Digital Communication I: Modulation and Coding Course

Term 3 - 2009

Lecture 1

Course information

- Scope of the course
  - Digital Communication systems
- Practical information
  - Course material
  - Lay-out of the course in terms of Lectures, Tutorials, Lab assignment, Exam
  - Staff
  - More detailed information on the lab
  - Lay-out of the course indicating which parts of the course are easier/more difficult.
  - More information on:

  http://www.signal.uu.se/Courses/CourseDirs/ModDemKod/2009/main.html
- Introduction to digital communication systems

Scope of the course

- Communications is a process by which information is exchanged between individuals through a common system of symbols, signs, or behaviour

"It is about communication between people; the rest is technology"

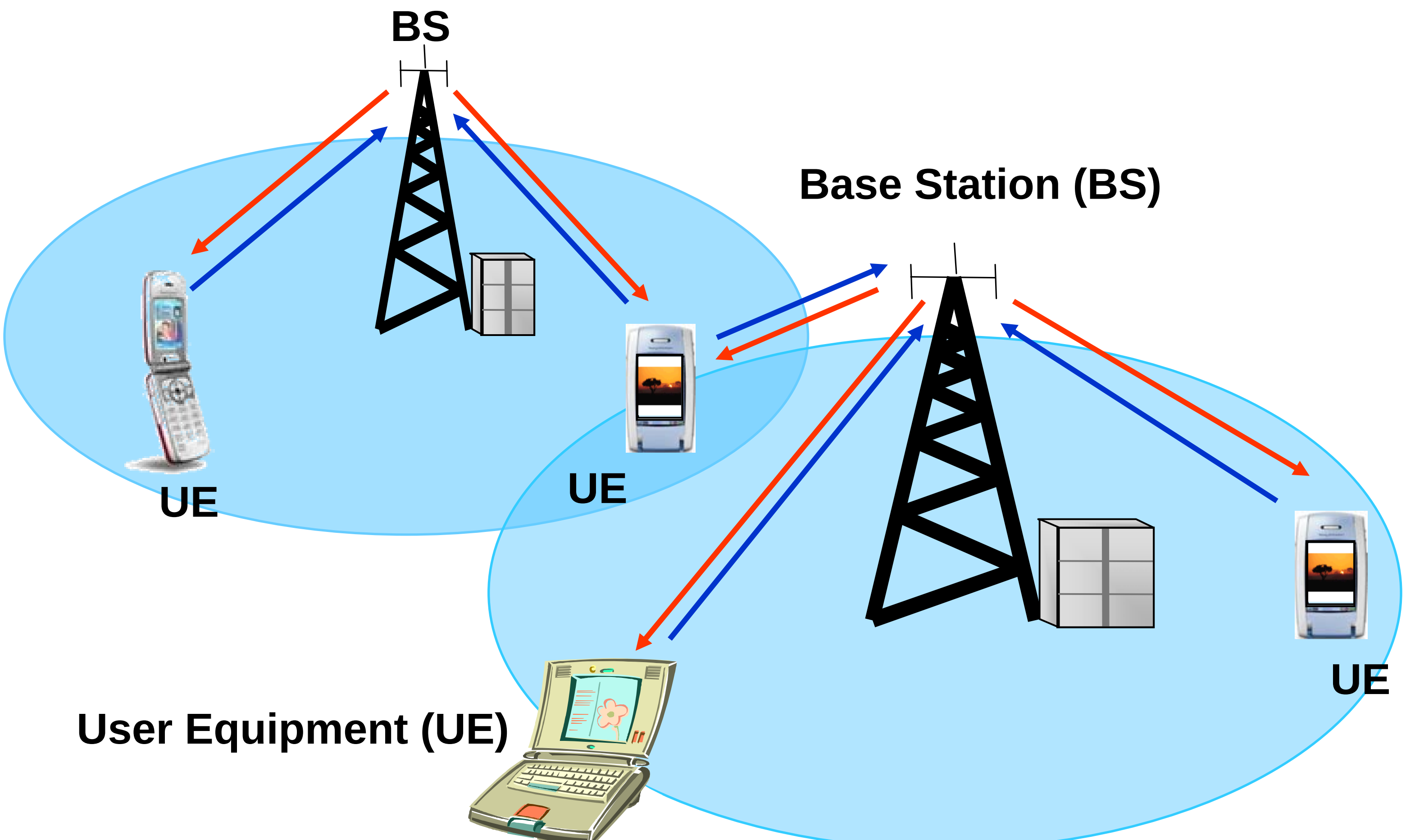
- Communication systems are reliable, economical and efficient means of communications
  - Public switched telephone network (PSTN), mobile telephone communication (GSM, 3G, 4G...), broadcast radio or television, navigation systems, ...

