MO-AM-1

Shielding

Prof.dr. Frank Leferink

University of Twente, Enschede, The Netherlands

Thales Nederland, Hengelo, The Netherlands

leferink@ieee.org

http://utep.el.utwente.nl/te

What is shielding?

- Electronic circuit in a conducting enclosure: 'shielding'
- Objective: to keep the electromagnetic field:
  - Inside the enclosure, and/or
  - Outside the enclosure
- Basic shielding theory, based on transmission line theory and mismatches at the boundaries
- Theory is applicable to <u>infinite large</u> conducting plates

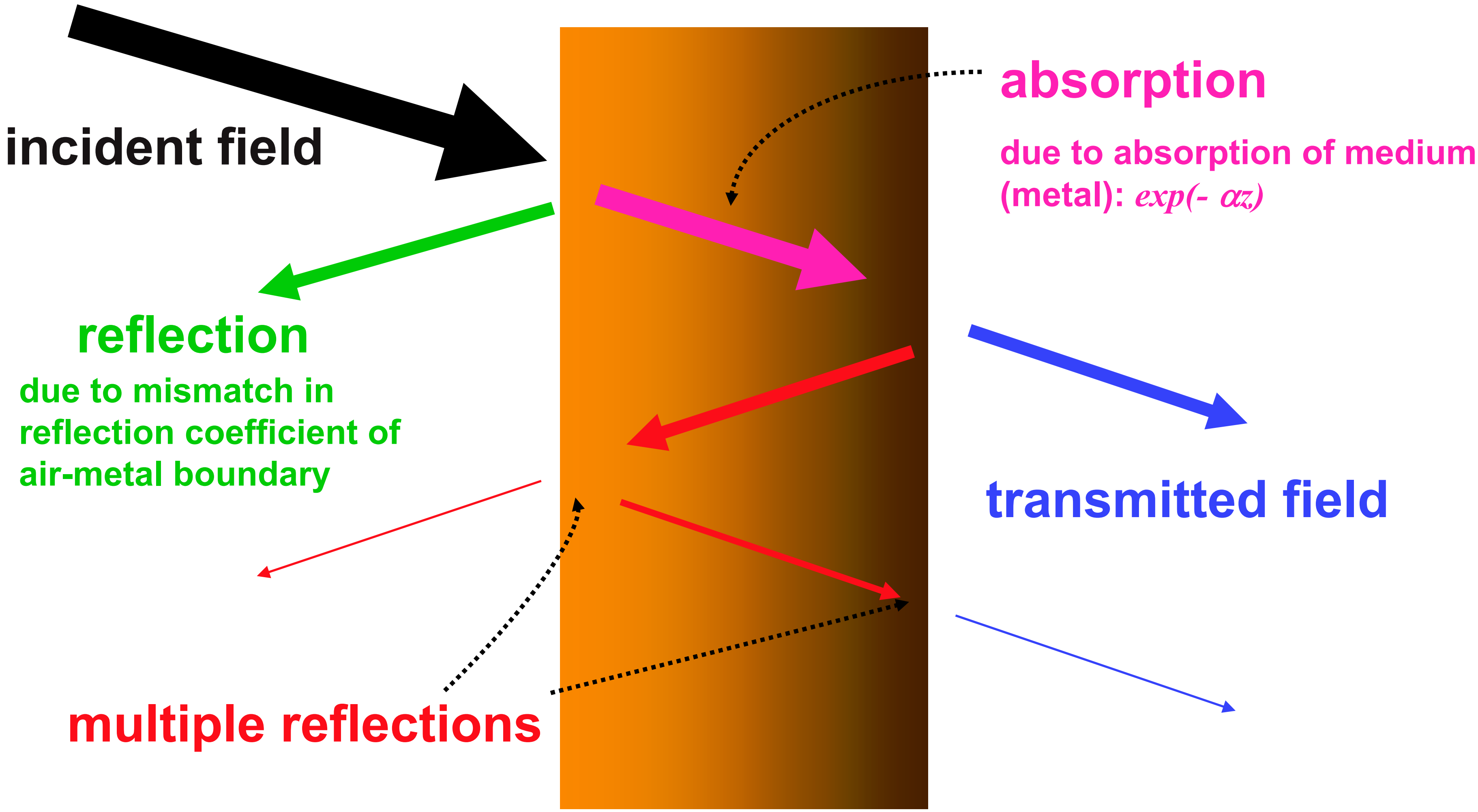
- The shielding effectiveness SE, is defined as

$$SE_E = 20\log\left|\frac{\hat{E}_i}{\hat{E}_t}\right| \quad \text{and} \quad SE_H = 20\log\left|\frac{\hat{H}_i}{\hat{H}_t}\right|$$

i=incident, t=transmitted

- Discontinuities such as apertures/holes, seams but also the geometrical structure (3-D cabinet instead of 2-D infinite plate) have a large impact on actual shielding effectiveness

Shielding of an ∞ large plate



$$SE = A + R + M \quad [\mathrm{dB}]$$

Shielding of an ∞ large plate, 2

- Assumption: source of the electromagnetic field is far away (with respect to the wavelength) so we can assume a plane wave, i.e. only a E_x and H_y perpendicular and in a ratio of

$$\eta_0 = \sqrt{\mu_0 / \varepsilon_0}$$

- Thickness plate is t
- Assumption: only air at both sides of the metal plate
- For simplifications, assume
  - material is a good conductor, so intrinsic impedance $\eta << \eta_0$
  - skindept material much smaller than thickness material $\delta << t$
- Then

$$SE = 20\log\left|\frac{\hat{E}_i}{\hat{E}_t}\right| \cong 20\log e^{\frac{t}{\delta}} + 20\log\left|\frac{(\eta_0+\hat{\eta})^2}{4\eta_0\hat{\eta}}\right| + M \quad \text{[dB]}$$

$$= A + R + M \quad \text{[dB]}$$

Shielding of an ∞ large plate, 3

$$SE = 20\log\left|\frac{\hat{E}_i}{\hat{E}_t}\right| \cong 20\log e^{\frac{t}{\delta}} + 20\log\left|\frac{(\eta_0+\hat{\eta})^2}{4\eta_0\hat{\eta}}\right| + M \quad [\text{dB}]$$

$$= \quad A \quad + \quad R \quad + \quad M \quad [\text{dB}]$$

- **Absorption term: due to skin effect at higher frequencies f the current flows only in the skin of the materials**

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \frac{1}{\sqrt{\pi f \mu\sigma}}$$

- **Resulting in**

$$A = 20\log e^{\frac{t}{\delta}} = 131.4\, t\, \sqrt{f \mu_r \sigma_r} \quad [\text{dB}]$$

- **Increases with square root of the frequency at a dB scale!!!**

- **Reflection term: due to impedance mismatch**

- **Multiple reflection term is often negligable small**

Shielding ∞ large plate, Reflection, 1

- The primary attenuation of the electric field component is due to the impedance mismatch air-material, while the reflection attenuation of the magnetic field component is mainly achieved by the impedance mismatch material-air
- This means that the attenuation of the magnetic component of the field in the material due to absorption is important
- So we can conclude that
  - Reflection attenuation for the electric component is independent of the thickness of the material of the conducting plate
  - Reflection attenuation for the magnetic component is influenced by the thickness of the material,
- Simplified:
  - Shielding of electric field component via reflection,
  - Shielding of magnetic field component via absorption

Shielding ∞ large plate, Reflection, 2

- We can simplify the reflection term by filling in the terms for the intrinsic impedance η for a good conductor

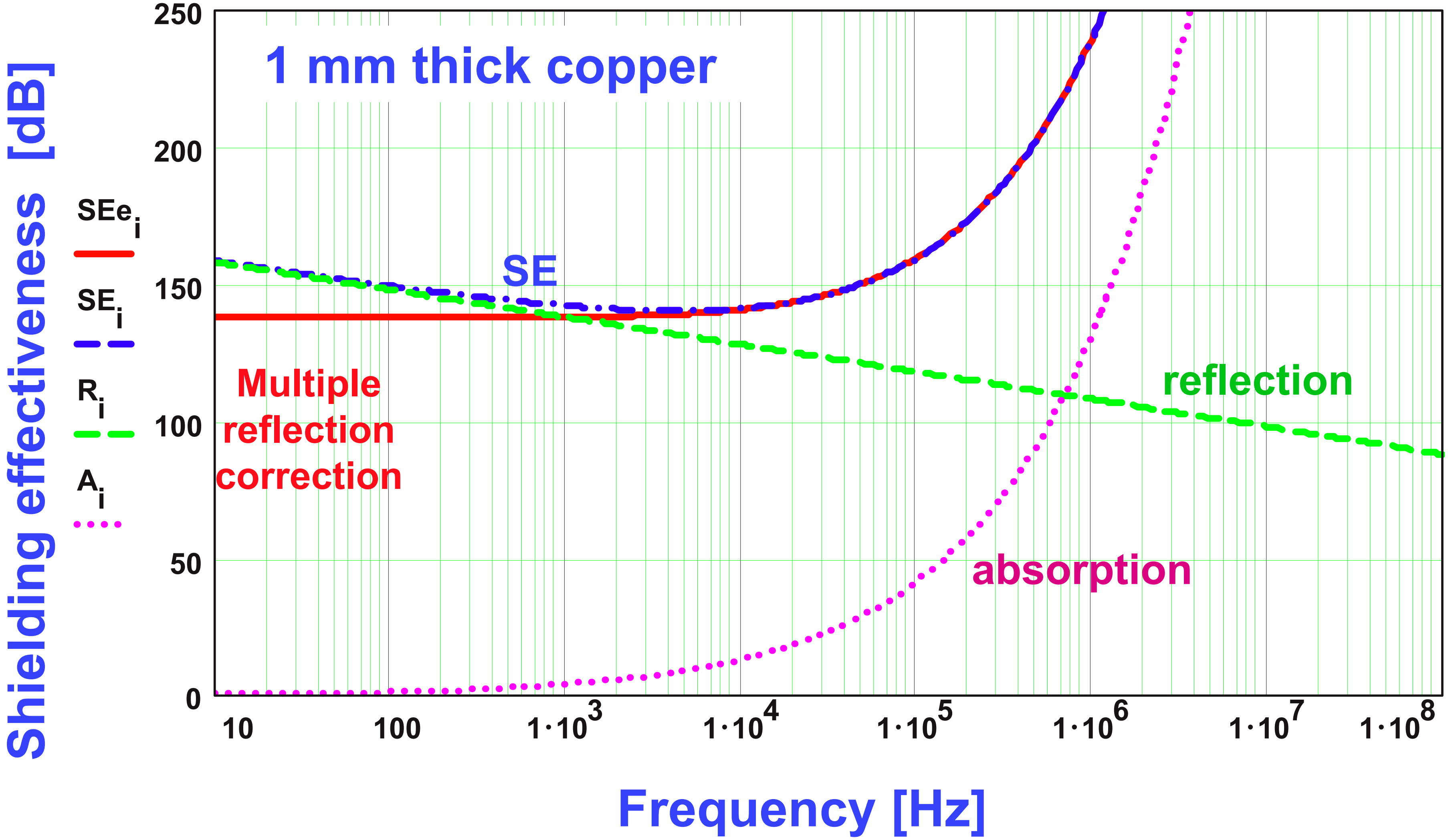
$$R = 20\log\left|\frac{(\eta_0+\hat{\eta})^2}{4\eta_0\hat{\eta}}\right| \cong 20\log\left|\frac{\eta_0}{4\hat{\eta}}\right| \cong 20\log\left(\frac{1}{4}\sqrt{\frac{\sigma}{\omega\mu_r\varepsilon_0}}\right) \quad \text{[dB]}$$

- We often use the <u>relative</u> conductivity (relative with respect to copper). We also know that for conducting material the permittivity equals the permittivity of air $\varepsilon=\varepsilon_{0,}$, then

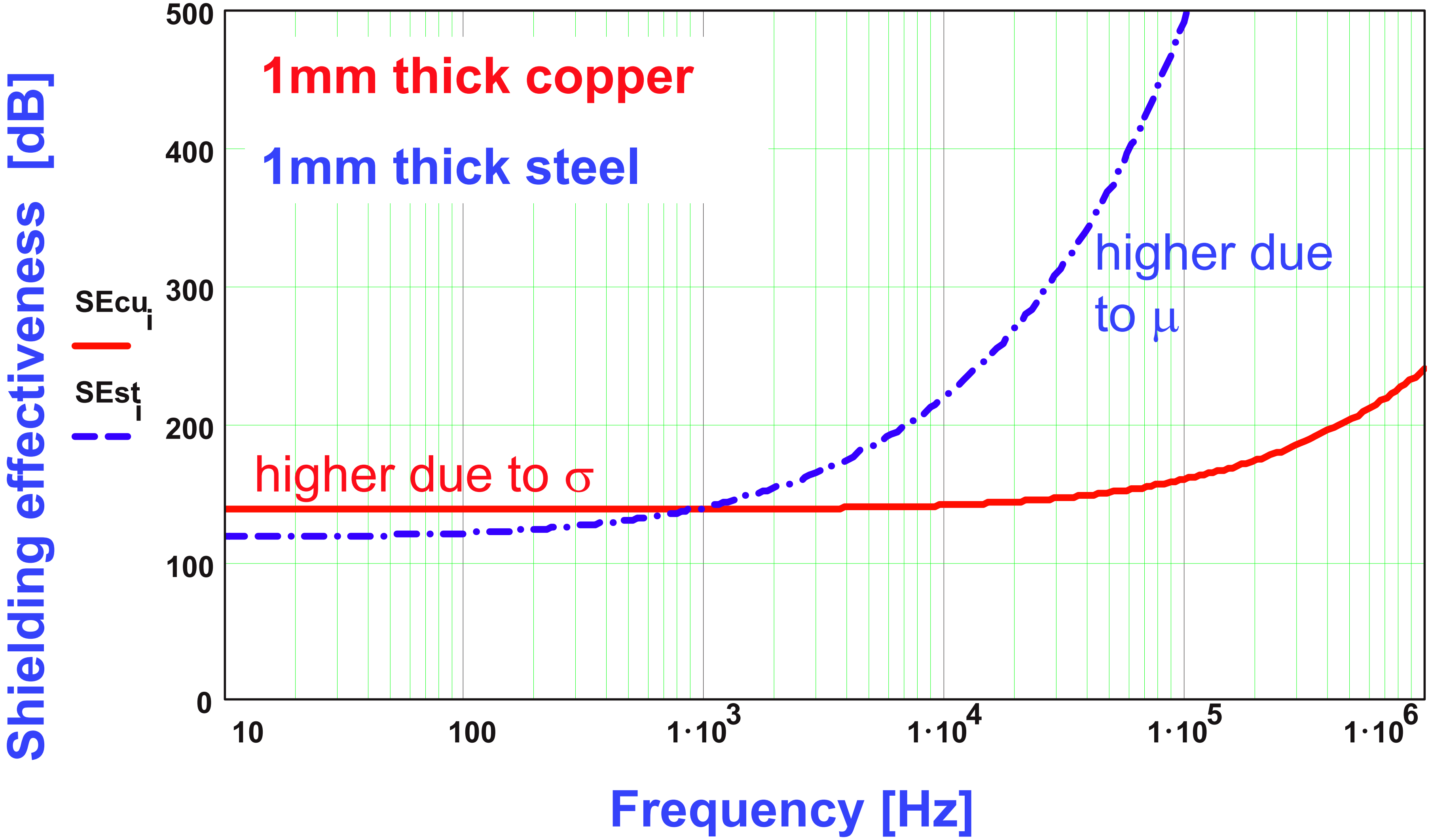
$$R \cong 20\log\left(\frac{1}{4}\sqrt{\frac{\sigma}{\omega\mu_r\varepsilon_0}}\right) = 168 + 10\log\left(\frac{\sigma_r}{\mu_r f}\right) \quad \text{[dB]}$$

