Shielding

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References

Basic:

Ott H. W., *Electromagnetic Compatibility Engineering*, Wiley, Hoboken, NJ, 2009

Additional:

Williams T., *EMC for Product Designers*, Elsevier-Newnes, 4-th ed., Oxford, 2007

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Source of illustrative materials

All the illustrative materials have been taken from:

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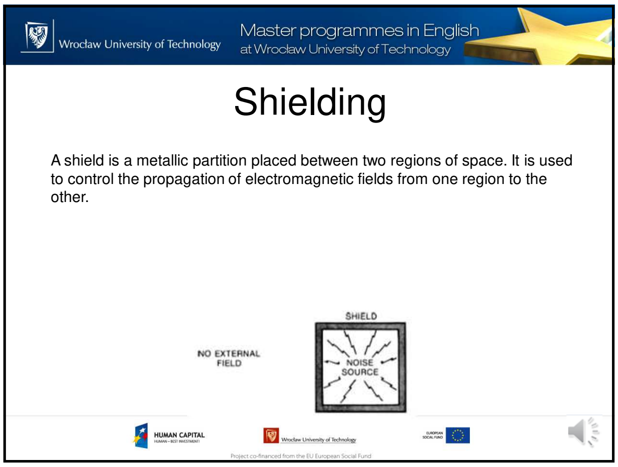
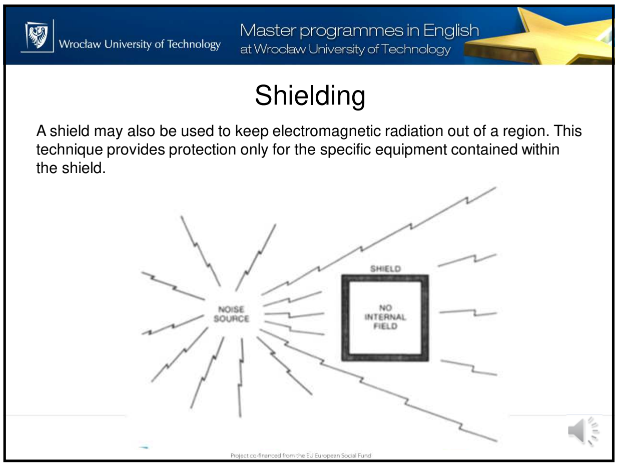


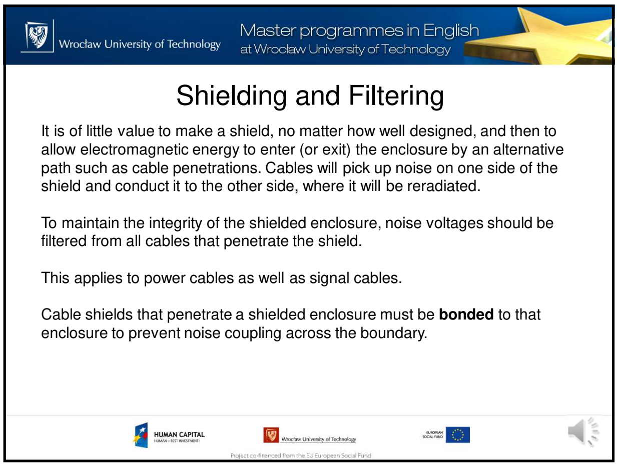
Shielding

A shield is a metallic partition placed between two regions of space. It is used to control the propagation of electromagnetic fields from one region to the other.



Shielding

A shield may also be used to keep electromagnetic radiation out of a region. This technique provides protection only for the specific equipment contained within the shield.



