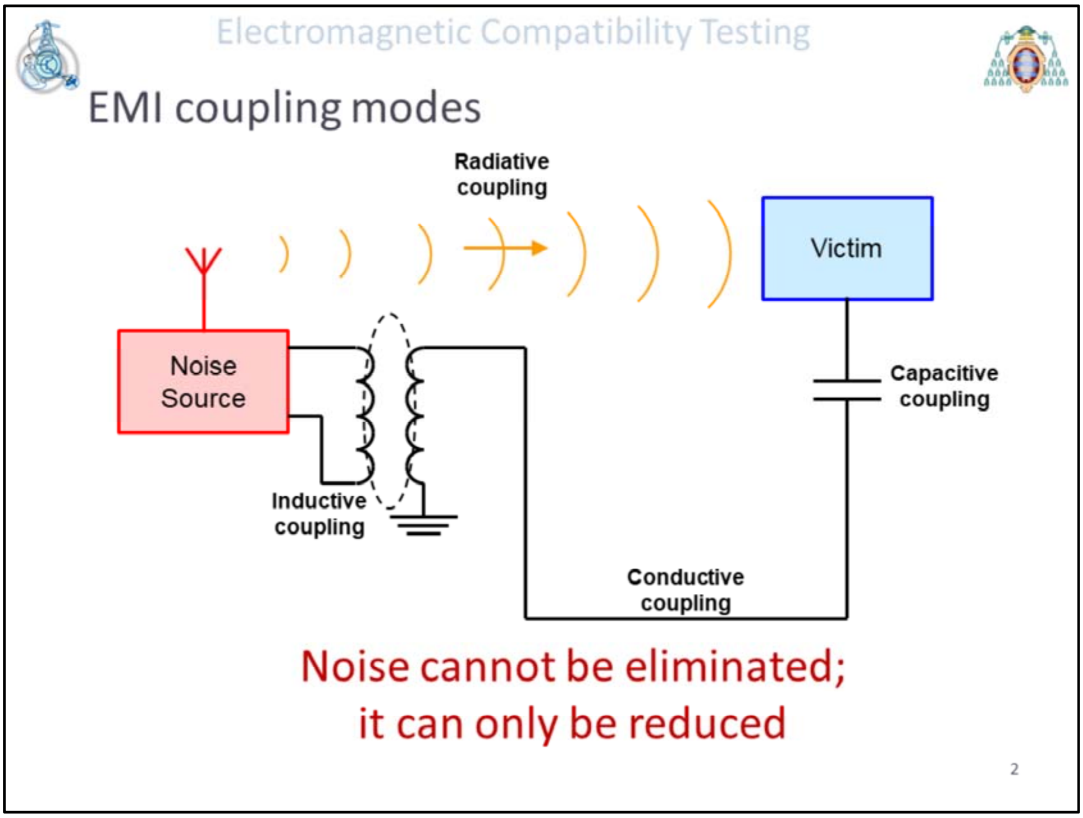
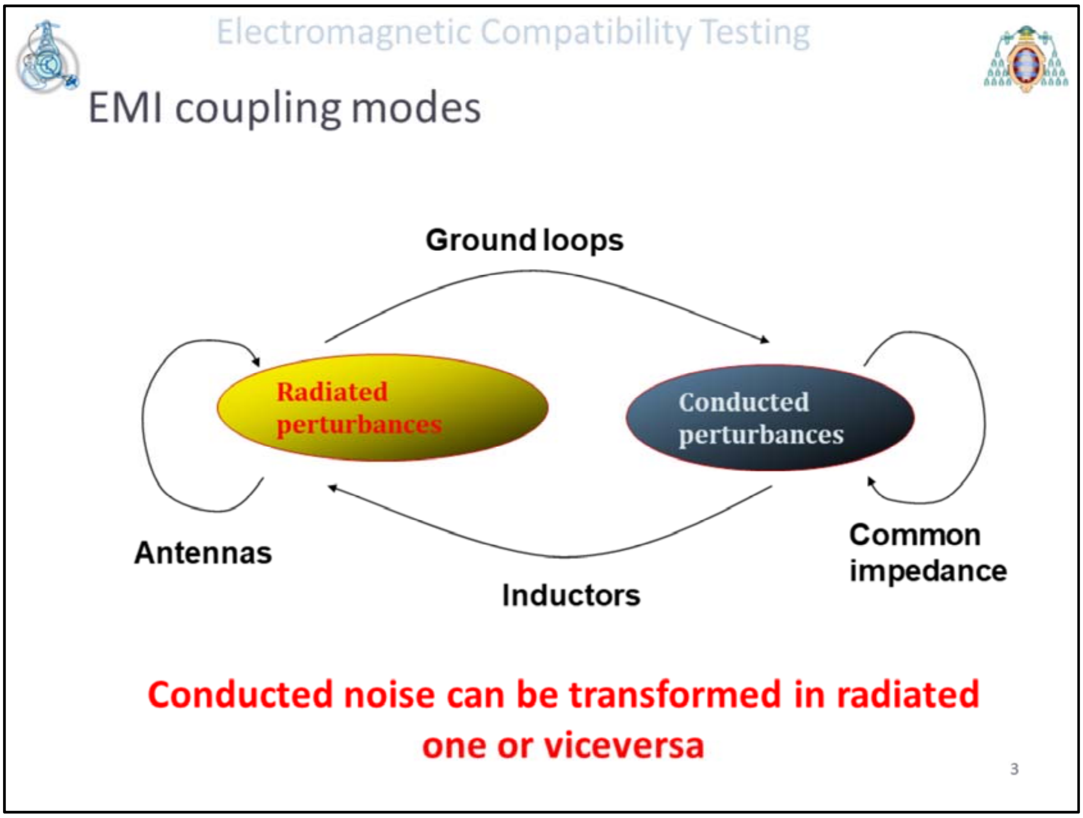
Electrical Energy Conversion and Power Systems

Universidad de Oviedo

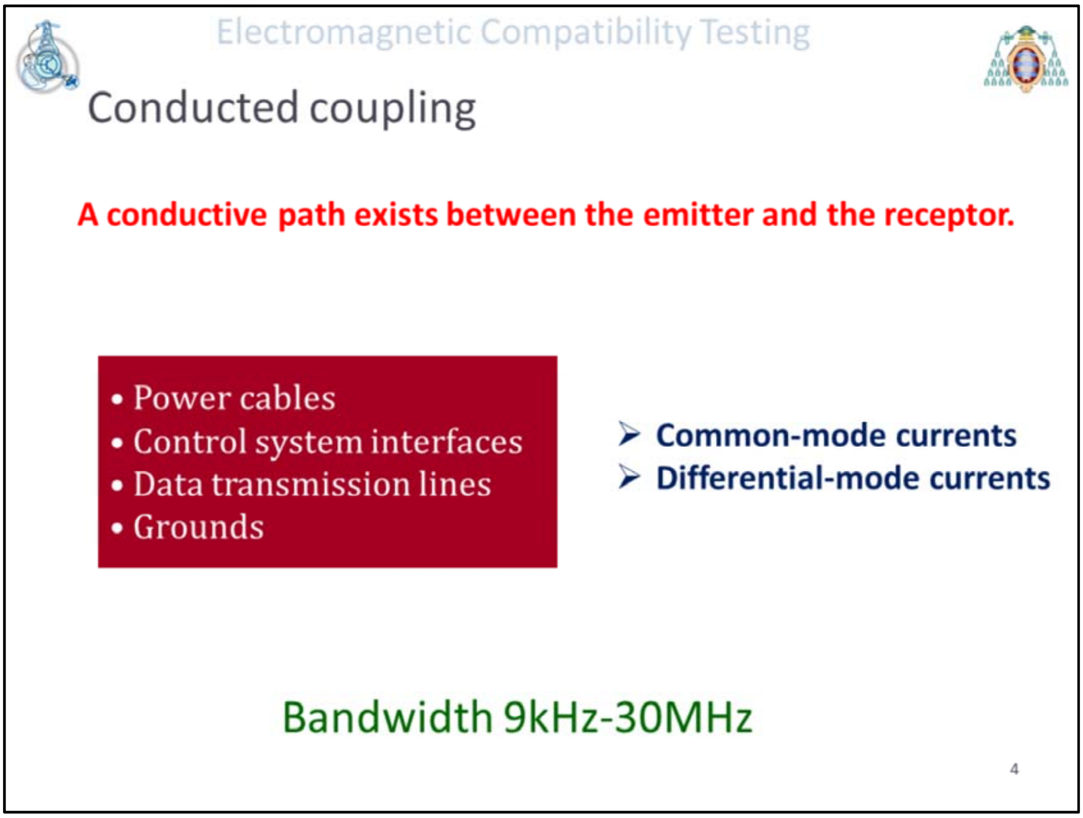
Coupling modes



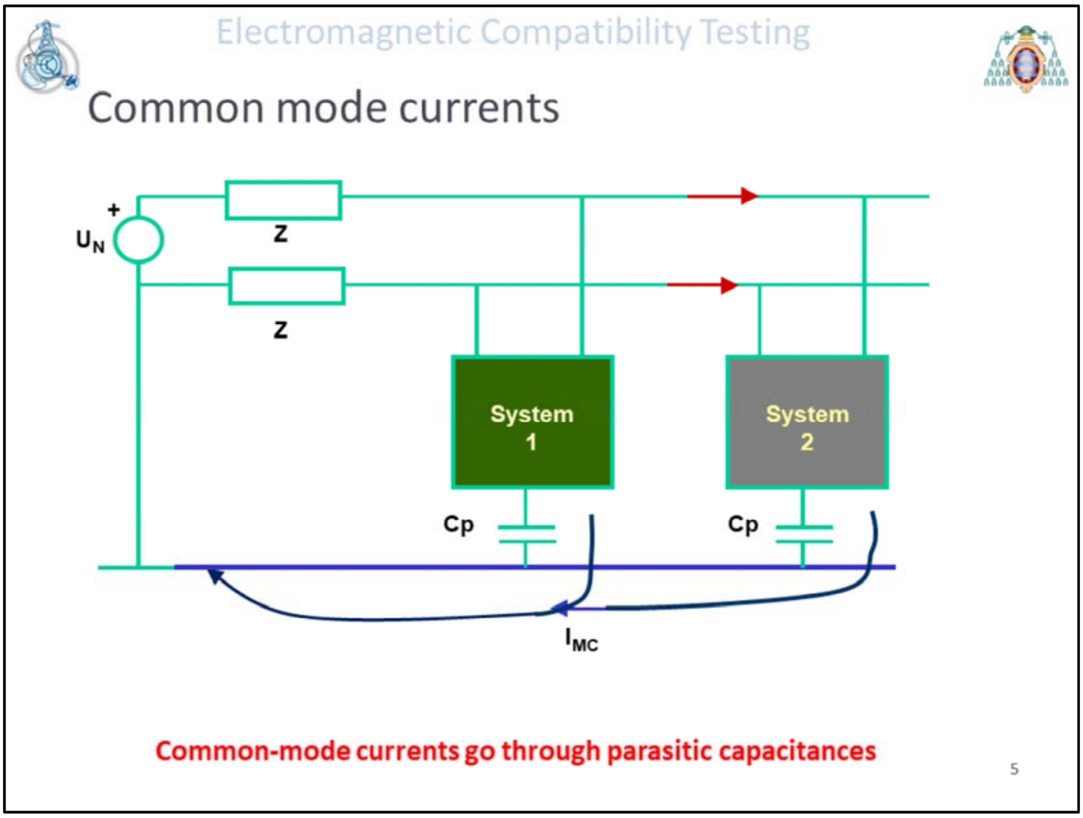
The electromagnetic noise generated by the equipment was reduced to comply with the regulations, but we cannot set the objective of eliminating it totally.



