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Communication Systems

What’s “communication”?

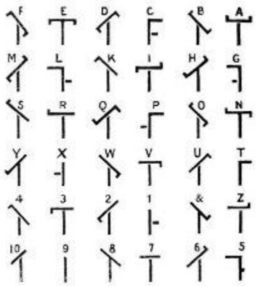
- **Communication** (from Latin *commūnicāre*, meaning "to share") is the purposeful activity of information exchange between two or more participants in order to convey or receive the intended meanings through a shared system of signs and semiotic rules.

- “Communication is simply the act of transferring information from one place to another.”

From Communication to Telecommunication

- Greek prefix *tele*- (τηλε-), meaning "distant“
- Telecommunication: long-distance transmission of information without the physical exchange of an object bearing the message

First example: Chain of beacons on hilltops (semaphore systems)



“Modern” Telecommunication Systems

- New inventions starting in the XIX century
  - Telegraph, (1837)
    - The first transatlantic telegraph cable was successfully completed on 1866
  - Telephone, (1876)
  - Radio, 1890’s
    - The first transatlantic radio transmission was established in 1901
  - Television, 1929

- Definition according to International Telecommunication Union (ITU)

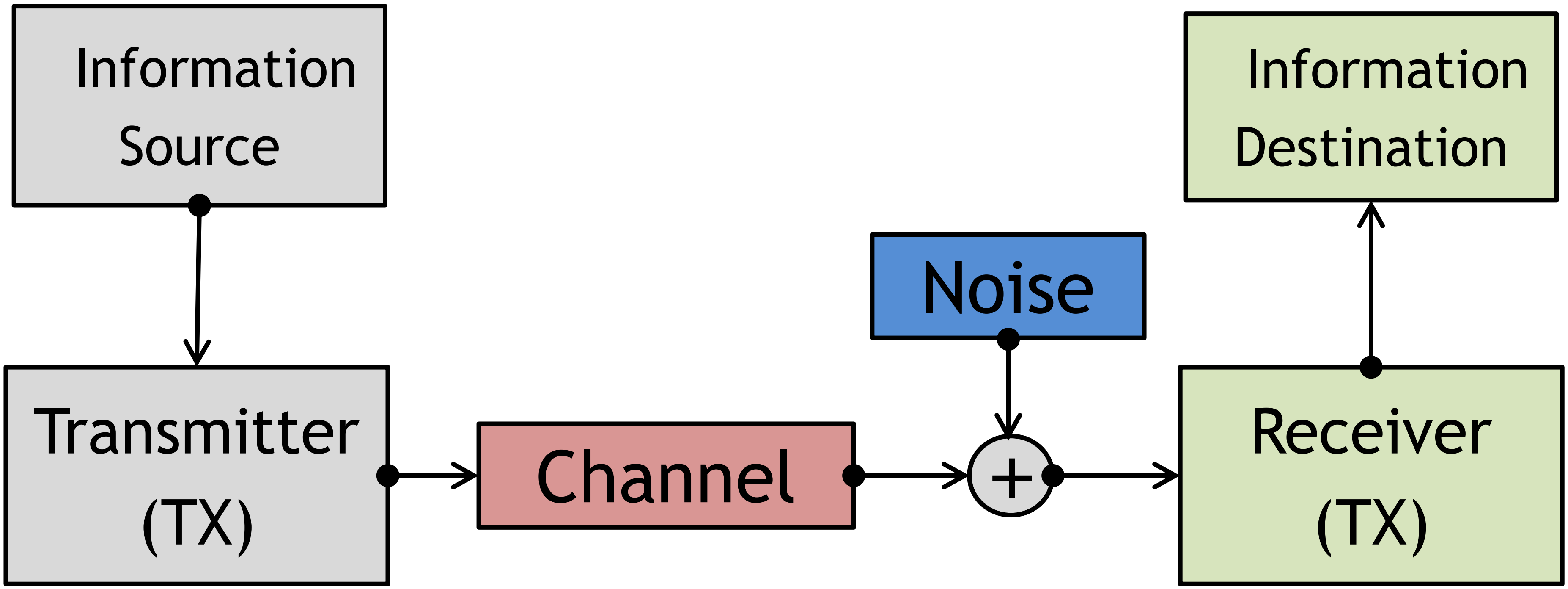
  “Any transmission, emission or reception of signs, signals, writings, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems.”

Model of communication

The first major model for communication was introduced by Claude Shannon and Warren Weaver for Bell Laboratories in 1949

1. An information source, which produces a message
2. A transmitter, which encodes the message into signals
3. A channel, to which signals are adapted for transmission
4. A noise source, which distorts the signal while it propagates through the channel
5. A receiver, which 'decodes' (reconstructs) the message from the signal.
6. A destination, where the message arrives.

