Electrical Energy
Conversion and
Power Systems

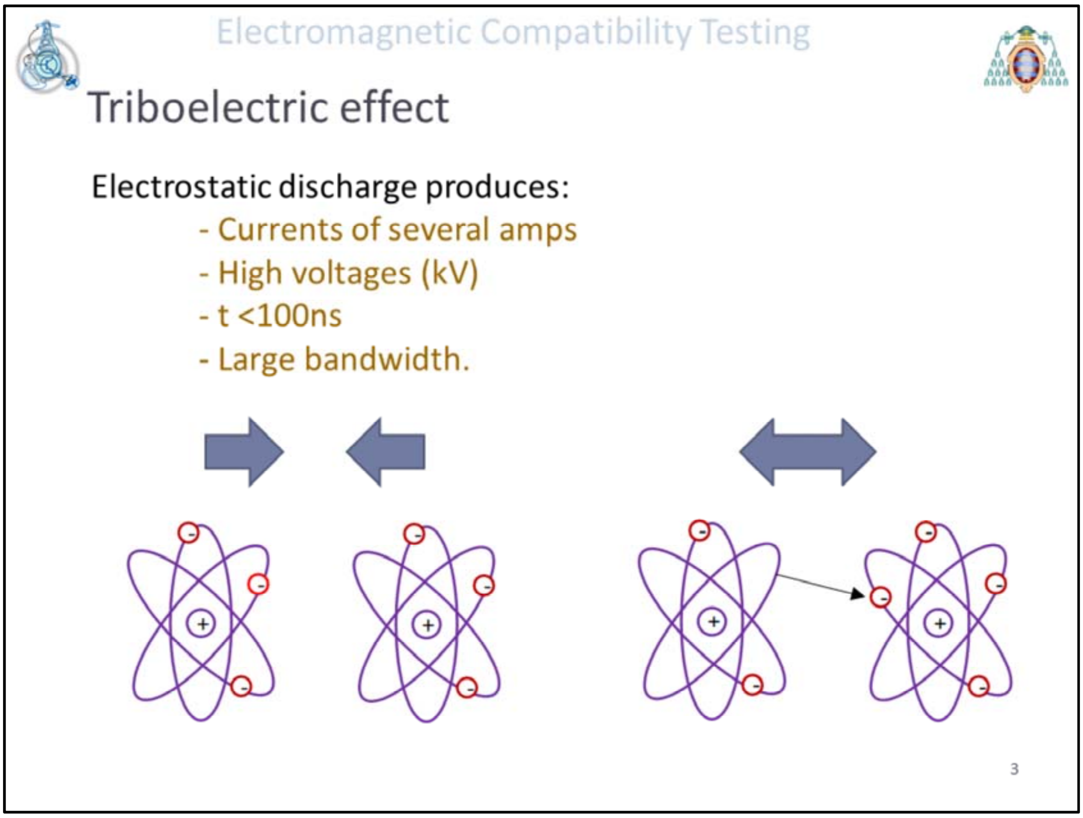
Universidad
de Oviedo

ESD & Shielding

Triboelectric effect

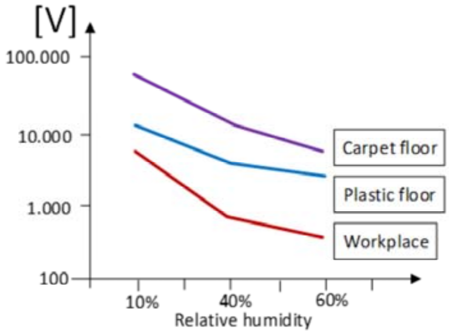
The **triboelectric effect** (also known as *triboelectric charging*) is a type of contact electrification in which certain materials become electrically charged after they come into contact with another different material through friction

Negative	Conductor - Insulator
Silicone rubber	Insulator
Polyethylene	Insulator
Saran	Insulator
Synthetic rubber	Insulator
Silver	Conductor
Nickel/copper	Conductor
Hard rubber	Insulator
Steel	Conductor
Cotton	Insulator
Paper	Insulator
Aluminum	Conductor
Silk	Insulator
Wool	Insulator
Nylon	Insulator
Glass	Insulator
Positive	**Conductor - Insulator**



The friction between the materials causes transfer of electrons and electrostatic charge of the materials

Electrostatic discharge



Typical voltage levels at different relative humidities		
Generation	0-25% RH	65-90% RH
Walking across carpet	35.000 V	1.500 V
Walking across vinyl tile	12.000 V	250 V
Worker at bench	6.000 V	100 V
Chair with urethane foam	18.000 V	1.500 V

Electrostatic discharge

Insulators

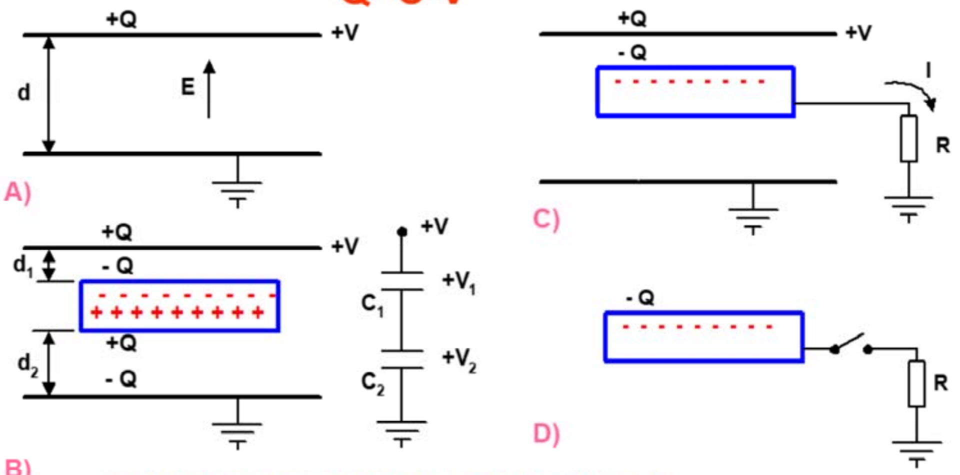
A considerable amount of charge can be generated on the surface of an insulator. Because an insulating material does not readily allow the flow of electrons, both positive and negative charges can reside on an insulating surface at the same time, although at different locations

Conductive Materials

Due to its low electrical resistance, conductive materials allows electrons to flow easily across its surface or through its volume. When a conductive material becomes charged, the charge will be uniformly distributed across the surface of the material.

