Digital communications and High-Rate transmission

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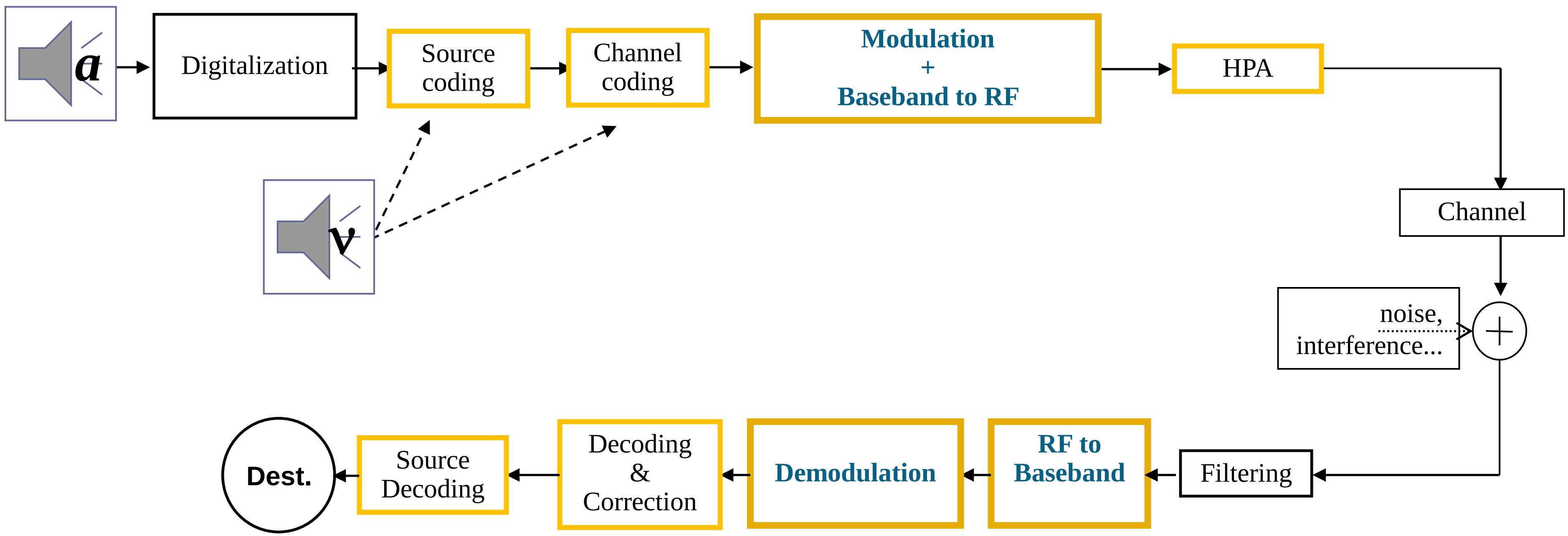
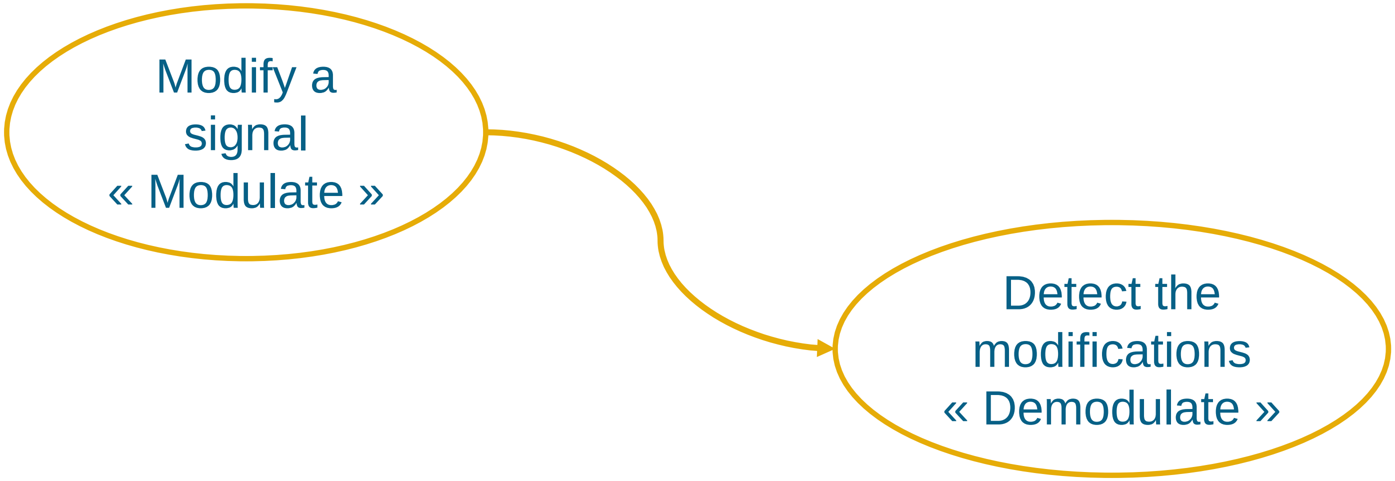
General diagram of communication chain



Introduction

- Analog modulations
- Digital modulations

Modulations – principle

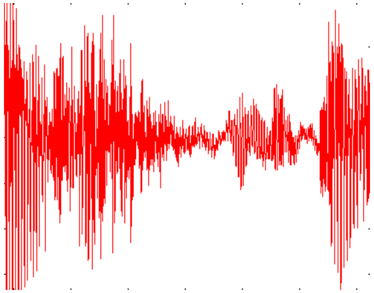


- Any change (reliably detectable) in signal* characteristics can carry information.
- Characteristics:
  - Amplitude
  - Phase
  - Frequency

(*): A pure carrier is generated at the transmitter.

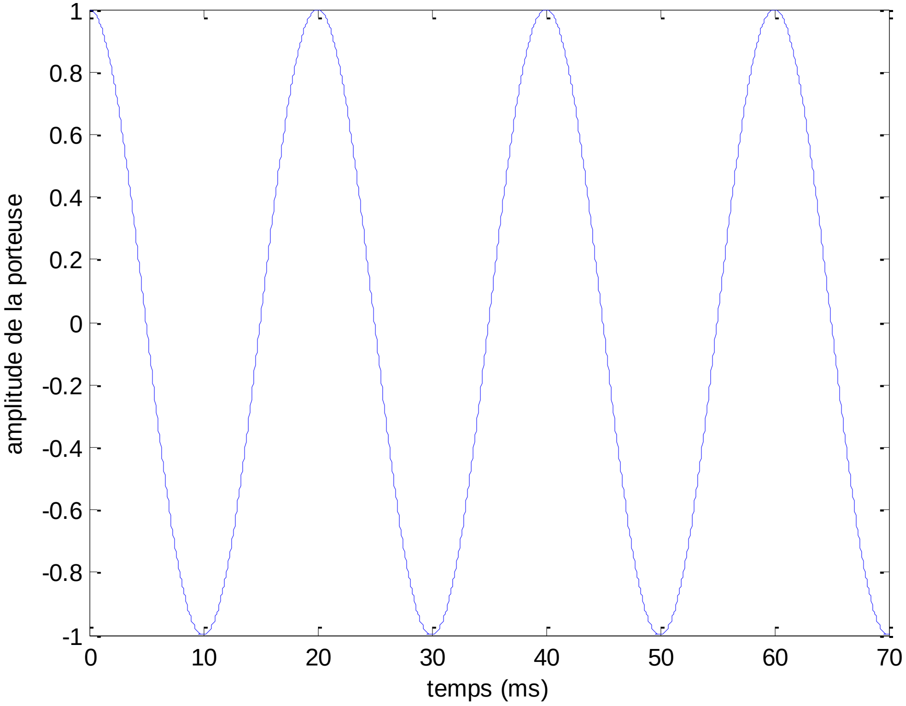
Analog Modulations – principle

The carrier $cos(2\pi F_p t)$ is modulated by the analog signal being transmitted $u(t)$ 



period : 20 ms

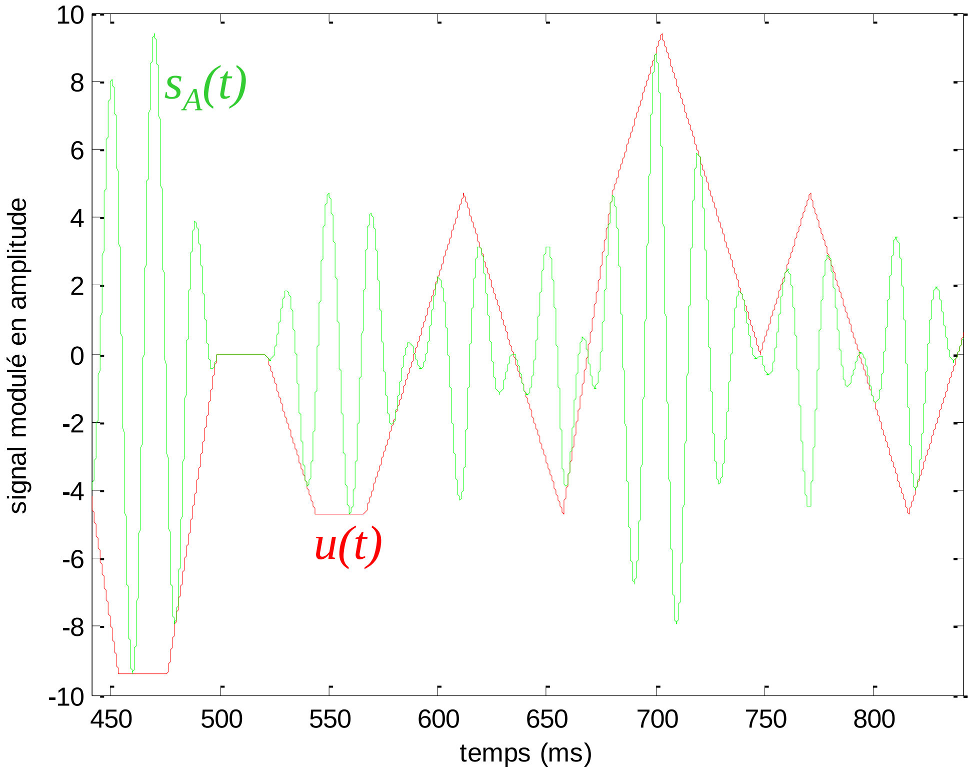
$F_p = 50\ Hz$



Analog Modulations– Amplitude

- The amplitude of a high-frequency carrier signal is varied in proportion to the instantaneous amplitude of the modulating message signal:

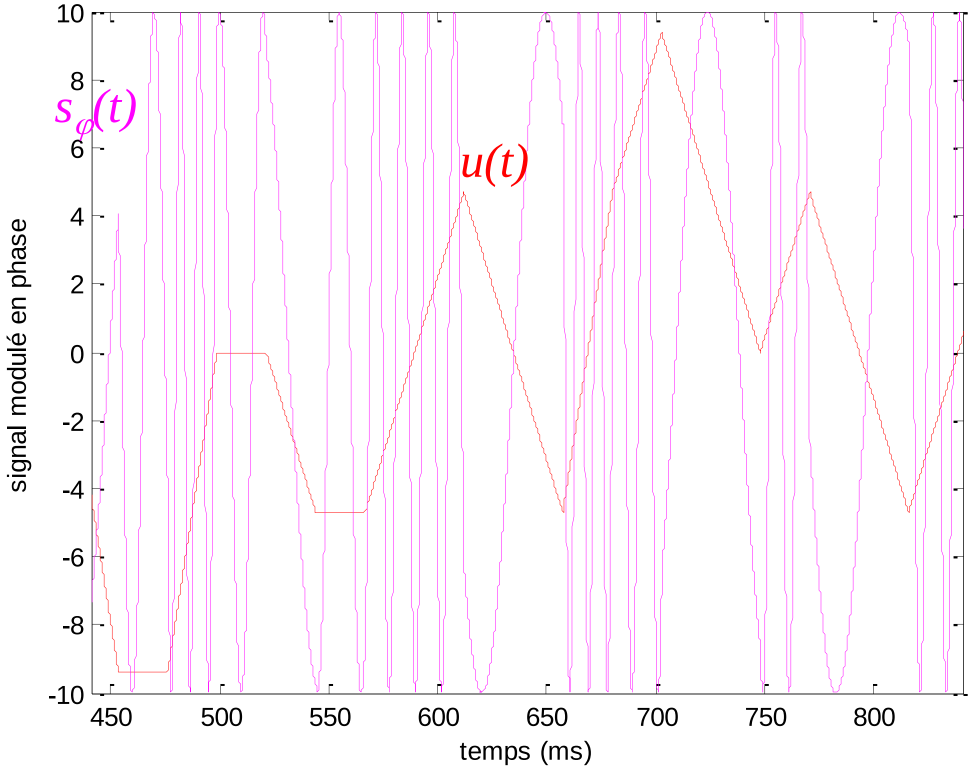
$$s_A(t) = u(t) \times cos(2\pi F_p t)$$



Analog Modulations – Phase

- Phase modulation (PM) changes only the phase of the signal.:

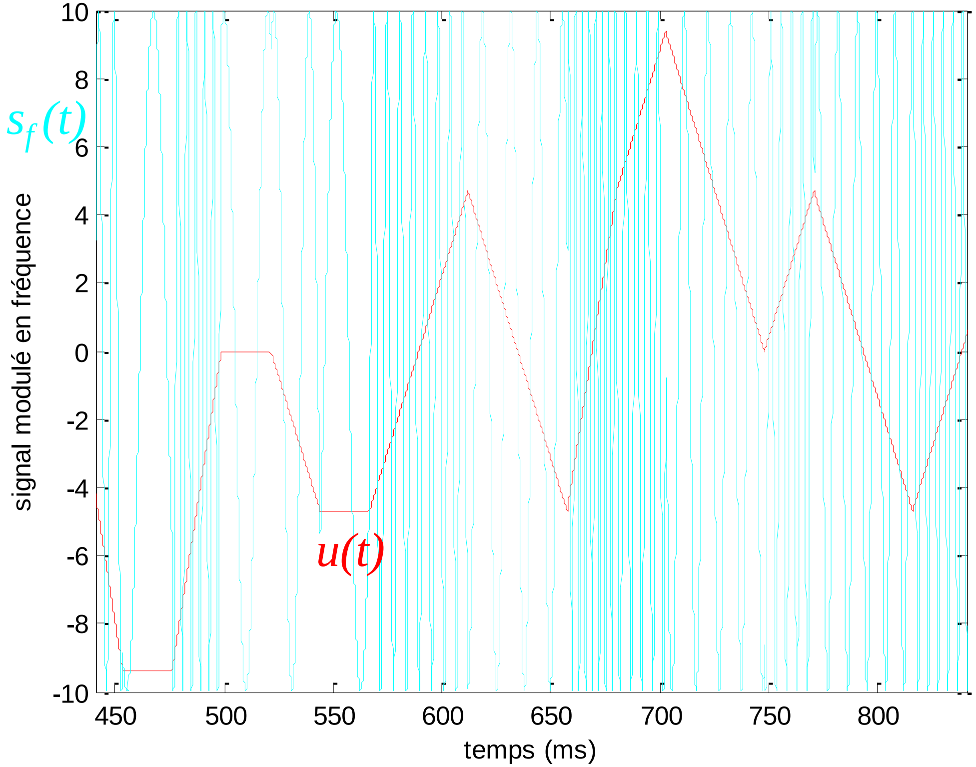
$$s_\varphi(t) = cos(2\pi F_p t + u(t))$$



Analog Modulations – Frequency

- The amplitude of the modulating carrier is kept constant while its frequency is varied by the modulating message signal:

$$s_f(t) = cos(2\pi(F_p + u(t)) \times t)$$



Digital modulations – principle 1/

- Rôle :

  Coupling the information data to « **modulated signal»**

  physical representation that can be transmitted

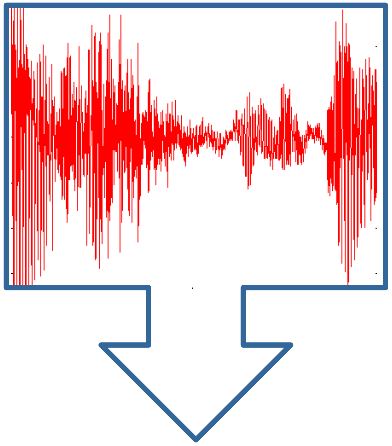
  over the channel : ***Coupling the message to the channel***.