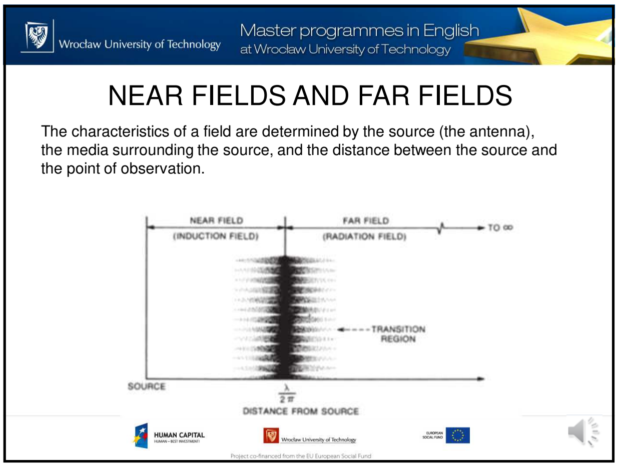
Shielding and Filtering

It is of little value to make a shield, no matter how well designed, and then to allow electromagnetic energy to enter (or exit) the enclosure by an alternative path such as cable penetrations. Cables will pick up noise on one side of the shield and conduct it to the other side, where it will be reradiated.

To maintain the integrity of the shielded enclosure, noise voltages should be filtered from all cables that penetrate the shield.

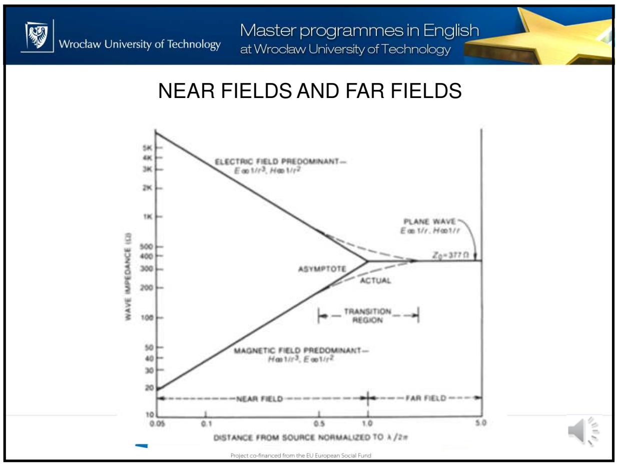
This applies to power cables as well as signal cables.

Cable shields that penetrate a shielded enclosure must be **bonded** to that enclosure to prevent noise coupling across the boundary.

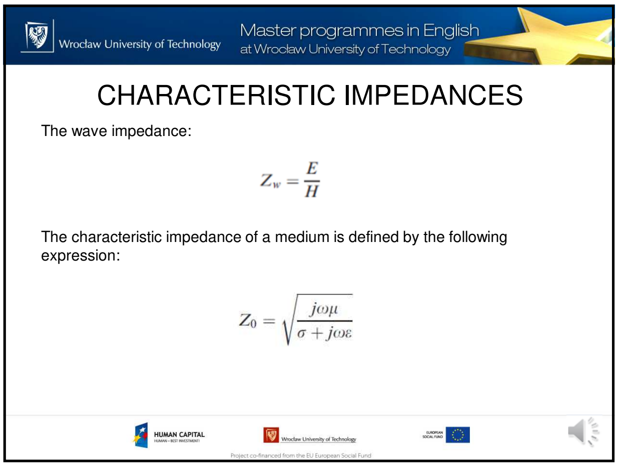


NEAR FIELDS AND FAR FIELDS

The characteristics of a field are determined by the source (the antenna), the media surrounding the source, and the distance between the source and the point of observation.



NEAR FIELDS AND FAR FIELDS



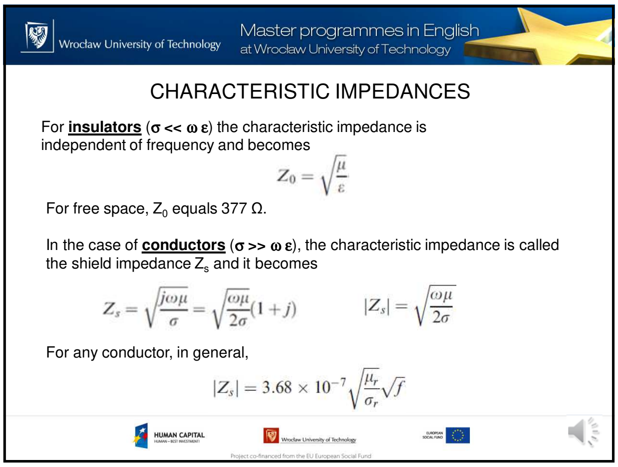
CHARACTERISTIC IMPEDANCES

The wave impedance:

