S-72.245 Transmission Methods in Telecommunication Systems (4 cr)

Introduction

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S-72.245 Transmission Methods in Telecommunication Systems (4 cr)

- Lectures: Timo Korhonen, Otakaari 7, room 214, 2. Floor, tel. 09 451 2351 (hall S4 on Tuesdays 14-16)
- Tutorials:Research Scientist Seppo Saastamoinen (seppo.saastamoinen@hut.fi), Research Scientist Liu Yanshuang (liuyansh@cc.hut.fi):
  - Arranged in Finnish and English:
    - English tutorials will start on 30th of September 8-10, in hall S1
    - Finnish tutorials start on 30th of September at 14-16 in hall S1 and on Friday 1st of October, 14-16 in hall S1
- Text books:
  - A.B. Carlson: Communication Systems, IV ed
  - B.P. Lathi: Digital and Analog Communication Systems
  - W. Stallings: Wireless Communications and Networks
  - J. G. Proakis: Digital Communications
- Grading: Closed-book exam. Participation to voluntary tutorials can increase your course grade by the maximum of 1. For further info, see course homepage.
- NOTE: About 50% of exam questions based directly on tutorials
- Homepage: **http://www.comlab.hut.fi/opetus/245**
- **Follow the course homepage for the very latest course info!**

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Course Outline, Fall 2004

-Course introduction
-Transmission channels
-Linear and exponential analog modulation and detection
-Noise in analog carrier wave transmission
-Baseband and carrier wave systems
-Sampling and pulse coded modulation
-Digital transmission and channel coding
-Applications

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Course Overview - Agenda

- Role of regulation and market
- Fundamental technical concepts
  - information
  - bandwidth
  - data rate
  - signal power and energy in time and frequency domain
- Telecommunication channels
- Telecommunication systems and their basic features
- Reassuring communication quality & correctness / channel adaptation
    - modulation
    - coding
      - source
      - channel
- References: A.B. Carlson: Communication Systems, IV Ed., Chapter 1: Introduction, some parts from other references.

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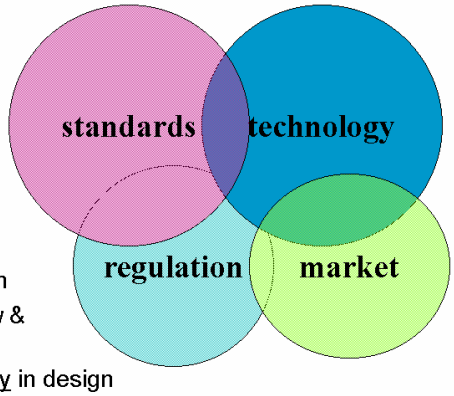
Network Products/Services and Market

- Requirements for successful telecommunication product/service development:
  - cost effective implementation
  - regulations must allow and support implementation
  - there must be a market
    - already existing
    - create a market!
  - for commercial implementation
    - designer should know & listen customers
    - there must be usability in design
    - output should be applicable/fashionable
    - outputs should be marketed appropriately



Ref: [6, Part II] pp. 43 5

Telecommunication Systems Transmit Information -What is Information?

- Consider two sentences, which one carries more information?
  - The sun will rise tomorrow.
  - There will be a tornado tomorrow.
- The measure of information is its probability: If an event x_i has the probability $P(x_i) = P_i$, it has the **self-information**

$$I_i \equiv -\log_b P_i = \log_b \frac{1}{P_i}$$

- Note that self-information is 0 for $P_i = 1$. The properties of self-information can be summarized as

$$\begin{cases} I_i \geq 0, 0 \leq P_i \leq 1 \\ I_i > I_j, P_i < P_j \end{cases} \qquad \begin{cases} P_i \to 0, I_i \to \infty \\ I_{ij} = \log_b \frac{1}{P_i P_j} = \log_b P_i^{-1} + \log_b P_{ij}^{-1} = I_i + I_j \end{cases}$$

