Protection of the experiment set-up at low temperatures against EMI (pickup)

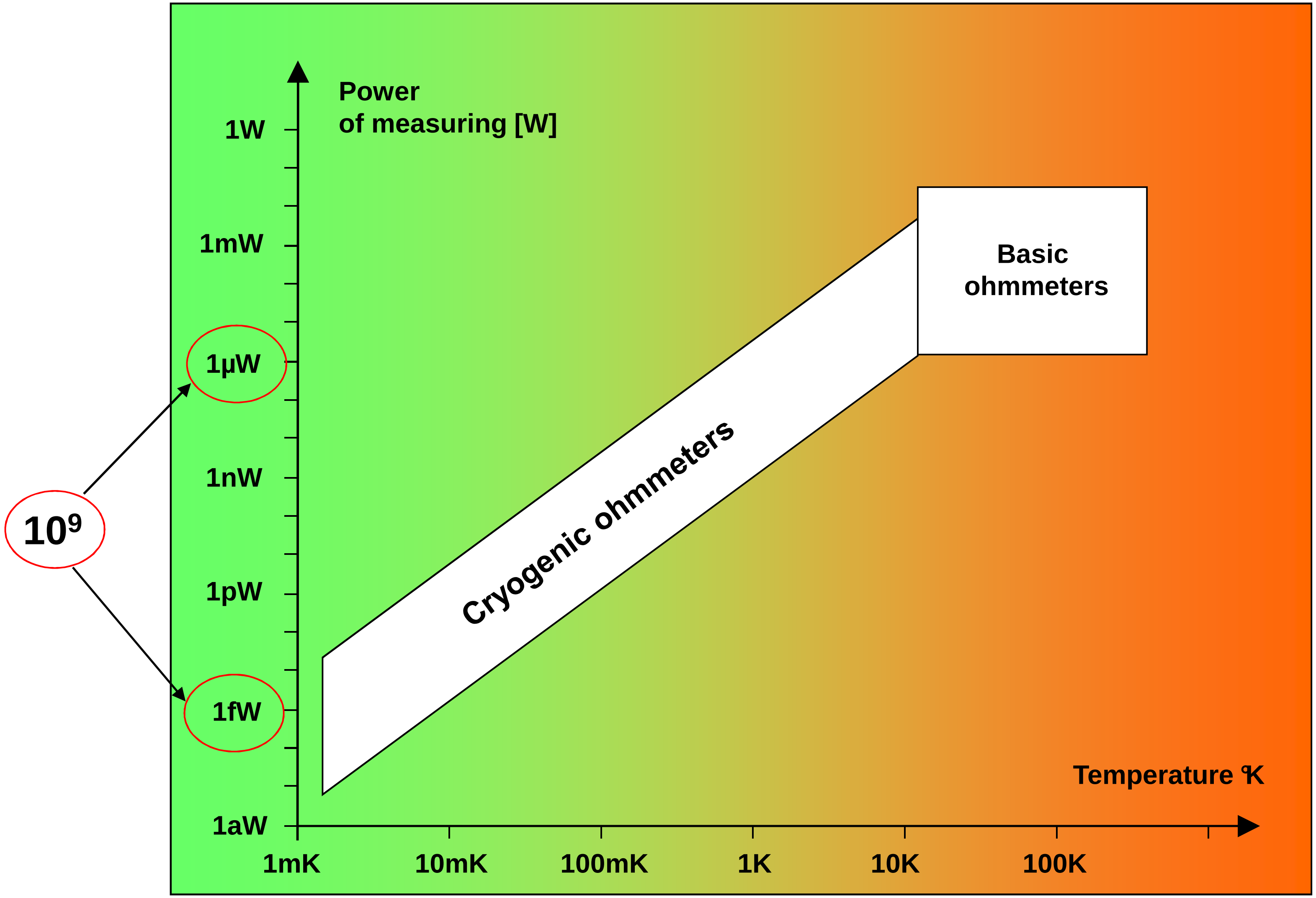
Characteristics of measurements at very low temperatures

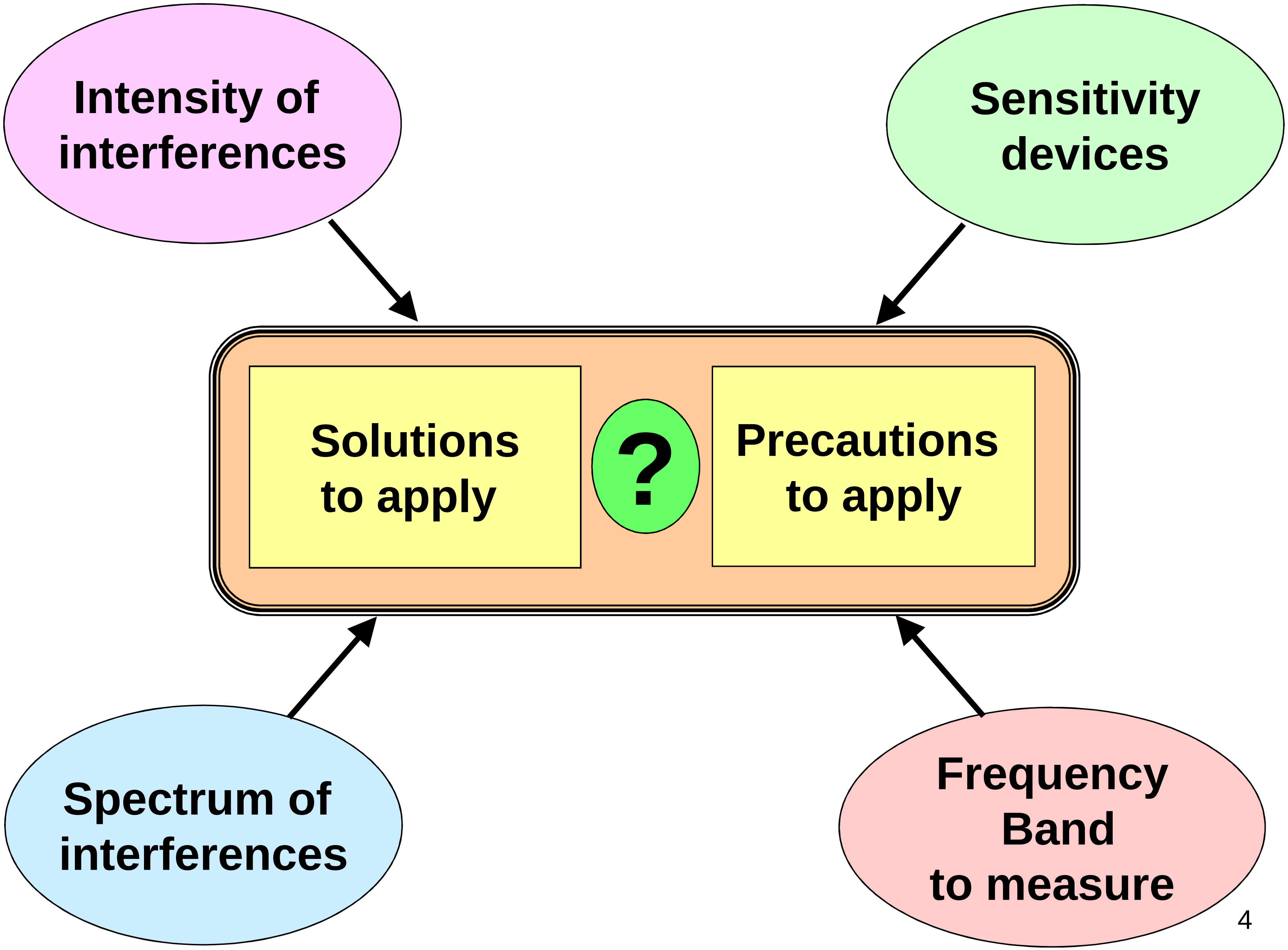
- Very reduced heat contribution
- Very low signal level (pA, fW…)
- Measuring at the same level of the amplifiers noise energies :

  - Amplifiers FET : 10^{-24} J
  - Amplifiers S.Q.U.I.D.* : 10^{-29} J

***Superconducting Quantum Interfernece Device**

Example: measuring resistor




Intensity of interferences
Sensitivity devices
Solutions to apply
?
Precautions to apply
Spectrum of interferences
Frequency Band to measure

Interferences Origin

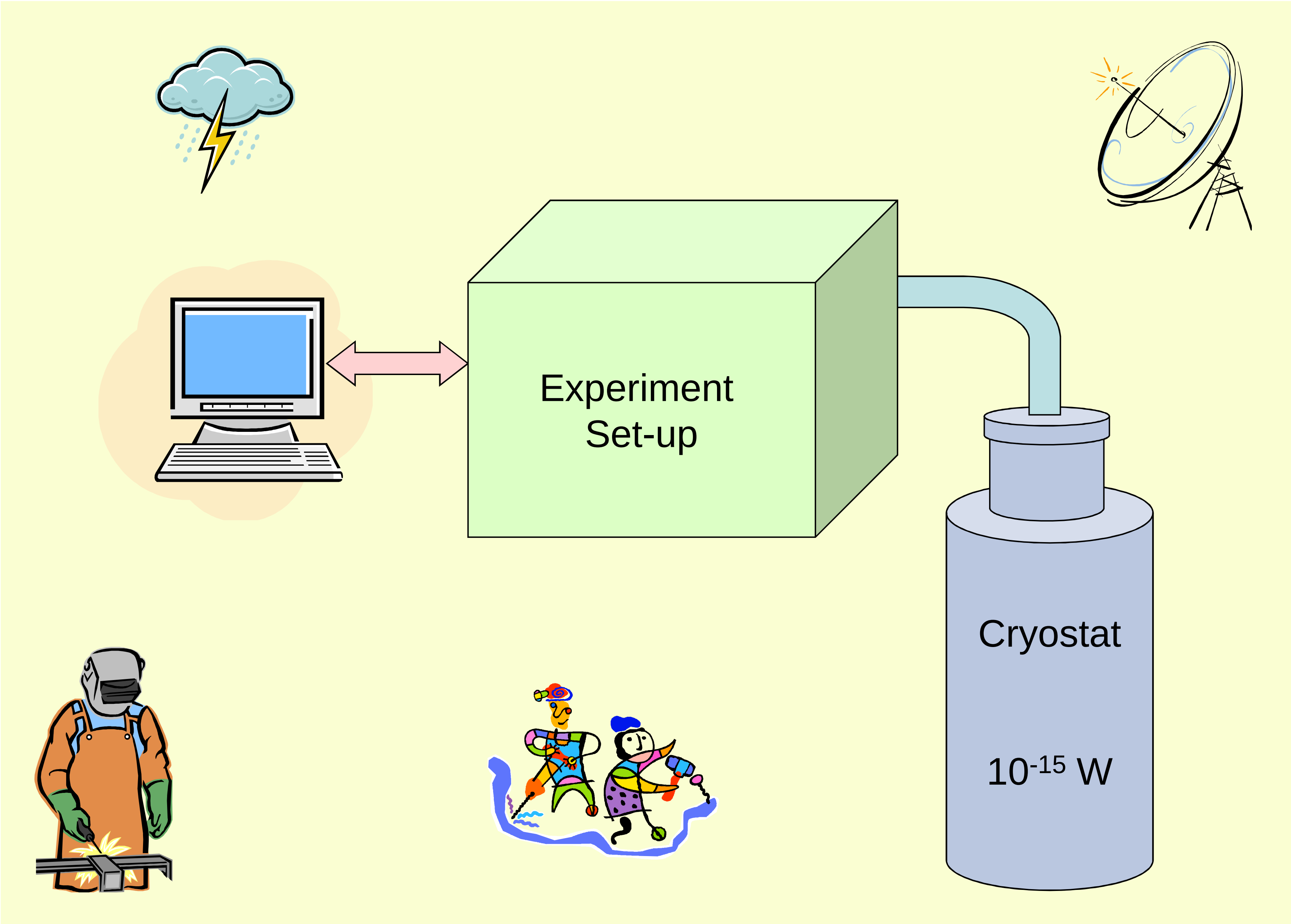
1 . Electromagnetic (Mainly)

Switching power supplies, mobile, wireless devices, GPS, fluorescent lamps, Wi-Fi …

(Rise in frequency of the interference source)

2 . vibrations

- Pumps, ventilators, vibrations of the ground earth
- Acoustics waves


Experiment
Set-up
Cryostat
10-15 W

Consequences

- **High protection against the electromagnetic pickup**

Protection on <u>all the frequency band</u>,

from *Hz* to *GHz*

- **Protection against vibrations**

1 . Electromagnetic Interference (Pickup)