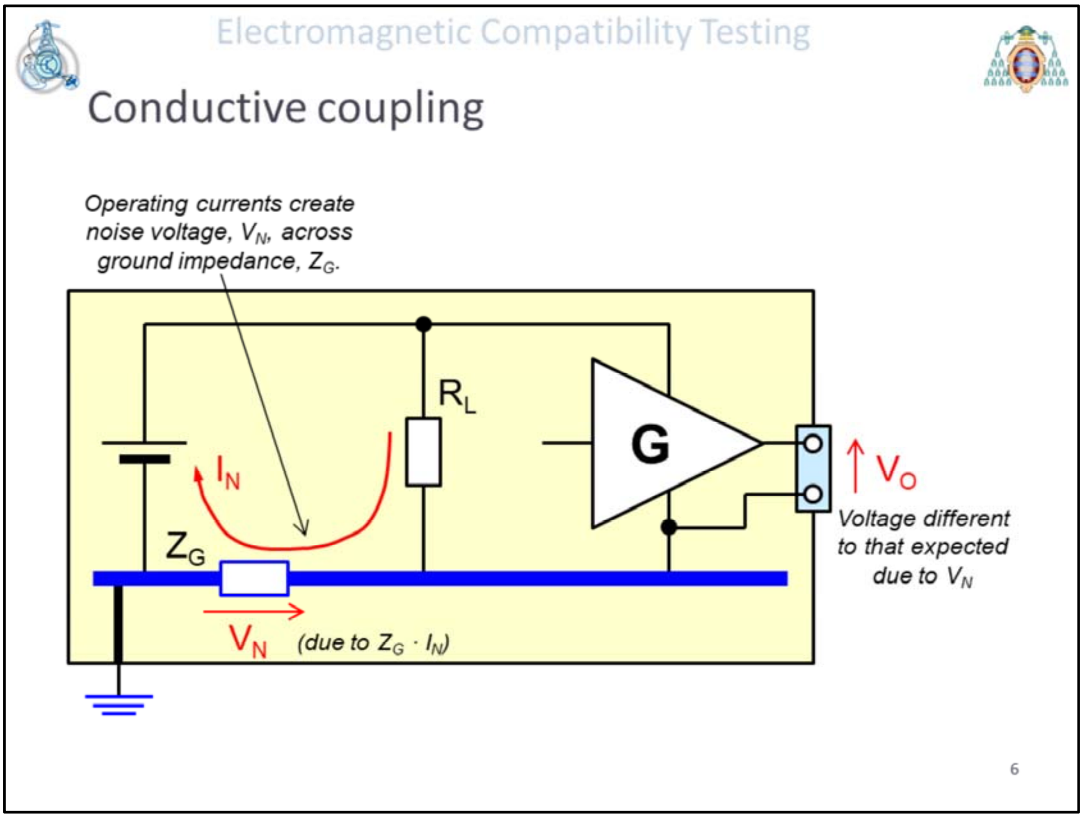
The harmonics of current flowing through the cables can also become electromagnetic radiation since the cables can behave like antennas. For the same reason, radiated electromagnetic noise can become noise voltages in the circuits since the tracks and the wiring can also act as antennas



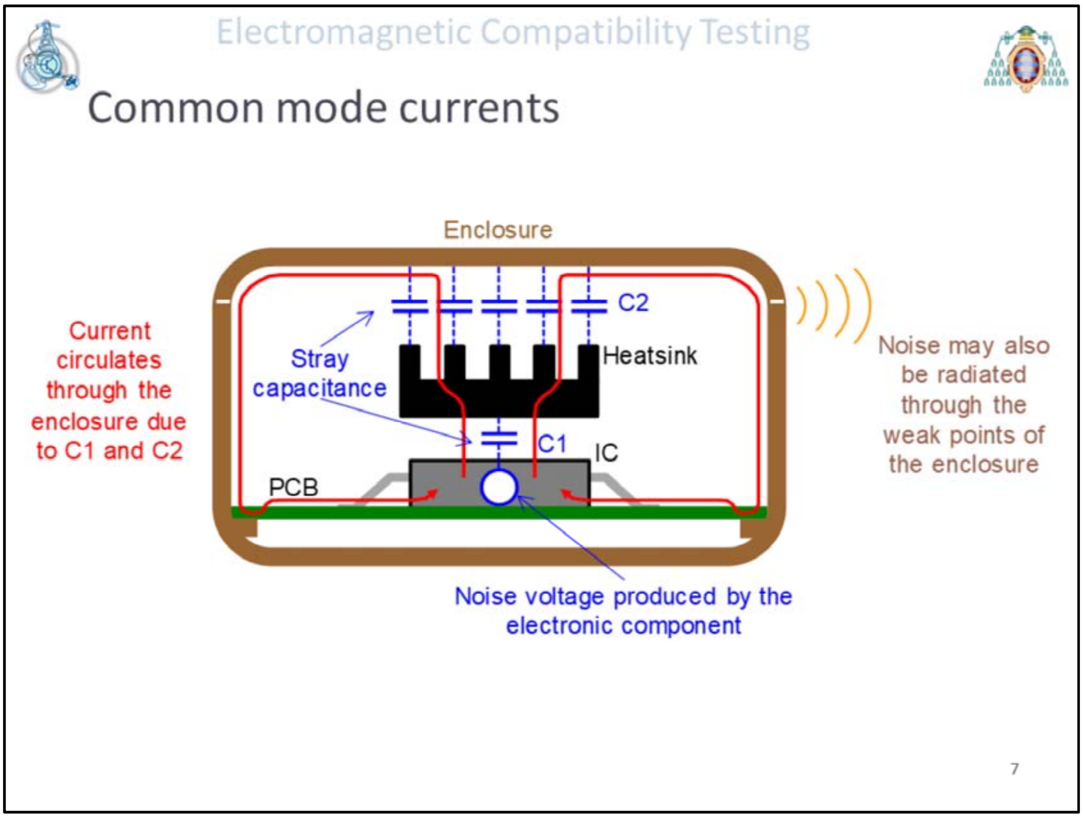
Conducted noise is analyzed between 9kHz and 30MHz. In order to eliminate this noise, it is very important to identify what type of currents generate it: common-mode currents or differential-mode currents.



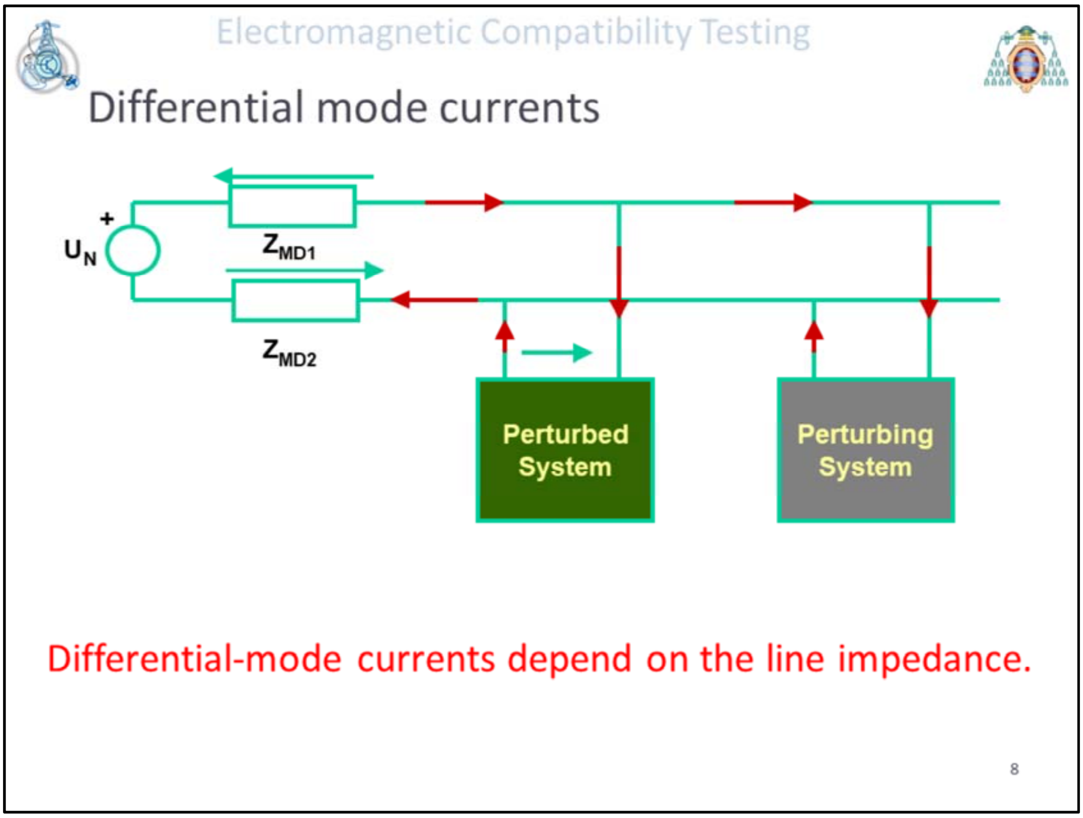
The common path for common-mode currents are the parasitic capacitances and their return through the mass of the circuit



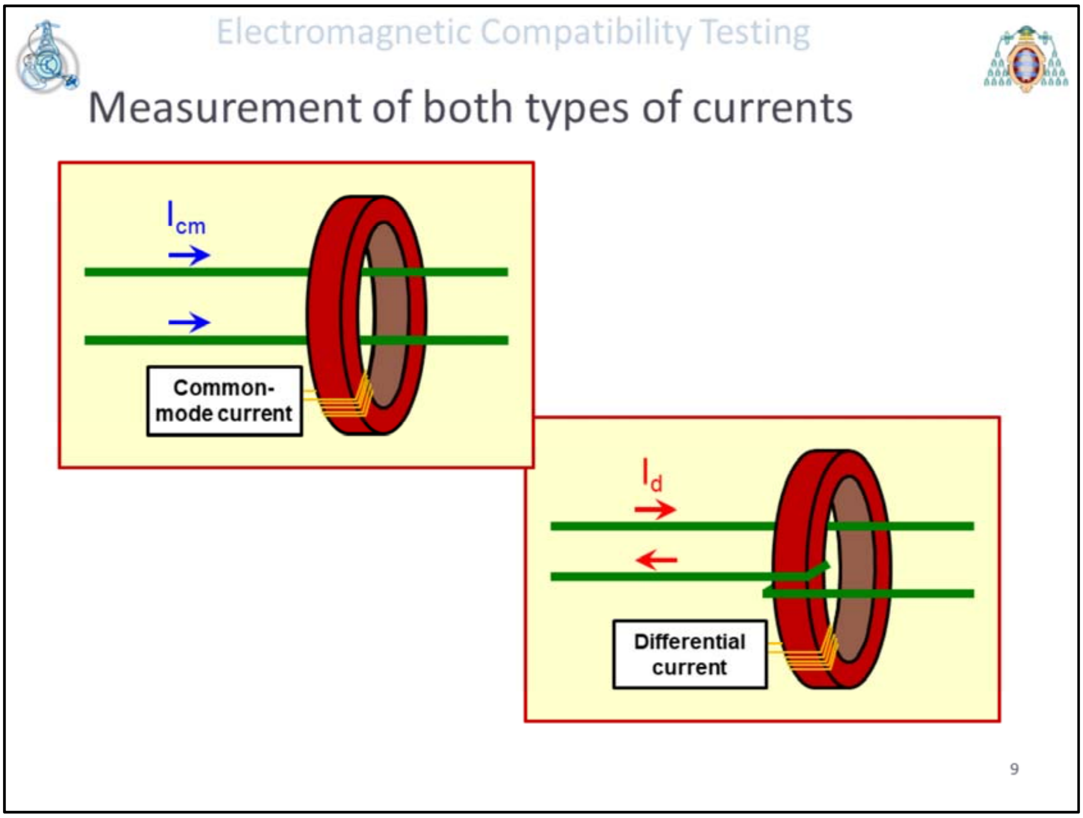
In this case current I_N causes a voltage drop across impedance Z_G in the ground connection. Since the amplifier G shares the same connection to ground, the output of said amplifier will be conditioned by the value of voltage V_N.



Metallic structures such as radiators, metal boxes, etc. present non-negligible parasitic capacitances due to their high surface area, thus offering a low-impedance path to common mode currents. It is very convenient to connect these structures to a zero potential.



Differential-mode currents are conditioned by the impedance of the line.



In order to identify the origin of electromagnetic noise in the equipment, it is convenient to identify the type of currents that generate it, since the solutions that can be provided differ depending on the type of current.

To measure common-mode current, both conductors are directly threaded through a toroid. By doing so, only common-mode currents will cause magnetic field in the same direction in the toroid. With this configuration, differential-mode currents through the cables will generate opposite magnetic fields in the magnetic core that cancel each other and do not generate voltage across the additional winding (top figure).

On the contrary, if one of the cables forms a loop around the toroid (bottom figure) only differential-mode currents create fields in the same direction in the magnetic core and, therefore, only these currents will induce a voltage across the additional winding.

CURRENT PROBES

TRANSFER IMPEDANCE

The reading of the current probe output, V (in microvolts), divided by the current probe transfer impedance, Z_T results in the CM current in the conductor under test, I_C (in microamps).

$$I_C = V/Z_T$$

$$I_C\,(dBuA) = V(dBuV) - Z_T(dB\Omega)$$

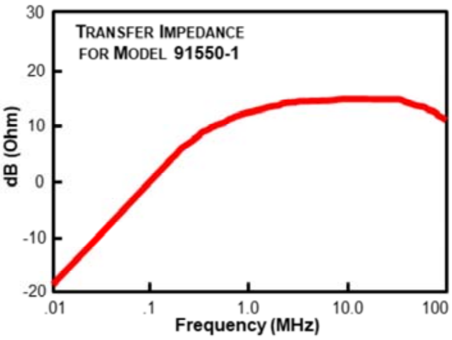
To determine the typical transfer impedance of the current probe throughout the frequency range, make a known RF current (I_C) flow through the primary test conductor and note the voltage (V) obtained across a 50-Ohm load.

The Fischer F-33-1 probe, which is a commonly used troubleshooting tool, has a flat frequency response from 2 to 250 MHz. Its transfer impedance is about 5Ω (+14 dBΩ, as show on the graph in the next slide). Thus, a 1-μA current will give rise to a 5-μV output voltage across the current probe.

CURRENT PROBES

PREDICTING PASS/FAIL

To predict whether a particular cable will pass or fail radiated emissions, measure the CM current at the offending frequency, determine the transfer impedance of the probe, Z_T (dBΩ), and solve for I_C



I_C(dBuA) = V(dBuV) – Z_T(dBΩ)

To calculate the E-field level (in V/m):

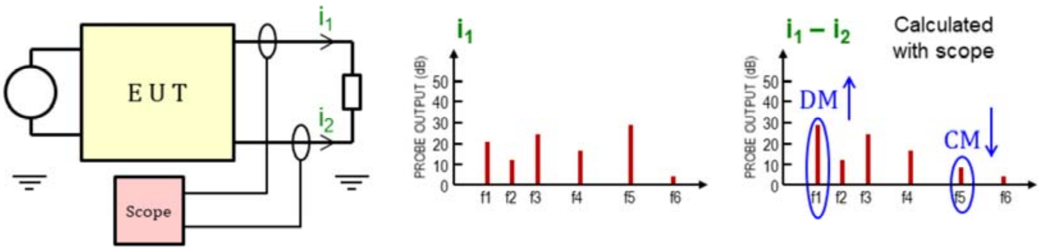
$$\left|E_{C,\max} = 1.257\cdot10^{-6}\cdot\frac{|I_C|\cdot f\cdot L}{d}\right|$$

H.W.Ott,

where L(m) is the length of the cable and f(Hz) is the offending harmonic frequency. Use a test distance, d=3m or d=10m to predict the outcome at those test distances.

