EC5.102: Information and Communication

(Lec-10)

Modulation-1

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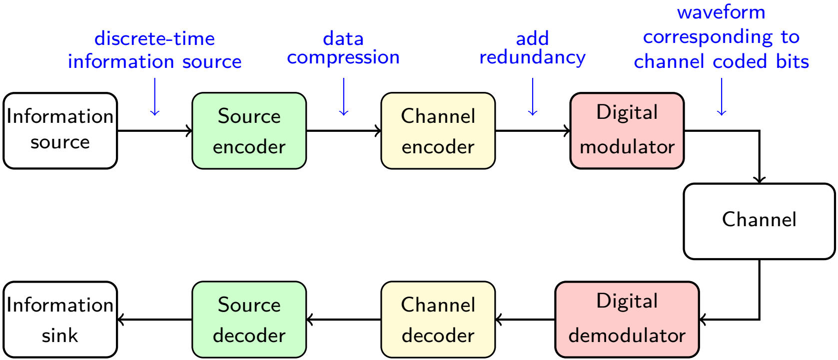
Reference Books

- Upamanyu Madhow, *"Introduction to Communication Systems"*
- B. P. Lathi and Z. Ding, *"Modern digital and analog communication systems"*.
- A. Goldsmith, *"Wireless communication"*.

Block diagram of a digital communication system

Digital communication system

- Block diagram of digital communication system

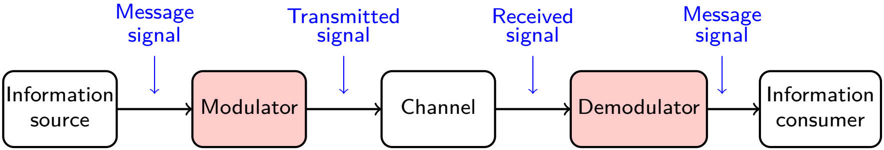


We will now focus on the modulator block

Block diagram of a analog communication system

Analog acommunication system

- Block diagram of analog communication system

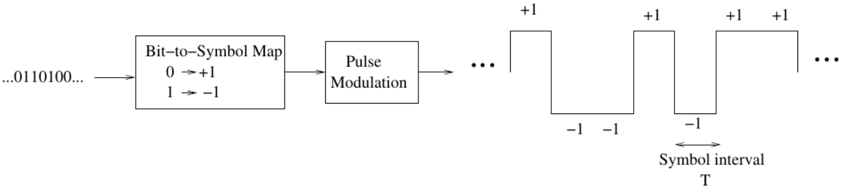


We will focus on the modulator block

Introduction to modulation

What is modulation?

- Digital modulation is the process of translating bits to analog waveforms that can be sent over a physical channel.
- Pulse modulation



  - Mathematical representation of pulse modulation
  - Can we use any other waveform, instead of a pulse?
  - Is pulse modulation used in practice?
  - Do we need “fancy” modulation schemes?

Need for modulation

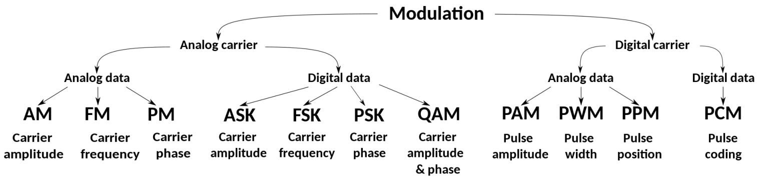
- We will see an overview of what happens: Details to study in "Communication theory" course.
- Why do we need modulation? ▸ Link
- One of key need for modulation: Height of the antenna will be huge if we send audio (low frequency) signals directly!
- The Advantages of using modulation techniques are:
  - Reduce the height of Antenna
  - Increases the range of communication
  - Avoids mixing of signal
  - Allows multiplexing of signals
  - Allows Adjustments in Bandwidth
  - Shift digital signal to analog signal

Basic idea in modulation

- In the modulation process two signals are used namely
  - Modulating signal $m(t)$
  - Carrier signal $c(t)$
- Modulating signal is nothing an information source (it is typically a low frequency signal)
- Carrier signal is nothing but a very high frequency signal that carries information content of $m(t)$ and travels on a communication channel.

