TECHNICAL ACADEMY

WÜRTH ELEKTRONIK

A Practical Guide to EMI Shielding of Electronic Devices

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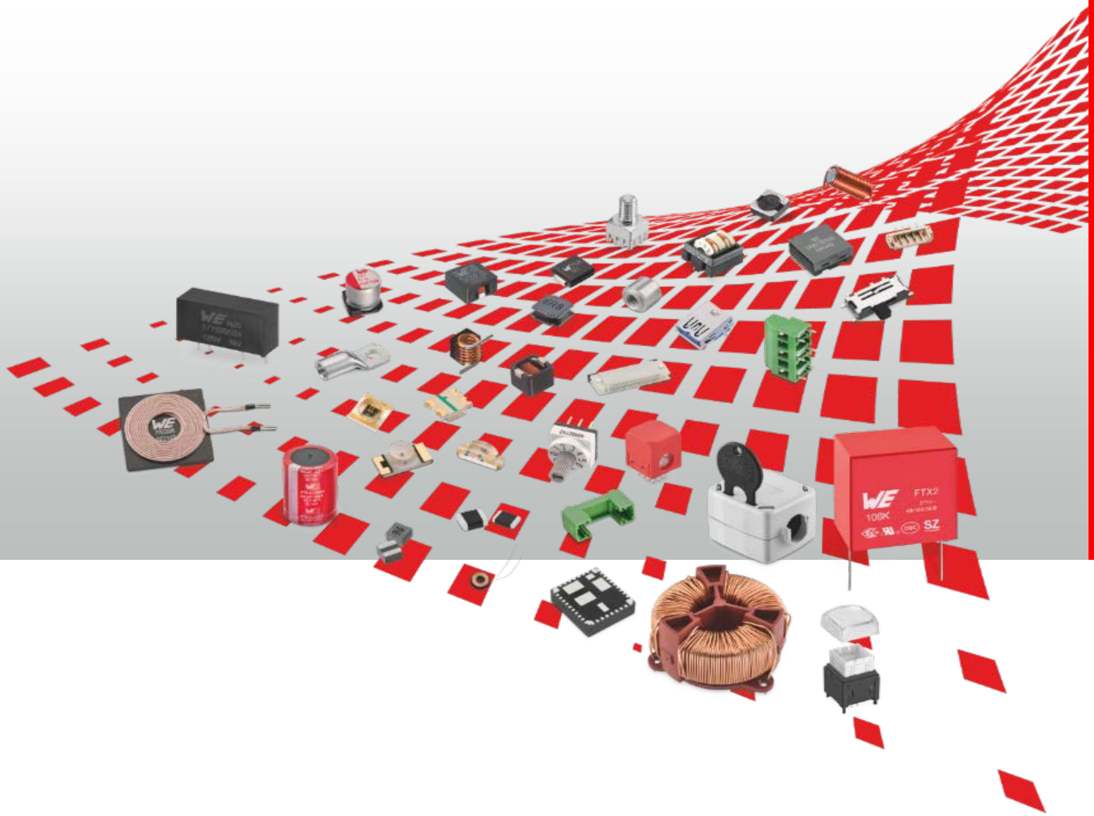


more than you expect

Agenda

- Introduction
- Basics
- Shielding apertures
- Shielding solutions

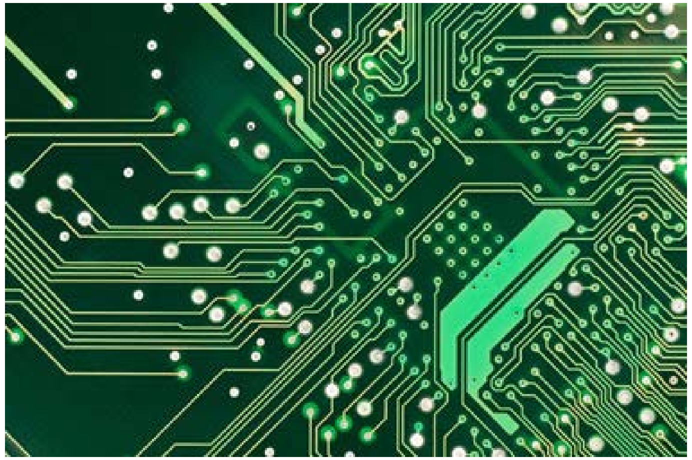
Introduction

What does „electromagnetic shielding“ mean?

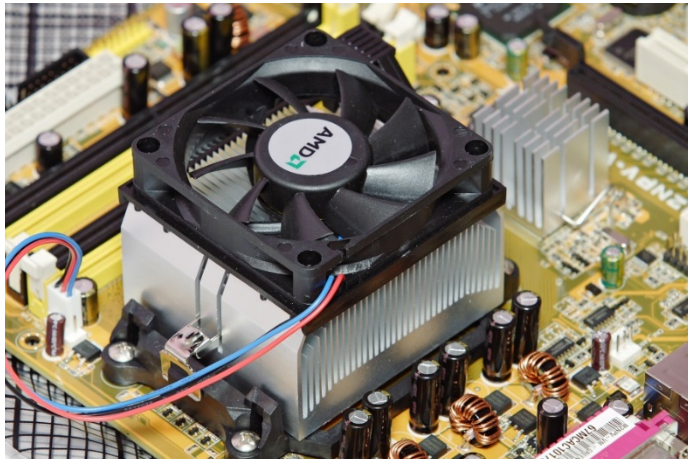
Basics

- Electromagnetic fields are radiated from and received by conductive structures.
- Possible antennas:

Cables, interfaces, apertures

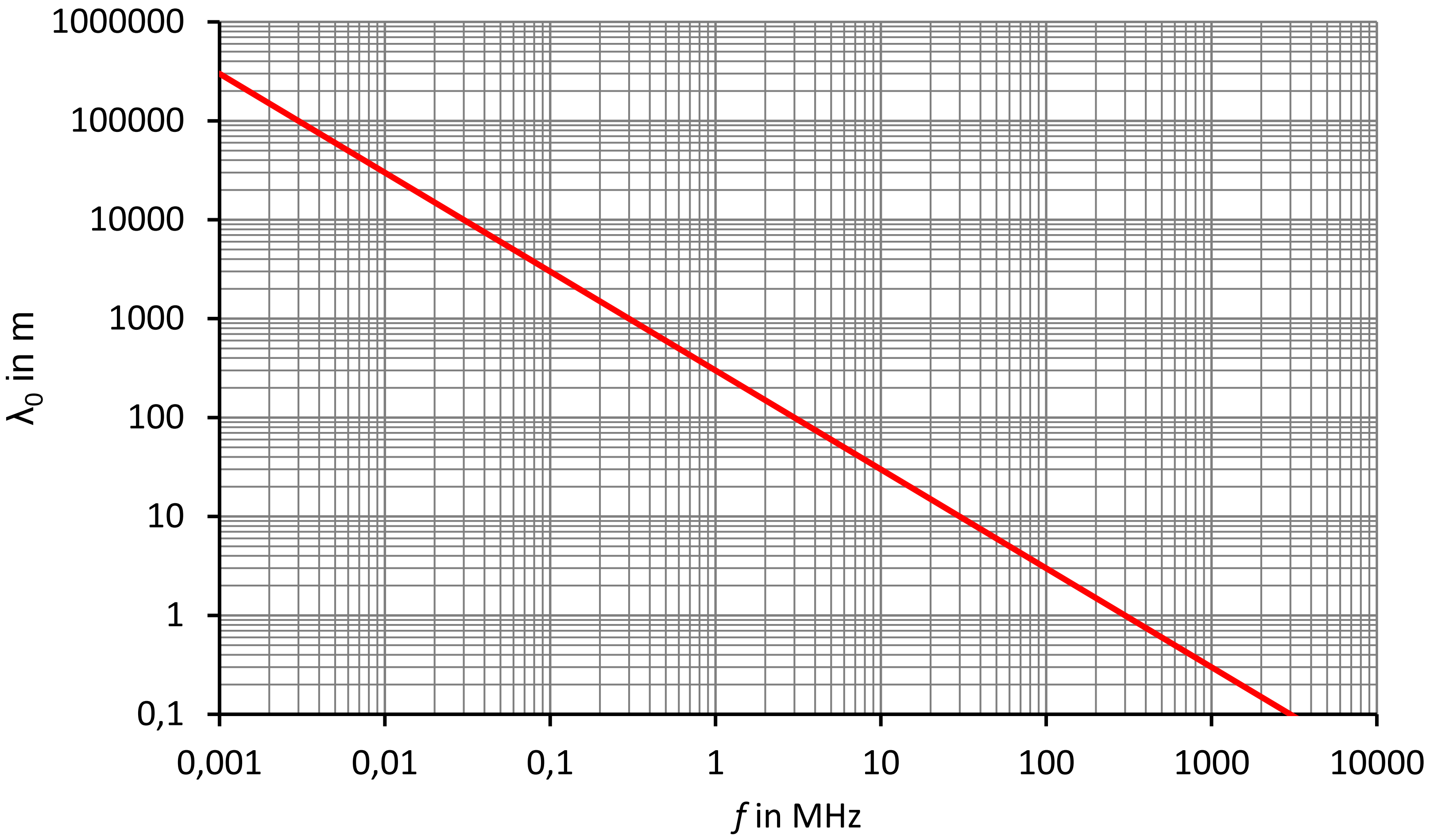


Traces, groundplanes, vias, slits



Components, heatsinks, integrated circuits

Basics – Wavelength



- Relation between frequency and wavelength:

$$\lambda_0 = \frac{c_0}{f}$$

- Examples:

  $f = 500\text{kHz} \rightarrow \lambda_0 = 600\text{m}$

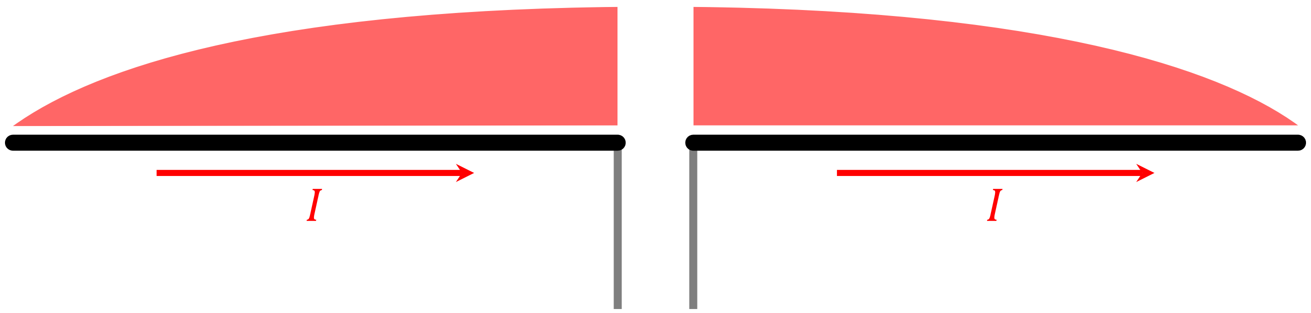
  $f = 8\text{MHz} \rightarrow \lambda_0 = 37{,}5\text{m}$

  $f = 100\text{MHz} \rightarrow \lambda_0 = 3\text{m}$

  $f = 2{,}45\text{GHz} \rightarrow \lambda_0 = 12{,}5\text{cm}$

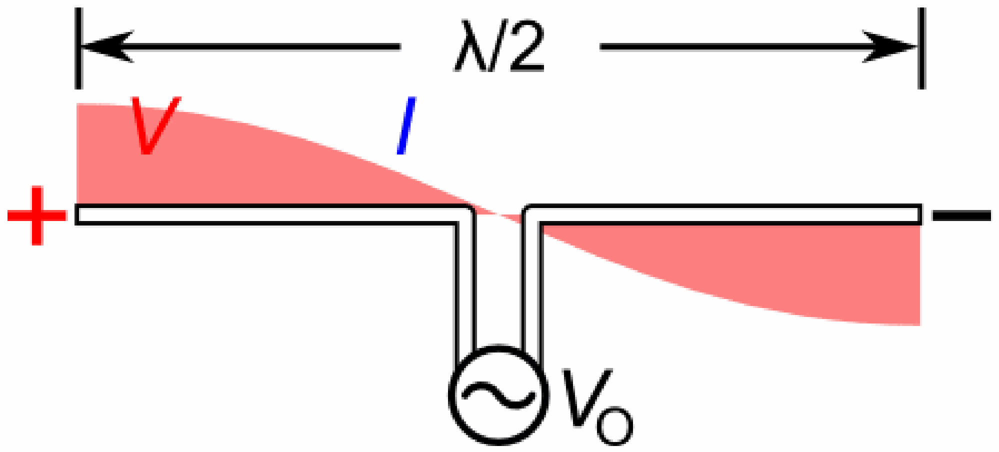
Basics – Half-wavelength dipole

- A conductive structure is not a **proper antenna** for each frequency.
- The **relation** between the structure dimension and the wavelength is crucial.
- The relation is optimal if the structure length is equal to **half of the wavelength** (half-wavelength dipole).
- A significant antenna effect is observable for a length up **one twentieth** of the wavelength.



