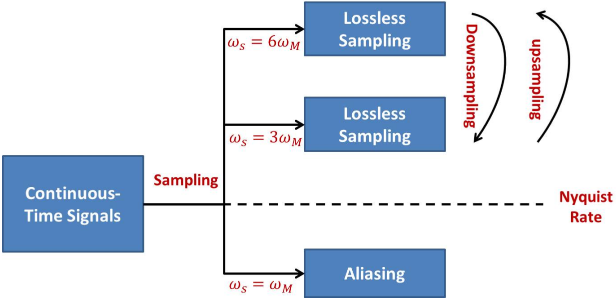
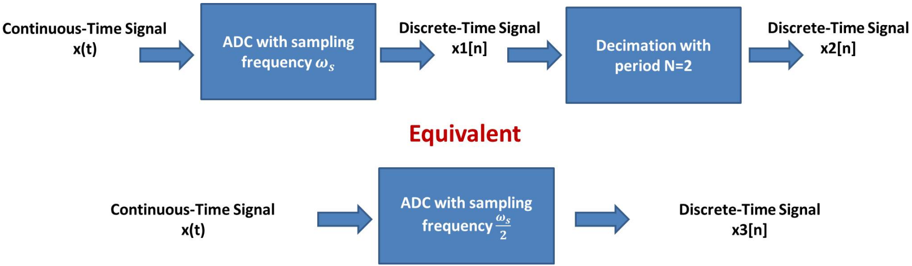
Anything Else?



- Downsampling: to reduce the sampling frequency (decimation)
- Upsampling: to generate a DT signal with higher sampling frequency
- As long as Nyquist rate is satisfied, the transform between low-sampling-frequency version and high-sampling-frequency versions is lossless.

Downsampling

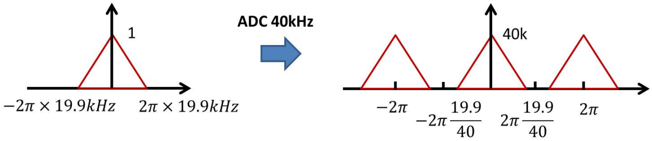
- Downsampling: a general procedure to reduce the sampling frequency



When do we need downsampling?

Downsampling Example (1/2)

- Suppose we have a clip of voice, $x(t)$, with bandwidth $=$19.9kHz
- It can be converted to DT signal with sampling frequency 40kHz, denoted as $x_1[n]$

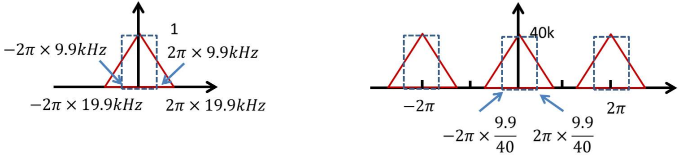


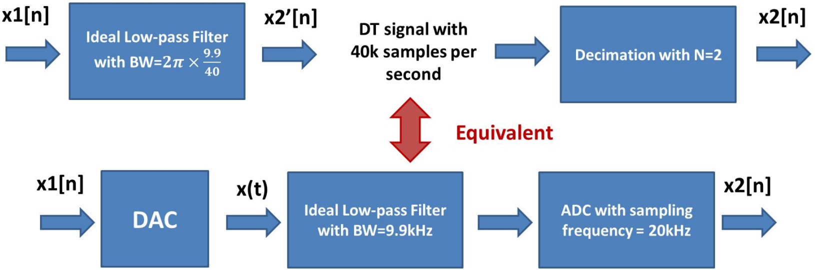
- Based on $x_1[n]$, if we want to save the voice information within 9.9kHz into another DT signal, what can we do?

One Choice:

How can we generate x2[n] in discrete-time domain?

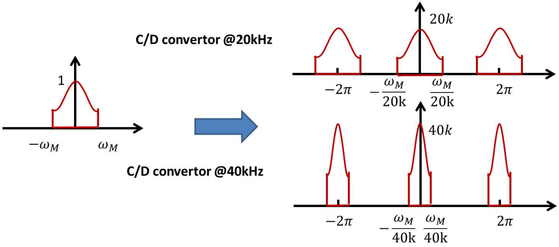
Downsampling Example (2/2)





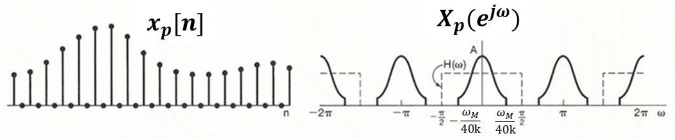
Upsampling

- Upsampling: a procedure to generate a sequence with higher sampling frequency
- Superpose the following two digital sound clips
  - Audio clip 1: Bandwidth= 19.9kHz, sampled at 40kHz
  - Audio clip 2: Bandwidth= 9.9kHz, sampled at 20kHz
- Double the sampling frequency of audio clip 2 (40kHz)
- How to do upsampling in discrete-time domain?



