EMC

WARRINGTON - Monday 17 May - Alain CHAROY

AEMC POWER CONVERTERS FOR PARTICLE ACCELERATORS - a.charoy@aemc.fr

- **Introduction**
- **Differential Mode Immunity**
- **Differential Mode Emissions**
- **Common Mode Emissions**
- **Electromagnetic Radiations**

EMC terms and lab assessment conditions

Electromagnetic emission

Standardized test

Given EM disturbance

Defined Measuring **equipment**

Standardized Measuring conditions

Emission-test level

Emission-test limit

Single emitter

Deterministic situation

The best situation is to undertake EMC tests & to solve EMC problems before they appear *in situ*

Electromagnetic susceptibility

Standardized test

Given EM disturbance

Defined Disturbance **source**

Standardized Measuring conditions

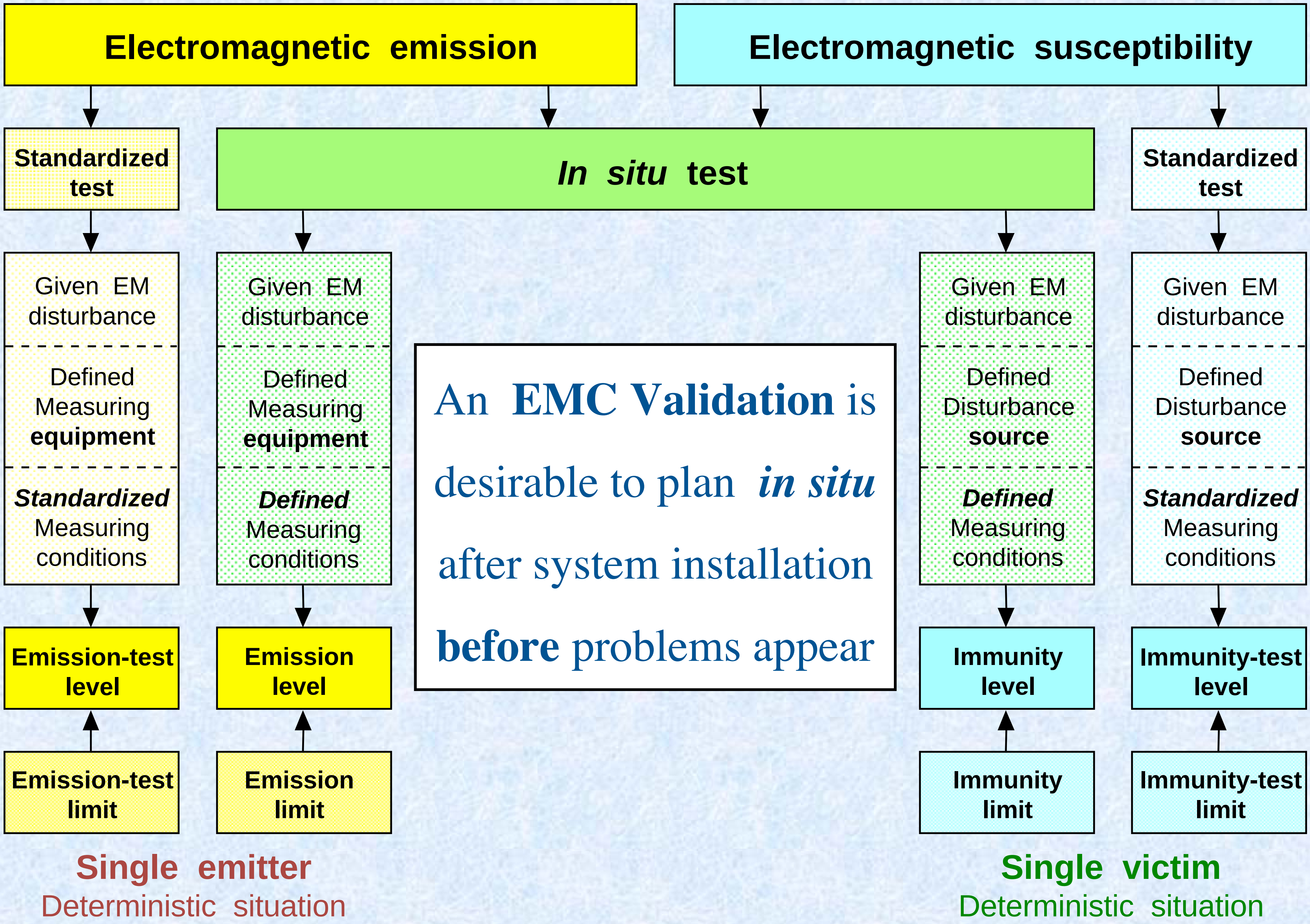
Immunity-test level

Immunity-test limit

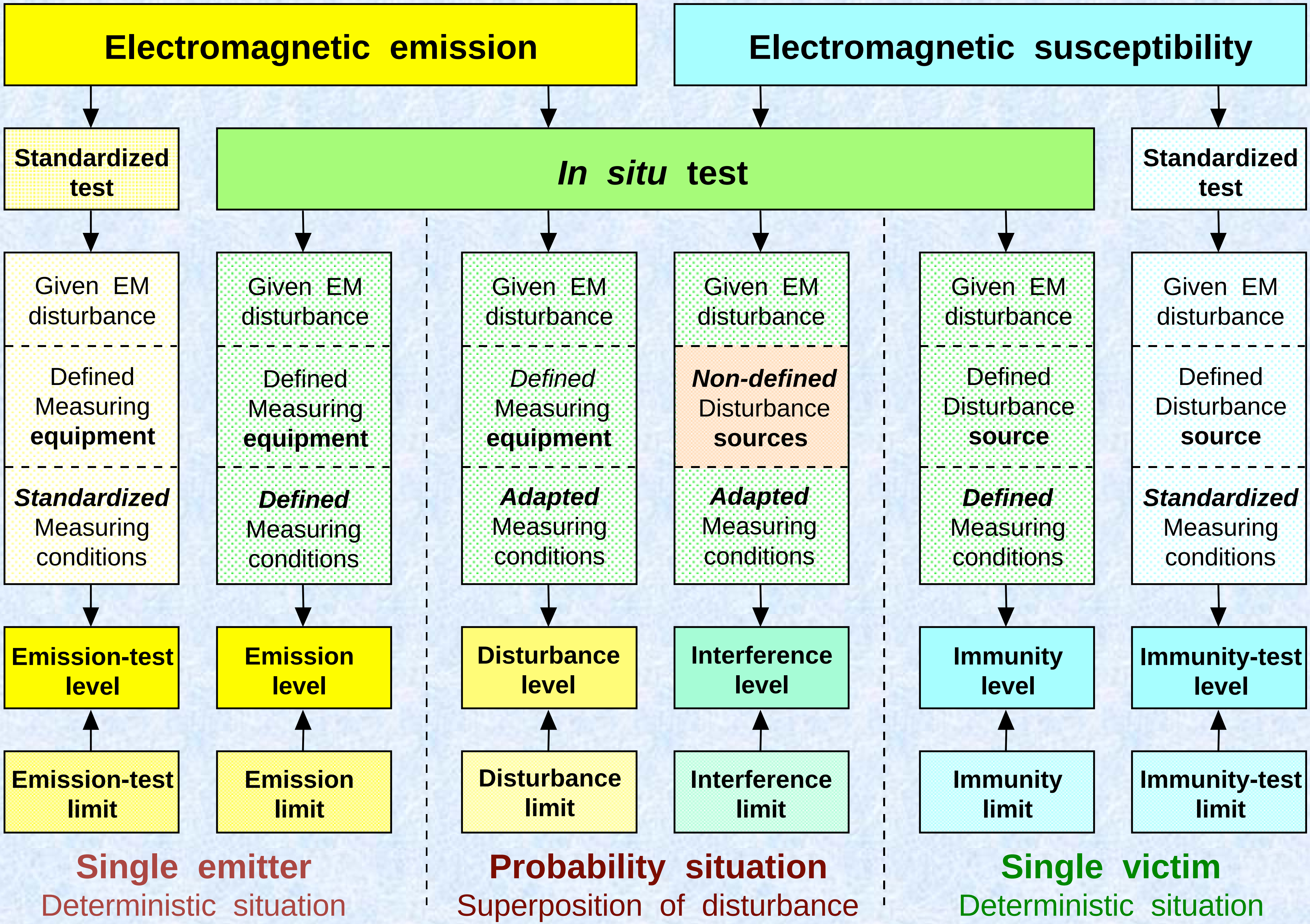
Single victim

Deterministic situation

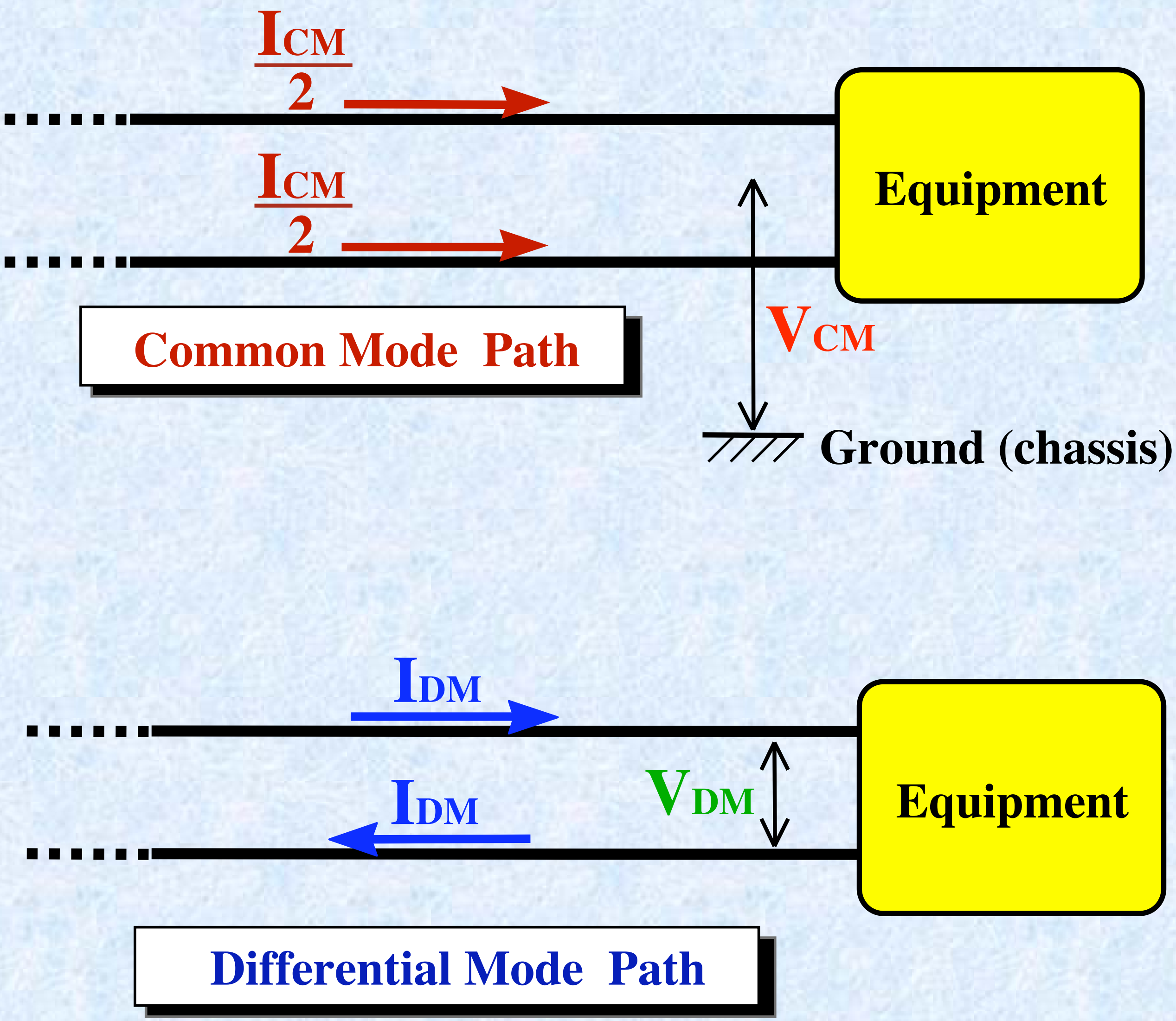
EMC best controlling conditions



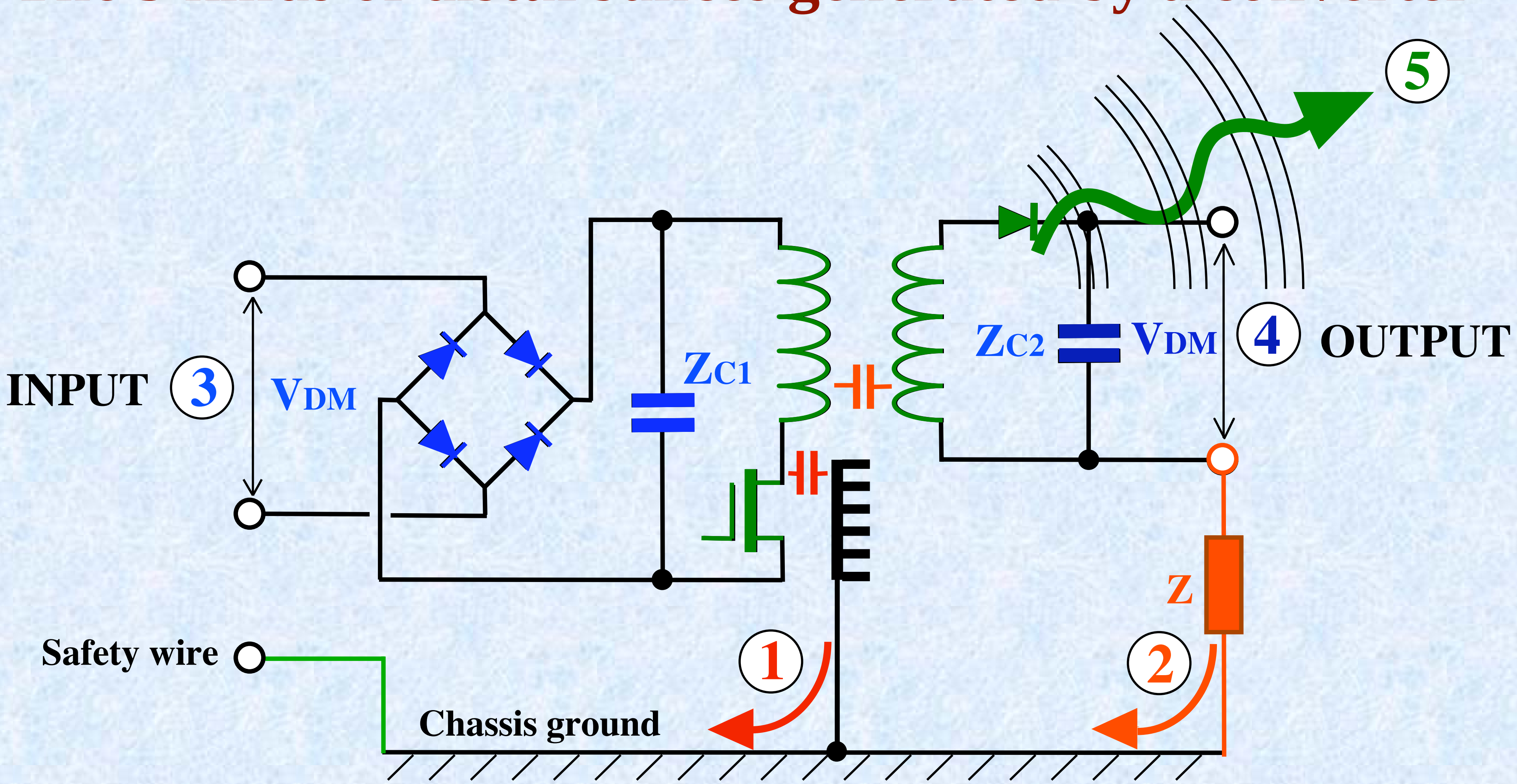
EMC troubleshooting



Common Mode & Differential Mode



The 5 kinds of disturbances generated by a converter



1 Input-to-Chassis Common Mode

