Higher School of Communication of Tunis

مخبر التجديد في الأجهزة الجوالة المتواصلة والمتعاونة
Innovation of COMmunicant and COoperative Mobiles

Autumn School of EMC: IoT&IoT

2nd to 4th November 2023

Interferences of Things & IoT

Fethi CHOUBANI

2 November 2023

Outline

Introduction

Definitions

Coupling mechanisms

Measurements

Mitigation techniques

To be continued....

Introduction

● *Certification from iNARTE (**International Association for Radio, Telecommunications and Electromagnetics**)*

● *Pre-Certification preparation for students, PhD students, Engineers, with collaboration of ISIKef* ***(2h Exam scheduled at the end)***

● *EMI/EMS issues reenforced by IoT components and devices* ***(See opening talk)***

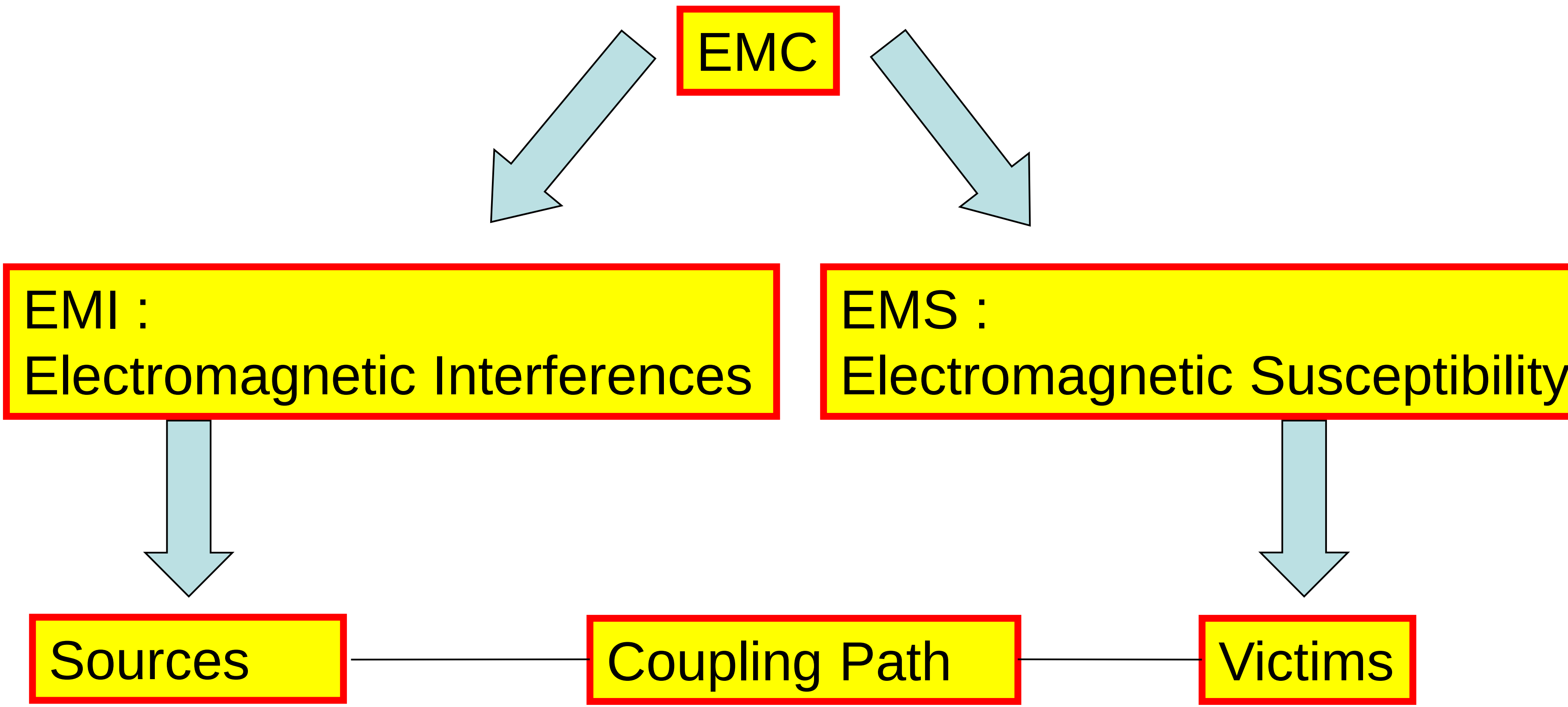
● EMC is a multidisciplinary field, and no one knows everything: ***Support by many friends and colleagues (Amplifiers, Budget link, Electrical networks, Filters, Signals and Spectra, TRLs Antennas and Propagation) + Student Posters (complementary content)***

● *2 Credits for PhD students :* ***Support by EDTIC***

● Present High topics: ***Panel Discussions (Potential health risks of EM fields and 5G controversy)***

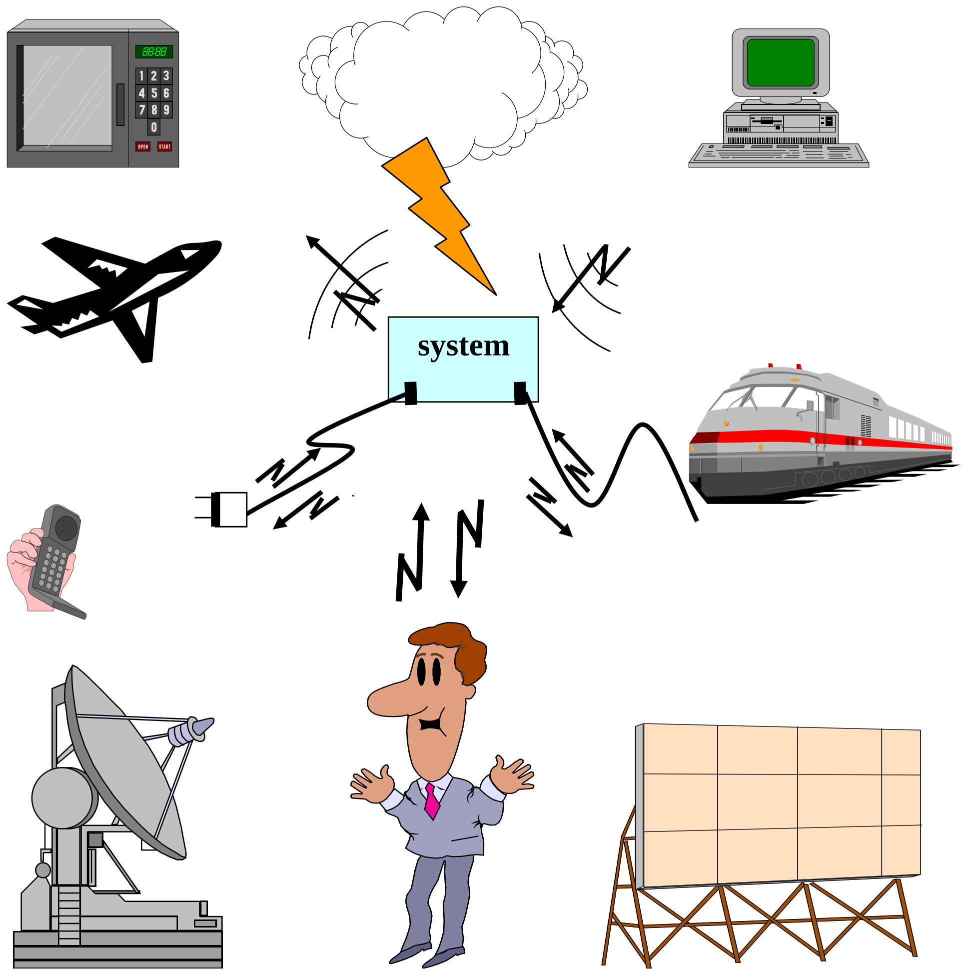
EMC=EMI+EMS

The ability of a device, unit of equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. [IEC 61000-1-1]



Sources of EMI

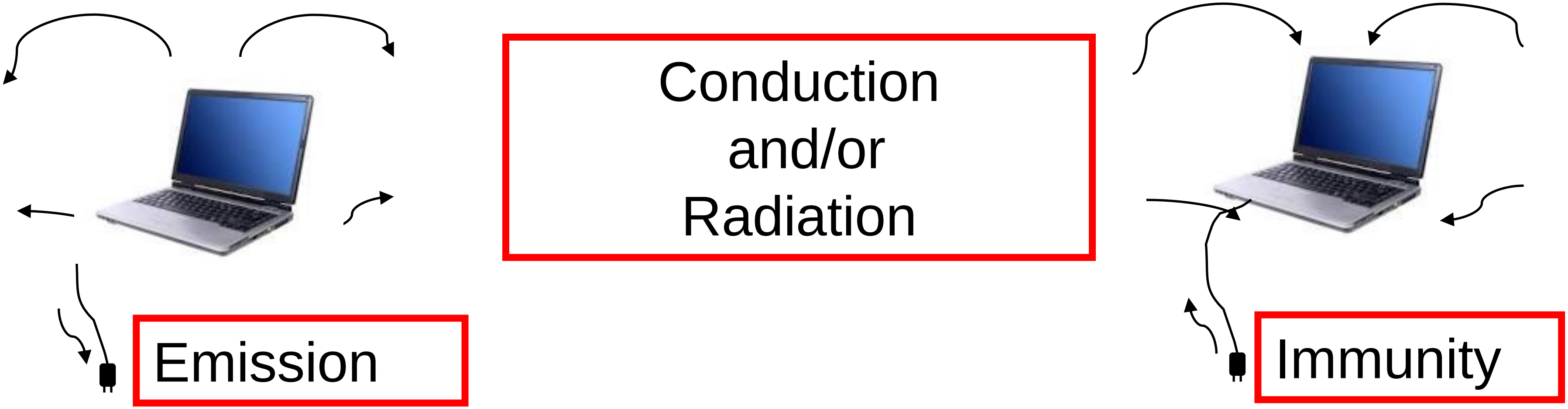
- RF devices
- Electronics/computers
- Cell phones/radios
- Wireless/RF energy
- Microwave equipment
- Power lines
- Electric motors
- Electrostatic discharge (ESD)
- Lightning (LEMP)
- Nuclear event (HEMP)
- Others……



SUP'COM
Higher School of Communication of Tunis

Conduction/Radiation

Innov'COM
Innovation of COMmunicant and COoperative Mobiles



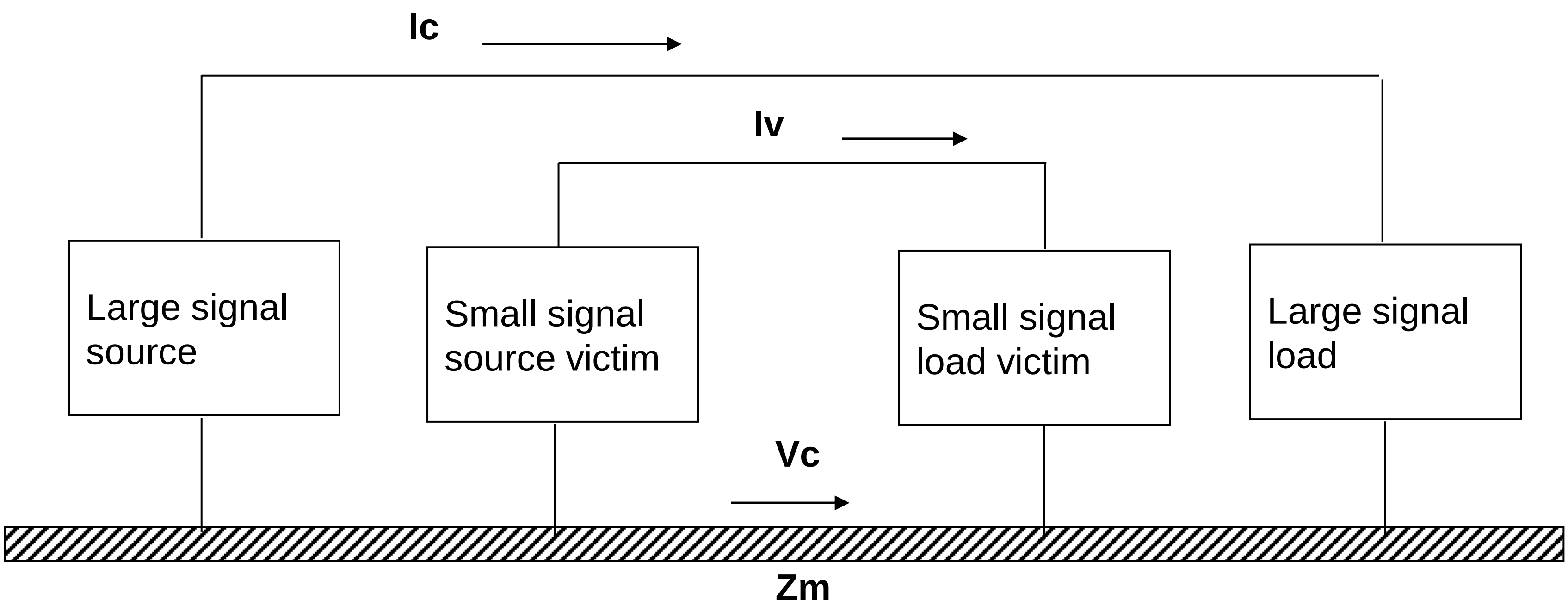
EMI is defined as any unwanted electrical or electromagnetic energy that causes undesirable responses, degraded performance, or failure in electronic equipment.

Four (4) coupling mechanisms:

- Common impedance (or conducted) coupling
- Electric field (or capacitive) coupling
- Magnetic field (or inductive) coupling
- Radiated coupling

Coupling Mechanisms

Common impedance coupling



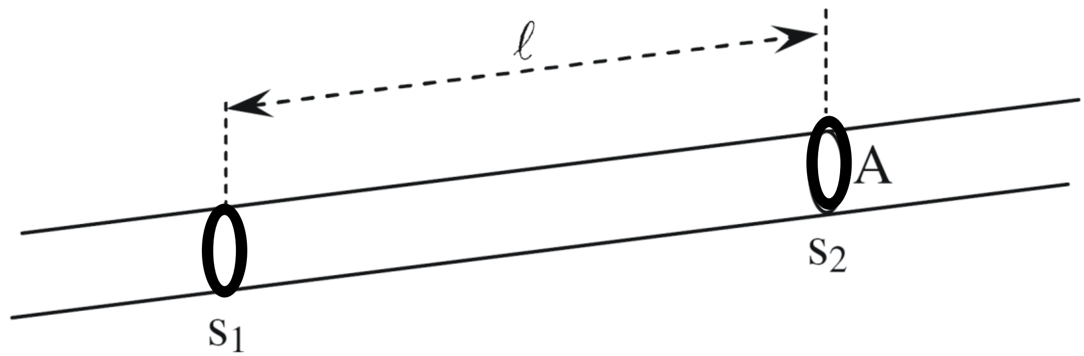
Zm : finite common impedance between large and small signal circuits

Vc = Zm (Ic + Iv)

Solution for reduction of Vc : single point or star grounding arrangement

Common impedance coupling

$$\delta = \frac{1}{\sqrt{\pi F \mu \sigma}}$$



F: Frequency (Hz)

μ : Permeability

ρ : resistivity (Ω.m)

σ : 1/ρ : Conductivity (S/m)

l : length (m)

A : Area (m²)

Silver: ρ =16.10^{-9} **Copper: ρ =17.10^{-9}**

Au: ρ =22.10^{-9} **Aluminium: ρ =28.10^{-9}**

Tin: ρ =111.10^{-9} ……

Others:

Water: ρ =1.8 10^{5} **Glass : ρ =10^{17}**

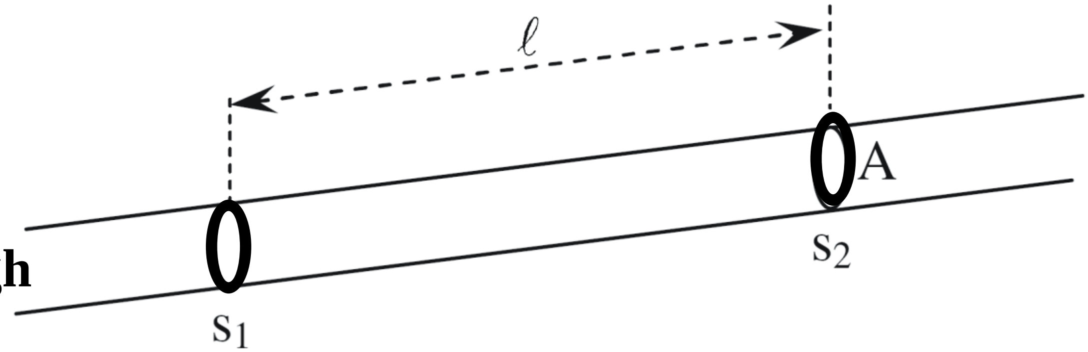
Polystyrene: ρ =10^{20} ……

Common impedance coupling

Resistance of a rod wire at low frequencies (i.e. δ>> a):

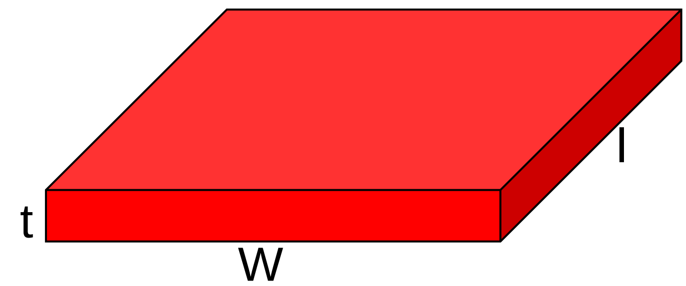
$$R = \frac{l}{\sigma\, A} = \frac{l}{\sigma\, \pi a^2}$$

a= radius of wire



Resistance of a rod wire at high frequencies (i.e. δ << a):

$$R = \frac{l}{\sigma\, A} = \frac{l}{\sigma\, 2\pi a \delta}$$



Resistance of a circuit board trace at low frequencies (i.e. δ>> t):

