COMS3100/7100

Introduction to Communications

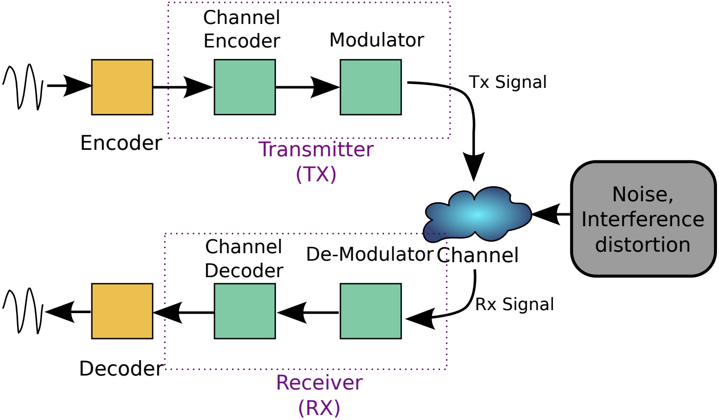
Lecture 9: Amplitude Modulation

This lecture:

1. What is Modulation?
2. AM Signals and Spectra.
3. AM Modulation and Demodulation.
4. Double-Sideband Suppressed Carrier.

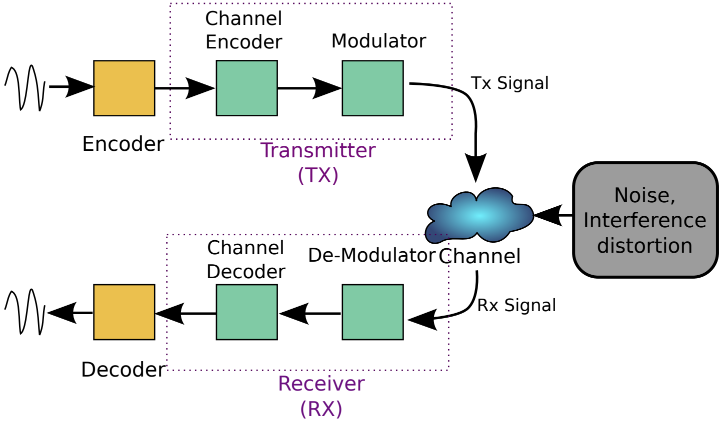
Ref: CCR pp. 152–159, 176–177, Couch pp. 302–312.

Communications Course So Far



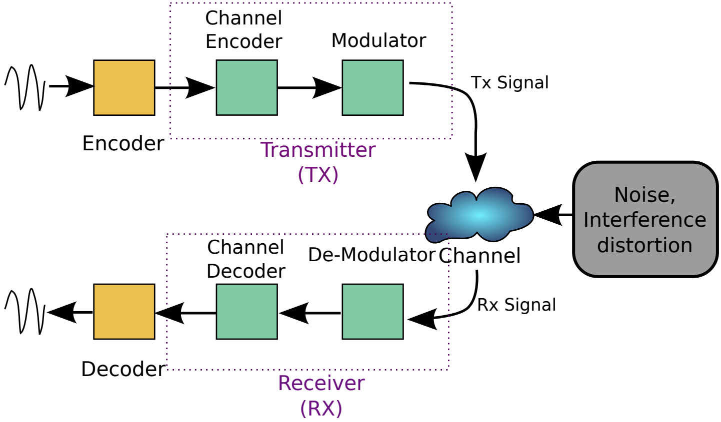
Lecture 2: Representation of Signals
Lecture 3: Representation of Systems
Lecture 4: Systems: LTI

Communications Course So Far



Lecture 5: Fourier Representation (Frequency)
Lecture 6: Transmission and Filtering
Lecture 7: Correlation and Spectral Density

Communications Course So Far



Lecture 8: Bandpass Signals
Lecture 9: Modulation (AM)
Lecture 10: Modulation (FM)

What is Modulation?

Often, the message is itself a signal, e.g., an audio signal, and to produce a signal that is suitable for transmission through the channel, we effect some transformation on the message signal.

Modulation

- We call this modulation.
- Modulation is often performed with respect to another signal, called the carrier.
- We say the message modulates the carrier to produce the transmitted signal.