Types of modulation

- Types of modulation:
  - Analog modulation
  - Digital modulation
- Detailed classification:



- Our focus:
  - AM: Analog data + analog carrier
  - PSK: Digital data + analog carrier

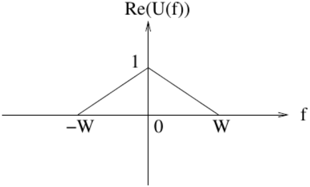
Pre-requisites: Signals and systems

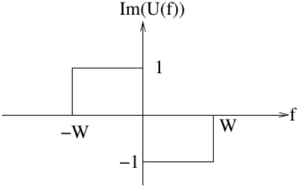
Pre-requisites

- Complex numbers, complex signals
- Fourier transform (FT)
- What is FT of $\cos(2\pi f_0 t)$?
- Modulation property of FT
- Note: Fourier transform of a real valued signal is conjugate symmetric.
- Baseband vs passband signal

Baseband signal

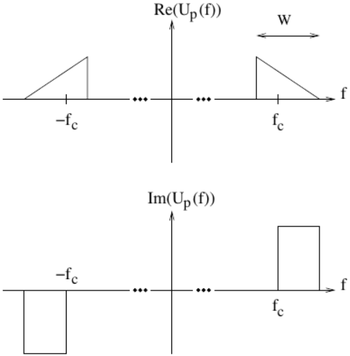
- A signal $u(t)$ is said to be baseband if the signal energy is concentrated in a band around DC, and $U(f) \approx 0, |f| > W$ for some $W > 0$.
- Example of the spectrum $U(f)$ for a real-valued baseband signal:





Passband signal

- A signal $u(t)$ is said to be passband if its energy is concentrated in a band away from DC, with $U(f) \approx 0, \quad |f \pm f_c| > W$ where $f_c > W > 0$.
- Example of the spectrum $U_p(f)$ for a real-valued passband signal:

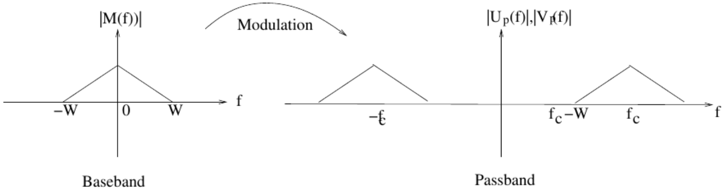


- Note: Typically, f_c is much larger than the signal bandwidth W

Key idea in modulation

Key idea in modulation

- How to design a passband transmitted signal to carry information contained in the basebase signal?



- How do it? Multiply $m(t)$ it by a sinusoid at f_c.

$$u_p(t) = m(t)\cos(2\pi f_c t) \leftrightarrow U_p(f) = \frac{1}{2}(M(f - f_c) + M(f + f_c))$$

- Instead of a cosine, we could also use a sine!

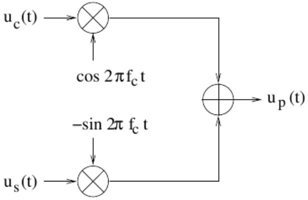
$$u_p(t) = m(t)\sin(2\pi f_c t) \leftrightarrow V_p(f) = \frac{1}{2j}(M(f - f_c) - M(f + f_c))$$

Key idea in modulation

- If we use both cosine & sine carriers, we can construct a passband signal

$$u_p(t) = u_c(t)\cos(2\pi f_c t) - u_s(t)\sin(2\pi f_c t)$$

$u_c(t)$ and $u_s(t)$ are real baseband signals of bandwidth at most W, $f_c > W$.



