Communications Theory

Introduction

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8. Design of a system and quality metrics
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9. Analog vs Digital communications systems

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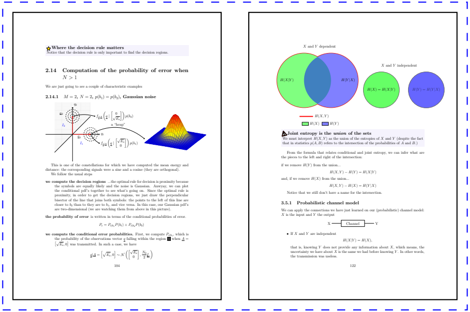
Material

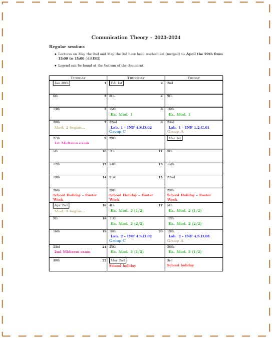
To be found in Aula Global:

- *Ad-hoc* notes

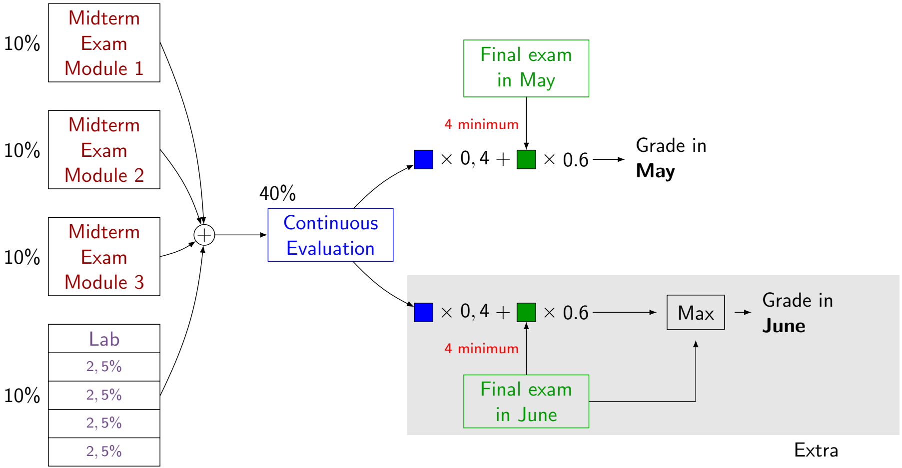


- Slides

Planning of the course



Evaluation of the course



Contents of the course

1. Noise in communications systems: stochastic processes, white noise, SNR

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3. Fundamental limits in communications
4. Analog modulations

What is the purpose of a communications system?

Goal: to transmit information between two points that are somehow connected by some physical medium

...the physical medium might be: a cable, the air, empty space...

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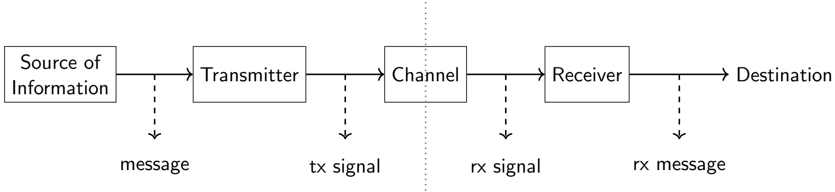
- ...plenty more

Block diagram

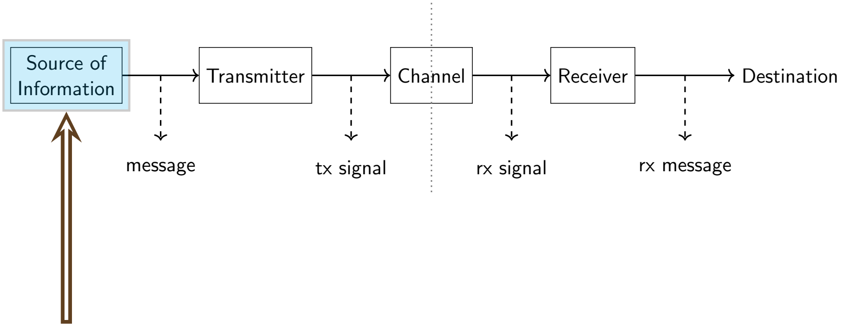
When focusing on the *functionality*, the structure of a typical communications system is:



message: physical manifestation of the information

We study each of the above blocks separately...