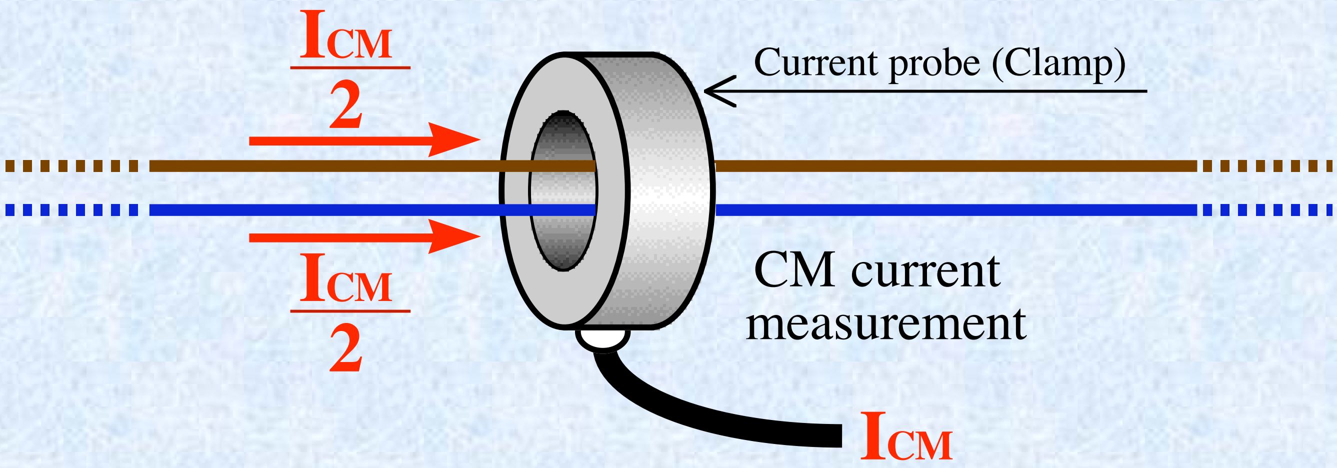
2 Input-to-Output Common Mode

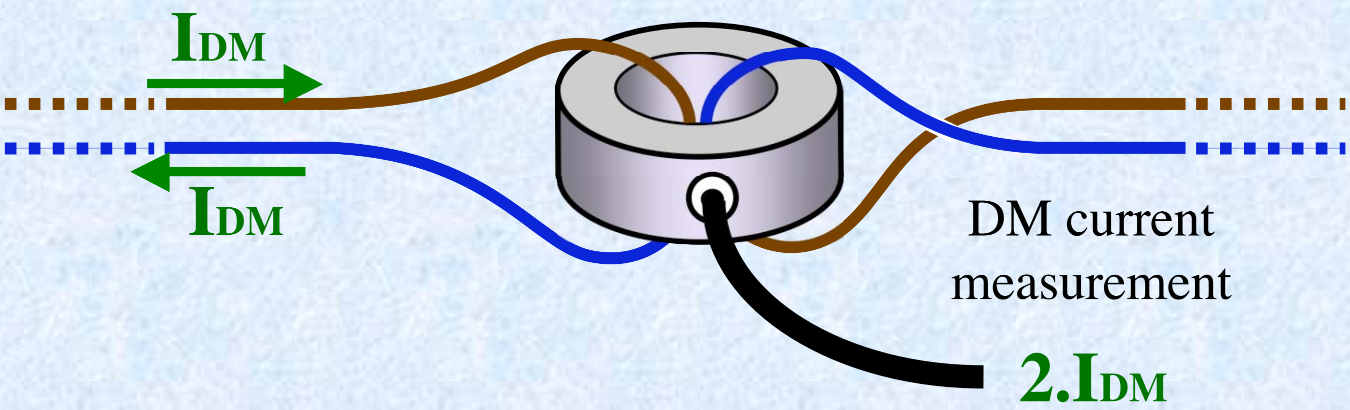
3 Input Differential Mode

4 Output Differential Mode

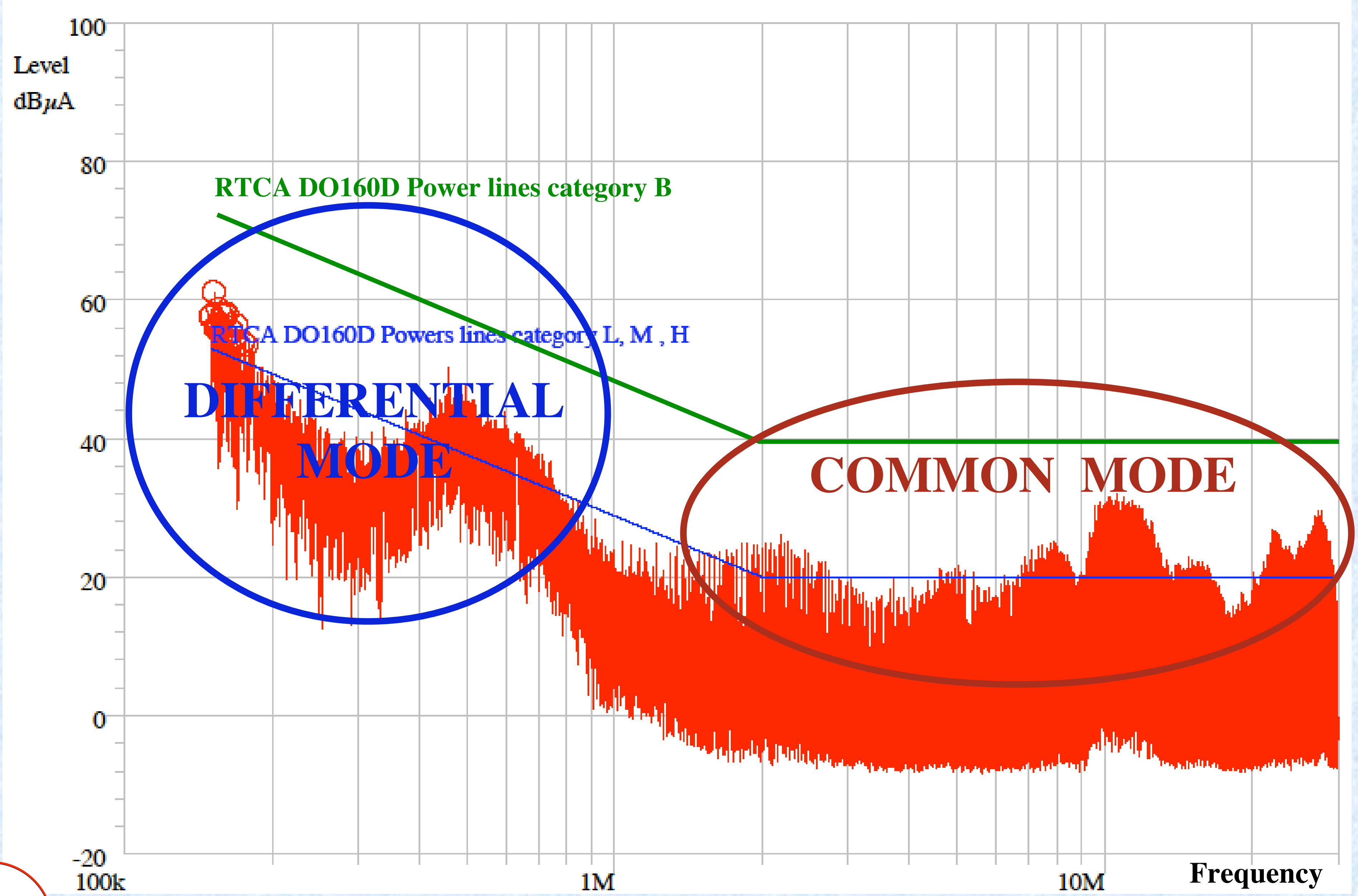
5 Electromagnetic radiations (E & H)

How to measure CM & DM currents ?

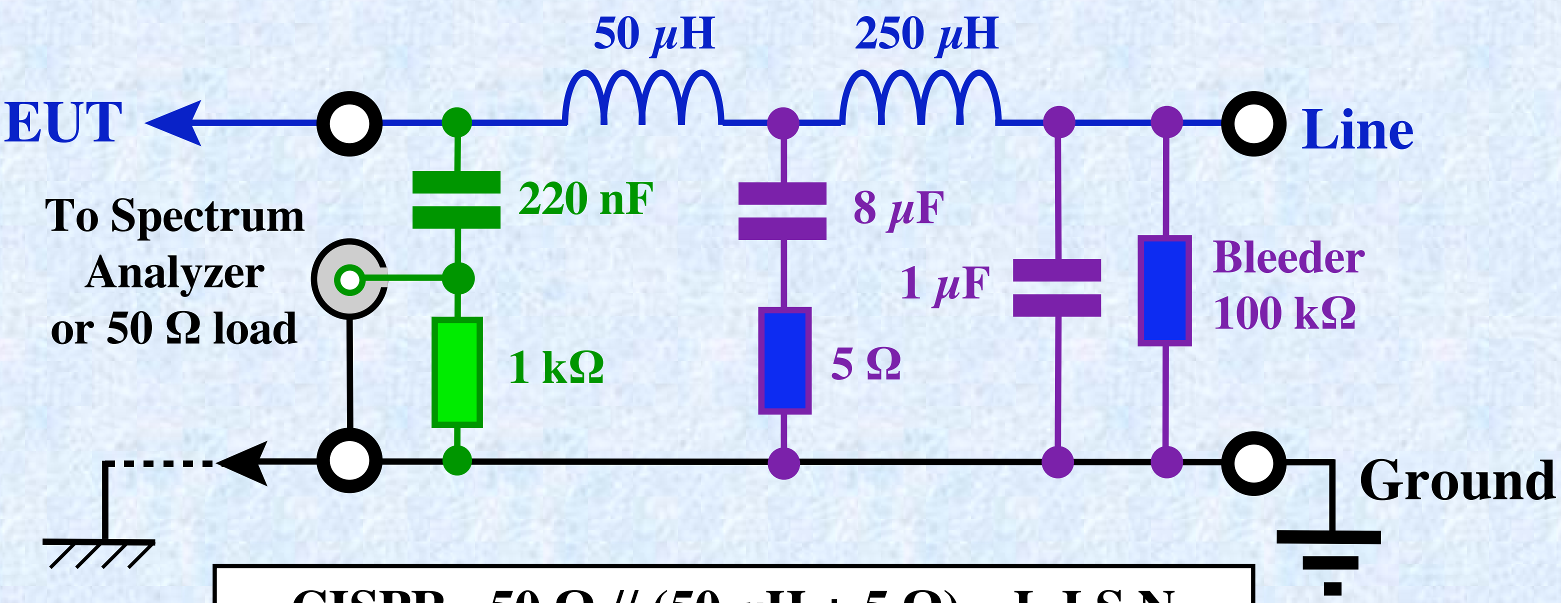




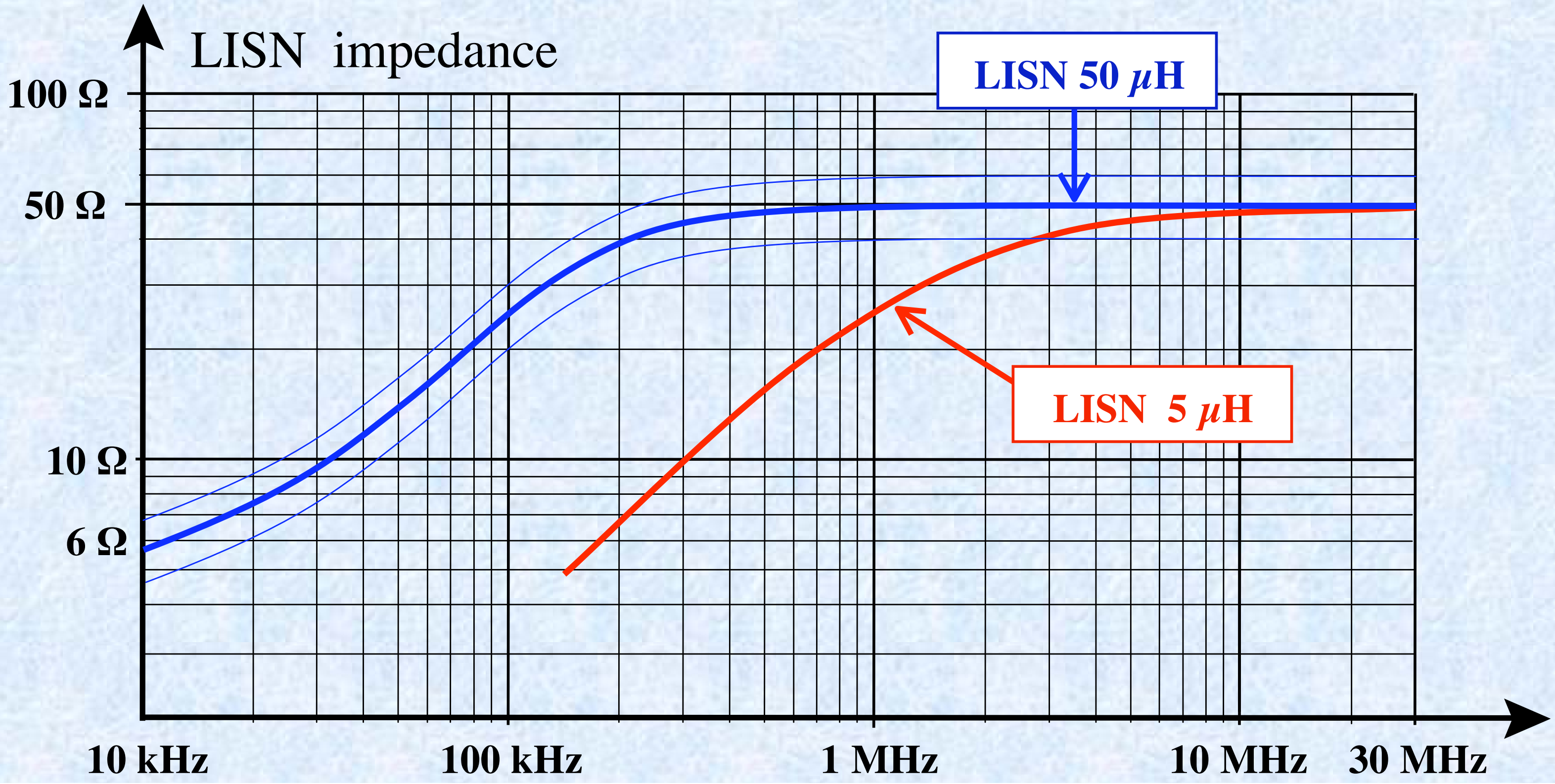
Typical input current of a 5 kVA filtered converter



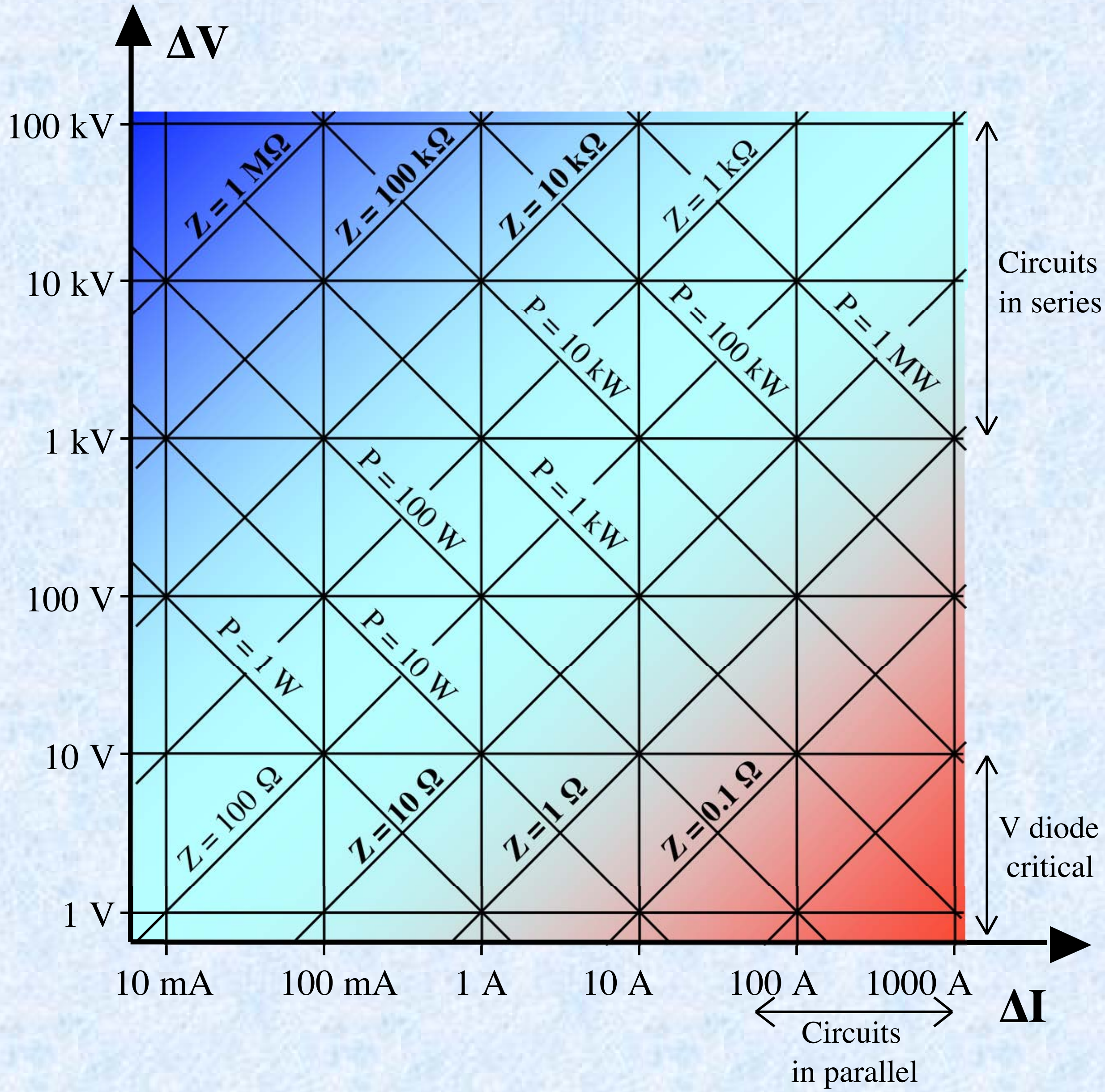
How to measure a disturbing voltage ?



CISPR 50 Ω // (50 μH + 5 Ω) L I S N



A concealed key point: the switching dynamic impedance



Any switching circuit should be positioned in this plane…

High impedance zone

E field dominates, so:

- Reduce parasitic capacitors
- Limit high ΔV/Δ t trace lengths
- Choose low ε_r materials (air !)
- Use lower V circuits in series

Low impedance zone

H field dominates, so:

- Reduce ESR and ESL
- Limit high Δ I/Δ t loop areas
- Choose "sandwich" geometries
- Use lower I circuits in parallel

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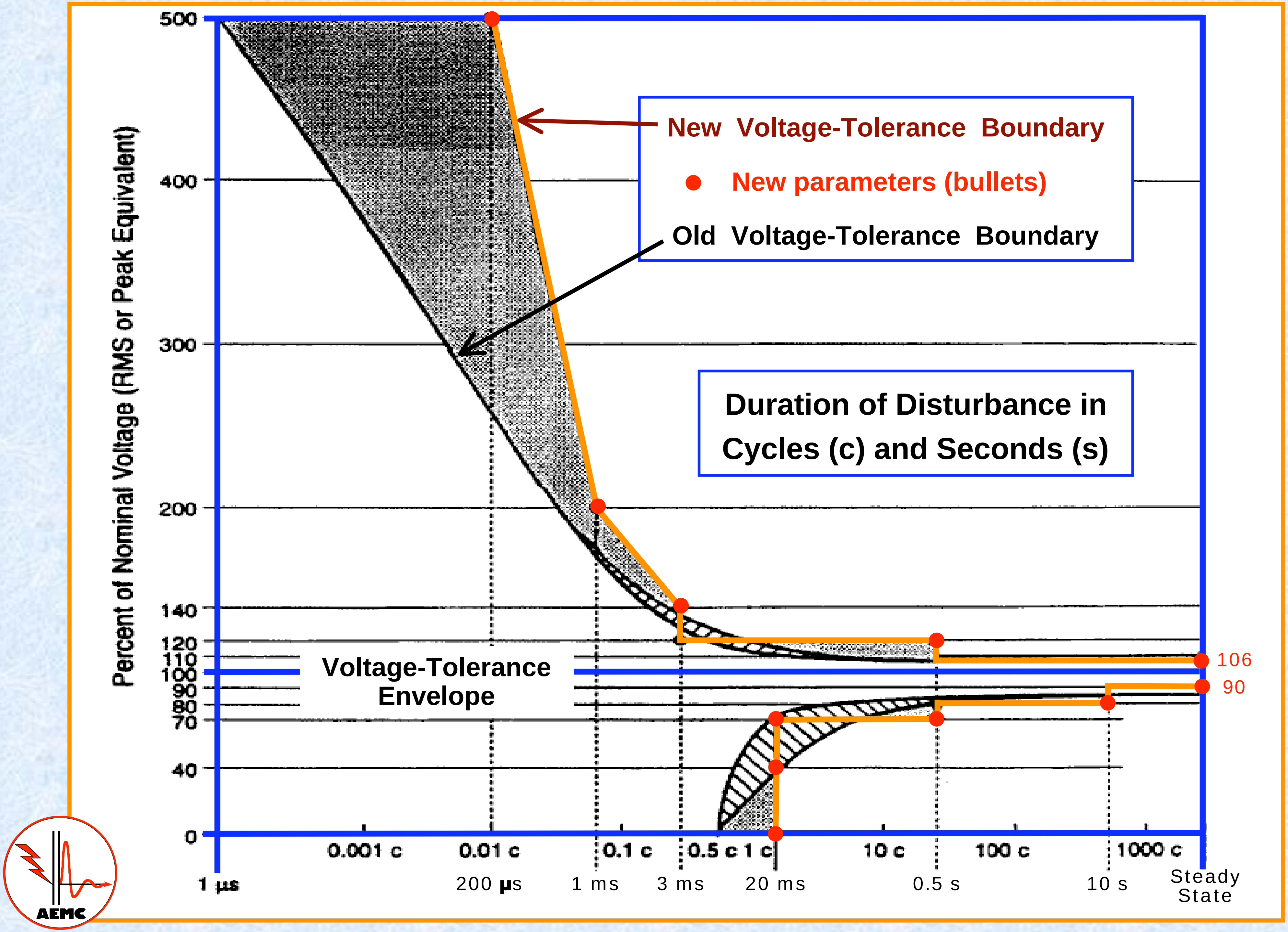
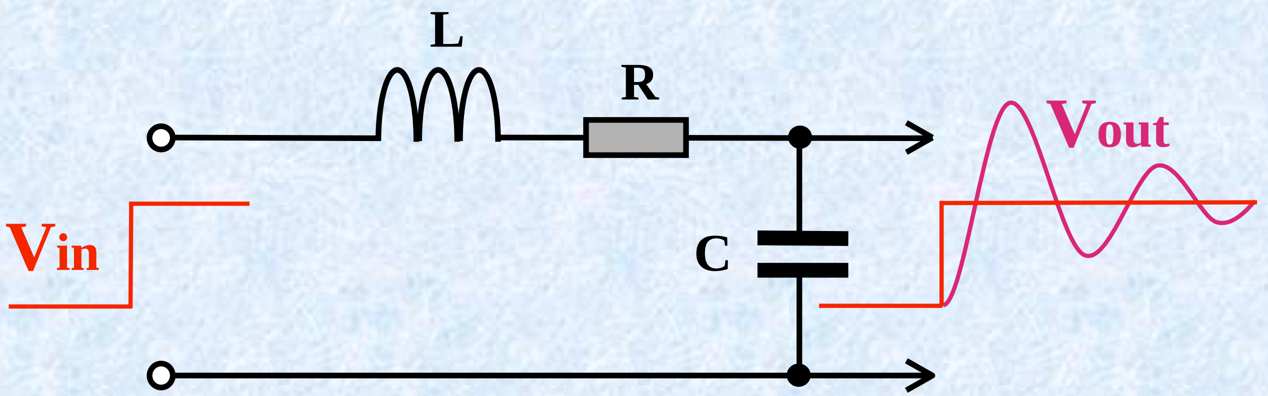
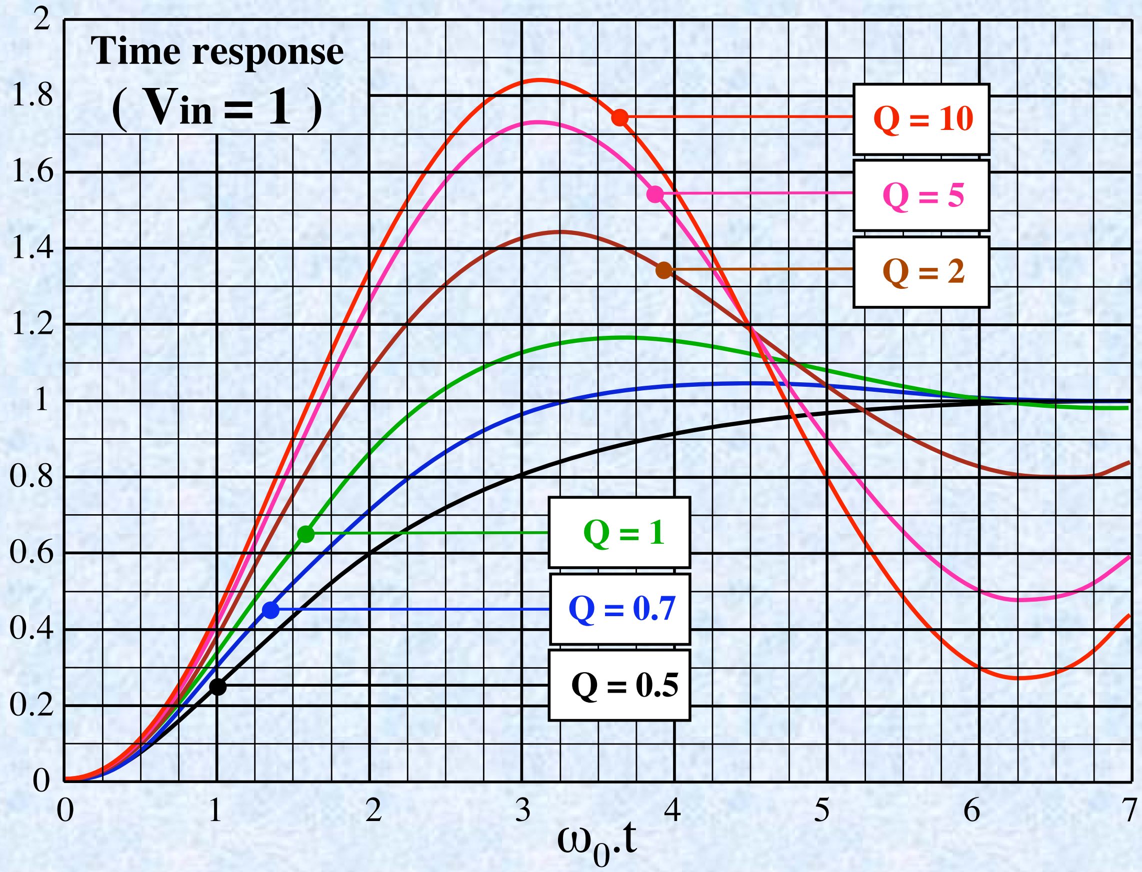
The voltage tolerance boundary