- Note that for binary, equal probable symbols

$$P(x_1) = P(x_2) = 1/2, I_1 = I_2 = \log_2 2 = 1\text{bit}$$

Ref: [2] Chapter 16.1 6

Transmitting Information by Telecommunication Systems

- Telecommunication systems utilize varying **currents, voltages** (eg. varying electromagnetic fields) to store and convey information
- Telecommunication systems are dedicated to **transporting information** for instance from point to point (unicast) or point to multi-point (multicast) using links and networks
- Telecommunication messages are transmitted via various **medium** (or **media**) as by
  - copper wires (twisted cable pairs, coaxial cables...
  - Microwave beams and wave guides
  - optical fibers and free-space radiators
- Signal is **adapted to the transmission** and medium by *modulation and coding* (=adaptation to physical transmission)
- Modulation/coding method must be selected as dictated by
  - medium
  - information sources (statistics, rate ... - QoS point of view)

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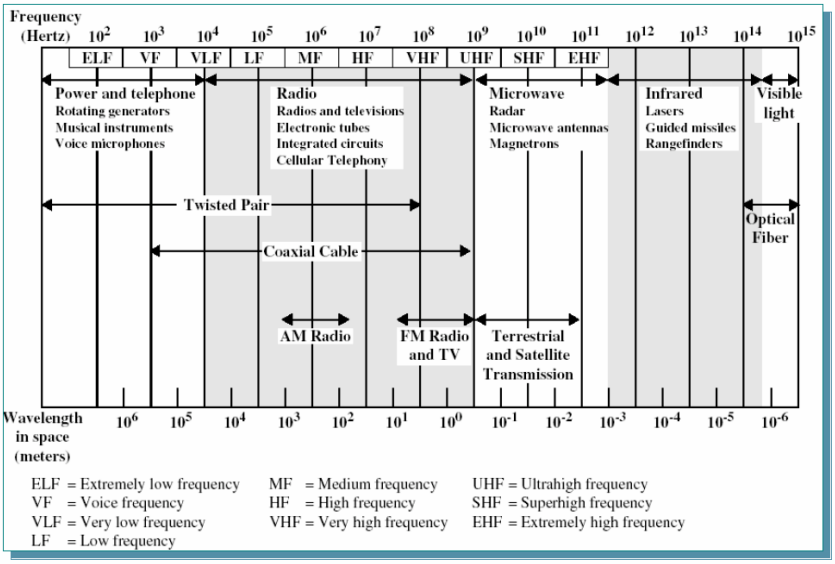
Mediums and Electromagnetic Spectra [5]



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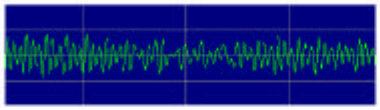
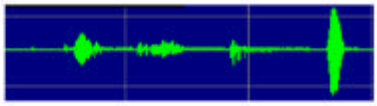
Signals

- A set of voice tones:



  - Several tones superimposed (added)
  - Tones can not be separated from the time domain representation
  - **Frequency components** can be separated from frequency domain representation

- *"This is some speech"*



  - Bursts
  - Amplitude varies
  - Frequency (phase) varies
  - Many other practical sources are bursty as
    - video signals
    - Ethernet data packets

- Often analog sources are digitized for transmission that carries several benefits as
  - error correction & detection
  - easy multiplexing
  - easy adaptivity

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Classification of Signals

- Deterministic signals
- Random signals; pure or pseudo-random
- Energy signals; pulses
- Power signal; periodic
- Continuous time - discrete time:

$$x(t), x[n] = x(nT_S), X(f), X[k]$$

- Analog - digital
- Real - complex
- Time variable (Average power) - constant (DC-level)

