TAF STAR – TAF OPE

UE Cœur A (CPC & PCPO)

Cours 1

Physical channels of propagation: introduction

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Outline

- Historical approach to (physical) communications
- Communication media and channels
- Signal and information

Historical approach to communications

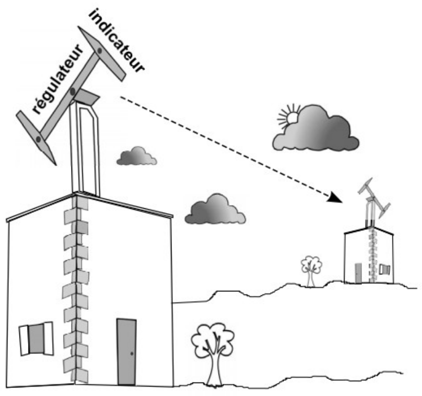
« *On ne connaît pas complètement une science tant qu'on n'en sait pas l'histoire* ».
Cours de philosophie positive, Auguste Comte (1798-1857).

"You don't know a science completely until you know its history"

1. **Birth of (tele)communications**
2. **The emergence of radio communications**
3. **Sources of information**
4. **Transmission media**
5. **From telecommunications to networks**

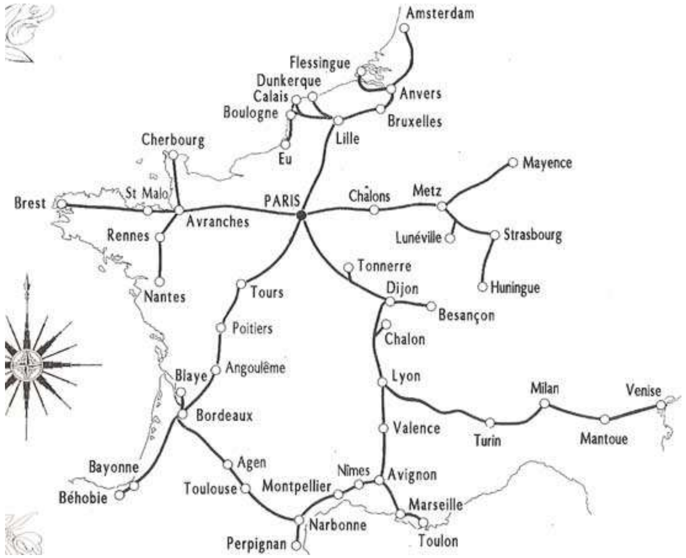
« Birth » of telecommunication

- **The origins**
  - **Acoustic signals**: shouts, whistles, bells, horns
  - **Optical signals**: flames, smoke, lighthouses
- **Chappe's optical telegraphy (1792-1850)**



Extrait du vocabulaire - Télégraphe Chappe **Page 50**

1	Absenter		Enrôlé		HUDSON (baie)
	Actif		Equivalent		HUDSON (détroit)
	Age		Etoffe		Huée
	Antipathie		Sur eux		Huer
5	Assesseur	35	Extorqué	65	HUESCA
	Aumône		Félicitation		HULST
	Après avoir		Fois		HONDURAS
	Baisse		Friche (en)		Hune
	Bénéficier		Général		Hunier
10	Bouclier	40	GRAVELINES	70	HUMINGE
	Buisson		HESSORS		HUMINGUE (pont)
	Caravane		HYERES		HUNTINGTON
	Avec celui		HILSDELSHEIM		HURON
	Chargement		Historien		Hussard
15	Civiliser	45	Hivernage	75	Escadron
	Commodité		HOCHSTET		Hydraulique
	Conduire		HOGUE (Cap)		Hymne
	Consternation		Hollandais		Hypocrisie
	Conviction		Hollande		Hypothèque
20	Craindre	50	HOLSTEIN	80	Idée
	Débaucher		Honfleur		Identifier
	Défense		Hongrie		Indentité
	Démonter		Hongrois		Idôlatre
	Devenir		Horaire		Idôlatrer
25	Dire	55	HORN (Cap)	85	Idôlatrie
	Domination		Horloge		Idole
	Donner une idée de		Hospice		Ignorance
	Echouer		Hottentots		Ignorant
	Electriser		HOTWIEL		Ignoré
30	Empoisonnement	60	HOUNDEL (le)	90	Ignorer
					ILANTE
					ILDEFONSE (Saint)



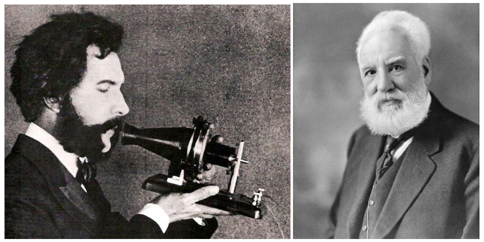
- 5000 km of line
- 534 stations
- 29 major cities
- 700 km travelled in 20 minutes
- Alphabet: 2x7x7 = 98 messages

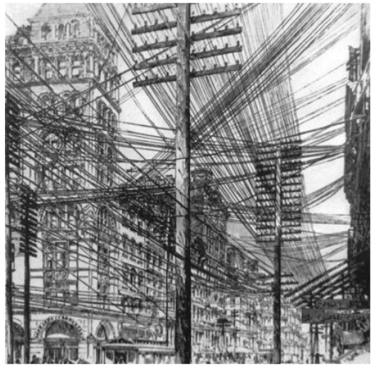
Development of the electric telegraph

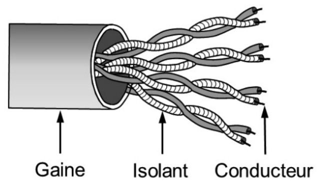
- **1820** : Oersted (DK) and Ampère (F): first remote transmission (magnetic field created by a current and action of a magnetic field on a wire)
- **1831** : Faraday (UK) discovers induction currents in a conductor
- **1833** : Gauss and Weber (D) demonstrate the first 10 km needle telegraph
- **1835-1840** : Morse (USA) Cooke and Wheatstone (UK): development of the first efficient telegraph ("20 words per minute")
- **1841** : Joule (UK) demonstrates resistive losses in a conductive material
- **1844** : First electric telegraph link between Baltimore and Wahington, using the "Morse" code.
- **1848** : Von Siemens (D) develops the insulation of copper wires with a latex-based gum (called “Gutta-Percha”)
- **1858** : Transatlantic link (by submarine cable) between Ireland and Newfoundland (100 words in 67 minutes, message from Queen Victoria to the American President)