Charging process

$Q=C\cdot V$



An external field cannot generate any field inside a conductive enclosure--> Antiestatic covers, paint,etc.

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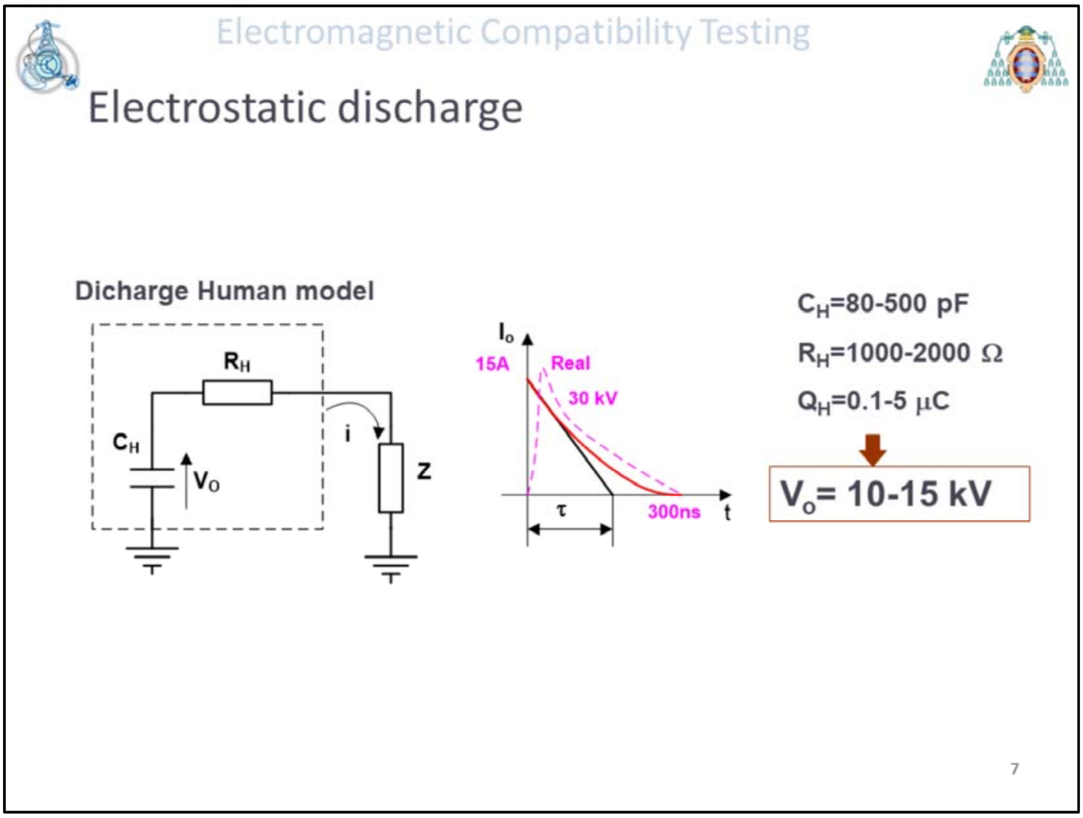
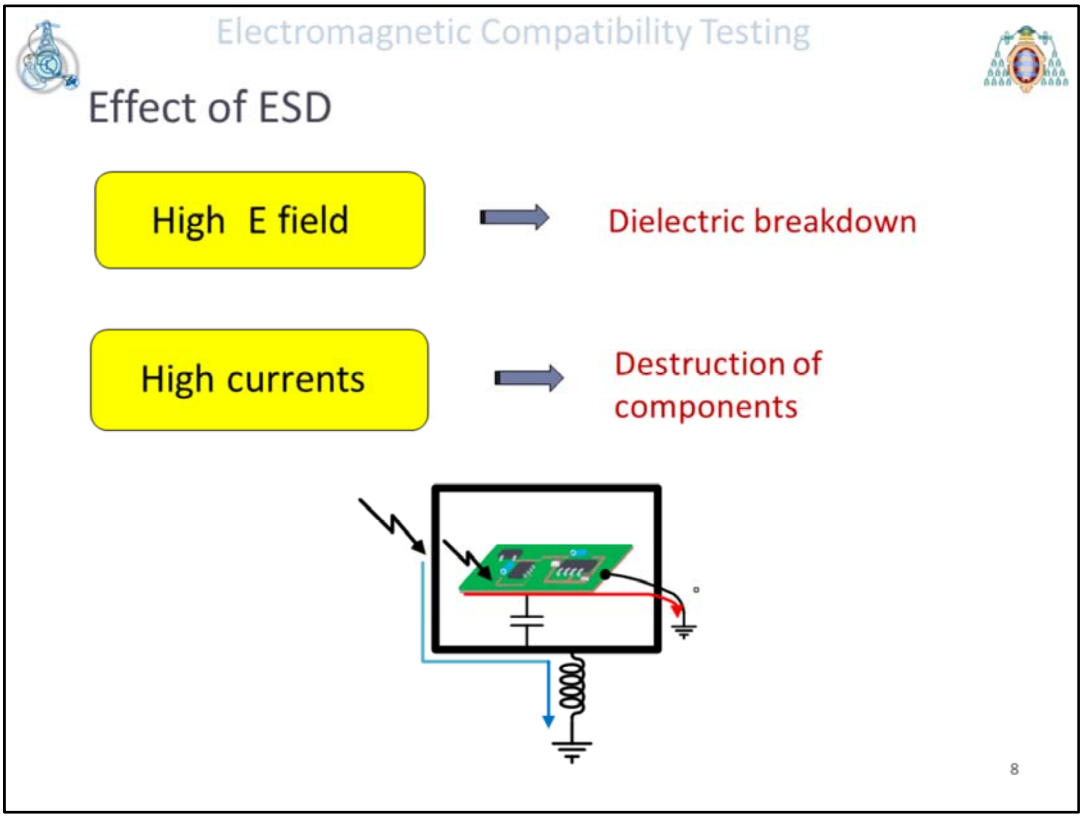
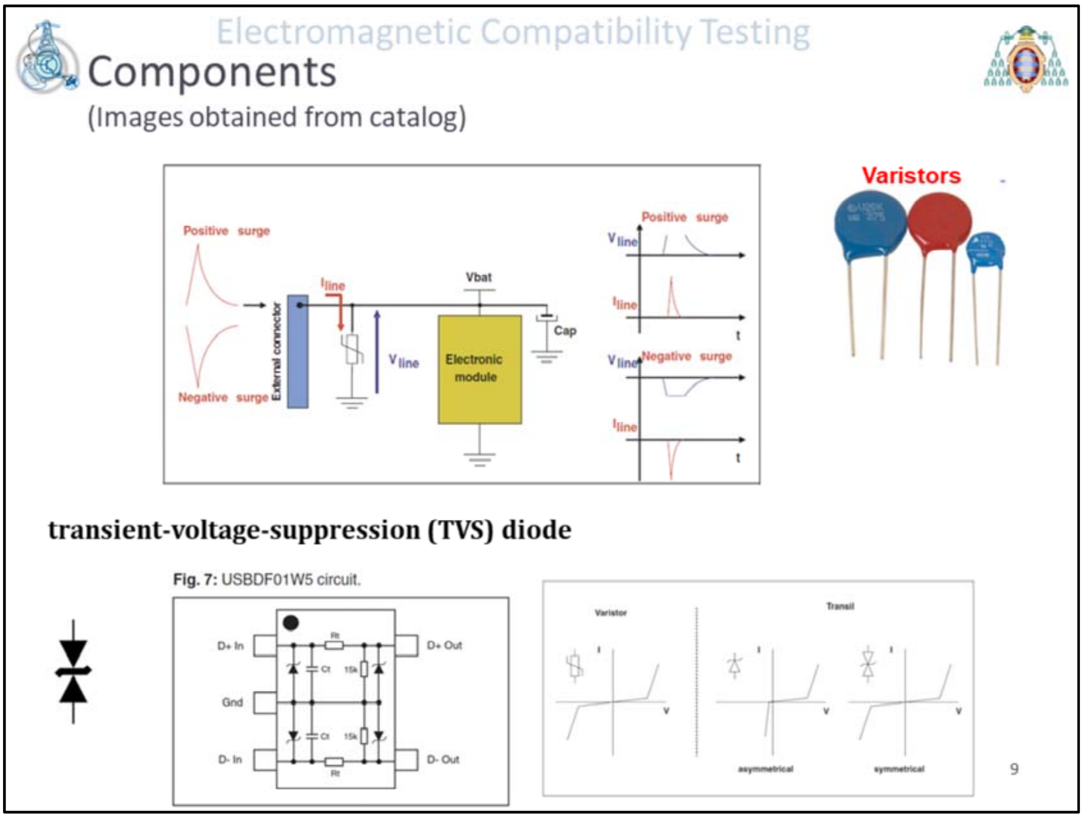


