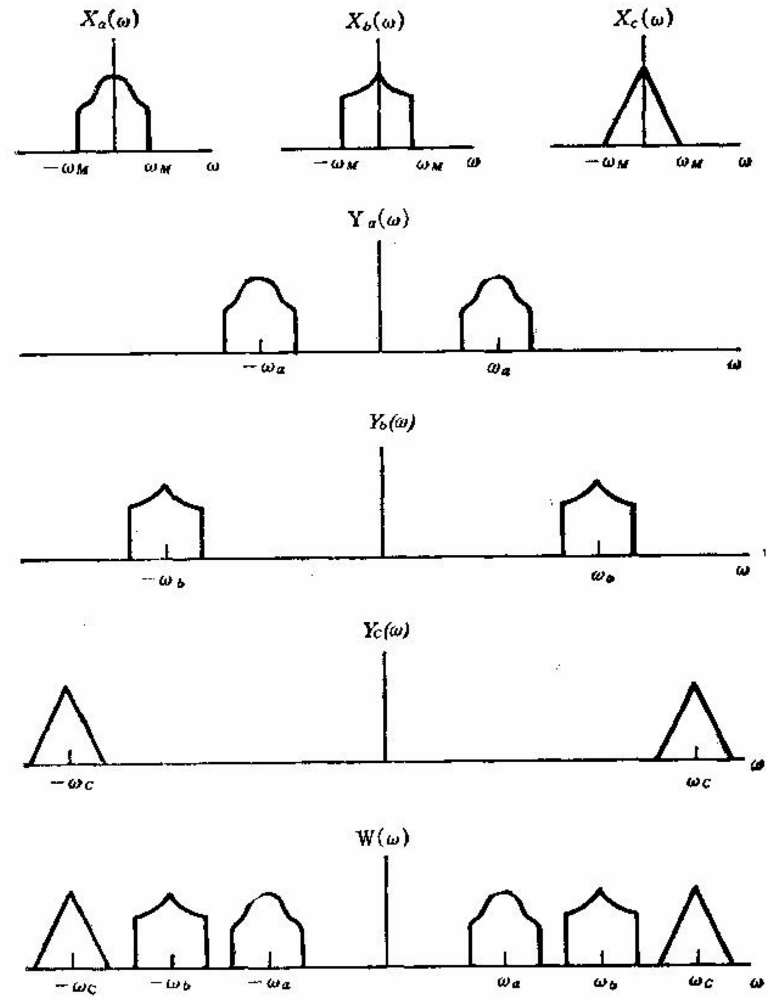


Why do we need “modulation”?

- A communication channel only operates at a certain frequency range
  - telephone cables, terrestrial (over the air broadcast), ethernet, optical fiber, etc.
- Modulation translates a signal from its baseband to the operating range of the channel
- By modulating different signals to different frequency bands, they can be transmitted simultaneously over the same channel → frequency division multiplexing

Frequency Division Multiplexing

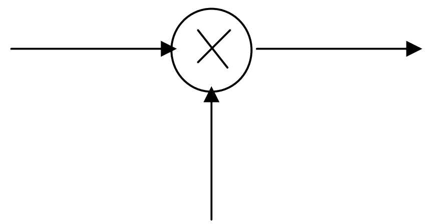
- To transmit the three signals over the same channel, each signal is shifted to a different carrier frequency and then summed together.
- From Figure 7.22 in Signals and Systems



How do we shift the frequency of a signal?

- By multiplying with a sinusoid signal !

$x(t)$



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

$\cos(\omega_c t)$

carrier signal

ω_c : carrier frequency

Basic Equalities

- Basic equality

$$x(t)e^{j2\pi f_c t} \leftrightarrow X(f - f_c)$$
$$x(t)e^{-j2\pi f_c t} \leftrightarrow X(f + f_c)$$
$$x(t)\cos(2\pi f_c t) \leftrightarrow \frac{1}{2}\left(X(f - f_c) + X(f + f_c)\right)$$