- The course is aiming at introducing fundamental issues required for understanding and designing a (digital) communication system

Scope of the course ...

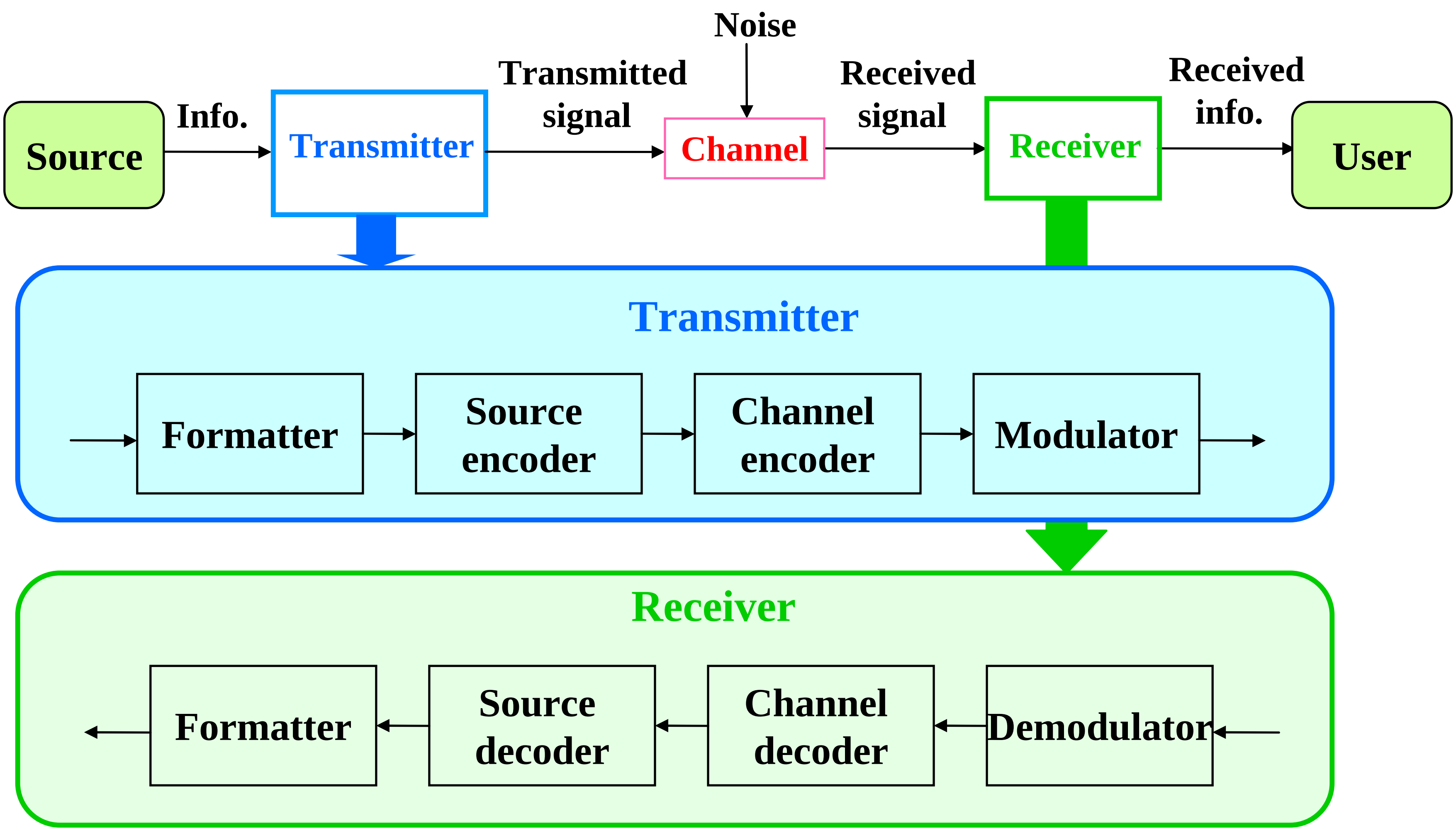
- Example of a (digital) communication system:

  Cellular wireless communication systems (WLAN, WSN…)



Scope of the course ...

