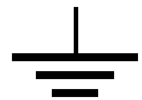
Grounding and earthing

Véronique Beauvois, Ir.
2019-2020

Grounding and earthing



General definition:

-Earth’s ground considered for electrical installations as a reference of 0V

-Variable electrical conductivity – naturally electrical currents are flowing.

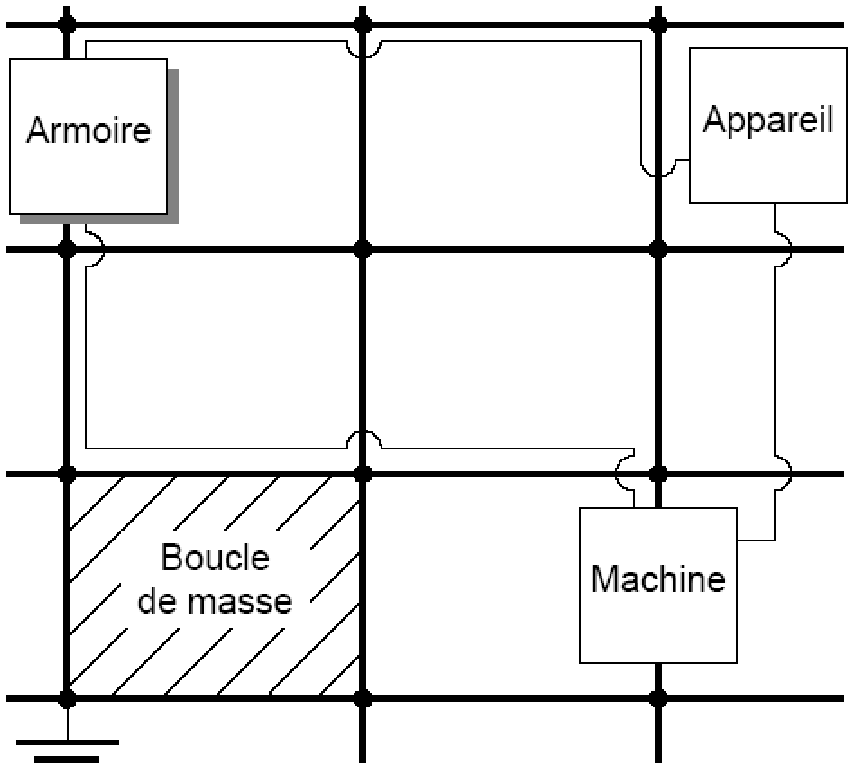
Key-roles:

- Lightning current flowing
- Leakage current flowing
- Protection of persons

(IEC 364 – Electrical Installations of Buildings
& IEC 50164 – Lightning protection components)

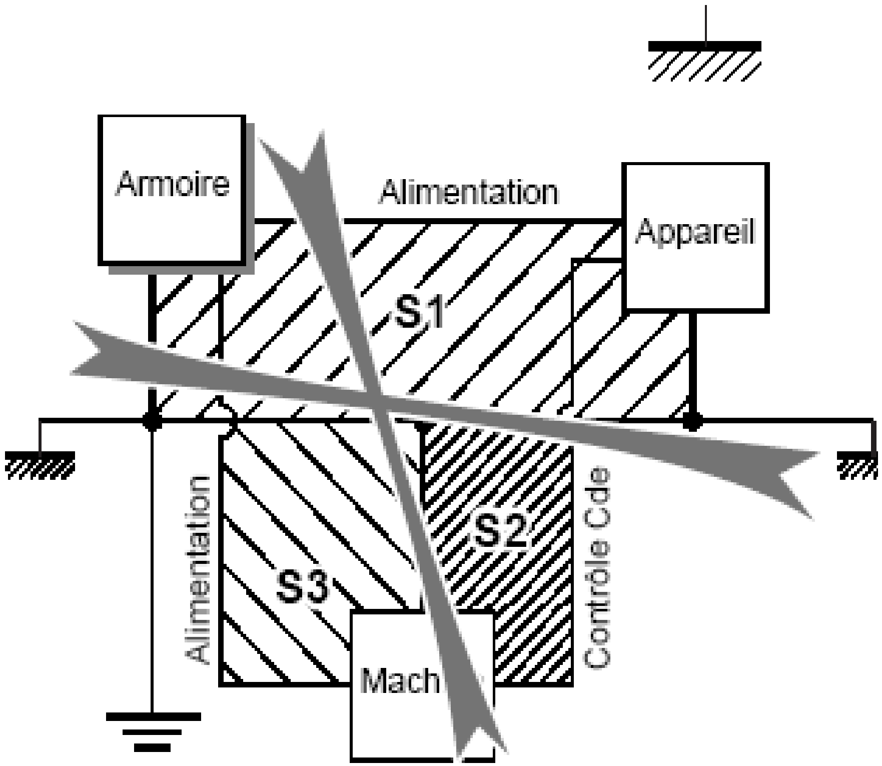
Grounding and earthing

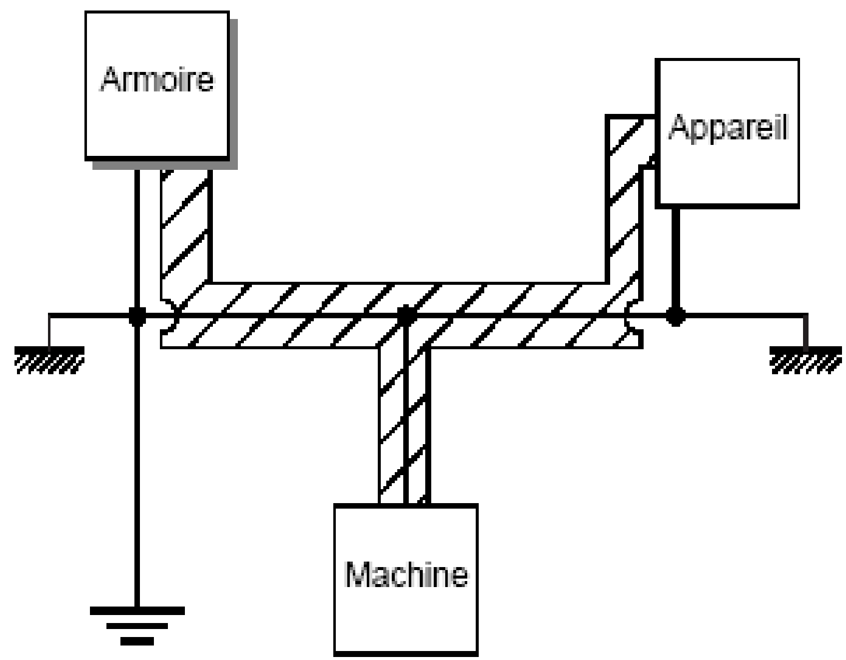
Earthing/grounding and EMC:
For a lot of EMC phenomena (transient disturbances, HF currents…), earhting conductors are not efficient as they are very long and the used topology means a high impedance versus HF.
The only solution is **meshing** to get **equipotentiality**.
Mesh size: $\pm\ \lambda/10$.
All electrical elements, components, should be connected as shielding, screens, CM connections of filters (remember some remarks on good implementation in *Components*).



Loop between grounding = surface beween 2 grounding cables, resulting of a systematic meshing of ground to insure equipotentiality.
Solution?
To reduce loop size with a small mesh size.

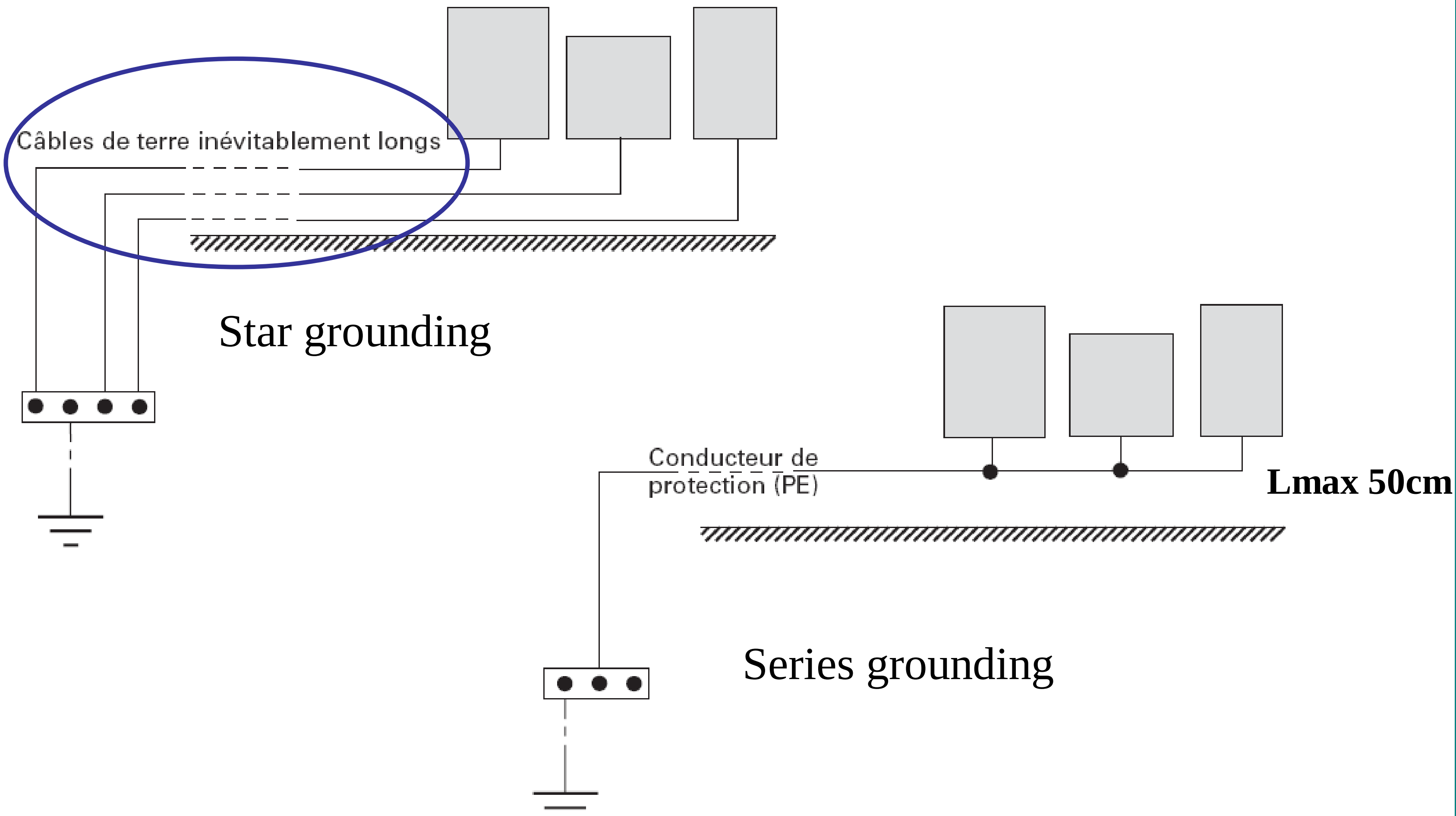
Grounding and earthing



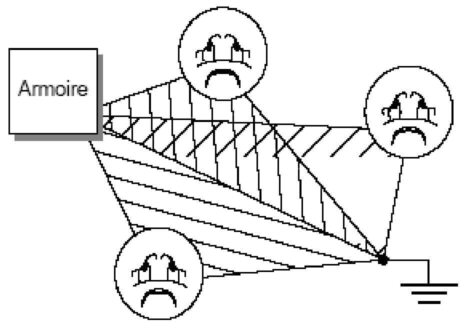


Grounding loop: surface loop between a power/signal cable and a corresponding grounding cable.
Solution? To reduce loop size with a very short distance between power/signal cable and corresponding grounding cable (all along the cables).

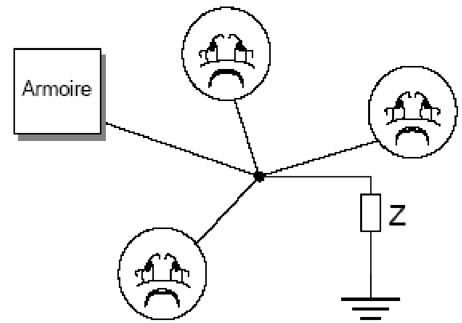
Grounding and earthing

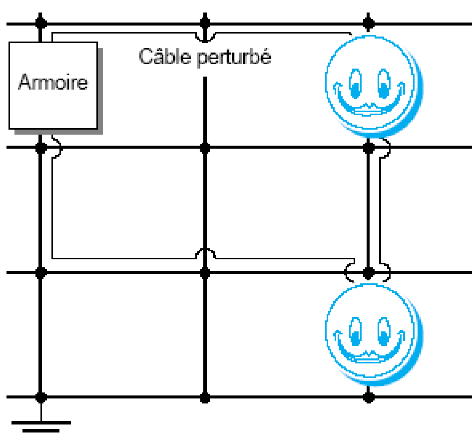


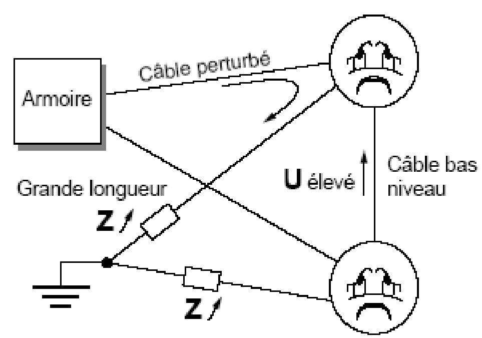
Grounding and earthing



Boucles de masse de grande surface







Forte impédance commune
==> ddp entre les équipements

Grounding and earthing

Building:

• ground meshing by level

• connect all metallic structures of building to the ground (pipes, ducts, duckboards…)

• in sensitive zone (computers, data, measurements), consider a small meshed system

Equipment:

• Connect all metallic structures together

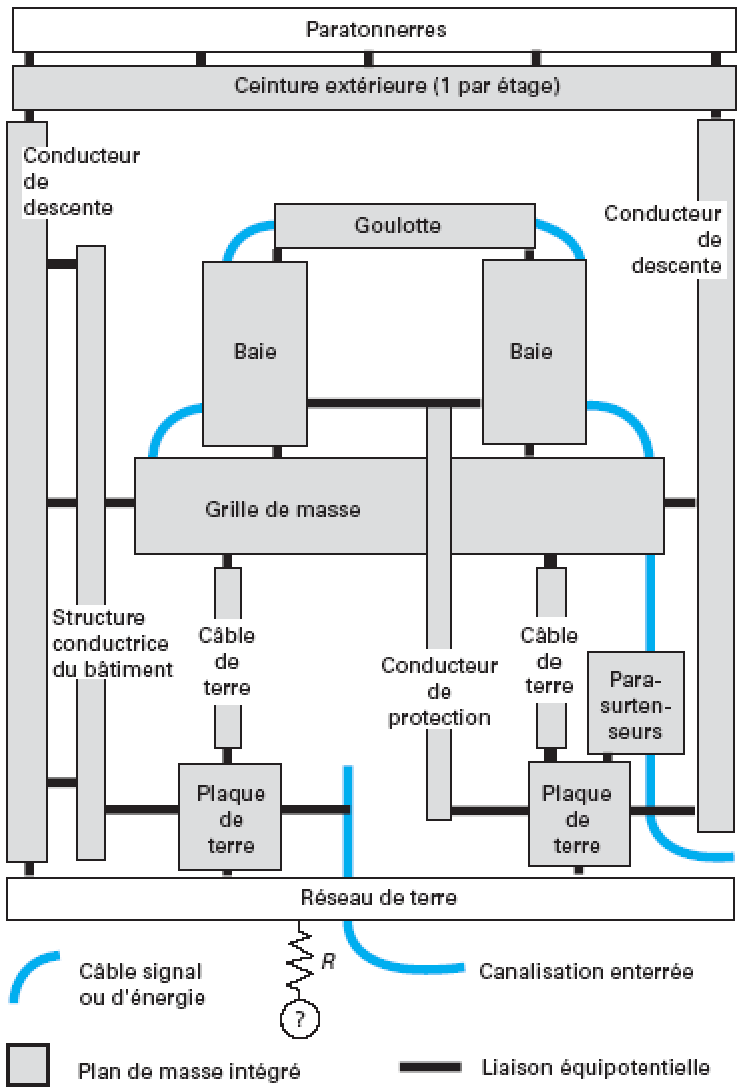
Rack:

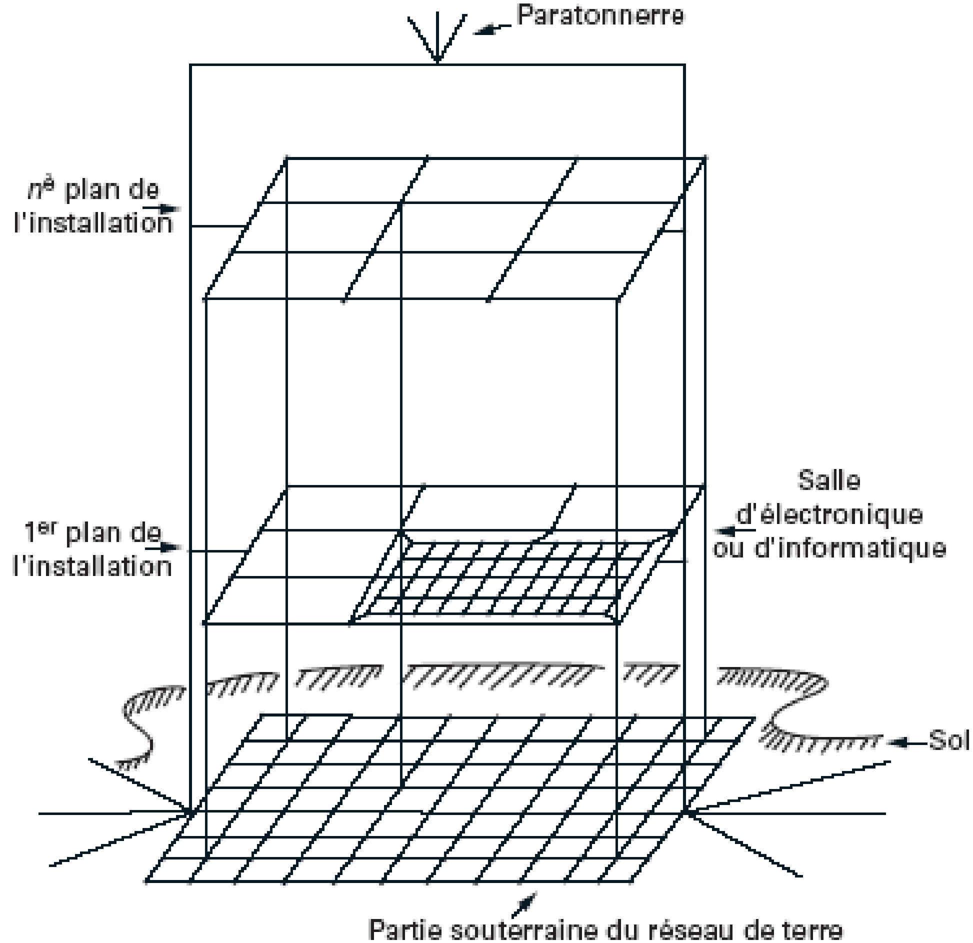
• a metal plate in the bottom of the rack

• insulating coating and painting

• good contact between components and metal plate (green-yellow cabling is not sufficient for EMC).

Grounding and earthing





Shielding

Véronique Beauvois, Ir.
2019-2020

Shielding

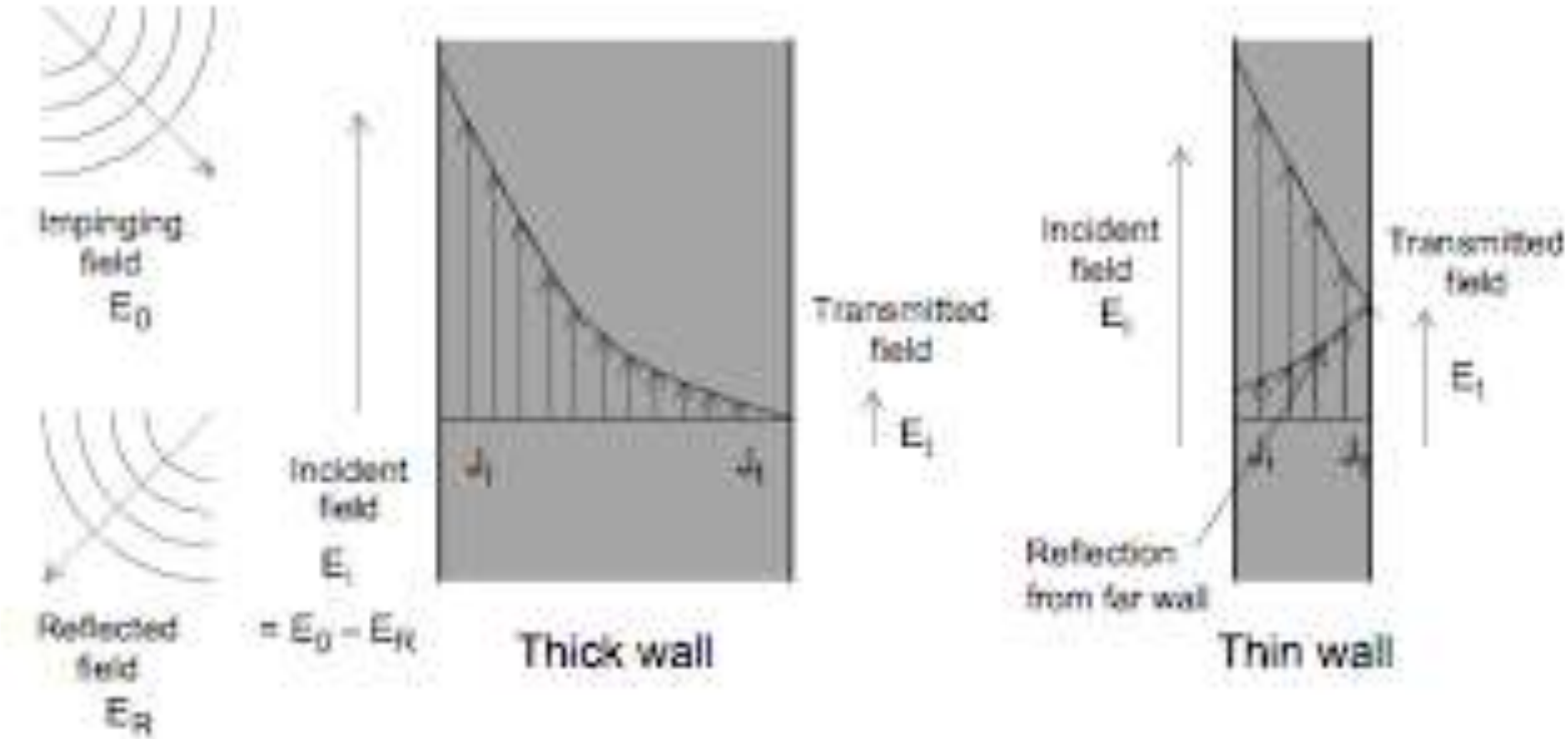
A variable electric field and a infinite conducting wall, will induce currents in the wall. These currents will generate a reflected E-field in opposite direction.