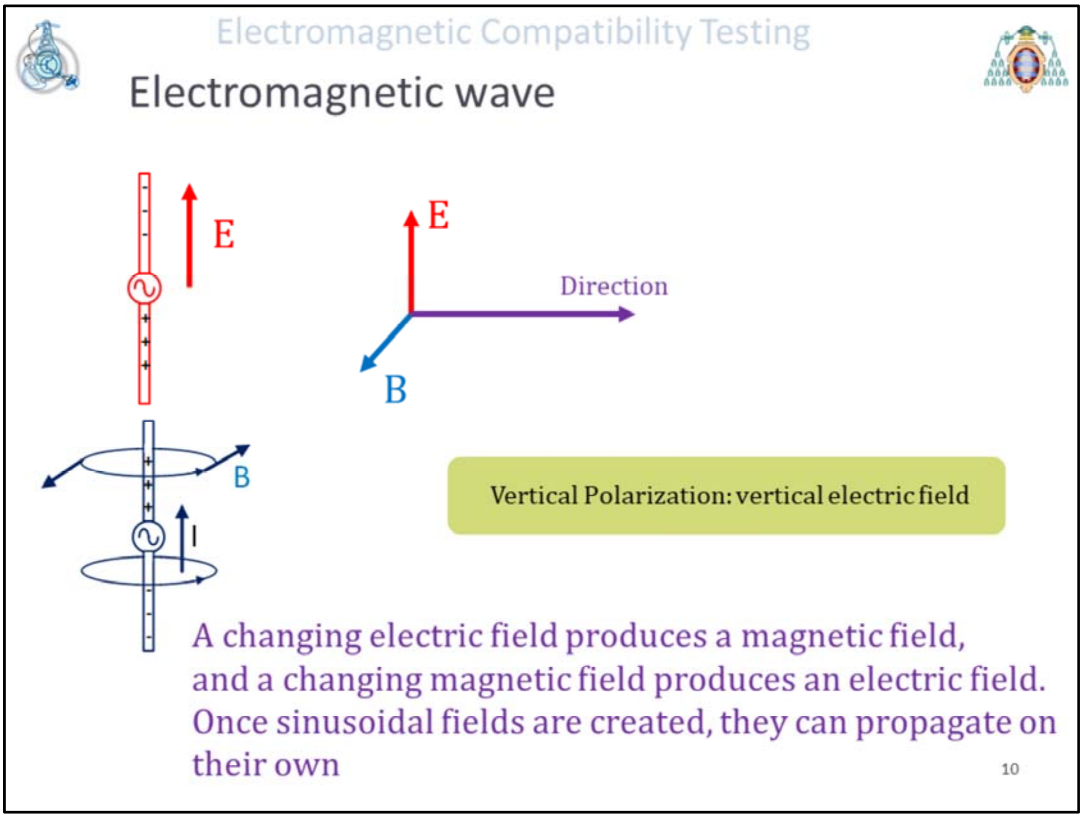
The process of electrostatic discharge caused by the human being through a resistance and a capacitor can be characterized with a model. The voltages reached can reach thousands of volts and tens of amps