Z_T(dBΩ)=20log (Z_T/1Ω)

DIFFERENTIAL CURRENT MEASUREMENTS

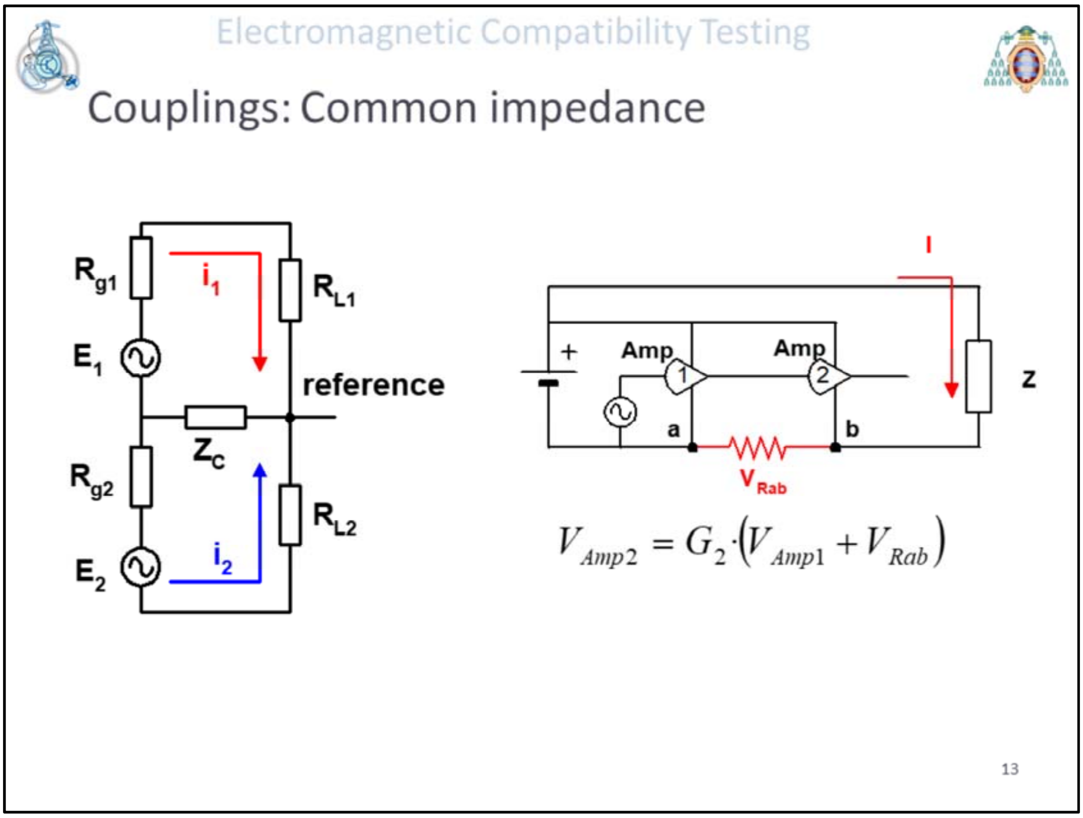


a) Frequency f1 increased by 6 dB⇒the currents in the wires are flowing in opposite directions.

b) At f5, there is a strong reduction of almost 30 dB. This indicates that the currents at this frequency on cables 1 and 2 are nearly identical in amplitude and direction.

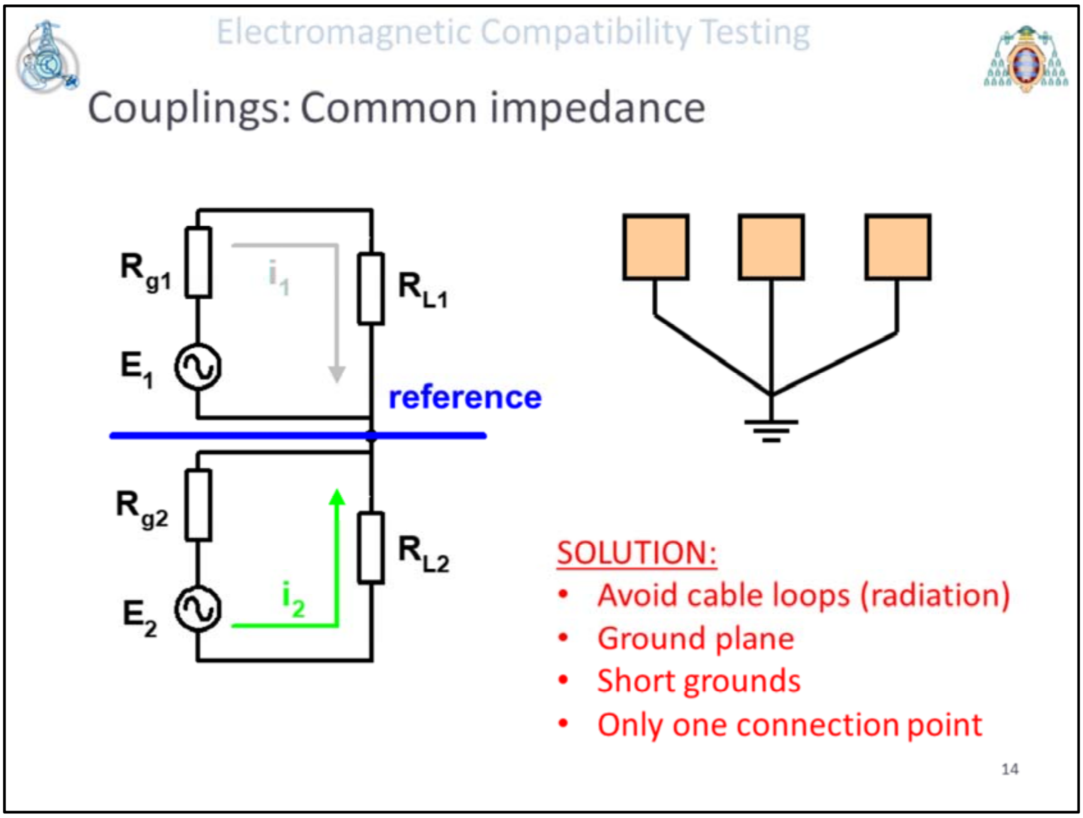
c) The net current at other frequencies (f2,f4, and f6) remains unchanged indicating that the current on cable 1 does not significantly appear on cable 2. These currents must either radiate from the EUT (which we have assumed is not happening for this example) or must appear on the power cable.

D.C.Smith 12

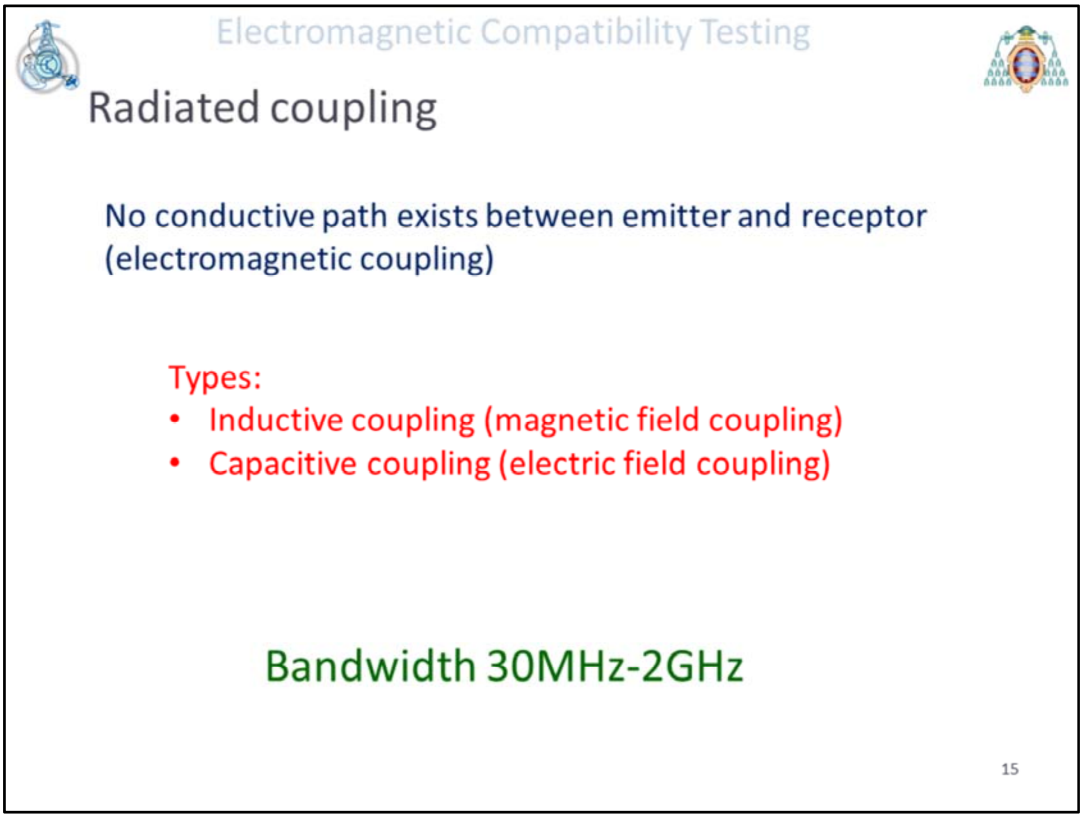


The impedance that is shared by two or more circuits is called common impedance and can be a major problem of interference.

In the circuit of the figure it can be seen that Amplifier 2 amplifies the signal coming from Amplifier 1 plus the voltage drop across the common resistance R_{ab}.

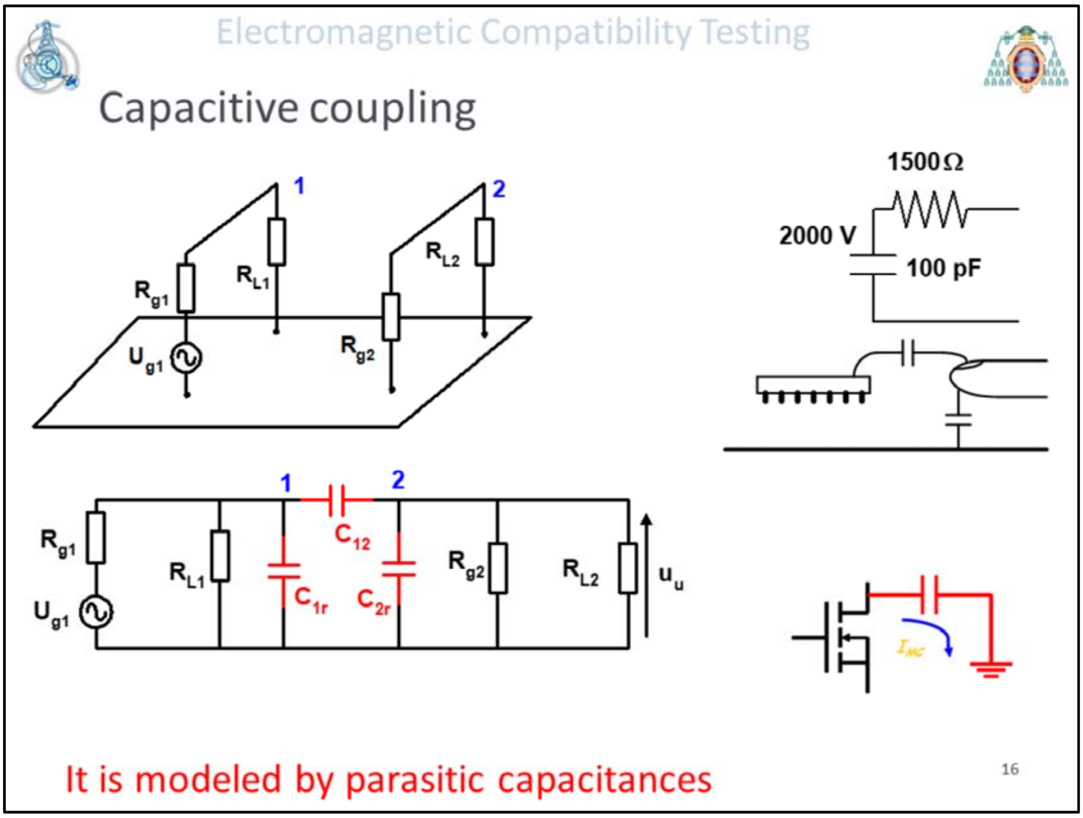


To minimize common impedance, star connection to ground is recommended.