Source of information



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Messages produced might come in different formats

- voice
- text
- images
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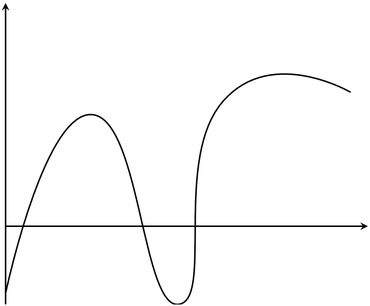
Sources can be

- analog
- digital

...according to the way in which information is represented

Analog source

It produces messages that are modeled as a continuous waveform.



This could represent variation in the air pressure, temperature variation, bitcoin price, price of stocks...

Digital source

It produces a sequence of *symbols* belonging to a **finite** set (the *alphabet*), each one sent during a certain time interval.

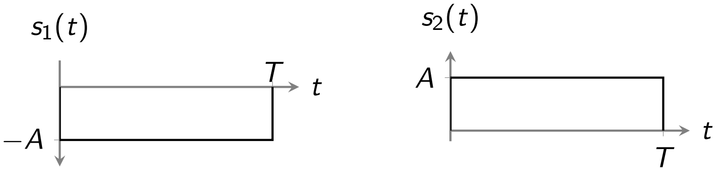
a symbol
“a thing that represents or stands for something else” (Oxford English Dictionary)

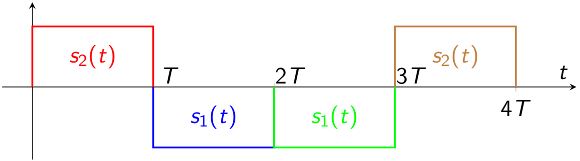
For us,

- a **symbol** translates into a (continuous-time) signal transmitted during a *symbol period* (usually denoted as T)
- the **alphabet** is a set of symbols

Digital source: examples I

Alphabet:





Digital source: examples II

More examples of alphabets

- $\{☺, ☹\}$

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- {☺, ☹}
- $\{A\sin(w_0 t), -A\sin(w_0 t)\}$

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More examples of alphabets

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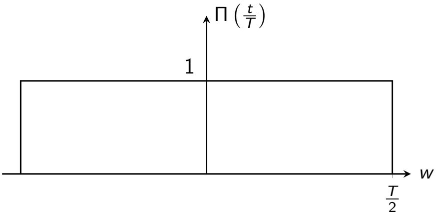
  (the signals are *digital in amplitude*)
- $\{A\sin(w_1 t), A\sin(w_2 t)\}$
  (the signals are *digital in frequency*)
- $\left\{A\Pi\left(\frac{t}{T}\right), -A\Pi\left(\frac{t}{T}\right), 3A\Pi\left(\frac{t}{T}\right), -3A\Pi\left(\frac{t}{T}\right)\right\}$ where $\Pi\left(\frac{t}{T}\right)$ is a rectangular pulse of length T centered at 0, i.e.,



(the signals are *digital in amplitude*)

Two different kinds of communication systems

type of source → type of communications system:

- **digital** source → digital communications system

  examples: Fiber-optic communication (internet), HDTV...pretty much everything

- **analog** source → analog communications system

  examples: old TV, radio (for how long??)

how come we use digital communications system for nearly everything???

Two different kinds of communication systems

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  → digital communications system?

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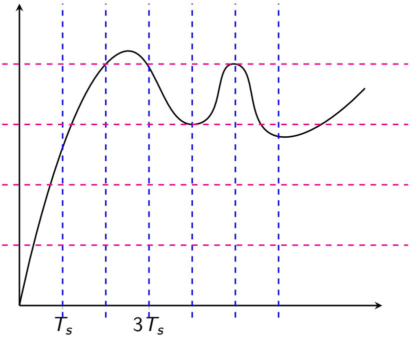
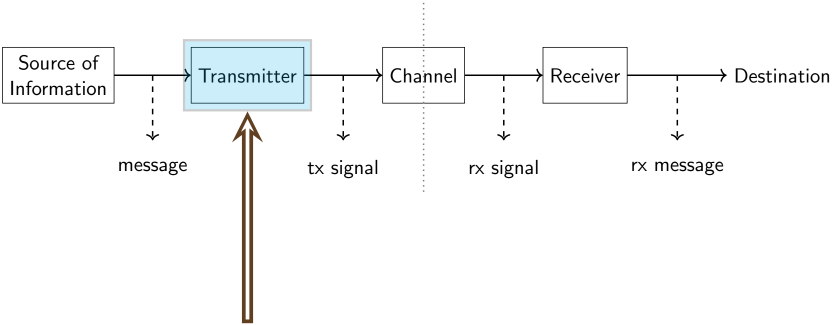
Digitizing signals



- **sampling** to discretize the time axis
  - no information loss if *Nyquist* condition holds
- **quantization** to discretize the amplitude
  - information loss