- So the reflection term is
  - large for low frequencies
  - reduces with the square root of the frequency, 10dB/dec

Shielding ∞ large plate, examples



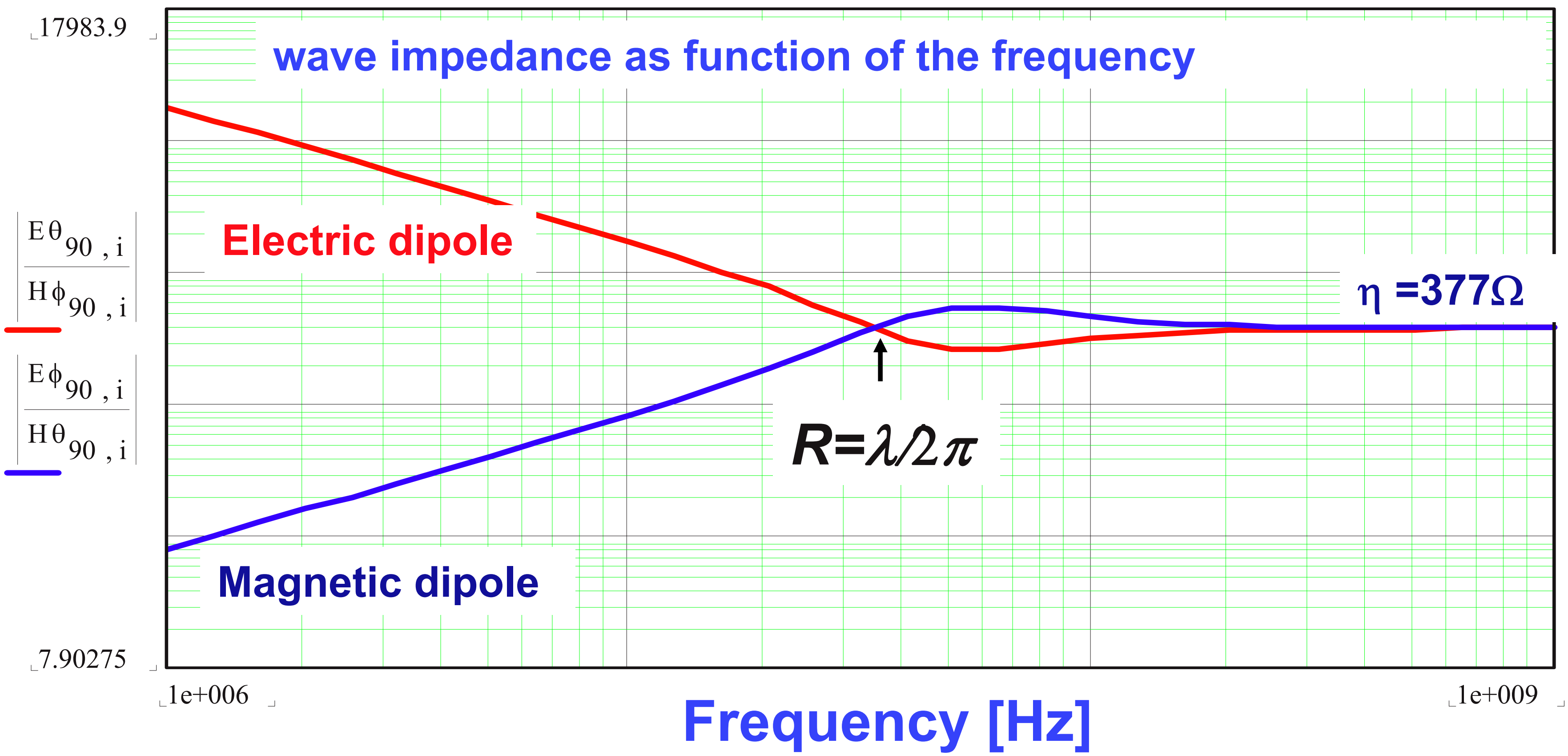
Shielding ∞ large plate, examples



SE ∞ large plate, near field, 1

Until now we assumed that the incident wave was a plane wave at large distance of the source, a so-called plane wave

At short distance of a source the wave impedance depends of the type of the source and the distance to the source



SE ∞ large plate, near field, 2

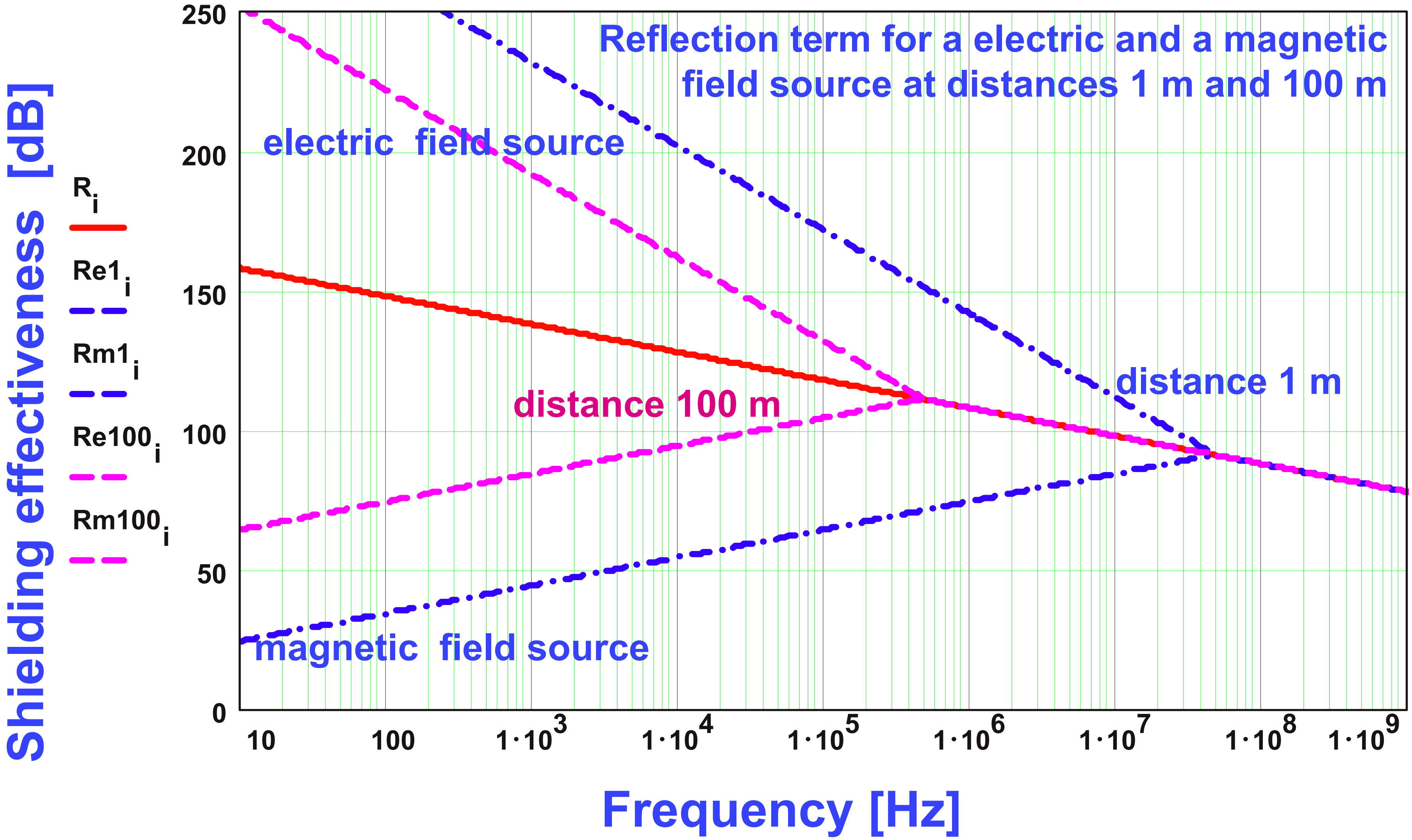
- The absorption term is independent of the wave impedance of the incident field.
- The reflection term is based on impedance mismatch and
  - for a dominant electric field source, upto a distance $R=c/2\pi f$, we can write

$$R_E = 20\log\left|\frac{(\hat{Z}_w+\hat{\eta})^2}{4\hat{Z}_w\hat{\eta}}\right| \cong 322 + 10\log\left(\frac{\sigma_r}{\mu_r f^3 r^2}\right) \quad [\mathrm{dB}]$$

  - for a dominant magnetic field source

$$R_M = 20\log\left|\frac{(\hat{Z}_w+\hat{\eta})^2}{4\hat{Z}_w\hat{\eta}}\right| \cong 14.6 + 10\log\left(\frac{f r^2 \sigma_r}{\mu_r}\right) \quad [\mathrm{dB}]$$

SE ∞ large plate, near field, 3



SE ∞ large plate

- Notice that
  - electrical field sources can be shielded easily: (thin) impedance mismatch
  - to shield magnetic field sources we need thick material for absorption term, and the reflection term is lower for magnetic field sources, thus more difficult

- The absorption term can be influenced by the permeability μ_r:

$$A = 20\log e^{\frac{t}{\delta}} = 131.4\ t\ \sqrt{f\,\mu_r\sigma_r} \quad [\mathrm{dB}]$$

but high-permeable material gives low conductivity σ_r, which means that the reflection term is inferior: combination (high μ and high σ) often difficult

- Magnetic fields can be shielded best by local actions (less weight), for instance shielding only the switched mode power supply transformer by using iron, mu-metal etc.

SE cabinets, 1

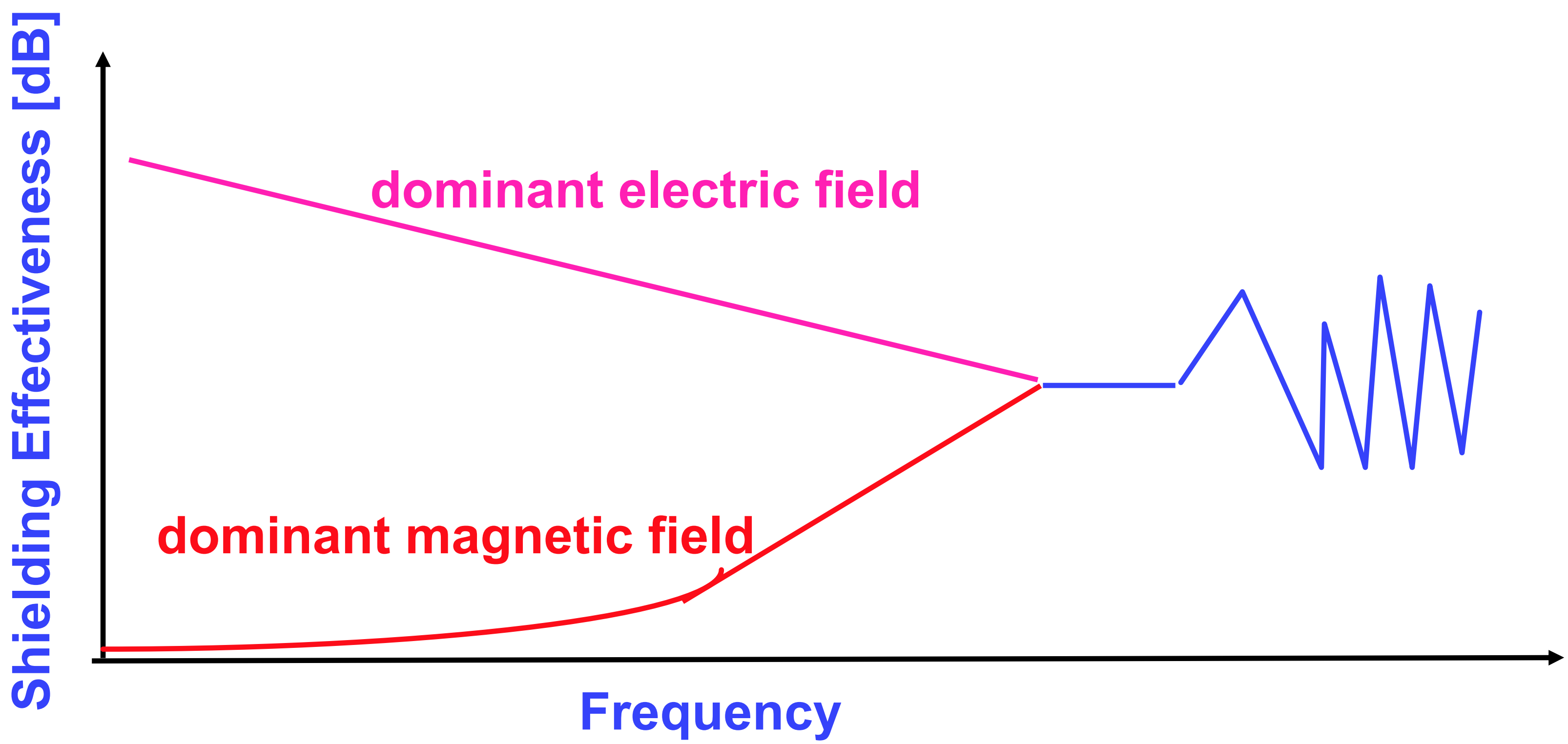
- We discussed the SE of an infinite large conducting plate. If we make a cabinet from this plate we have to cope with several effects:
  - The currents inside the material cannot completely compensate the fields anymore because the dimensions of the cabinet are small with respect to the wavelength
  - The corners of the cabinet will conduct a higher intensity of the compensation currents
  - The leakage of the seams will become more important
  - The fields inside the cabinet start to resonate if a standing wave can exist in the cabinet

$$f = \frac{c}{2}\sqrt{\left(\frac{n_a}{l}\right)^2 + \left(\frac{n_b}{w}\right)^2 + \left(\frac{n_c}{h}\right)^2}$$

- Example: PC, 15 x 40 x 50 cm, first resonance 320 MHz, and very resonant above 1 GHz