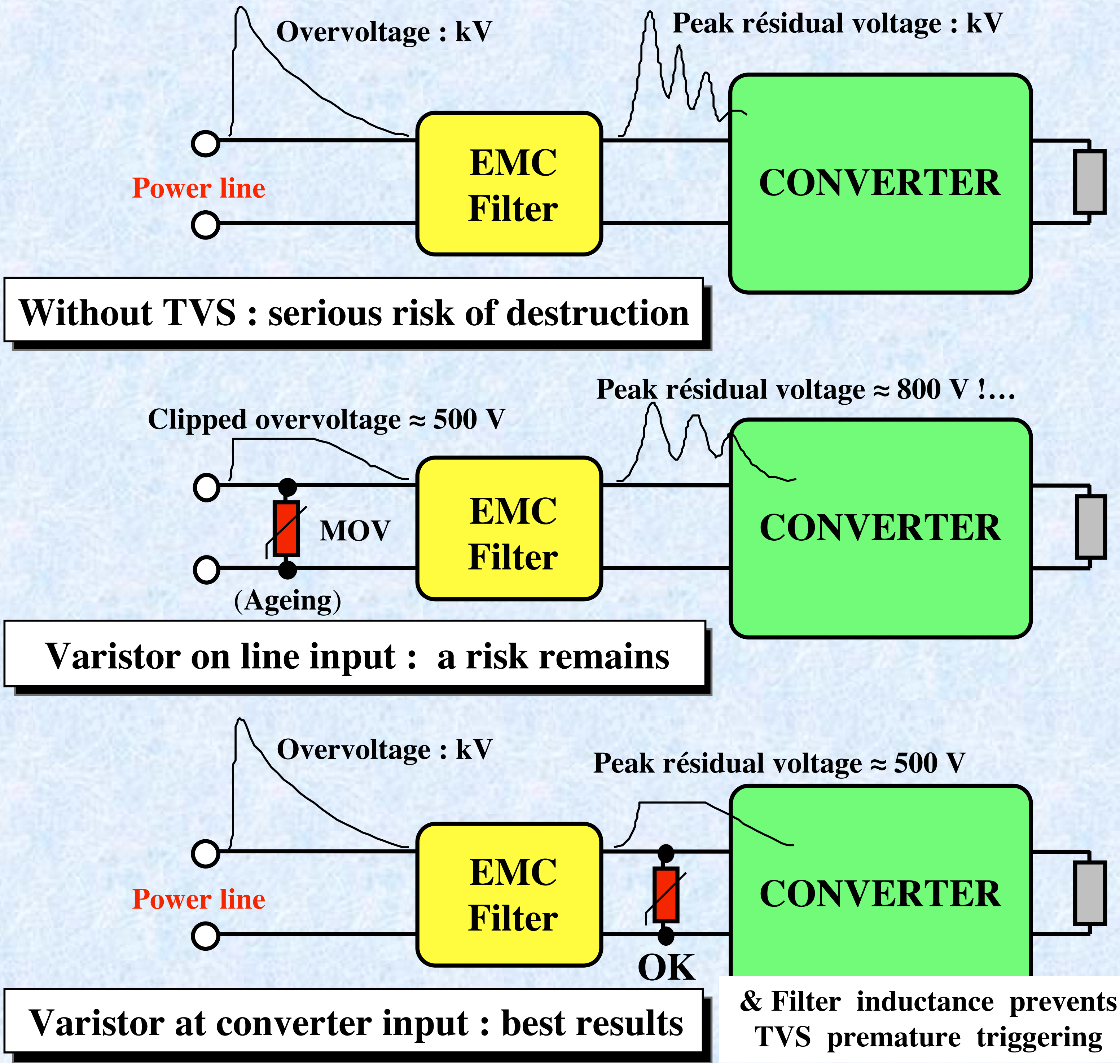
Transient Turn-on Overvoltage

Self-pulsation : $\omega_0 = \dfrac{1}{\sqrt{L.C}}$ Quality Factor : $Q = \dfrac{L.\omega_0}{R}$

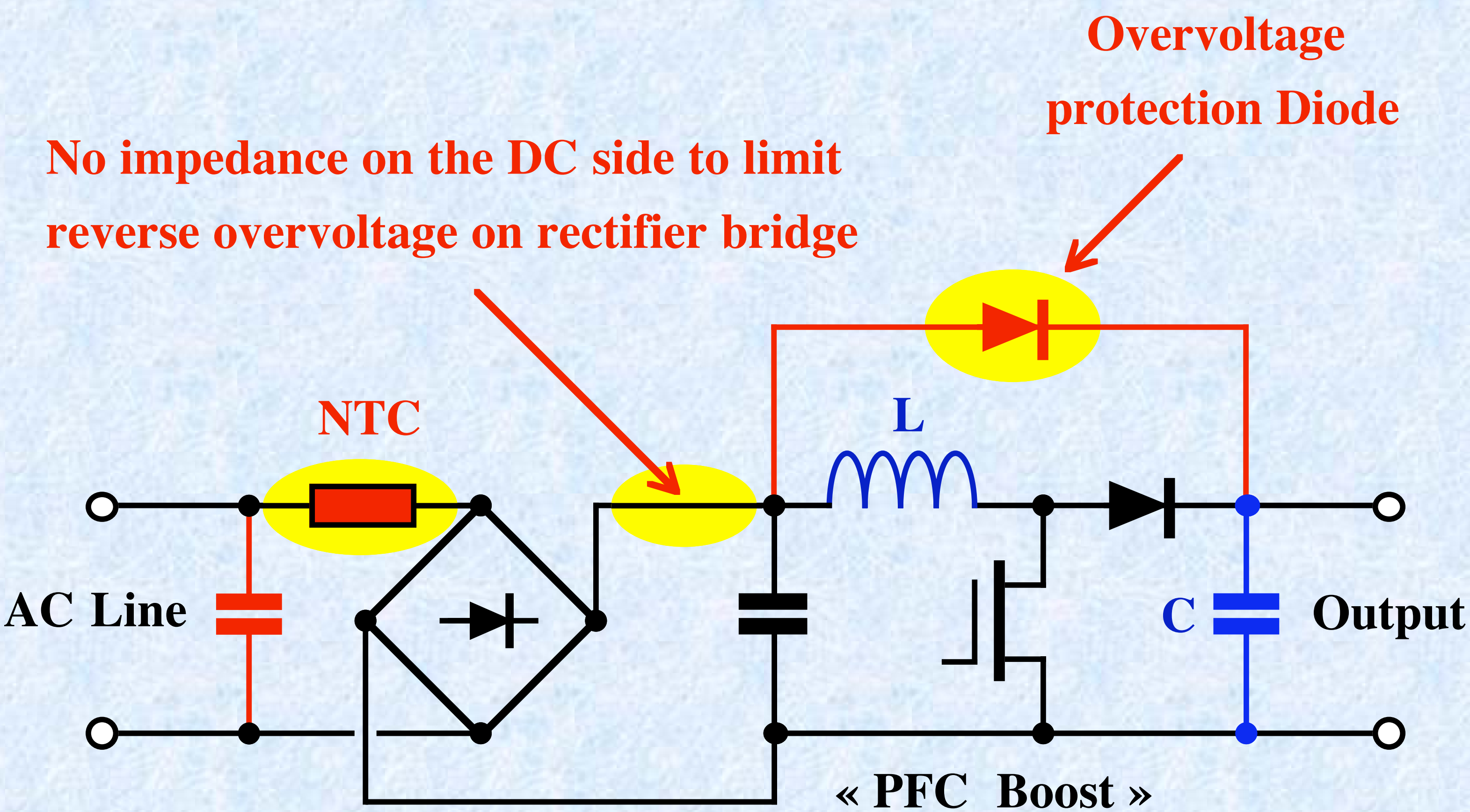




Where to install a DM Voltage Transient Suppressor ?

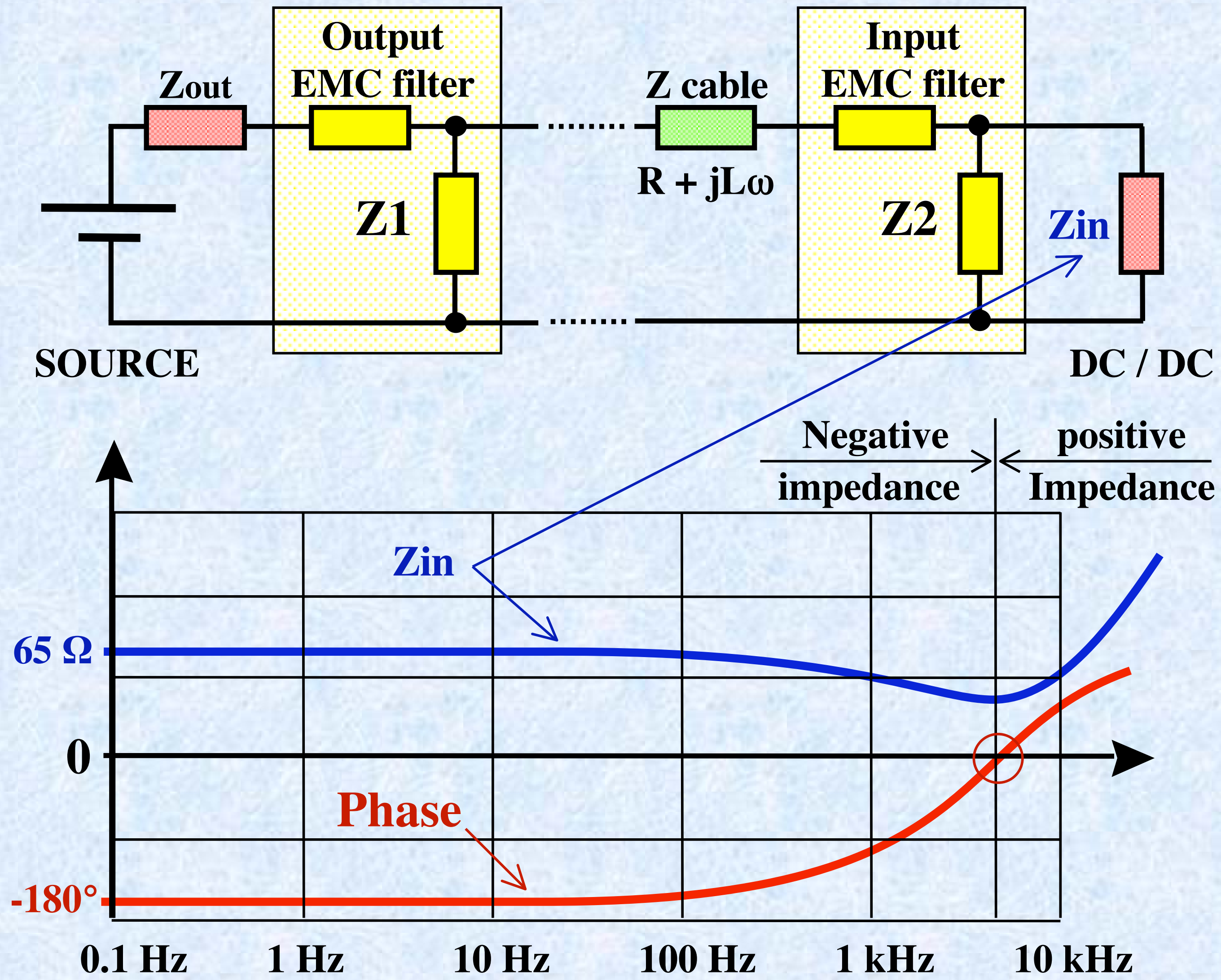


Where to add protection components ?



A **Diode** avoids output voltage doubling
A **NTC thermistor** limits inrush current

The problem of the negative impedance of a DC/DC converter



Risks :

- No Start Up
- Output voltage instability
- Destruction of DC / DC converter

Solutions :

- Add a large capacitor at DC / DC input
- Reduce cable inductance (several pairs in //)
- Reduce the converter regulation bandwidth

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Some problems of converters harmonics

- **Harmonics are generated by non sinusoidal currents. For an electric network, harmonics are a low frequency problem (< 2 kHz and in Differential Mode only).**
- **Usually, even harmonics are low (because + and – half-waves look the same). Most of inverters and AC / DC converters without PFC exceed normalized levels.**
- **Odd harmonics of converters can be severe (> 50 % @ H3 ; > 30 % @ H5).**
- **For most single – phase converters without PFC on a 3 phase network, the 3rd harmonics (150 Hz) is an “homopolar” current. So, $I_{neutral}$ can exceed I_{phase}.**
- **Anti-harmonic or active filters are useful for a low power source (electric generator).**
- **For a high power network, the problem of harmonics is not the voltage distortion but the mastering of cabling protection scheme (cables & circuits breakers).**

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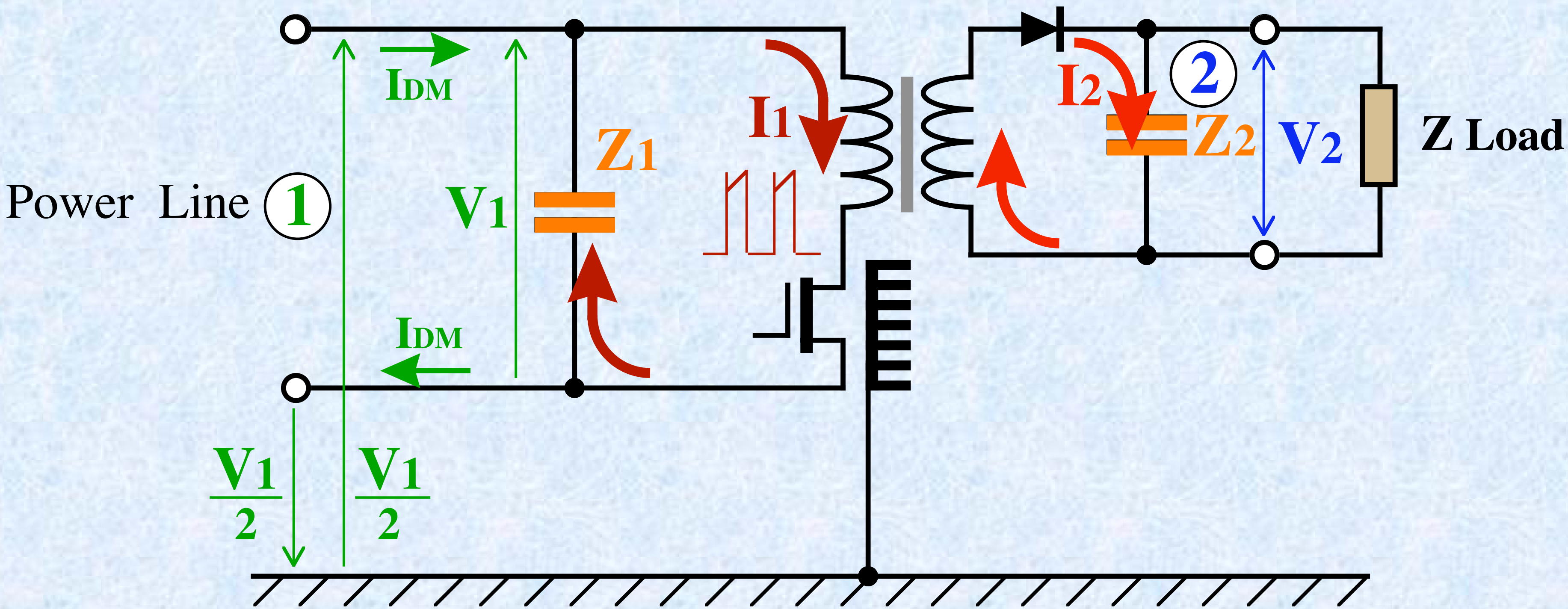
Differential Mode interferences



1 $V_1 \approx Z_1 \, . \, I_1$ (**If Z LISN >> Z1** - Generally, $V_1 = f(F)$)

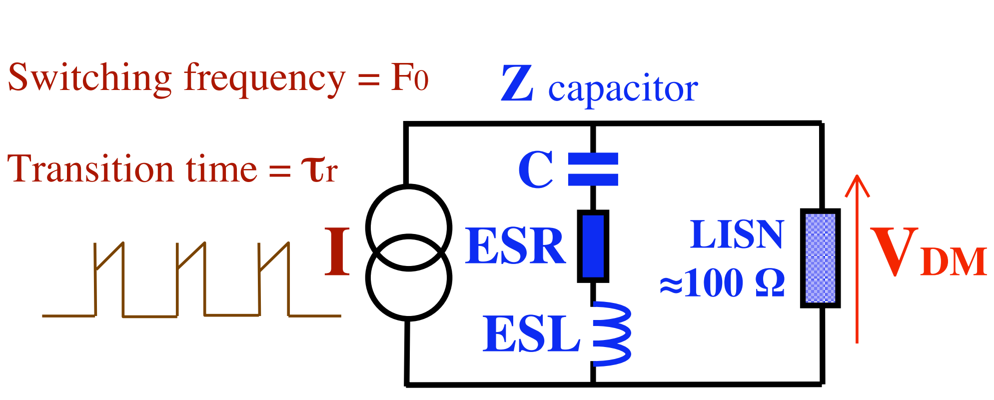
V_1 is not applied to the secondary, so it does not disturb the load.