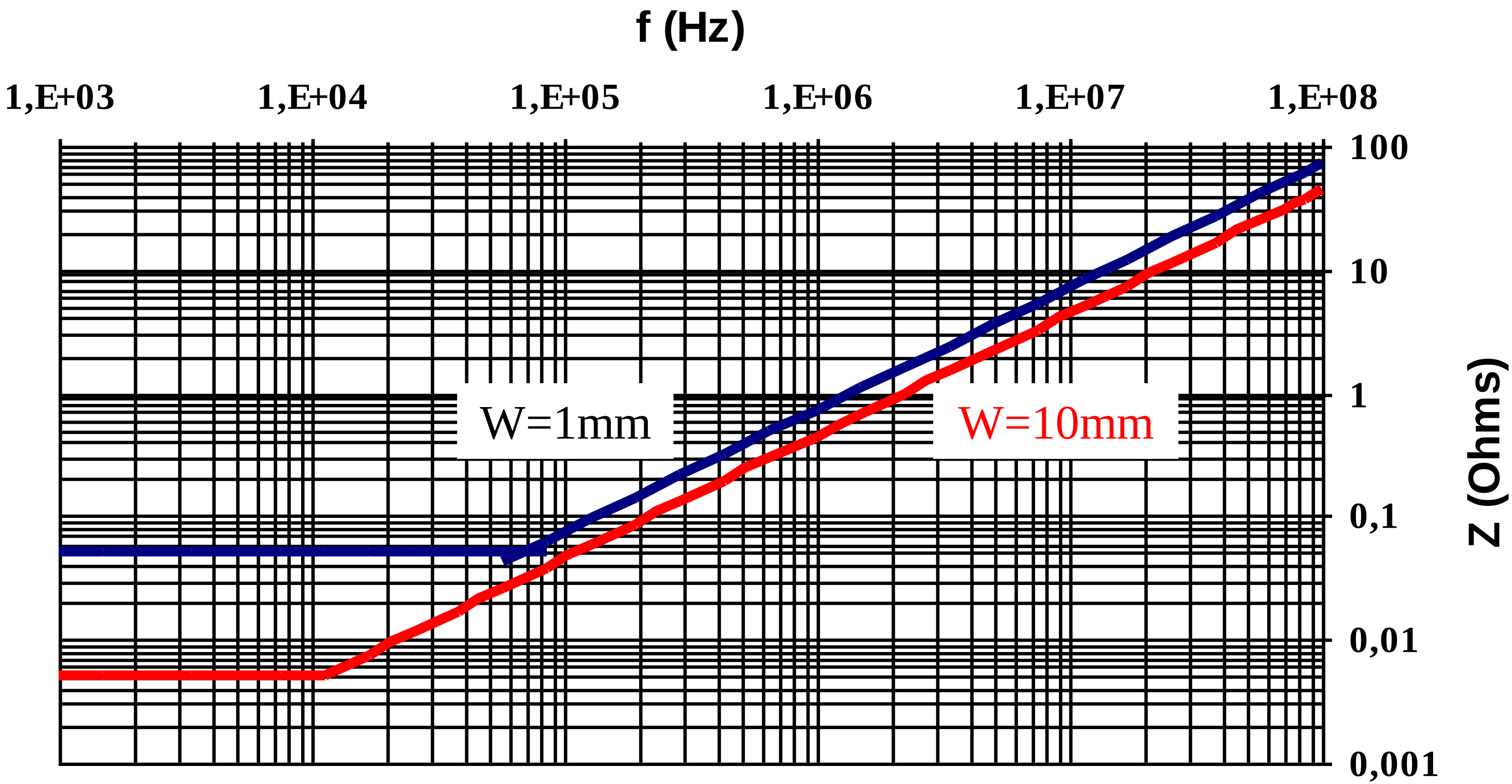
$$R = \frac{l}{\sigma\, A} = \frac{l}{\sigma\, wt}$$

Resistance of a circuit board trace at high frequencies (i.e. δ << t):

$$R = \frac{l}{\sigma\, A} = \frac{l}{\sigma\, 2wt}$$

(we assume t<<w)

Impédance de pistes de Cu de 10 cm (e=35um)



Exercise

The DC resistance per unit length of a cylindrical copper wire with a 0.5mm Diameter is approximately:

a) 80 mΩ/m
b) 800 mΩ/m
c) 1.80 Ω/m
d) 180 Ω/m

Answer:

The conductivity of copper is approximately $6x10^7$ S/m .

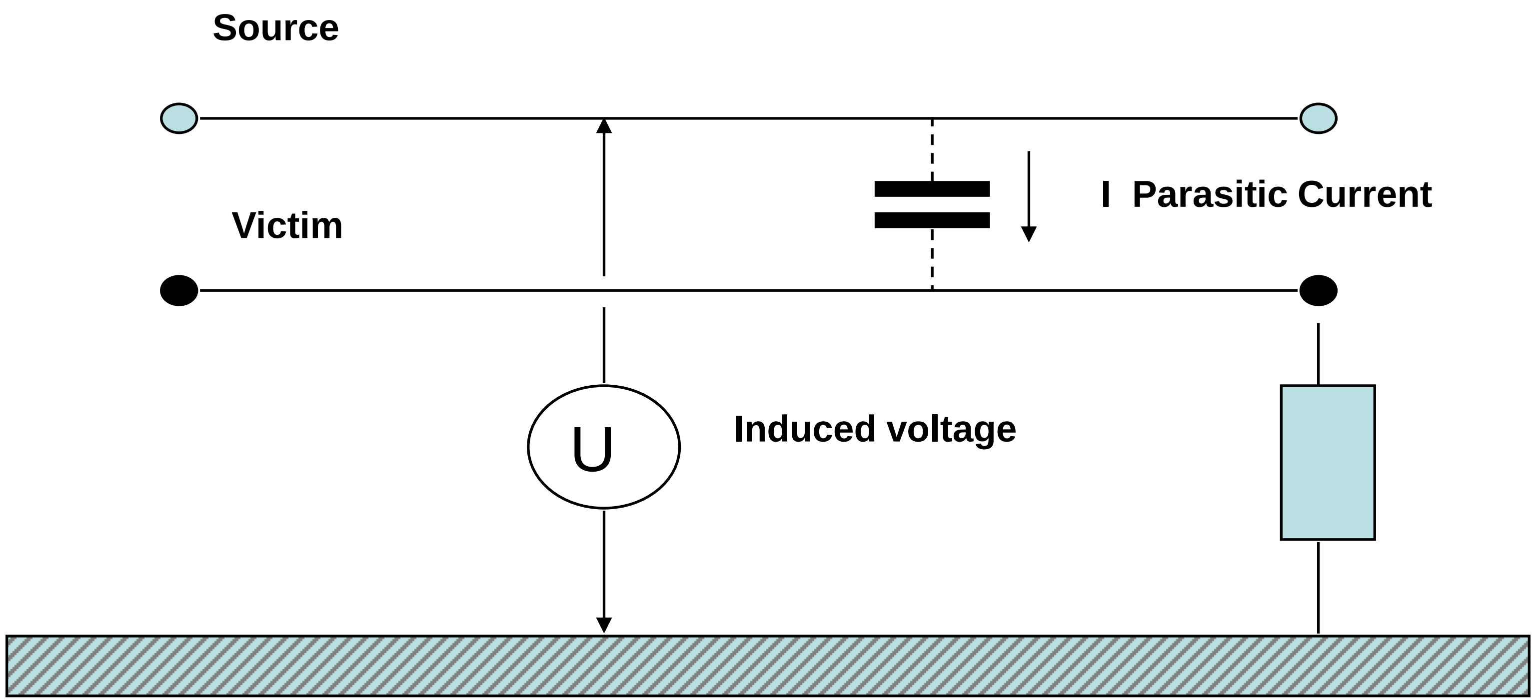
The resistance per unit length of wire is therefore:

$$R = \frac{l}{\sigma A} = \frac{l}{\sigma \pi a^2}$$

$$R = \frac{1}{(6x10^7\ S/m)\pi(0.25x10^{-3}m)^2} \approx 85\ m\Omega$$

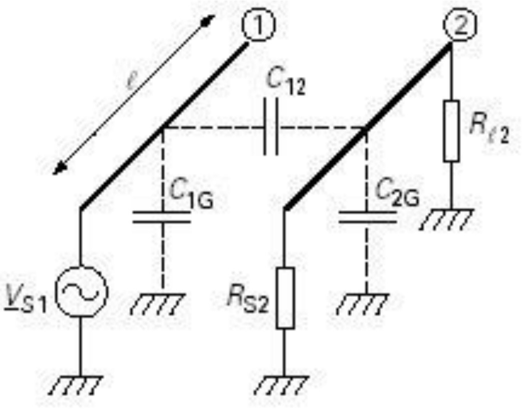
Coupling Mechanisms

xTalk: Capacitive coupling

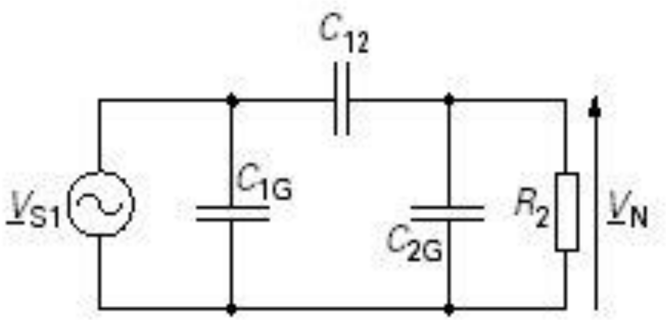


V1 $\Rightarrow$ E $\equiv$ mutual capacitance

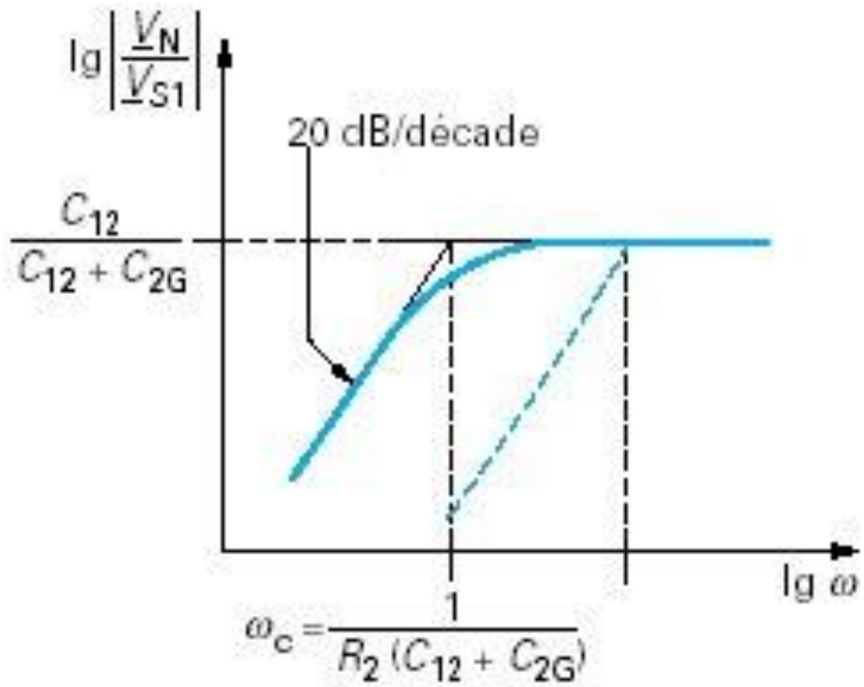
xTalk: Capacitive coupling



ⓐ description physique

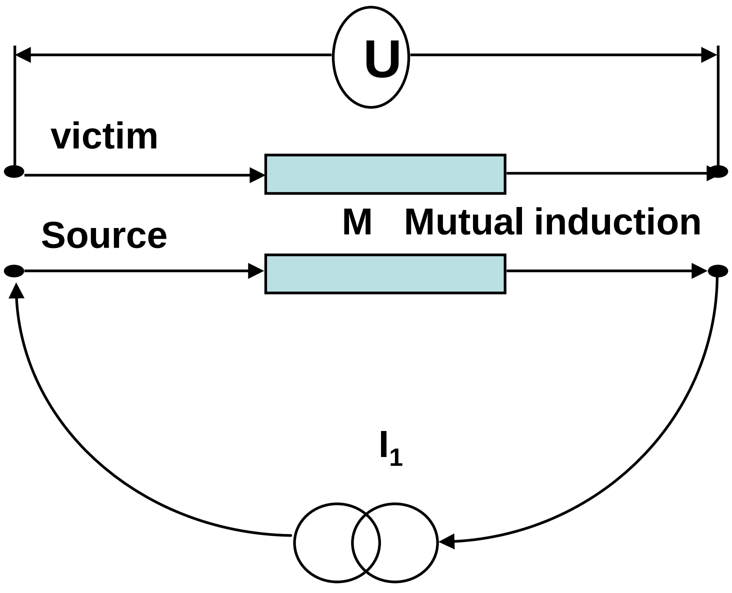


ⓑ schéma équivalent



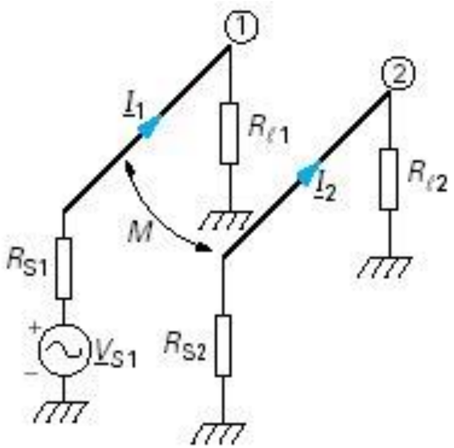
ⓒ variation du module de la fonction de transfert

xTalk: Inductive Coupling

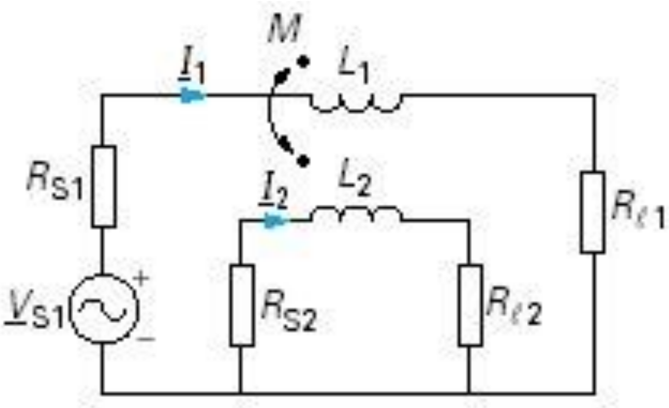


Lentz: I $\Rightarrow$ B $\Rightarrow$ ϕ $\Rightarrow$ induced voltage

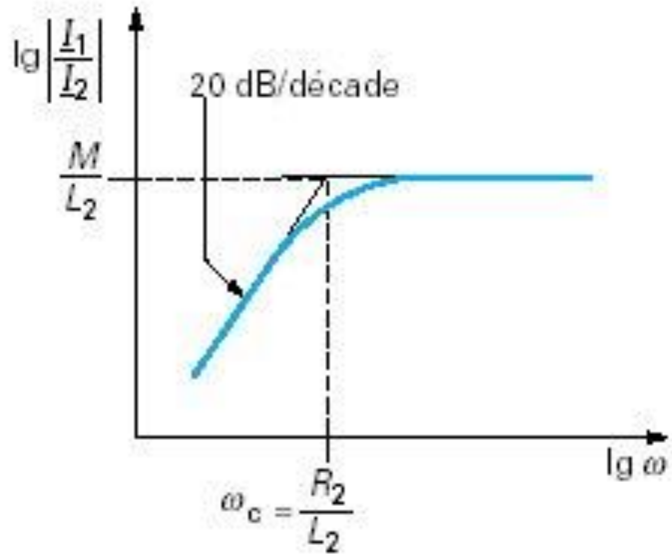
xTalk: Inductive Coupling



(a) description physique



(b) modèle équivalent



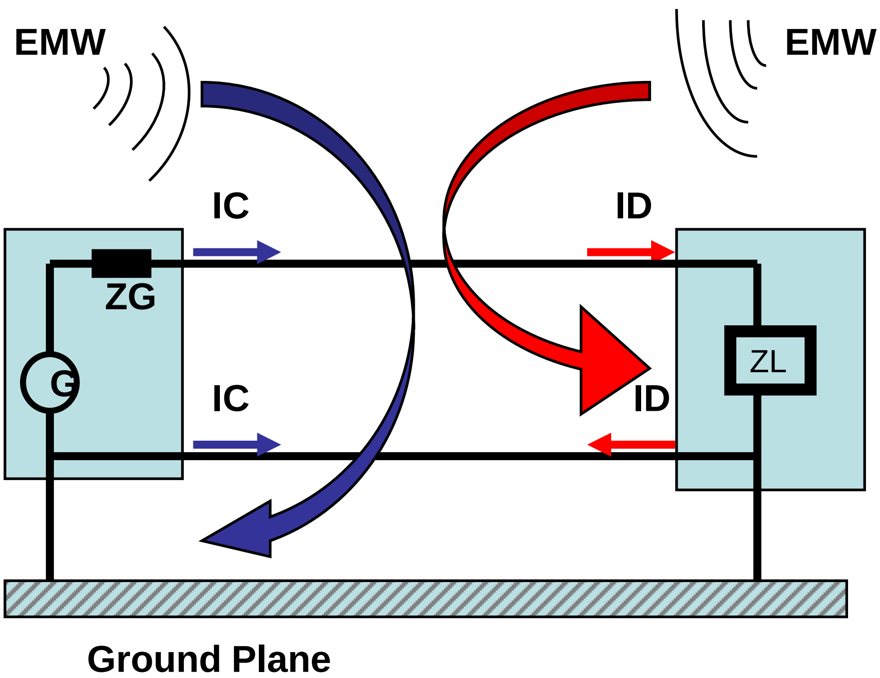
(c) variation du module de la fonction de transfert

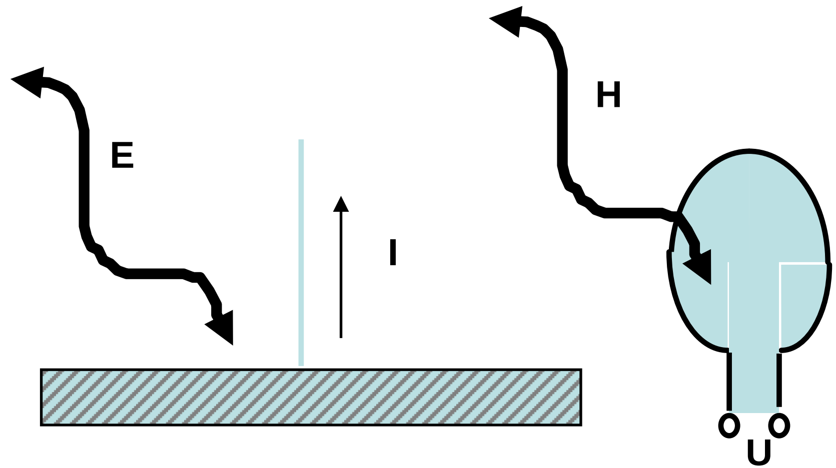
$$\frac{I_2}{I_1} = -\frac{\dfrac{jM\omega}{R_2}}{1 + j\dfrac{L_2\omega}{R_2}}$$

Where: $R_2 = R_{ch2} + R_{G2}$

EMW to Wires and Loops

$$\frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}} = 120\pi \cong 377\Omega$$





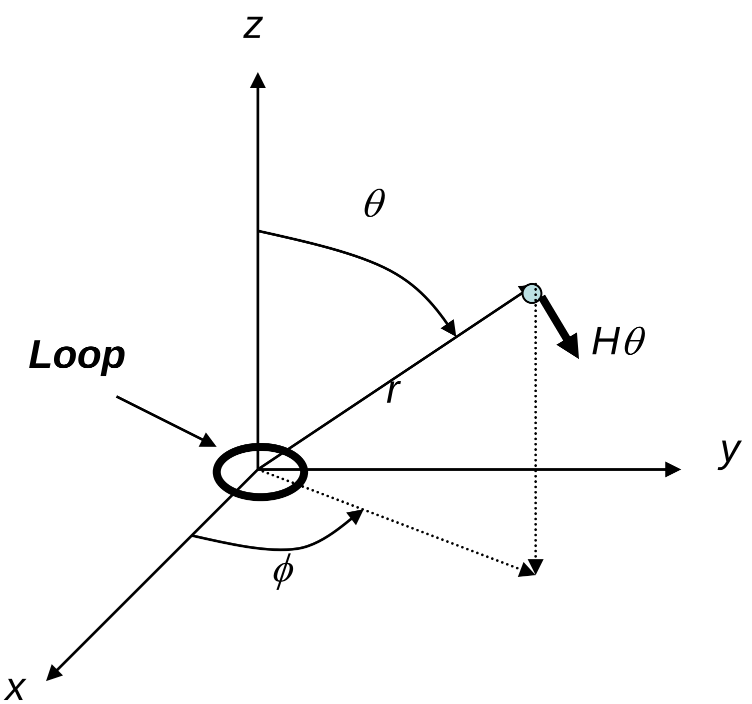
Wire or Loop ? ≡ Electric or Magnetic dipole?

