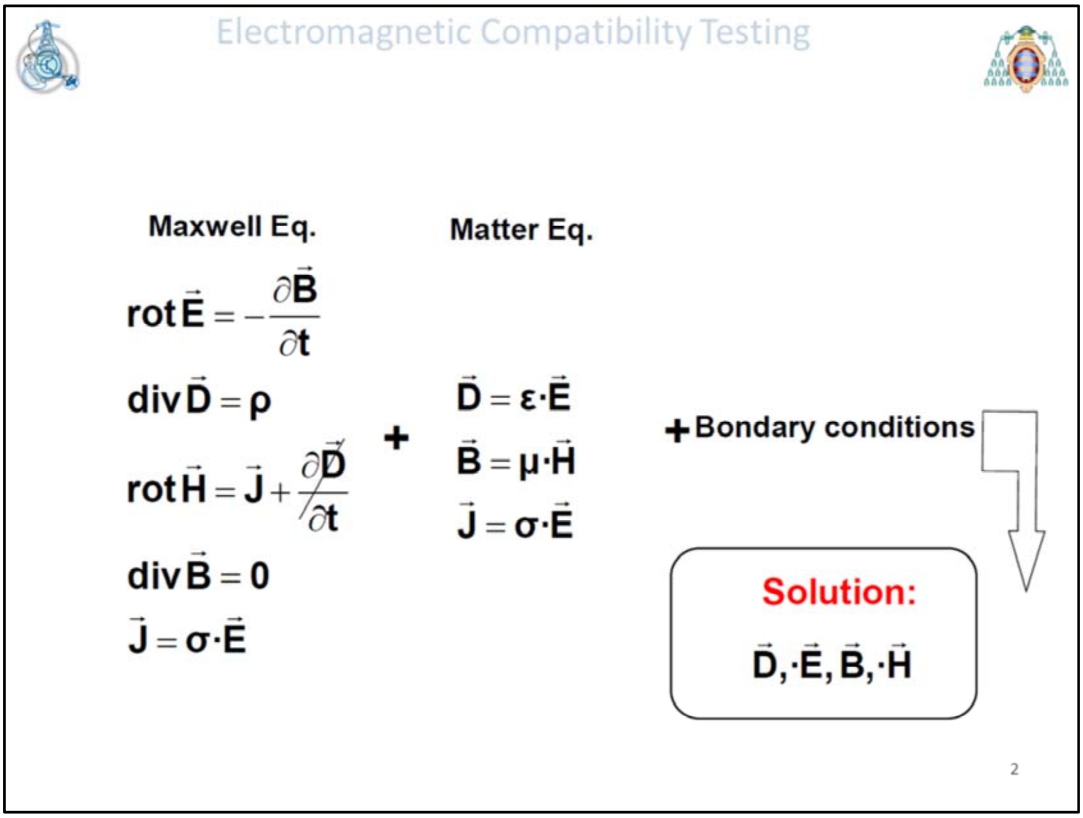
Electromagnetic
Compatibility
Testing

Universidad
de Oviedo

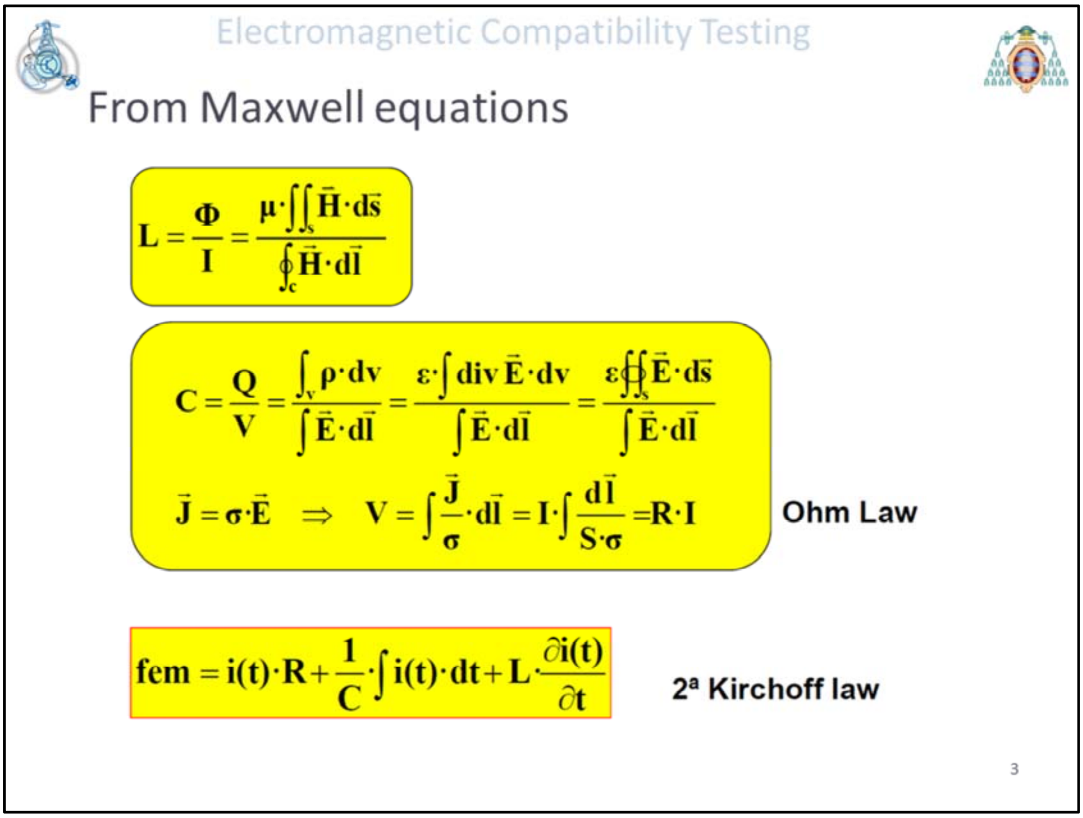
# Lesson 2: Real Components

In this presentation, the real behavior of passive devices in the field of electromagnetic compatibility will be analyzed.

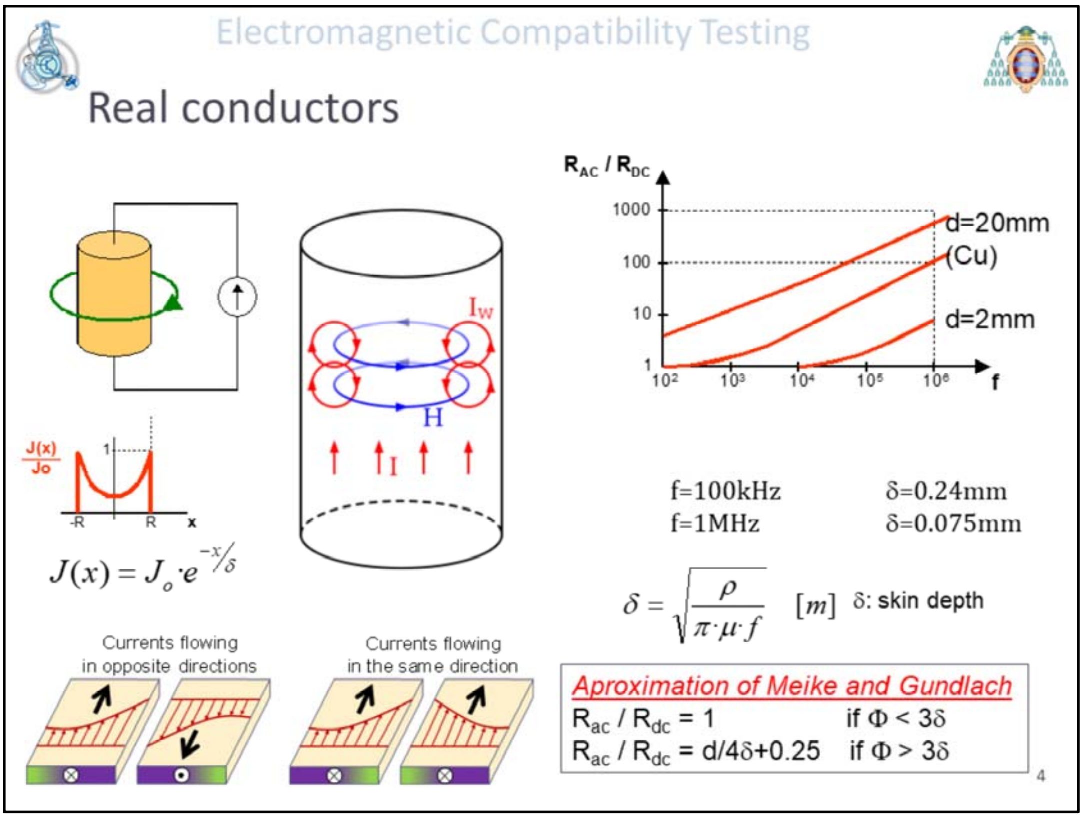
They will therefore cease to be considered ideal elements.