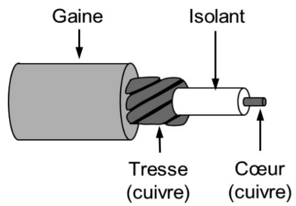
The « talking » telegraph

- **1854** : Bourseul (F) demonstrates that the acoustic vibrations of the human voice can be transmitted in the same way as the telegraph. No one took him seriously... he had to wait until 1889 to be recognised.
- **1876** : Bell (USA) patented the invention of the telephone, which had been developed by one of his colleagues (Meucci (I)) shortly before ... Meucci was recognised as the "father" of the telephone in 2002
- **1880** : First telephone exchange (USA) and telephone lines
- **1890** : Heaviside (UK) models the distributed constant transmission line
- **1890-1900** : Kaup (DK) and Pupin (SB) propose line impedance matching to increase range (the so-called “Pupin coils”)
- **1929** : First "regional" Paris-Bordeaux cable in 1929. Development of twisted pair telephone links
- **1931** : Patent of the coaxial cable by Haffel (USA), based on an idea launched in 1880 by Heaviside. Telephone links were developed on this physical medium until the 1960s



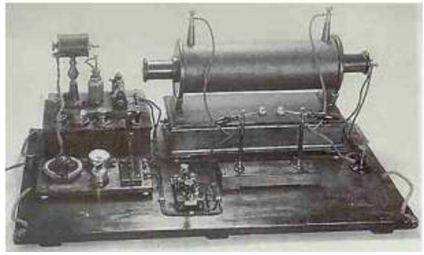


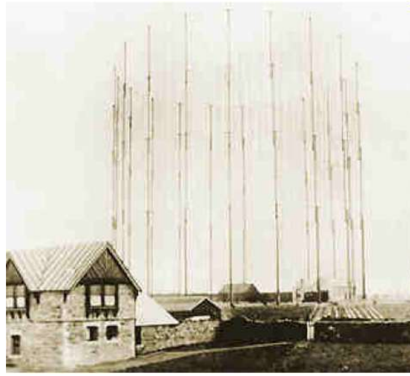




Emerging of radio-communications

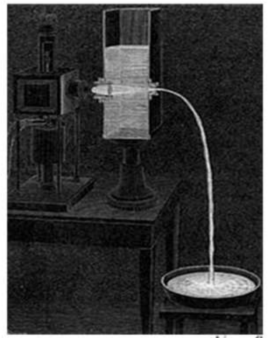
- **1860-1887**: Maxwell (UK) and Hertz (D) synthesise studies on electromagnetism and the propagation of electromagnetic waves
- **1890**: Branly (F) and Lodge (UK): filings coherer to detect waves
- **1896**: First antenna by Popov (R) to transmit and receive waves
- **1897**: Marconi makes the first radio transmission over 12km in Salisbury (UK) (telegraphic signal, TSF)
- **1901**: First transatlantic radio link by Marconi between southern England and Newfoundland (3400 km)
- **1906**: Lee de Forest (USA) invents the triode tube to amplify signals
- **1915**: Campbell (USA) invents the electrical "filter
- **1917**: Levy (F) and Armstrong (USA) develop the "super-heterodyne" radio reception
- **1925**: Marconi makes the first intercontinental radio communication (shortwave)
- **1926**: Yagi and Uda (JP) invent the "rake" antenna
- **1924-39**: Development of high power RF sources
- **1940-50**: Development of radar, microwave and radio navigation

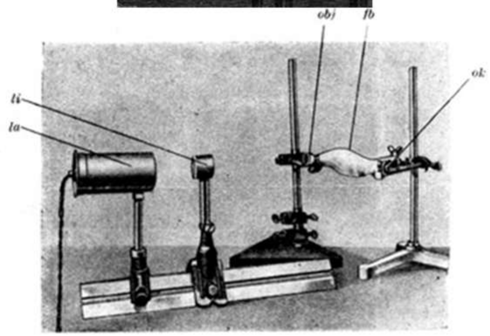




Fibre optic transmission (1/3)

- **Ancient Greece**: transport of light in glass cylinders
- **Italian Renaissance**: "millefiori" of Venetian craftsmen
- **1854**: John Tyndall's light fountain
- **1880**: Alexander G. Bell's photophone
- **1888**: Roth and Reuss use glass tubes to illuminate the human body
- **1926**: Hansell transmits images and faxes with glass or plastic fibres
- **1930**: Lamm transmits the image of a light bulb filament in a bundle of quartz fibres
- **1954**. Van Heel (NL) proposes the first optical fibre, with a core (index n_c) and a cladding of index $n_g < n_c$.
- **1957**: Cutiss and Hirschiwitz develop the endoscope



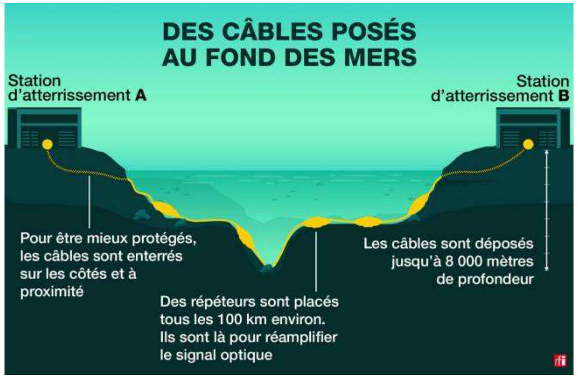


Fibre optic transmission (2/3)