$$Z_w = \frac{E}{H}$$

The characteristic impedance of a medium is defined by the following expression:

$$Z_0 = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$$



CHARACTERISTIC IMPEDANCES

For **insulators** ($\sigma << \omega\,\varepsilon$) the characteristic impedance is independent of frequency and becomes

$$Z_0 = \sqrt{\frac{\mu}{\varepsilon}}$$

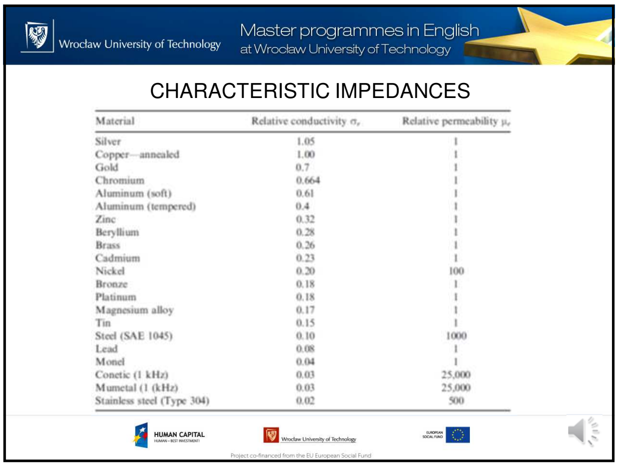
For free space, Z_0 equals 377 Ω.

In the case of **conductors** ($\sigma >> \omega\,\varepsilon$), the characteristic impedance is called the shield impedance Z_s and it becomes

$$Z_s = \sqrt{\frac{j\omega\mu}{\sigma}} = \sqrt{\frac{\omega\mu}{2\sigma}}(1+j) \qquad |Z_s| = \sqrt{\frac{\omega\mu}{2\sigma}}$$

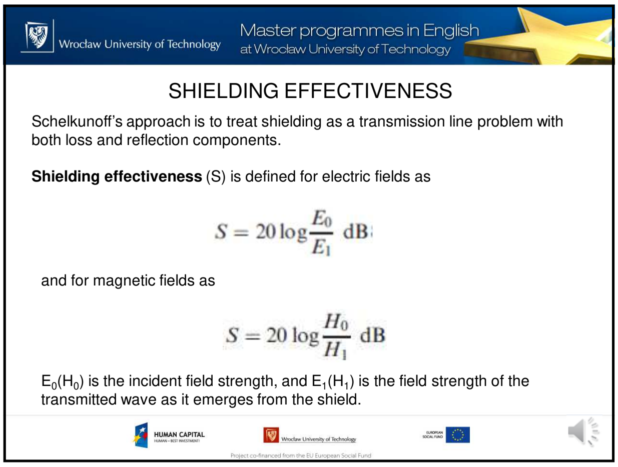
For any conductor, in general,

$$|Z_s| = 3.68 \times 10^{-7}\sqrt{\frac{\mu_r}{\sigma_r}}\sqrt{f}$$



CHARACTERISTIC IMPEDANCES

Material	Relative conductivity σ_r	Relative permeability μ_r
Silver	1.05	1
Copper—annealed	1.00	1
Gold	0.7	1
Chromium	0.664	1
Aluminum (soft)	0.61	1
Aluminum (tempered)	0.4	1
Zinc	0.32	1
Beryllium	0.28	1
Brass	0.26	1
Cadmium	0.23	1
Nickel	0.20	100
Bronze	0.18	1
Platinum	0.18	1
Magnesium alloy	0.17	1
Tin	0.15	1
Steel (SAE 1045)	0.10	1000
Lead	0.08	1
Monel	0.04	1
Conetic (1 kHz)	0.03	25,000
Mumetal (1 (kHz)	0.03	25,000
Stainless steel (Type 304)	0.02	500



SHIELDING EFFECTIVENESS

Schelkunoff's approach is to treat shielding as a transmission line problem with both loss and reflection components.