Maxwell's equations allow to determine the existing electromagnetic fields depending on the properties of the materials



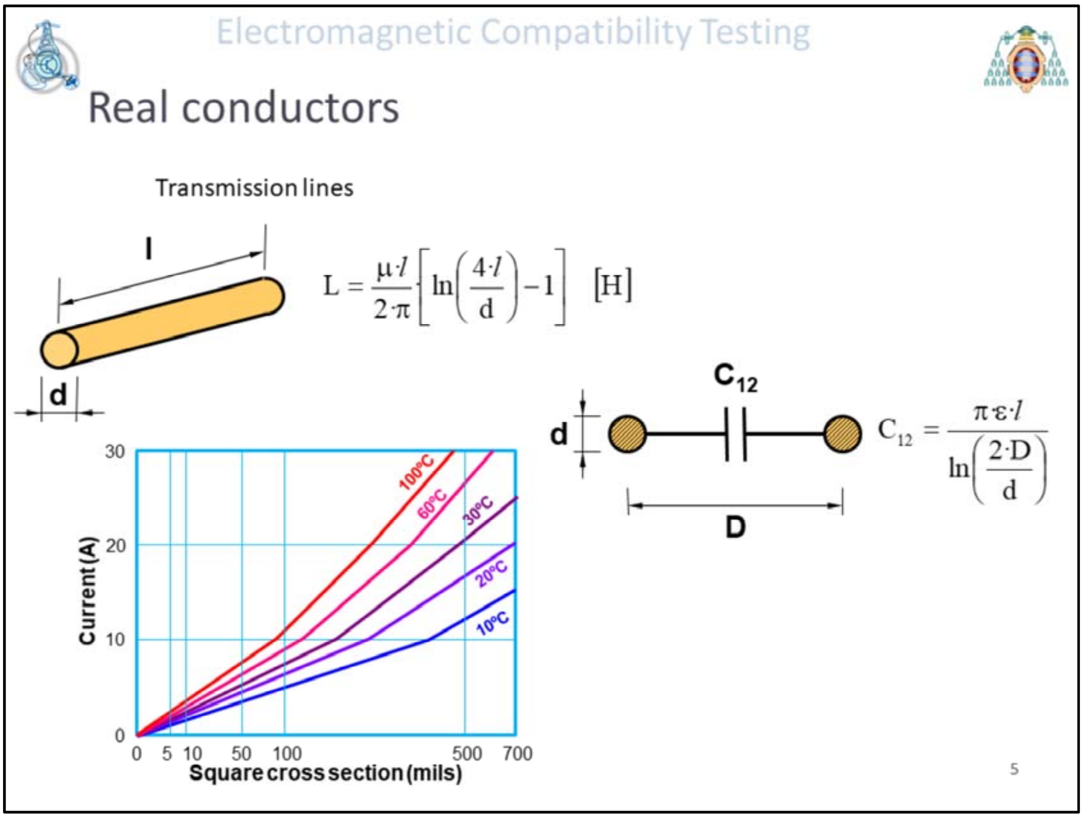

Once the existing electromagnetic field distribution is known, the energy due to the magnetic field can be associated with the L parameter (inductance), that due to the electric field can be linked to parameter C (capacity) and heat dissipation in a resistance R can be evaluated through Ohm's law.




One of the phenomena that appear in real drivers is the skin effect. The existence of alternating fields caused by the alternating current that passes through a conductor causes the induction of currents in the conductor itself, giving rise to a redistribution of the current on the surface of the conductor.

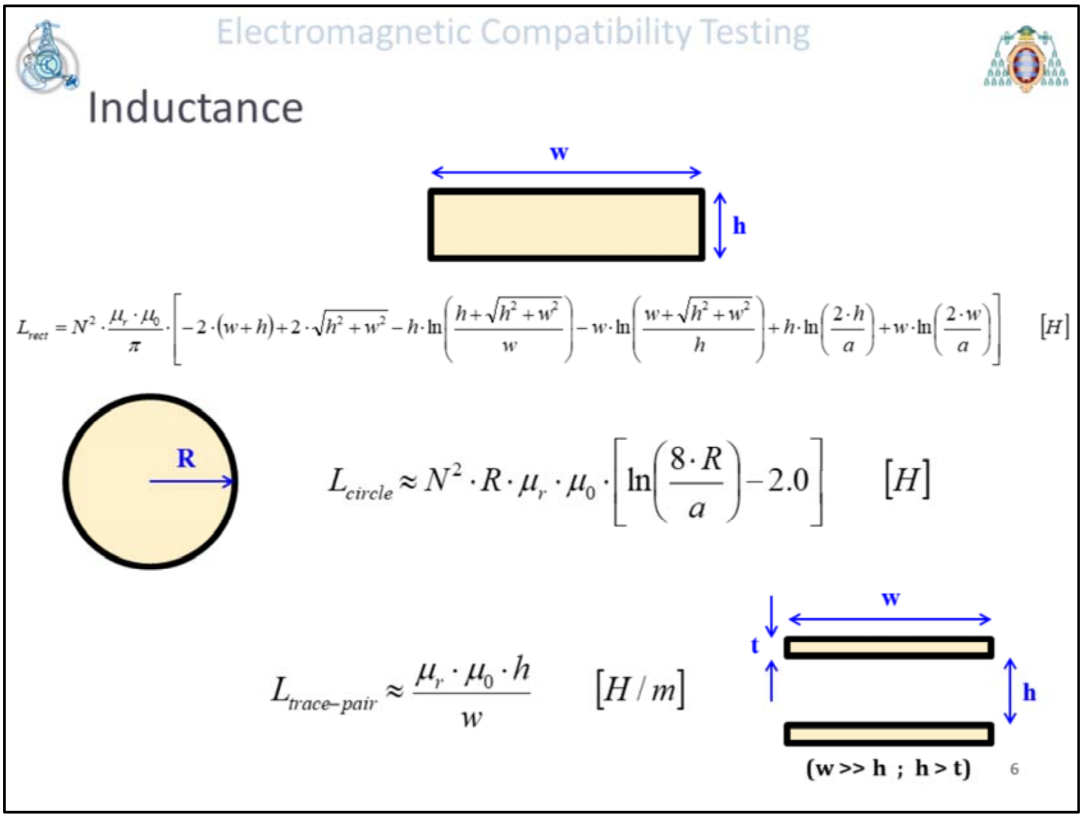
This effect is more visible when the frequency increases, giving rise to an increase in resistance with frequency.

This effect is quantified by the parameter δ (*delta*), also known as depth skin.

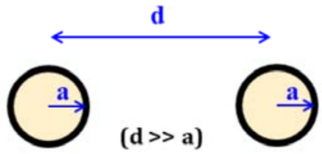



To characterize a real conductor it is necessary to take into account its inductance per unit length or parasitic capacity with other conductors.

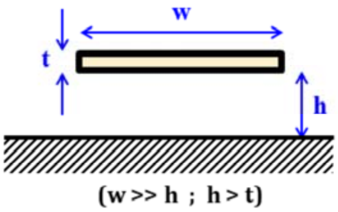
On the other hand there is a limit as to the current density in a conductor for a given temperature.



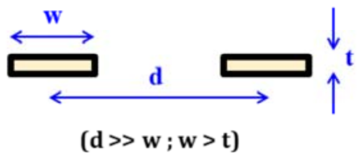

Depending on the geometry there are several formulas that the inductance per unit length to be calculated



