Digital Communications
Introduction

1) Definitions
2) Propagation channel
3) Elements of the communication channel
4) Performance criteria

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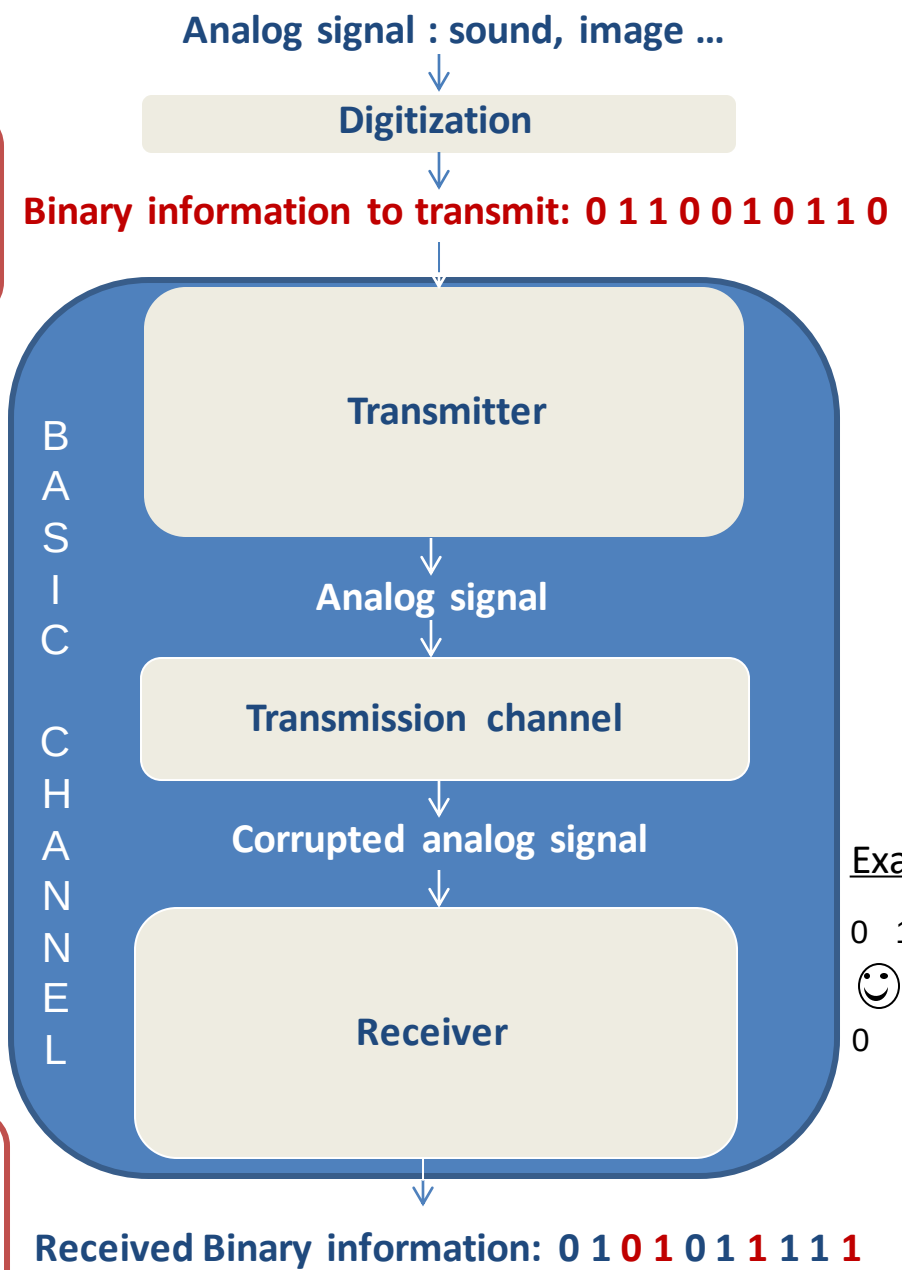
Basic digital transmission channel

Transmit a given bit rate Rb = Number of bits to be transmitted per second.

DVB example:
BER<10^{-10}, (QEF transmission)
Rb ~ 30 à 40 Mbps

Obtain a given Bit Error Rate:

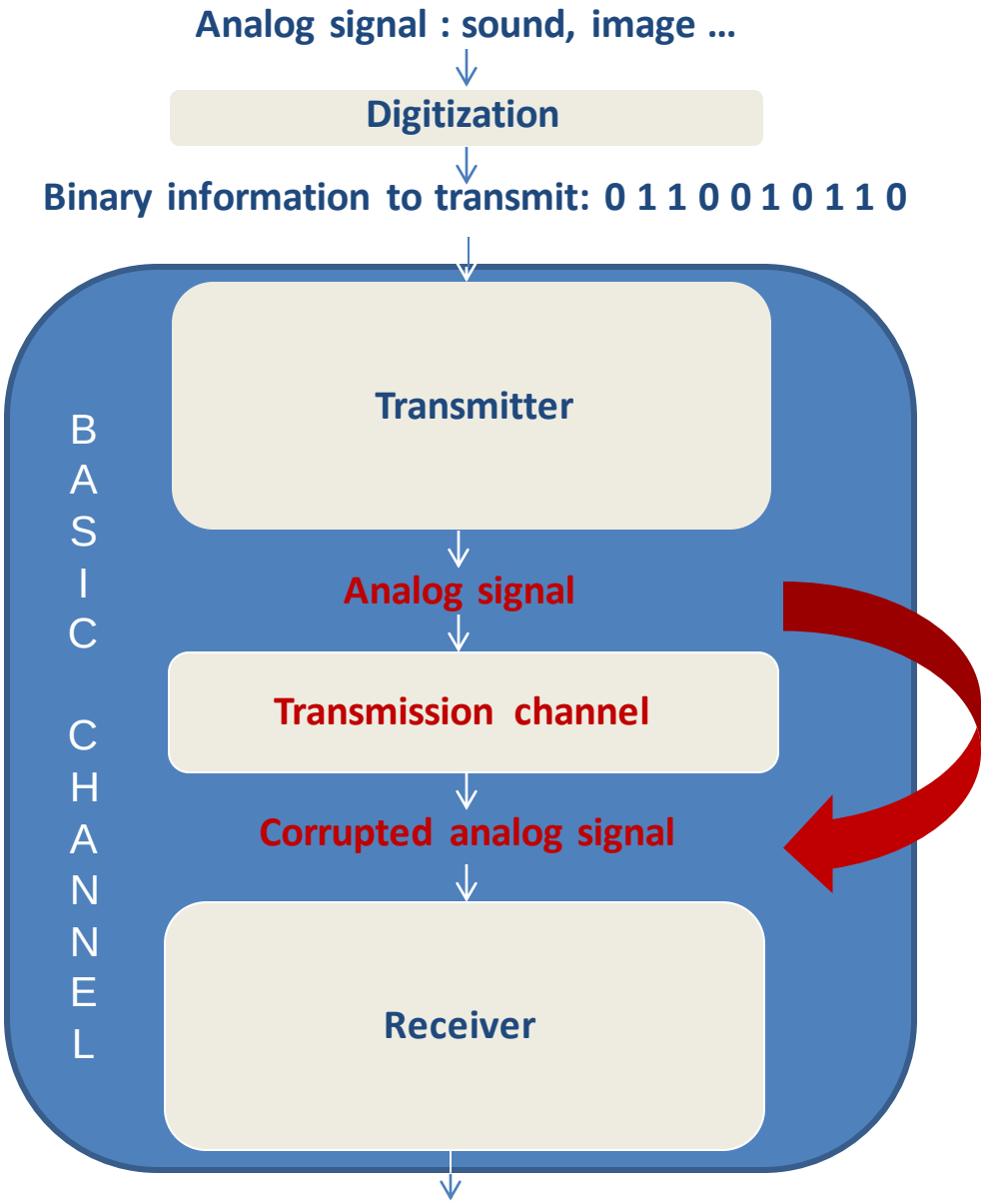
$$BER = \frac{\text{Number of erroneous bits}}{\text{Number of transmitted bits}}$$



Example:

BER = 4/10

Basic digital transmission channel



Propagation channel

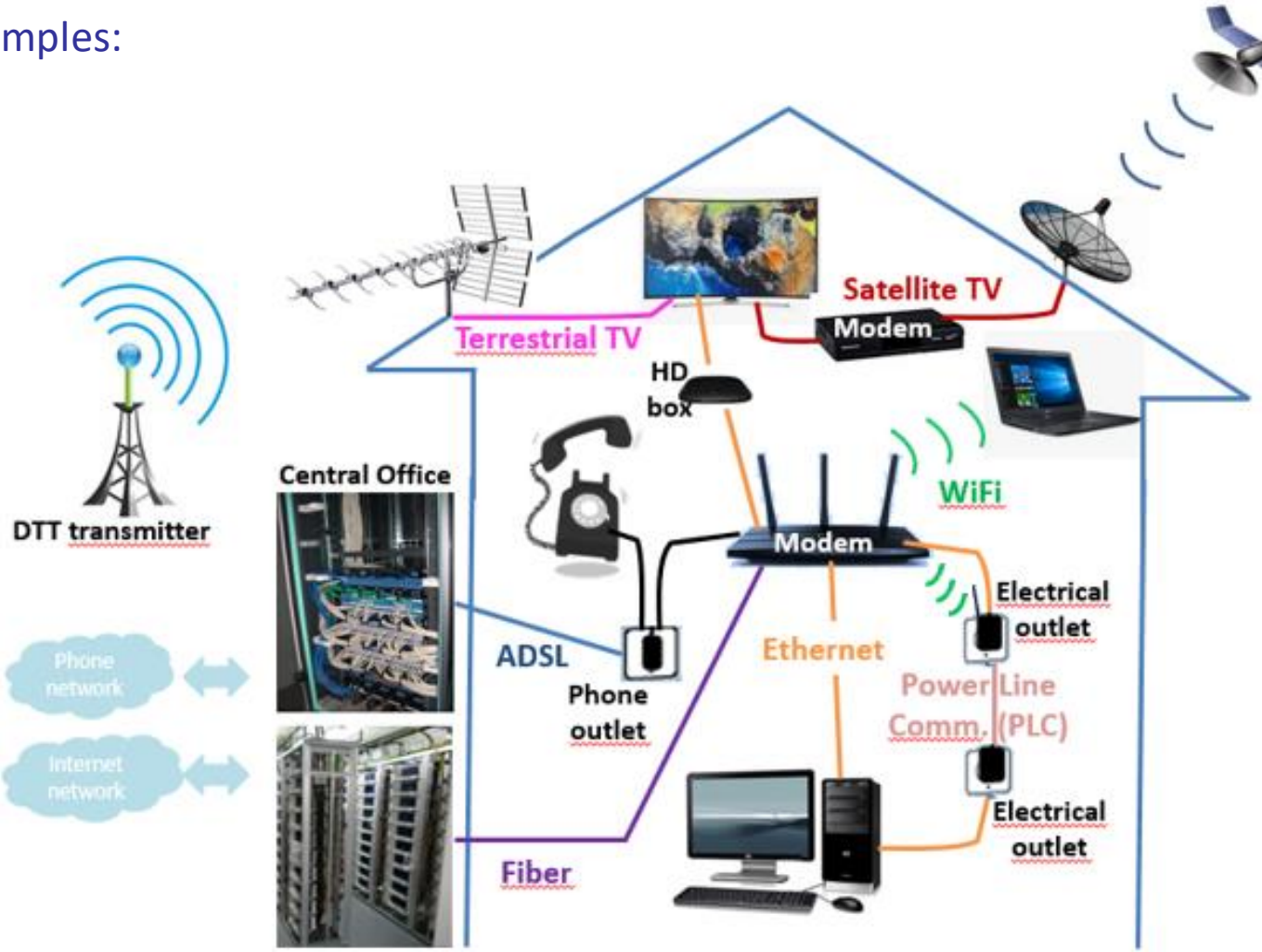
- Wired transmissions: xDSL, optical fiber, cable TV, power Line communications…

  ⇒ Propagation on copper, coaxial cables or optical fibers via electrical or optical signals .

- Wireless transmissions: WiFi, Terrestrial TV, Satellite transmissions, GSM, 3G, 4G …

  => Propagation in free space via radio (or Hertzian): frequencies < 3000 GHz

- Examples:



Copper

Coaxial cable

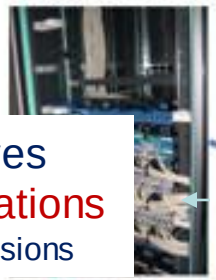
Fiber

Propagation channel
Telecommunication Standards / Recommandations

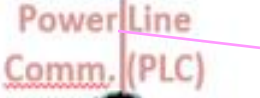
Radio waves, ETSI standards
VHF and UHF (470-862 MHz) frequency bands

Radio waves, ETSI standards
(European Telecommunications Standards Institute)
Transmission in bands
L : 1.4-1.6 GHz, C : 4-6GHz,
Ku : 10.7-12.45 GHz and Ka : 20-30 GHz

Radio waves, IEEE standards
(Institute of Electrical and Electronics Engineers)
Transmission in ISM (around 2,4 GHz) and UNII (around 5 GHz) bands



Electrical waves
ITU recommandations
Baseband transmissions



Electrical waves,
ITU recommandations
(International Telecommunication Union)
Transmission between 1,5 and 30 MHz

Electrical waves, IEEE standards
Baseband transmission

Optical waves,
ITU recommandations

Propagation channel : **distorsions/constraints**

- Attenuation of the transmitted signal

  Absorption, scattering due to atmospheric gases, to clouds, to rain, skin effect for cooper (Increases with increasing frequency),

- Baseband or carrier modulated transmission

- Shared communication channel

  → Multiplexing methods, regulation agencies.

