EMV DESIGN AUF DER PCB UND SCHIRMUNG

Dominik Zeller und Hans Peter Kaiser, M.Sc.
Field Application Engineers

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Referenten

Hans Peter Kaiser, M.Sc.

Field Application Engineer
EMC & Inductive Solutions

Phone: +43 664 469 5090
Mail: hans-peter.kaiser@we-online.com
Webex: https://we-online.webex.com/meet/hans-peter.kaiser

Nach Abschluss der HTL-Mödling im Fachbereich Elektrotechnik, Studium am Technikum Wien.
Absolvent des Bachelor-Studiengangs Elektronik und Wirtschaft und des Masterstudienganges Innovations- und Technologiemanagement. Seit 2011 bei Würth Elektronik beschäftigt.
Die Hauptaufgaben liegen in der Aus- und Weiterbildung der Vertriebsmannschaft und in der technischen Kundenberatung sowie in der Organisation und Durchführung von Fachseminaren.

Dominik Zeller

Field Application Engineer
Electromechanics

Phone: +43 664 888 72082
Mail: dominik.zeller@we-online.com
Webex: https://we-online.webex.com/meet/dominik.zeller

Nach dem Abschluss der HTL Leonding, Fachschule für Elektronik und Nachrichtentechnik und dem Aufbaulehrgang für Fachhochschulen in Steyr folge ein Studium im Bereich Hard- und Software Systemengineering.
Leitung der Reparaturabteilung der Firma Hitzinger. Seit 2015 bei Würth Elektronik und seit 2019 im internationalen Field Application Engineer Team als Bindeglied zwischen Produktmanagement und den Elektronikentwicklern im Markt.

Agenda

- EMC
  - Legal requirements
  - EMI countermeasures
  - Important concepts related to EMC
- Shielding
  - Theoretical aspects of shielding
  - The usage of shielding in connectors
  - Reducing coupling effects
  - Shielding materials

Electromagnetic compatibility (EMC) is the ability of a device not to disturbe or get disturbed by any electrical or electromagnetic effect.

EMC

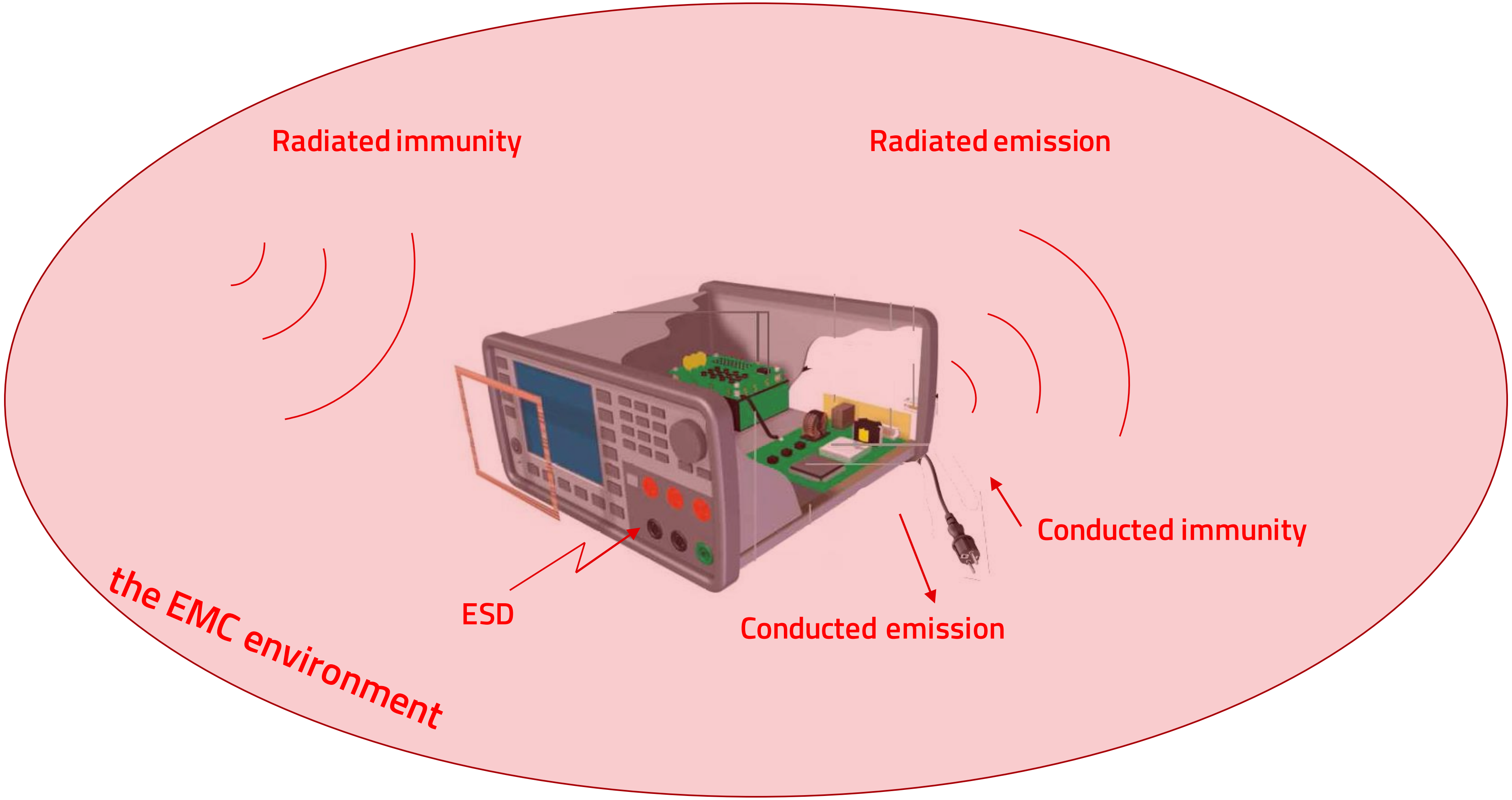
Legal requirements

EMI countermeasures

Important concepts related to EMC

Introduction

Legal requirements



Introduction

Standards

In Austria: EMC-Guideline 2014/30/EU

international:

IEC 61000-1 - Allgemeines, Definitionen und Interpreta

IEC 61000-2 - Umgebungsbedingungen

IEC 61000-3 - Grenzwerte und Oberschwingungen

IEC 61000-4 - Prüf- und Messverfahren

IEC 61000-5 - Installationsrichtlinien und Abhilfemaßn

IEC 61000-6 - Fachgrundnormen Störaussendung/Stör

europäisch:

Informationstechnische Einrichtungen

Industrielle, wissenschaftliche und medizinische HF-Ger

Signalübertragung auf Niederspannungsnetzen

Rundfunkempfänger

Haushaltsgeräte

29.3.2014 DE Amtsblatt der Europäischen Union L 96/79

RICHTLINIE 2014/30/EU DES EUROPÄISCHEN PARLAMENTS UND DES RATES

vom 26. Februar 2014

zur Harmonisierung der Rechtsvorschriften der Mitgliedstaaten über die elektromagnetische Verträglichkeit (Neufassung)

(Text von Bedeutung für den EWR)

