TUTORIAL ON DIGITAL MODULATIONS

Part 1: Introduction to digital communication systems. Fundamental quantities.

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Part 1:

Introduction to digital communication systems.

Fundamental quantities

Summary:

- Introduction to digital communication systems.
- The 5 Fundamental quantities: Bit rate, Bandwidth,

  Power, Error rate, Complexity.

Digital communication:

Information is made by sequence of symbols, and is transmitted over a channel.

Information is discrete in:

-Time (sequences - time is slotted: discrete time axis).

-Values (symbols - belongs to a discrete alphabet).

(Note: for analog communication, information may be continuous both in time and values.)

Some examples:

- Human writing (symbols=letters, channel=paper)
- Morse telegraph (symbols = made by dots/lines, channel=wire)
- GSM (symbols=bits, channel=wireless)
- CD/DVD (symbols=bits, channel=disk)

Digital communication systems considered in this tutorial.

We focus on systems characterized by these two properties:

1. Symbols = **bits**

   → Discrete alphabet = Binary alphabet {0,1}

   → Information = binary sequences

Note: Even when analog information must be transmitted (voice, etc.), we suppose that by sampling and quantization (+source coding), it has already been converted into binary information sequences.

2. Transmission channel = **wireless or wired channel** (no disks or other media)

Wireless channel:

Transmitter and receiver are connected by two antennas

Wired channel:

Transmitter and receiver are connected by a cable

Digital communication systems <u>considered in this tutorial</u>.

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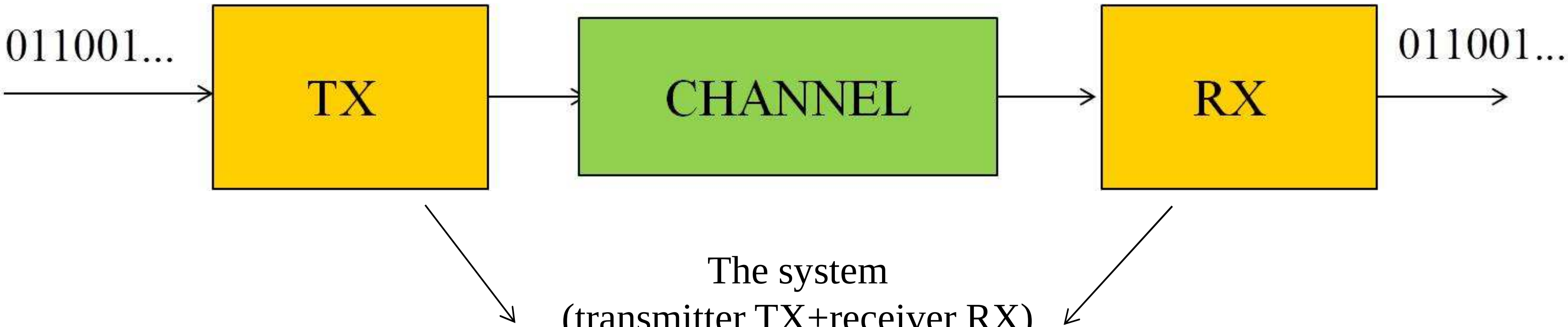
binary information sequences are transmitted over a wireless or wired channel



The system
(transmitter TX+receiver RX)
exists to transmit binary
information sequence
over the channel

Examples of digital communication systems

- Copperline modems (V90 / xDSL)
- Ethernet
- Powerline communication
- Optical Fiber modems

wired

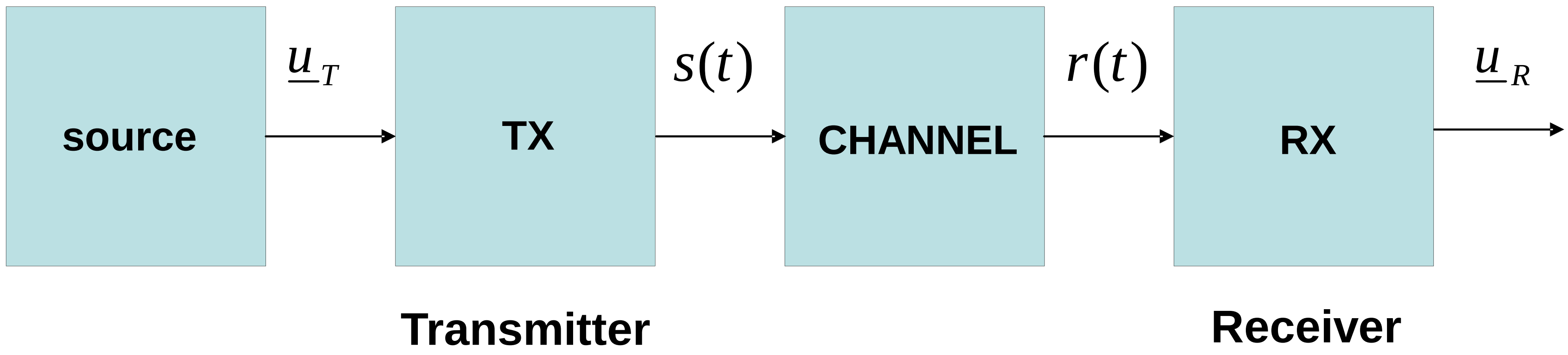
Examples of digital communication systems