Modulation (2)

- Sometimes the modulation is as simple as multiplication with the carrier, cf. the Fourier modulation properties.
- In continuous-wave (CW) modulation, the carrier is a sinusoid. ($\cos(2\pi f_c t)$).
  - This is the traditional mode for all-analogue communications.
- In pulse modulation, the carrier is a pulse train.
  - This is a mode that allows for digital communications.

CW Modulation

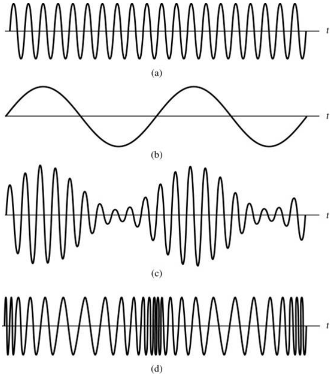
$$g(t) = A(t)\cos\left(2\pi f_c t + \varphi(t)\right)$$

The two principal subclasses of CW modulation are:

amplitude modulation, in which the carrier amplitude is varied with the message signal and

angle modulation, in which the phase angle of the carrier is varied with the message signal.

Examples of CW Modulation



(a) Carrier wave. (b) Sinusoidal modulating signal.
(c) Amplitude-modulated signal. (d) Angle-modulated signal.

Benefits of Modulation

Make message better suited to the channel

There are three practical benefits that result from modulation:

1. Modulation can shift the spectral content of a message signal into a band which is better suited to the channel.
   - Antennas only efficiently radiate and admit signals whose wavelength is similar to their physical aperture.
   - Hence, to transmit and receive, say, voice, by radio we need to shift the voice signal to a much higher frequency band.

Benefits of Modulation

Multiplexing

2. Modulation permits the use of multiplexing.
   - Multiplexing means allowing simultaneous communication by multiple users on the same channel.
   - For instance, the radio frequency spectrum must be shared and modulation allows users to separate themselves into bands.

Benefits of Modulation

Some immunity to noise/interference

3. Modulation can provide some control over noise/interference.
   - As we will see, frequency modulation (FM) permits a tradeoff between bandwidth and noise.

AM Modulation

This lecture focuses on AM Modulation

Next lecture will be on phase modulation (of which FM is a subset of)

AM Signals and Spectra

(Double-sideband) amplitude modulation (AM) is a technique from the very beginning of CW radio transmission at the dawn of the 20th century.

- It is still in use today because of its simplicity.

Modulating AM Signals

A message signal $x(t)$ is amplitude modulated as follows:

1. An envelope signal $\check{g}(t)$ is obtain by amplifying and biasing the message signal, so that

$$\check{g}(t) = g_{\mathrm{I}}(t) = A_{\mathrm{c}}\left[1 + \mu x(t)\right].$$

- The modulation index $\mu > 0$ is chosen to ensure that $\check{g}(t) > 0$, and to conserve power.

Modulating AM Signals (2)

2. The signal is then mixed with the carrier, a sinusoid of frequency f_c, to produce the AM signal

$$x_c(t) = g(t) = g_I(t)\cos 2\pi f_c t.$$

Modulating AM Signals (3)

3. The AM signal can then be radiated through the antenna.

AM radio typically uses

- 148.5 kHz – 283.6 kHz (9 kHz channel spacing) navigational aids + radio in other countries. (shortwave)
- 520 kHz – 1610 kHz (9 kHz spacing) (typical commercial radio) (medium wave)

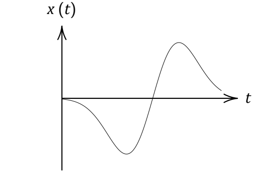
Frequency-Domain Analysis

... of an AM Signal

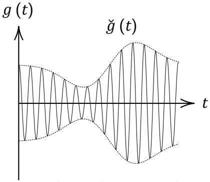
Suppose $x(t) \overset{\text{FT}}{\longleftrightarrow} X(f)$ and $g(t) \overset{\text{FT}}{\longleftrightarrow} G(f)$.
Then

$$G(f) = \frac{1}{2}A_\mathrm{c}\left[\delta(f - f_\mathrm{c}) + \delta(f + f_\mathrm{c})\right] + \frac{1}{2}\mu A_\mathrm{c}\left[X(f - f_\mathrm{c}) + X(f + f_\mathrm{c})\right].$$

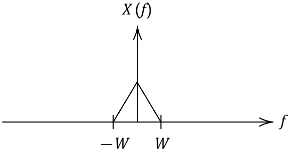
Frequency Domain Analysis (2)



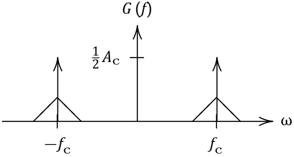
Message signal in the time domain.