This is necessary to comply with limit condition E=0 on the wall. The amplitude of the reflected wave determines the **loss by reflection**. As the wall has a finite conductivity, a part of the current penetrates the wall and a part of this current will be present on the other side of the wall, emitting its own wave.

Eincident over Etransmitted defines the **shielding efficiency**.

The thickness of the wall influences the attenuation of the current. **Loss by absorption** depends of the number of skin depths in the wall thickness.

Shielding



Ei/Et > S.E. = 20 log (Ei/Et) (dB)

Skin depth represents the property to limit the current at the internal surface of a conductor.
It decreases when : frequency increases, conductivity increases and permeability increases.
At each skin depth, E is decreased by 1/e or 8.6 dB.
e.g. aluminium, skin depth is 0.015 mm @ 30 MHz.

In the case of high frequencies, very thin conductors are efficient for shielding.

Loss by reflection

These losses are related to the ratio of wave impedance (E/H, in far-field conditions 377 Ω) and impedance of the wall (frequency, conductivity and permeability).

For a good conductor (copper, aluminium), losses by reflection are important.

If frequency increases, losses are decreasing for E and increasing for H.

Plane wave	$R = 168 - 10 \log_{10} ((\mu_r/\sigma_r).f)$ dB
E-field	$R_E = 322 - 10 \log_{10} ((\mu_r/\sigma_r).f^3.r^2)$ dB
H-field	$R_H = 14{,}6 - 10 \log_{10} ((\mu_r/\sigma_r)/f.r^2)$ dB

Loss by absorption

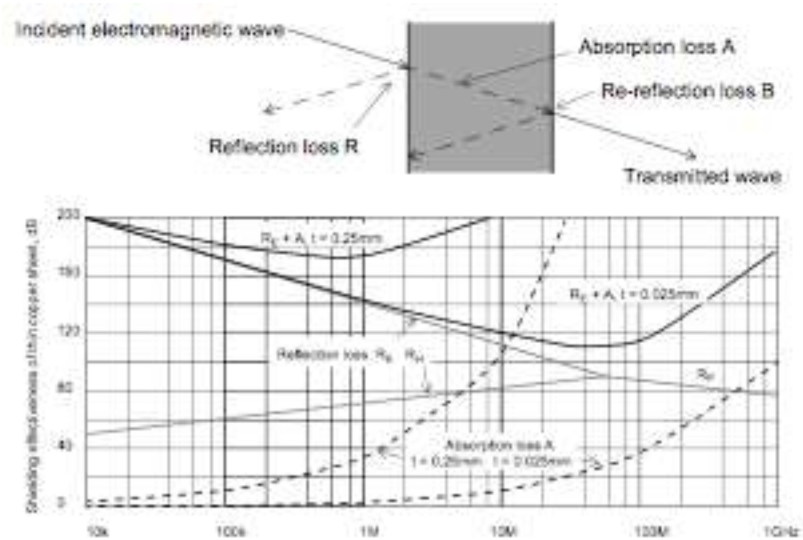
As already mentioned those losses depend of the wall thickness and skin depth, depending of material properties.

If thickness is constant, steel is better than copper regarding those losses.

At high frequency, this is the major part of losses, they are increasing as the square of frequency.

$A = 20 \log(E_0/E_1) = 20 \log e^{t/\delta} = 20.(t/\delta).\log e = 8{,}69.\ (t/\delta)\ \text{dB}$

Where t is the thickness of the wall and δ the skin depth.



Shielding

Shielding efficiency

The ratio between field without wall and field with wall.

This is the sum of 3 losses:

SE (dB) = R(dB) + A(dB) + B(dB)

R : reflection losses (E,H)

A : absorption losses

B : contribution of multiple reflections and transmissions inside the wall.

Shielding

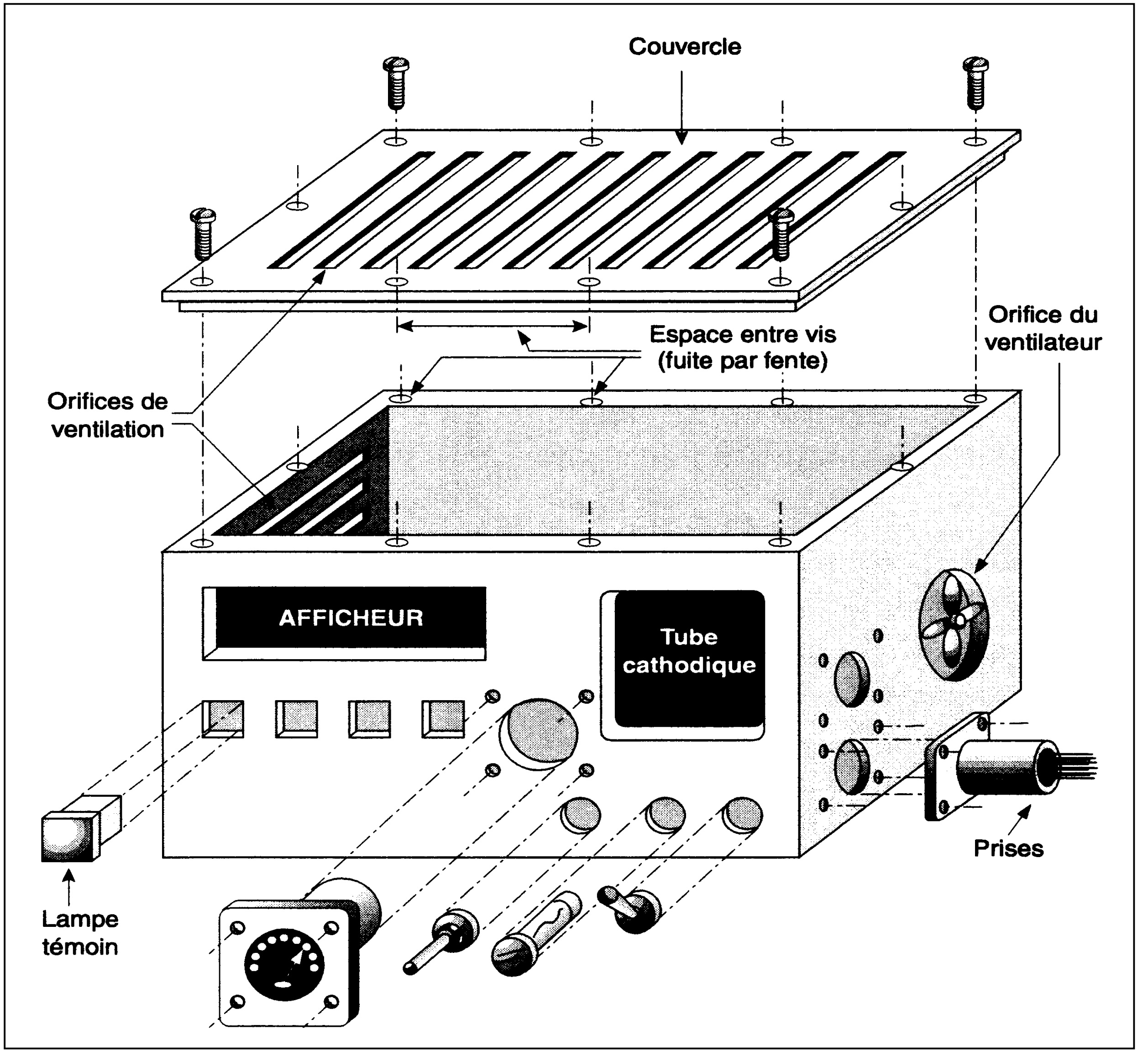
Different kind of envelops:
- completely conductive (rack, drawer, box);
- metallic structure with insulating panels;
- completely insulating material.

For insulating material, some treatments exist to add a conductive coating.
We have already mentioned that it is efficient in high frequency.

Shielding

Solutions:

- Conductive painting
- Spraying fusion metal
- Metal film deposit
- Vaporisation under vacuum conditions

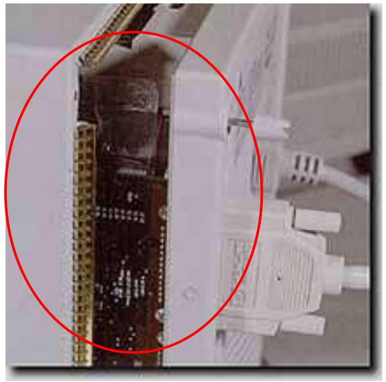

Couvercle
Espace entre vis
(fuite par fente)
Orifice du
ventilateur
Orifices de
ventilation
AFFICHEUR
Tube
cathodique
Prises
Lampe
témoin

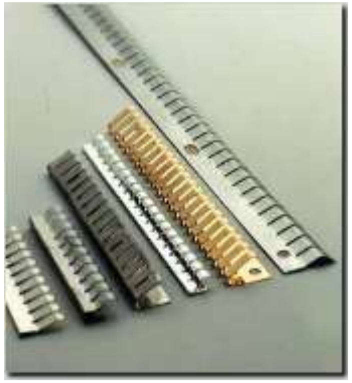
Shielding

Solutions:

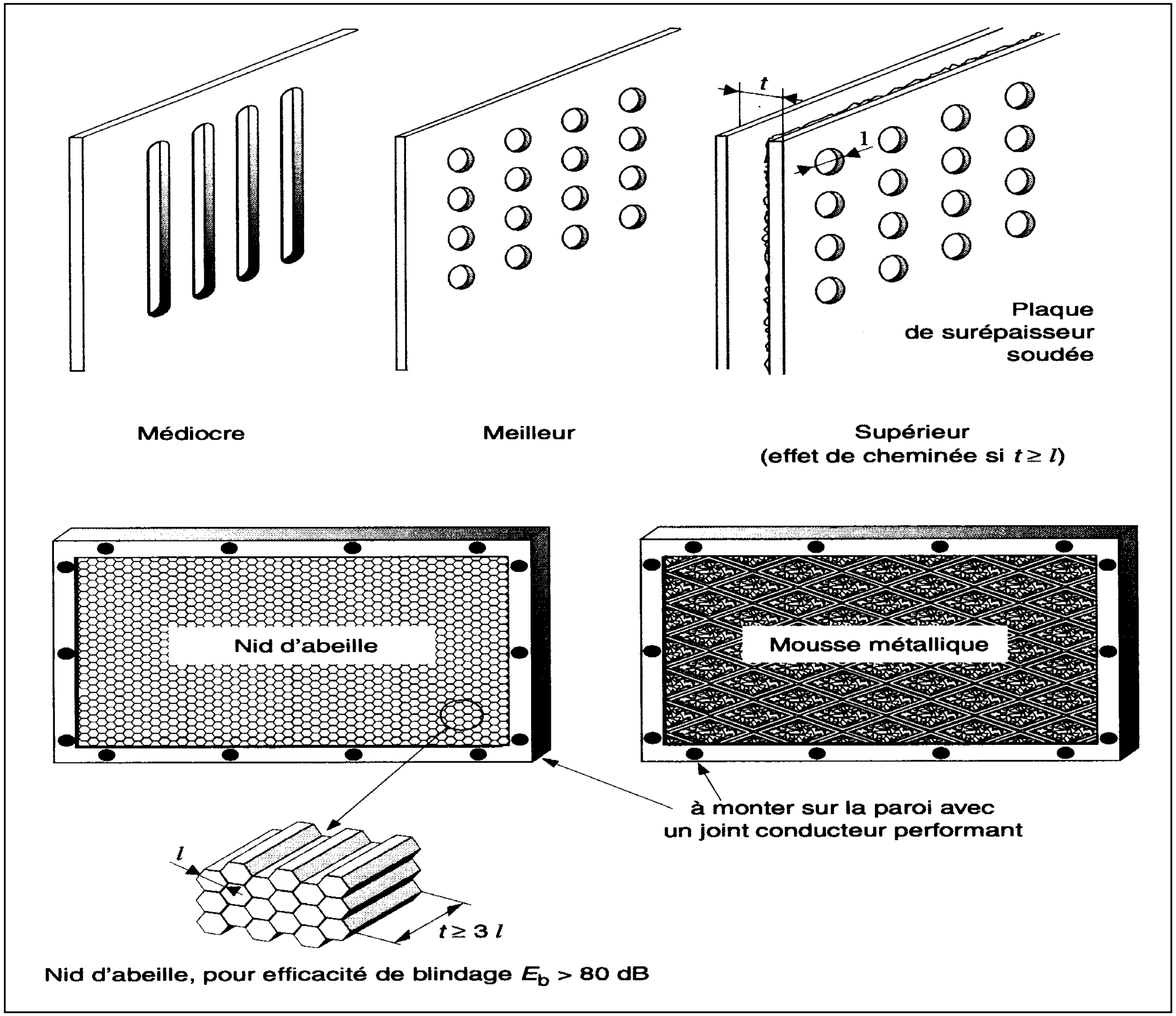
-Doors and panels separation

- Distance between 2 fixings (screws…)
- Increasing the number of fixings (screws, different sorts of gaskets)
- Contact surfaces to clean: no painting…



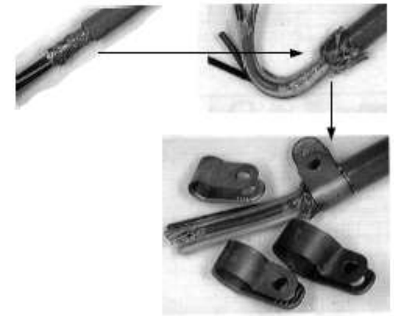


Shielding



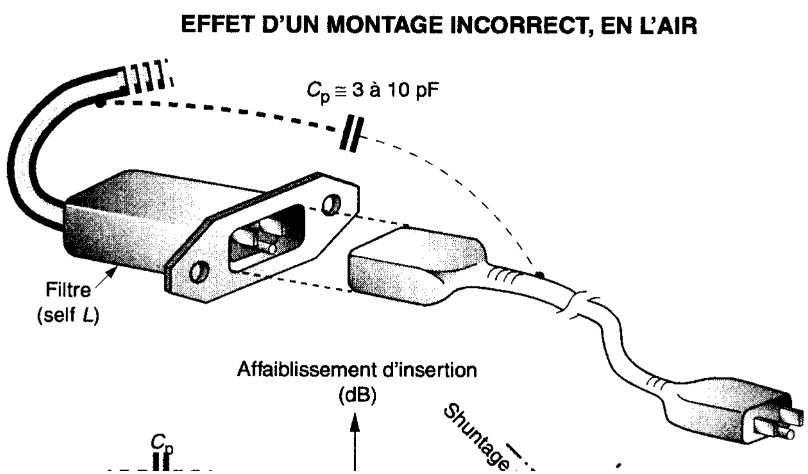
t
1
Plaque
de surépaisseur
soudée
Médiocre
Meilleur
Supérieur
(effet de cheminée si $t \geq l$)
Nid d'abeille
Mousse métallique
à monter sur la paroi avec
un joint conducteur performant
l
$t \geq 3\,l$
Nid d'abeille, pour efficacité de blindage E_b > 80 dB

Shielding



Cabling:

-Not shielded cables: filters
-Shielded cables: connections of shielding with structure, walls
-Non electric “cables”: waveguide for non metallic ducts, good connection for metallic ducts



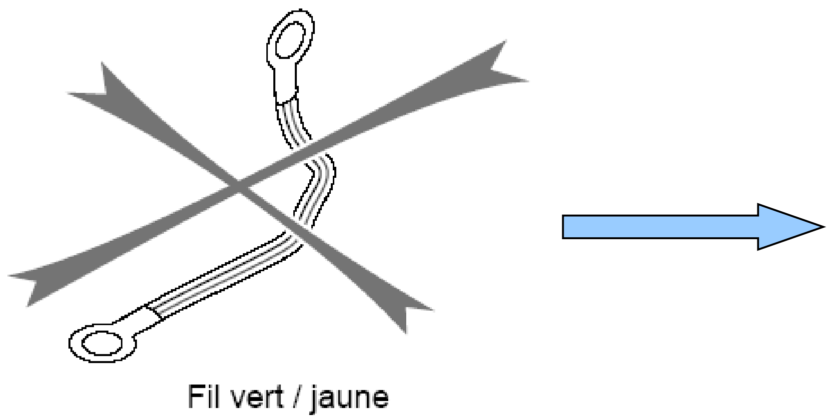
Design rules
For electrical circuits

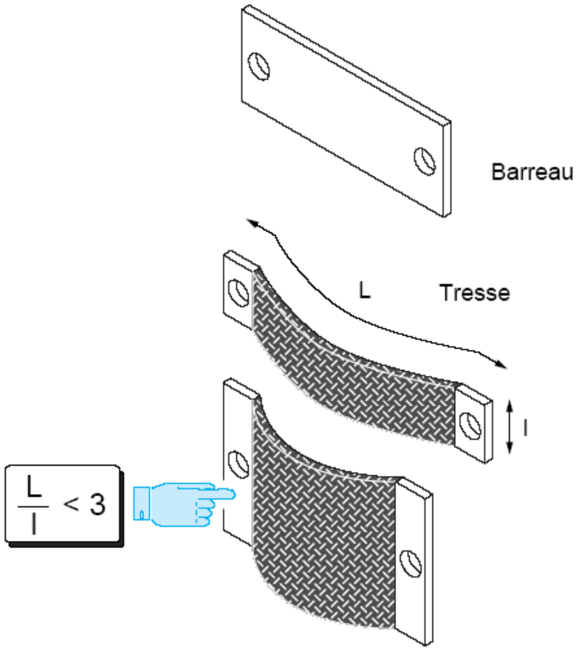
Véronique Beauvois, Ir.
2019-2020

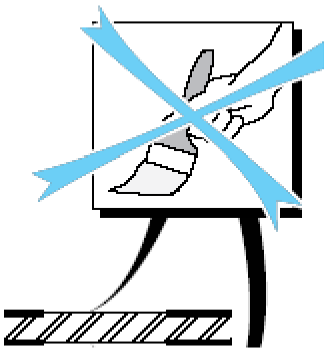
Design rules

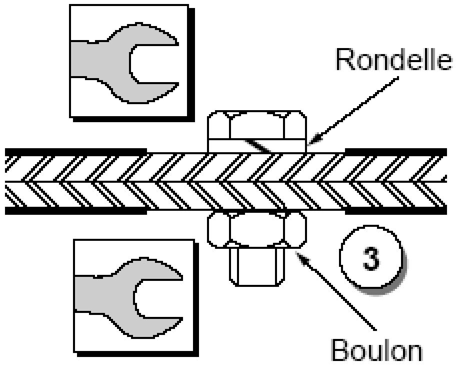
Grounding/earthing in racks - connections