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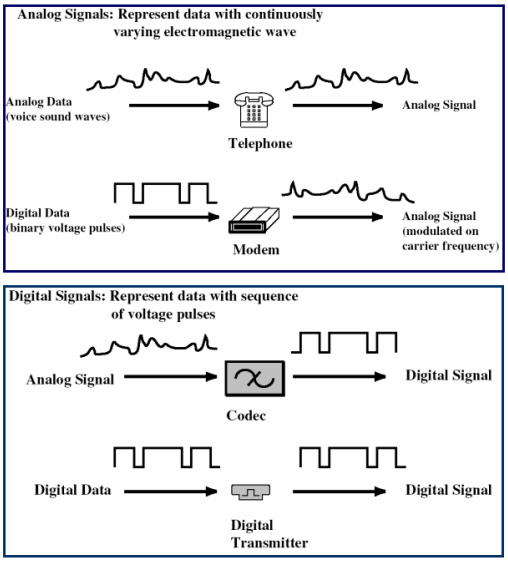
Analog and Digital Signals [5]



Why on the right hand side of the figure signals are analog or digital?

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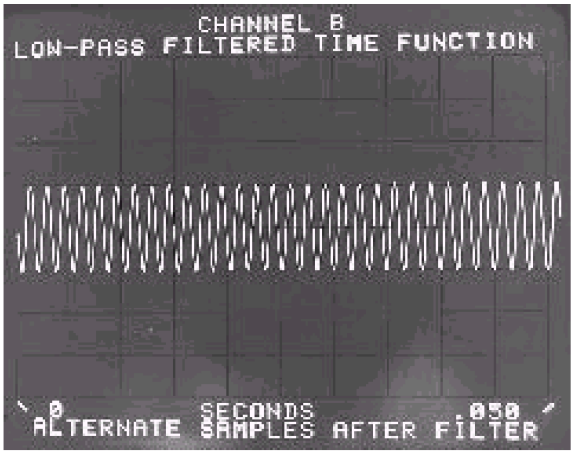
Time Domain Representation Can Only Seldom Reveal Small Signal Impairments



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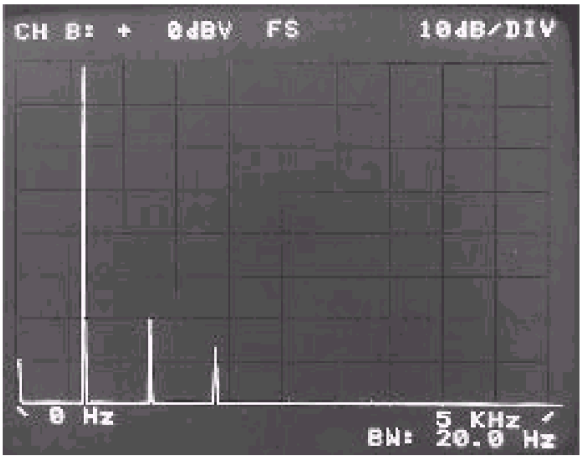
Frequency Domain Representation of the Same Signal Reveals More!



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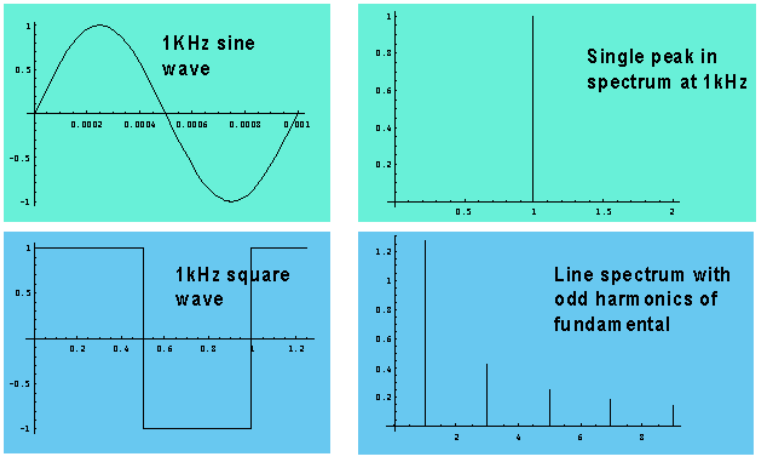
Examples of Signal Spectra

- All finite signals have spectra that can be determined via Fourier transformation (pulses) or Fourier series (periodic signals)