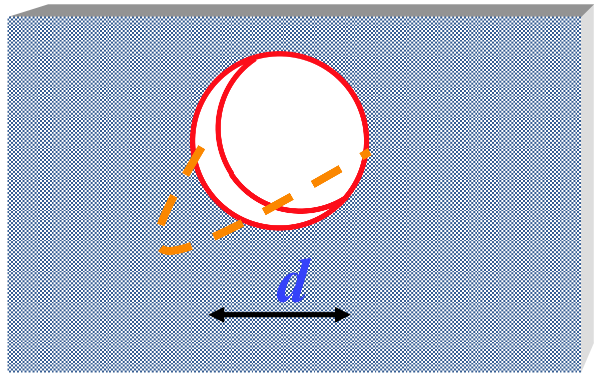
SE cabinets, 2

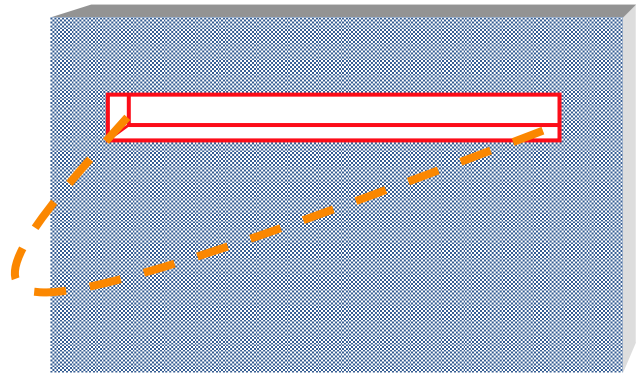
☞ **In practical applications the shielding effectivenss of a cabinet is often much less than 100 dB, the influence of holes and cable penetrations not included.
The Shielding Effectiveness figure often has the form:**



Apertures, 1

- A simple hole is 'open' if the diameter equals the half-wavelength $d = \lambda/2$

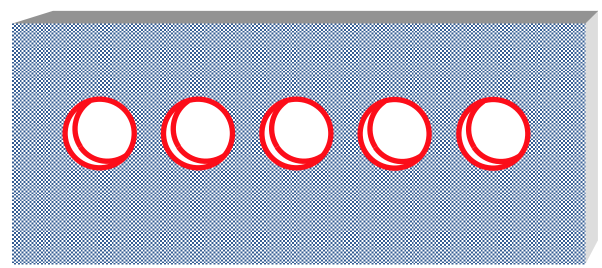




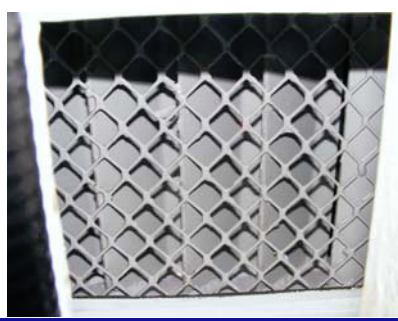
- This results in a <u>reduction</u> of the shielding effectiveness (compared to the infinite large plate equations)

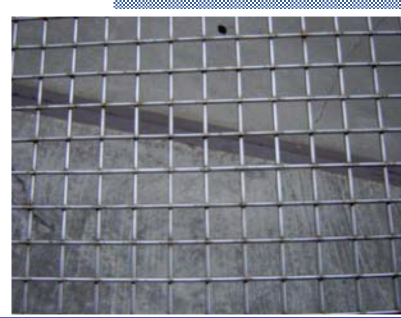
$$SE_{hole} = 20\log\left(\frac{\lambda}{2d}\right)$$

- Better: series of smaller holes



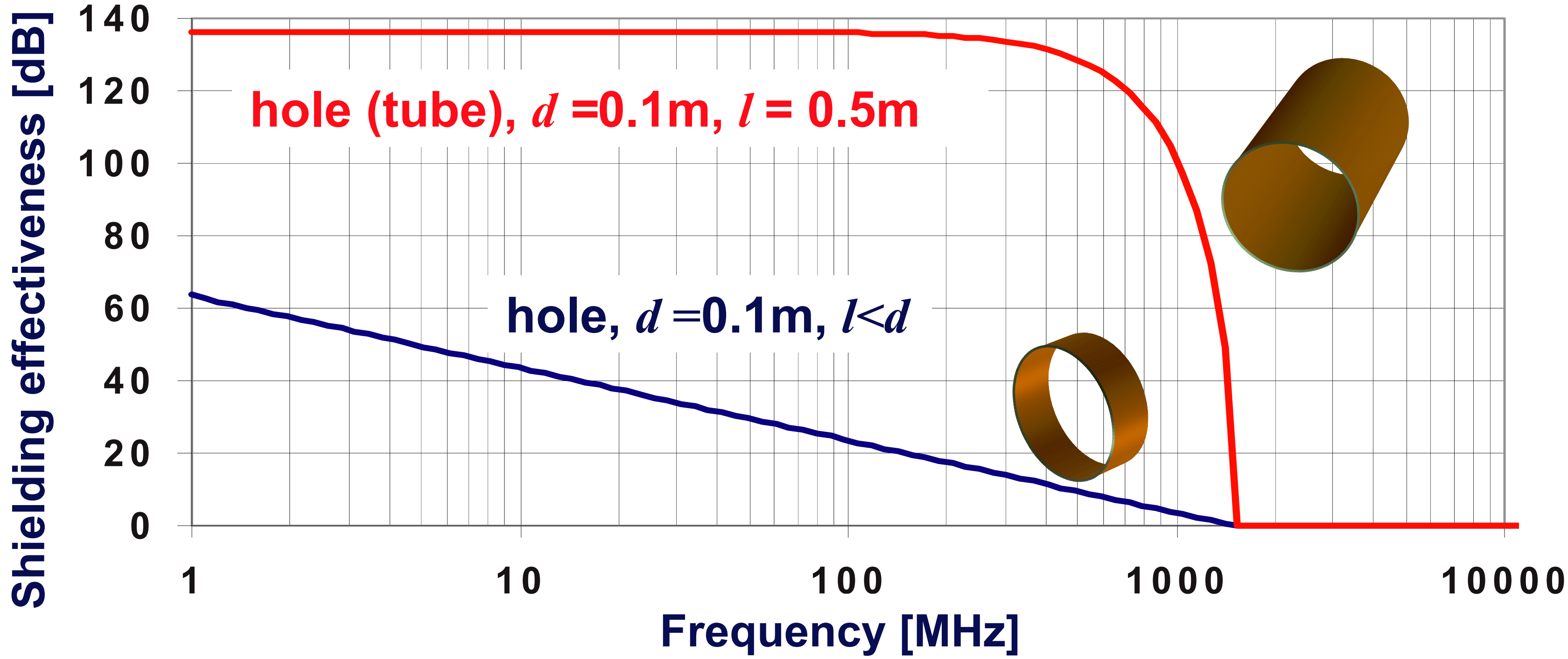
- Example:





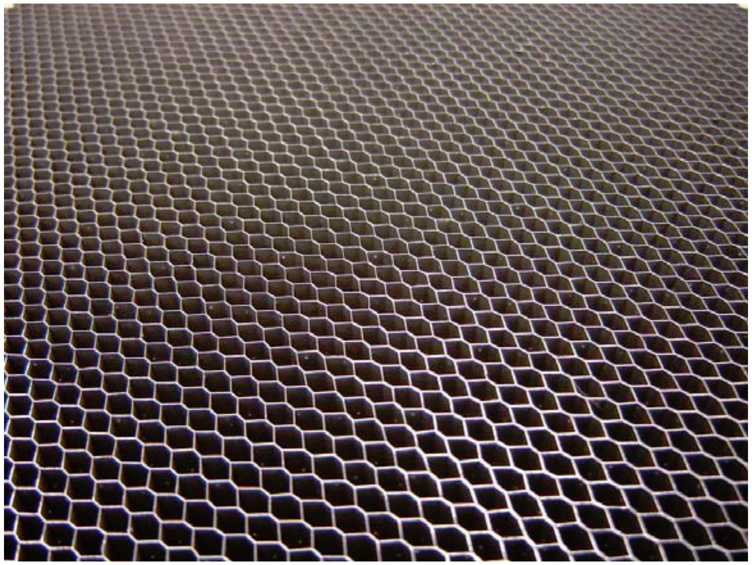
Holes, 2

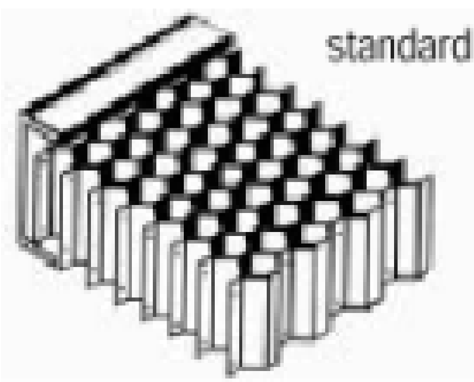
- If we observe the hole in three dimensions, i.e. including the depth (thickness material), then we find that the depth causes an elliptical increase of the shielding effectiveness (exponent at logaritmic scale): exp(-αl): the so-called waveguide-beyond-cuttoff (WBCO)

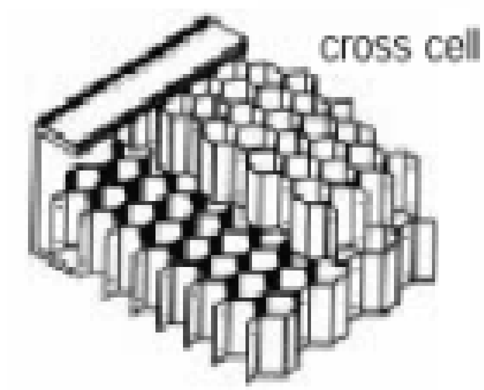


- Often applied in honeycombs for ventilation panels

Honeycomb ventilation panels

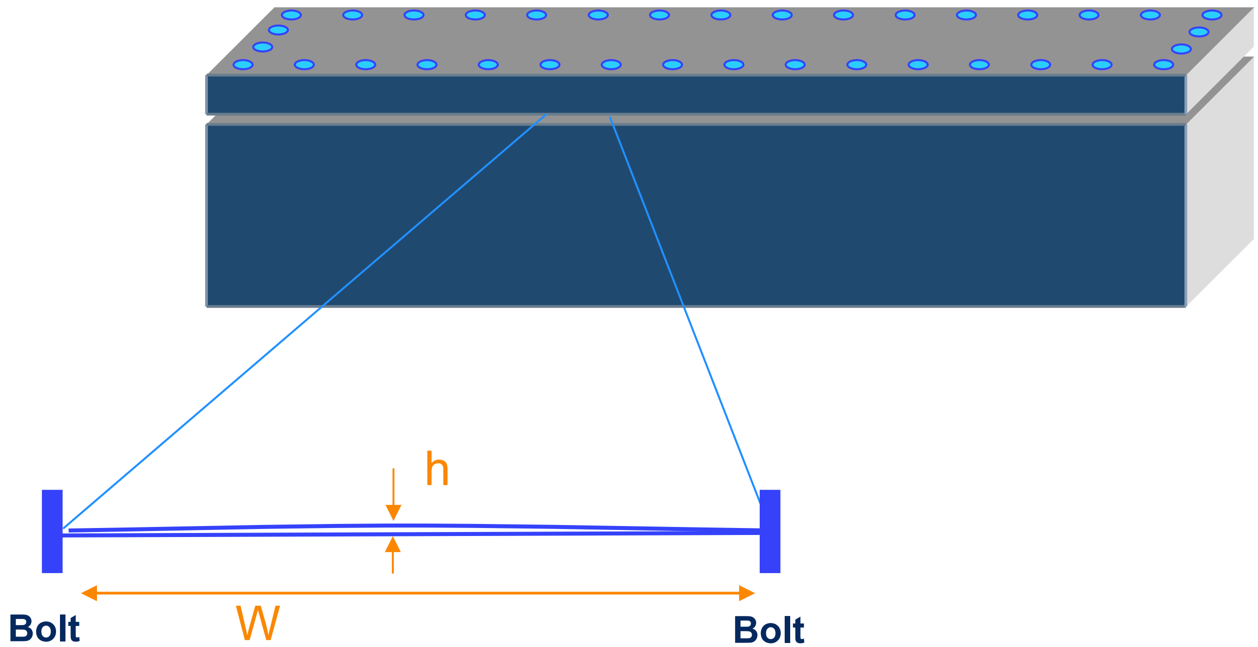






Seams

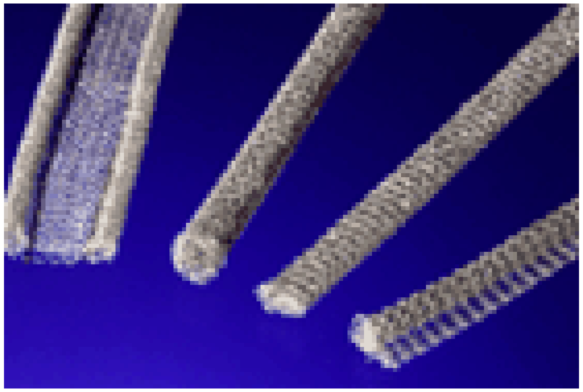
- For seams the same effect can be applied: the seam is open is a half wavelength fits in it

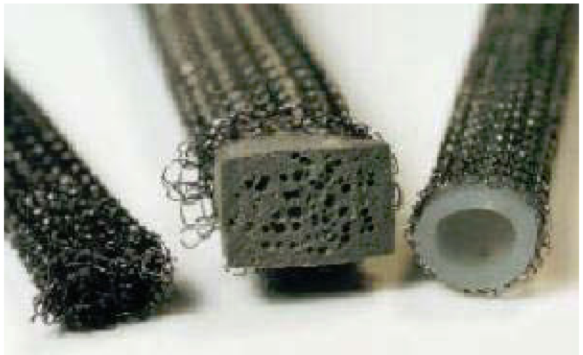


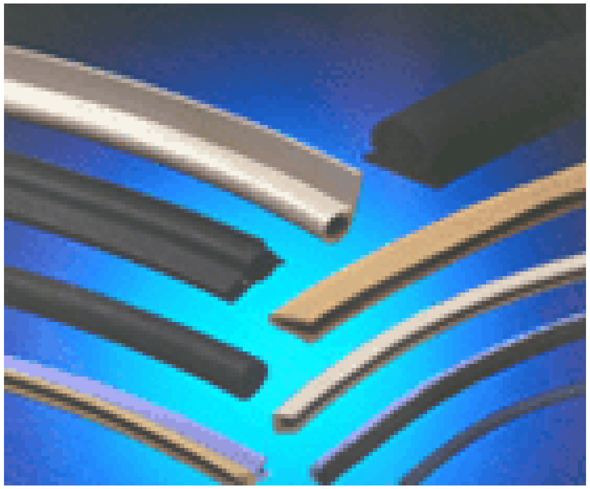
- The attenuation increases by using more screws or rivets: the seam length becomes smaller
- A gasket can be used to obtain conductive continuity between the materials; For doors often fingerstocks
- Be aware of corrosion due to different materials