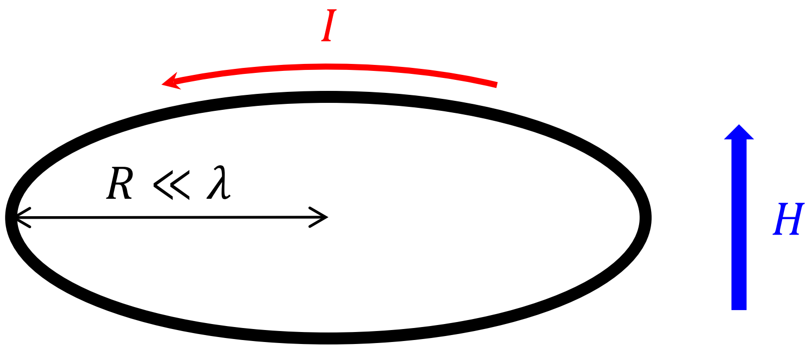
Basics – Elementary dipole

- The most basic antenna is an **electric** (Hertzian) **dipole**. Its length ℓ is small compared to the **wavelength** considered.
- Along its dimension a locally constant, temporally changing current I is flowing. Charges are accumulated at the ends.
- The electric dipole generates an **electric field**.



Basics – Elementary dipole

- A second elementary antenna is created by a **current loop** or **magnetic dipole**. Its radius R is small compared to the **wavelength** considered.
- Along its circumference a locally constant, temporally changing current I is flowing.
- The magnetic dipole creates a **magnetic field**.



Basics – Characteristic wave impedance

- The **characteristic wave impedance $\boldsymbol{Z_\mathrm{W}}$** is equal to the relation of the electric field strength to the magnetic field strength at a distance r from the antenna.

$$Z_\mathrm{W} = \frac{E}{H}$$

- Characteristic wave impedance of the electric dipole in the **near field**:

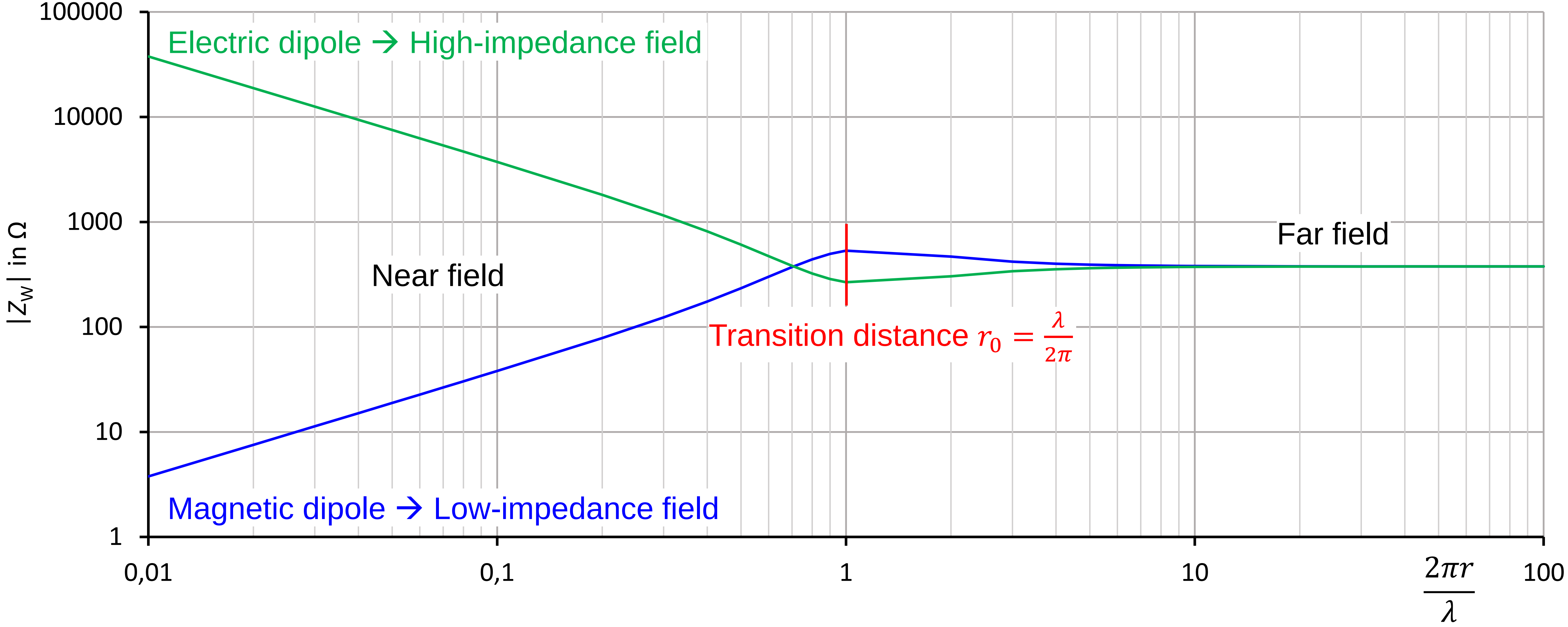
$$|Z_\mathrm{W,e}| = Z_\mathrm{W0} \cdot \frac{\lambda}{2\pi r}$$

- Characteristic wave impedance of the magnetic dipole in the **near field**:

$$|Z_\mathrm{W,m}| = Z_\mathrm{W0} \cdot \frac{2\pi r}{\lambda}$$

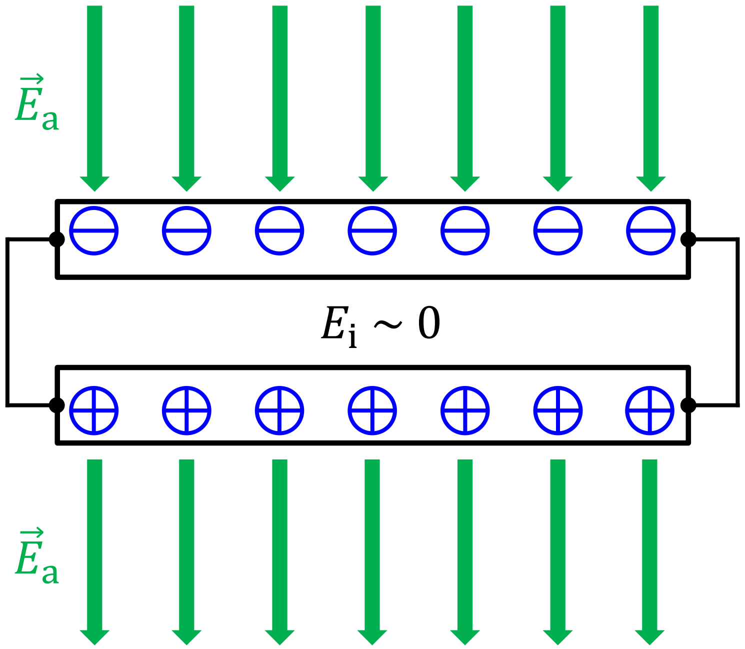
- The factor $Z_\mathrm{W0} = \sqrt{{}^{\mu_0}/_{\varepsilon_0}} = 377\Omega$ is named the free-space characteristic wave impedance (**far field**).
- From an EMC perspective most of the relevant noise sources can be described by one of the elementary dipoles.

Basics – Characteristic wave impedance



Basics – Shielding of electric fields

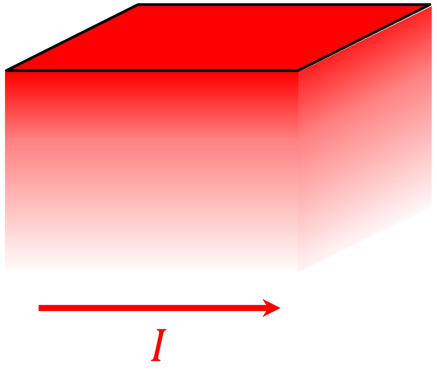
- Electric fields can be **shielded easily**.
- Electric field lines start and end on charges.
- It has to be assured that free charges are able to be **balanced**.
- Shielding effect of **electrically conducting** and **connected plates** on a static electric field:



Basics – Shielding of magnetic fields

- Shielding of magnetic fields is more difficult, particularly static and low-frequency fields.