- Proof on the board

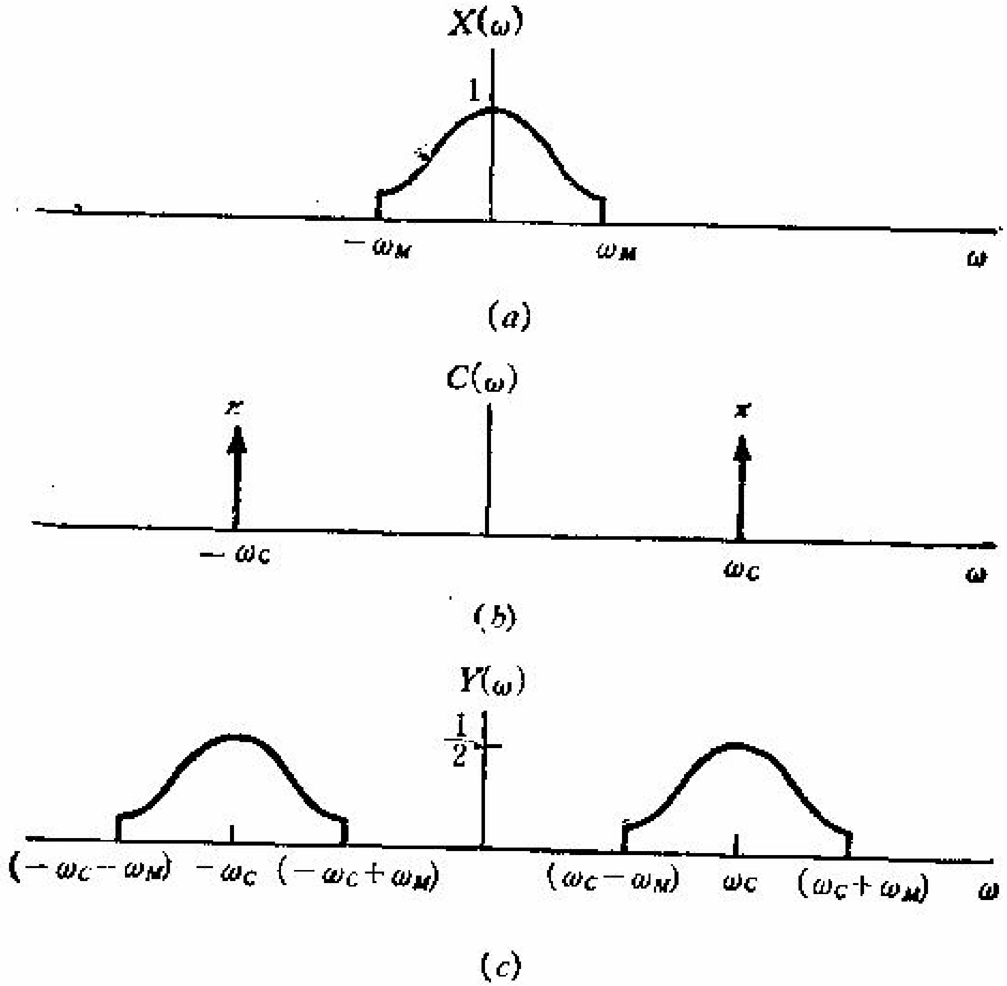
Frequency Domain Interpretation of Modulation