- Noise

  → External noise = other signals received in addition to the useful communication signal.

  → Internal Noise = due to electronic devices/components inside the receiver.

- One or several paths between the transmitter and the receiver

  => flat fading or frequency selective channel

- Limited allocated bandwidth

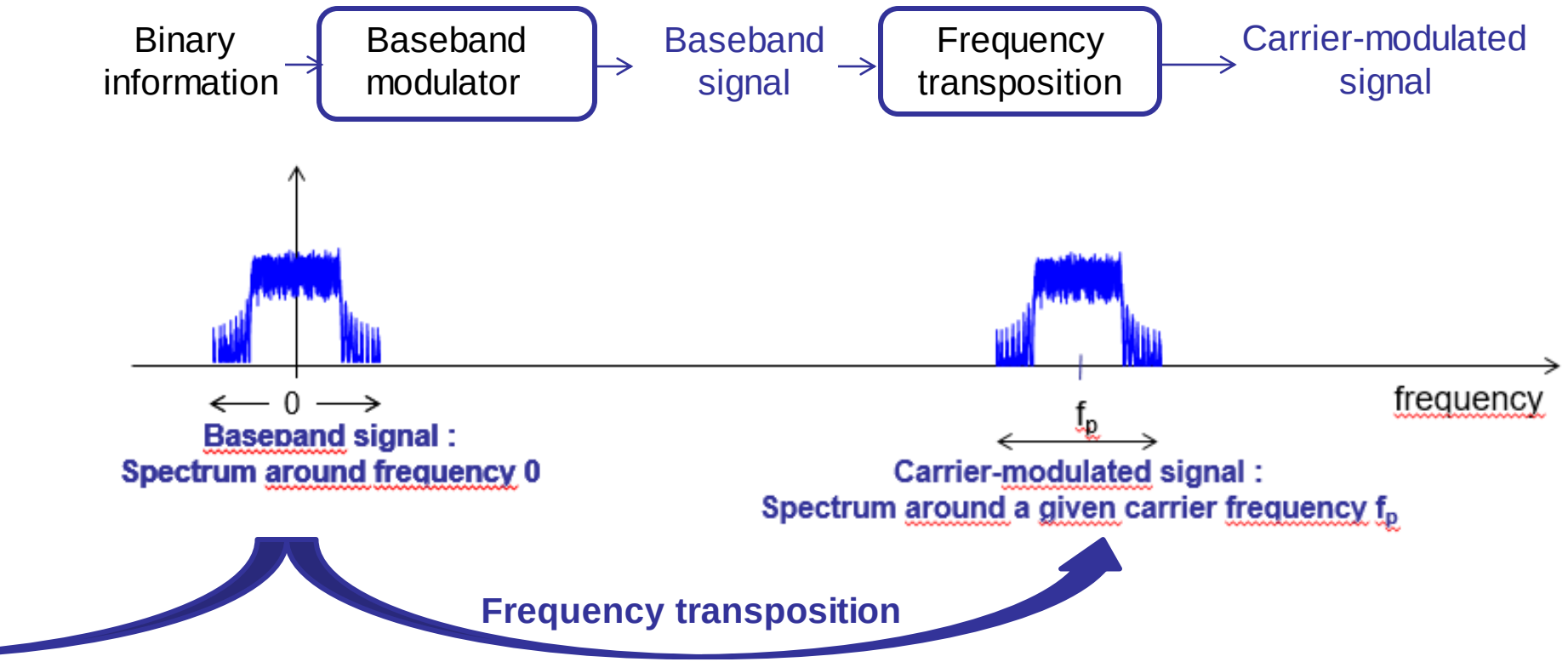
- Fixed or Mobile transmission

  => stationnary or non stationnary channel

Attenuation effect on a DVB-S transmission
(absorption, scattering due to atmospheric gases, clouds and rain)

Propagation channel

Baseband or carrier modulated transmission



Example of a fixed satellite DVB-S transmission DVB-S :

Propagation in bands

L : 1.4-1.6 GHz, C : 4-6 GHz, Ku : 10.7-12.45 GHz and Ka : 20-30 GHz

Shared propagation channel : **frequencies regulation**

- Depending on the countries : regulatory agencies or a ministries

Examples :

→ In France : ARCEP (Autorité de Régulation des Communications Electroniques), ANRT (Agence Nationale de Régulation des Fréquences), CSA (Conseil Supérieur de l'Audiovisuel)

→ In the United States of America : FCC (Federal Communications Commission)

→ In Japan: MIC (Ministry of Internal Affairs and Communications)

- Collaborations between states:

Examples :

→ ORECE : Organe des Régulateurs Européens des Communications Electroniques in Europ,

→ NARUC : National Association of Regulatory Utility Commissioners (regulators of individual states) in the United States,

→ ARTAC : Association des Régulateurs de Télécommunications de l'Afrique Centrale, in Africa,

- International Telecommunication Union (ITU)

→ Responsible for the telecommunications regulation in the world

→ 193 member states and 700 associated members (from Information and Communication Technology sector).

→ Forum in which the states and the private sector coordinate together.

- Unlicensed bandwidth

→ industrial, scientific and medical (ISM) : (902-928 MHz, 2.400-2.4835 GHz)

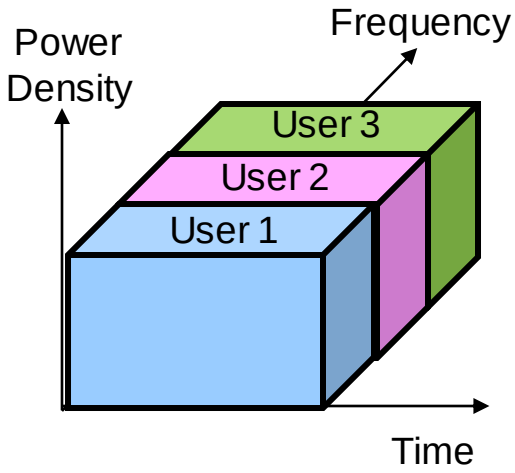
→ Unlicensed National Information Infrastructure (UNII) : 5 .15-5.25 GHz, 5 .25-5.35 GHz

→ UNII-3/ISM : 5.725-5.850 GHz

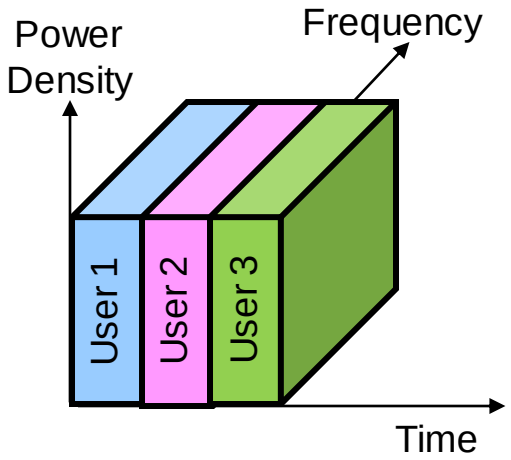
Shared propagation channel : **Multiplexing methods**

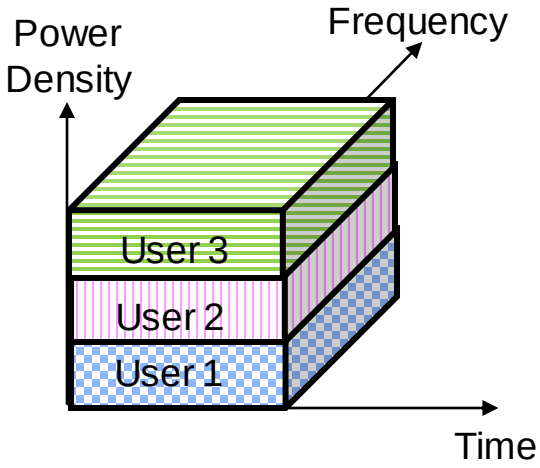
→ Examples of multiplexing methods

FDM
(Frequency Division Multiplexing)

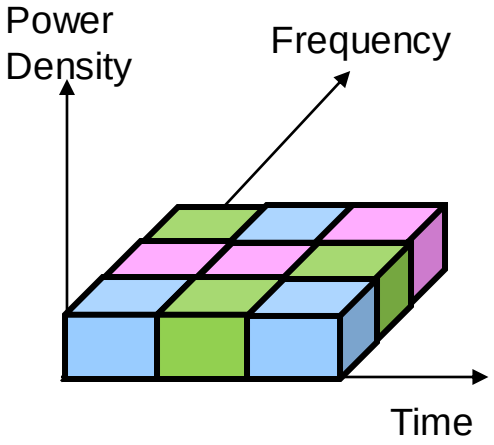


TDM
(Time Division Multiplexing)



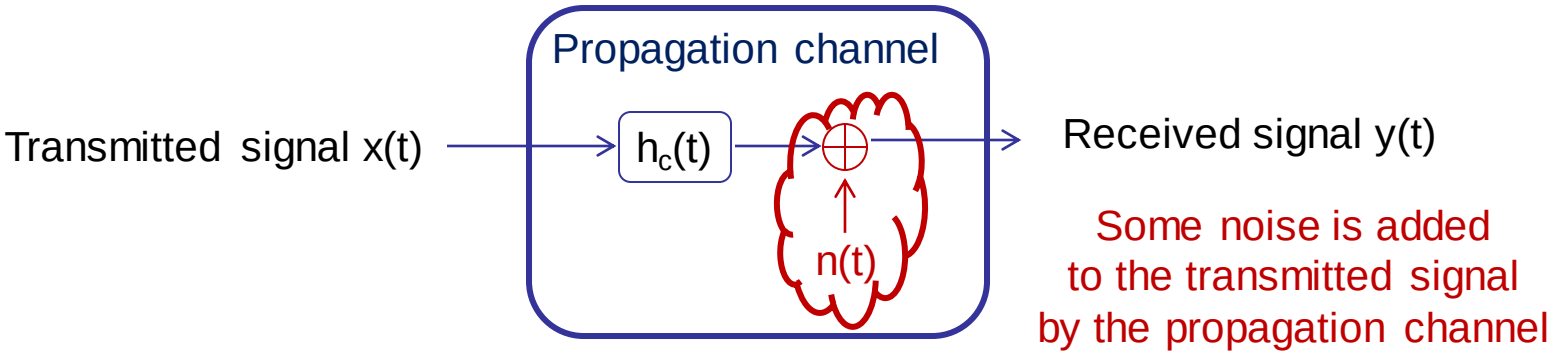


CDM
(Code Division Multiplexing)



MF-TDM
(Multi Frequency - Time Division Multiplexing)

Propagation channel : **Additive noise**



- Noise characteristics :

→ White noise, with PSD = $N_0/2$ whatever is the frequency, with $N_0=k(T_e+T_i)$
- k = Bolztmann constant
- T_e = external noise temperature
- T_i = internal noise temperature

→ Gaussien Noise, with power σ^2

→ Added at the receiver input, assuming then that its components are ideal,

→ A dégradation measurment: the Signal to Noise Ratio or SNR

$$SNR_{dB} = 10 \log \frac{P_{useful\ signal}}{P_{noise}}$$

Propagation channel

Example of free space propagation for fixed satellite telecommunication systems

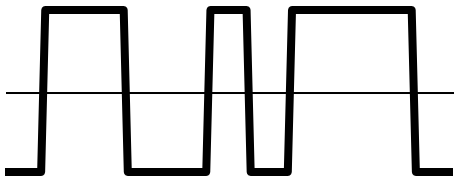
→ Additive noise:

- → Other signals received in addition to the useful communication signal.
  - – Coming from natural sources: atmosphere (storm, lightning, thunder), earth, sky (sun, milky way)
  - – Coming from artificial sources: human activity.
- → Electronic devices in the receiver: amplifiers, antenna, etc.