Models of communication

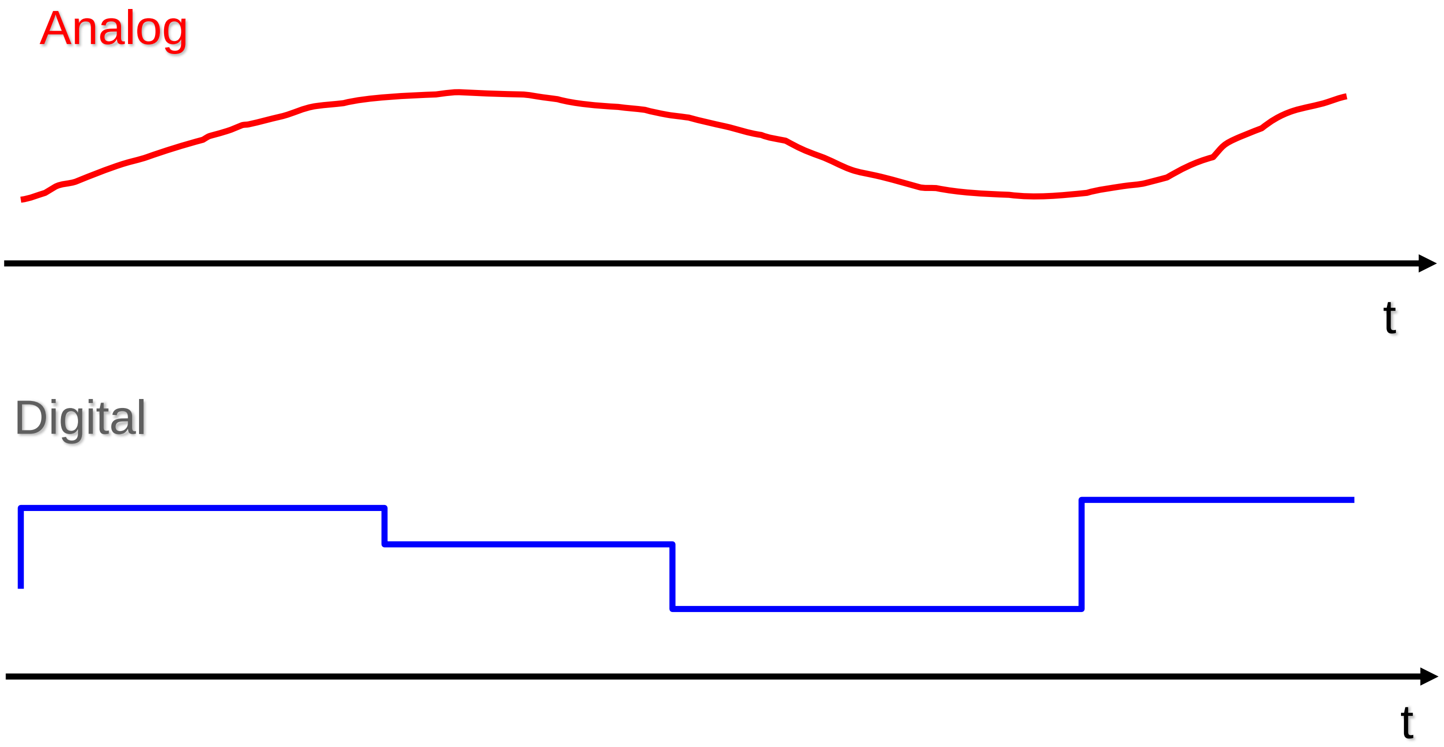


Information sources

- All natural information sources are ANALOGUE, that is they are:
  - Time continuous
  - With infinite possible values within a given range
    - i.e. with all values between a minimum and a maximum

- Artificial information sources are DIGITAL, that is they are:
  - With a finite set of possible values (within a given range)
  - We call this set of values alphabet
  - (Not time continuous)

Analog vs. digital



Analog sources

Audio

– An audio signal is time continuous and with infinite possible values comprised between a minimum and a maximum

Sensors

- Temperature, speed, pressure, flow, etc.
- In general, if we use a sensor to measure a natural ”quantity” we have an analog source

Digital sources

Text

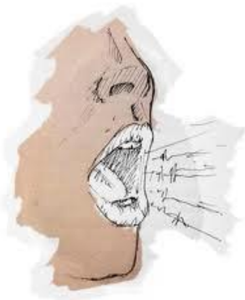
- A text is made of a finite number of characters (alphabet) lined up to form words → sentences → paragraphs → chapters → books

Data

- A file is composed of bits (binary digits = binary alphabet)

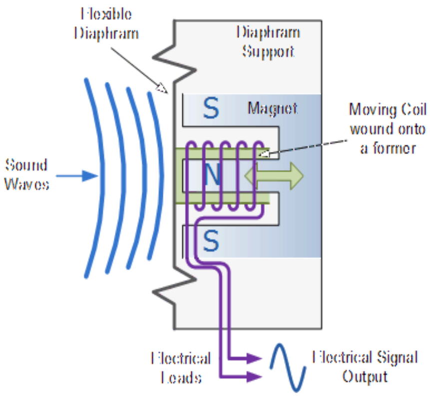
They are all "artificial" !!!

Example of analog signal: audio



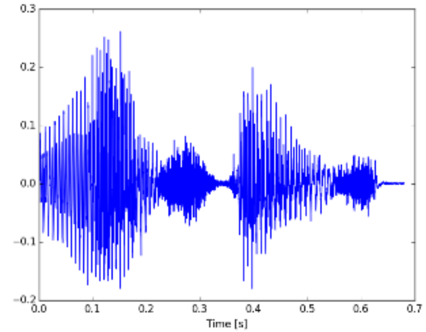
pressure variation

Microphone



Resistance
Inductance
Capacity

variation



Pros and cons of analog signals

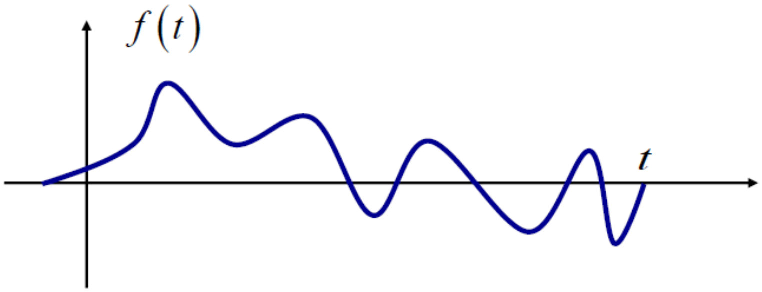
- Pros
  - Information can be taken directly from the source
  - It does not need any “translator”
- Cons
  - Transport is more sensible to disturbances
  - It cannot be compressed
  - It is more difficult to be stored

Pros and cons of digital signals

- Pros
  - Transport is more immune to disturbances
  - It can be compressed
  - It can be easily stored and maintained without degradation of the signal
- Cons
  - Information needs to be converted to digital form (quantization)

Signals

- A signals is a real (or complex) function of time
- We use signal to carry information
  - Usually information is conveyed by the “shape”
    - Scaling and delay of a signal are irrelevant