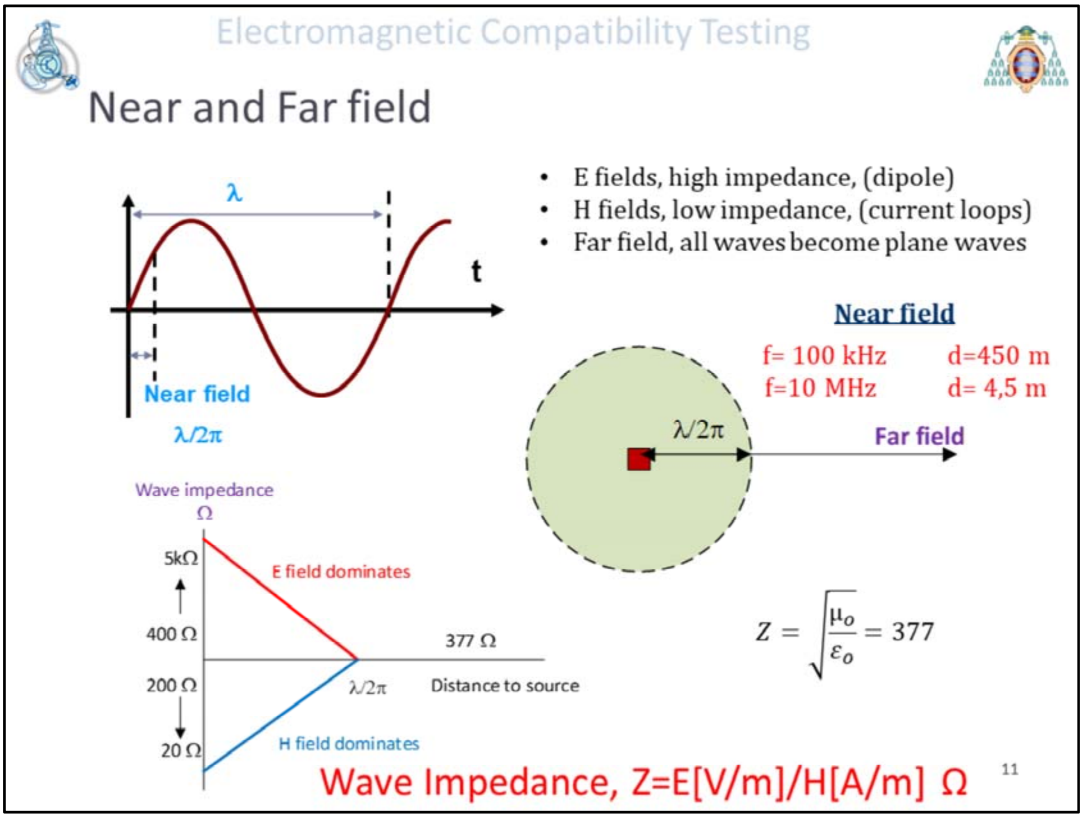
Encapsulating circuits in metallic boxes is not a solution to prevent electrostatic discharges if the ground connection is not adequate. Providing alternative paths to ground for the conduction of currents caused by ESD is a recommended practice



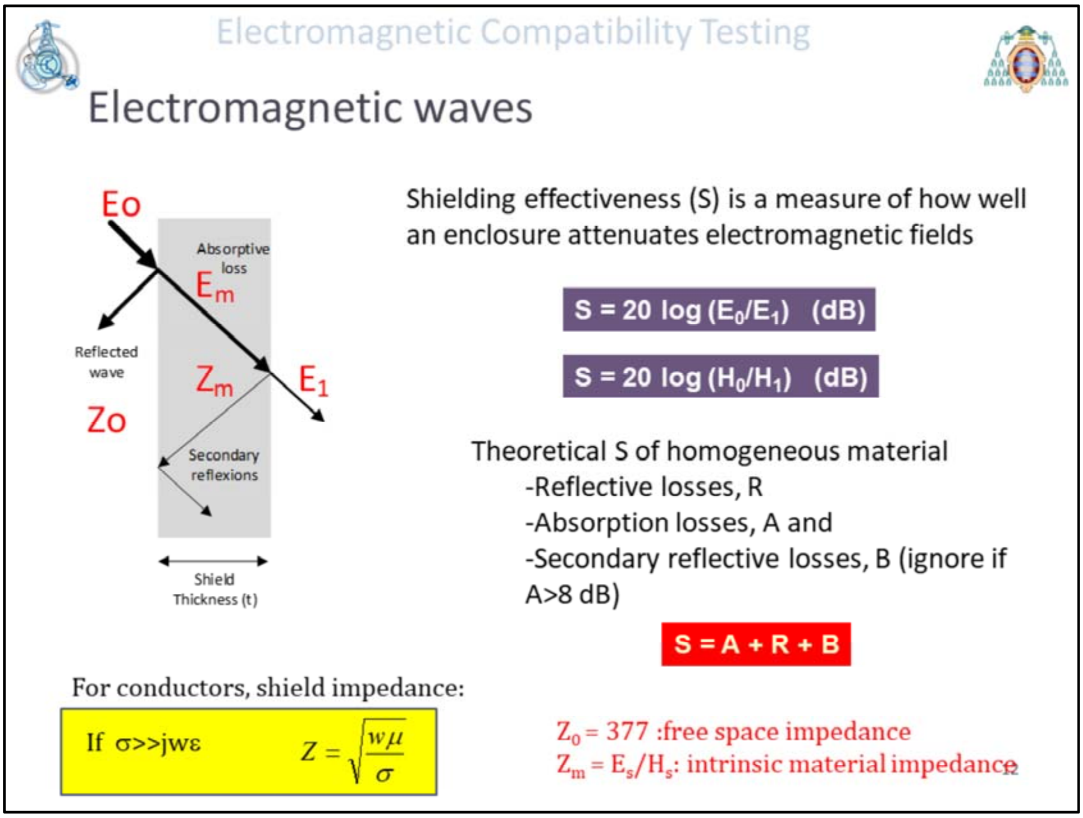
The components used to eliminate the effect of electrostatic discharges are varistors and transils (TVS). They have a sufficiently fast response to suppress overvoltages, fixing the nominal voltage value of the device.