From Figure 7.5 in Signals/Systems

$x(t)$

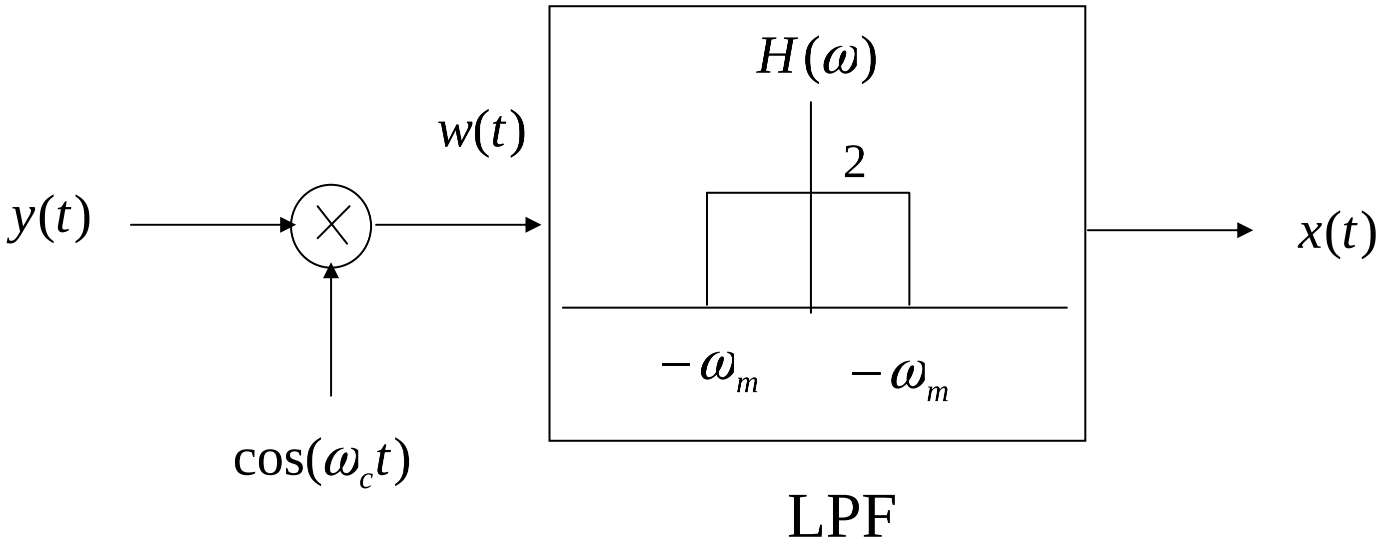
$\cos(\omega_c t)$

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



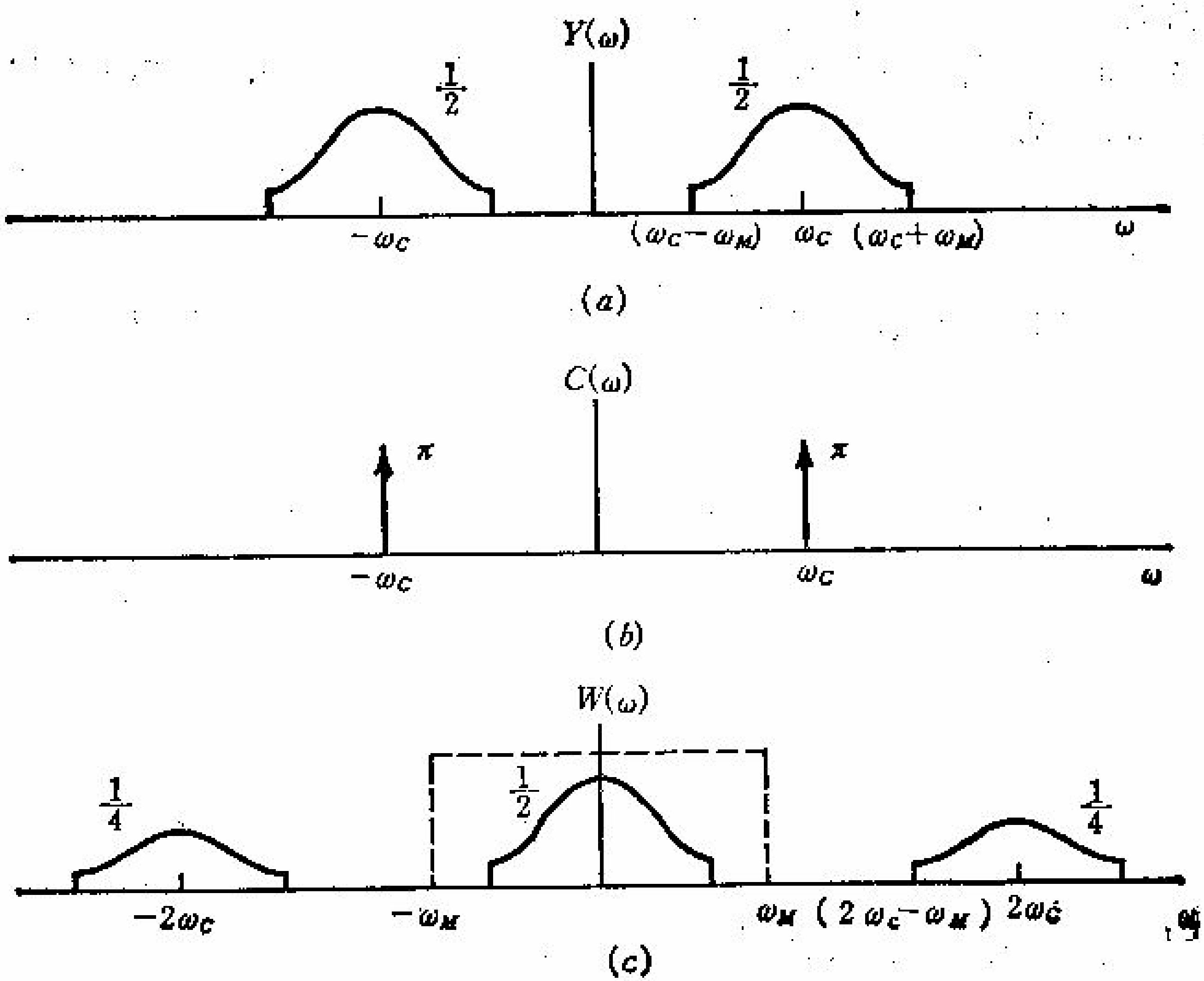
How to get back to the baseband? (Demodulation)

- By multiplying with the same sinusoid + low pass filtering!



Frequency Domain Interpretation of Demodulation

Figure 7.7 in Signals and Systems



Temporal Domain Interpretation

Modulation:

$$y(t) = x(t)\cos(2\pi f_c t)$$

Demodulation:

$$w(t) = y(t)\cos(2\pi f_c t) = x(t)\cos^2(2\pi f_c t)$$

Using the equality $\cos^2(\theta) = \frac{1}{2}\left(1+\cos(2\theta)\right)$

$$w(t) = \frac{1}{2}\left(1+\cos(4\pi f_c t)\right)x(t) = \frac{1}{2}x(t) + \frac{1}{2}x(t)\cos(4\pi f_c t)$$

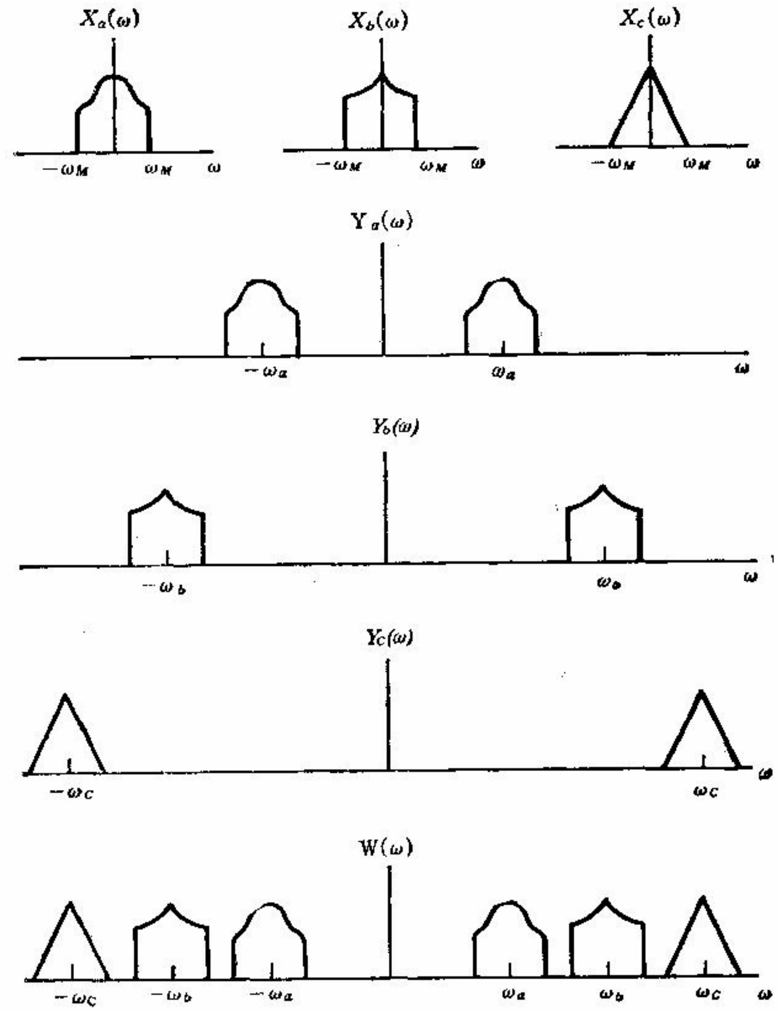
The LPF will retain the first term and remove the second term.