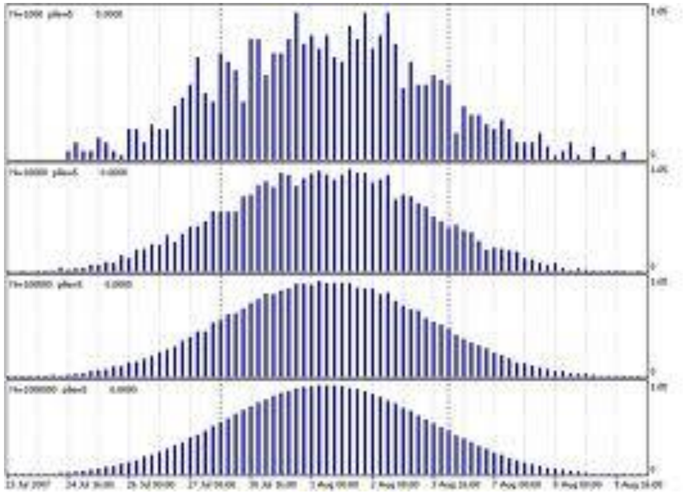


Signal Characterization

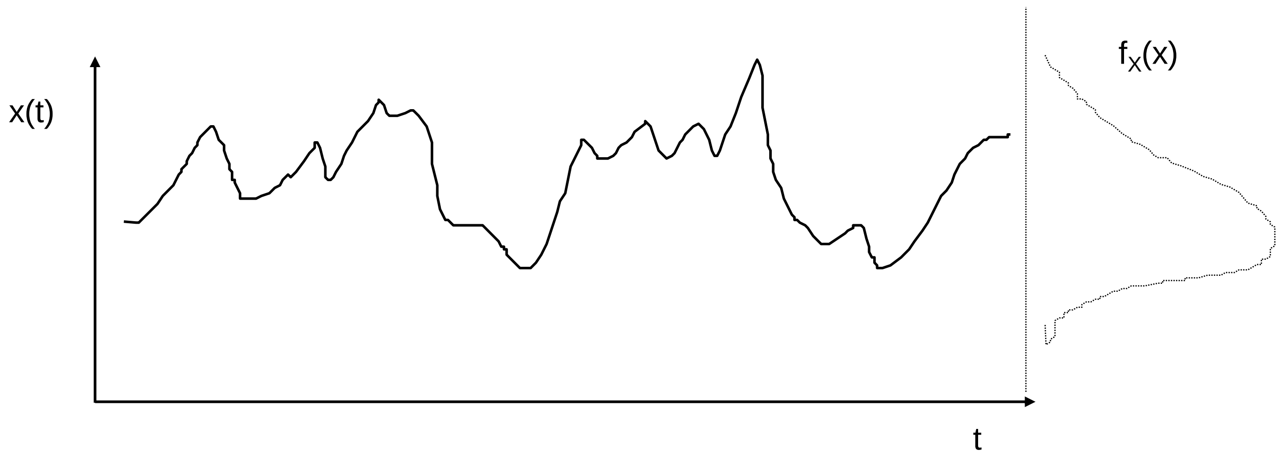
- Time: signal shape or trace
- Amplitude: probability density function
- Frequency: PSD or Spectrum

Probability density function (PDF)

- The simplest way to estimate a signal PDF is to observe it for a long time
- And to put them on histograms



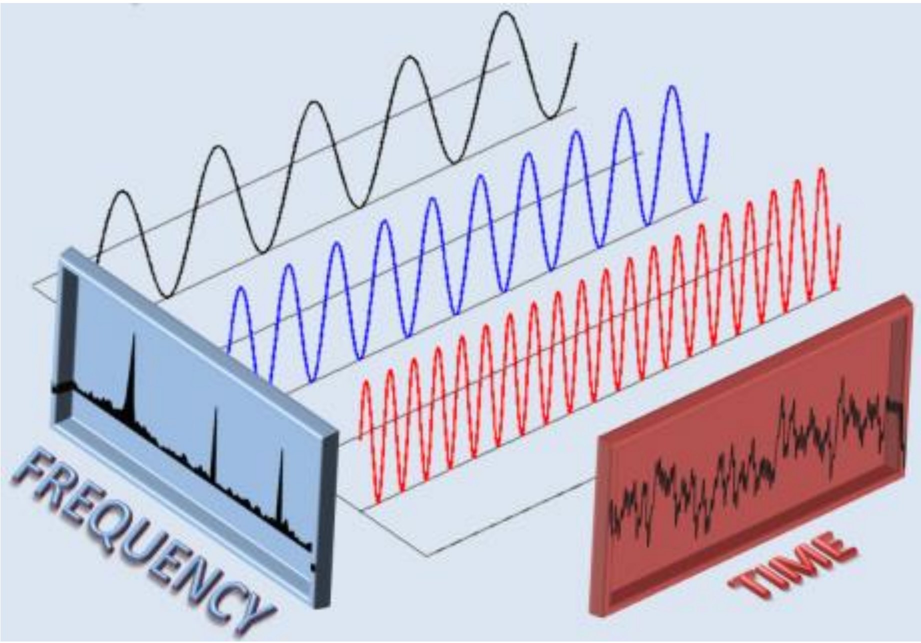
What PDF tells



The probability density function describes the general distribution of the magnitude of the random process, but it gives no information on the time or frequency content of the process

PSD or “The Spectrum”

- The spectrum of a signal is the representation of the amplitude (energy) of each sinusoidal function (frequency component) that is composing the signal

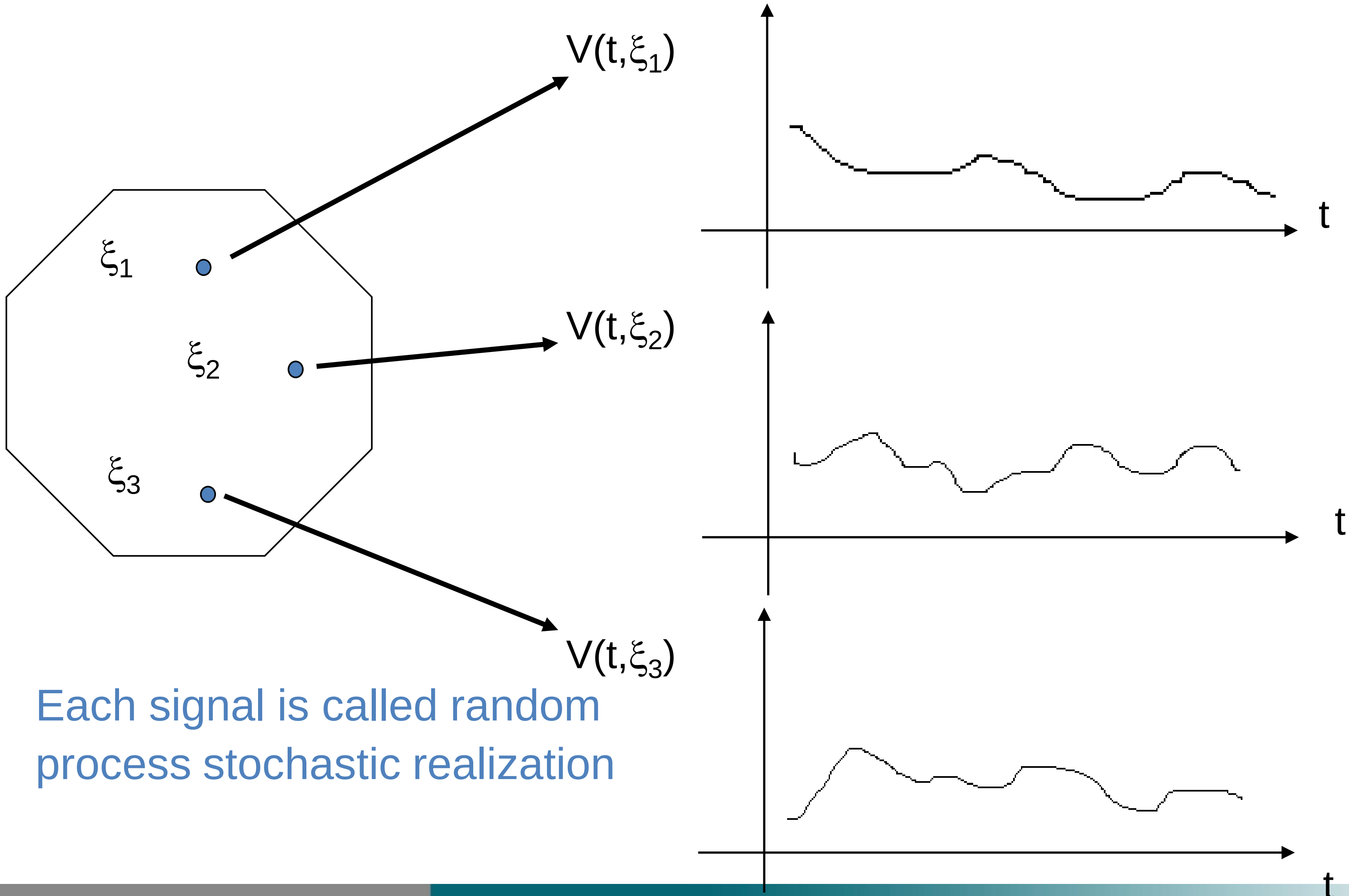


Random process

- Deterministic signals do not carry any information
  - We need to consider classes of signals not specific signal
  - They can be characterized statistically
- Disturbance signals (noise) too are not deterministic
  - They can be characterized statistically