Transmitter



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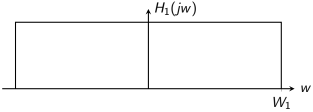

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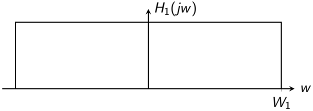
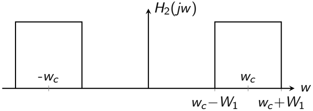


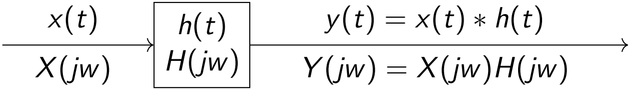
- passband...e.g.,



$(w_c \gg W_1)$

Transmission I

Here, we model the channel as an LTI system,



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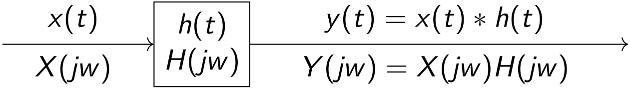
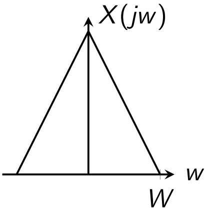


so, what happens if the spectrum of the signal to be transmitted is



Can the signal travel through both channels?

Transmission II

- $x(t)$ can travel through the baseband channel (*baseband* transmission)
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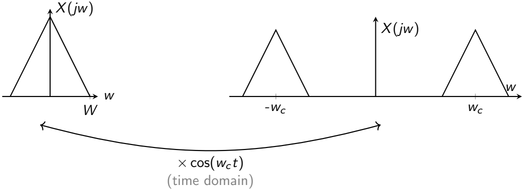
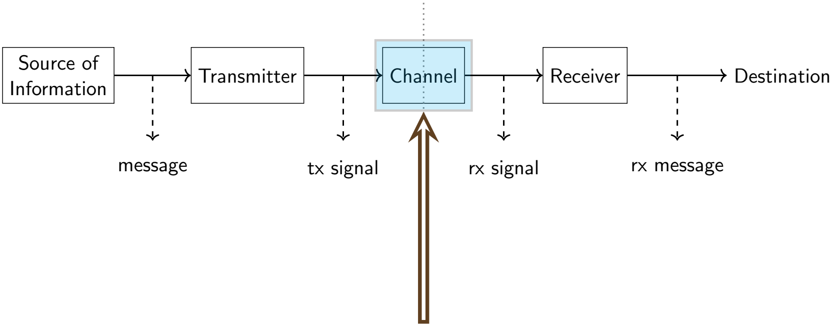


...and we have *passband* transmission
The above operation is called modulation and $\cos(w_c t)$ is the so-called carrier signal

Channel


Source of Information
Transmitter
Channel
Receiver
Destination
message
tx signal
rx signal
rx message

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It is the physical medium through which information propagates

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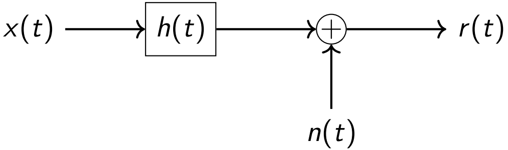
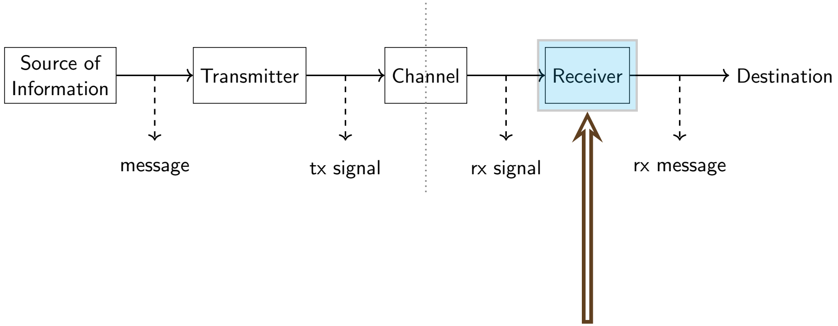
The channel is usually modeled like this:



Receiver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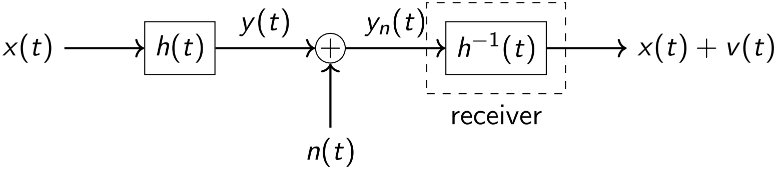
Receiver