PE - PEN

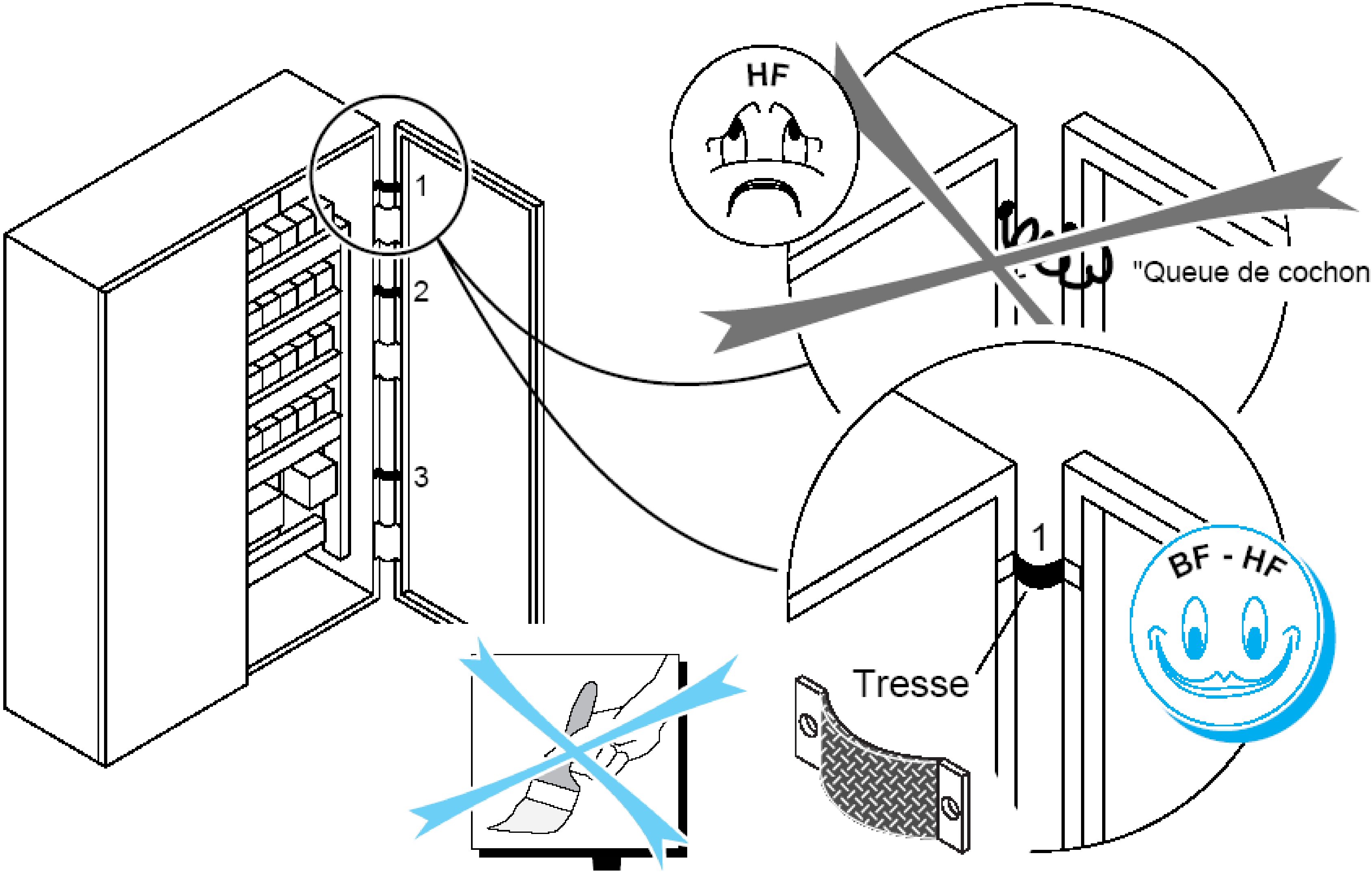








Design rules



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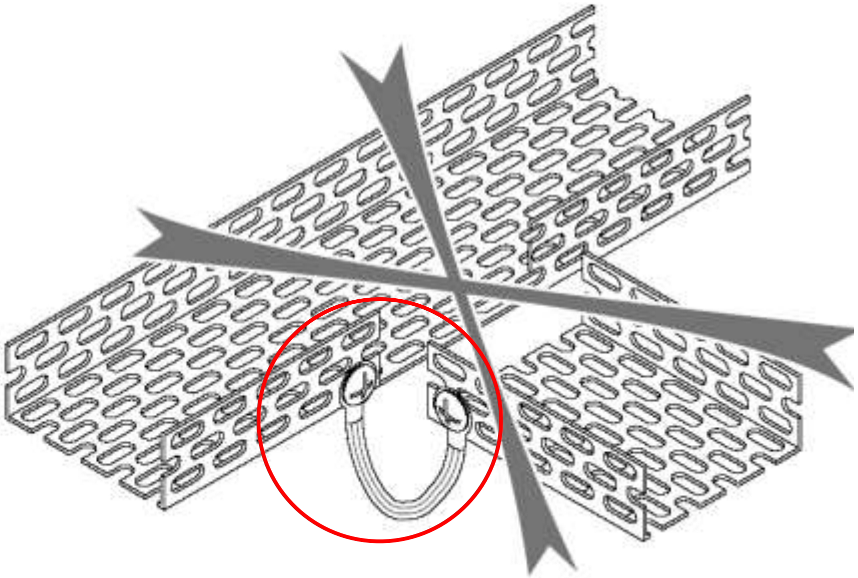
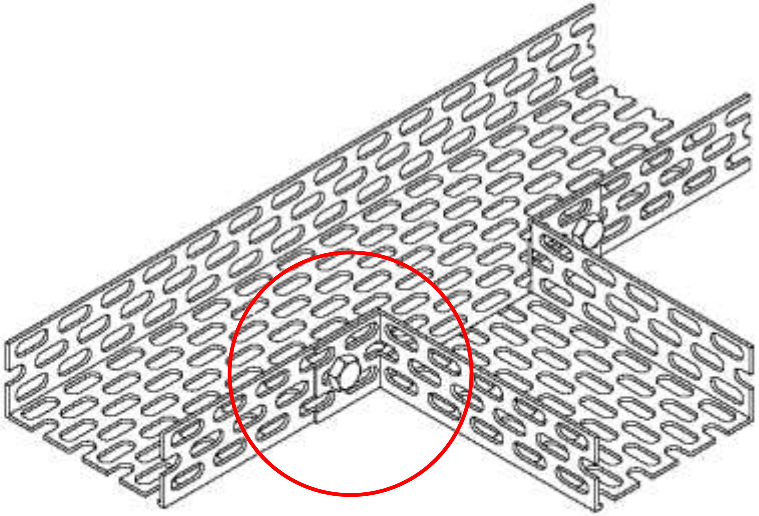
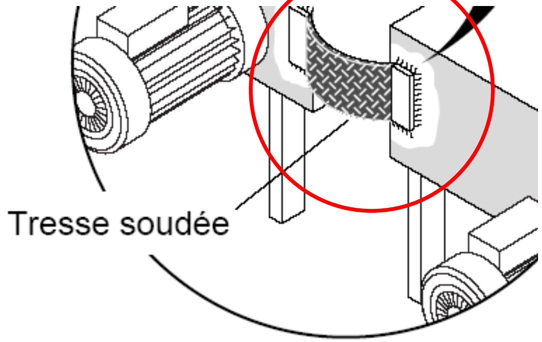
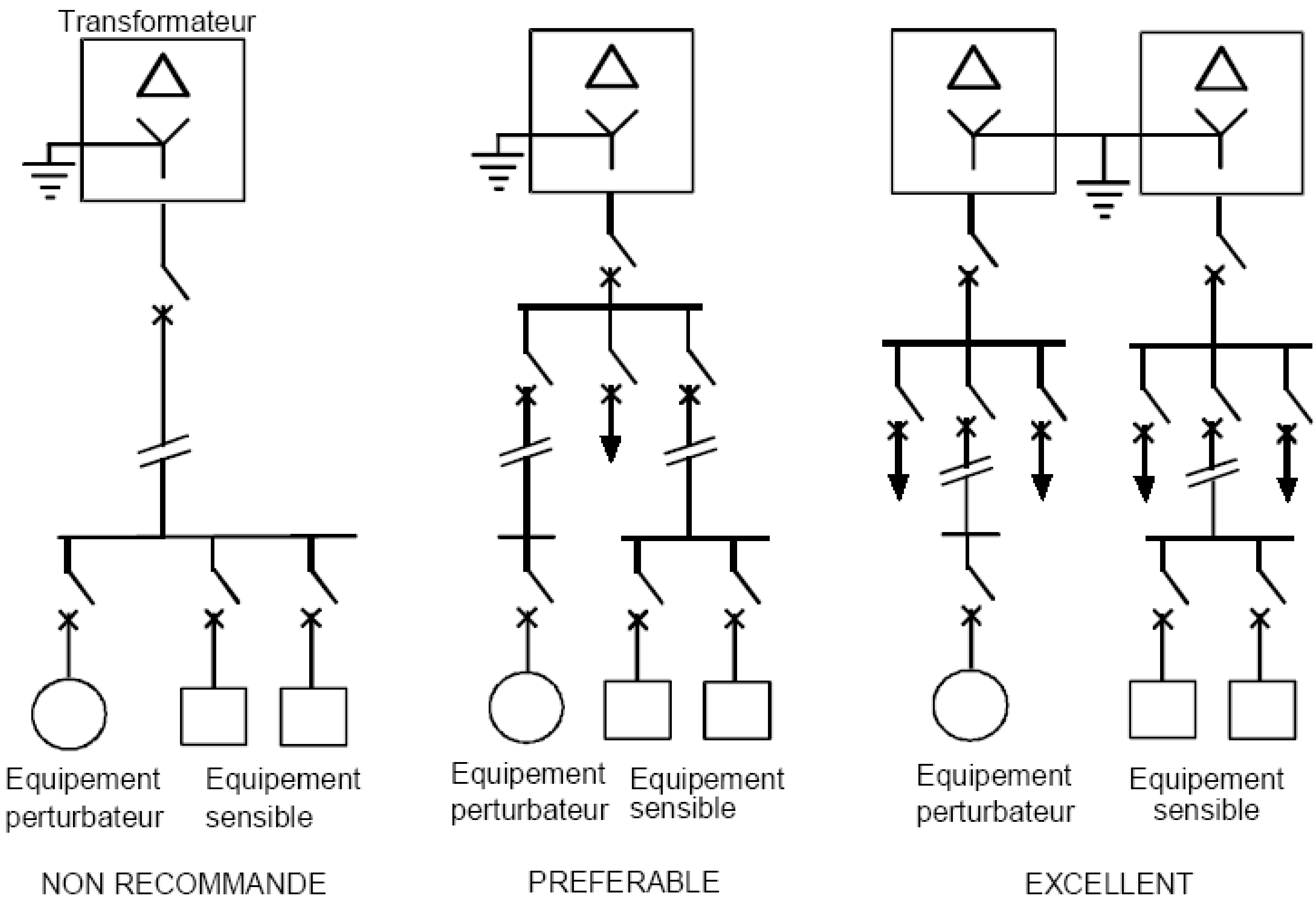






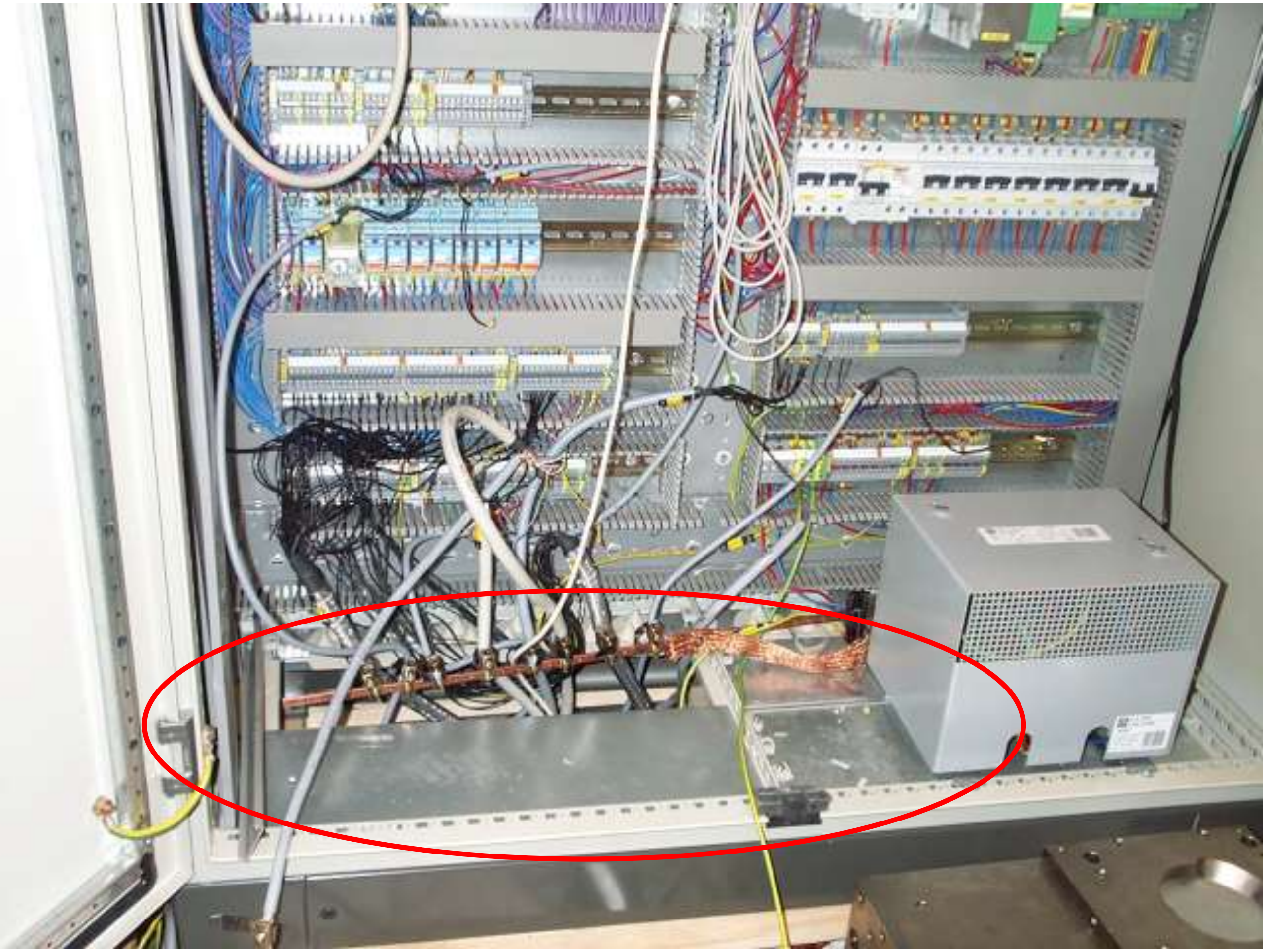
Design rules

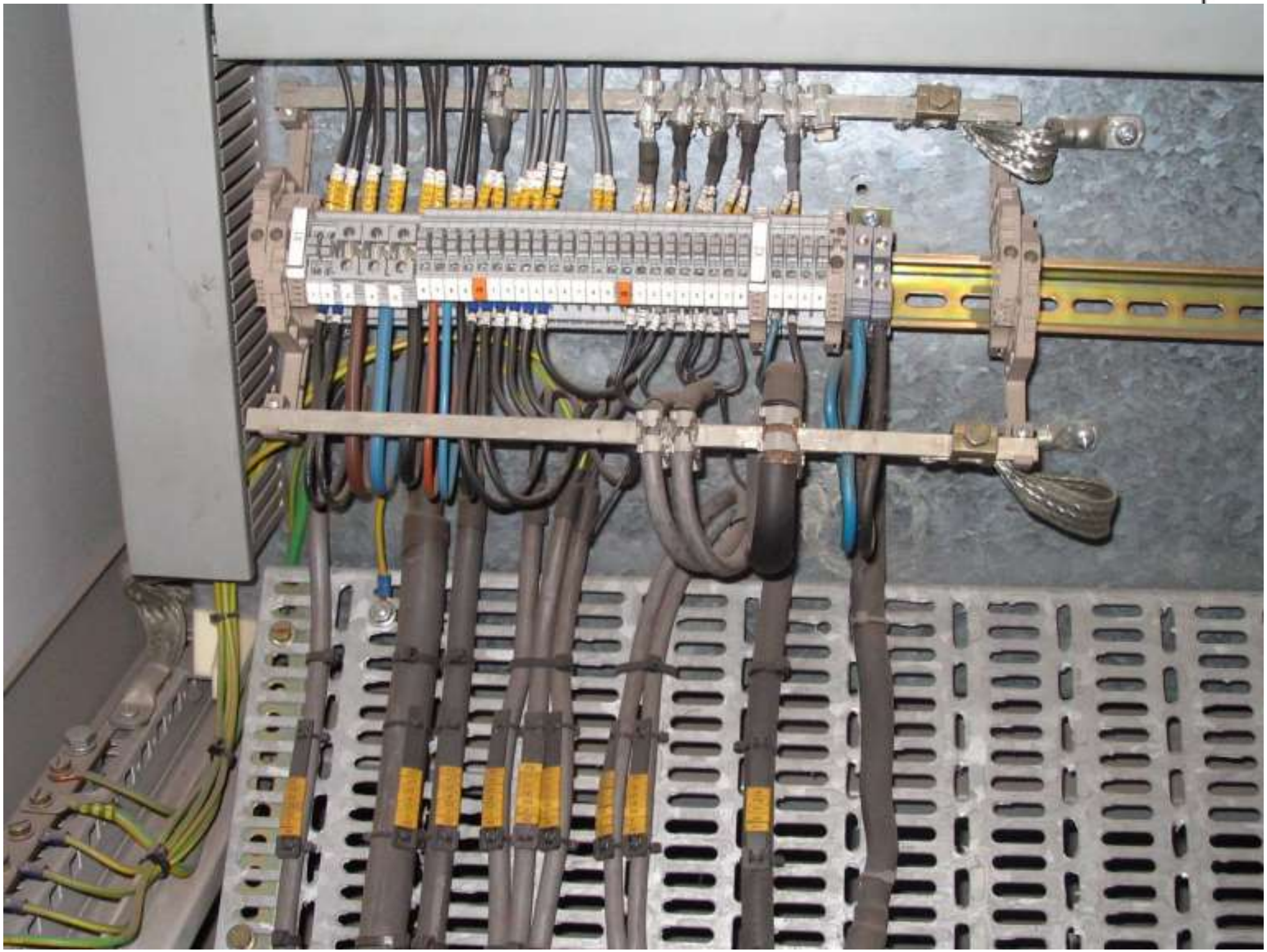
Power supplies management



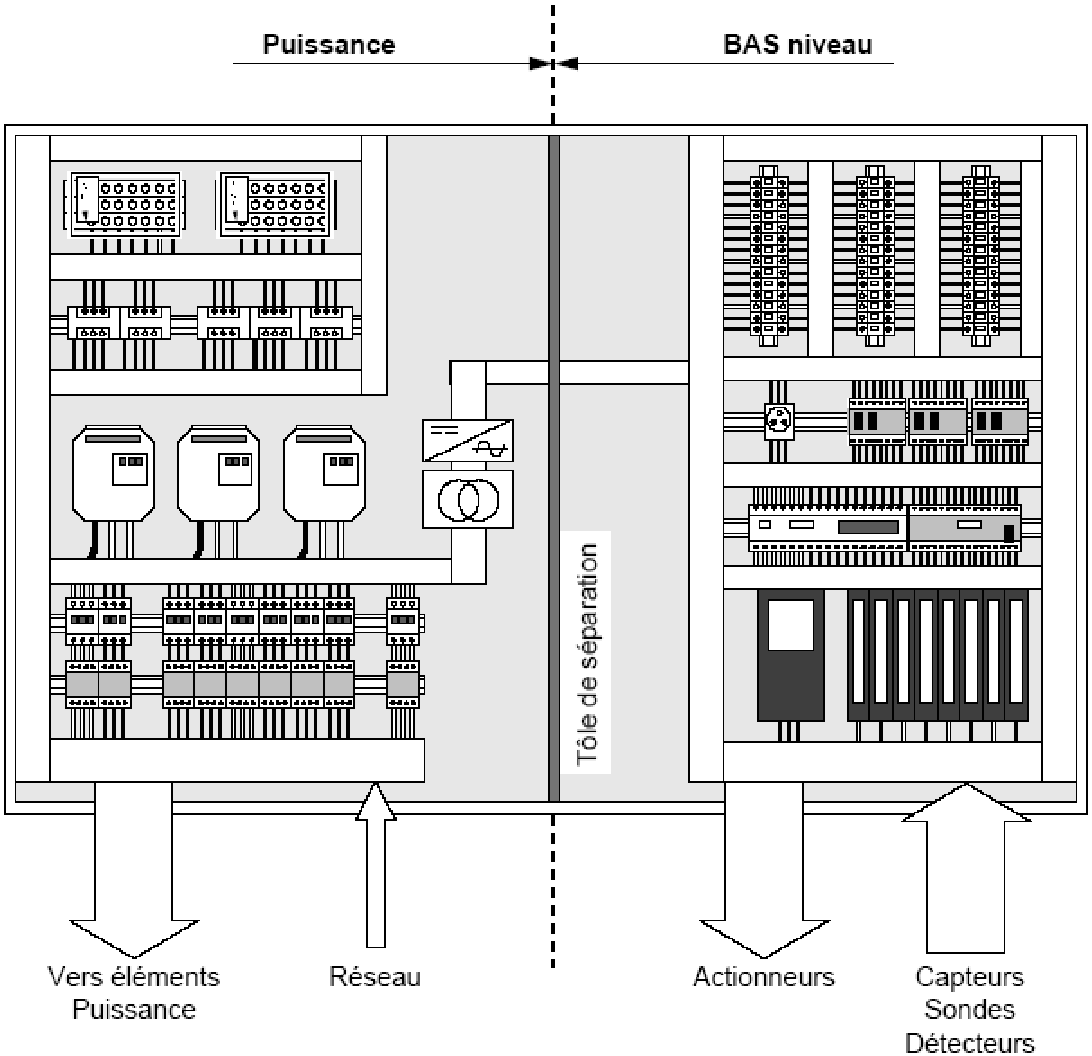
[EN 50174-2]