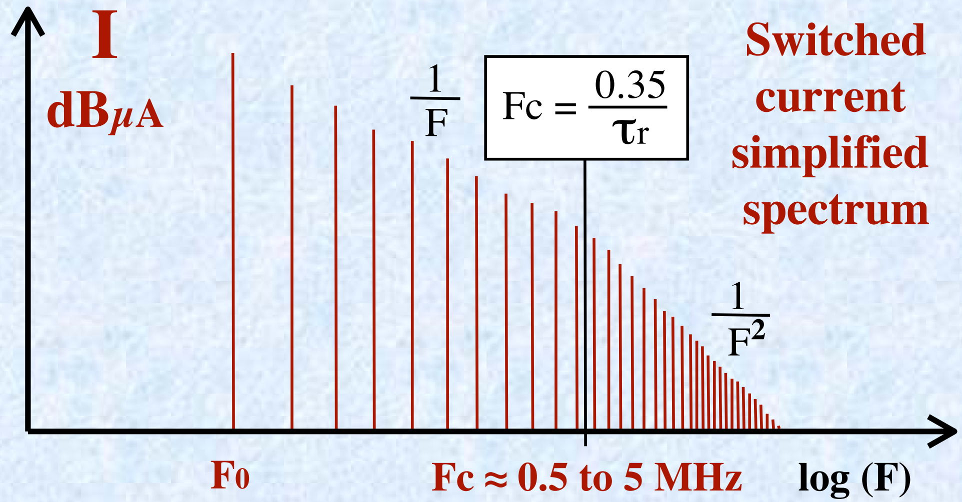
2 $V_2 \approx Z_2 \, . \, I_2$ (**If Z Load >> Z2** - Generally, $V_2 = f(t)$)

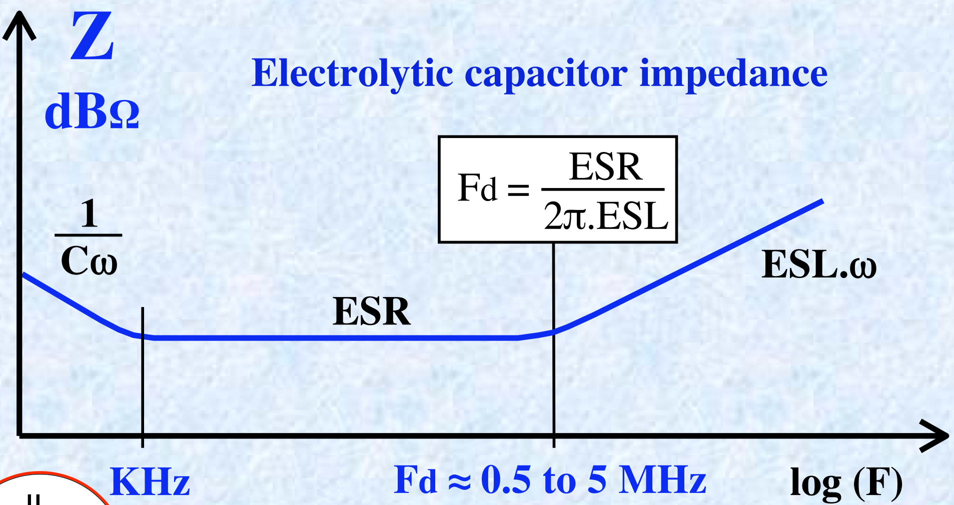
V_2 may be disturbing (typically if peak-to-peak $V_2 \geq 1$ V)

Differential Mode Emission Spectrum Without Filtering

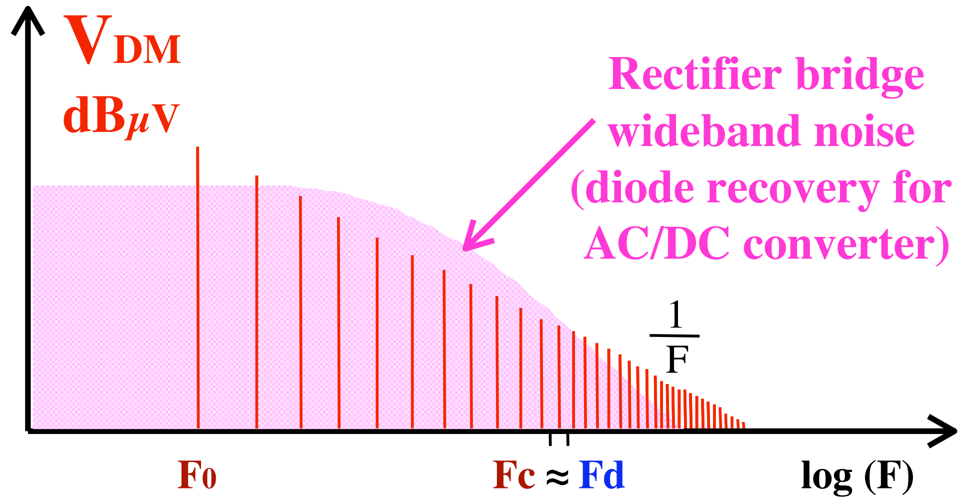
Converter DM Equivalent Scheme



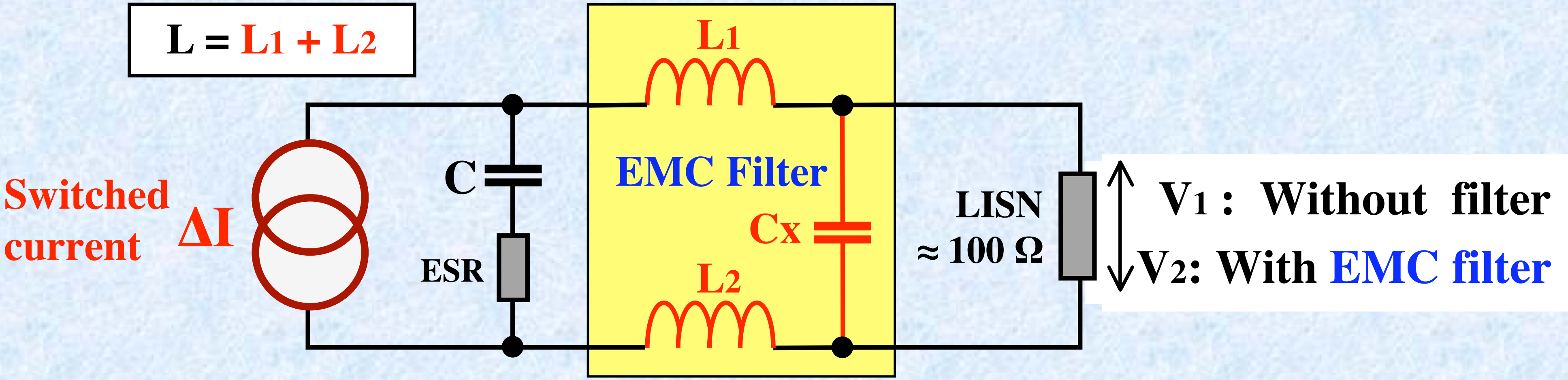




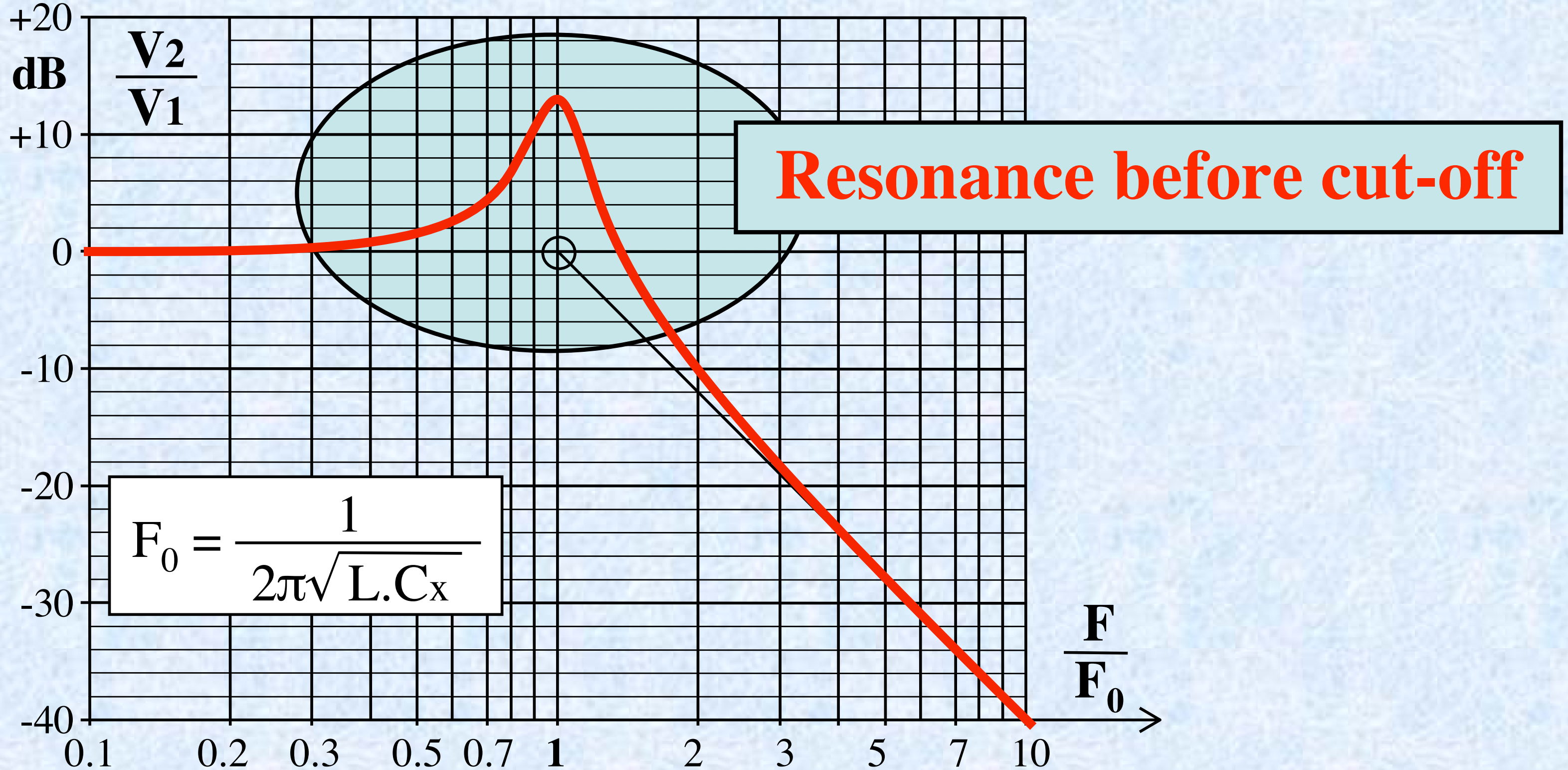
Convolution Result



Insertion Loss of a Differential Mode EMC Filter

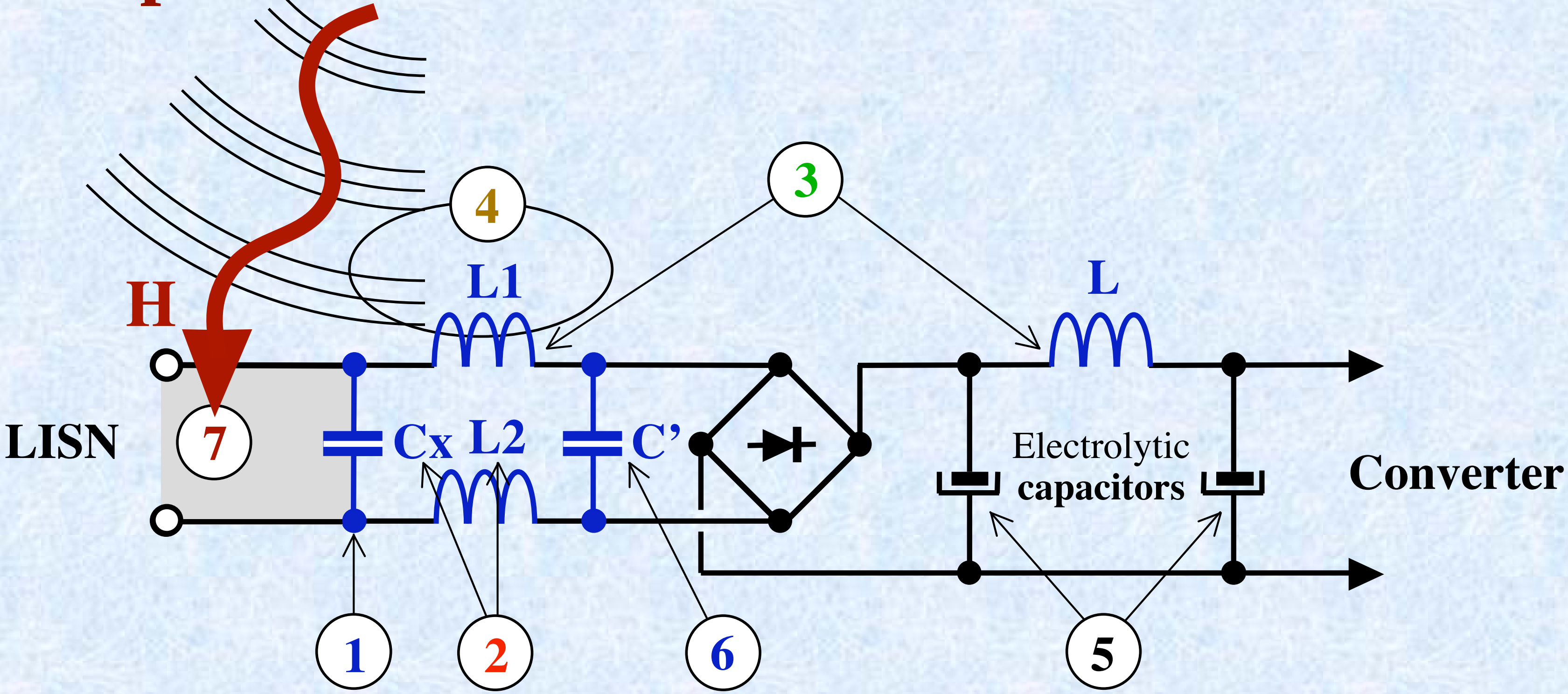


DM equivalent scheme of a converter with an EMC filter



$$F_0 = \frac{1}{2\pi\sqrt{L.C_x}}$$

Traps of a Differential Mode EMI filter



1 - Choose the proper structure (to mismatch the impedances)

2 - Choose (L1+L2) x Cx value so that $F_{resonance}$ < lowest frequency to filter

3 - Verify that no inductance saturates at max current (Max P & Min V)

4 - Limit H field coupling to leakage inductance (in air) of L1 & L2

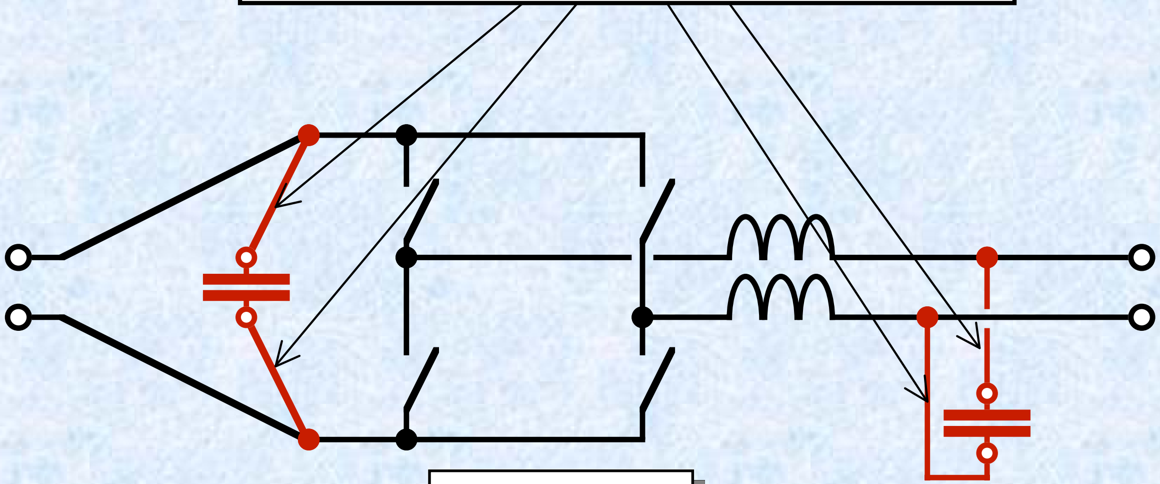
5 - Safety margin necessary to compensate electrolytic caps ESR dispersion

6 - Add **C'** as needed to reduce wideband recovery noise of rectifier bridge

7 - Limit H field-to-loop coupling to avoid parasitic voltage pick-up.

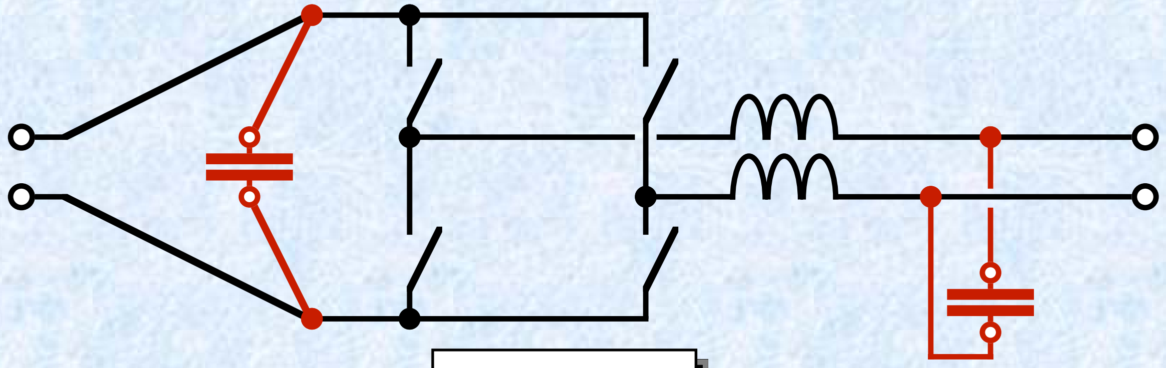
Take care of Differential Mode cabling…

Those cabling inductances reduce filtering effectiveness

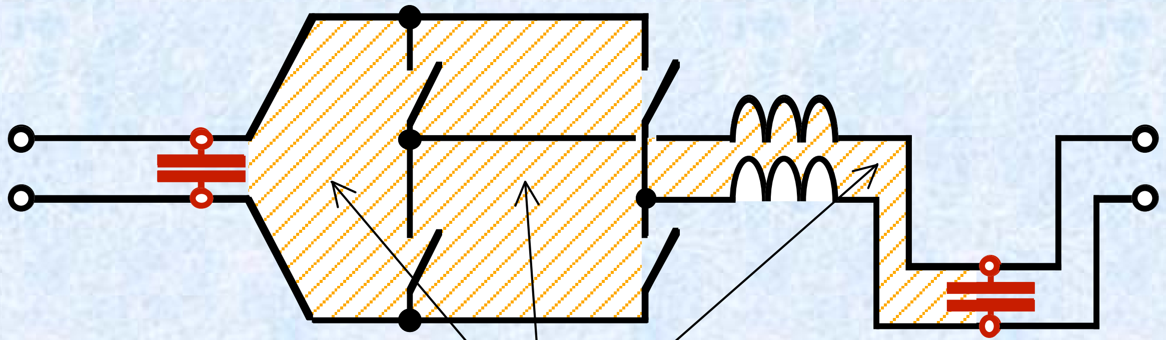


NO !

Take care of Differential Mode cabling…

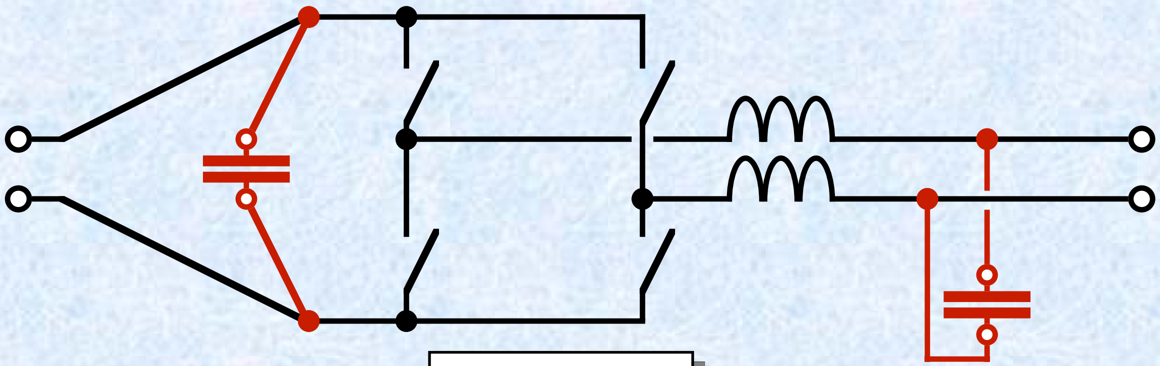


NO !