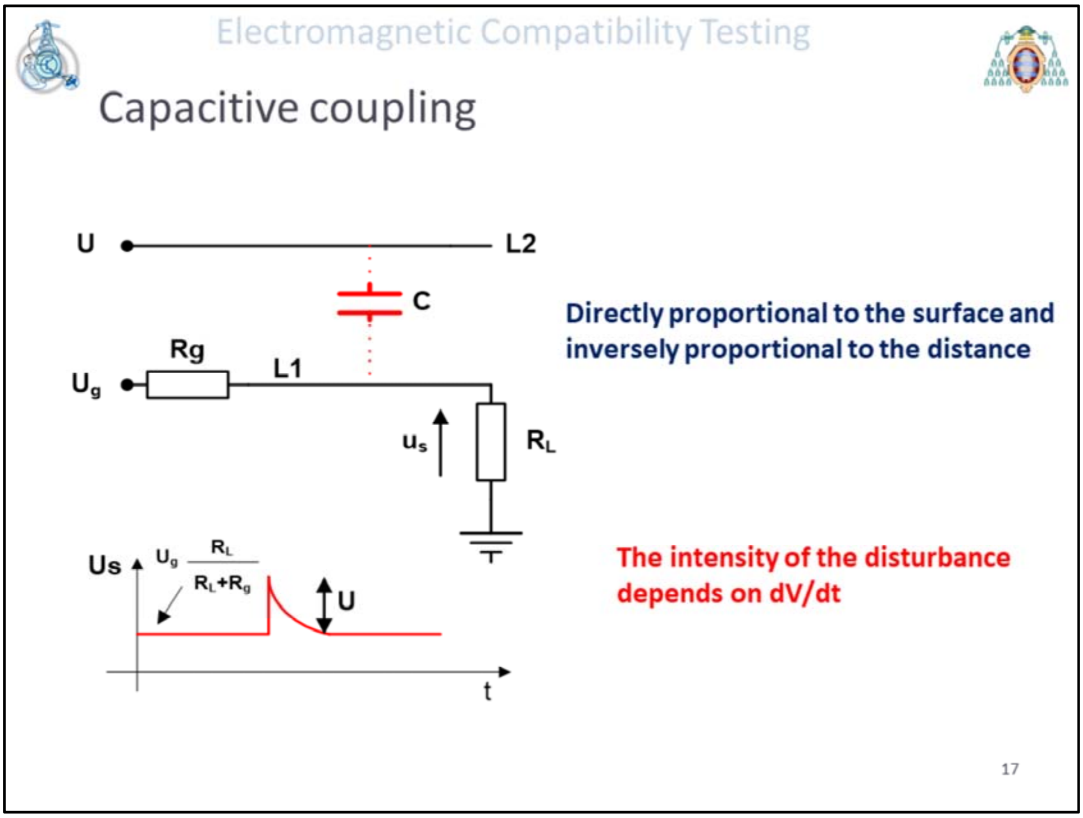


Radiated emission tests are performed between 30MHz and 2 GHz (typical for industrial equipment).

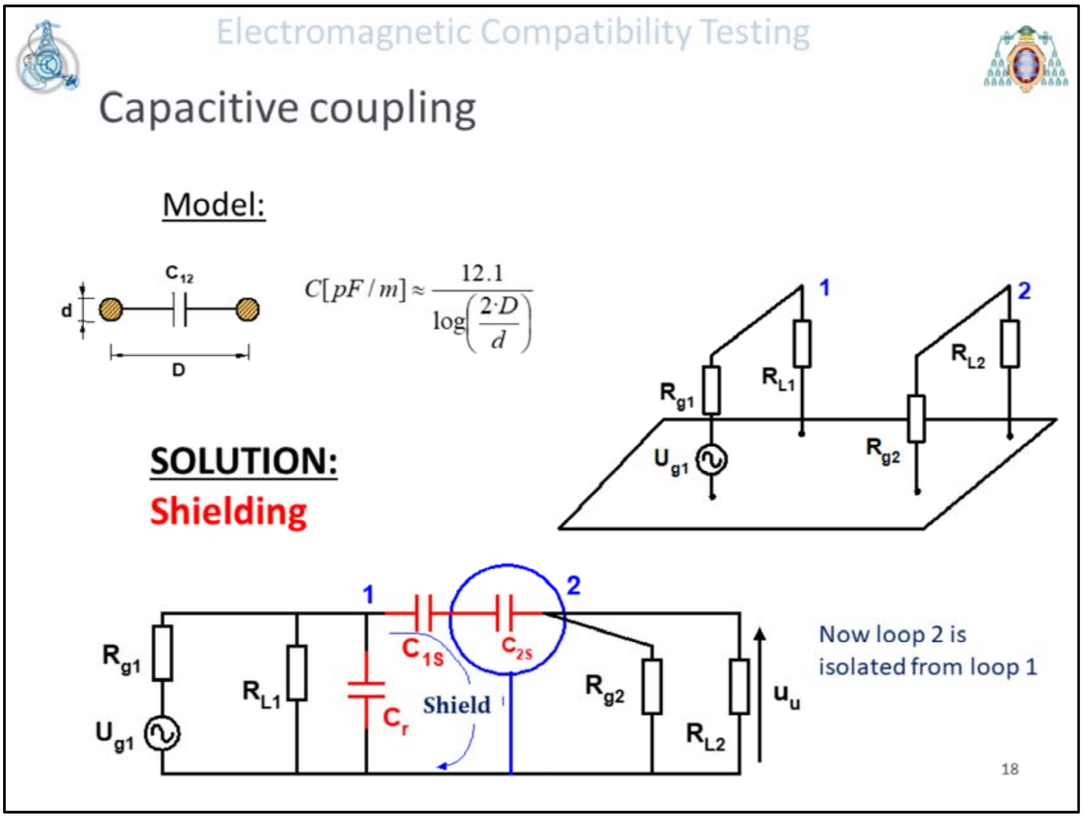
In these tests, couplings between circuits can occur both by magnetic fields and by electric fields (near field).



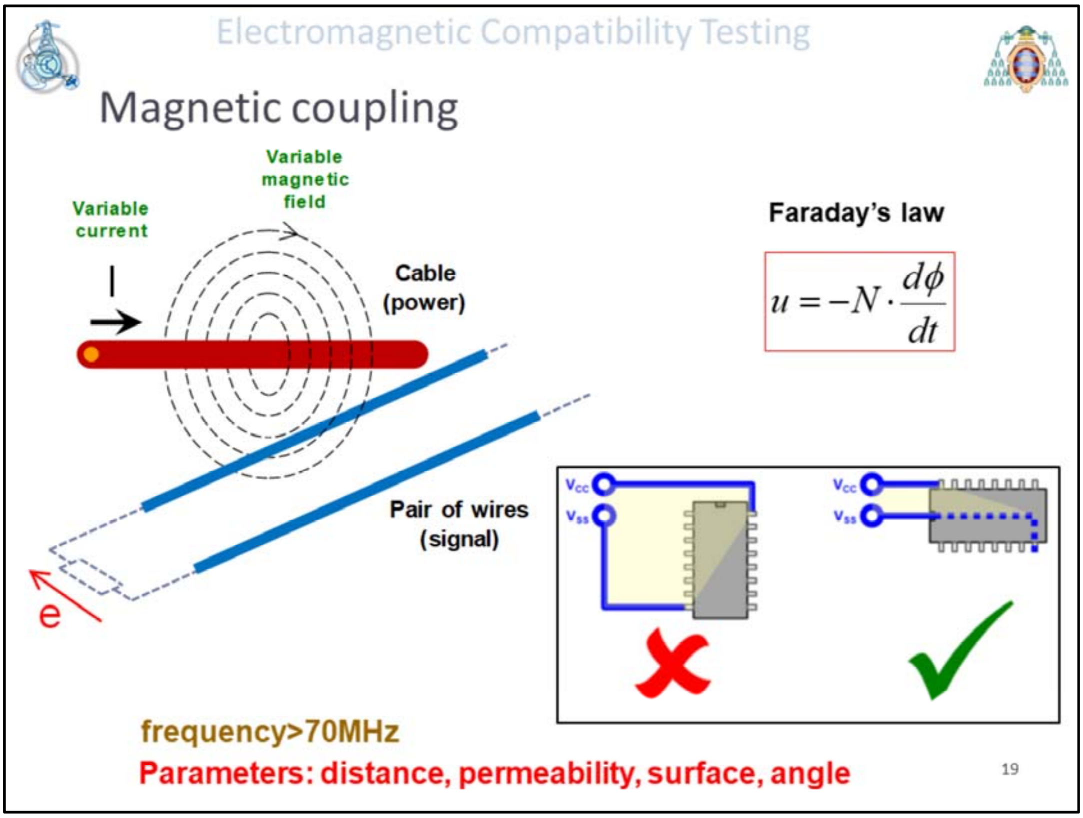
Electric-field coupling is modeled by parasitic capacitances that represent the energy stored in the form of electric field.



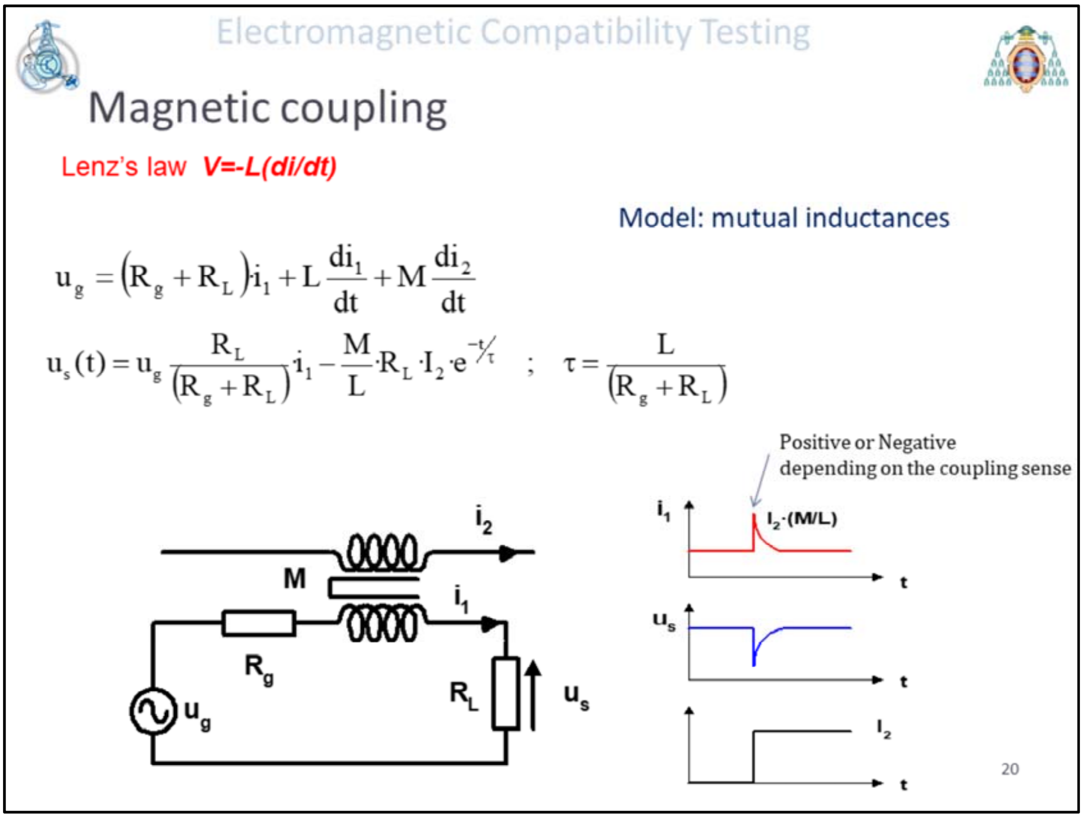
Voltage variations in line L2 are easily transmitted to line L1 and vice versa due to the presence of a parasitic capacitance between them.



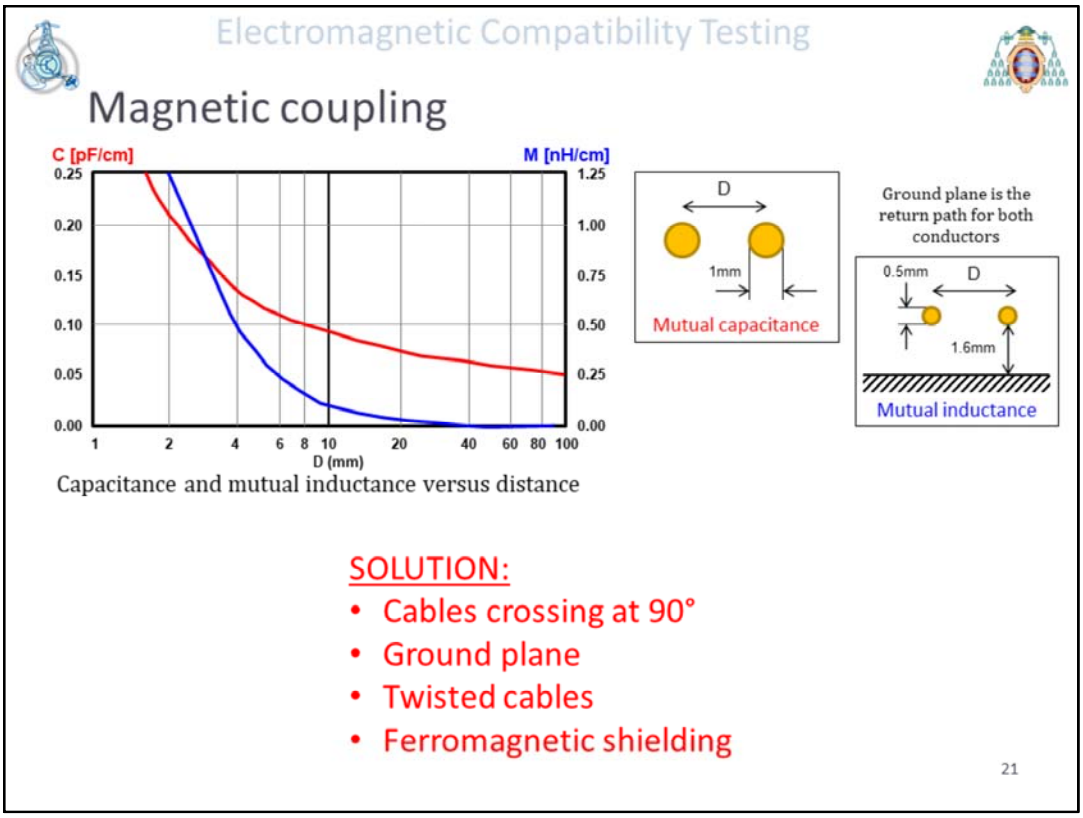
To avoid coupling originated by electric fields, the only solution involves shielding. The screen provides a low-impedance path that prevents currents generated in circuit 1 from reaching circuit 2. A typical example of shielding can be found in coaxial cables



When an alternating current circulates through a cable, it creates an alternating field that can reach other circuits, thus inducing noise in them. This induced voltage will be proportional to the area defined by the affected circuit and to the intensity and variation rate of the field generated.

