Digital Communications Channel

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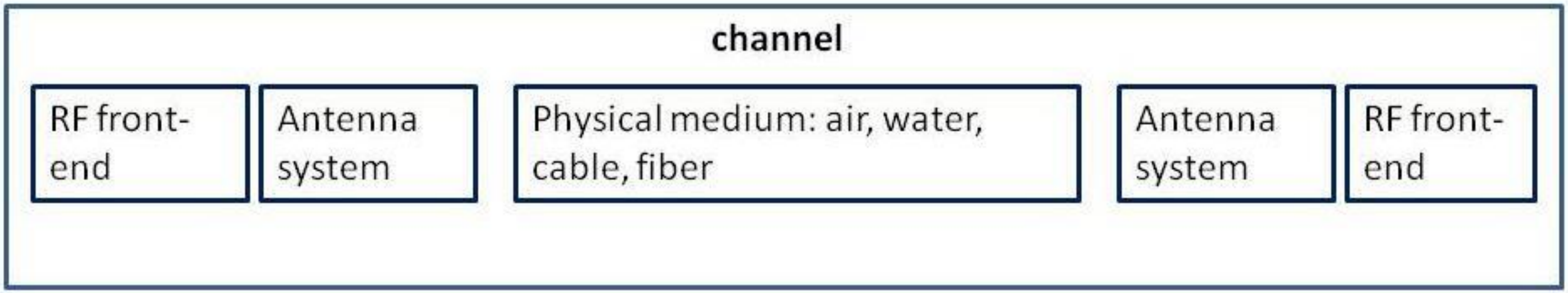
DIGITAL COMMUNICATION SYSTEM
Channel



Channel

In general, the channel is that part of the communication medium that is given and not under the control of the designer.

❑For an antennas designer, the channel is the physical medium (air, water,)

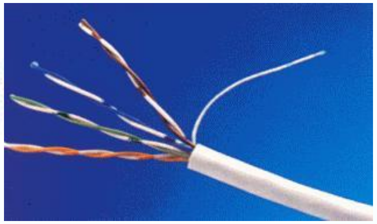
❑For a RF-front-end designer is the physical medium + the distorsions introduced by the antenna.

❑For a digital communication designer, it include the physical medium, antennas, RF front-end (amplifier, filter, up and down converter, D/A e A/D).