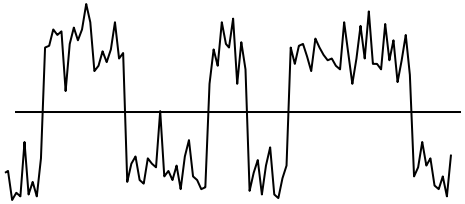
→ Examples of introduced distorsions

Examples :

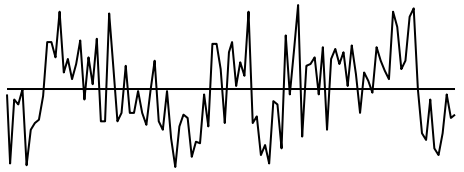
NRZ-type transmitted signal



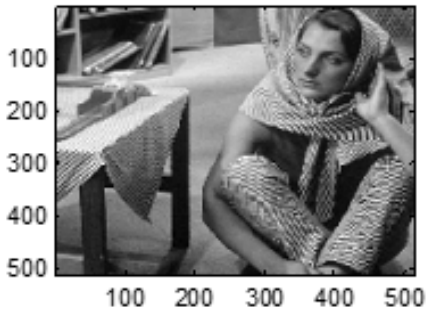
Noisy signal, SNR_{dB} = 10 dB



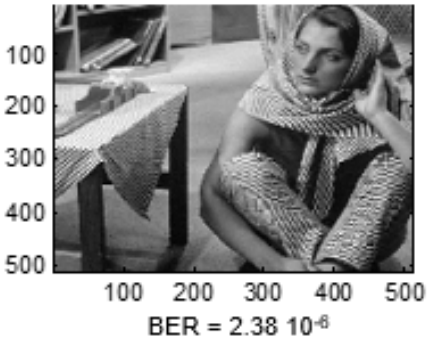
Noisy signal, SNR_{dB} = 0 dB



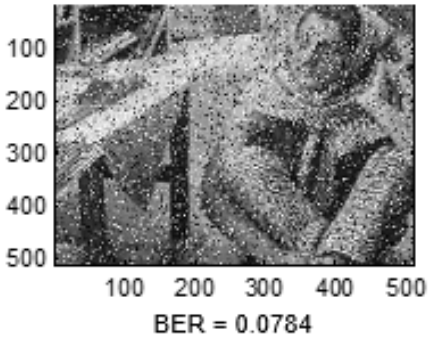
Transmitted image



Received image, SNR_{dB} = 10 dB



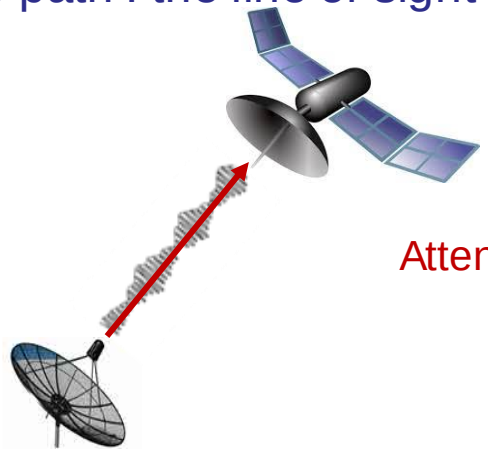
Received image, SNR_{dB} = 0 dB



Propagation channel

One or several paths between the transmitter and the receiver

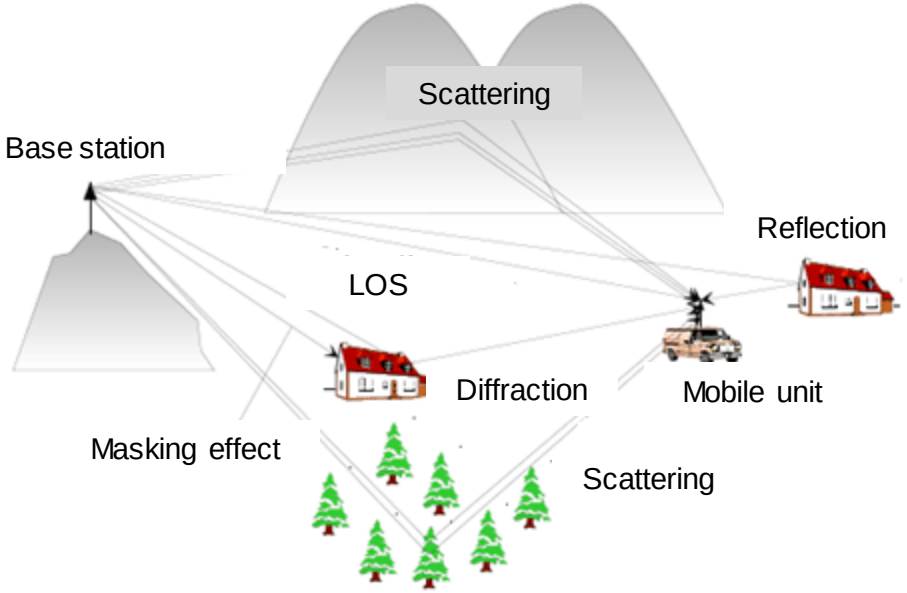
- Only one path : the line of sight (LOS) between the transmitter and the receiver



Attenuation and delay introduced by the channel

$$y(t) = \alpha\, x(t-\tau)+n(t)$$

- Several paths between the transmitter and the receiver (« multi-paths » channel)



Several attenuations and delays introduced by the channel

$$y(t) = \sum_{k=0}^{N-1} \alpha_k\, x(t-\tau_k)+n(t)$$

Propagation channel

One or several paths between the transmitter and the receiver

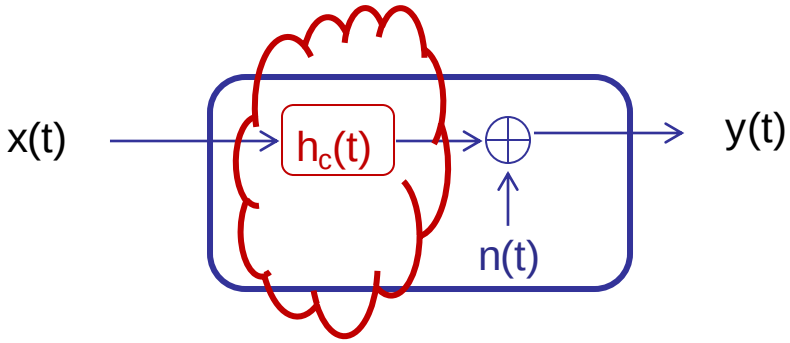
- Only the line of sight between the transmitter and the receiver

$$y(t) = \alpha x(t-\tau) + n(t) = \alpha \delta(t-\tau) * x(t) + n(t)$$

- Severals paths between the translitter and the receiver (« multi-paths » channel)

$$y(t) = \sum_{k=0}^{N-1} \alpha_k x(t-\tau_k) + n(t) = \sum_{k=0}^{N-1} \alpha_k \delta(t-\tau_k) * x(t) + n(t)$$

- Propagation channel model

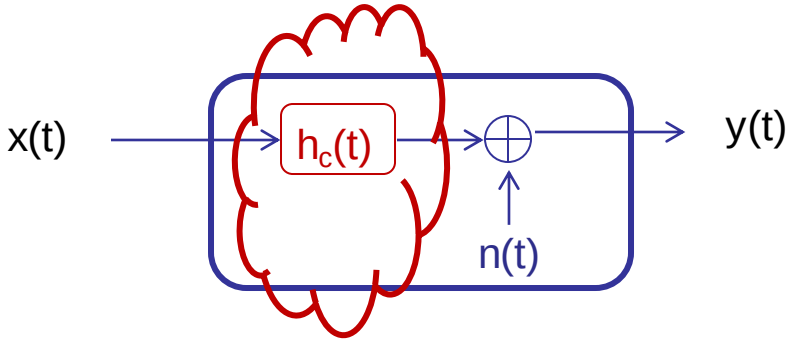


The transmitted signal is filtered by the propagation channel

Propagation channel

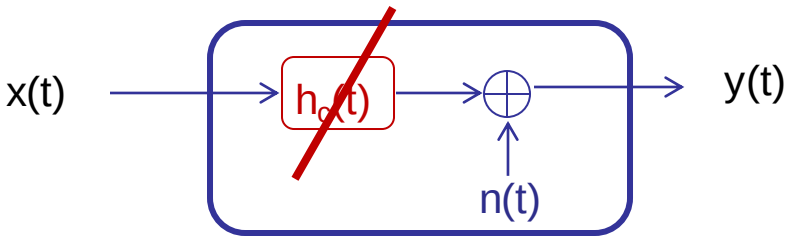
One or several paths between the transmitter and the receiver

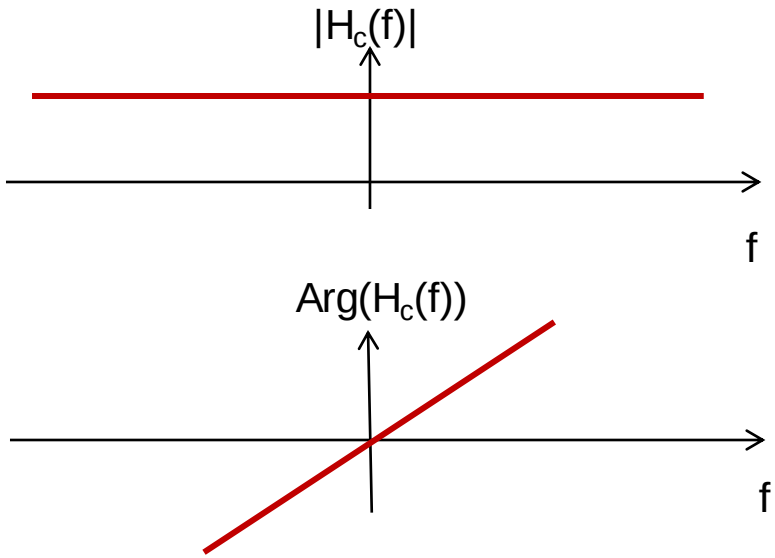
- Propagation channel model



The transmitted signal is filtered
by the propagation channel

- AWGN (Additive White Gaussian Noise) channel



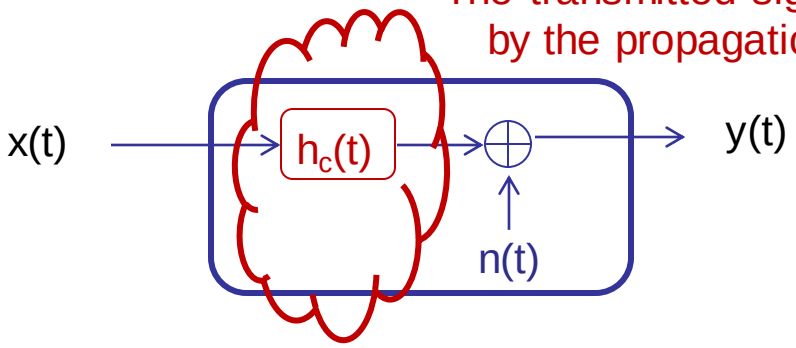


Propagation channel

One or several paths between the transmitter and the receiver

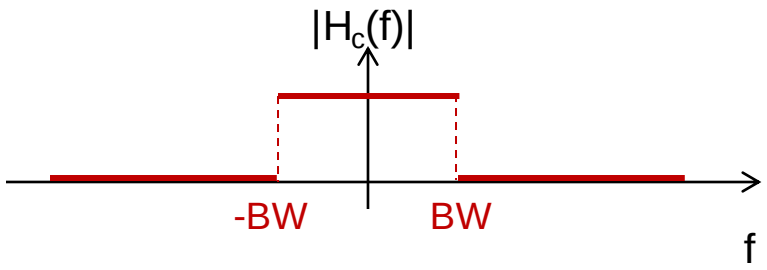
- Propagation channel model

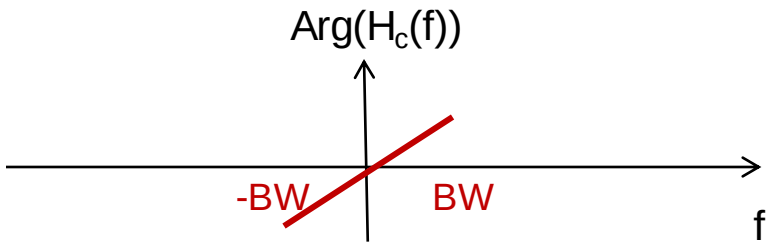
The transmitted signal is filtered by the propagation channel



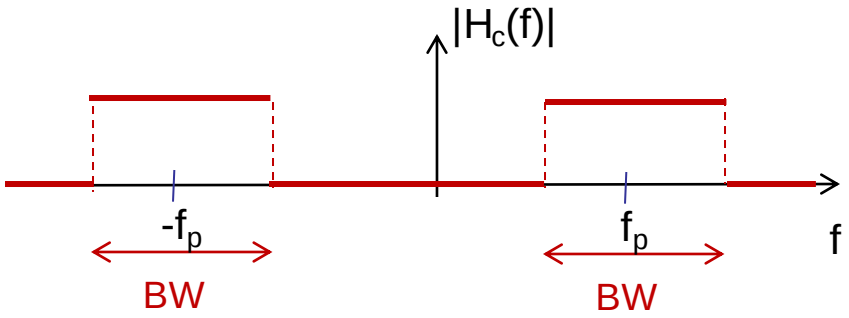
- Limited bandwidth AWGN channel

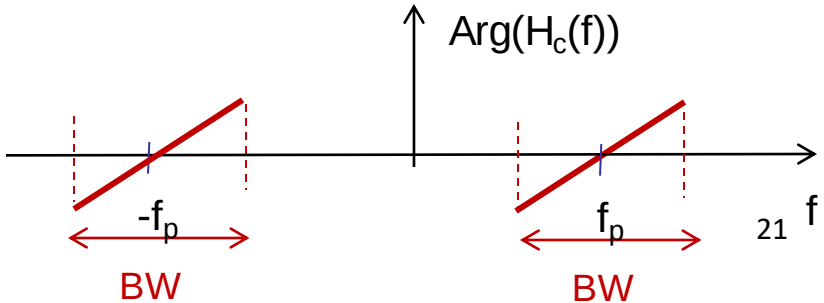
Baseband transmission:





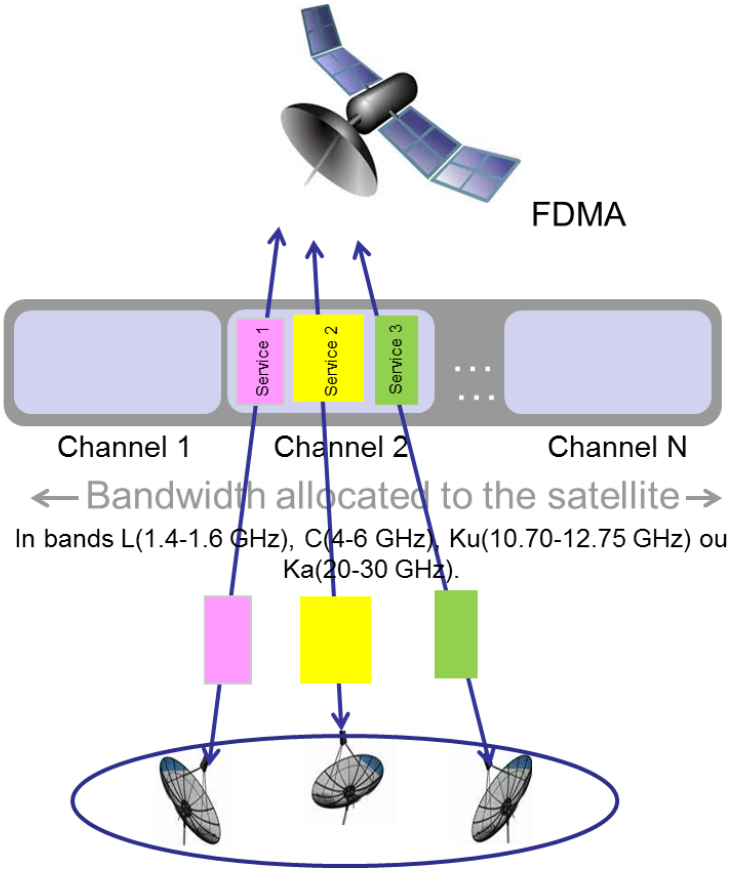
Carrier modulated transmission:

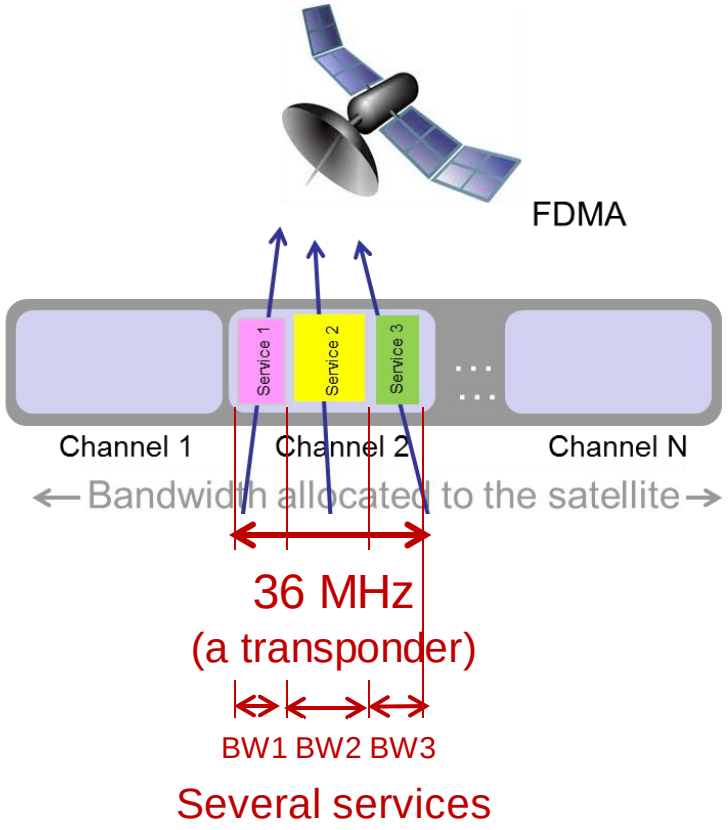




Propagation channel

Example of a band limited AWGN channel: DVB-S fixed satellite transmission



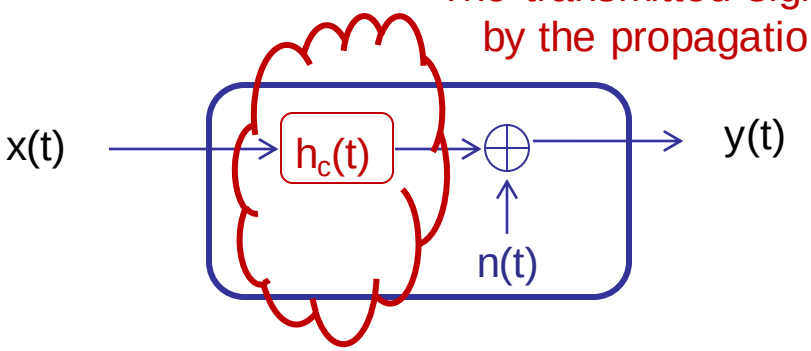


Propagation channel

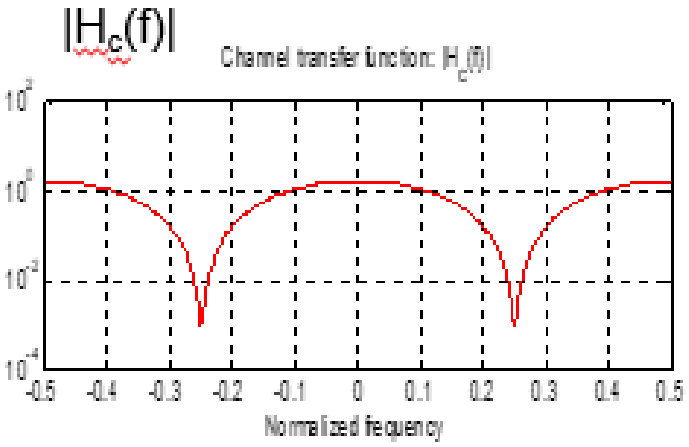
One or several paths between the transmitter and the receiver

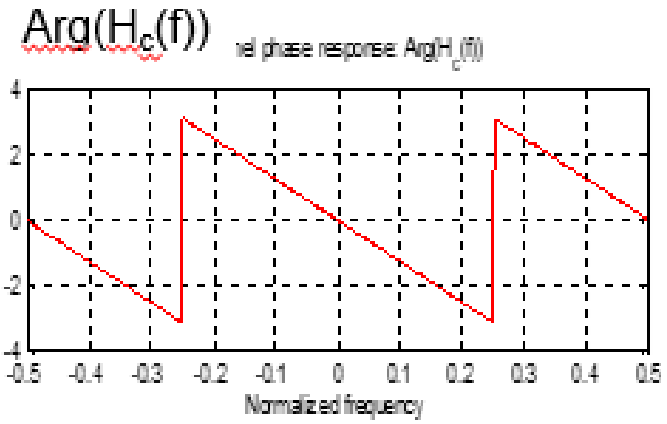
- Propagation channel model

The transmitted signal is filtered by the propagation channel



- Frequency selective channel

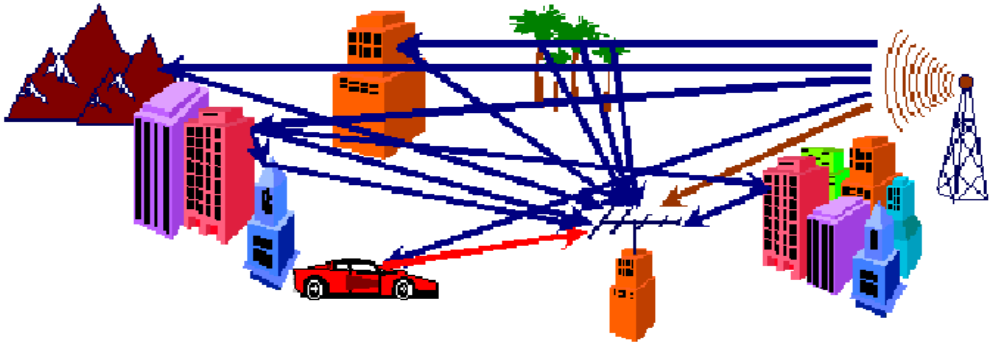




→ « Channel coherence bandwidth »: widest frequency band for which the channel can be considerated as « flat »

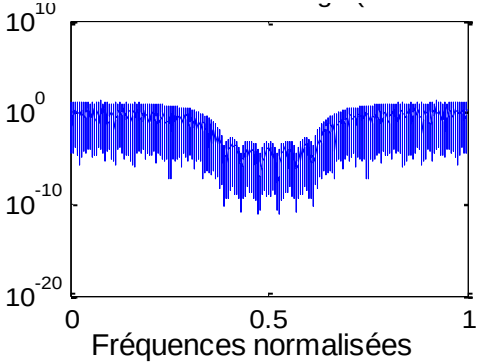
Propagation channel

Example of a frequency selective channel: DTV (DVB-T) transmission

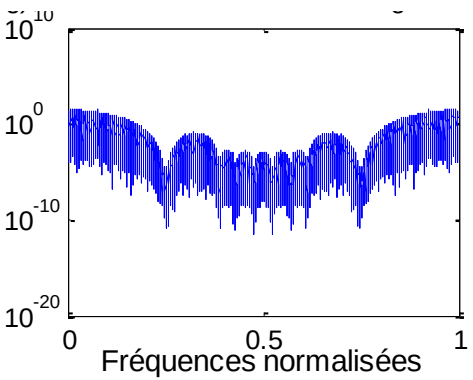


- Example of distorsions introduced by a frequency selective channel

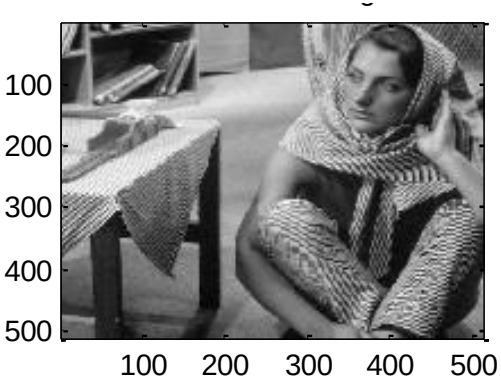
PSD of the transmitted signal:



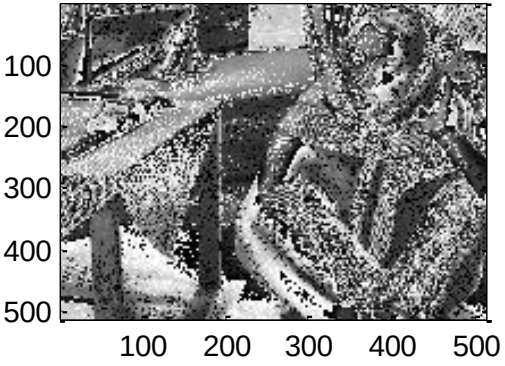
PSD of the received signal:



Transmitted image:

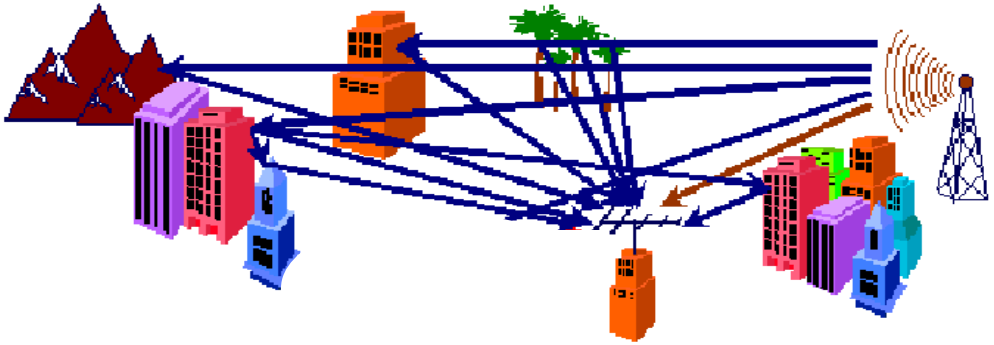


Received image:



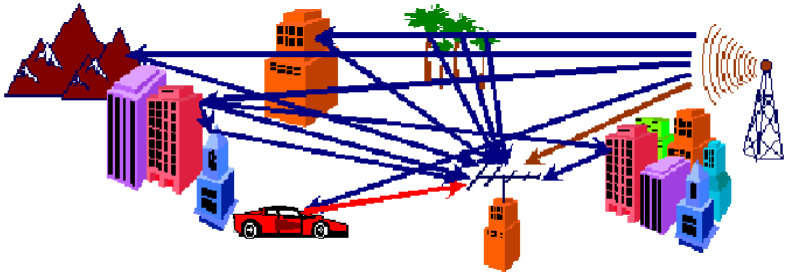
Propagation channel
Fixed or mobile transmission