Ref: [2] Chapter 2

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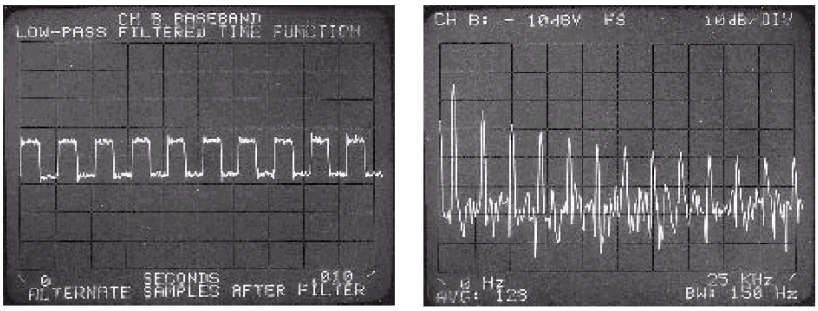
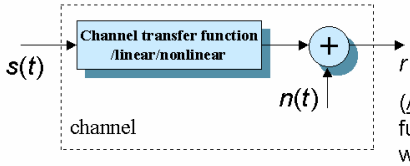
Noise and Interference

- In practical communication systems signals are blurred by noise and interference:

Time domain **Frequency domain**



Modeling Transmission Channels



$r(t) = s(t) \otimes c(t) + n(t)$

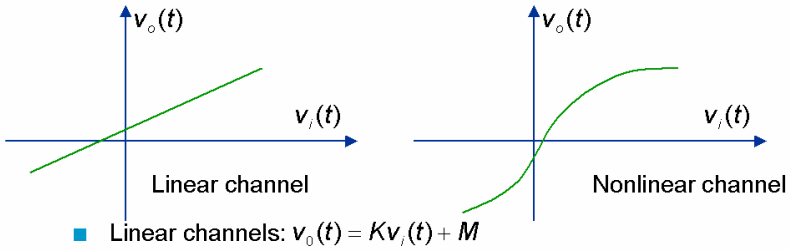
(AWGN channel (usually transfer function is linear) and *n(t)* is Gaussian, white noise)

- Information is always transmitted in channels as radio path (wireless cellular channel, microwave link, satellite link) or in wireline channels as coaxial cable, fiber optic cable or wave guide. Note that information storage is also a transmission channel
- Most common channels we discuss are **linear** Additive, White Gaussian Noise (AWGN) channels or linear, fading channels
- Note that the AWGN channel output is convolution of channel impulse response *c(t)* and channel input signal *s(t)* and has the noise term *n(t)* as additive component:

$$r(t) = s \otimes c(t) + n(t) = \int_u s(t)c(\tau - t)dt + n(t)$$

(*u*: where integrand exists)

Linear and Nonlinear Channels



- Linear channels: $v_0(t) = Kv_i(t) + M$
  - generate never new frequency components
  - characterized by transfer function
- Non-linear systems:
  - characterized by transfer characteristics
- Note: Often non-linearity in transmission is generated by transmitter or receiver, not by the channel itself
- Non-linear systems can generate new frequency components, example:

$$v_o(t) = a_0 + \sum_{u=1}^{N} a_u v_i^u(t) \text{ with } v_i(t) = \sin(\omega t), N = 2$$

produces $v_o(t) = a_0 + a_1 \sin(\omega t) + a_2 / 2(1 - \cos(2\omega t))$

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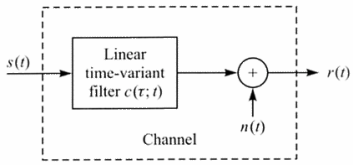
Time-variable Channel



- Most information channels are time-variable (fading) channels: cable, microwave link, cellular channel. Received signal is

$$r(t) = n(t) + s(t) \otimes c(\tau; t)$$

- In frequency domain, (in differential time instant) there exists a frequency response $C(\tau_1; f) \approx C_1(f)$ and for this instance we may write

$$R_1(f) = N(f) + S(f)C_1(f)$$

- Channel variations / transmission errors compensated at the receiver:
  - equalization flattens frequency response (tapped delay line, decision feedback equalizer (DFE))
  - equalization assisted by channel estimation
  - channel errors can be compensated by channel coding (block and convolutional codes)