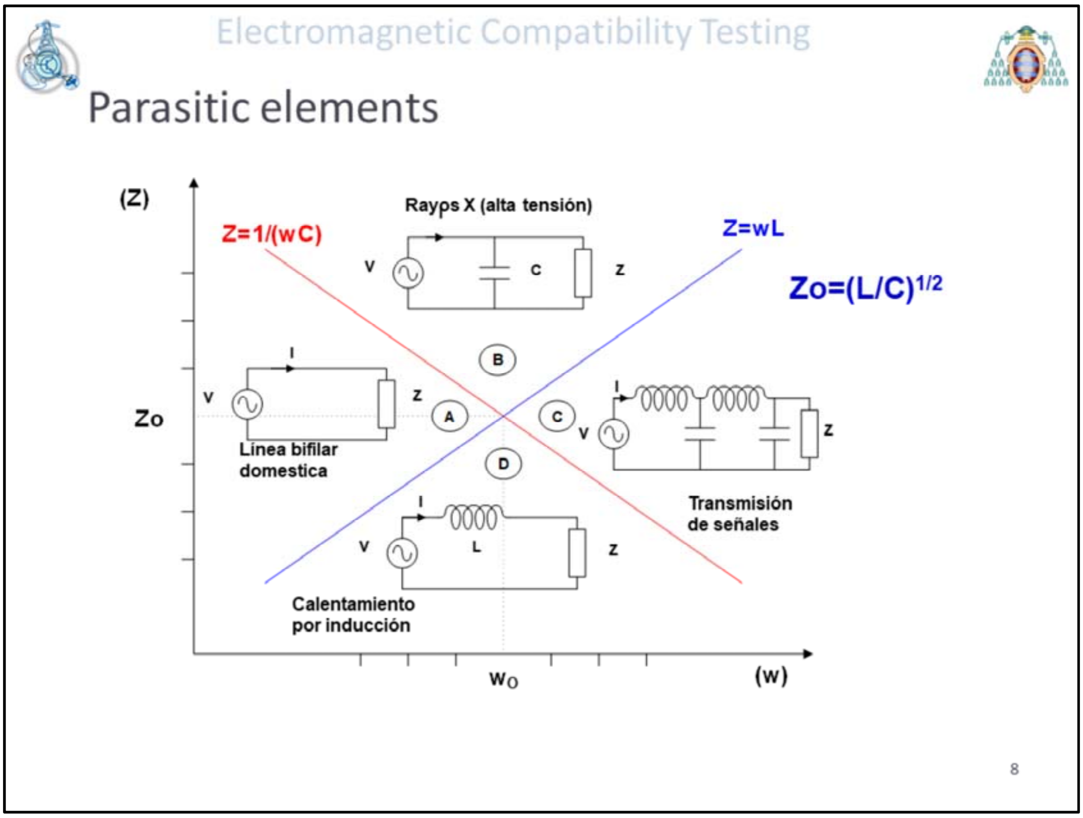

$$L_{wire-pair} \approx \frac{\mu_r \cdot \mu_0}{\pi} \cdot \cosh^{-1}\left(\frac{d}{2 \cdot a}\right) \qquad [H/m]$$



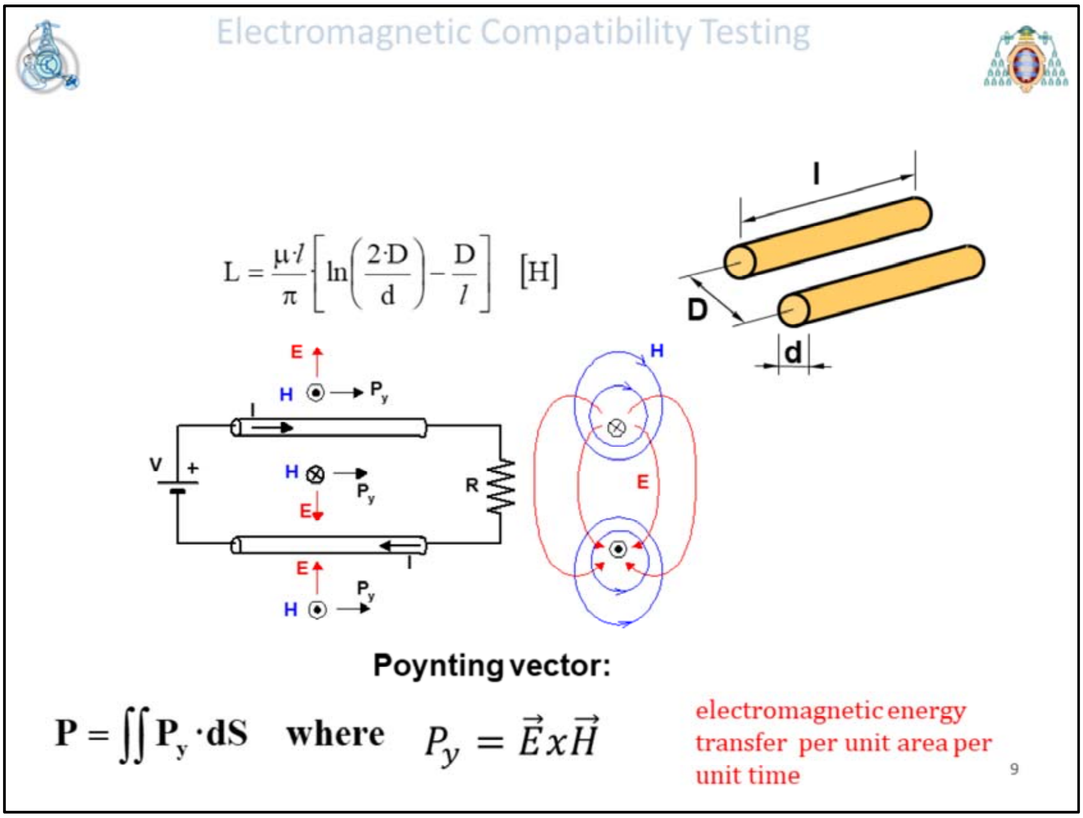

$$L_{trace-ground} \approx \frac{\mu_r \cdot \mu_0 \cdot h}{w} \qquad [H/m]$$




$$L_{trace-hr} \approx \frac{\mu_r \cdot \mu_0}{\pi} \cdot \cosh^{-1}\left(\frac{d}{w}\right) \qquad [H/m]$$




Traditionally, when the working frequency is low (50Hz) and the current or voltage is also low, we can neglect the parasitic elements due to the magnetic (inductance) and electric (capacitance) fields; section "A". If the voltage or current is high (Sections B and D respectively) the electric and magnetic fields will be high and parasitic capacitance and inductance can not be ignored. Finally, if the frequency is high (communication systems), distributed parameters will be used (section C)




By calculating the Poynting vector, it is possible to identify how the transmission of power from the primary source to the load in an electrical system is carried out.

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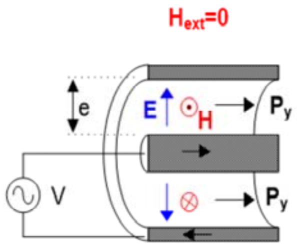
Electrical energy delivered to the load is flowing entirely through the dielectric

$H_{ext}$=0, there is no net current in the outside

$$\oint \vec{H}\cdot d\vec{l} = I = 0$$




$$H = \frac{I}{2\cdot r\cdot \pi} \qquad E = \frac{V}{e}$$

$$P_y = E \times H = \frac{V}{e}\cdot\frac{I}{2\cdot\pi\cdot r} \qquad P = \iint P_y \cdot dS = P_y \cdot S = P_y \cdot (e \cdot 2\cdot\pi\cdot r)$$

$$P = \left(\frac{V}{e}\frac{I}{2\pi r}\right)(e2\pi r) = V\cdot I$$

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In the case of a coaxial cable, the calculation of the transferred power can be made by evaluating the magnetic and electric fields, obtaining the traditional formula of P = V · I

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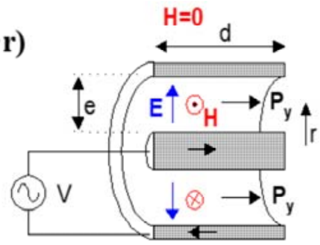
$$v = \frac{d}{t} \qquad P[W] = \frac{(E_{mag} + E_{elec})}{t} = E \cdot H \cdot (e \cdot 2\pi \cdot r)$$

$$v = \frac{d}{t} = d \cdot \frac{P}{E_{mag} + E_{elec}} = \frac{E \cdot H \cdot e \cdot (2 \cdot \pi \cdot r) \cdot d}{E_{mag} + E_{elec}}$$

$$E_{mag} = \tfrac{1}{2} \cdot \mu_o \cdot \mu_r \cdot H^2 \cdot e \cdot d \cdot (2\pi \cdot r)$$

$$E_{elec} = \tfrac{1}{2} \cdot \varepsilon_o \cdot \varepsilon_r \cdot E^2 \cdot e \cdot d \cdot (2\pi \cdot r)$$




$$\Rightarrow \quad v = \frac{1}{\left(\tfrac{1}{2}\varepsilon \frac{E}{H}\right) + \left(\tfrac{1}{2}\mu \frac{H}{E}\right)} \quad \Rightarrow$$