DAS EUROPÄISCHE PARLAMENT UND DER RAT DER EUROPÄISCHEN UNION —

gestützt auf den Vertrag über die Arbeitsweise der Europäischen Union, insbesondere auf Artikel 114,

auf Vorschlag der Europäischen Kommission,

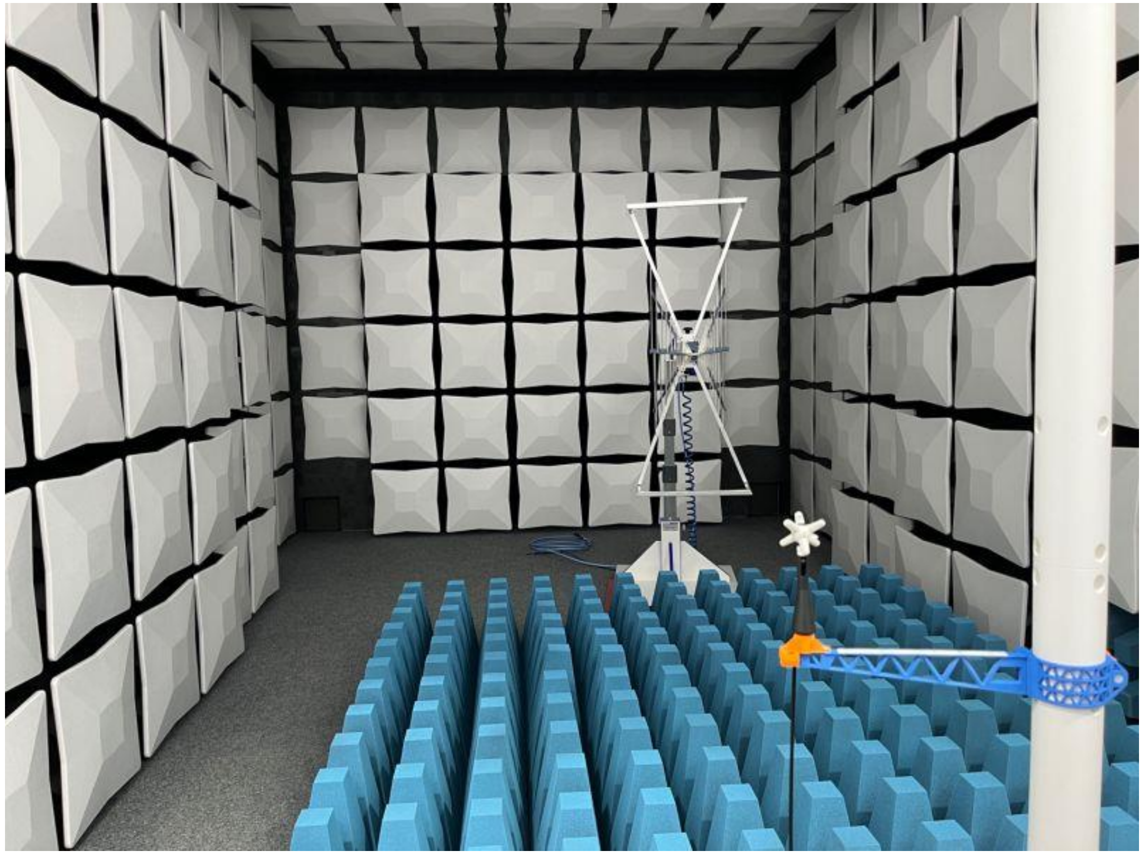
nach Zuleitung des Entwurfs des Gesetzgebungsakts an die nationalen Parlamente,

Rechtsvorschriften angewandt werden sollen, um eine einheitliche Grundlage für die Überarbeitung oder Neufassung dieser Rechtsvorschriften zu bieten. Die Richtlinie 2004/108/EG sollte an diesen Beschluss angepasst werden.

(4) Die Mitgliedstaaten sollten gewährleisten, dass Funkdienstnetze, einschließlich Rundfunkempfang und Amateurfunkdienst, die gemäß der Vollzugsordnung für den Funkdienst der Internationalen Fernmeldeunion (ITU) betrieben werden, Stromversorgungs- und Telekommunikationsnetze sowie die an diese Netze angeschlossene Geräte gegen elektromagnetische Störungen geschützt wer-

Introduction

The EMC lab



Würth Elektronik HIC Freiham

Introduction

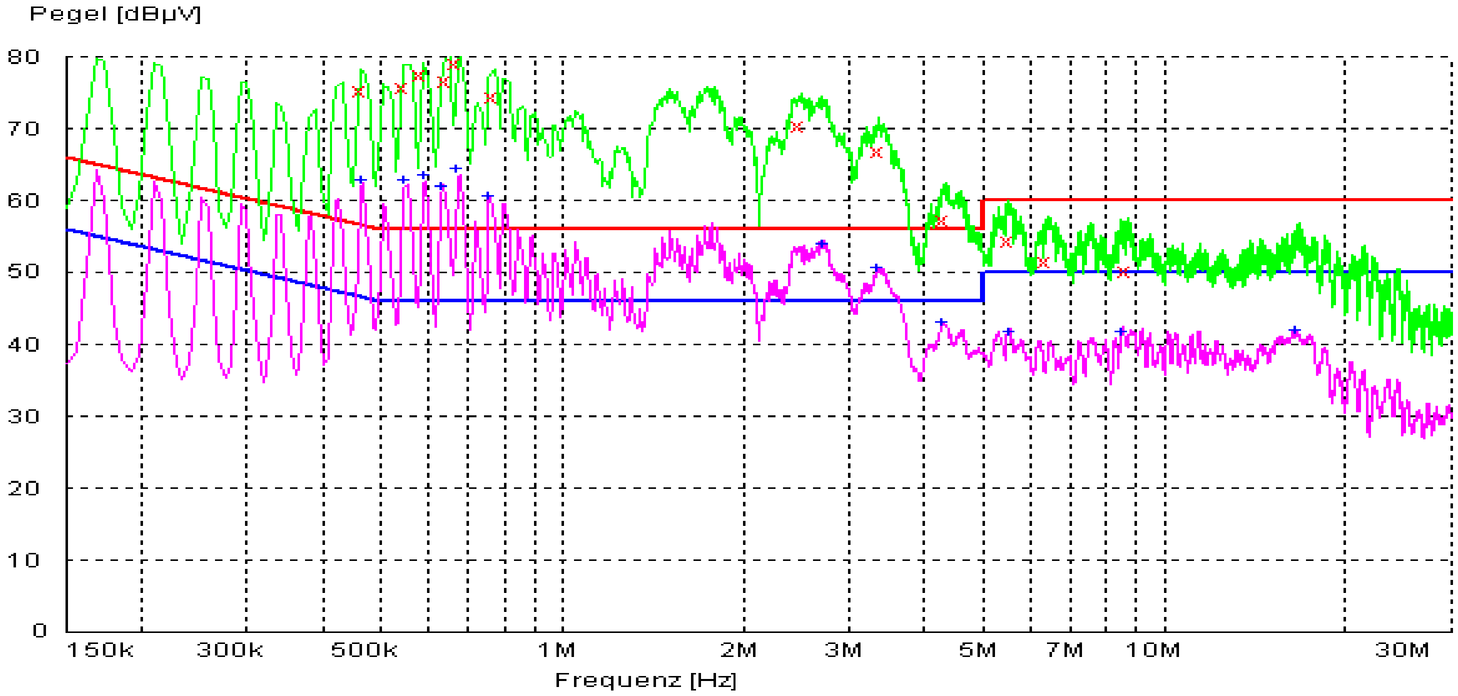
Conducted Emission

- Conducted emission over a broad frequency range
- Induced by ripple current on the input side (Common mode ; Differential mode)
- EMC requirements for