1.1 Transmission modes

1.2 Protection against interferences

1.1 Transmission modes

1.1.1 By **conduction**

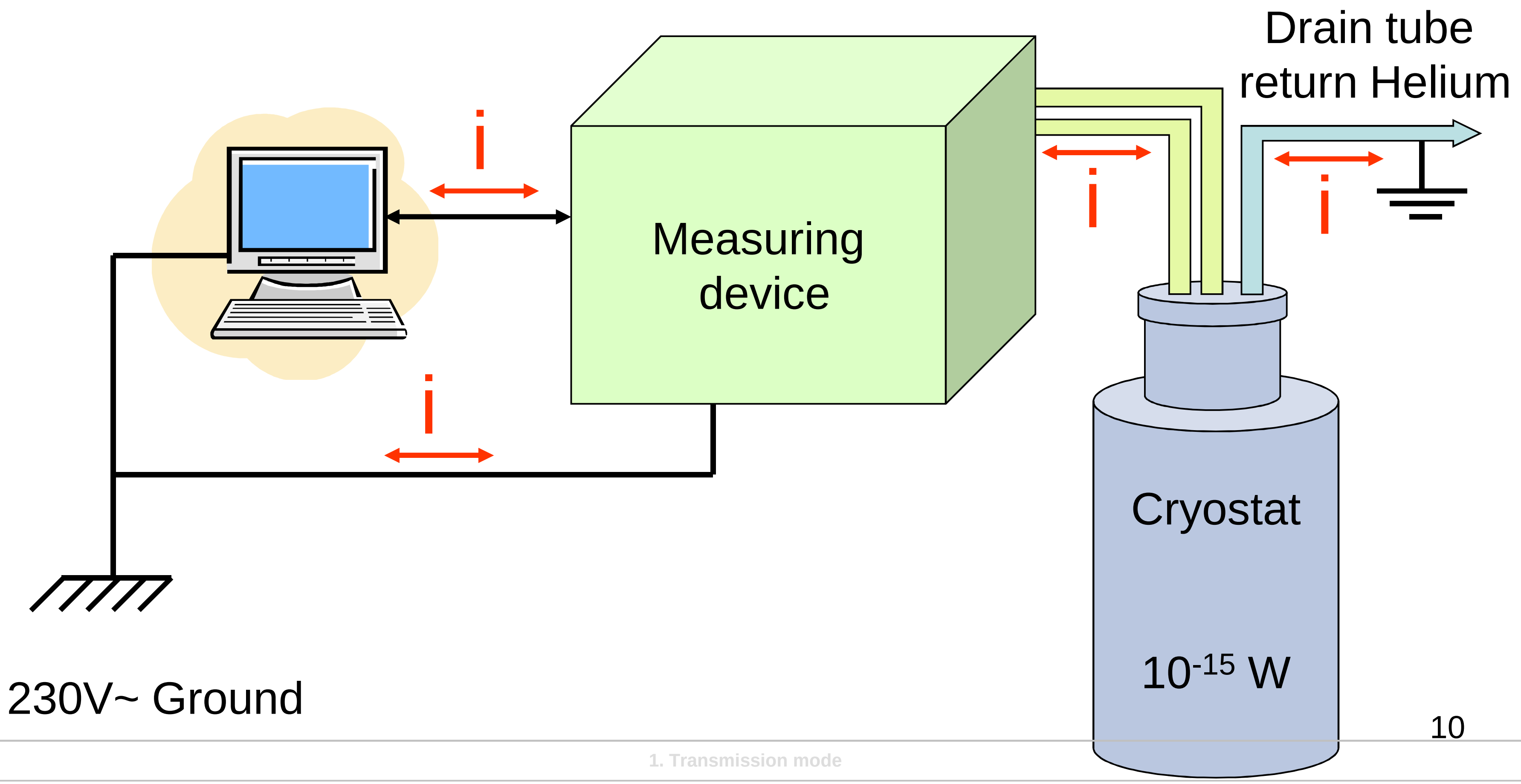
- 230V~ cable
- Cable connected to computers
- Connections with various grounds (230V~ , water cooling circuit…)
- « Loops of grounds »

1.1.2 By **radiation**

- R.F. radiation
- Electric or magnetic fields: leakage field of electrical transformer or switching power supply, motors, PC Screen etc. …

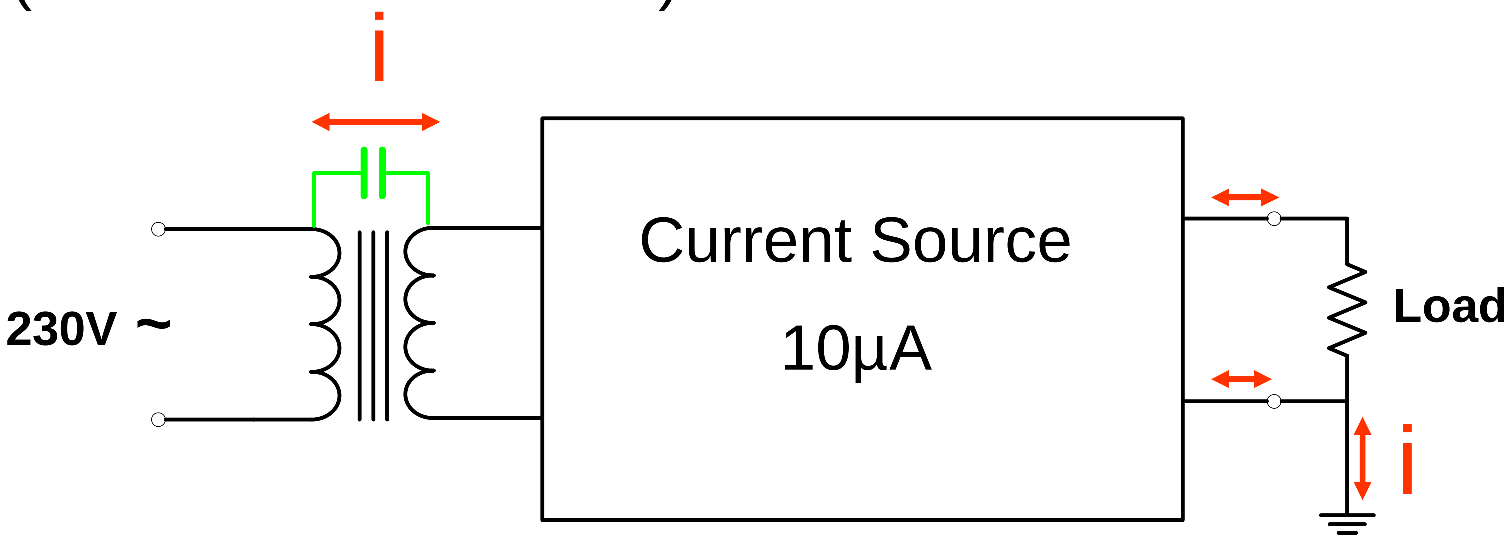
1.1.1 Transmission by conduction

Often by various grounds, 230V~,
main power supply or digital links…



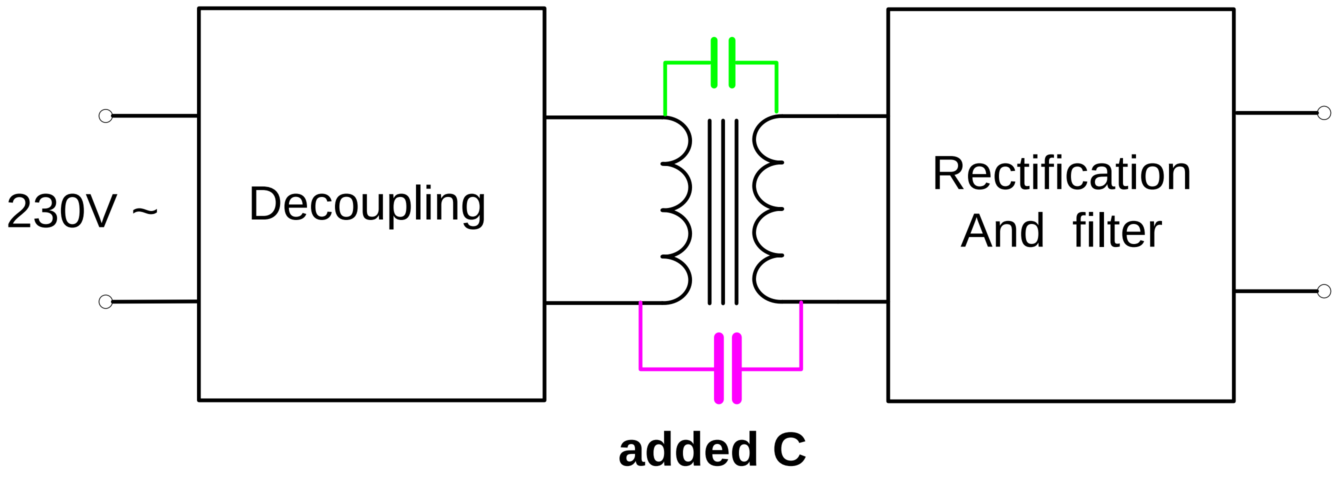
Example 1 :

- Transmission by main transformer
  - Capacitor about 100pF → Leakage current ~ 3µA (30% of current source)



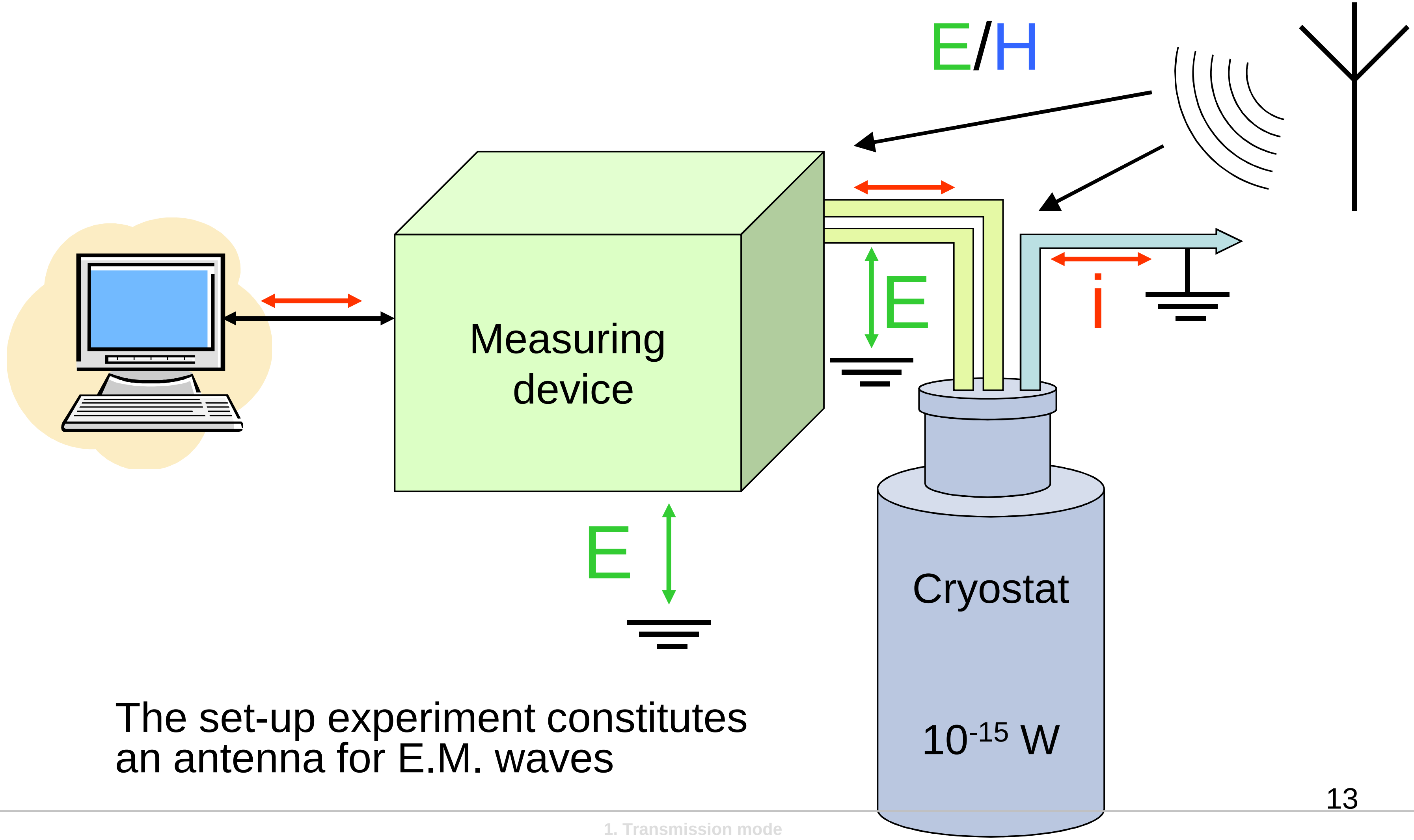
Example 2 :

- Switching power supply
  - Added capacitor ~ 1 to 100nF → leakage current : 30µA à 3mA !