- Exemples :
  - **filtering** the modulated signal to limit the signal bandwidth (causing ISI) to the channel bandwidth
  - Shift the baseband signal spectrum to the desired carrier frequency

Digital modulations – principe 2/

- Provide an efficient representation of the information data by source coding :
  - Signal analysis
  - Compression: reduce the redundancy

- Channel coding: encodes the data in such a way as to minimize the effects of noise and interference (channel):
  - Tx side : adds extra bits to the input data
    - Repetition code
    - Block codes, convolutional codes, turbo-codes
  - Rx side :error detection and correction



1 0 1 0 0 1 1 1…

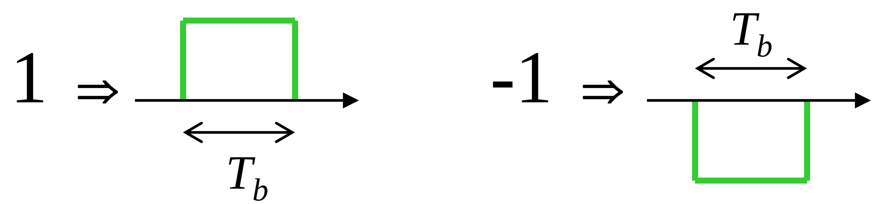
<u>example</u> : voice signals in mobile networks

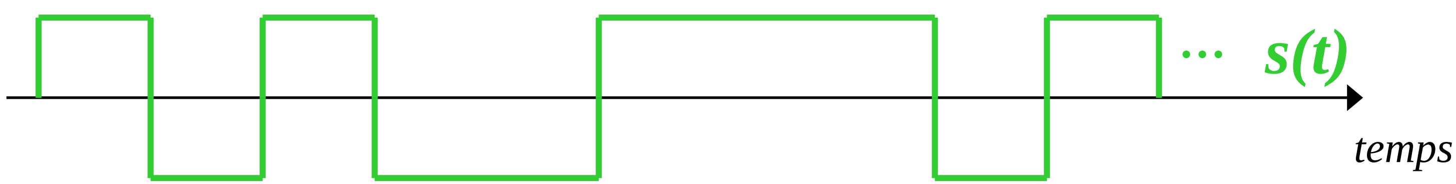
Source coding : bit rate = 12,2 kbit/s

Channel coding : bit rate = 22,8 kbit/s

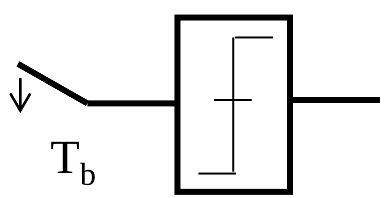
Digital modulations – pulse shaping

- Mapping and pulse shaping
  - convert the binary stream 1/0 into a symbol stream +1/-1
  - Every bit is transmitted during T_b
  - Signal construction : ***s(t)***



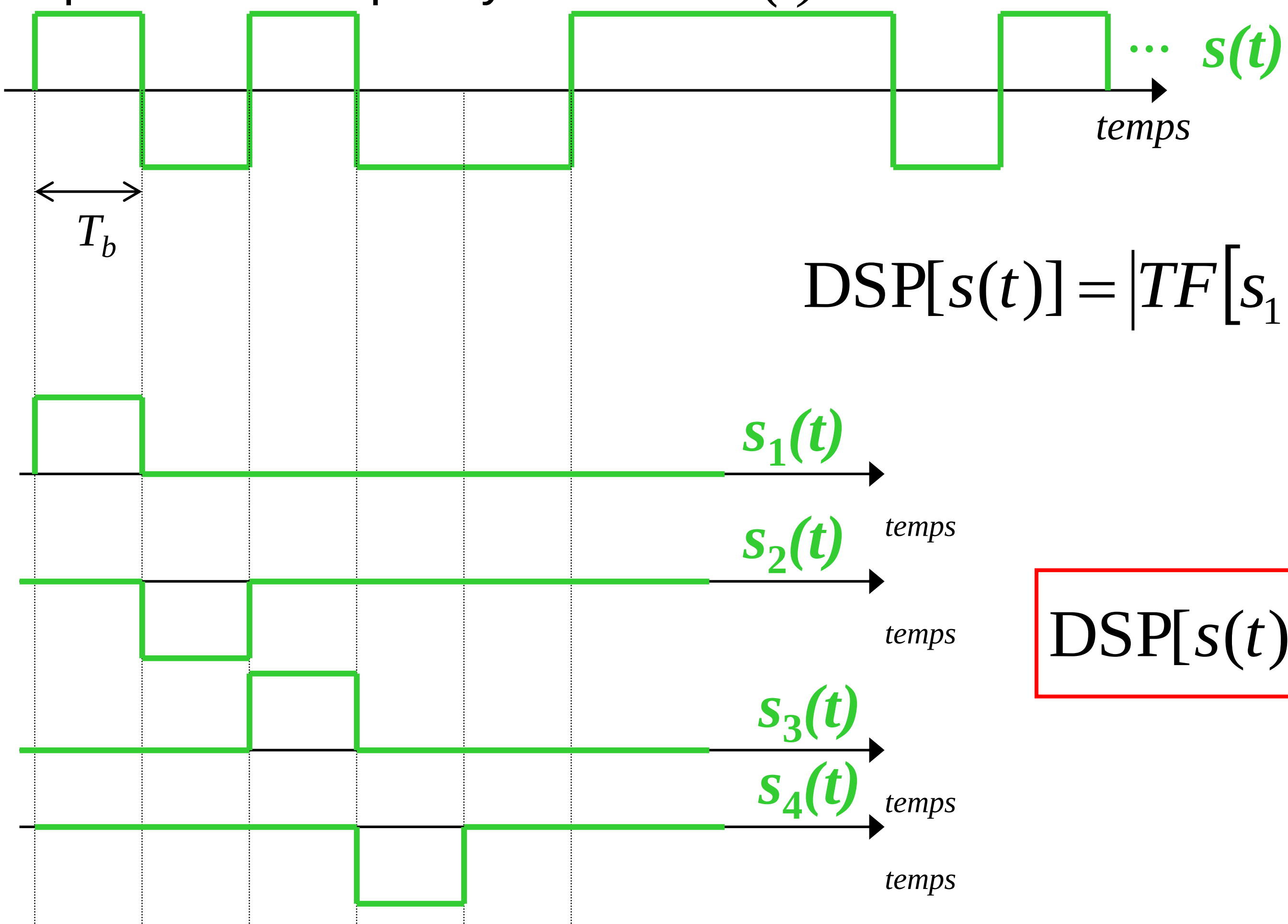


  - Demodulation: threshold detection



Digital modulations– Spectrum 1/

Spectrum occupancy : PSD de *s(t)*



$$\mathrm{DSP}[s(t)] = \left|TF\left[s_1(t) + s_2(t) + \ldots\right]\right|^2$$

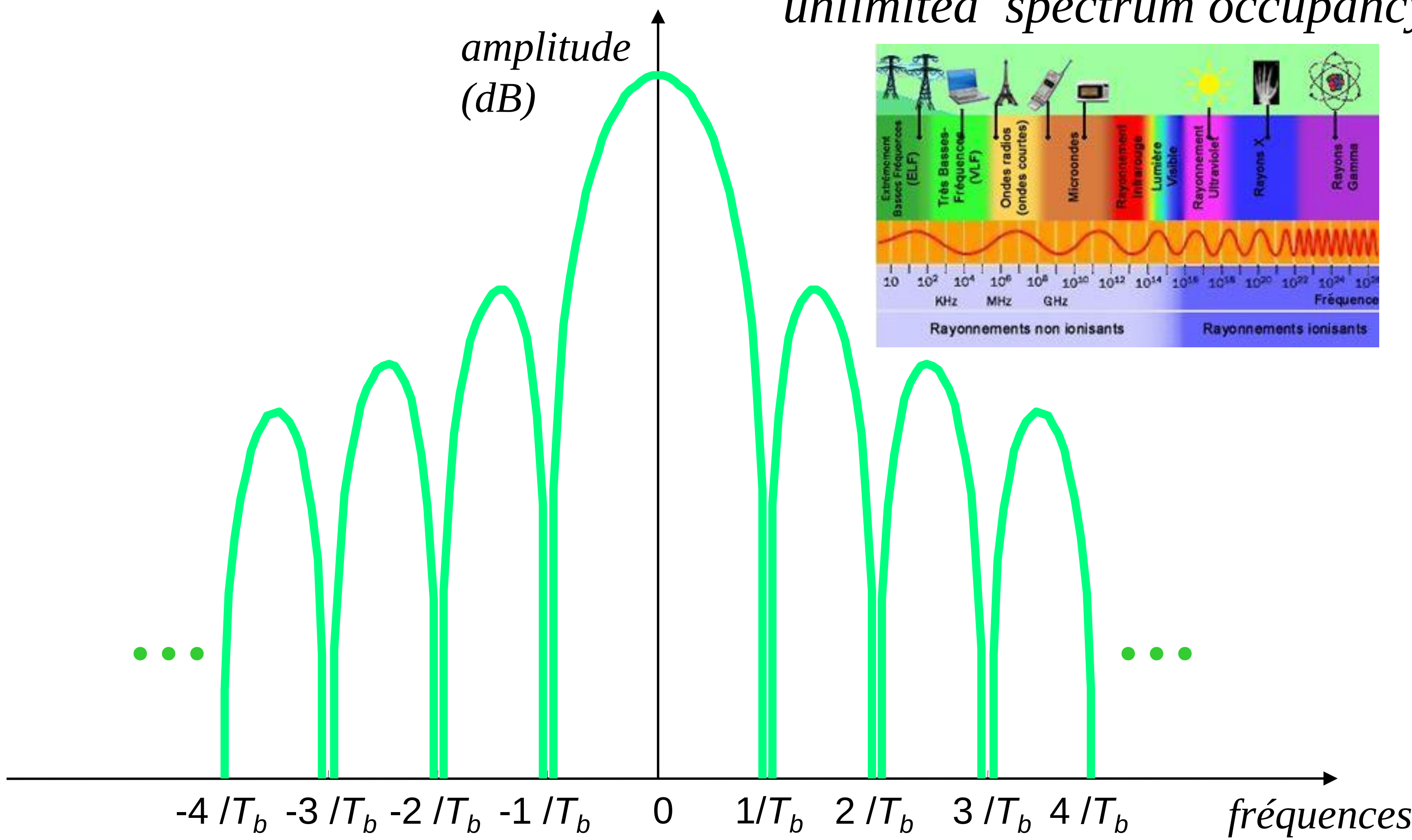
$$\boxed{\mathrm{DSP}[s(t)] = \left|TF\left[s_1(t)\right]\right|^2}$$

$$\propto \left|\ \mathrm{sinc}\left(\pi\ f\ T_b\right)\right|^2$$

Digital modulations – spectrum 2/

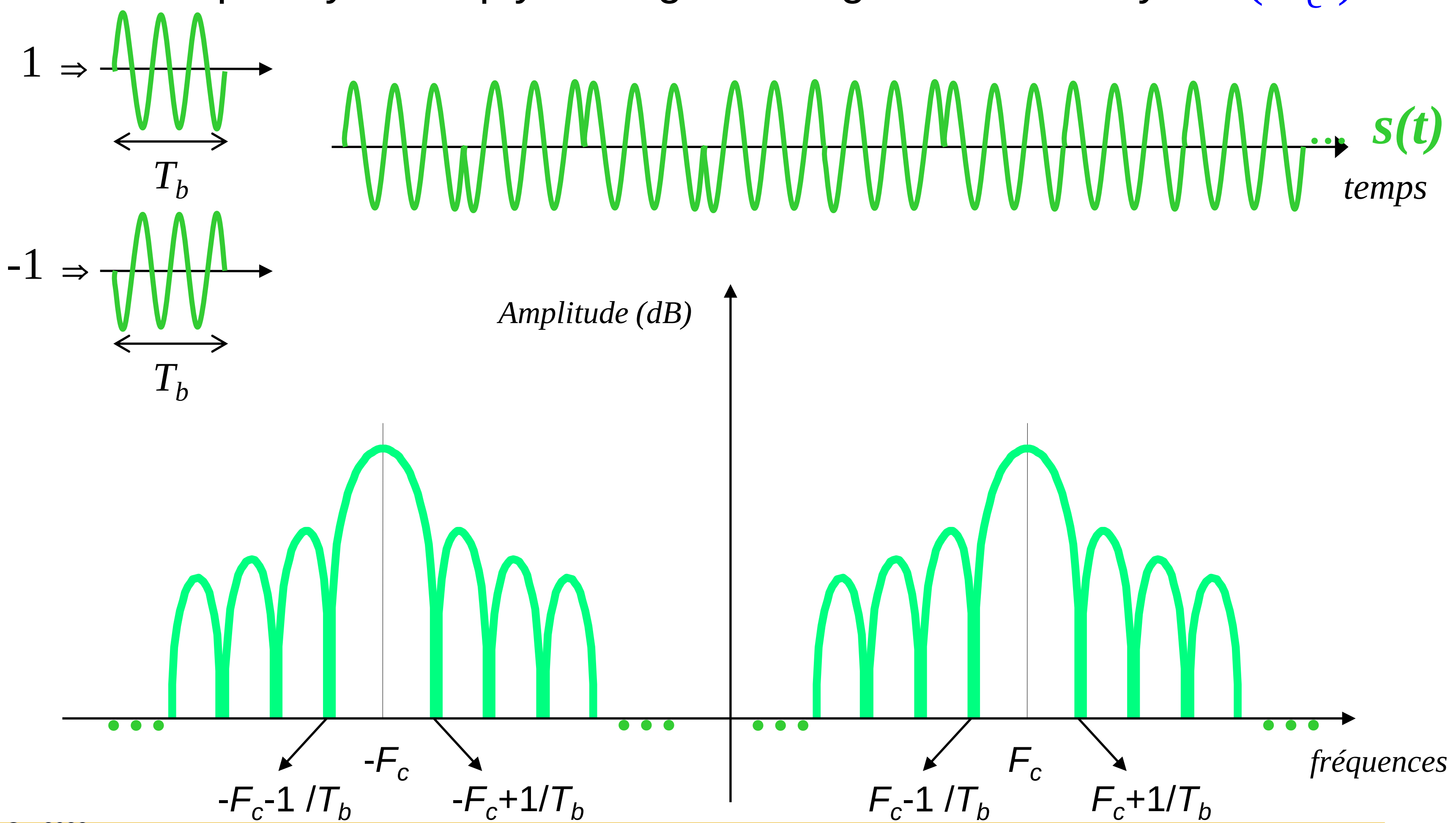
Rectangular pulse shape:

unlimited spectrum occupancy



Digital modulations – RF signal

- Carrier frequency : multiply the signal being transmitted by $\cos(\omega_c t)$



Digital modulations– reception

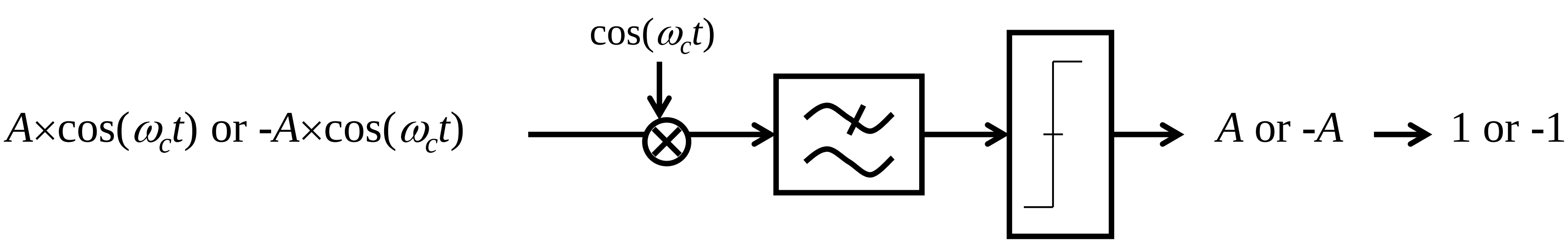
- At Tx, the modulation :
  - $1 \Rightarrow A\times\cos(\omega_c t)$ during T_b
  - $-1 \Rightarrow -A\times\cos(\omega_c t)$ during T_b

- At Rx, we get :

  $A\times\cos(\omega_p t)$ or $-A\times\cos(\omega_p t)$ during T_b

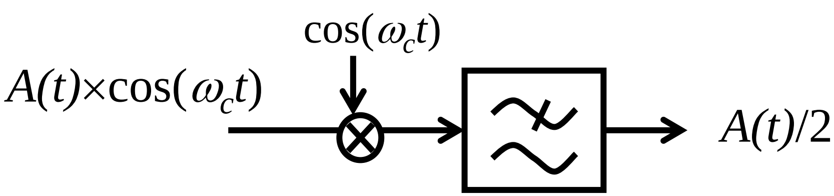
$\Rightarrow$ Demodulation of the received signal: every T_b seconds

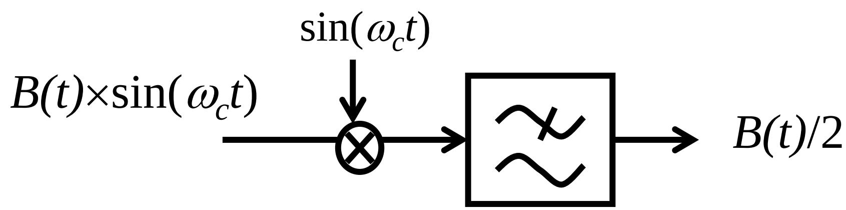
Multiply by $\cos(\omega_c t) \Rightarrow$ Low-pass filter $\Rightarrow$ threshold decision :