DIGITAL COMMUNICATION SYSTEM
Physical Medium

Guided propagation

fiber



twisted pair

Coaxial cable

Free propagation

Mobile broadcast channel

Mobile radio channel

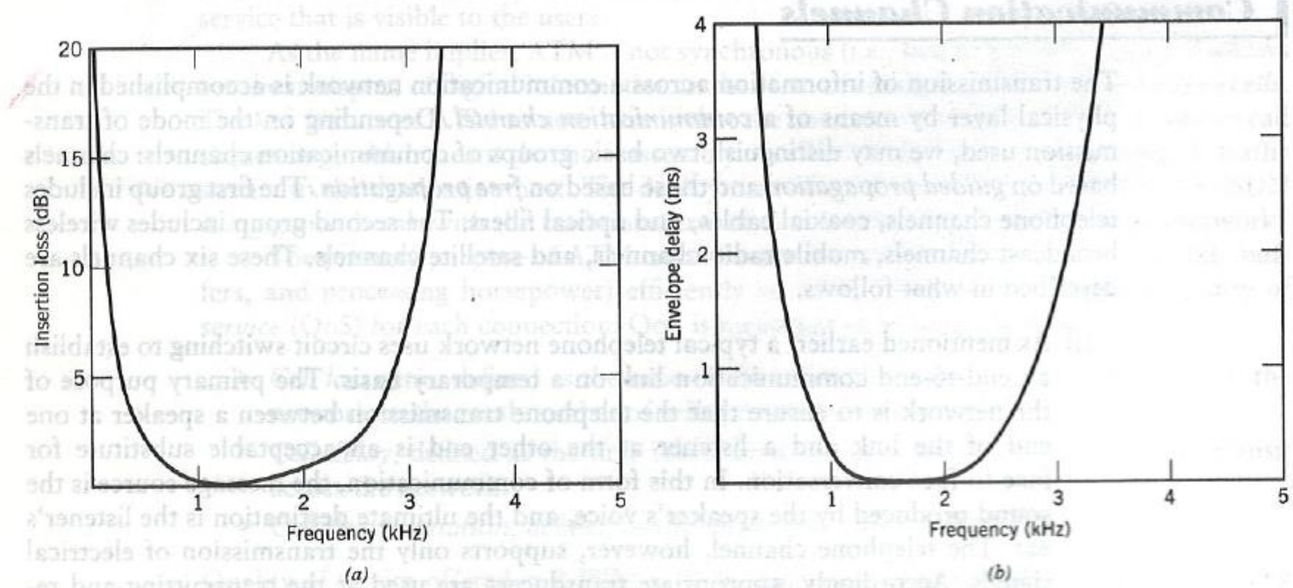
Satellite channels

DIGITAL COMUNICATION SYSTEM
Physical Medium

Telephone channel

It is a bandlimited channel → the communication system (TX and RX) must minimize the bandwidth requirements subject to a satisfactory transmission of human voice.

Human voice has frequencies that ranges from 20 to 8000Hz. However, the speech signal (male or female) is essentially limited to a band of 300 to 3100Hz in the sense that frequencies outside this band do not contribute much to the articulation efficiency and intellegibility.



Telephone channel

insertion loss $10\log\frac{P_0}{P_L}$ dove P_L is the power delivered to a load from a source via the channel and P_0 is the power delivered to the same load when it is connected directly to the source

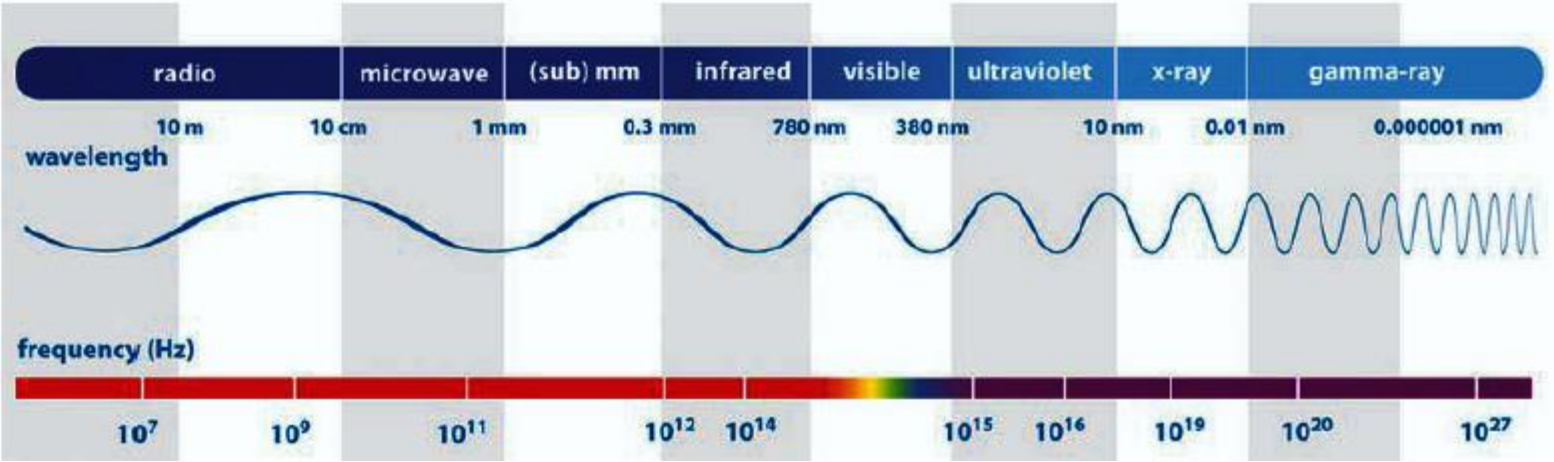
envelope delay is the negative of the derivative of the phase response with respect to the angular frequency $\omega = 2\pi f$