- Transmission from space: Space missions, satellite communication, GNSS (GPS, Galileo, Glonass, …)
- Digital Television: DVB (T,S,H)
- Cellular systems: GSM/UMTS/LTE
- Long range systems: digital radio links
- Medium range systems: Wi-Fi, WiMAX
- Short range systems: Wireless sensor networks Zigbee, Bluetooth, Ultrawideband, RFID

wireless

5 Key quantities for digital communication systems

1. **Bit-rate** R_b [bit/s]
2. **Bandwidth** B [Hz]
3. **Power** P [W]
4. **Error Rate**
5. **Complexity** [€,W,m^3,…]

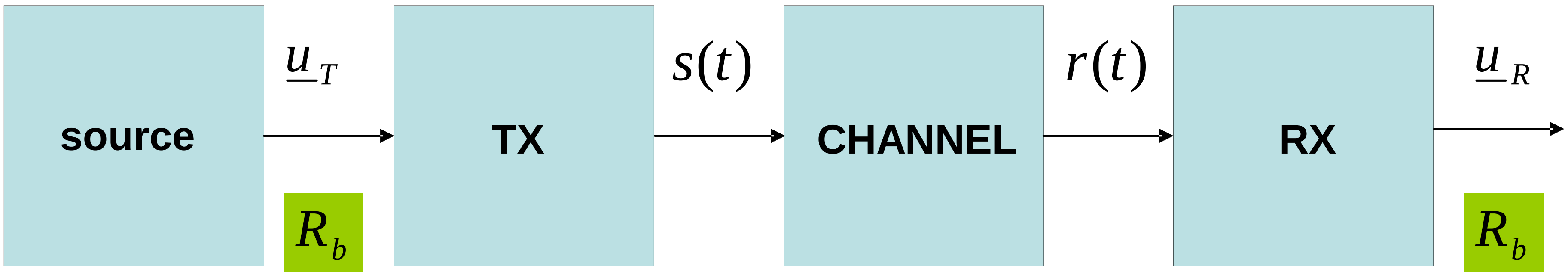


$\underline{u}_T$	Transmitted binary information sequences
$s(t)$	Transmitted signal (waveform)
$r(t)$	Received signal (waveform)
$\underline{u}_R$	Received binary information sequences

1 - Bit-rate R_b [bps]

Binary information sequences are characterized by their "speed"

→ **Bit-rate** = number of bits transmitted in a second [bit/s, bps]



Examples of bit-rate:

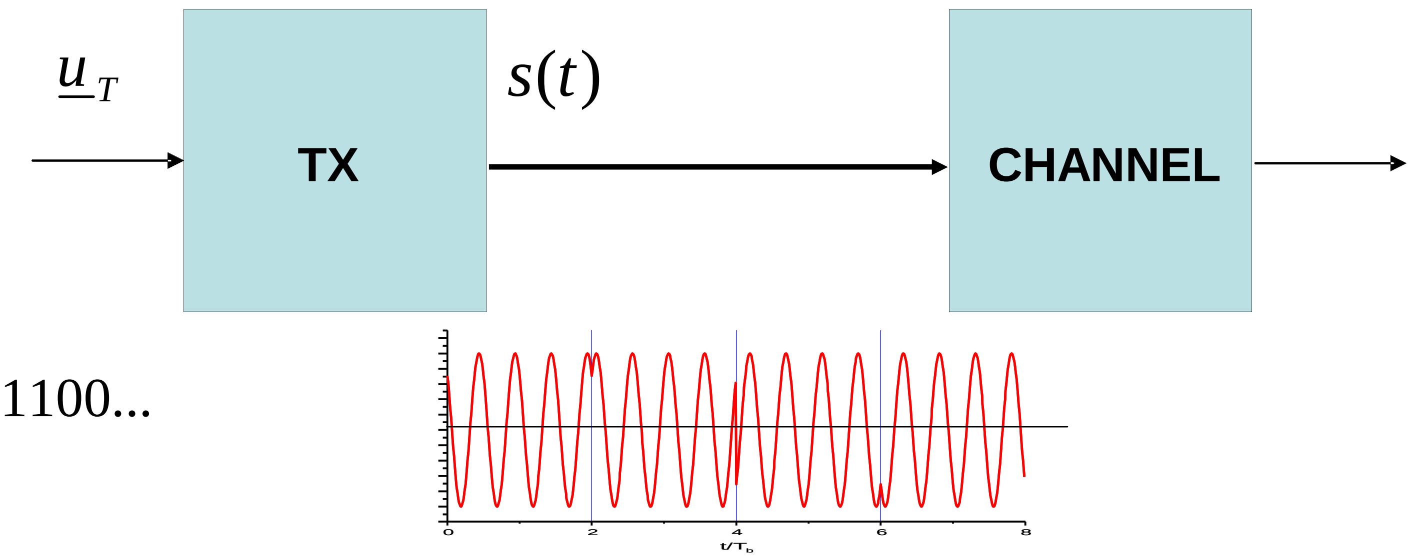
- xDSL: up to tens of Mbps
- Ethernet: up to 100 Gbps
- Optical Fiber modems: up to Terabps
- GSM: 9600 bps/UMTS: some Mbps/LTE: hundreds of Mbps
- DVB (S,T): tens of Mbps
- Wi-Fi: tens/hundreds of Mbps, WiMAX: hundreds of Mbps
- GPS/Galileo: bps