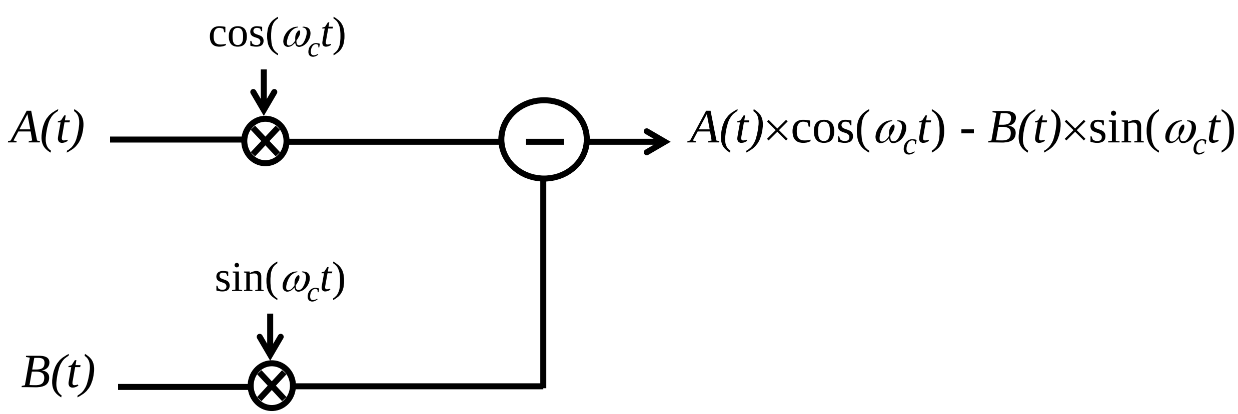
Digital modulations– I/Q formats 1/

- Generalization : **In-phase** & **Quadrature** components



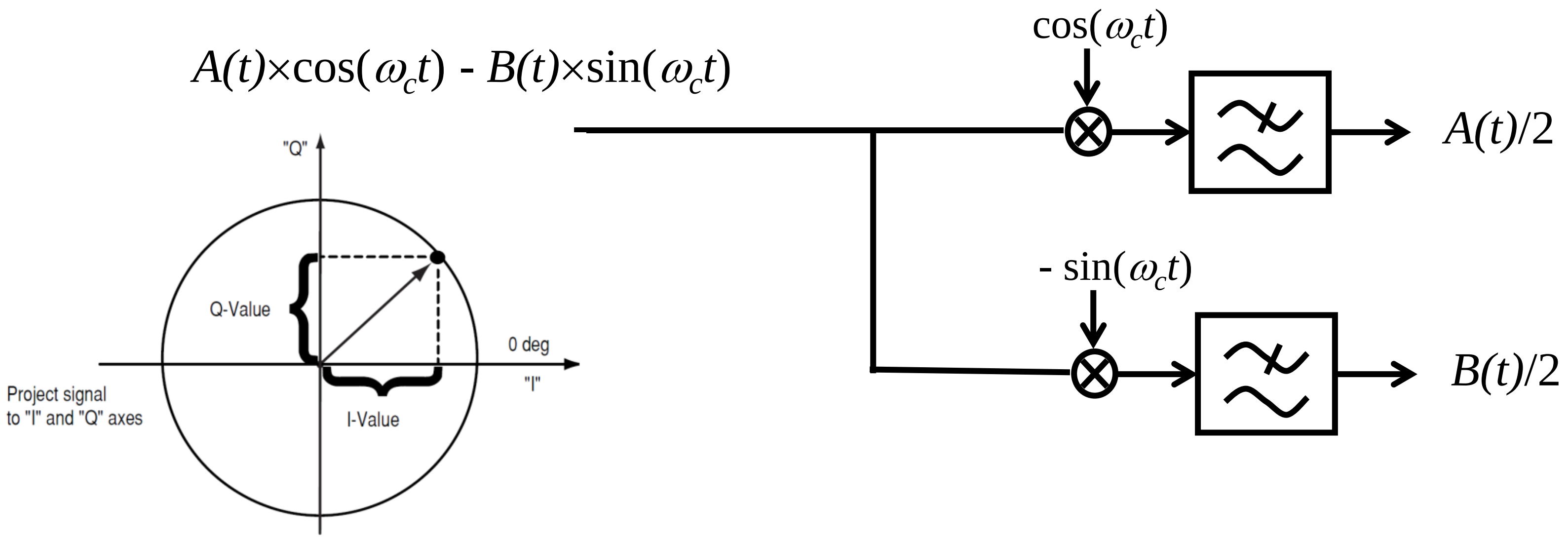


At Tx side :



Digital modulations– I/Q formats 2/

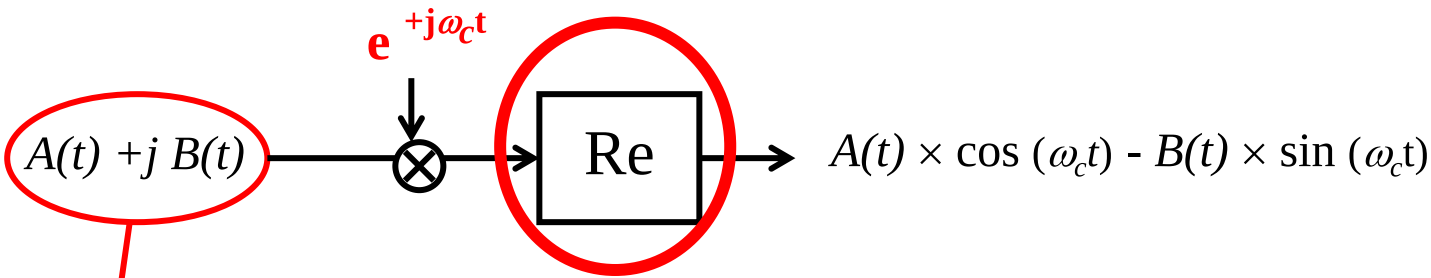
At Rx side :



- SIN and COS are orthogonal $\Rightarrow$ two independent signals $A(t)$ et $B(t)$ can simultaneously be sent on I and Q channels and received with simple circuits.
  - $A(t)$: In-phase channel
  - $B(t)$: Quadrature channel

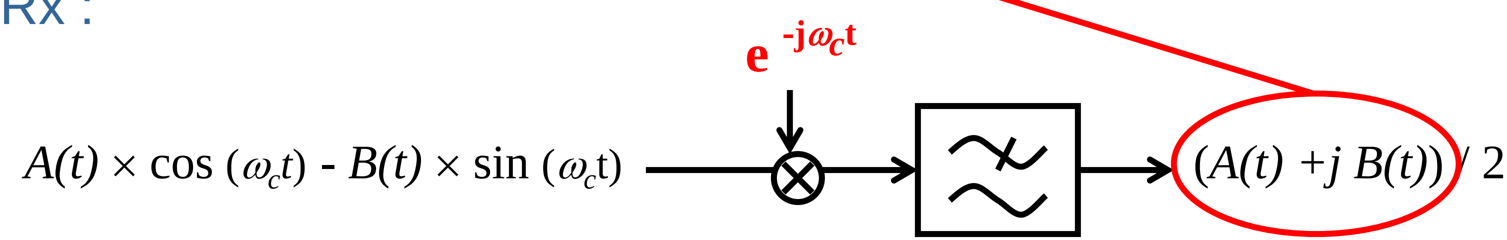
Digital modulations – envelope ℂ

- At Tx :

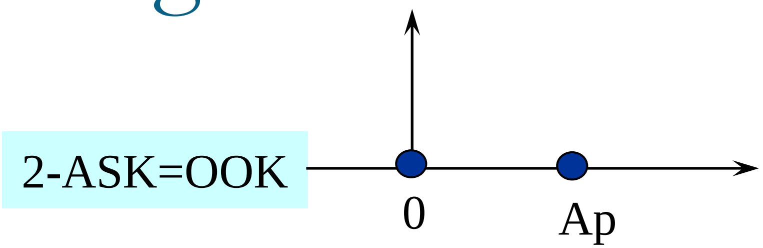


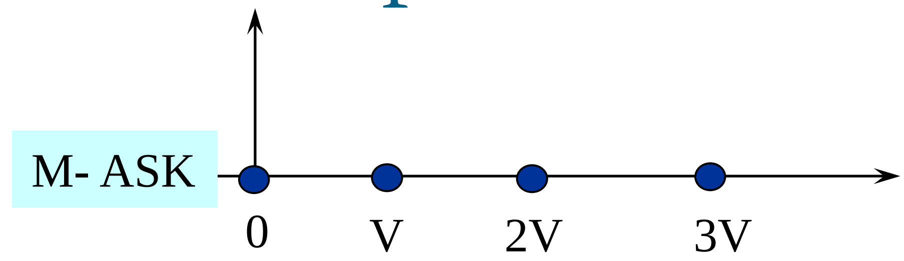
«complex envelope » : mathematical tool

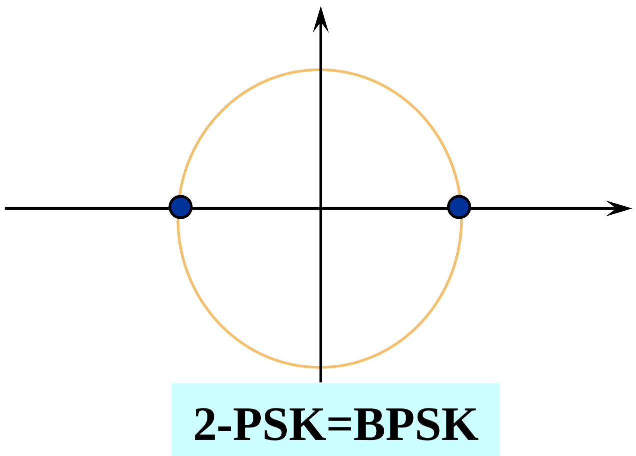
- At Rx :

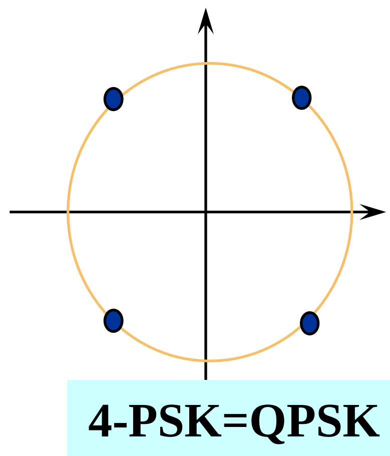


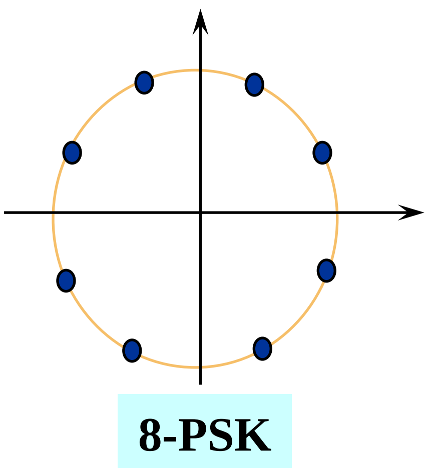
Digital modulations – Examples







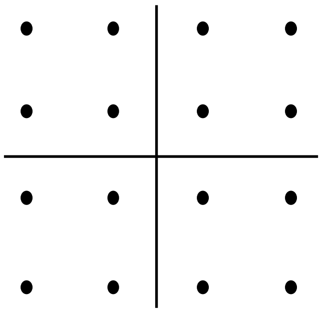




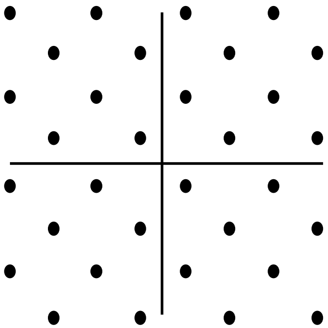
M: possible symbols

$$\Rightarrow \log_2 \boldsymbol{M} \;\; [\boldsymbol{bits\ per\ symbol}]$$

Digital modulations – Examples



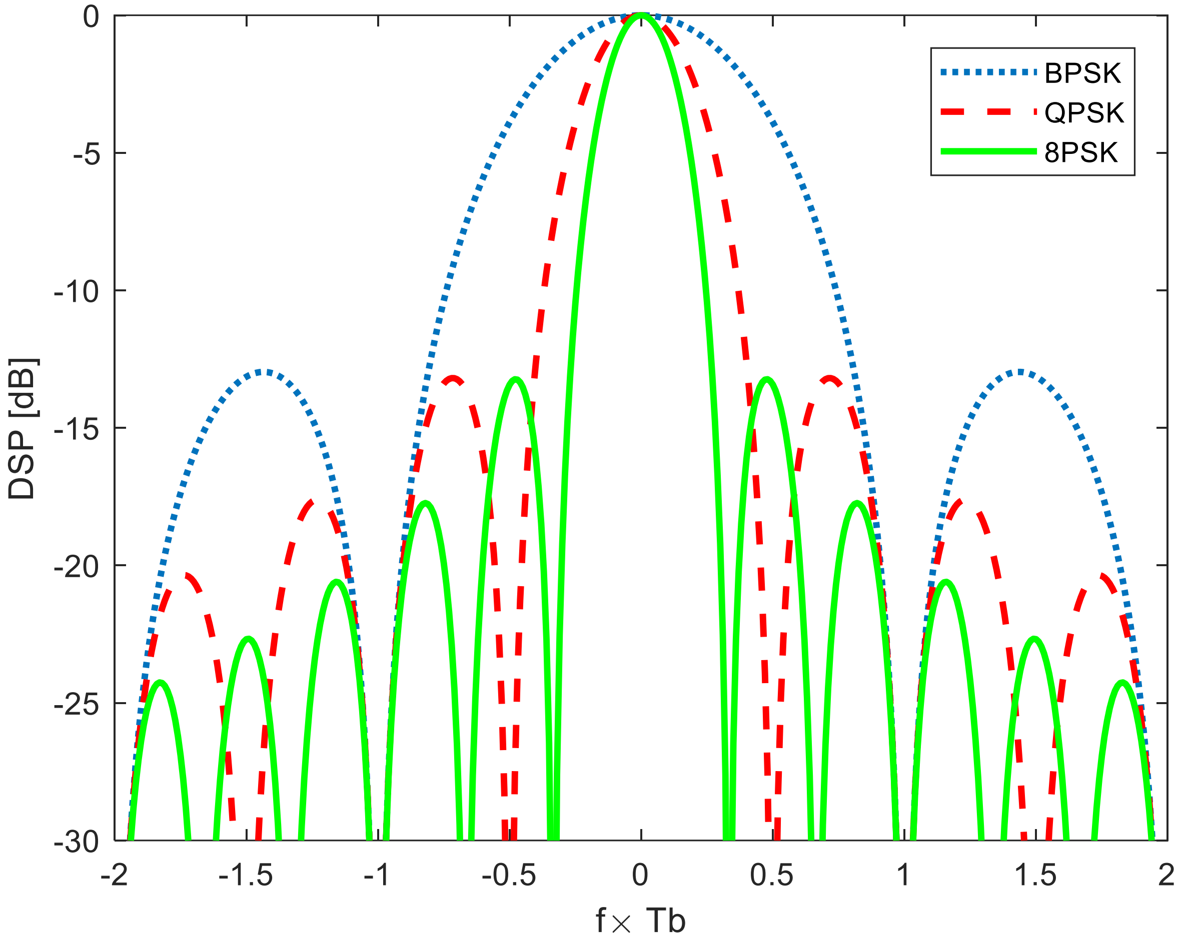
16-QAM



32-QAM

$$\boxed{\textbf{bit rate} = \textbf{symbol rate} \times \log_2 M}$$

Digital modulations – PSD



Same bit rate ⇒ narrow occupied bandwidth

Digital modulations– filtering

- Any fast transition in a signal, whether it be amplitude, phase, or frequency $\Rightarrow$ wide occupied bandwidth.
- Filtering serves to smooth these transitions $\Rightarrow$ narrow bandwidth.
- On the Rx, reduced bandwidth improves sensitivity because more noise and interference are rejected.
- **ISI problem:** The symbols blur together and each symbol affects those around it. This is determined by the impulse response of the filter.