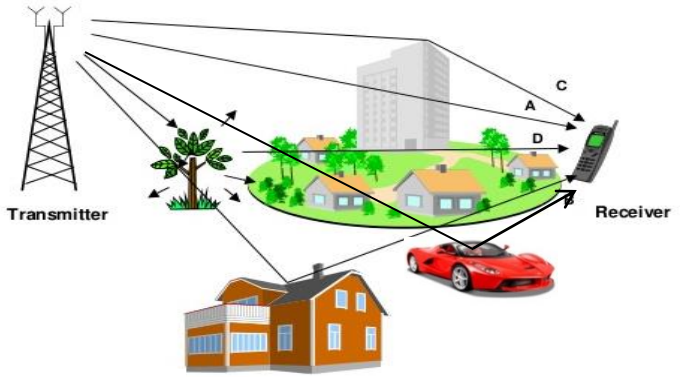
- Fixed transmission



$$y(t) = \sum_{k=0}^{N-1} \alpha_k x(t - \tau_k) + n(t)$$

- Mobile transmission

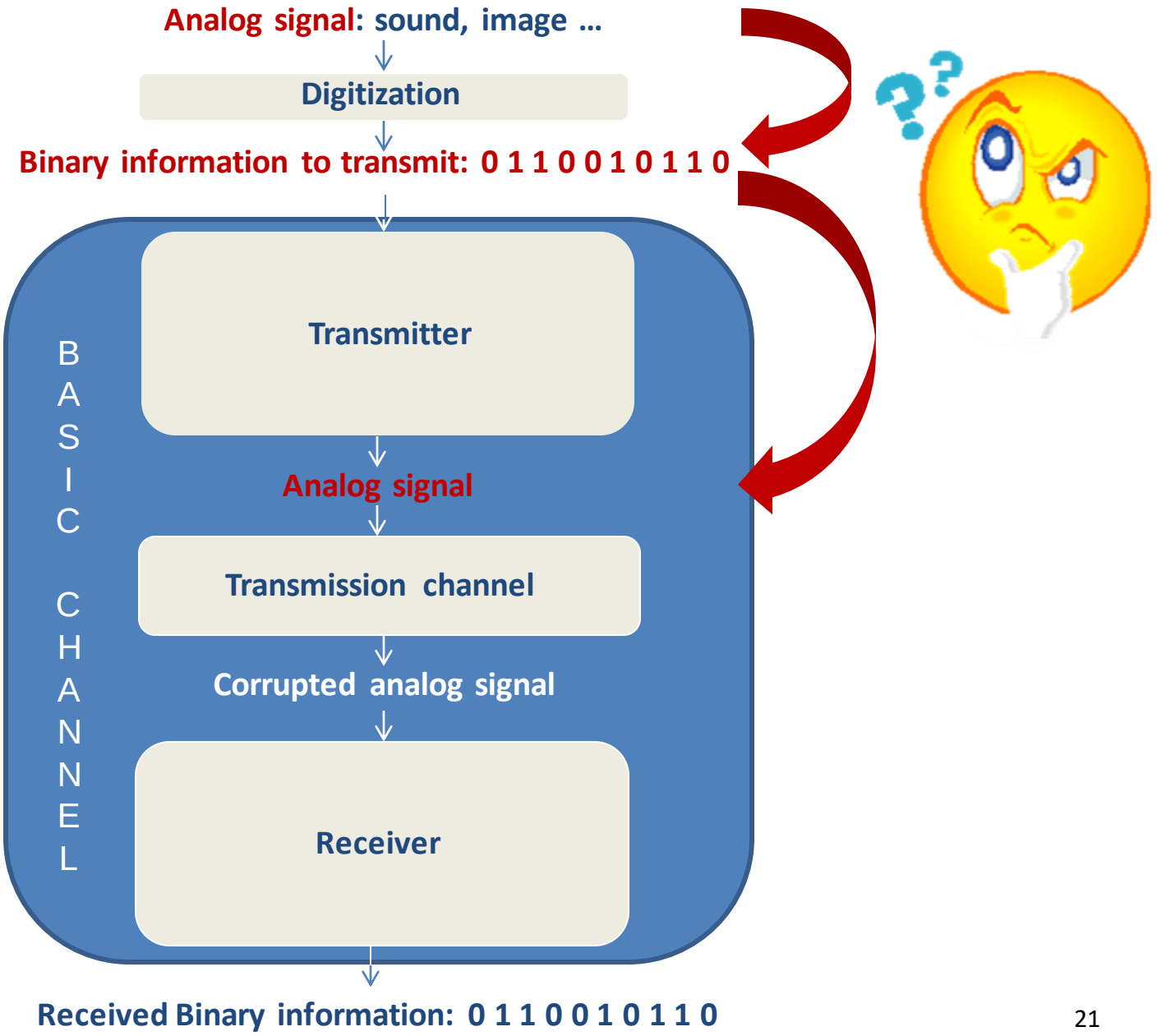




$$y(t) = \sum_{k=0}^{N-1} \alpha_k(t) x(t - \tau_k(t)) + n(t)$$

→ « Channel coherence time » : duration for which the channel impulse response can be considered as invariant (stationnary channel)

Basic digital transmission channel



Basic digital transmission channel

Analo Signal : sound, image ...

Digitization

Binary information to transmit: 0 1 1 0 0 1 0 1 1 0

BASIC CHANNEL

Transmitter

Analog signal

Transmission channel

Corrupted analog signal

Receiver

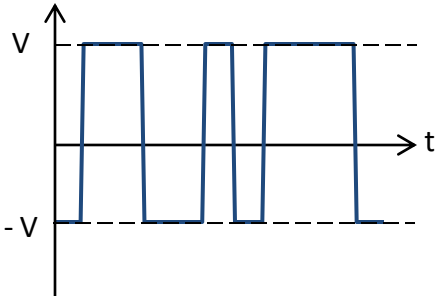
SNR

BER

Received binary information: 0 1 0 1 0 1 1 1 1 1

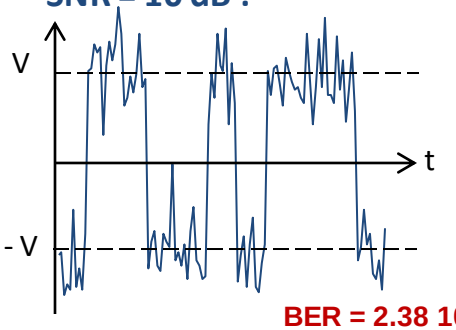
Example :

Analog signal:



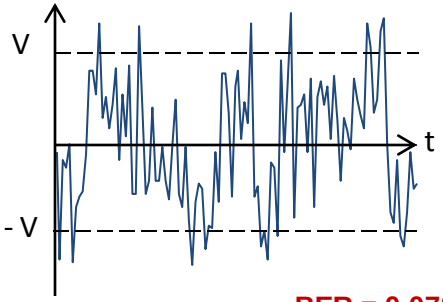
Corrupted analog signal:

SNR = 10 dB :



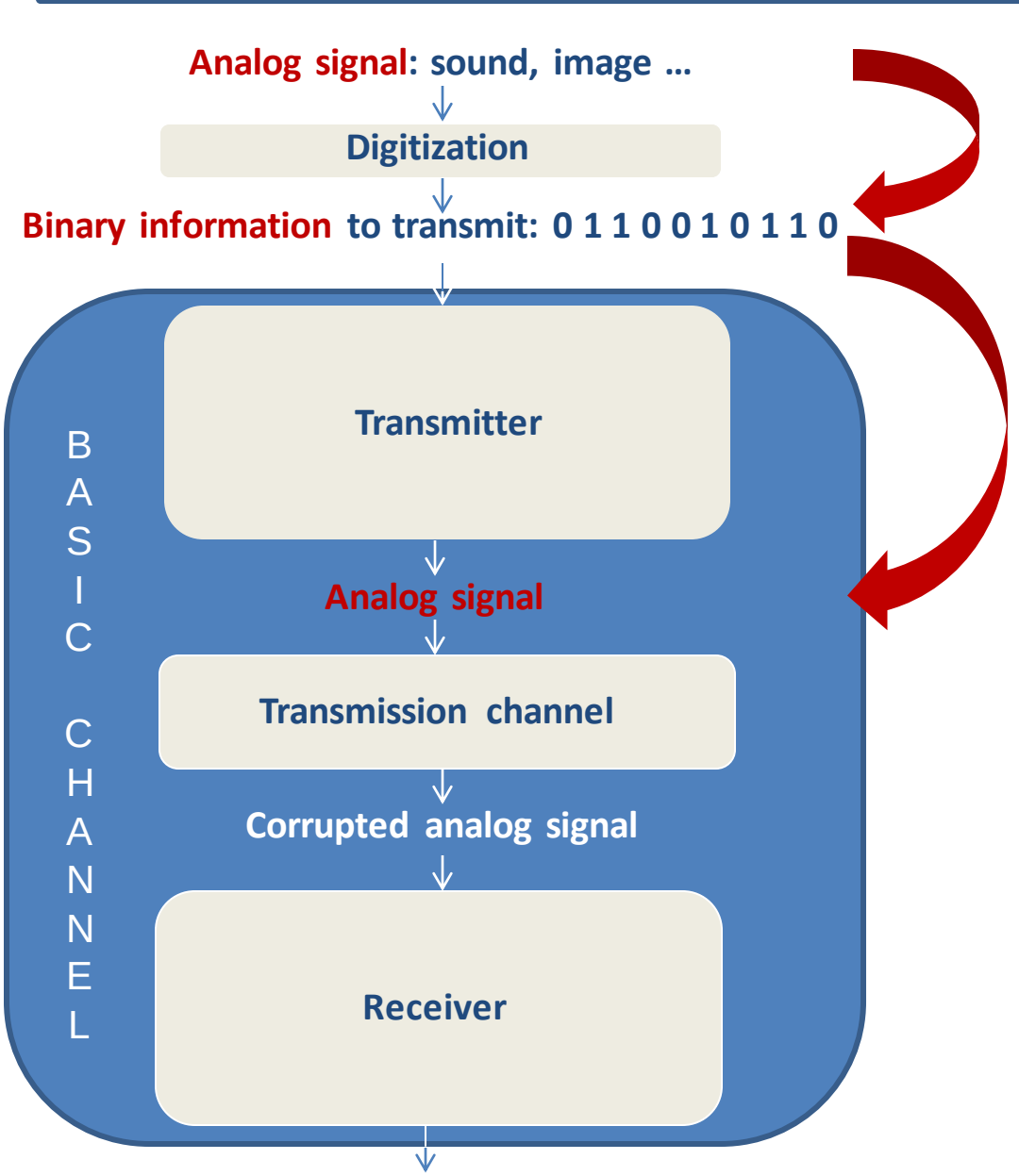
BER = $2.38\ 10^{-6}$

SNR = 0 dB :



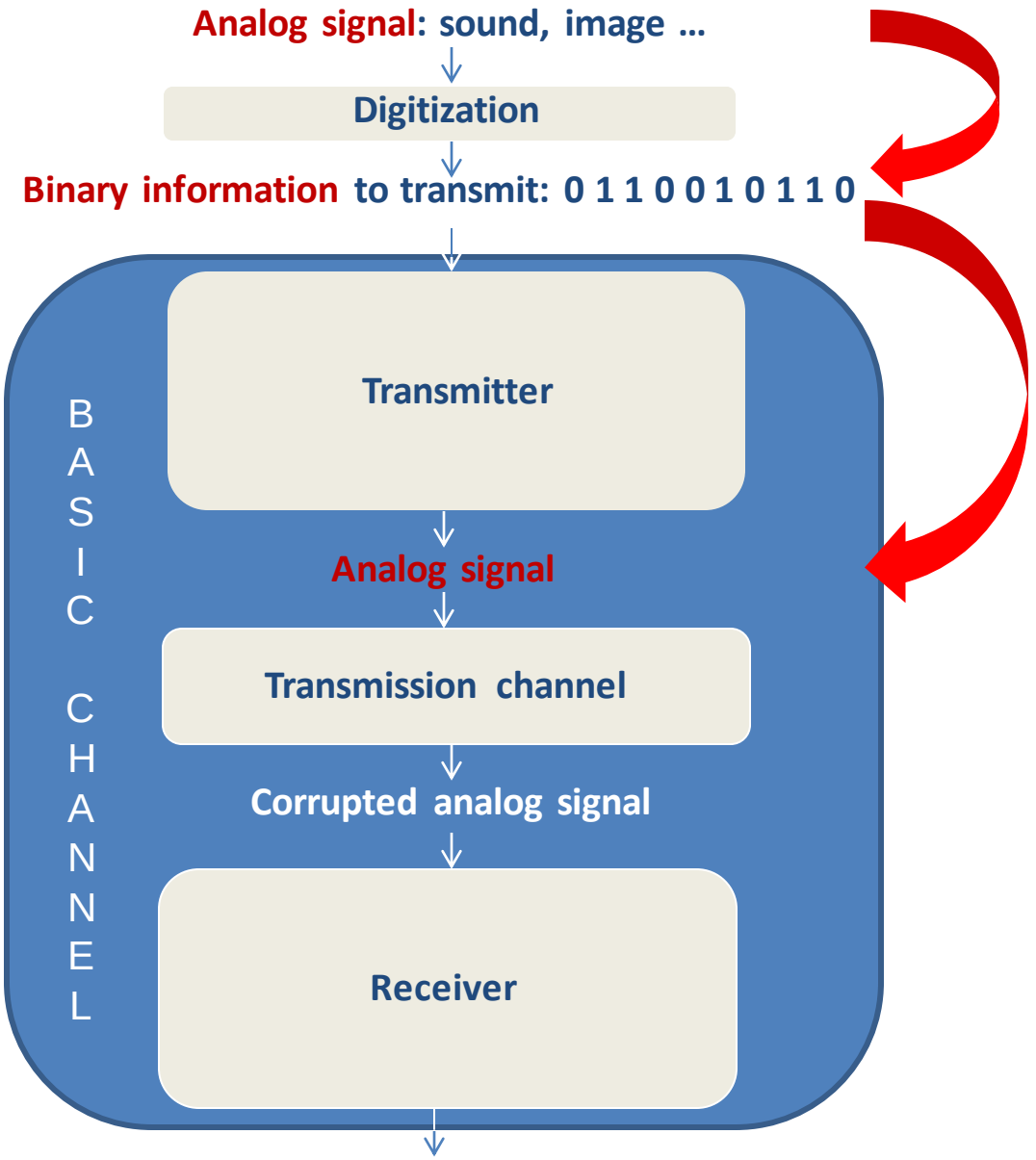
BER = 0.0784

Basic digital transmission channel



Transmission quality is improved:
Quality criterion is the Bit Error Rate (BER) which can be very low even with corrupted received analog signals. Of course BER is a function of SNR.

Basic digital transmission channel



Transmission quality is improved:
Quality criterion is the Bit Error Rate (BER) which can be very low even with corrupted received analog signals. Of course BER is a function of SNR.

Price to pay: occupied bandwidth is larger for digital transmissions.