Design rules

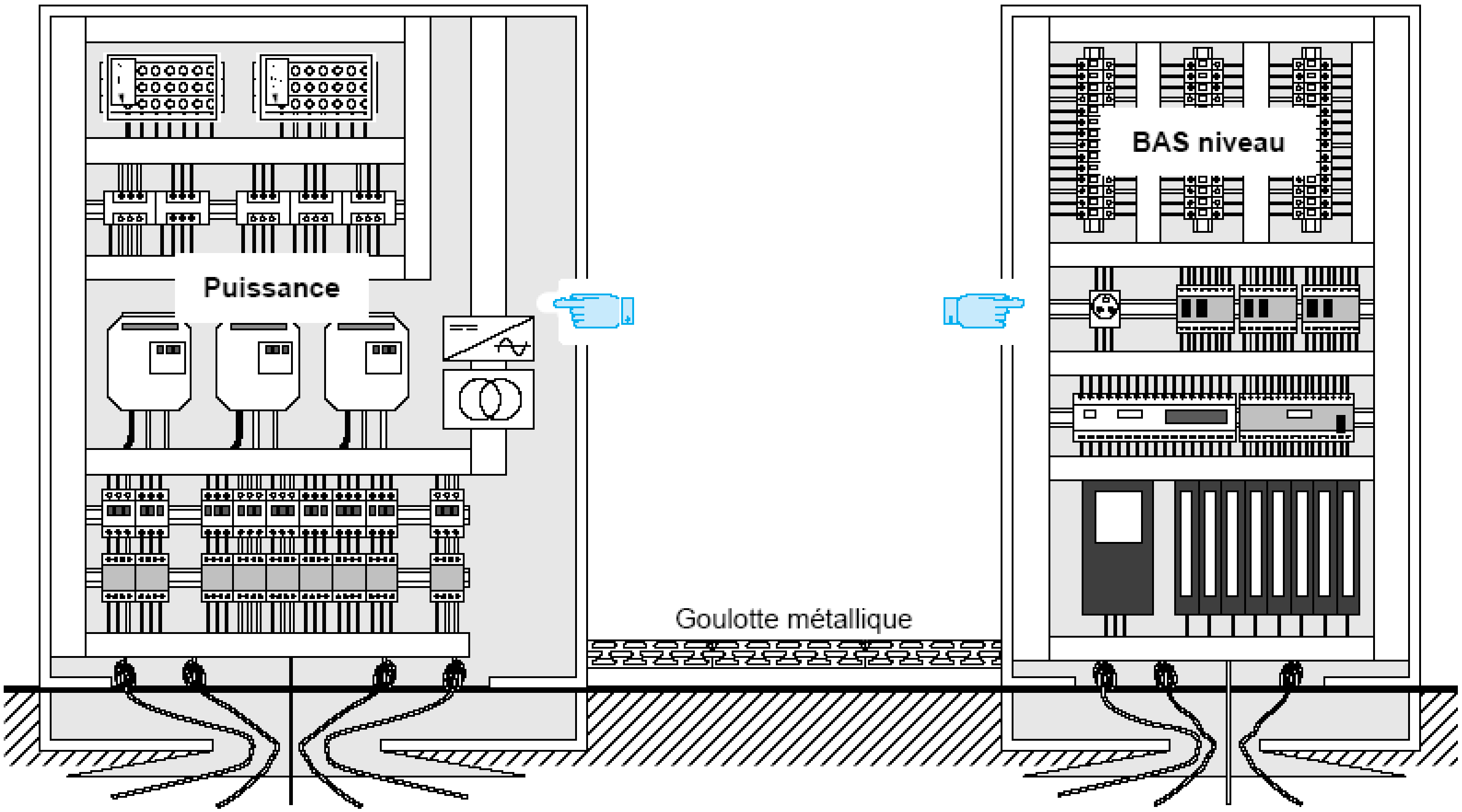




Design rules



Design rules



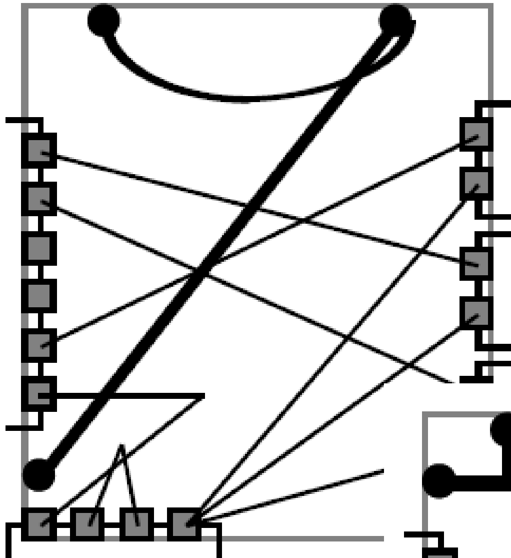
Design rules

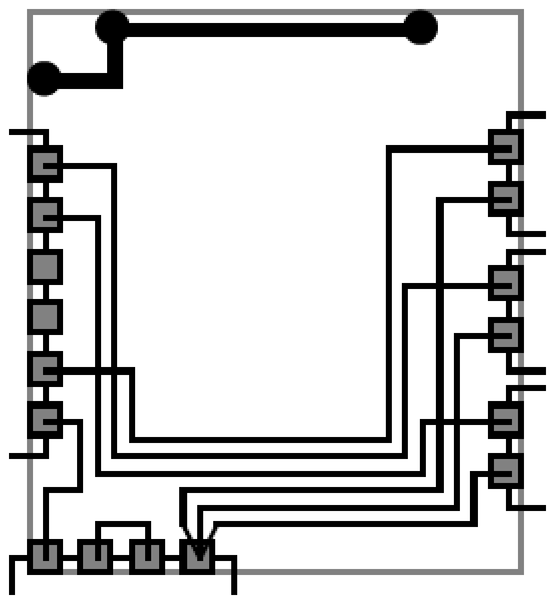
mauvais :

angles d'intersections quelconques

nombreuses boucles

courants faibles et courants forts mélangés





bon :

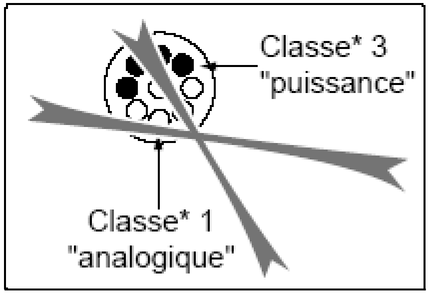
angles droits

boucles de surfaces minimales

courants faibles et courants forts séparés (éventuellement par une séparation métallique)

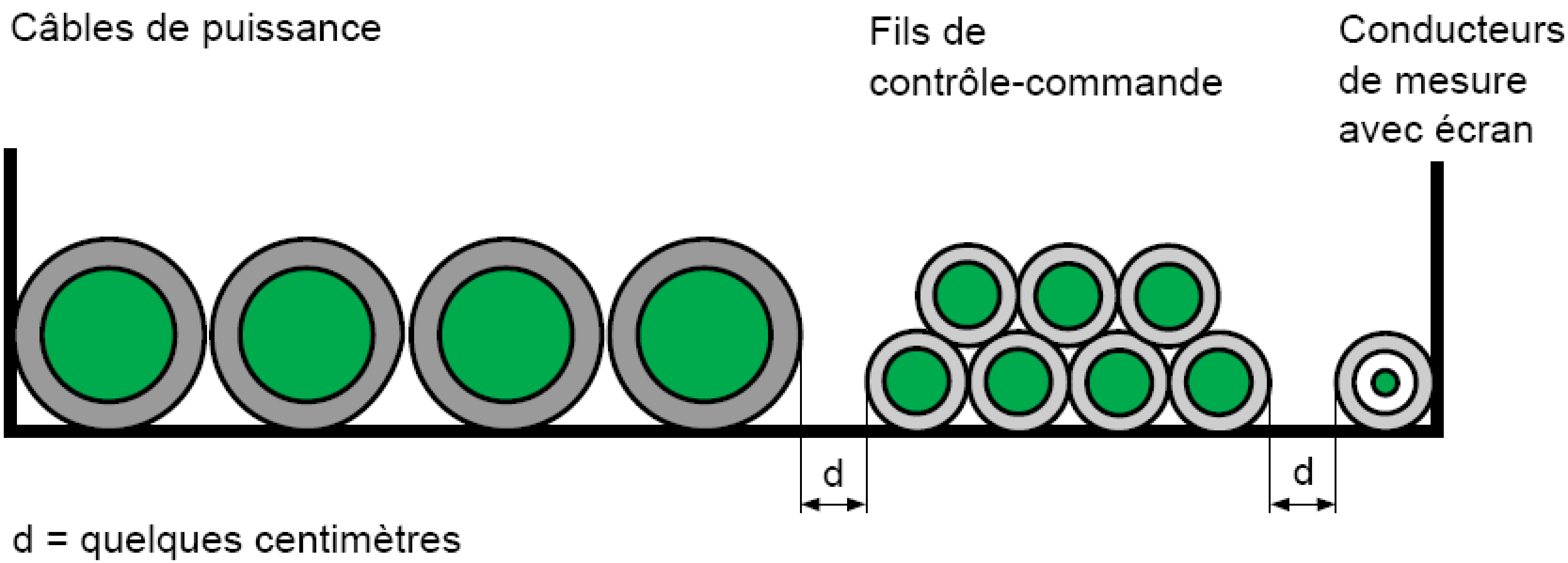
Cabling rules

- Equipotentiality of grounding (LF & HF) is ensured
- Do not use sensitive signals and disturbing signals in the same cable



- Reduce the parallel length of sensitive signals cables and disturbing signals cable
- Limit cable lengths
- Shielded cables permits those signals cables in the same cable tray.

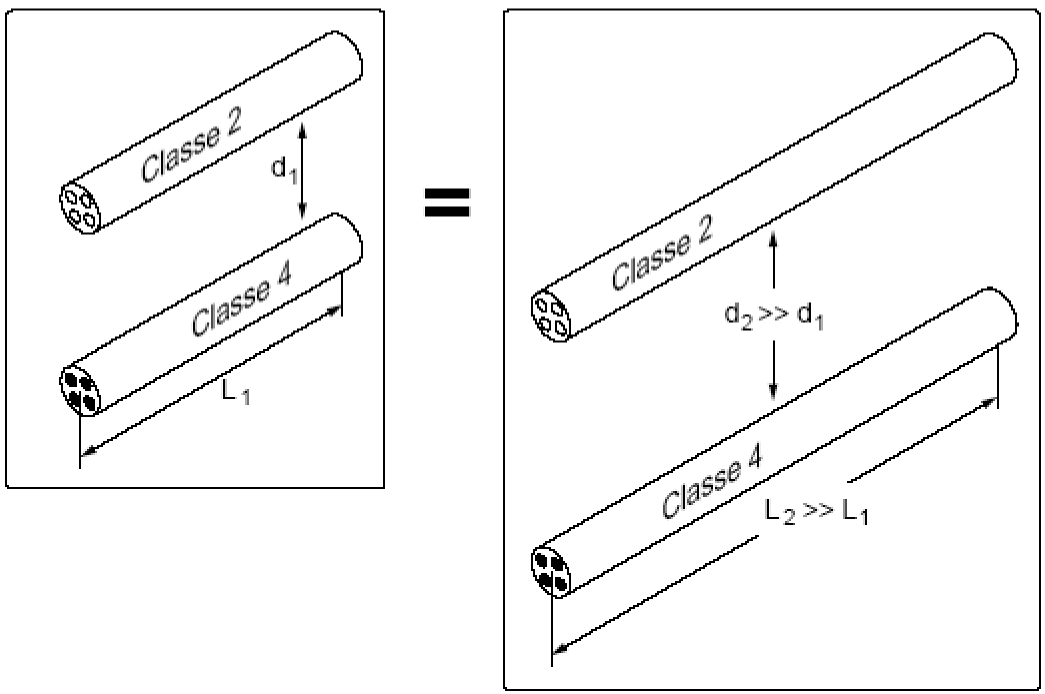
Design rules



Design rules

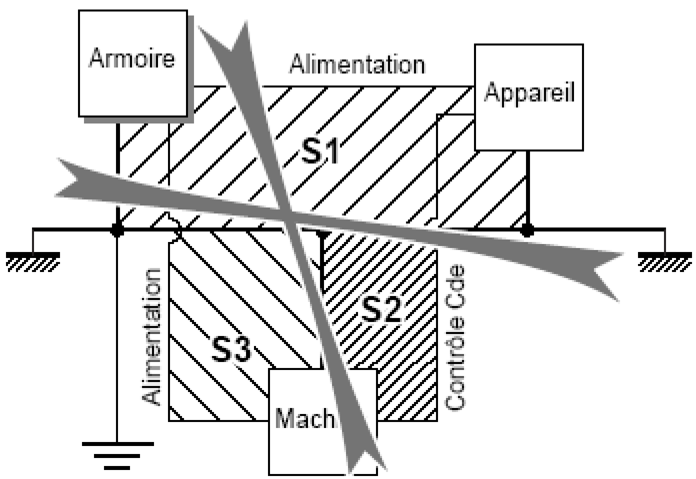
Cabling rules

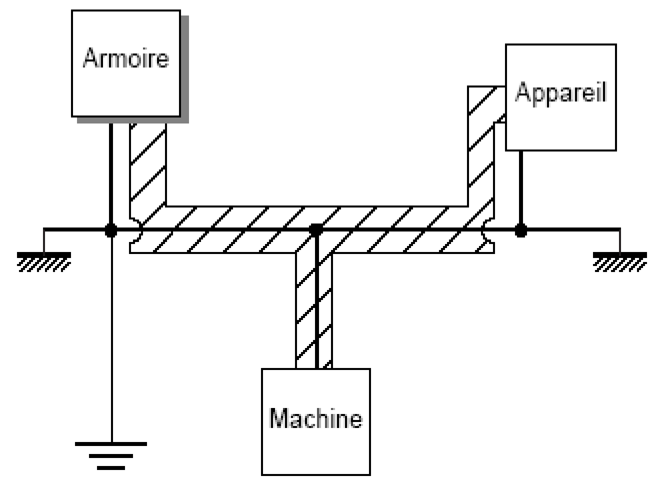
- Keep distance between sensitive cables and disturbing cables (costless and efficient solution) – this distance increases with the length of parallel cables.



Design rules
Cabling rules

- Reduce grounding loop surfaces

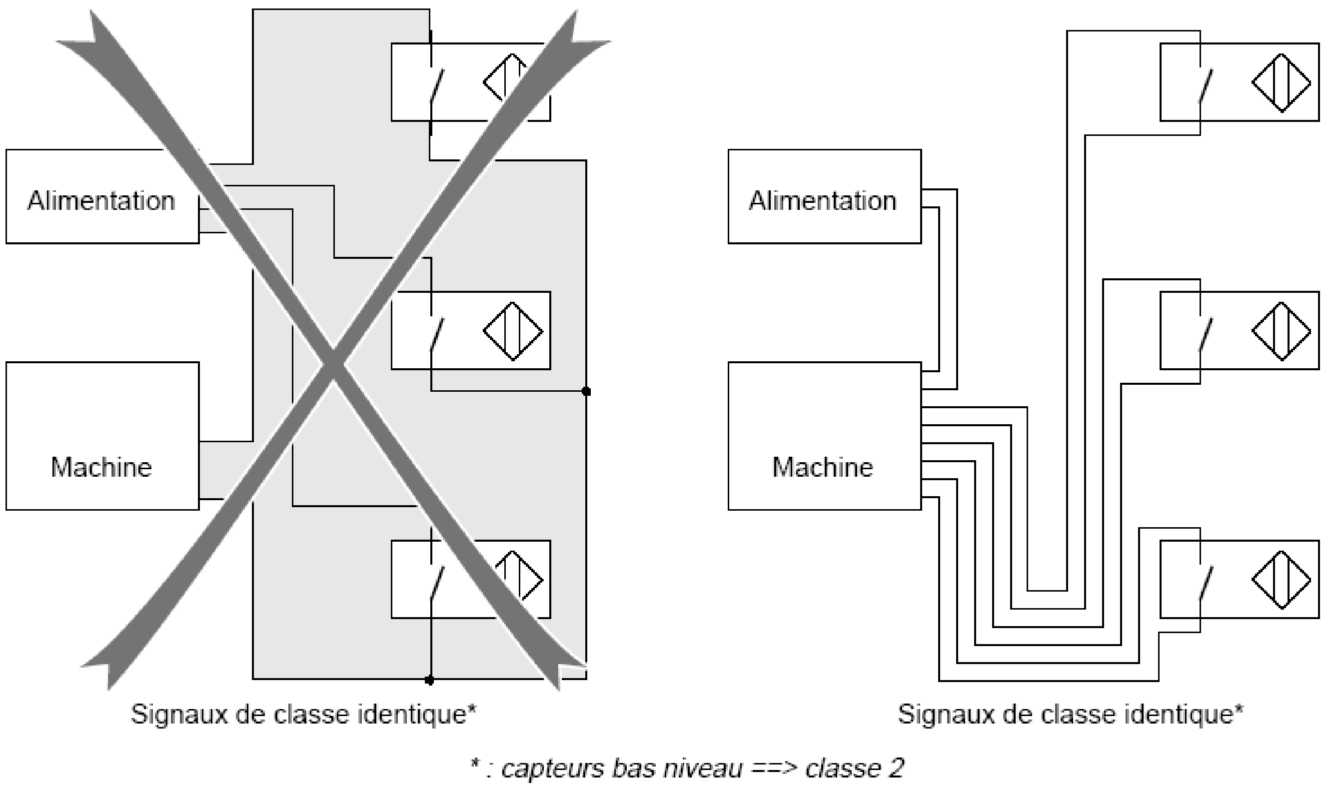




Design rules

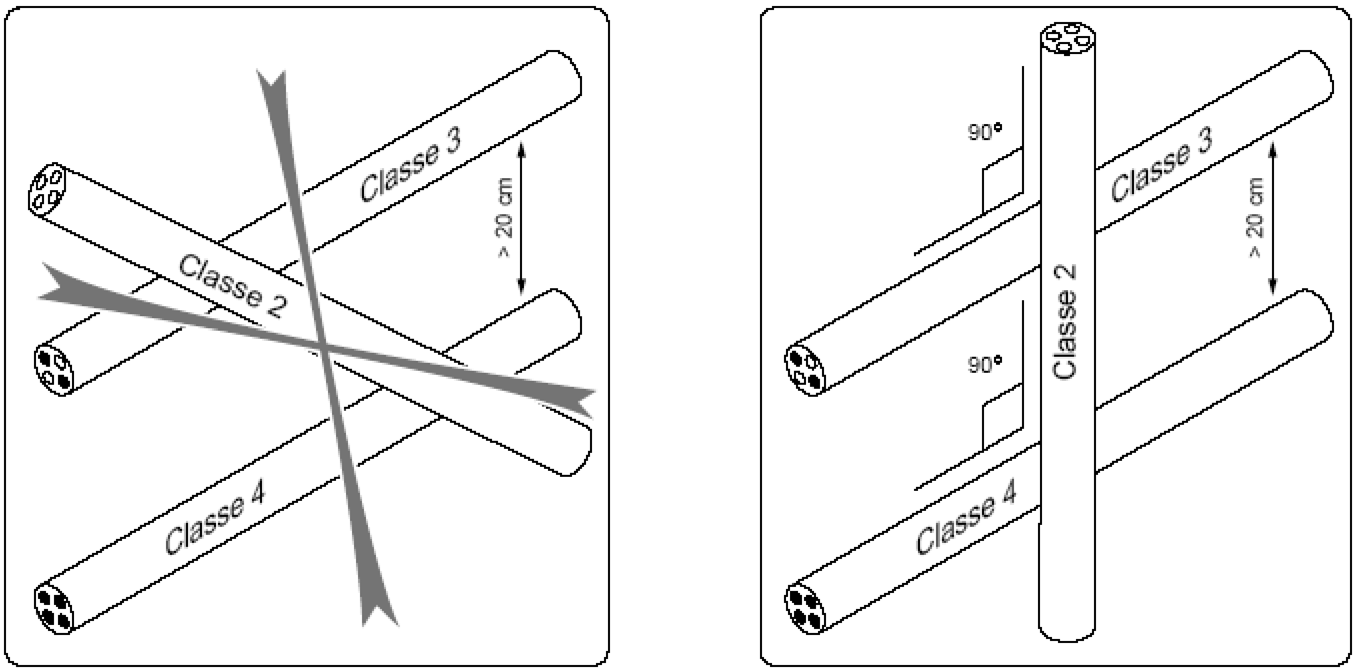
Cabling rules

- Signal conductor near grounding conductor



Design rules

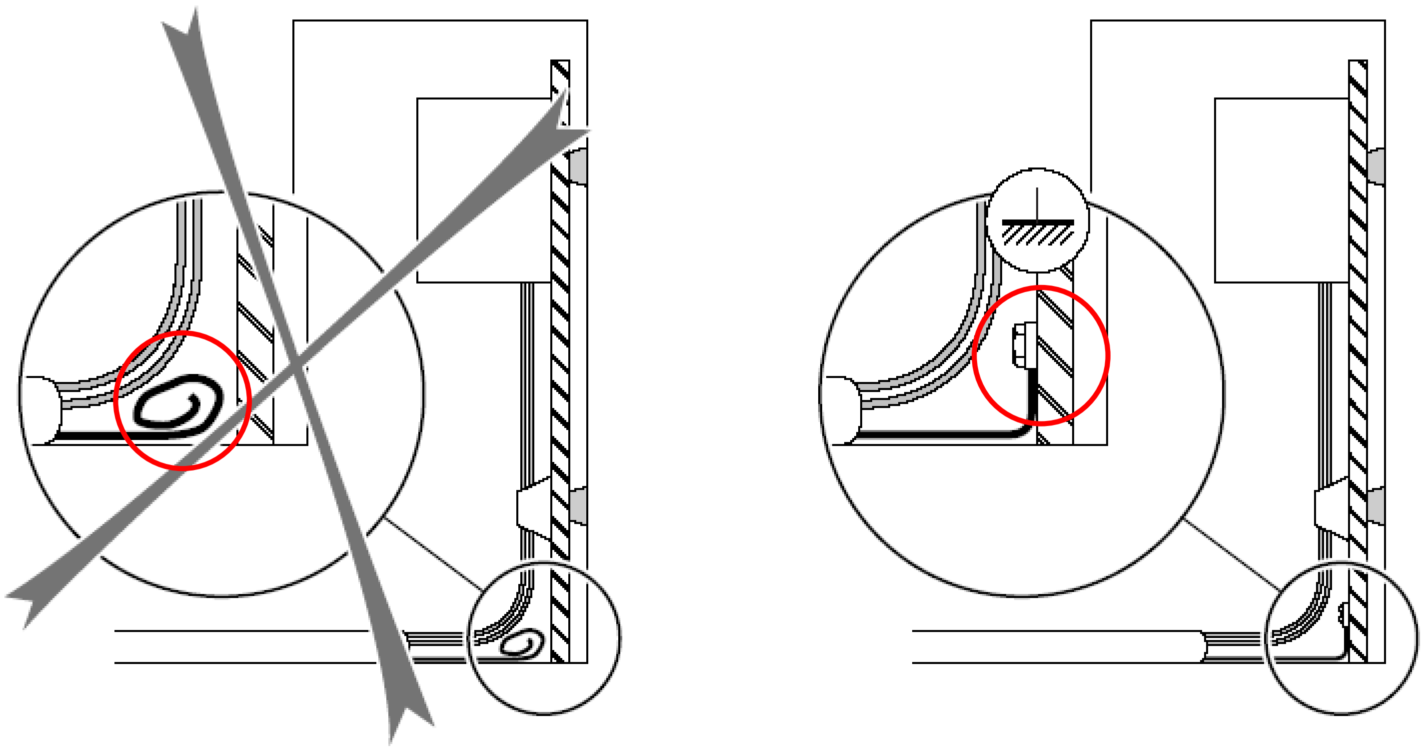
Cabling rules



Design rules

Cabling rules

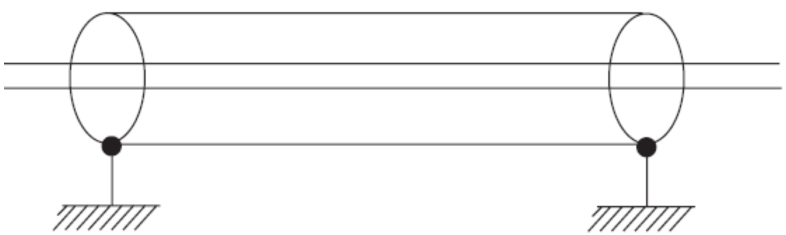
- Any unused conductor should be connected to ground at both ends