**Propagation speed**

**Electromagnetic impedance**
**E/H [Ω]**

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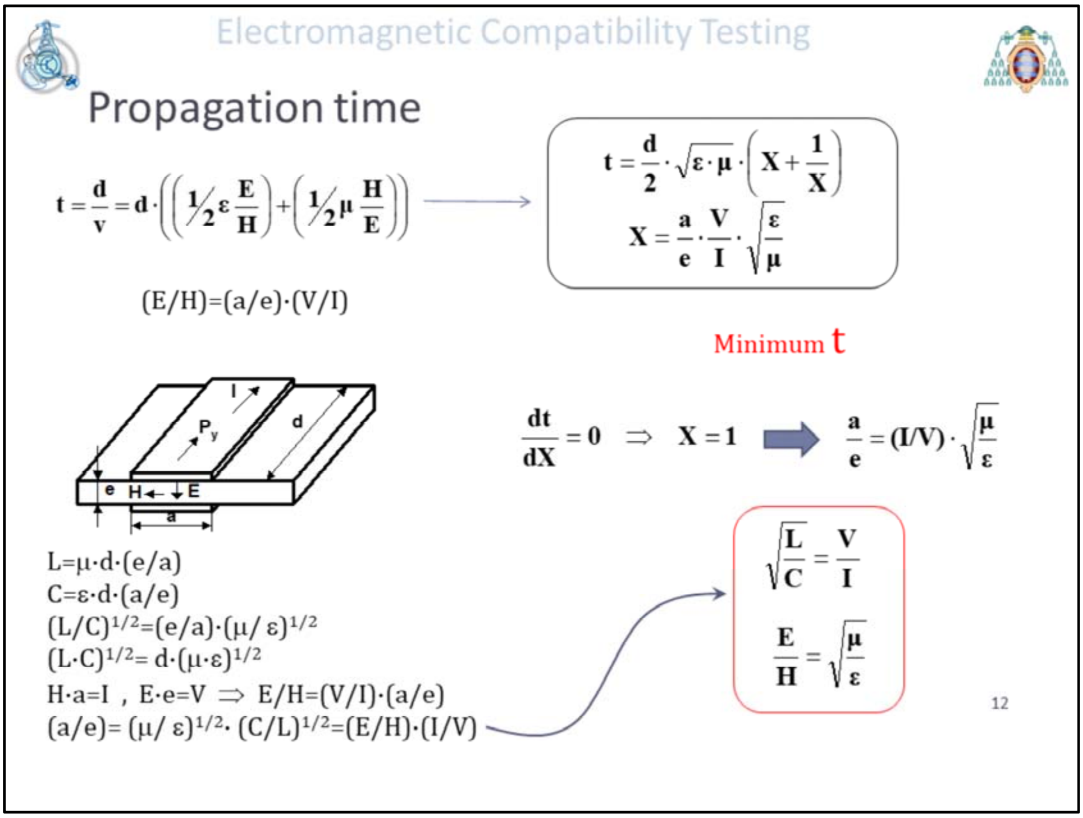
Once the magnetic and electric fields are known, it is also possible to determine the propagation speed.

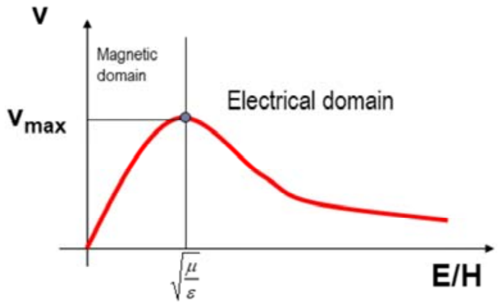



To minimize propagation time, the impedance of the material must equal the wave impedance.

$H \cdot a = I$ , $E \cdot e = V \Rightarrow E/H = (\mu/\varepsilon)^{1/2}$

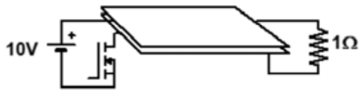
$(V/e) \cdot (a/I) = (\mu/\varepsilon)^{1/2}$

| | |
|---|---|
| $(\mu/\varepsilon)^{1/2}$ | **material impedance** |
| $(L/C)^{1/2}$ | **line impedance** |
| $(E/H)$ | **wave impedance** |



PCB ($\varepsilon_r$=4.5) , de 100 W, 10 V, 10 A:

(V/I)=1 Ω
$(\mu/\varepsilon)^{1/2}=377/4.5^{1/2}=178\ \Omega$




Maximum speed if $\frac{E}{H}=\sqrt{\frac{\mu}{\varepsilon}}=178\Omega$

$$\frac{a}{e}=(I/V)\cdot\sqrt{\frac{\mu}{\varepsilon}}=\frac{178}{1}$$ ⇒ e=0.2 mm
a=36 mm

Propagation speed:

$$v=\frac{1}{\sqrt{\mu\cdot\varepsilon}}=141\cdot10^6\ [m/s]$$

If we use a MOSFET with 3ns transient response
It would be desirable to have at least
the same propagation time. Therefore the maximum
Track length:

Track length
$d=v\cdot t=141\cdot10^6\ m/s\cdot 3\ ns=40\ cm$

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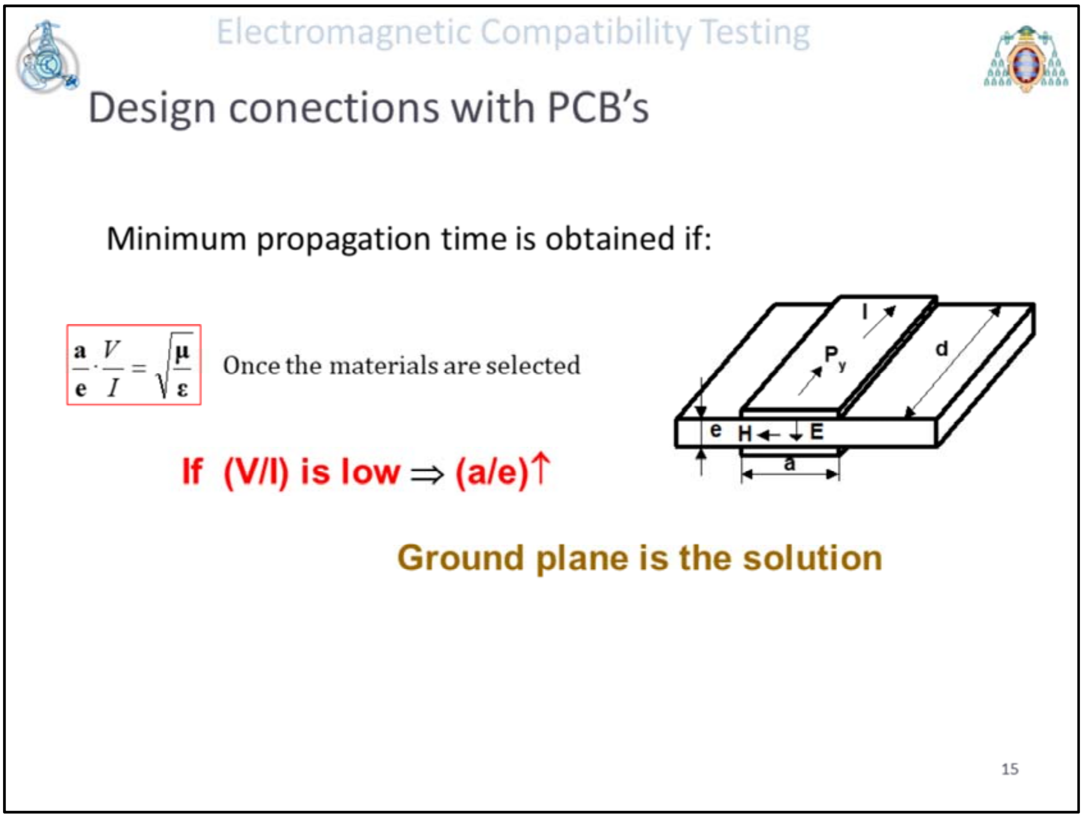
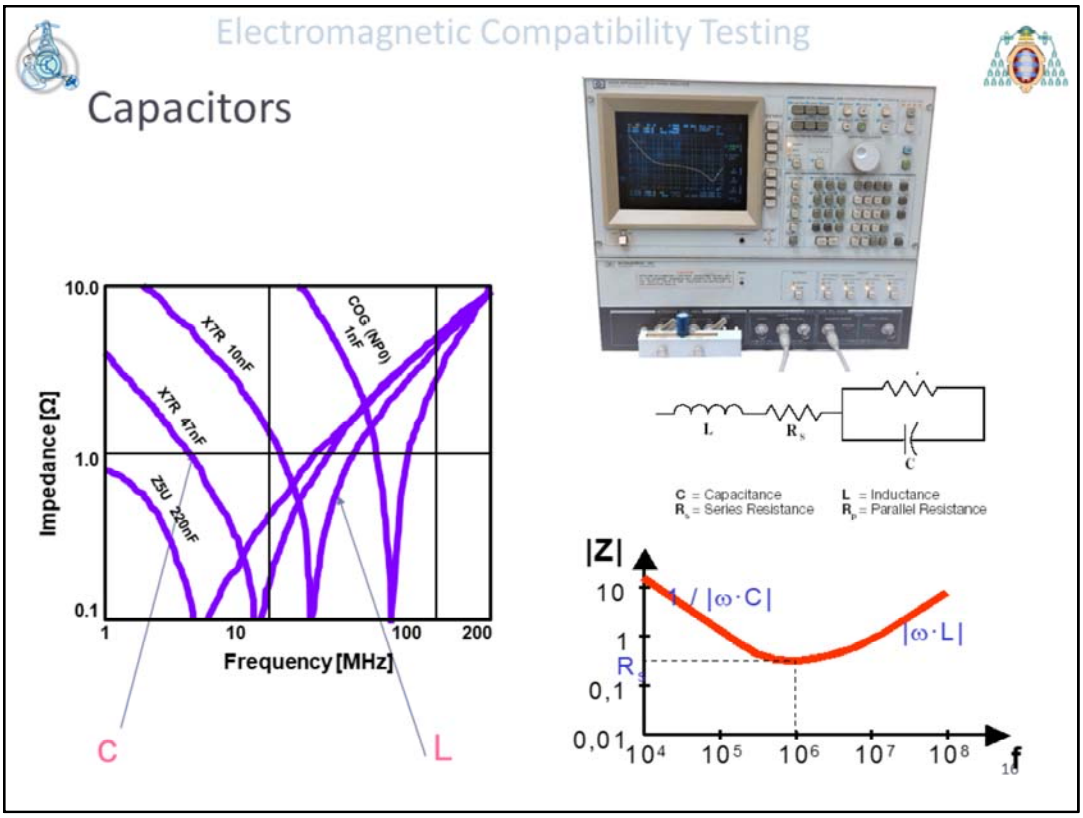
In this example, the length of a track is calculated to achieve a propagation time of 3ns