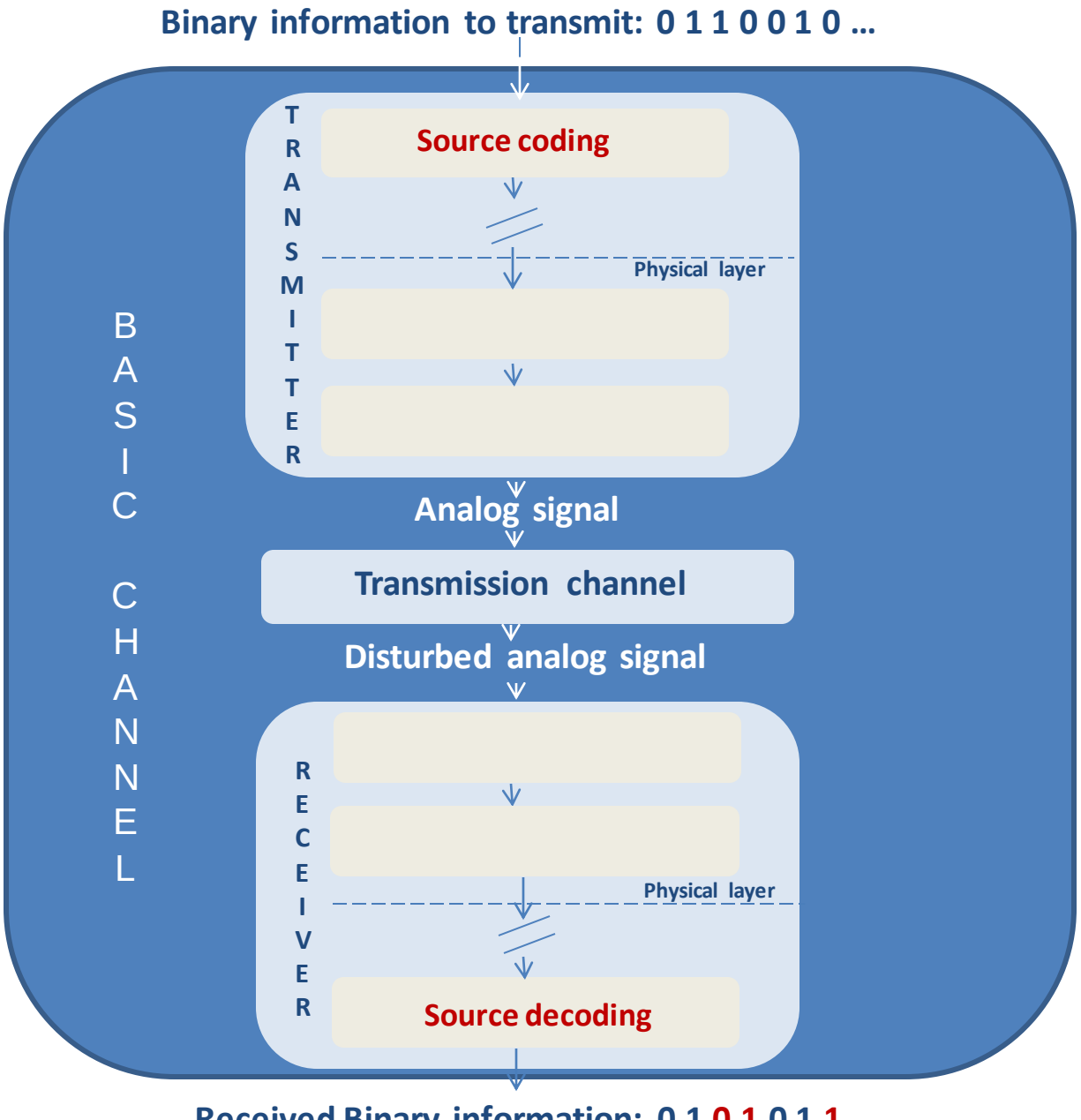
Example : fixed phone digitization

B_{analog} = 3.1 kHz

$B_{digital}$ ~64 kHz (Fe=8kHz, nb=8 bits)

But source coding will help on this point !

Basic digital transmission channel: source coding



Example of source coding : Huffman coding

Message to transmit: EMMENE MOI A LA MER

Natural binary coding:

9 different characters = > 4 bits per character (2^4=16)

E	M	Espace	A	N	I	O	R	L
4/19	4/19	4/19	2/19	1/19	1/19	1/19	1/19	1/19
0000	0001	0010	0011	0100	0101	0110	0111	1000

19x4 = 76 bits to be sent, example with 2G transmission (9,6 kbps) : 0,79 ms

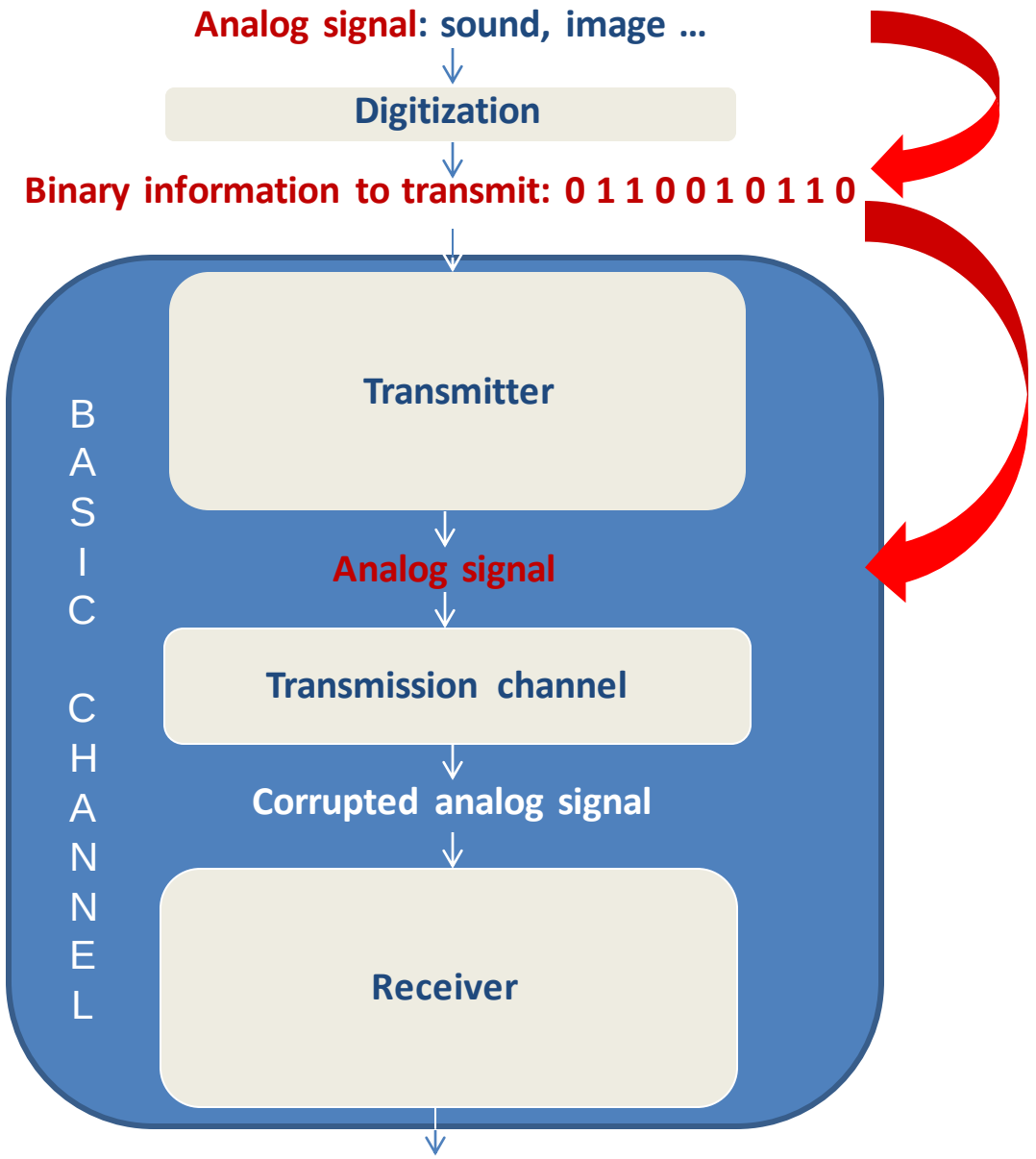
Smarter code (Huffman) :

E	M	Espace	A	N	I	O	R	L
4/19	4/19	4/19	2/19	1/19	1/19	1/19	1/19	1/19
01	10	11	0000	0011	00100	00101	00010	00011

12x2+3x4+4x5 = 56 bits to be sent, example with 2G transmission (9,6 kbps) : 0,58 ms

Gain : 26,32 %

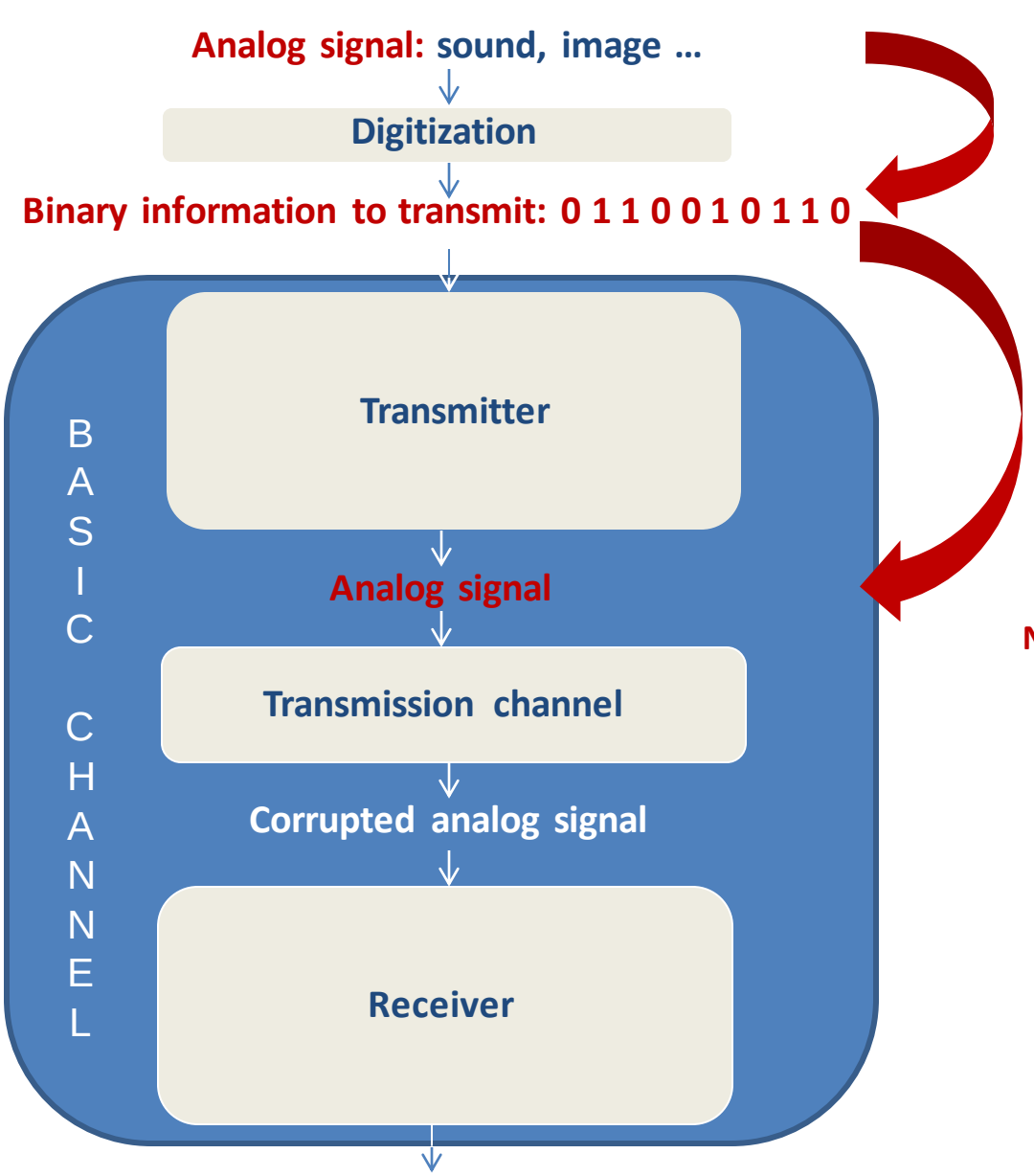
Basic digital transmission channel



Transmission quality is improved:
Quality criterion is the Bit Error Rate (BER) which can be very low even with corrupted received analog signals. Of course BER is a function of SNR.

Of course there is a price to pay: occupied bandwidth is larger for digital transmissions.
But source coding will help on this point !