Shielding effectiveness (S) is defined for electric fields as

$$S = 20\log\frac{E_0}{E_1}\ \text{dB}$$

and for magnetic fields as

$$S = 20\log\frac{H_0}{H_1}\ \text{dB}$$

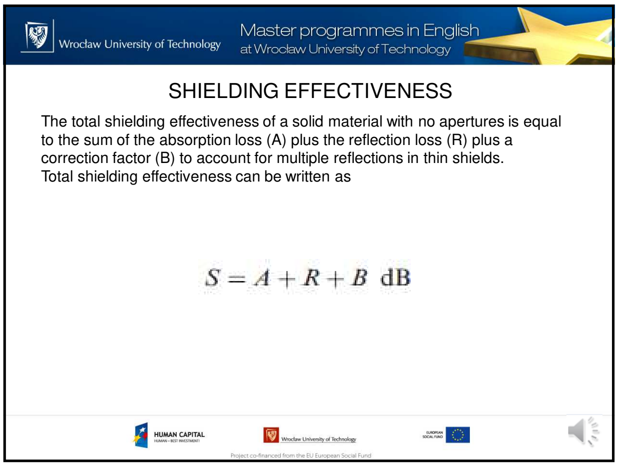
$E_0(H_0)$ is the incident field strength, and $E_1(H_1)$ is the field strength of the transmitted wave as it emerges from the shield.

SHIELDING EFFECTIVENESS

In the design of a shielded enclosure, there are two prime considerations:

(1) the shielding effectiveness of the shield material itself and

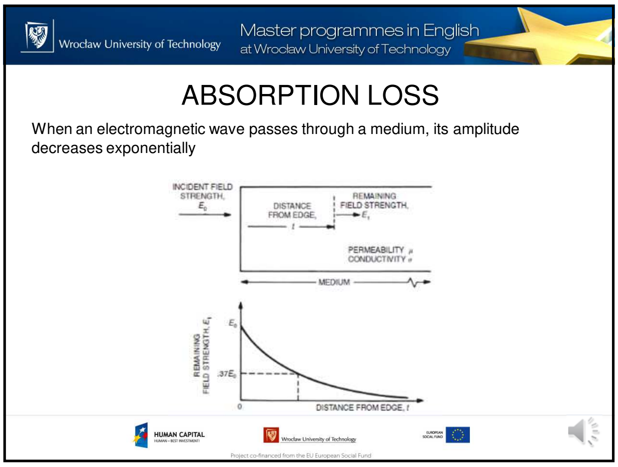
(2) the shielding effectiveness resulting from discontinuities and apertures in the shield.



SHIELDING EFFECTIVENESS

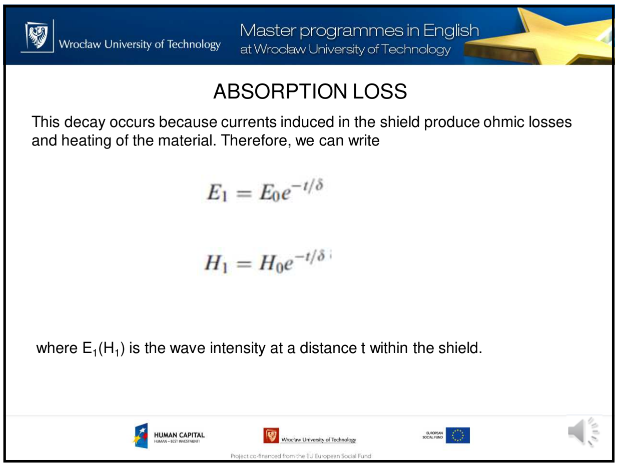
The total shielding effectiveness of a solid material with no apertures is equal to the sum of the absorption loss (A) plus the reflection loss (R) plus a correction factor (B) to account for multiple reflections in thin shields.
Total shielding effectiveness can be written as

$$S = A + R + B \ \text{dB}$$



ABSORPTION LOSS

When an electromagnetic wave passes through a medium, its amplitude decreases exponentially