  - Medical power supply : I must be < 100/300µA

1.1.2 Transmission by radiation



The set-up experiment constitutes an antenna for E.M. waves

Types of coupling

- At low frequency :

  Wavelength >> dimensions of the set-up,

  Can be considered separately:

  – Coupling with the magnetic field(inductive)

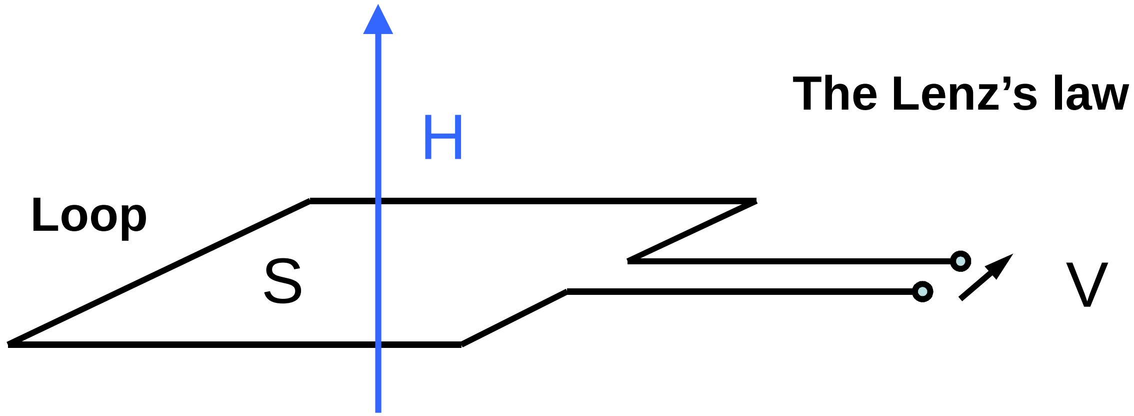
  – Coupling with the electric field (capacitive)

- At high frequency :

  – Coupling with both components of fields

Coupling with the magnetic field

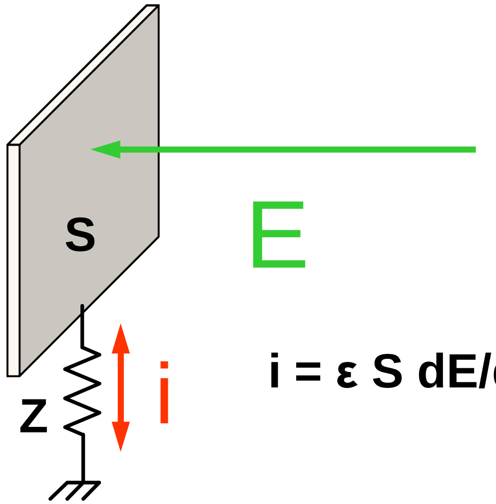
and inductive coupling



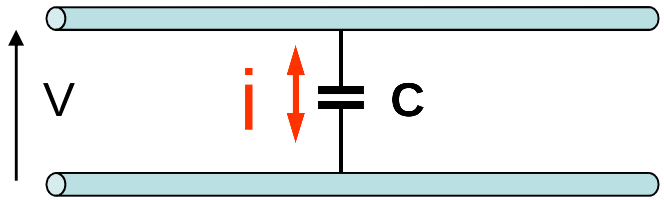
The Lenz's law **V = µ S dH/dt**

– Sources of interference fields
  - LF : Electric transformer, Motors, networks cables
  - 10 à 500KHz : Switching power supply
  - > 500KHz : RF transmitter, electric arcs…
– Order of magnitude :
  - From 1Hz to 1MHz : 10nV/cm^2 to 1µV/cm^2
  - Leakage field of electric transformer at 5cm : 1 to 100µV/cm^2

Coupling with the electric field
and capacitive coupling



$i = \varepsilon\, S\, dE/dt$



$i = C\, dV/dt$

- Sources of interfering fields
  - 10 to 500 KHz : 230V~ cable, switching power supply
  - > 500KHz : Radiation of the transmitters
- Order of magnitude on a single conductor
  - from 1Hz to 1 MHz : 10nA to 1µA/cm

1.2 Protection against the E.M. interference

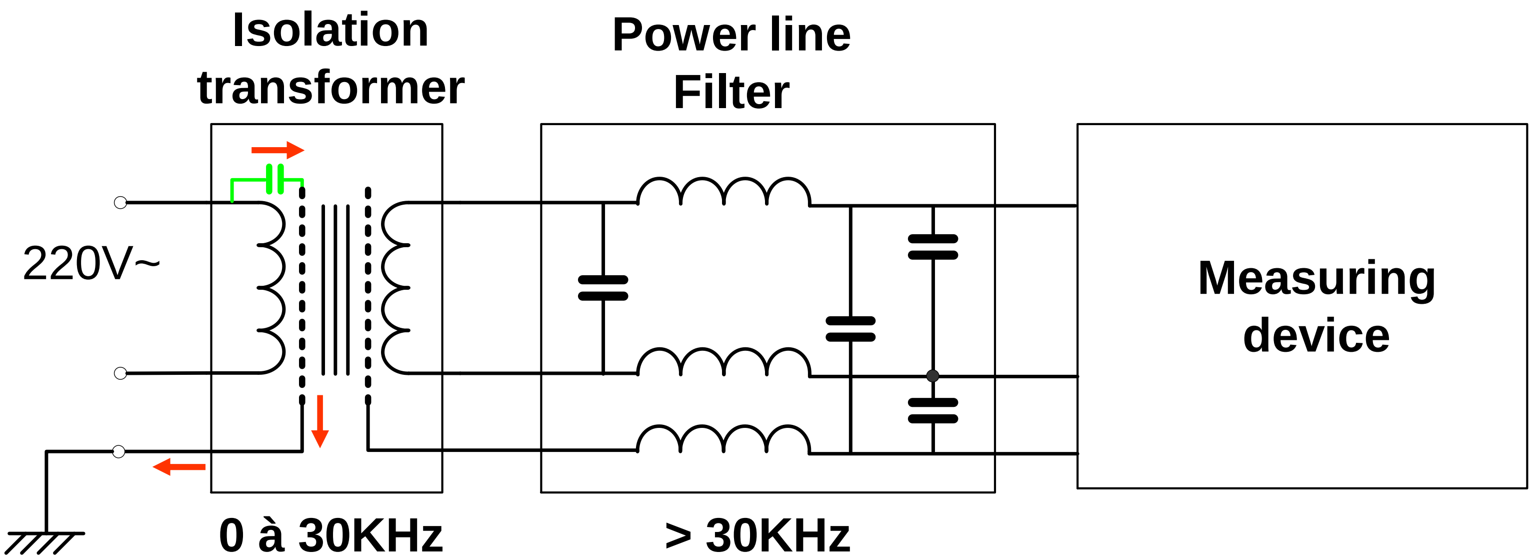
1.2.1 Interference **by conduction**

1.2.2 Interference **by Radiated**

or induced by electric and magnetic fields

1.2.1 Interference by conduction

- Interposition of a Barrier
  - Main supply : **Shielded transformer**, **filter**



  - Digital Transmission : Optocoupler, impulse transformer, **optical fibres**, WiFi…

1.2.2 Radiated interference

or induced by electric and magnetic field

- Faraday cage
  - Efficient if skin deepth (skin effect) is higher than:

$$E = \sqrt{\frac{\rho}{f\mu_r\mu_0}}$$ ♥

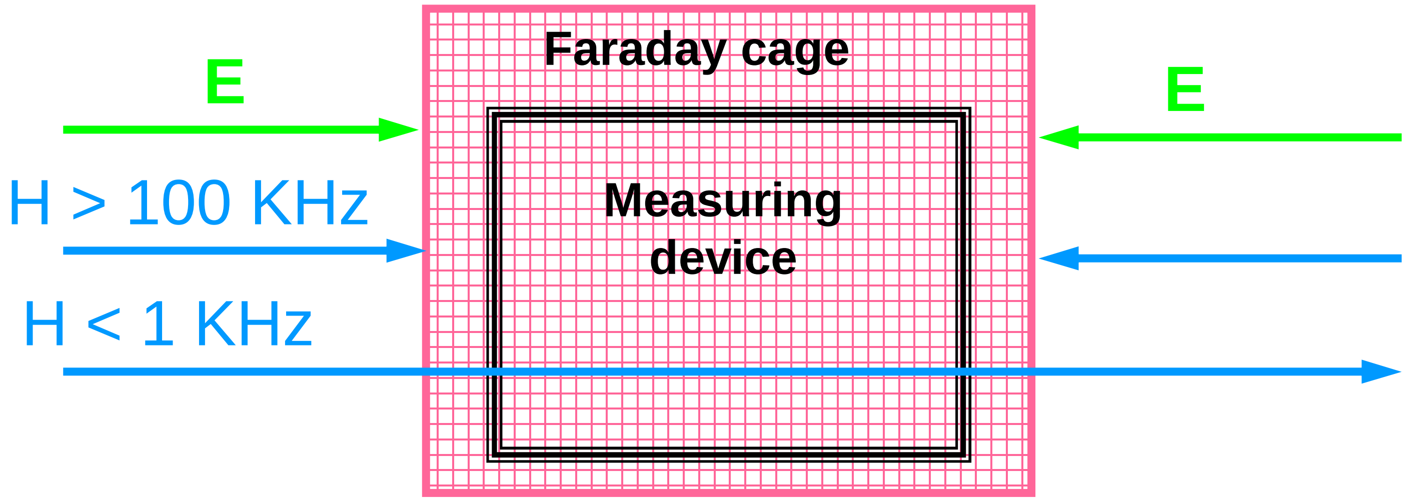
μo : perméabilité magnétique du vide (4p.10-7)

μr : perméabilité magnétique relative du conducteur (on prendra 1 pour le cuivre)
f : fréquence en Hz
ρ : résistivité du conducteur en W.m (18.10-9 W.m pour le cuivre)

  - Examples :
    - Copper, at 1 MHz : E = 66 µm
    - Copper, at 50 Hz : E = 9 mm
  - Good attenuation for frequencies higher > 100KHz

Inconvenience of the Faraday cage

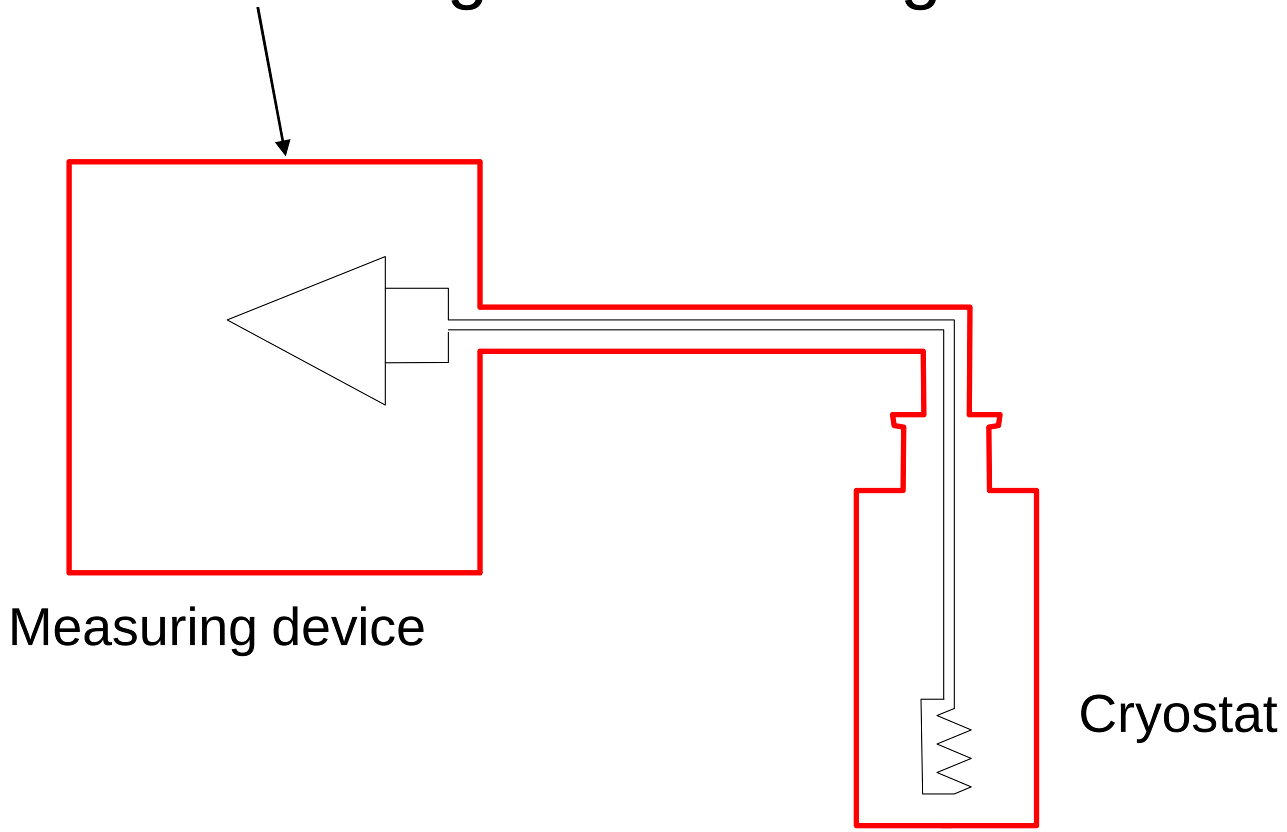
- Inefficient for continous magnetic field and low frequencies



- The device produces interfence must be placed outside
- Not easy to made
- Expensive

Solution…

- « Faraday cage » but reduced to a whole of screens and shieldings surrounding the sensitive circuits



Weaknesses of this Faraday screen room

- 1 - Transparency to the low frequency magnetic fields
- 2 - Many connecting cable
- 3 - Connectors
- 4 - Boxes and cases

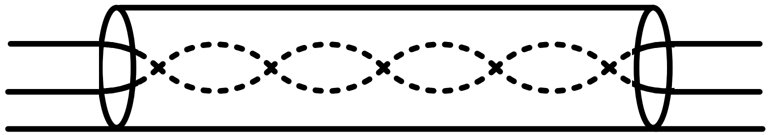
• 1- Transparency to the low frequency magnetic fields

How to protect itself ?