Basic digital transmission channel

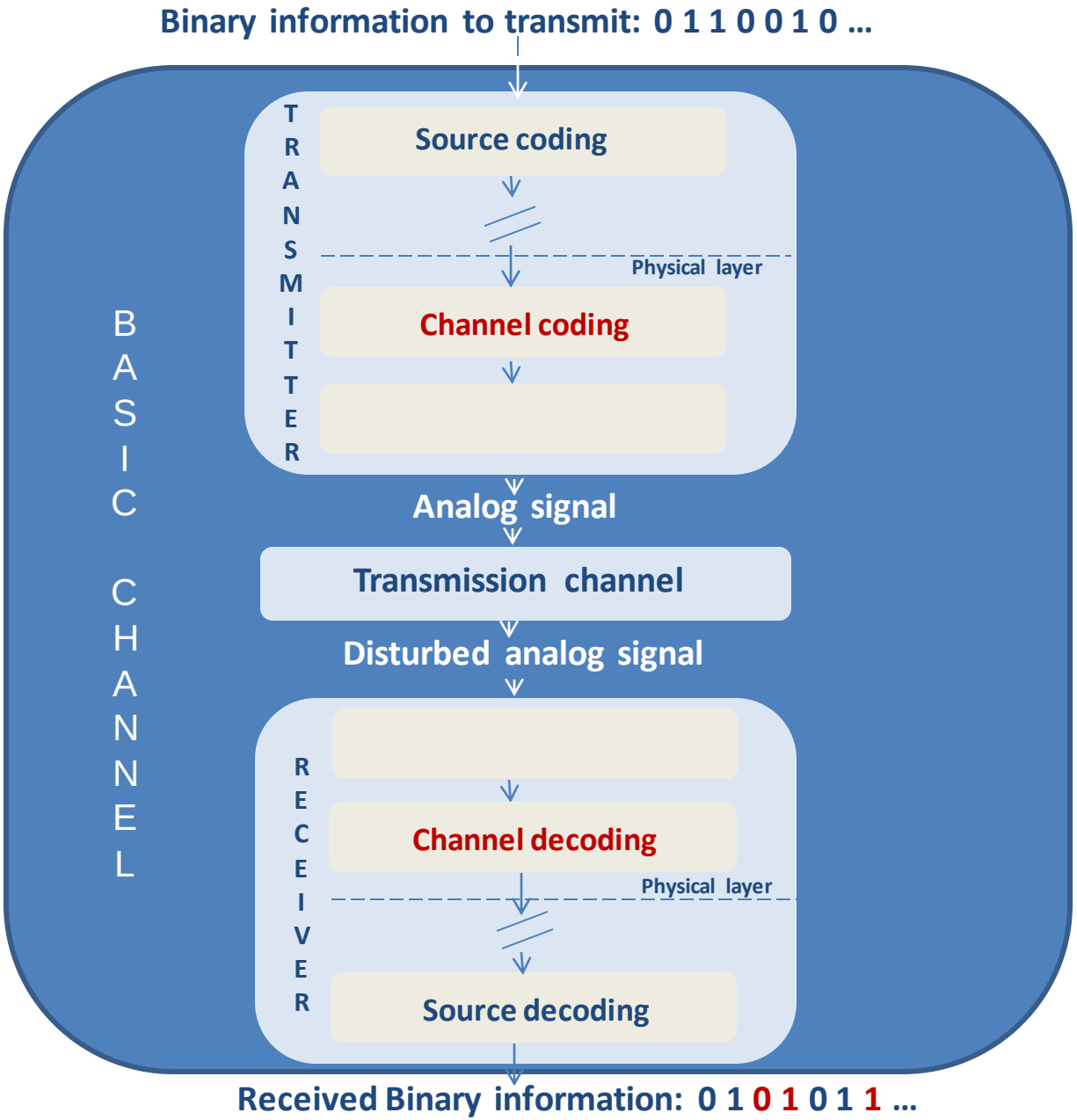


Transmission quality is improved:
Quality criterion is the Bit Error Rate (BER) which can be very low even with corrupted received analog signals. Of course BER is a function of SNR.

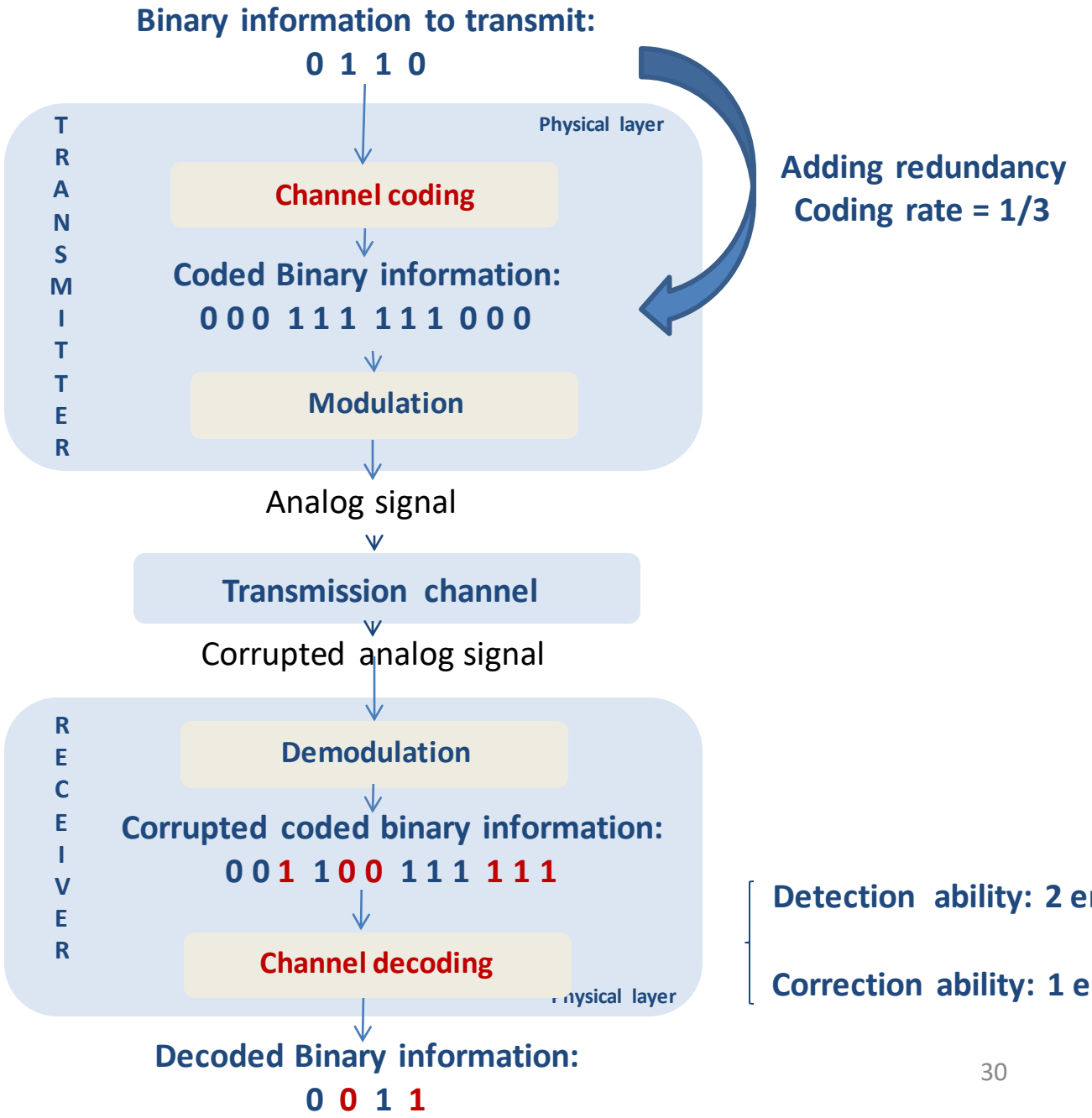
New functions (digital functions) can be used in the transmission channel, like channel coding allowing to obtain the same BER with a lower transmitted power.

Of course there is a price to pay: occupied bandwidth is larger for digital transmissions.
But source coding will help on this point !

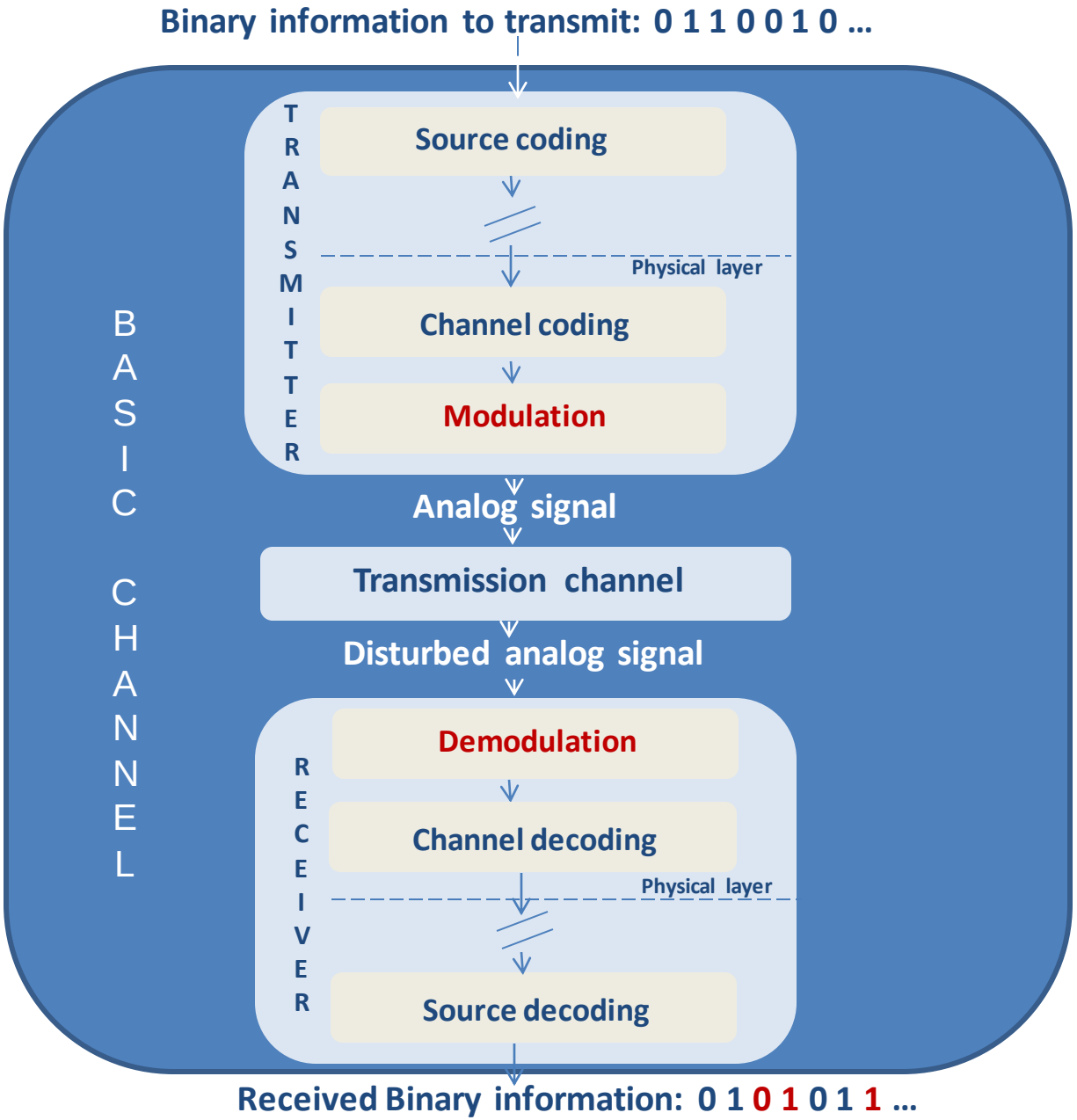
Basic digital transmission channel: channel coding