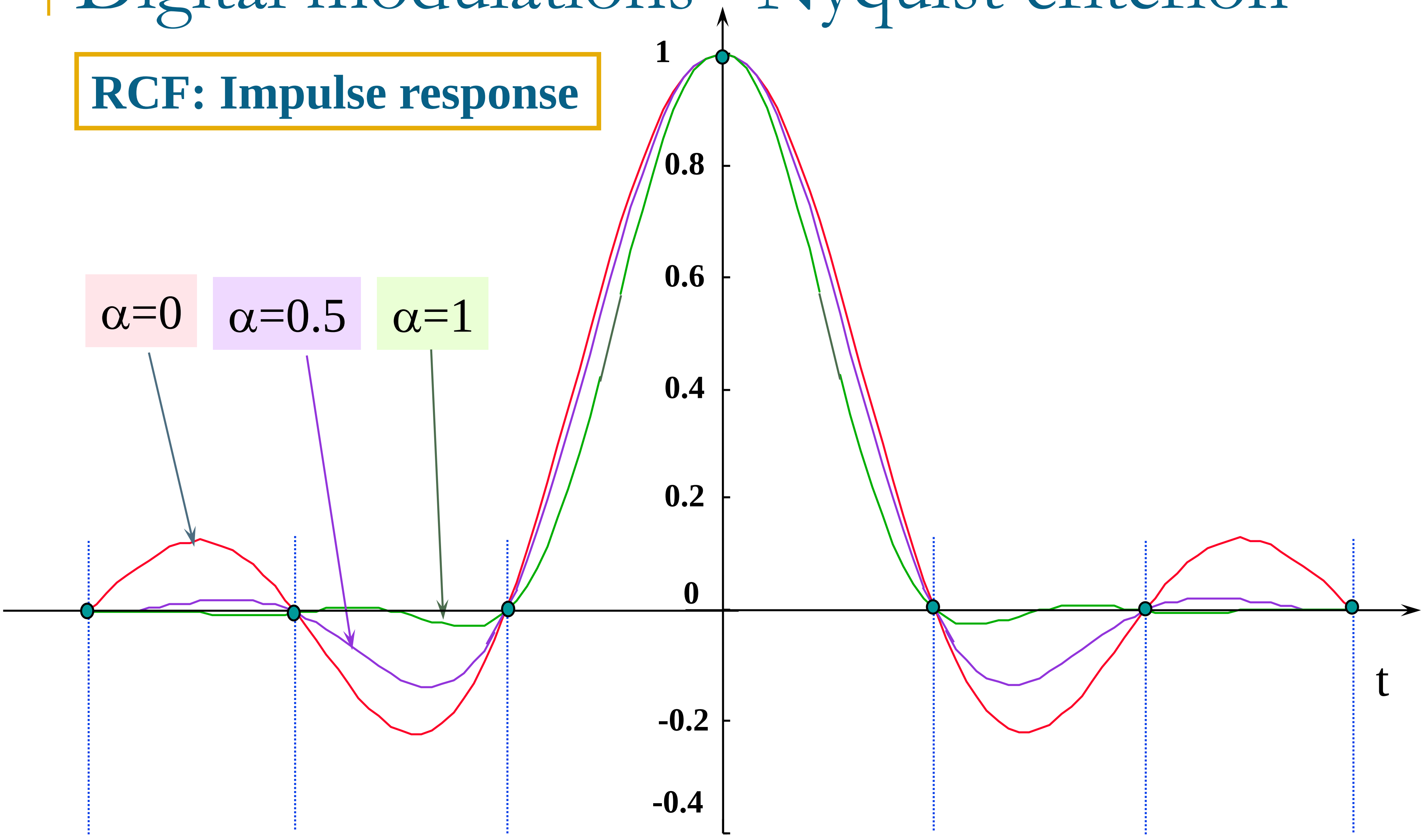
Digital modulations– Nyquist criterion

- **Nyquist or raised cosine filter:** The time response of the filter goes through zero with a period that exactly corresponds to the symbol spacing.
- Adjacent symbols do not interfere with each other at the symbol decision times*.
- Root Nyquist filters: the filter is usually split: half being in **Tx** and half in **Rx.**