- Wire, Loop, surface, slot
- cable, feed line

⟺

Reciprocity
E, H ⇔ V, I

Radiating Loop



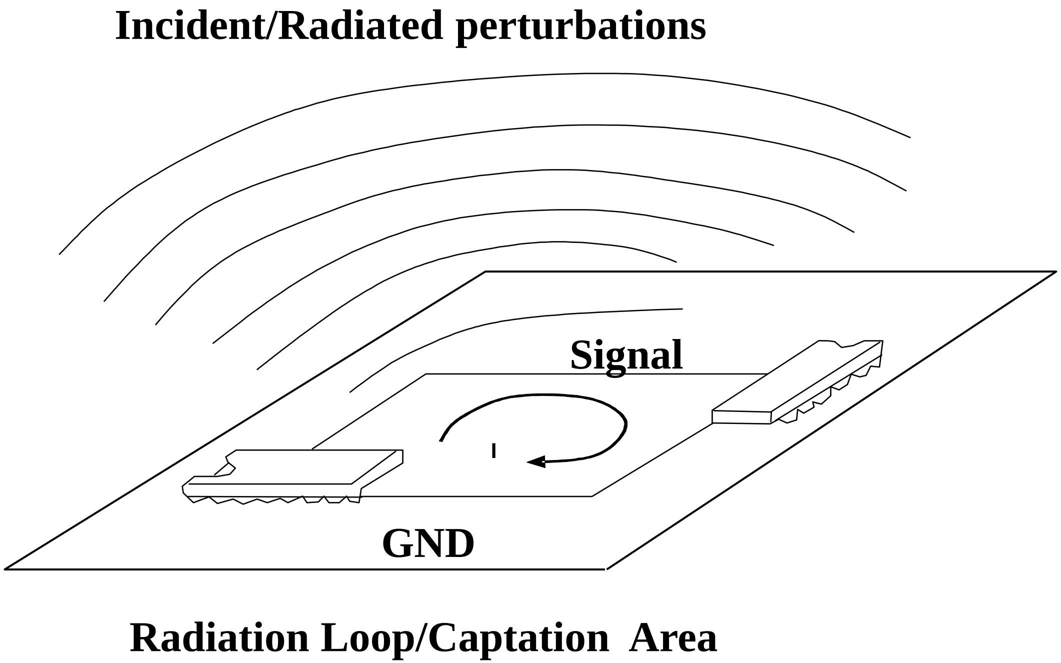
Near field (freq independant):

$$H = H_0 \sqrt{\frac{3\cos(2\theta) + 5}{8}}$$

Far Field (freq dependant):

$$H = \frac{IS\beta^2}{4\pi r} \sin\theta$$

Receiving Loop



- Low Frequency : Length << λ

$$e = -\frac{\partial \phi}{\partial t} = -j\omega * (\mu_0 \mu_r) * H * S * \cos(\vec{B}, \vec{S})$$

How to reduce e

F↓ !!!!!!

Relative Permeability ↓ air

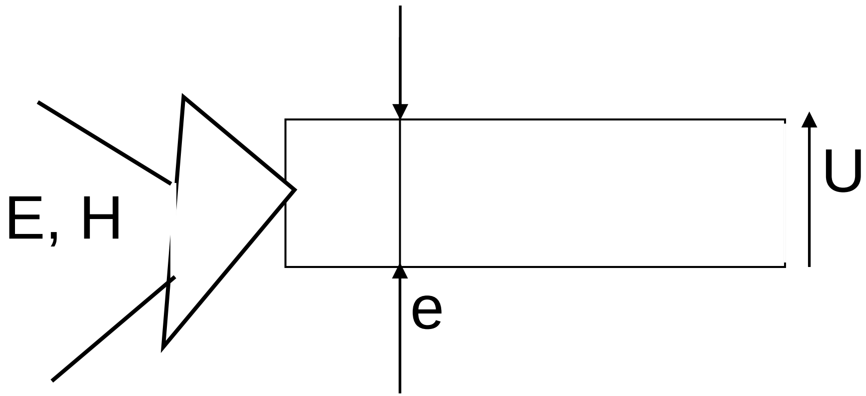
H ↓

Area ↓

Cos(B,S) ↓

Receiving Loop

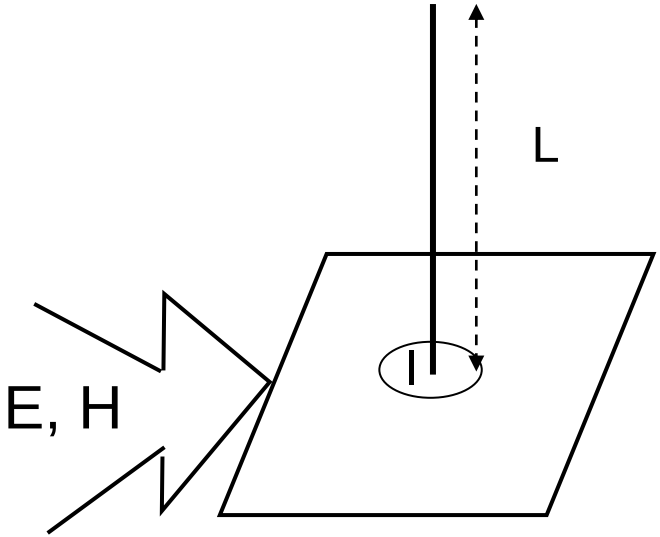
- H F   Length, L≅ λ



Worst case : $$\mathbf{U_{max} = 600 \, . \, e \, . \, H}$$

$$\mathbf{U : V \;,\; e : m \;,\; H : A/m}$$

Receiving Wire



- Low Frequency : L << λ/4

$$\mathbf{I} \cong \frac{\mathbf{E\,L}}{\mathbf{100\,\lambda}} \quad ;\ \mathbf{I:A\ ,\ E:V/m\ ,\ L:m\ ,\ \lambda:m}$$

Example: f= 945 kHz , L= 10 m, E= 300 V/m

→ I ≅ 94,5 mA

- High Frequency L≅ λ (Worst case)

$$I_{\max} = \frac{E\lambda}{240}\ ;$$

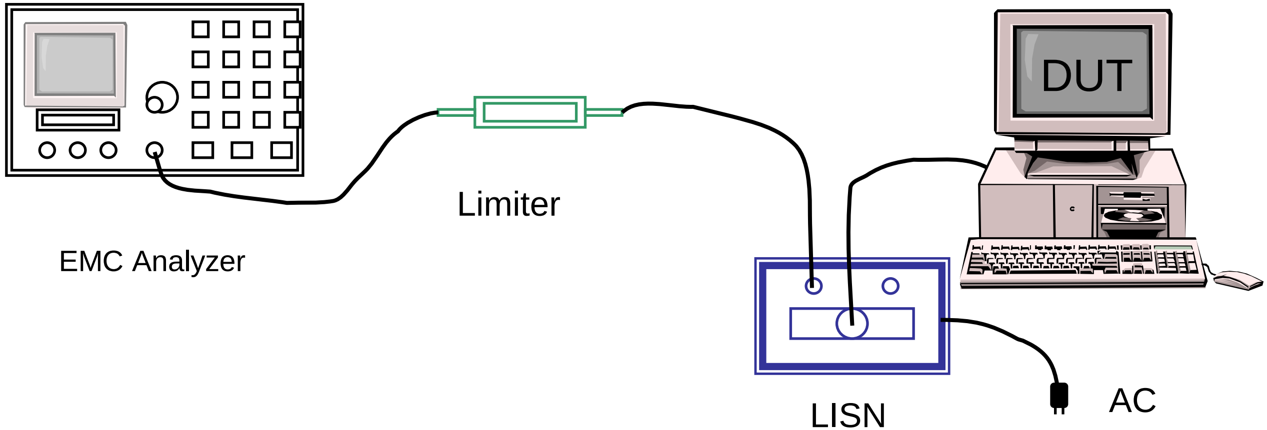
$$\mathrm{I}_{\max} : \mathrm{A}\ ,\ \mathrm{E} : \mathrm{V/m}\ ,\ \lambda : \mathrm{m}$$

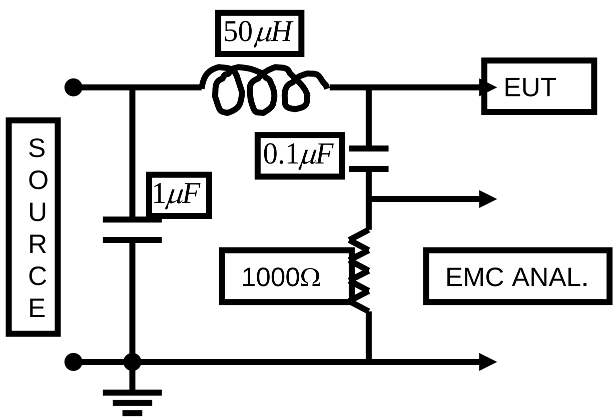
Example: f = 100 MHz, L= 1 m, E= 10 V/m

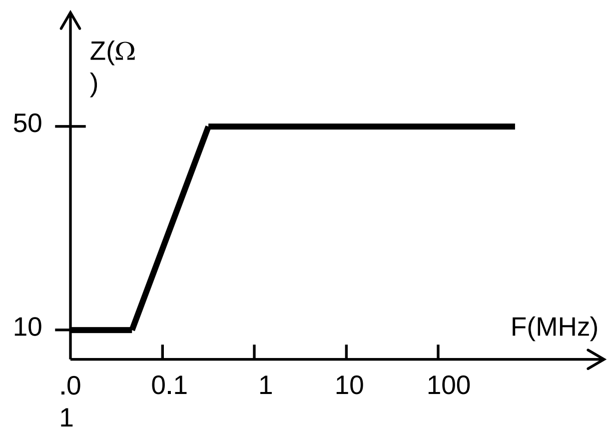
→ I_{max} = 125 mA

EMC Measurements

Conduction

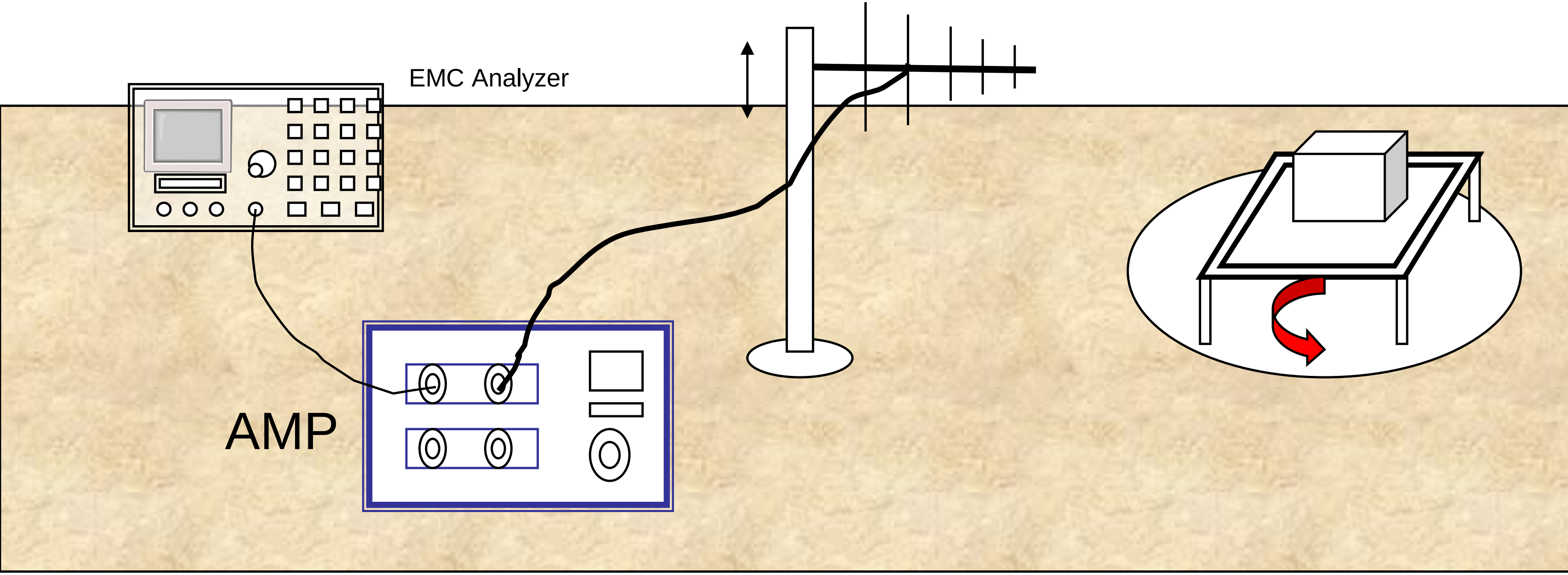






EMC Measurements

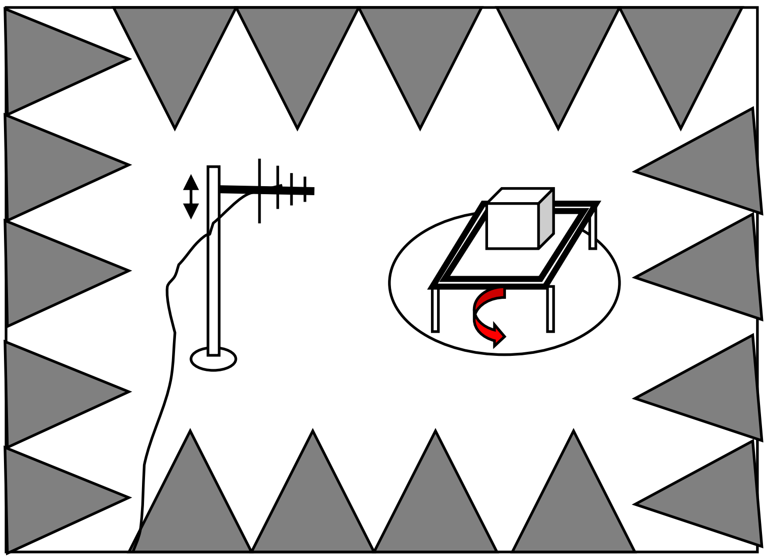
Radiation/OATS

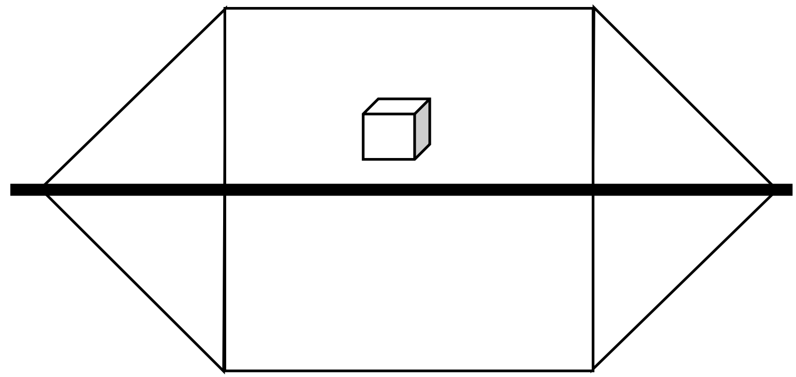


Ambients in OATS ⇒ Anechoic Chamber / TEM / GTEM Cell

EMC Measurements

Anechoic chamber
TEM/GTEM cell





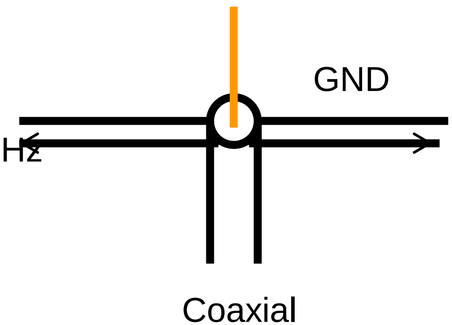
Efficency for low frequencies !!
High cost
Small Size

EMC Antennas and AF

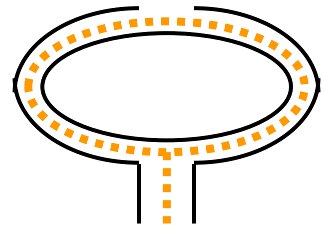
$$E(\mu V/m) = V_e(\mu V)\ .\ K(m^{-1}) \quad ou \quad E(dB\mu V/m) = V_e(dB\mu V) + K(dB)$$