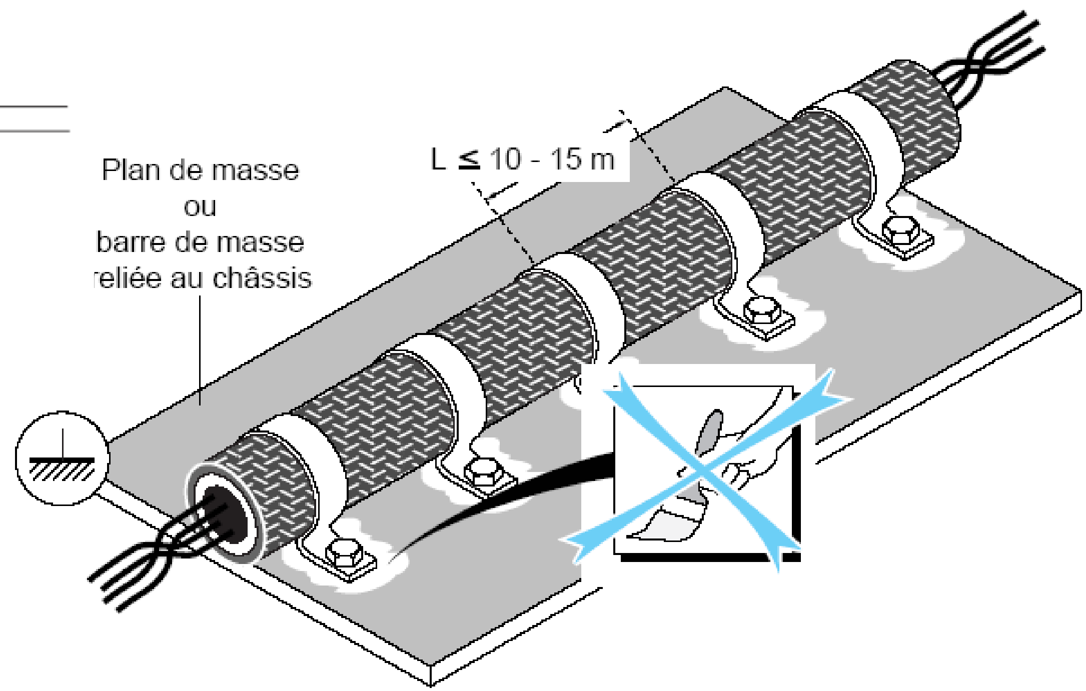


Design rules

Cabling rules

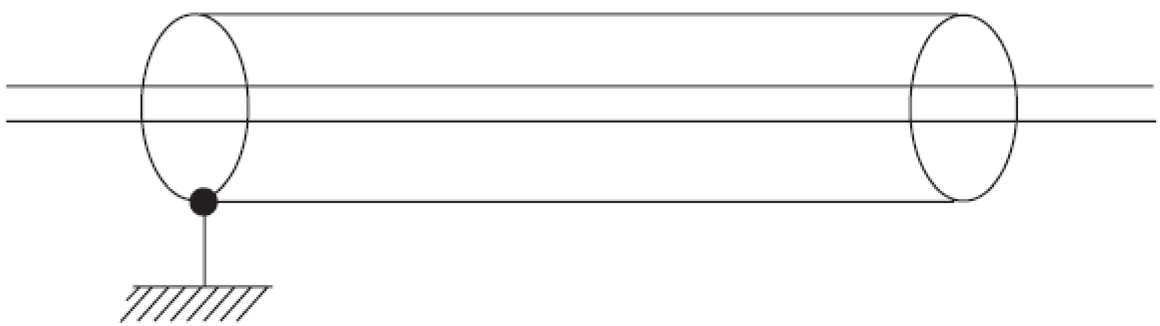
- Shielding connections?
    - at both ends?
        - very efficient against external HF disturbances
        - no voltage between cable and ground





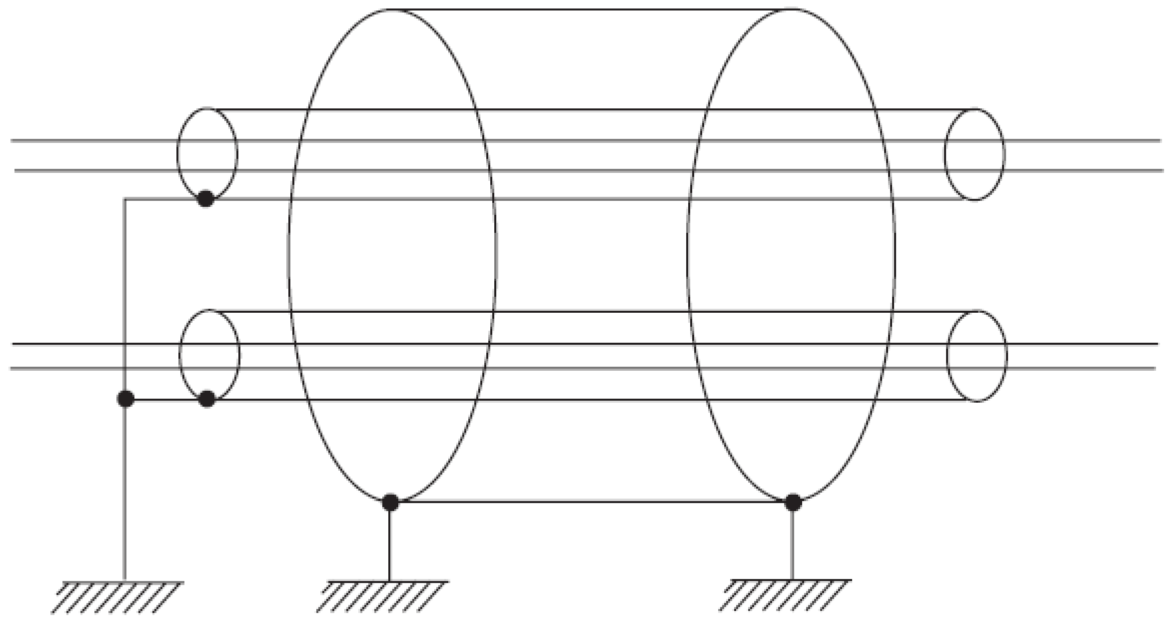
Cabling rules

- Shielding connections?
  - at 1 end?
    - not efficient against external HF disturbances
    - to delete low frequency signals in shielding called « ronflette »



Protection BF

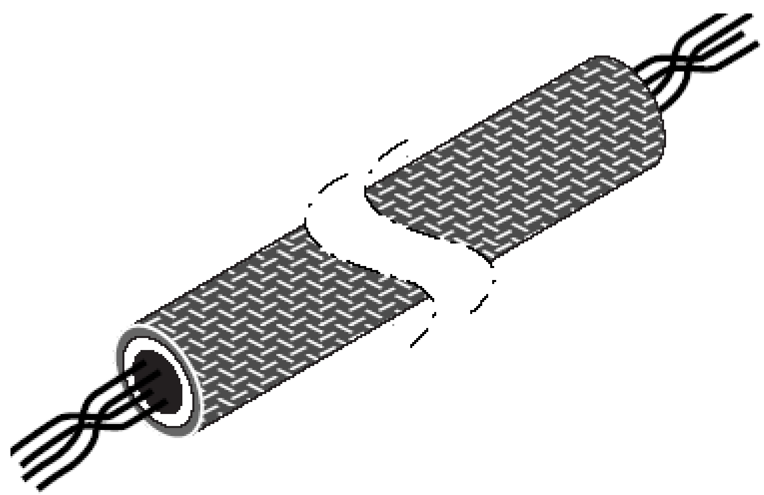
Cabling rules



Protection HF + BF

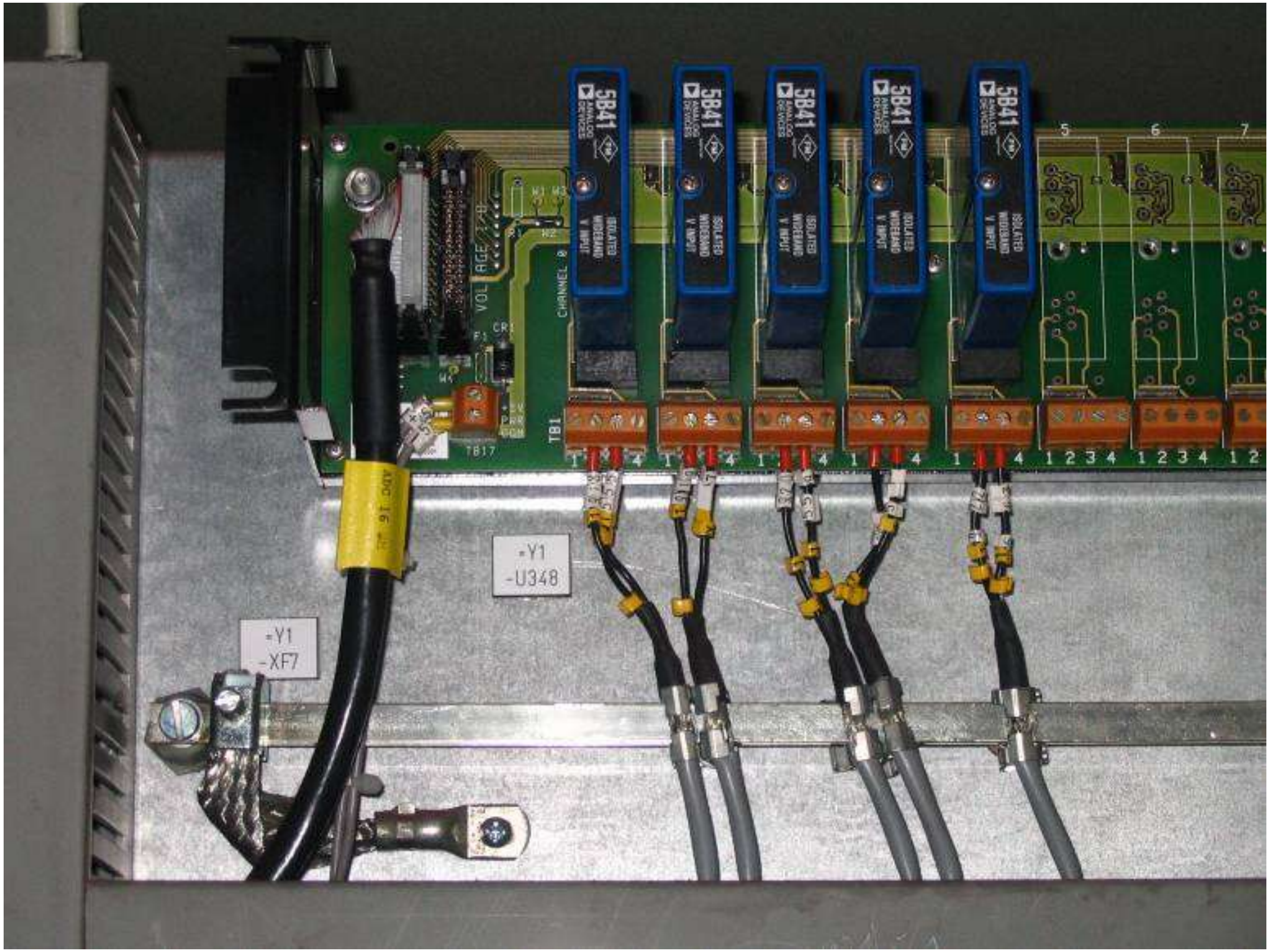
Cabling rules

- Shielding connections?
    - not connected?
    ⚠ - FORBIDDEN if accessible to touch (voltage between shielding and ground)
    - not efficient against external HF disturbances



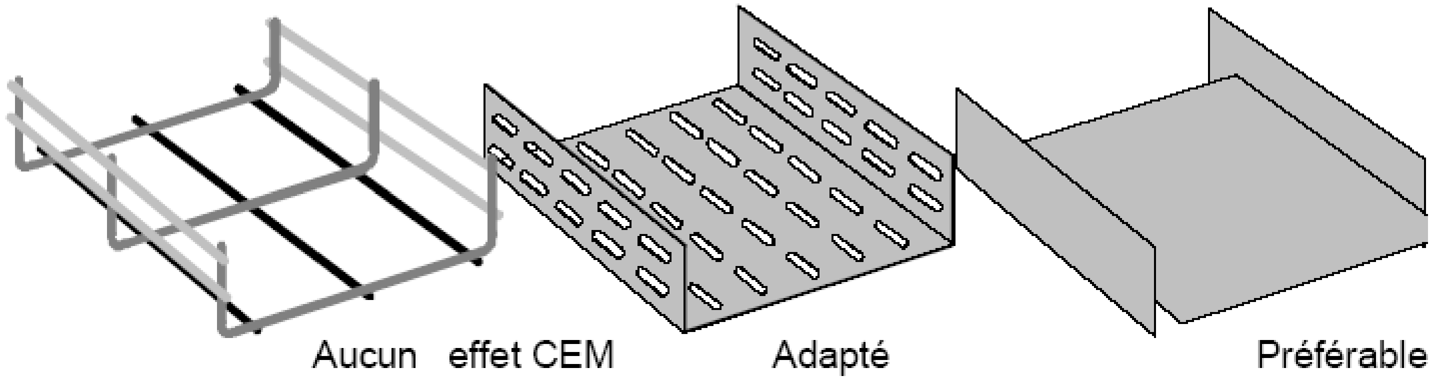
Design rules

Cabling rules

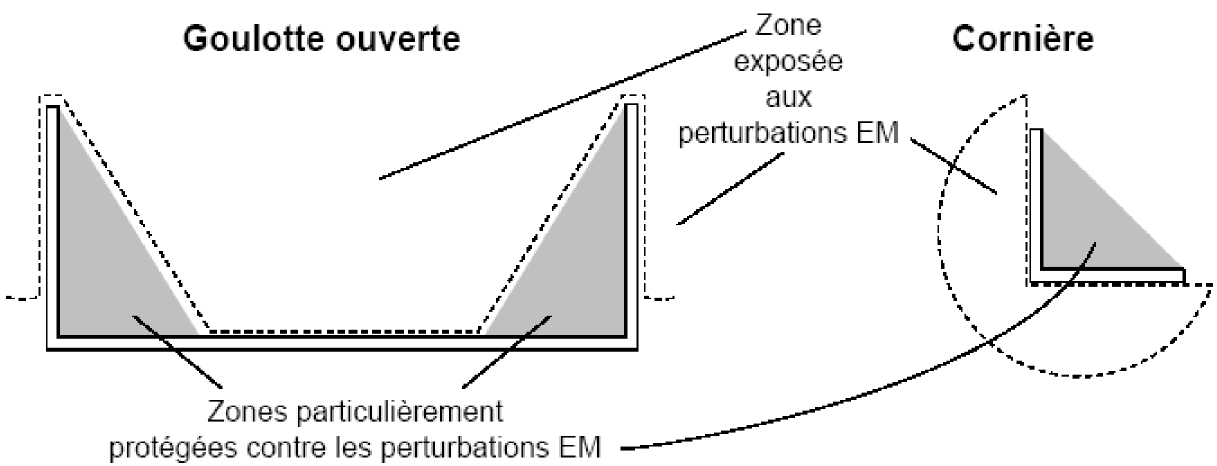


Design rules

Cabling rules

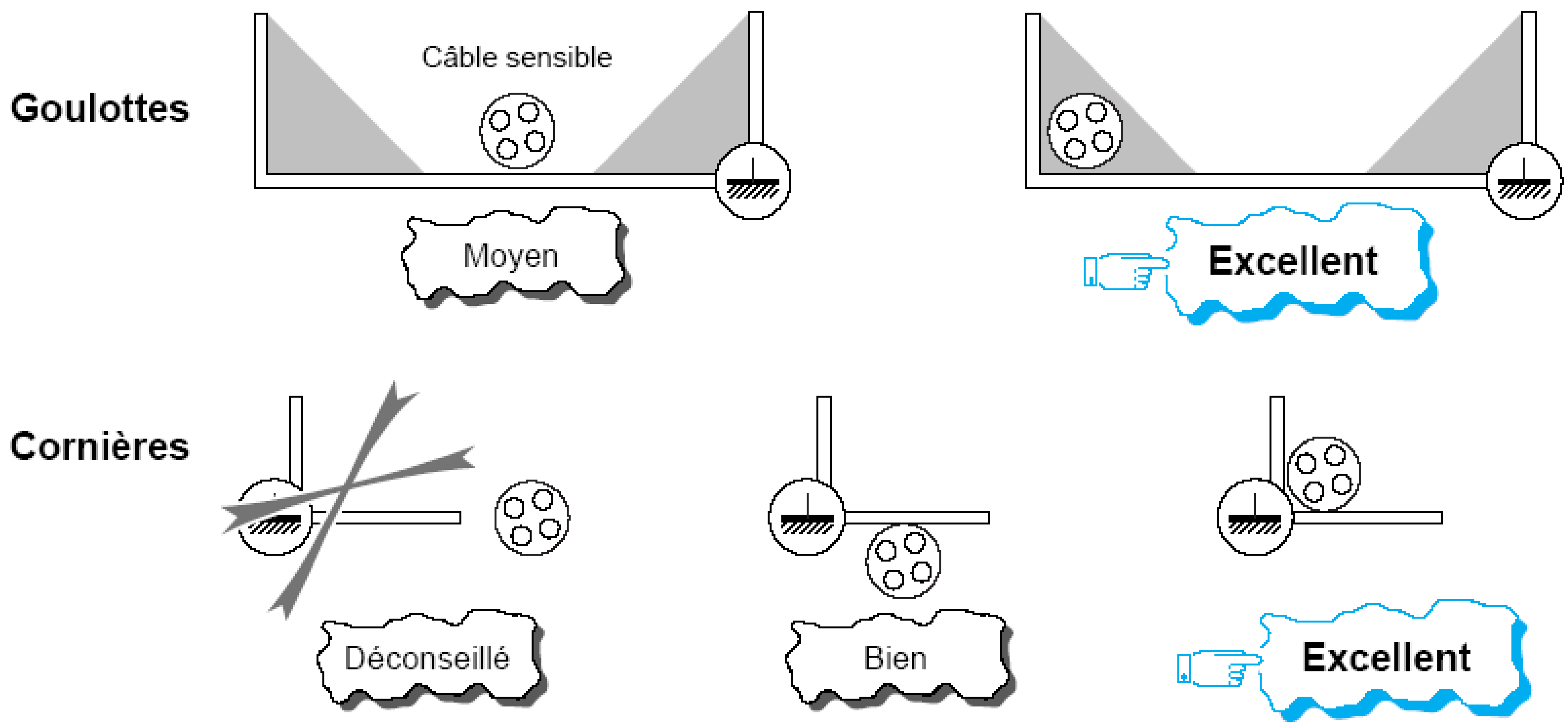


[EN 50174-2]