the telephone channel is a DISPERSIVE channel

denoting a phase dispersed in another phase, as in a colloid

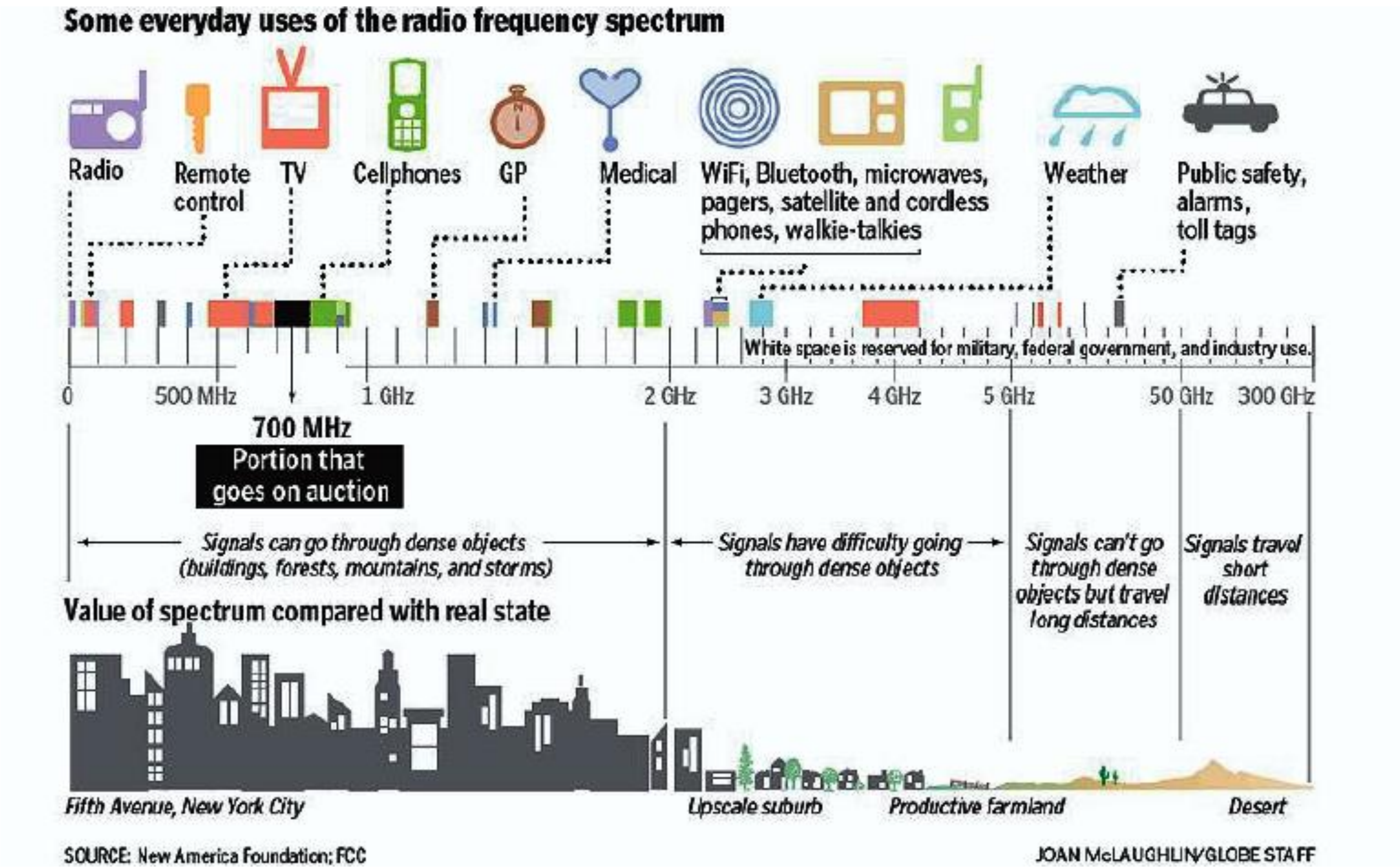
DIGITAL COMUNICATION SYSTEM
Physical Medium