AM signal in the time domain.



Message signal in the frequency domain.

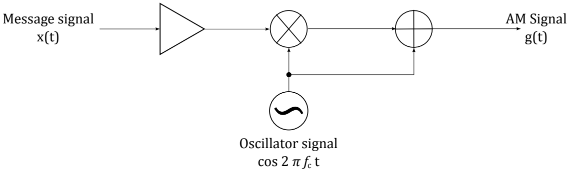


AM signal in the frequency domain.

AM Modulation and Demodulation

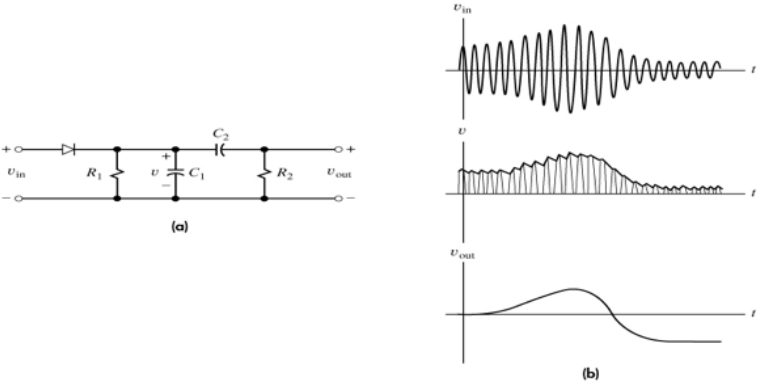
A System for Amplitude Modulation

Basic AM requires only an amplifier, a summer and a mixer.



A System for Amplitude Demodulation

To demodulate the received signal, i.e., to recover the original message signal, we can use an envelope detector circuit.



System for AM Demodulation (2)

- A diode is used to half-wave rectify the received signal.
- The R_1C_1 filter then smooths to recover an approximation of the original envelope.
- R_2C_2 removes the bias.

DSB AM

Is power inefficient

A problem with AM is that it is inefficient with power.

- With $|x(t)| \leq 1$, at least half the power is used in the carrier.

DSB-SC AM

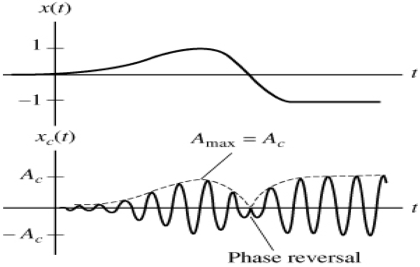
Double-Sideband Suppressed Carrier

- Instead, in double-sideband suppressed carrier (DSB-SC), the natural envelope is just an amplification of the message, i.e.,

$$\check{g}(t) = A_c x(t).$$

Demodulation of DSB-SC AM

- A simple envelope detector cannot be used: a product detector is needed instead.

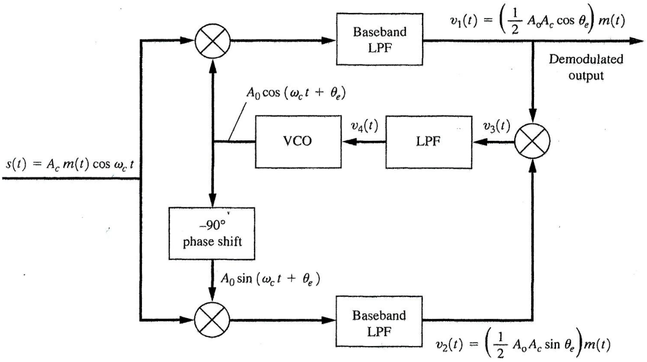


Demodulation of DSB-SC AM (2)

- The receiver needs accurate phase information to recover the message $\Rightarrow$ a carrier recovery circuit is needed.

Costas Loop

Shown below is a Costas Loop for carrier recovery in DSB-SC.



- It is assumed that the phase error θ_e is small.
- The input to the VCO is roughly proportional to θ_e.