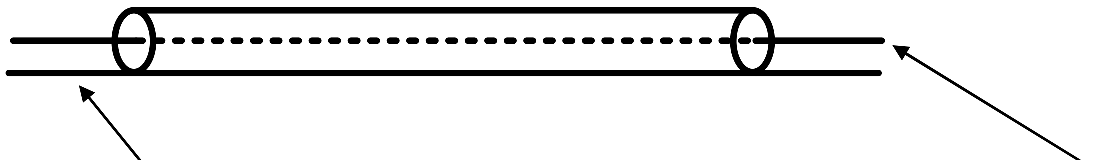
- 1.1 - Loop surfaces reduction
- 1.2 - Magnetic shieldings

• 1.1 - Loop surfaces reduction

- Connection by twisted pair



- Connection by coax

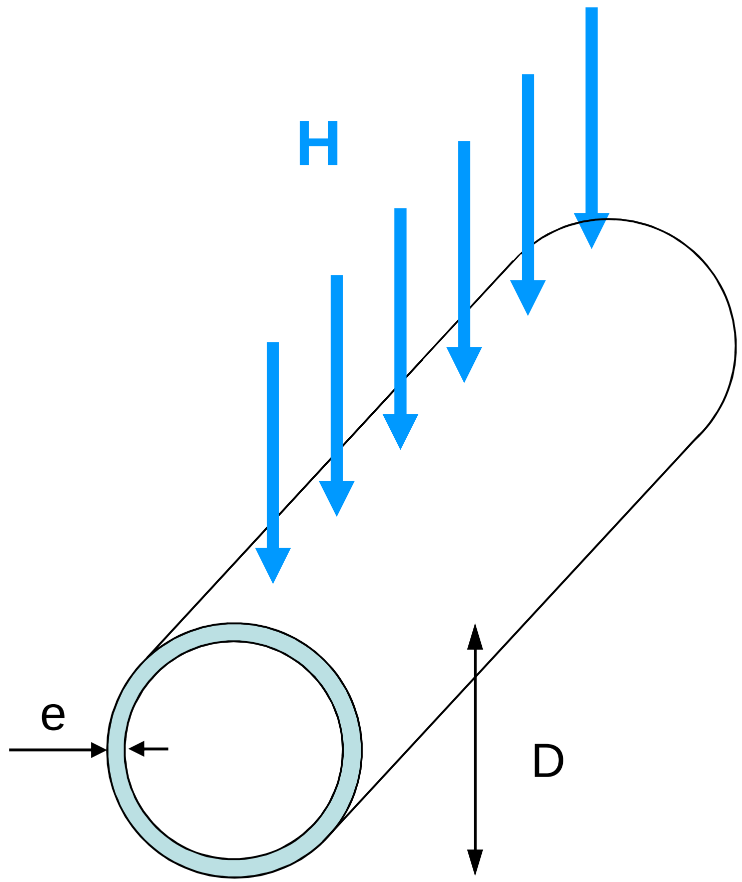


- P.C.B. : A reference wire walks olong with the signal wire (the ground is not a perfect equipotential at low frequency)

• 1.2 - Magnetic shieldings

- Case or basic tube steel
  - Small attenuation : factor 2 to 5 (at 50 Hz)
- Case : Mumetal, Co-Netic, MµShield…
  - Attenuation 300 to 1000
- Rolling up of amorphous metal ribbon
  - Attenuation 300 to 1000
  - No annealing
- Ferromagnetic & copper alternate layers

Calculation of a cylindrical shielding

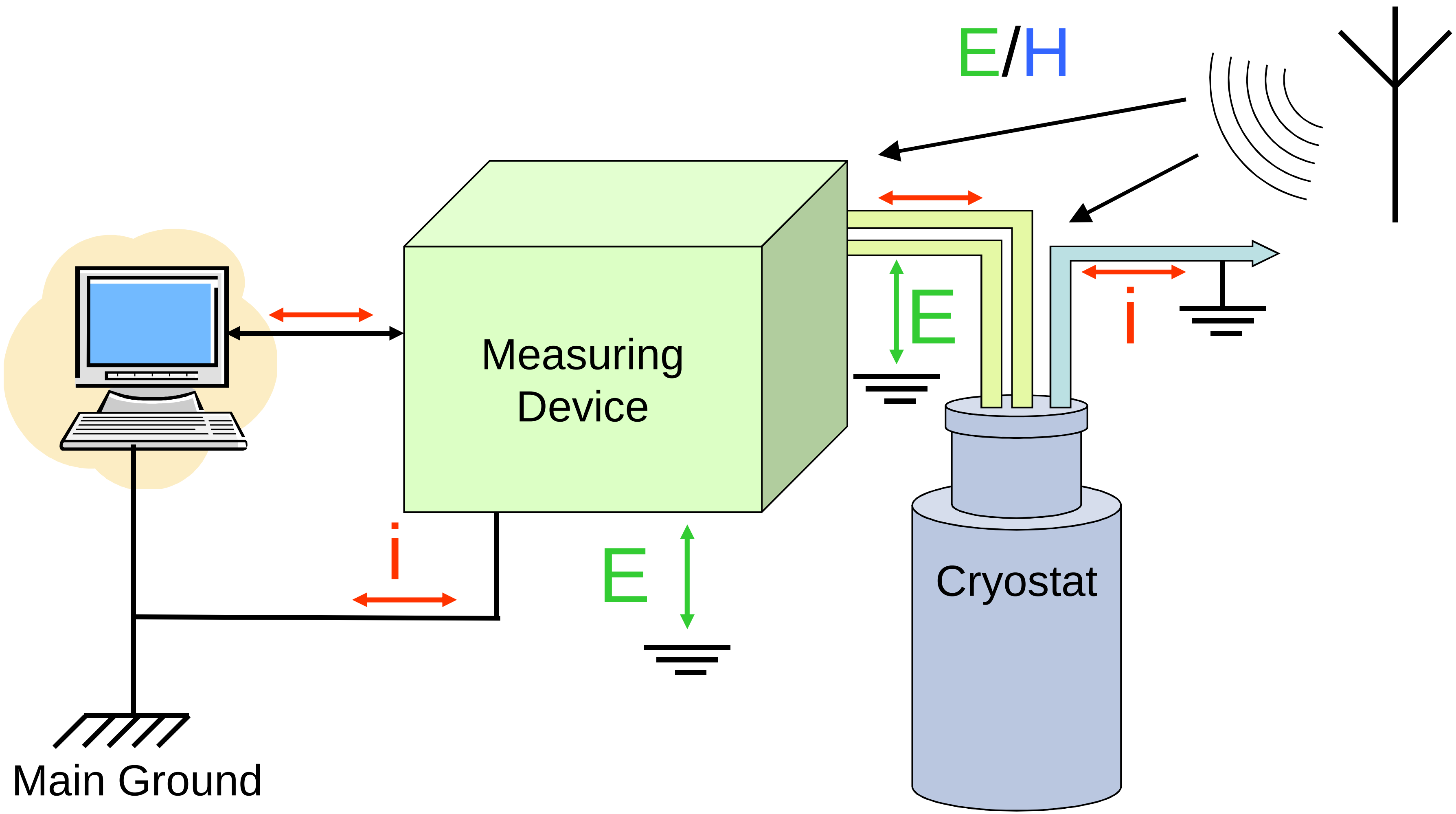


Attenuation : A = μ*e / D

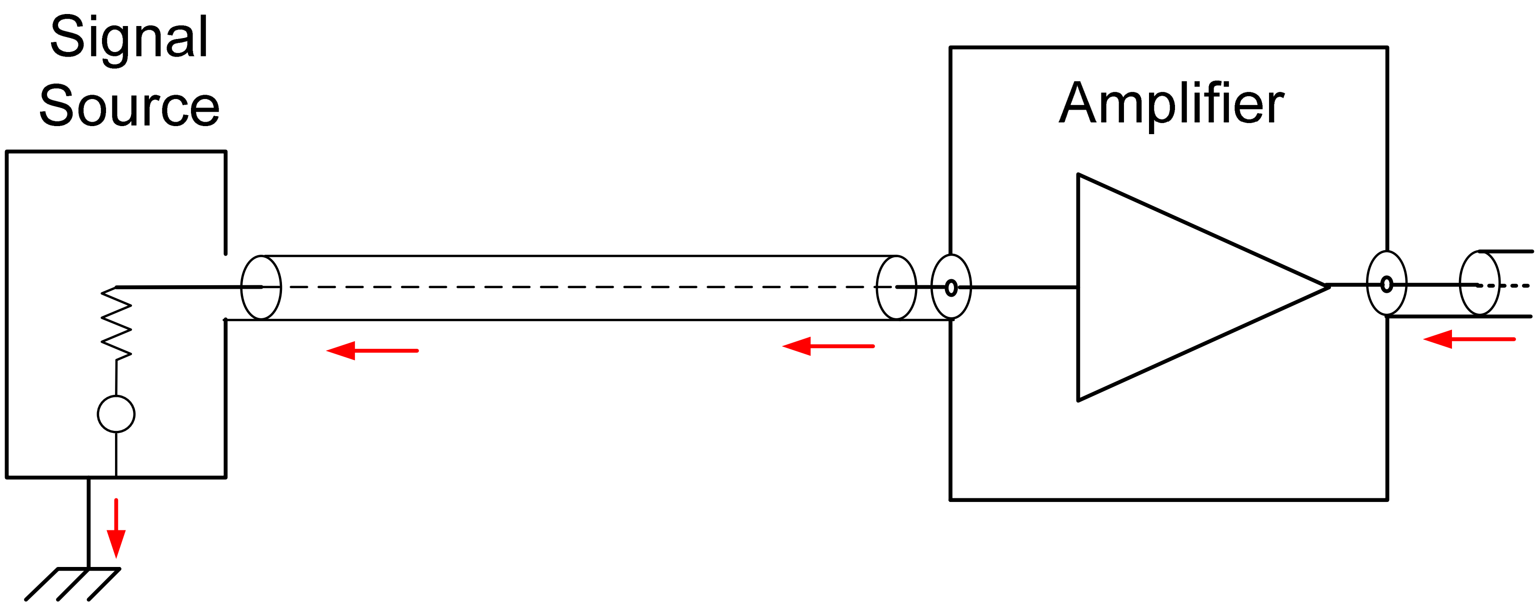
Thickness : e > 1,25*D*H / B

μ : Permeability of material
D : Diameter of the tube
e : Thickness of the tube
H : External magnetic field
B : Induction in material

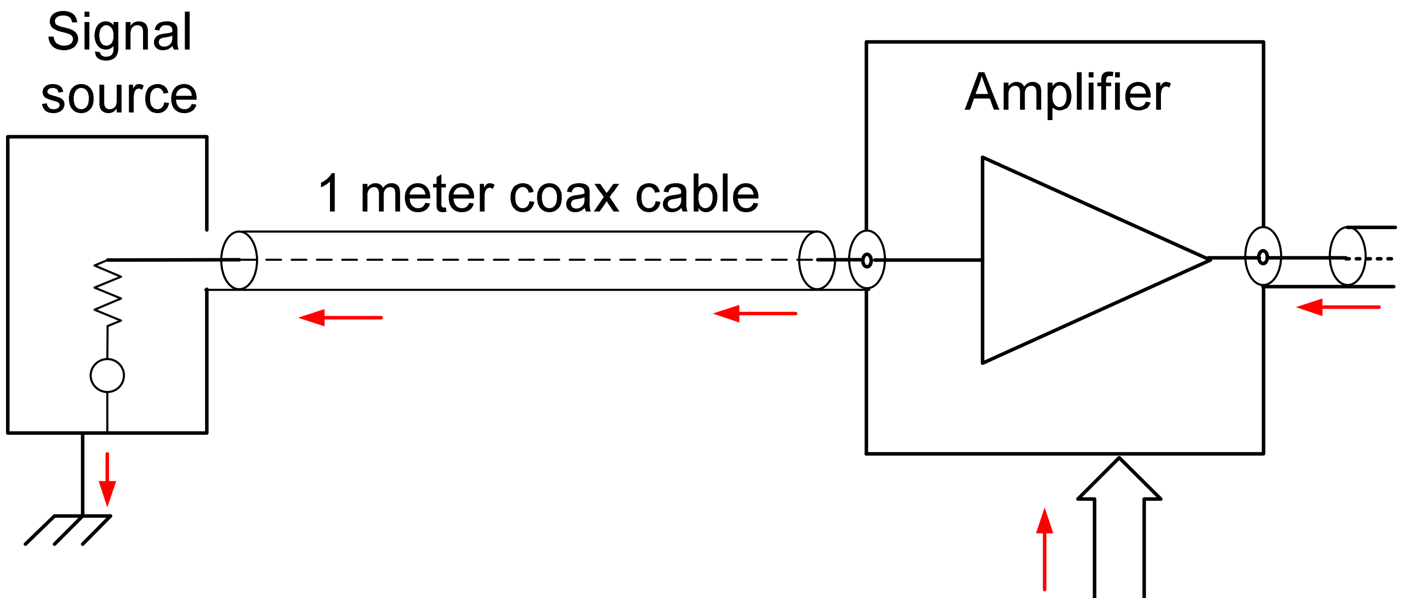
• 2 - Connecting cables

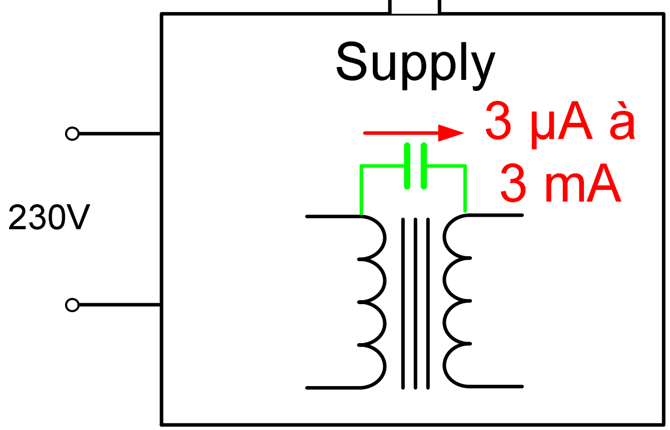


• 2.1 - Interference by the currents in the shieldings



Example :