(to be measured) **(Read)** **(Given)**

Vertical wire
(W/wo amplifier)
ΔF=100Hz to 30 MHz
(E Field)

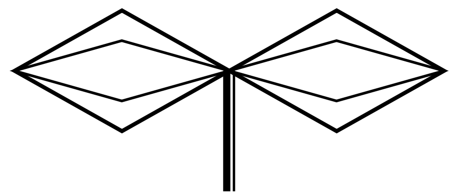


Loop
ΔF=10KHz to 30 MHz
(H Field)



Resonant dipoles
(w/wo amplifier)
ΔF=30MHz to 1 GHz

Biconic Antenna
ΔF=20 MHz to 300 MHz

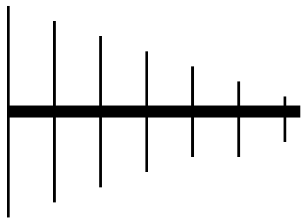


EMC Measurements

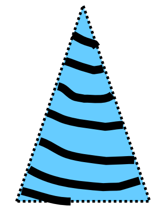
EMC Characterization

Log-periodic antenna

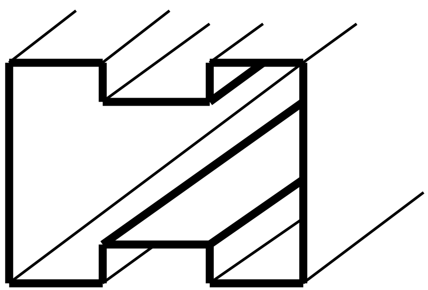
ΔF=200 MHz to 1 GHz



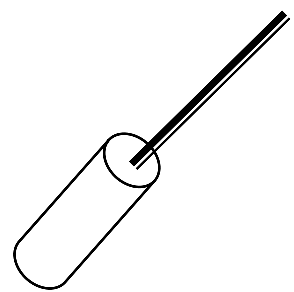
Log-spiral antenna
ΔF1=200 MHz to 1 GHz
ΔF2=1 GHz to 10 GHz



double-ridged horn
ΔF1=200 MHz to 2 GHz
ΔF2=1 GHz to 18 GHz



Search coil '

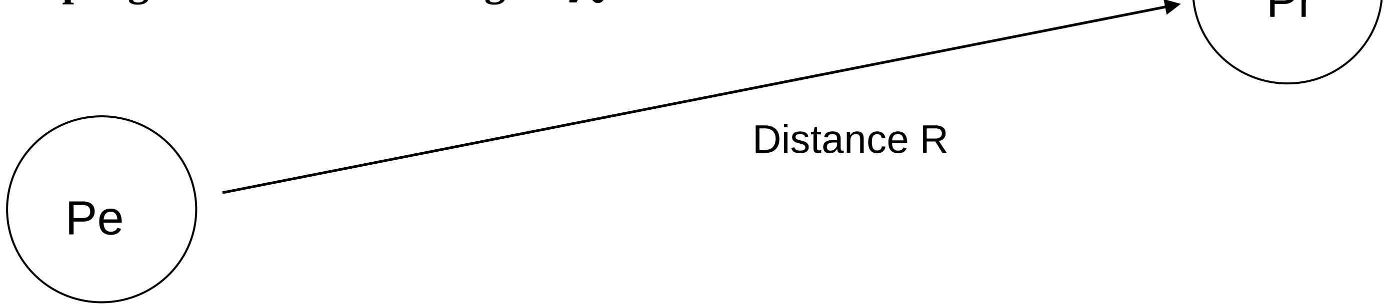


FRIIS transmission equation

FRIIS transmission equation

Pr : Received power by antenna of isotropic gain Gr

Pe : Transmitted power by antenna of isotropic gain Ge at wavelength λ



FRIIS : $$\mathrm{Pr} = GeGr\big(\lambda/(4\pi R)\big)^2 Pe$$

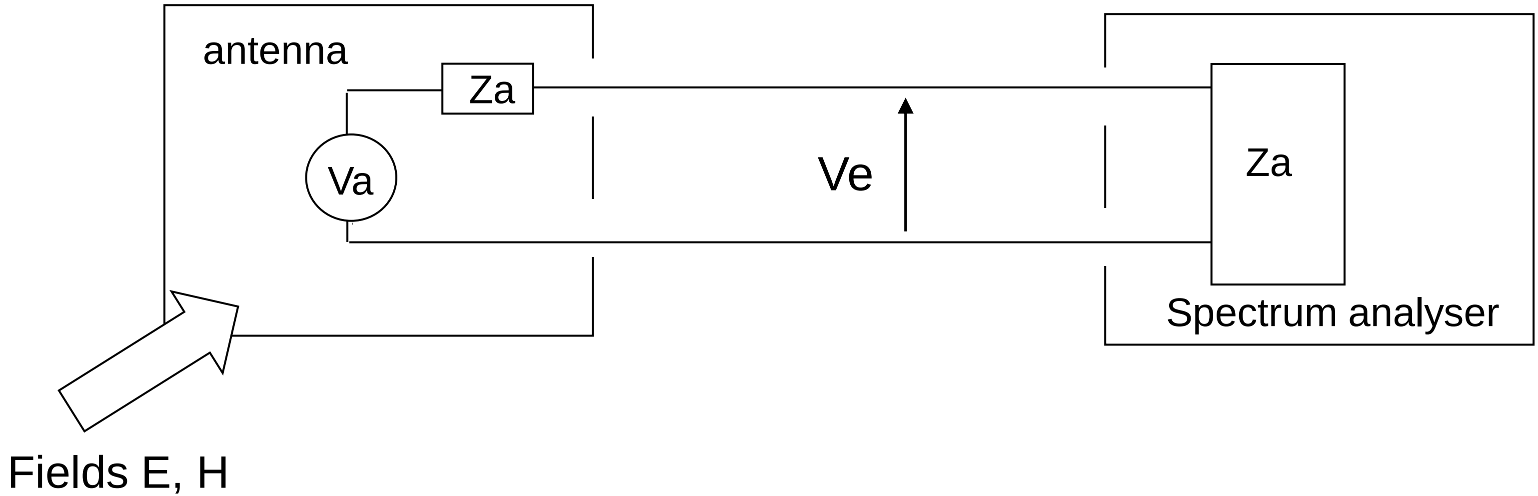
Electric field created by a isotropic antenna at the distance R :

$$\mathbf{E} \approx \frac{\mathbf{1}}{\mathbf{R}}\sqrt{\mathbf{30Pe}}$$ (With E : V/m and R : m)

Example: For GSM with Pe (max) =2W and R=4 m we obtain: $E \approx 2\ V/m$

EMC Measurements

Antenna Factor

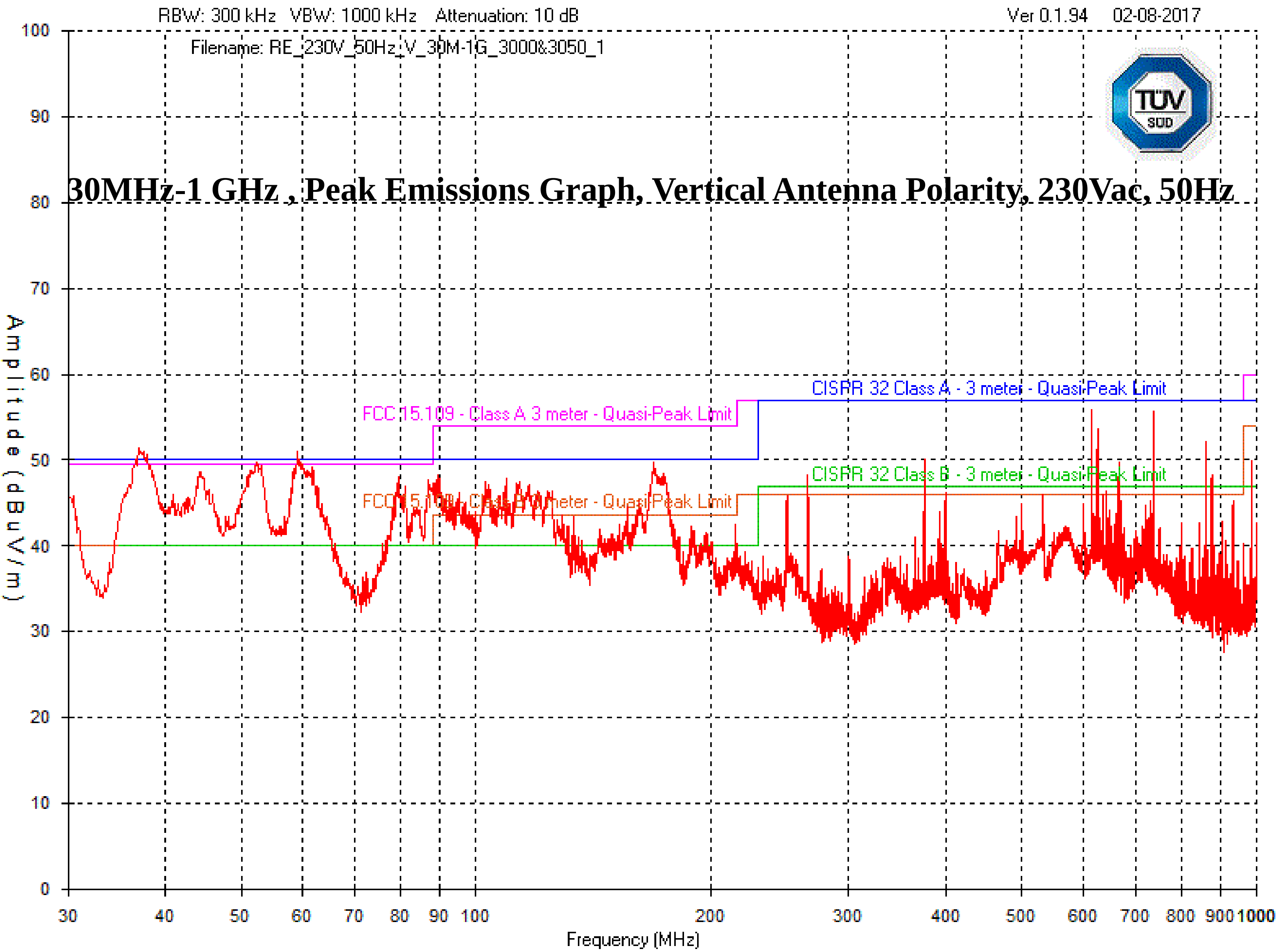


E=Ve K   Avec (E : V/m and K : 1/m) or (E : µV/m and K : 1/m)

E = Ve + K (E : dBµV/m and K : dB)

$$G = 20\log(9.73/\lambda) - AF$$

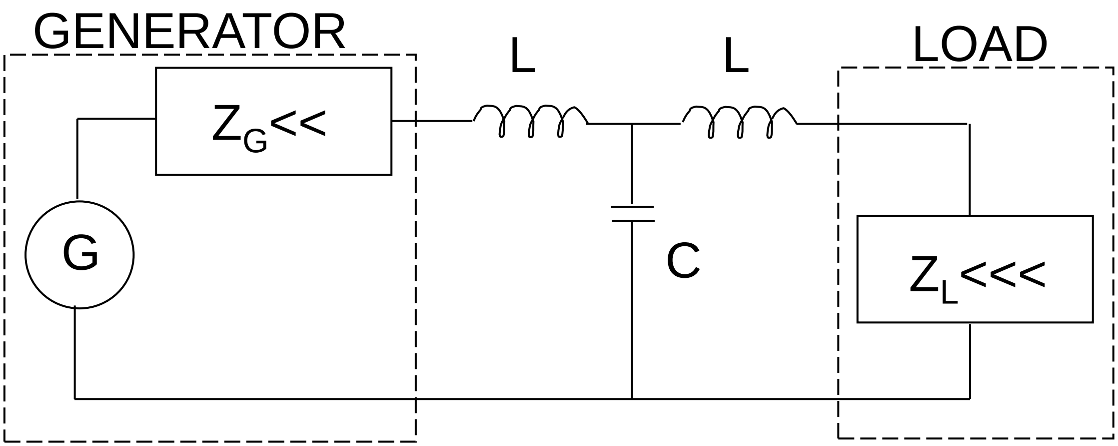
Measurements vs Standards

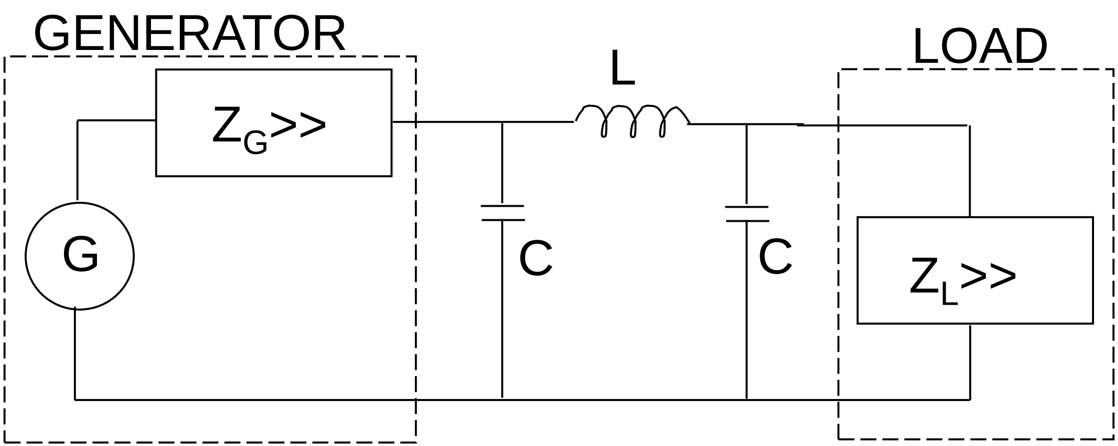


Mitigation Techniques

Filtering

- Low pass filter, band stop filter, ….



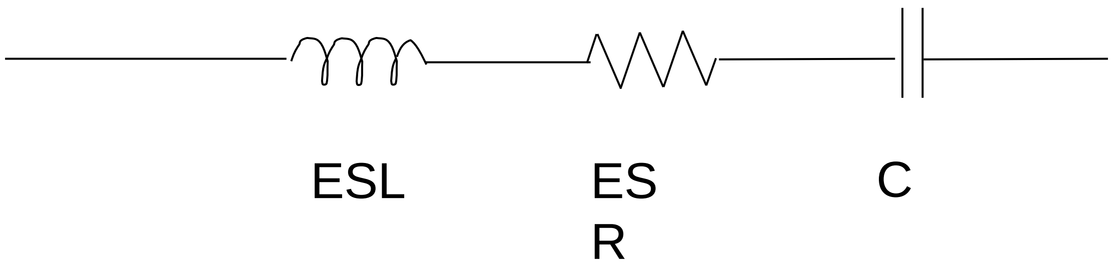


L with Z_G, Z_L small

C with Z_G, Z_L large

Design Guides

Typical Capacitor Model



Electrolytic capacitors made of tantalum or aluminium:

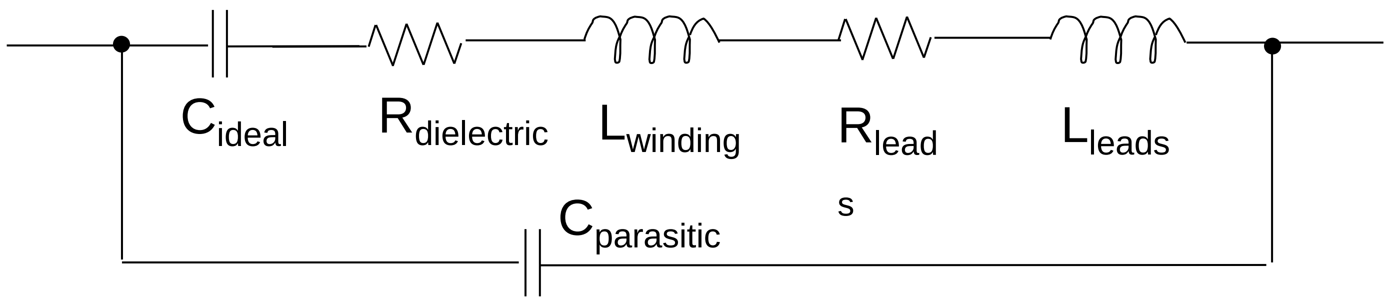
- high capacitance
- but high ESL
- generally only used for low frequency and energy storage

mylar capacitors are small relatively inexpensive and used trough ten to a few hundredths of a MHz