  „Conducted Emission“

  in accordance with

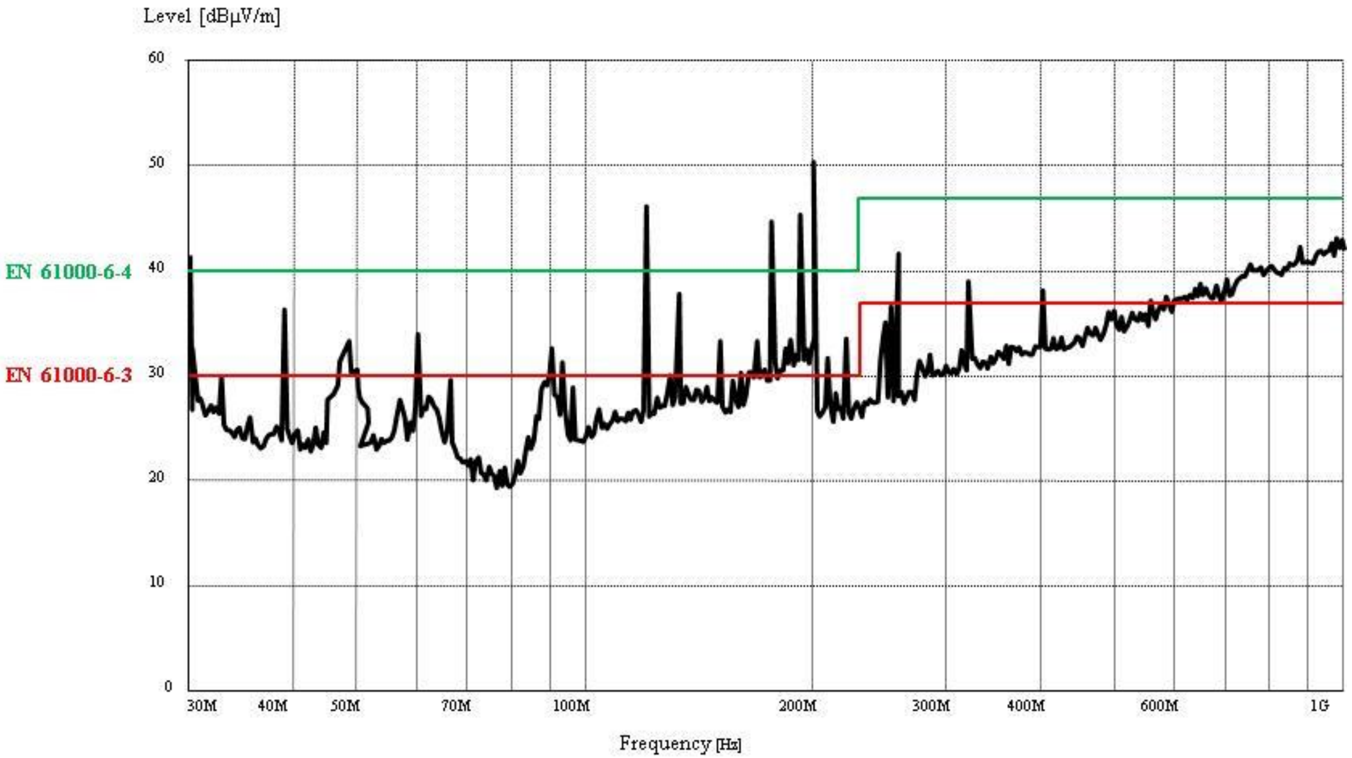
  ETSI, CEN, CENELEC



Introduction

Radiated Emission

- Radiated Emission over a broad frequency range caused by:
  - Power path on the circuit board
  - Inductors and DC/DC converter
  - other unintentional sources
- EMC requirements for „Radiated Emission“ in accordance with ETSI, CEN, CENELEC
- e.g..: EN 61000-6-4 (**Industry**) QP
- e.g..: EN 61000-6-3 (**Consumer**) QP

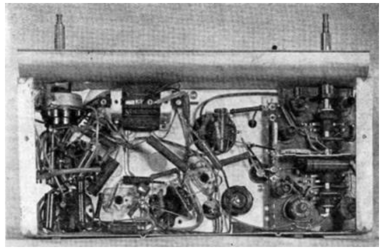


EMC

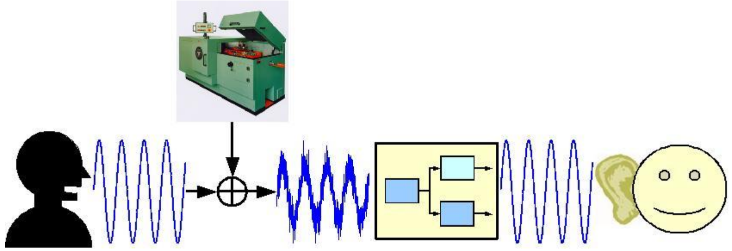
General countermeasures

1) Improving the general layout of the circuit board and the overal construction of the device

One problem – a lot of solutions and opinions



2) Filters



3) Shielding

Ground concepts

Definition of Ground

In electrical engineering, ground or earth is the reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the earth.

Wikipedia

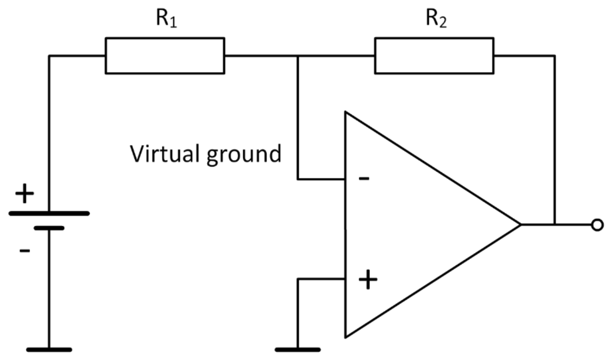
Ground concepts

Types of ground

There are different types of grounds

- Floating grounds
  - Reference points in an isolated system. Battery or the patient side of a medical device

- Virtual grounds
  - These nodes can be found in a negative feedback circuit at the inverting terminal of an operational amplifier

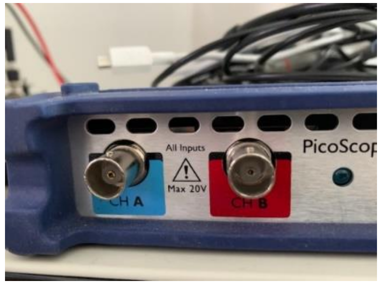


Ground concepts

Types of ground

There are different types of grounds

- AC grounds
  - These nodes have low-impedance AC values. Due to this fact they cannot be used as a ground but as a reference point.
- Earth grounds
  - In large systems this is literally connected to the ground
- Housing ground
  - Similar purpose as earth ground, however the device is not connected locally to the ground