2 – Bandwidth B [Hz]

A KEY ASPECT. A binary information sequences is a sequence of bits.

To be transmitted over a wireless or wired channel, it must be transformed into a physical waveform: the **transmitted signal** $s(t)$

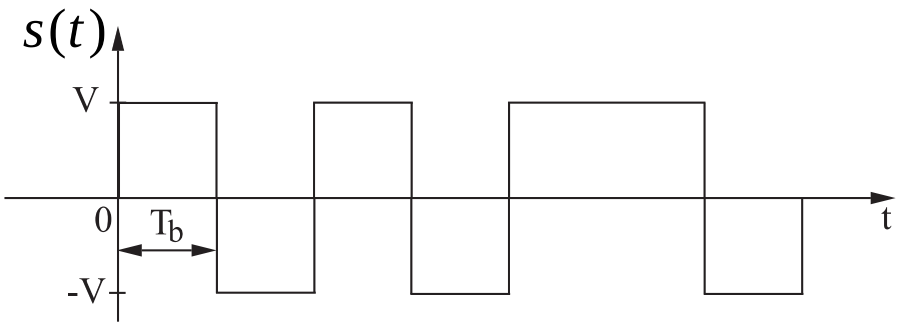
[a voltage evolving in time]



$\underline{u} = 01100...$

Simplest example of association $\underline{u}_T$ → $s(t)$ (bipolar NRZ):