Gaskets, 1

Knitted wire mesh



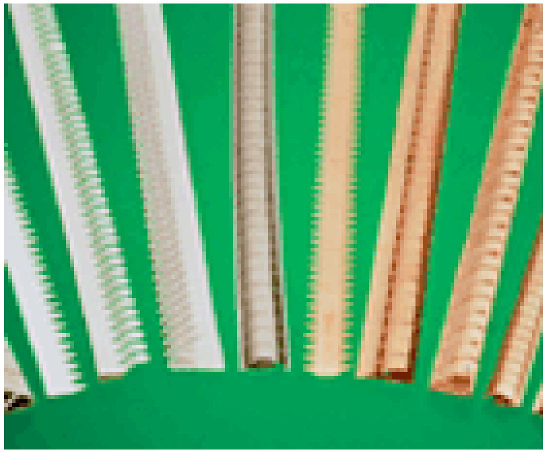




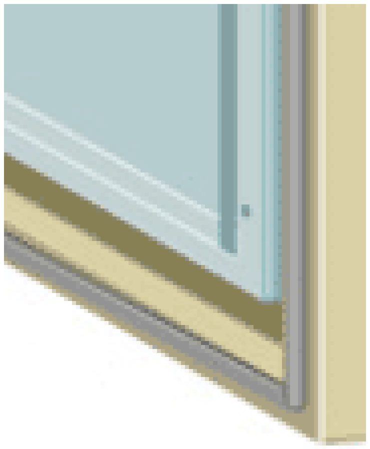
Conductive fabric over foam gasket

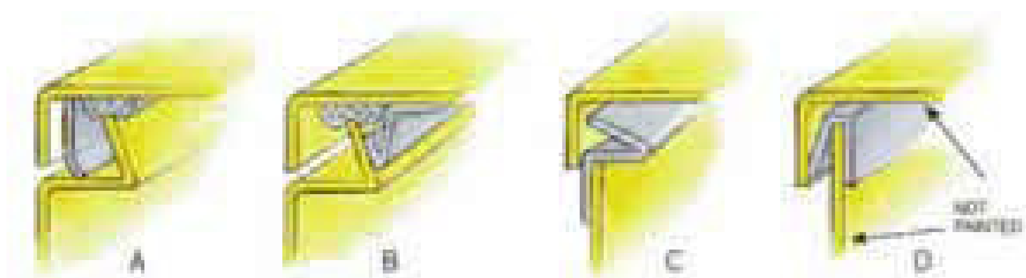
Extruded conductive elastomers

Fingerstocks

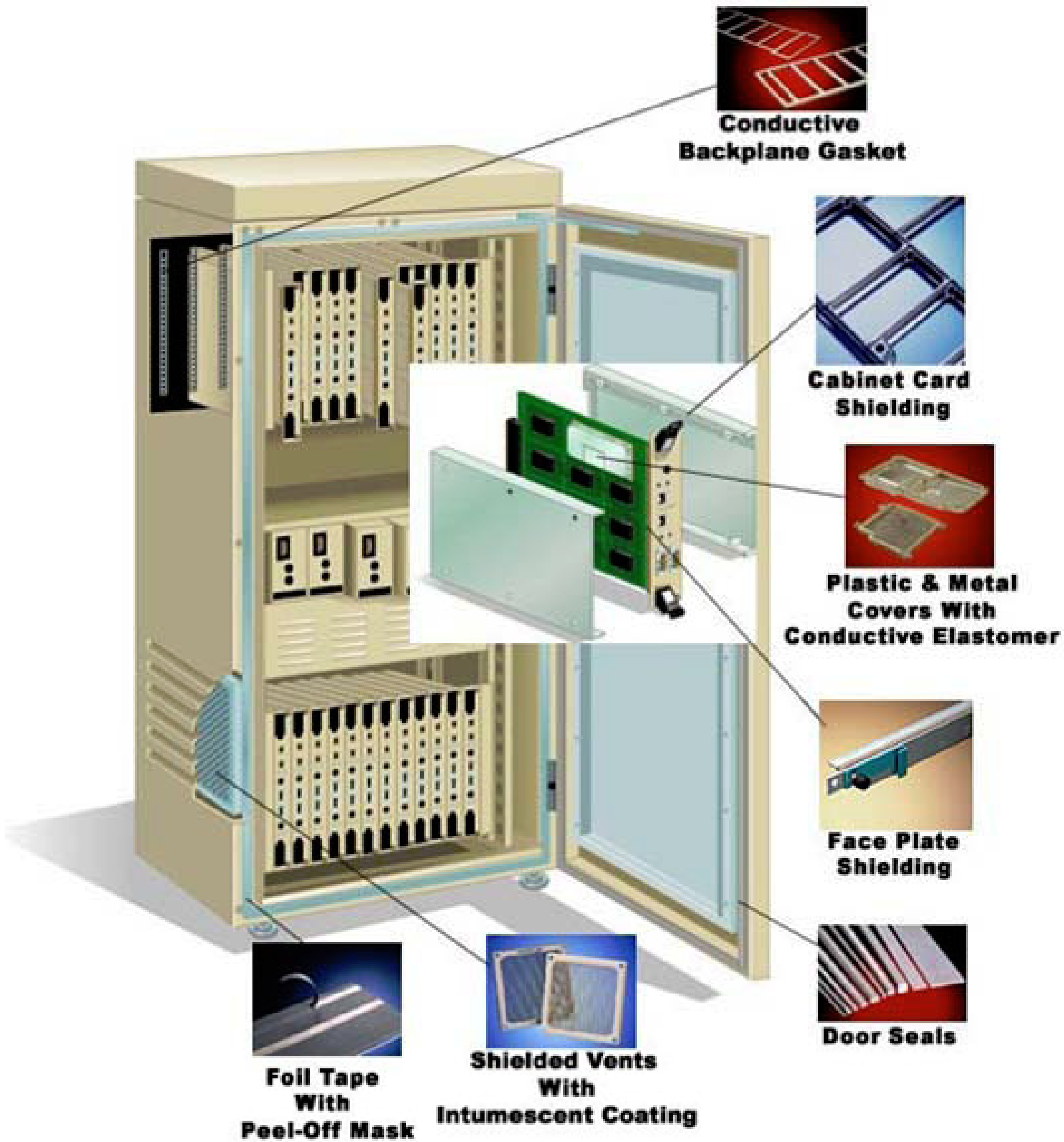


Gaskets, 2





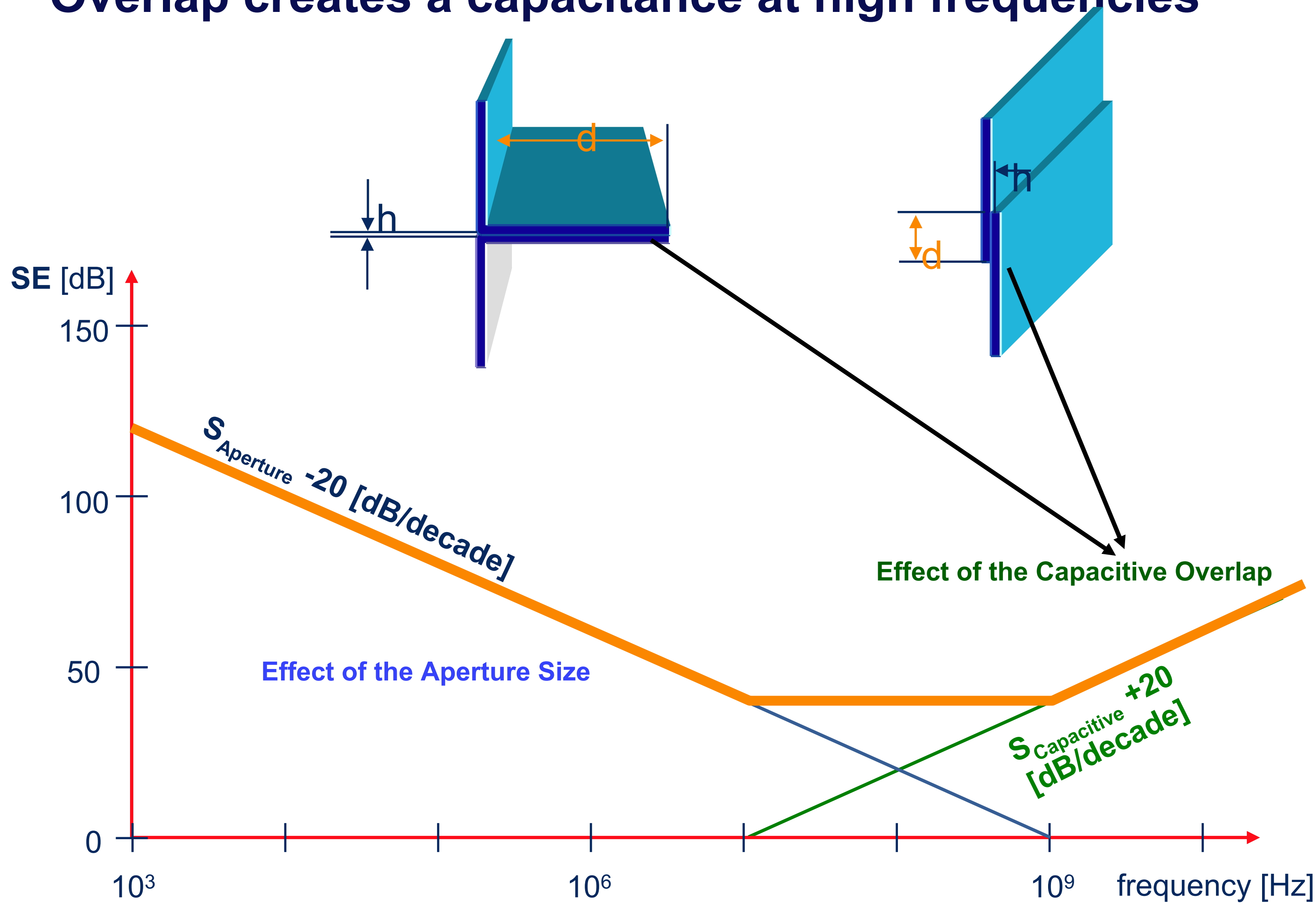
Picture: Chomerics



Picture: Chomerics

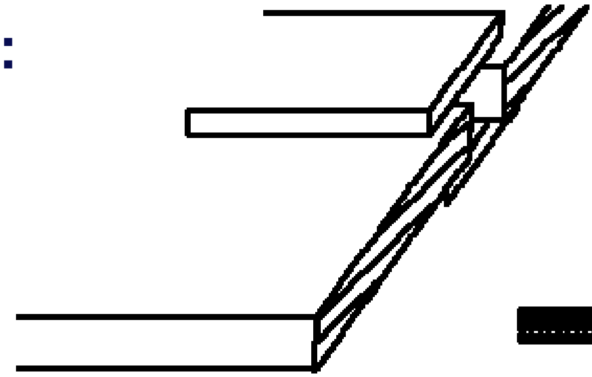
Effect of overlap for seams

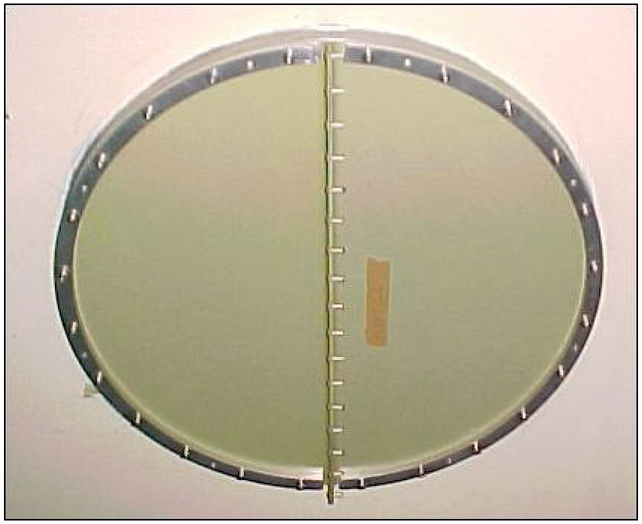
☞ **Overlap creates a capacitance at high frequencies**