Wireless channel



DIGITAL COMUNICATION SYSTEM
Physical Medium

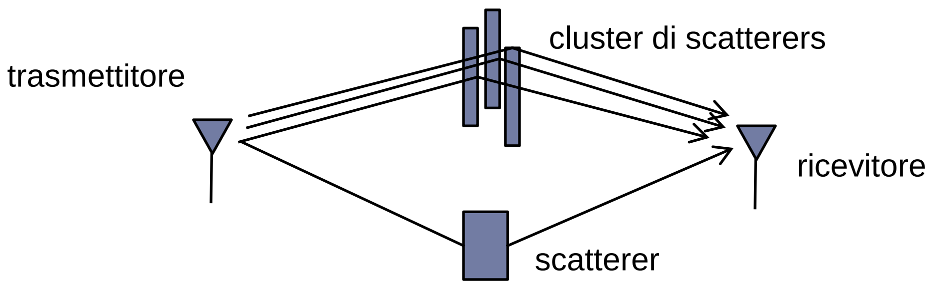
Wireless channel

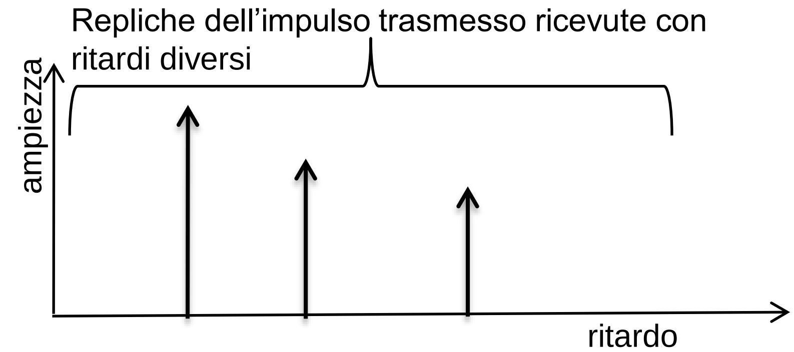


DIGITAL COMUNICATION SYSTEM
Physical Medium

Wireless channel

Replicas of the transmitted pulse received with
Different delays

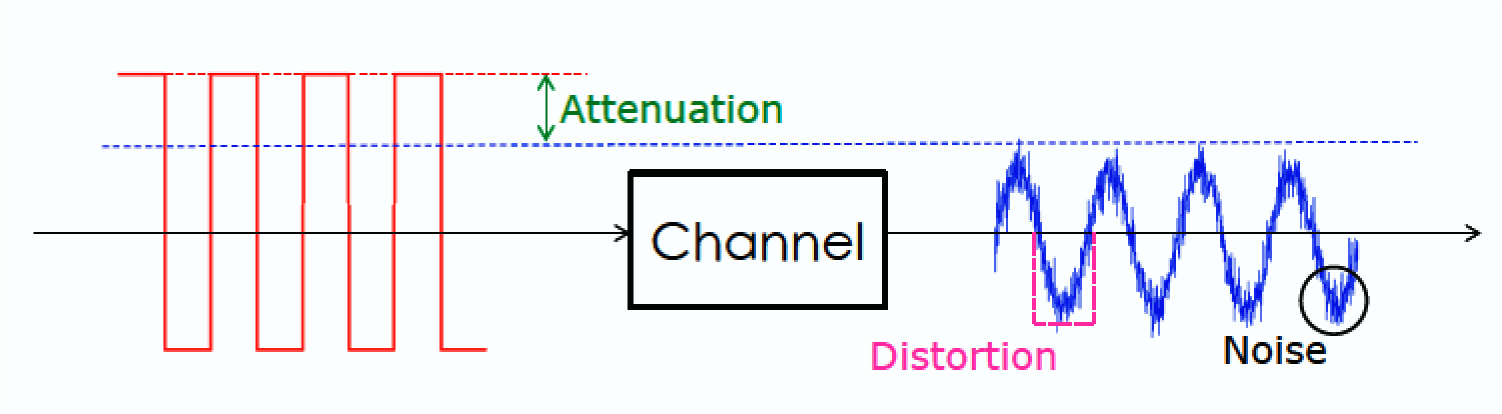




denoting a phase dispersed in another phase, as in a colloid

Multipath propagation makes the wireless channel a DISPERSIVE channel

DIGITAL COMUNICATION SYSTEM
Distorsions and Noise



The output of the channel (or a generic point of the communication system) can be divided in a **desired component (**useful signal or signal) and an **undesired component**:

Undesired component

$$y(t) = s(t) + d(t) + n(t)$$

signal distorsion noise

DIGITAL COMUNICATION SYSTEM
Distorsions and Noise

Note: the distintion is conventional but conceptually important

Both distorsion and noise are undesidered

…but

Distorsion is directly related to the signal, it is the result of a transformation T[.] of the signal performed by the channel/system (i.e. no signal = no distorsion)