$$\underline{u}_T = \quad 1 \quad 0 \quad 1 \quad 0 \quad 1 \quad 1 \quad 0$$



Bit 1: voltage +V for $T_b = 1/R_b$ s

Bit 0: voltage –V for $T_b = 1/R_b$ s

binary information sequences

⇩

transmitted signal $s(t)$

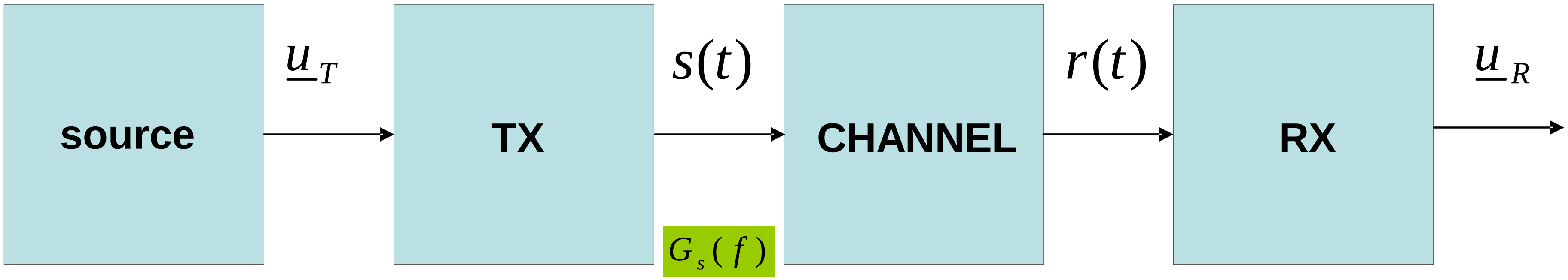
⇩

s(t) is characterized by a given behavior on the frequency axis

→ **power spectral density (spectrum)** $G_s(f)$

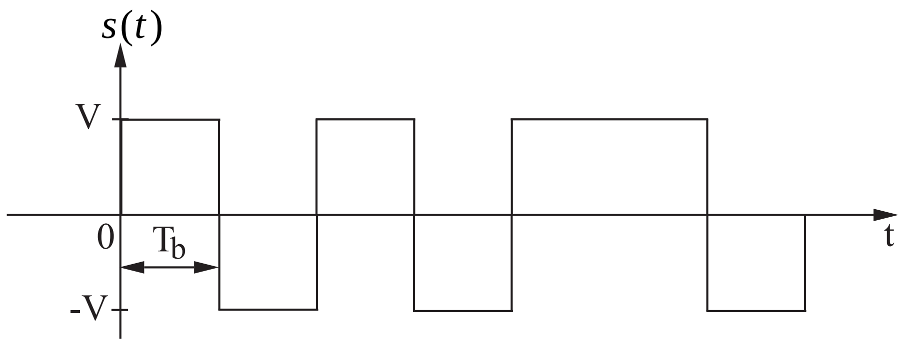
[distribution of the power on the frequency axis, will be fully addressed later]

$$\text{power } P_s = \int_{-\infty}^{+\infty} G_s(f)\,df$$



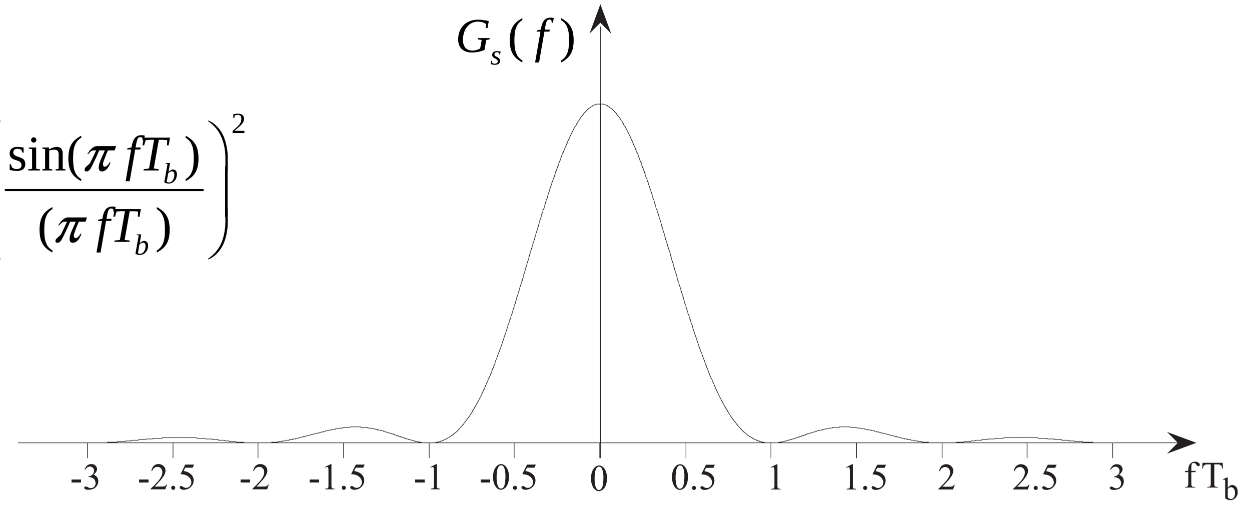
NRZ example

Transmitted waveform (time behavior)

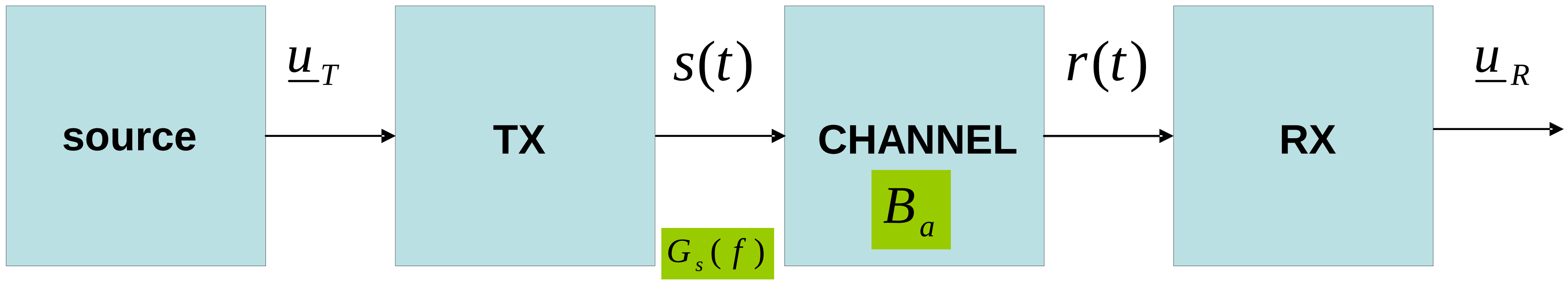


Power spectral density (frequency behavior)

$$G_s(f) = \alpha \left(\frac{\sin(\pi f T_b)}{(\pi f T_b)} \right)^2$$



CHANNEL AVAILABLE BANDWIDTH B_a [Hz]