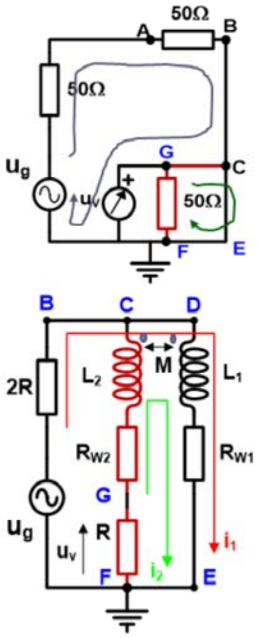


The circuit of the figure shows the electric model of a magnetic coupling. Variations of current in one of the lines (i_2) affects the voltage across the load due to the magnetic coupling between both circuits, represented by two coupled coils



The magnetic and electrical coupling depend on the distance between conductors, as can be seen in the attached graph. Solutions to minimize this coupling include twisting the cables, including ferromagnetic shielding, etc.

Magnetic coupling + common impedance



$Z_1 = R_{W1} + jwL_1 \qquad Z_2 = R + R_{W2} + jwL_2$

$$u_g = (2R + Z_1)\cdot I_1 + (Z_1 - jwM)\cdot I_2$$

$$0 = (Z_1 - jwM)\cdot I_1 + (Z_1 + Z_2 - jw2M)\cdot I_2$$

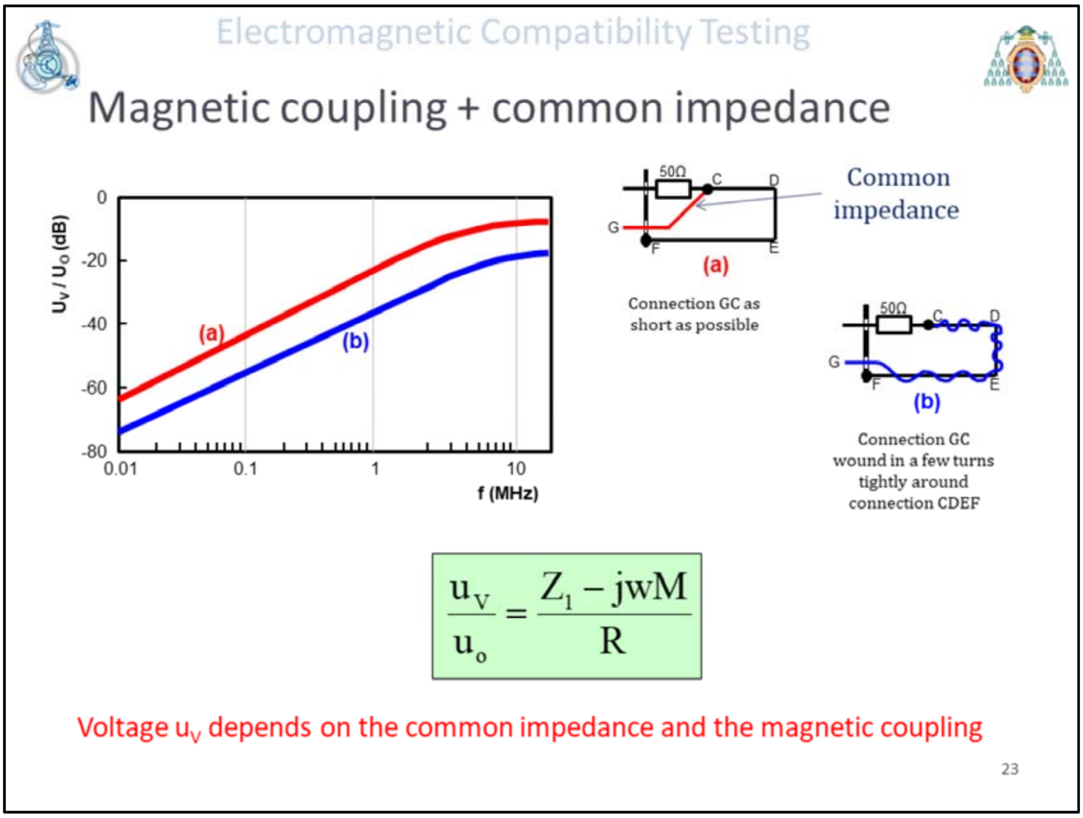
$u_V = -I_2 R$, normalizando respecto a $u_o = \frac{u_g}{2}$

$$\frac{u_V}{u_o} = \frac{2R(Z_1 - jwM)}{2R(Z_1 + Z_2 - jw2M) + (Z_1 Z_2 + w^2 M^2)}$$

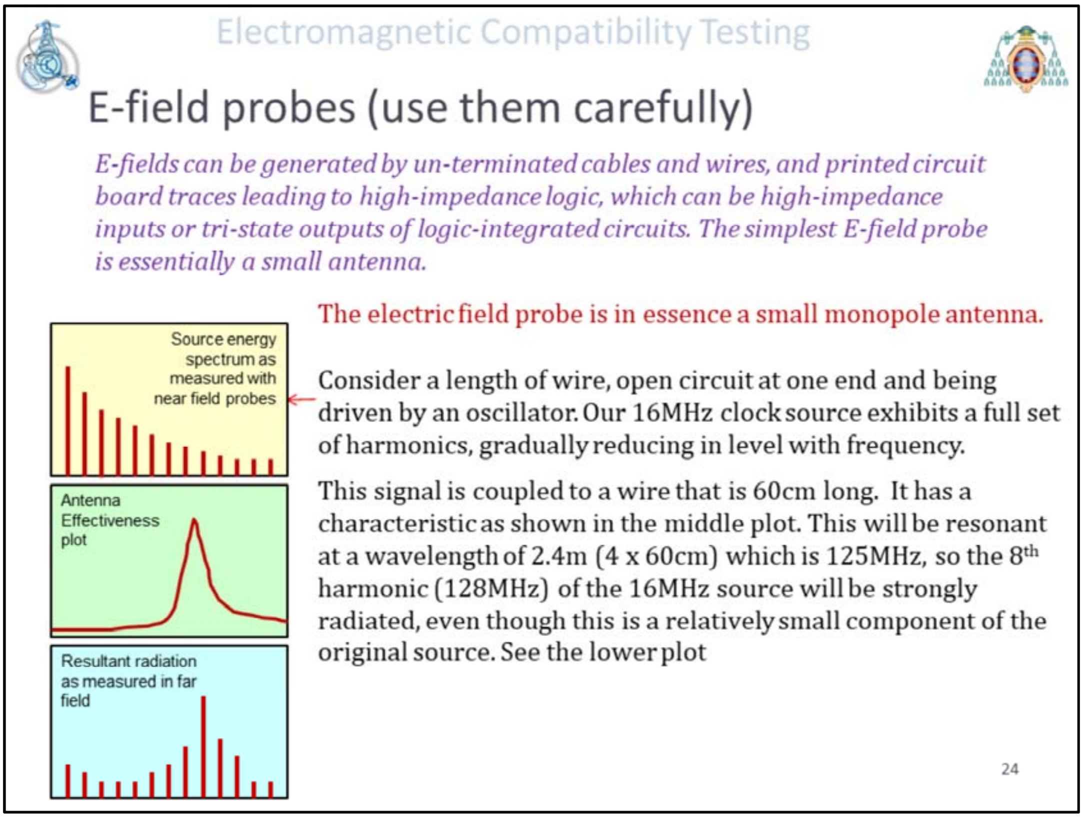
If $R >> Z_1$

$R >> R_{w2} + jwL_2$ $\Rightarrow$ $\frac{u_V}{u_o} = \frac{Z_1 - jwM}{R}$

Magnetic coupling reduces voltage noise



In the indicated experiment it can be seen that twisted cables (b) reduce the magnetic coupling effect by more than 10dB.



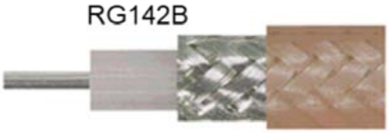
Near field probes allow the identification of noisy components, but the gain of the probe with frequency must also be taken into account, since some harmonics may be attenuated by the probe although its amplitude is important.

Cables

RG58C

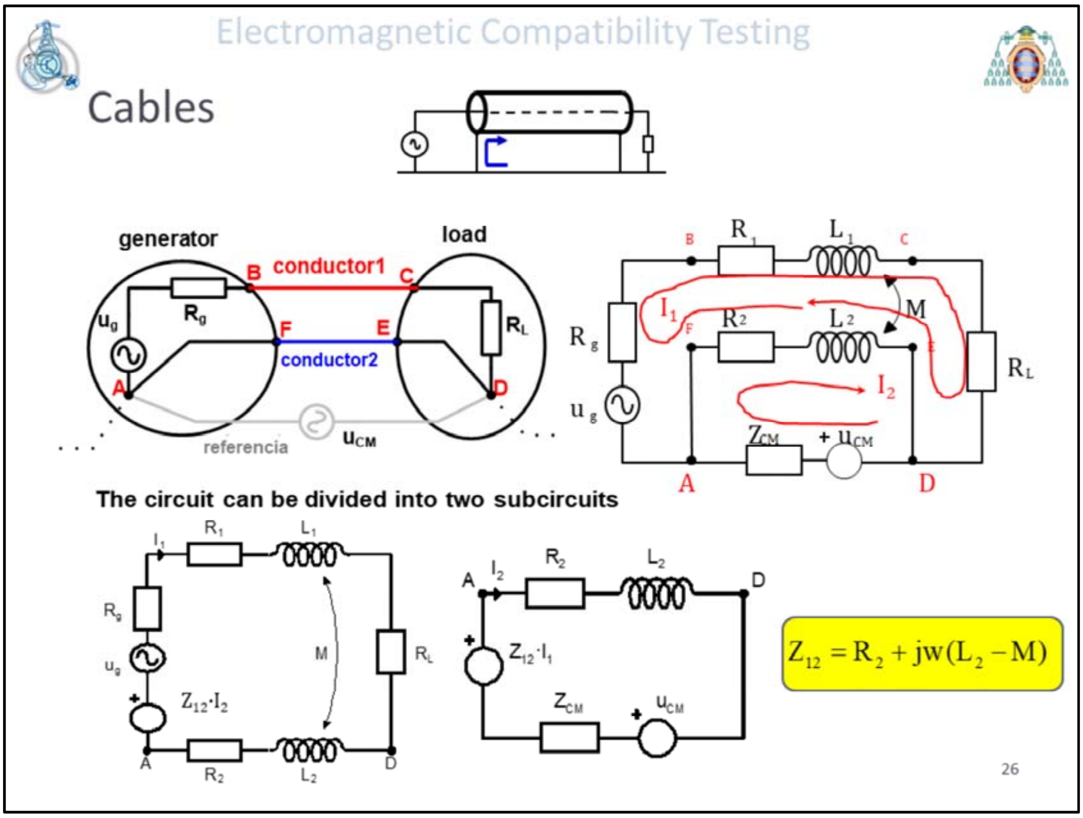
RG174

RG142B

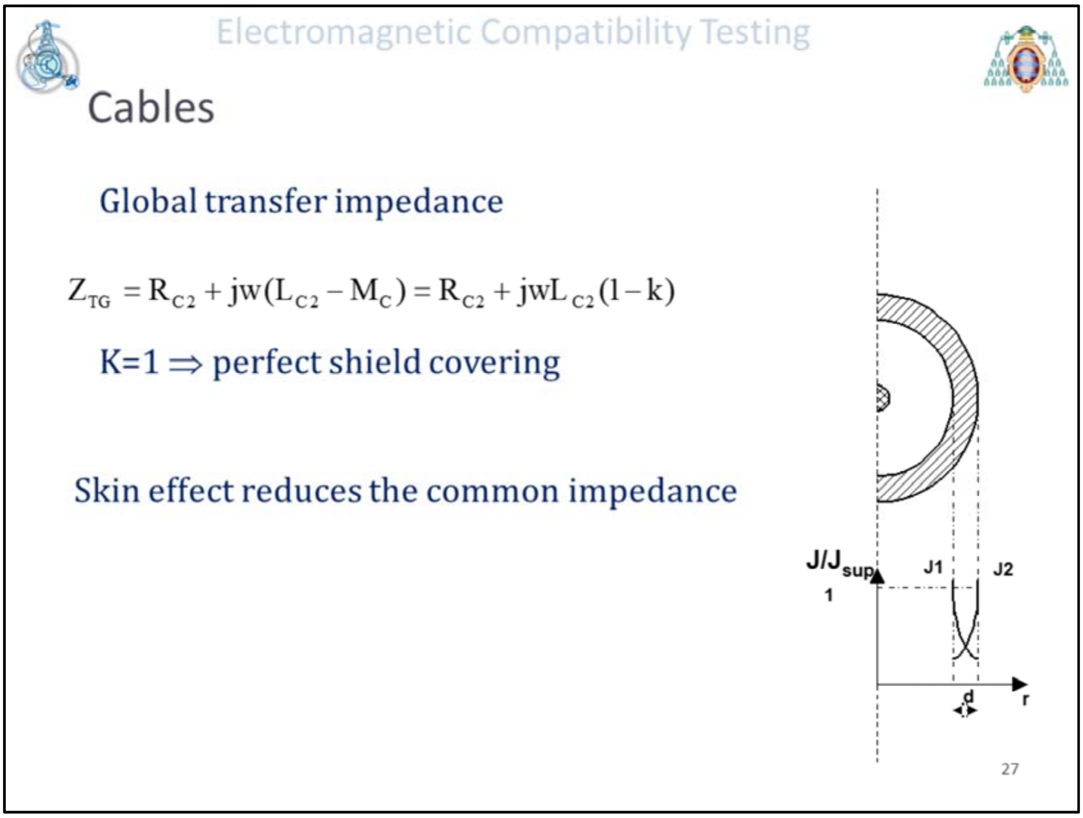


RG188

Catalog images



The figures show the electrical modeling of a coaxial cable and how it can be analyzed by means of two electrical circuits in which impedance Z_{12} (or transfer impedance) appears



The skin effect allows separating the currents induced by external fields from those generated by internal fields in a shielded conductor like the one in the figure on the right.