General structure of a communication system



Scope of the course …

- Learning fundamental issues in designing a digital communication system (DCS):
  - Utilized techniques
    - Formatting and source coding
    - Modulation (Baseband and bandpass signaling)
    - Channel coding
    - Equalization
    - Synchronization
    - ....
  - Design goals
  - Trade-off between various parameters

Practical information

- Course material
  - Course text book:
    - “Digital communications: Fundamentals and Applications” by Bernard Sklar,Prentice Hall, 2001, ISBN: 0-13-084788-7
  - Additional recommended books:
    - “Communication systems engineering”, by John G. Proakis and Masoud Salehi, Prentice Hall, 2002, 2nd edition, ISBN: 0-13-095007-6
    - “Introduction to digital communications”, by Michael B. Pursley, Pearson, Prentice Hall, 2005, International edition, ISBN: 0-13-123392-0
    - ”Digital communications”, by Ian A. Glover and Peter M. Grant, Pearson, Prentice Hall, 2004, 2nd edition, ISBN: 0-13-089399-4
  - Material accessible from course homepage:
    - News
    - Lecture slides (.ppt, pdf)
    - Laboratory syllabus (Lab. PM)
    - Set of exercises and formulae
    - Old exams

Schedule & Requirements

- 13 lectures:
  - from week 4 to week 11
  - I expect everyone to read the book. Please do so! It is a well written book and it will pay off to go through the material.
  - During the lectures I will guide you through the material and emphasize parts I deem important.
- 10 tutorials:
  - week 5 to week 11
  - The tutorials will cover important examples. Please, try to browse through the material in advance.
- 1 mandatory laboratory work:
  - Week 10-11 (?). Book laboratory time by contacting Daniel Aronsson
  - Final written exam on 16th of March 2009
- To pass the course you need to
  - *pass the lab* (no grade given) **and**
  - *pass the exam with minimum grade 3.*

Staff

- Course responsible and lecturer:
  - Anders Ahlén
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  - Email: anders.ahlen@signal.uu.se
- Lab responsible
  - Daniel Aronsson
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  - Phone: 018-471 3071
  - Email: daniel.aronsson@signal.uu.se

Laboratory work (compulsory)

- *Aim:* Study a digital communication system either on radio channels or audio channels and examine the quality of the received signal
- You will work in groups of 2-3 students.
- Each group will:
  - Download all files and information from the course homepage.
  - Prepare themselves carefully according to the lab instructions. If you have any questions, contact Daniel.

    Make sure to be well prepared.
  - Choose one time-slot (2 hours) for performing the laboration under Daniel's supervision.
  - Perform the lab at the allocated time.

Course Lay-out

- Lec1: Introduction. Important concepts to comprehend. Difficulty: 2. Importance: 2.
- Lec2: Formatting and transmission of baseband signals. (Sampling, Quantization, baseband modulation). Difficulty: 6. Importance: 7.
- Lec3: Receiver structure (demodulation, detection, matched filter receiver). Diff.: 5. Imp: 5.
- Lec4: Receiver structure (detection, signal space). Diff: 4. Imp.=:4
- Lec5: Signal detection; Probability of symbol errors. Diff: 7. Imp: 8.
- Lec6: ISI, Nyquist theorem. Diff: 6. Imp: 6.
- Lec7: Modulation schemes; Coherent and non-coherent detection. Diff: 8. Imp: 9.
- Lec8: Comparing different modulation schemes; Calculating symbol errors. Diff: 7. Imp: 9.
- Lec9: Channel coding; Linear block codes. Diff: 3. Imp:7.
- Lec10: Convolutional codes. Diff: 2. Imp:8.
- Lec11: State and Trellis diagrams; Viterbi algorithm. Diff: 2. Imp: 9.
- Lec12: Properties of convolutional codes; interleaving; concatenated codes. Diff: 2. Imp: 5.
- Lec13:

Helpful hints for the course

- It is good custom to print out slides for each lecture and bring them along.
- Take extra notes on these print-outs (I may complement the slides with black board notes and examples). Thus, make sure not to squeeze in too many slides on each A4 when printing the slides.
- Try to browse through the slides before each lecture. This will really help in picking up concepts quicker.
- Try to attend the lectures/tutorials. Otherwise, ask a friend for extra notes.
- I will frequently try to repeat important concepts and difficult sections during the subsequent lecture(s), so that you will have several chances to make sure that you have understood the concepts/underlying ideas.
- Download old exams early during the course, so that you get an idea of level of difficulty and what is important.
- Don't forget to prepare yourself before you take the lab!