Any channel is characterized by an **available bandwidth** B_a**:**

“most of” the spectrum $G_s(f)$ must be contained within B_a.

Two typical reasons:

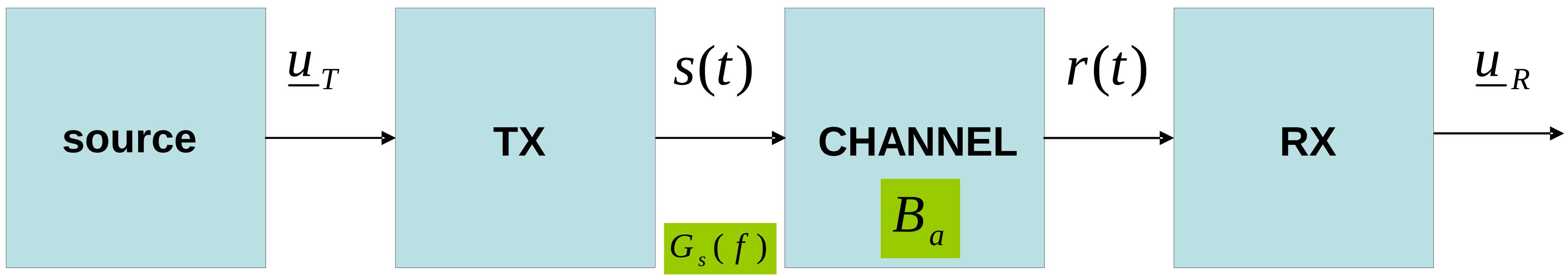
Out of B_a, channel frequency response is very bad. Typical for **wired channels**: the transmission medium (the cable) is completely dedicated to the communication system: in line of principle we could use all the frequencies, but we choose to limit them at a given maximum frequency because at higher frequencies the cable response is too bad (cables have a low-pass frequency response).

Out of B_a, other systems are transmitting on adjacent bands. Typical for **wireless channels**: many users sharing the same transmission medium (the air). Each system has a pre-assigned limited available band and it cannot disturb the systems transmitting on the other bands.

Examples of available bandwidths:

- xDSL: 0 to some MHz (1.1 for ADSL, 2.2 for ADSL2+, 8/17 for VDSL)
- UMTS: 5 MHz bands around 1800 MHz

CHANNEL AVAILABLE BANDWIDTH B_a [Hz]



Design of the transmitted signal $s(t)$

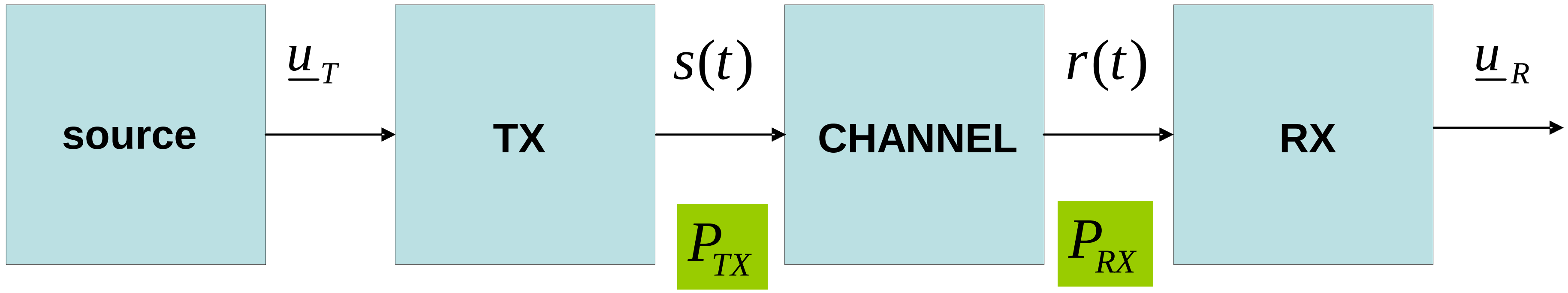
"Most of" its spectrum $G_s(f)$ must be contained within the channel available bandwidth B_a.