The electromagnetic wave is formed by an electric field perpendicular to a magnetic field and both perpendicular to the direction of propagation



The term “near field” is used when the distance to the focus is less than the wavelength divided by two times pi



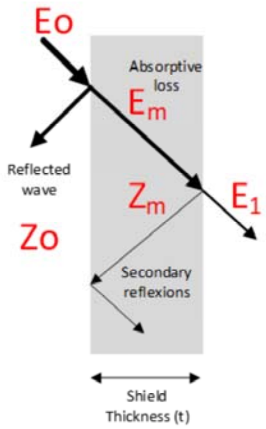
Effectiveness of a shield is associated to the ratio intensity of the incident wave to the wave that is capable of crossing the shield.

Electromagnetic waves

The amplitude of the reflected field must satisfy the relation,

If t->∞ infinite thickness

$$|E_{ref}| = |E_O| \cdot \Gamma_E$$



$$\Gamma_E = \frac{Z_m - Z_O}{Z_m + Z_O}$$: Field reflection coeficient

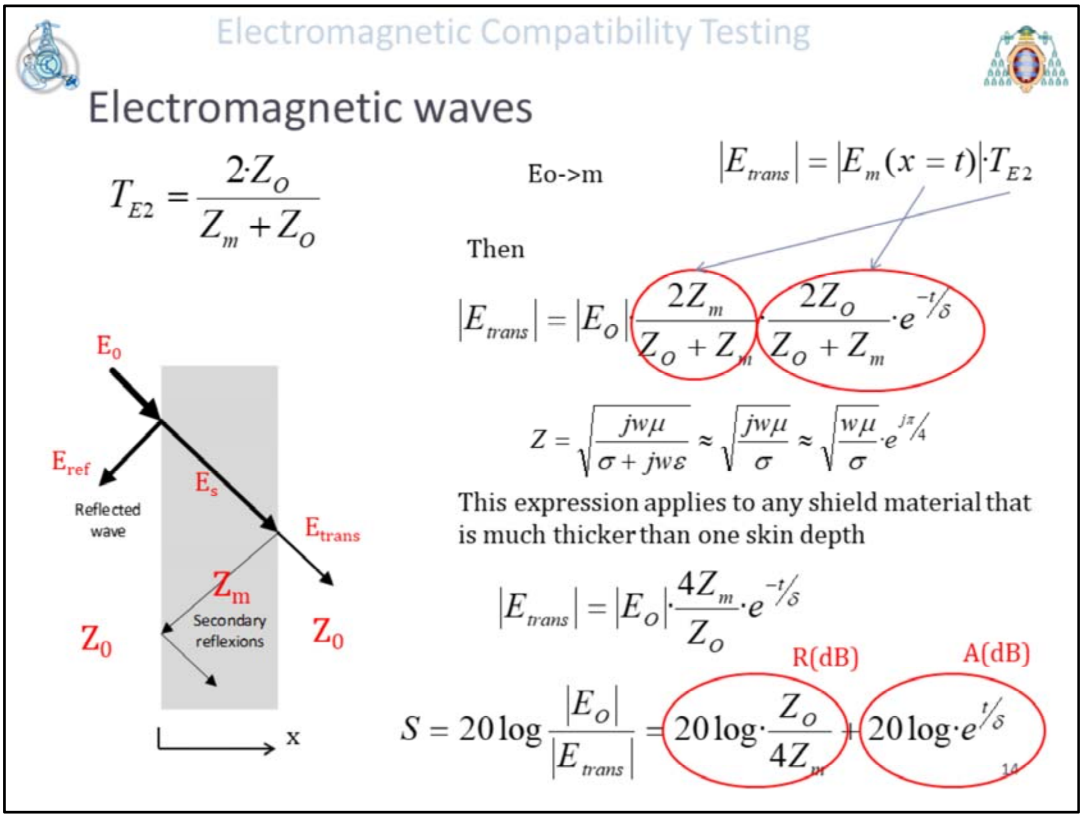
$$|E_m| = |E_O| \cdot T_E$$

$$T_E = \frac{2 \cdot Z_m}{Z_m + Z_O}$$: Field transmission coeficient

If the material is lossy σ≠0, the transmited wave decreases

$$|E_m(x)| = |E_m(x=0)| \cdot e^{-x/\delta}$$

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$ Skin depth



The final result shows the two most important terms: losses by reflection and losses by absorption.