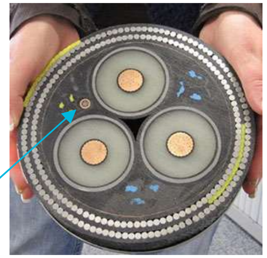
- **1960** : Invention of the laser by Maiman (US) with a ruby crystal. Optical fibres have losses of 100 dB/km
- **1966** : Kao (UK/US) predicts that the combination of single-mode optical fibre and laser will be the basis for very long distance and very high speed communications (Nobel Prize in Physics 2009)
- **1970** : First "single mode" optical fibre developed by Corning: losses of 17 dB/km
- **1975** : First telecommunications system on optical fibre by British Telecom.
- **1982** : Achievement of single mode optical fibre with minimum losses of 0.2 dB/km at $\lambda = 1.55\ \mu m$
- **1987** : Payne (UK), Désurvires (F) and Giles (USA) invent the fibre optic amplifier (5000 GHz bandwidth!)
- **1990** : Beginning of the worldwide deployment of optical fibre, which will allow the construction of the Internet.

Fibre optic transmission (3/3)

- **1956** :TAT-1 is the first electric submarine "telephone" cable: 36 circuits (2.3 Mbit/s) over 3700 km
- **1988** : First transatlantic fibre optic submarine cable (TAT-8): 40,000 telephone circuits (2.5 Gbit/s), but the amplification is electrical...
- **1996** : TAT-12 incorporates optical amplification technology for the first time and carries 60 Gbit/s
- **2000** : The world's longest optical cable (Se-Me-We-3) is put into service: 39,000 km long
- **2001** : TAT-14 carries 50 million circuits (3.2 Tbit/s) over 15,000 km
- **2018** : Marea cable between Virginia Beach and Bilbao (6600 km): financed by Microsoft & Facebook, 160 Tbit/s over 8 pairs of fibres (71 million streaming videos in parallel).
- **In total** : more than one billion km of fibre deployed on earth (25,000 times around the earth)



Optical fibres



Cables section

Optical amplifiers/Repeaters

Back to basics

- **Living in a logarithmic world: the dream!**
  - Easily represent large power scales: from kW to pW
  - Allows sophisticated power balances to be established with simple addition and subtraction.
- **The classical (and fatal !) error : confusion between dBx and dB**
  - dBx : power ratio with respect to a reference (dBm, dBi, dBV)
  - dB : power ratio between two values

$$P_{\mathrm{dBW}} = 10\log_{10}\left(P_{\mathrm{W}}\right) \qquad P_{\mathrm{dBm}} = 10\log_{10}\left(P_{\mathrm{mW}}\right)$$

P	1 µW	1 mW	10 mW	1W
P_{dBm}	-30	0	10	+30

$$P_0 \longrightarrow \boxed{\text{Atténuation Gain}} \longrightarrow P_1$$

$$G_{\mathrm{dB}} = 10\log_{10}\left(\frac{P_1}{P_0}\right)$$

$G < 0$: attenuation
$G > 0$: amplification

dBW ≠ dB

Back to basics : manipulating power units !

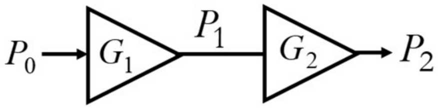
Basic relations

$$P_0 \longrightarrow \boxed{G_{\text{lin}} = \frac{P_1}{P_0}} \longrightarrow P_1$$

- $G_{\text{dB}} = 10\log_{10}\left(\frac{P_1}{P_0}\right)$

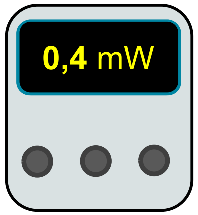
$$= \underbrace{10\log_{10}\left(P_1^{\text{mW}}\right)}_{P_1^{\text{dBm}}} - \underbrace{10\log_{10}\left(P_0^{\text{mW}}\right)}_{P_0^{\text{dBm}}} \Rightarrow \boxed{\text{dB}_m - \text{dB}_m = \text{dB}}$$

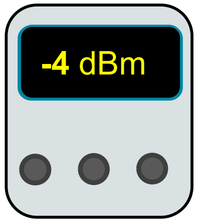
- $P_1^{\text{dBm}} = 10\log_{10}(G_{\text{lin}}P_0) \Rightarrow \boxed{\text{dB}_m + \text{dB} = \text{dB}_m}$
- $P_0^{\text{dBm}} = 10\log_{10}\left(\frac{P_1}{G_{\text{lin}}}\right) \Rightarrow \boxed{\text{dB}_m - \text{dB} = \text{dB}_m}$
- $G_{\text{tot}}^{\text{dB}} = 10\log_{10}(G_1^{\text{lin}}G_2^{\text{lin}})$

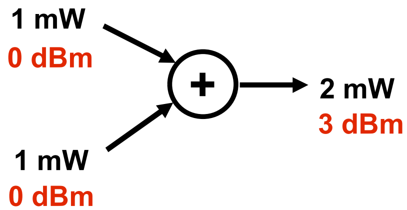


$\Rightarrow \boxed{\text{dB} + \text{dB} = \text{dB}}$

« 0 + 0 = 3 »