[This will be one of the main scopes of the course]

3 – Power P [W, dBm]

TRANSMITTED POWER $P_{TX}(t)$

RECEIVED POWER $P_{RX}(t)$



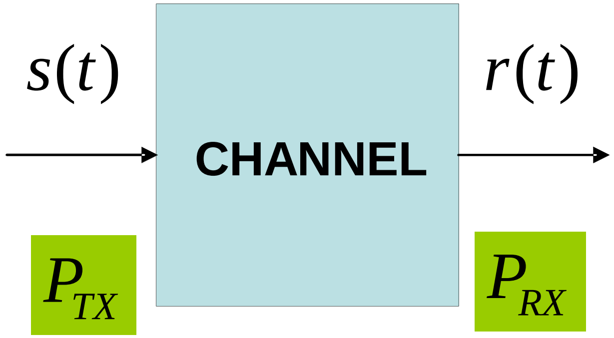
Transmitted power is limited by a number of factors

- Avoid interference with adjacent channels
- EM compatibility
- Max power transmitted by a device working at that frequency
- Total power (battery)
- Linearity constraints

Received power is connected to transmitted power (distance, frequency, environment,system,….)

Example: Line of Sight wireless link

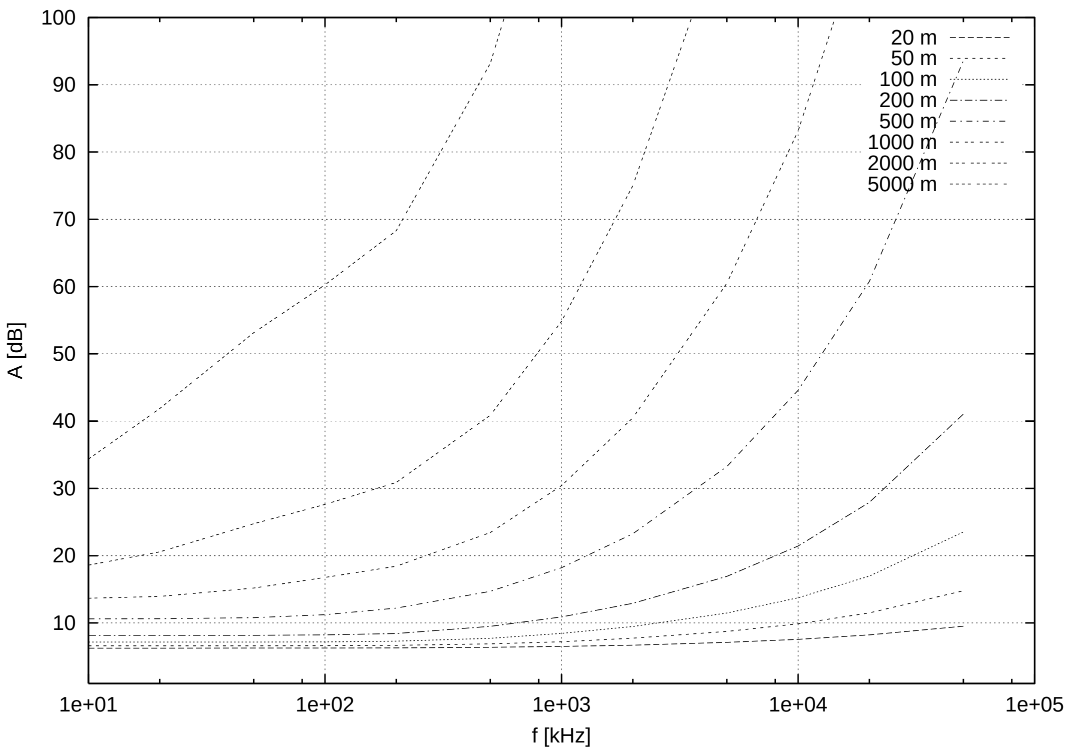
$$P_R = P_T \frac{G_T G_R}{\left(\frac{4\pi d}{\lambda}\right)^2}$$

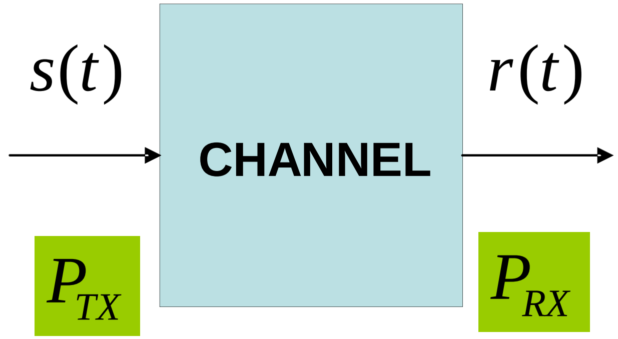


Received power is connected to transmitted power (distance, frequency, environment,system,….)