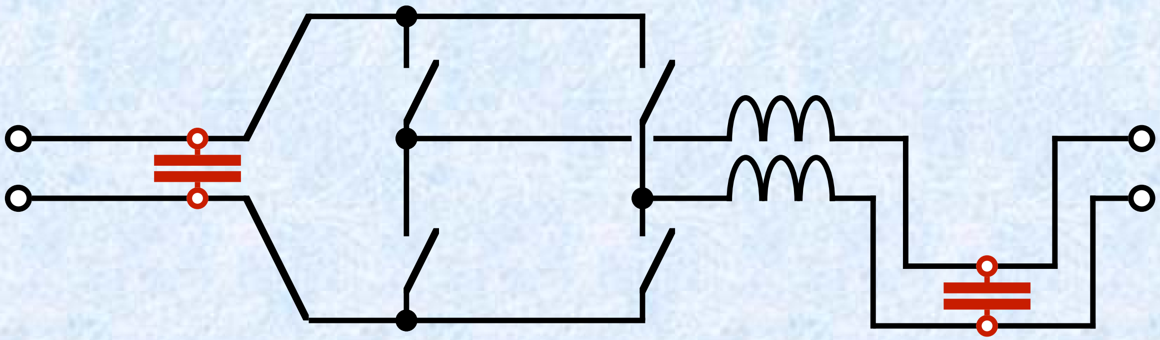


Those areas radiate if they carry high $\Delta I / \Delta t$

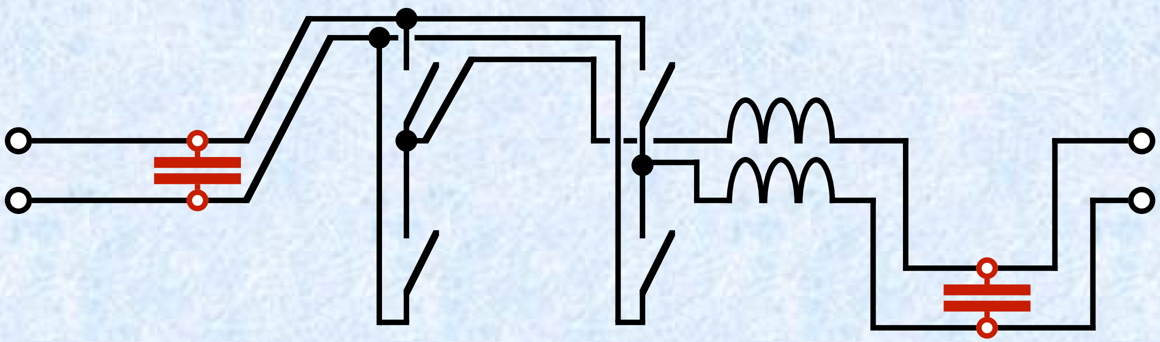
Take care of Differential Mode cabling…



NO !

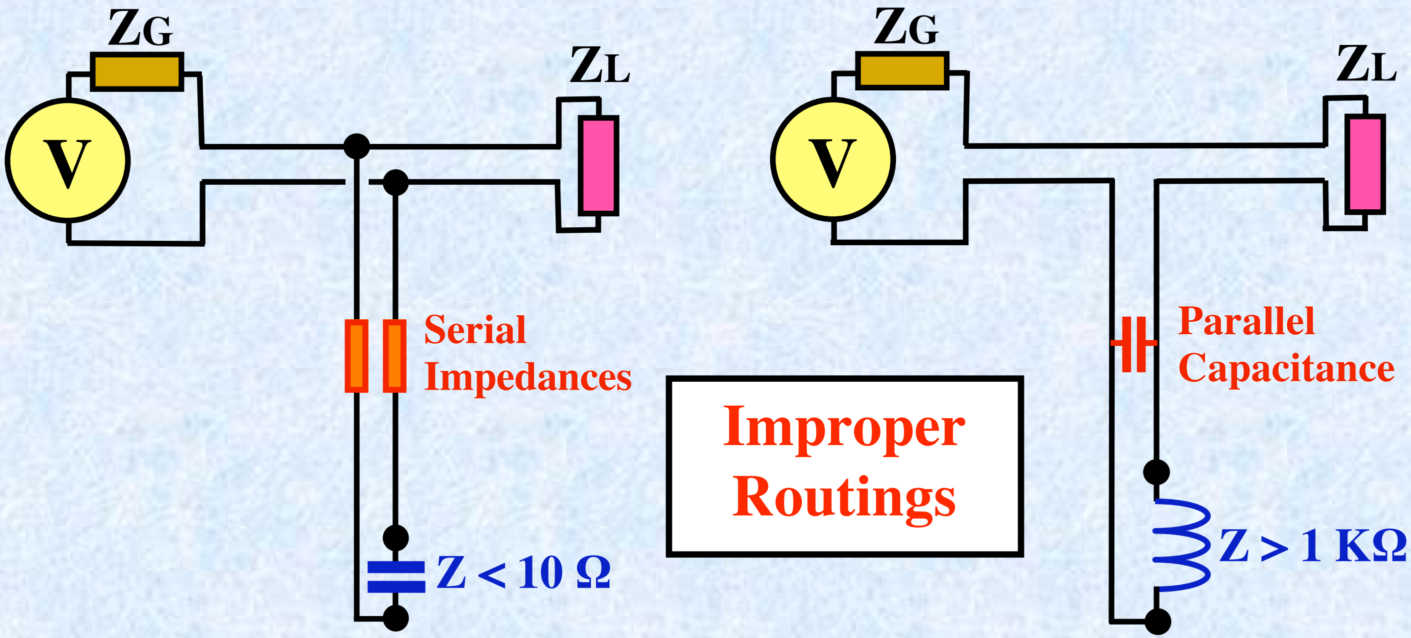


BETTER

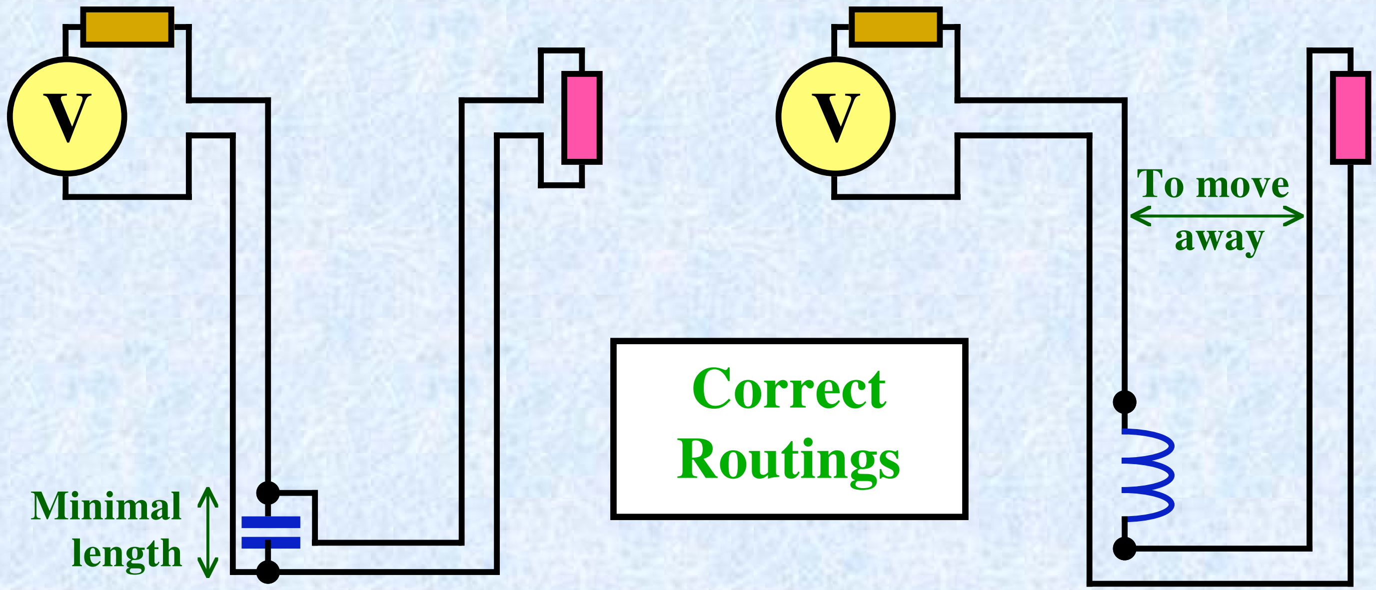


BEST !

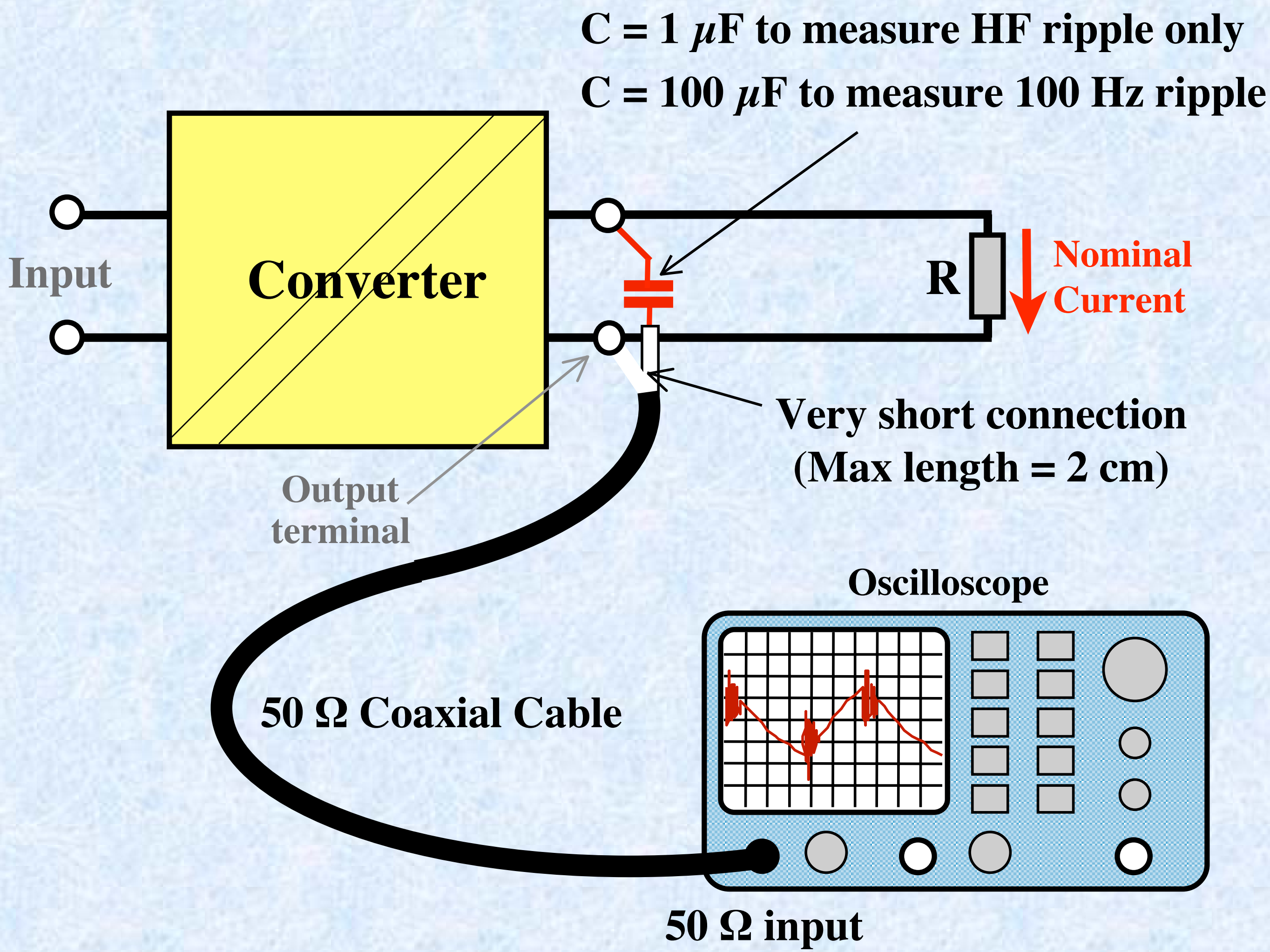
How to reduce cabling parasitic impedances…



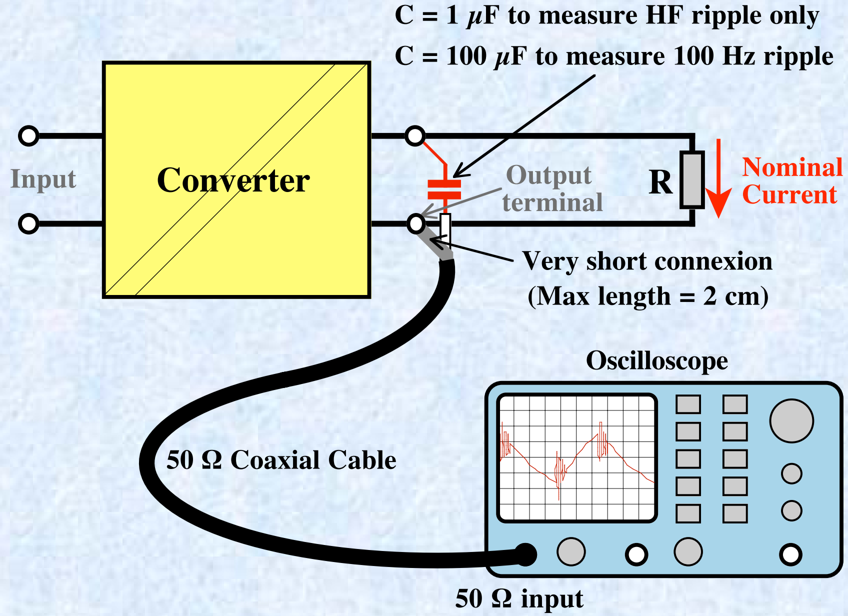
To reduce the cabling areas is necessary, but insufficient

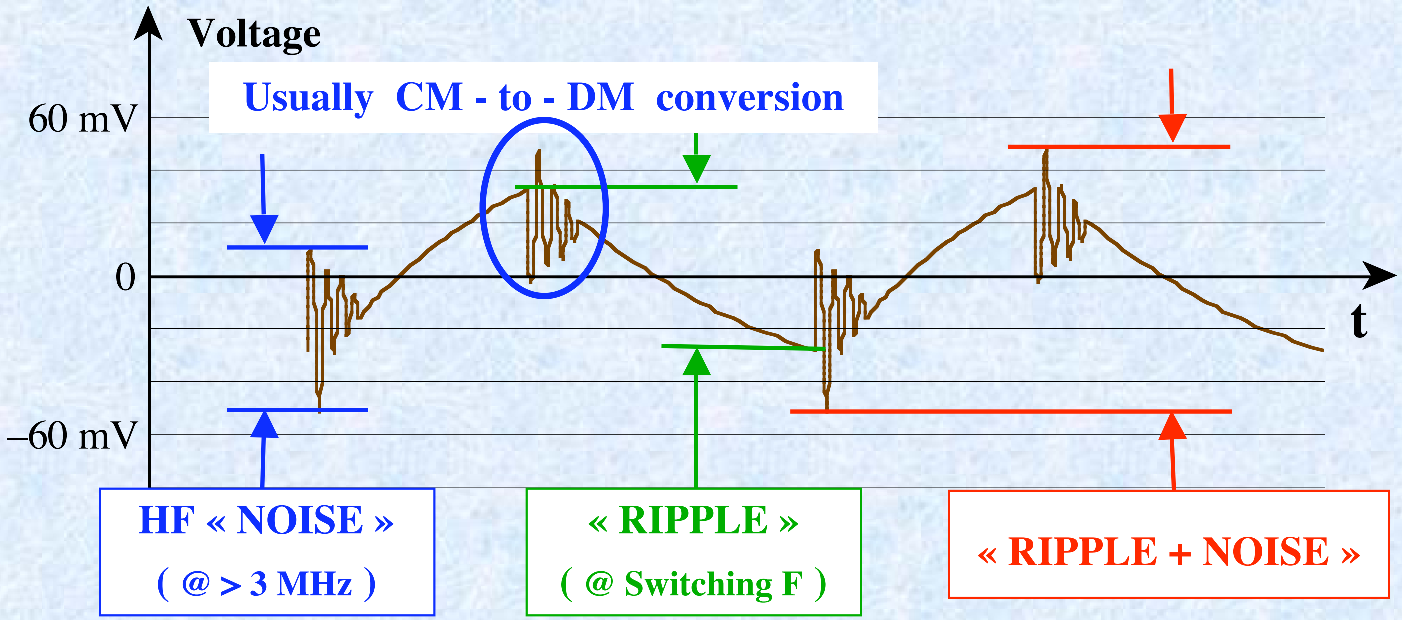


How to measure Output Ripple…



How to analyse Output Ripple





10 mV : Excellent — 100 mV : Average — 1 V : Excessive

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- **Common Mode Emissions**
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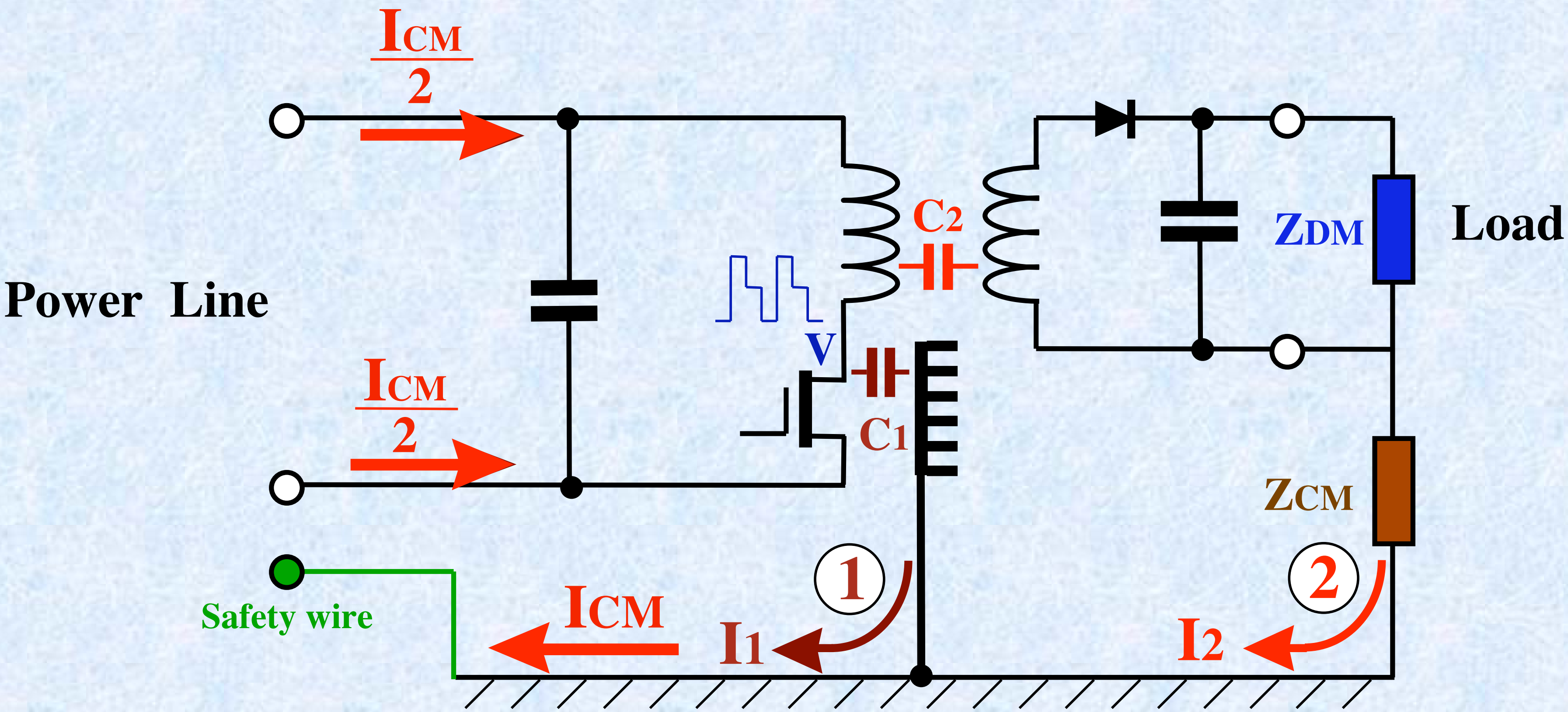
Common Mode interferences



1 $I_1 = C_1 \,.\, \Delta V / \Delta t$

I_1 doesn’t circulate through the load, so it is little disturbing.