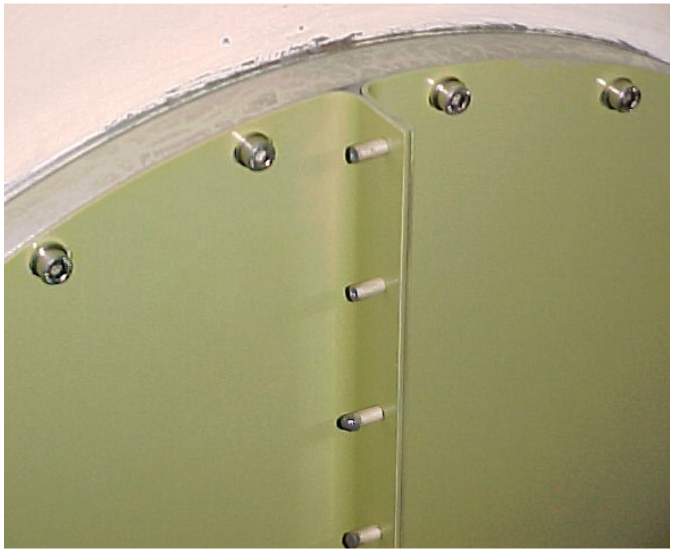


Experiments

☞ **Experiments:**

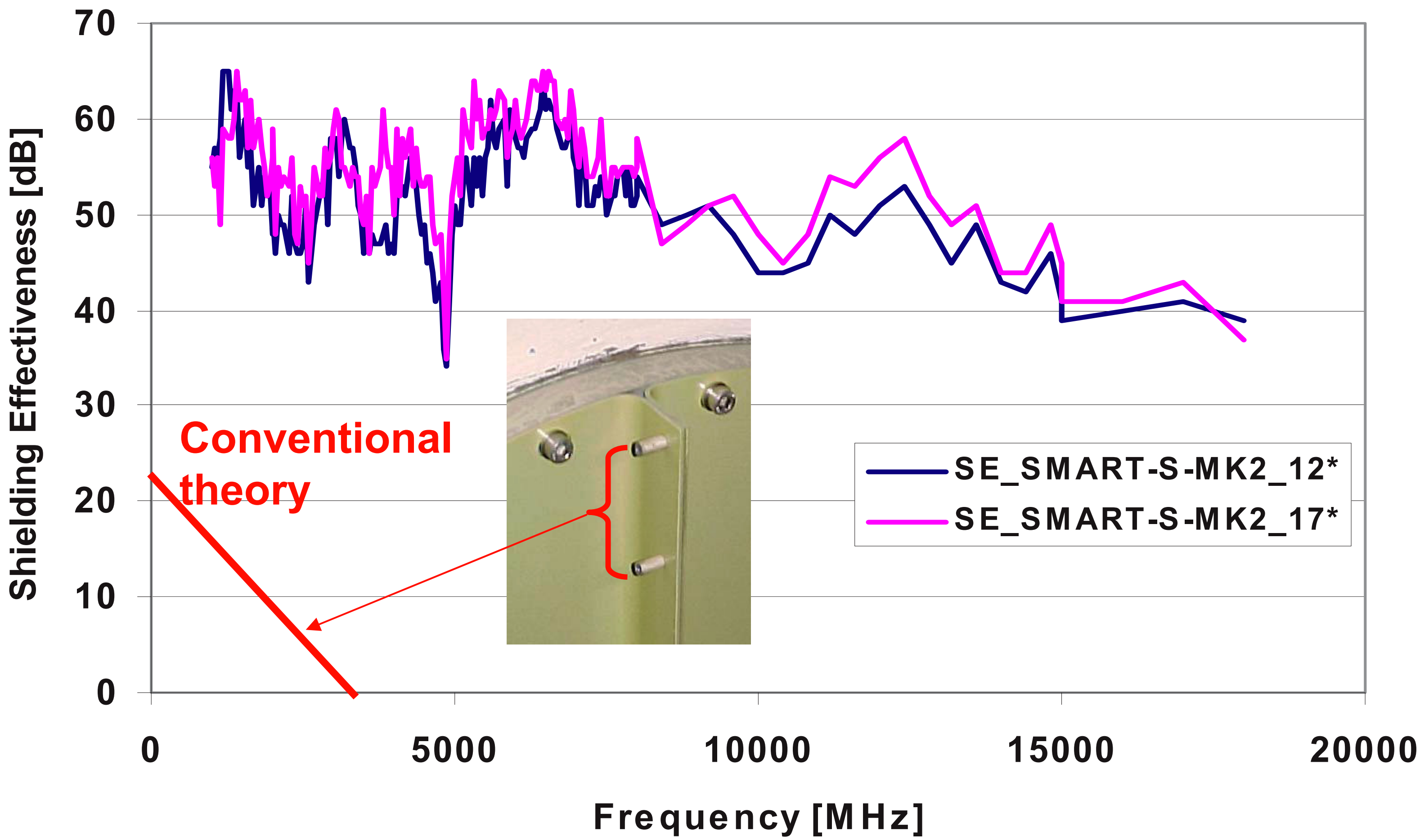






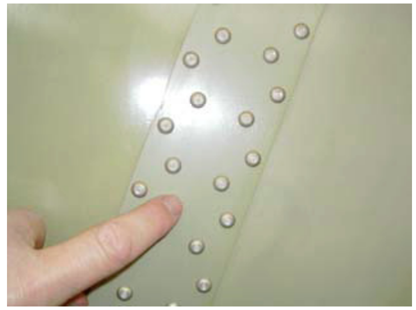
Experiments

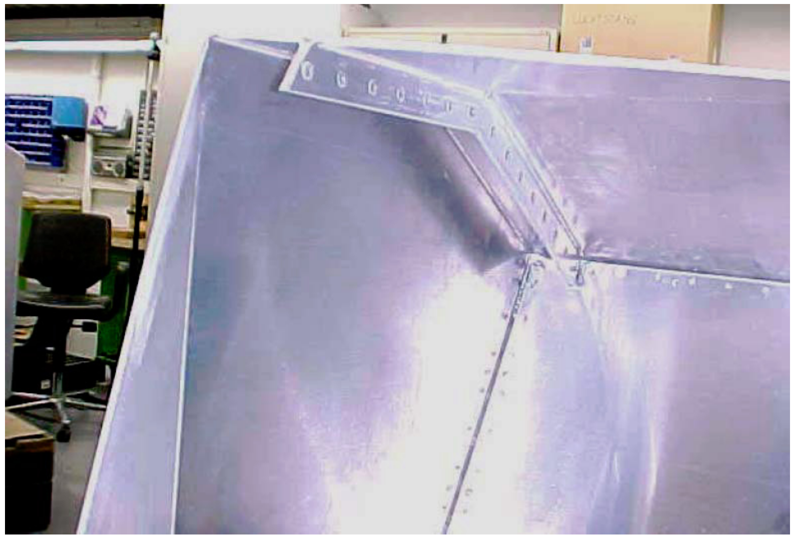
☞ **Simple corner, 12 or 17 rivets**



☞ **So: by using a large overlap you do not a conductive (welding, gaskets) connection!**

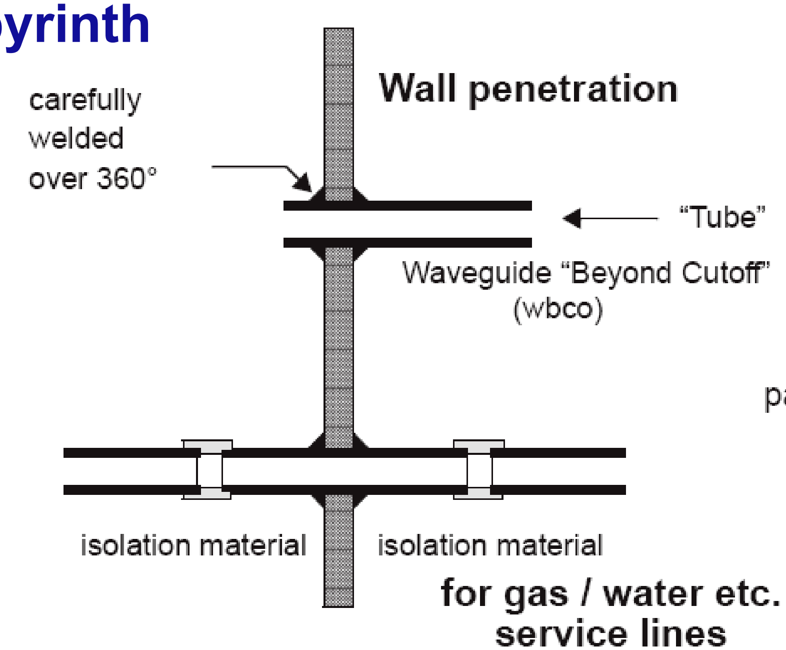
Rivets, instead of welding

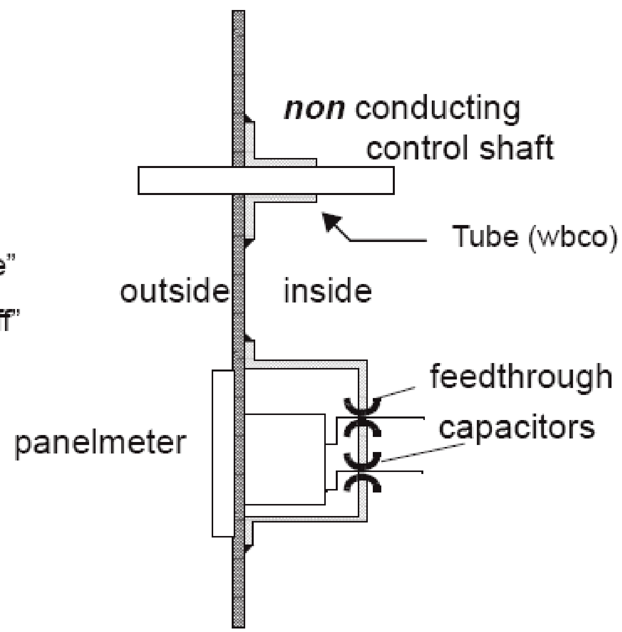




Feedthroughs

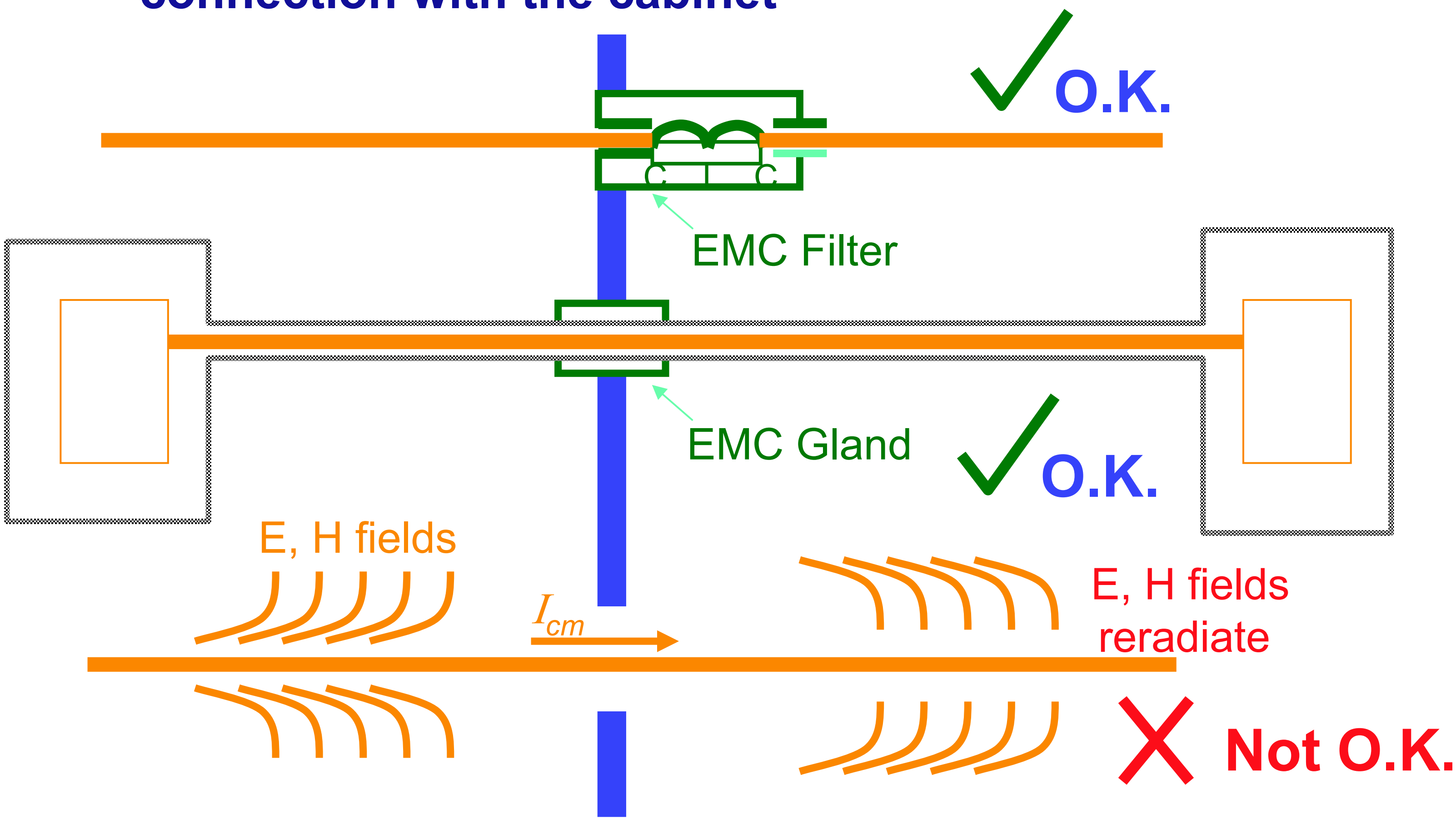
- **Light**
  - **Monitor: either wire gauze (moire effect) or a conductive coating (reduction light to appr. 85%)**
  - **Optical fibers: by means of a WBCO (long tube)**
- **Air and liquid**
  - **via gauze or**
  - **via honeycomb, or**
  - **via labyrinth**





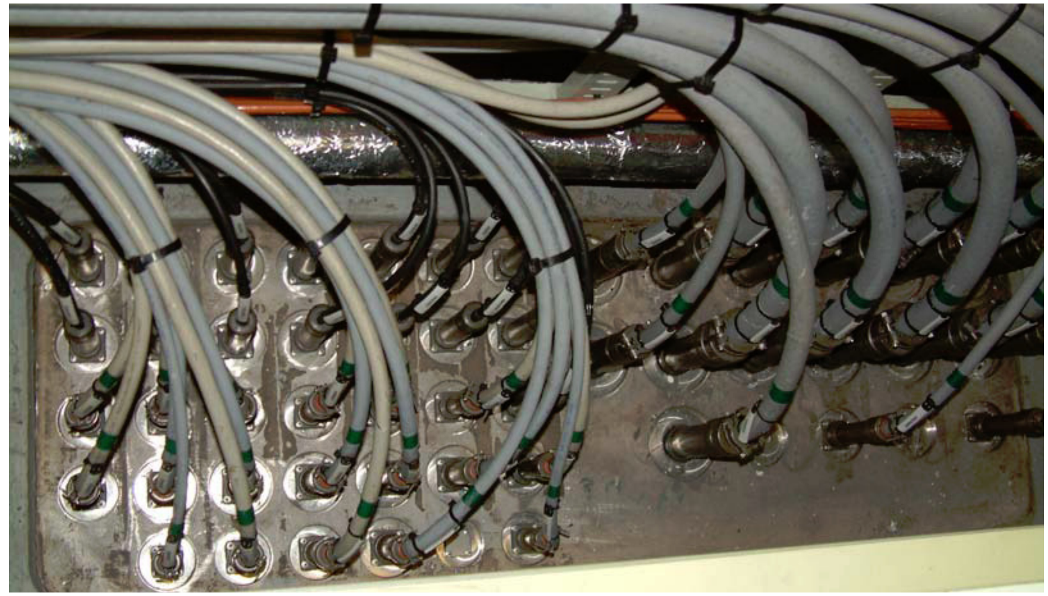
Feedthroughs

- Electrical feedthroughs (cables): either
  - Filter at the point of entrance of the cable
  - Glands, metal connectors etc.: metal circumferential connection with the cabinet