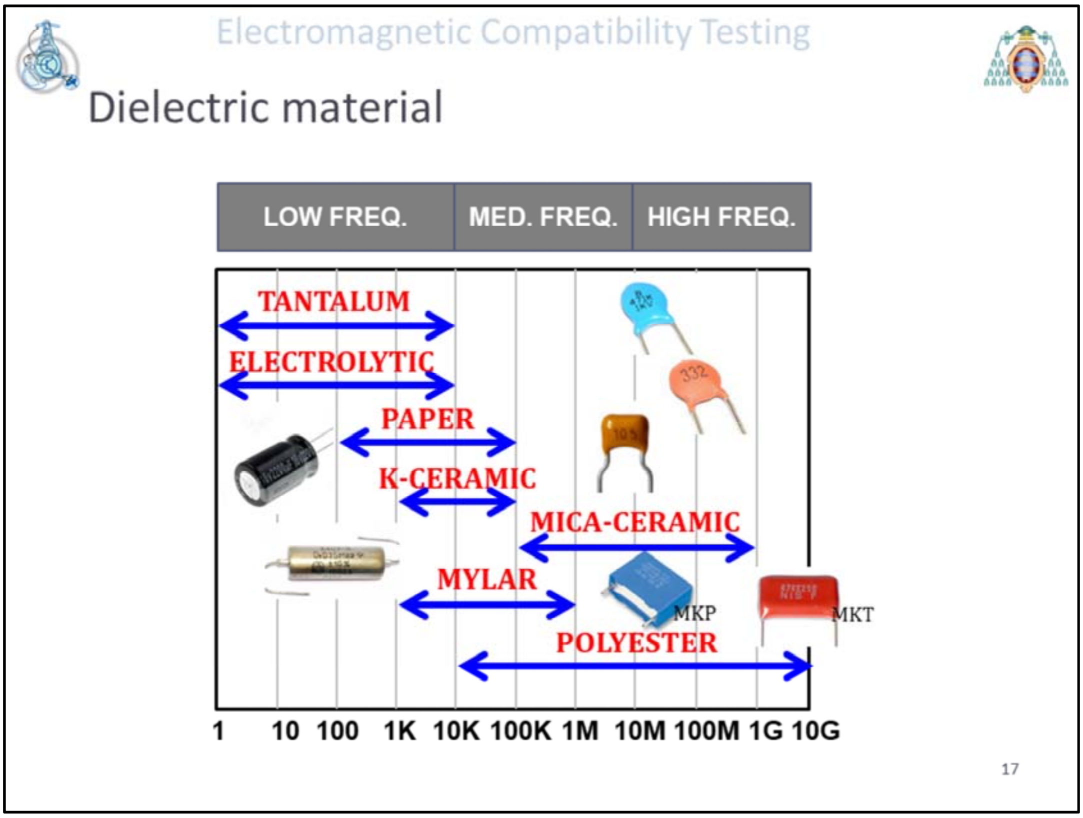



It can be observed that, to obtain high propagation times, the width of the tracks must also be large, the ground plane being a highly recommended solution

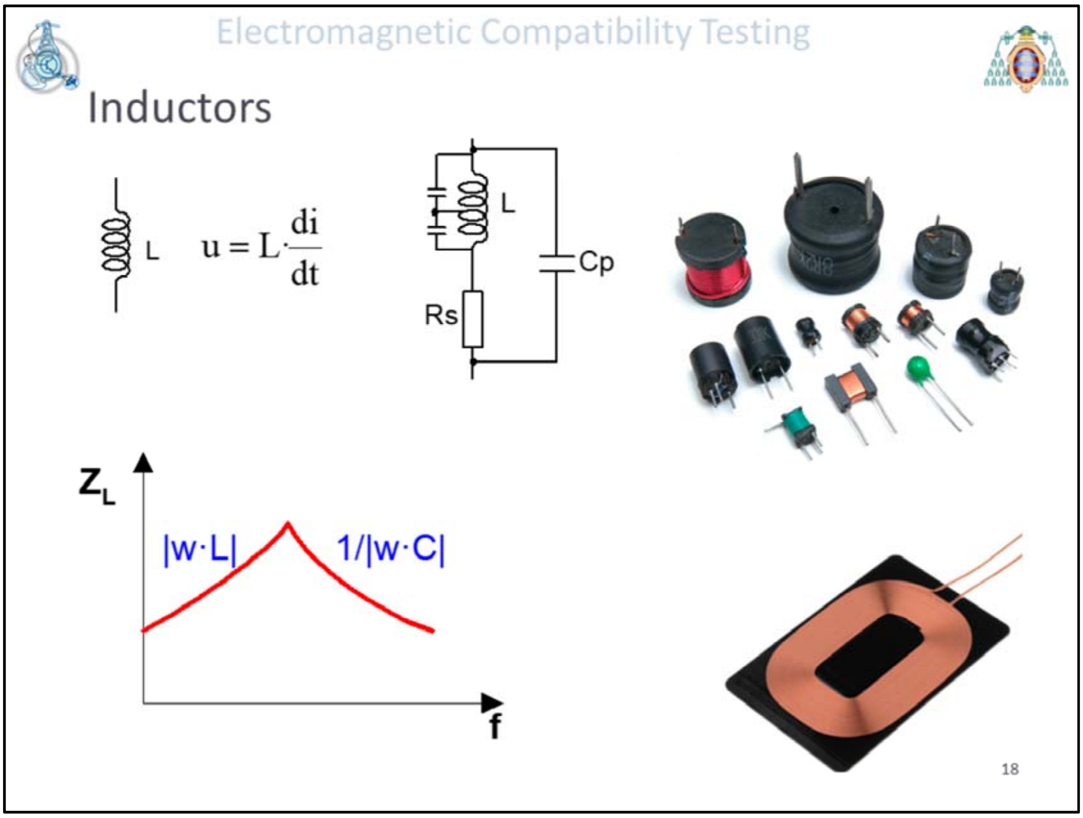



If we analyze the behavior of a real capacitor as a function of frequency, it is observed that after a certain frequency the impedance of the capacitor increases.

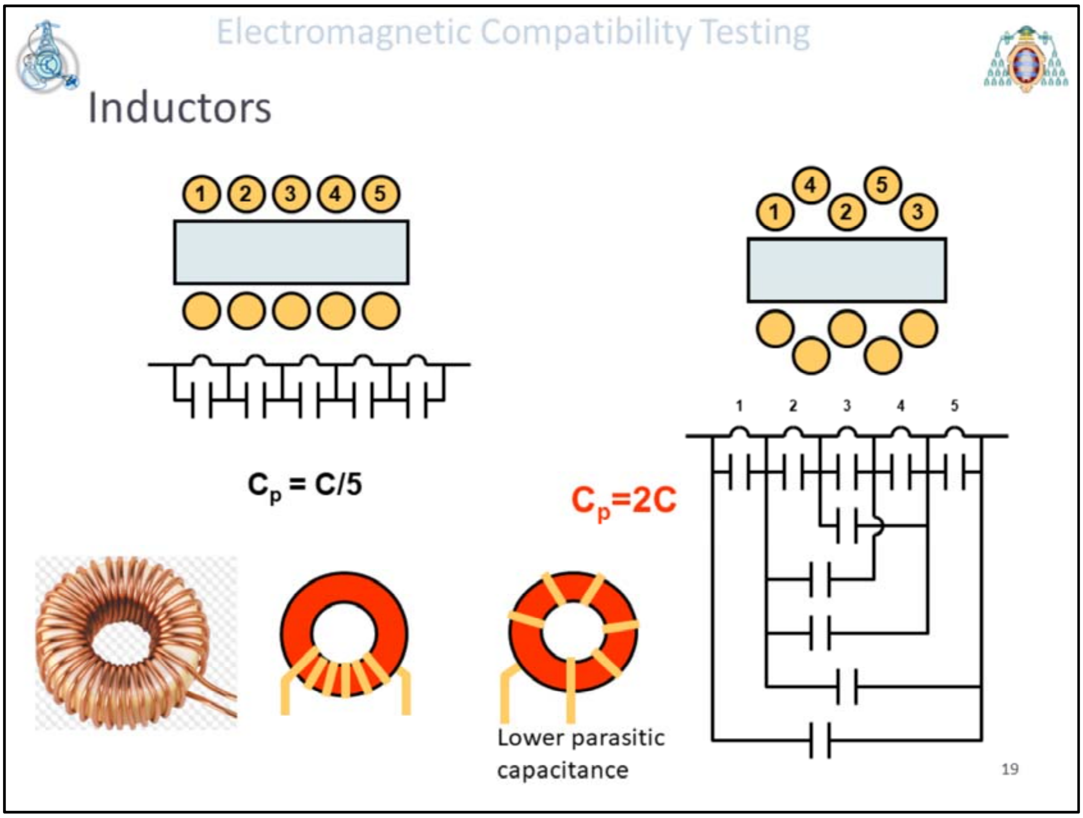
This phenomenon is due to the parasitic inductance that we must place in series with the capacitor.