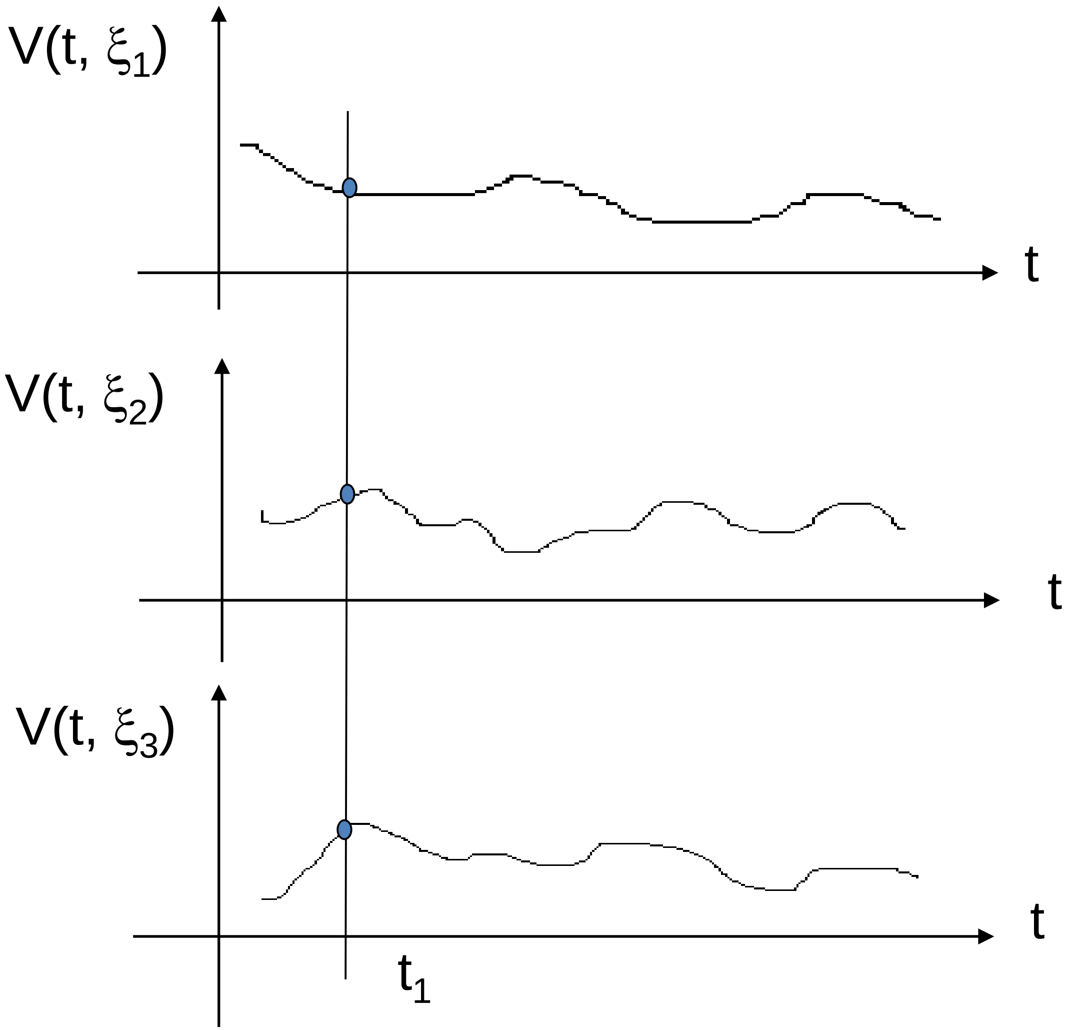
- A random process it's a collection of random variables representing the evolution of a system of random values over time
  - It's the probabilistic counterpart of a deterministic process
  - In random processes there is some indeterminacy: even if the initial conditions are known, it is not known how it will evolve

Random process realization



Each signal is called random process stochastic realization

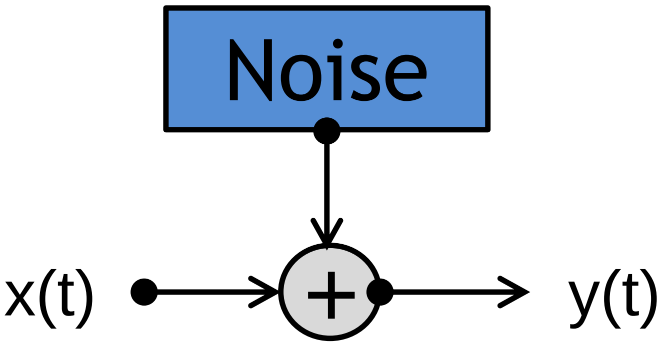
Random process realization

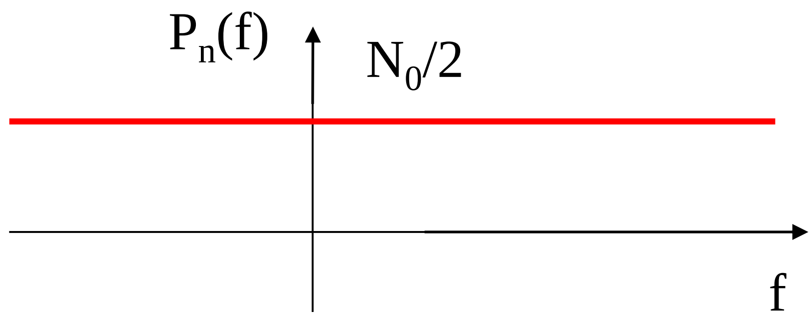


1. Given ξ_N, the function $v(t,\xi_N)$ is a random process realization
2. Given t_1, values $v(t_1,\xi_i)$ are random variables
3. $v(t_1,\xi_N)$ is a number

Noise

- It can be modeled as a random process
- The most used model for noise is the AWGN
  - Additive White Gaussian Noise
- Stationary random process, zero average, Gaussian pdf, constant PSD