- Categorization of shielding solution types:
  - Against static and low-frequency fields → **High-permeable** materials
  - Against medium-frequency fields → Using of **skin effect**
  - Against high-frequency fields → **Reflection** and **absorption**

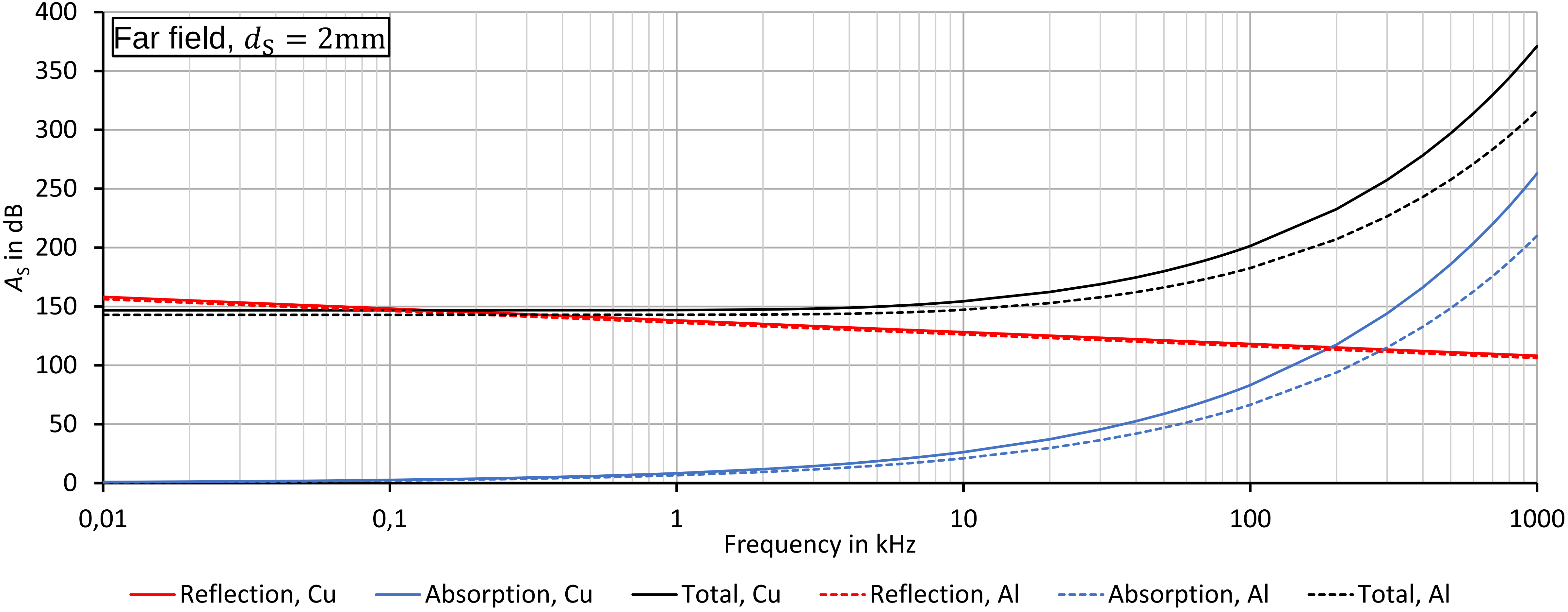


Basics – Shielding of magnetic fields

- **High-permeable** materials are used for shielding of static and low-frequency fields (16⅔ Hz, 50 Hz).
- The shielding effect is more efficient,
  - the higher the permeability,
  - the thicker the shield,
  - the smaller the shielded volume.

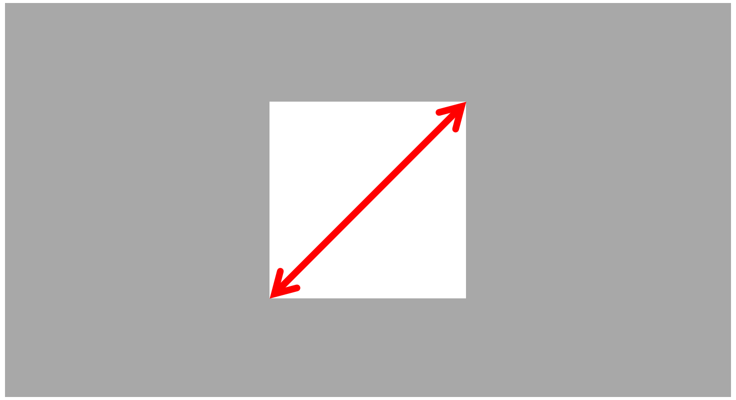
Material	Relative permeability μ_r
Nickel	100
Steel	1000
Stainless steel	500
Mumetal	25000

Basics – Theoretical shielding attenuation



Shielding apertures

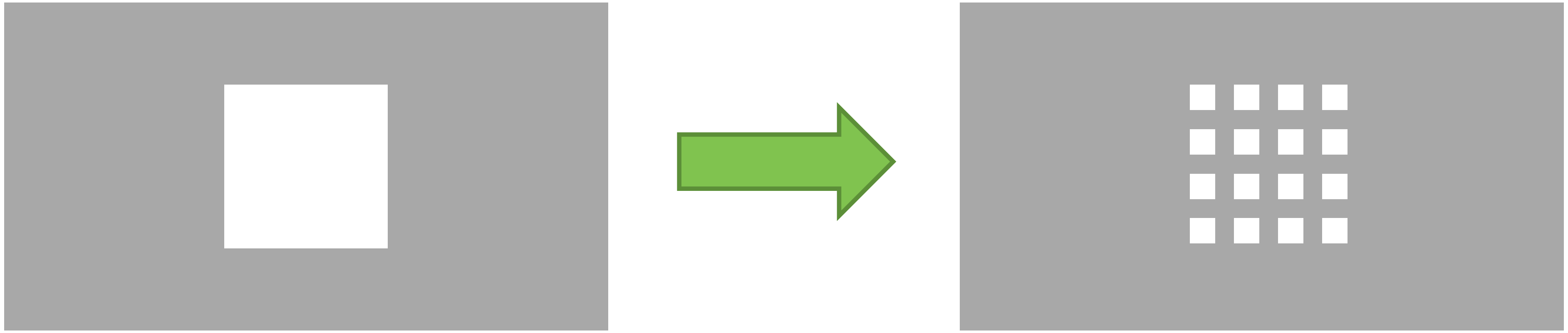
- The limit for determining the shielding attenuation by **measurement** lies at 120 dB.
- There‘s no perfect shield, i.e. completely closed.
- There is a greater impact of **apertures** in the shield on the magnetic shielding attenuation than on the electric shielding attenuation.
- For higher frequencies the **decrease** in shielding effectiveness due to leakage is more significant than the **theoretical** shielding attenuation of a material.
- The **maximum linear dimension** of an aperture is crucial, not its area.



Shielding apertures

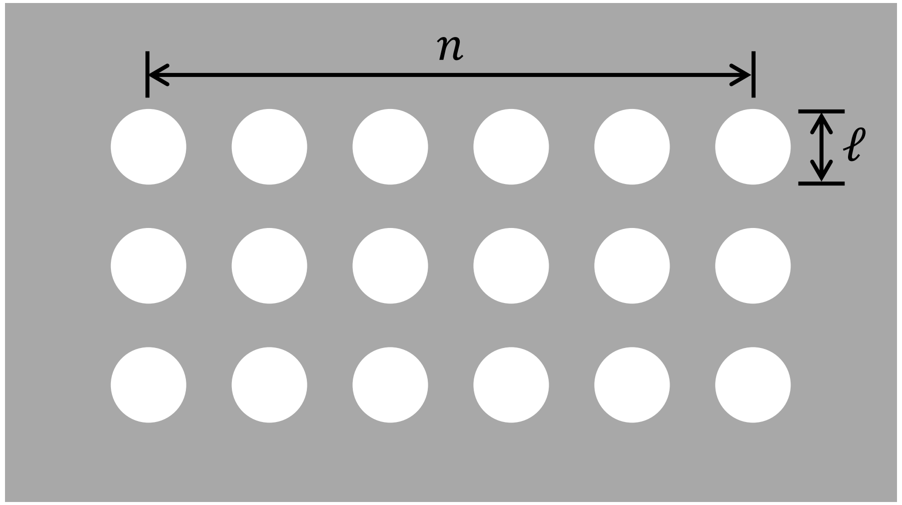
- An aperture with length $\ell = {}^{\lambda}/_{2}$ shows the same behavior as a **half-wavelength dipole**.
- When the **electric** field vector is oriented **perpendicularly** in relation to the slit, the shielding attenuation at the corresponding frequency is 0 dB.

- If a larger aperture is required, e.g. for ventilation of the interior, the area should be devided into many smaller apertures.



Shielding apertures

- For a two-dimensional **breadboard** the maximum number of holes lying **in a single row** is crucial for the reduction in shielding effectiveness.



- Shielding attenuation with apertures:

$$A_{\mathrm{S,Ap}} = 20 \cdot \log\left(\frac{\lambda}{2 \cdot \ell \cdot \sqrt{n}}\right) \mathrm{dB}$$

Shielding apertures

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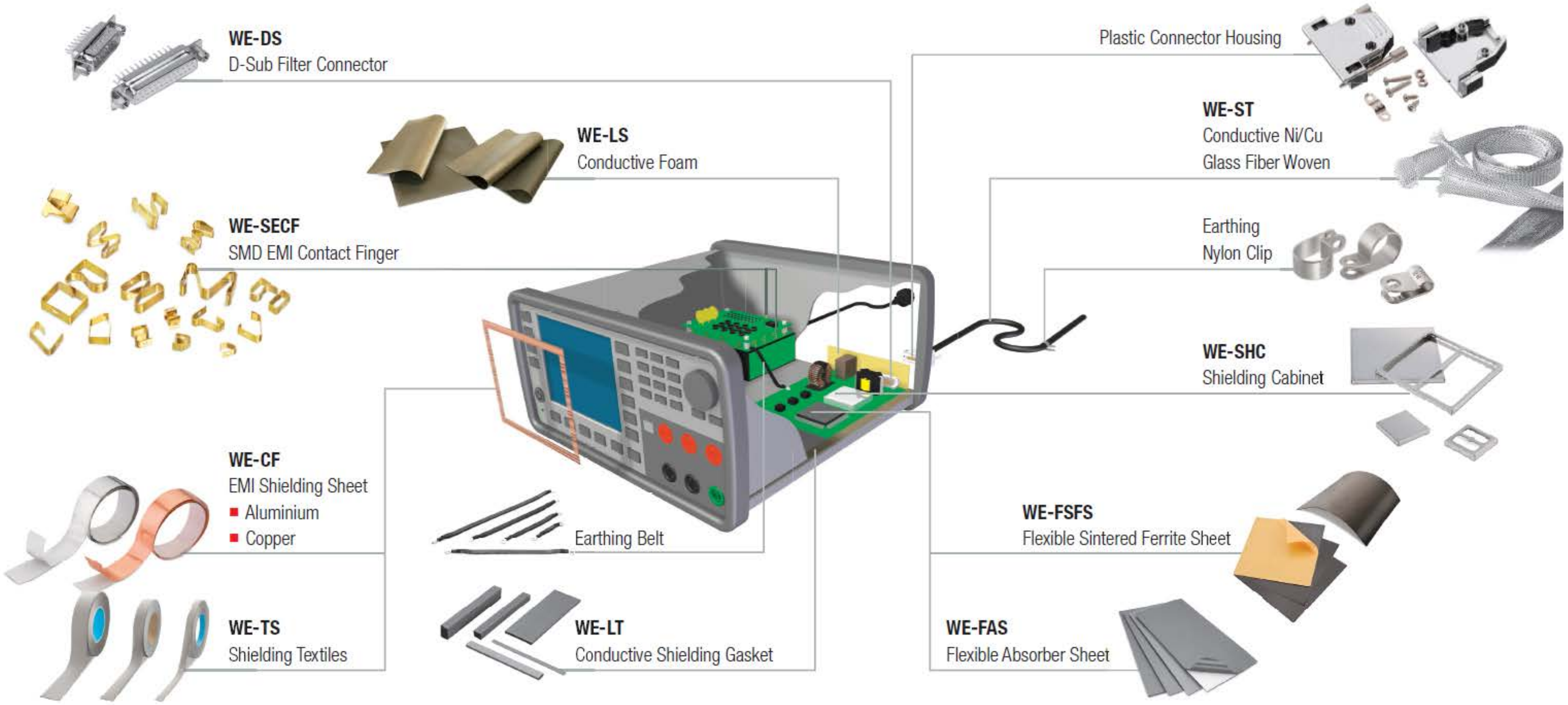
- Maximum slit length for 20 dB attenuation:

Frequency in MHz	Length in cm
30	50
50	30
100	15
300	5
500	3
1000	1,5
3000	0,5
5000	0,3

- Decrease in shielding attenuation for $n > 1$:

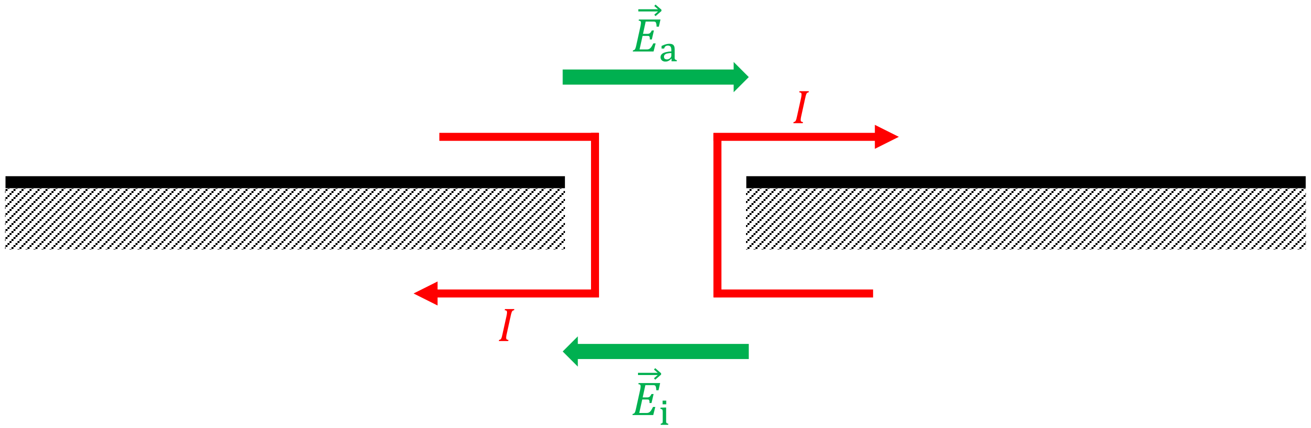
n	ΔA_S in dB
2	-3
4	-6
6	-8
10	-10
20	-13
40	-16
80	-19
100	-20

Shielding solutions – Overview

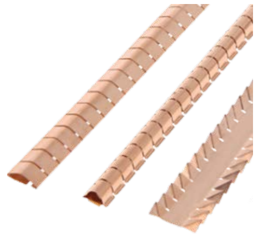


Shielding solutions – Casing joints

- It is important to ensure a **large-scale conductive transition** at joints of a casing (edges, covers, doors).
- Joint without a conductive transition:

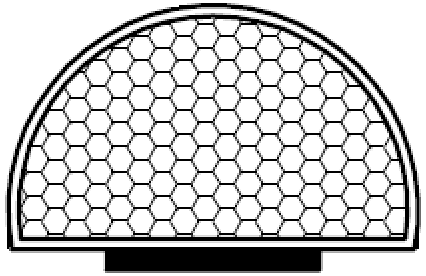


- Establishing a conductive transition:
  - Conductive fabric gasket
  - Spring contact strip



Shielding solutions – Casing joints

- Conductive fabric gasket consists of **foam material**, surrounded by **nickel-copper fabric**. Adhesive tape is attached on one side.
- Maximum degree of protection: IP54
- Fire protection in railway applications → EN 45545-2:2013+A1:2015 → R22/R23



- <u>Application examples:</u>

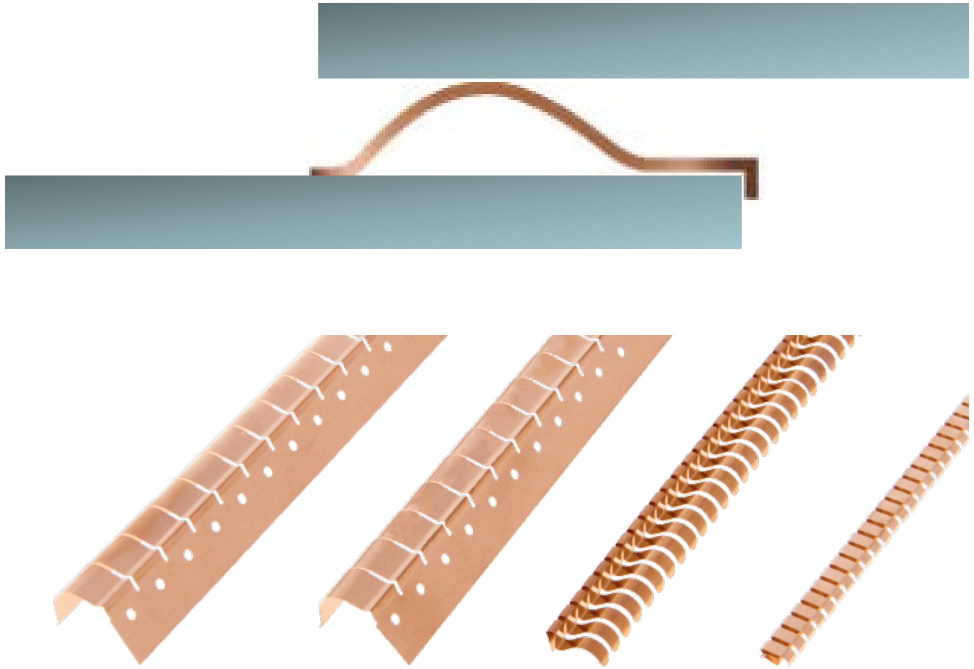
Shielding solutions – Casing joints

- Suitability of material pairings:

Base material	Nickel-copper	Aluminum
Zinc	−−	++
Aluminum	−−	++
Copper	+	−
Tin	+	−
Nickel-silver	+	−
Lead	+	−
Nickel	++	−−
Silver	++	−−
Nickel-copper	++	−−
Gold	++	−−

Shielding solutions – Casing joints

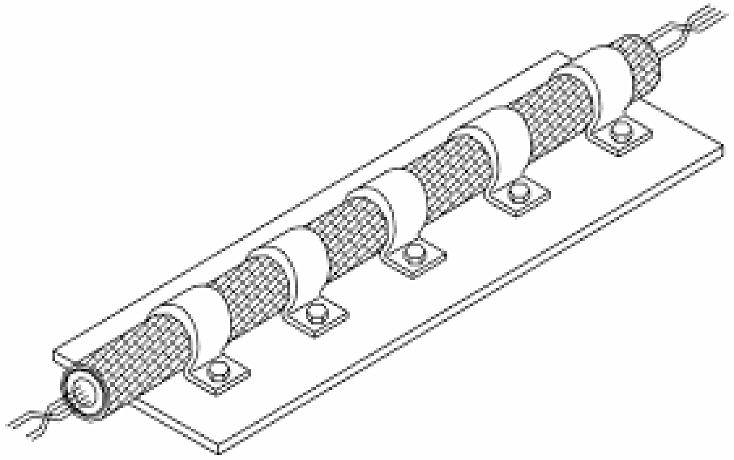
- Spring contact strips are made of copper-beryllium or stainless steel.
- Application example:



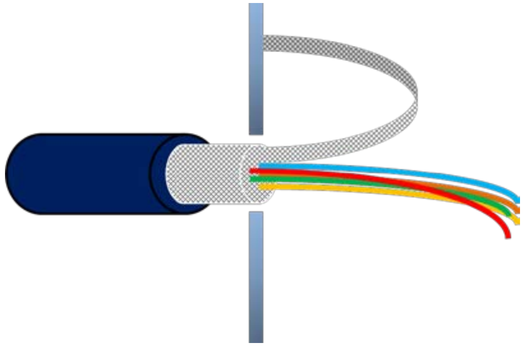
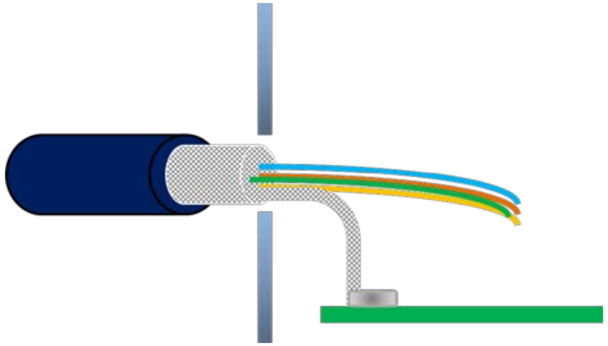
Shielding solutions – Cable

- Shielding of cables and cable bundles:



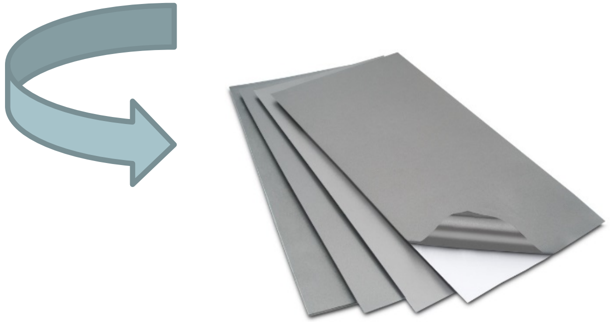


- Avoidance of following types of junctions:

Shielding solutions – Cable

- Shielding of **flat wire cables** with conductive textile or metallic adhesive tape:



- Electric contact at both ends is necessary.

Shielding solutions – Interface

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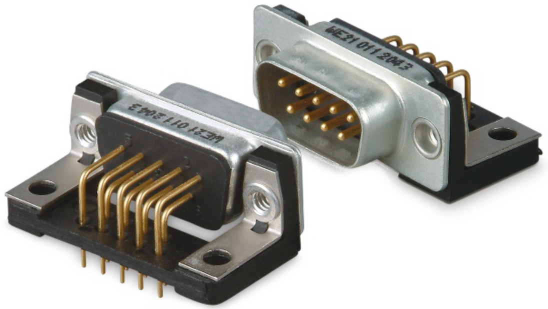
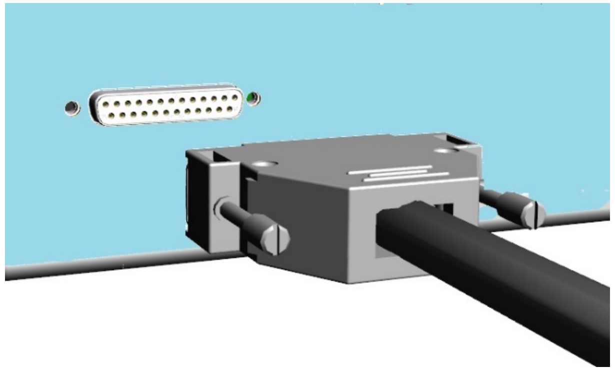
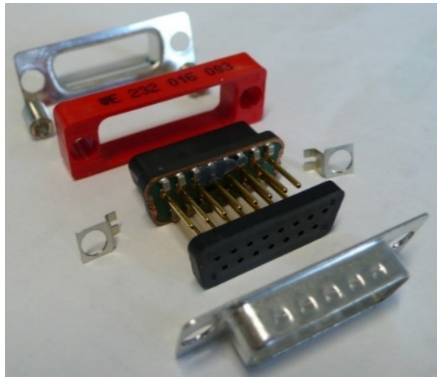
- Filtered **D-SUB interface** for RS-232, RS-485 or power supply (max. 5 A @ 100 V_{DC}):



