AV312 - Lecture 2

Vineeth B. S.

Department of Avionics,
Indian Institute of Space Science and Technology.

Figures from “Communication Systems” by Simon Haykin

July 29, 2016

Announcements

- AV332 (lab) starting from next Monday
  - Prithi Yadav, Ananthalekshmi, Abhishek Chakraborthy, Rakesh Kumar, Karthikeyan
- Monday - 2nd and 3rd hours for Anoop
- Tuesday - 3rd and 4th hours for AV312

Review

- Elements of a communication system
- Sources of information - message bandwidth
- Ideal filter models for channels - bandwidth
- Modulation process
- You should review signals and systems!

Today's plan

- Review amplitude modulation
- Modulation process
- Amplitude modulation and demodulation
  - AM
  - DSBSC
  - SSB
- Scribes are Abhiroop and Abhrajit

Amplitude modulation (DSBSC)

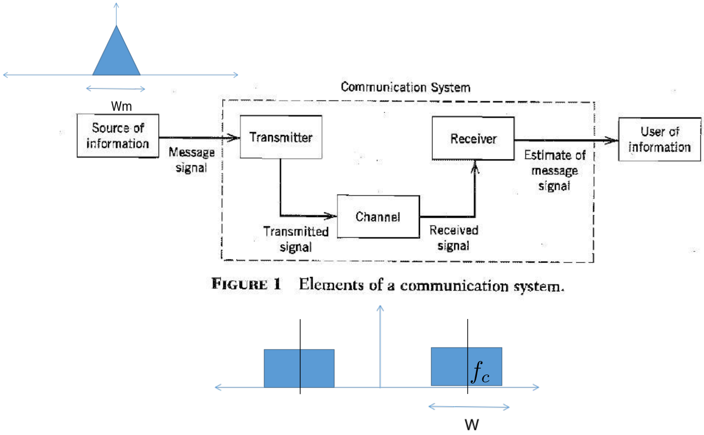
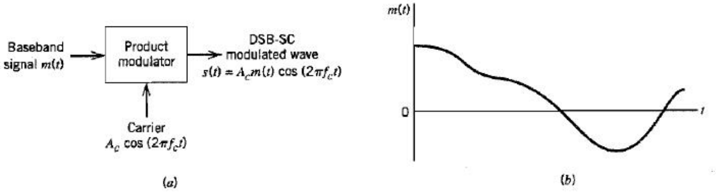


FIGURE 1 Elements of a communication system.

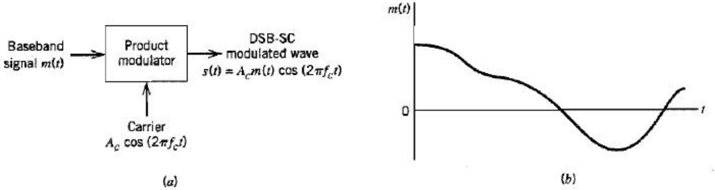
- Assume that $W_m < W$
- Design the transmitter and receiver so that we obtain a "good" reproduction of the source signal at the destination

Amplitude modulation (DSBSC)



- FT of the signal $s(t)$

Amplitude modulation (DSBSC)



- FT of the signal $s(t)$
- The center frequency of the channel's bandpass response is f_c
- $s(t) = A_c m(t) cos(2\pi f_c t)$
- $S(f) = A_c M(f) * \frac{1}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right]$
- $S(f) = \frac{A_c}{2}\left[M(f - f_c) + M(f + f_c)\right]$

What should the receiver do?

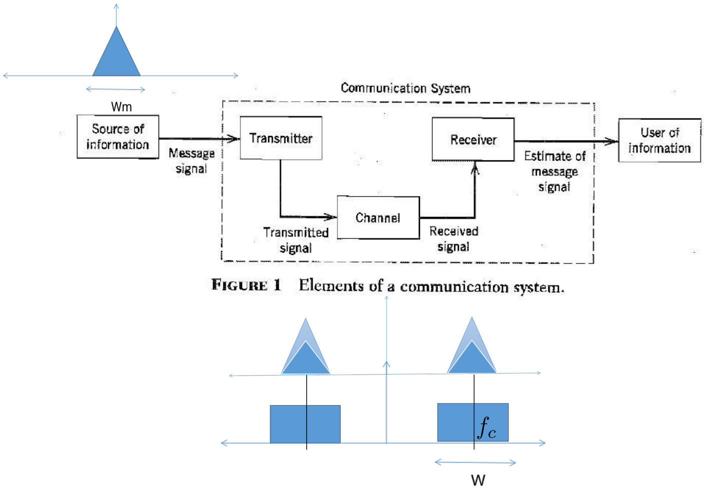


FIGURE 1 Elements of a communication system.