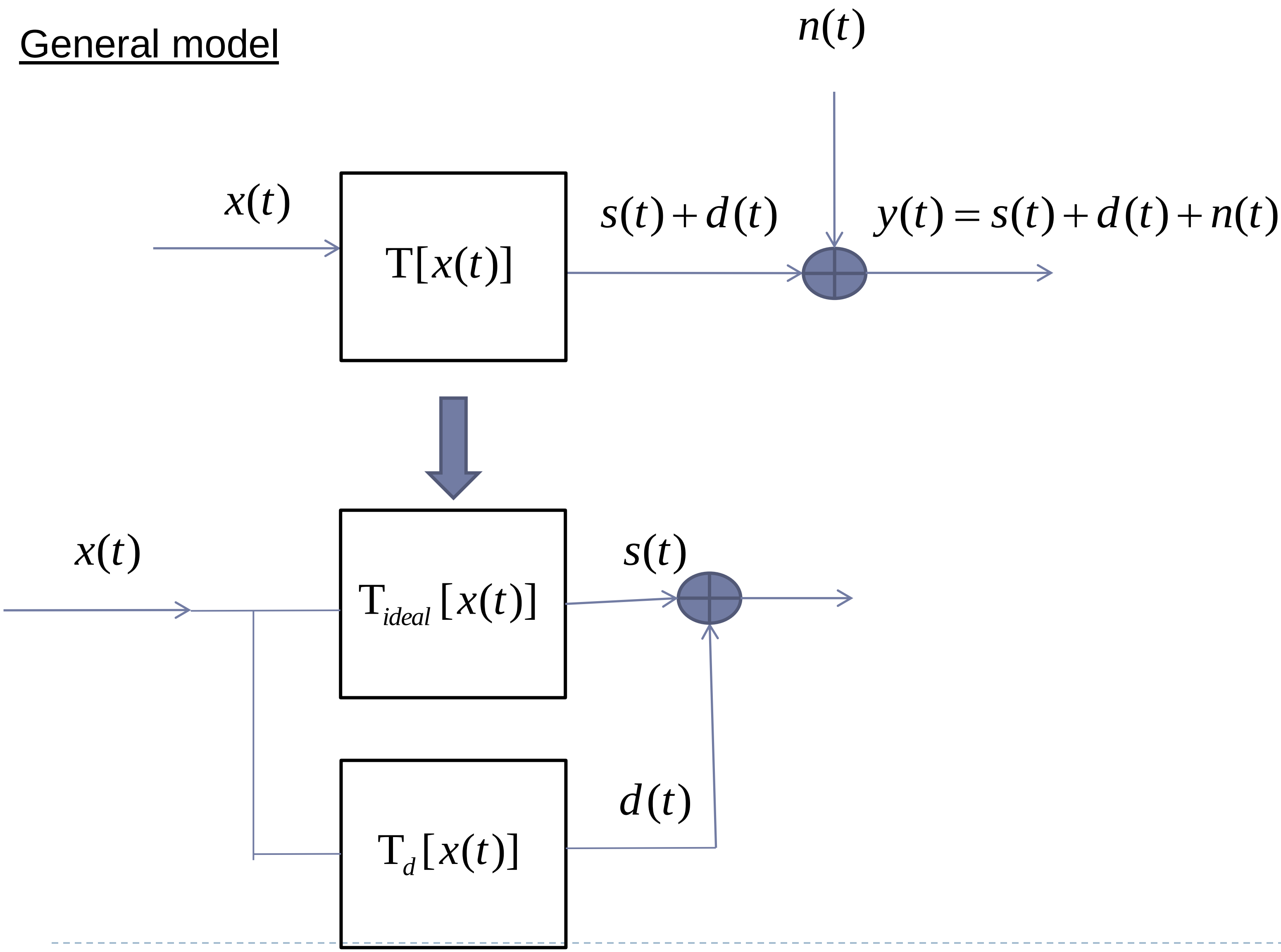
Noise is independent from the signal

Another difference is that

- the distorsion can be reduced (ideally to zero);
- the noise can be reduce only up to a certain limits
  (fundamental limits of information theory)

DIGITAL COMUNICATION SYSTEM
Distorsions and Disturbance

General model



Distorsionless transmissions

A channel behaves like an **ideal transmission line** if the output signal has only:
some delay compared to the input;
A different amplitude than the input (just a scale change)

(basically, it has the same shape of the input)
We can describe the output of an ideal transmission line (distorsionless transmission) as:

$$s(t) = Kx(t - t_0)$$

where K and t_0 are constants.

Distorsionless transmissions

In the frequency domain, we can describe the output through its Fourier transform:

$$S(f) = H(f)X(f)$$

$$H(f) = Ke^{-j2\pi f t_0}$$

⇩

To achieve ideal distorsionless transmission, the overall system response must have a constant magnitude response and its phase shift must be linear with frequency.