Shielding resistance of the coax :

17 mΩ

Induced voltage :

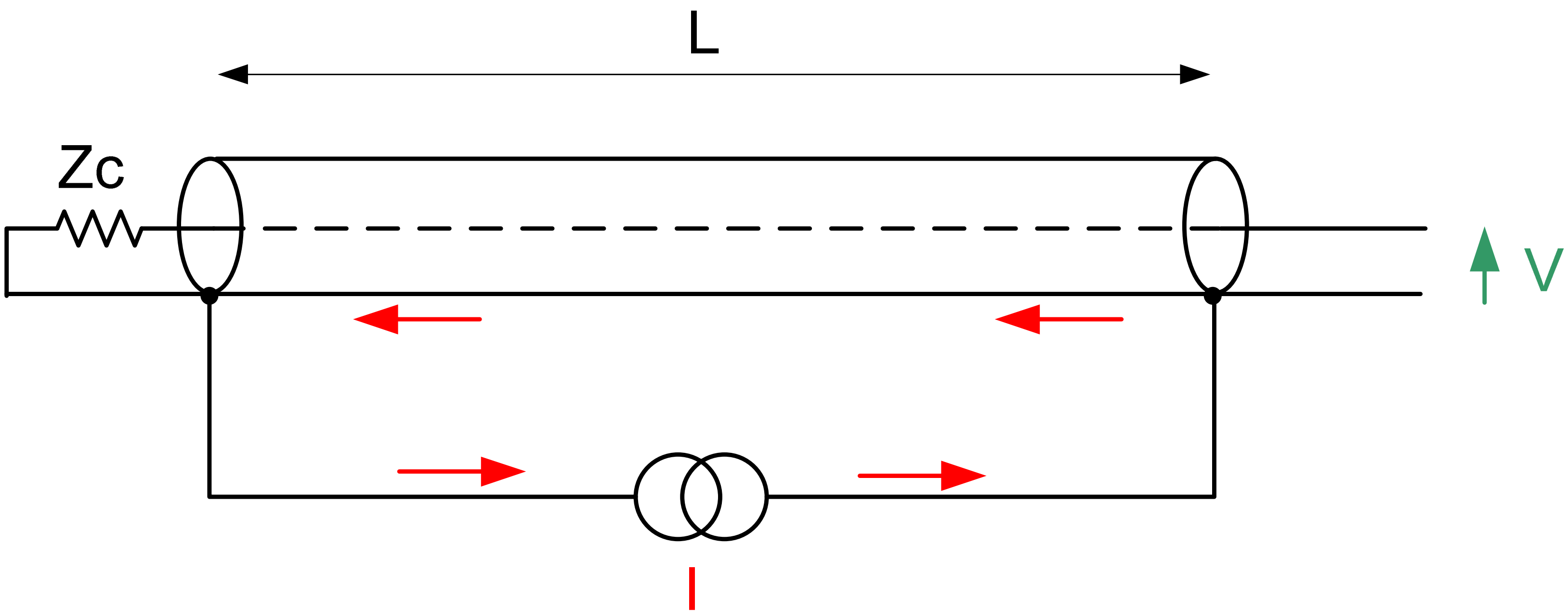
Linear power supply : **50 nV**

Switching power supply : **50μV**

Remedies

- Short cable, cable with low impedance transfer
- Connection by twisted pair
- Reduce the current in the shieldings
- Differential amplifier
- Isolation amplifier