Today, we are going to talk about:

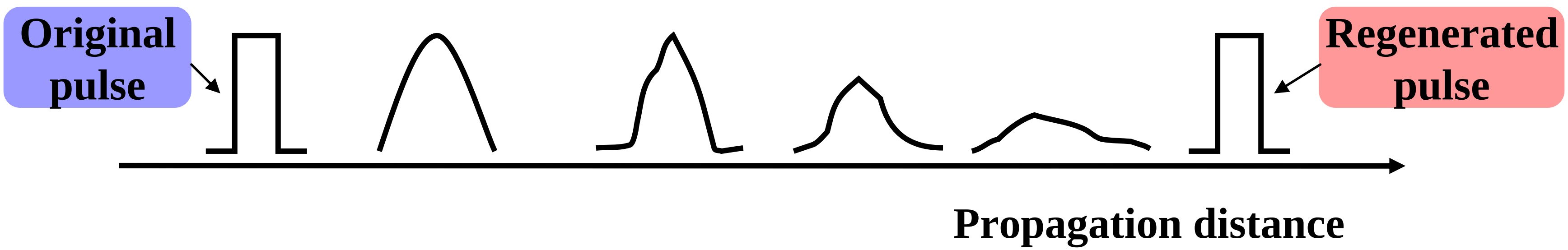
- What are the features of a digital communication system?
  - Why “digital” instead of “analog”?
- What do we need to know before taking off toward designing a DCS?
  - Classification of signals
  - Random processes
  - Autocorrelation
  - Power and energy spectral densities
  - Noise in communication systems
  - Signal transmission through linear systems
  - Bandwidth of a signal

Digital communication system

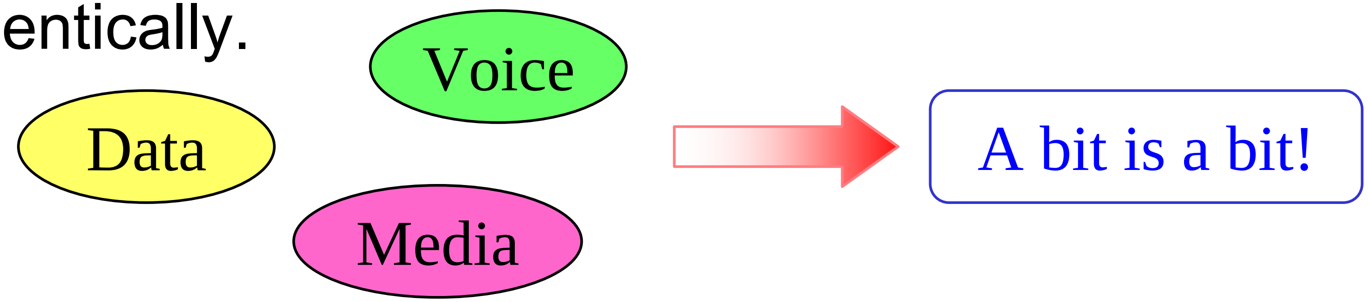
- Important features of a DCS:
  - The transmitter sends a waveform from a finite set of possible waveforms during a limited time
  - The channel distorts, attenuates the transmitted signal and adds noise to it.
  - The receiver decides which waveform was transmitted given the noisy received signal
  - The probability of an erroneous decision is an important measure for the system performance

Digital versus analog

- Advantages of digital communications:
  - Regenerator receiver



  - Different kinds of digital signal are treated identically.

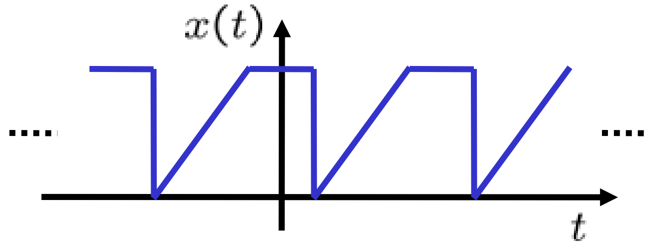


Classification of signals

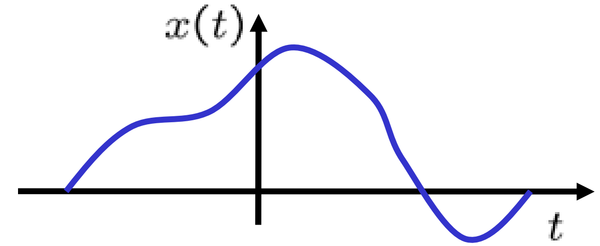
- Deterministic and random signals
  - Deterministic signal: No uncertainty with respect to the signal value at any time.
  - Random signal: Some degree of uncertainty in signal values before it actually occurs.
    - Thermal noise in electronic circuits due to the random movement of electrons
    - Reflection of radio waves from different layers of ionosphere
    - Interference