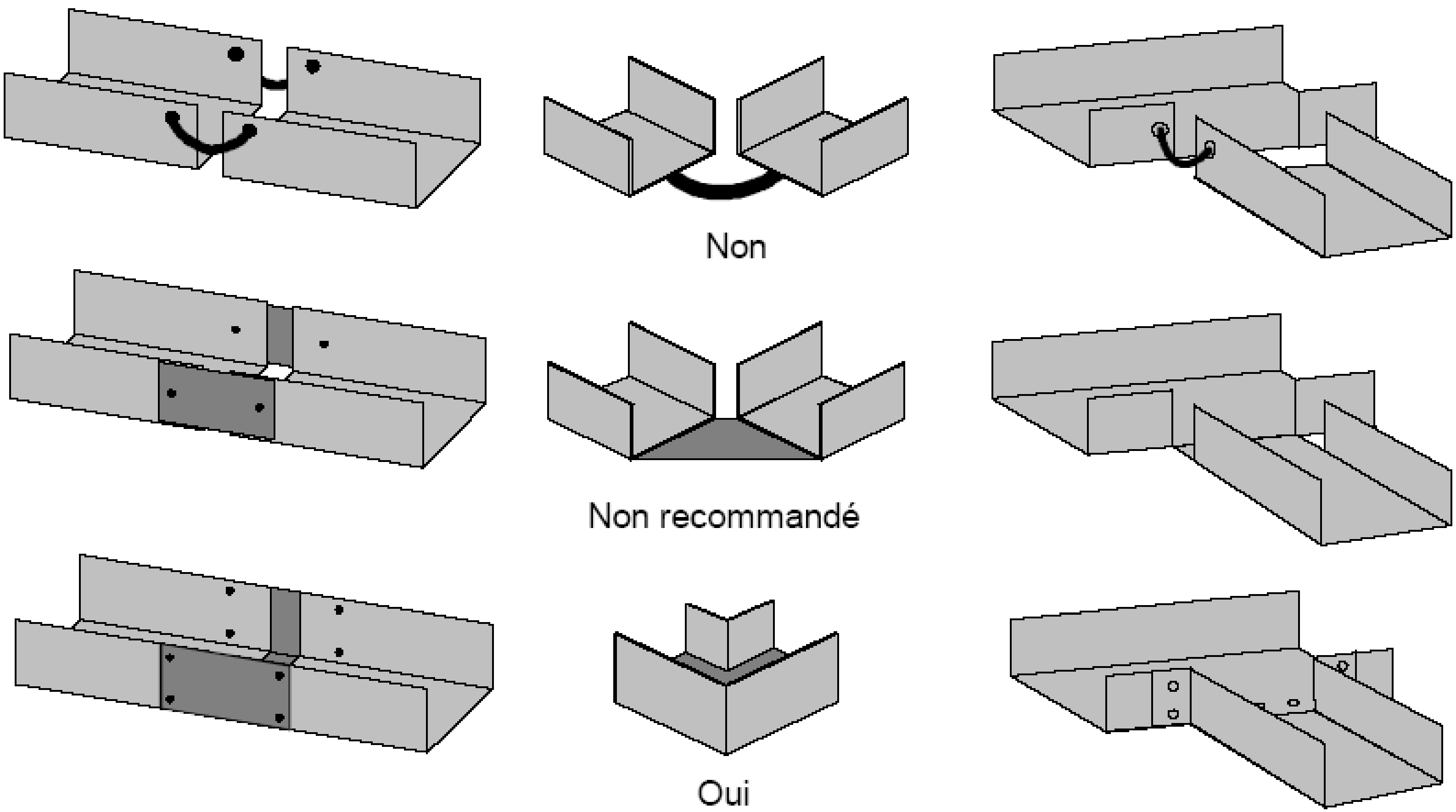
Design rules

Cabling rules



Design rules

Cabling rules



[EN 50174-2]

Design rules
For electronic circuits and PCBs
(part I)

Véronique Beauvois, Ir.
2019-2020

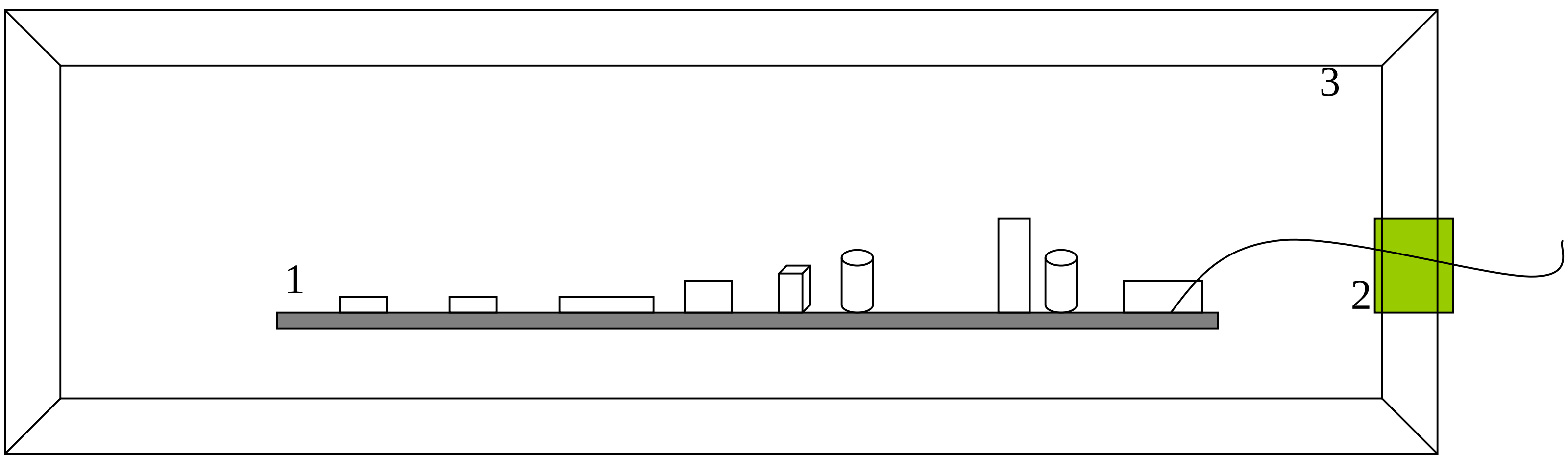
Why?

-Frequency is increasing (wireless, Bluetooth)
-Speed is increasing (clock, Mbit/sec)
-t_r and t_f are decreasing
-Components density is increasing (SMD)
-Tracks density /cm² is increasing

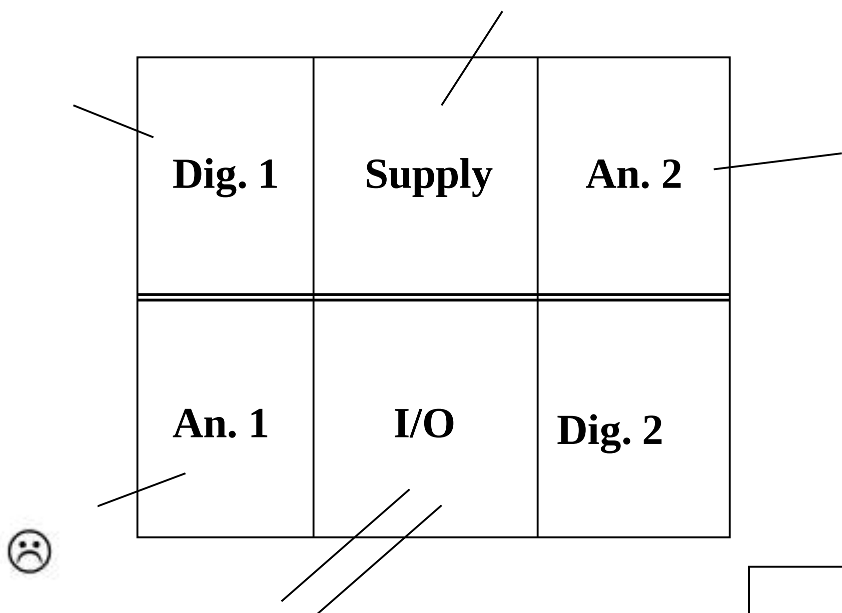
→ Broadband spectrum interferences
PCB design (PCB design software!)

Protections classification:

- Primary: circuit design (decoupling, balanced configuration, speed and bandwidth limitations) - PCB design and grounding,
- Secondary: external circuit interfaces, cabling (filtering), connectors,
- Tertiary: full shielding (cost)



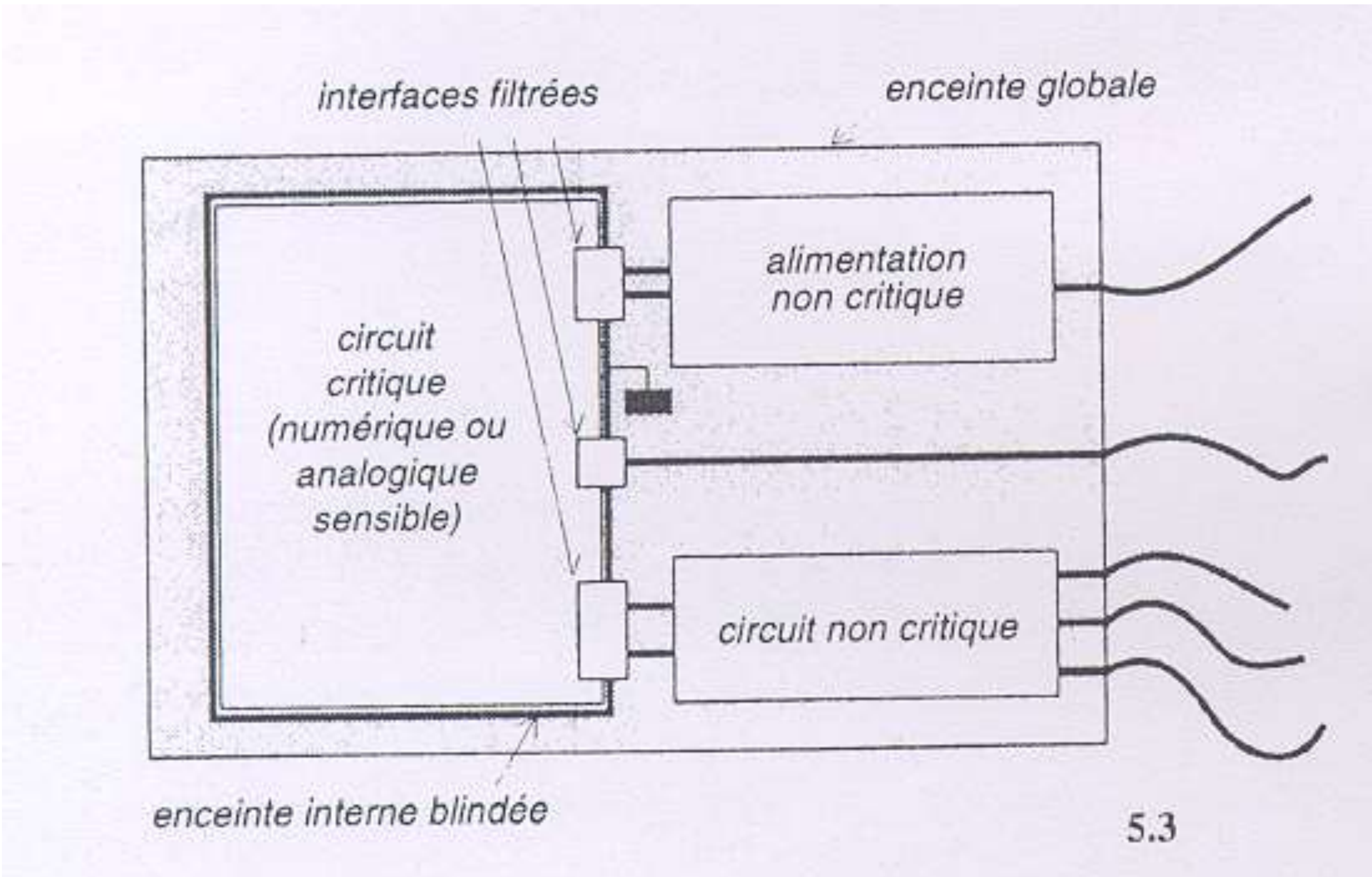
1st step: to take care of the division of the circuit



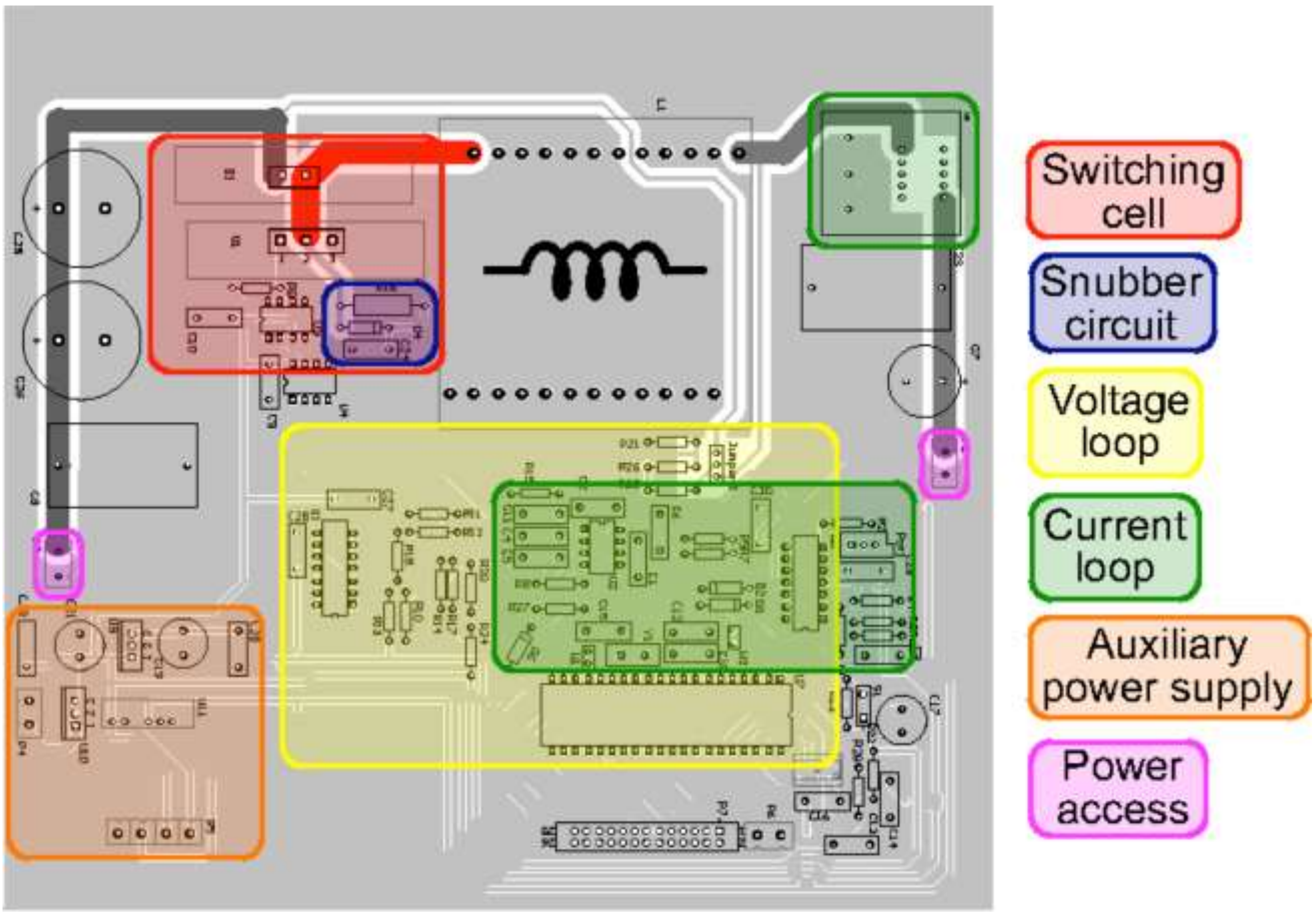
Different ports are all over the perimeter – shielding and ports filtering ⇒

To spot critical zones:
- Sources (µP, video…)
- Victims (low level analogue…)

Divided circuit



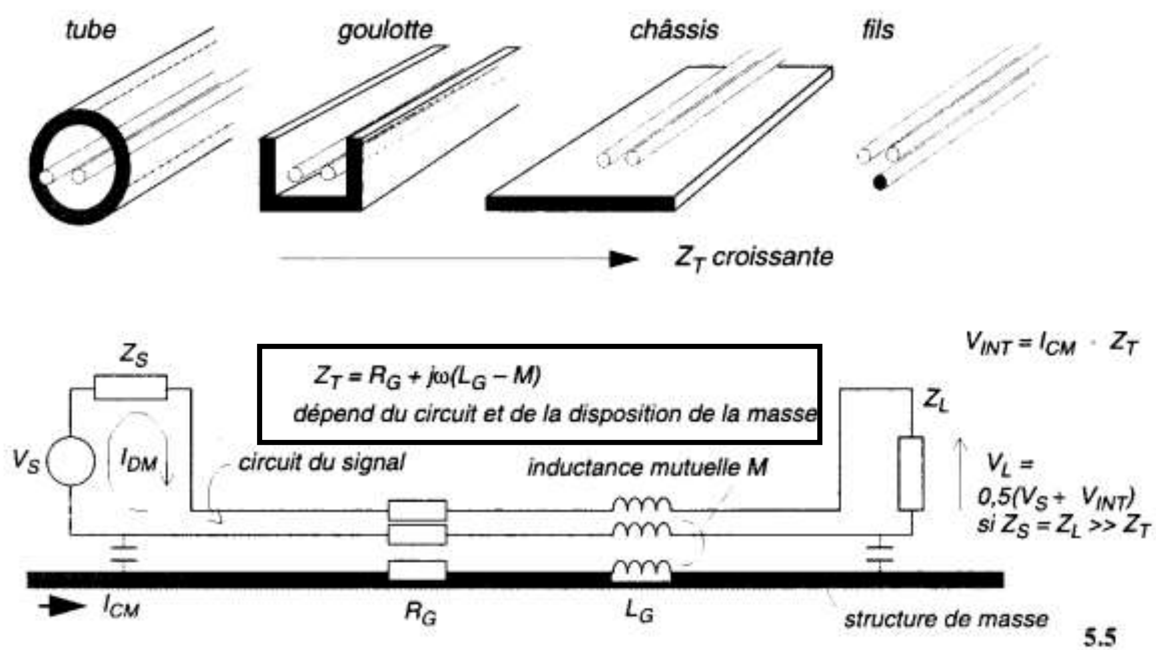
Divided circuit



Circuit design and grounding

2nd step: Grounding

- do not confuse ground and earth (PE)
- grounding role: to give a reference for all connections
- low impedance track to send the current to the source
- low transfer impedance solutions

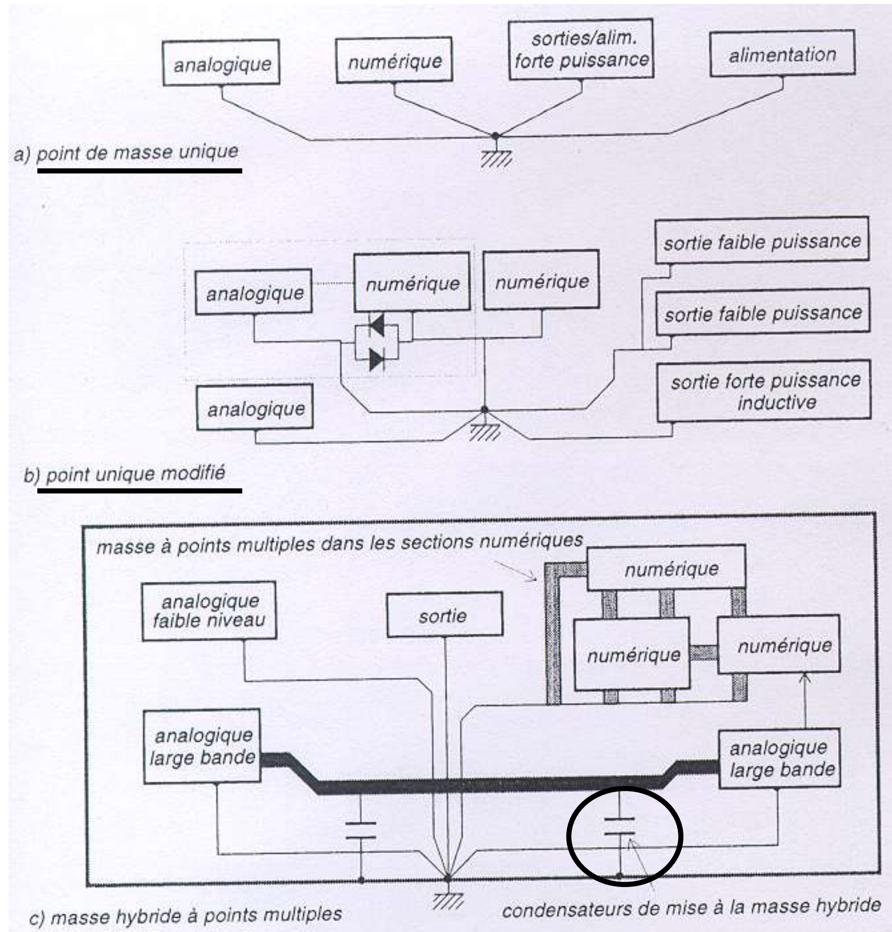


Circuit design and grounding

a) To suppress common grounding Z (OK up to some MHz, then Cp et U_{CM} due to length of links).

b) Similar circuits linked together, noisy circuits near grounding point.

c) A lot of short connections (<0.1λ) for digital circuits.