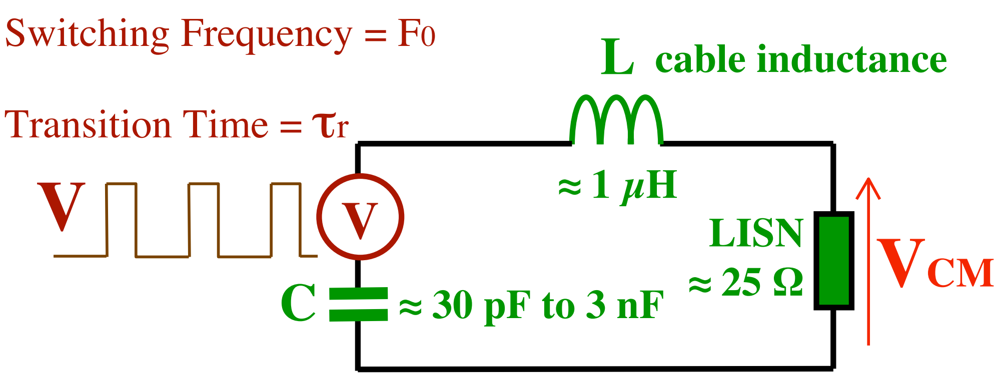
2 $I_2 \approx C_2 \,.\, \Delta V / \Delta t$ (but possibly modified by Z_{CM})

I_2 can circulate through the load, so it may be very disturbing.

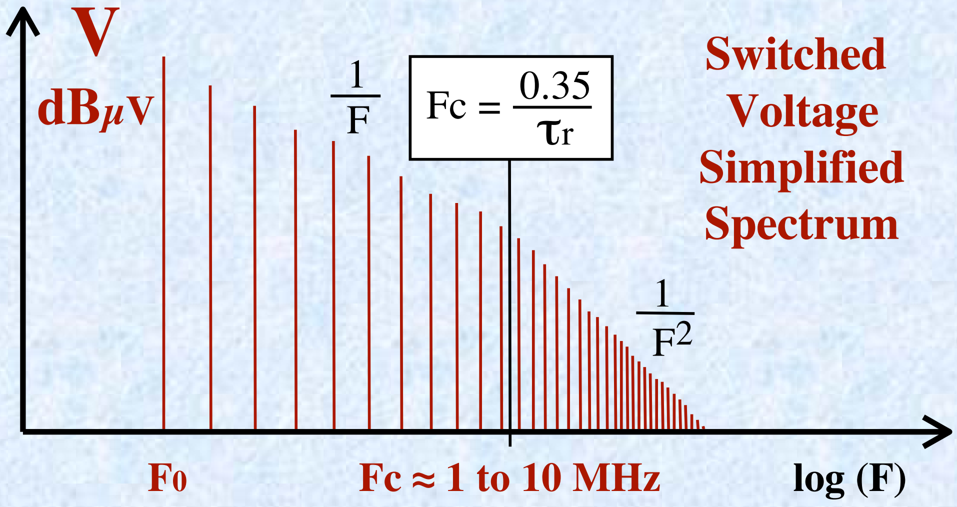
Measured total CM current : $I_{CM} = I_1 + I_2$

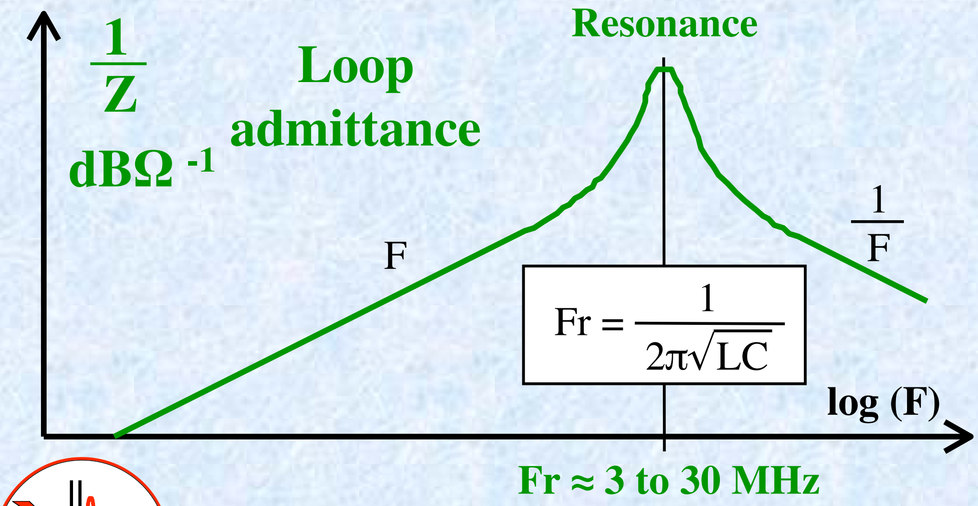
Common Mode Emission Spectrum Without Filtering

Converter CM Equivalent Scheme

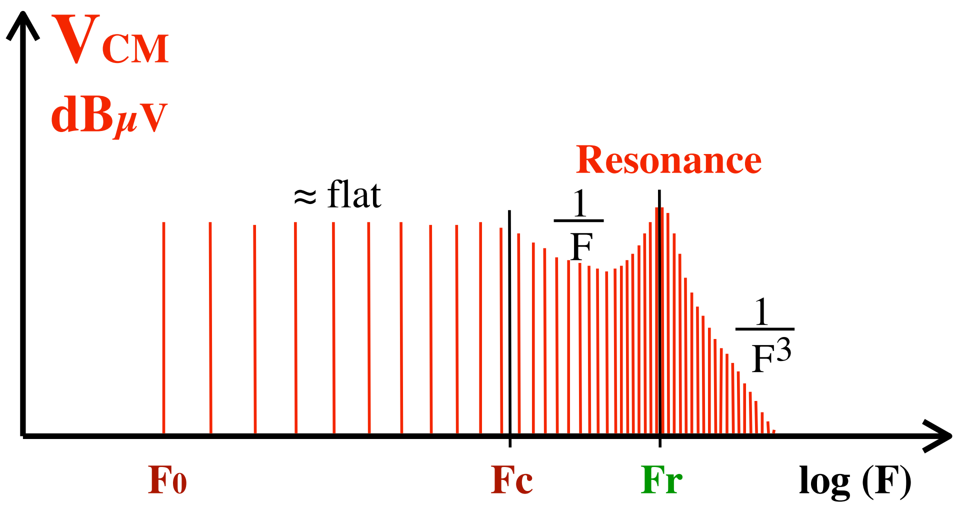


C : Parasitic cap between "hot conductors" & ground

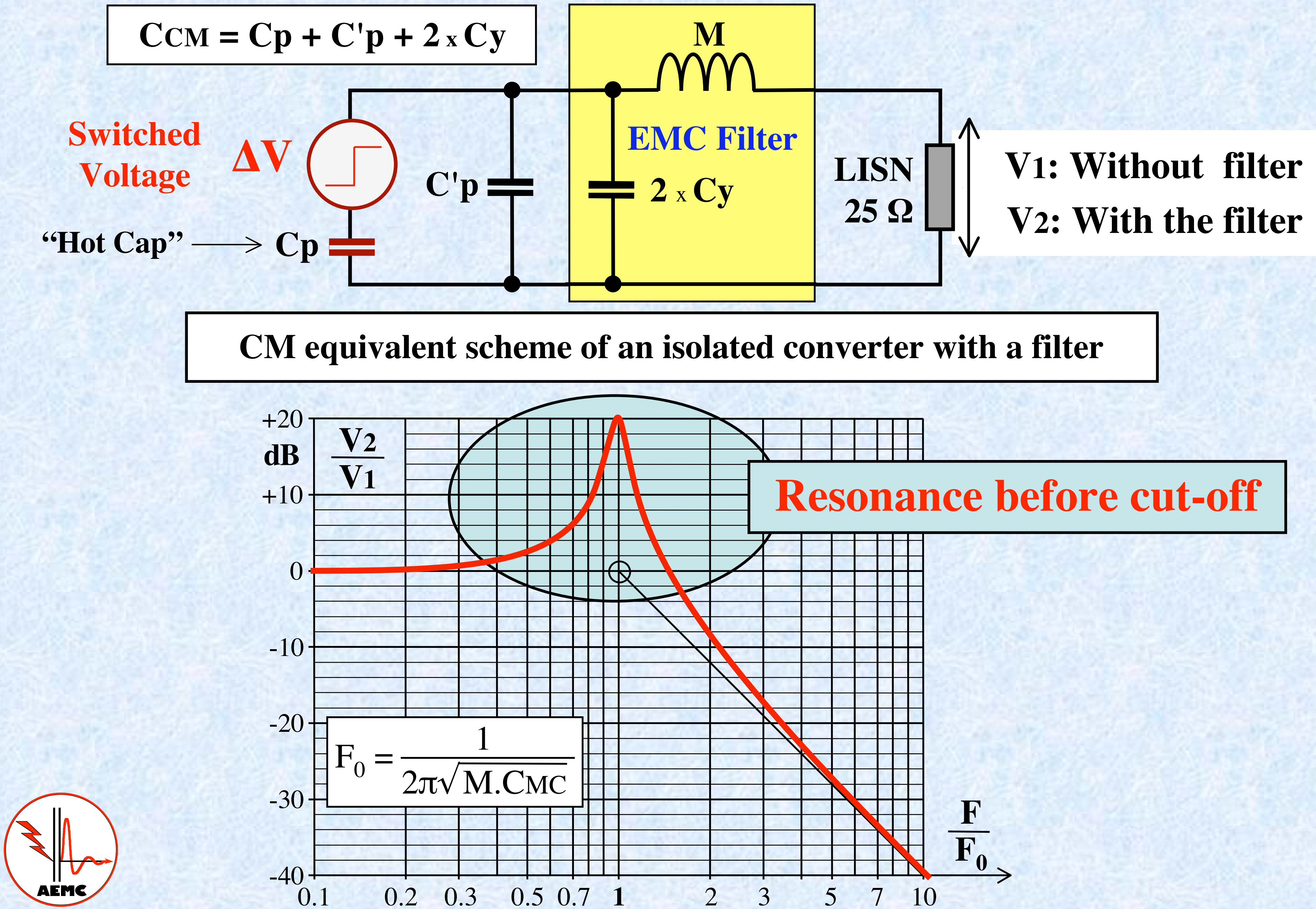




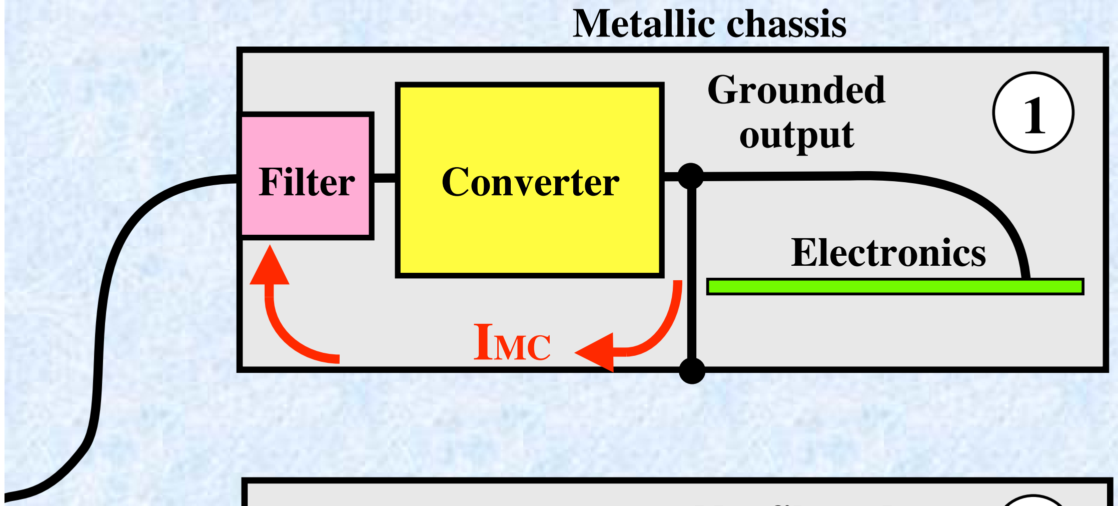
Convolution Result



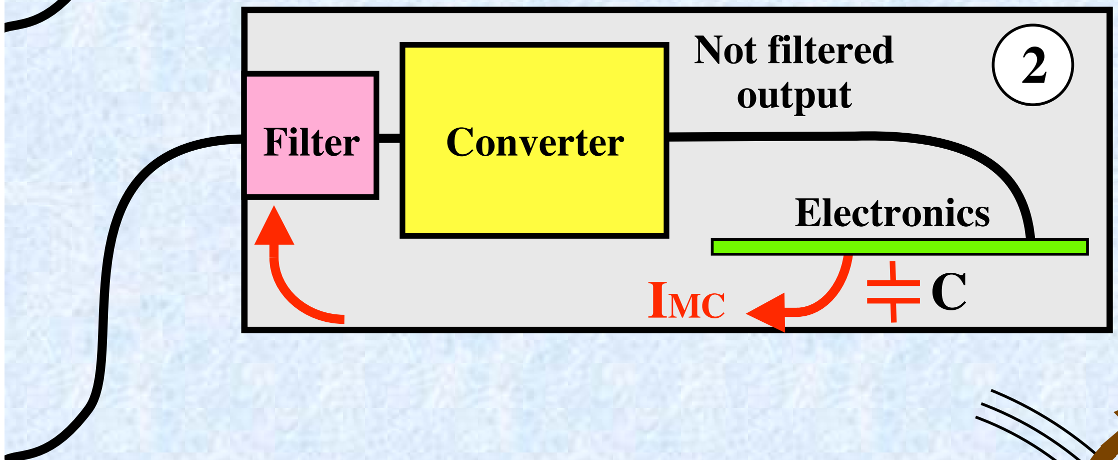
Insertion Loss of an EMC Common Mode Filter



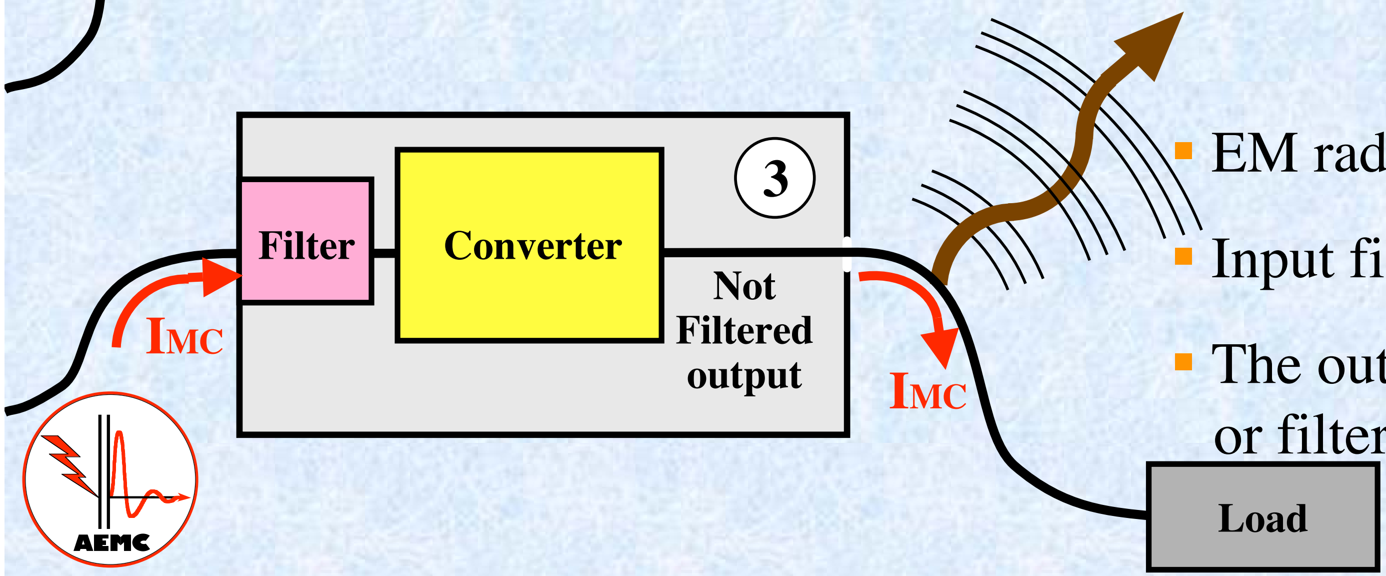
The 3 cases of Primary-to-Secondary Common Mode



- No disturbance outside of the chassis
- No CM noise in electronic circuits
- EMC filter easy to optimize

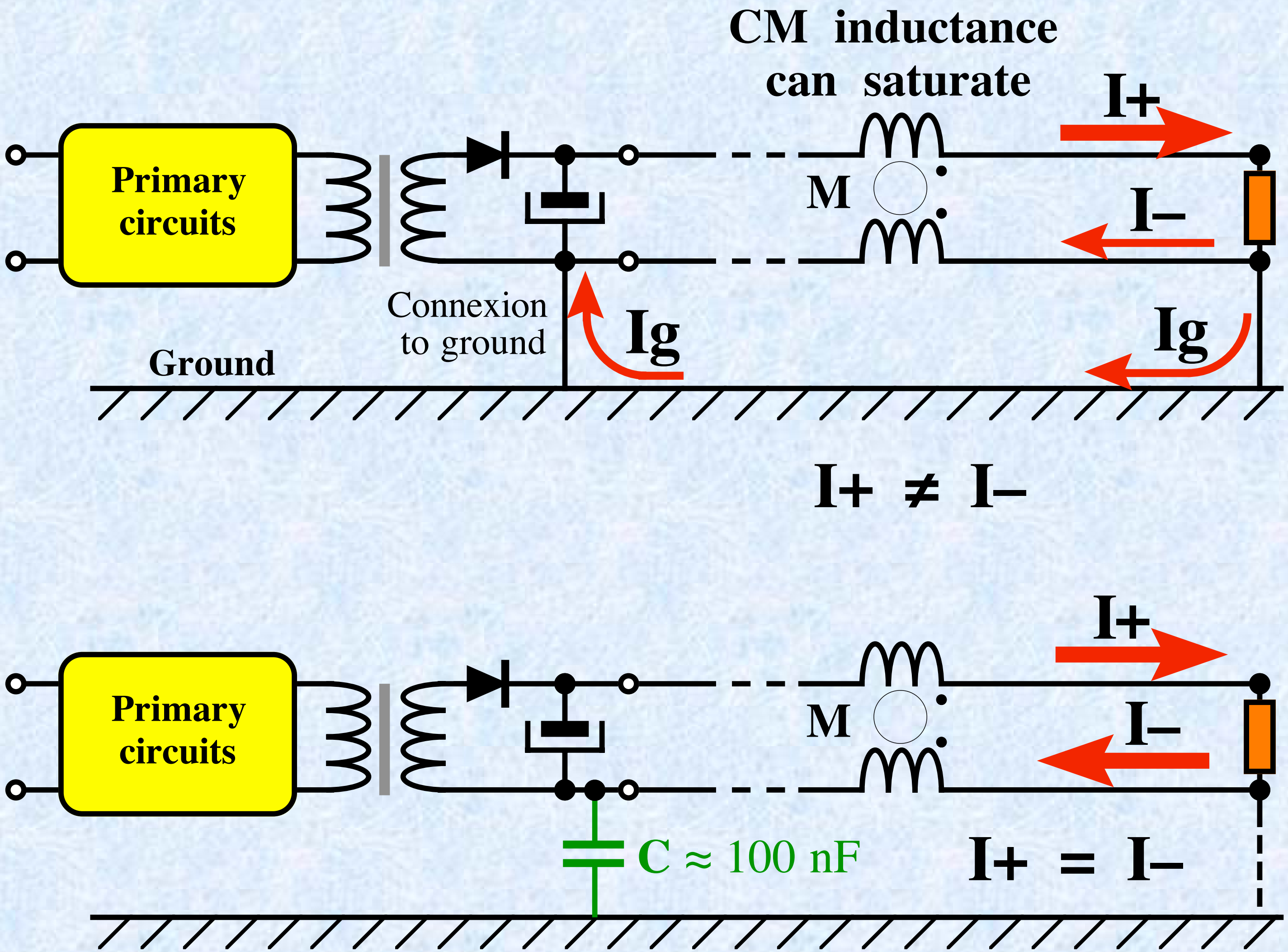


- No disturbance outside of the chassis
- CM Noise through electronic circuits
- EMC filter more difficult to optimize