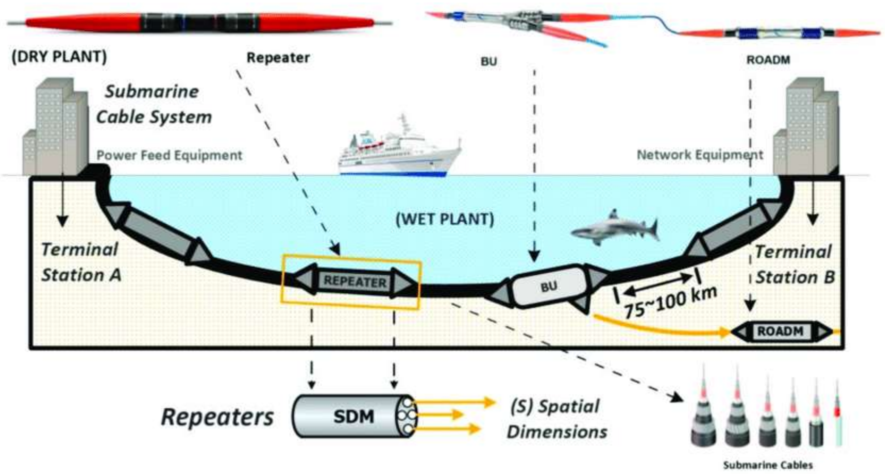
Exercise : fill in the table …

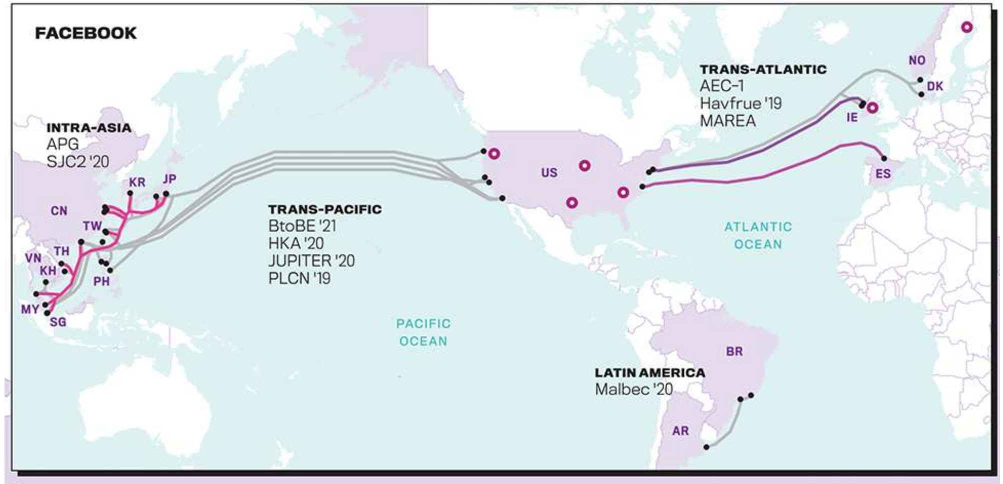
$$\log(ab) = \log(a) + \log(b)$$
$$\log(a/b) = \log(a) - \log(b)$$

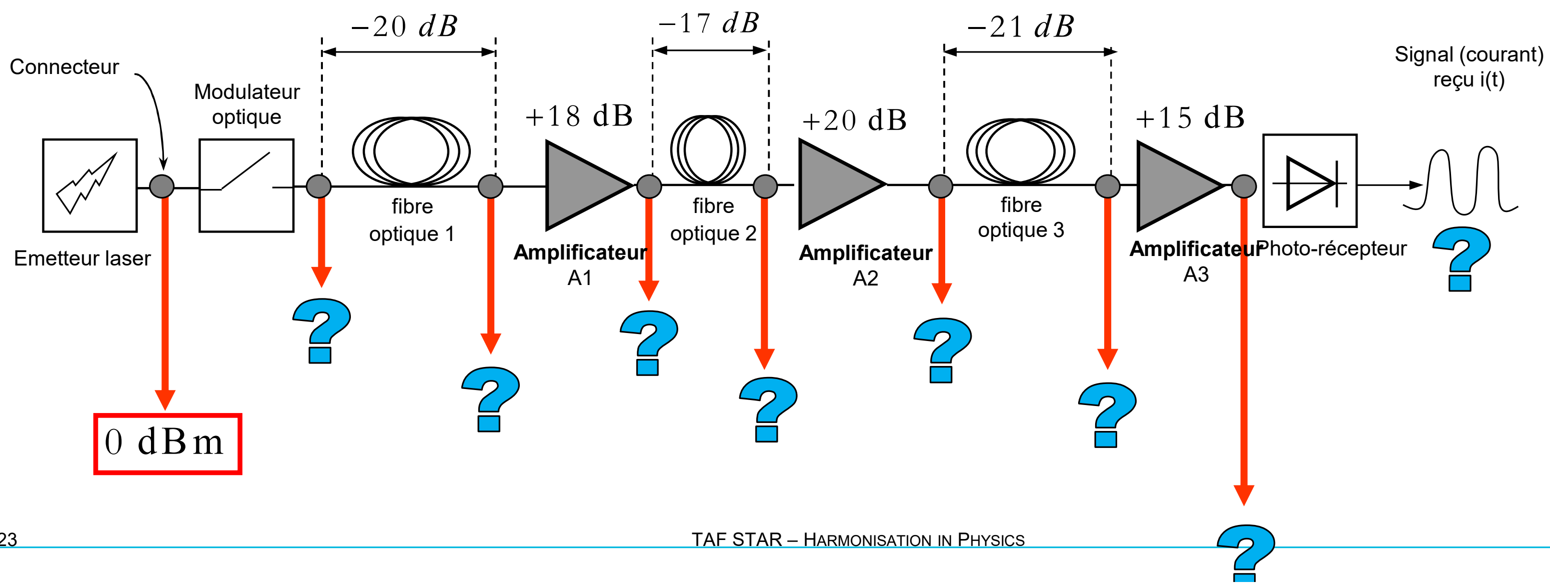
Linéaire	Log.	Linéaire	Log.	Linéaire	Log.
1	**0** dB(m)	5 = 10/2	**7** dB	8π	**14** dB
5/4	**1** dB	2π	**8** dB	10π	**15** dB
$\pi/2$	**2** dB	8=2x4	**9** dB	40	**16** dB
2	**3** dB	10	**10** dB	$\sqrt{2}$	**1,5** dB
5/2	**4** dB	4π	**11** dB	$\sqrt{2}/2$	**-1,5** dB
π	**5** dB	16 = 8x2	**12** dB	1/2	**-3** dB
4 = 2x2	**6** dB	20	**13** dB	1/4	**-6** dB