Therefore the skin effect minimizes the effect of the common impedance.

Cables

(1) Coaxial Cable 50 Ω (RG58)

94% covering
R_C=16 mΩ
(L_{C2}-M)=3.6nH y
L_{C2}=1uH/m⇒k=0.996

Z_{TG}(44MHz)=1Ω ⇒ a 10-μA common mode current will produce 10uV
To obtain 10μA, only 1mV/m (60dBuV/m) would be required, which is very easy to reach.
(this noise can be similar to the signal of a sensor)

The EM fields can generate currents of 10mA per V/m

Cables

Electrical characteristics

Frequency, MHz	RL	Attenuation, dB
0.772	-	1.8
1.0	20.0	2.0
4.0	23.0	4.0
8.0	24.5	5.8
10.0	25.0	6.5
16.0	25.0	8.2
20.0	25.0	9.3
25.0	24.3	10.4
31.25	23.6	11.7
62.5	21.5	17.0
100.0	20.1	22.0

Maximum conductor resistance at 20ºC	9.38 ohms / 100m
Resistance unbalance	5%
Unbalance capacitance of the pair related to ground	330 pF / 100m
Resistance at frequency 0.772 – 100MHz	85 – 115 ohms
Maximum operation capacitance	5.6 nF / m

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Cables

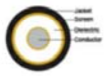
CNT-240

Construction	
Conductor Material	: Solid Bare Copper
Stranding	: 1/1.42mm
Dielectric	: Foamed Polyethylene (FPE)
Diameter of Dielectric	: 3.81mm
Screen Material (1)	: Bonded Aluminium Tape
Coverage (1)	: 100%
Screen Material (2)	: Tinned Copper Wire Braid
Coverage (2)	: > 90%
Outer Sheath Material	: Polyethylene, UV Resistant
Outer Sheath Colour	: Black
Electrical Characteristics	
Impedance	: 50 Ω
Velocity of Propagation	: 83%
Capacitance	: 24.4 pF/ft (80.0 pF/m)
Voltage Withstand	: 1.5 kV
Jacket Spark	: 5.0 kV (rms)
Conductor Resistance	: ≤ 10.9 Ω/km
Outer Conductor Resistance	: ≤ 12.8 Ω/km
Return Loss (30-2800MHz)	: ≥ 15 dB
Peak Power	: 5.6 kW
Physical Characteristics	
Overall Diameter	: 6.1mm
Min. Bend Radius	: 19.1mm
Temperature Rating	: -30°C to +85°C
Weight	: 50 kg/km

HELIAX

Construction

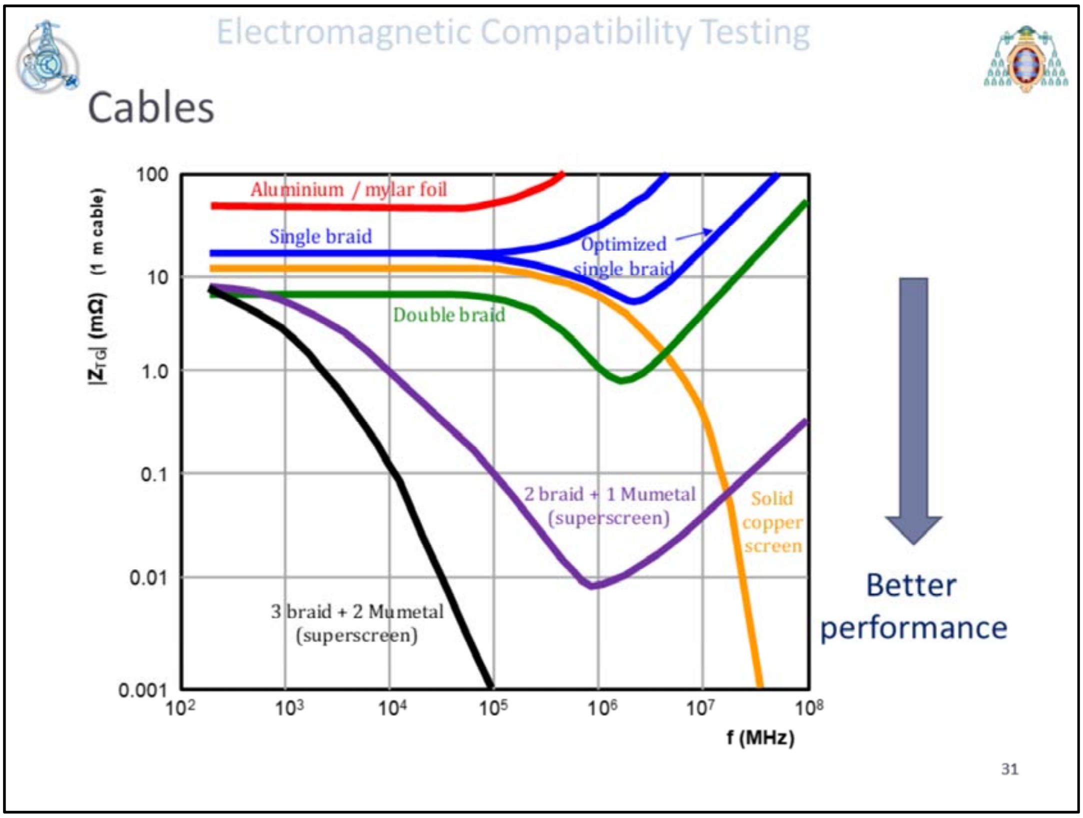
Conductor	Helical Corrugated copper tube 9.40 ± 0.20 [mm]
Dielectricum	Cellular PE 22.20 ± 0.30 [mm]
Screen	Corrugated Cu tube 24.90 ± 0.30
Jacket	Black SHF1
Outer diam	27.50 ± 0.20 [mm]
Weight	430 [kg/km]
Jacket marking	NEK Kabel RF LLF 7/8" Hiflex



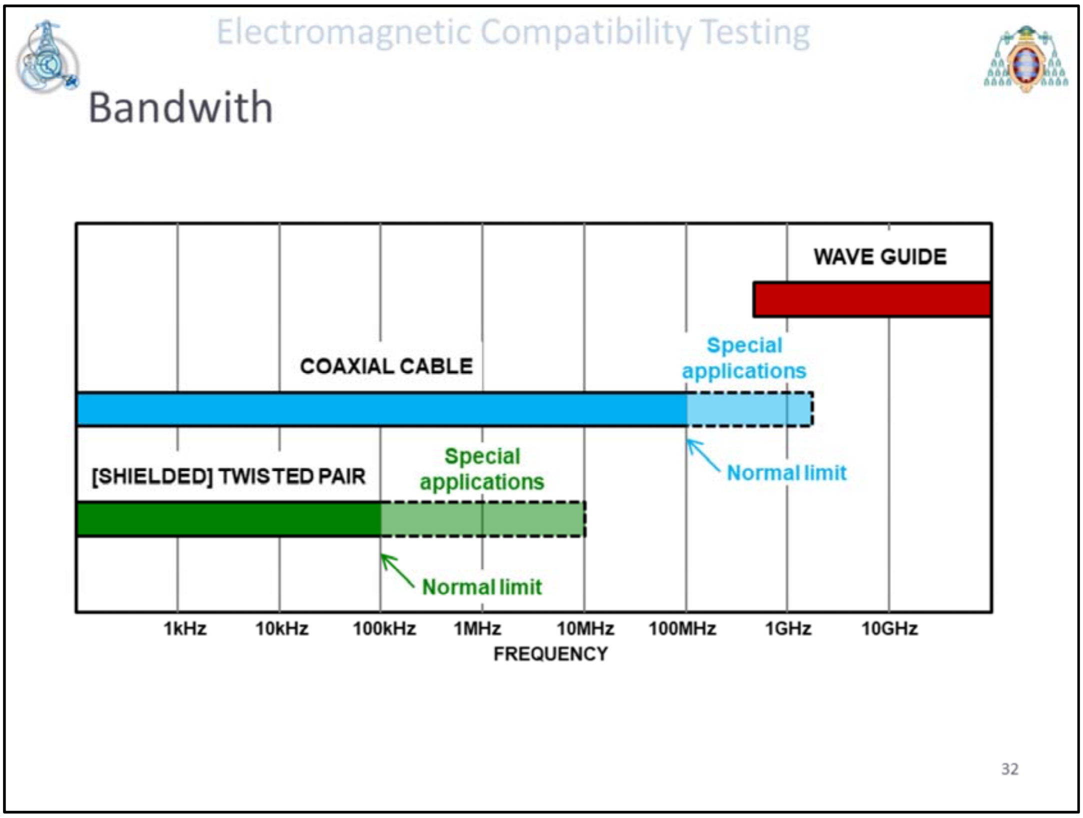
Specifications

Operating temperature	-40 to +70 [°C]
Temperature flexible	-20 [°C]
Screen resistance	1,3 [Ω/km]
Recommended clamp spacing	1 [m]
Peak RF voltage	2,8 [kV]
Characteristic impedance	50 ± 2 Ω
Conductor resistance	2.5 [Ω/km]
Capacitance	74 [pF/m]
Velocity factor	0,88
Min. bending radius	90 [mm]
Min. bending radius flexible	120 [mm]

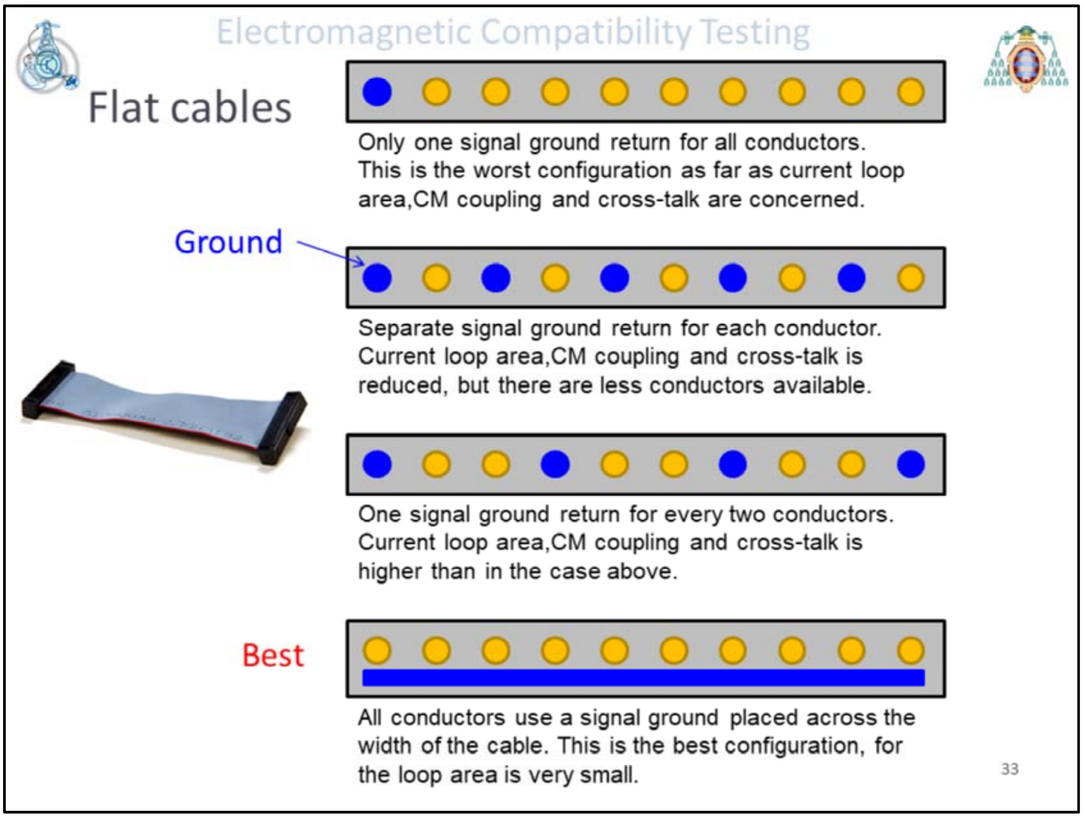
Catalogue images



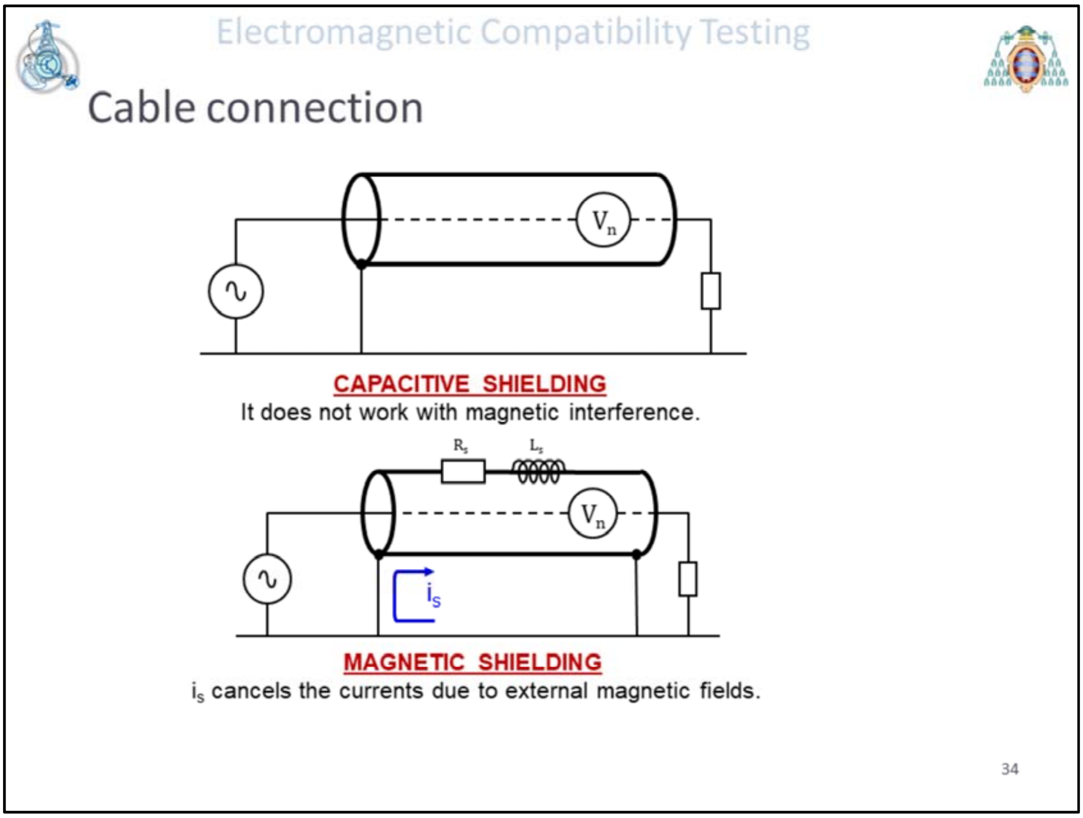
The figure shows how the incorporation of shielding in cables reduces the global transfer impedance