In other words:

1) The channel must attenuate or amplify all frequency components equally
2) All the signals' components must arrive with identical time delay in order to add up COHERENTLY

Distorsionless transmissions

The time delay is related to the phase through:

$$t_0 = \frac{\theta(\text{radians})}{2\pi f\,(\text{radians/second})}$$

$$\Downarrow$$

Envelope delay:

$$\tau(f) = -\frac{1}{2\pi}\frac{d\theta(f)}{df}$$

$$\Downarrow$$

In a distortionless channel the envelope delay is constant

DIGITAL COMUNICATION SYSTEM
Channel

In practice a signal will be distorted in passing through the channel (or some parts of a system)
This means that the amplitude will not be just scaled and the phase will be not linear.

Equalization
operation performing phase and/or amplitude correction to correct this distorsion

Noise

Classification of noise according to the physical nature

External Interference	Crosstalk, multiple access interference
External sources of noise	Atmospheric noise Cosmic noise Artificial noise
Internal sources of noise	**Thermal noise** Shot noise Flicker noise

DIGITAL COMUNICATION SYSTEM

Noise

Classification of noise according to the physical nature

External Interference

Undesired signals within the bandwidth of the desired signal, which are generated by other communication systems, such as:

- Interference generated from the overlapping in the frequency domain of radio broadcasting signals
- Crosstalk in telephone systems: signals destinated to other users
- Multiple Access Interference: kind of crosstalk but in the wireless communication systems (the wireless medium must be shared among different users)

It is possible to reduce it through normative and technical solutions

Noise

Classification of noise according to the physical nature

External sources of noise

Atmospheric noise

Example: a storm nearby – the electromagnetic signals generated by a thunderstorms might make the signal not distinguishable for some time.

Cosmic noise

Important source of electromagnetic radiations that are received on the Earth are: the Sun, milky way and galaxies

On the other hand, a satellite receiver receives the electromagnetic radiations emitted by the Earth

Noise

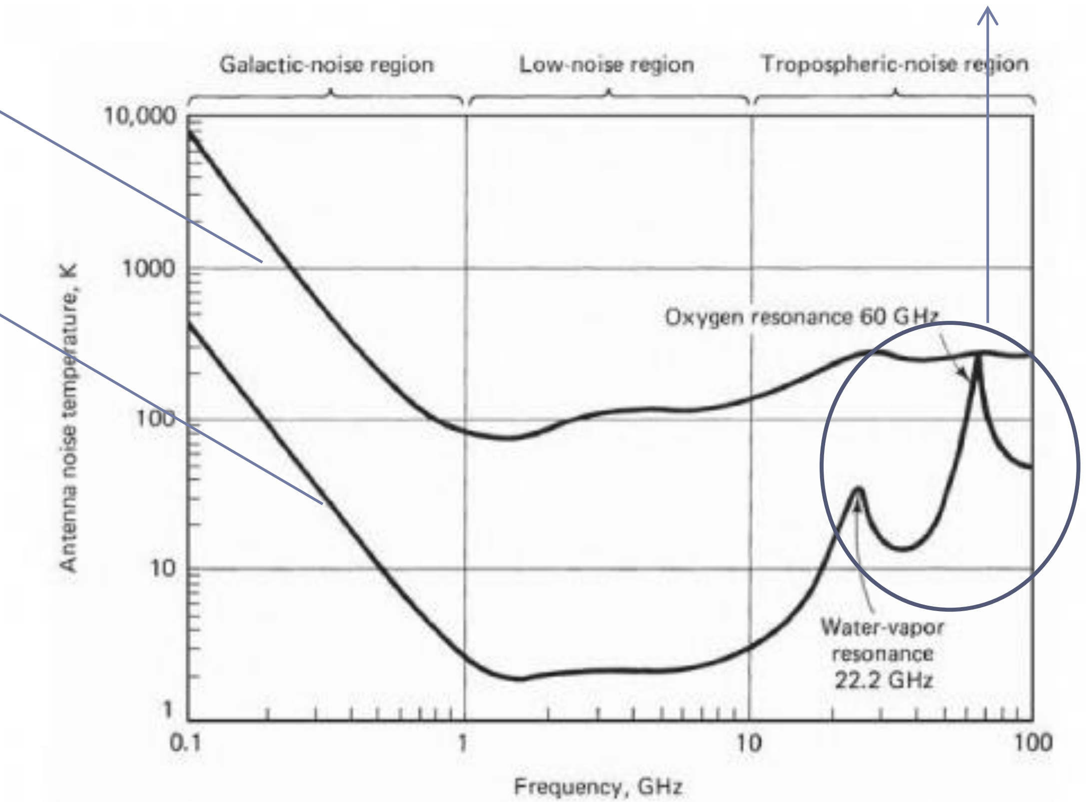
Classification of noise according to the physical nature