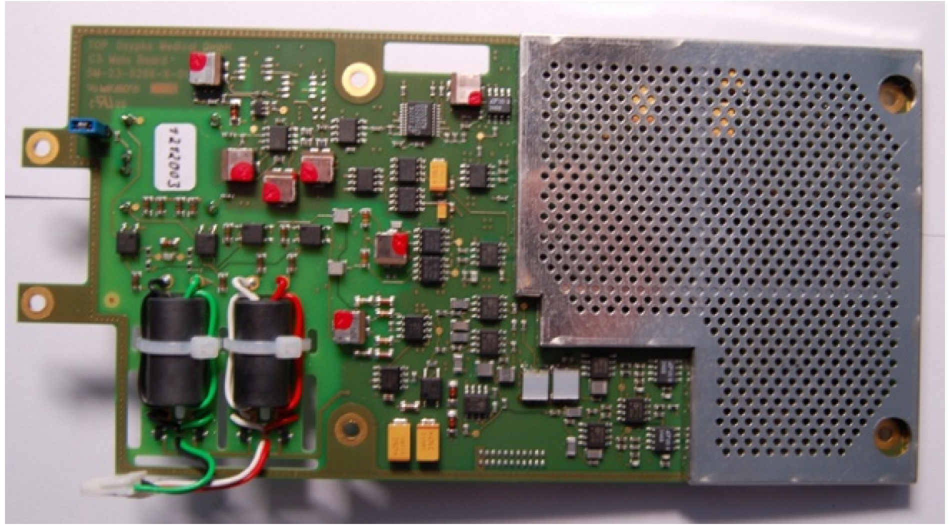



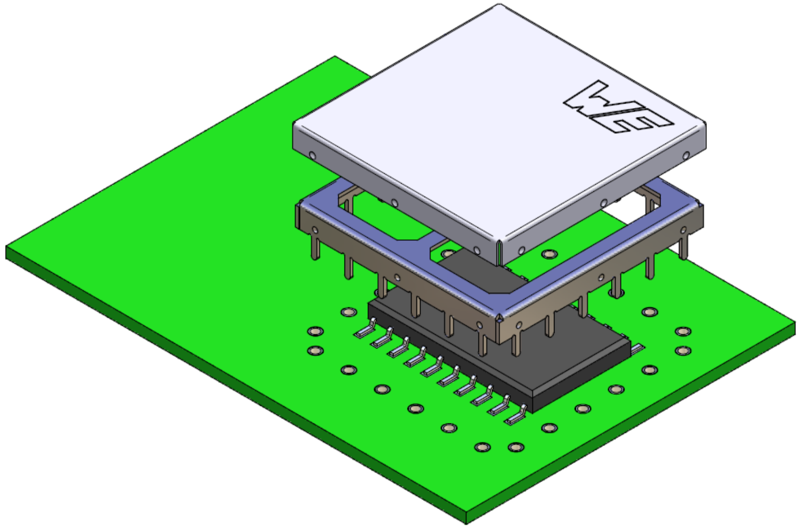
- D-SUB filter adapter:



Shielding solutions – Board Level Shielding

- Copper **groundplanes** are useful for electric field shielding.
- Noisy or sensitive components or circuitry can be shielded **locally**.

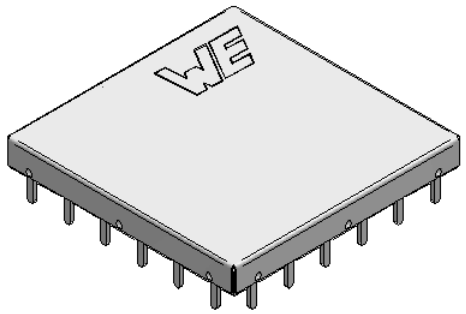


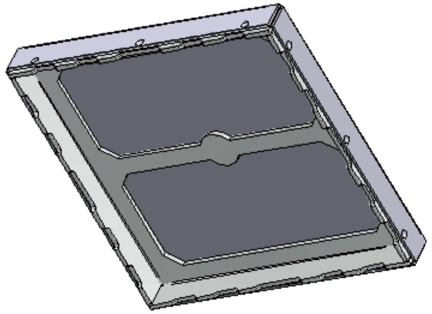


- Important: Low-impedance connection to the local circuit ground

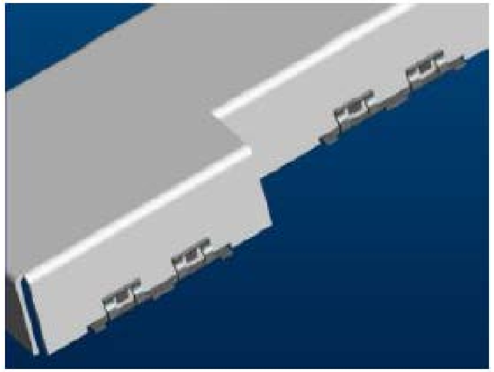
Shielding solutions – Board Level Shielding

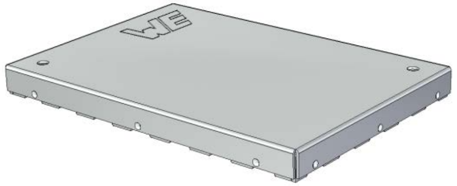
- One- or two-piece cabinet:

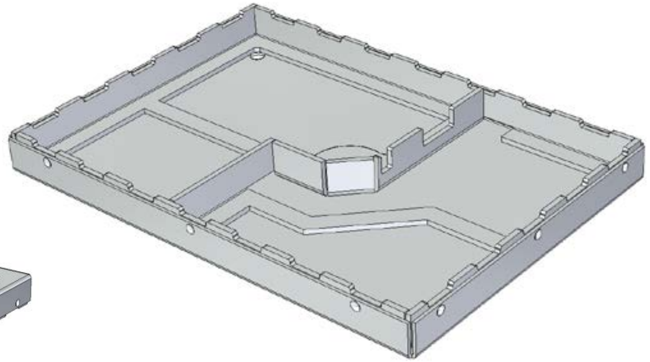




- SMT clips:





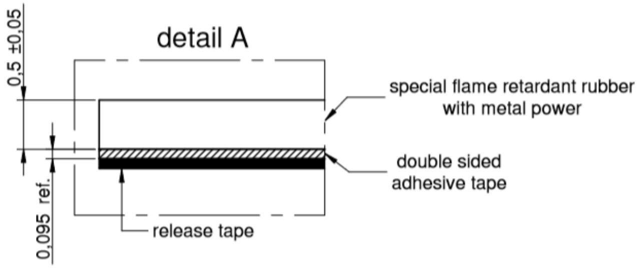


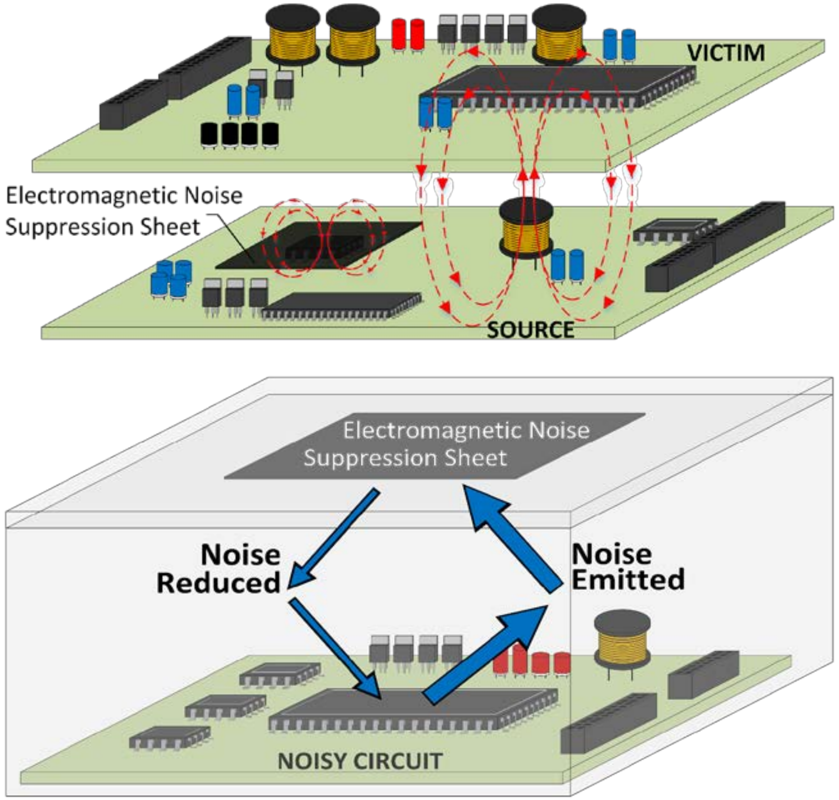
Shielding solutions – Board Level Shielding

- Do-it-yourself shielding cabinet:
    - Tin-plated steel plate (0,2 mm)
    - Square pattern (5 mm)

Shielding solutions – Board Level Shielding/Housing

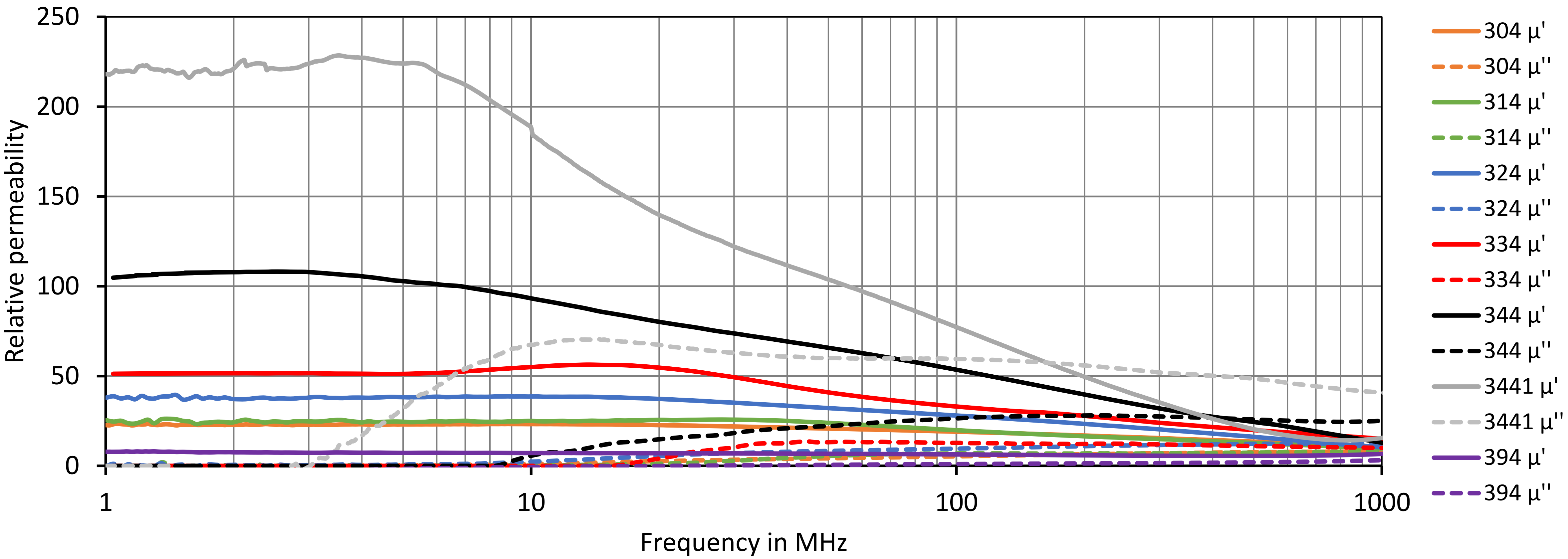
- **Flexible absorption sheet** with adhesive surface for sticking to a circuit board or to the housing
- Mode of operation → **Reflection** and **absorption** in the near and far field