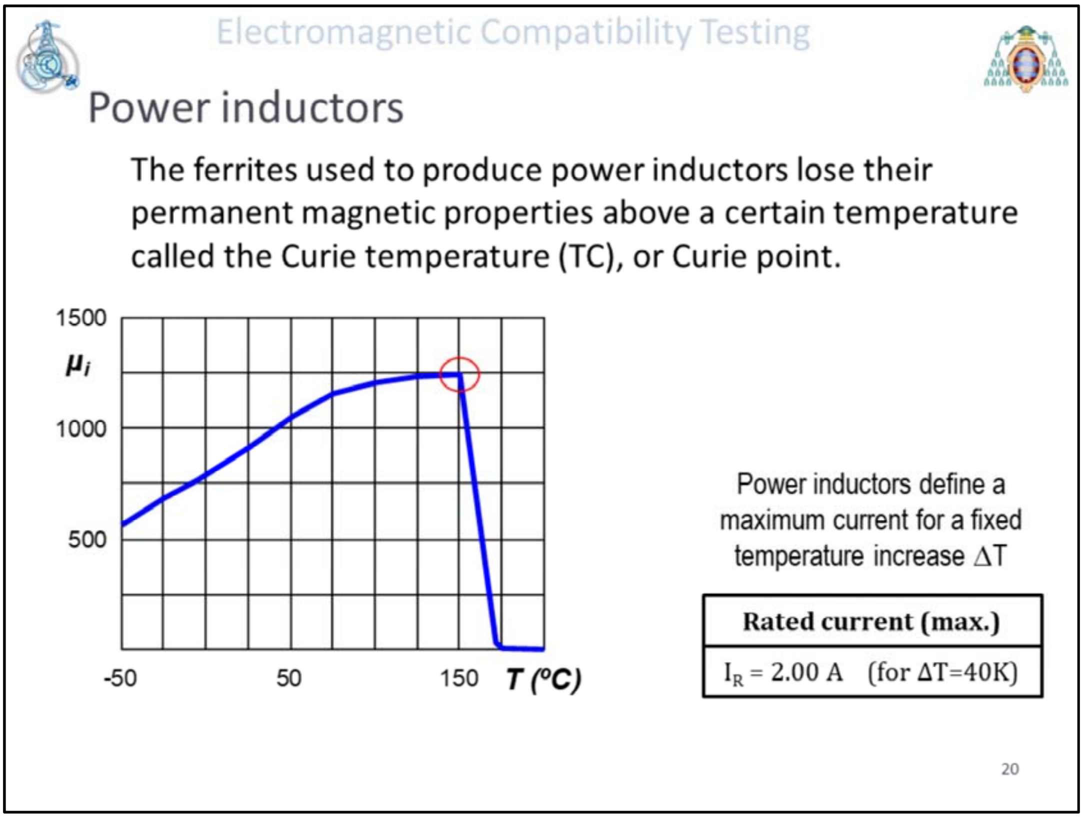

The selection of the type of capacitor based on the materials used in its manufacture and the frequency of work to which it will be subjected, is a critical aspect. Thus electrolytic capacitors should not be used in high-frequency applications due to their high parasitic inductance. The graph shows the use of different technologies.



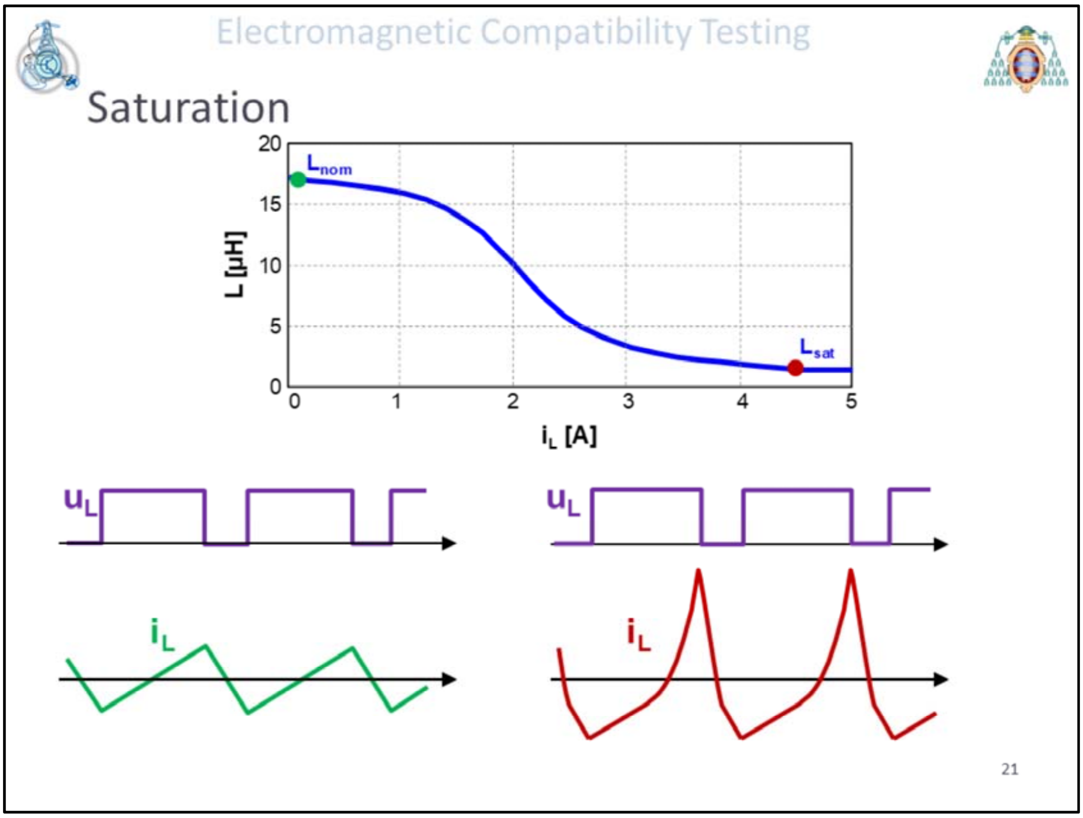

Because of the way coils are actually constructed, their impedance begins to decrease after a certain frequency. This is due to the presence of parasitic capacitance between the windings.




By increasing the distance between conductors, the parallel parasitic capacitance of the equivalent model is minimized.