Linéaire	Log.
$\pi/4$	**-1** dB
5/8	**-2** dB
$\pi/8$	**-4** dB
5/16	**-5** dB
$\pi/16$	**-7** dB
5/32	**-8** dB
1/8	**-9** dB

Exercise : **power** budget on an optical fibre link







Main physical transmission media




Support	Câble symétrique	Câble coaxial	Fibre monomode	Ondes radio
Propagation	guidée	guidée	guidée	libre
Matériau	métal (Cu)	métal (Cu)	silice	Air
Bande-passante (Hz)	$10^5 - 10^6$	10^8	10^{12}	10^9
Atténuation	20 dB/km (1 MHz)	20 dB/km (1 GHz)	0,2 dB/km (193 THz)	$\text{AEL} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$
Sensibilité au bruit	forte	faible	nulle	forte
Confidentialité	limitée	correcte	élevée	nulle
Coût support	faible	élevé	modéré	nul
Coût interfaces	très faible	faible	élevé	assez faible
Applications	téléphone	réseaux locaux	très haut débit	mobiles, satellites

+ Acoustic channels ...

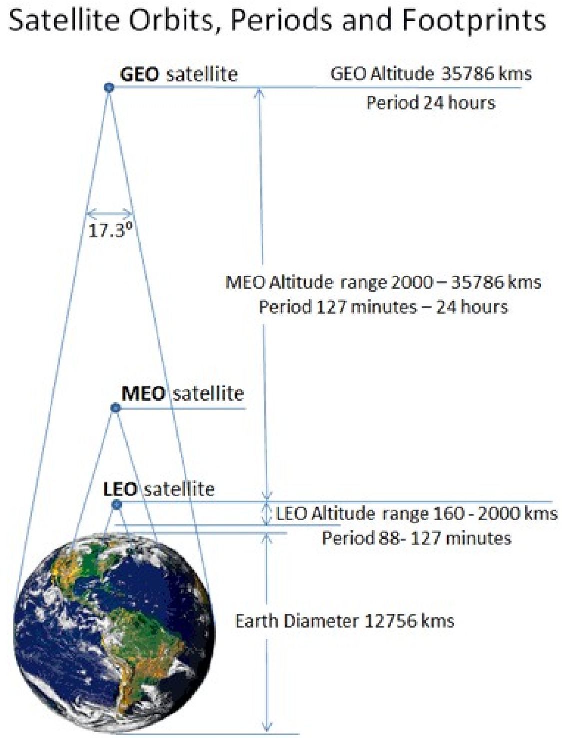
Exercise : satellite beam power measurement

A **field strength meter** is used to measure the electrical power **received by a satellite antenna**. Its input impedance has the modulus $|Z| = 75\,\Omega$.

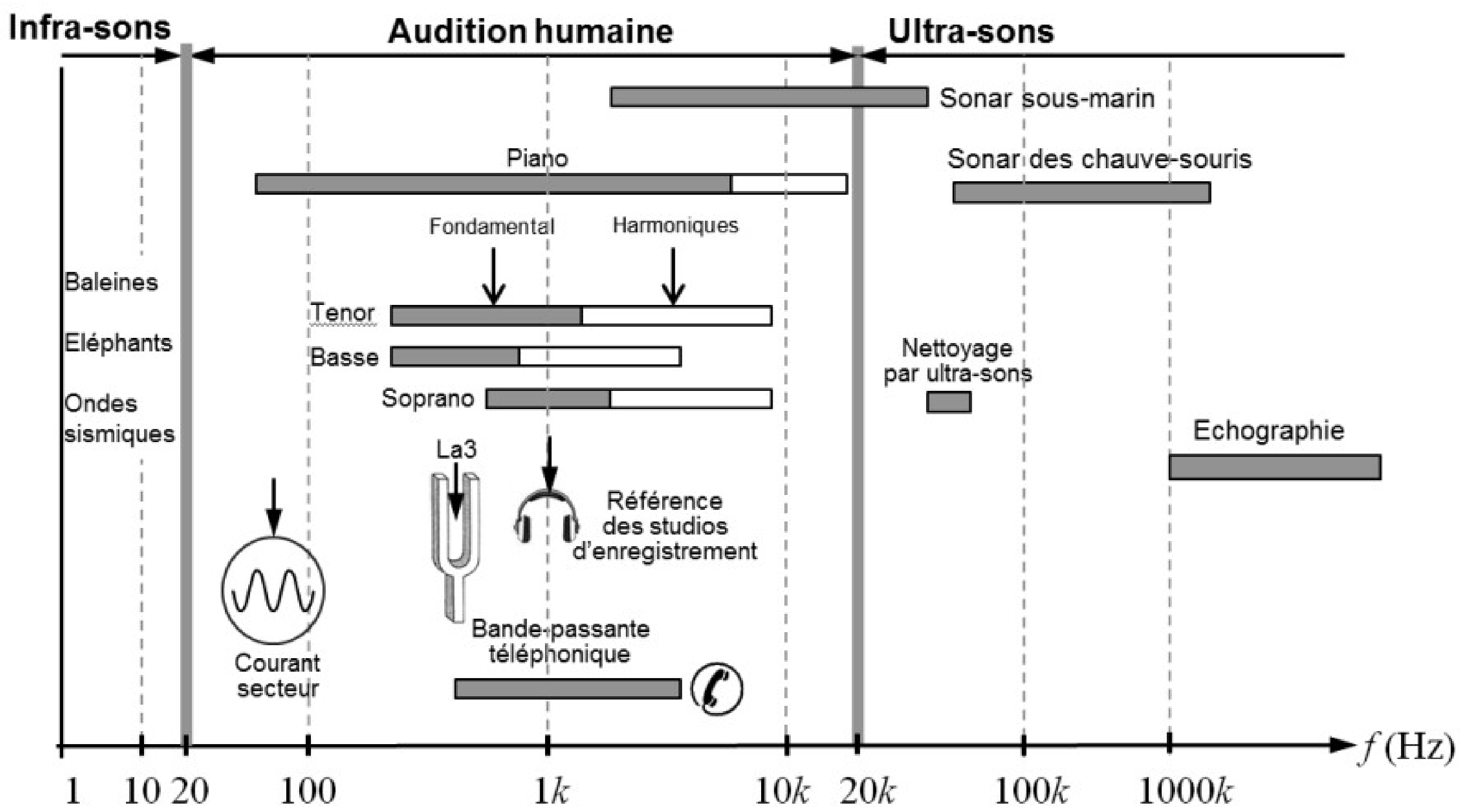
a) An initial **measurement of this signal** gives a result of 69,2 dBμV. Give the value of this power in **dBm**, in volts (rms value) and in watts.