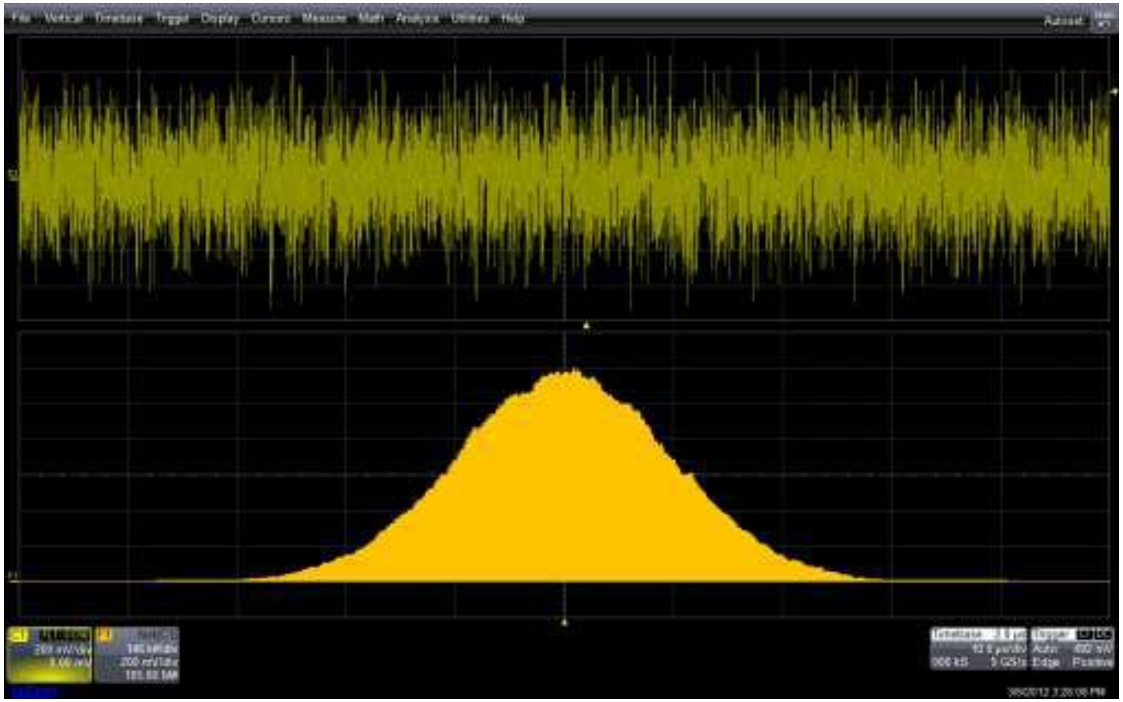




Example: Gaussian noise

An example of a random process than produces a Gaussian or normal distribution of amplitude values.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(X-\mu)^2}{2\sigma^2}}$$



Discrete-time signal

- Digital signal processing (DSP) techniques are very powerful and they have strongly developed in last decades
- We need discrete-time signals (eventually also discrete in amplitude) to allow such processing
- How can we properly sample a time continuous signal with losing information?

Sampling theorem

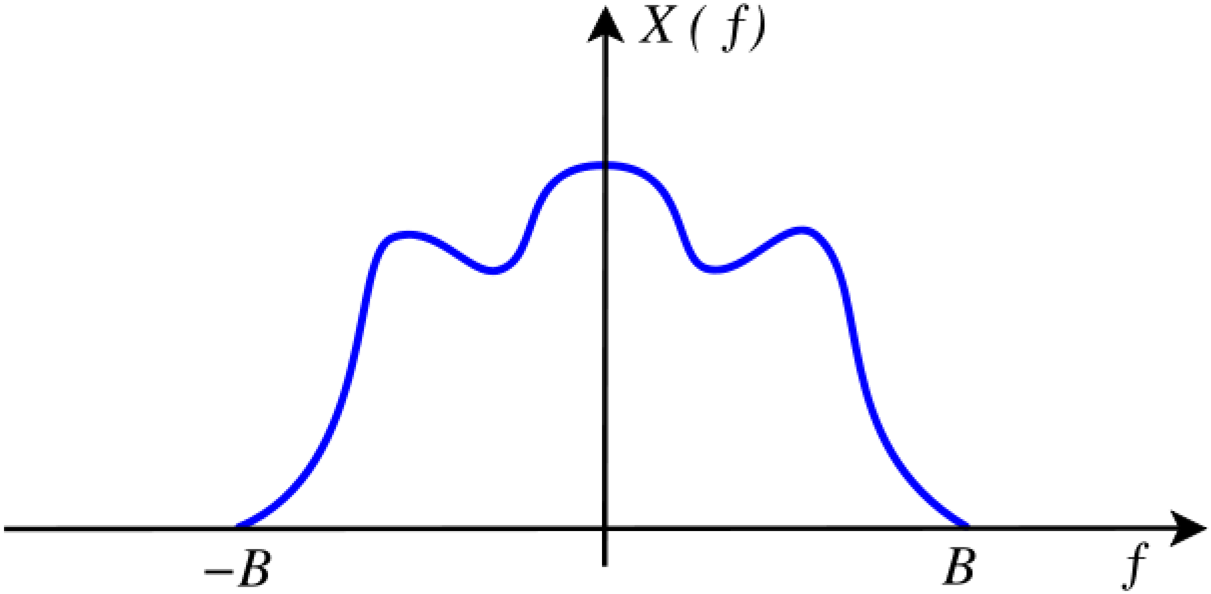
- It establishes a sufficient condition for a sampling rate that allow to capture all the information from a continuous-time signal
- It apply only to bandlimited signals
  - The PSD is zero outside of a finite region of frequencies

THEOREM

A time continuous signal containing no frequencies higher than B hertz, it is completely determined by giving its ordinates at a series of points spaced $1/(2B)$ seconds apart.

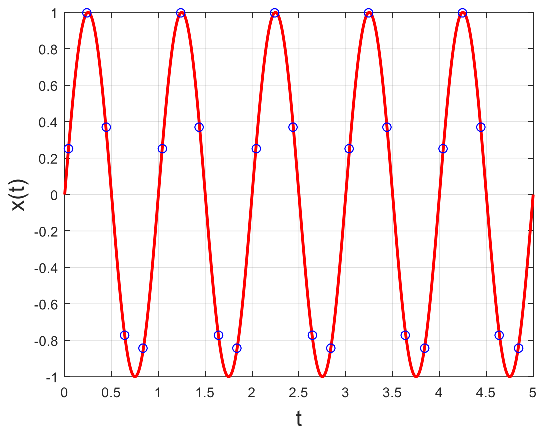
A sufficient sample-rate f_s is therefore $2B$ samples/second, or anything larger.