External sources of noise

Antenna pointing just above the horizont

Antenna pointing the azimuth

Any absorption generates thermal noise



Noise

Classification of noise according to the physical nature

External sources of noise

Artificial noise

It is produced by electronic devices such as engines, microwave oven, etc. It is particularly important in highly dense populated areas and industrial discricts. Many of this type of noise has a contribution that decreases as the frequency increases.

It is possible to reduce it through normative and technical solutions

Particularly important it is the noise produced by the electric alternate current of the power grid. It is a signal at 50Hz, so it can be deleted by placing a notch at 50Hz!

Noise

Classification of noise according to the physical nature

Internal sources of noise

Thermal noise: from thermal agitation of electrons
Shot noise: from granural structure of the electric current
Flicker: from the structural imperfections of components and circuits

These noises are more important as they cannot be reduced as the previous sources of noise and they represents the fundamental limit on the performance of any communication systems

Noise

Classification of noise according to the physical nature

Thermal noise

It is the result of the thermal agitation of the free electrons in the wires.
Due to this disorganized movement,
a voltage v(t) will appear at both ends of the wire, which can be modeled as a **random process**.
v(t) has zero mean as the movement is equiprobable in both directions (otherwise there would be an accumulation of charges).
If we short circuit the ends of the wire, a current $i(t)$ can be seen, also with zero mean, related to the voltage $v(t)$ as:

$$v(t) = R\, i(t)$$

The spectral density of the two random process $v(t)$ and $i(t)$ is:

$$W_v(f) = 2kTR\gamma(f)$$

$$W_i(f) = 2kTG\gamma(f)$$

Noise

Classification of noise according to the physical nature

Thermal noise

The spectral density of the two random process v(t) and i(t) is:

$$W_v(f) = 2kTR\gamma(f)$$

$$W_i(f) = 2kTG\gamma(f)$$

$$\gamma(f) = \frac{hf}{kT}\left(e^{-\frac{hf}{kT}} - 1\right)^{-1}$$

where:
$G=1/R$ is the conduttance, T the absolute temperature of the wire, k is the Boltzmann constant (= $1{,}38 \cdot 10^{-23}\ J/K$) e h is the Planck constant (=$6{,}6262 \cdot 10^{-34}\ Js$)

$\gamma(f)$ decreases as the frequency increases and it is equal to 1 when:

$$f << kT/h = 2{,}1 \cdot 10^{10}\,T \quad Hz$$

at the typical temperature $T = 300K$ ⇒ when $f << 6 \cdot 10^{12} \quad Hz$

⇓

Noise

Classification of noise according to the physical nature

Thermal noise

Typically it is reasonable to assume that:

$$W_v(f) = 2kTR$$

$$W_i(f) = 2kTG$$

Usually the thermal noise is modeled as a **WHITE** noise as the power spectral density is uniform with the frequency

Noise

Classification of noise according to the physical nature

Flicker noise

Also known as excess noise, it is present in most of the electronic devices at low frequencies. It is usually negligible already at frequency of the order of few KHz and it is strictly related to the technology.

Power spectral density $$W_{I_f}(f) = k\frac{I^2}{f}$$

Noise

Classification of noise according to the physical nature

shot noise

In electronics shot noise originates from the discrete nature of electric charge. Shot noise also occurs in photon counting in optical devices, where shot noise is associated with the particle nature of light.

Power spectrail density $W_{I_S}(f) = eI\alpha(f)$

$$e = \text{electron charge} = 1{,}6 \cdot 10^{-19}\, C$$

$$I = \text{mean current}$$

$$\alpha(\mathrm{f}) = \left| \frac{I_0(f)}{I_0(0)} \right|^2$$

$$\alpha(\mathrm{f}) \approx 1 \quad \text{for} \;\; \mathrm{f} << 1/\tau_e$$

$$\tau_e = 10^{-10}\, s$$

→ Below gigahertz the shot noise can be considered white

Noise

Statistical classification of noise

Many sources of noise can be classified as:

1) Impulsive noise
2) Regular noise

Strictly speaking, all the noises are impulsive, but in some cases the overall behaviour is characterized by some type of regularity that allows to simplify the analysis.