The figure indicates the frequencies of use according to the type of cable

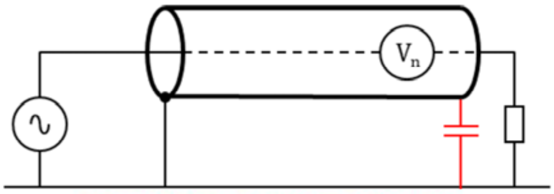


In the case of flat cables, the selection of which conductors act as a mass or signal conditions their noise immunity.



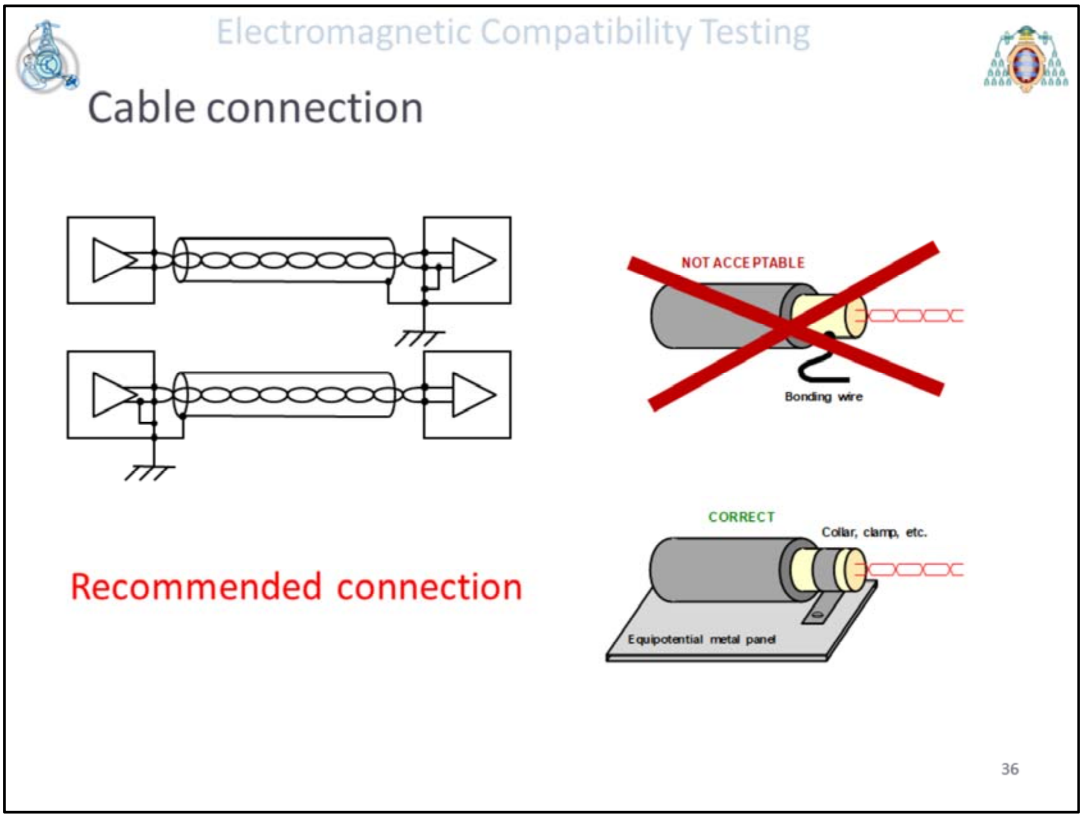
The shields of the cables are connected in a single end to ground when we want to prevent the capacitive coupling and in both ends to minimize the coupling by magnetic field.

Cable connection

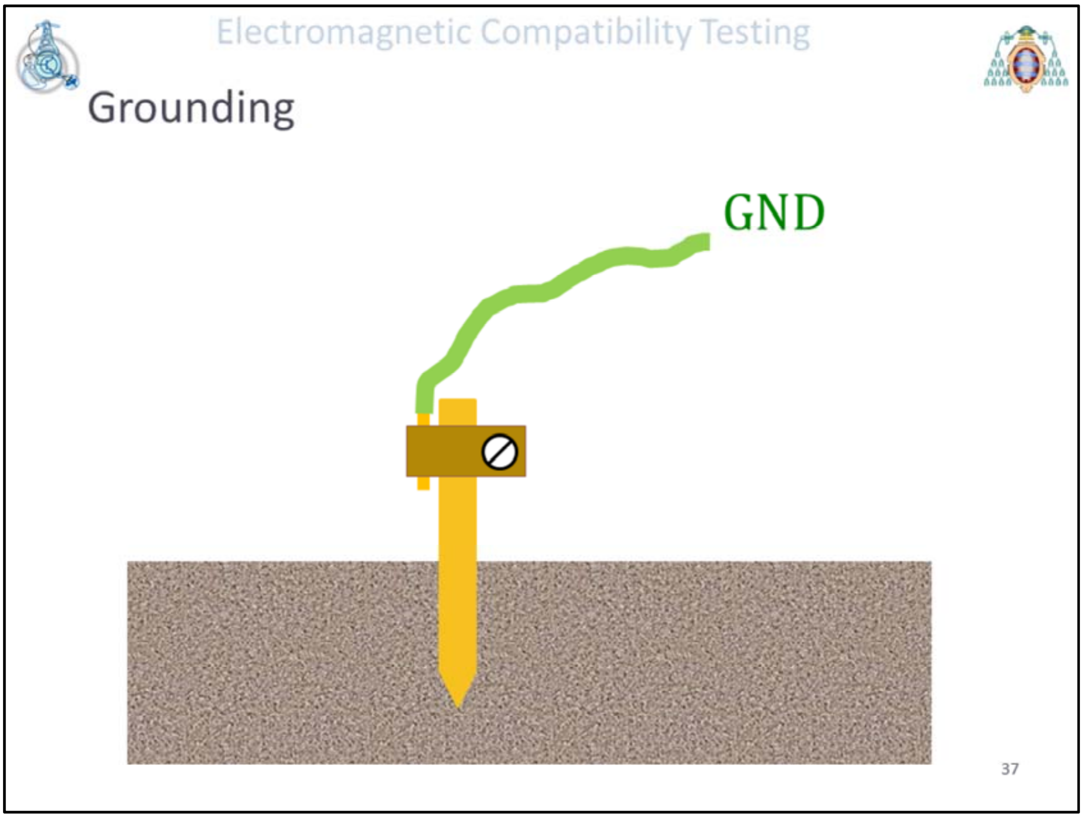


CAPACITIVE / INDUCTIVE SHIELD

Low frequency ➡	High impedance ➡	Shield connected in one point
High frequency ➡	Low impedance ➡	Shield connected in both ends



It is very important to properly connect the cable screen to ground. The figure shows the proper way to do it. Otherwise, we can introduce a loop between the internal conductor and the non-negligible area screen in which noise voltages could be induced.

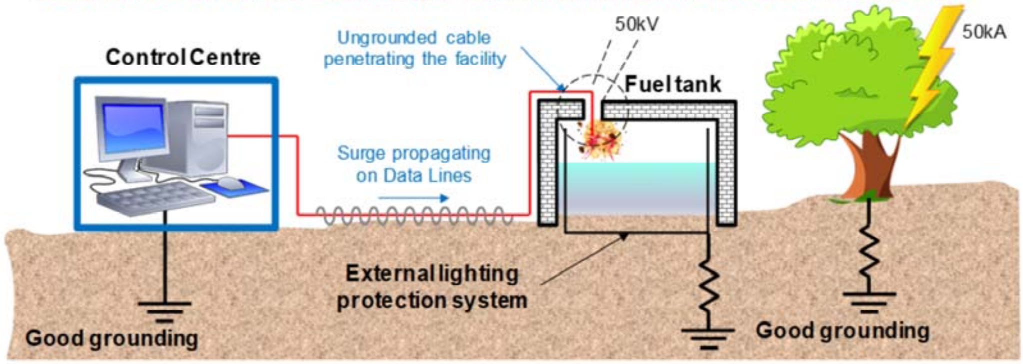


The connection to ground has a fundamental function: the protection of people.

Grounding

Electrical circuits may be connected to earth for several reasons.
In mains powered equipment, exposed metal parts are connected to ground to prevent user contact with dangerous voltage if electrical insulation fails

The <u>ungrounded</u> cable penetrating the fuel tank caused a potential difference between the cable and the facility's structure, and thus caused its explosión.



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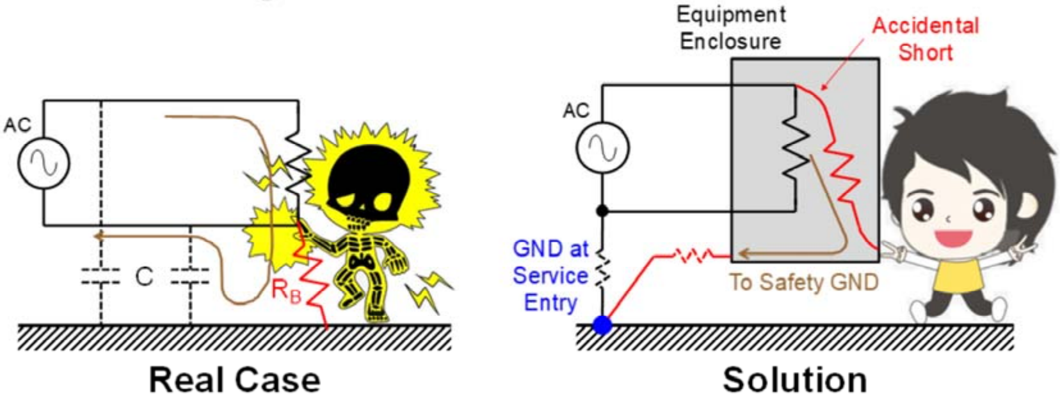
Grounding



"Floating" systems may compromise safety

Figures from: https://es.pngtree.com/freepng/electric-shock-hand-painted_3066462.html
https://es.pngtree.com/freepng/cartoon-happy_2967869.html

Grounding

Spanish regulation MI-BT-039:

The grounding resistance must avoid 24V in any metallic point .

The grounding resistance must be lower than 5 Ω in the transformation centre.