Impedance transfer of the cables

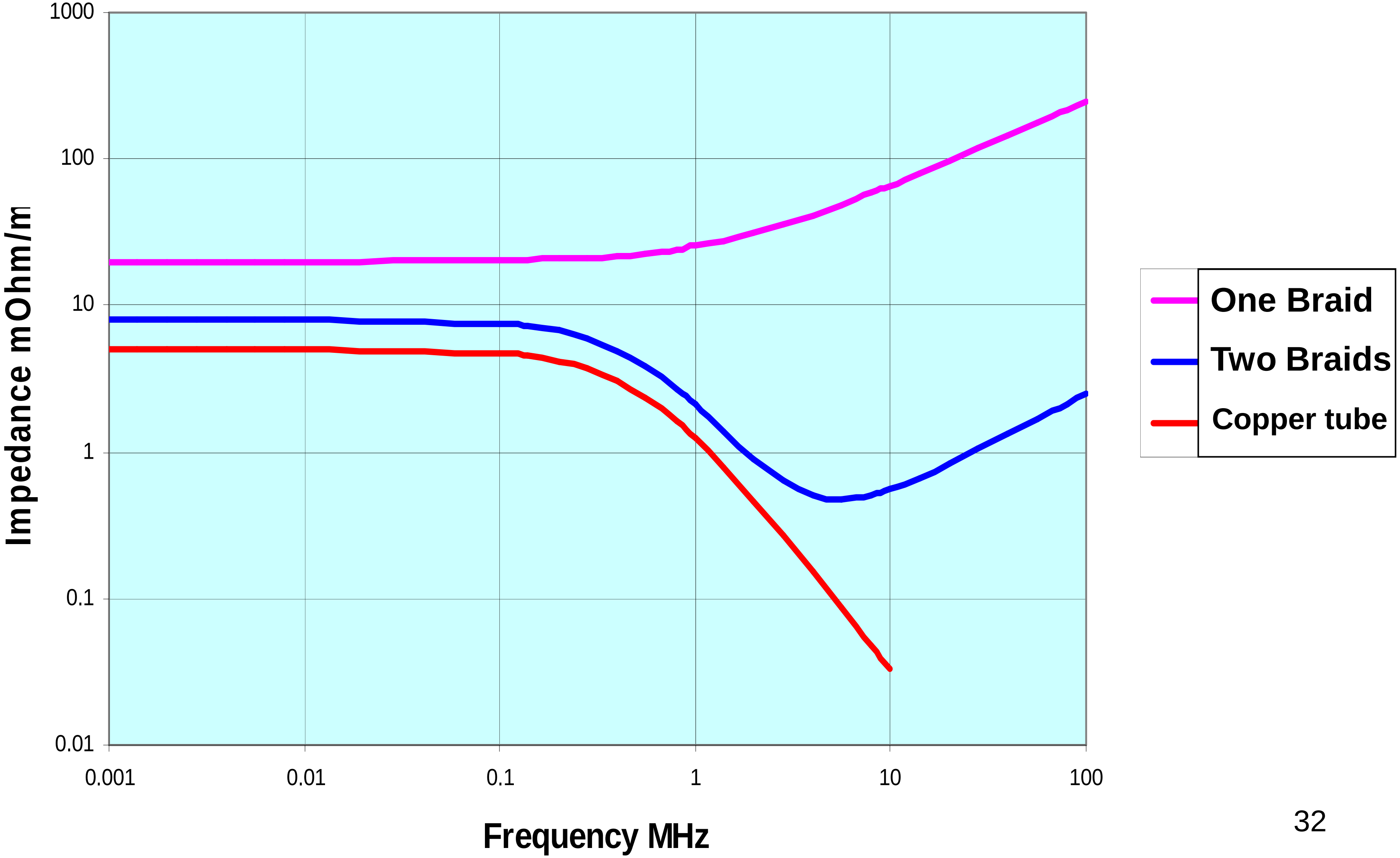


$$Z_t = \frac{2V}{L * I}$$

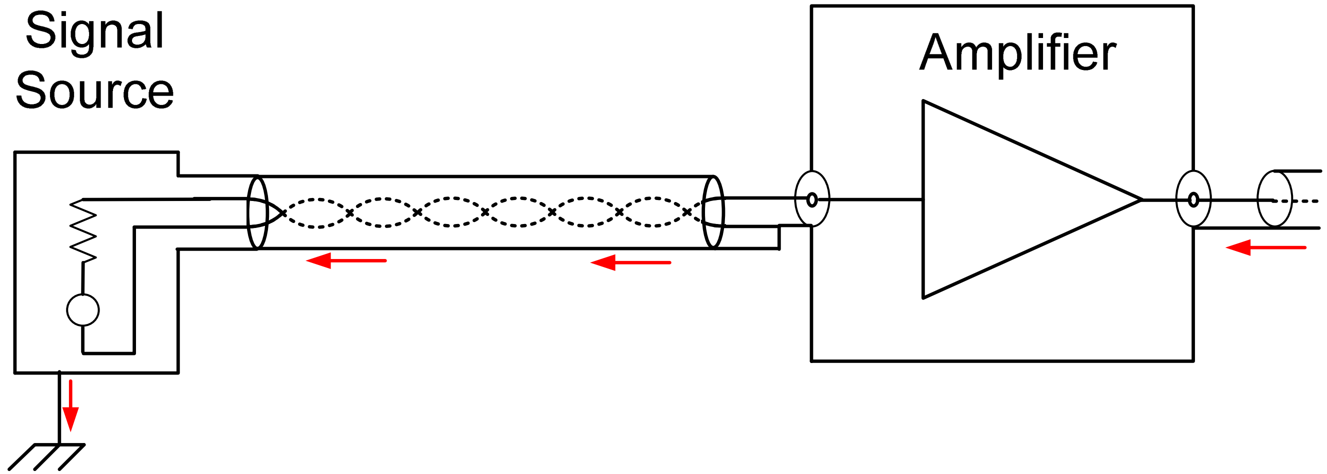
Must be as low as possible

Impedance transfert of coax câble

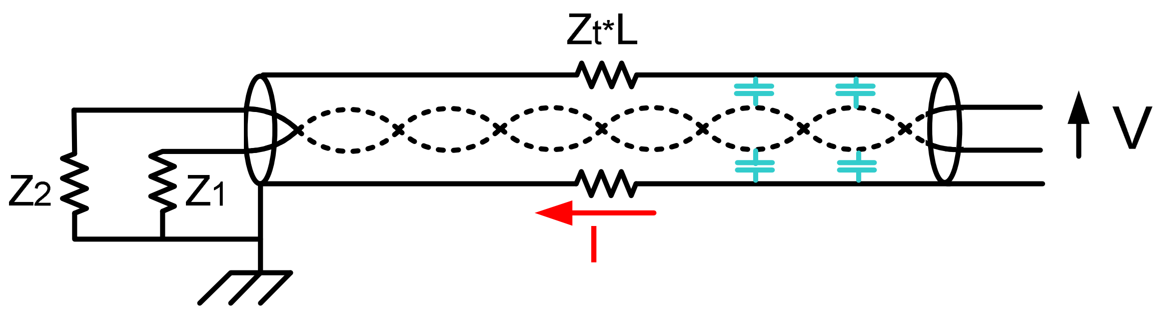
for some types of shielding



Connection by twisted pair

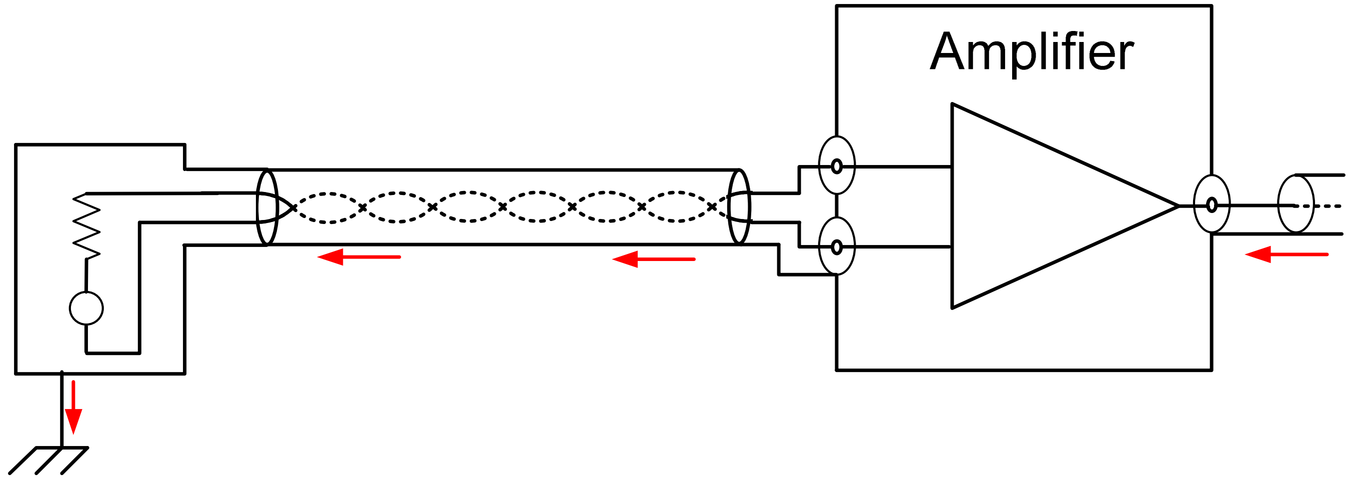


Residual effect



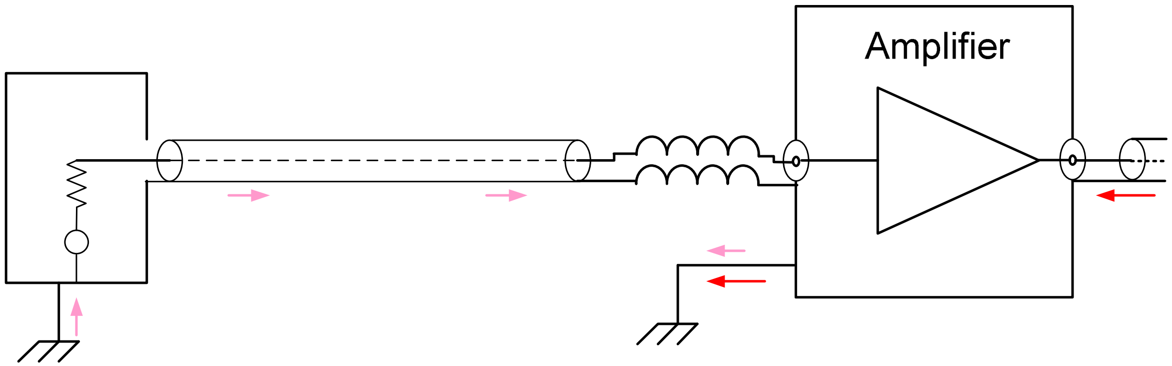
$V \neq 0$ si $Z_1 \neq Z_2$

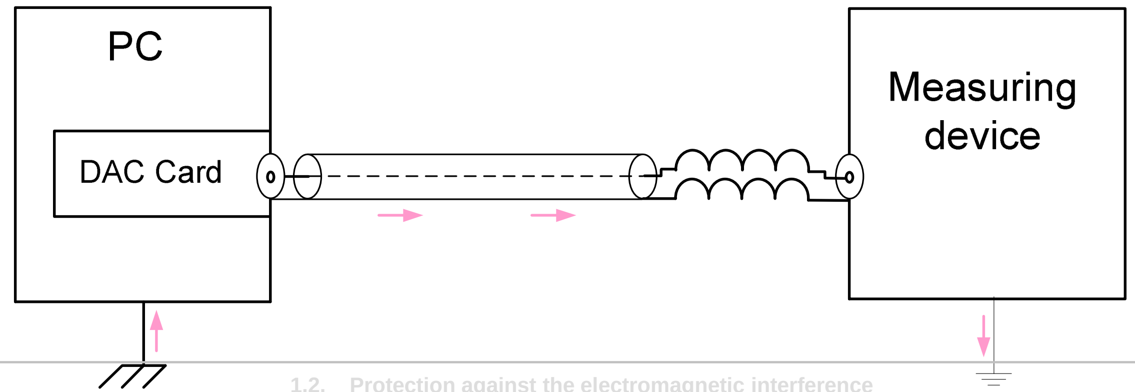
Good compensation with a differential amplifier



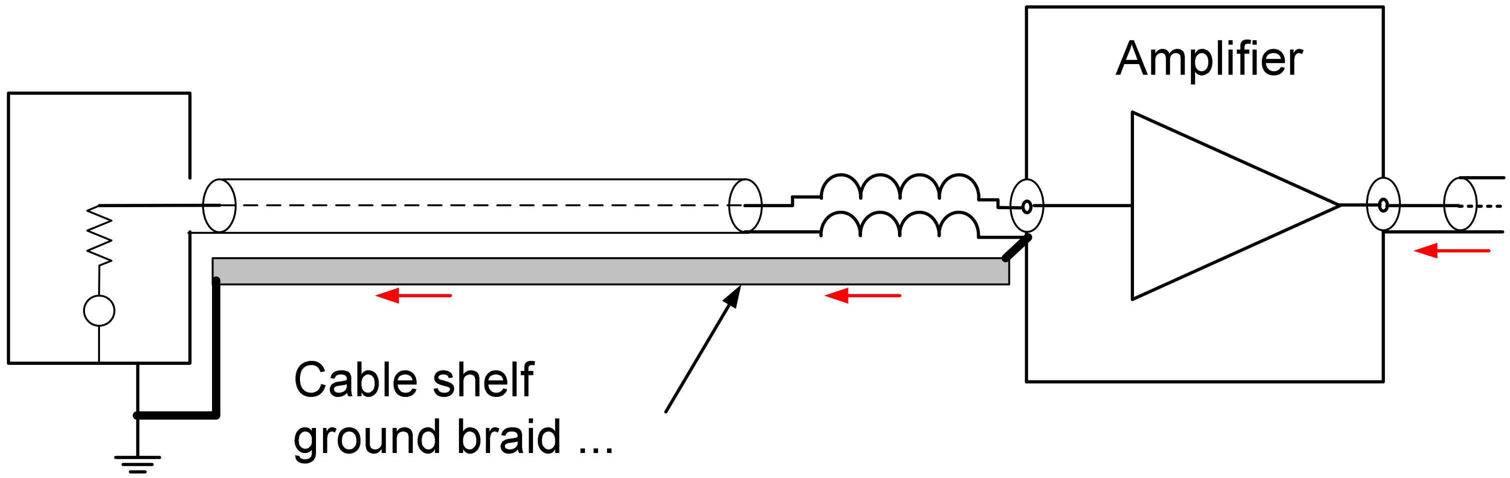
Reduction of the current in the shieldings

- Inductance of common mode





Double grounding circuit

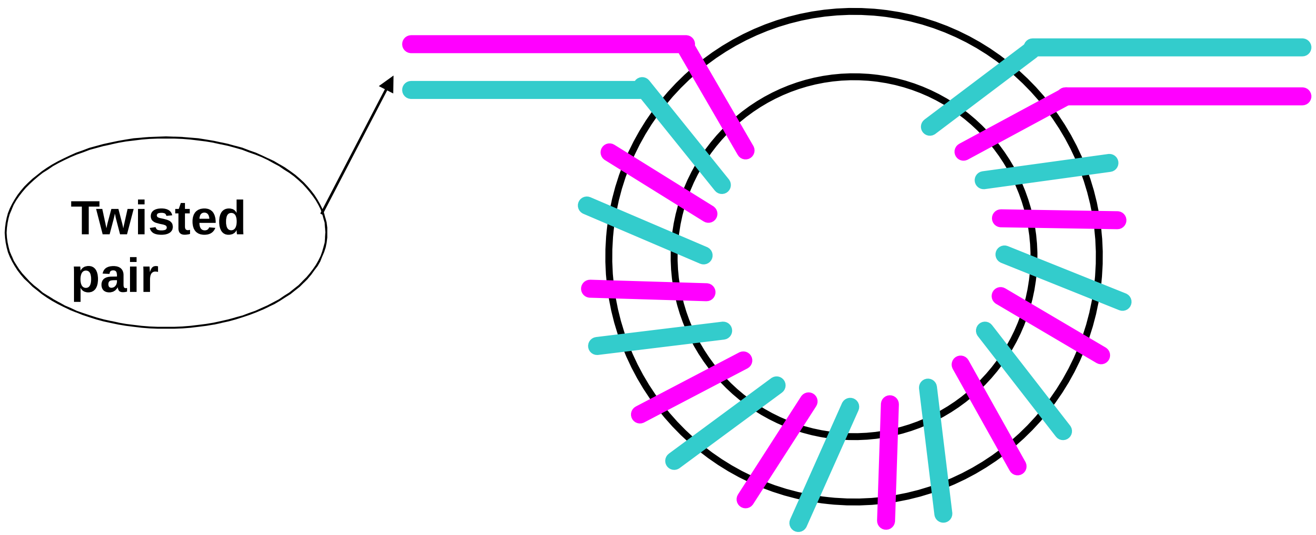


Some types of inductances of common mode :

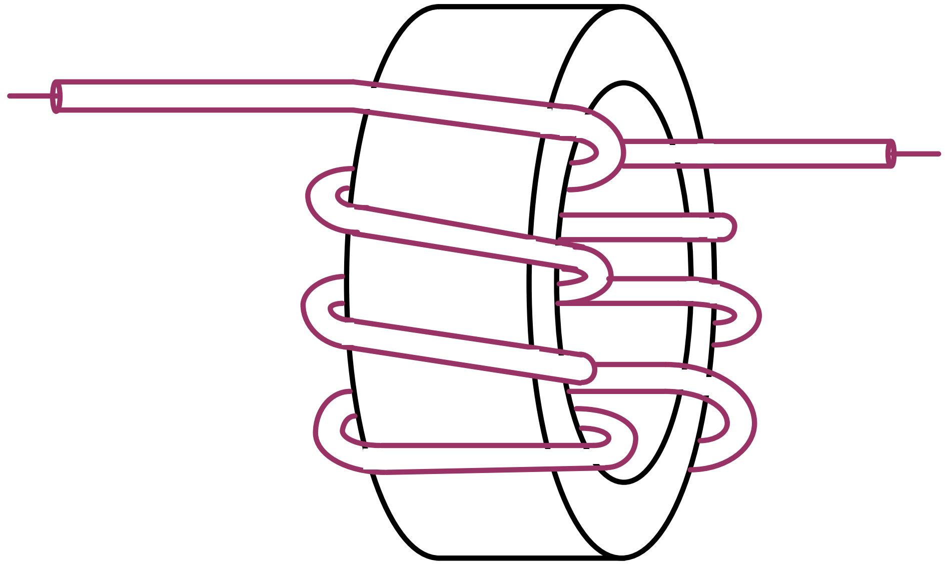
From 100KHz to 10MHz

Inductance on tore ferrite of 0,1 to 100mH

wound « two wire in hand »



Broad band signal: Coax wound on tore

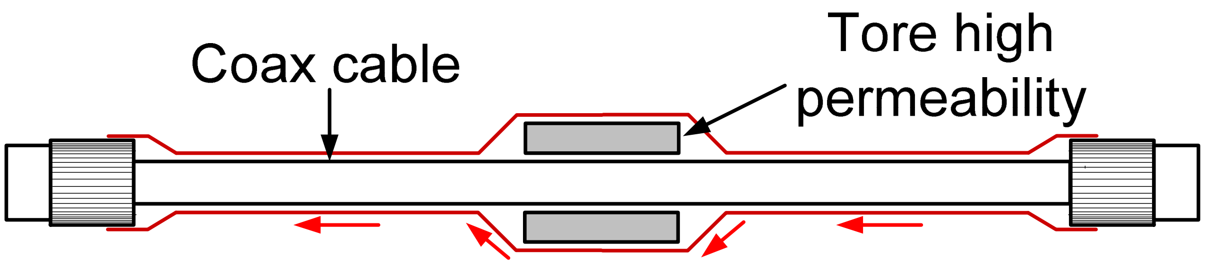


Nature of tore depending on frequency band

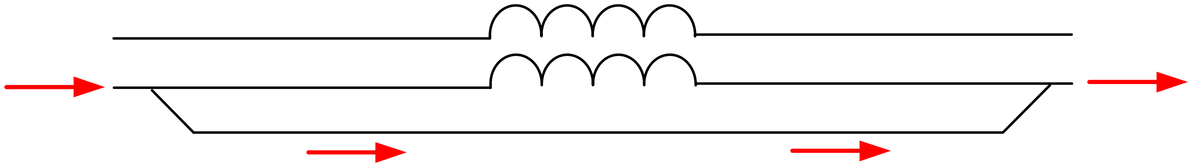
- 10KHz to 1MHz : Alloy high permeability
- 100KHz to 100 MHz : Ferrite