b) A **noise measurement** taken under the same conditions gives a result of 57,8 dBμV. Give the value of this power in watts.

c) What is the measured **signal-to-noise ratio** in dB?



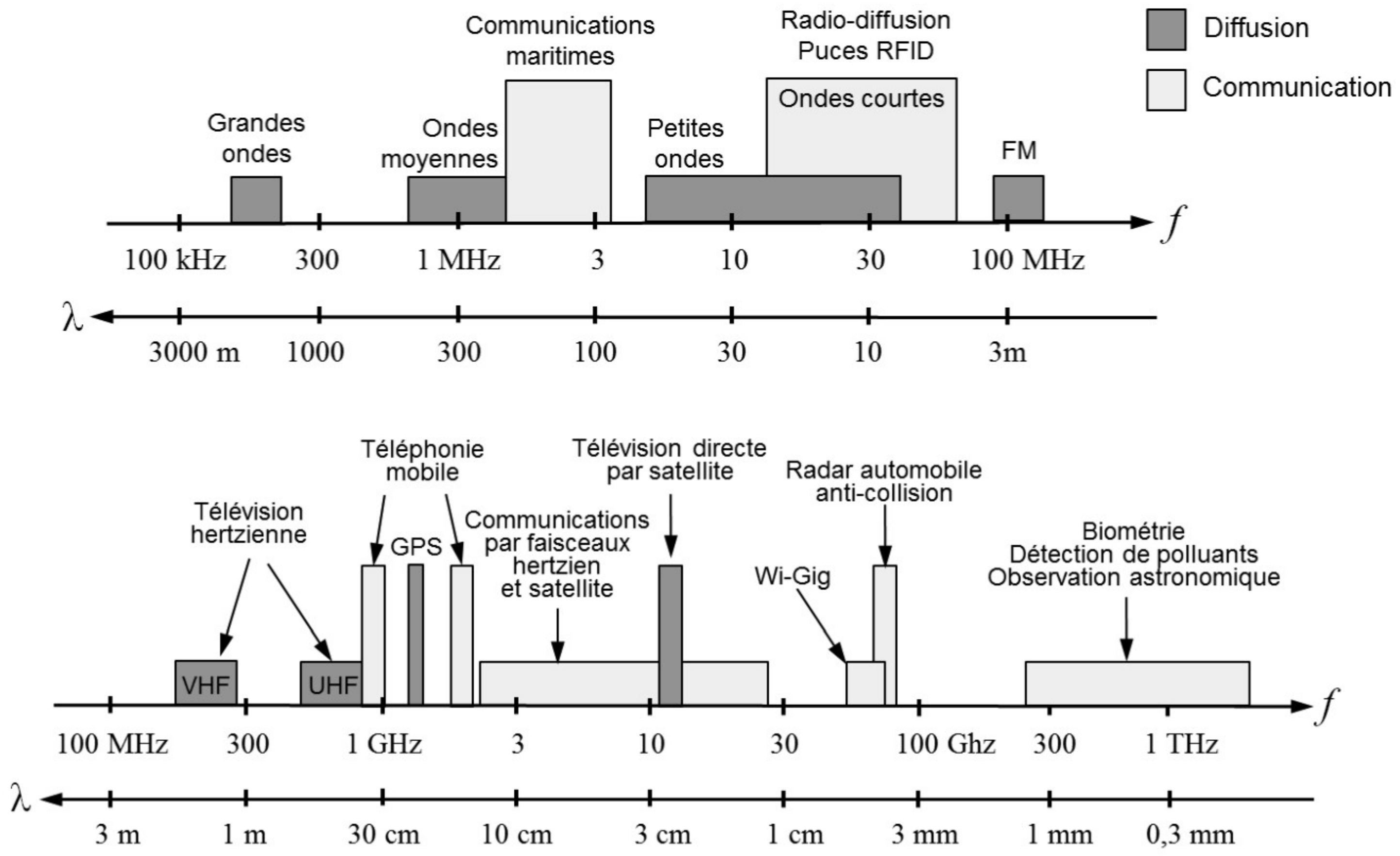
Acoustic channel: carrier frequencies



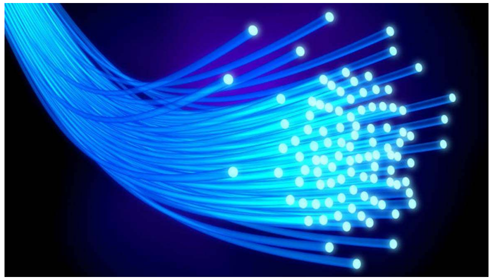
Electromagnetic channel: carrier frequencies