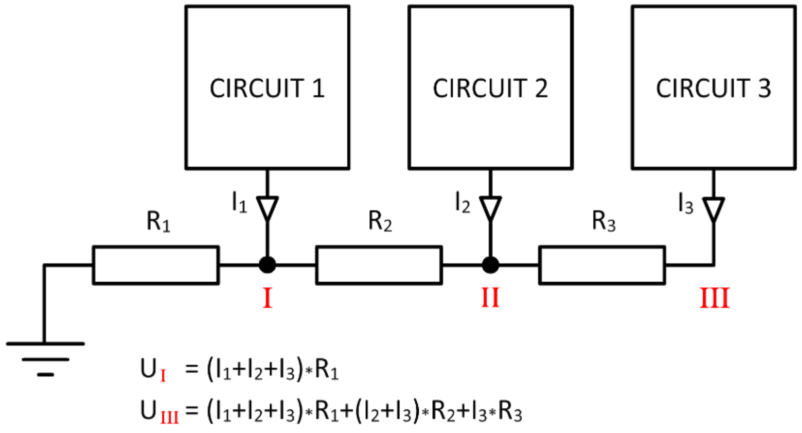


Ground concepts

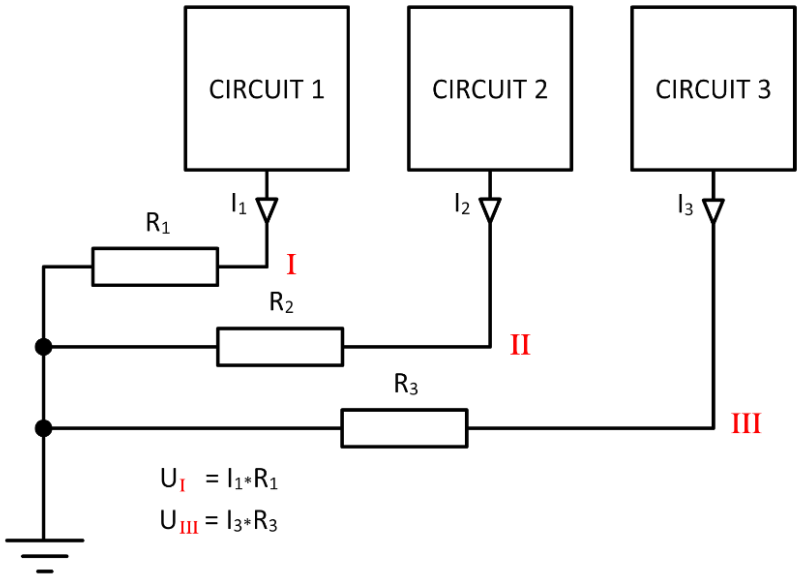
Ground structures

There are different ground structures

- Single Point Ground



Serial single point ground



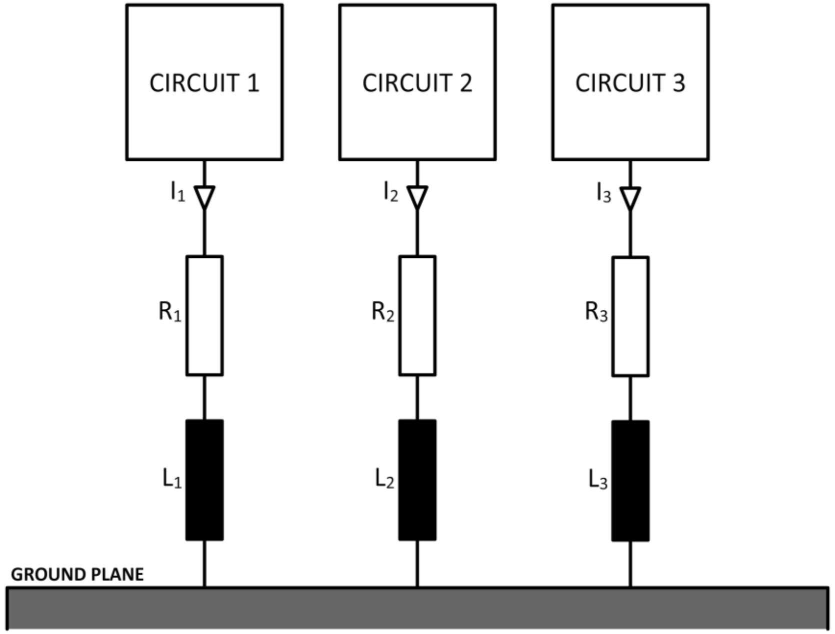
Parallel single point ground

Ground concepts

Ground structures

There are different ground structures

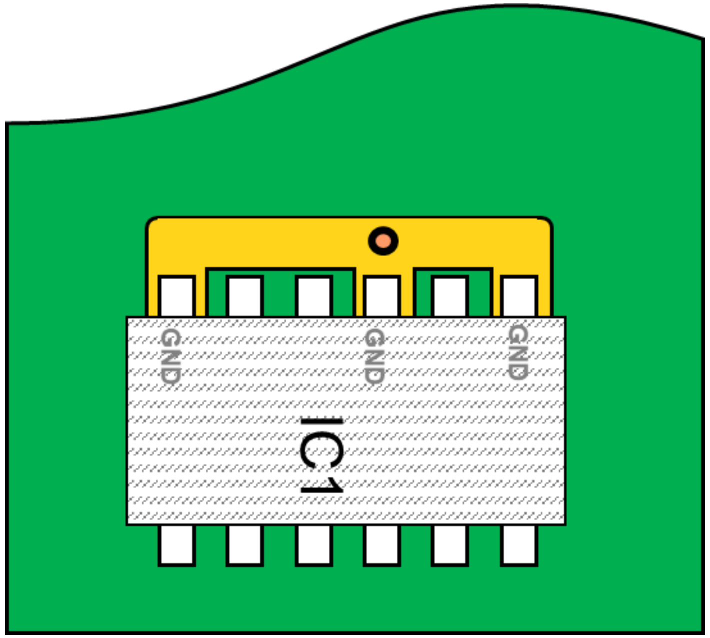
- Multi Point Ground



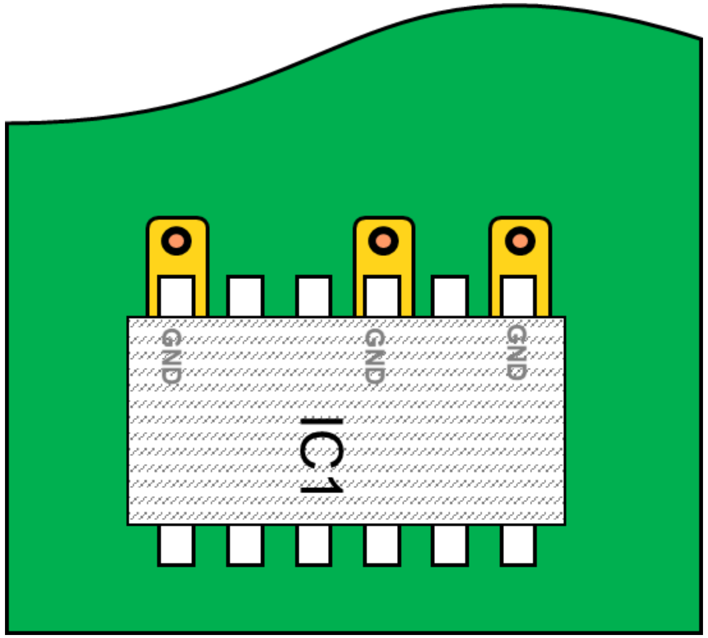
Ground concepts

Ground structures

High impedance connection



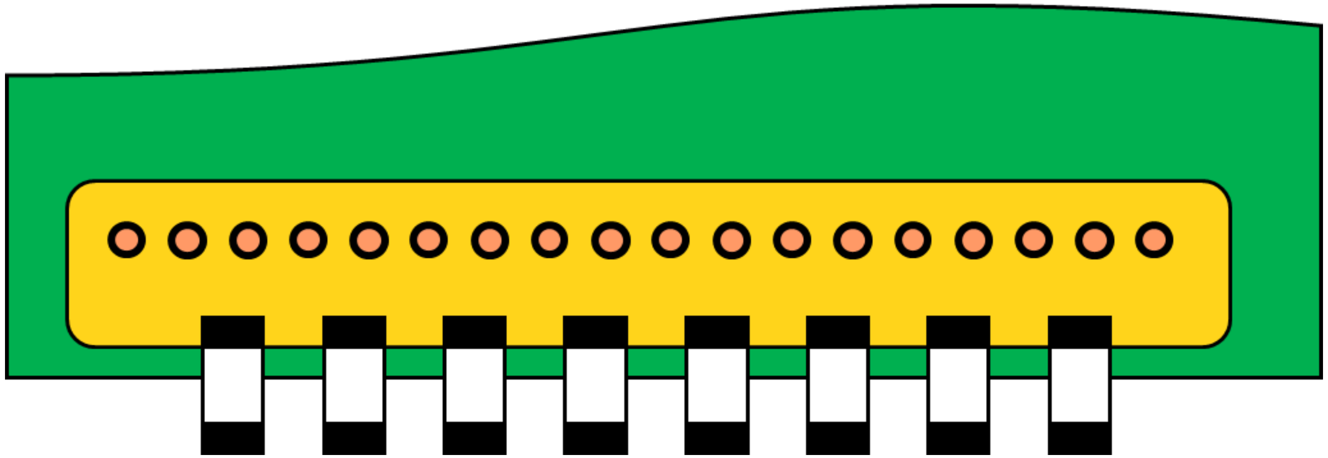
Low impedance connection



Ground concepts