Classification of signals …

- Periodic and non-periodic signals

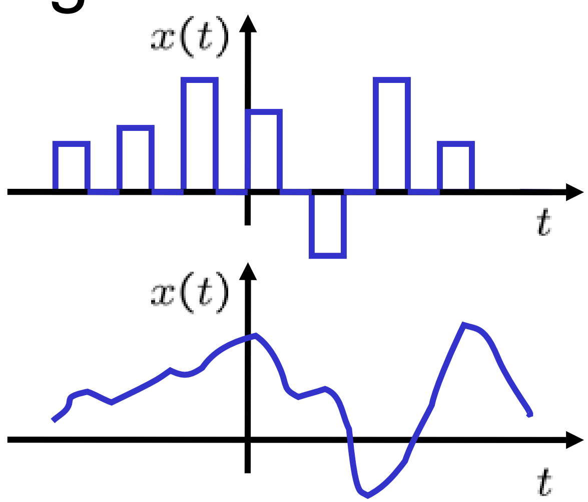


A periodic signal

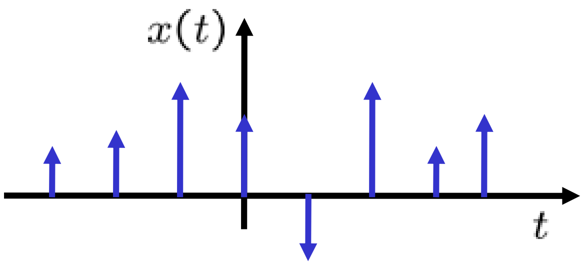


A non-periodic signal

- Analog and discrete signals



Analog signals



A discrete signal

Classification of signals ..

- Energy and power signals
  - A signal is an energy signal if, and only if, it has nonzero but finite energy for all time:

$$E_x = \lim_{T\to\infty} \int_{T/2}^{T/2} |x(t)|^2 dt = \int_{-\infty}^{\infty} |x(t)|^2 dt$$

$$(0 < E_x < \infty)$$

  - A signal is a power signal if, and only if, it has finite but nonzero power for all time:

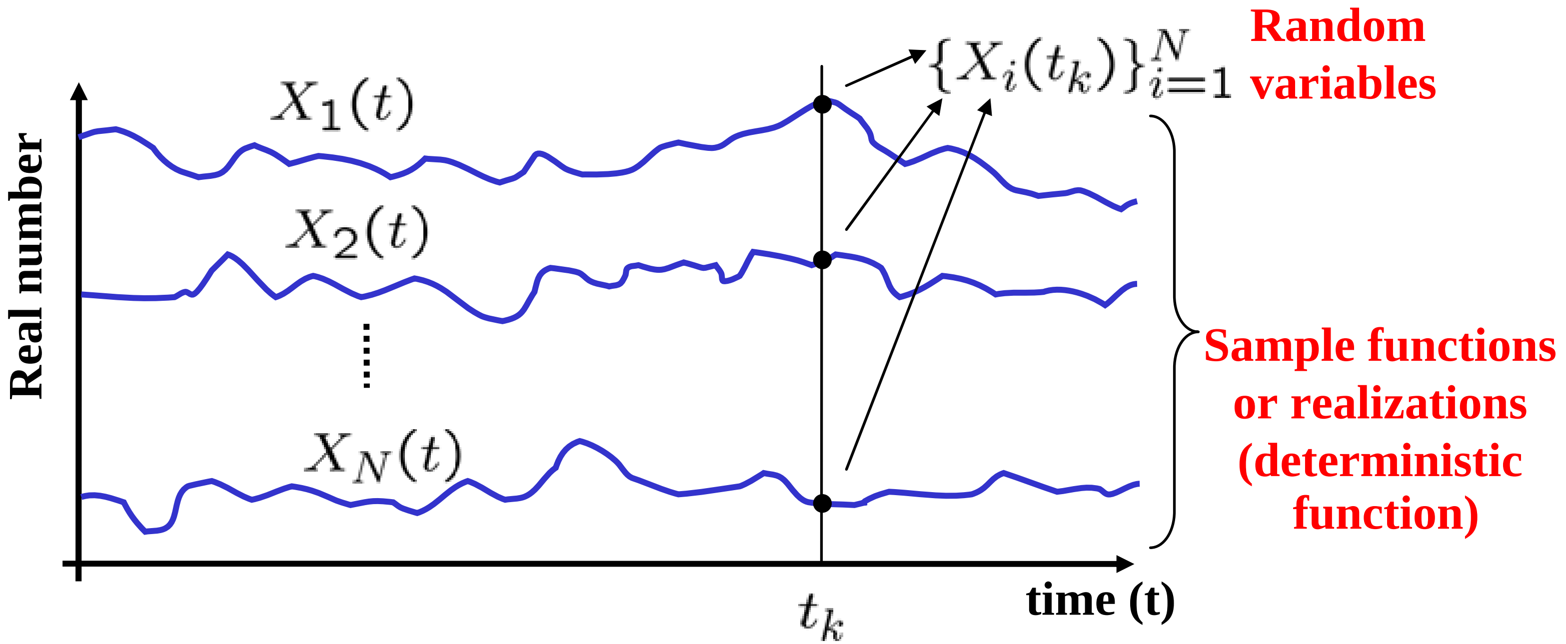
$$P_x = \lim_{T\to\infty} \frac{1}{T} \int_{T/2}^{T/2} |x(t)|^2 dt$$