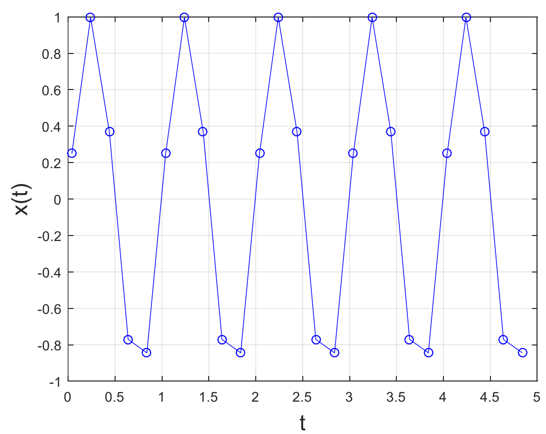
Sampling theorem

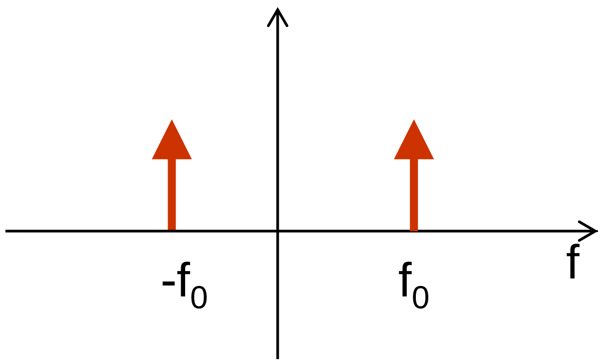


$$f_c \triangleq \frac{1}{T_c} > 2B \rightarrow T_c < \frac{1}{2B}$$

Intuitive interpretation: interpolation







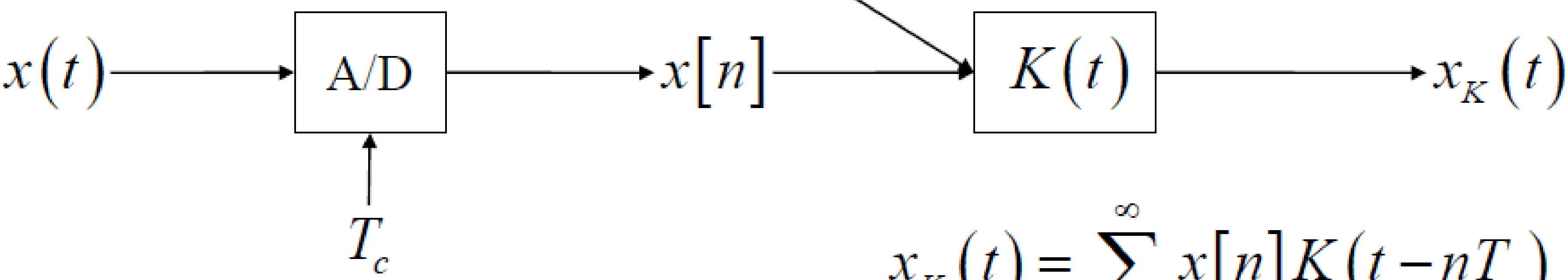
It's bandlimited:
sampling theorem is valid

$f_s=5f_0$
Sampling theorem is satisfied.
How can we reconstruct "perfectly" the signal from these sample?
Some information is lost?
No!!!

Sampling theorem

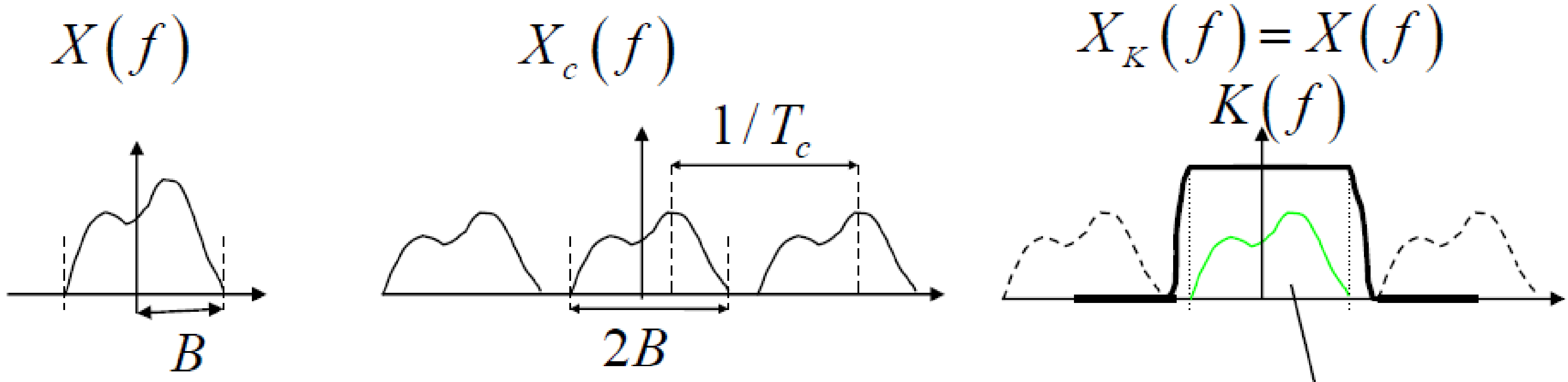
$$x_c(t) = \sum_{n=-\infty}^{\infty} x[n]\,\delta(t - nT_c)$$

Filtro interpolatore (ricostruttore)