Mitigation Techniques

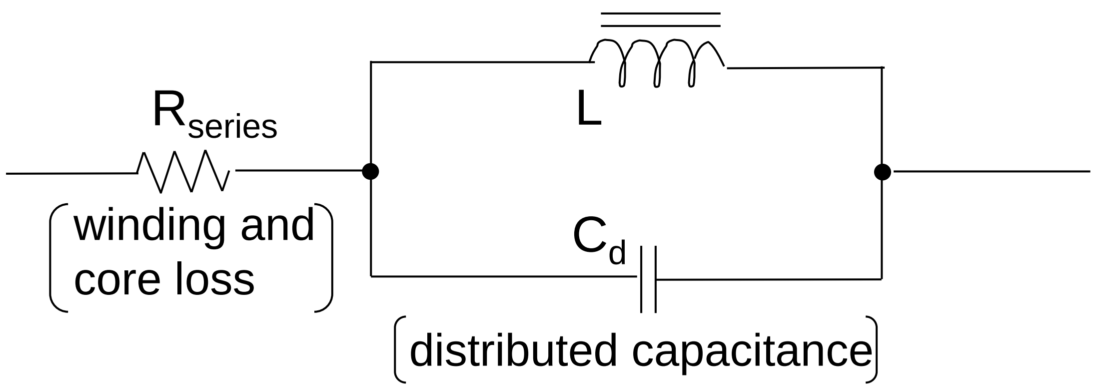
HF Capacitor Model

* High frequency capacitor model



- parallel resonant frequency

* Typical inductor model

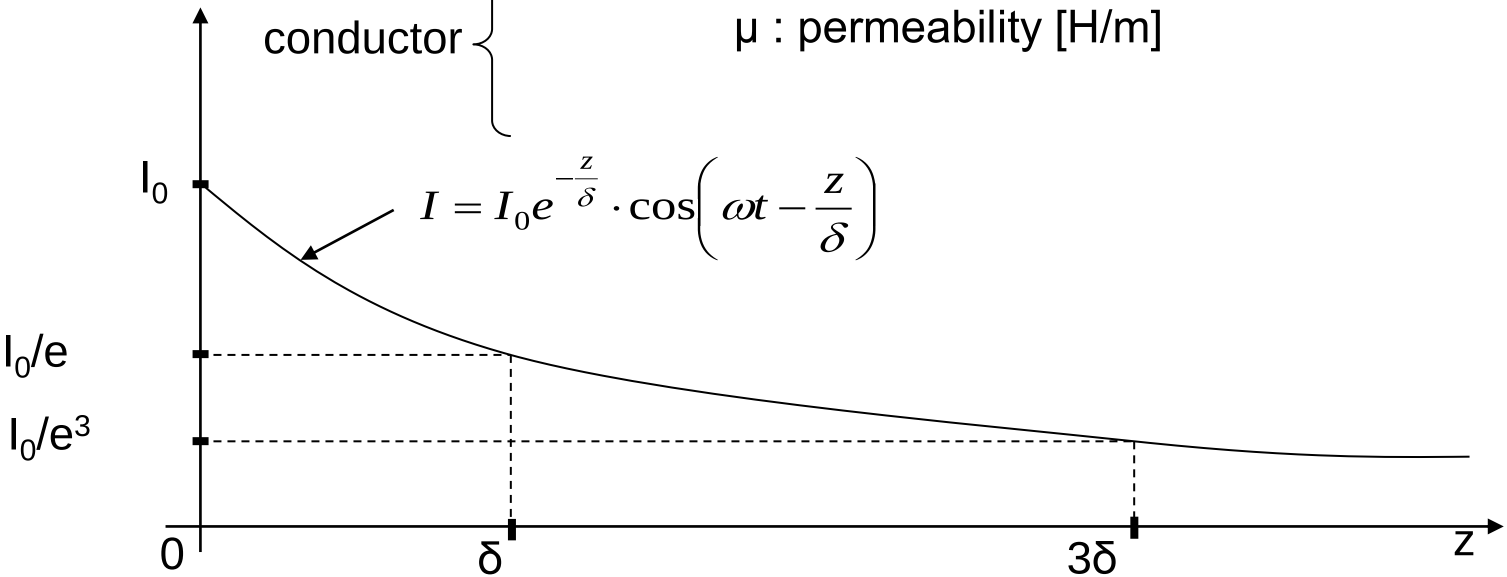


Shielding

* skin effect

σ : electrical conductivity [S/m]

μ : permeability [H/m]



$$I = I_0 e^{-\frac{z}{\delta}} \cdot \cos\left(\omega t - \frac{z}{\delta}\right)$$

Skin depth : $\delta = \sqrt{\dfrac{1}{\pi \cdot f \cdot \mu \cdot J}}$ δ [m] and f [Hz]

* N.A.

copper

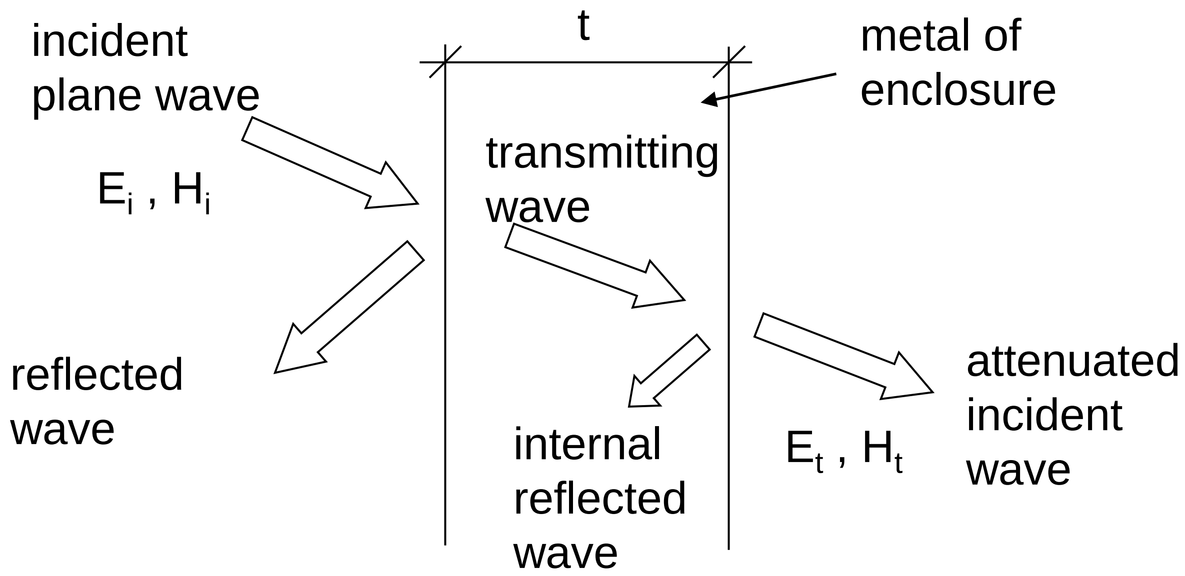
$\sigma = 5.8 * 10^7$ [S/m]

$\mu = \mu_0 = 4\Pi * 10^{-7}$ [H/m]

f	50 Hz	10 kHz	1 MHz	100 MHz	10 GHz
delta	9.35 mm	0.66 mm	66 µm	6,6 µm	0,66 µm

Mitigation Techniques

Shielding effectiveness



Electric filed : SE_e (dB) = 20 log (E_i/E_t)

Magnetic filed : SE_h (dB) = 20log (H_i/H_t)

Conducting factors : SE = R + A + B

R : reflection loss in dB

A : transmission or absorption loss in dB

B : internal reflection loss in dB (usually neglected)

Mitigation Techniques

SE Summary

* Absorption loss : $$A[dB] = 8.68 \cdot \frac{t}{\delta}$$

* Near filed zone :

- magnetic filed $$R_h[dB] = 131.43t\sqrt{f\mu_r\sigma_r} + 74.6 - 10\log\left(\frac{\mu_r}{\sigma_r \cdot f \cdot r^2}\right)$$

- electric filed $$R_e[dB] = 131.43t\sqrt{f\mu_r\sigma_r} + 141.7 - 10\log\left(\frac{\mu_r \cdot f^3 \cdot r^2}{\sigma_r}\right)$$

* for plane waves :

$$SE_e = SE_h = 131.43t\sqrt{f\,\mu_r\sigma_r} + 108.1 - 10\log\left(\frac{\mu_r}{\sigma_r} f\right)$$

with : r = Source-to-Shield Distance in m , t = Shield Metal Thickness in mm

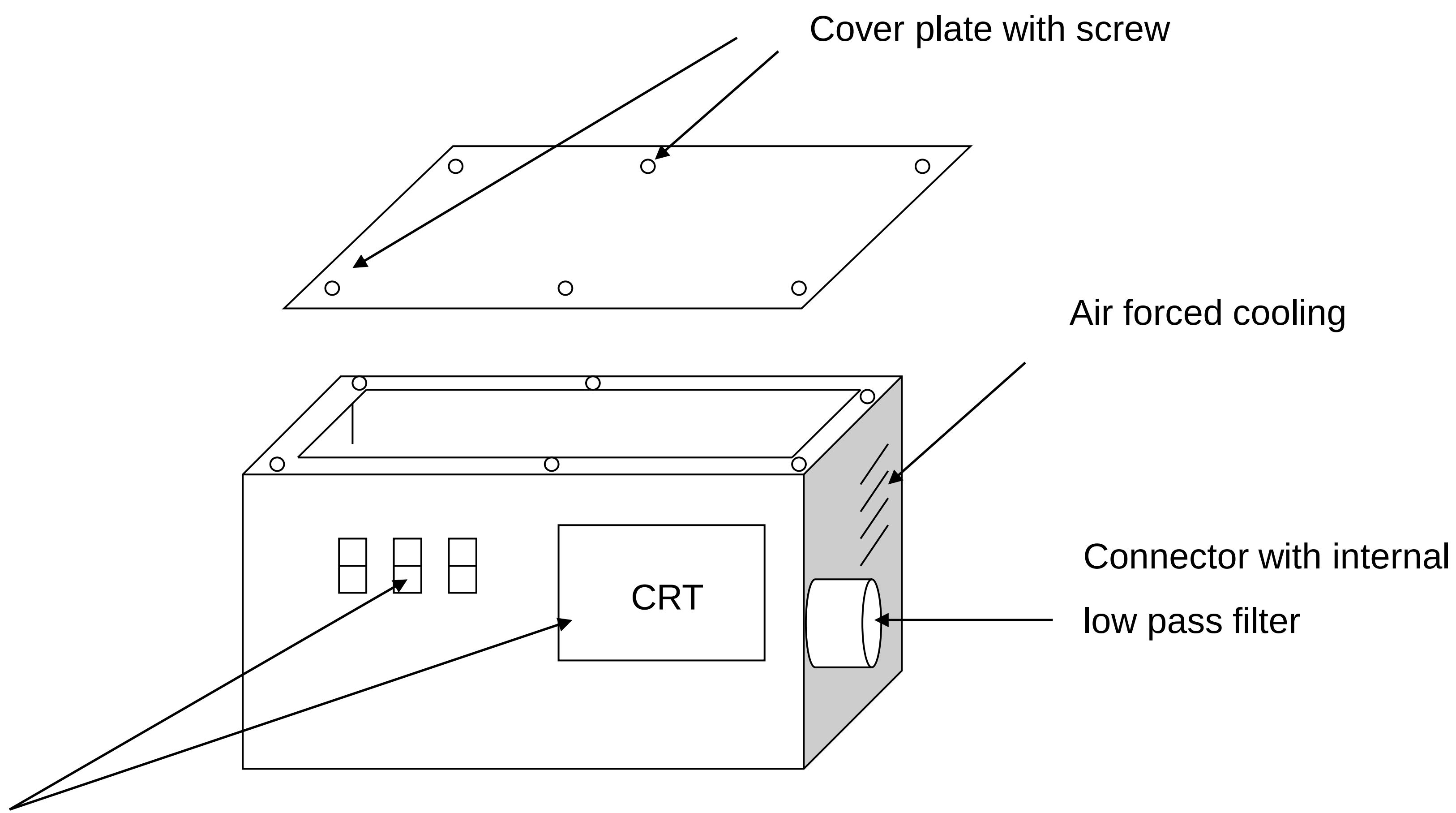
f = Frequency in MHz , δ = Skin Depth in mm

μ_r = Relative Permeability of Copper , σ_r = Conductivity Relative to Copper

<u>Example</u>: f = 10 kHz , r = 10 cm , σ_{cu}= 5.7 10^7 S/m , $\mu = \mu_0 = 4\pi 10^{-7}$ H/m ,
t = 0,8 mm A ~ 10 dB , SE_e ~ 118 dB , SE_h ~ 44 dB ($SE_e >> SE_h$)

Mitigation Techniques

Control Apertures Leakages

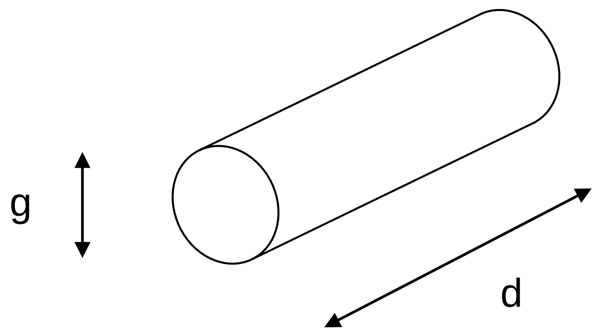


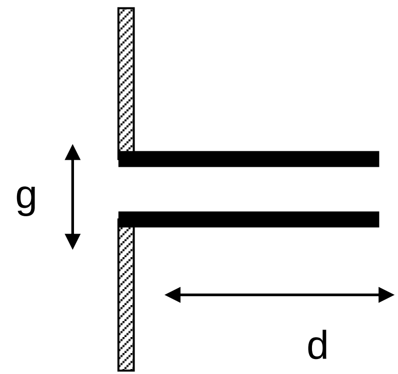
viewing window apertures (optically transparent and RF reflective)for alphanumeric display or CRT

Mitigation Techniques

Apertures and HoneyComb Shielding

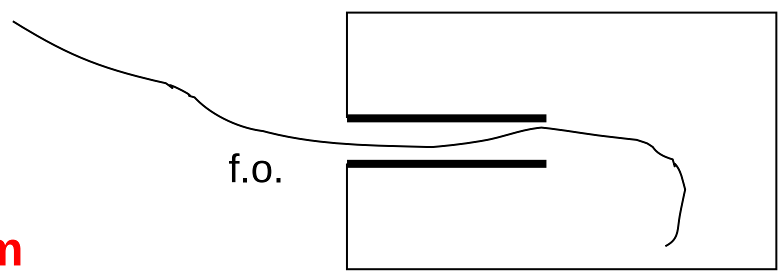
Deep aperture with round holes





A (dB) = 32 (d/g)

Typical application : input of fiber optic (f.o.)



Example. : g = 3 mm and d = 15 mm

A = 160 dB

Mitigation Techniques

Transfert Impedance

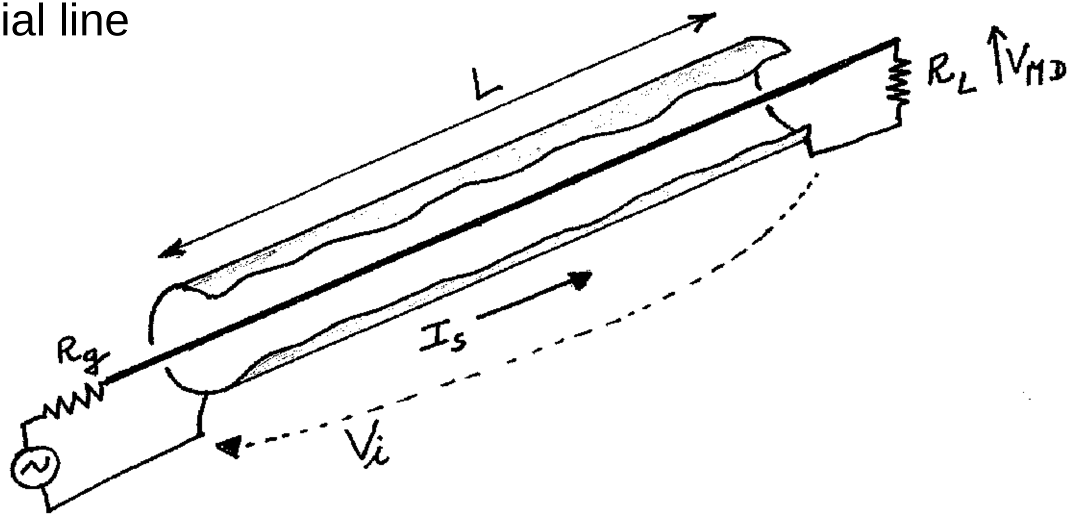
Transfert impedance Zt of coaxial line

$$\mathbf{l} < \frac{\lambda}{2}$$

$$\mathbf{Zt} = \frac{\mathbf{Vi}}{\mathbf{Is.l}} \quad \Omega$$

Zt : (V/m) l : (m)

Vi : (V) Is : (A)



Example. : l=5m coaxial line with Is=100 mA and f= 1 MHz

RG58/U : Zt= 14 mΩ/m $\Longrightarrow$ **Vmd = 3.5 mV (single shield)**

RG214 : Zt= 5 mΩ/m $\Longrightarrow$ **Vmd = 1.25 mV (double shield)**

Exercise :

Which of the following cable transfer impedance measurement results corresponds to the cable with the best shielding

a) 2 mΩ
b) 10MΩ
c) 0dB
d) 100dB

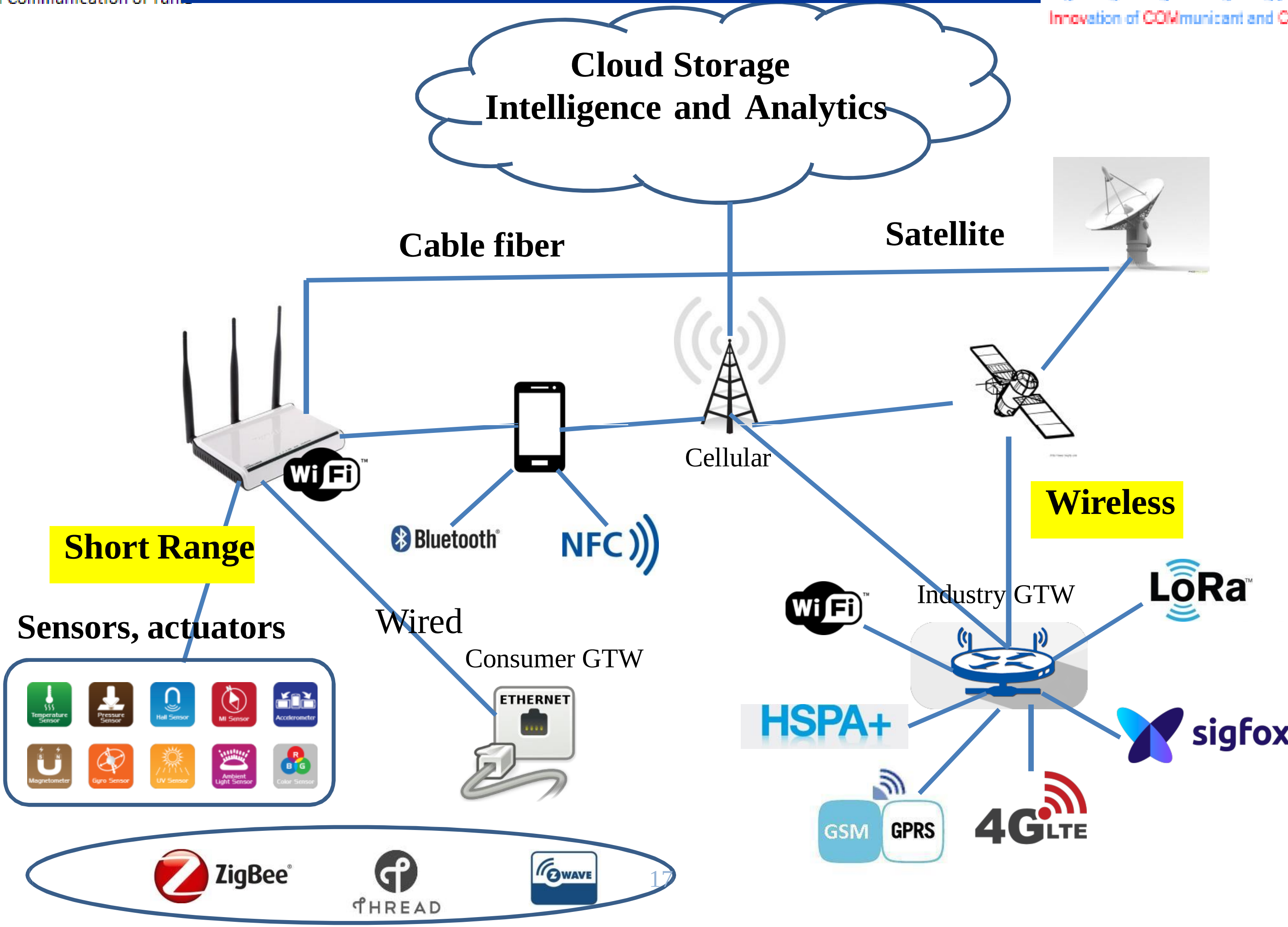
Answer:

Cable Transfer impedance measurements induce a current on the cable shield and measure the voltage induced in the signal wire terminations.
The transfer impedance is the ratio of the induced voltage to the excitation current.

