Digital Communication I: Modulation and Coding Course

Spring - 2015

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Lecture 1a: Course Introduction

Course information

- Scope of the course
  - Digital Communication systems
- Practical information
  - Course material
  - Lay-out of the course in terms of Lectures, Tutorials, Project assignment, Exams
  - More detailed information on the Project
  - Lay-out of the course indicating which parts of the course are easier/more difficult.
  - Complete syllabus at: http://doctord.webhop.net
  - 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"

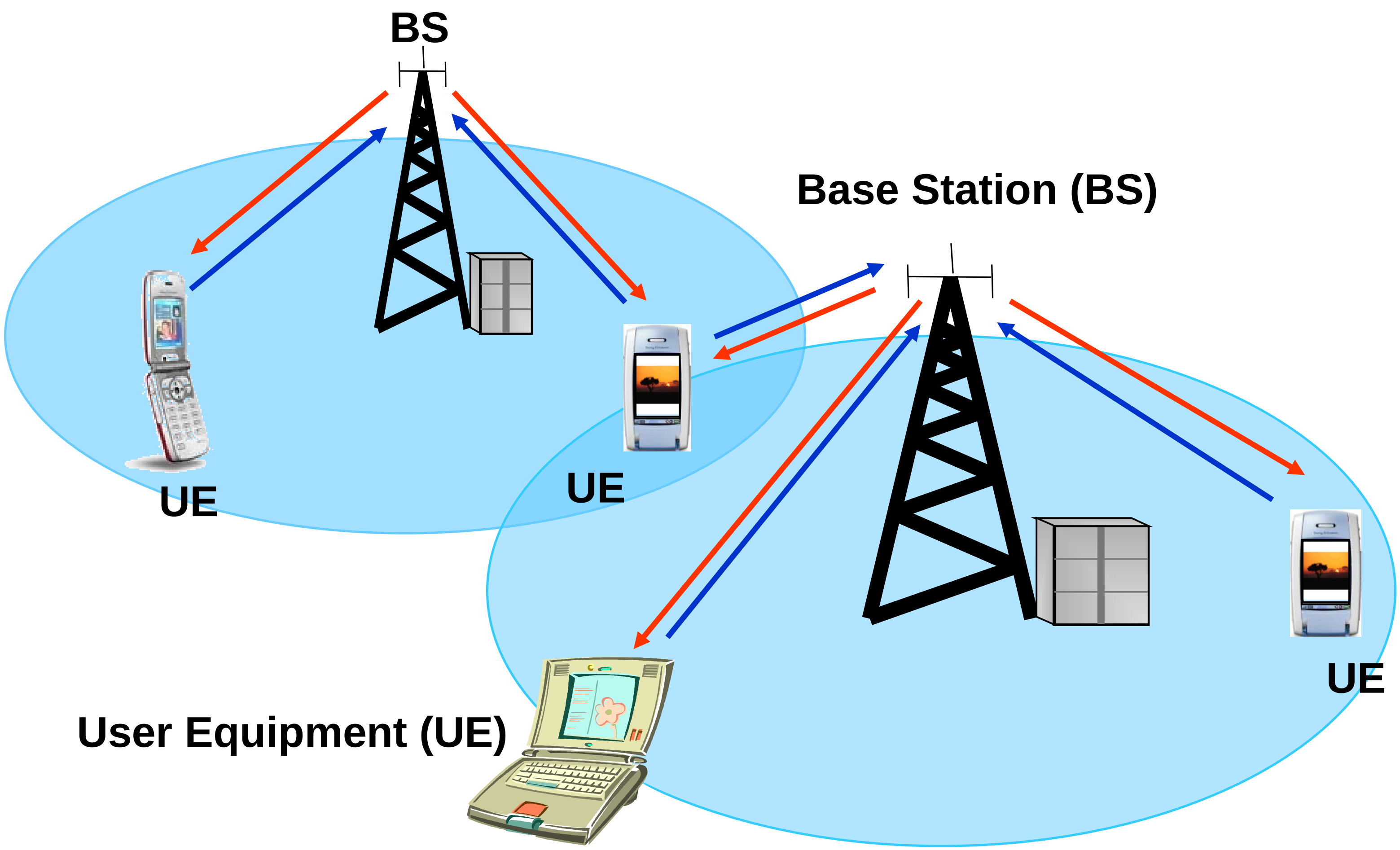
- Communication systems are reliable, economical and efficient means of communications
  - Public switched telephone network (PSTN), mobile telephone communication (GSM, 3G, 4G...), broadcast radio or television, navigation systems, ...