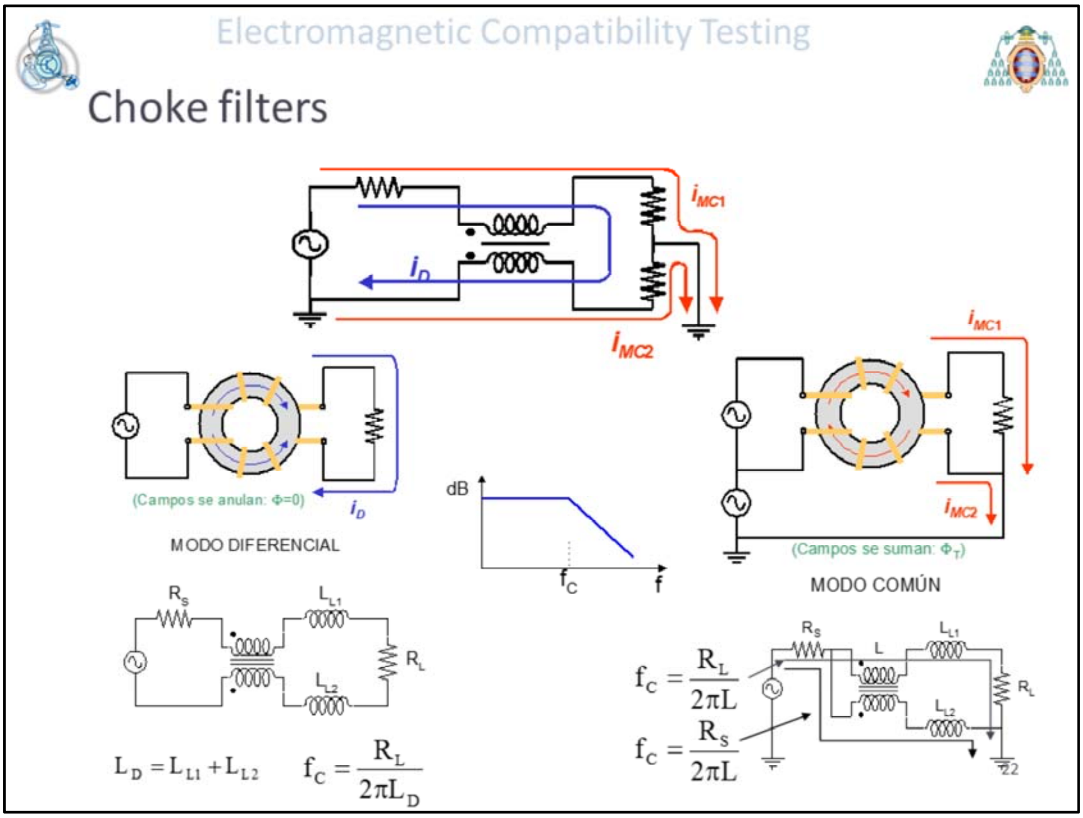



Another parameter to take into account is the temperature at which the magnetic material loses its magnetic properties (Curie Temperature).

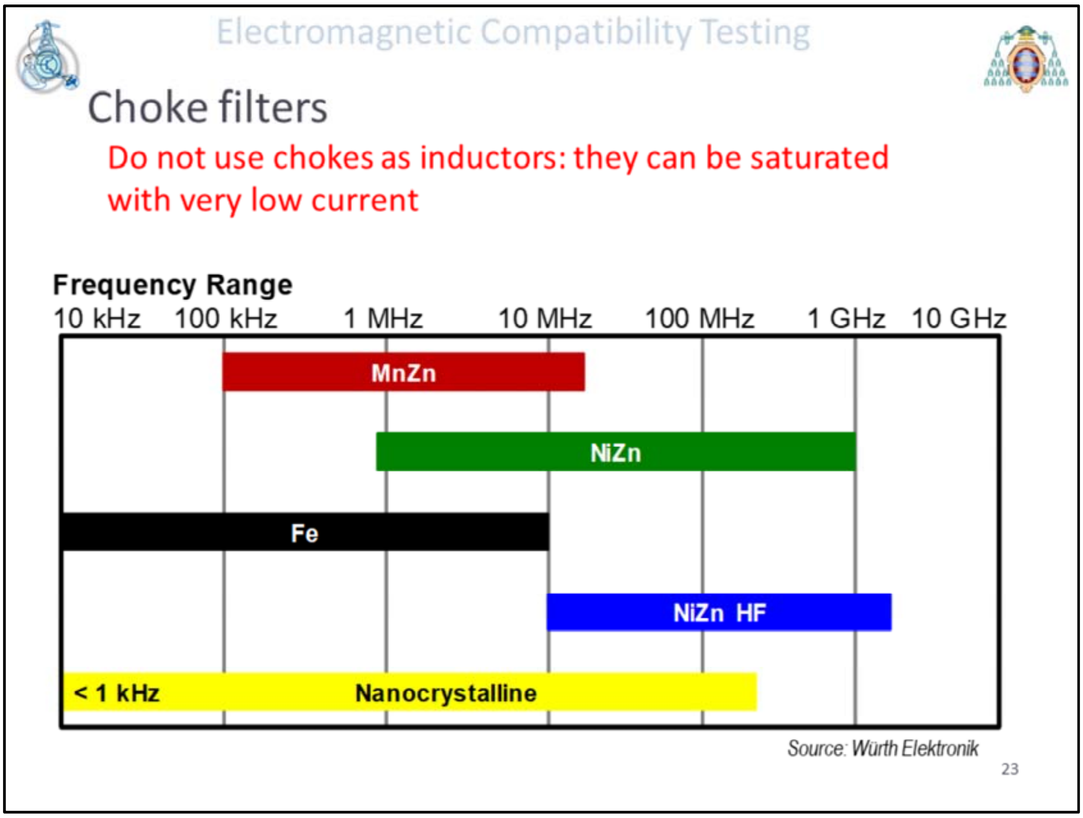



When a coil is subjected to high currents, the magnetic material can reach saturation and this causes a significant reduction in the value of the equivalent inductance, which contributes in many cases, to the current increasing even more.

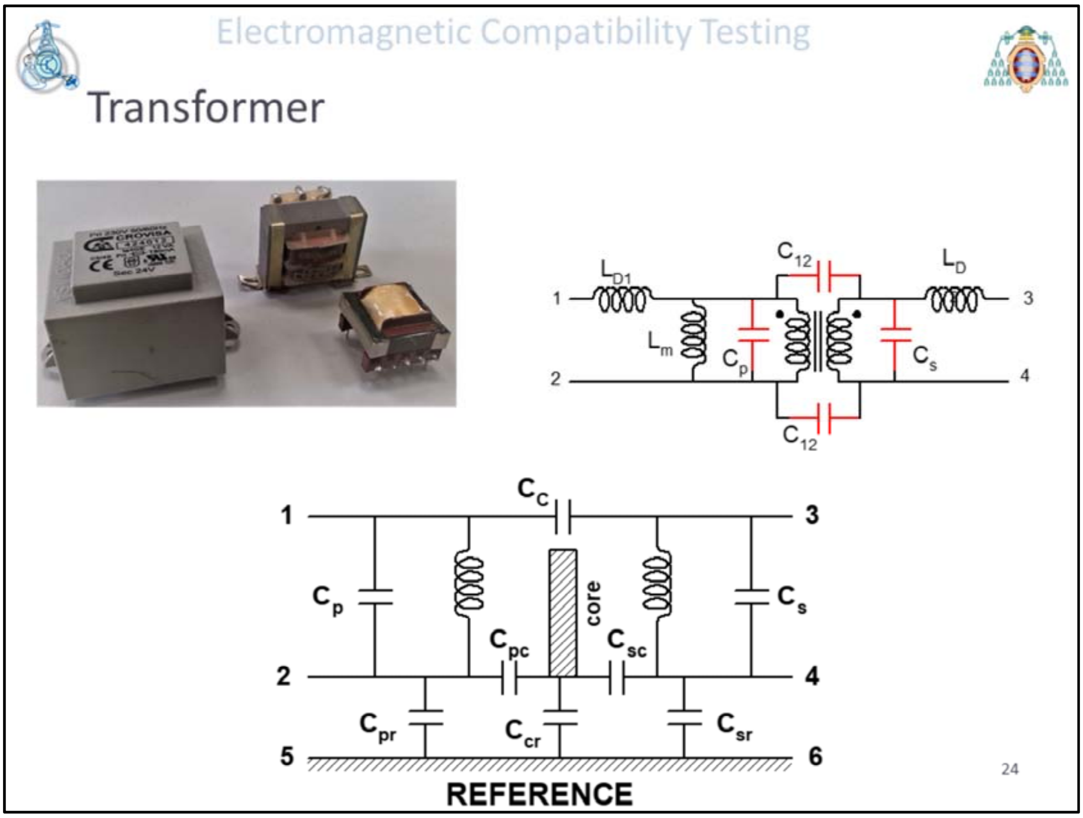
The figure on the right shows the current when the coil is saturated