Example

- How to transmit a signal with frequency ranging in (-5KHz,5KHz) using a channel operating in (100KHz,110KHz)? What should be the carrier frequency ? Draw the block diagrams for the modulator and demodulator, and sketch the spectrum of the modulated and demodulated signals.

Frequency Division Multiplexing: Frequency domain interpretation

Figure 7.22 in Signals and Systems



$y_a(t) = x_a(t)\cos(\omega_a t)$

$y_a(t) = x_a(t)\cos(\omega_a t)$

$y_a(t) = x_a(t)\cos(\omega_a t)$

$w(t) = y_a(t) + y_b(t) + y_c(t)$

FDM Transmitter

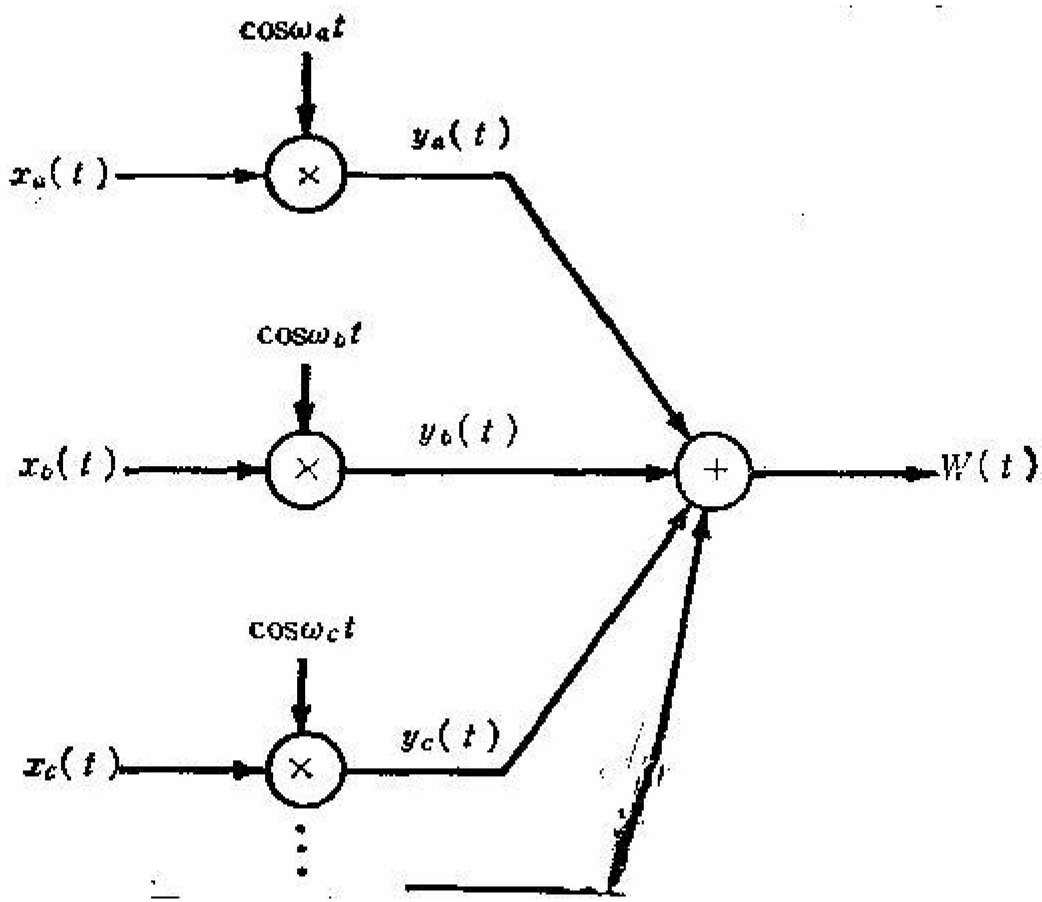


Figure 7.21 in Signals and Systems

FDM Receiver

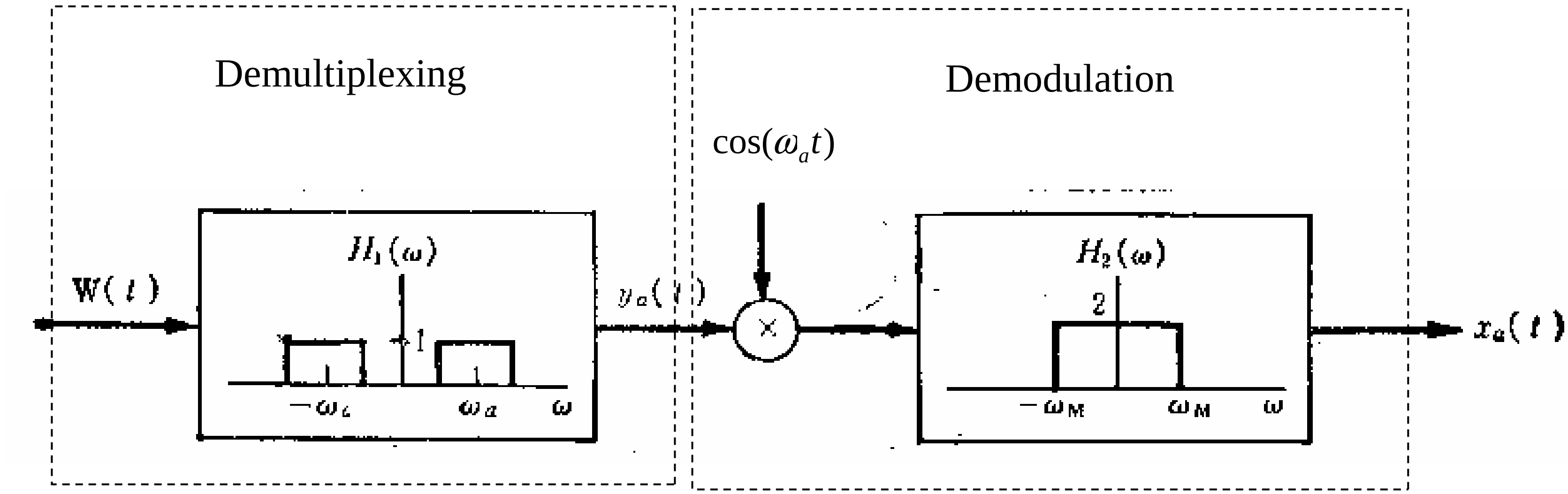


Figure 7.23 in Signals and Systems

Example

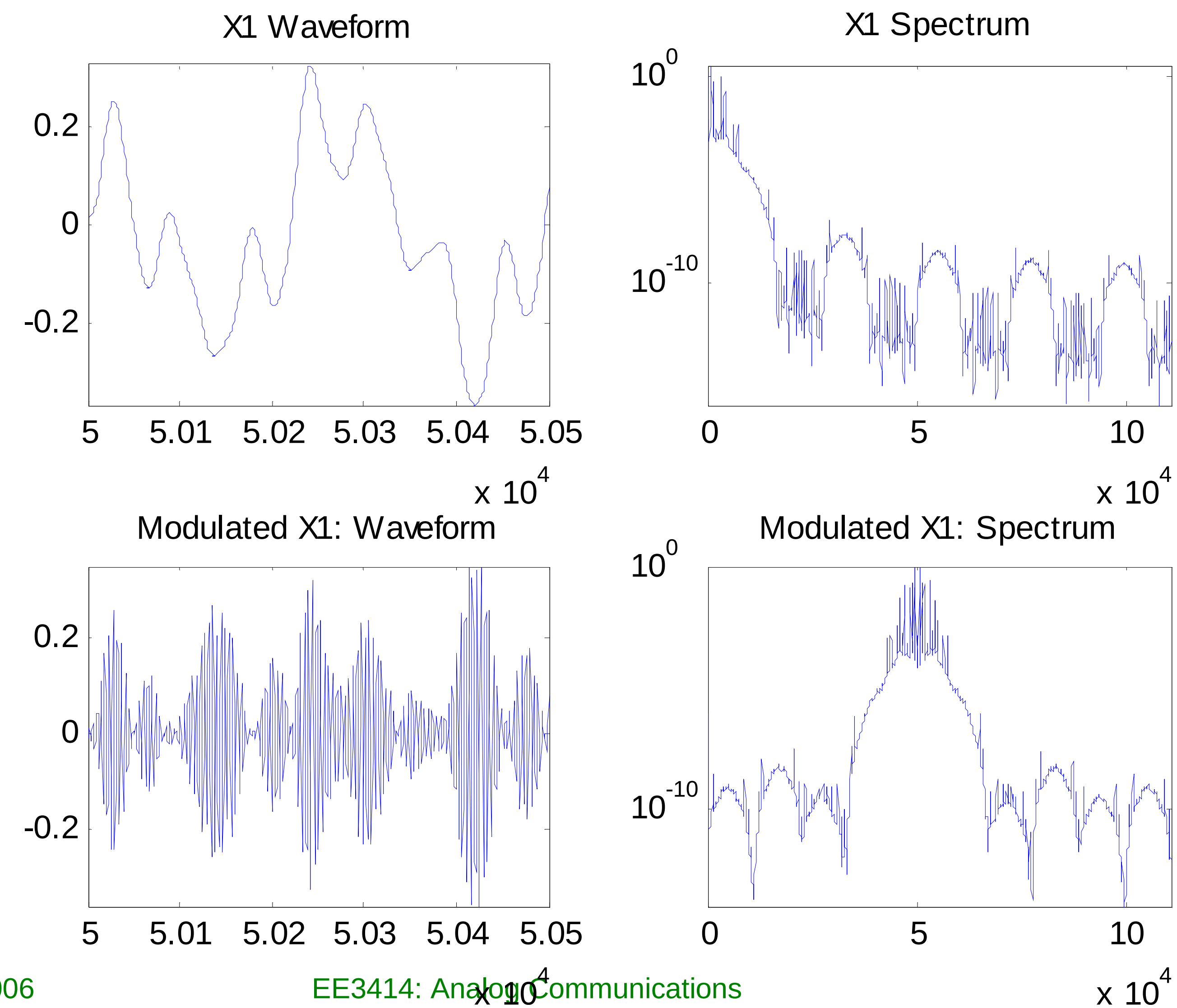
- How to transmit two signals each with frequency ranging in (-10KHz,10KHz) over a channel operating in the frequency range (300KHz,340KHz)? Draw the block diagrams for the modulator and demodulator, and sketch the spectrum of the modulated and demodulated signals.