Amplitude demodulation (DSBSC)

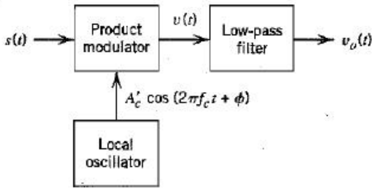


FIGURE 2.7 Coherent detector for demodulating DSB-SC modulated wave.

- Obtain $v(t)$ and $v_o(t)$
- Obtain the FTs of the signals $v(t)$ and $v_o(t)$

Amplitude demodulation (DSBSC)

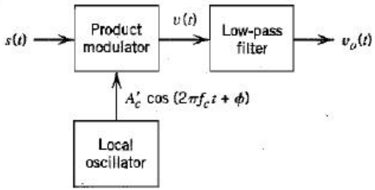


FIGURE 2.7 Coherent detector for demodulating DSB-SC modulated wave.

- Obtain $v(t)$ and $v_o(t)$
- Obtain the FTs of the signals $v(t)$ and $v_o(t)$
- Coherent demodulation is required! (Phase angle recovery)

The modulation and demodulation process

- Motivating reasons
  - Many channels are bandpass in nature
  - Frequency division multiplexing
- What is the simplest signal that can pass through a bandpass channel undistorted ?

The modulation and demodulation process

- Motivating reasons
  - Many channels are bandpass in nature
  - Frequency division multiplexing
- What is the simplest signal that can pass through a bandpass channel undistorted ?
- $A_c cos(2\pi f_c t + \phi)$

The modulation and demodulation process

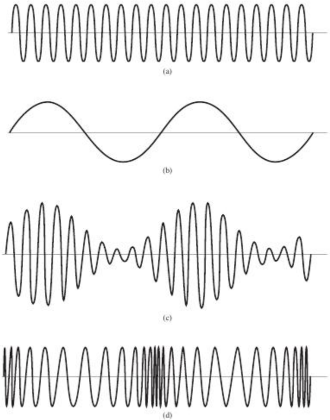
- Motivating reasons
  - Many channels are bandpass in nature
  - Frequency division multiplexing
- What is the simplest signal that can pass through a bandpass channel undistorted ?
- $A_c cos(2\pi f_c t + \phi)$
- The message signal $m(t)$ is used to modulate some characteristic of this simple signal
  E.g. $A(t)cos(2\pi f_c t + \phi)$, where $A(t) = A_c m(t)$
- The cosine carries the message signal
- The message signal modulates the carrier signal
- The process of changing the carrier signal's property(ies) in accordance with the message signal is called modulation
- Recovering the message signal from the modulated carrier signal after passing through the channel is demodulation

Possibilities

- The carrier signal is $c(t) = A_c cos(2\pi f_c t + \phi)$
- We can change two properties: the amplitude and the phase angle

Possibilities

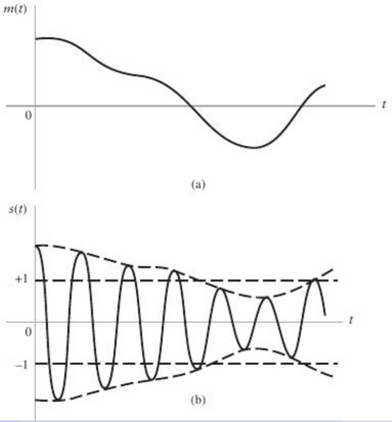
- The carrier signal is $c(t) = A_c cos(2\pi f_c t + \phi)$
- We can change two properties: the amplitude and the phase angle