(*) ISI does exist at all time except at the symbol times

Digital modulations– Nyquist criterion

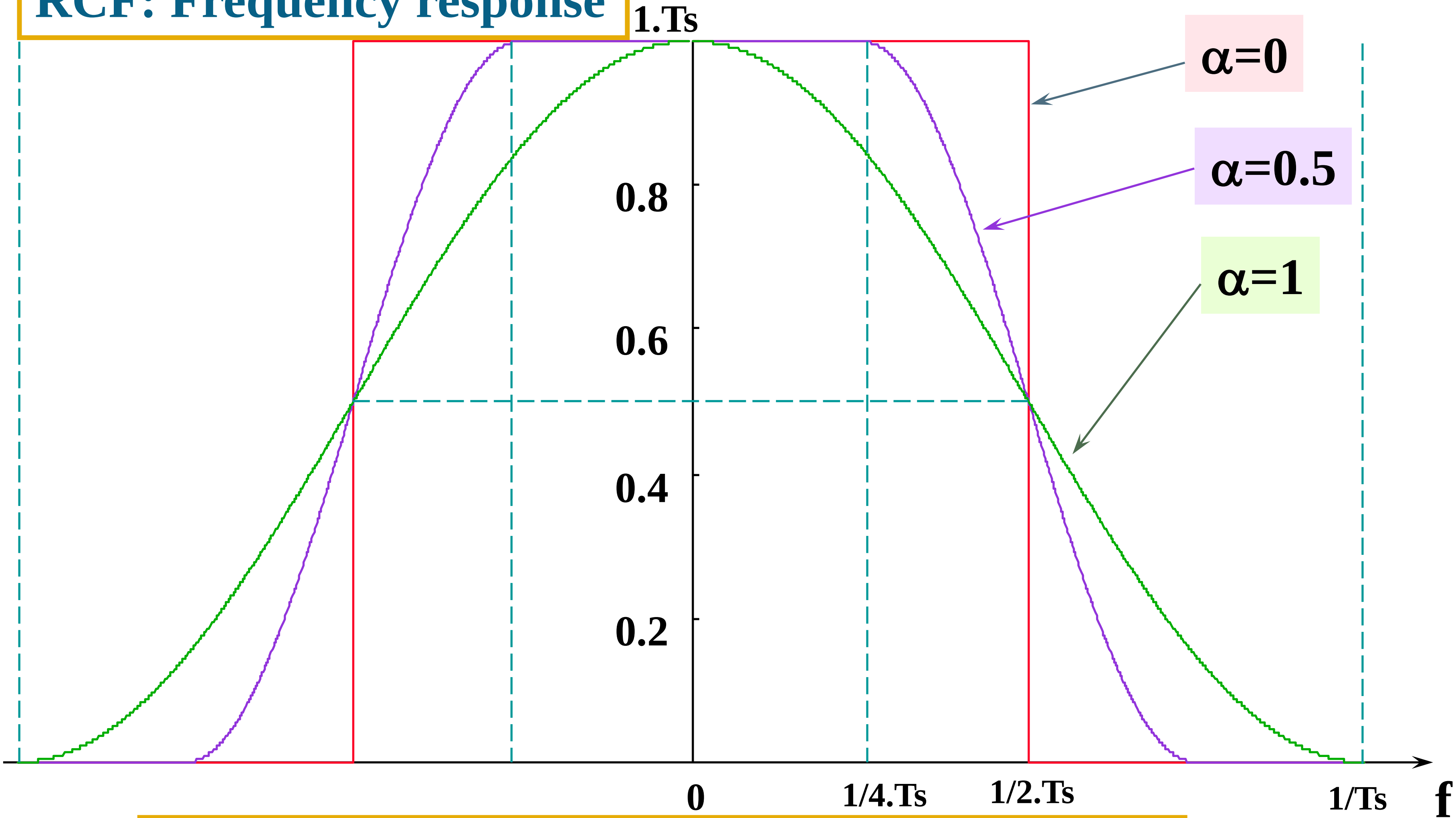
RCF: Impulse response



(*) ISI does exist at all time except at the symbol times

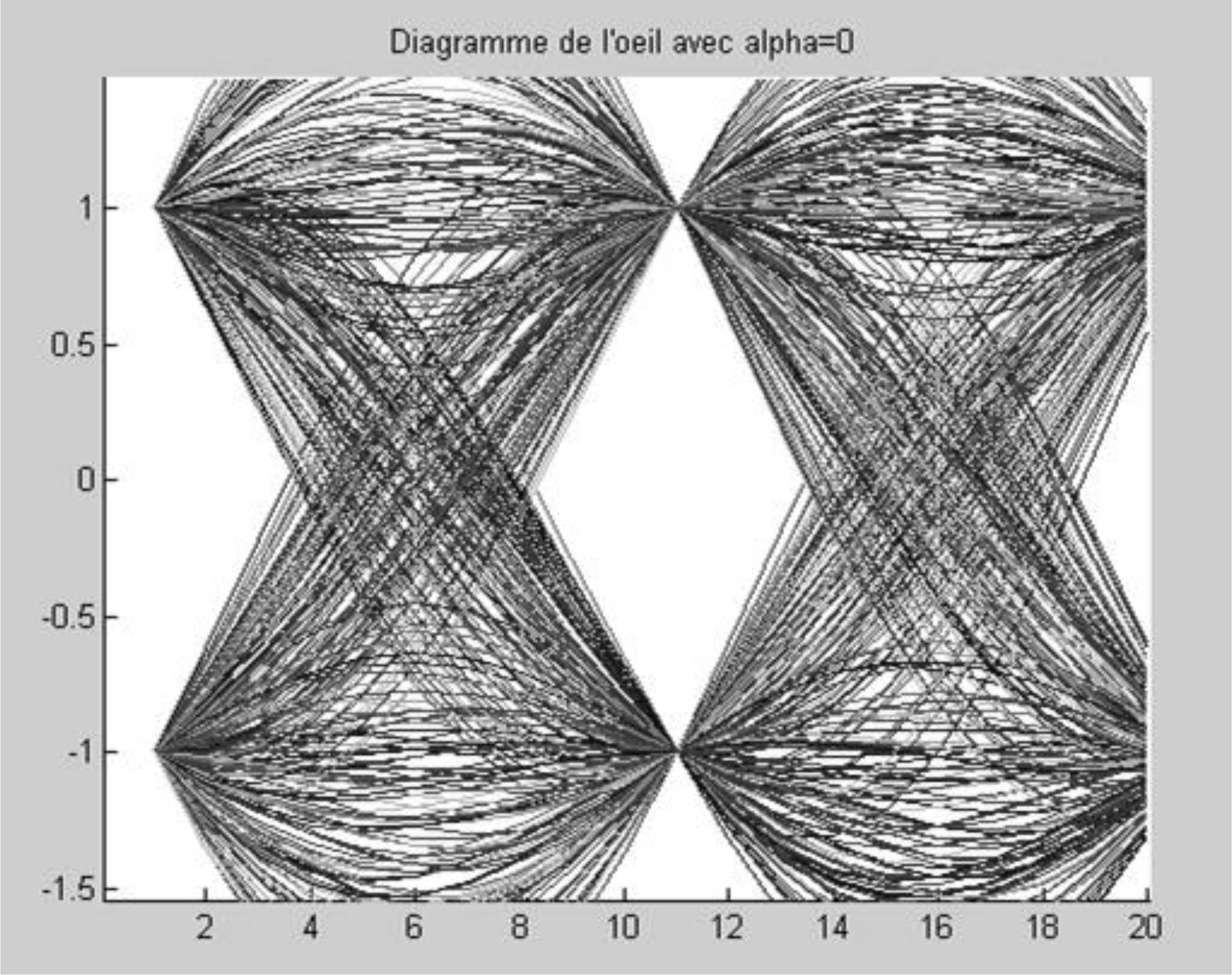
Digital modulations– Nyquist criterion

RCF: Frequency response

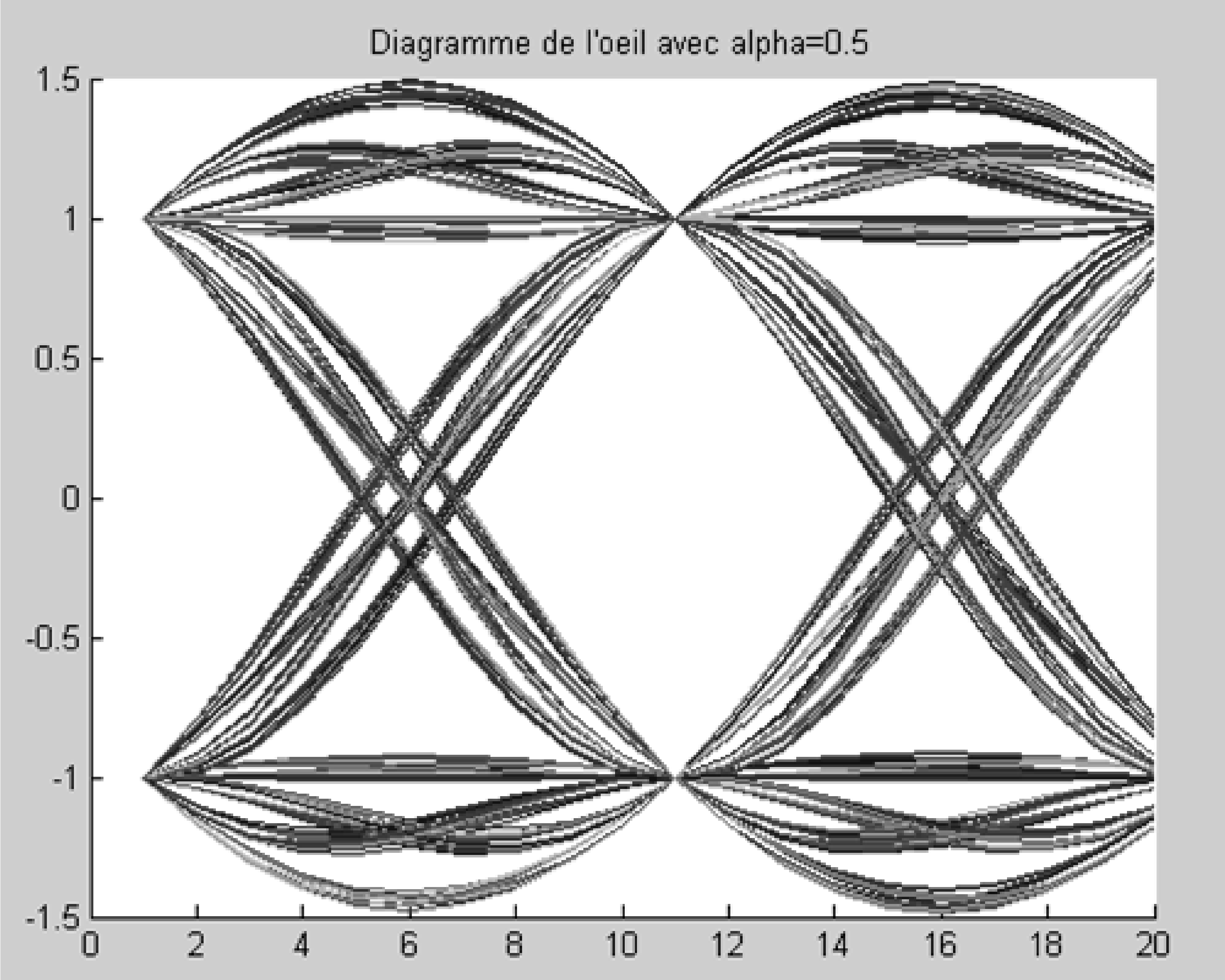


Occupied bandwidth = $(1+\alpha)$ ×symbol rate

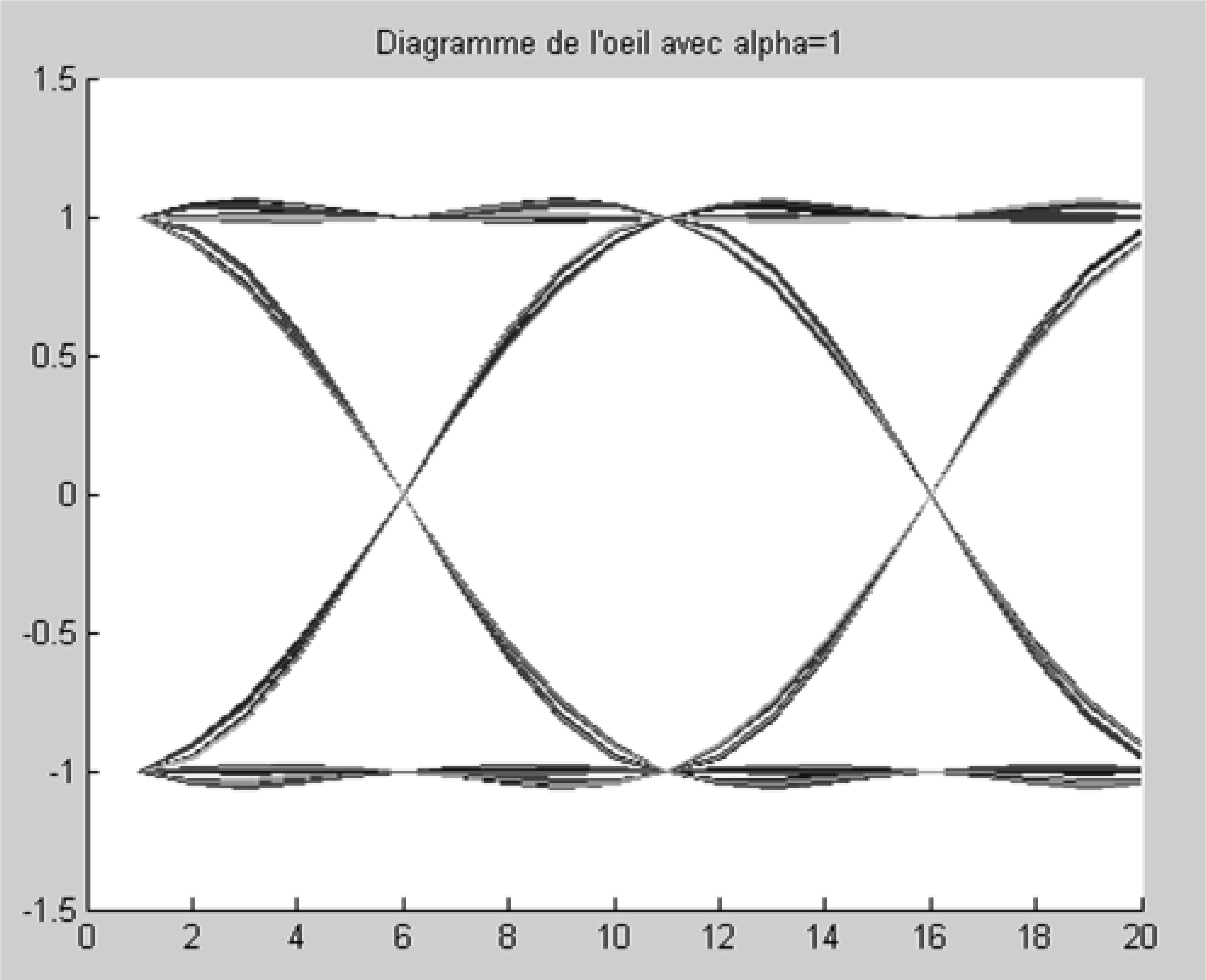
Digital modulations– Nyquist criterion



Digital modulations– Nyquist criterion

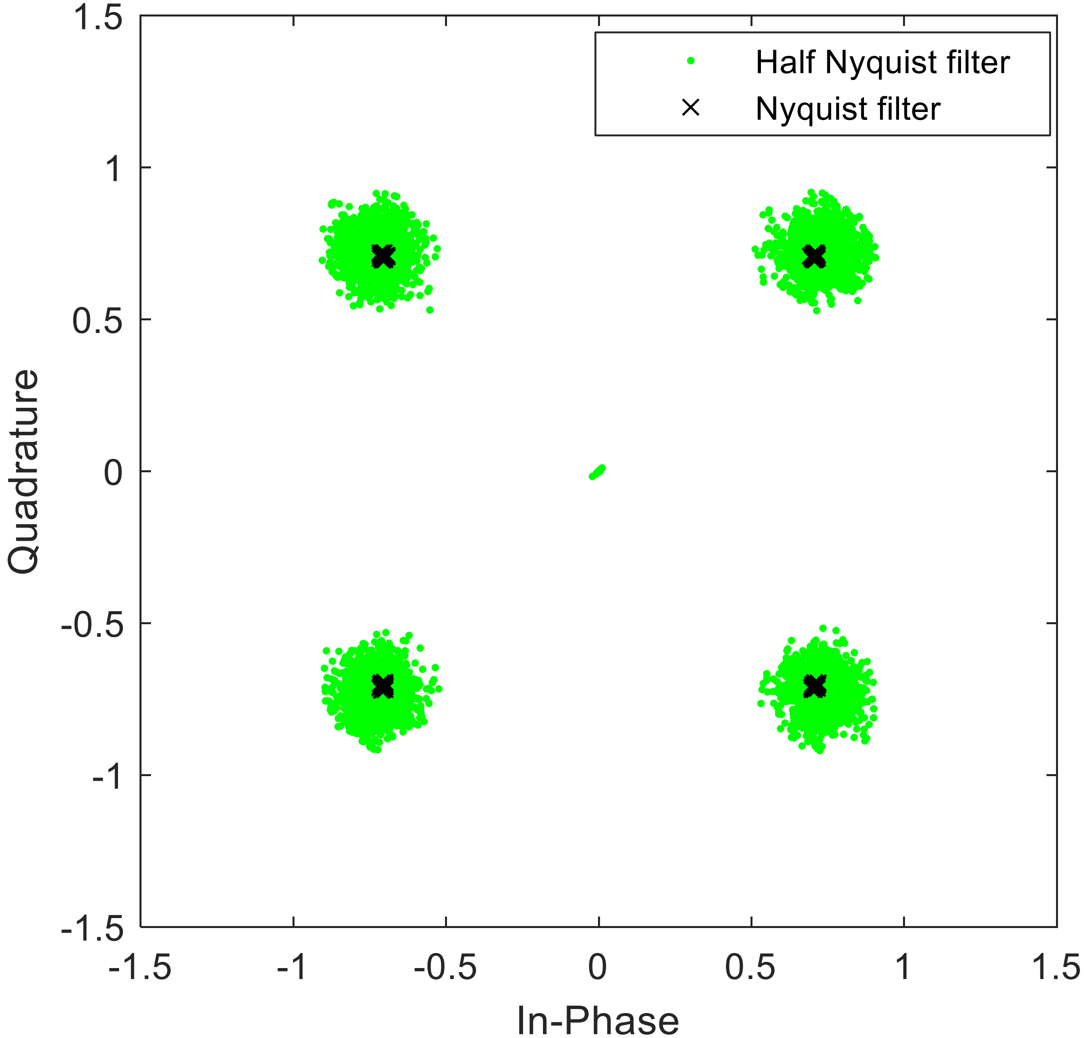


Digital modulations– Nyquist criterion



Digital modulations– Nyquist criterion

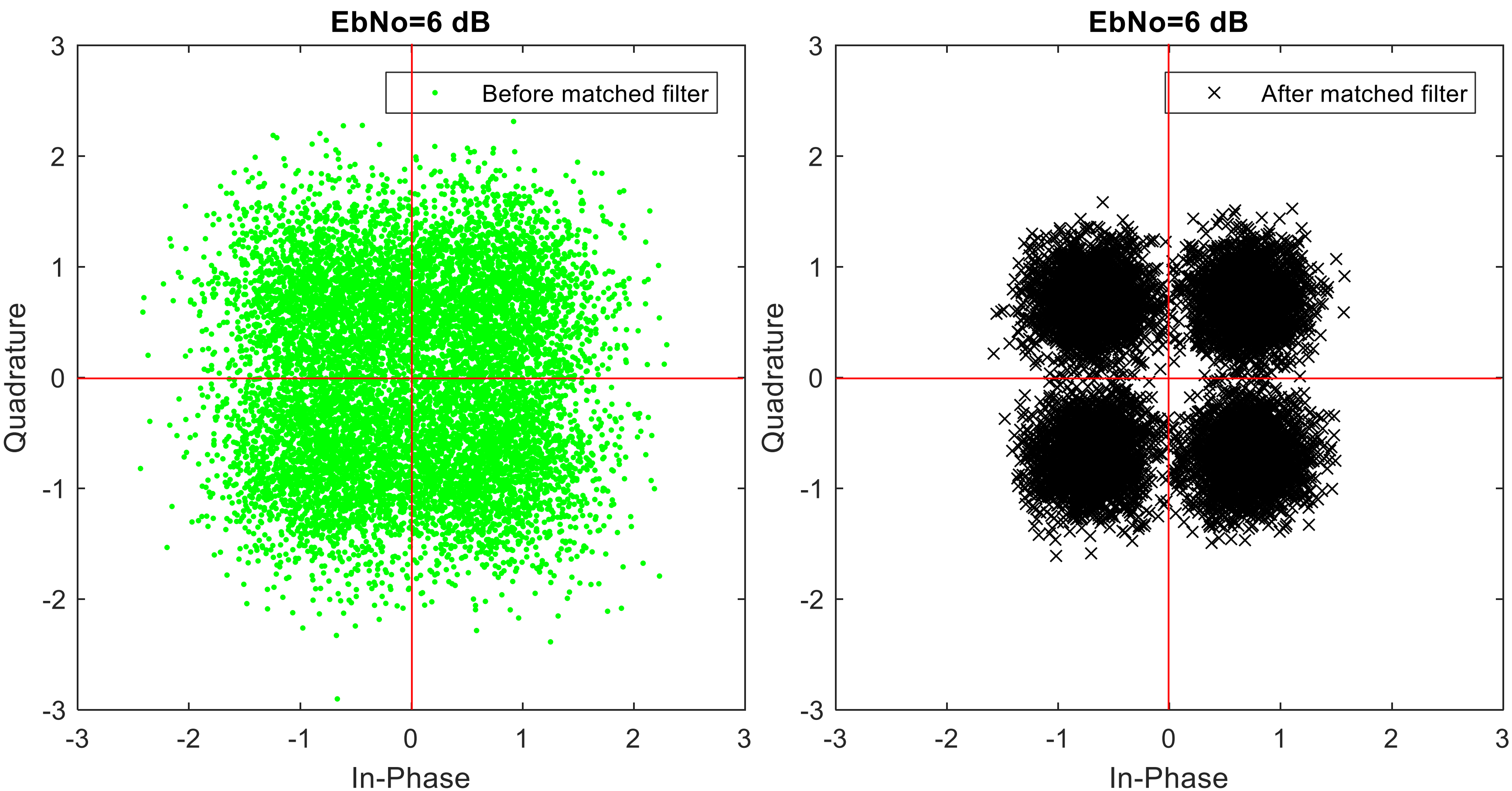
- Root Nyquist filters: the filter is usually split: half being in **Tx** and half in **Rx.**



RCF: $\boldsymbol{\alpha = 0.1}$

Noise =0

Digital modulations– matched filter

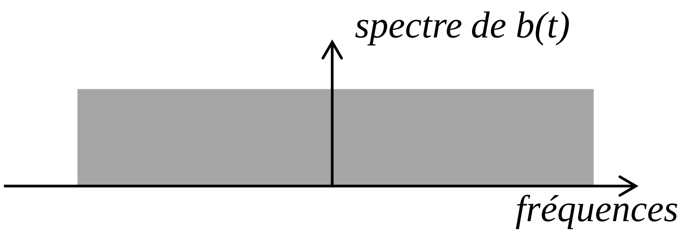


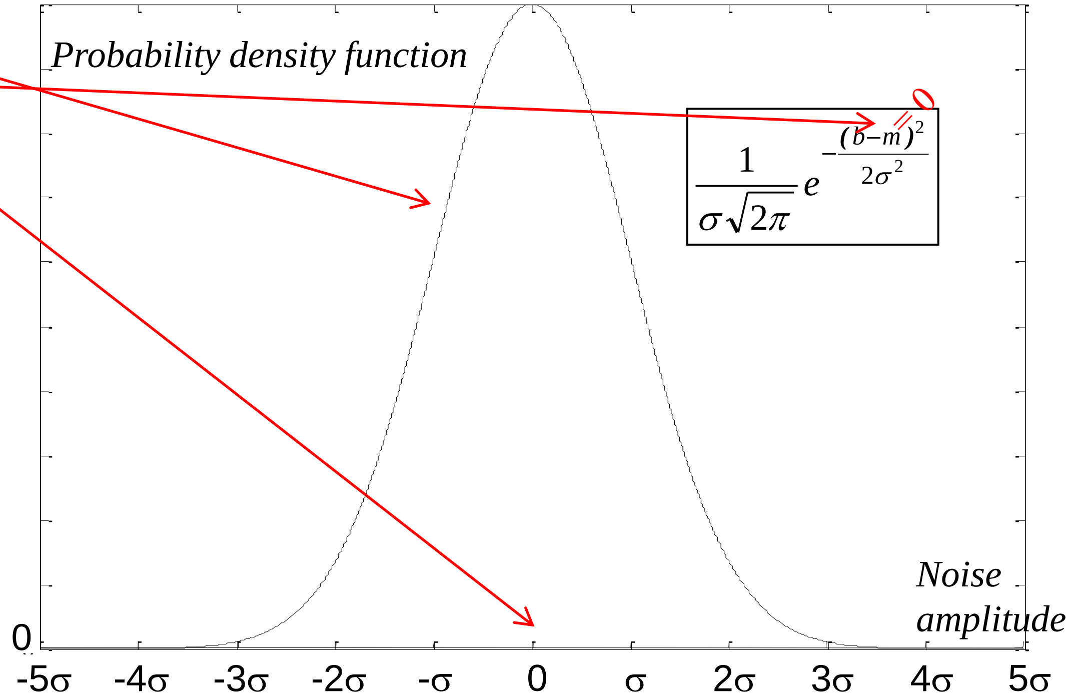
Rectangular filter: No ISI

Digital modulations – noise

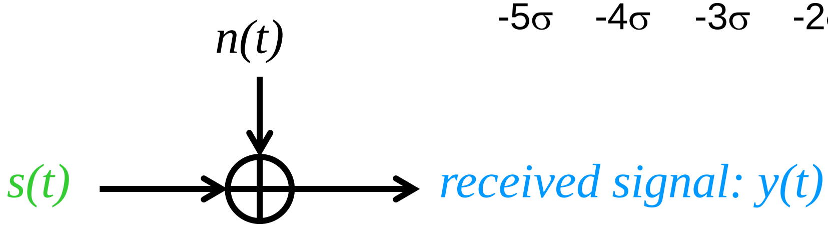
AWGN:

White ⇐
- Gaussian
- Zero mean
- independant



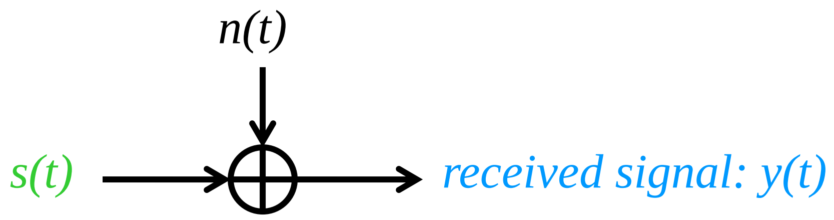


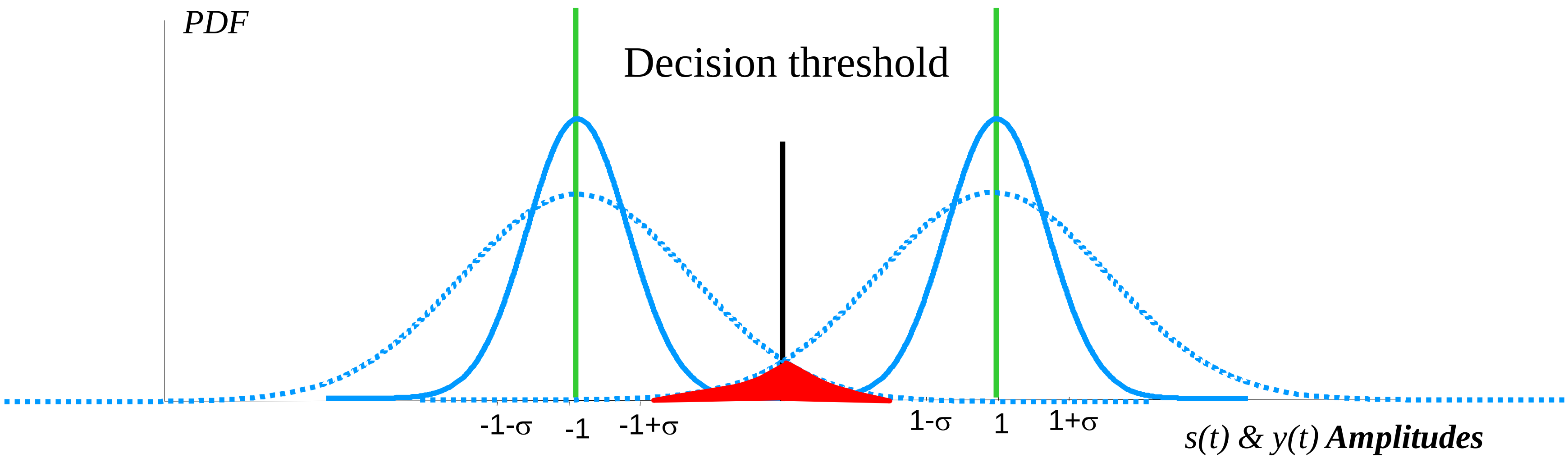
- additive



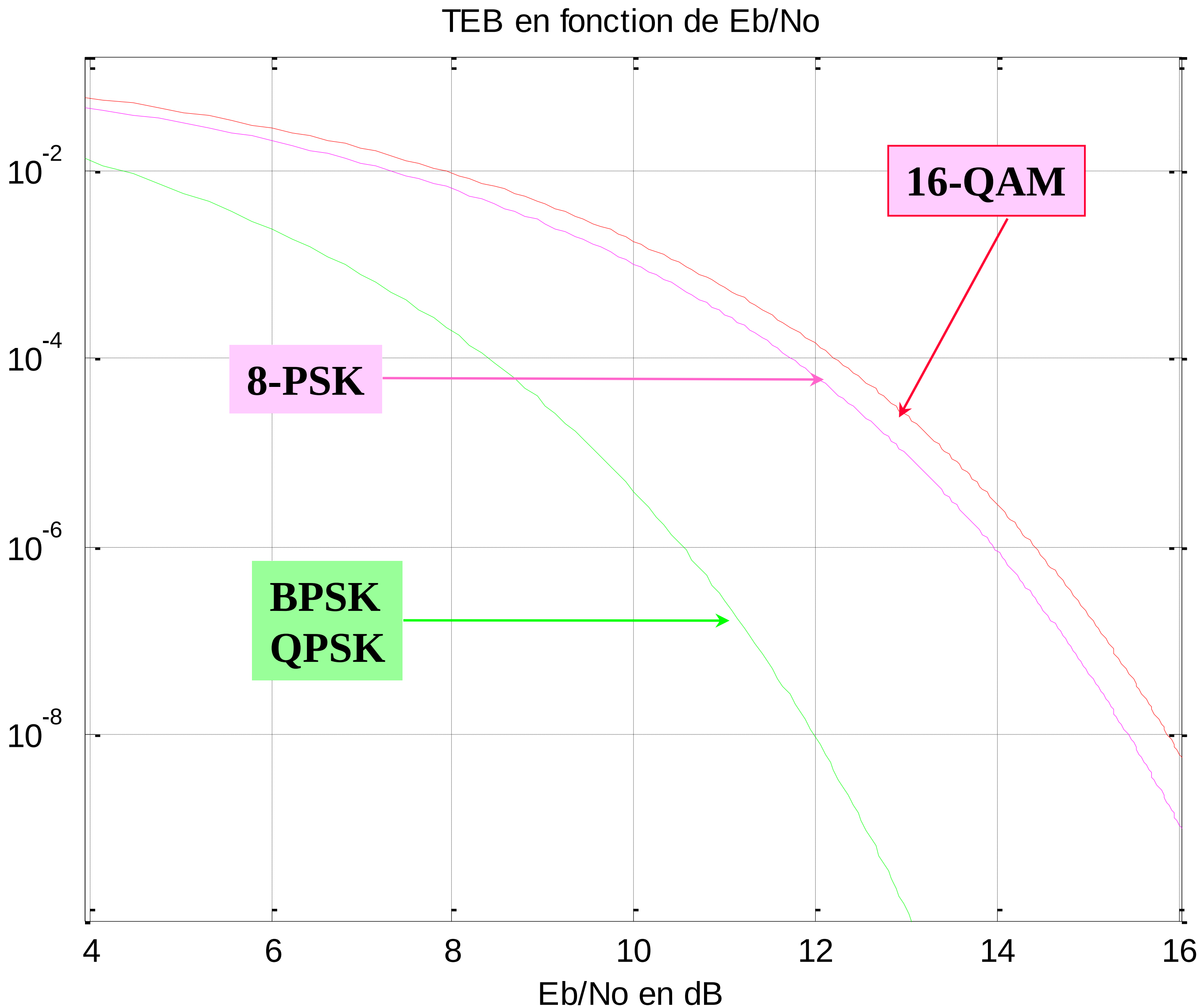
Digital modulations – errors

- Error probability:





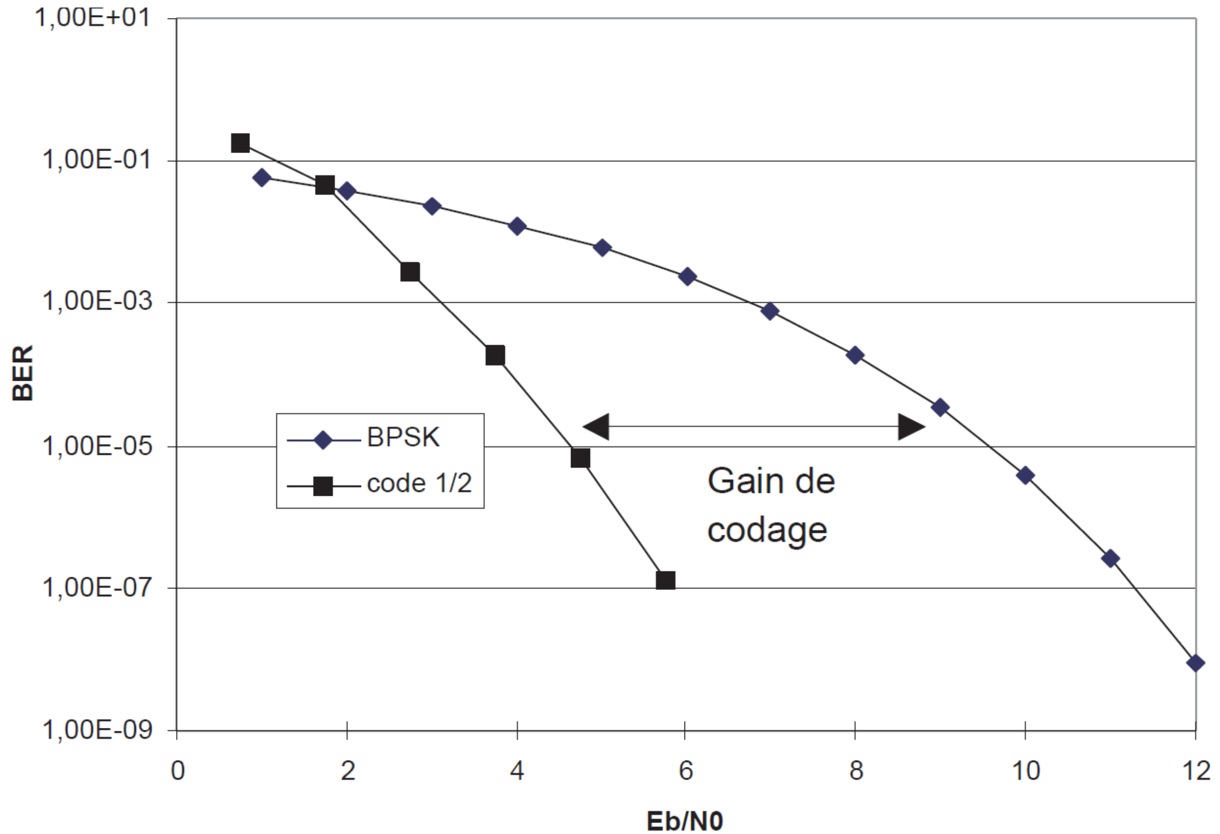
Digital modulations – Performances



Digital modulations – Coding

k bits → Encoder → n bits

Code rate: k/n



Digital modulations – Coding

- **Satellite Communications**
  - Convolutional (Viterbi): 1/2, 2/3, 3/4, 5/6, 7/8

  The earliest digital satellite systems – installed in the 1970s used simple Viterbi decoders to implement the FEC function.

  - Reed Solomon (RS): 188/204, 216/236

  Concatenated Reed-Solomon and Viterbi coding scheme, which was introduced in early 80s

  - Turbo: 1/3, 2/5, 1/2, 2/3, 3/4, 5/6, 6/7, 7/8 [In 1993]

  allow near-Shannon1 limit performance with codes that are relatively easy to implement in hardware.

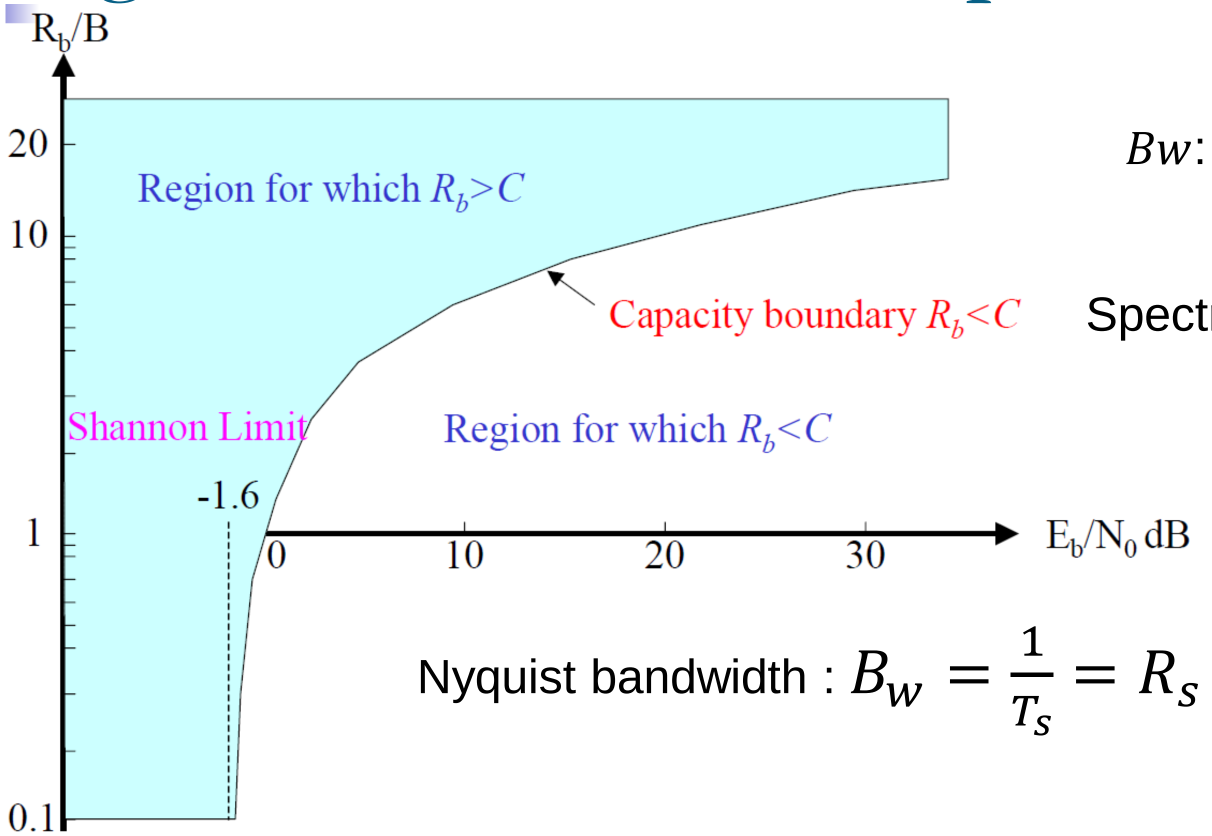
  iterating between two Convolutional decoders with an interleave process

  - LDPC (Low Density Parity Check): 1/4, 1/3, 2/5, 1/2, 3/5, 3/4, 5/6, 8/9, 9/10

  provide performance similar to turbo codes but can actually outperform Turbo codes if the block size is very large.

  very attractive for broadband and direct to home consumer applications

Digital modulations – Spectral Efficiency



Bw: Nyquist bandwidth

Spectral efficiency: $\eta = \frac{R_b}{B_N}$

Nyquist bandwidth : $B_w = \frac{1}{T_s} = R_s$ baud rate

$$R_b = Bw \log_2\left(1 + \frac{C}{N}\right) = Bw \log_2\left(1 + \eta \frac{E_b}{N_0}\right) \text{ [b/s]}$$

$$B_N = B_w \Rightarrow \eta = \frac{R_b}{R_s} \Rightarrow \frac{E_b}{N_0} = \frac{2^\eta - 1}{\eta}$$

Broadband communications

- includes several high-speed transmission technologies such as:
  - Digital Subscriber Line (DSL)
  - Wireless
  - Broadband over Powerline
  - **Satellite**
  - **Fiber**

Broadband communications

- **Digital Subscriber Line (DSL)**
  - wireline transmission technology
  - Fast data transmission over copper telephone lines already installed to homes and businesses
  - Data rate range: several hundred of Kb/s to Mb/s
  - Quality depends on the distance between the user's home and the closest internet provider facility.
  - **Asymmetrical DSL (ADSL):** provides faster speed in the downstream direction than the upstream direction (typically used by residential customers)
  - **Symmetrical Digital Subscriber Line (SDSL)** : dedicated to businesses for services. Significant bandwidth is required for both down and up stream.
  - High data rate DSL (HDSL) and Very High Data rate DSL (VDSL).

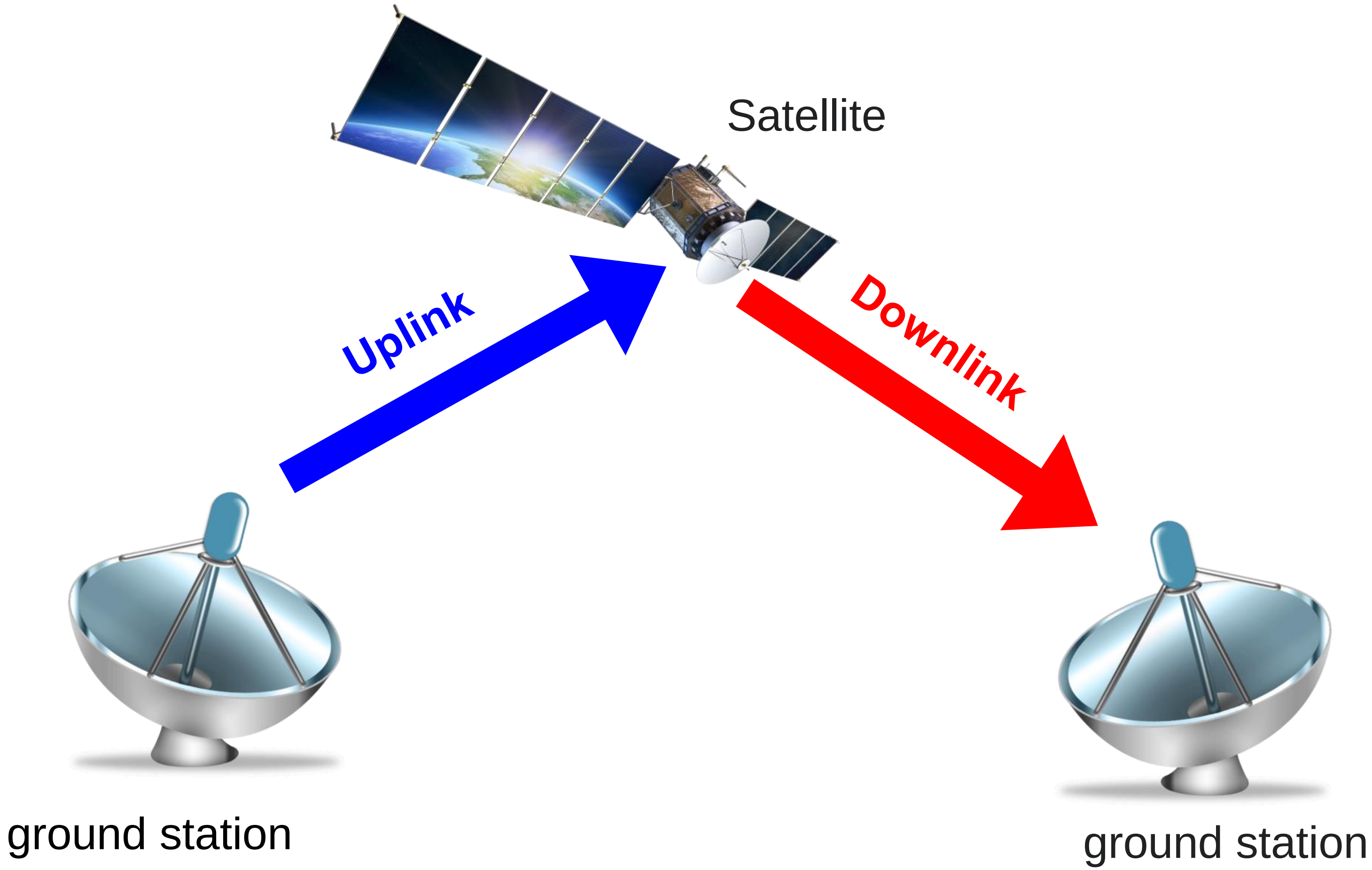
Broadband communications

- **Wireless**
  - Mobile wireless broadband services: 4G
  - Wireless Local Area Networks (WLANs): WiFi
  - Data rate range: several hundred of Kb/s.
- **Broadband over Powerline**
  - Method of Power Line Communication (PLC)
  - Broadband over the existing low- and medium-voltage electric power distribution network.
  - Data rate range: similar to DSL.

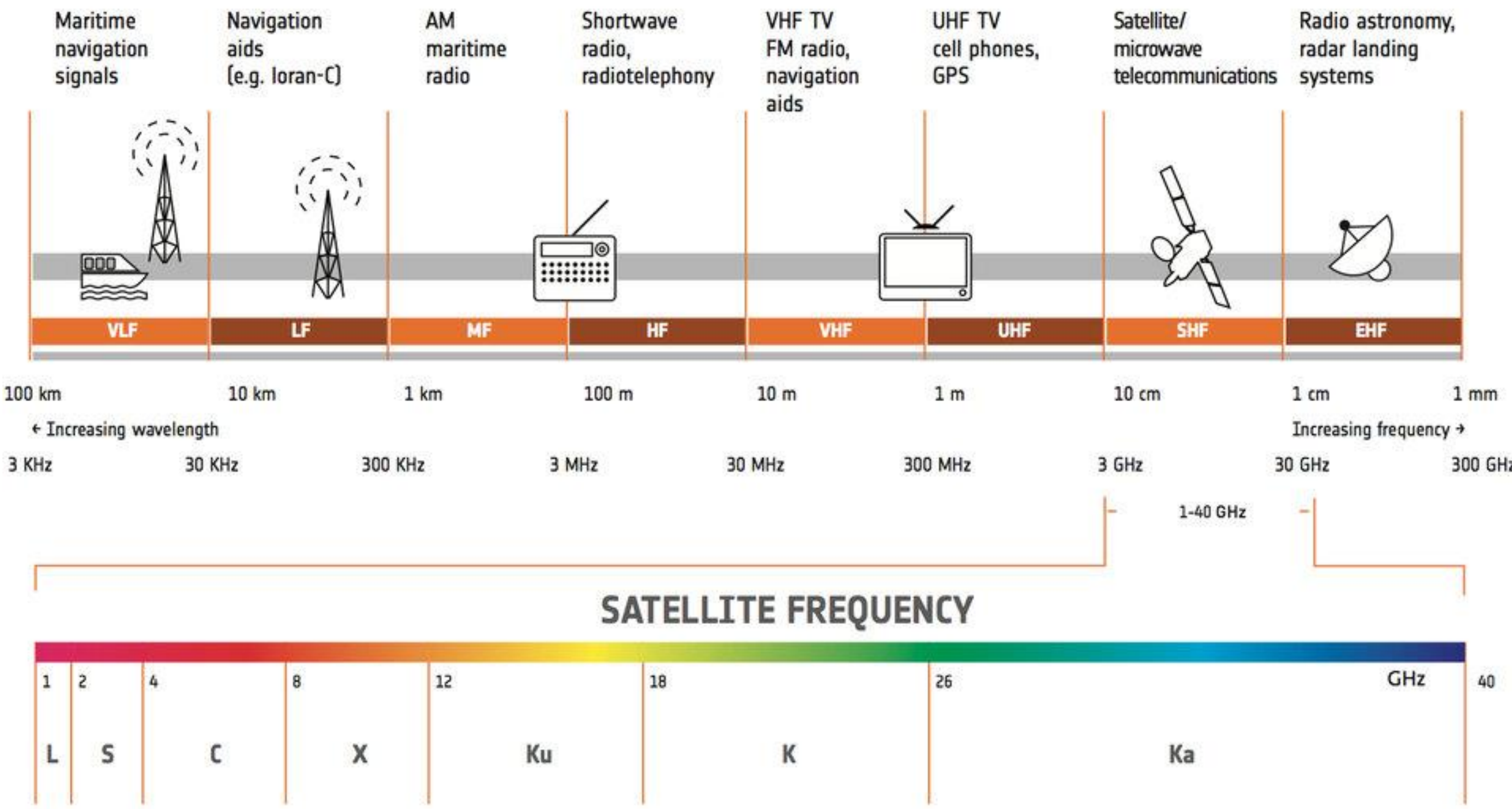
Broadband communications

- **Satellite**
  - Useful for serving remote or sparsely populated areas.
  - Downstream and upstream speeds for satellite broadband depend on several factors
    - consumer’s line of sight to the orbiting satellite.
    - weather conditions.
- **Fiber**
  - converts electrical signals carrying data to light and sends the light through transparent glass fibers about the diameter of a human hair.
  - Data rate range: hundreds of Mb/s to Gb/s (far exceeding DSL).
  - Data rate depends on various factors: fiber type, distance, …

Satellite communications



Satellite Frequency bands



Satellite Frequency bands

- **L-band (1-2 GHz)**

  Global Positioning System (GPS) carriers and also satellite mobile phones.