Smaller values imply better shielding.

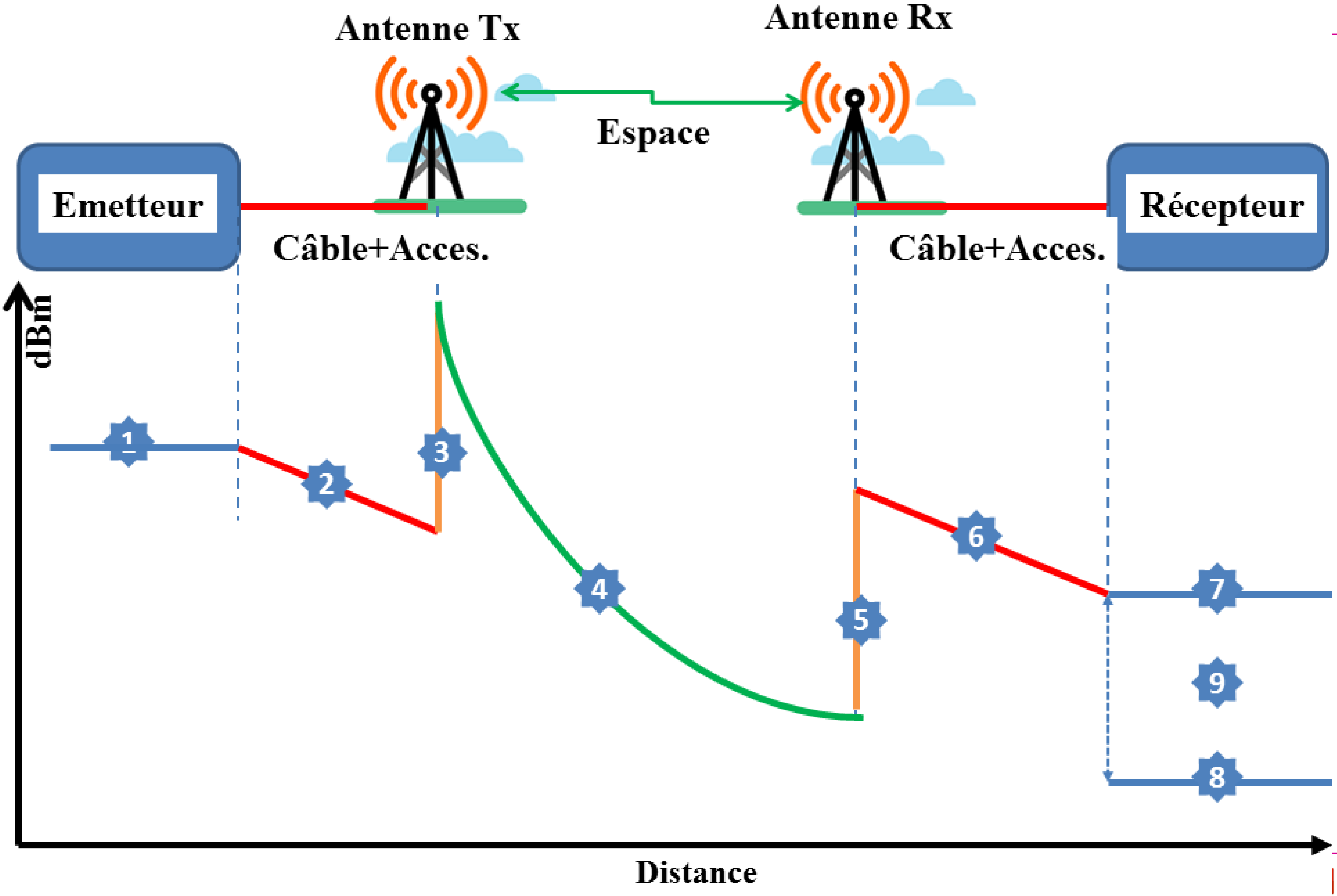
Note that the last two options are not impedances.

IoT: Architecture



IoT: Communications AND Radio

Budget Link



Antenne Tx
Antenne Rx
Espace
Emetteur
Récepteur
Câble+Acces.
Câble+Acces.
dBm
1
2
3
4
5
6
7
8
9
Distance

Rapport Signal à Bruit

S = Received Signal/Power

B= N=Noise)

S/B= S/N, SNR, C/I, C/N, C/(N+I)

Radio planning
Antennas, MiMo
LNA, PA, Gmax

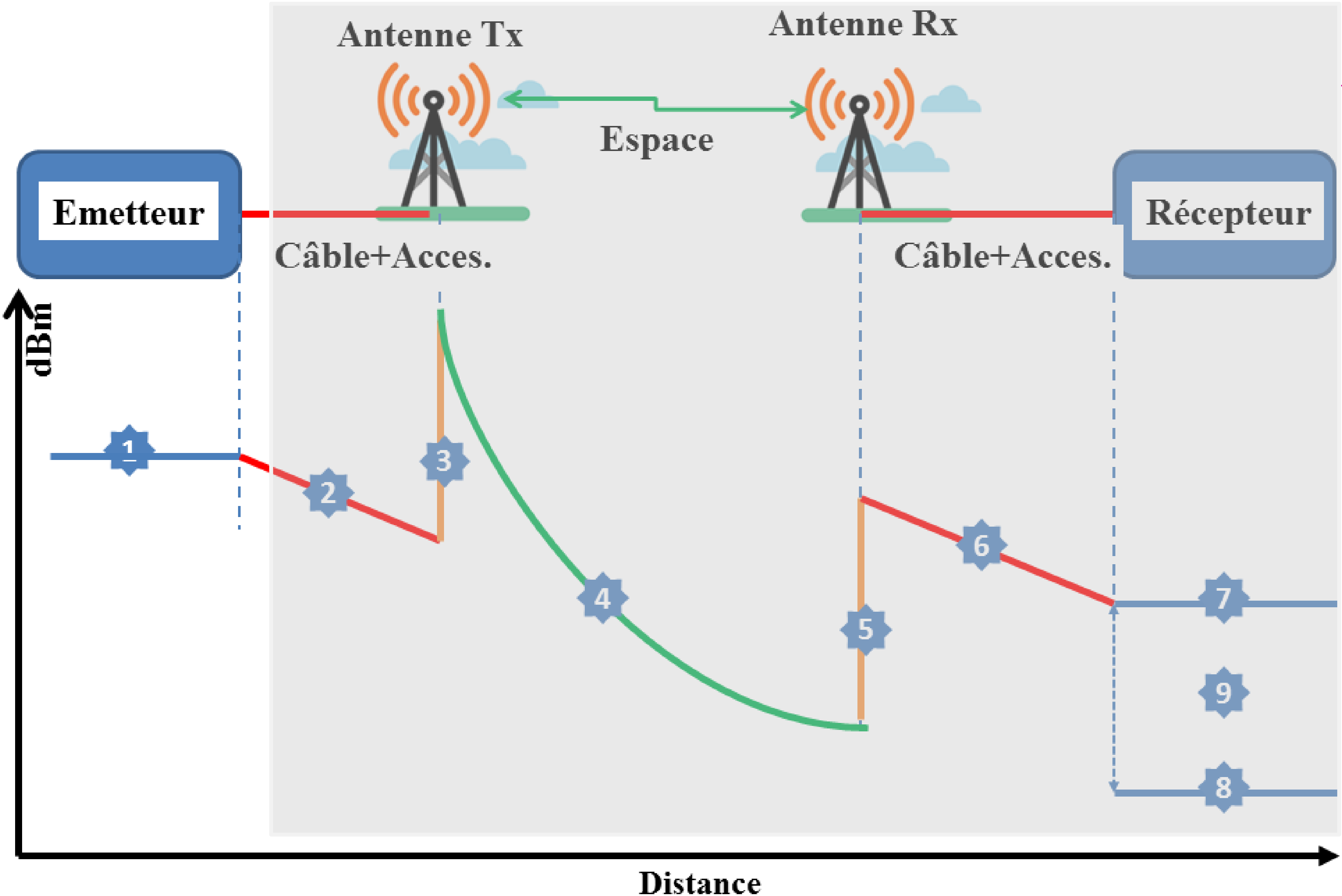
$$\frac{S}{B}$$

Matching
Power Control
Cable Loss

Components, Filtring
Processing, Modulation,
Nonlinearities & Linearization

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \frac{1}{\alpha_B \alpha_G \alpha_A} \quad (w)$$

Pt = Transmitted Power,
Pr = Received Power
Gt = Transmitter Antenna Gain
Gr = Receiver Antenna Gain
d = Distance between transmitter and receiver
α_B , α_G , α_A **= Losses of connectors, guides and hydrometeor, respectively**
+ : Matching, Polarization, Antenna Pointing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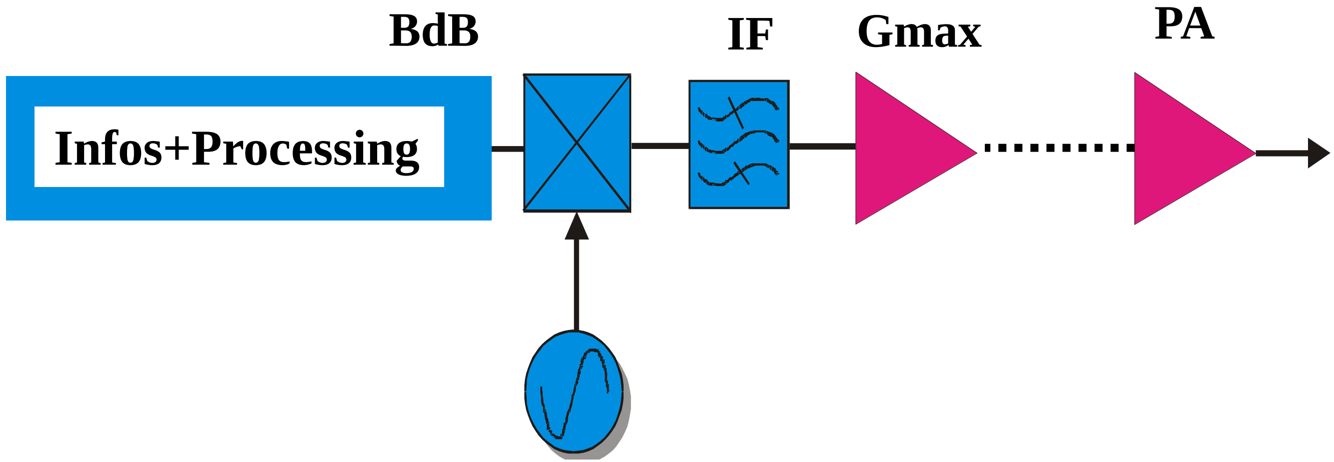
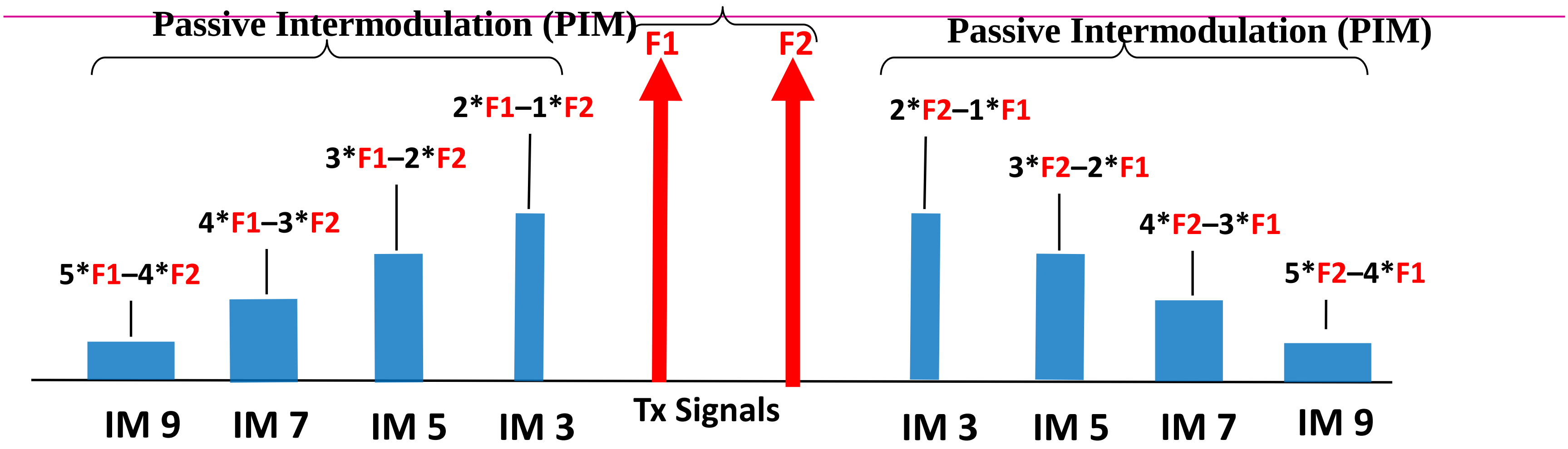
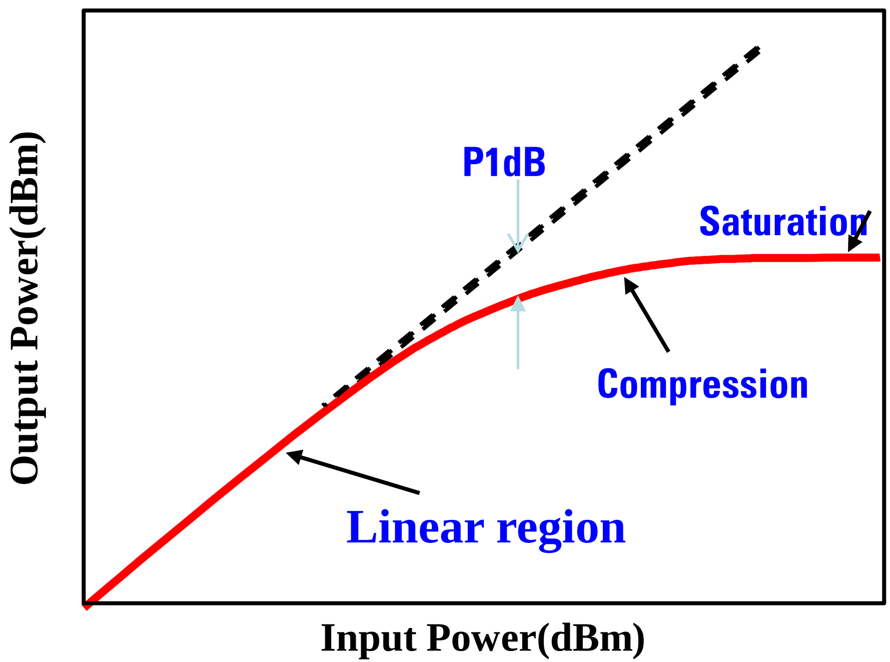
Block Diagram of a Transmitter



Technology	Range (m)	Power(mW)
BlueTooth	~ 10	~ 2,5
WiFi	~ 50	~ 80
3G/4G	~ 5000	~ 500
Lora(LPWAN)	~ 2000-5000 (urbain), 5000-15000(rural) ~ > 15000(LOS)	~ 20 (dépend.region)

PA, Non-linearities, IM Products



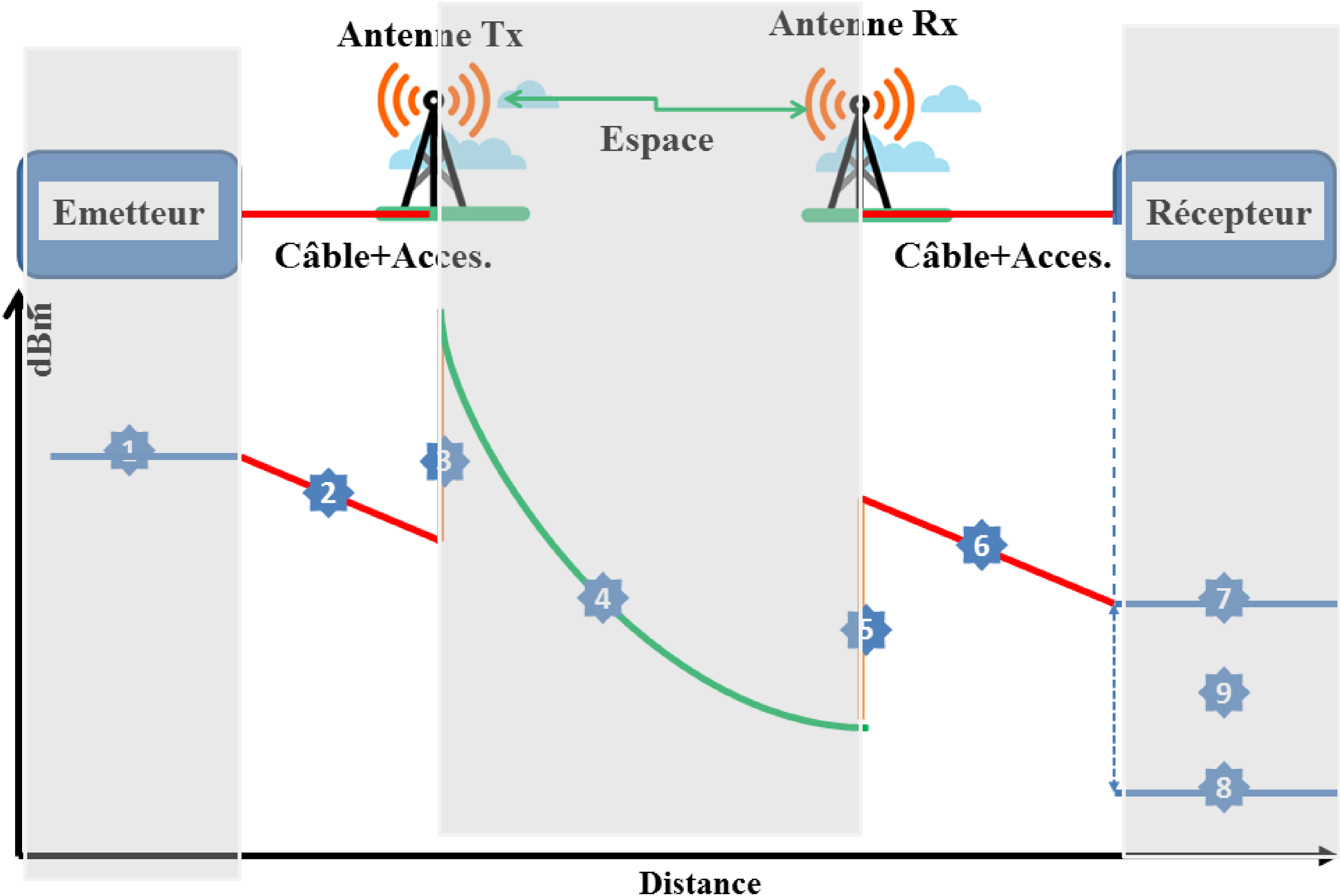


Temp ↗ ⇨ Heating

Termination: critical

Interferences

Interferences + Spurious Noise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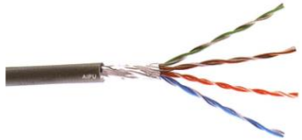
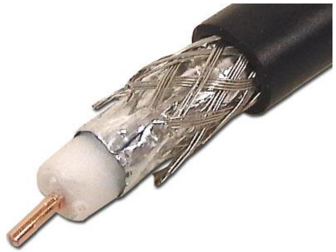
Lignes de Transmission (Structures de guidage)