$$(0 < P_x < \infty)$$

  - General rule: *Periodic and random signals are power signals.* Signals that are *both deterministic and non-periodic are energy* signals.

Random process

- A random process is a collection of time functions, or signals, corresponding to various outcomes of a random experiment. For each outcome, there exists a deterministic function, which is called a sample function or a realization.



Random process …

- Strictly stationary: If none of the statistics of the random process are affected by a shift in the time origin.

- Wide sense stationary (WSS): If the mean and autocorrelation functions do not change with a shift in the origin time.

- Cyclostationary: If the mean and autocorrelation functions are periodic in time.

- Ergodic process: A random process is ergodic in mean and autocorrelation, if

$$m_X = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} X(t) dt$$

and

$$R_X(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} X(t) X^*(t-\tau) dt$$

, respectively.

Autocorrelation

- Autocorrelation of an energy signal

$$R_x(\tau) = x(\tau) \star x^*(-\tau) = \int_{-\infty}^{\infty} x(t)x^*(t-\tau)dt$$

- Autocorrelation of a power signal

$$R_x(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t)x^*(t-\tau)dt$$

  - For a periodic signal:

$$R_x(\tau) = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} x(t)x^*(t-\tau)dt$$

- Autocorrelation of a random signal

$$R_X(t_i, t_j) = \mathsf{E}[X(t_i)X^*(t_j)]$$

  - For a WSS process:

$$R_X(\tau) = \mathsf{E}[X(t)X^*(t-\tau)]$$

Spectral density

- Energy signals:

$$E_x = \int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-\infty}^{\infty} |X(f)|^2 df \qquad X(f) = \mathcal{F}[x(t)]$$

  - Energy spectral density (ESD): $$\Psi_x(f) = |X(f)|^2$$

- Power signals:

$$P_x = \frac{1}{T_0} \int_{T_0/2}^{T_0/2} |x(t)|^2 dt = \sum_{n=-\infty}^{\infty} |c_n|^2 \qquad \{c_n\} = \mathcal{F}[x(t)]$$

  - Power spectral density (PSD):

$$G_x(f) = \sum_{n=-\infty}^{\infty} |c_n|^2 \delta(f - nf_0) \qquad f_0 = 1/T_0$$

- Random process:
  - Power spectral density (PSD): $$G_X(f) = \mathcal{F}[R_X(\tau)]$$

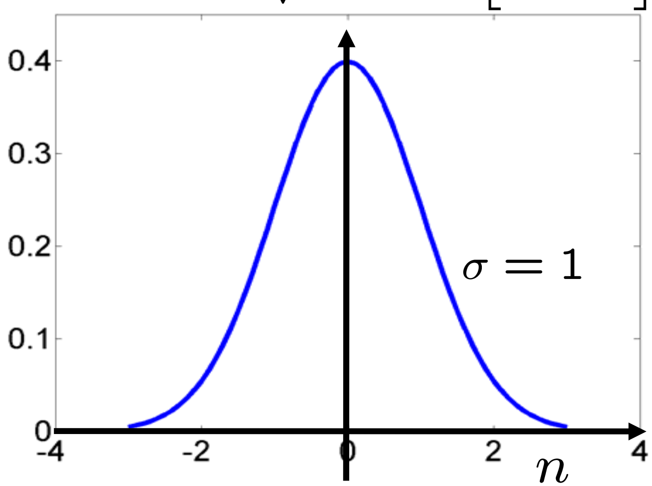
Properties of an autocorrelation function

- For real-valued (and WSS in case of random signals):
  1. Autocorrelation and spectral density form a Fourier transform pair.
  2. Autocorrelation is symmetric around zero.
  3. Its maximum value occurs at the origin.
  4. Its value at the origin is equal to the average power or energy.

Noise in communication systems

- Thermal noise is described by a zero-mean Gaussian random process, n(t).
- Its PSD is flat, hence, it is called white noise.