It must recover the information transmitted as faithfully as possible

Among other things, it must

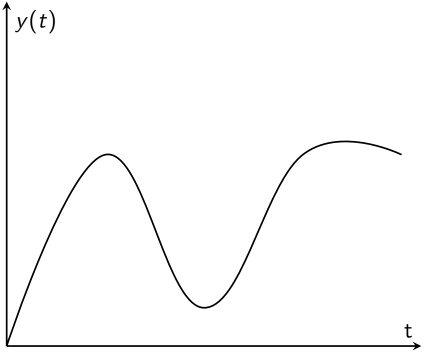
1. Demodulate, i.e., carry the signal back to its original frequency band
2. Reject disturbances
3. Fix channel distortions whenever possible

Ideally, we would like to find $h^{-1}(t)$ such that



Receiver in an analog system

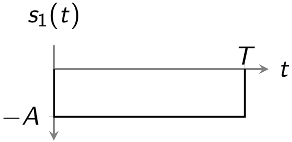
2 and 3 are challenging in an analog system...
Let us assume we receive

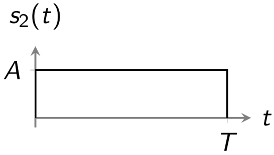


Was this the signal actually transmitted?

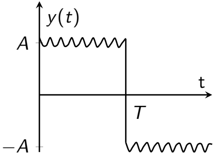
Receiver in an digital system

We know the alphabet of the system, e.g.,





If we receive...



- we **know** disturbances and/or distortions occurred
- we can *estimate* what was transmitted (making a *decision*)

This is the point of digital communication systems!!

Design of a system

When designing a system, we have to take into account (among other things):

- Quality
- Available technologies
- Cost
- Resources consumption

...we briefly review each one of them

Quality

We need a metric for the quality of a system so that the latter can be properly designed and compared against others

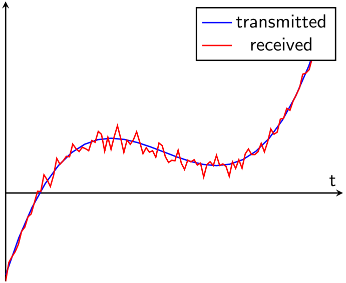
Different metrics for the two different kind of systems:

- analog system $\rightarrow$ fidelity
- digital system $\rightarrow$ error probability

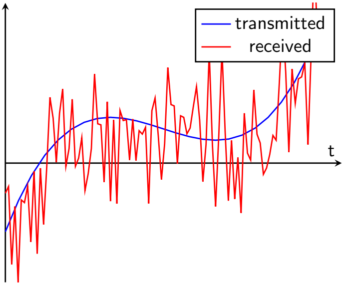
Quality in an analog system I

Fidelity refers to whether the received signal resembles the transmitted one.

Example #1



Example #2



On the left, the transmitted signal is *recognizable* in the received one...no so much on the right

Quality in an analog system II

We need a *quantitative* measure of fidelity: it is the signal-to-noise ratio (SNR), which is defined as

$$\frac{\mathbf{S}}{\mathbf{N}} \quad \begin{array}{l} \rightarrow \text{ power of the signal} \\ \rightarrow \text{ power of the noise} \end{array}$$

Other parameter related to the quality: **bandwidth**

telephone AM radio FM radio HiFi system

$-$ quality $\longrightarrow$ $+$ quality

Quality in a digital system

We can count how many *symbols* were correctly received...and the **probability of error** is estimated as

$$P_e = \frac{\text{number of symbols incorrectly received}}{\text{overall number of symbols transmitted}}$$

Clearly,

- $\uparrow$ quality $\Rightarrow \downarrow$ probability of error (P_e)

Just like in analog systems, the **bandwidth** also has an impact here

- $\uparrow$ bandwidth $\Rightarrow \uparrow$ quality

Available technologies, Cost and Resources consumption

- before implementing a communications system, we should investigate the **available technologies**
  - is it worth it to use state-of-the-art technology? (how many people have access to it?)
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  - how much is a terminal going to cost?
  - how much the base station?
- **resources** don't come for free
  - can we take up as much bandwidth as we like?
  - how much transmission power is too much? (health factors, other systems deployed in the same space)

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- more reliable, flexible and cheaper circuits
- **encryption**
- versatility: the same communications system can transmit any kind of information (ultimately, everything is bits!!)

Drawbacks of digital communication systems

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- synchronicity between transmitter and receiver is required
- a larger amount of bandwidth (expensive!!)
- almost every source of information is analog (not a problem in practice...)

The advantages trump the drawbacks