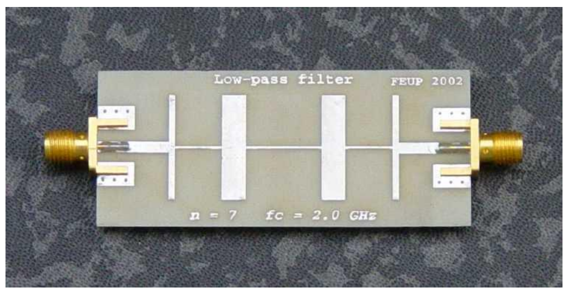
Ligne bifiliare ou Multiconducteurs

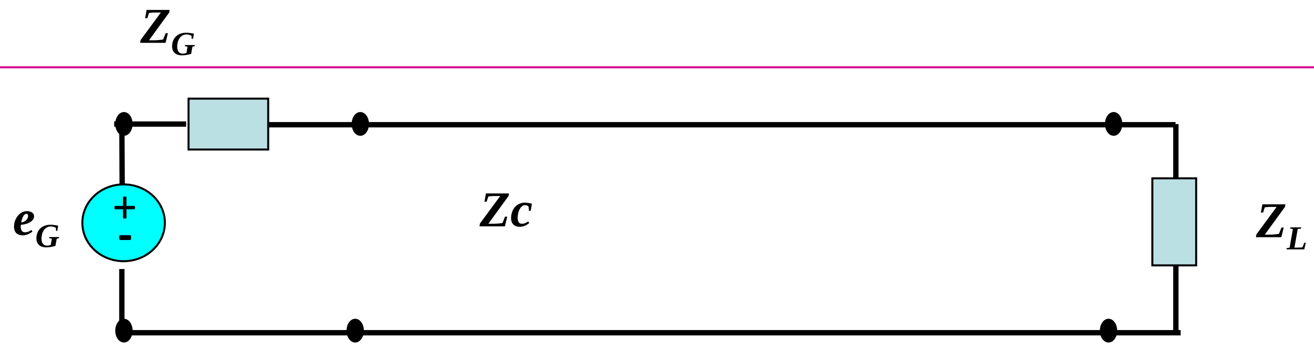
Câbles coaxiaux



Lignes microrubans

Characteristic Z, Reflection Coefficient, SWR, Matching



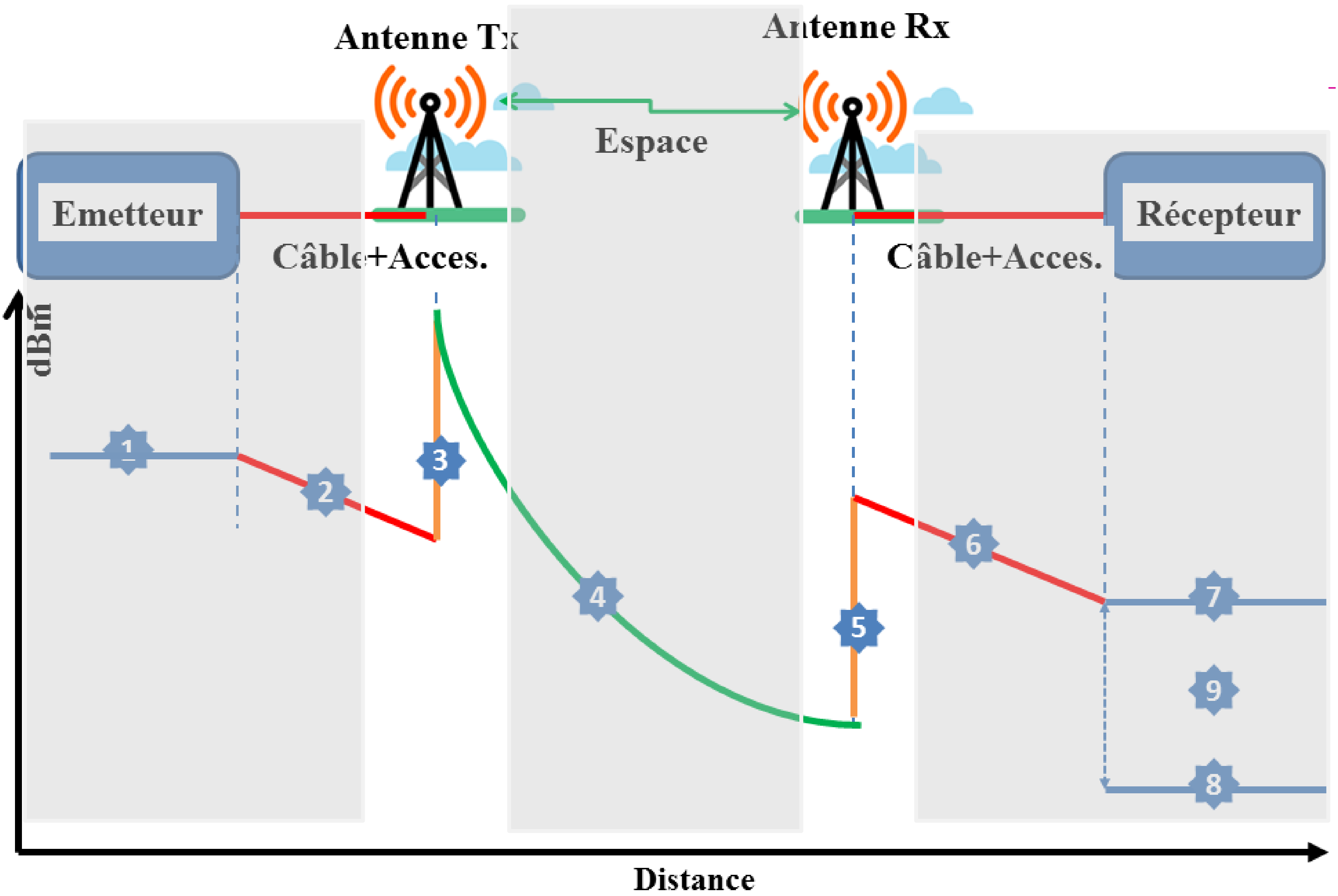
Coaxial: $Z_c = \frac{60}{\sqrt{\varepsilon_r}} Ln \frac{D}{d}$ $\qquad \Gamma_L = \frac{Z_L - Z_c}{Z_L + Z_c}$ $\qquad VSWR = ROS = \frac{1 + |\Gamma_L|}{1 - |\Gamma_L|}$

Matching : $\boldsymbol{Z_L = Z_c \leftrightarrow \Gamma_L = 0 \leftrightarrow VSWR = 1}$ $\qquad \boldsymbol{P_t = P_{inc}(1 - |\Gamma|^2)}$

½inch Cable Loss:

Type	900MHz	1800MHz	2100MHz
½ inch	7	10	11

- **Exemple: Loss of a 67m portion at 1800MHz**
- ***Answer= 67x0,1=6,7dB + Coonector Losses → Lees than 25% of power transmitted***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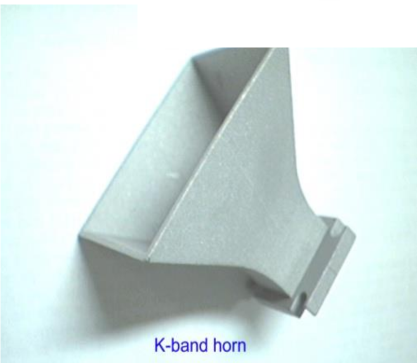
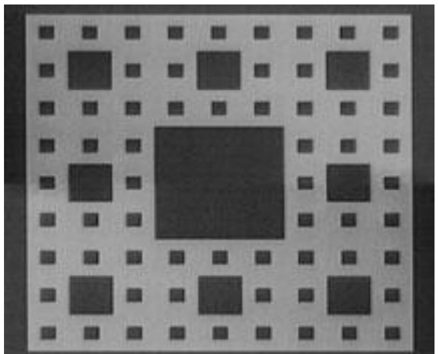
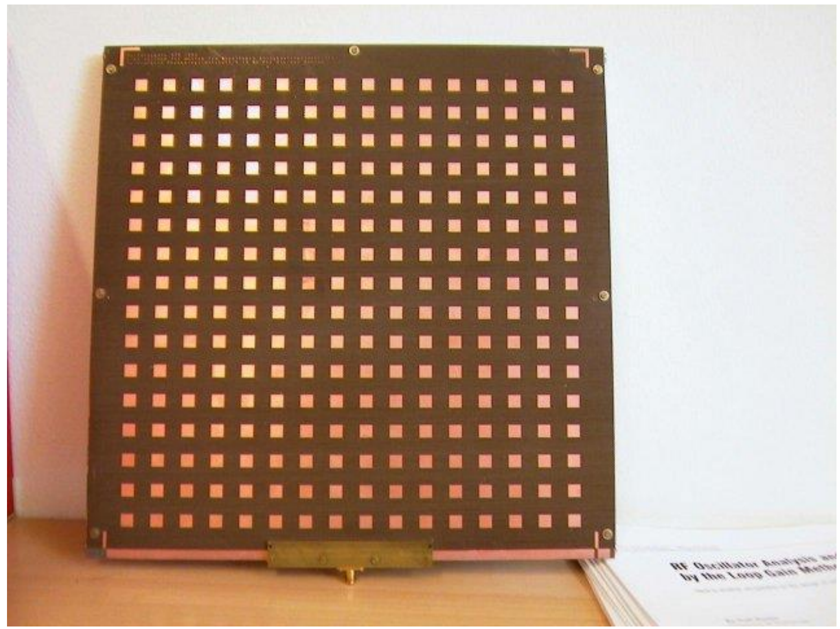
Different kinds of Antennas



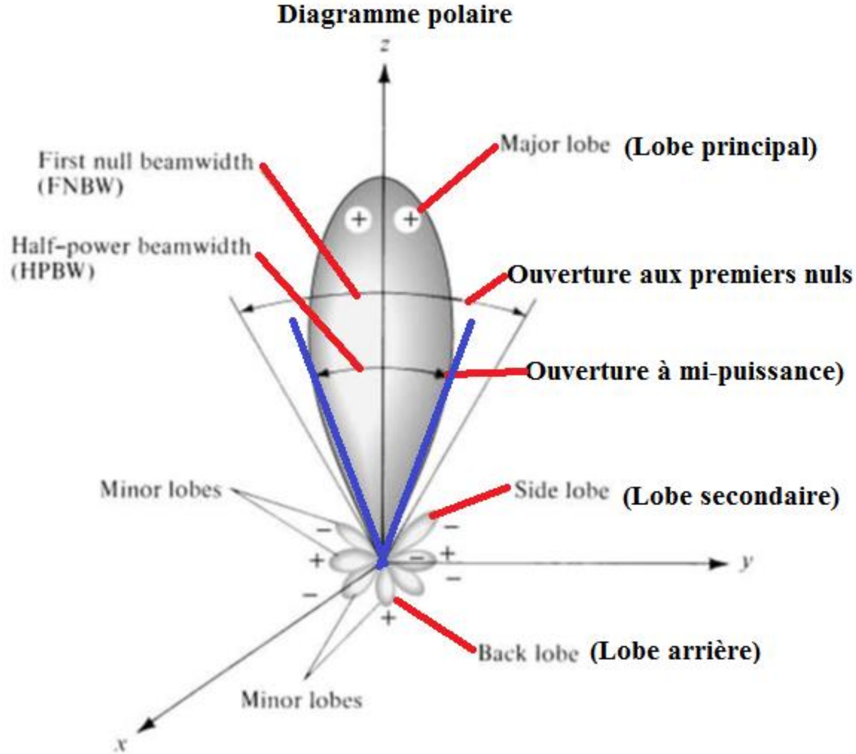


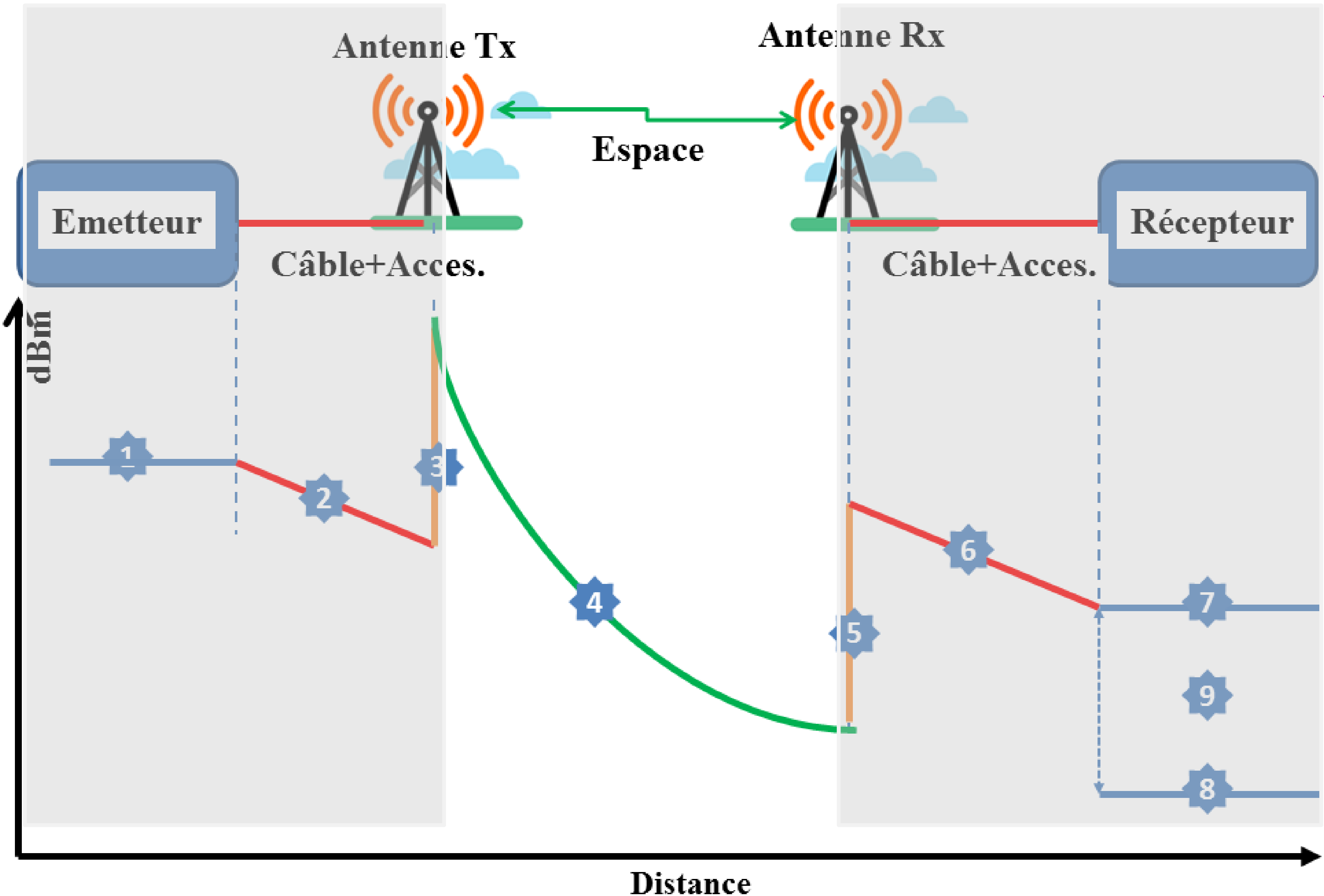


Antennas Characteristics



- Reciprocity
- Radiation Pattern
- Gain & Directivity vs Effective area
- Radiation Resistance, Impedance and Resonance
- Image principle and Effect of Ground Planes
- Polarization
- Arrays, Nonintentional