Ground structures

GND island → Low impedant connection to GND

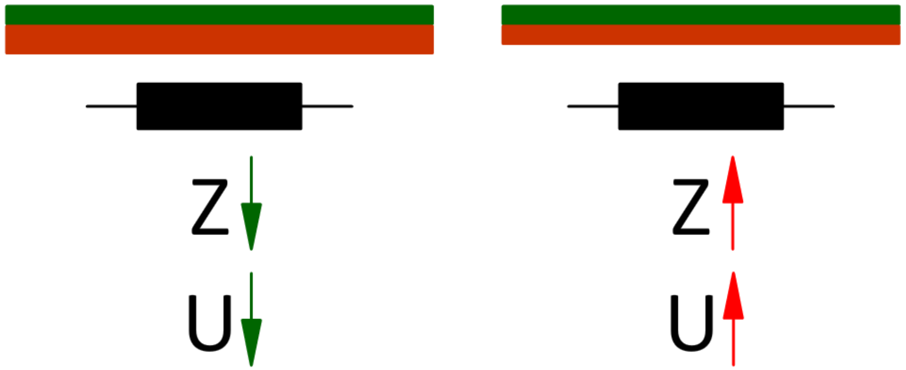


Ground concepts

Summary

A good ground is a low-impedance ground

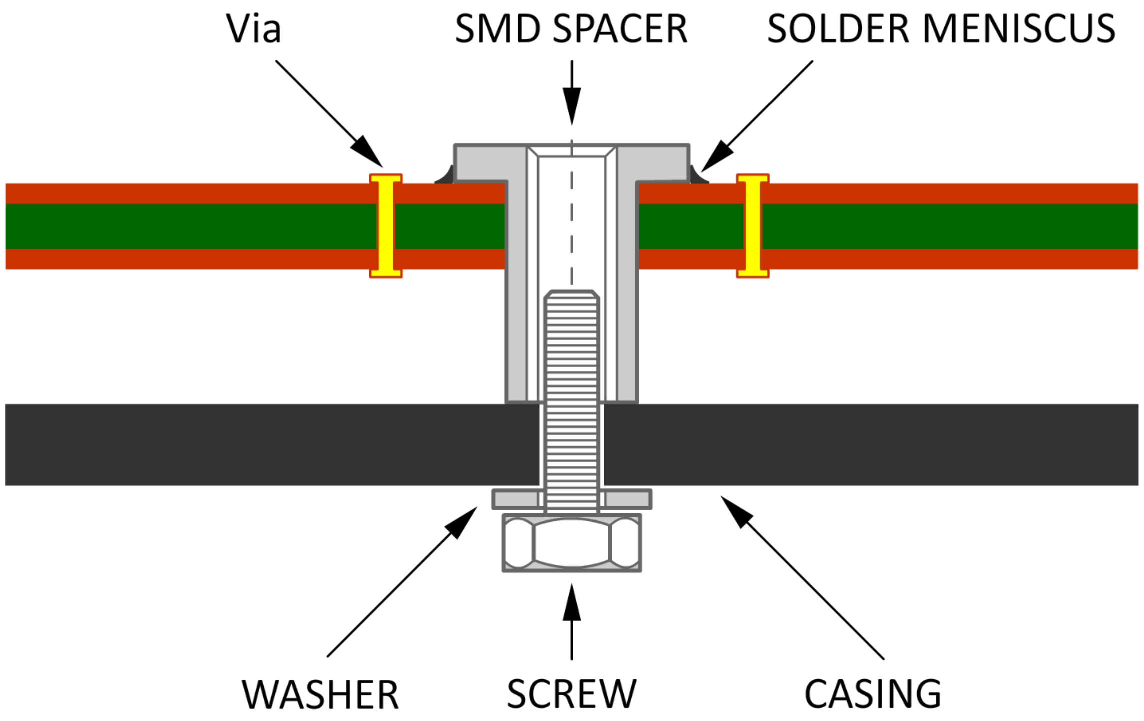
- No or little interferences
  - Smaller voltage difference
- Higher signal purity
  - Filter will work better
- Power, signal and analog parts should be separated and embedded in a good ground concept



Ground concepts

SMD Spacer for ground connections

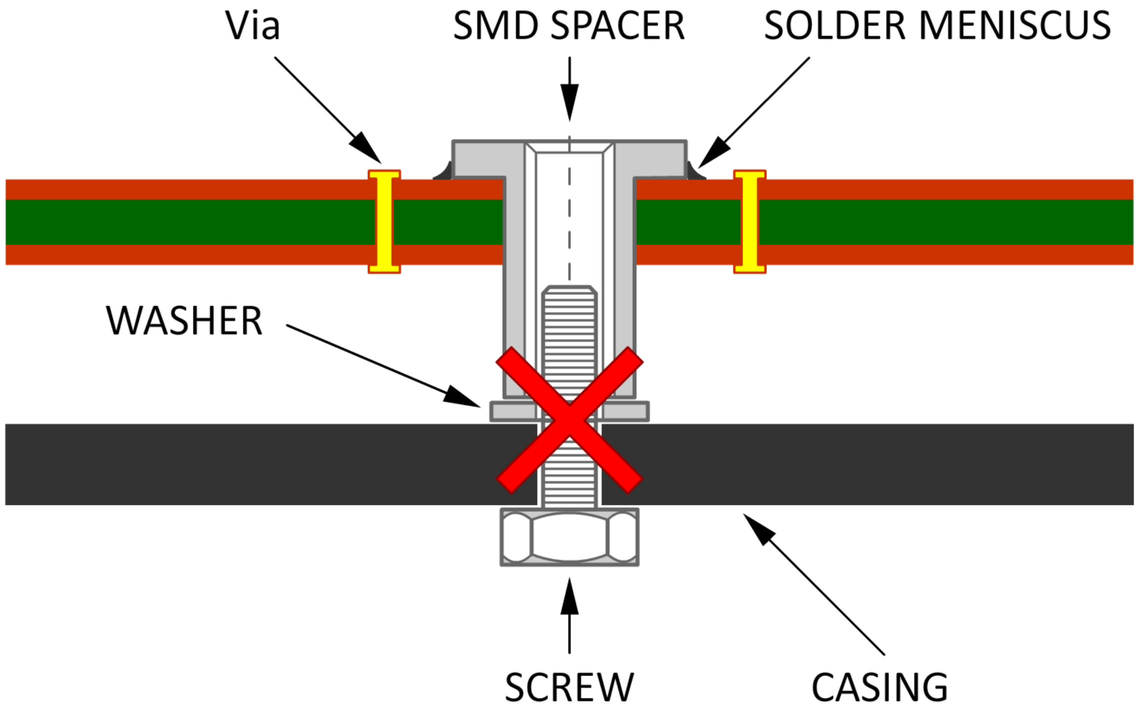
- Tin plated SMD spacers
- Solid solder pad and a big surface area
- Large contact transitions area