- **S-band (2–4 GHz)**

  Weather radar, and some communications satellites, especially those of NASA for communication with ISS.

- **C-band (4–8 GHz)**

  Primarily used for satellite communications, for full-time satellite TV networks. Commonly used in areas that are subject to tropical rainfall, since it is less susceptible to rain fade than Ku band.

- **X-band (8–12 GHz)**

  Primarily used by the military. Used in radar applications.

- **Ku-band (12–18 GHz)**

  Used for satellite communications. In Europe, Ku-band downlink is used from 10.7 GHz to 12.75 GHz for direct broadcast satellite services, such as Astra.

- **Ka-band (26–40 GHz)**

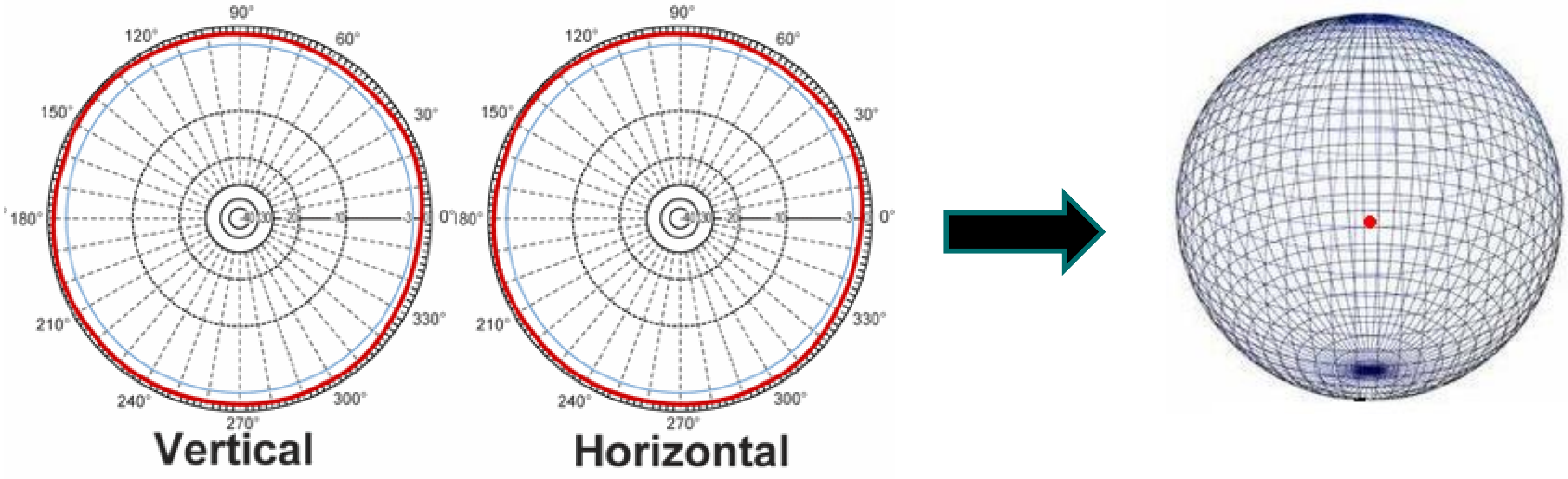
  Communications satellites, uplink in either the 27.5 GHz and 31 GHz bands, and high-resolution, close-range targeting radars on military aircraft.

The Space Link

- Based on Shannon formula, we can get an estimation of the maximum achievable data rate. Therefore for a given bandwidth, we need to know:
  - Receive power
  - Noise power
- **link-power budget calculations** relate two quantities, the transmit power and the receive power.
- Usually made using **decibel.** Variable between [] brackets are used to denote decibel quantities using the basic power definition.

The Space Link

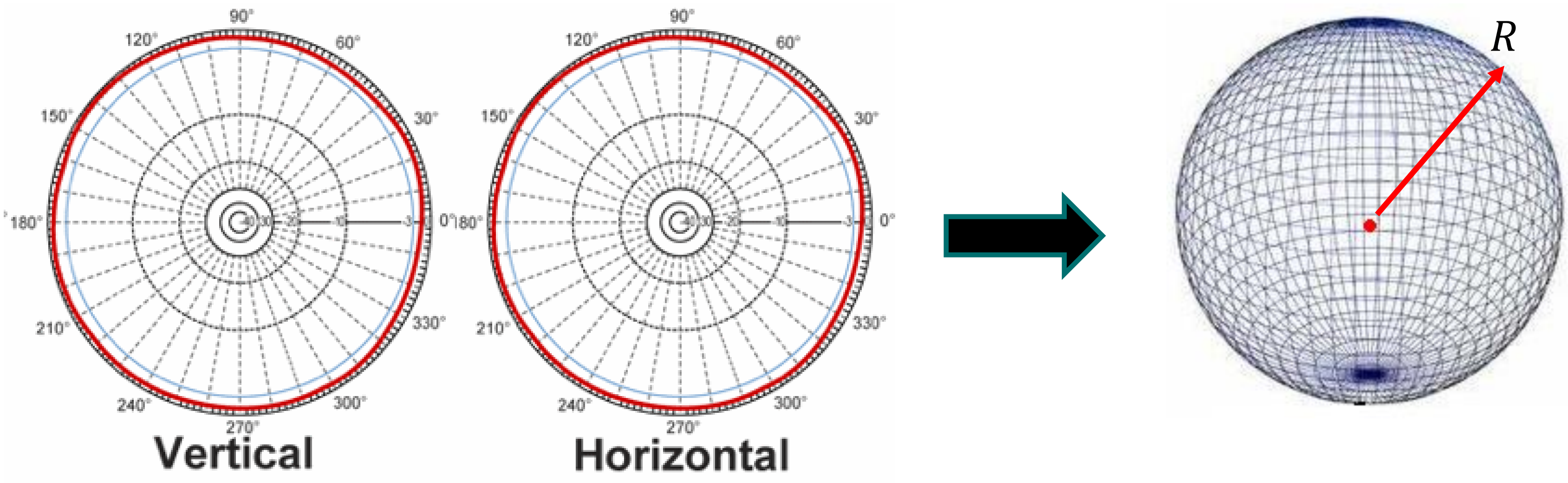
Isotropic transmitter:



- Transmit antenna is the center of a sphere
- The power from the antenna is uniformly distributed on the surface of the sphere.

The Space Link

Isotropic transmitter:

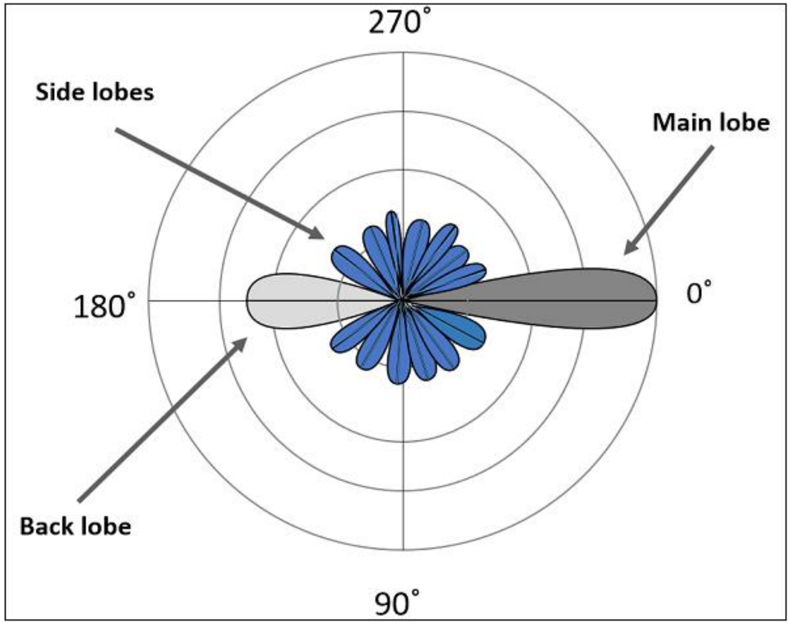


- Transmit antenna is the center of a sphere,
- The power from the antenna is uniformly distributed on the surface of the sphere,
- **Power Flux Density** at a distance R is the power flow per unit surface area

$$PFD = \frac{P_t}{4\pi R^2} \quad w/m^2$$

The Space Link

Antenna with gain :



- **Power Flux Density** at a distance R is the power flow per unit surface area

$$\mathrm{PFD} = \frac{P_t G_t}{4\pi R^2} \qquad w/m^2$$

- In dB terms since we deal with very large number (for GEO R=36000 km)

$$[\mathrm{PFD}] = 10\log(P_t G_t) - 20\log R - 10\log(4\pi) \qquad dBw/m^2$$

The Space Link

Antenna with gain :

- **Power Flux Density** at a distance R is the power flow per unit surface area

$$\text{PFD} = \frac{P_t G_t}{4\pi R^2} \quad W/m^2$$

$$[\text{PFD}] = 10\log(P_t G_t) - 20\log R - 10.99 \quad dBw/m^2$$

- **Effective Isotropic Radiated Power (EIRP)**

$$EIRP = P_t G_t \quad W$$

- It is often expressed in dB relative to 1w,

$$[EIRP] = [P_t] + [G_t] \quad dBw$$

Where, $[P_t] =$ and $[G_t] =$

The Space Link

- **Example:** A satellite downlink at 12 GHz operates with a transmit power of 6 W and an antenna gain of 48.2 dB. Calculate the EIRP in dBw.

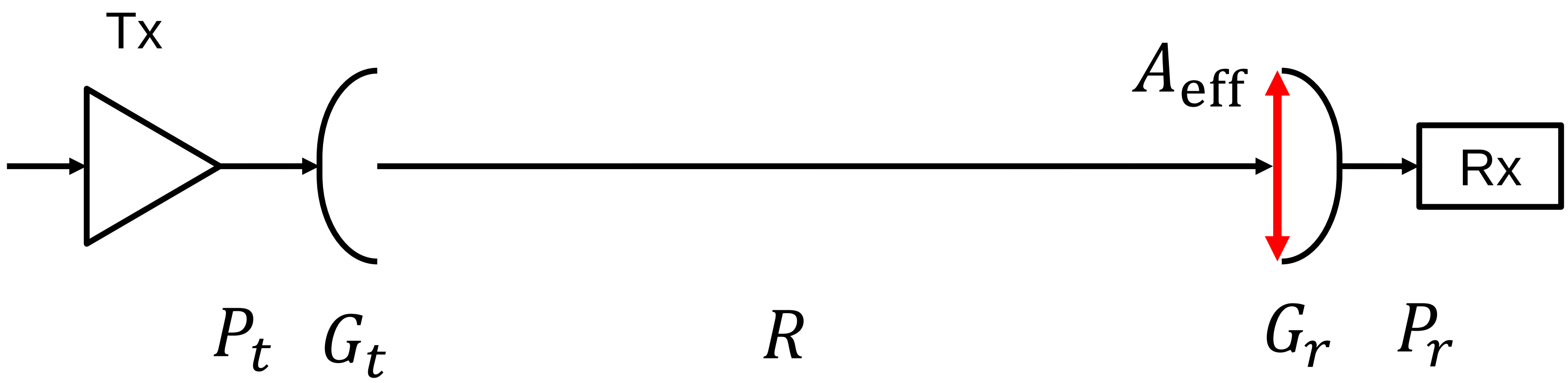
The Space Link

- **Antenna gain (**paraboloidal antenna case)

$$G = \eta(10.472 f D)^2$$

  - f is the carrier frequency in GHz
  - η is the aperture efficiency (the typical value is 0.55)
  - D is the reflector diameter in m

Free-space transmission



- **Receive power:** with effective aperture A_{eff} at distance R

$$P_r = \frac{EIRP}{4\pi R^2} A_{\text{eff}} \quad W$$

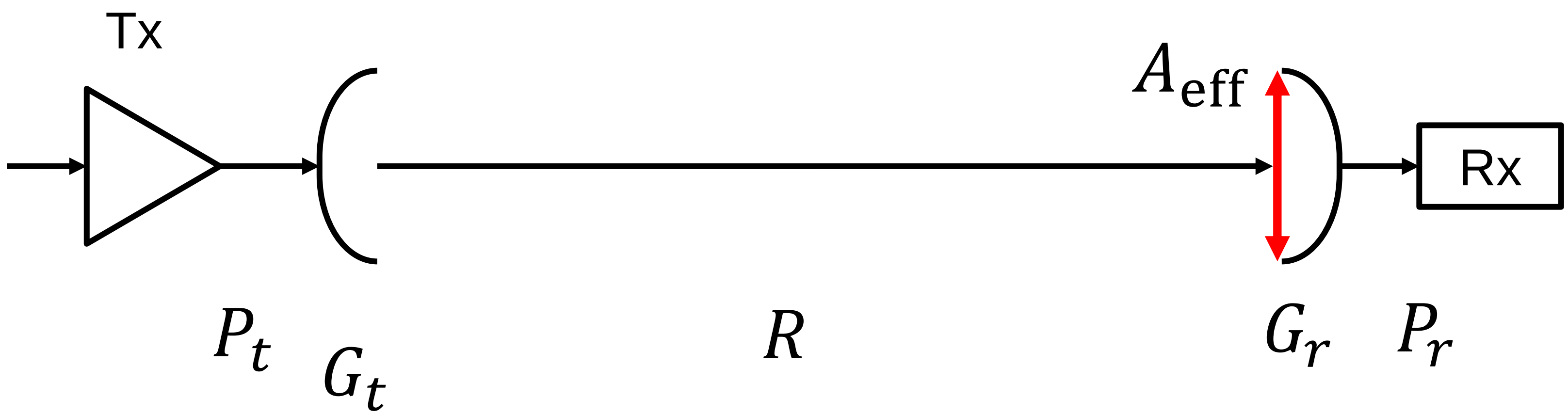
- Receive antenna gain G_r (inversely proportional to the square of the wavelength),

$$G_r = \frac{4\pi}{\lambda^2} A_{\text{eff}} \Rightarrow A_{\text{eff}} = \frac{G_r}{\frac{4\pi}{\lambda^2}}$$

- We can rewrite,

$$P_r = \frac{EIRP}{4\pi R^2} \frac{G_r}{\frac{4\pi}{\lambda^2}} = EIRP\ G_r \frac{1}{\left(\frac{4\pi R}{\lambda}\right)^2} \quad W$$

Free-space transmission



- **Receive power:**

$$P_r = \frac{EIRP}{4\pi R^2}\frac{G_r}{\frac{4\pi}{\lambda^2}} = EIRP\ G_r\ \frac{1}{\left(\frac{4\pi R}{\lambda}\right)^2} \quad W$$

Free Space Loss: $\left(\frac{4\pi R}{\lambda}\right)^2$

In dB terms, we have,

$$[P_r] =$$

- Received power is increased by increasing antenna gain

Free Space Loss

- **FSL in dB:** Consider the frequency rather than wavelength and give the expression of [FSL]

$$\mathrm{FSL} = \left(\frac{4\pi R}{\lambda}\right)^2 \Rightarrow [\mathrm{FSL}] =$$