Upconversion
(baseband to passband)

- $u_c(t)$: In-phase/I-component and $u_s(t)$: Quadrature/Q-component
- IMPORTANT: Modulation consist of encoding the message in $u_c(t)$ & $u_s(t)$

Amplitude modulation (AM)

Key idea in amplitude modulation

- Recall: A passband signal has the form

$$u_p(t) = u_c(t)\cos(2\pi f_c t) - u_s(t)\sin(2\pi f_c t)$$

  $u_c(t)$: I-component, $u_s(t)$: Q-component

- Modulation consist of encoding the message in $u_c(t)$ & $u_s(t)$: IMPORTANT
- Key idea in AM: The message modulates the I-component.
- In AM, the Q-component occasionally plays a "supporting role" (Not going to discuss details)
- Many variants of AM are introduced. We will focus on:
  - Double Sideband Suppressed Carrier (DSB-SC)
  - Conventional AM

DSB-SC Amplitude modulation

DSB-SC Amplitude modulation

- Recall: A passband signal $u_p(t) = u_c(t)\cos(2\pi f_c t) - u_s(t)\sin(2\pi f_c t)$

- The message $m(t)$ modulates the I-component of the passband signal:

$$u_{DSB}(t) = Am(t)\cos(2\pi f_c t)$$

- As the name suggests, the amplitude of the carrier is varied according to the amplitude of the message.

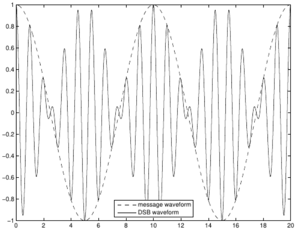
- After taking FT,

$$U_{DSB}(f) = \frac{A}{2}(M(f - f_c) + M(f + f_c))$$

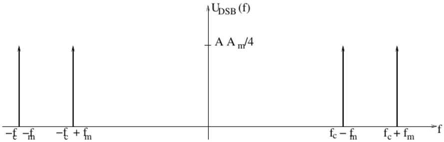
- Example-1: $m(t) = A_m \cos(2\pi f_m t)$

- Example-2: Arbitrary basesband $m(t)$

Example-1: $m(t) = A_m \cos(2\pi f_m t)$



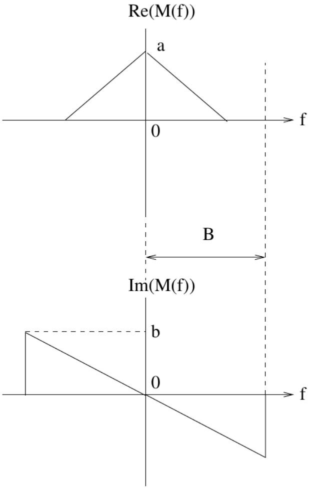
(a) DSB time domain waveform



(b) DSB spectrum

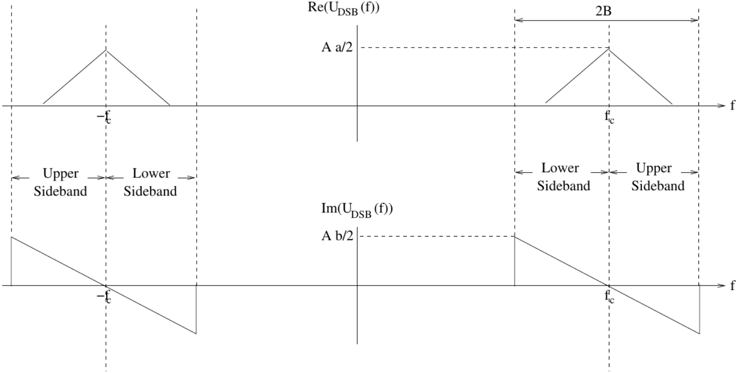
DSB-SC signal in the time and frequency domains for $m(t) = A_m \cos(2\pi f_m t)$

Example-2: Arbitrary basesband $m(t)$



Example message spectrum

Example-2: Arbitrary basesband $m(t)$



The spectrum of the passband DSB-SC signal for the message on previous slide

Comments: DSB-SC

- If $m(t)$ has a bandwidth of B, $u_{DSB}(t)$ has a bandwidth of $2B$.
- Why the name "double-side band"?
  - In some sense we have sent two bands, lets call them upper side band and lower side band.
- Note: Information resides in one of the band and hence we are wasting bandwidth. Is it fine if we just transmit single-side band?
- Why the name "supressed carrier"?
  - If $m(t)$ has zero DC value, i.e, $M(0) = 0$, then there is no component at f_c.
  - So in such cases, the carrier frequency is suppressed. Hence the name suppressed carrier.
- How to demodulate DSB-SC signal? Not going to discuss