The generic model of an impulsive noise is:

$$n(t) = \sum_{n=-\infty}^{+\infty} g_n s(t - t_n; \alpha_n)$$

The three sequences $\{t_n\}, \{g_n\}, \{\alpha_n\}$ are **random** and the statistical characterization of noise requires to consider the joint statistical distribution of the three sequences.

Often, they can be considered independent, so we only need to consider the single statistics of the three sequences.

Noise

Statistical classification of noise

When $n(t)$ can be modeled as a Gaussian random process?

According to the Central Limiti Theorem, n(t) is Gaussian if the number of pulses on the average present in one time instant is high.

Let us define this average number of pulses (density) as:

$$\delta = \bar{n}\bar{T}$$

where:

$\bar{n}$ is the average number of pulses per second

$\bar{T}$ the average duration of the pulses

Examples: $\bar{n} = 10^3 \; \bar{T} = 1s \quad \delta = 10^3$ ⇒ **Gaussian is a good approximation**

$\bar{n} = 10^3 \quad \bar{T} = 10^{-4}s \quad \delta = 0.1$ ⇒ Central Limiti Theorem not applicable

Noise

Statistical classification of noise

Note: the Central Limit Theorem is applicable if the amplitudes of the pulses is of the same order of magnitude (equally distributed random variables)

If we isolated pulses with very high amplitude, overlapped to much more dense pulses with very low amplidute, the noise is impulsive.

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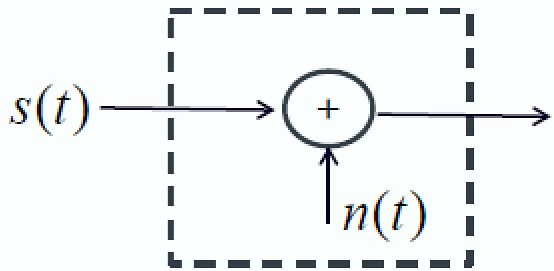
Mathematical models

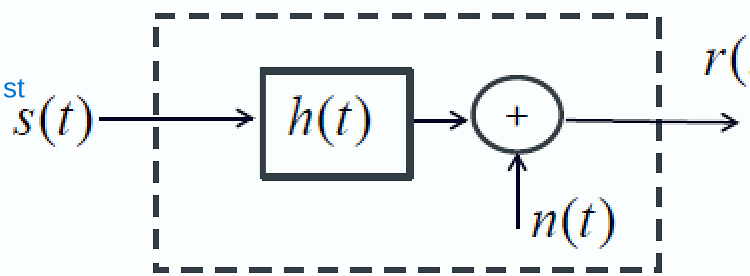
- The additive noise channel



$$r(t) = s(t) + n(t)$$

- Linear filter channel

gaussein rp st



$$r(t) = s(t) * h(t) + n(t)$$

$$= \int_0^{\infty} h(\tau) s(t-\tau) d\tau + n(t)$$

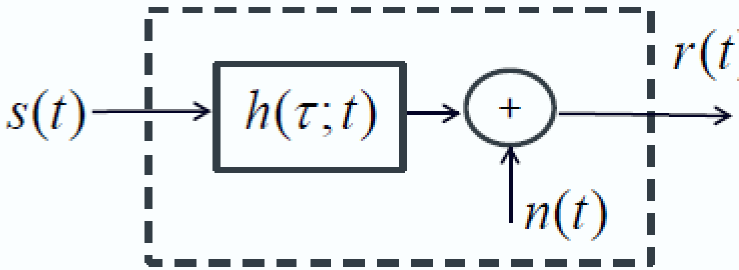
impuse reponse ht

yt in gaussian

DIGITAL COMUNICATION SYSTEM

Mathematical models

- Linear time-variant filter channel



$$r(t) = s(t) * h(\tau;t) + n(t)$$
$$= \int_{-\infty}^{\infty} h(\tau;t)s(t-\tau)d\tau + n(t)$$

- Consider a multi-path signal propagation

$$h(\tau;t) = \sum_{k=1}^{L} a_k(t)\delta(t-\tau_k)$$