$$x_K(t) = \sum_{n=-\infty}^{\infty} x[n]\,K(t - nT_c)$$

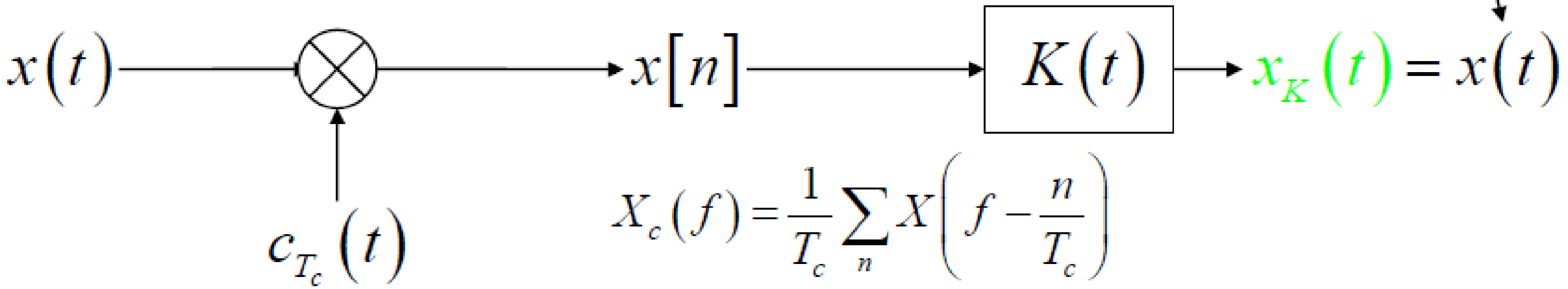
Sampling theorem



Supporto limitato

$$x_c(t) = \sum_n x(nT_c)\,\delta(t - nT_c)$$

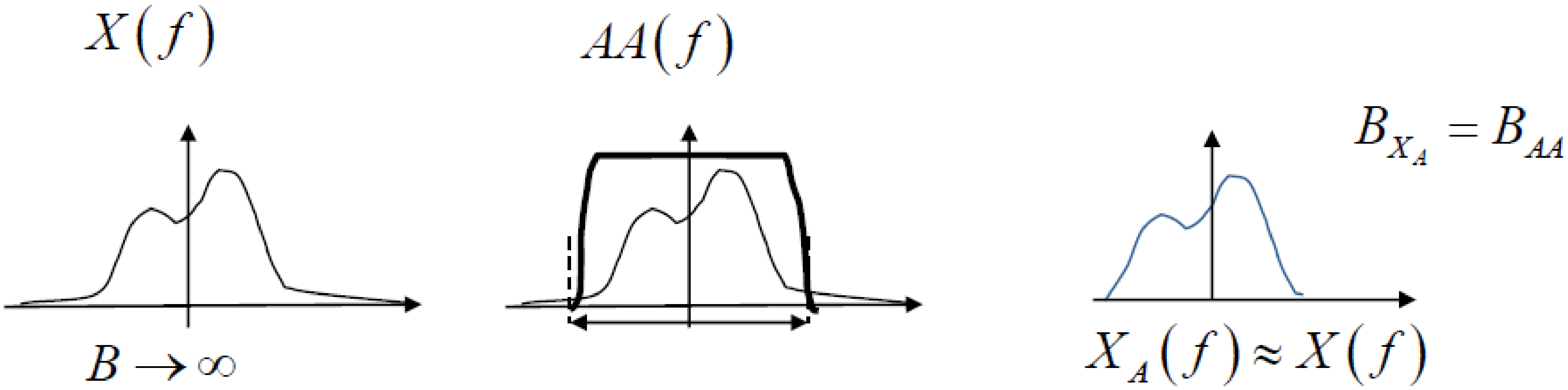
$$\Updownarrow$$



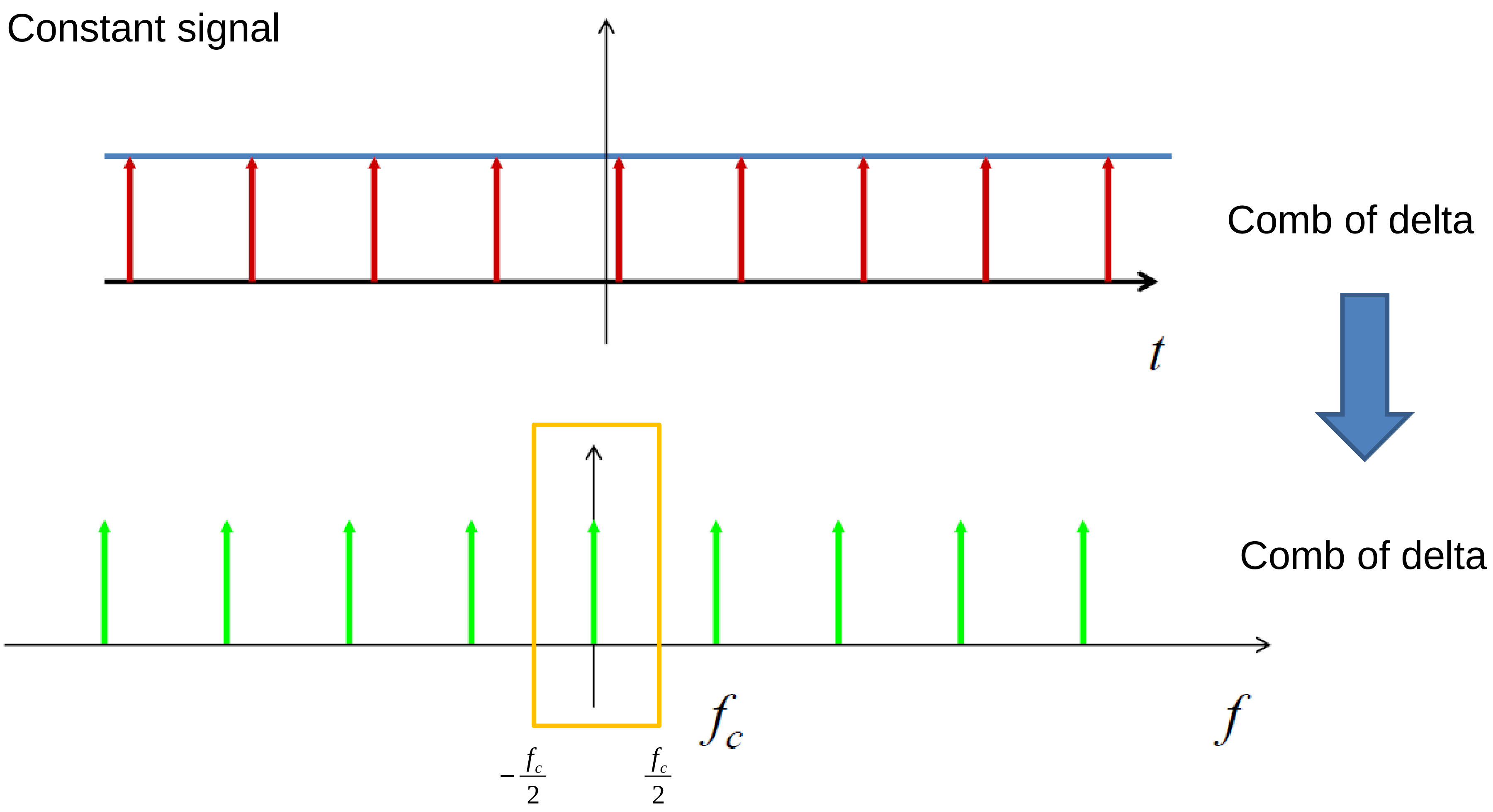
$$X_c(f) = \frac{1}{T_c} \sum_n X\left(f - \frac{n}{T_c}\right)$$

Real signals: not bandlimited

- To avoid aliasing, before sampling is applied we can insert an anti-aliasing filter