Beyond 30MHz : one or few tubes of ferrite

Double ground circuit

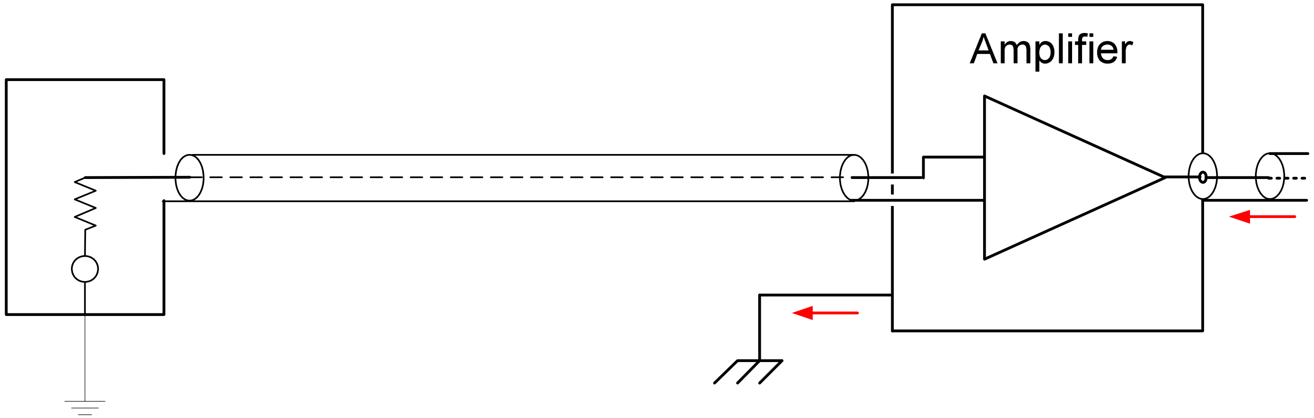


Equivalent diagram

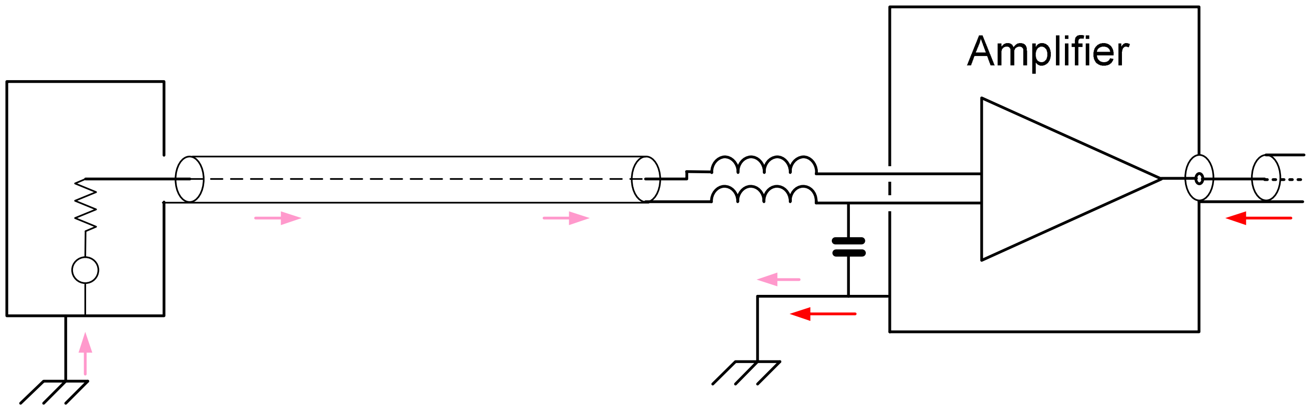


Differential amplifier

Flotting input mode

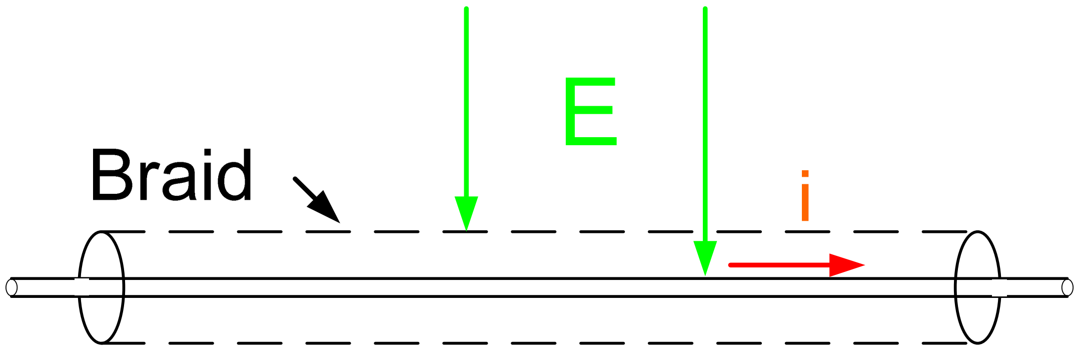


With inductance of common mode to compensate the differential amplifier rejection fall



• 2.2 - Electric field interference

- Covering rate of the braid : 70 à 95%
- Residual coupling ~ 0,1pF/m

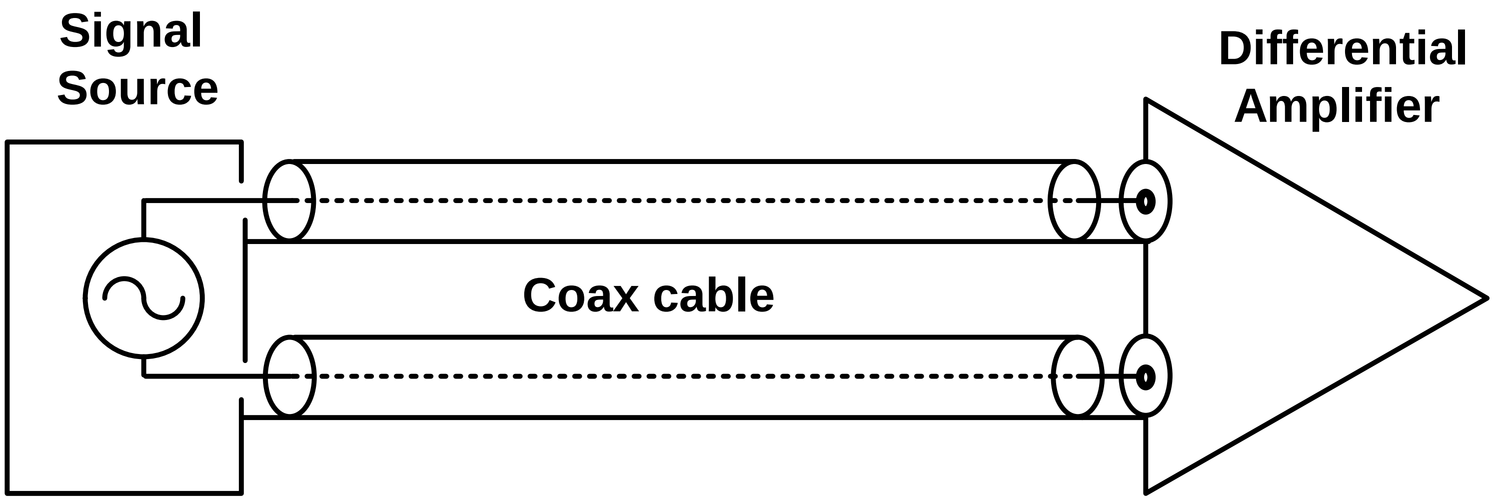


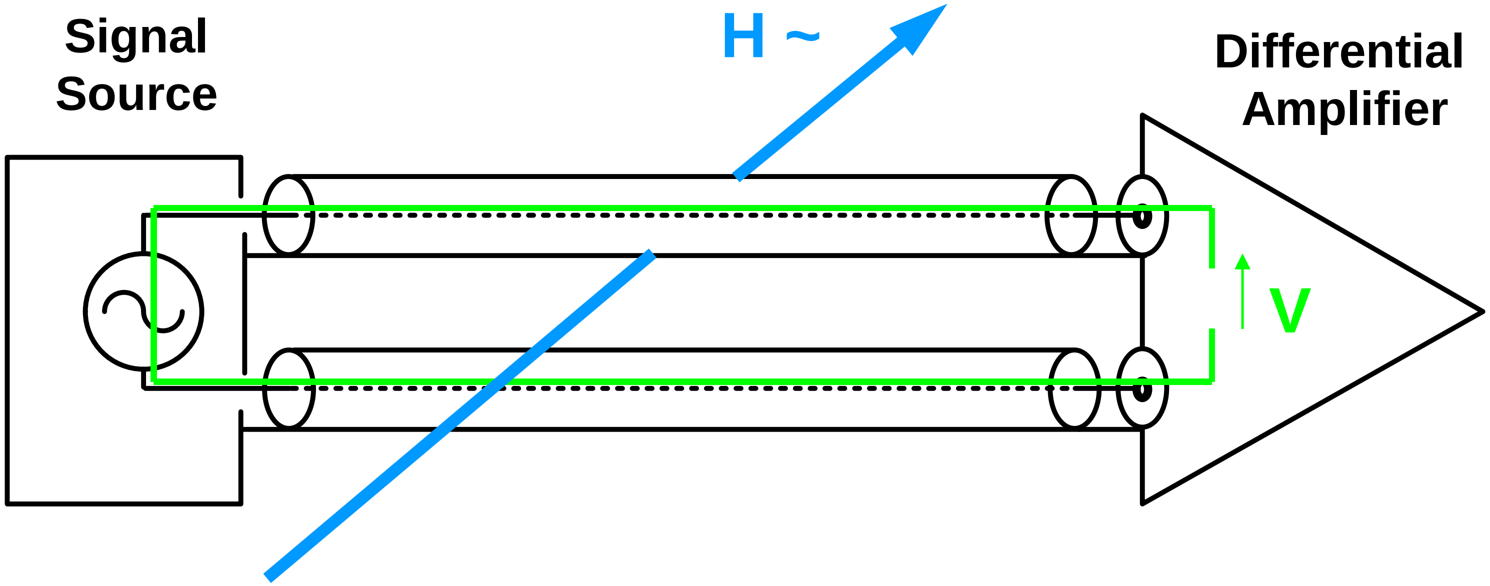
- Use shielded cables by two braids or by braid plus aluminized sheet
- protect the cable by a conductrice sheath

Basic rules for chosing the cables

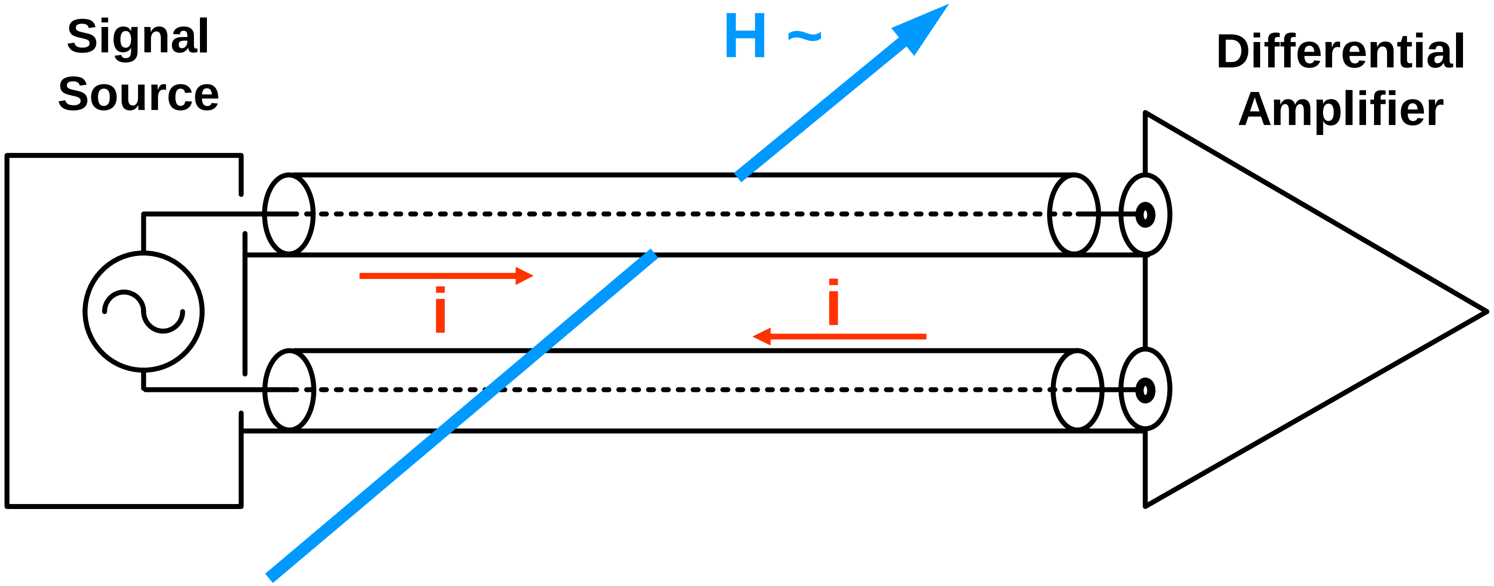
- µV level sensitivity, use :
  - Coax cable, (no basic shielded cable)
  - Shielded cable by braid, (covering rate > 95%)
- 10nV level sensitivity, use :
  - Short coax cable (< 20cm)
  - Double braid cable or braid + aluminized sheet
  - Twisted pairs Shielded + aluminized sheet
- nV level sensitivity, use :
  - Rigid and short coax cable
  - Triaxial cable
  - Case connected directly on the cryostat

Anything wrong ?