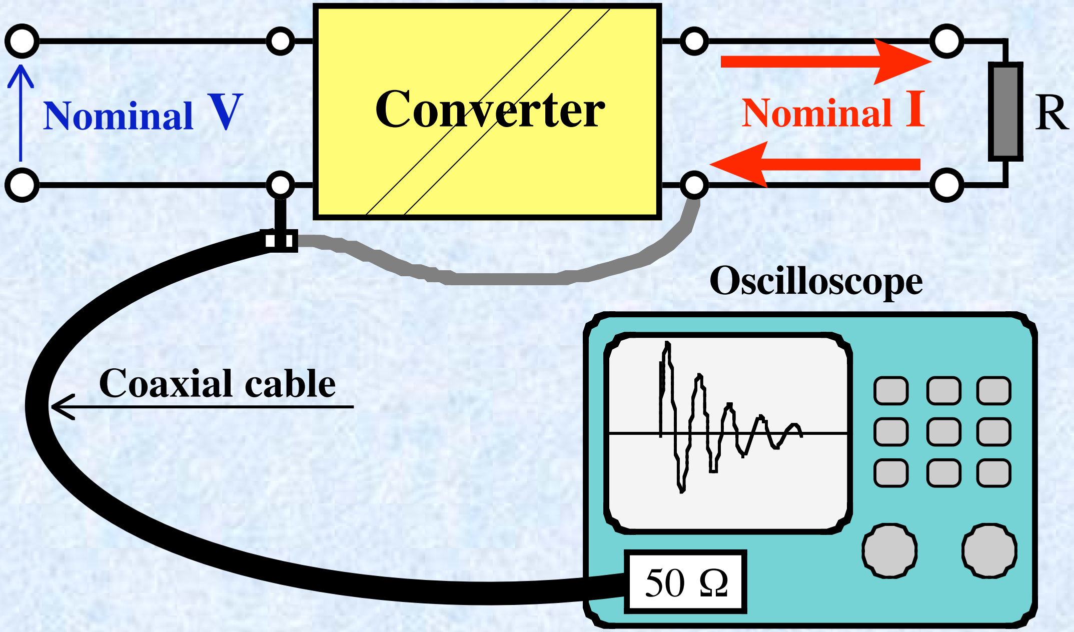
- EM radiations outside of the chassis
- Input filter impossible to optimize
- The output cable must be shielded or filtered

To float or not to float the output, that's the question…



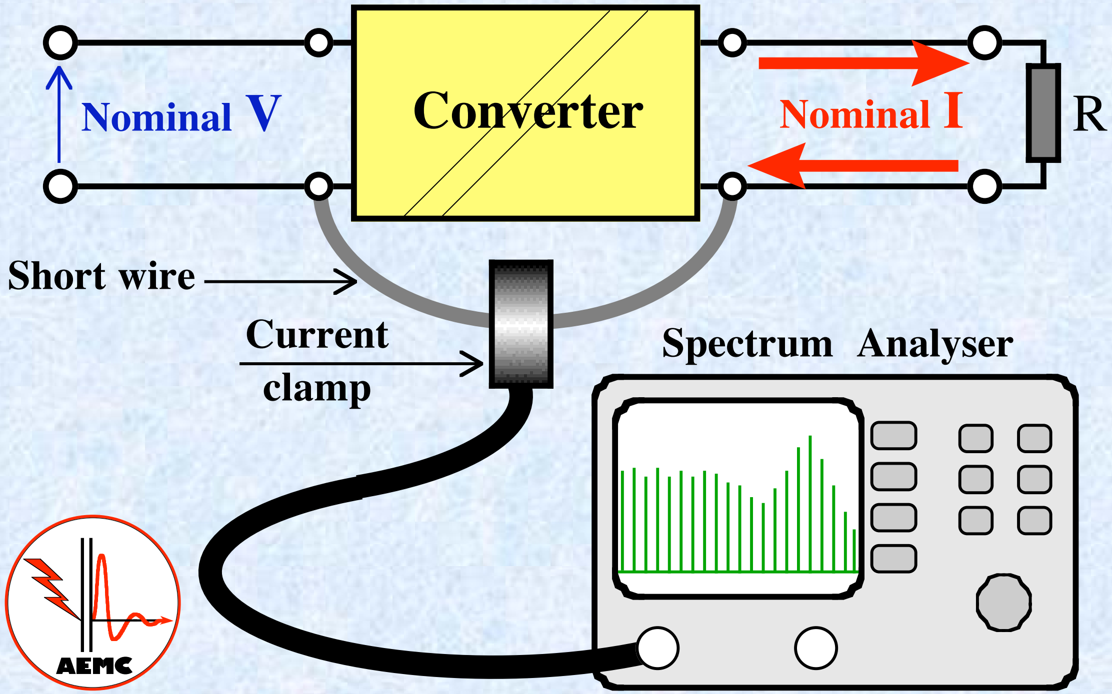
A (nearly) universal solution

How to measure Primary - to - Secondary C. M. current ?



Time measurement

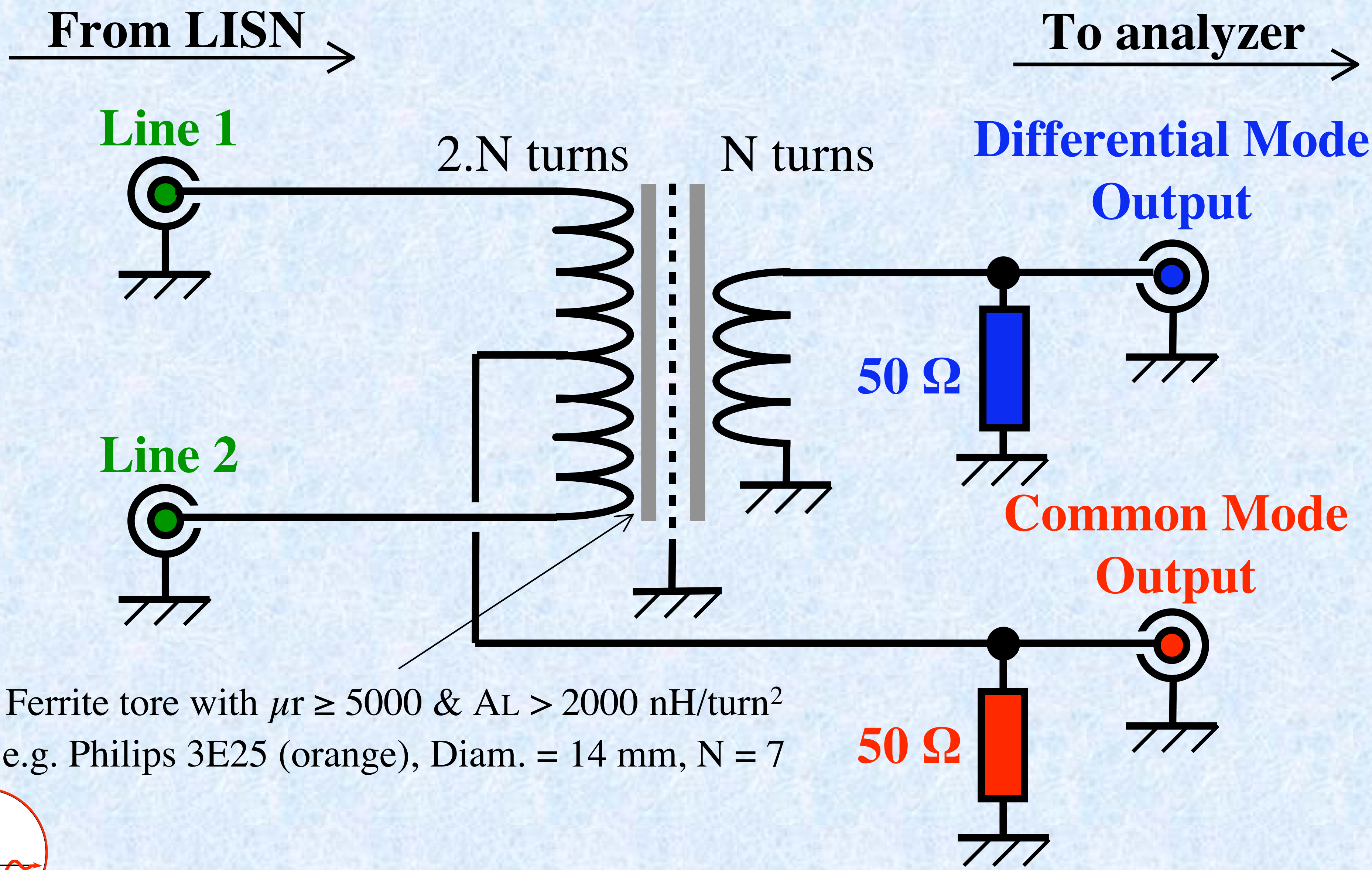
- 50 mV/mA sensitivity
- 100 MHz bandwidth
  - 1 mA peak-peak = Excellent
  - 10 mA peak-peak = Average
  - 100 mA peak-peak = Excessive



Frequency measurement

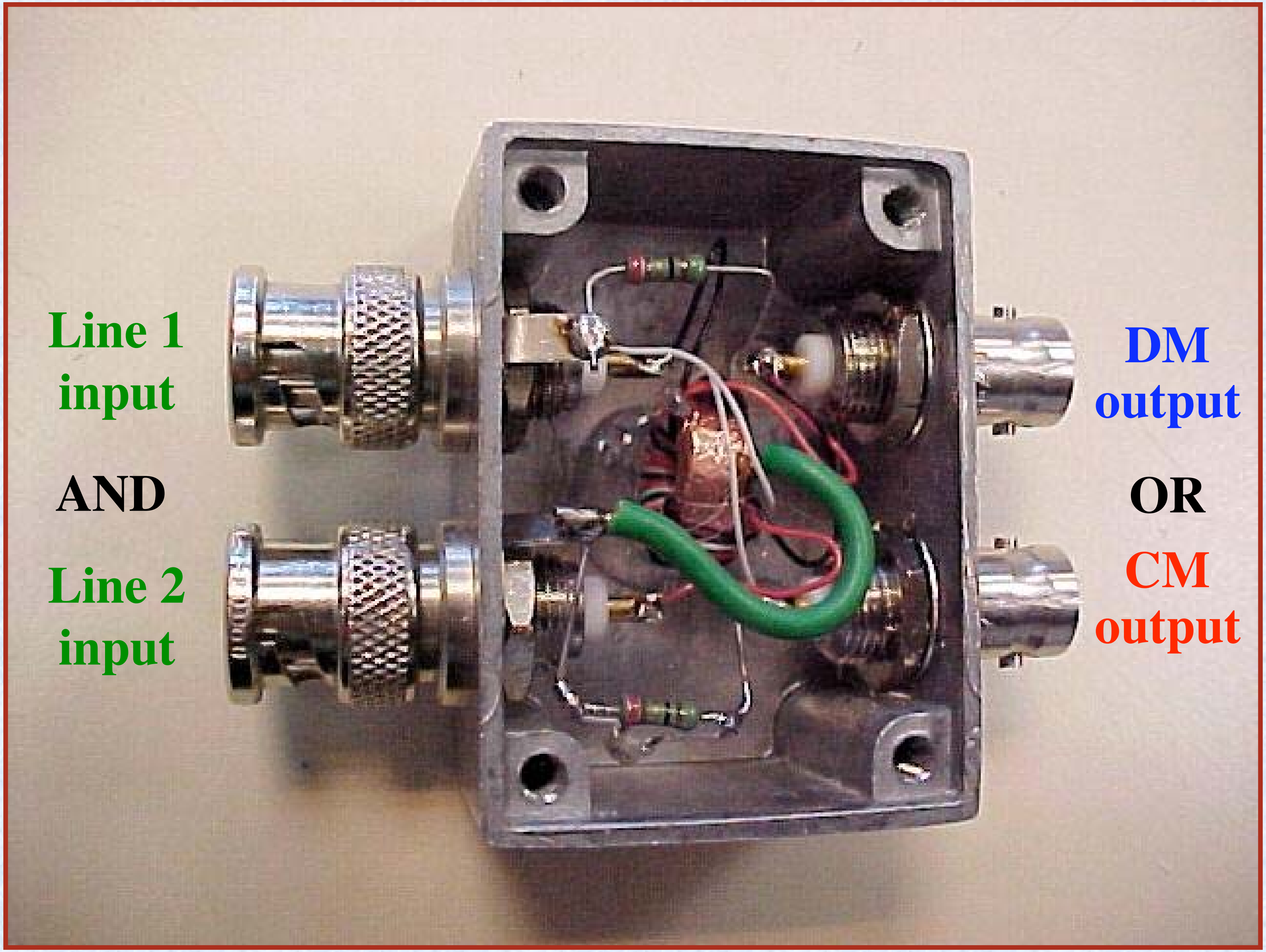
- 9 or 10 kHz RBW, Peak detection
- Span : 0.1 to 50 MHz (100 MHz)
  - 10 dBμA = Excellent
  - 30 dBμA = Average
  - 50 dBμA = Excessive

This simple " CM / DM SEPARATOR " reduces by 10 + the time and difficulty to optimize a single-phase EMC filter

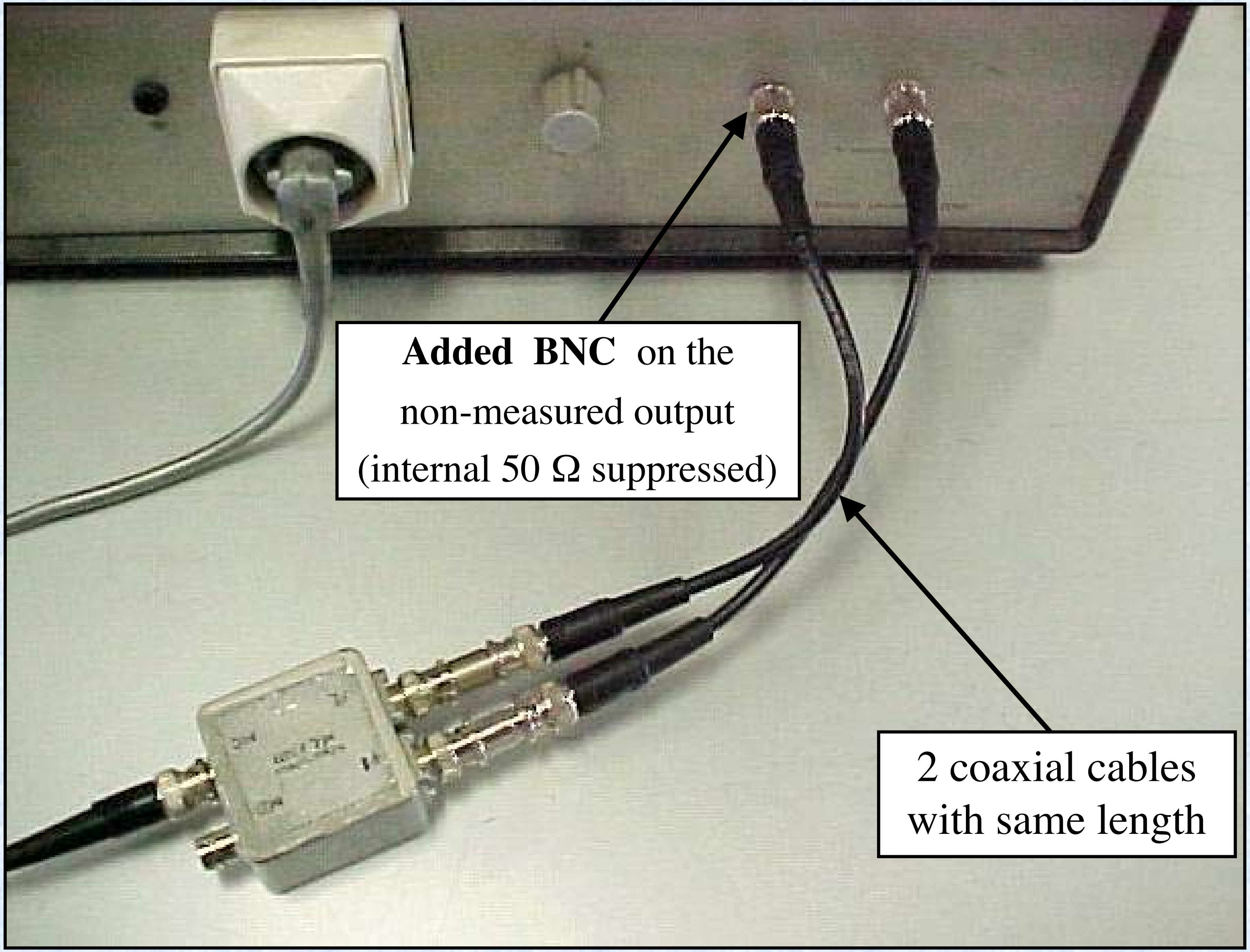


Ferrite tore with $\mu r \geq 5000$ & $A_L > 2000$ nH/turn^2
e.g. Philips 3E25 (orange), Diam. = 14 mm, N = 7

Practical realisation of a " CM / DM SEPARATOR "



CM / DM separator adaptation on a commercial LISN



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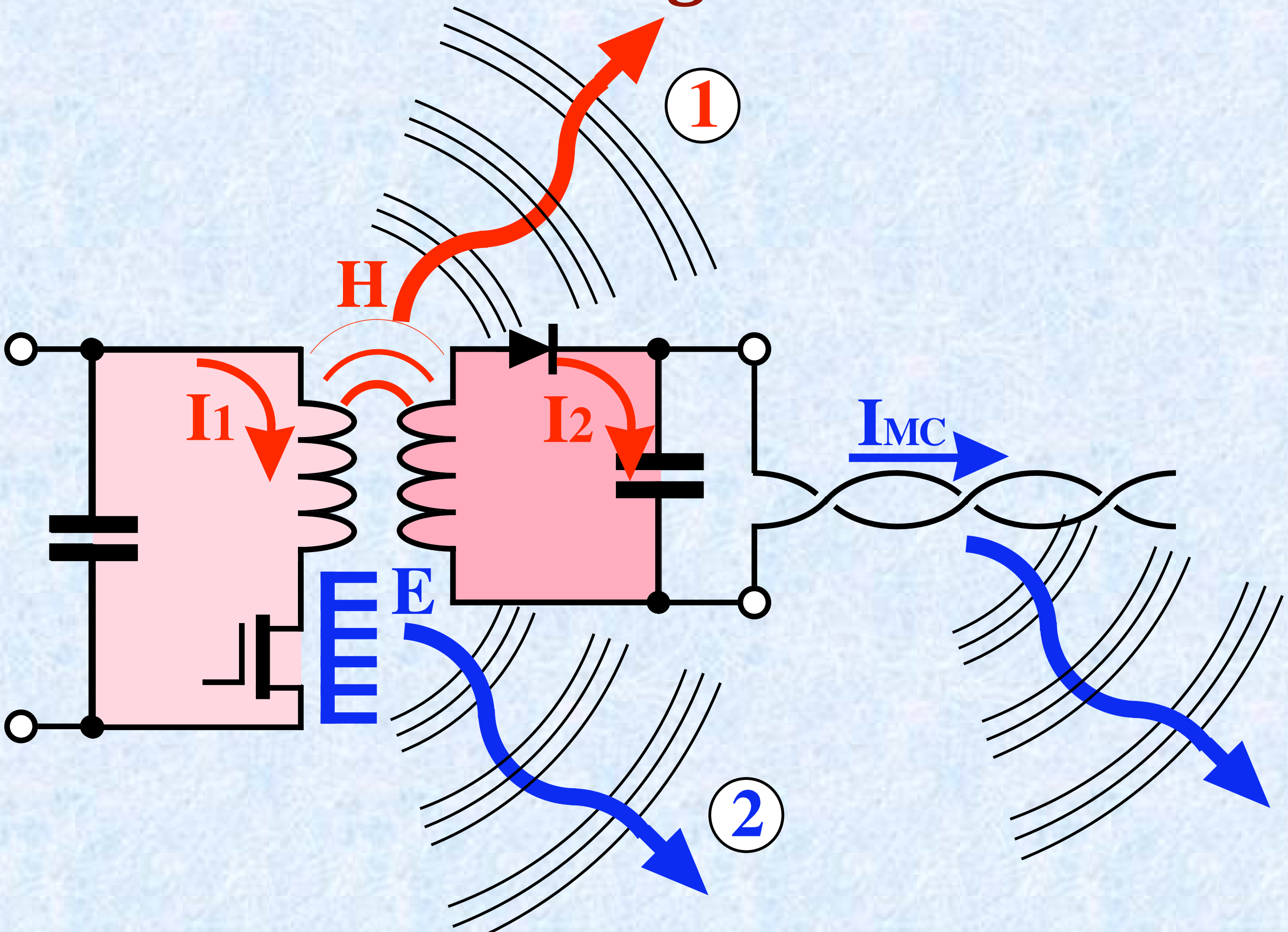
Sources of Electromagnetic Radiations