- The course is aiming at introducing fundamental issues required for understanding and designing a (digital) communication system (You will do a Design Project!)

Scope of the course ...

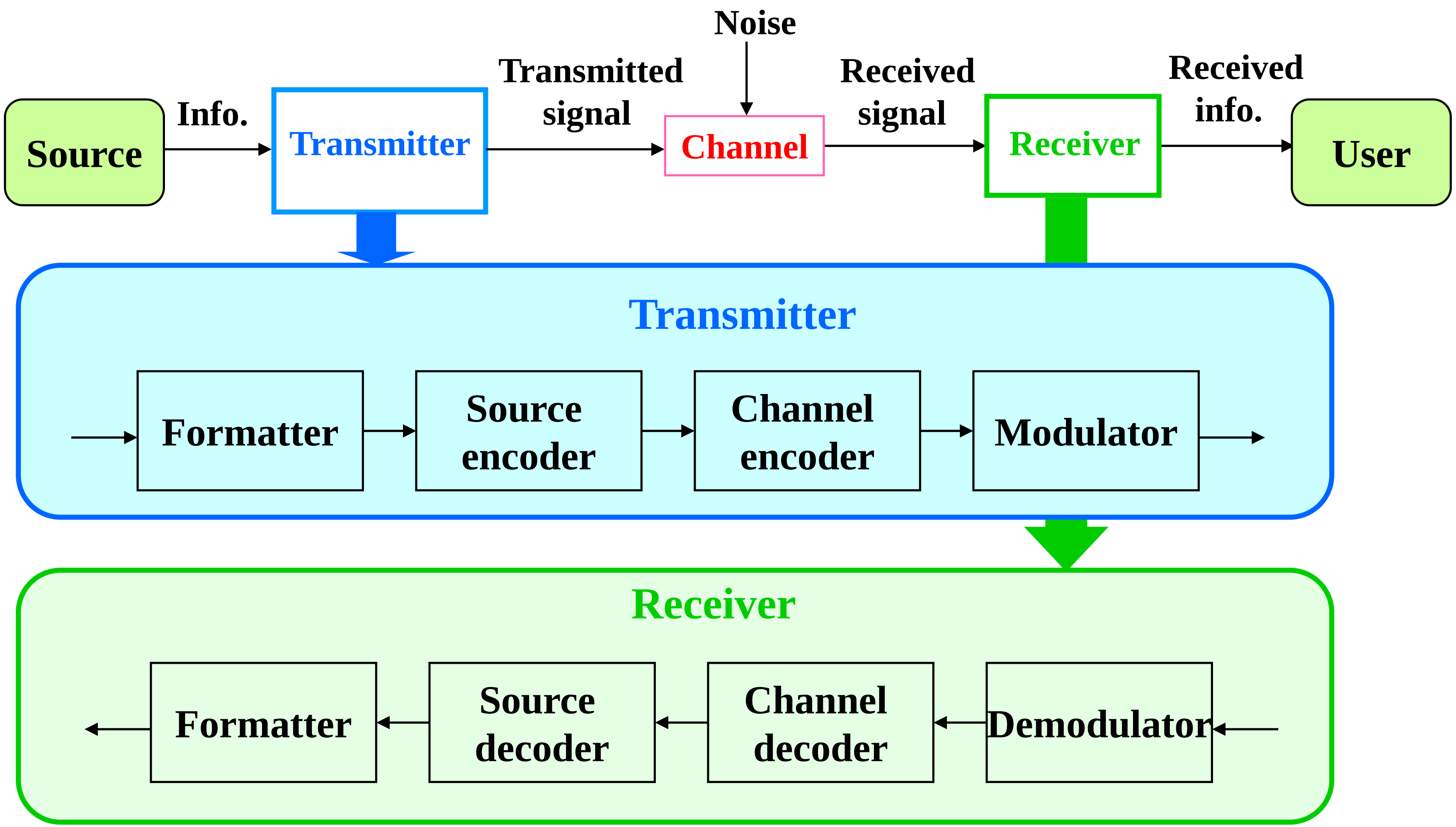
- Example of a (digital) communication system:

  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

* Not covered in this course

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:
    - "Analog and Digital Communications", Hsu, Hwei, (Schaum's Outlines), ISBN: 0-07-140228-4
    - "Communication systems engineering", by John G. Proakis and Masoud Salehi, Prentice Hall, 2002, 2nd edition, ISBN: 0-13-095007-6
  - Materials accessible from my homepage: http://DoctorD.webhop.net
    - Lecture slides (ppt)
    - Tutorial Notes (pdf)
    - Syllabus

Instructor

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Course Lay-out

- Lec 1: Introduction. Important concepts to comprehend. Difficulty: 2. Importance: 2.
- Lec 2: Formatting and transmission of baseband signals. (Sampling, Quantization, baseband modulation). Difficulty: 6. Importance: 7.
- Lec 3: Receiver structure (demodulation, detection, matched filter/correlation receiver). Diff.: 5. Imp: 5.
- Lec 4: Receiver structure (detection, signal space). Diff: 4. Imp.=:4
- Lec 5: Signal detection; Probability of symbol errors. Diff: 7. Imp: 8.
- Lec 6: ISI, Nyquist theorem. Diff: 6. Imp: 6.
- Lec 7: Modulation schemes; Coherent and non-coherent detection. Diff: 8. Imp: 9.
- Lec 8: Comparing different modulation schemes; Calculating symbol errors. Diff: 7. Imp: 9.
- Lec 9: 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.
- You will be required to do a Design Project using MatLab to simulate your design and demonstrate it’s performance in the presence of noise and Inter-Symbol interference (ISI). This includes a Design report and an in class PowerPoint presentation.

Helpful hints for the course

- This course uses knowledge from the pre-requisite courses (EE301, …) so go back and review your notes. We will review/introduce Signal/System analysis topics as they are used.
- It is good a practice 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 page when printing the slides.
- Try to browse through the slides before each lecture and read the chapter in the text. This will really help in picking up concepts quicker.
- Attend the lectures and ask questions! If you miss a class, ask a friend for extra notes.
- I will frequently 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.

Today, we are going to talk about:

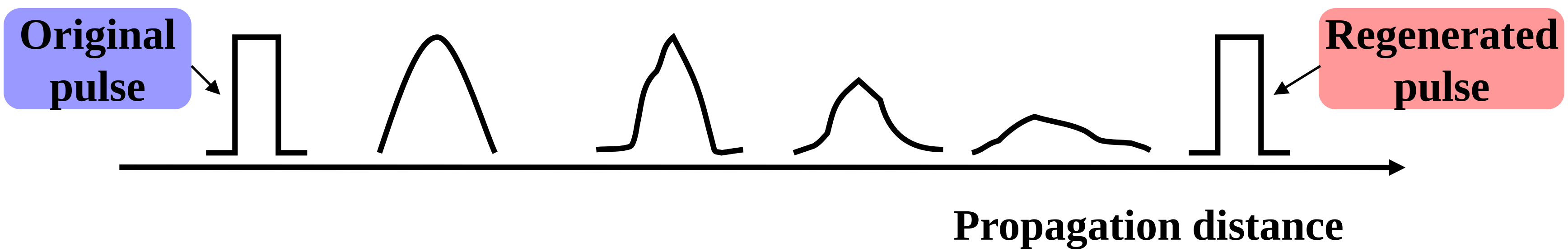
- What are the features of a digital communication system?
  - Why “digital” instead of “analog”?
- What do we need to know before taking off toward designing a DCS?
  - Classification of signals
  - Random processes – see Noise
  - Autocorrelation
  - Power and energy spectral densities
  - Noise in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