- The modulated signal is $A(t)cos(\phi(t))$

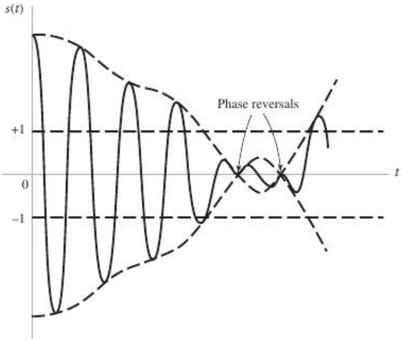
Amplitude modulation (AM)

- $m(t)$ is the message signal (baseband; e.g. voice)
- $c(t) = A_c cos(2\pi f_c t)$ is the carrier
- AM signal $s(t) = A_c(1 + k_a m(t))cos(2\pi f_c t)$
- Here k_a (in volts^{-1}) is the amplitude sensitivity of the modulator



Amplitude modulation (AM)

- If $(1 + k_a m(t)) < 0$, then we have envelope distortion



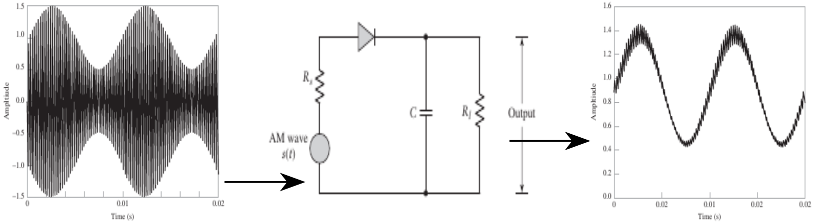
- We also have envelope distortion if $f_c < \frac{W_m}{2}$, W_m is the bandwidth of $m(t)$.
- $|k_a m(t)| < 1$ for no-envelope distortion (k_a could be negative also)

Amplitude modulation (AM)

- What is the FT $S(f)$ of $s(t)$?
- What is meant by upper and lower sidebands?

Envelope Demodulation for AM

- A simple low complexity circuit for envelope demodulation



- Suppose r_f is the forward resistance of the diode, R_s is the source resistance
- Then $(r_f + R_s)C \ll \frac{1}{f_c}$
- And $\frac{1}{f_c} \ll R_l C \ll \frac{1}{W}$

Amplitude modulation (AM)

- Very low complexity modulation and demodulation
- Wastes power by sending a copy of the carrier along with the message signal
- Also wastes bandwidth!

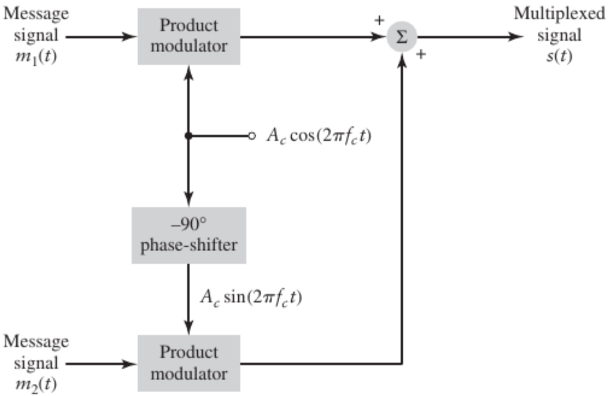
Double sideband suppressed carrier (DSBSC)

- $s(t) = A_c m(t) cos(2\pi f_c t)$ vs $s(t) = A_c(1 + k_a m(t)) cos(2\pi f_c t)$
- What are the similarities?
- What are the differences?

Double sideband suppressed carrier (DSBSC)

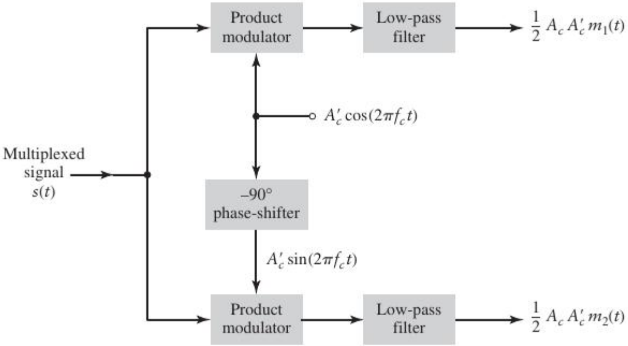
- $s(t) = A_c m(t) cos(2\pi f_c t)$ vs $s(t) = A_c(1 + k_a m(t)) cos(2\pi f_c t)$
- What are the similarities?
- What are the differences?
  - Carrier - needs carrier recovery
  - Complexity is higher!
- Carrier/phase recovery
  - Pilot tone (separate band)
  - Phase locked loop (PLL)
  - Costas receiver for DSBSC