Practical considerations

Far filed (plane wave)

Low frequency → Reflective losses (use conductive material)
High frequency → Absorption losses (use magnetic material)

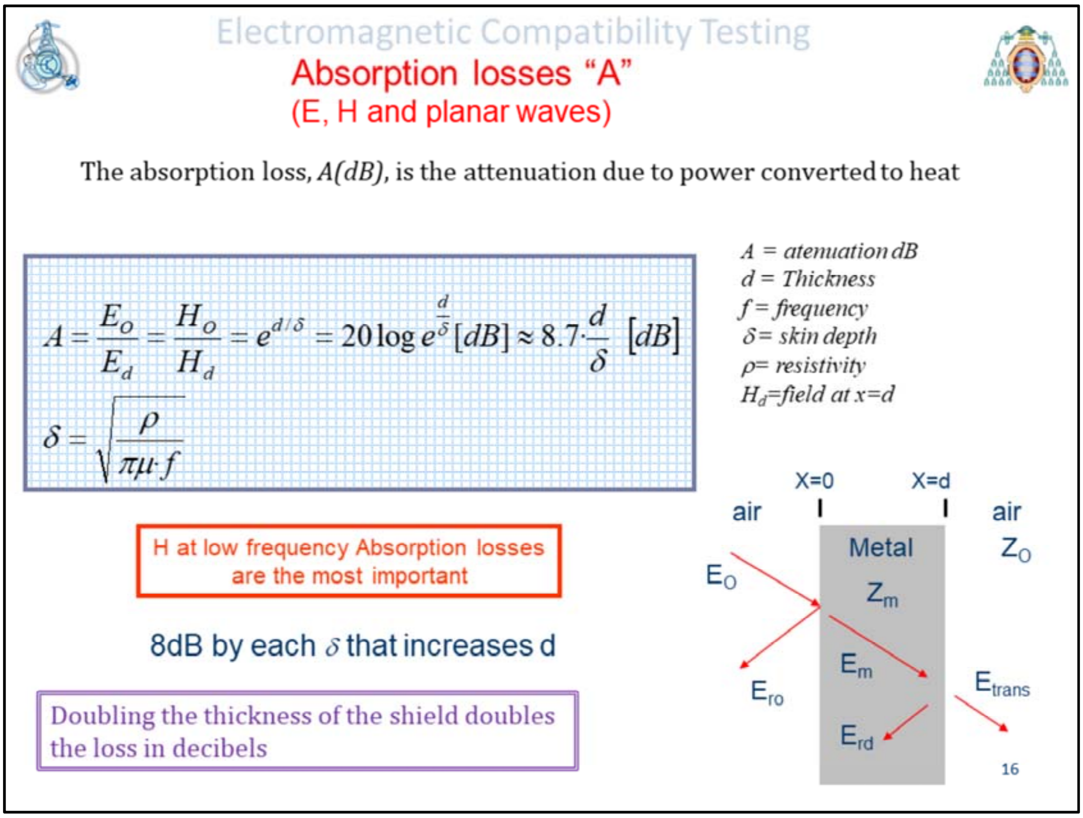
Near field

Electric field E

Low frequency → Reflective losses
High frequency → Absorption losses

Magnetic field H

Low and High frequency → Absorption losses

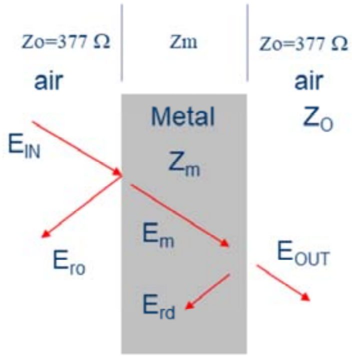


Absorption losses depend fundamentally on thickness and skin depth.

Electromagnetic Compatibility Testing

Reflective losses "R"

$$R = \frac{E_{IN}}{E_{OUT}} = \frac{H_{IN}}{H_{OUT}} = \frac{(Z_O + Z_m)^2}{4(Z_O Z_m)}$$



Zo=377 Ω

$$|Z_m| = \frac{E_M}{H_M} = \sqrt{\left|\frac{jw\mu}{jw\varepsilon + \sigma}\right|} = \frac{\sqrt{2}}{\sigma \cdot \delta}$$

$$\delta = \sqrt{\frac{\rho}{\pi\mu \cdot f}}$$

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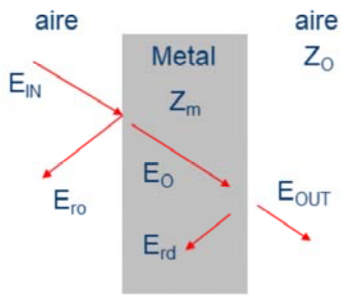
Reflective losses depend on the impedances of the different media involved

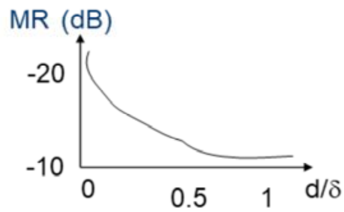
Secondary reflective losses "MR"

$$MR = 20 \cdot \log\left(1 - e^{\frac{-2d}{\delta}}\right) = \frac{2d}{\delta}\,[dB]$$

(for low values of d/δ)

MR is important if absorption losses are low





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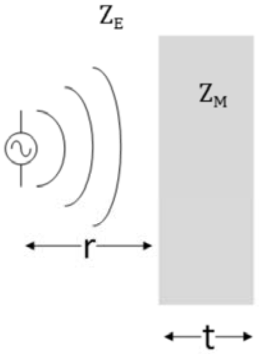
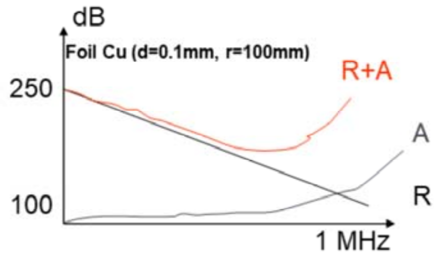
Near field: E dipole

$$Z_E = \frac{1}{2\pi\cdot\varepsilon_o f\cdot r}$$





r: distance from the source to the shield

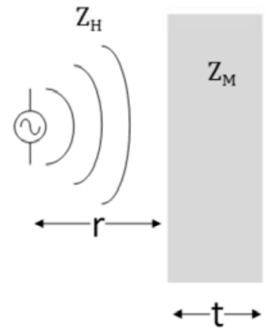
$$R_E = \left|\frac{(Z_E + Z_m)^2}{4 Z_E Z_m}\right| \approx \frac{1}{4\sqrt{2}}\cdot\frac{\sigma\delta}{w\cdot\varepsilon_o\cdot r}$$