Digital communication system

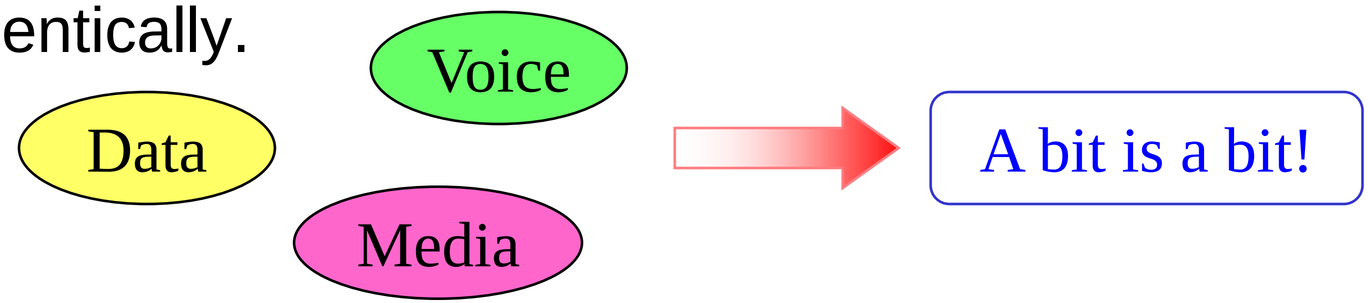
- Important features of a DCS:
  - The transmitter sends a waveform from a finite set of possible waveforms during a limited time
  - The channel distorts, attenuates the transmitted signal
  - The receiver decides which waveform was transmitted given the distorted/noisy received signal. There is a limit to the time it has to do this task.
  - The probability of an erroneous decision is an important measure of system performance

Digital versus analog

- Advantages of digital communications:
  - Regenerator receiver



  - Different kinds of digital signal are treated identically.

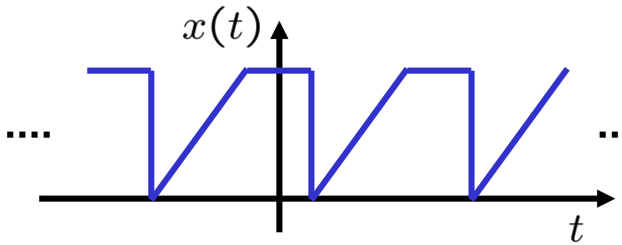


Classification of signals

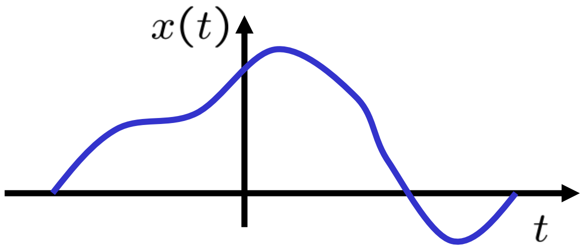
- Deterministic and random signals
  - Deterministic signal: No uncertainty with respect to the signal value at any time.
  - Random signal: Some degree of uncertainty in signal values before it actually occurs.
    - Thermal noise in electronic circuits due to the random movement of electrons. See my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

Classification of signals …

- Periodic and non-periodic signals

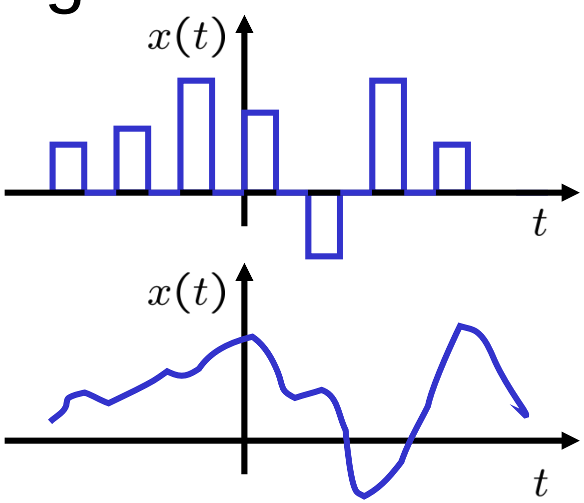


A periodic signal

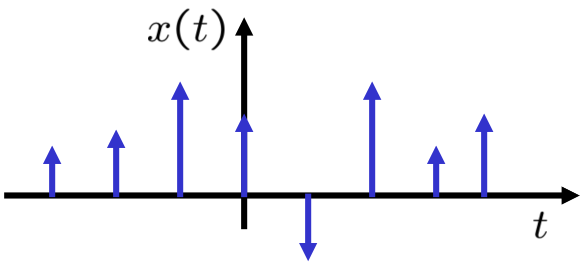


A non-periodic signal

- 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:

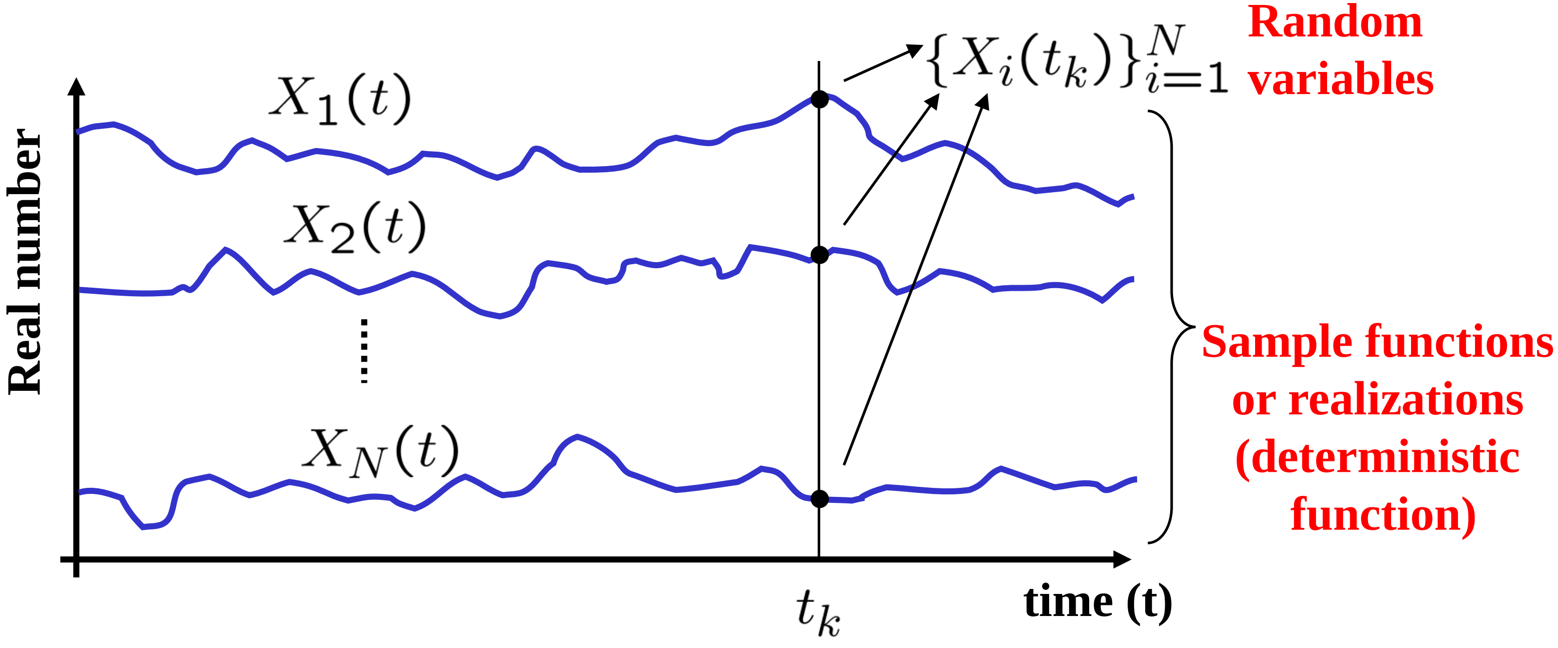
$$P_x = \lim_{T \to \infty} \frac{1}{T} \int_{T/2}^{T/2} |x(t)|^2 dt$$

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

  - 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 (ensemble) 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. In other words, you get the same result from averaging over the ensemble or over all time.

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):

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

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

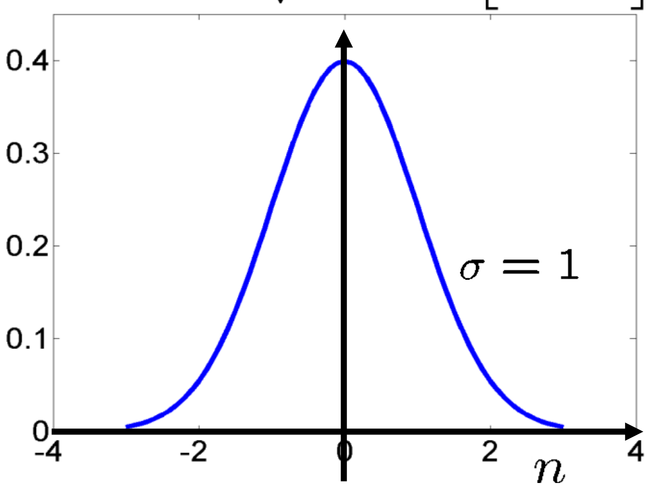
Properties of an autocorrelation function

- For real-valued (and WSS in case of random signals):
  1. Autocorrelation and spectral density form a Fourier transform pair. – see **Linear systems**, **noise**
  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. σ is the *Standard Deviation* and σ^2 is the *Variance* of the random process.