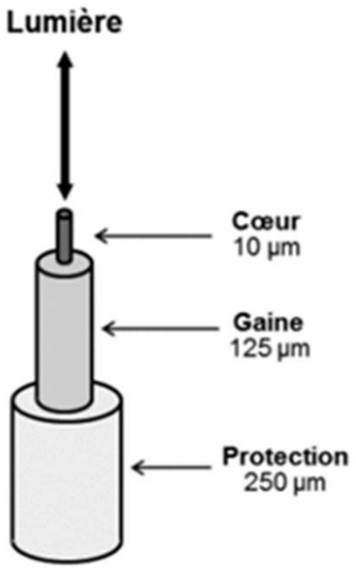
Low
radio-frequencies

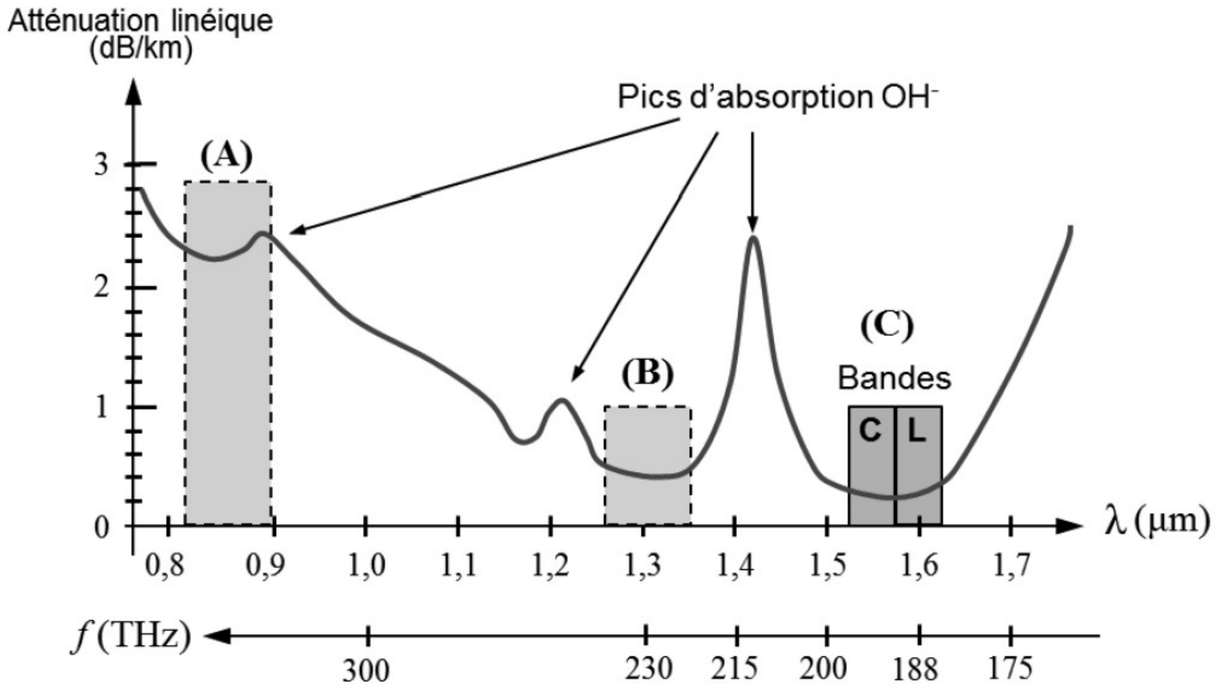
High
radio-frequencies



Optical (fibre) channel: carrier frequencies







$$\Delta f = -c\frac{\Delta\lambda}{\lambda^2}$$

$$\mid \Delta f \mid = 3 \cdot 10^8 \cdot \frac{(1.6-1.5)10^{-6}}{(1.5\,10^{-6})^2} = 12500 \text{ GHz}$$

Different information sources (non-exhaustive list …)

- **Geophysical sources**: temperature, pressure, velocity, meteorology, seismic
- **Space sources**: cosmic images, space probes
- **Tracking sources**: radar, sonar, lidar
- **Biological sources**: X-ray imaging, MRI, ultrasound, electrocardiogram, electroencephalogram, electro-myogram, electro-oculogram
- **Structural sources**: vibration diagnosis of a bridge, a vehicle, a building, a moving structure
- **Telecommunications sources**: data, speech, music, image and video signals transmitted in a communications channel
- **Sources of inter-personal exchanges**: speech, writing, gestures, physiognomy, interpreted by the brain (very complex signals)

Physical quantities and units

Definition

- **Physical quantity** (Wikipedia): any property of nature that can be quantified by measurement or calculation, and whose various possible values are expressed using a real or complex number generally accompanied by a unit of measurement
- **With unit** (length, mass) or **without unit** (angle, refractive index)
- Relationships between physical quantities :

$$F = m\gamma \qquad q(t) = C\frac{\mathrm{d}v(t)}{\mathrm{d}t} \qquad v_s(t) = \int_{-\infty}^{+\infty} v_e(u)h(t-u)\,\mathrm{d}u$$

Main quantities

Grandeur	Unité	Symb. dimens.
Longueur	mètre (m)	L
Masse	kilogramme (kg)	M
Quantité de matière	mole (mol)	N
Temps	seconde (s)	T
Intensité lumineuse	candela (cd)	J
Température	kelvin (K)	Θ
Courant électrique	ampère (A)	I

The 7 quantities of the International system (S.I.)