Quadrature carrier multiplexing



- Bandwidth conservation using two DSBSC signals for $m_1(t)$ and $m_2(t)$

Quadrature carrier multiplexing (Receiver)



Single sideband modulation

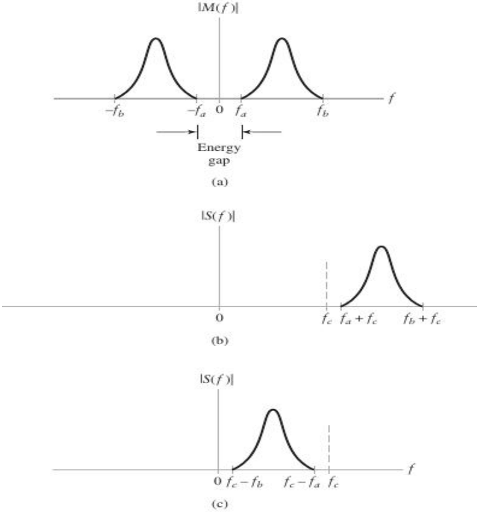
- Suppose $m(t)$ is a real-valued CT signal
- What is the relationship between $M(f)$ and $M(-f)$?

Single sideband modulation

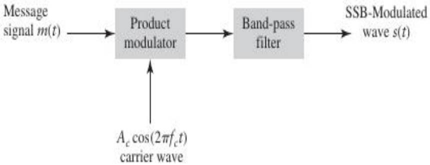
- Suppose $m(t)$ is a real-valued CT signal
- What is the relationship between $M(f)$ and $M(-f)$?

$$
\begin{aligned}
M(f) &= \int_{-\infty}^{\infty} m(t)e^{-j2\pi ft}dt \\
M^*(f) &= \int_{-\infty}^{\infty} m^*(t)e^{j2\pi ft}dt \\
&= \int_{-\infty}^{\infty} m(t)e^{j2\pi ft}dt \\
&= M(-f)
\end{aligned}
$$

Single sideband modulation



- A intuitive approach
- Applicable to speech signals, $f_a \approx 100 Hz$



Hilbert transform

- CT signal $g(t)$ with FT $G(f)$
- The Hilbert transform (HT) $\hat{g}(t)$ is

Hilbert transform

- CT signal $g(t)$ with FT $G(f)$
- The Hilbert transform (HT) $\hat{g}(t)$ is

$$\hat{g}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{g(\tau)}{t - \tau} d\tau$$

- The inverse HT is

$$g(t) = -\frac{1}{\pi} \int_{-\infty}^{\infty} \frac{\hat{g}(\tau)}{t - \tau} d\tau$$

Hilbert transform

- CT signal $g(t)$ with FT $G(f)$
- The Hilbert transform (HT) $\hat{g}(t)$ is

$$\hat{g}(t) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{g(\tau)}{t-\tau} d\tau$$

- The inverse HT is

$$g(t) = -\frac{1}{\pi}\int_{-\infty}^{\infty} \frac{\hat{g}(\tau)}{t-\tau} d\tau$$

- Interpret HT as a LTI system

Hilbert transform

- CT signal $g(t)$ with FT $G(f)$
- The Hilbert transform (HT) $\hat{g}(t)$ is

$$\hat{g}(t) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{g(\tau)}{t-\tau} d\tau$$

- The inverse HT is

$$g(t) = -\frac{1}{\pi}\int_{-\infty}^{\infty} \frac{\hat{g}(\tau)}{t-\tau} d\tau$$

- Interpret HT as a LTI system
- Verify that FT of $\frac{1}{\pi t}$ is $-j \times \mathrm{sgn}(f)$

Properties of Hilbert transform

- Show that $|G(f)| = |\hat{G}(f)|$
- Show that HT(HT($g(t)$)) = -$g(t)$
- Show that $\int_{-\infty}^{\infty} g(t)\hat{g}(t) = 0$
- Why is HT useful in the context of SSB ?