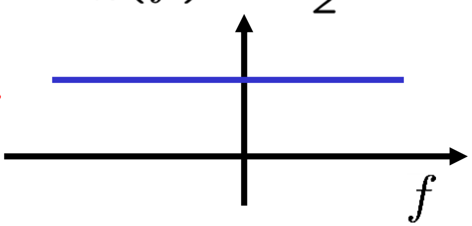
$$p(n) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{n^2}{2\sigma^2}\right]$$



Probability density function

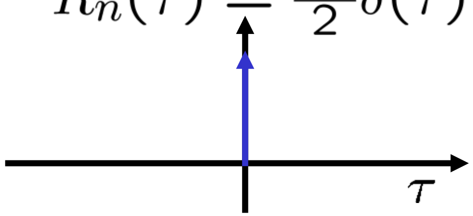
$$G_n(f) = \frac{N_0}{2} \text{ [w/Hz]}$$

Power spectral density

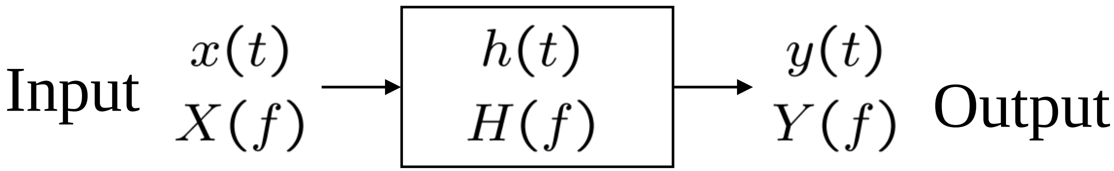


$$R_n(\tau) = \frac{N_0}{2}\delta(\tau)$$

Autocorrelation function



Signal transmission through linear systems



Linear system - see my notes

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

- Ideal distortion less transmission:

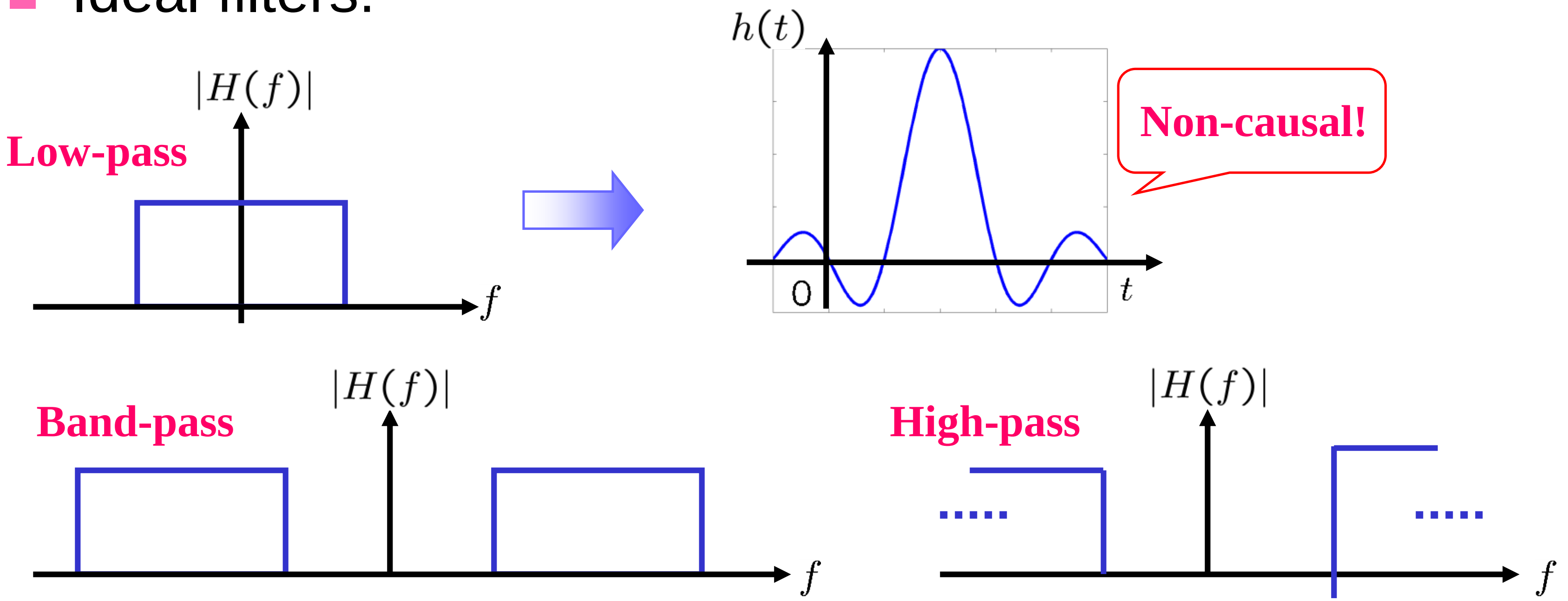
  All the frequency components of the signal not only arrive with an identical time delay, but also are amplified or attenuated equally.