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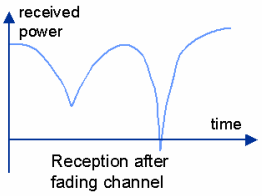
Interleaving

- In fading channels, received data can experience burst errors that destroy large number of consecutive bits. This is harmful in channel coding
- Interleaving distributes **burst errors** along data stream
- A problem of interleaving is introduced extra delay
- Example below shows block interleaving:



Received interleaved data: 1 0 0 0 1 1 1 0 1 0 1 1 1 0 0 0 1 1 0 0 1

Block deinterleaving :

1 0 0 0 1 1 1
0 1 0 1 1 1 0
0 0 1 1 0 0 1

Recovered data: 1 0 0 0 1 0 0 0 1 0 1 1 1 1 0 1 1 0 1 0 1

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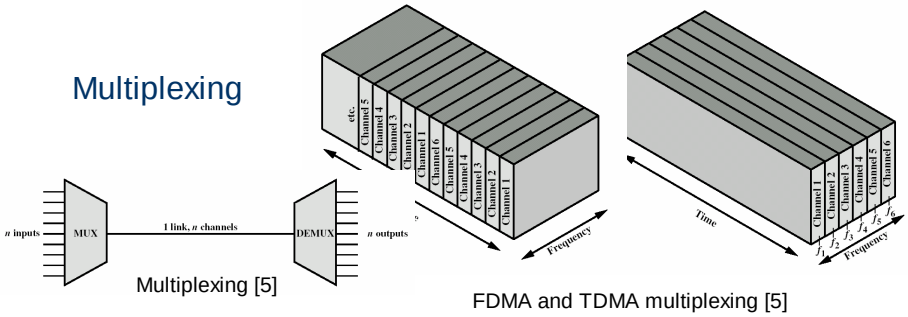
Multiplexing



Multiplexing [5]

FDMA and TDMA multiplexing [5]

- Multiple information channels are transported by using **multiplexing**
- In **multiple access,** same channel is used to transmit multiple messages to different users
- **Fixed multiple access (originally for circuit switched networks)**:
  - **TDMA** (time division multiple access), users occupy different time slots
  - **FDMA** (frequency division multiple access), users occupy different frequency bands
  - **CDMA** (code division multiple access), users occupy the same frequency band but modulate their messages with different codes
- **Statistical multiple access (packet networks), example:**
  - **ALOHA**: Station send a packet and waits for acknowledgement (AC) for the maximum time of round trip delay. If AC not received (collision), send again!

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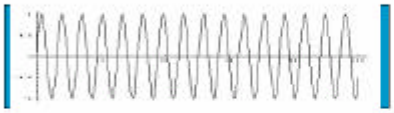
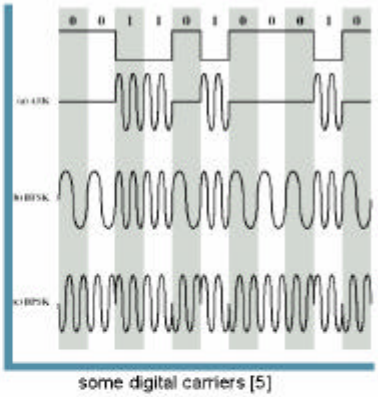
Unmodulated and Modulated Sinusoidals

- The unmodulated sinusoidal wave is parameterized by constant amplitude, frequency and phase



unmodulated sinusoidal



some digital carriers [5]

- In unmodulated sinusoidal all parameters known, convoys no information!
- Mathematically and experimentally convenient formulation whose *parameterization* by variables enables presenting all carrier wave modulation formats by

$$x(t) = A(t)\cos\left[\omega_c t + \phi(t)\right]$$

Amplitude modulation (AM)..., Amplitude Shift Keying (ASK)...