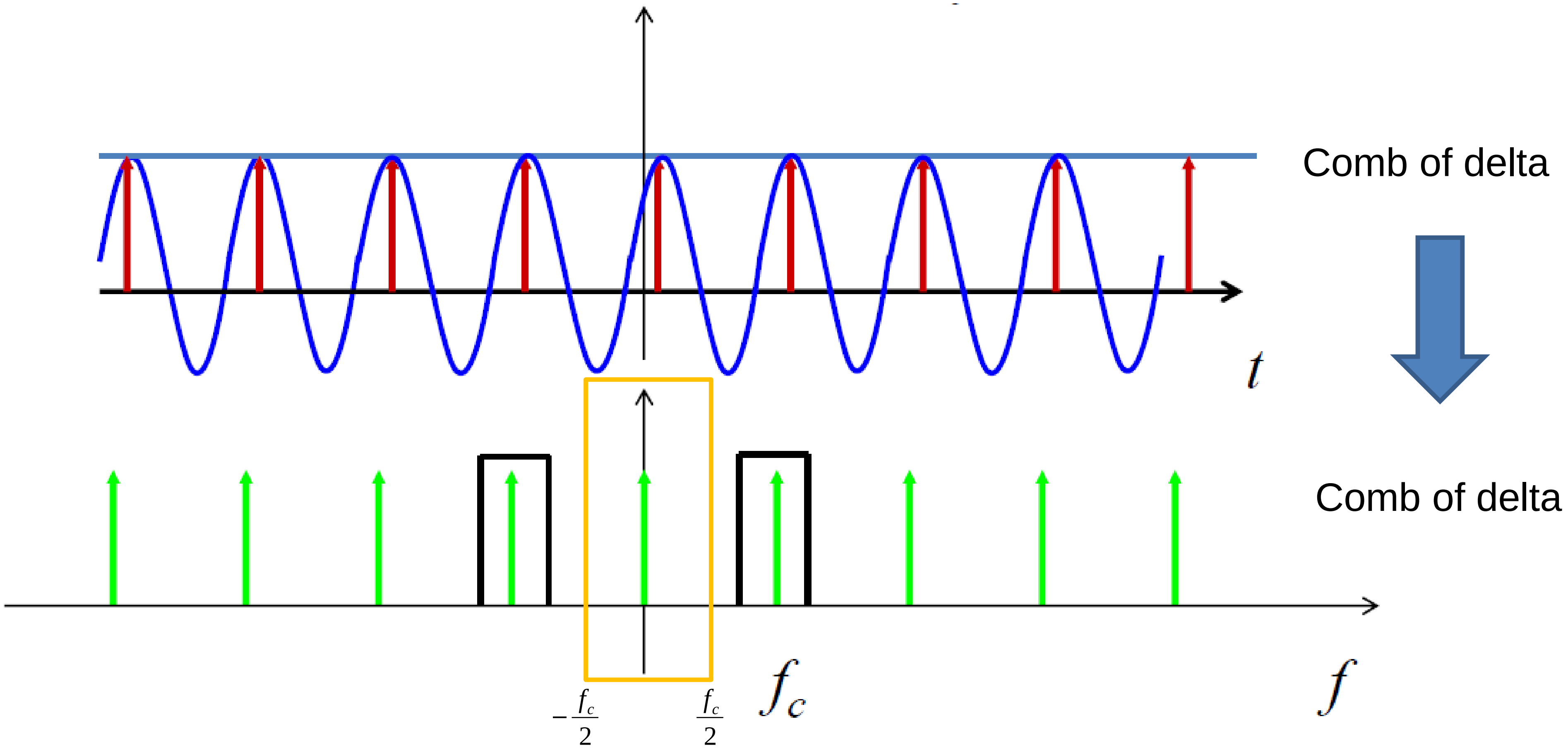


A periodic spectrum



A periodic spectrum

Sinusoidal signal

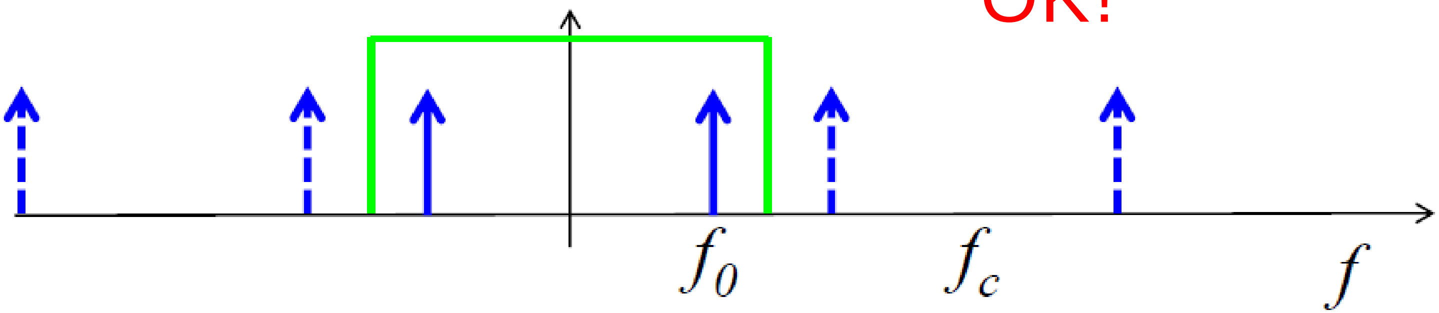


Aliasing: sinusoidal signal

$f_c > 2f_0$

$f_0 < \frac{f_c}{2}$ sovracampionamento

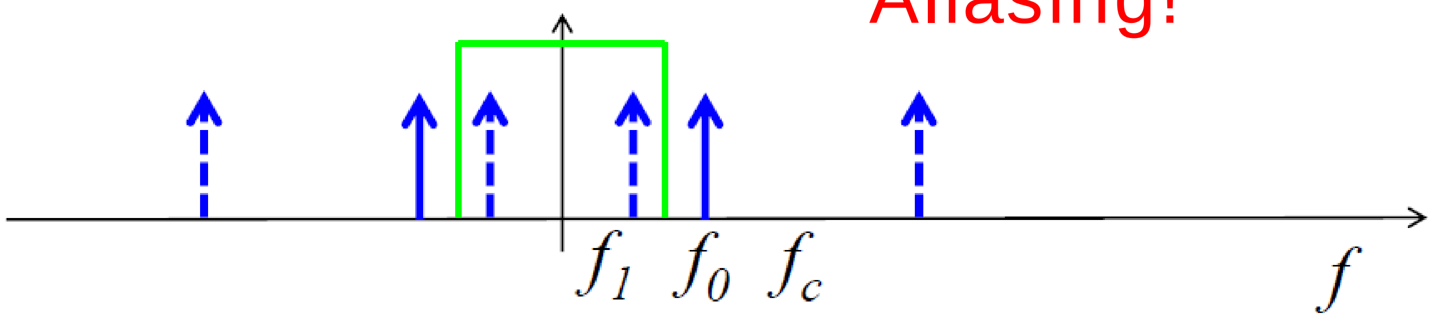
OK!



$f_c < 2f_0$

$f_0 > \frac{f_c}{2}$ sottocampionamento

Aliasing!



Aliasing: sinusoidal signal

- If sampling theorem satisfied (fc>f0) we have at least two samples per period
- If we undersample, a sinusoid we will reconstruct with smaller frequency