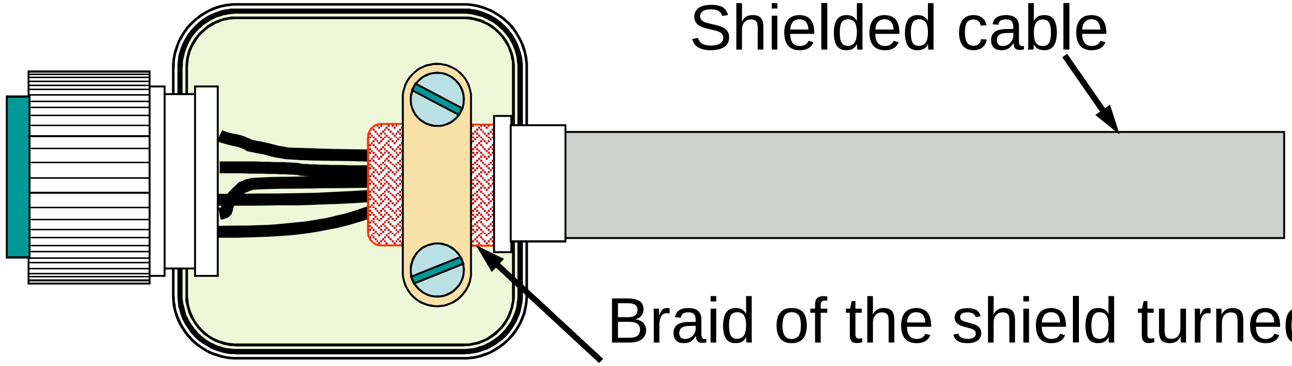
Induced voltage in the loop formed between the coax



The current i induced in the loop made by the shields are opposed to the flux variation
These currents reduce the interference voltage with an increasing effectiveness folowing the frequency
(starting at ~ 10KHz)

• 3 - Connectors

- Braid of the shield carefully connected to the case of the connector



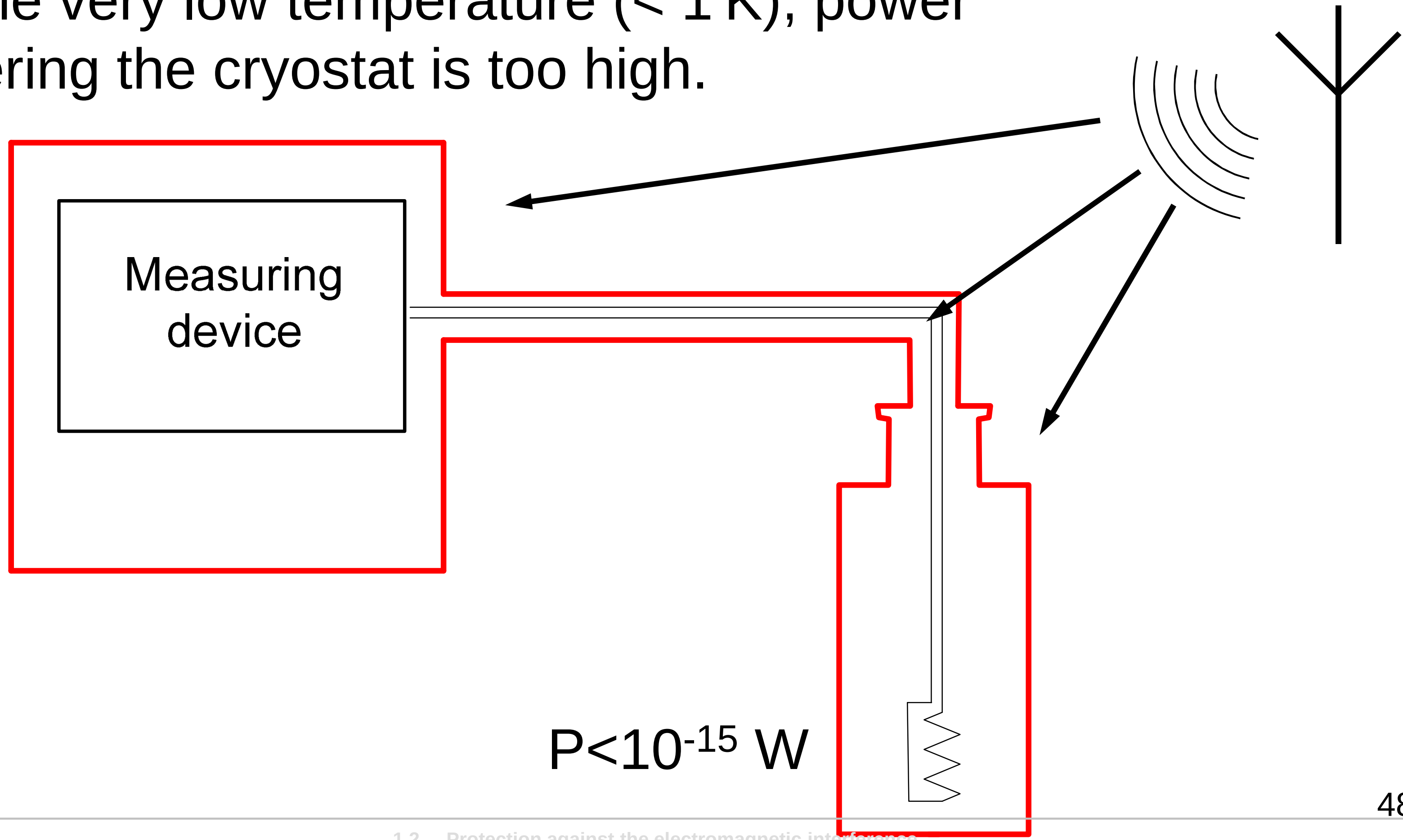
choose connectors which ensure a continuity of the shielding on 360°

• 4 - Boxes & cases

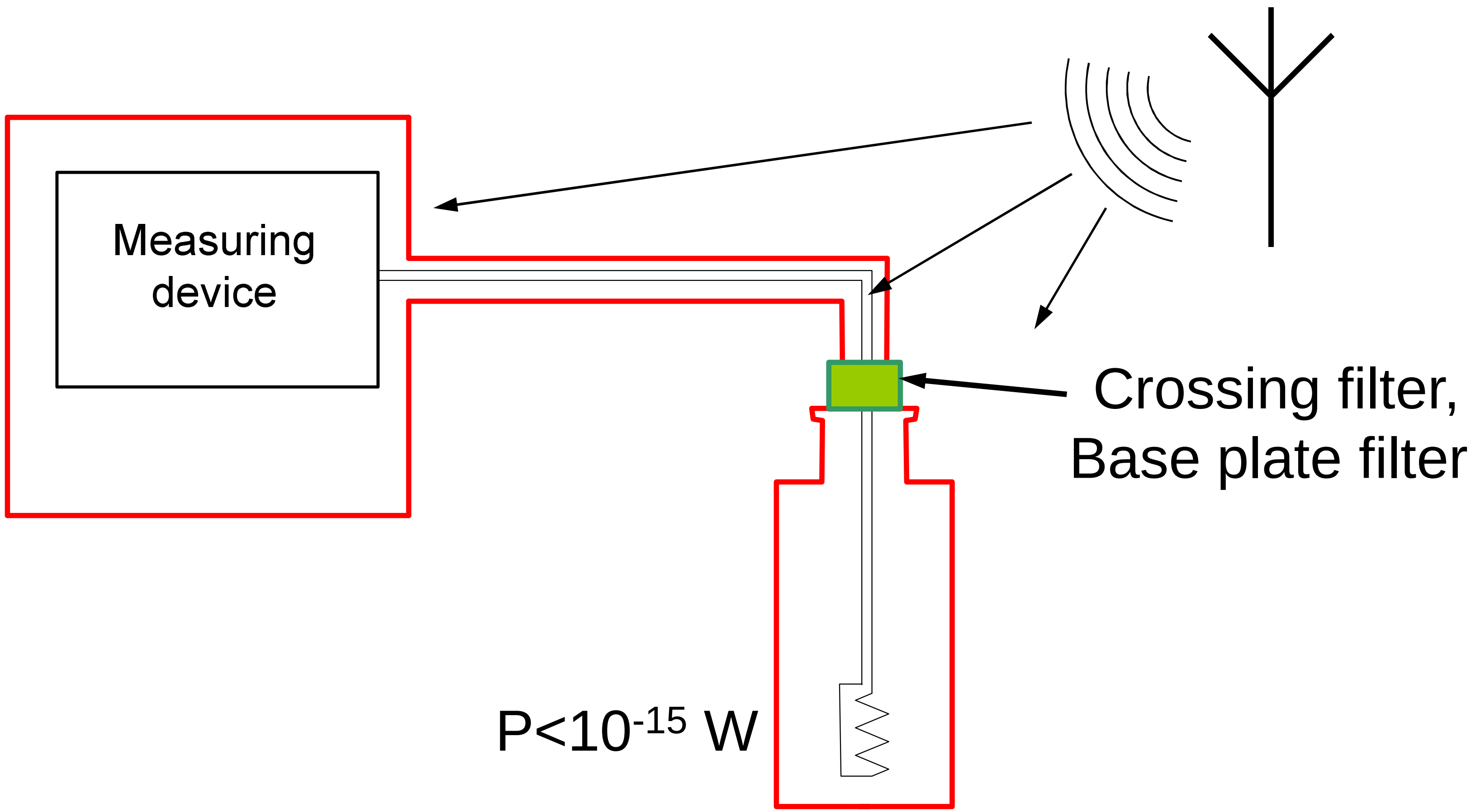
- Closed boxe
- Good continuity between walls
  - Short contact points :
    Lenght between 2 points << λ
- Seal HF
  - Metal knitting seal
  - Conducting rubber

Problem of the high frequencies

The effectiveness of shieldings cables decreases
With the frequency increase.
At the very low temperature (< 1K), power
entering the cryostat is too high.

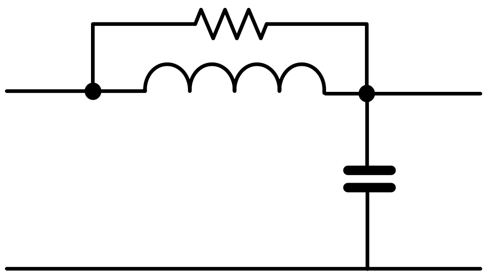


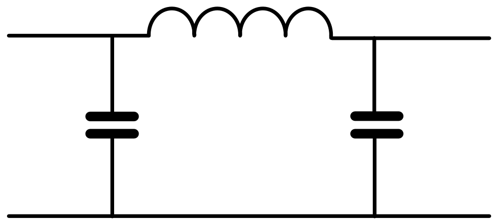
Installation of crossing filter



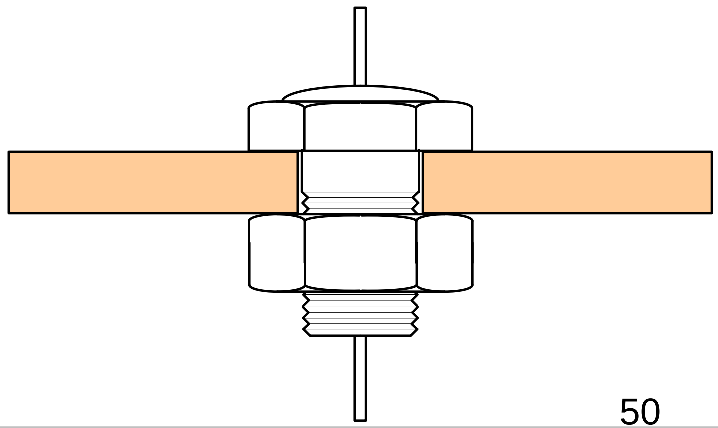
Crossing filter

- Type : C, RC, LC, RLC, made in L, T or PI
  - Cutoff frequency < 1MHz (if possible)





  - <u>Crossing capacitor</u>
  - Inductance at High resonance frequency



2. Interference due to vibrations

- Ground vibration
- Acoustic noises

Both Generate :

- – Release of heat
- – electric interference signals: microphonism

Protection against ground vibration

- insert between the cryostat and the ground a low-pass mechanical filter :
  - Antivibratory table
  - Heavy support: concrete, case of sand… resting on elastic feet: springs, blocks of rubber, insulators with air cushion…

Protection against acoustic noise

- Generally negligible effect
- If necessary, to lock up the electronic in a made box of dense walls and to cover them with materials absorbing (polyurethane foam …)

Microphonism

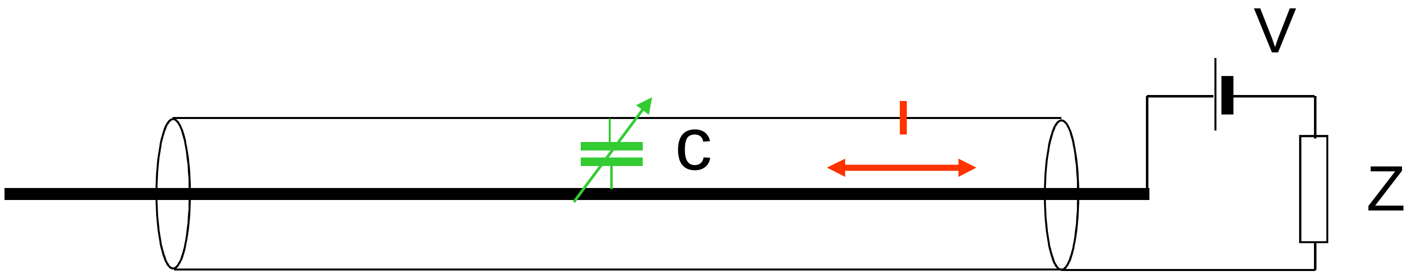
- Vibration of a cable in a magnetic field
- Vibration of a cable under power
- triboelectric Effect
- Microphonism of transformers
- Piezoelectricity

Vibration of a cable in a magnetic field

- Very important effect in the field of a coil
- transmit the signal per twisted pair or coax

To note: The vibrations can be generated by a AC current circulating in wire → Twist the wire back and forth of the current

Vibration of cable under power



I = V*dC/dt

- Assign especially the circuit to high impedance

Triboelectric effect

- Observed mainly in the cables
- Electric charge generated by the friction of dielectric on the shielding
- Value : from pA to nA !
- Assign especially the circuit to high impedance
- Use cable treated anti-signal

  (dielectric covered with a conducting layer)

Microphonism into transformers

- Transformers of impedance adaptation to the amplifiers input
- Field of the low frequencies (1Hz à 100KHz
- Dependent on the magnetic properties of the core

Piezoelectricity

- The interference effects occur mainly in certain ceramic capacitor (dielectric with high permittivity)

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