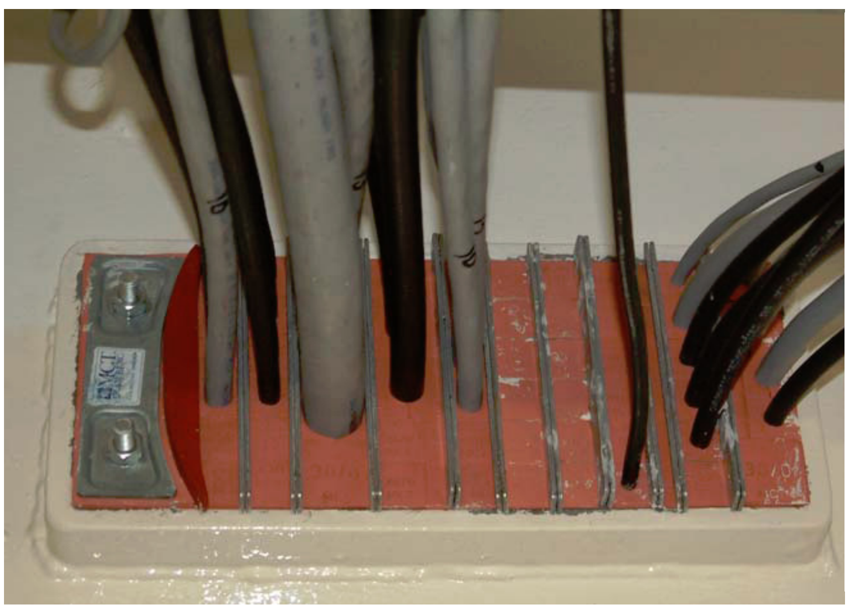


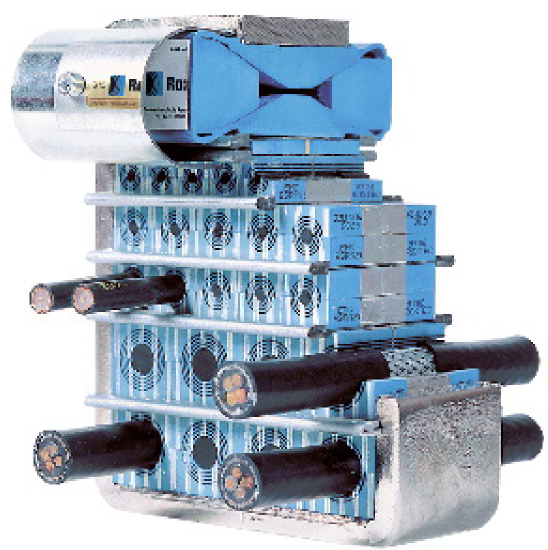
Feedthrough, cables

- ☞ **Many cables via glands: expensive**



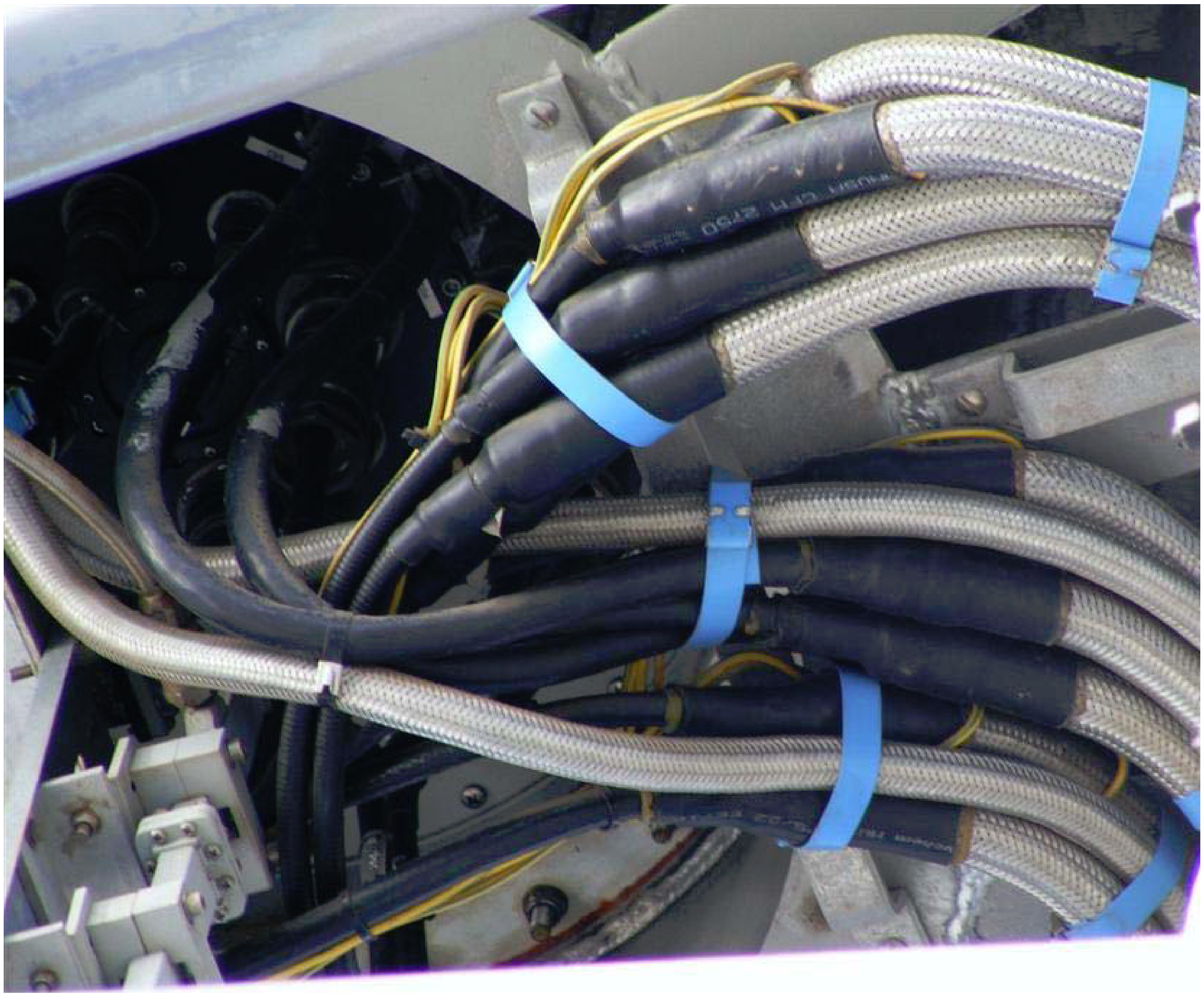
- ☞ **Cheaper solution**



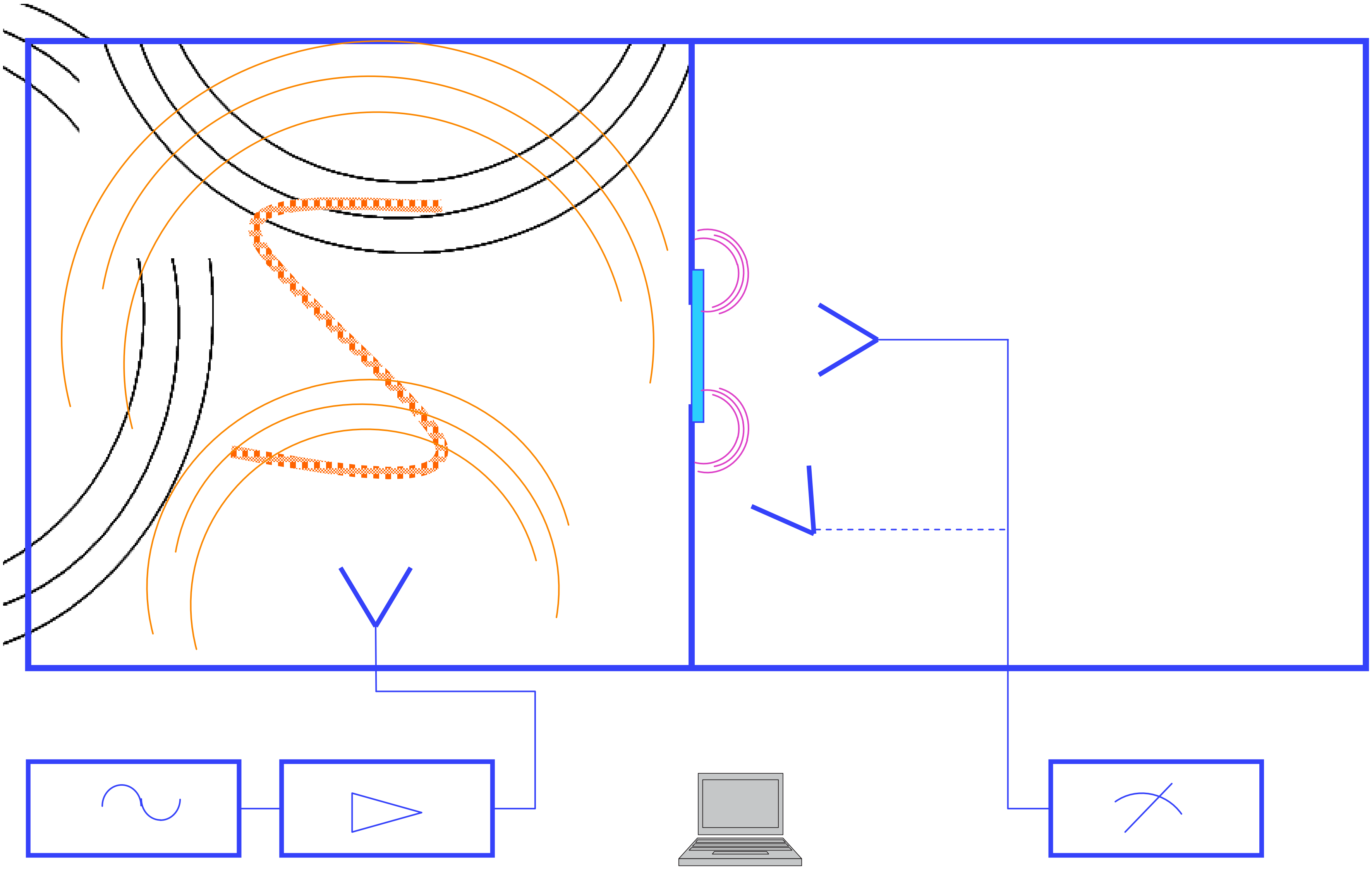


Feedthrough, cables, 2

- ☞ And this is <u>not</u> the way to ground/bond cable shields



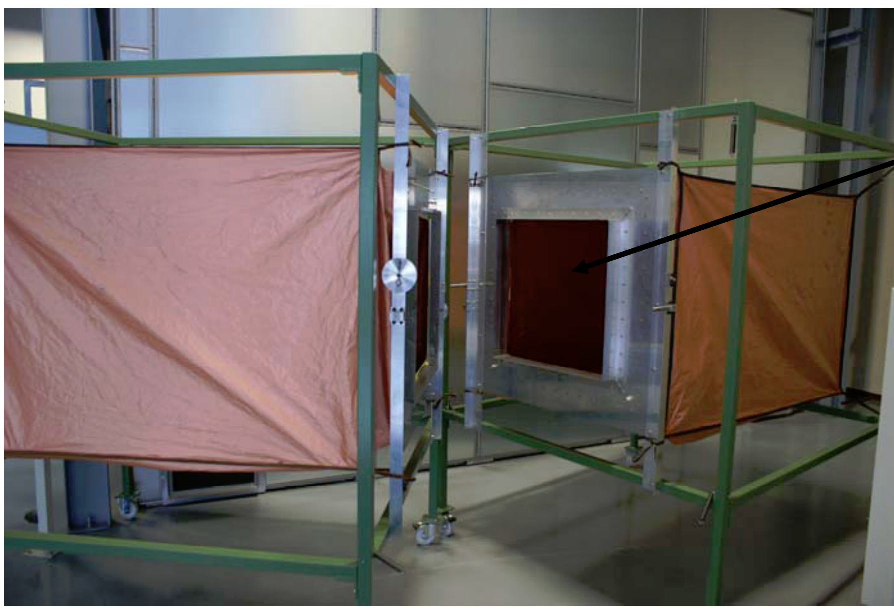
Measuring shielding effectiveness



Measuring shielding effectiveness

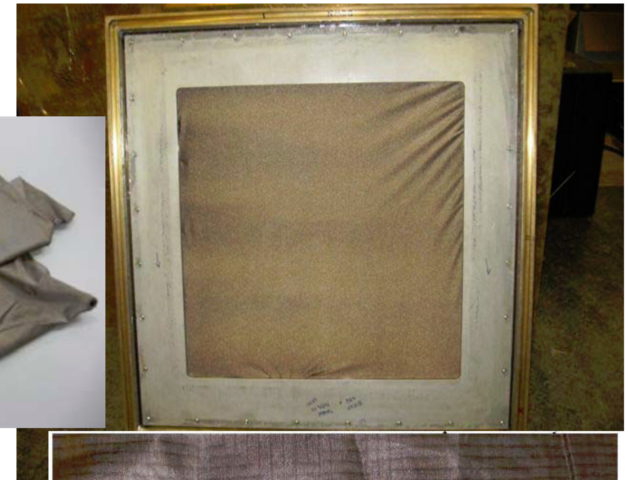
Dual VIRC:

two chambers connected via a common wall, with the tested material in the wall



Many, many materials….

Conductive fabric (shieldex types)



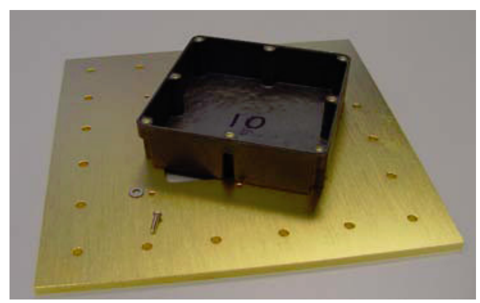
Composite panels
(Glass Reinforced Plastics)
with conductive fabric

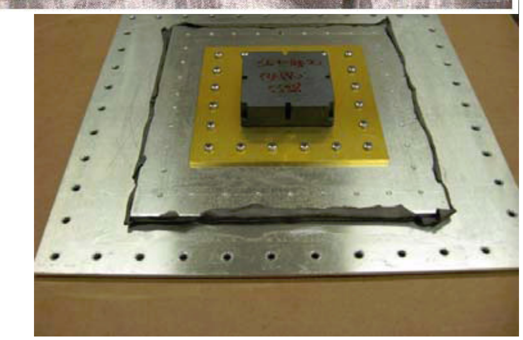
Composite panels with carbon fibers

Composite panels with metal paint

Composite panels with thin metallic fibers

Conductive composite box





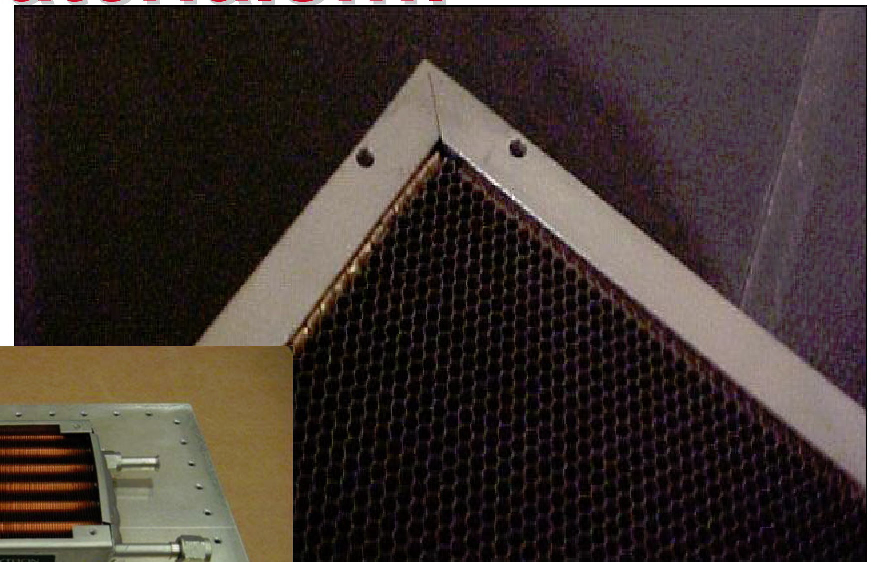
Many, many materials….