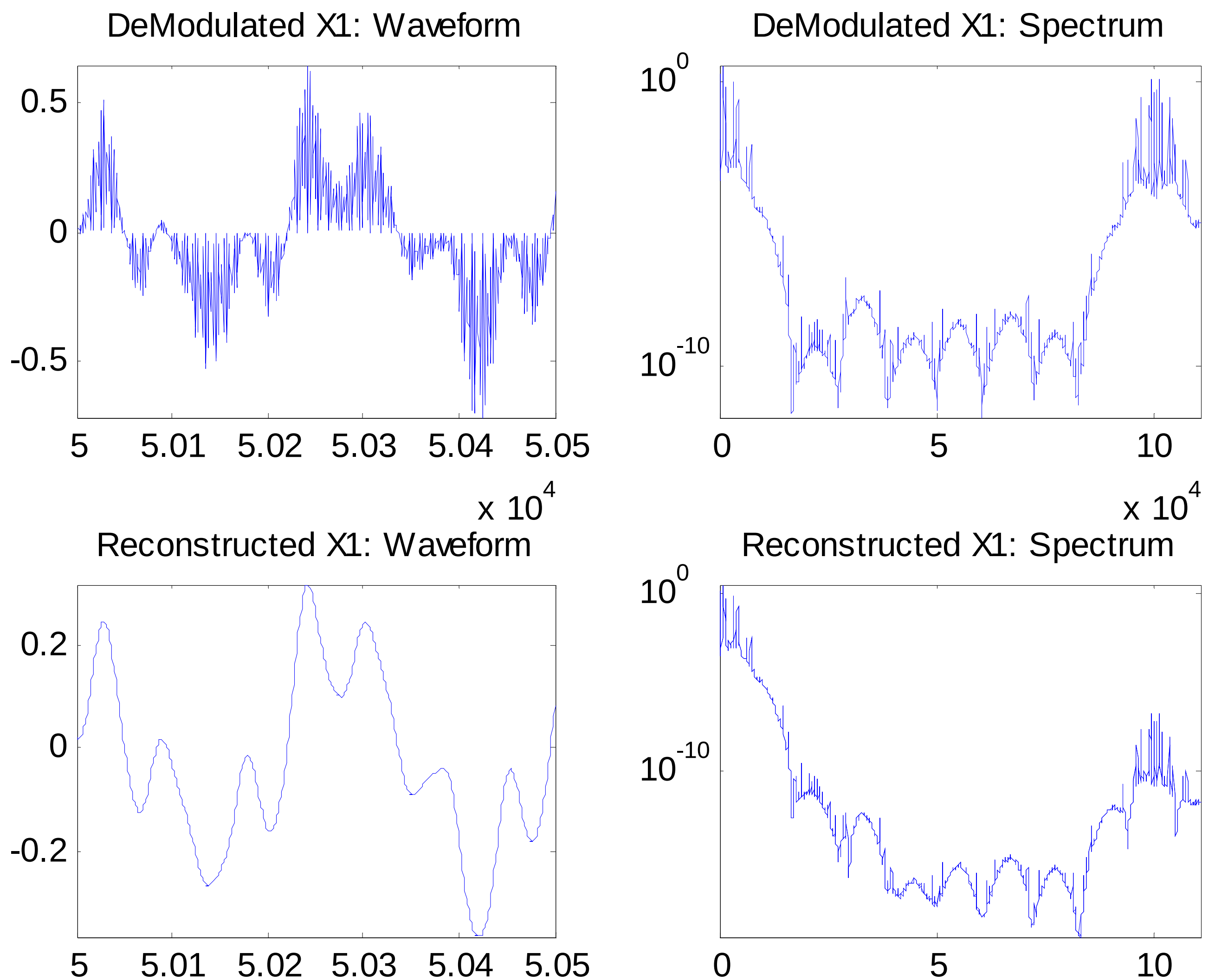
Demo: modulating a sound signal

(amplitude_modulation.m)