  AKA "Linear Phase" or ""Constant group Delay".

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

Signal transmission … - cont'd

- Ideal filters:



- Realizable filters:

RC filters

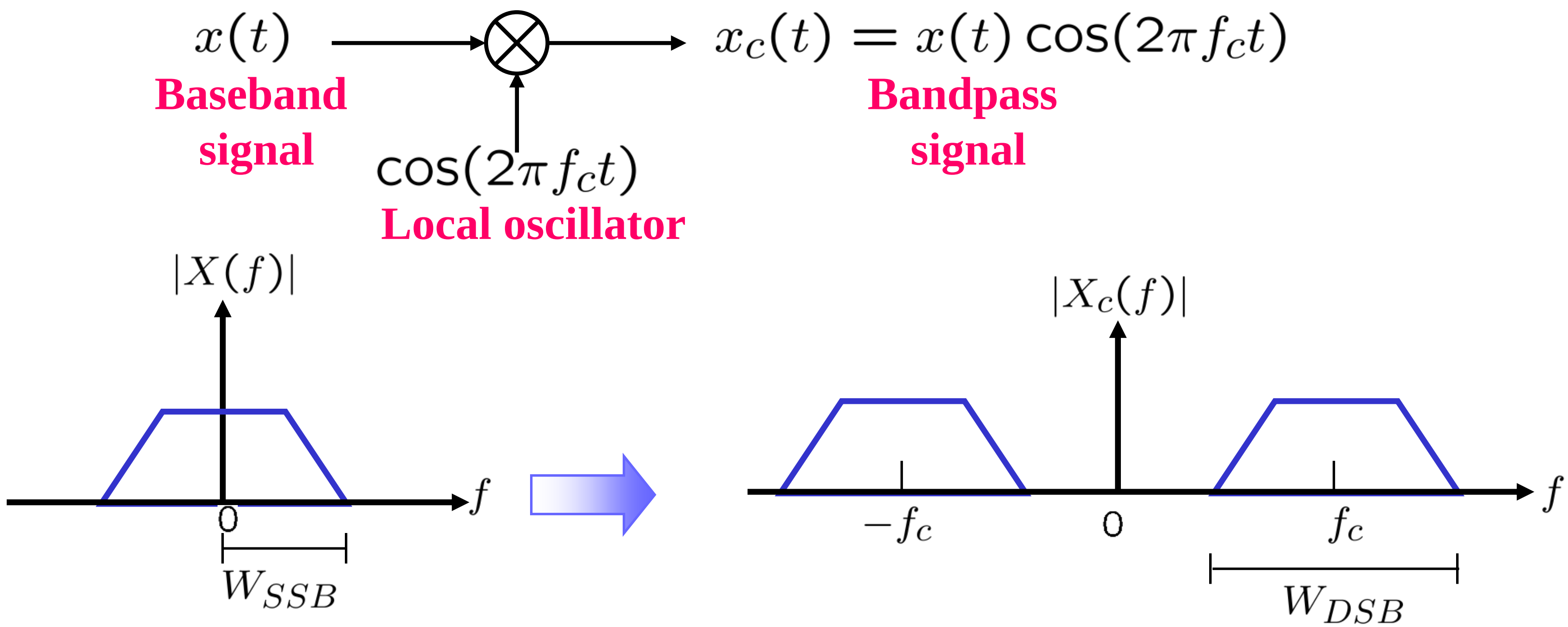
$$H(f) = \frac{1}{1 + j2\pi fRC}$$

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! We approximate “Band-Limited” in our analysis!

Bandwidth of signal …

- Different definition of bandwidth:

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