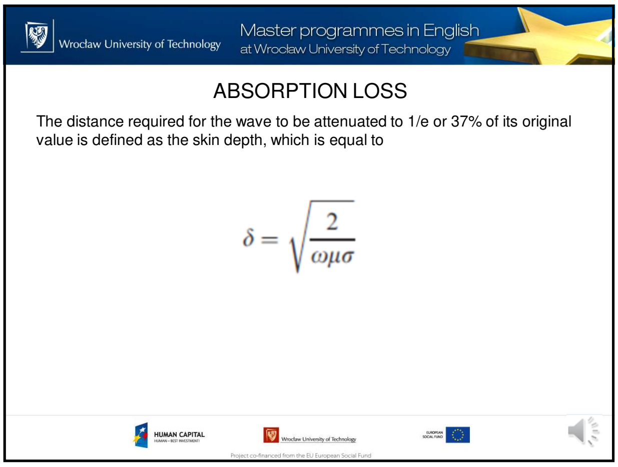
ABSORPTION LOSS

This decay occurs because currents induced in the shield produce ohmic losses and heating of the material. Therefore, we can write

$$E_1 = E_0 e^{-t/\delta}$$

$$H_1 = H_0 e^{-t/\delta}$$

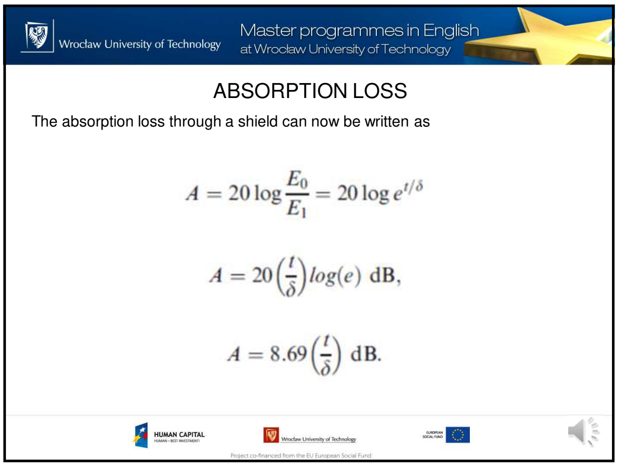
where $E_1(H_1)$ is the wave intensity at a distance t within the shield.



ABSORPTION LOSS

The distance required for the wave to be attenuated to 1/e or 37% of its original value is defined as the skin depth, which is equal to