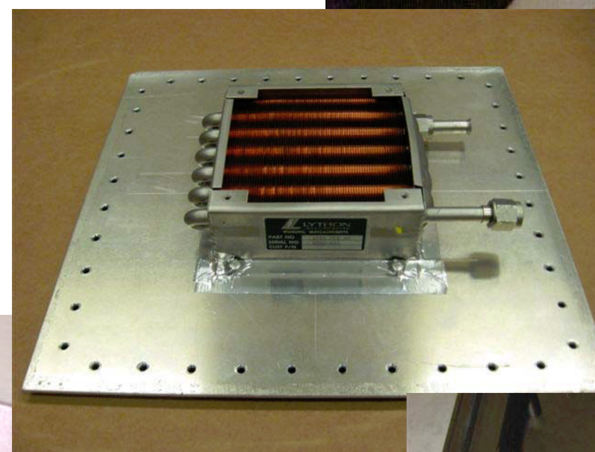
Honeycomb panels

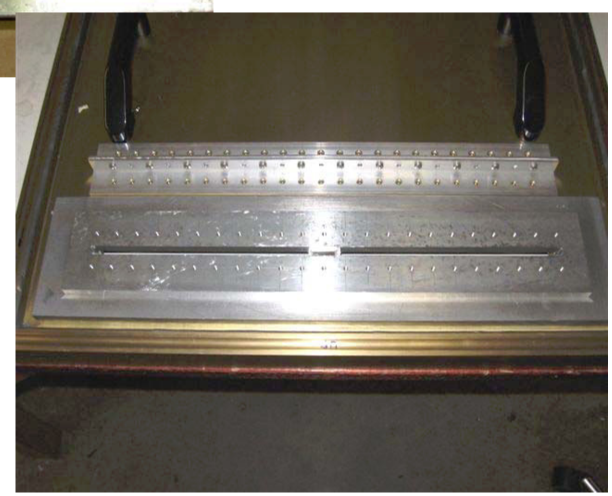
Joined panels

Various wire mesh

SE of heat exchanger



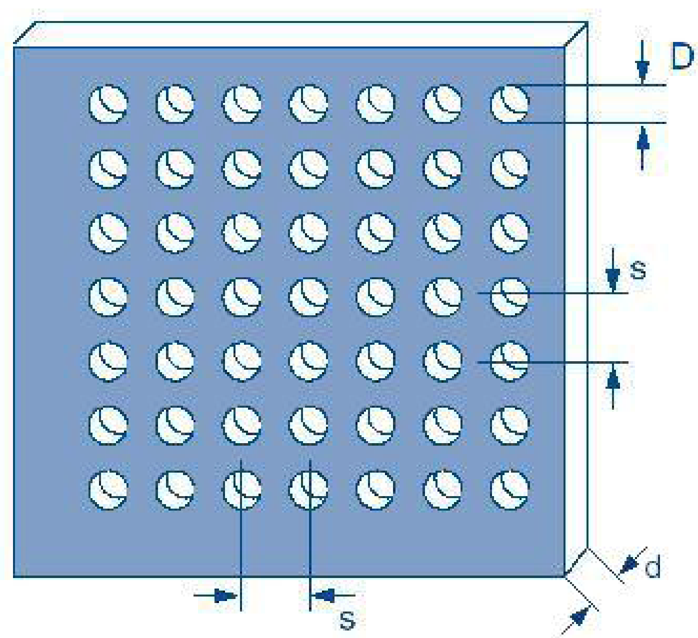


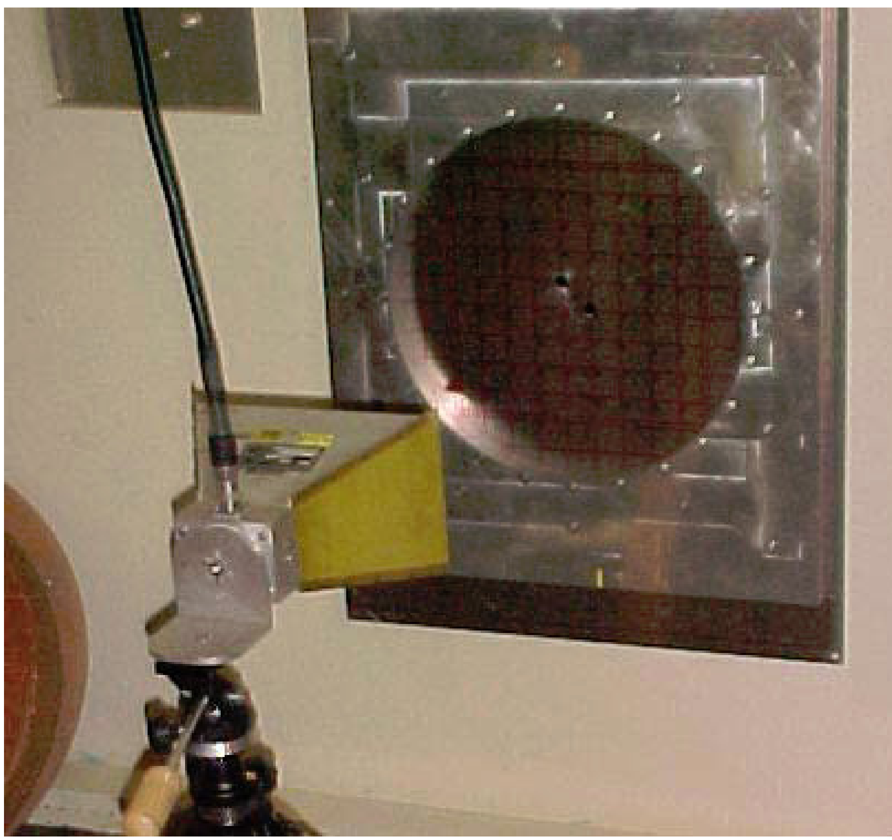


Many, many materials….

Various wire mesh

Panels with multiple holes

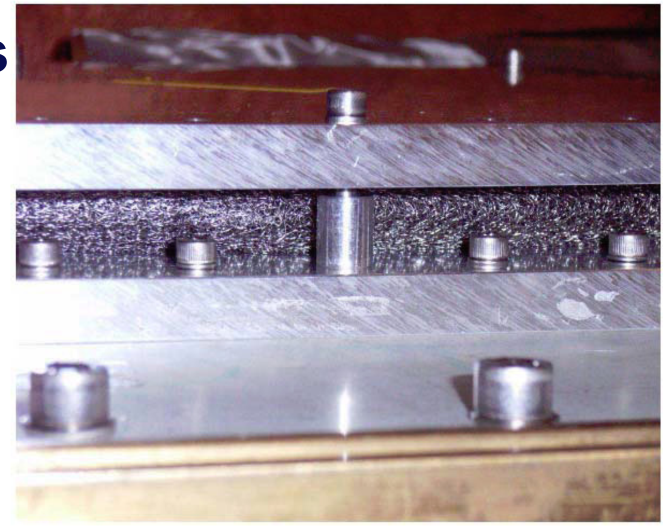




Many, many materials….

Aluminum panels with various gaskets

All metal gasket (large, 22 mm)

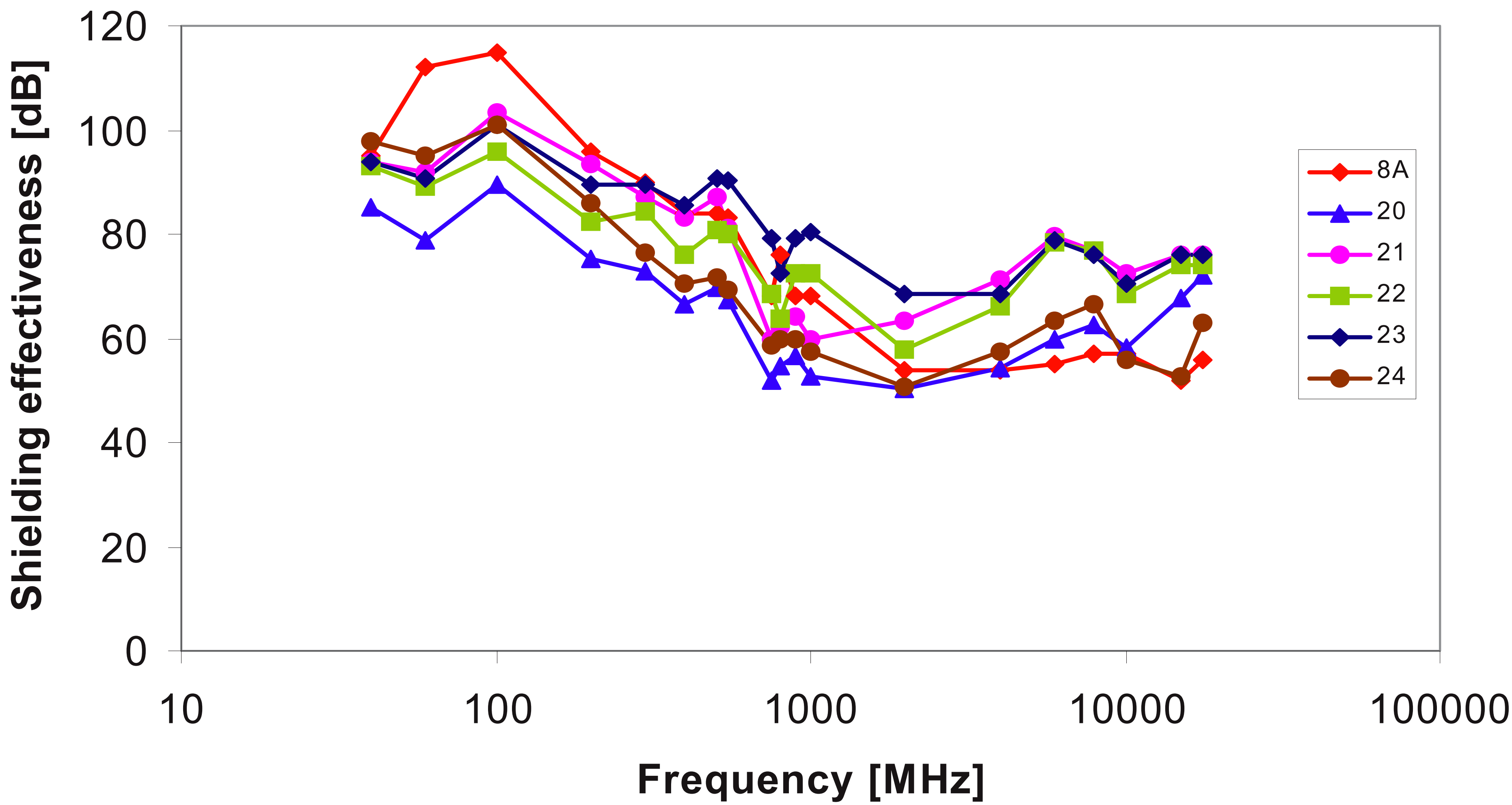


Detail gasket measurement

All metal gaskets (small, 5 mm)

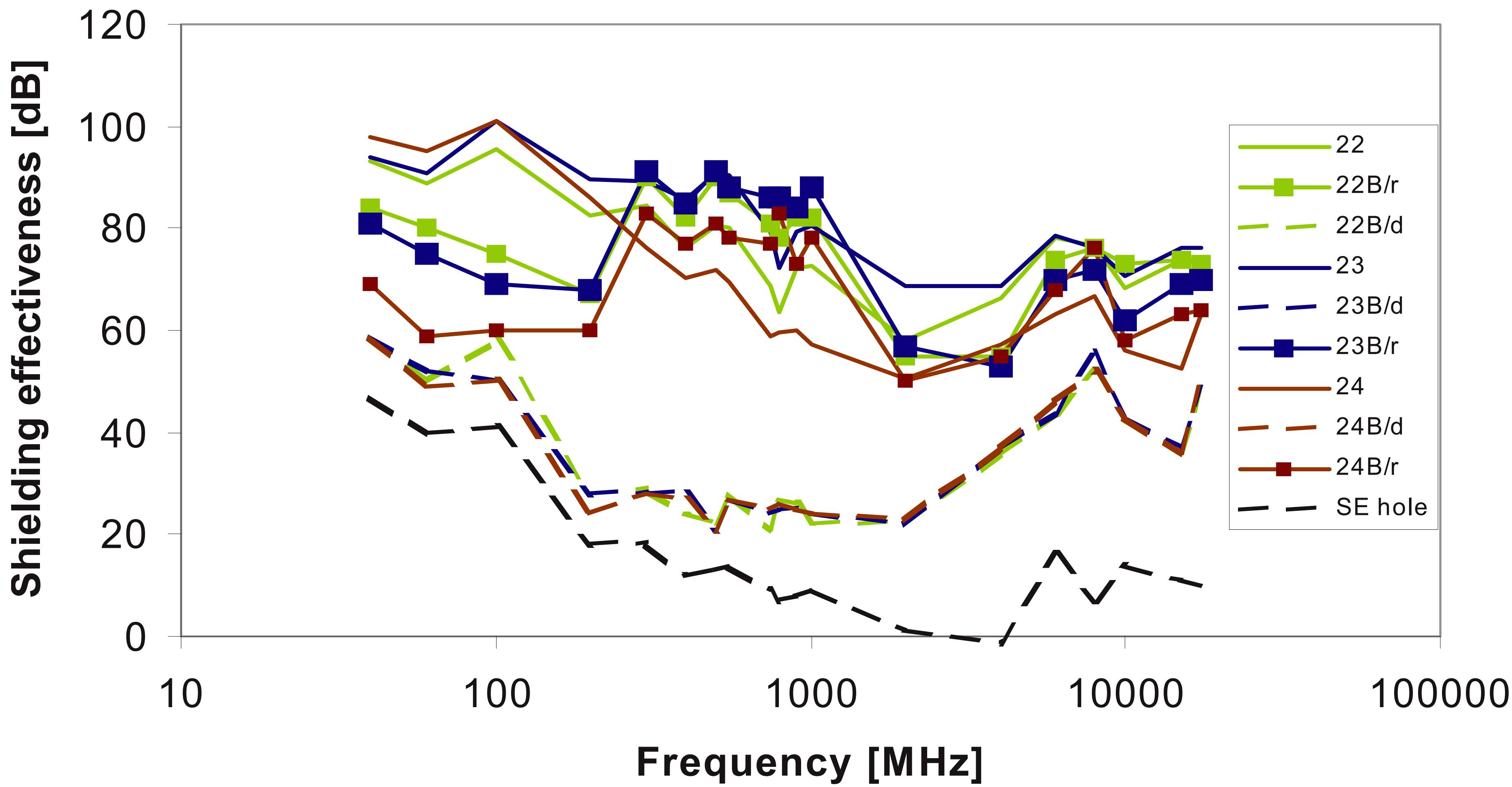
Spiral / spring gasket (5 mm)

SE of composite panels



☞ **Conclusion:**
the material itself (silver paint, copper paint, thin copper fabric) is not the most important