Characteristics

- **High conductivity**
- **Zero voltage or constant voltage**

If w->0 ⇒ R_E will be high

Near field: H dipole



$$Z_H = 2\pi\mu f \cdot r$$

$$R_H = \left|\frac{(Z_H + Z_m)^2}{4 Z_H Z_m}\right| \approx \frac{w \mu_o r \sigma \delta}{4\sqrt{2}}.$$

If $Z_H >> Z_m$. This ecuation is not correct

- Low frec. Low effectiveness.
- High frec. Absorción

d=r: distance from the source to the shield

- A_H *(absorción)* increases if *f* or r increase
- A_H increases with high permeability
- Increase with "thickness"

magnetic materials are the most appropriate ones

Planar waves

$Z_O=377\Omega$
Far field ($r>>\lambda/2\pi$)
It is not very common

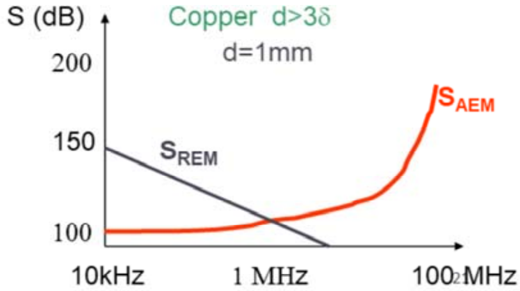
$$R_{EM}=\left|\frac{Z_O}{4\cdot Z_m}\right|=\frac{377\sigma\delta}{4\sqrt{2}}$$ **Reflective losses**

At low frequency (d/δ low) MR and absorption are negligible

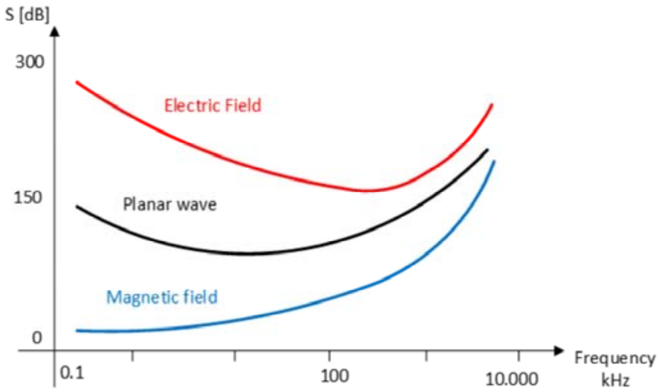
At f↓ **reflective losses are important**.

- Good conductors (high σ)

$\sigma >> \omega\varepsilon$



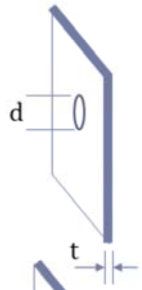
0.02-in-thick solid aluminium shield



Electric field, plane wave, and magnetic field shielding effectiveness of a 0.02-in-thick solid aluminium shield.

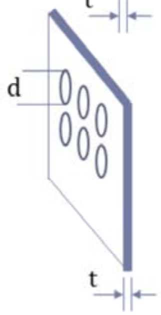
Practical considerations

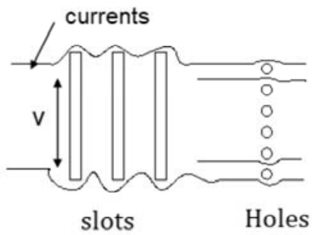
Holes/Apertures d>t



If $\lambda/2 < d$ SE≈0dB

If $\lambda/2 > d$ SE≈20Log ($\lambda/2d$)





If $\lambda/2 < d$ SE≈0dB

If $\lambda/2 > d$ SE≈20Log ($\lambda/2d$)-10Log(n)

n:number of holes

Waveguide

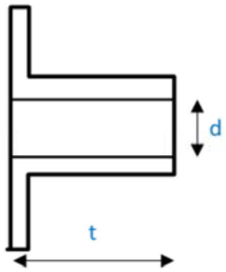
Circular waveguide

Cutoff frequency below which it becomes an attenuator

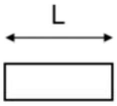
$$f_C = \frac{6.9 \cdot 10^9}{D} \left[Hz\right]$$

Effectiveness for f<fc

$$\lambda_{max} = \frac{D}{2\pi} \qquad S = 32 \cdot \frac{t}{D} \left[\mathrm{dB}\right]$$



Rectangular waveguide



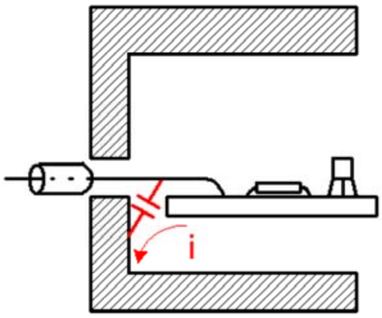
$$f_C = \frac{5.9 \cdot 10^9}{L} \left[Hz\right]$$