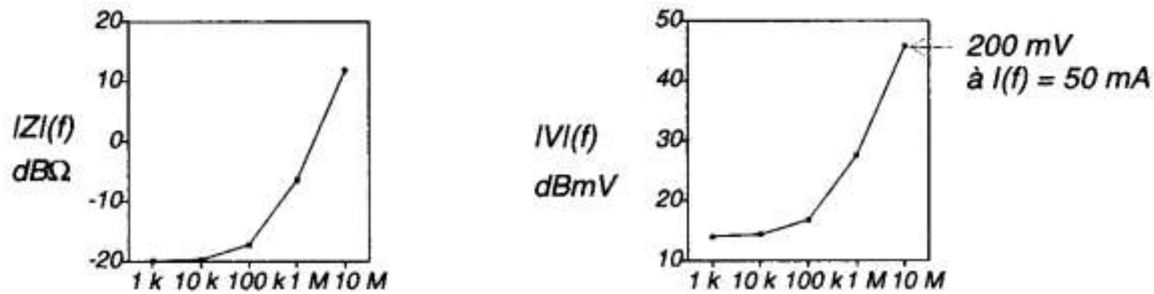


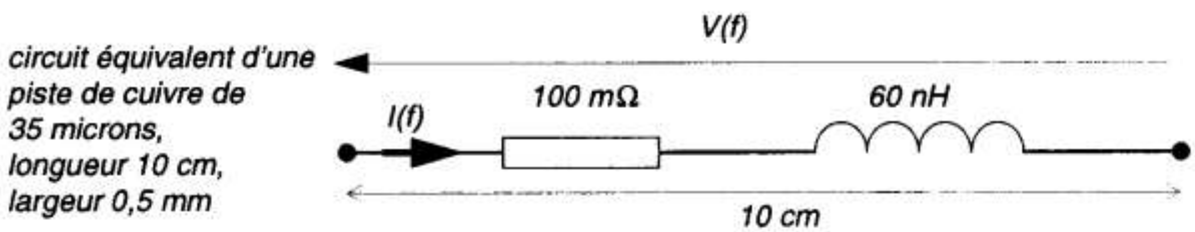
Circuit design and grounding

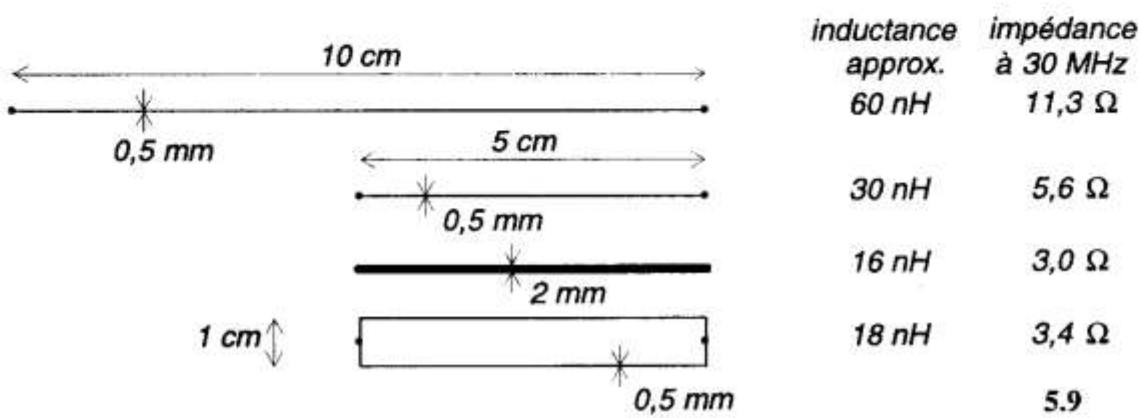
- 1 PCB side/ 1 side versus 2 sides
- Multi-layer PCB (ground plane)
- Reduce impedance
- Grounding track // and near signal track
- Grounding: grid or ground plane
- SMD (to reduce loop surface, length, PCB size)
- ...

Circuit design and grounding

Track impedance

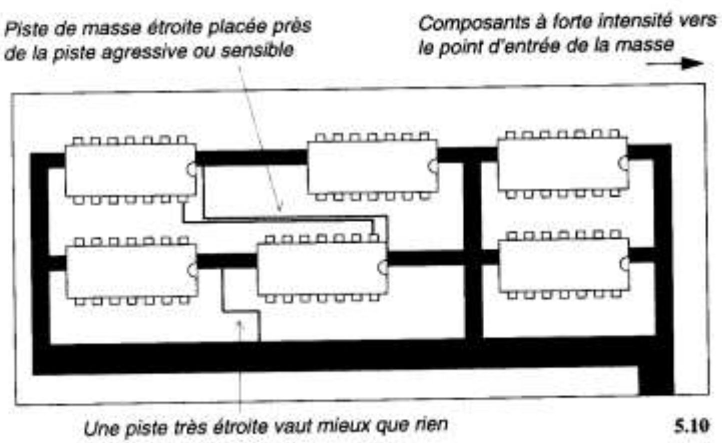


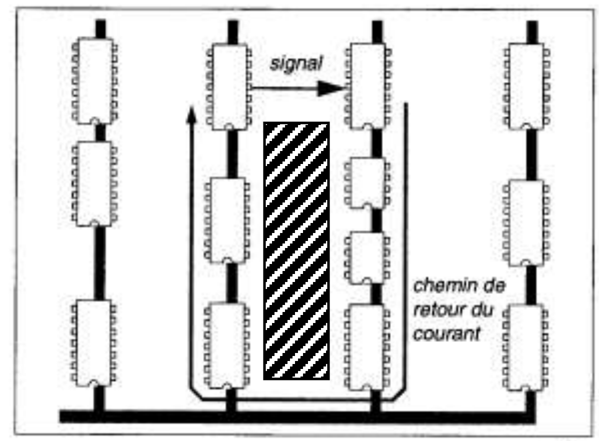




Circuit design and grounding

Grid or meshed grounding

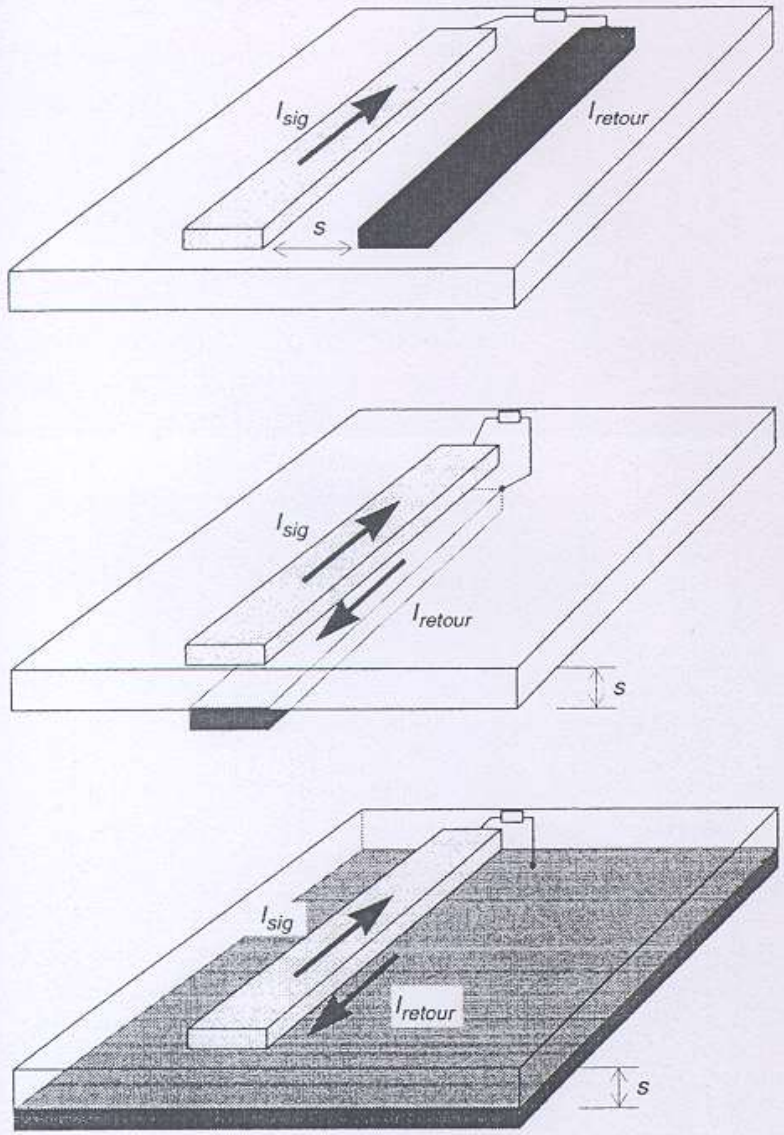




The number of return path for current to ground should be important to reduce L.
Tracks with width >>

The comb configuration is not a good solution.

S détermine dans tous les cas l'inductance globale de la boucle

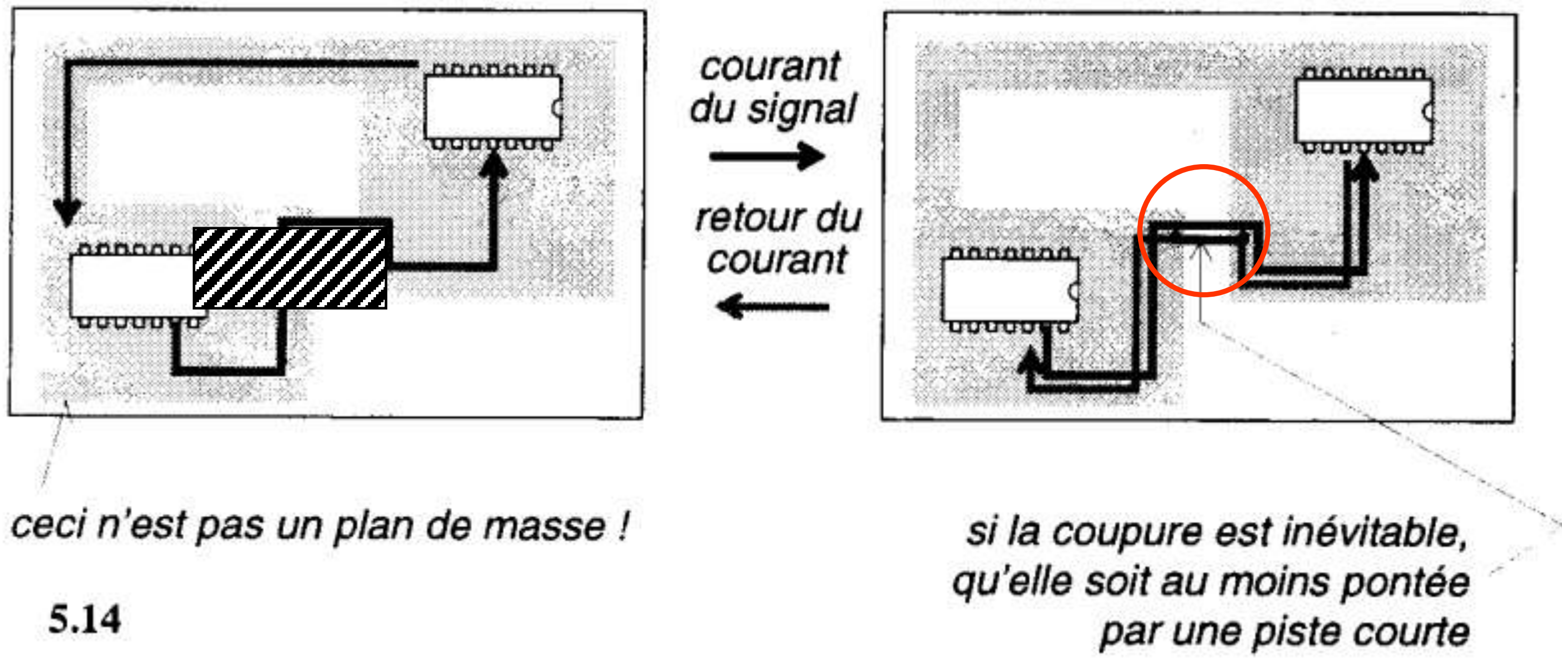


pistes parallèles

pistes de part et d'autre de la platine

plan de masse sur la face opposée de la platine, offre un chemin de retour à toute piste de l'autre côté

5.13



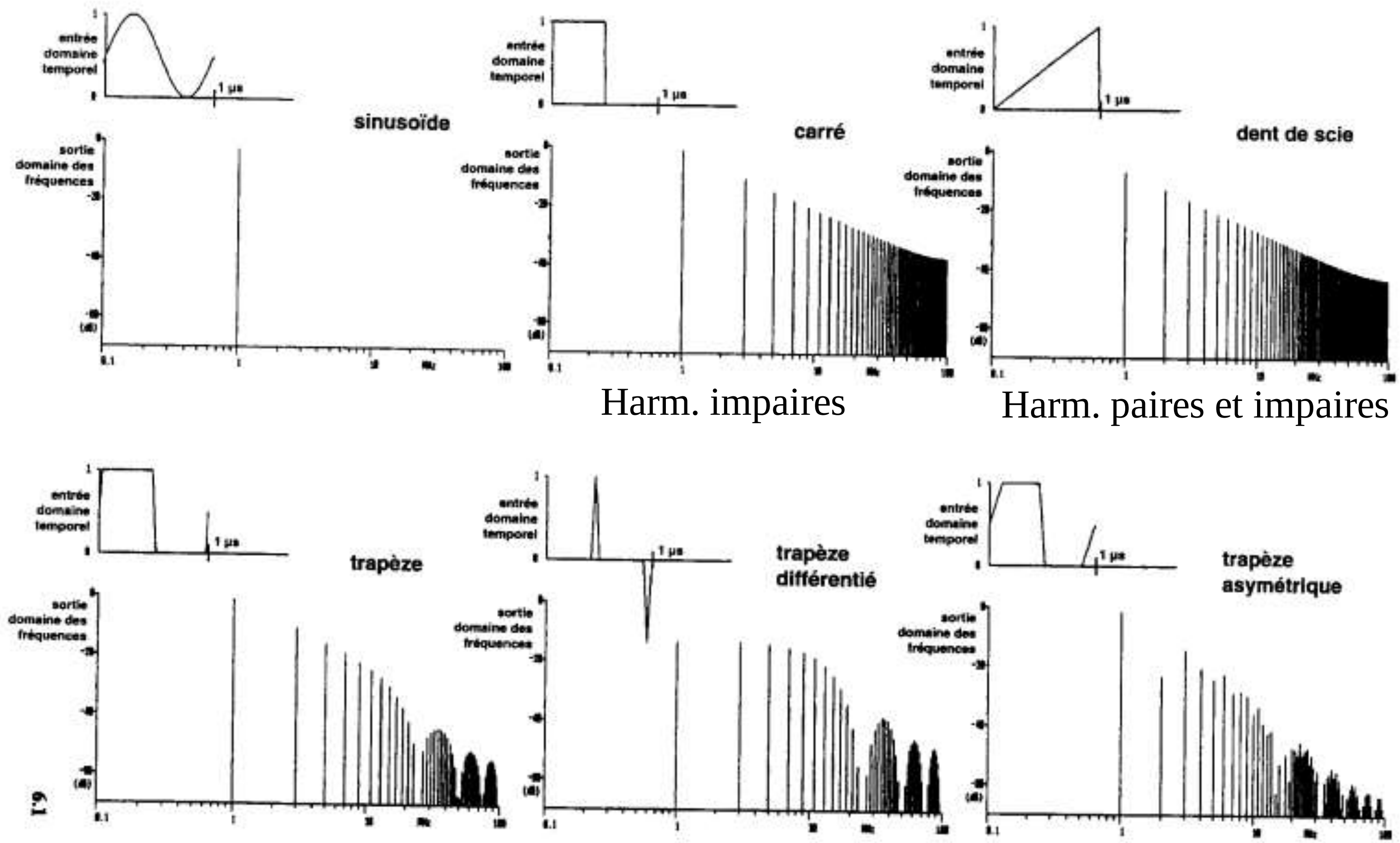
5.14

- Do not interrupt ground plane
- If this interruption is mandatory, add a bridge (as short as possible and near the critical track)
- No slot in the ground plane (multi-layer is ideal).

Design rules
For electronic circuits and PCBs
(part II)

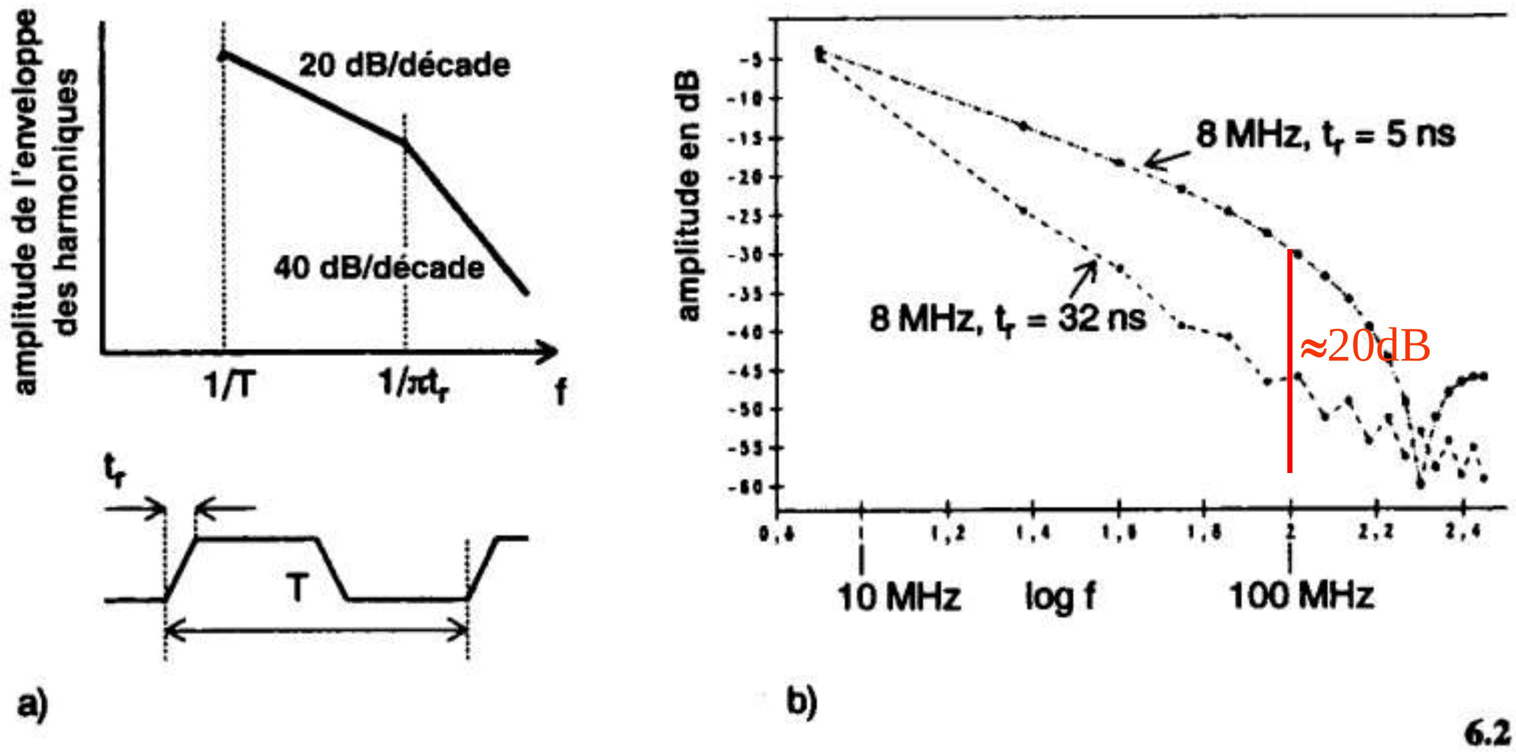
Véronique Beauvois, Ir.
2019-2020

t <---> f



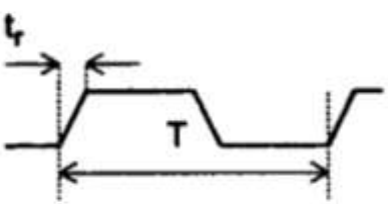
entrée domaine temporel
1 µs
sinusoïde
sortie domaine des fréquences
carré
dent de scie
Harm. impaires
Harm. paires et impaires
trapèze
trapèze différentié
trapèze asymétrique
(dB)

t <---> f

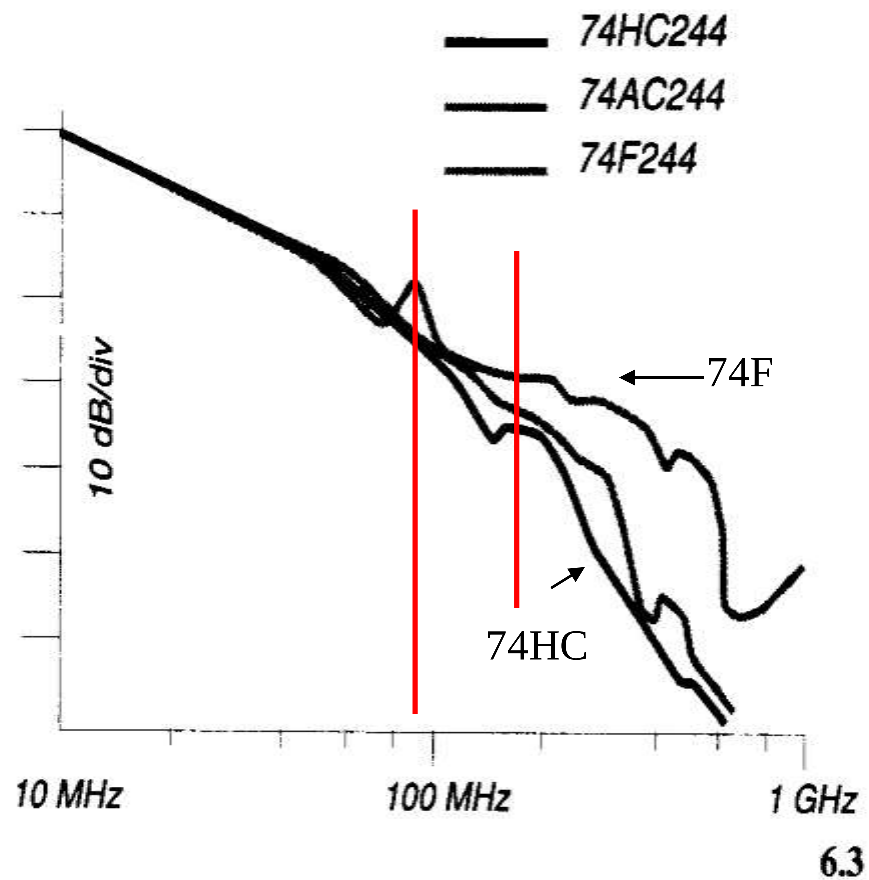


How to choose the logic family?