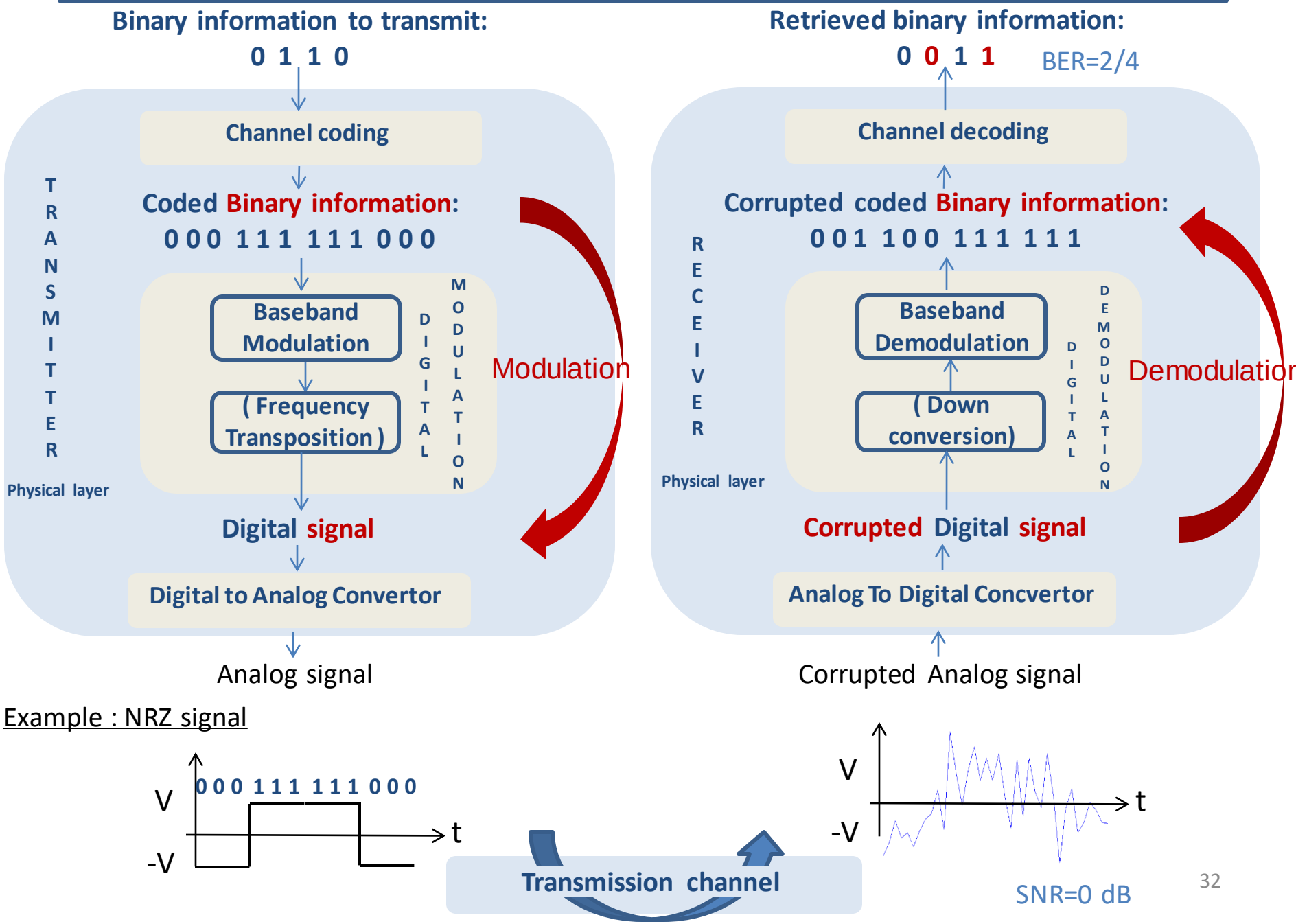
Example of channel coding



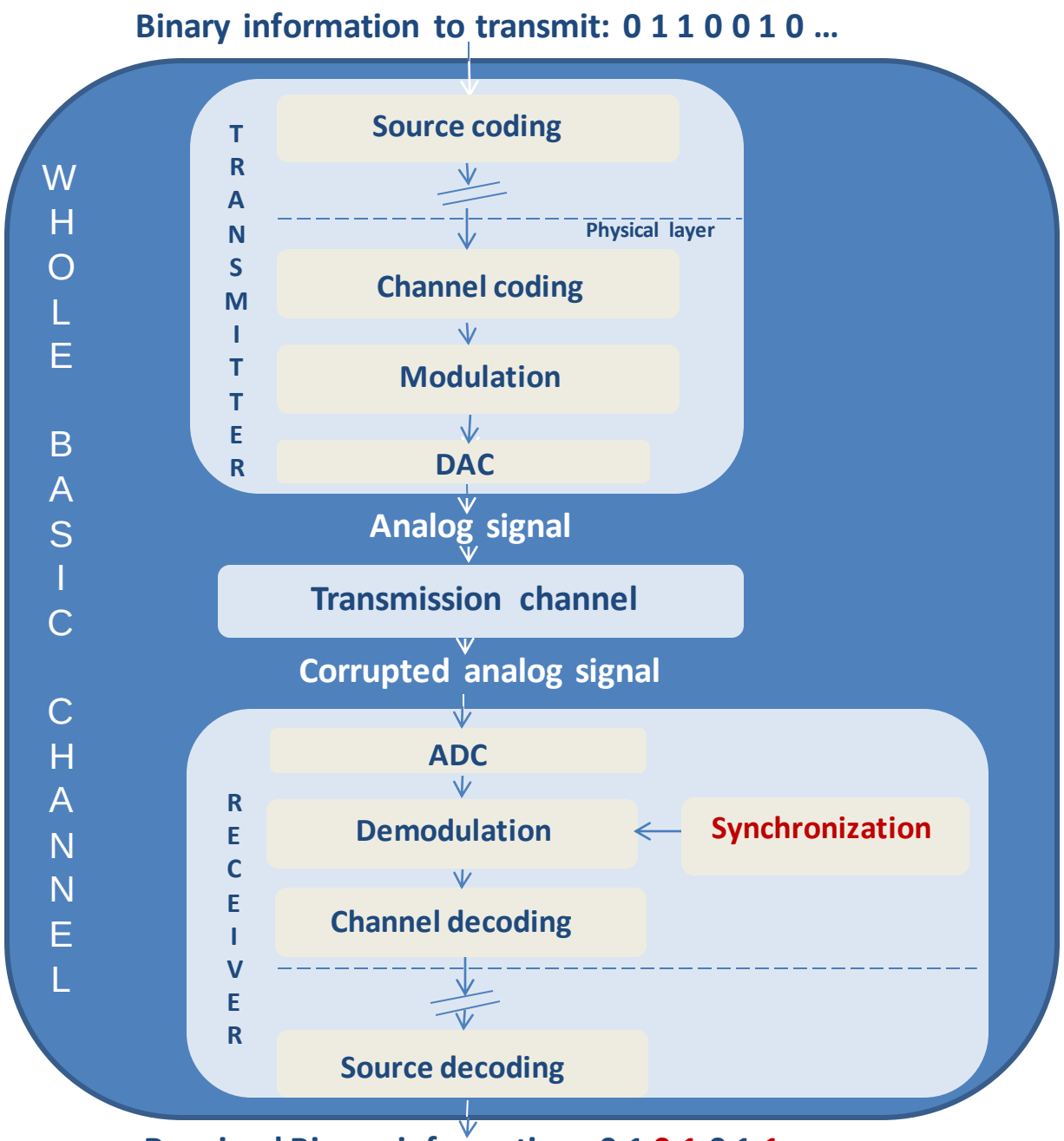
Basic digital transmission channel: modulation



Example of Modulation

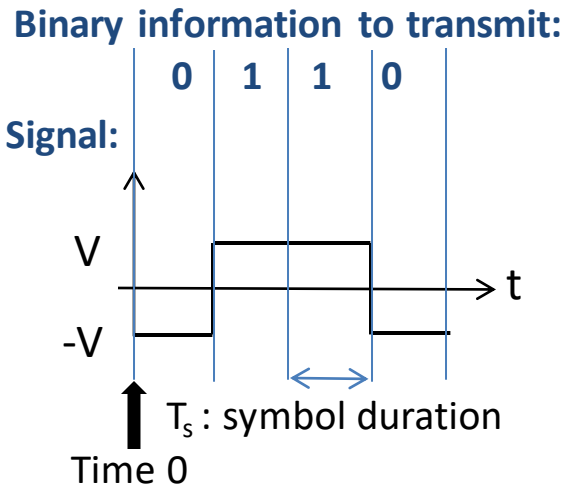


Basic digital transmission channel: synchronization

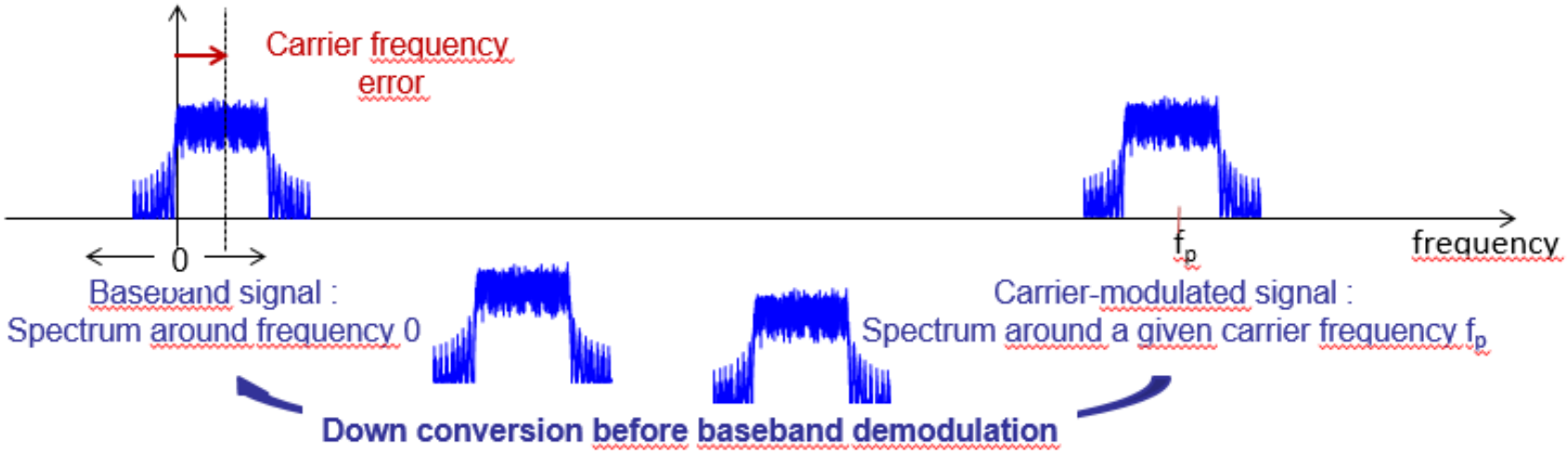


Synchronization on the clock (« in time ») and on the carrier (« in frequency »)

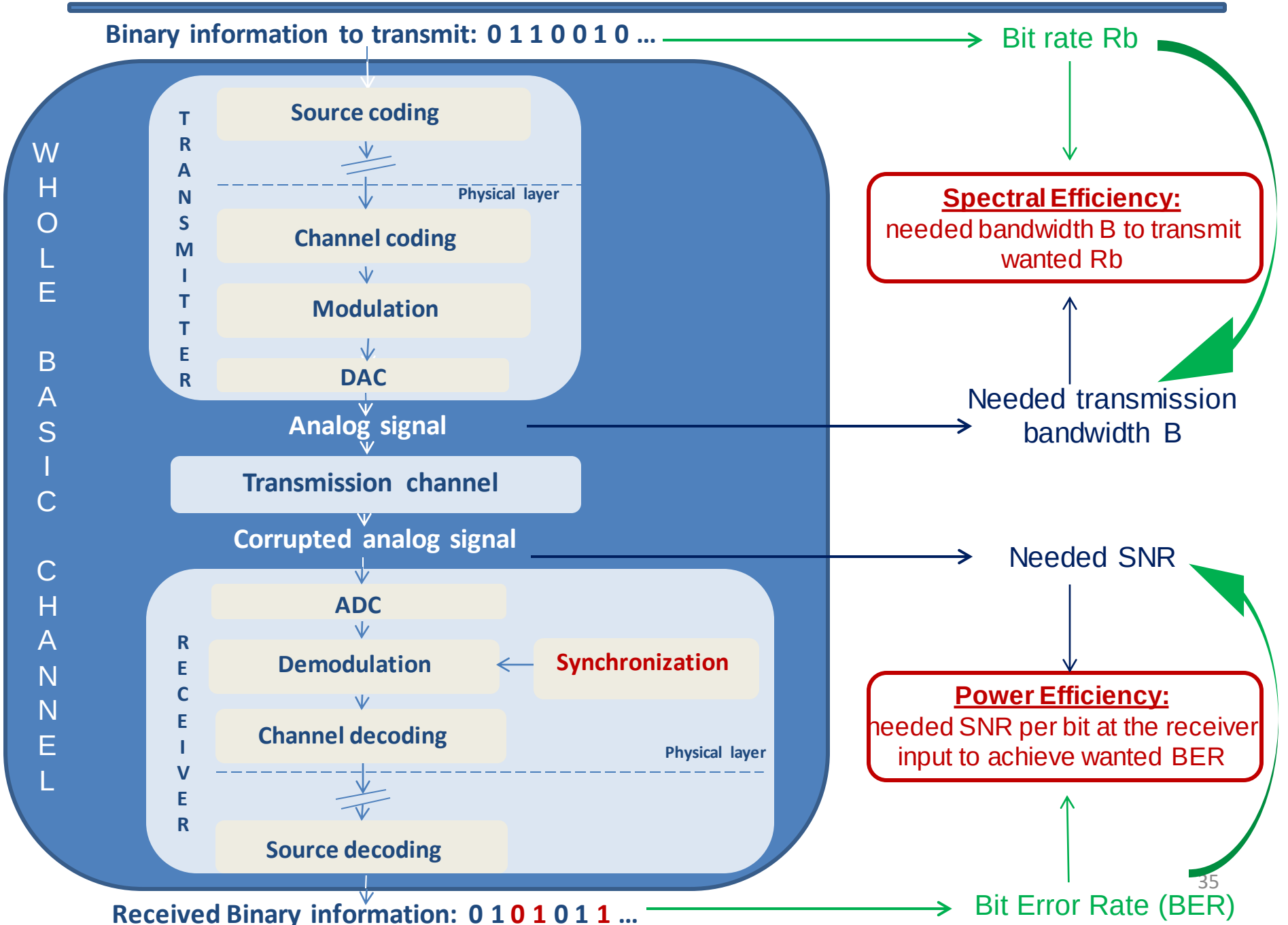
- On the clock



- On the carrier (for carrier-modulated transmissions)



Basic digital transmission channel: performance criteria



Basic digital transmission channel: example

Channel transmission is designed to:

- Transmit a given bit rate Rb = Number of bits to be transmitted per second.

It will cost in terms of:

- Needed bandwidth B in the transmission channel

- Needed SNR at the receiver input => needed transmitted power.

- Achieve a given Bit Error Rate

Rb **B** **SNR**

Table D.1: Example of System performance over 33 MHz transponder

Bit Rate R_u (after MUX) [Mbit/s]	Bit Rate R'u (after RS) [Mbit/s]	Symbol Rate [Mbaud]	Convolut. Inner Code Rate	RS Outer Code Rate	C/N (33 MHz) [dB]
23,754	25,776	25,776	1/2	188/204	4,1
31,672	34,368	25,776	2/3	188/204	5,8
35,631	38,664	25,776	3/4	188/204	6,8
39,590	42,960	25,776	5/6	188/204	7,8
41,570	45,108	25,776	7/8	188/204	8,4

DVB-S example: satellite broadcasting for muti-media contents

Quasi Error Free (QEF) transmission:

BER < 10^{-10}

$$BER = \frac{\text{Number of erroneous bits}}{\text{Number of transmitted bits}} < 1$$

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→ J.J. Spilker, « Digital communication by satellite », Prentice Hall
→ Digital Video Broadcasting (DVB): Framing structure, channel coding and modulation for 11/12 GHz satellite services, norme ETSI EN 300 421.
→ Digital Video Broadcasting (DVB): User guidelines for the second generation system for broadcasting, interactive services, news gathering and other broadband satellite applications (DVB-S2), norme ETSI EN 102 376.