Frequency increases the impedance of the grounding

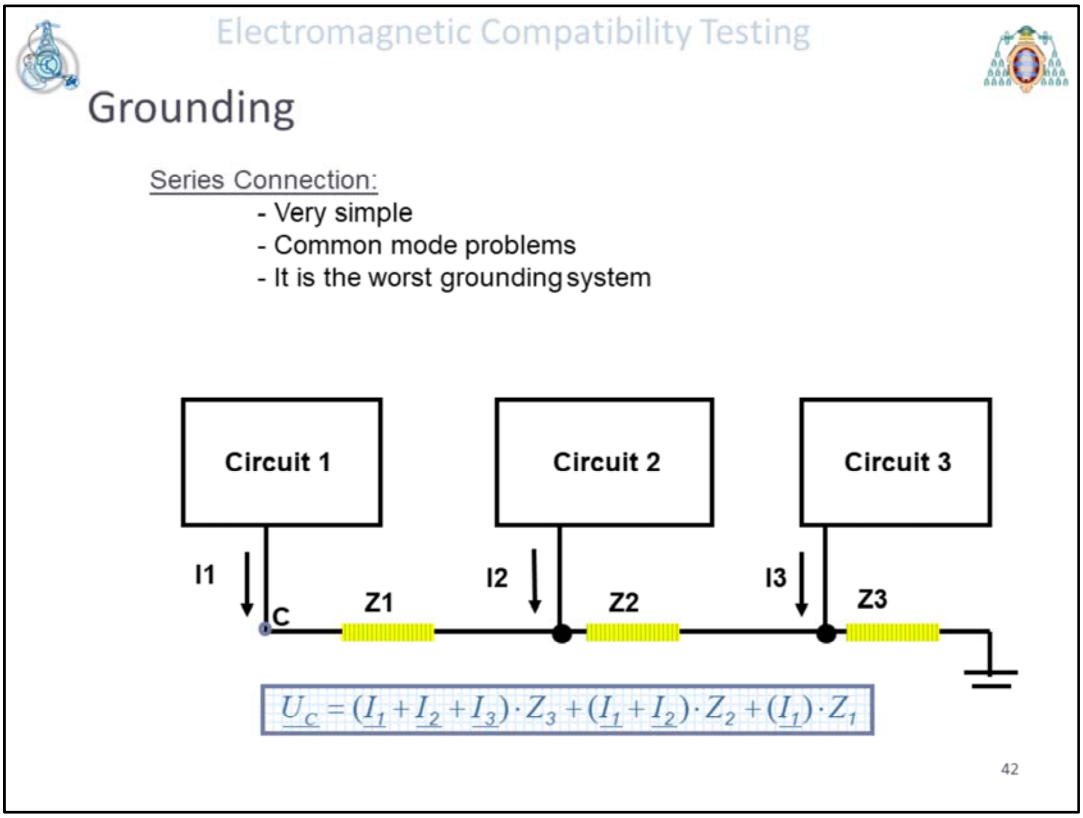
Grounding

Three basic objectives

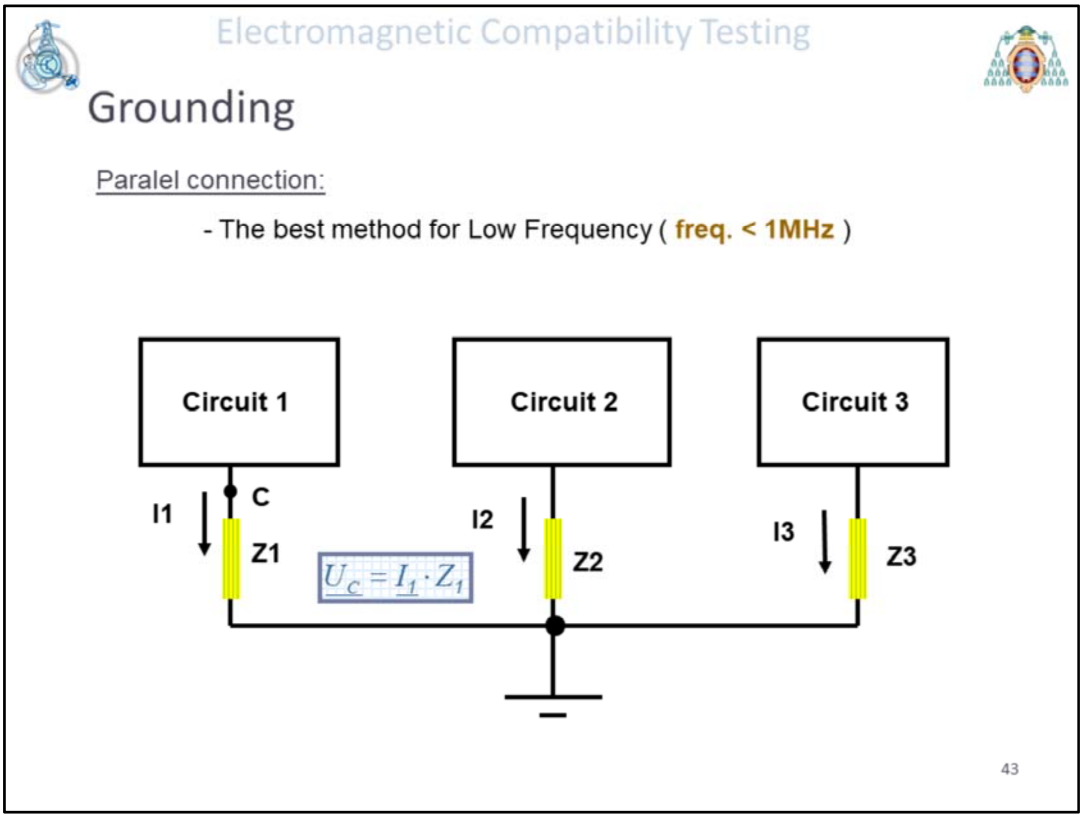
1. Not to interrupt the ground return path

2. Return the current through the smallest possible loop

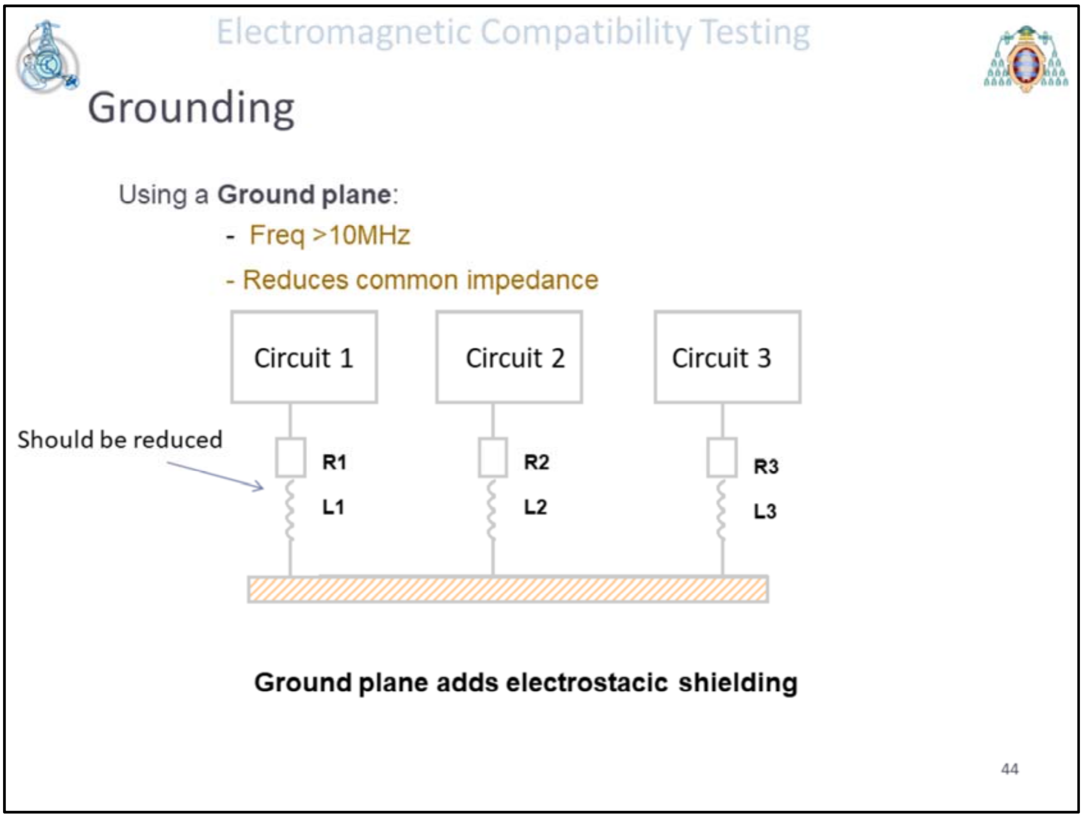
3. Be aware of possible common impedance coupling in the ground



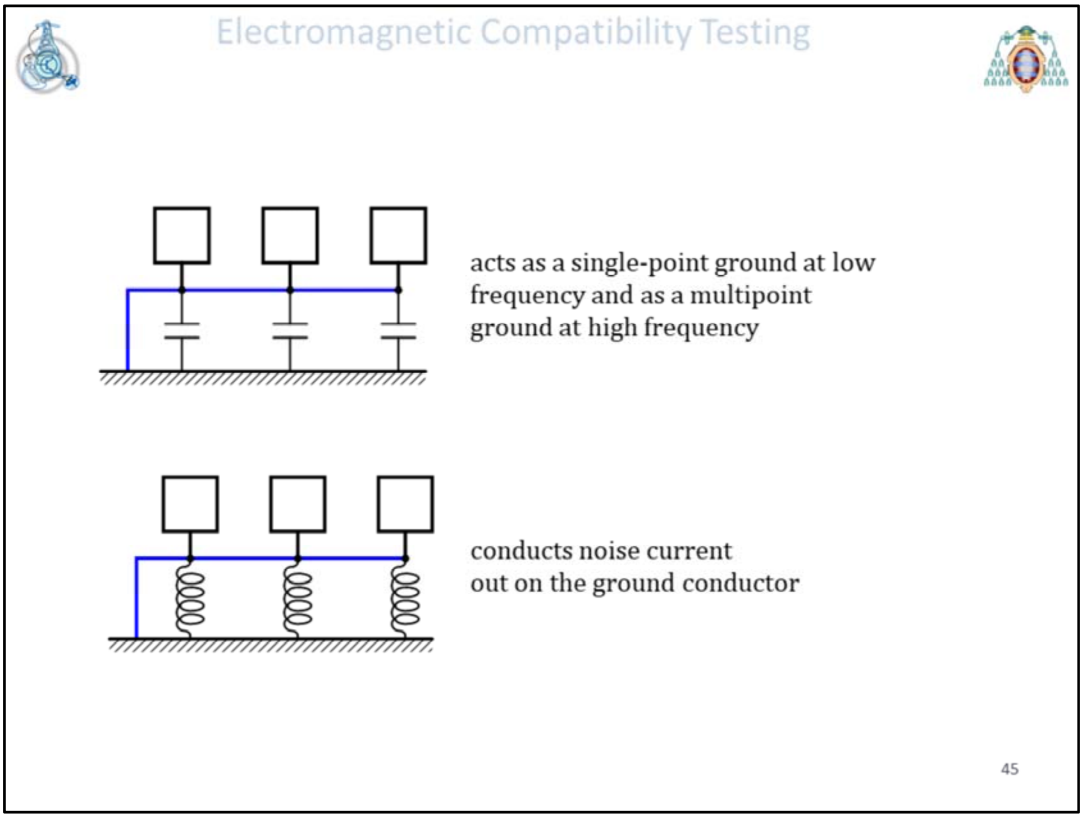
This type of connection is probably the simplest one, but it generates problems of common impedance that give rise to fluctuations in the voltage of point C due to the currents that flow to earth through circuits 2 and 3



The solution to this problem is the star connection



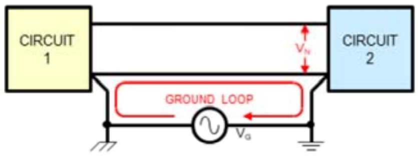
Star connections must be made trying to minimize grounding impedance, especially the parasitic inductance. In order for this to be so, we will avoid long cables or we will use ground planes.



The figure at the top shows how to implement a star connection for high-frequency currents.

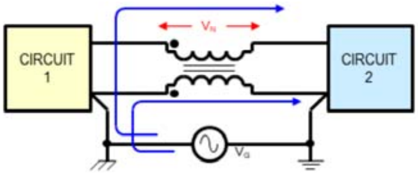
On the contrary, if you want to maintain a ground plane clean of high-frequency harmonics, inductances must be incorporated that uncouple the circuit from the ground plane.

Ground loop

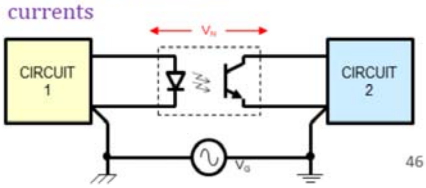


1.- A difference in ground potential VG between the two grounds may couple a noise voltage VN

2.- Any strong magnetic field can induce a noise voltage into the loop formed by the signal conductors and the ground



A common-mode choke can be used to break the ground loop between two circuits. It is a high impedance for common-mode currents



Optical coupling can be used to break the ground loop

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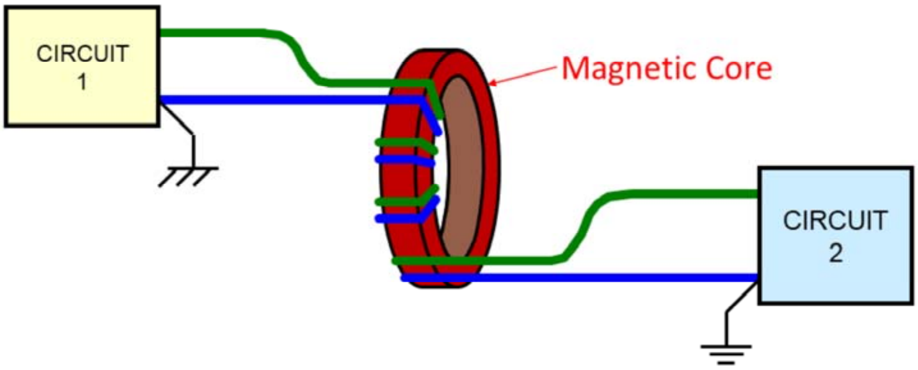

An easy way to place a common-mode choke in the circuit is to wind both conductors around a toroidal magnetic core

Grounding

The technique:

- Proper segregation of ground paths
- Careful location of ground nodes
- Elimination of "ground loops"

The grounding scheme inside a system must accomplish the following goals:

- Analog, low-level circuits must have extremely noiseless dedicated returns; typically wires are used, dictating a single point, "star" grounding scheme.
- Analog, high-frequency circuits (RF, video, etc.) must have low impedance, noise-free return circuits, generally in form of planes or their extensions (e.g. coaxial cables).
- Digital, logic circuit returns, especially high-speed digital circuit returns, must have low impedance over the entire bandwidth (determined by the "edge rates"), as power and signal returns share the same paths.
- Returns of powerful loads (e.g., solenoids, motors, relays, lamps, etc.) should be separated from all the above, even if they end up at the same power supply output terminal.
- For signals that communicate between parts of the equipment or system, the grounding scheme must provide a common reference with minimum ground shift (low common-mode noise) between system parts.