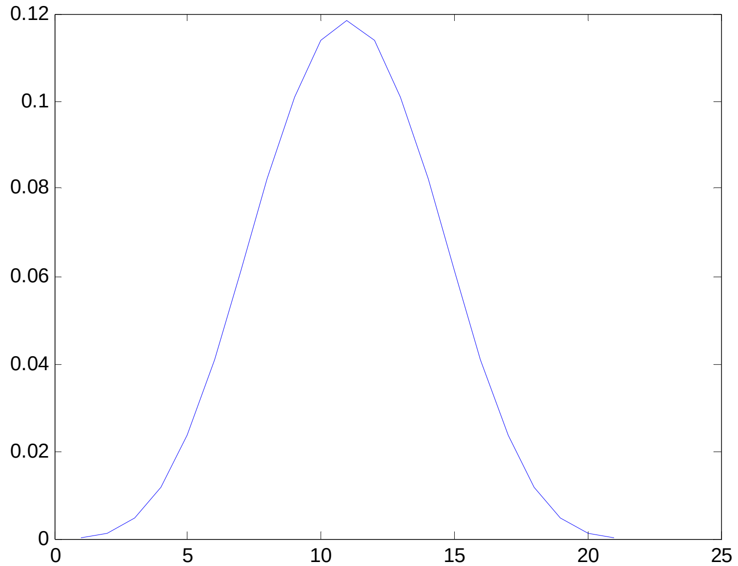
fs=22k

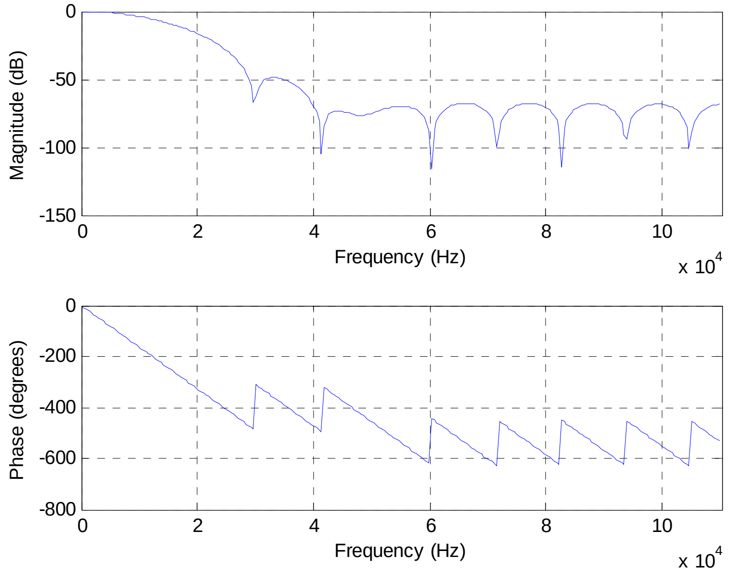
fc=50k




DeModulated X1: Waveform
0.5
0
-0.5
5
5.01
5.02
5.03
5.04
5.05
x 10^4
DeModulated X1: Spectrum
10^0
10^-10
0
5
10
x 10^4
Reconstructed X1: Waveform
0.2
0
-0.2
5
5.01
5.02
5.03
5.04
5.05
Reconstructed X1: Spectrum
10^0
10^-10
0
5
10