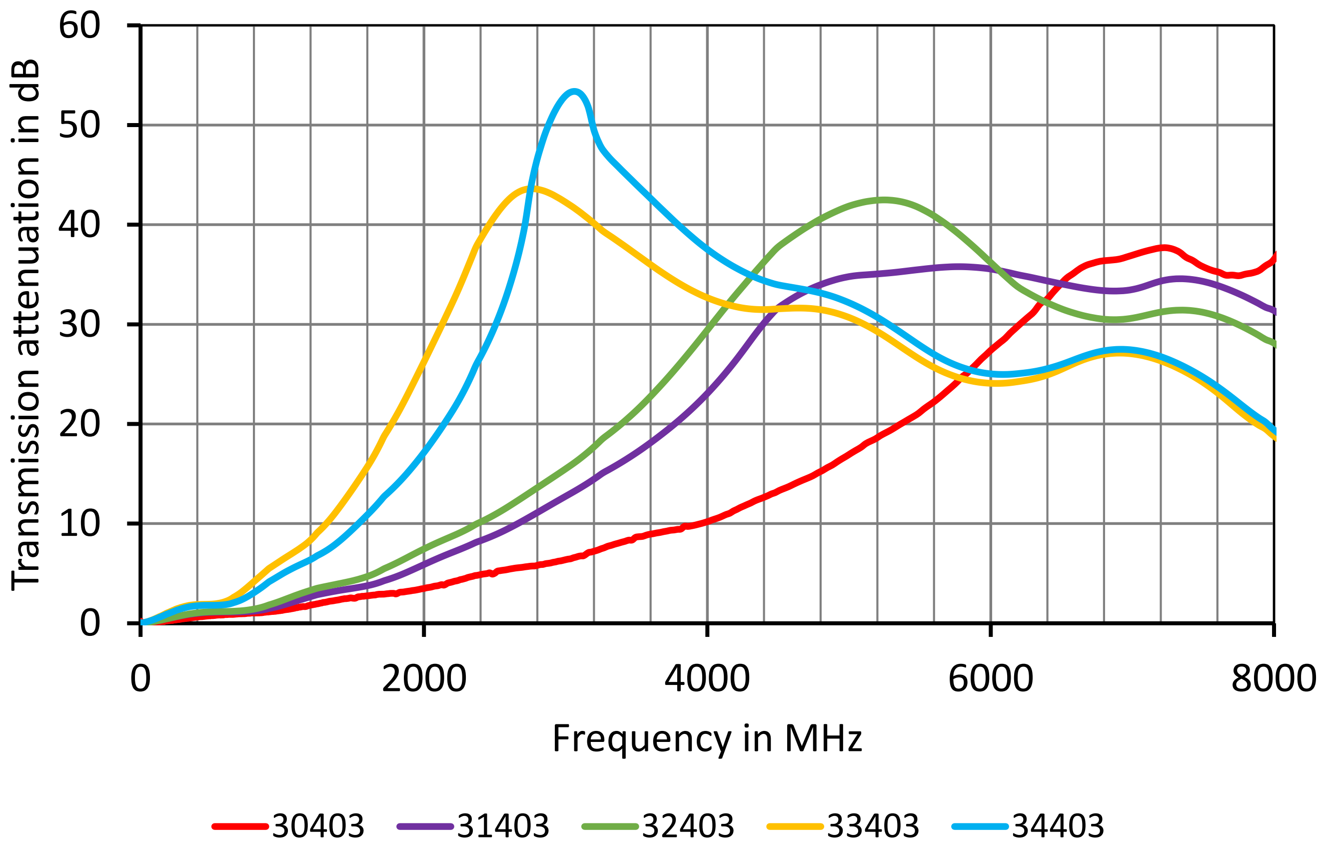
Shielding solutions – Board Level Shielding/Housing

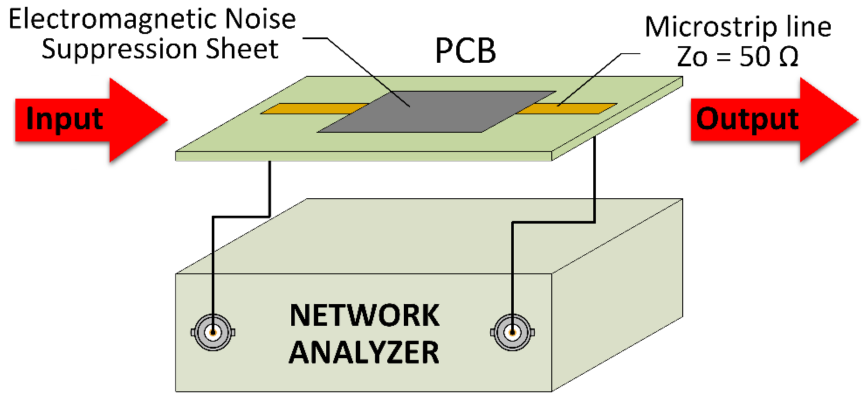
- Complex permeability of WE-FAS materials:

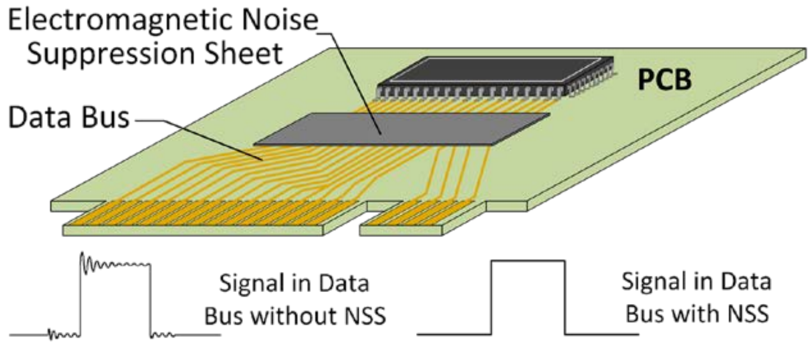


Shielding solutions – Board Level Shielding/Housing

- Transmission attenuation dependent on the material (thickness: 0,3 mm):







Shielding solutions – Board/housing

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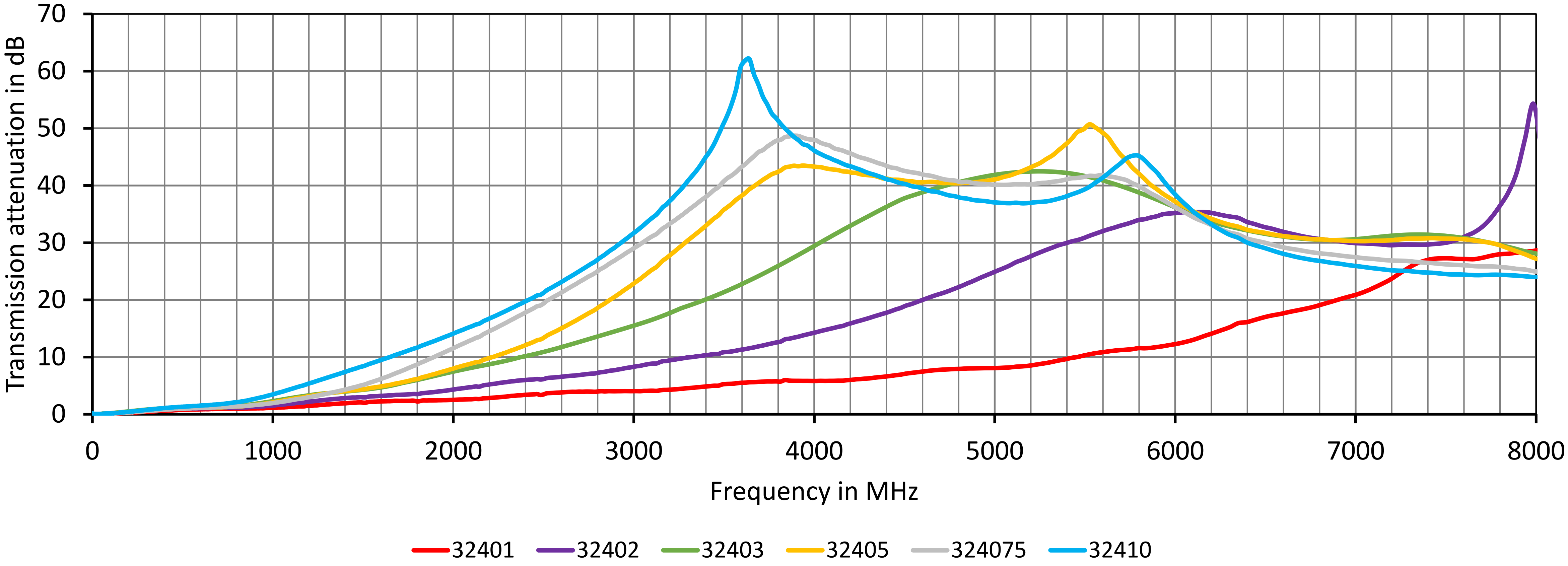
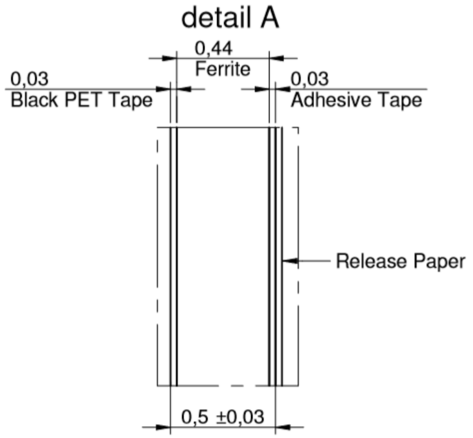
- Transmission attenuation dependent on the material thickness (material 324; 0,1…1 mm):



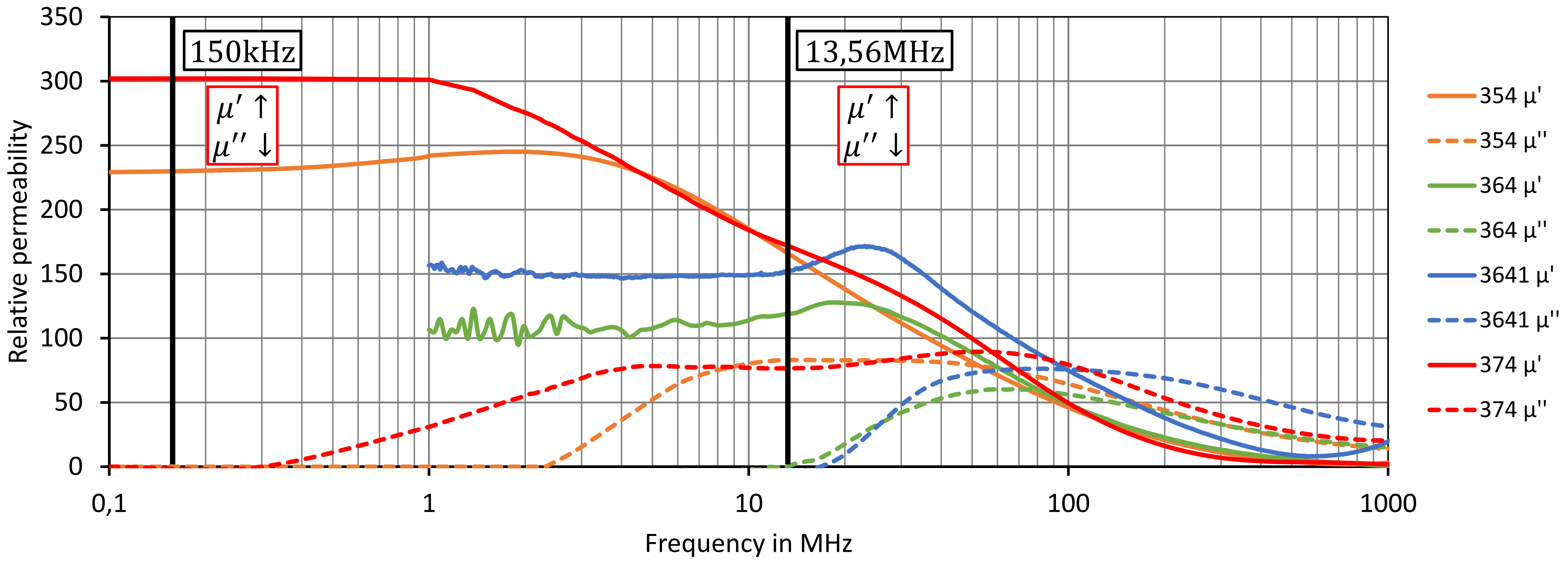
Shielding solutions – Communication standards