Example: copperline frequency response

$$P_R = \frac{P_T}{A}$$





attenuation increases with frequency and line length

Received power and noise power determines the **SIGNAL-TO-NOISE RATIO**

$$SNR = \frac{P_{RX}}{P_N}$$

As we will see (rather obvious), system performance increases with the SNR. The higher the SNR and the better the performance.

Very used parameter for system evaluation: **SENSITIVITY**: minimum received power where the system still achieves the required performance.

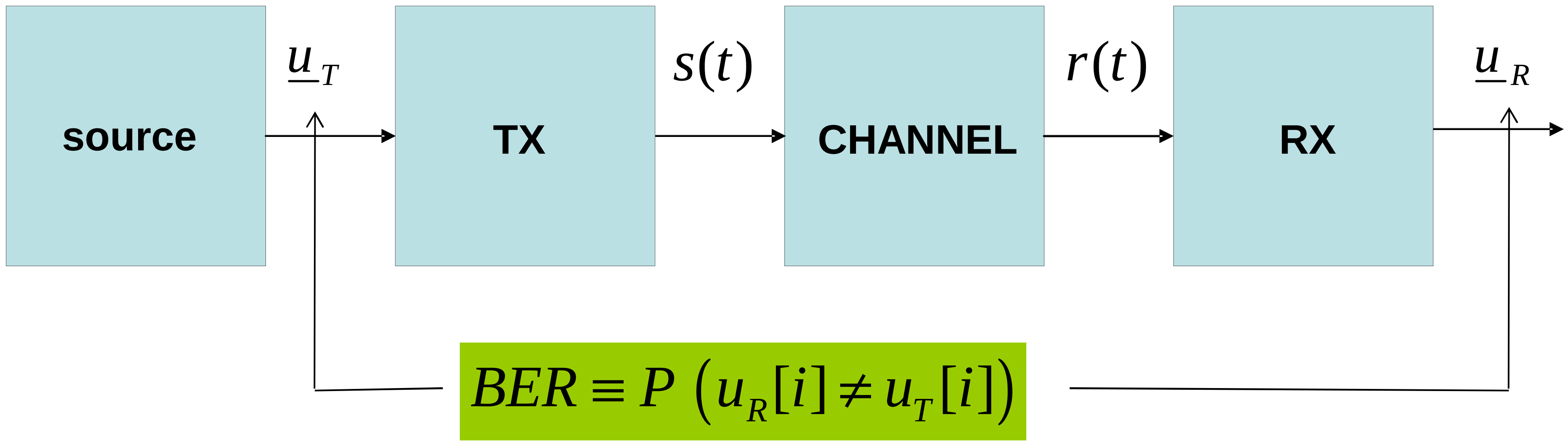
4 – Error rate

When transmitted over the channel, the waveform is changed. Main reasons:

- Channel frequency response
- Noise

$\longrightarrow \quad r(t) \neq s(t)$

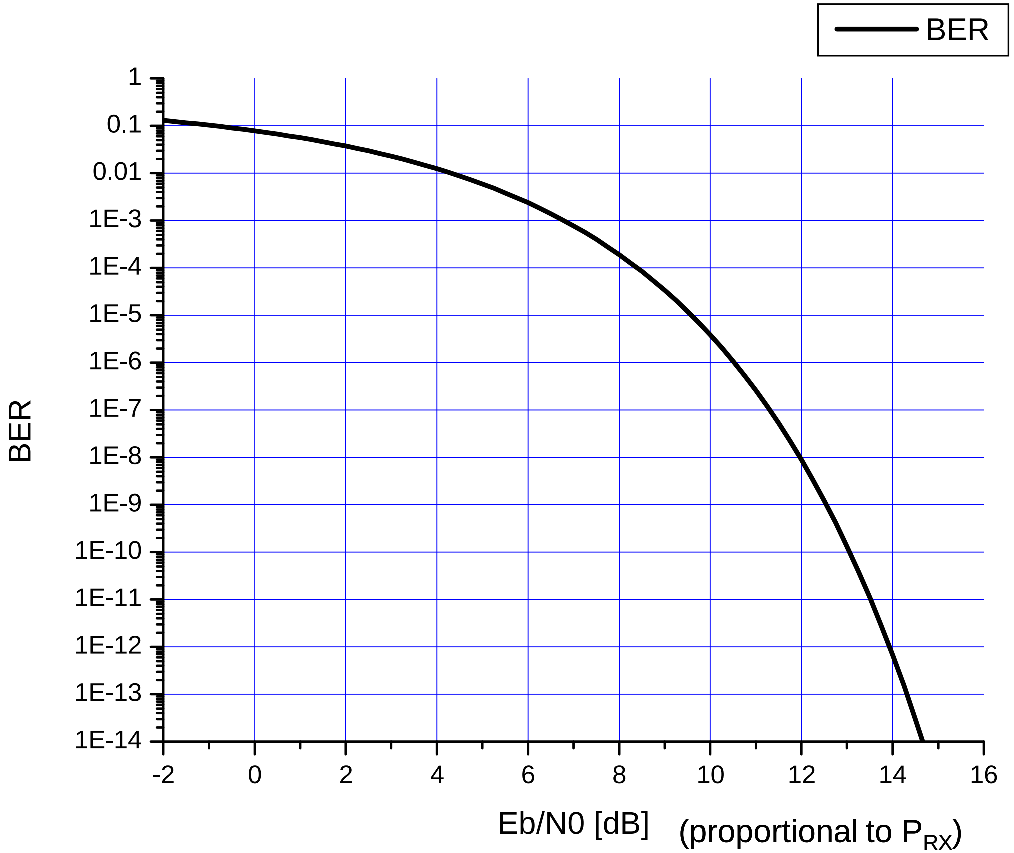
As a consequence we may have $\underline{u}_R \neq \underline{u}_T$