Ground concepts

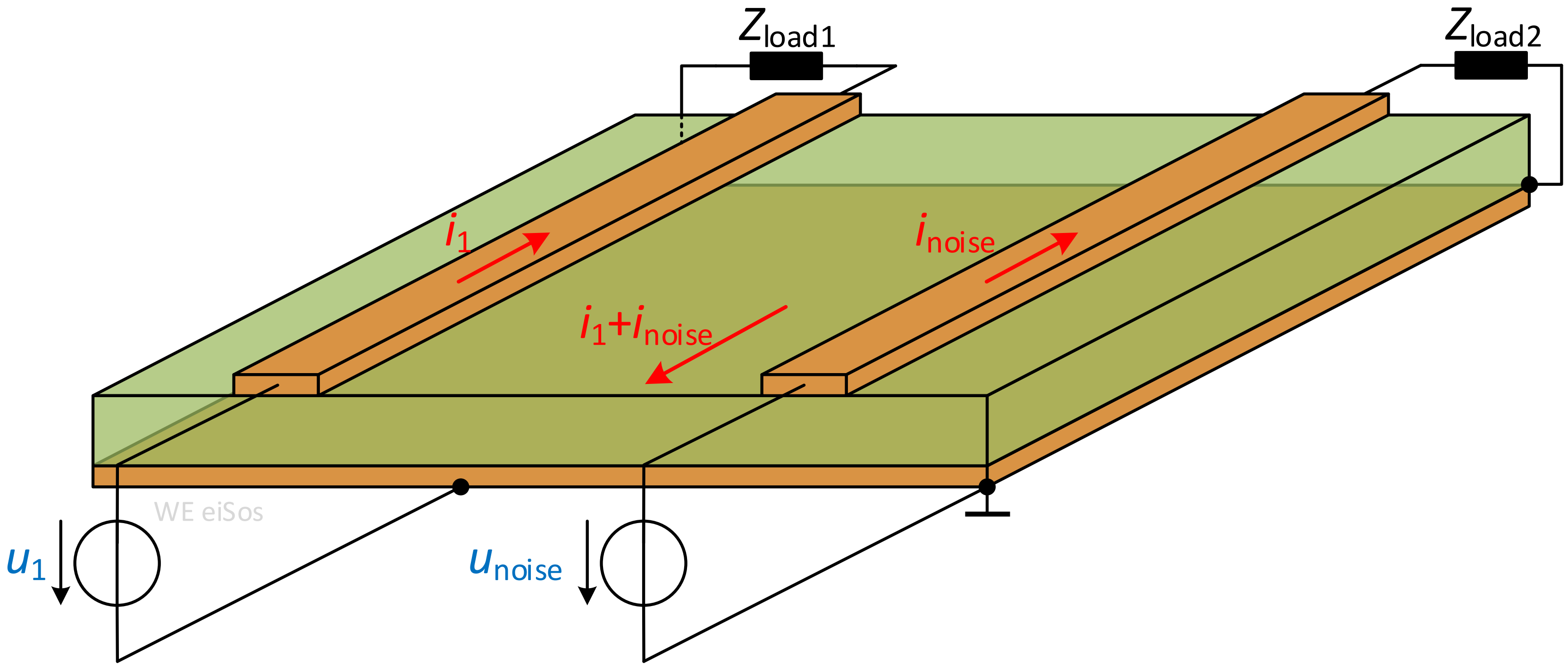
SMD Spacer for ground connections

- Tin plated SMD spacers
- Solid solder pad and a big surface area
- Large contact transitions area



Coupling effects

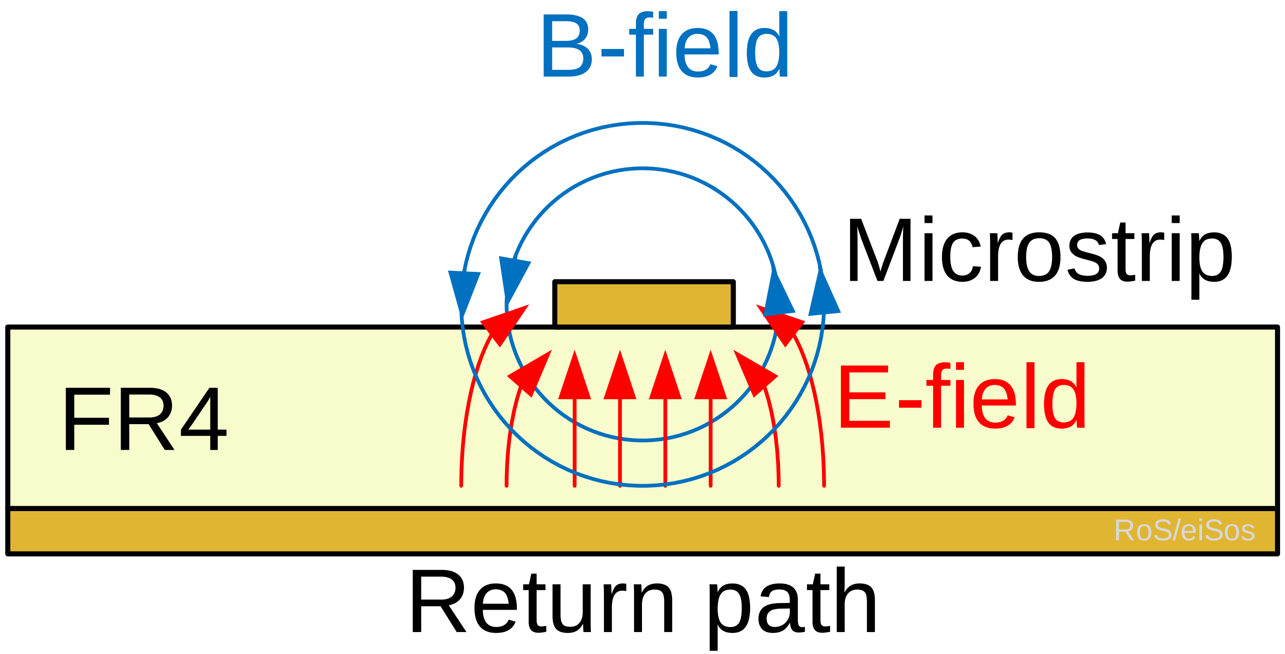
Overview



- Dominant **capacitive** coupling when $Z_{\mathrm{load},2} \rightarrow \infty$
- Dominant **inductive** coupling when $Z_{\mathrm{load},2} \rightarrow 0$
- **Impedance coupling** when they have the same common return (Ground plane)