Grandeurs	Nom de l'unité	Symboles	Equivalent S.I.
Force	newton	N	m kg s^{-2}
Pression	pascal	Pa	m^{-1} kg s^{-2}
Energie	joule	J	m^{2} kg s^{-2}
Puissance	watt	W	m^{2} kg s^{-3}
Fréquence	hertz	Hz	s^{-1}
Charge électrique	coulomb	C	As
Résistance électrique	ohm	Ω	kg s^{-3} A^{-3}
Potentiel électrique	volt	V	m^{2} kg s^{-3} A^{-1}
Capacité électrique	farad	F	m^{-2} kg^{-1} s^{4} A^{2}
Densité de champ magnétique	tesla	T	kg s^{-2} A^{-1}
Radioactivité	becquerel	Bq	s^{-1}

Some derived quanties

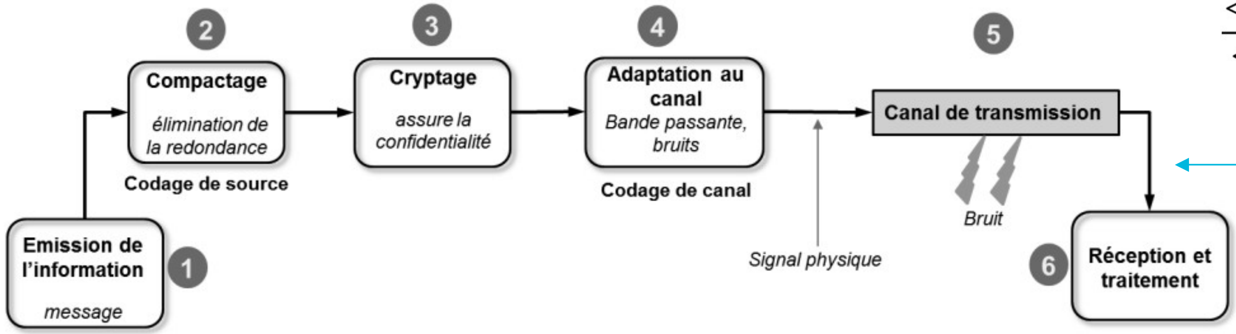
Fundamental constants

Widely used
in this teaching unit

Nom	Variable	Valeur	Unité
Constante d'Avogadro	N	$6{,}022 \cdot 10^{23}$	mol^{-1}
Charge élémentaire de l'électron	e	$1{,}6 \cdot 10^{-19}$	C
Vitesse de la lumière (vide)	c	$2{,}99792458 \cdot 10^{8}$	ms^{-1}
Constante de gravitation	G	$6{,}67 \cdot 10^{-11}$	$\mathrm{N\,m^2\,kg^{-2}}$
Constante de Boltzmann	k	$1{,}38 \cdot 10^{-23}$	$\mathrm{J\,K^{-1}}$
Constante de Planck	h	$6{,}63 \cdot 10^{-34}$	Js
Permittivité diélectrique du vide	ε_0	$8{,}85 \cdot 10^{-12}$	$\mathrm{F\,m^{-1}}$
Perméabilité magnétique du vide	μ_0	$4\pi \cdot 10^{-7}$	$\mathrm{H\,m^{-1}}$
Masse de l'électron	m_e	$9{,}10938 \cdot 10^{-31}$	kg
Masse du proton	m_p	$1{,}67262 \cdot 10^{-27}$	kg
Masse du neutron	m_n	$1{,}67493 \cdot 10^{-27}$	kg
Constante des gaz parfaits	R_0	$8{,}314462$	$\mathrm{J\,K^{-1}\,mol^{-1}}$

Information transmission

- **Simplified chain** (detailed in UE Coeur "digital communications")
  - Messages are transmitted from a source to a destination



$\frac{<P_{\mathrm{signal}}>}{<P_{\mathrm{noise}}>}$ is the signal-to-noise ratio (SNR)

  - Messages containing k symbols in an alphabet with n éléments (n^k symbols in total)
  - Equiprobable messages : amount of information $I = k\log_2(n)$ (Hartley, 1928)
  - If P_i is the probability of message M_i,then $I(M_i) = -\log_2(P_i)$ (Shannon, 1948)
  - **Entropy** of a repetitive and stationary source : $H_S = -\sum_{i=1}^{N} P_i \cdot \log_2(P_i)$

Capacity of a communication channel

- **Information rate**: number of elementary messages flowing in the communications channel per unit of time
- **Capacity** of a communications channel: maximum information rate that a communications channel can carry
- **Intuitive (but false) approach**: capacity is proportional to the bandwidth B (in Hz) of the transmission channel
  ➔ "*the bigger the pipe, the more information it can transmit in a given time*" :

$$C = \alpha B \quad \text{with} \quad \alpha = \text{cst}$$

- The capacity of a channel, as defined by Shannon (1948), for a source delivering a message in the form of a sequence of binary symbols (bits):

$$C = B \log_2 \left(1 + \frac{<P_{\text{signal}}>}{<P_{\text{noise}}>}\right)$$

➔ in bit/s

$\frac{<P_{\text{signal}}>}{<P_{\text{noise}}>}$ is the signal-to-noise ratio (SNR)

- **Example** : « old » wired telephone - SNR = 50 dB, $B = [300, 3400 \text{ Hz}]$
  - ▸ $C = (3400 - 300) \log_2(10^5) = 51490 \text{ bit/s}$
  - ▸ WARNING : the more B increases, the more $P_{\text{bruit}}^{\text{m}}$ increases, et the more C decreases !

From point-to-point transmission … to network

- Different communication system types
  - Point-to-point: cable, microwave link
  - Broadcasting: satellite TV, fibre to the home
  - Collection: oceanographic monitoring, micro-sensors
  - Local area network: connected terminals communicating via nodes (Ethernet)
- Layered network model (OSI, 1979)