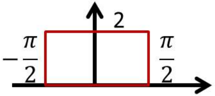
- Time expansion (Insert zeros):

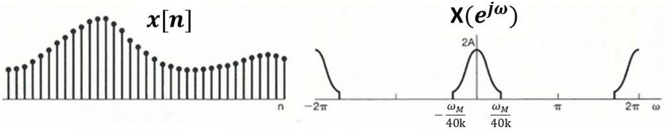
$$x_p[n] = x_{b(2)}[n] \longleftrightarrow X_p(e^{j\omega}) = X_b(e^{j2\omega})$$



- Low-pass filtering:

Ideal Low-Pass Filter:





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

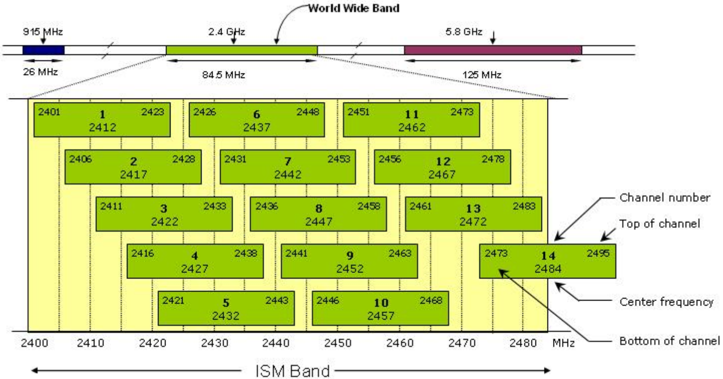
2020-Spring
Last Update on: May 19, 2020

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 $\sim$ [200Hz, 4kHz], microwave link $\sim$ [300MHz, 300GHz]
- Example 2: Wifi in industrial, scientific and medical (ISM) radio bands



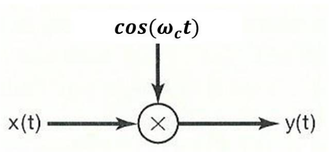
Amplitude Modulation

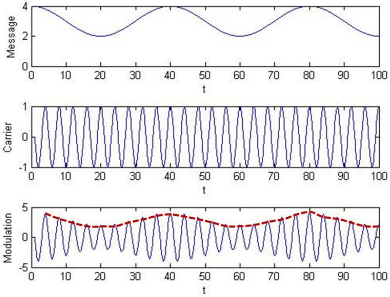
- General form

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

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

AM with a Sinusoidal Carrier

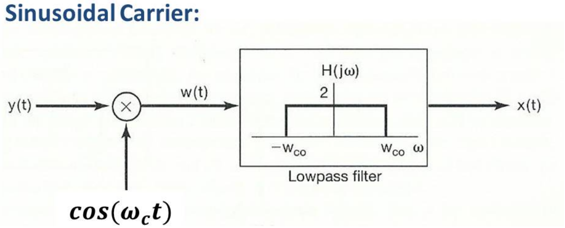




- Time & frequence domain expression

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

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.

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

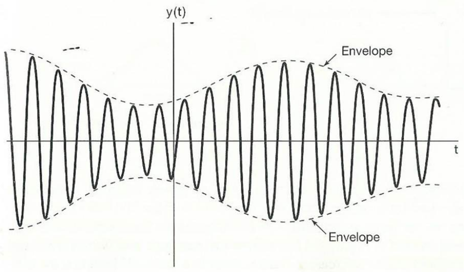
After lowpass filter

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

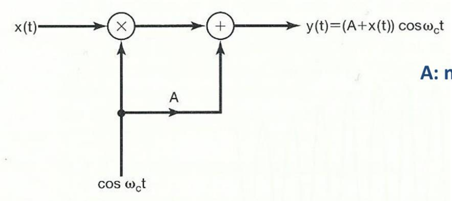
Modulator for Asynchronous Demodulation

- AM signal is like

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

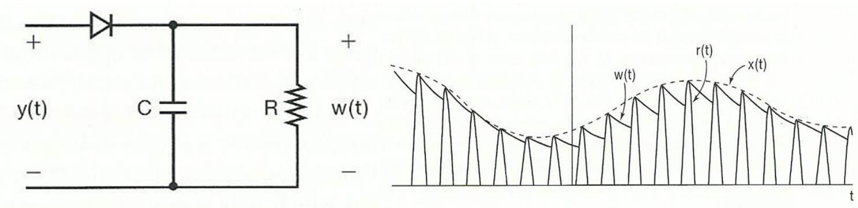


- Modulator structure (Percent Modulation)