Lowpass Filter

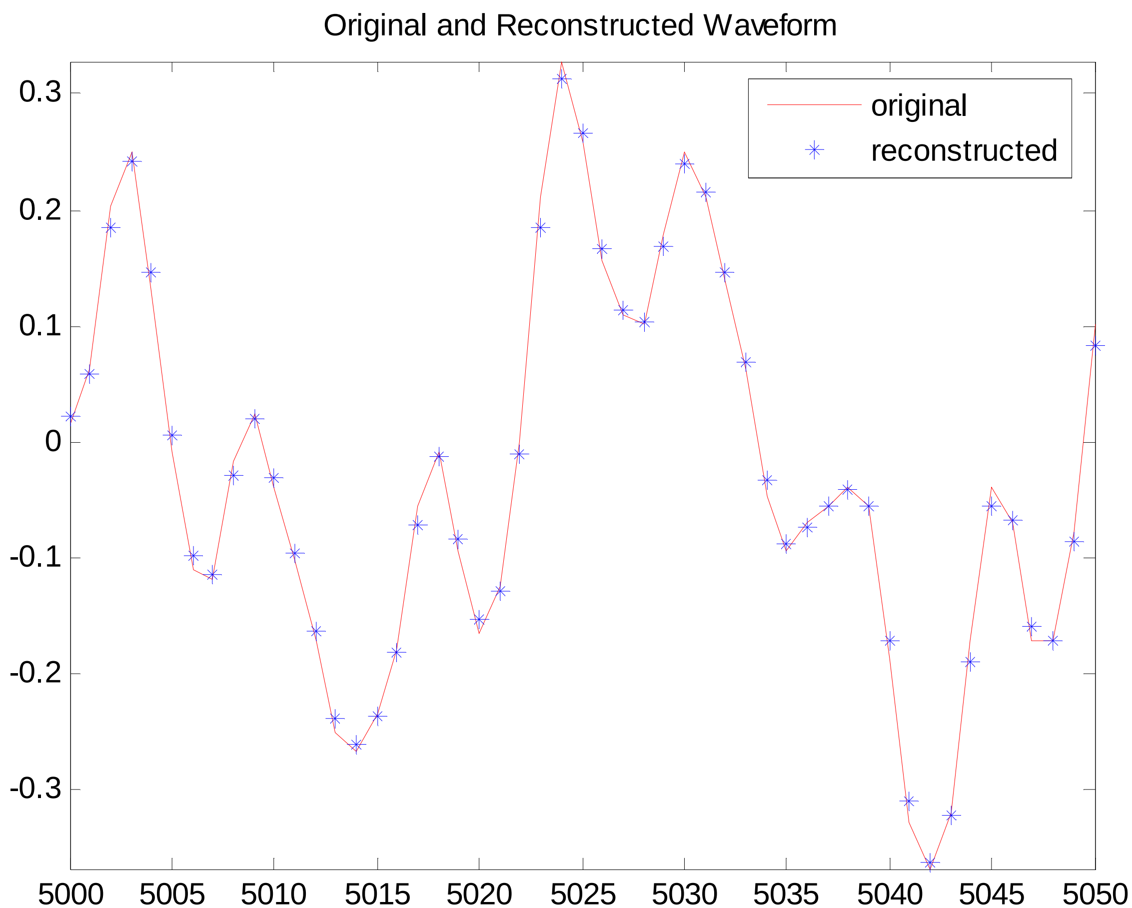




Length=20, Cut-off freq=11k

original

reconstructed

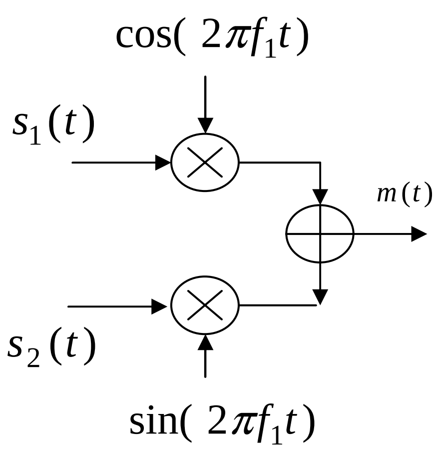


Quadrature Amplitude Modulation

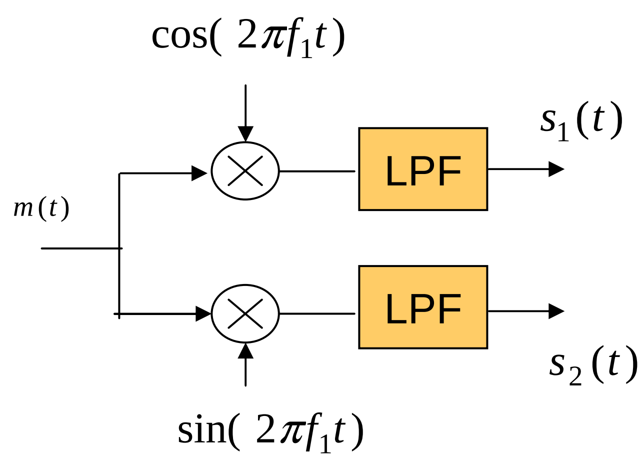
- With amplitude modulation: a signal with bandwidth B needs 2B channel bandwidth
  - This is called double sideband (DSB) AM
  - Other techniques can reduce the bandwidth requirement
    - Single sideband (SSB)
    - Vestigial sideband (VSB)
- By using QAM, we can send 2 signals each with bandwidth B over a channel bandwidth of 2B
  - Equivalent to each signal with bandwidth B

Quadrature Amplitude Modulation (QAM)

- A method to modulate two signals onto the same carrier frequency, but with 90º phase shift



QAM modulator



QAM demodulator

QAM in more detail

Proof (in time domain) the demodulator can separate the signal on board!
Discuss the sensitivity of the system to synchronization of the carrier signal.

Other Modulation Methods

- Amplitude modulation $y(t) = x(t)\cos(2\pi f_c t + \theta_0)$
  - The amplitude of the carrier signal is controlled by the modulating signal
  - Pitfall of AM: channel noise can corrupt the amplitude easily.
- Frequency modulation $y(t) = \cos(\theta(t)), \frac{d\theta(t)}{dt} = 2\pi f_c t + k_f x(t)$
  - The frequency of the carrier signal is proportional to the modulating signal
- Phase modulation $y(t) = \cos(2\pi f_c t + \theta_0 + k_p x(t))$
  - The phase of the carrier signal is proportional to the modulating signal

Application of Modulation and FDM

- AM Radio (535KHz--1715KHz):
  - Each radio station is assigned 10 KHz, to transmit a mono-channel audio (bandlimited to 5KHz)
  - Using Amplitude modulation to shift the baseband signal
- FM Radio (88MHz--108 MHz):
  - Each radio station is assigned 200 KHz, to transmit a stereo audio.
  - The left and right channels (each limited to 15KHz) are multiplexed into a single baseband signal using amplitude modulation
  - Using frequency modulation to shift the baseband signals
- TV broadcast (VHF: 54-88,174-216MHz, UHF:470-890MHz)
  - Each station is assigned 6 MHz
  - The three color components and the audio signal are multiplexed into a single baseband signal
  - Using vestigial sideband AM to shift the baseband signals.

What Should You Know

- Understand the bandwidth requirement
  - Channel bandwidth > signal bandwidth
- Understand the principle of amplitude modulation
  - Know how to modulate a signal to a certain frequency
  - Know how to demodulate a signal back to the baseband
  - Can write the equation and draw block diagram for both modulation and demodulation
  - Can plot the signal spectrum after modulation and demodulation
- Understand the principle of frequency division multiplexing
  - Can write the equation and draw block diagram for both modulation and demodulation, for multiplexing of two to three signals.
- Understand how do AM and FM radio and analog TV work in terms of modulation and multiplexing.

References

- A. M. Noll, Chapter 10.
- A. V. Oppenheim and A. S. Willsky, *Signals and Systems*, 2nd edition, Chapter 8, Sec. 8.1-8.3 (copies provided)