① **Sources of H field :**

Leakage fields of windings

Secondary loop areas

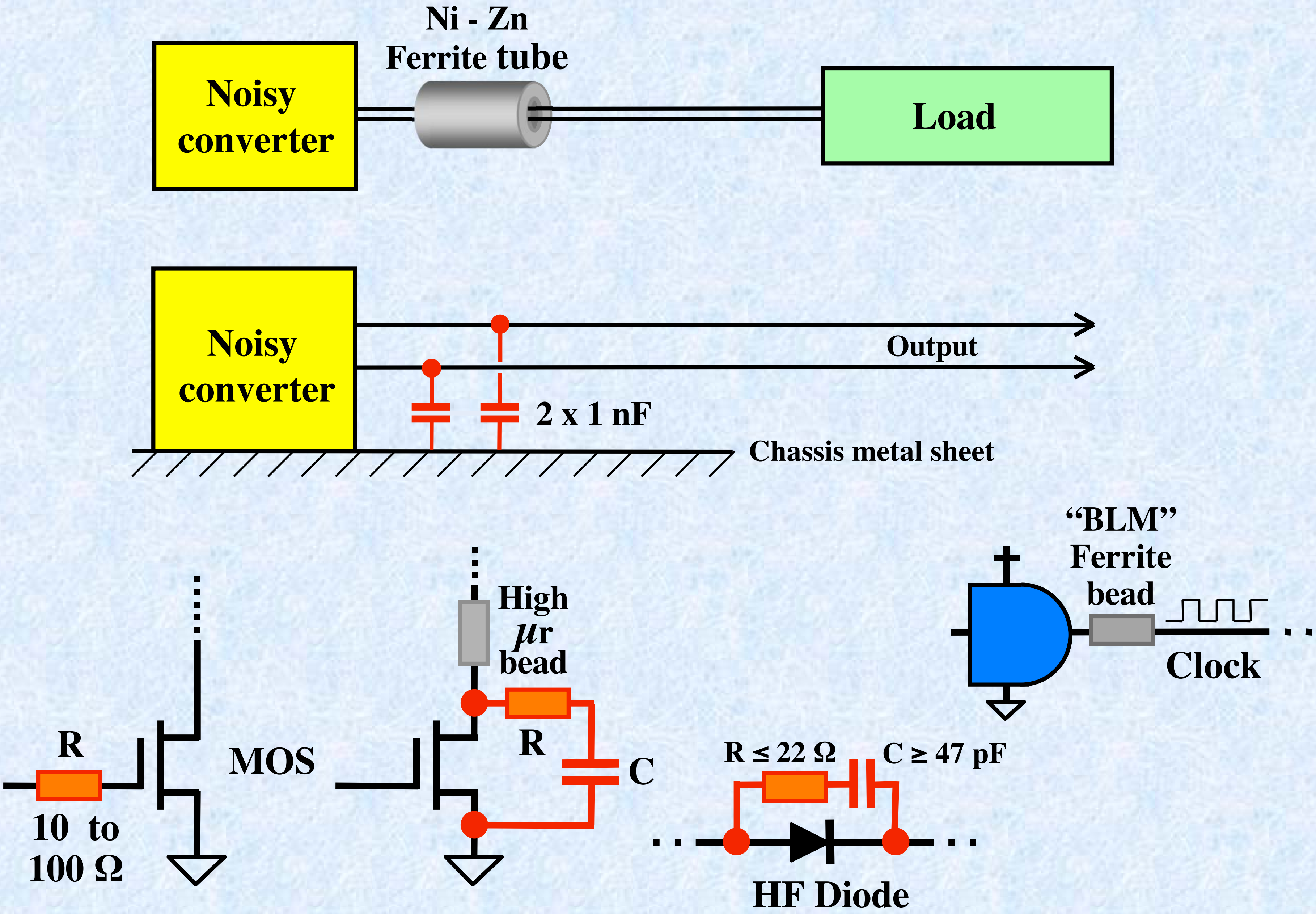
Primary loop area

② **Sources of E field :**

High ΔV/Δt conductive parts (Heat sink, ferrite core…)

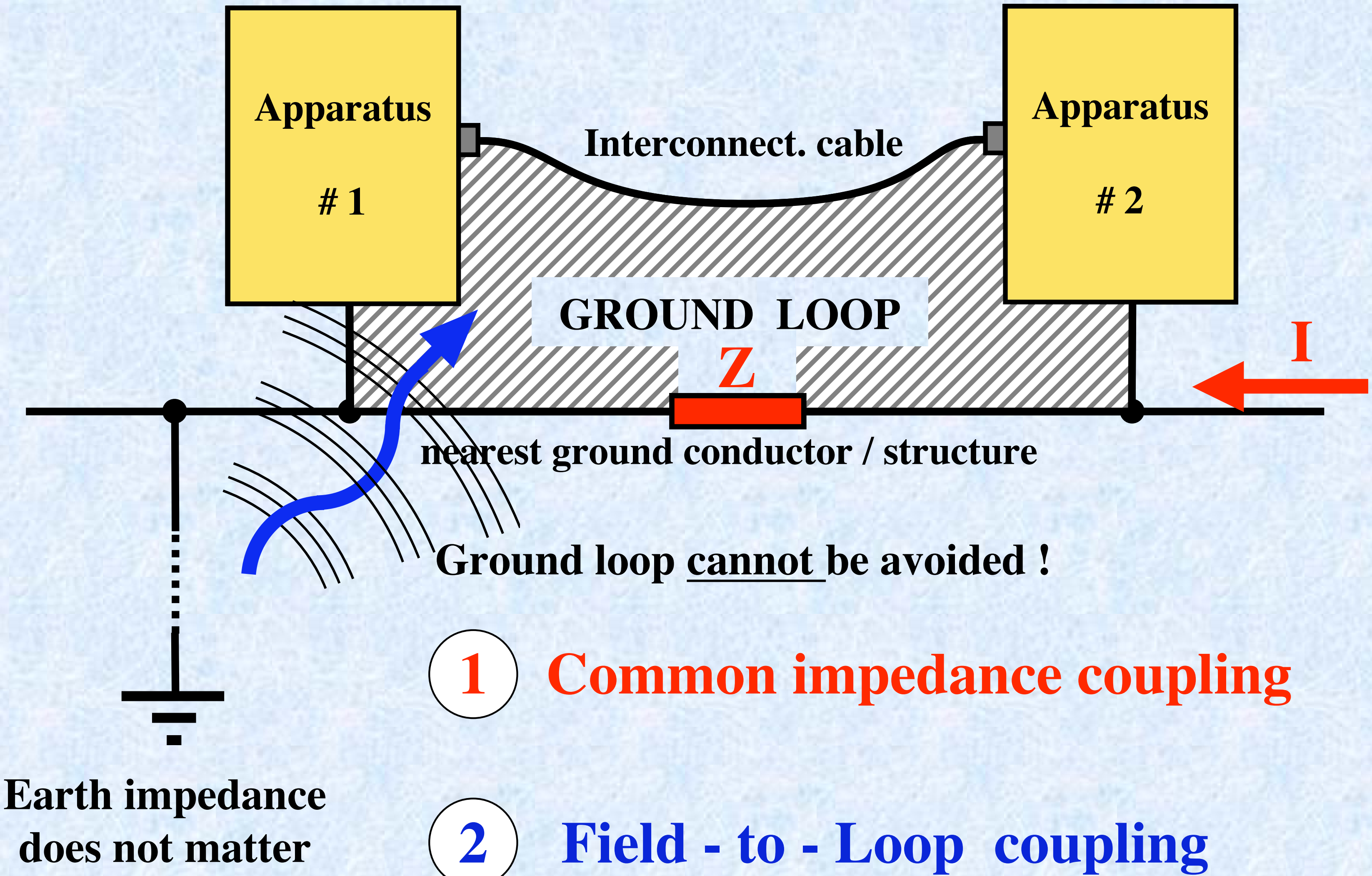
HF insufficiently filtered cables (e.g. output cable)

HF solutions must be installed close to the sources



Even small converters (few W) can be very noisy (I/O CM & radiation)

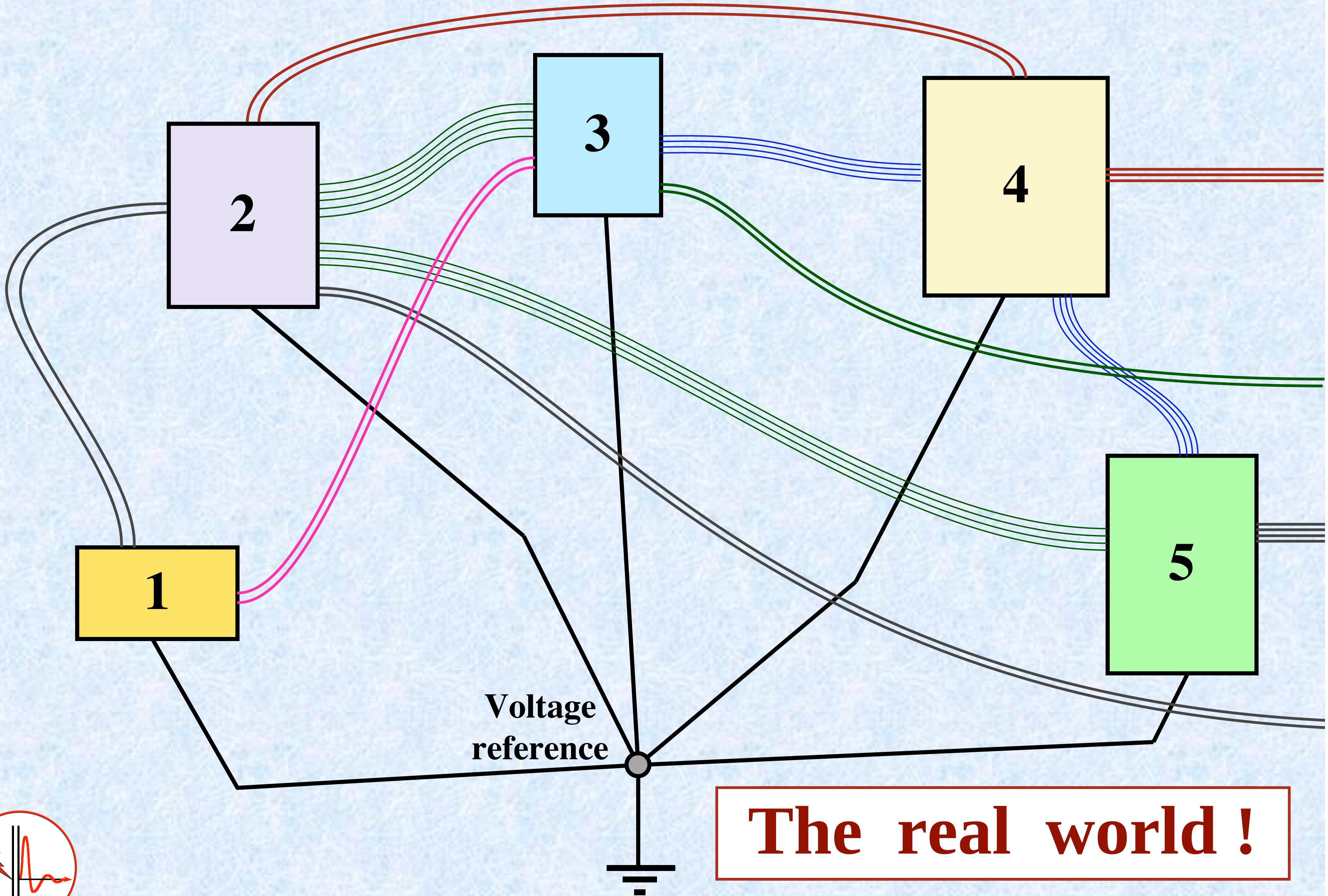
Ground Loop : Definition & Effects



1 Common impedance coupling

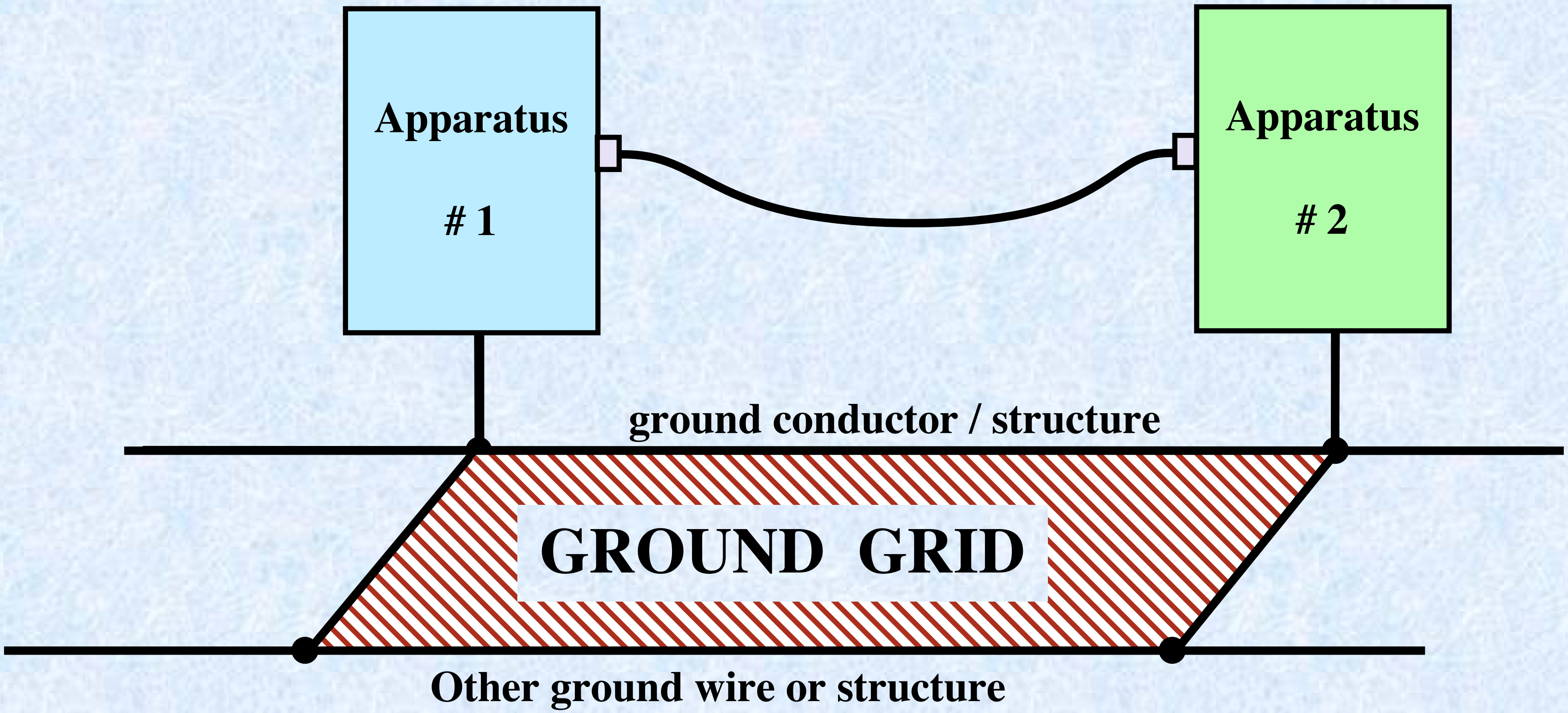
2 Field - to - Loop coupling

Star Grounding : Principle & Reality



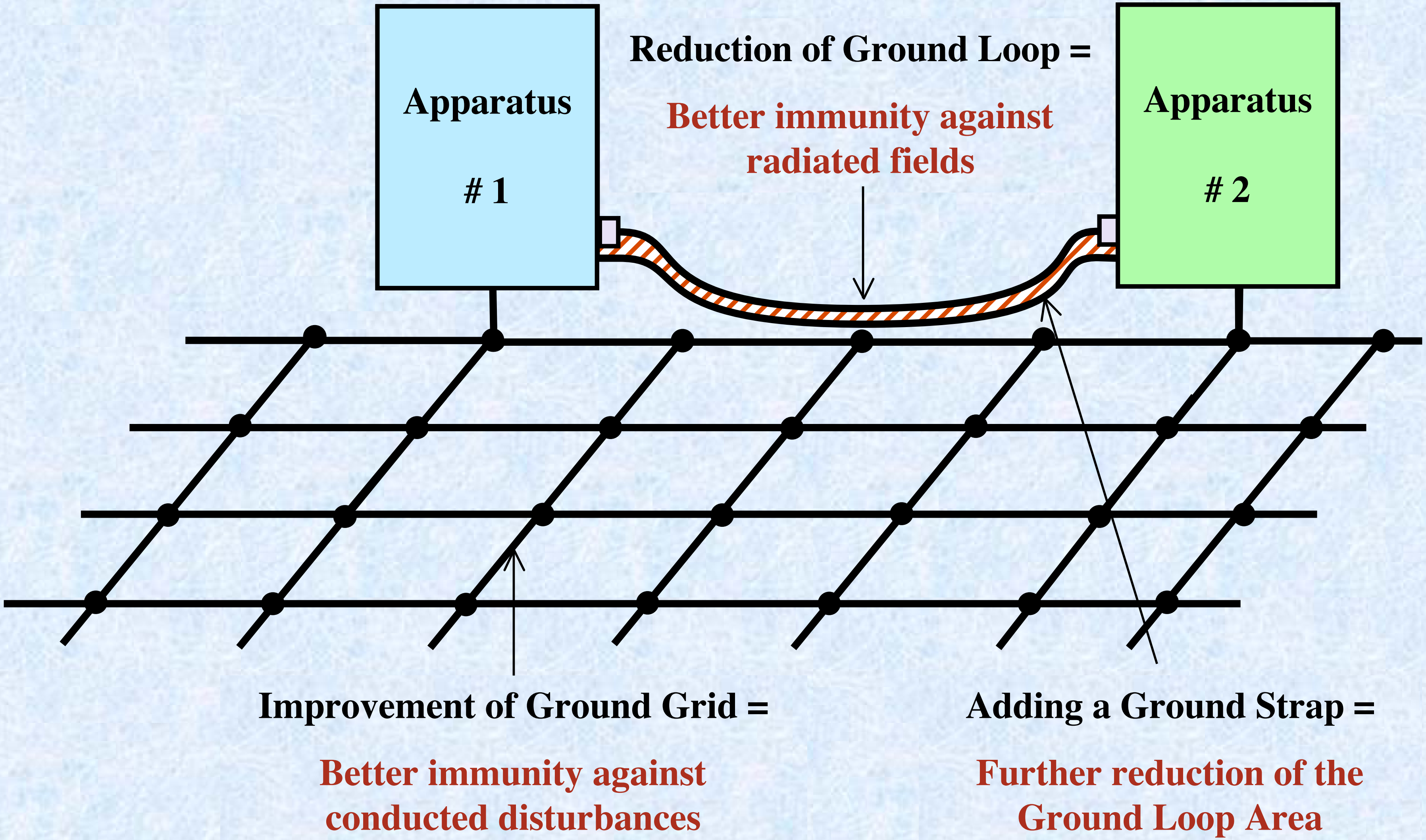
The real world !

Ground Grid : Definition & Effects



How to improve immunity ?

Ground Grid : Definition & Effects



A GROUND GRID is highly recommended !

Where to connect the shielded cables braid ?

- **Any power cable :** **At both ends, to chassis ground, without pigtail.**
- **High frequency coax :** **At both ends, to chassis ground, without pigtail.**
- **Digital link (except coaxial Ethernet):** **At both ends, to chassis ground…**
- **High impedance source (> 10 kΩ):** **At both ends, to chassis ground…**
- **Any cable inside an equipment :** **At both ends, to chassis ground…**
- **Any outer shield (not signal return):** **At both ends, to chassis ground…**
- **Low voltage signal cable, with low frequencies to transmit, with a low impedance source, in a noisy environment, without balanced transmission (bad CMRR):** **At one end only**

… But then good immunity will be hard to achieve !

Avoid aluminium foil with a drain wire (without braid).

Please, let us remember…

- EMC is not black magic (Just simple physics…)
- Some measurement equipments are required
- Usually, only simple equipments are sufficient
- It's good to be experienced (& confident enough)
- It's important to understand how system works
- It's useful to methodically analyse what happens
- It's efficient to foresee and simplify EMC problems
- It's necessary to know the orders of magnitudes
- It's politically effective to be persuasive (& smiling)
- It's essential never to become discouraged !…

Questions ?