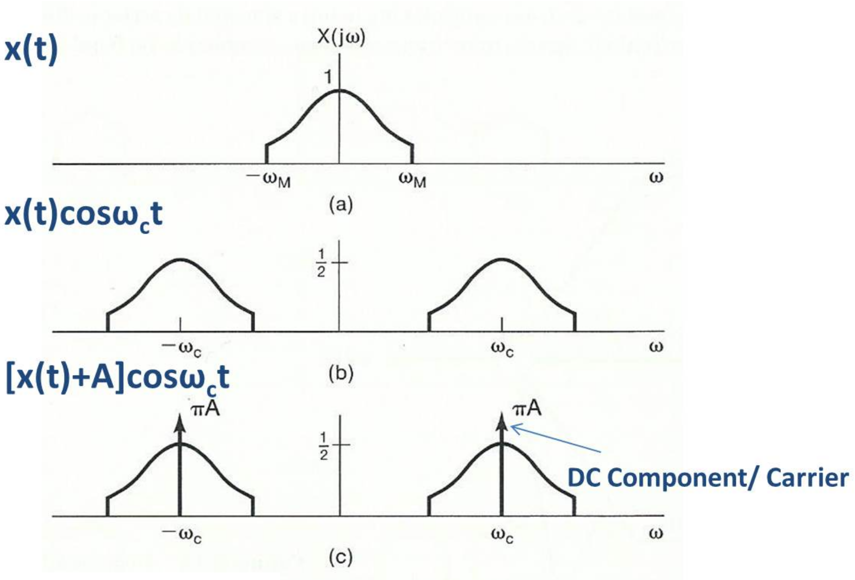
A: make sure A+x(t) is positive

Envelope Detector

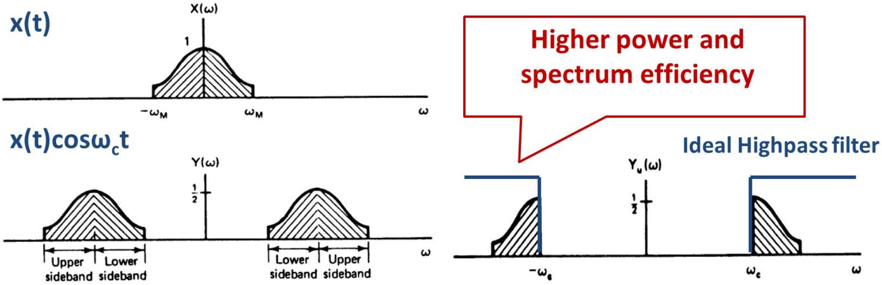


- Requirement: Carrier frequency >> Signal bandwidth
- Larger transmission power v.s. simpler receiver (asynchronous)
  - Public radio broadcasting
- Question
  - How to improve the quality of $w(t)$?

AM Spectrum w/o Carrier

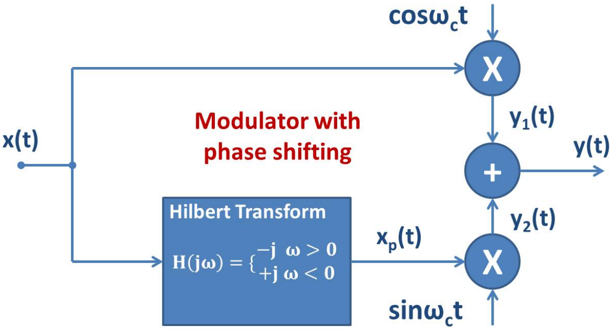


Single-Sideband AM



- 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

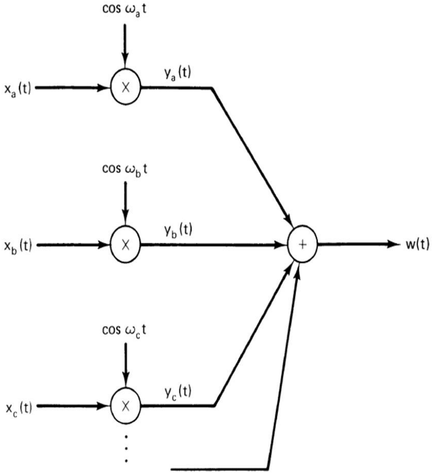


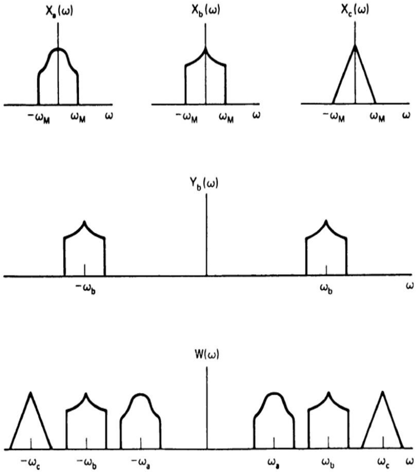
- Questions :
  - What's the output signal?
  - How to filter out the other sideband?

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 + $Acos\omega_c t$
- 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 passed through an ideal lowpass filter with cutoff frequency 400π and passband of 2, determine the signal obtained at the output of the lowpass filter.