Frequency modulation (FM), Frequency/Phase Shift Keying (FSK,PSK)...

Carrier-term

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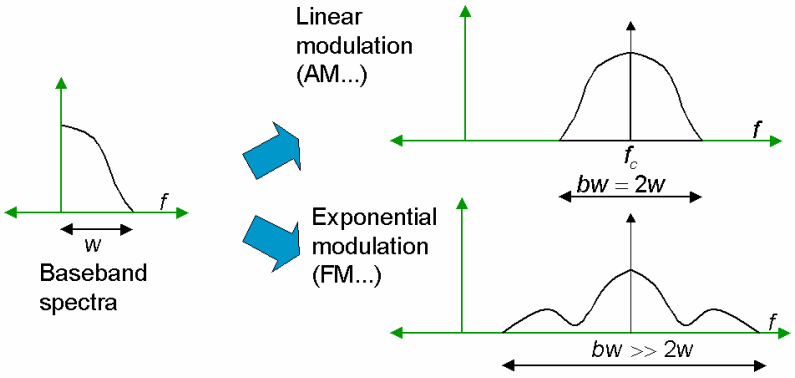
Baseband and Carrier Wave (CW) Systems



- Figures show baseband message transfer by linear (AM) and exponential modulation (FM)
- In linear modulation, transmission bandwidth is always below or equal to 2*W* (*W*: message bandwidth)
- Non-linear (angle modulation) spreads message on much larger transmission bandwidth that 2W

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Which Modulation Method to Apply?

- Modulation is done to enable the usage of medium for transmission. Thus the modulation method is selected based on
  - Message to be transmitted (source) as
    - voice/video (analog source)
    - data (digital source, machine-to-machine communications)
    - traffic statistics: continuous / bursty traffic
  - Allowed delay
  - Medium that is to be used
  - Networking type as
    - cellular wireless networks (GSM, AMPS*)
    - RF-LANs (802.11b Wi-Fi, HiperLAN /2)
    - wire-line local area networks (Ethernet LANs)
    - public switched telephone network (PSTN)

Channel determines modulation method

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*Advanced Mobile Phone Service

Coding

- Channel coding is done ...
  - For **detection and/or correction of errors** produced by the channel (as block and convolutional coding) by
    - noise
    - interference
    - distortion
      - linear
      - nonlinear
  - To alleviate **synchronization** problems (as Manchester coding)
  - To alleviate **detection** problems (as differential coding)
  - To enable **secrecy and security** (as scrambling or ciphering)
- Channel coding principles:
  - **ARQ** (Automatic Repeat Request) as go-back-N ARQ
  - **FEC** (Forward Error Correction) as block & convolutional coding

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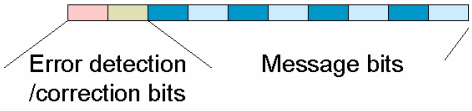
Coding

- Coding is classified to two flavors
  - *source coding*: makes transmitted bits equal probable - maximizes channel capacity
  - *channel coding*: protects message & adapts it to channel
- Channel coding means adding extra bits for message for error detection and/or correction
- In **systematic coding** message bits remain the same in coded word:



- In coded systems **soft decision** can be used that calculates the distance of the received code word to the allowed code words for instance by using a least-square metric

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Summary

- Telecommunication systems divided into
  - transmitters, channels, receivers
- Understanding of source statistics is important
  - Fixed multiple access for bulk data
  - Statistical multiplexing for demanding sources and networks
- Channels can be linear or non-linear. Non-linear channels generally more demanding due to introduced extra frequency components
- Coding is used to protect message in channels (channel coding) and to compress source information (source coding)
- Modulation is used to carry messages in carrier wave systems - Selection of modulation method affects
  - reception sensitivity
  - transmission bandwidth
  - applicability in networking applications

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References

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5 W. Stallings: Wireless Communications and Networks
6 Telia, Ericsson: Understanding Telecommunications, Part I-II
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7 A Leon-Garcia et al: Communication Networks, Mc GrawHill

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