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$



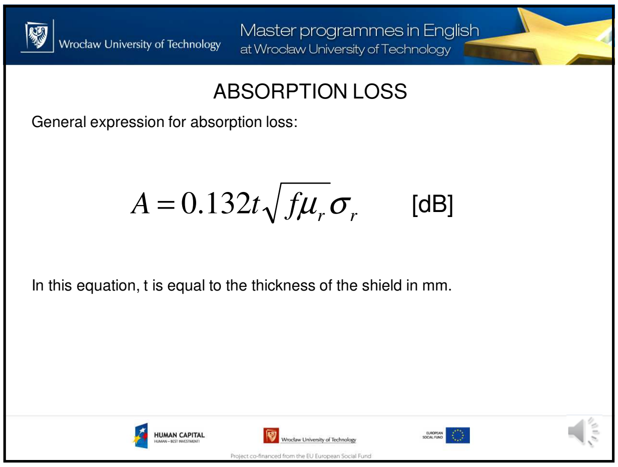
ABSORPTION LOSS

The absorption loss through a shield can now be written as

$$A = 20\log\frac{E_0}{E_1} = 20\log e^{t/\delta}$$

$$A = 20\left(\frac{t}{\delta}\right)log(e)\ \text{dB},$$

$$A = 8.69\left(\frac{t}{\delta}\right)\ \text{dB}.$$

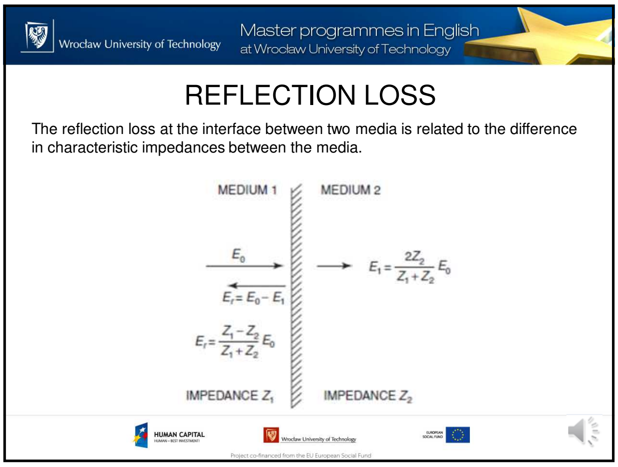


ABSORPTION LOSS

General expression for absorption loss:

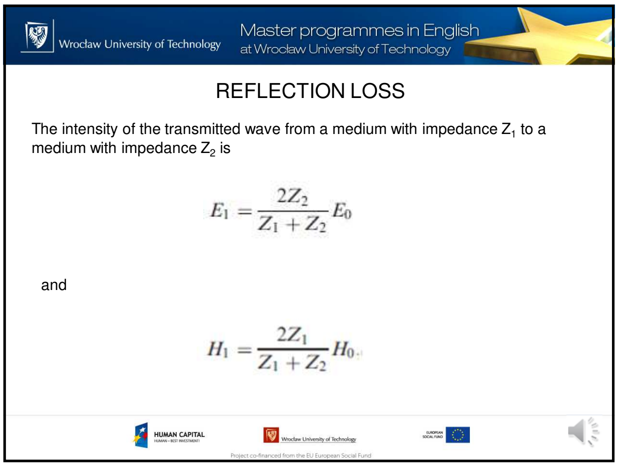
$$A = 0.132t\sqrt{f\mu_r\sigma_r} \qquad \text{[dB]}$$

In this equation, t is equal to the thickness of the shield in mm.



REFLECTION LOSS

The reflection loss at the interface between two media is related to the difference in characteristic impedances between the media.



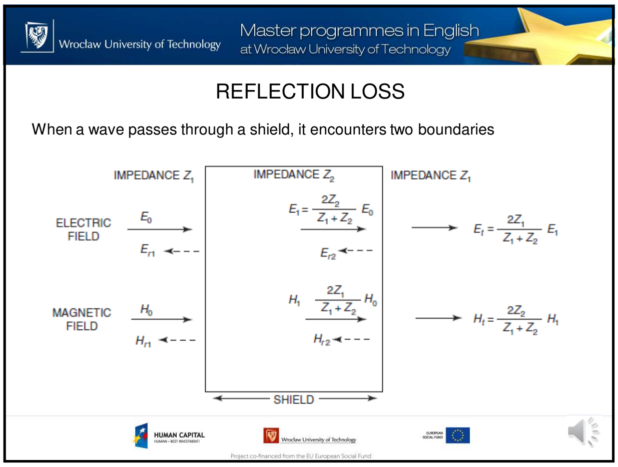
REFLECTION LOSS

The intensity of the transmitted wave from a medium with impedance Z_1 to a medium with impedance Z_2 is

$$E_1 = \frac{2Z_2}{Z_1 + Z_2}E_0$$

and

$$H_1 = \frac{2Z_1}{Z_1 + Z_2}H_0$$



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REFLECTION LOSS

When a wave passes through a shield, it encounters two boundaries

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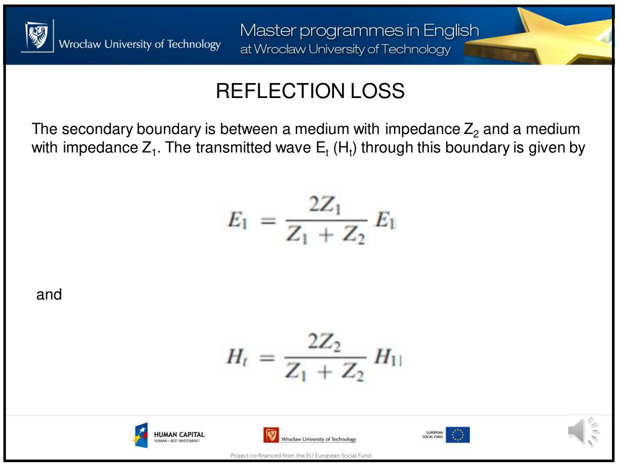