t <---> f

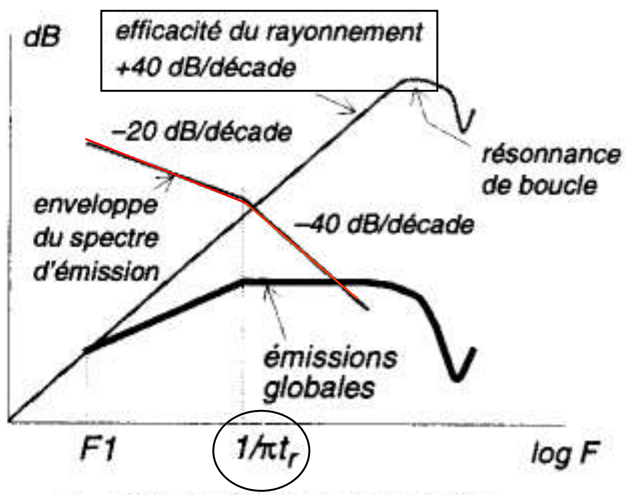


t_r
T
10MHz

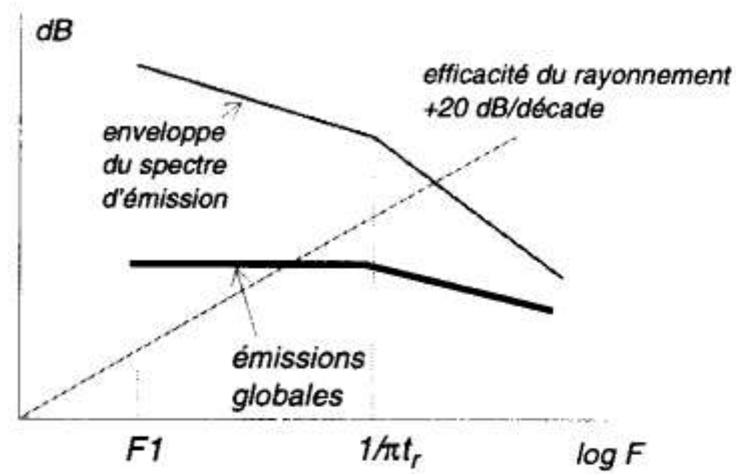


74HC244
74AC244
74F244
10 dB/div
74F
74HC
10 MHz
100 MHz
1 GHz
6.3

Differential mode R.E.	Common mode R.E.



a) Differential mode radiation



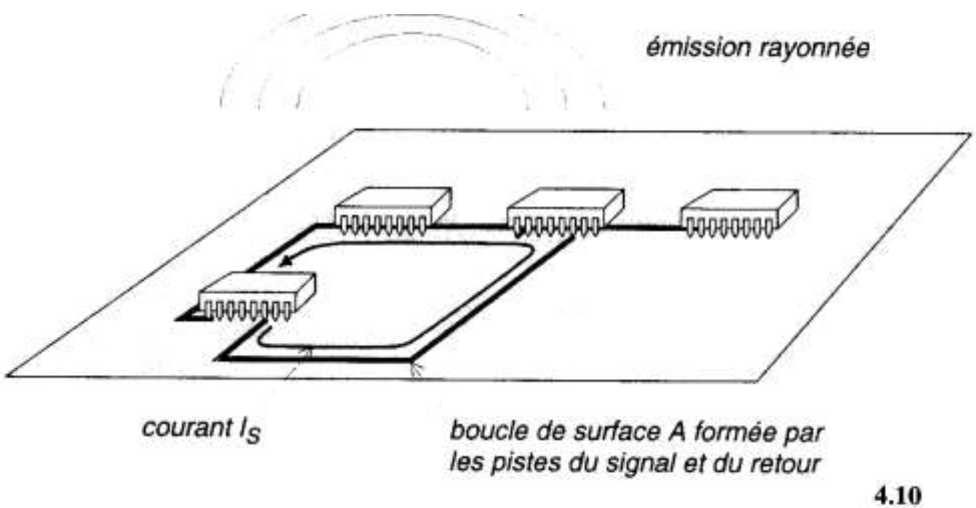
b) Common mode radiation

6.4

Table 6.1

Table 6.2

D.M. ----> R.E. of PCB



Loop = small if dimensions < $\lambda/4$, means 1m @ 75MHz

IC loops could be considered as small up to some 100 MHz

Maximum E-field of this loop @ 10 m measurement distance:

$E\,(V/m) = 263 \times 10^{-12} \times f(MHz)^2 \times A(cm^2) \times I_S\,(mA)$ ---> +40dB/dec

D.M. ----> R.E. of PCB

According to:

$E\,(V/m) = 263 \times 10^{-12} \times f(MHz)^2 \times A(cm^2) \times I_S\,(mA)$ ---> 40 dB/dec

Question: this PCB needs or not an additional shielding?

A=10 cm² ; Is=20 mA and f=50 MHz

E=42 dBµV/m means 12dB over the limit in class B

So if current I and frequency f are fixed, A could not be reduced, a shielding is necessary.

dynamic commutation current / component to charge or discharge the capacitor

Famille logique	t_r/t_f ns	ΔI mA	Surface de boucle en cm² ; fréquence d'horloge 4 MHz	10 MHz	30 MHz	100 MHz
4000B CMOS à 5 V	40	6	1000	400	-	-
74HC	6	20	45	18	6	-
74LS	6	50	18	7,2	2,4	-
74ALS	3,5	50	10	4	1,4	0,4
74AC	3	80	5,5	2,2	0,75	0,25
74F	3	80	5,5	2,2	0,75	0,25
74AS	1,4	120	2	0,8	0,3	0,15

Surface de boucle pour 30 dBµV/m 30 MHz - 230 MHz, 37 dBµV/m 230 MHz - 1000 MHz à 10 m

Limit EN 55022 cl.B

≈ Dim. case

Shielding + filtering

Utilisation : prenons l'exemple de la famille 74ALS avec F_{clk} = 30 MHz.
Le cas le plus défavorable est à 150 MHz (5ème harmonique)

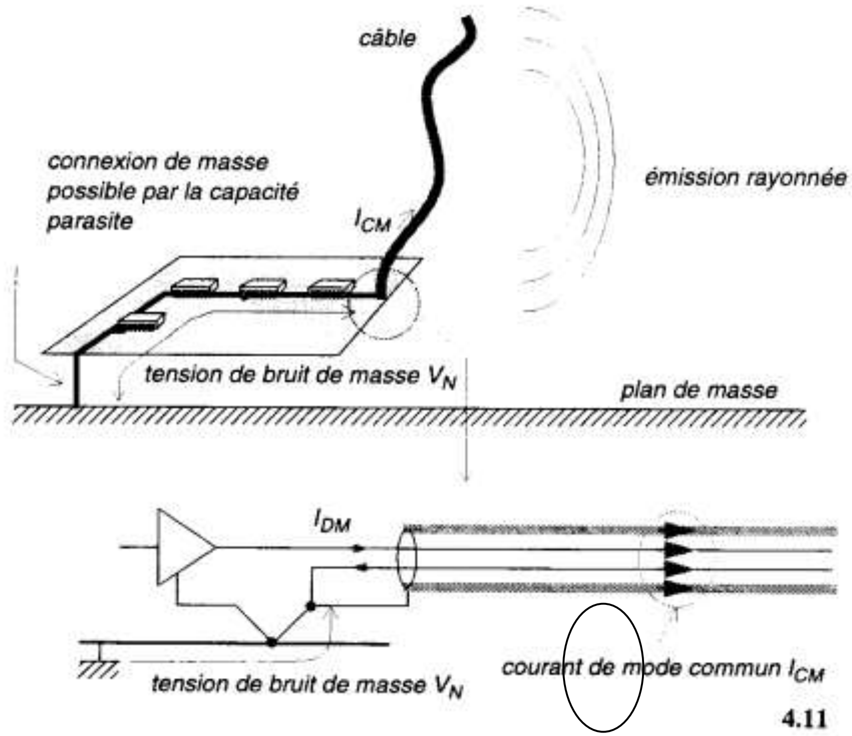
L'analyse de Fourier de la source de courant, en utilisant la section C.7 avec $(t + t_r)/T = 0,5$; T = 33,3 ns ; t_r = 3,5 ns et I =50 mA, donne 3,83 mA pour $I_{(5)}$, le courant du cinquième harmonique.

De l'équation (4.6), pour un champ E de 30 dBµV/m et $I_{(5)}$ comme ci-dessus à 150 MHz, la surface de boucle admissible est de **1,395 cm²** (arrondi à 1,4 dans le tableau).

Tableau 6.1 – Émission en mode différentiel : surface maximale permise.

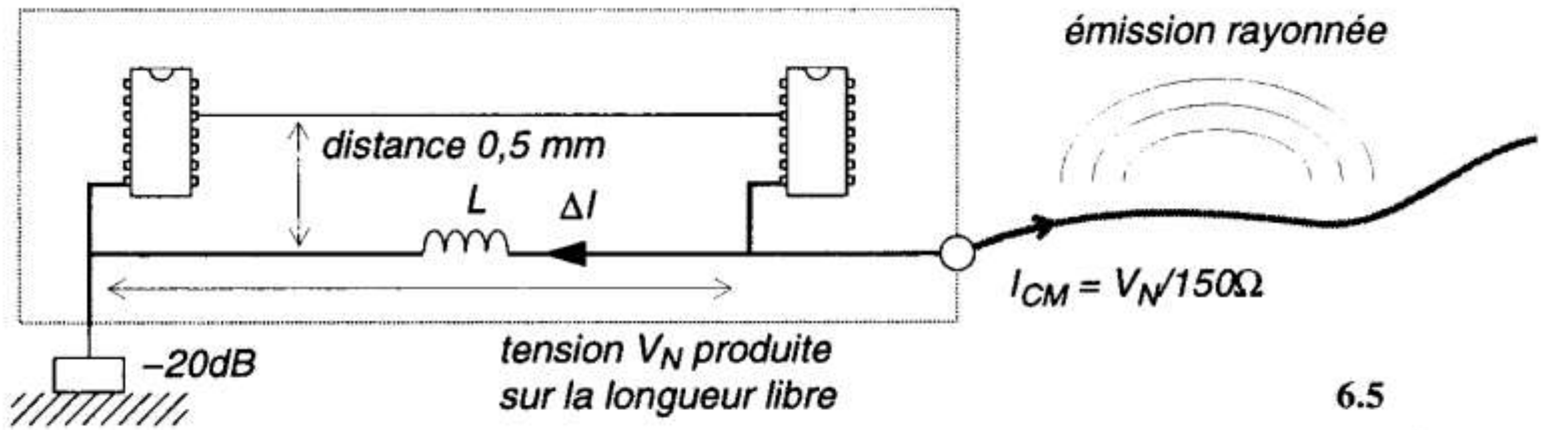
C.M. ----> R.E. of PCB

Cable length
resonance @30-100MHz



E (V/m) = 1,26 x 10^{-4} x f(MHz) x L(m) x I_{MC} (mA)
if the cable is represented by a short monopole (L<λ/4) @ 10m of the ground
e.g. 1m of cabling, E = 42dBµV/m, then Is = 20µA (/1000#I_{MD})

C.M. ----> R.E. of PCB



CM voltage to cable, ΔI on ground path
Differential noise voltage $V_N = \Delta I.j\omega.L$
(between reference ground and cable connection)
$Z \approx 150\Omega$ (constant with f)

Famille logique	t_r/t_f ns	ΔI mA	Longueur de piste en cm ; fréquence d'horloge 4 MHz	10 MHz	30 MHz	100 MHz
4000B CMOS à 5 V	40	6	180	75	-	-
74HC	6	20	8,5	3,2	1	-
74LS	6	50	3,25	1,3	0,45	-
74ALS	3,5	50	1,9	0,75	0,25	0,08
74AC	3	80	1	0,4	0,14	0,05
74F	3	80	1	0,4	0,14	0,05
74AS	1,4	120	0,4	0,15	0,05	-

Longueur de piste autorisée pour 30 dBµV/m 30 MHz - 230 MHz, 37 dBµV/m 230 MHz - 1000 MHz à 10 m ;
longueur du câble = 1 m ; agencement : pistes parallèles de 0,5 mm distantes de 0,5 mm (2,8 nH/cm).

Limit 55022 cl.B

Utilisation : prenons par exemple la famille 74HC avec F_{clk} = 10 MHz. Le cas le plus défavorable est à 90 MHz (9ème harmonique).

À partir de l'équation (4.7), pour une intensité de champ E de 30 dBµV/m et 1 m de câble, I_{CM} doit être égal à 2,8 µA.

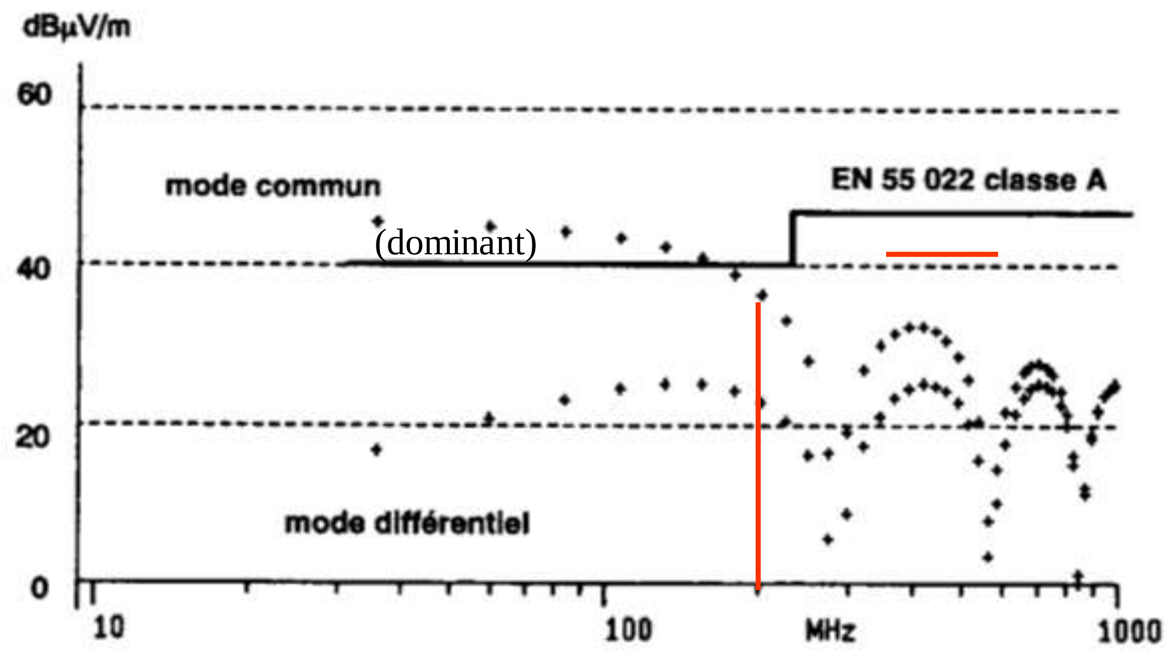
Selon $V_N = I_{CM} \times 150$, avec l'atténuation de couplage de 20 dB, V_N = 4,18 mV.

L'analyse de Fourier de la source de courant, en utilisant la section C.7 avec $(t + t_r)/T = 0,5$; T = 100 ns ; t_r = 6 ns et I = 20 mA, donne 0,826 mA pour $I_{(9)}$, le courant du neuvième harmonique.

Ensuite, suivant $L = V_N/2\pi f I(9)$, l'inductance aux bornes de laquelle on peut admettre V_N à $I_{(9)}$ et 90 MHz est de 8,95 nH, soit **3,19 cm** autorisés à 2,8 nH/cm.

Tableau 6.2 – Émissions en mode commun : longueur de piste admissible.

R.E. - Comparaison CM / DM



For the same signal in DM or CM

trapezoidal @12MHz, with t_r and t_f 3.5ns

CM Ipk 0.1mA in cable, with L 2m

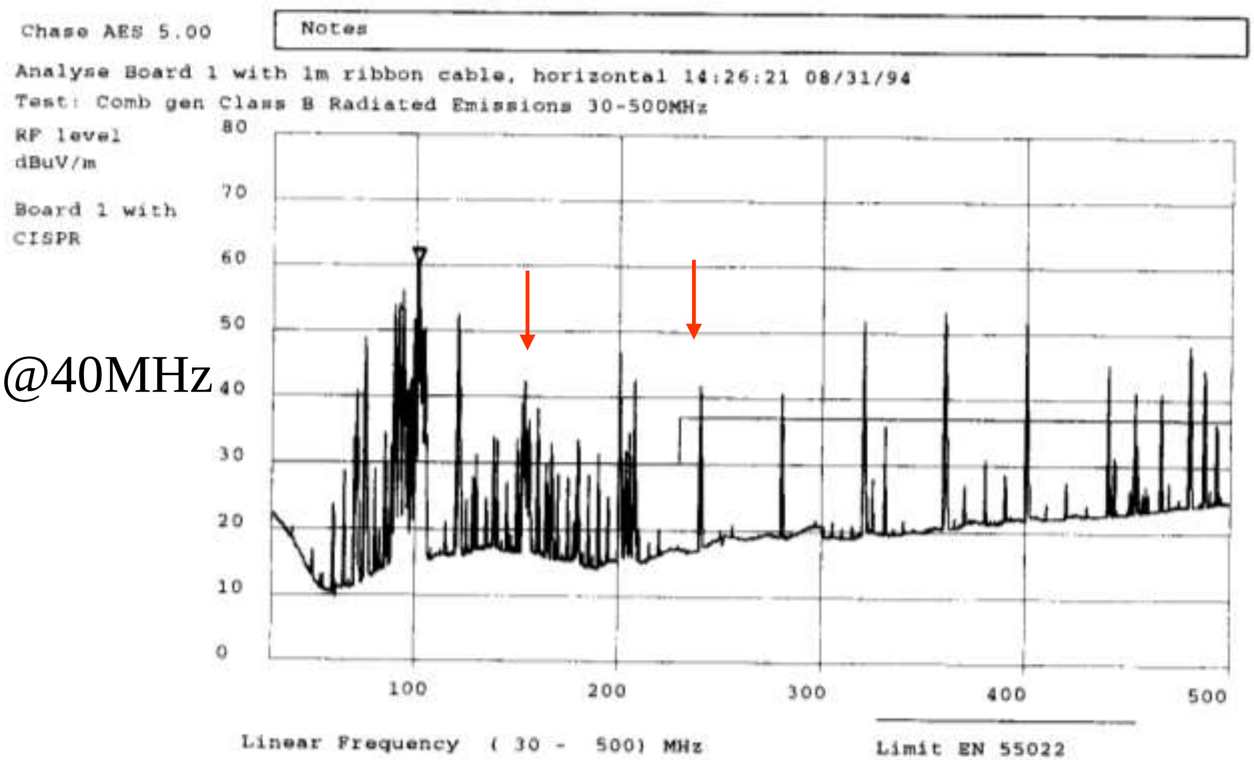
DM 20mA in a loop of 5cm²

E (V/m) = 263 x 10^{-12} x f(MHz)^2 x A(cm^2) x I_S (mA) loop-IC

E (V/m) = 1,26 x 10^{-4} x f(MHz) x L(m) x I_{MC} (mA) antenna-cable

R.E. > main source processor clock

Clock @40MHz



Commercial standards: no difference between N.B. and B.B.

- To reduce N.B. with buffer on lines and take care of ground plane.
- To reduce B.B. sources on data lines, video...