- **Flexible ferrite sheet** with adhesive surface for sticking to a circuit board or to the housing
- Mode of operation → **Reflection** in the near field, **redirection** of magnetic field lines
- Applications → Near field shielding, NFC, RFID, wireless power transfer (WPT)



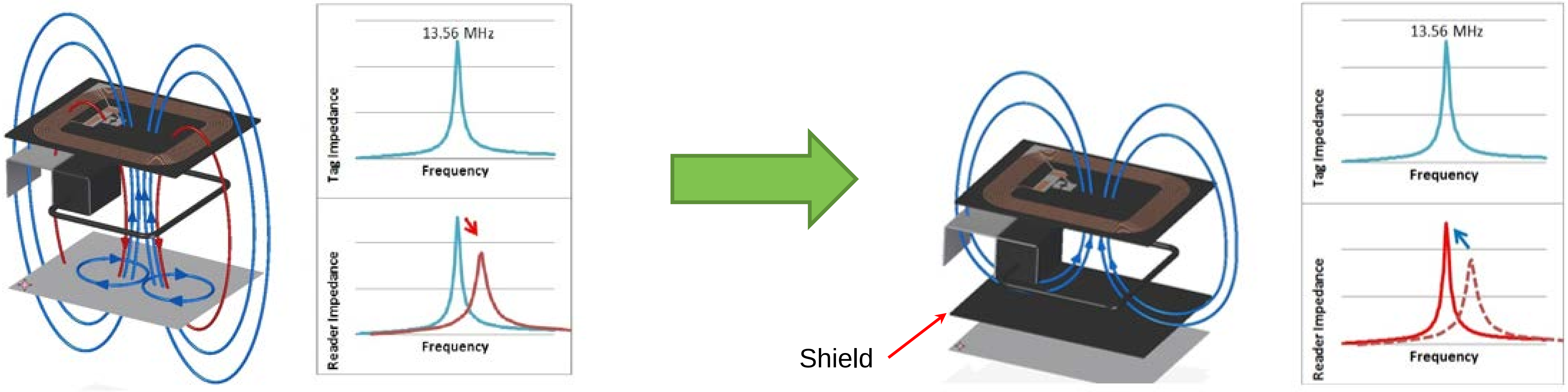
Shielding solutions – Communication standards

- Complex permeability of WE-FSFS materials:



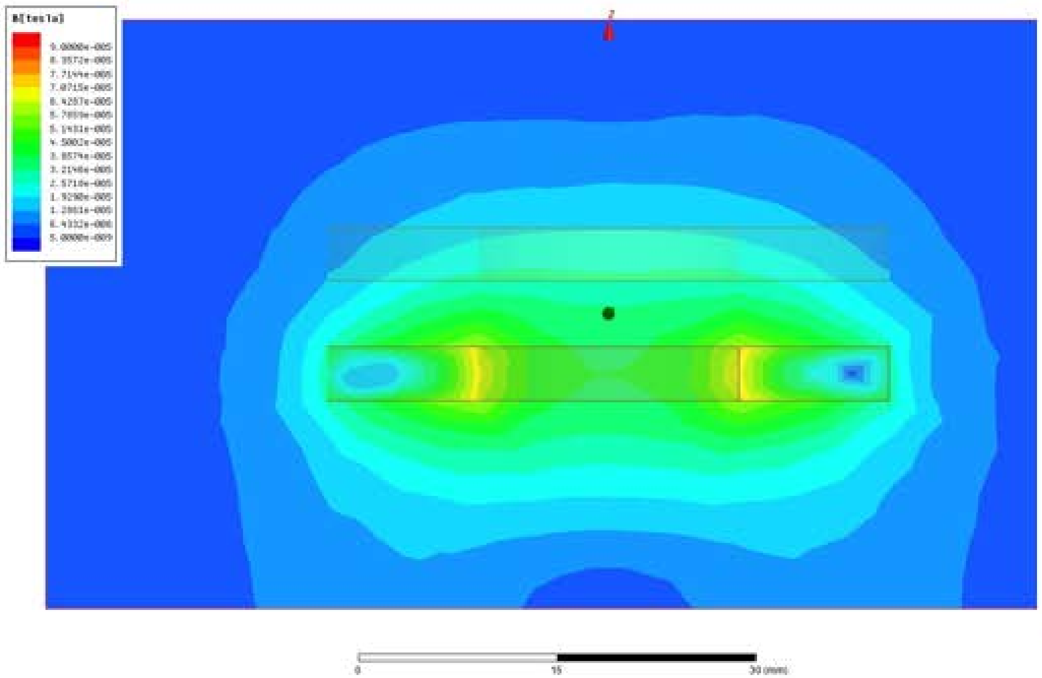
Shielding solutions – Communication standards

- Metallic surfaces in the vicinity of communication coils alter their inductance and detune the resonance.
- Magnetically active sheet inside the gap minimizes the impact of eddy currents inside the metal.

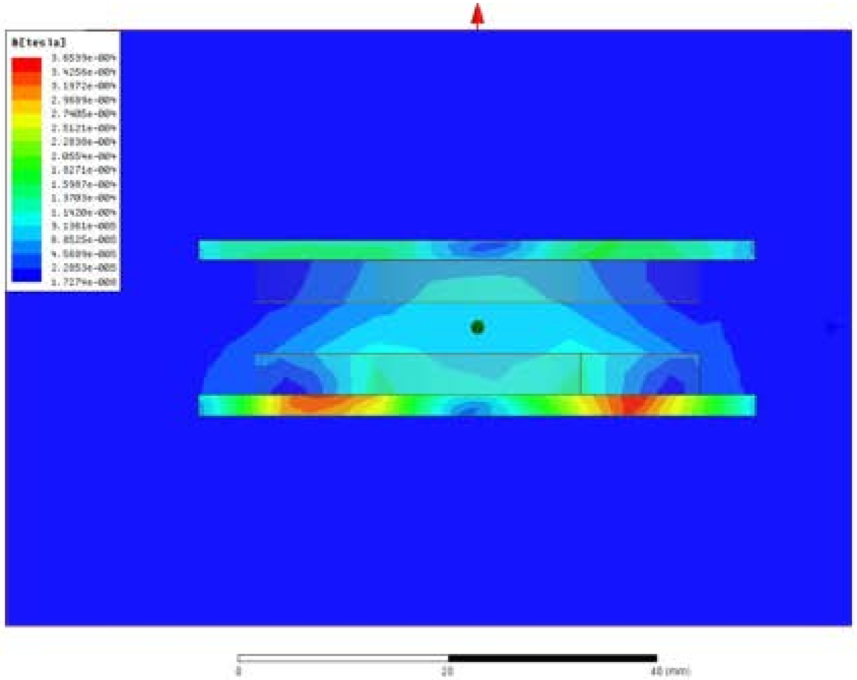


Shielding solutions – Communication standards

- Increase of efficiency for wireless charging coils



Without additional ferrite sheet



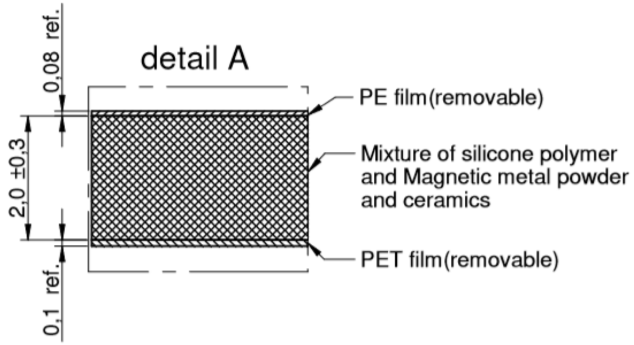
With additional ferrite sheet

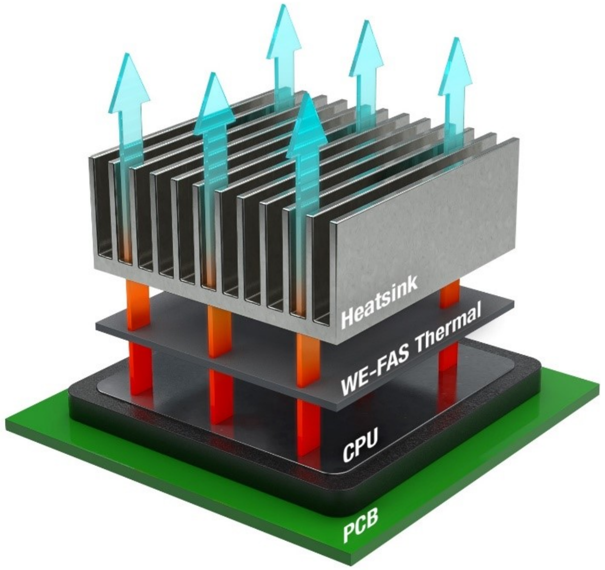
WIRELESS POWER CONSORTIUM

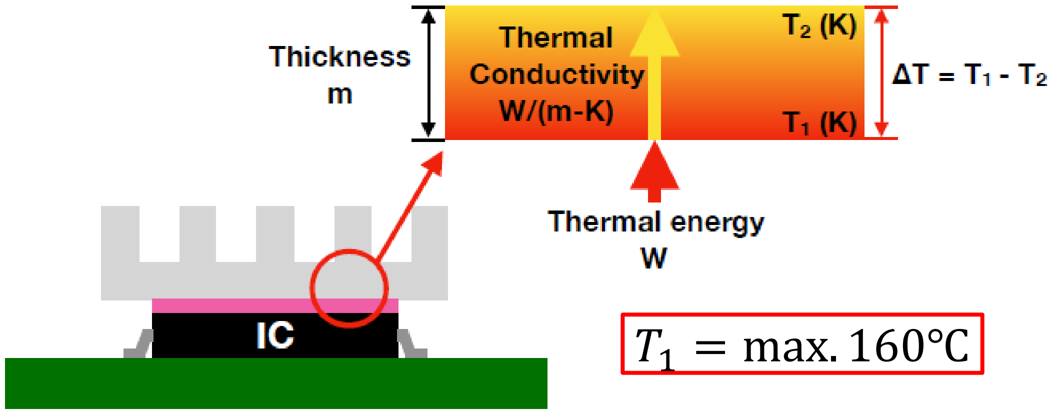
AirFuel™ Alliance

Shielding solutions – Heatsink

- Flexible ferrite sheet with imbedded ceramic particles for **heat conduction** ($\kappa = 1{,}4\mathrm{W} \cdot \mathrm{m}^{-1} \cdot \mathrm{K}^{-1}$)