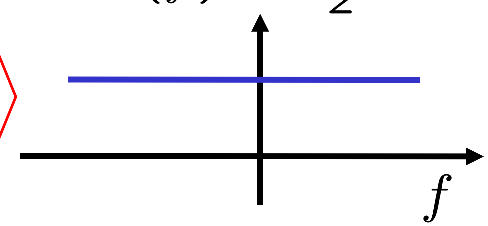
$$p(n) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{n^2}{2\sigma^2}\right]$$



Probability density function

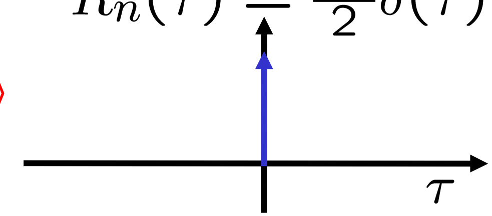
Power spectral density

$$G_n(f) = \frac{N_0}{2} \text{ [w/Hz]}$$

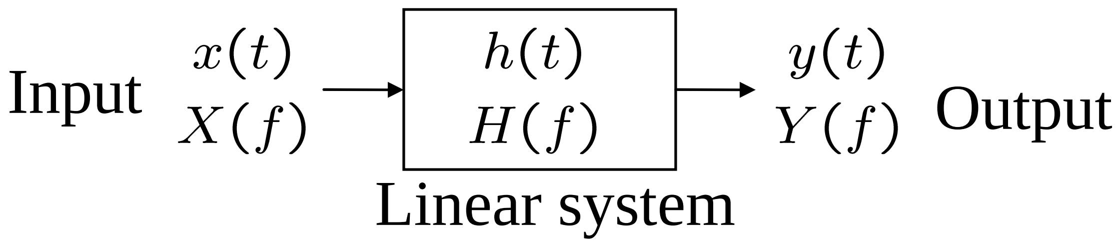


Autocorrelation function

$$R_n(\tau) = \frac{N_0}{2}\delta(\tau)$$



Signal transmission through linear systems



- Deterministic signals: $$Y(f) = X(f)H(f)$$
- Random signals: $$G_Y(f) = G_X(f)|H(f)|^2$$

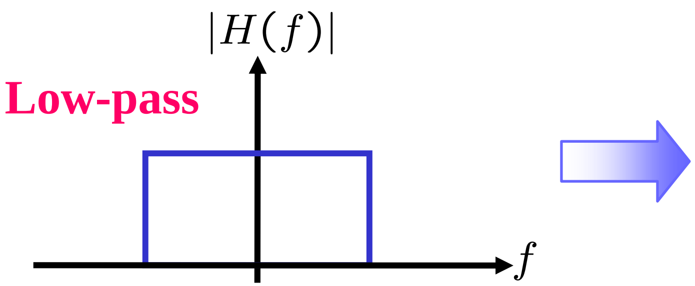
- Ideal distortion less transmission:

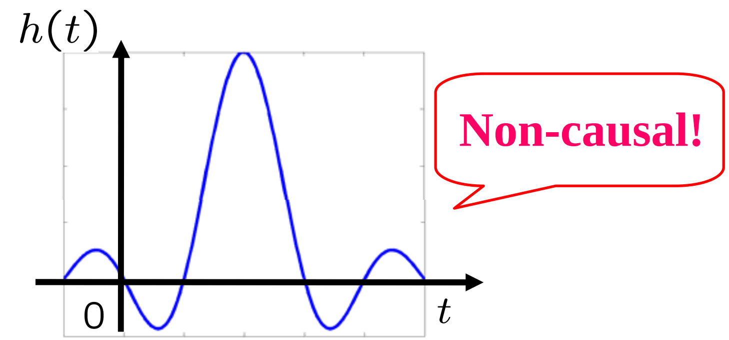
  All the frequency components of the signal not only arrive with an identical time delay, but also are amplified or attenuated equally.

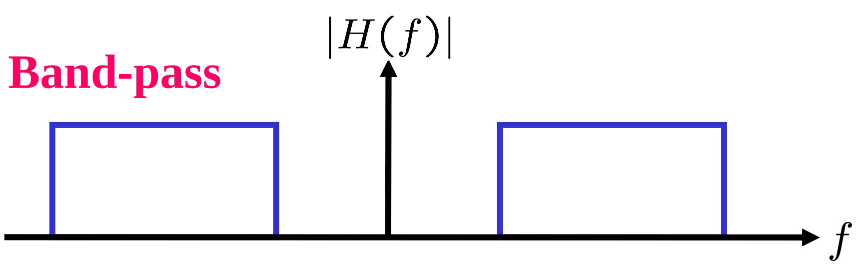
$$y(t) = Kx(t - t_0) \text{ or } H(f) = Ke^{-j2\pi f t_0}$$