Coupling effects

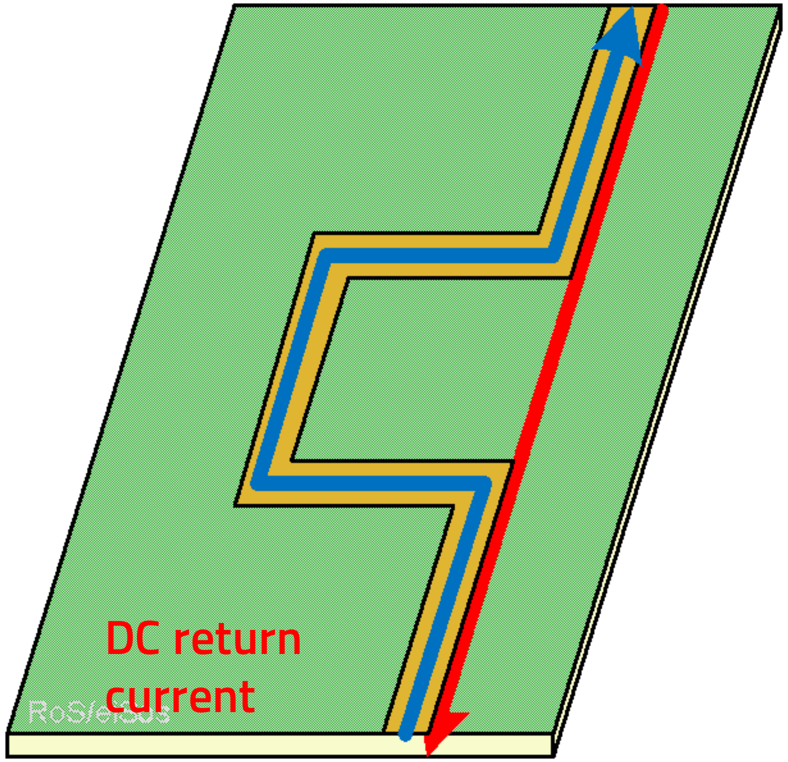
RF energy transmission



Coupling effects

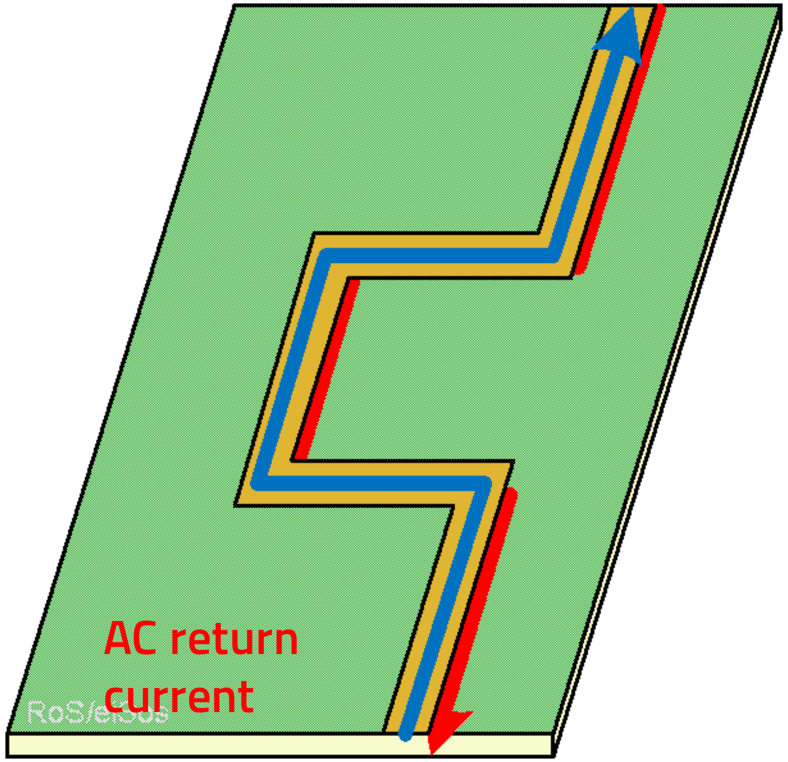
Path of least impedance

Microstrip



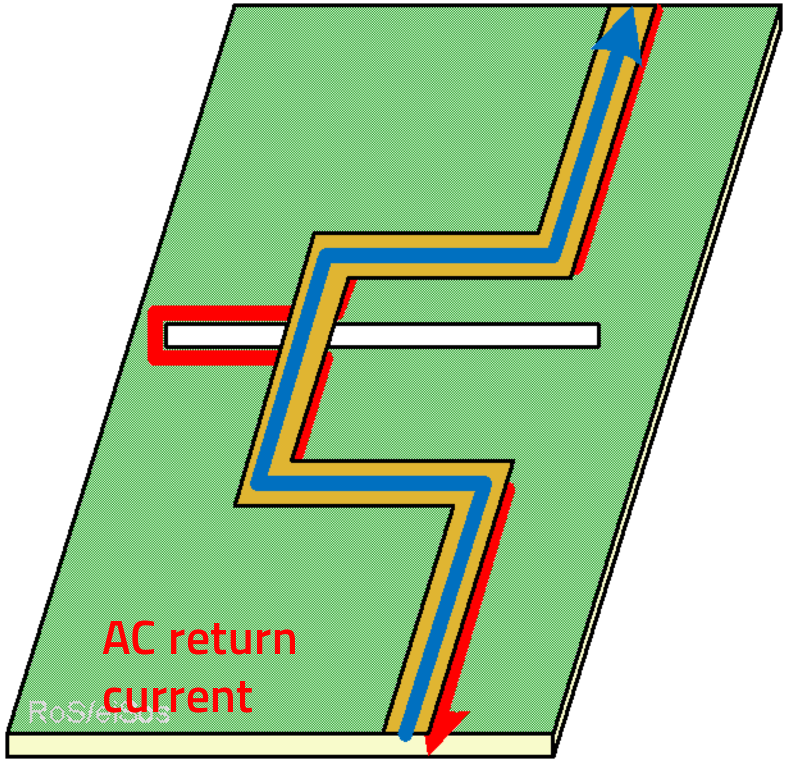
- Return path

Microstrip



- Return path

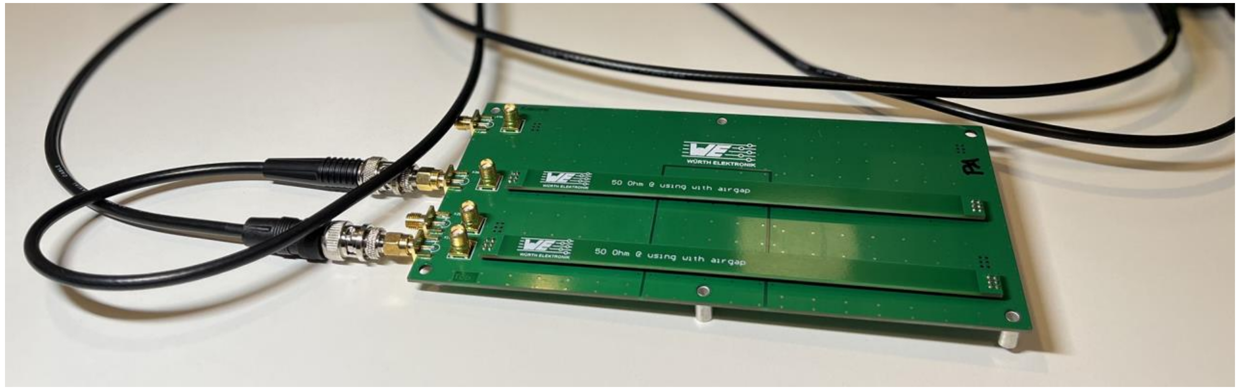
Microstrip

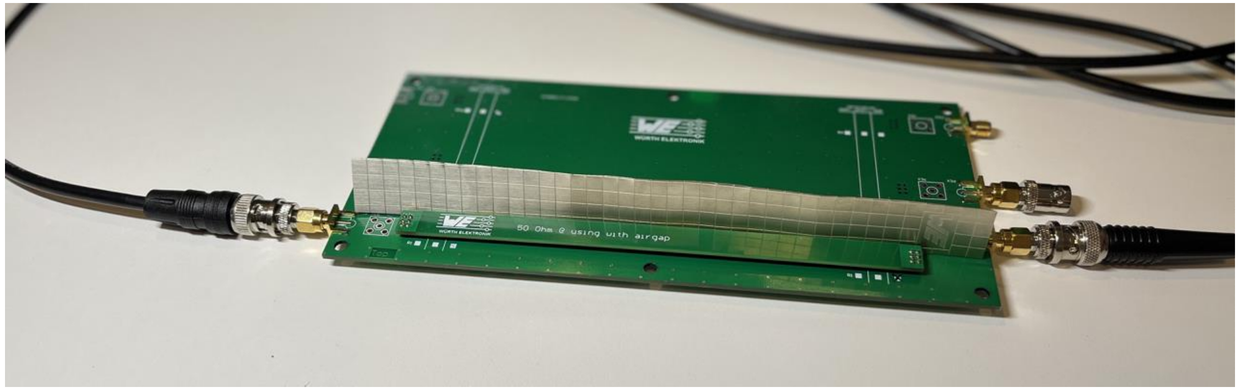