Is the probability than an information bits is received wrong

4 – Error rate

We will describe the error rate performance by curves like this one, where the Bit Error rate is represented as a function of the received power:

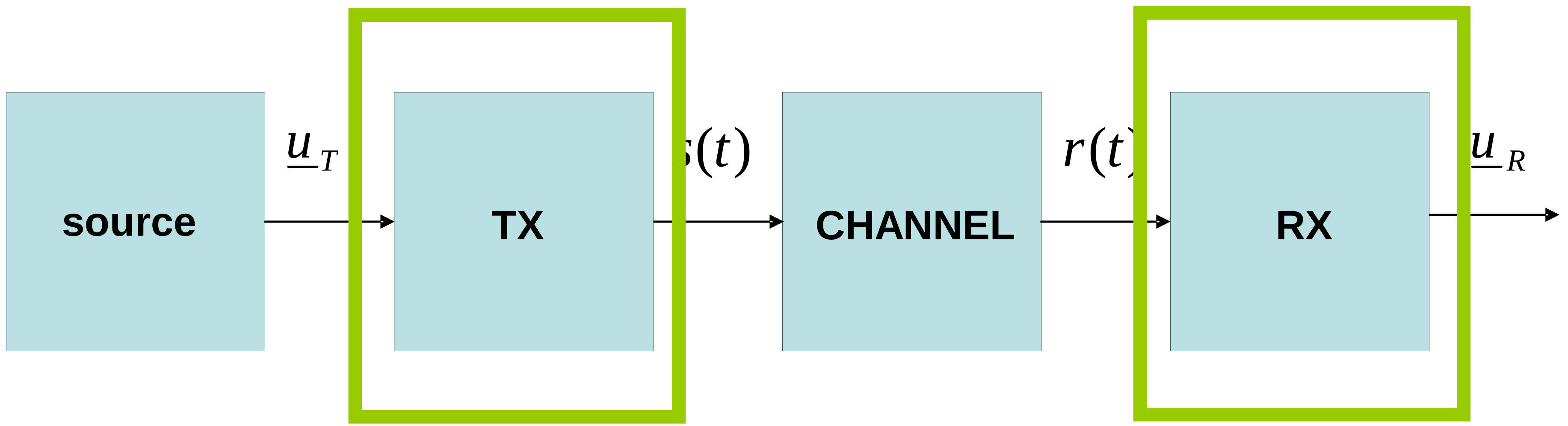


(proportional to P_{RX})

Modern systems require very low BER values (ex: MPEG $\rightarrow$ BER$\cong 10^{-10}$)

5 – Complexity

Engineering complexity of practical implementation.
(Consumed power/space in some frameworks)



Other quantities

DELAY D [s]

Difference between time instants

the information bits

enter TX ⇒ exit RX

Other quantities

AVAILABILITY [s]

Number of seconds where the system achieves the required performance

Practical example

Given an AVAILABLE BANDWIDTH B_a=20 MHz, centered around f_0=18 GHz

Design a digital transmission system which

- **transmits a BIT-RATE R_b=34 Mbps**
- **guarantees at least BER = 10^{-7} for a received POWER S=-40 dBm**
- **with maximum DELAY D=5 ms**
- **with minimum COMPLEXITY (cost)**