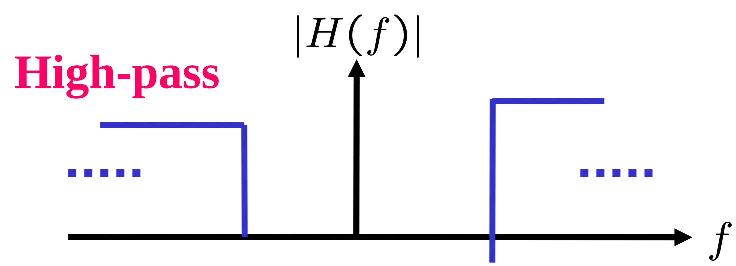
Signal transmission … - cont'd

- Ideal filters:









- Realizable filters:

RC filters

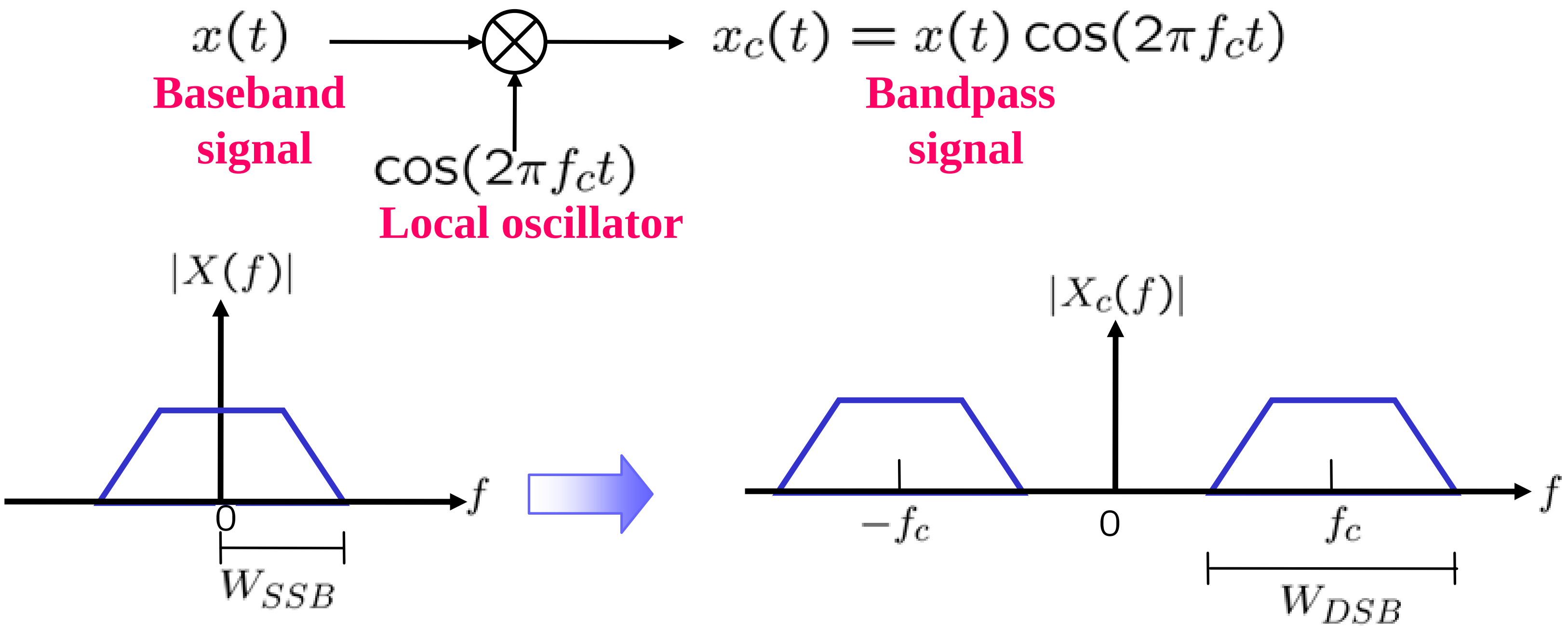
$$H(f) = \frac{1}{1 + j2\pi f RC}$$

Butterworth filter

$$|H_n(f)| = \frac{1}{\sqrt{1 + (f/f_u)^{2n}}}$$

Bandwidth of signal

- Baseband versus bandpass:



- Bandwidth dilemma:
  - Bandlimited signals are not realizable!
  - Realizable signals have infinite bandwidth!

Bandwidth of signal …

- Different definition of bandwidth:

a) Half-power bandwidth
b) Noise equivalent bandwidth
c) Null-to-null bandwidth
a) Fractional power containment bandwidth
b) Bounded power spectral density
c) Absolute bandwidth