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REFLECTION LOSS

The secondary boundary is between a medium with impedance Z_2 and a medium with impedance Z_1. The transmitted wave E_t (H_t) through this boundary is given by

$$E_1 = \frac{2Z_1}{Z_1 + Z_2} E_1$$

and

$$H_t = \frac{2Z_2}{Z_1 + Z_2} H_1$$

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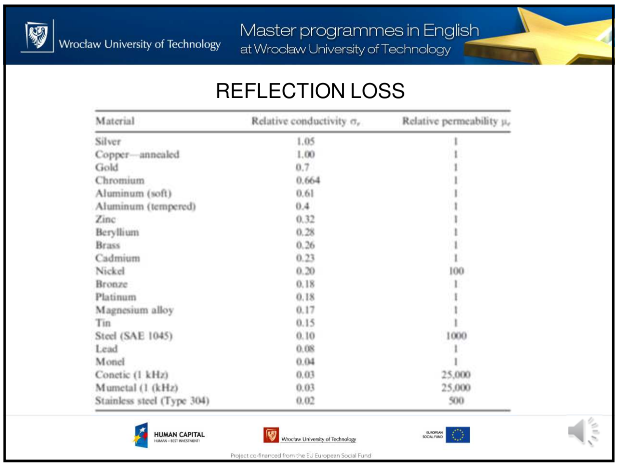

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REFLECTION LOSS

Material	Relative conductivity σ_r	Relative permeability μ_r
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Gold	0.7	1
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Generalized Equation for Reflection Loss

Neglecting multiple reflections a generalized equation for reflection loss can be written as

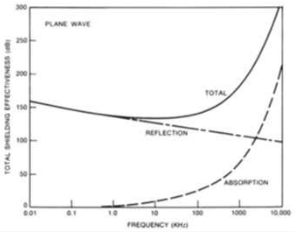
$$R = C + 10\log\left(\frac{\sigma_r}{\mu_r}\right)\left(\frac{1}{f^n r^m}\right)$$

where the constants C, n and m are listed below for plane waves, electric fields, and magnetic fields, respectively.

Type of Field	C	n	m
Electric field	322	3	2
Plane wave	168	1	0
Magnetic field	14.6	–1	–2

COMPOSITE LOSS

FAR FIELD For example, the overall attenuation (or shielding effectiveness) of a 0.020-in thick solid copper shield is shown below.



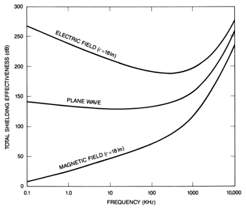
COMPOSITE LOSS

ELECTRIC FIELD At low-frequency, reflection loss is the primary shielding mechanism for electric fields. At high-frequency, absorption loss is the primary shielding mechanism.

MAGNETIC FIELD The reflection loss to a low-frequency magnetic field is small. Because of multiple reflections, this effect is even more pronounced in a thin shield. The primary loss for magnetic fields is absorption loss. Because both the absorption and reflection loss are small at low frequencies, the total shielding effectiveness is low. It is therefore difficult to shield low-frequency magnetic fields.

SUMMARY OF SHIELDING EQUATIONS

Figure below shows the composite shielding effectiveness of a 0.5mm thick solid aluminum shield for an electric field, plane wave, and a magnetic field. As can be observed in the figure, considerable shielding exists in all cases exept for low frequency magnetic fields.