When the thickness is similar to the hole dimension

$$S = 27 \cdot \frac{t}{L} \left[\mathrm{dB}\right]$$

$$\lambda_{max} = \frac{L}{2\pi}$$

* Lenth in inches
t: thickness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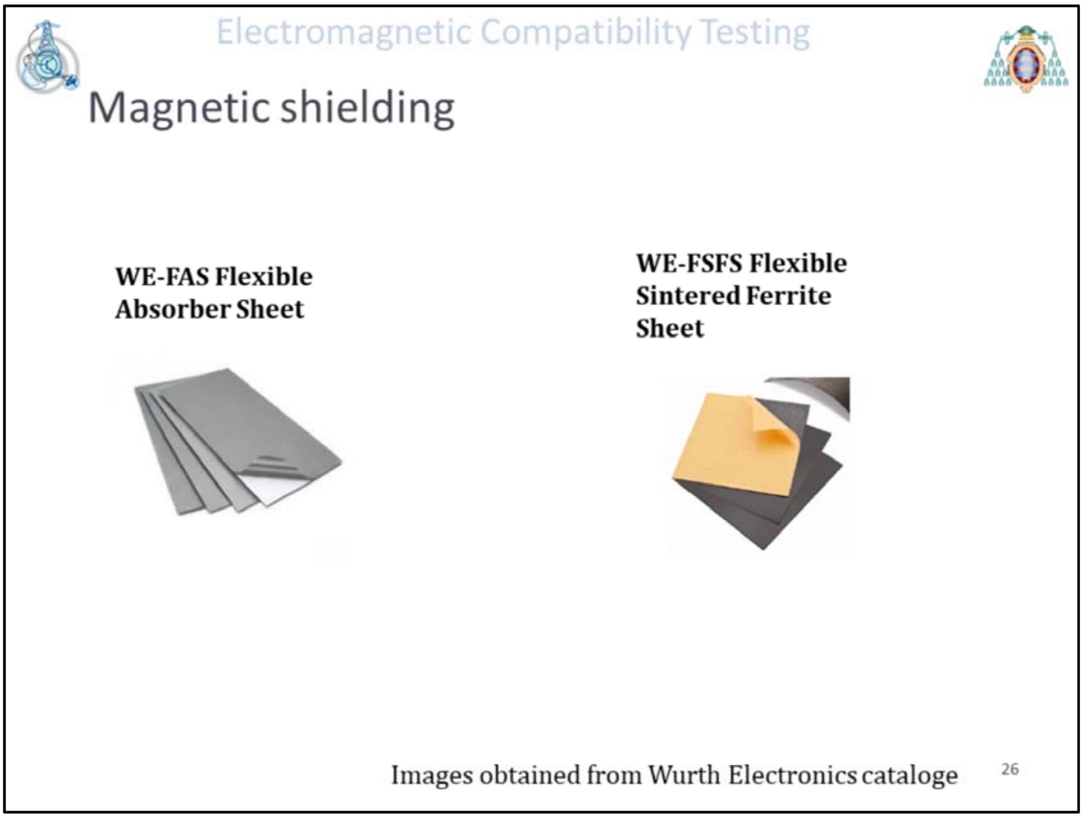
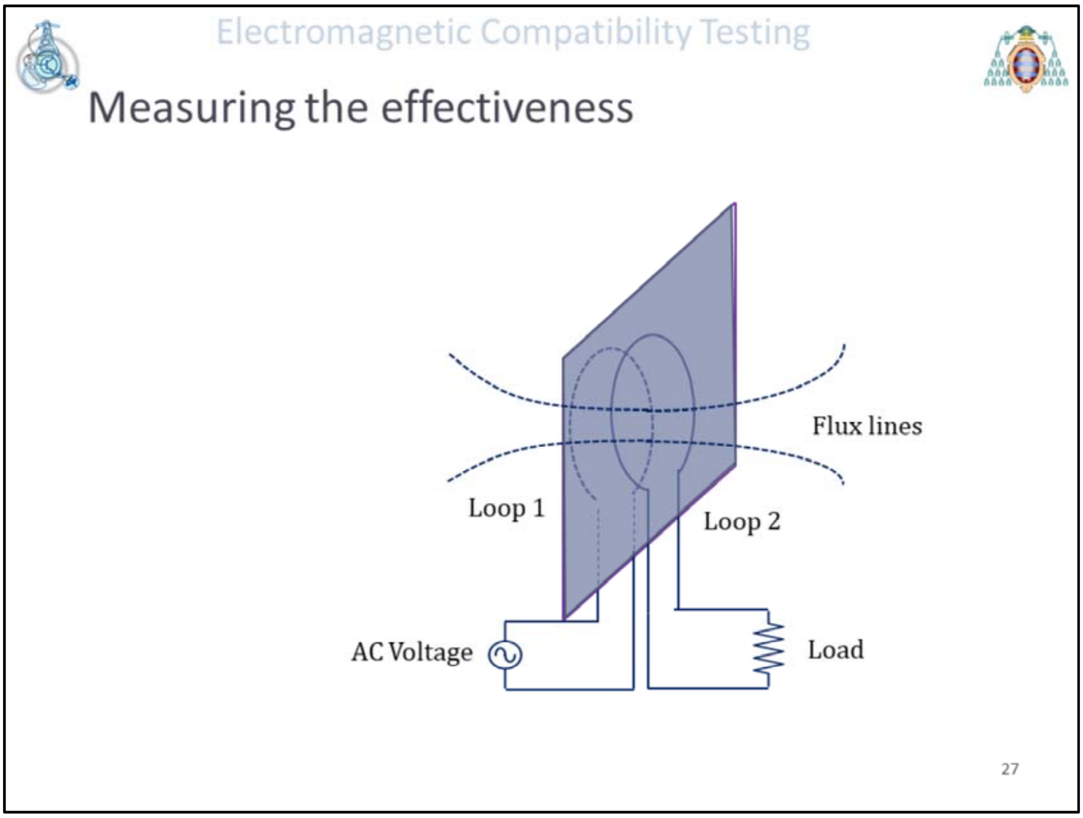


There are new magnetic adhesive materials to shield small components



To measure the effectiveness of a shielding you can use two loops, one connected to a source and the other one connected to the load. Placing the shield between both loops we will observe the voltage that appears across the load due to the field that crosses the shield