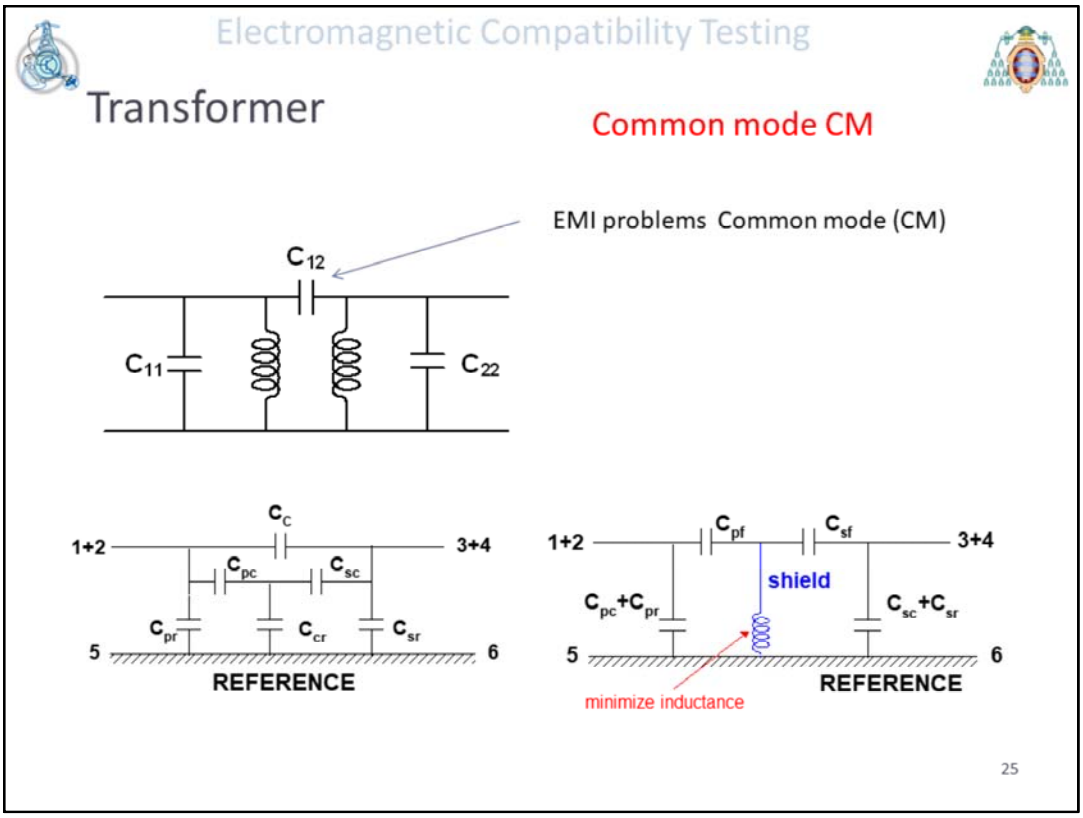

A type of coupled coils is known as a "choke filter". This type of filter is used primarily to reduce common-mode currents. The currents in differential mode, since they create flows in opposite directions in the magnetic material, are not affected nor can they saturate the magnetic core of these devices.



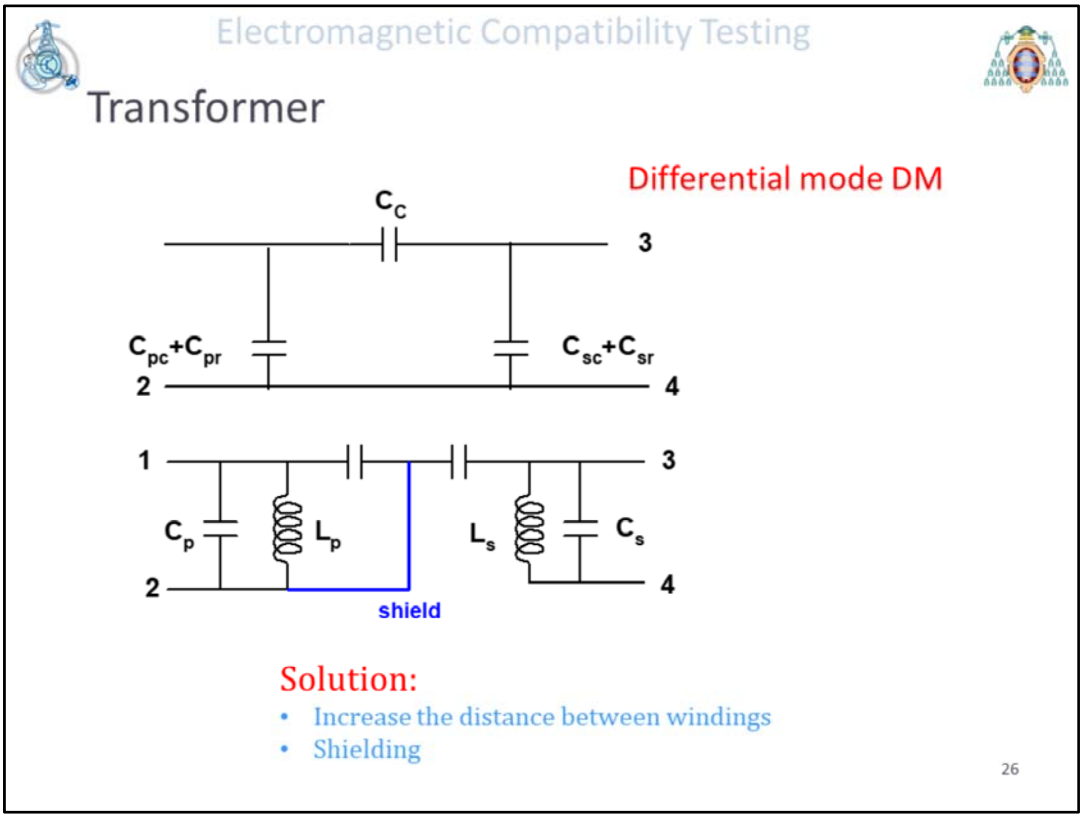

There are different types of magnetic materials. Depending on the frequency at which they will be used, the appropriate material must be selected.



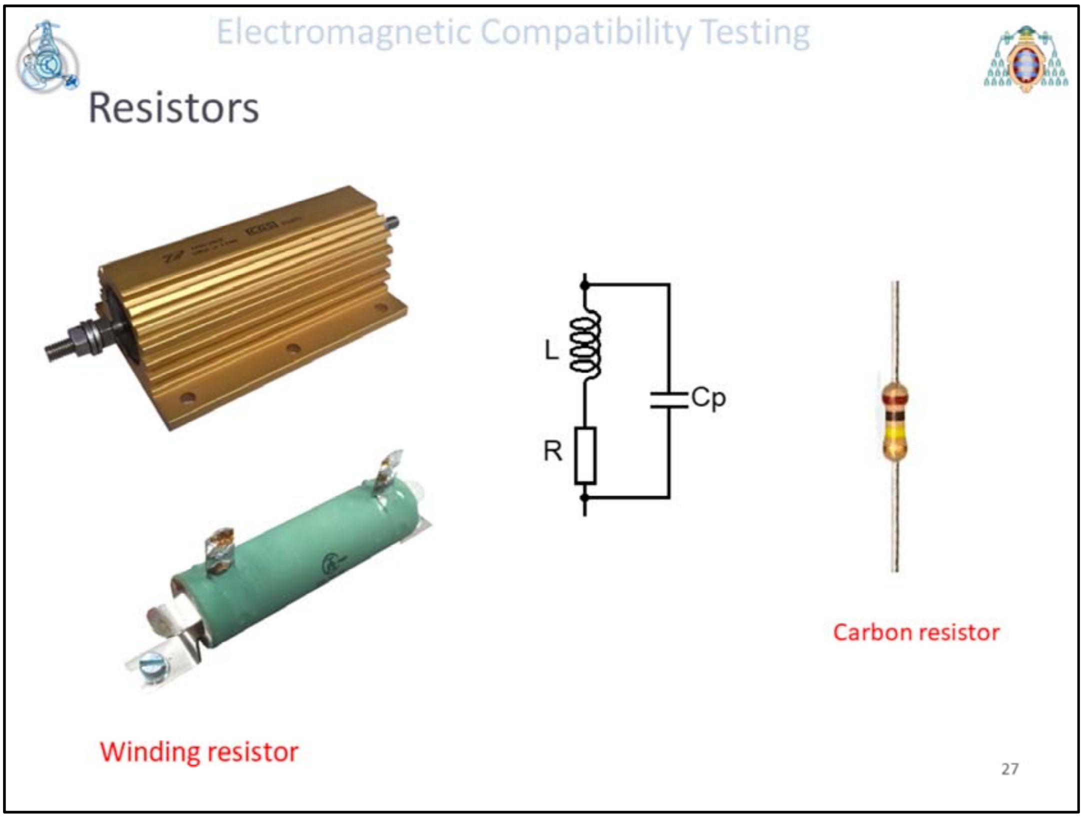

Although transformers introduce galvanic isolation between primary and secondary, when it comes to high-frequency signals, the existing parasitic capacitances may short-circuit both windings.




The way to mitigate the presence of parasitic capacities among the windings is the incorporation of shields




In a similar way, by connecting a shield between windings the existing parasitic capacitance between primary and secondary is divided in two. The high frequency currents of the primary will find a low-impedance path through the capacitor and the screen being confined to the primary, thus preventing them from reaching the secondary winding.




The technology of resistance manufacturing conditions the parasitic elements of its equivalent model. If the resistance is coiled, the series inductance will have a high value, which limits its use in high frequency.

On the other hand, the carbon resistors have low series inductance, and their use in high frequency is possible