Free Space Loss

- **FSL in dB:** Consider the frequency rather than wavelength and give the expression of [FSL]

$$\mathrm{FSL} = \left(\frac{4\pi R}{\lambda}\right)^2 \Rightarrow [\mathrm{FSL}] = 10\log\left(\frac{4\pi R}{\lambda}\right)^2, \lambda = \frac{c}{f}$$

$$[\mathrm{FSL}] = 10\log\left(\frac{4\pi f R}{c}\right)^2 = 20\log\left(\frac{4\pi}{c}\right) + 20\log(R) + 20\log(f)$$

$$= 20\log\left(\frac{4\pi}{c}\right) + 20\log(R[\mathrm{km}] \times 10^3) + 20\log(f[\mathrm{MHz}] \times 10^6)$$

$$[\mathrm{FSL}] = 32.4 + 20\log(R[\mathrm{km}]) + 20\log(f[\mathrm{MHz}])$$

Free Space Loss

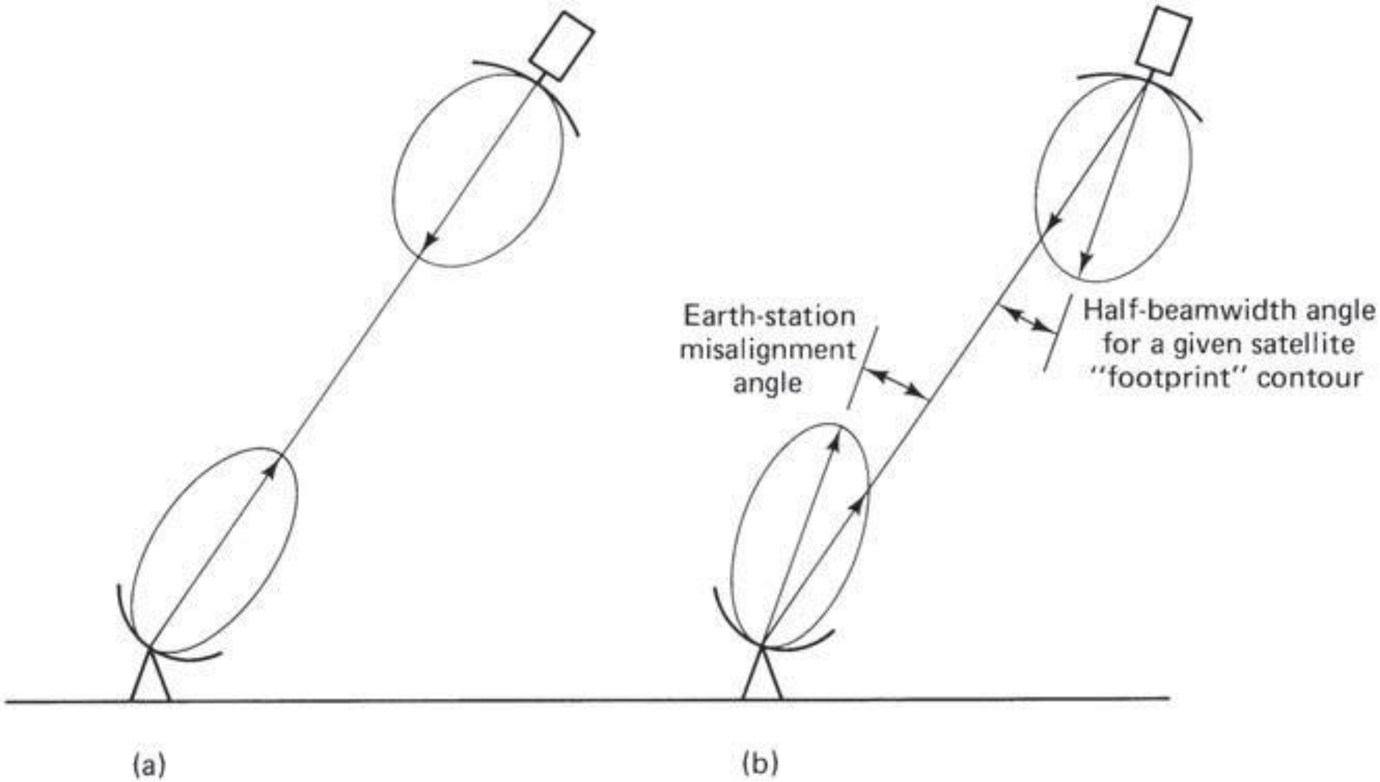
- **Example:** The range between a ground station and a satellite is 42000 km.
  - Calculate the FSL at a frequency of 6 GHz.
  - Compare the FSL in C-band, Ku-band and Ka-band.

Free-space transmission

Remarks:

- Antenna gain is inversely proportional to the square of the wavelength.
- the free-space loss is also inversely proportional to the square of the wavelength. So, two effects cancel.
- **For a constant EIRP, the received power is independent of frequency of operation.**
- What happens if the transmit power is a specified constant ?

Antenna misalignment losses (AML)



(a) Satellite and earth-station antennas aligned for maximum gain;
(*b*) Earth station situated on a given satellite "footprint," and earth-station antenna misaligned. AML are usually only a few tenths of a decibel.

The Link-Power Budget Equation

- The decibel equation for the received power:

$$[\boldsymbol{P_r}] = [\boldsymbol{EIRP}] + [\boldsymbol{G_r}] - [\boldsymbol{LOSSES}]$$

- The losses for clear-sky conditions are**:**

$$[\boldsymbol{LOSSES}] = [\boldsymbol{FSL}] + [\boldsymbol{RFL}] + [\boldsymbol{AML}] + [\boldsymbol{AA}] + [\boldsymbol{PL}]$$

- Where,
  - [PR] received power, dBW
  - [EIRP] equivalent isotropic radiated power, dBW
  - [FSL] free-space spreading loss, dB
  - [RFL] receiver feeder loss, dB
  - [AML] antenna misalignment loss, dB
  - [AA] atmospheric absorption loss, dB
  - [PL] polarization mismatch loss, dB

The Link-Power Budget Equation

- **Example:** A satellite link operating at 14 GHz has receiver feeder losses of 2.5 dB and a free-space loss of 207 dB. The atmospheric absorption loss is 0.5 dB, and the antenna pointing loss is 0.5 dB. Depolarization losses may be neglected. Calculate the total link loss for clear-sky conditions.

System noise

- Received power in a satellite link is very small, on the order of picowatts
- Amplification could be used to bring the signal strength up to an acceptable level **(only when the signal is significantly greater than the noise)**.
- Otherwise, amplification will be of no help (same amplification for both signal and noise). It will be worse if we consider the noise added by the amplifier.

System noise

Thermal noise:

$$P_N = kT_N B_N$$

- T_N is known as the equivalent (or effective) noise temperature (in Kelvin).
- It directly related to the physical temperature of the noise source but is not always equal to it.
- The noise temperatures of various sources which are connected together can be added directly to give the total noise.
- $B_N$is the equivalent noise bandwidth (in Hz): $1.12 \times B_{-3dB}$

Noise power spectral density

- White noise : constant spectral density (noise energy in Joules)

$$N_0 = \frac{P_N}{B_N} = kT_N$$

System noise

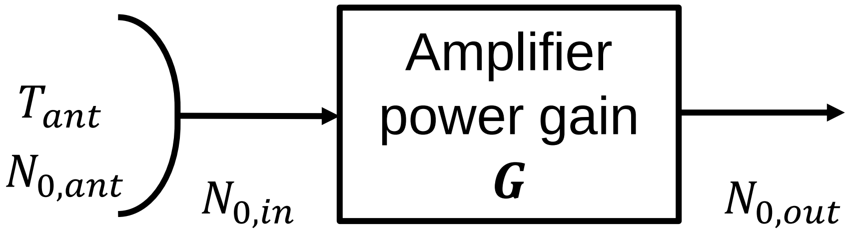
Thermal noise:

Example: An antenna has a noise temperature of 35 K and is matched into a receiver which has a noise temperature of 100 K. Calculate:

- the noise power density
- the noise power for a bandwidth of 36 MHz.

System noise

Amplifier noise temperature:



The input noise energy coming from the antenna:

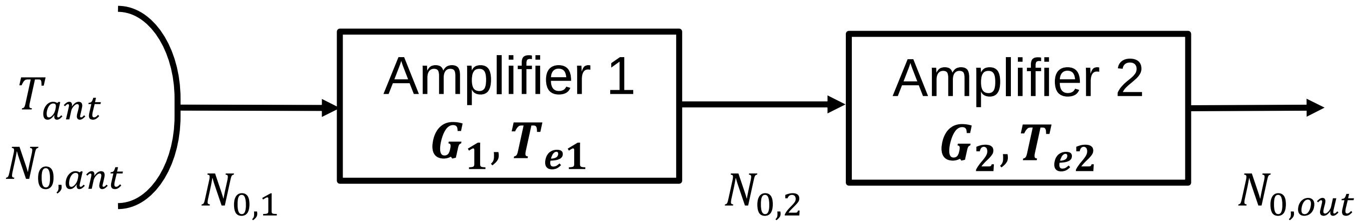
$$N_{0,ant} = kT_{ant}$$

- **Output noise energy = $\boldsymbol{G}$ x input noise energy + noise energy made by the amplifier**
- **Noise induced by the amplifier:** may be *referred to the input* in terms of an equivalent input noise temperature for the amplifier T_e

$$N_{0,out} = G\boldsymbol{k}(\boldsymbol{T_{ant}} + \boldsymbol{T_e}) = G\boldsymbol{N_{0,in}}$$

System noise

Amplifiers in cascade:



Total gain: $$G = G_1 G_2$$

- Noise energy of amplifier 2 referred to its own input: $k\,T_{e2}$
- Noise input to amplifier 2 from the preceding stages

$$G_1 k(T_{ant} + T_{e1})$$

- Noise energy *referred to amplifier 2 input*

$$N_{0,2} = G_1 k(T_{ant} + T_{e1}) + kT_{e2}$$

- Noise energy referred to amplifier 1 input:

$$N_{0,1} = \frac{N_{0,2}}{G_1} = k\left(T_{ant} + T_{e1} + \frac{T_{e2}}{G_1}\right)$$

System noise

system noise temperature:

- Noise energy referred to amplifier 1 input:

$$N_{0,1} = \frac{N_{0,2}}{G_1} = k\left(T_{ant} + T_{e1} + \frac{T_{e2}}{G_1}\right)$$

- System noise temperature:

$$N_{0,1} = kT_s \Rightarrow T_s = T_{ant} + T_{e1} + \frac{T_{e2}}{G_1}$$

- Noise temperature of the second stage is divided by the power gain of the first stage when referred to the input.
- **In order to keep the overall system noise as low as possible, the first stage (usually an LNA) should have high power gain as well as low noise temperature.**

$$T_s = T_{ant} + T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \ \ldots$$

System noise

Noise factor:

- Alternative way of representing amplifier noise,
- The source is taken to be at *room temperature*, denoted by T_0, usually taken as 290 K. The input noise from this source

$$kT_0$$

- Output noise from the amplifier (with G gain) is:

$$N_{0,out} = FGkT_0$$

- F is the amplifier noise factor.

$$[F] = 10\log(F)$$

System noise

Noise factor and noise temperature relationship:

- T_e be the noise temperature of the amplifier,
- The source is taken to be at *room temperature*, T_0 as required by the definition of the noise factor F

$$T_{ant} = T_0$$

- We must have the same noise output whatever the representation:

$$N_{0,out} = Gk(T_{ant} + T_e) = Gk(T_0 + T_e)$$

$$N_{0,out} = FGkT_0$$

$$\Rightarrow T_e = (F - 1)T_0$$

- In a practical satellite receiving system:
  - noise temperature is specified for low-noise amplifiers and converters,
  - noise factor is specified for the main receiver unit

System noise

Noise factor and noise temperature relationship:

- **Exercice:** An LNA is connected to a receiver which has a noise figure of 12 dB. The gain of the LNA is 40 dB, and its noise temperature is 120 K. Calculate the overall noise temperature referred to the LNA input.

System noise

Noise factor and noise temperature relationship:

- **Exercice:** An LNA is connected to a receiver which has a noise figure of 12 dB. The gain of the LNA is 40 dB, and its noise temperature is 120 K. Calculate the overall noise temperature referred to the LNA input.

- $[F] = 12\ dB \Rightarrow F = 15.85 \Rightarrow T_{e2} = (F-1)T_0$
- A gain of $[\mathrm{G}_1] = 40\ dB$ is a power ratio of $G = 10^4$, and therefore,

$$T_{in} = T_{e1} + \frac{T_{e2}}{G_1}$$

- decibel quantities must be converted to power ratios
- Although the main receiver has a very high noise temperature ($T_{e2} = 4306\ K$), its effect is made negligible by the high gain of the LNA ($G = 10^4$).

System noise

Absorptive networks:

- Contain resistive elements that introduce losses by absorbing energy from the signal and converting it to heat (Resistive attenuators, transmission lines, and waveguides).
- **Overall system noise temperature:**

System noise temperature referred to the input:

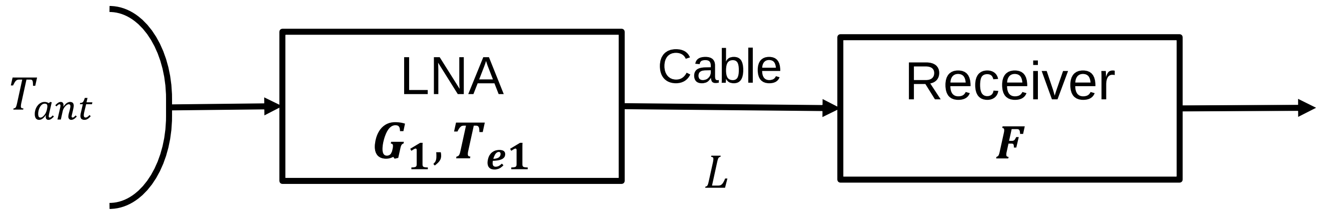
$$T_s = T_{ant} + T_{e1} + \frac{(L-1)T_0}{G_1} + \frac{L(F-1)T_0}{G_1}$$

- T_0 is the room temperature.
- L is the power loss. It is simply the ratio of input power to output power and will always be greater than unity.

System noise

Absorptive networks:

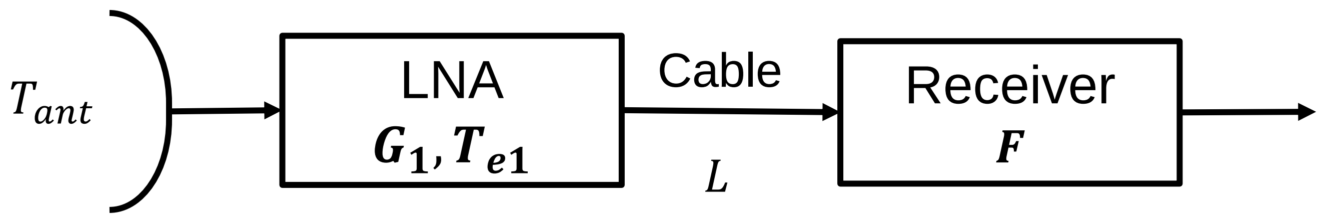
- **Exercice:** For the system shown in the following figure, the receiver noise figure is $[F] = 12\ dB$, the cable loss is $L = 5\ dB$, the LNA gain is $G_1 = 50\ dB$, and its noise temperature $T_{e1} = 150\ K$. The antenna noise temperature is $T_{ant} = 35K$ Calculate the noise temperature referred to the input T_s.



System noise

Absorptive networks:

- **Exercice:** For the system shown in the following figure, the receiver noise figure is $[F] = 12\ dB$, the cable loss is $L = 5\ dB$, the LNA gain is $G_1 = 50\ dB$, and its noise temperature $T_{e1} = 150\ K$. The antenna noise temperature is $T_{ant} = 35K$ Calculate the noise temperature referred to the input T_s.

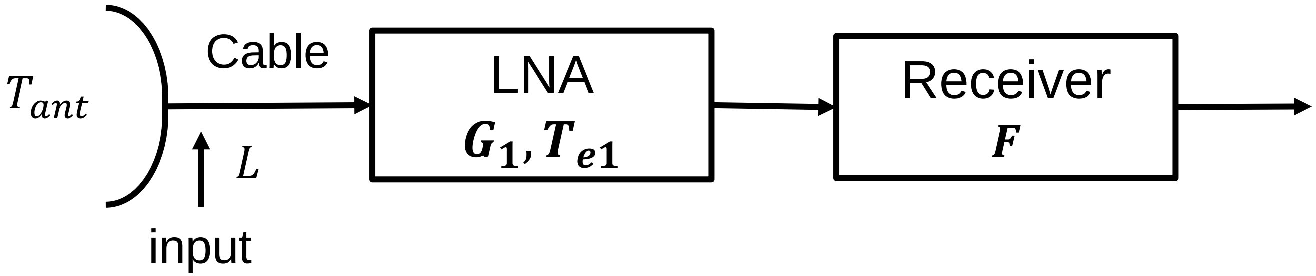


$$T_s = T_{ant} + T_{e1} + \frac{(L-1)T_0}{G_1} + \frac{L(F-1)T_0}{G_1}$$

System noise

Absorptive networks:

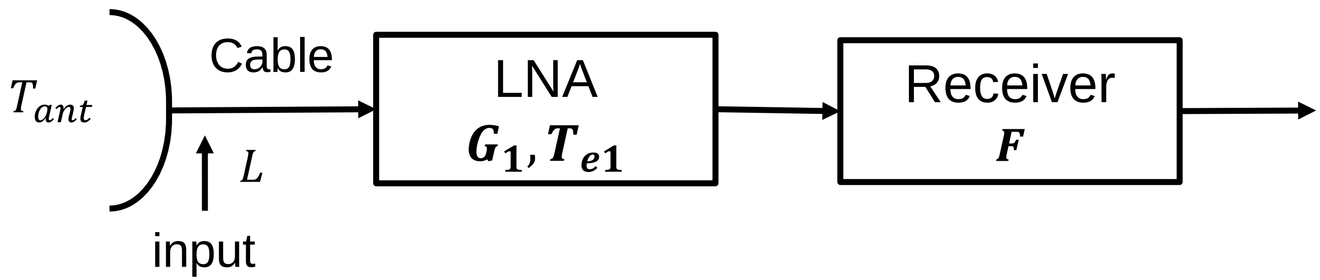
- **Exercice:** Same question for the following system.



System noise

Absorptive networks:

- **Exercice:** Same question for the following system.



- The cable precedes the LNA

$$T_e = (L-1)T_0$$

$$T_s = T_{ant} + T_e + L\,T_{e1} + \frac{L(F-1)T_0}{G_1}$$

- **Conclusion: the LNA must be placed ahead of the cable, which is why amplifiers are mounted right at the dish in satellite receive systems.**