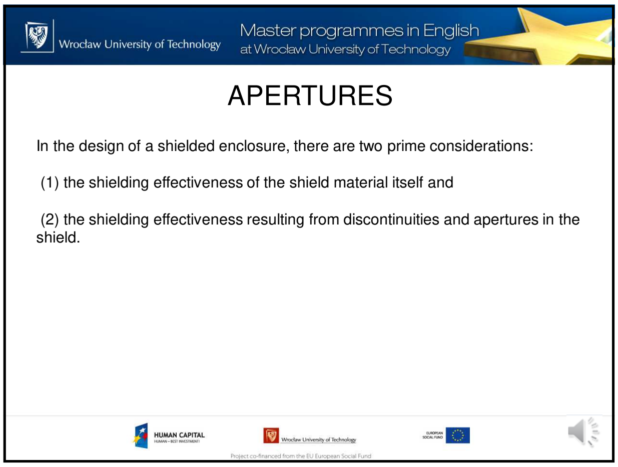
SUMMARY OF SHIELDING EQUATIONS

At high frequencies (above 1MHz), absorption loss predominates in all cases, and any solid shield thick enough to be practical provides more than adequate shielding for most applications.

SHIELDING WITH MAGNETIC MATERIALS

In summary,
a magnetic material such as steel or mumetal makes a better magnetic field shield at low frequencies than does a good conductor such as aluminum or copper.

At high frequencies the good conductors provide the better magnetic shielding. The magnetic shielding effectiveness of solid nonmagnetic shields increases with frequency.



APERTURES

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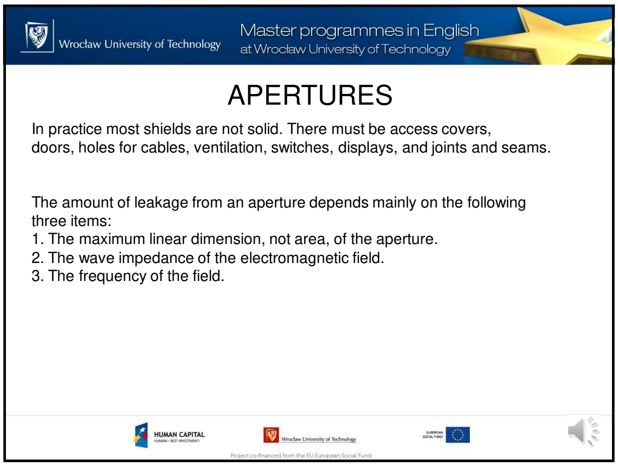
(1) the shielding effectiveness of the shield material itself and

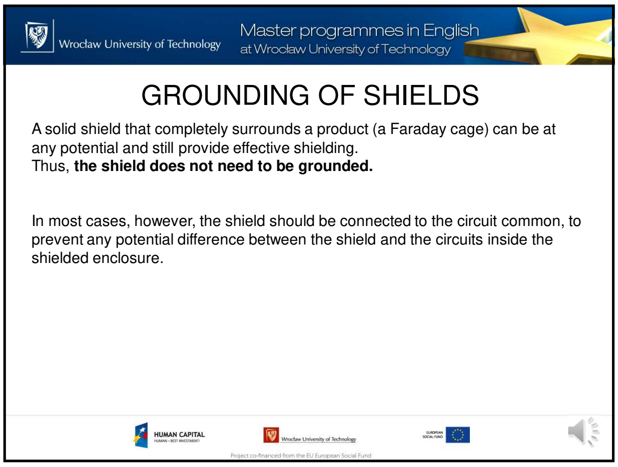
(2) the shielding effectiveness resulting from discontinuities and apertures in the shield.



APERTURES

In practice most shields are not solid. There must be access covers, doors, holes for cables, ventilation, switches, displays, and joints and seams.

The amount of leakage from an aperture depends mainly on the following three items:
1. The maximum linear dimension, not area, of the aperture.
2. The wave impedance of the electromagnetic field.
3. The frequency of the field.



GROUNDING OF SHIELDS

A solid shield that completely surrounds a product (a Faraday cage) can be at any potential and still provide effective shielding.
Thus, **the shield does not need to be grounded.**

In most cases, however, the shield should be connected to the circuit common, to prevent any potential difference between the shield and the circuits inside the shielded enclosure.