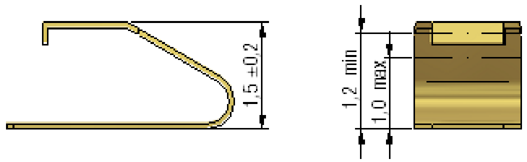


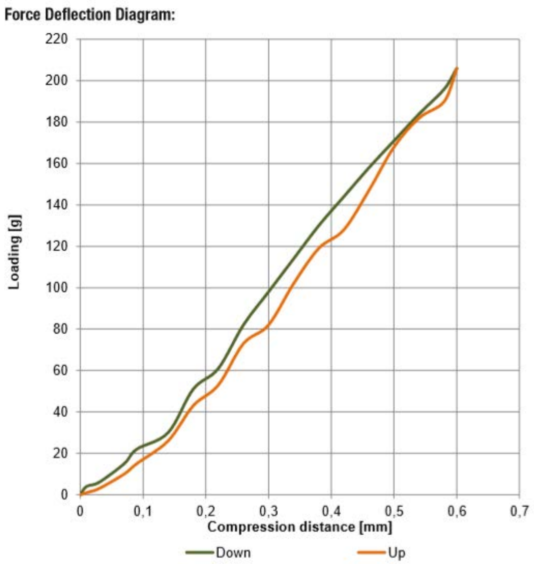


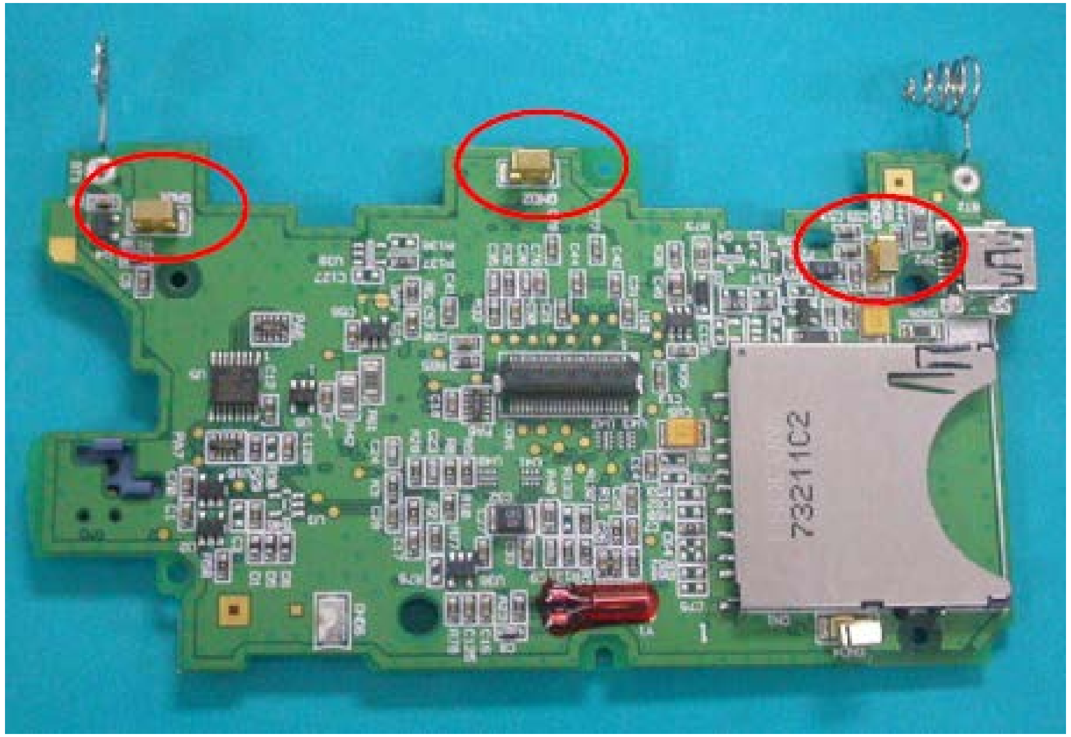
$$\boxed{T_1 = \text{max.}\, 160°\text{C}}$$

Shielding solutions – Board Level Shielding/Grounding

- Surface-solderable **contact springs**, made of copper-beryllium or phosphor-bronze
- Plating:
  - Au: 38 nm
  - Ni: 0,1...0,5 µm
  - Sn: 0,8…2 µm
- Phosphor-bronze is suitable for power circuitry currents.

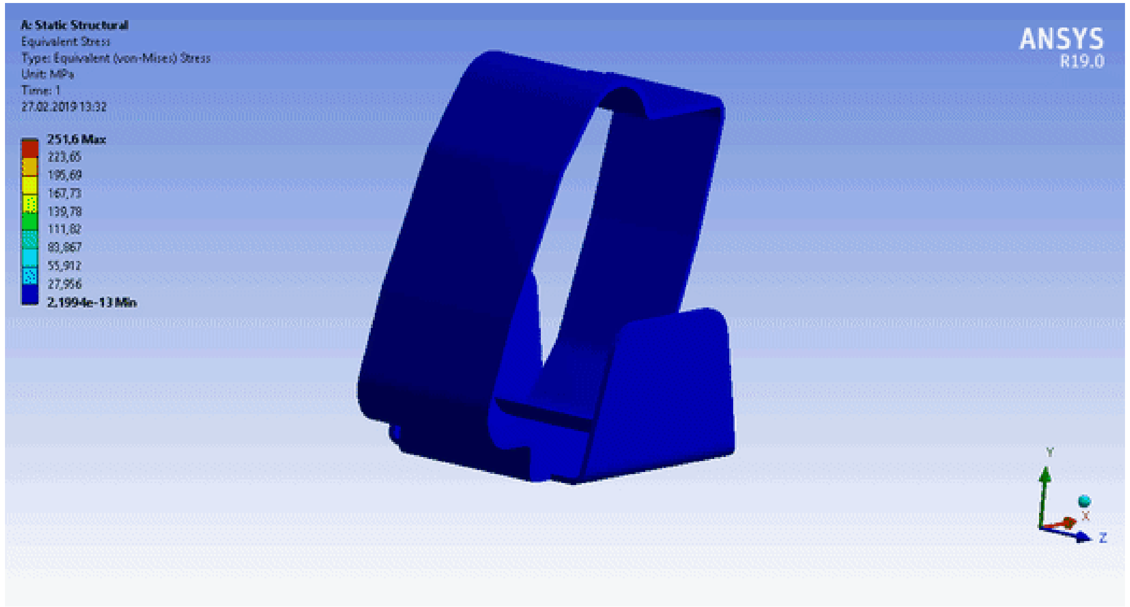






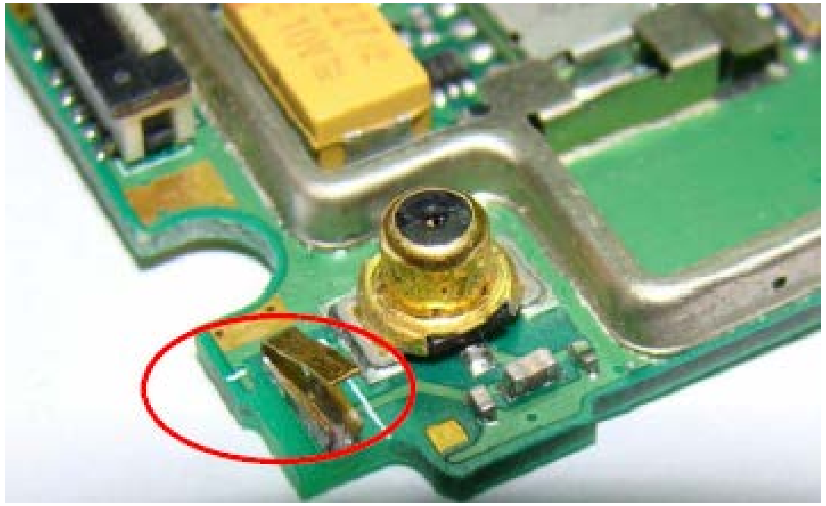
Shielding solutions – Board Level Shielding/Grounding

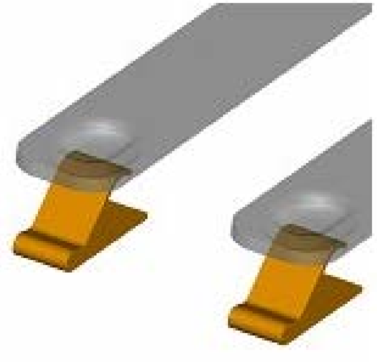
- Contact springs lose their resetting ability (elasticity) after **excessive compression**.
- Special designs avoid excessive compression → Compression Security System

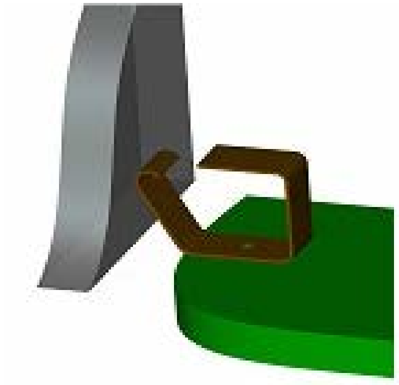


Shielding solutions – Board Level Shielding/Grounding

- Contact springs can be used as a link between two **RF circuits** or as a connection point for **RF antenna modules**.

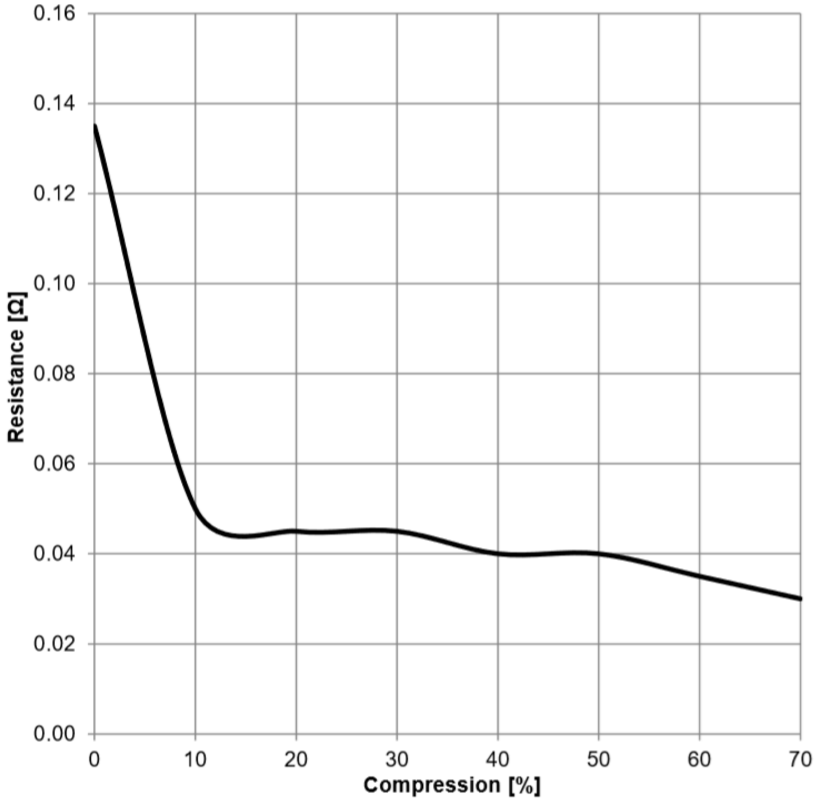






Shielding solutions – Board Level Shielding/Grounding

- Surface-solderable **cellular block** with **tin plating**
- Can be utilized like a contact spring
- Optimum compression: 20…70%



Shielding solutions – Grounding

- Conductive casing parts and groundplanes of separate circuit boards should have a **low-impedant** connection.
- **Mechanical** variants of a connection:

Spacer

Grounding strip