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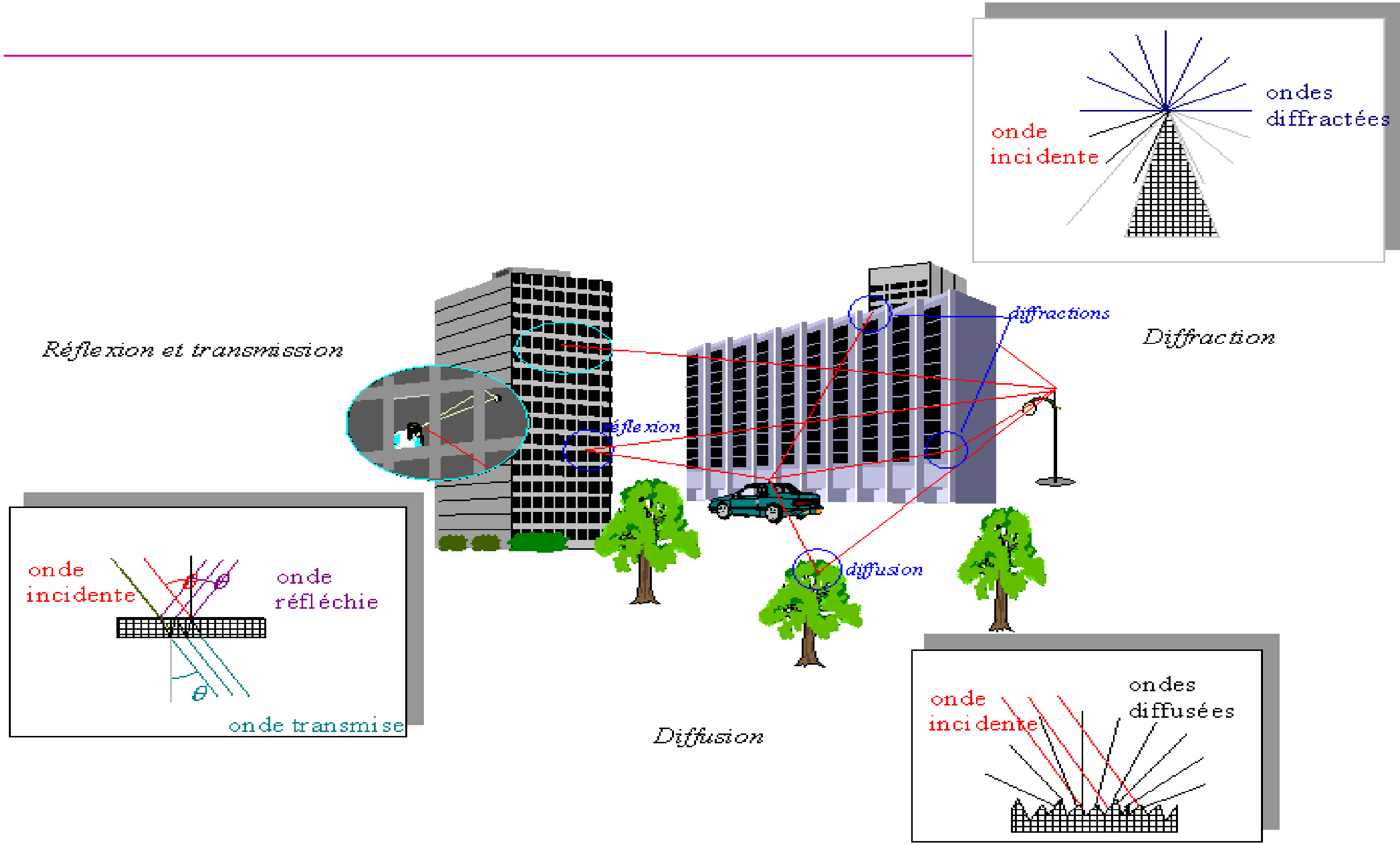
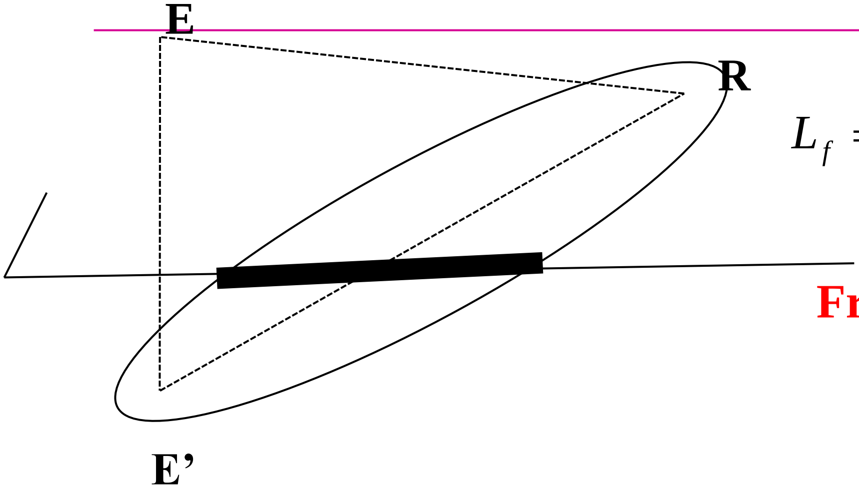
Propagation Mechanisms



- Indoor, Outdoor, Free space, LOS,Satellites, Models
- Reflection, Refraction, Diffraction, Scattering, Absorption, Doppler,…

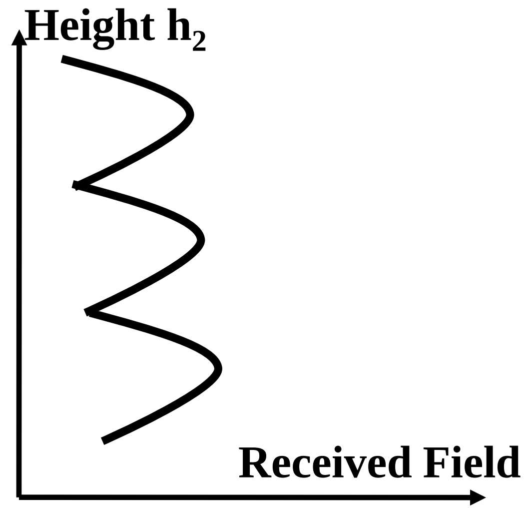
- Amplitude, Phase Distortion
- Slow and Fast Fading
- Propagation Models

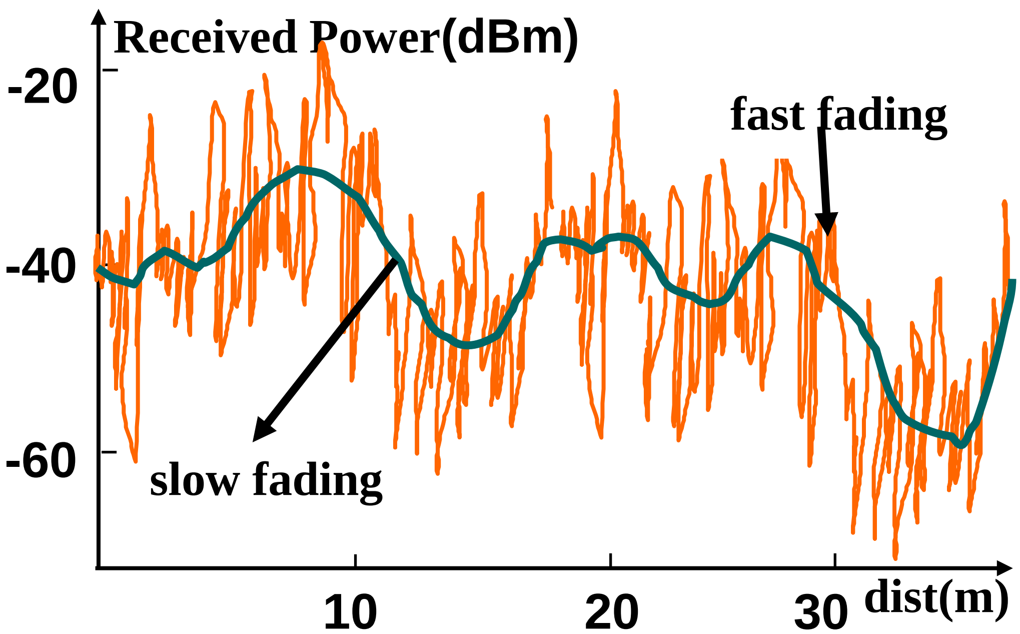
Other mechanismes



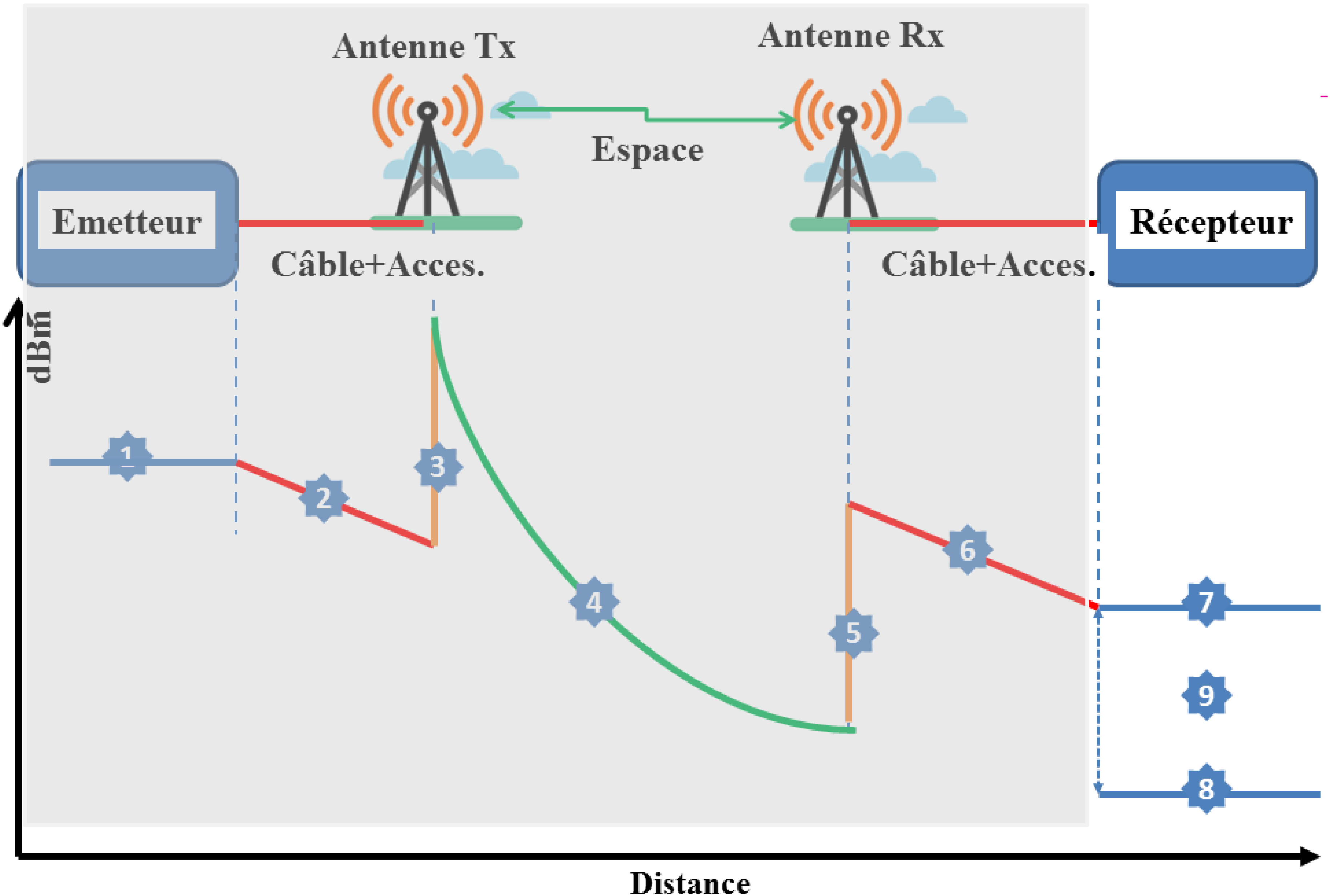
$$L_f = d\,\frac{\sqrt{1+4\dfrac{h_1h_2}{\lambda d}}}{1+\dfrac{(h_1+h_2)^2}{\lambda d}}$$

Fresnel Zone





Fading



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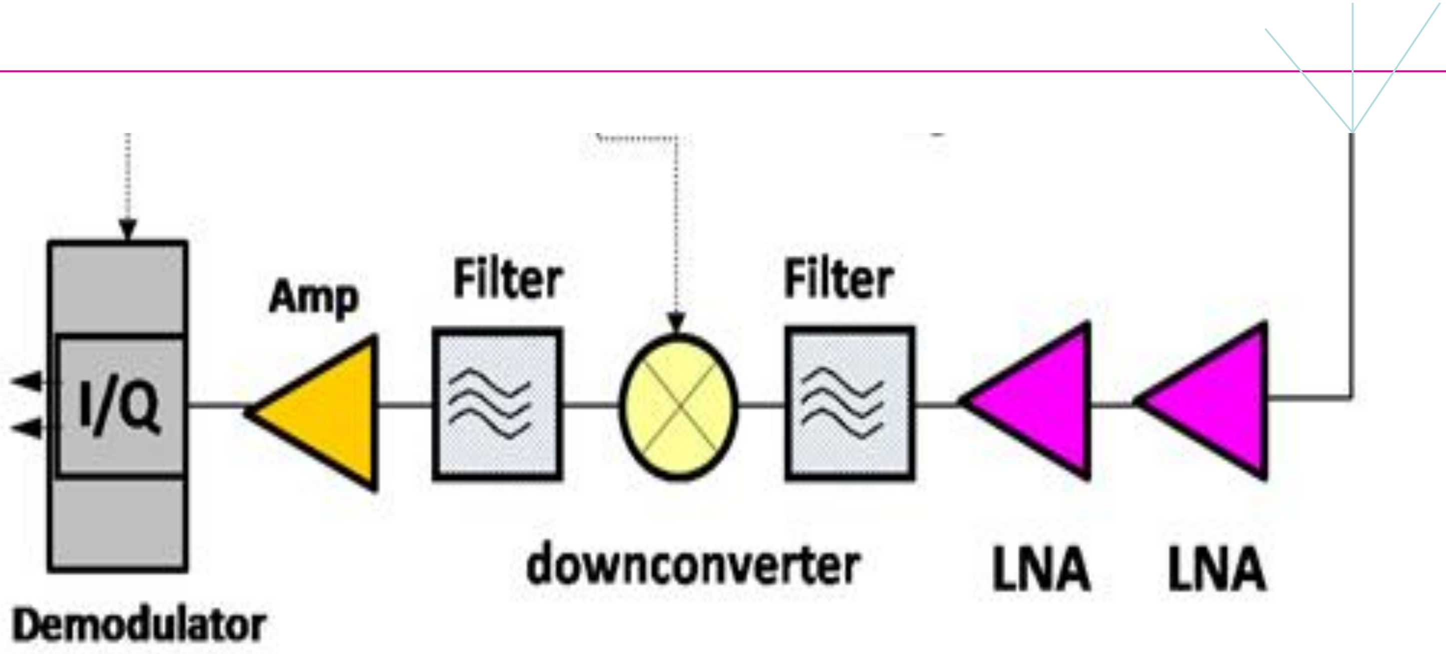
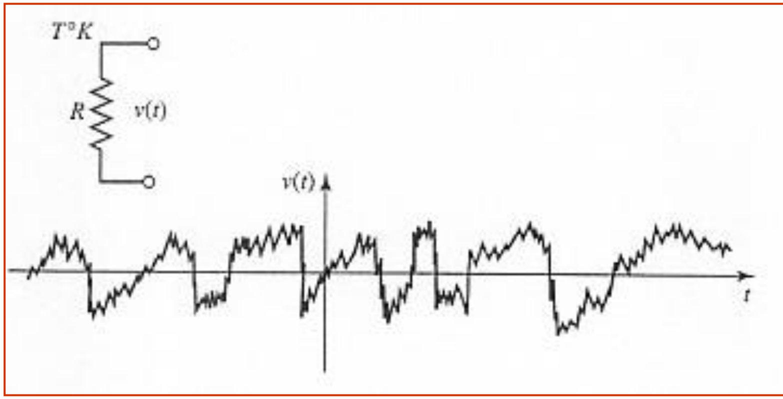
Receiver Block Diagram

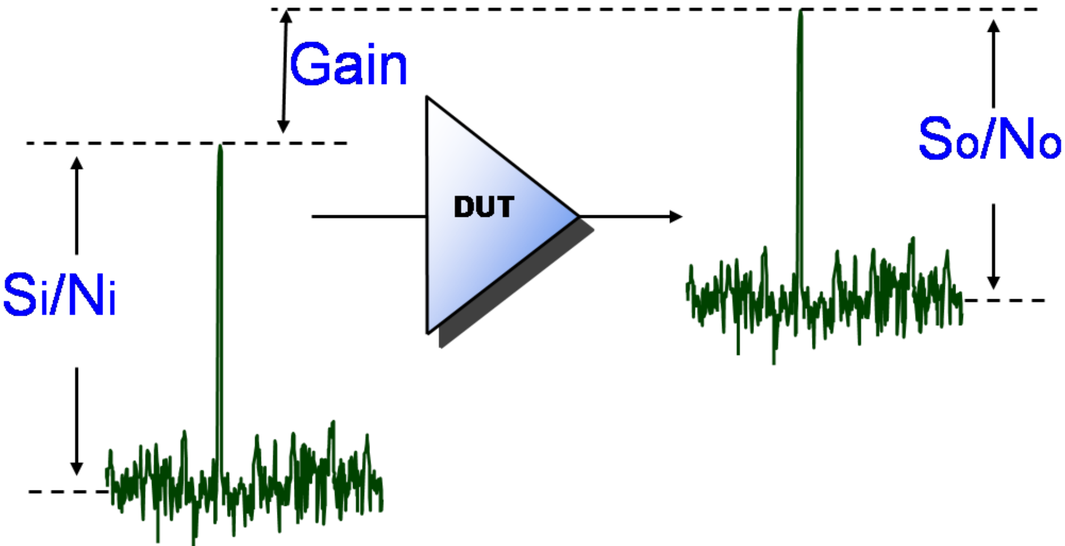


Receiver Sensibility
Margin
Low Noise Amplifier (LNA)

Noise and Noise Factor/Figure



Thermal Noise, Shot Noise, Flicker ,….
⇔ Thermal Noise generated by a resistor heated to an absolute temperature T°K:



$$P = kTB$$

k = *Boltzmann constant*

$= 1.3810^{-23}\ J/^\circ K$

T= Absolute Temperature in K

B= Noise Bandwidth in Hz

$$F = \frac{\left(\frac{S_i}{N_i}\right)}{\left(\frac{S_o}{N_o}\right)} \qquad NF = 10\log\left(\frac{\left(\frac{S_i}{N_i}\right)}{\left(\frac{S_o}{N_o}\right)}\right)$$

$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots. + \frac{F_n - 1}{G_1 G_2 \ldots G_{n-1}}$$

Conclusion: When consider RF techniques?

- **Component models (Bahavior of R, L, C, Diodes, Transistors)**

*** Single and coupled Transmisison Lines (xTalk, matching, coupling)**

*** Amplifiers (Gmax, LNA, PA), Oscillators, Mixers (NLinearities and IM products)**

*** Antennas and Propagation (Design and Radio Planning)**

*** Transmitters and Receivers (Range, sensibility and efficiency)**

*** EMC and interferences**

*** Electromagnetic Fields effects and Health risks**

Thank you شُكْرا *Merci*