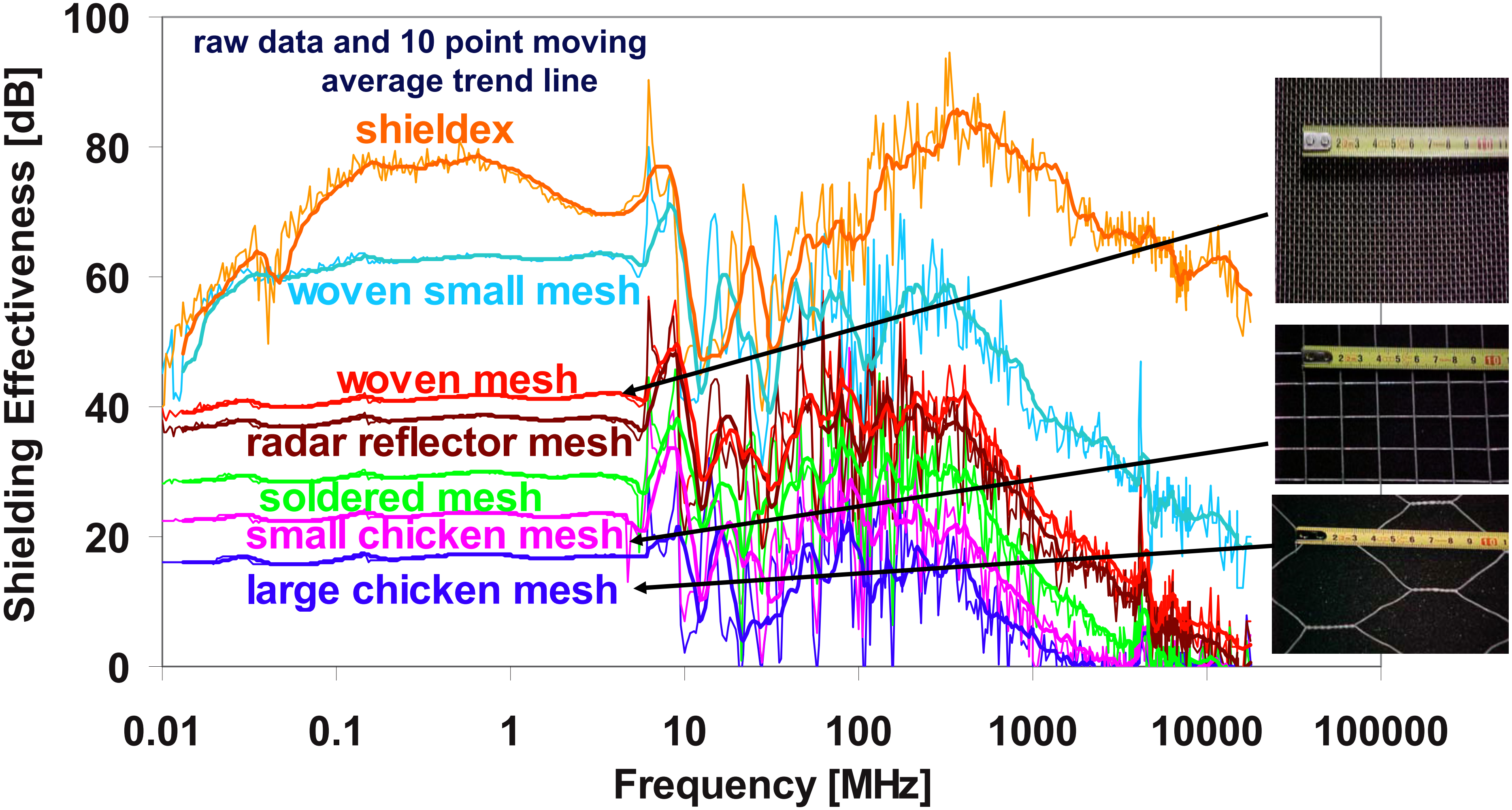
SE comp. panels, after damage and repair



☞ **Conclusion:**

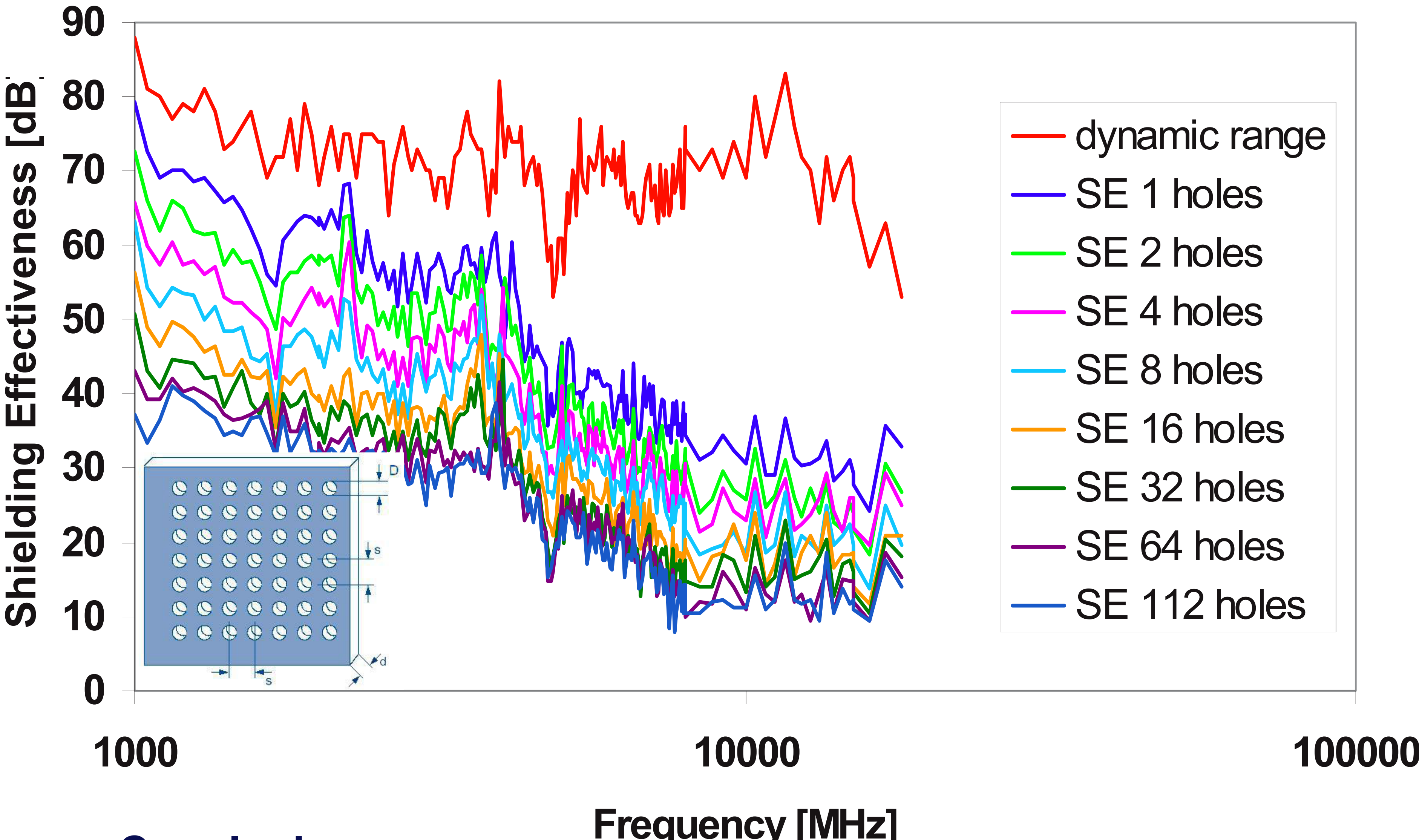
- **damage resulting in a hole destroys the performance**
- **repair of composite panels give very moderate results**

SE woven wire mesh



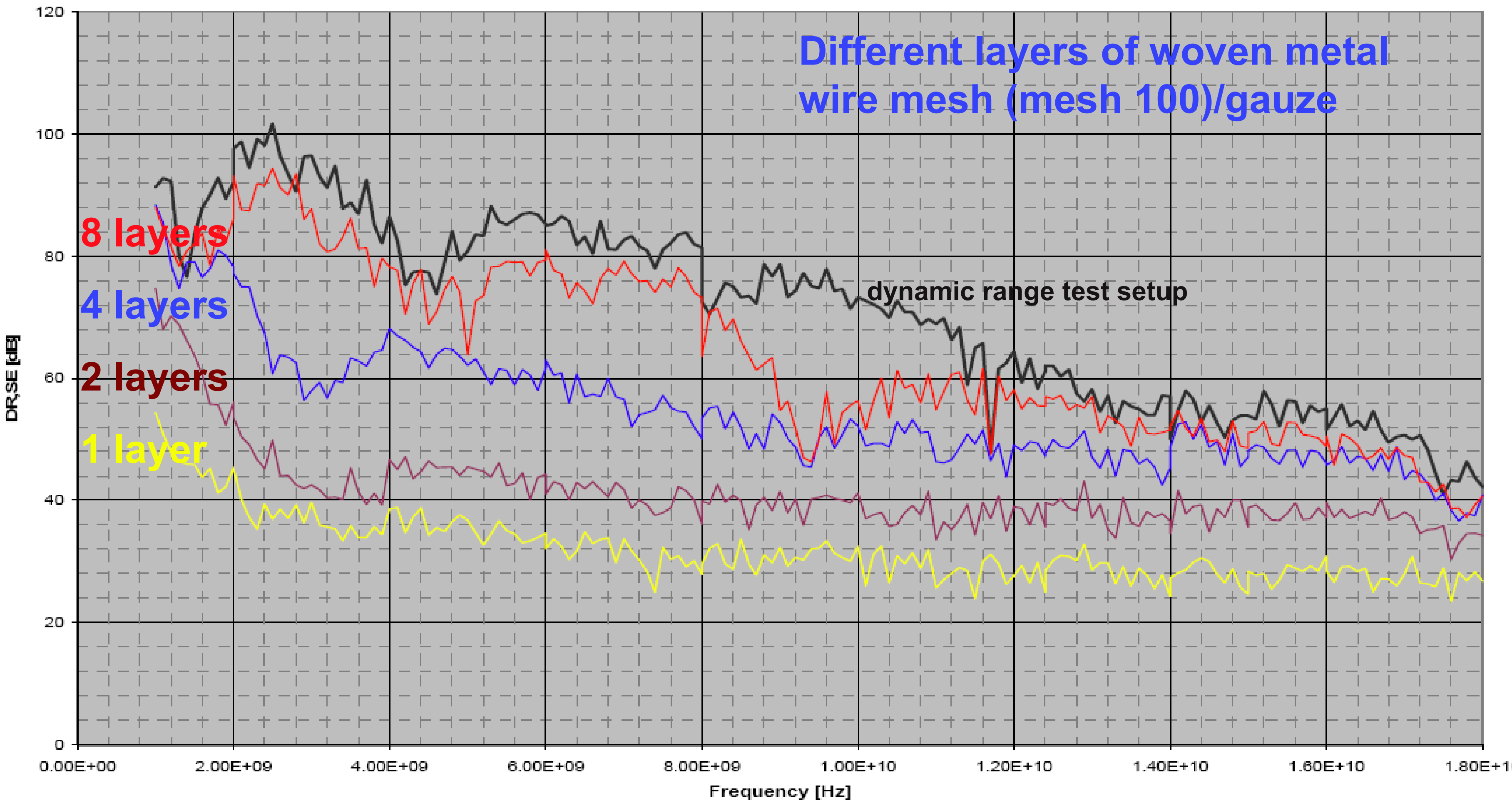
☞ **Conclusion:**
smaller aperture, higher shielding effectiveness

SE panel with holes



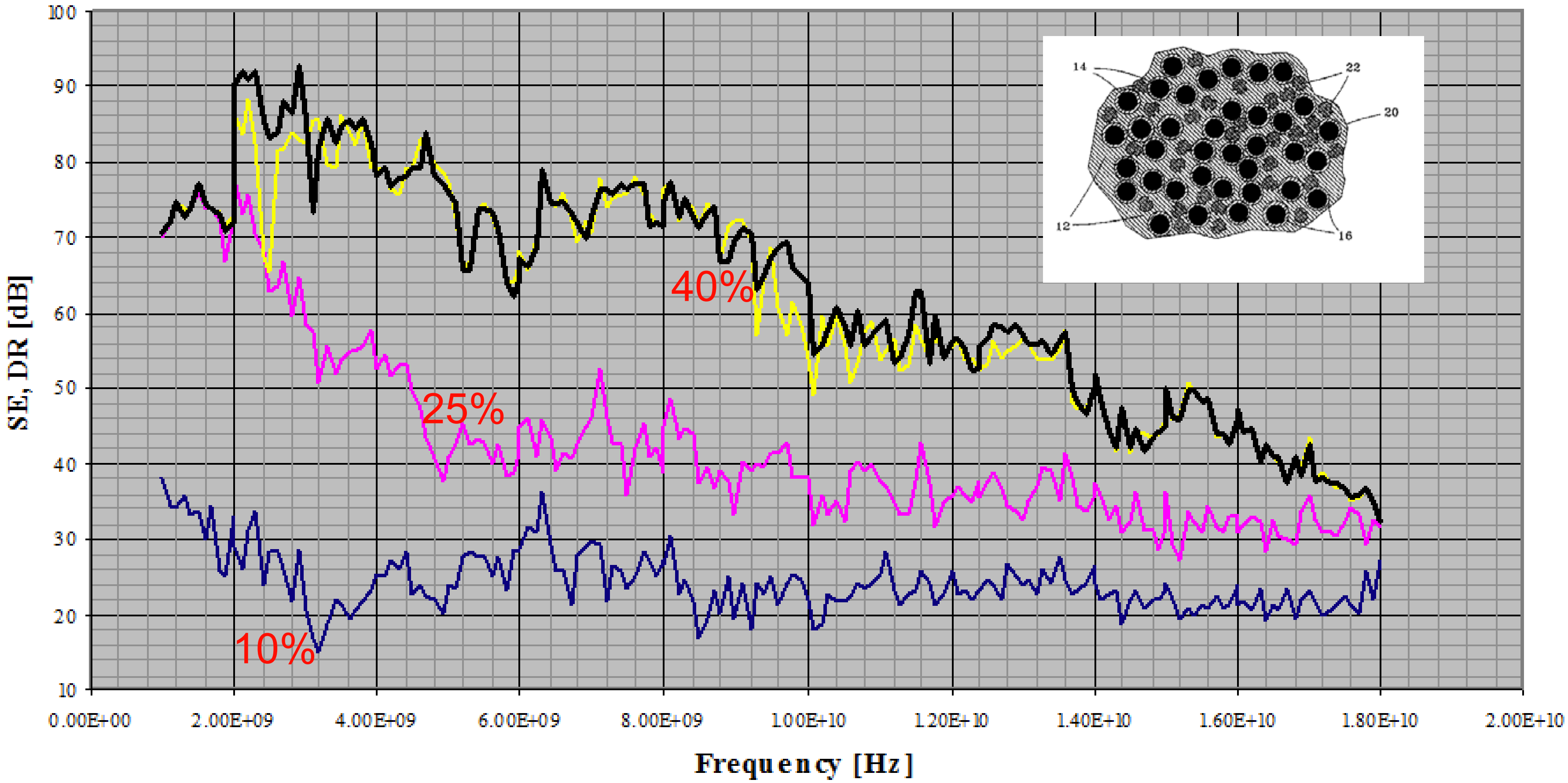
☞ **Conclusion:**
More holes (of same size), less shielding effectiveness

SE full metal wire mesh, different layers



☞ **Conclusion:**
shielding effectiveness is increasing by appr. 6 dB when adding an extra layer

SE as function of gasket compression



- **Conclusion:**
  elastomer gaskets with metal particles are only effective when compressed properly; 40% compression: good, but 10%: nearly no shielding

Rules to remember

- Dominant magnetic field: use thick, high μ (iron) material
- Use high-conductive (any metal) material for all other fields
- Reflection loss is independent of thickness
- Key to high-frequency shielding
  - Aperture control
  - Feedthrough control
- Aperture:
  - The smaller the dimension, the higher the SE: wavelength λ with respect to largest dimension ($\lambda/2d$)
  - More smaller apertures better than one big aperture
  - Increasing depth of aperture (tube) gives higher SE (if $d<l$)
- Feedthrough:
  - All cables that penetrate a shielded enclosure should be filtered or shielded
  - Shield of shielded cables should be bonded (360°) to the shielded enclosure

Questions?