- Slotted return path

Coupling effects

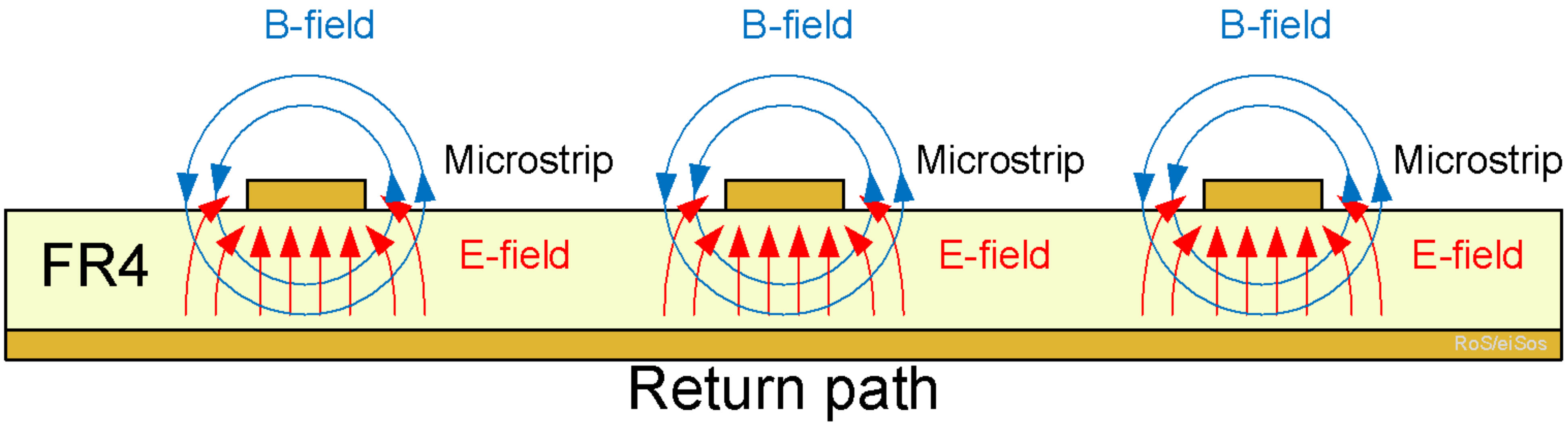
Return path of high frequency current





Coupling effects

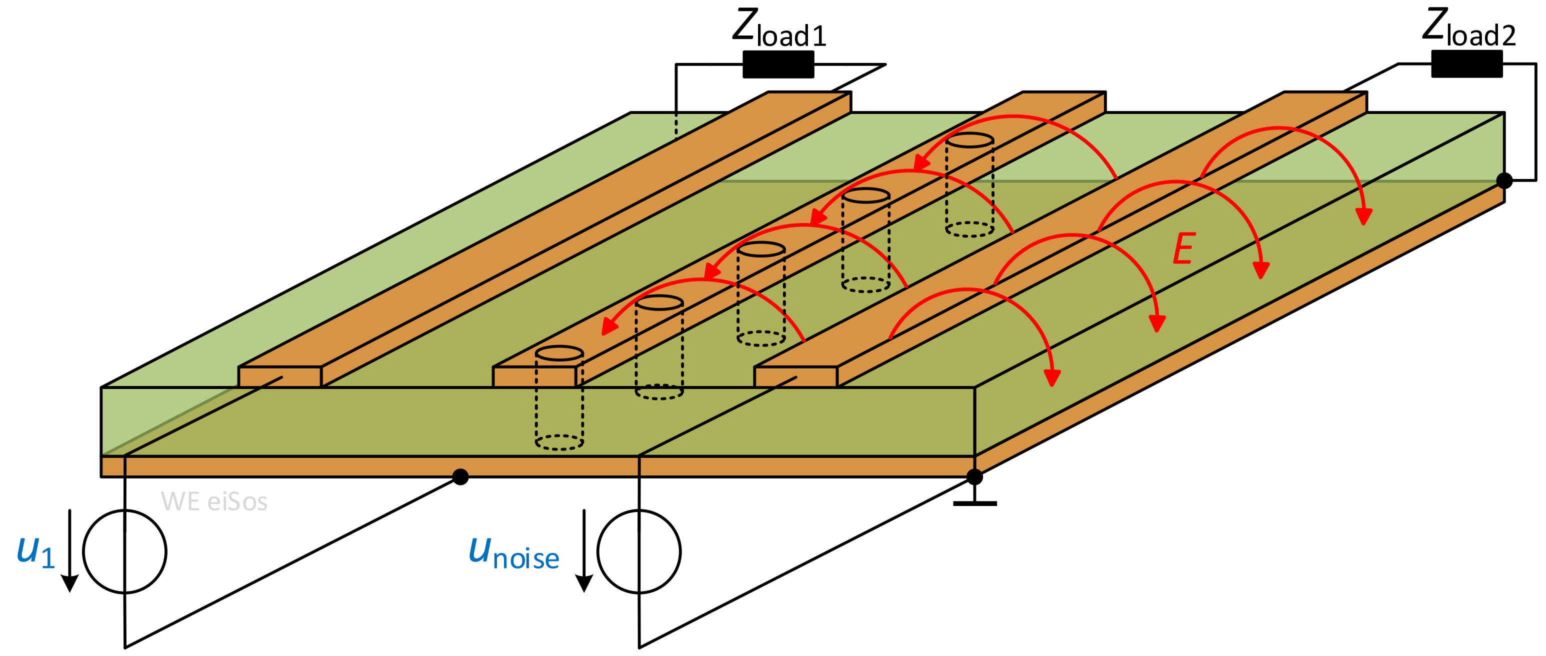
Minimize crosstalk



If the distance between two lines is arround tree times the thickness of the substrate, the crosstalk will go down to appoximately 1%

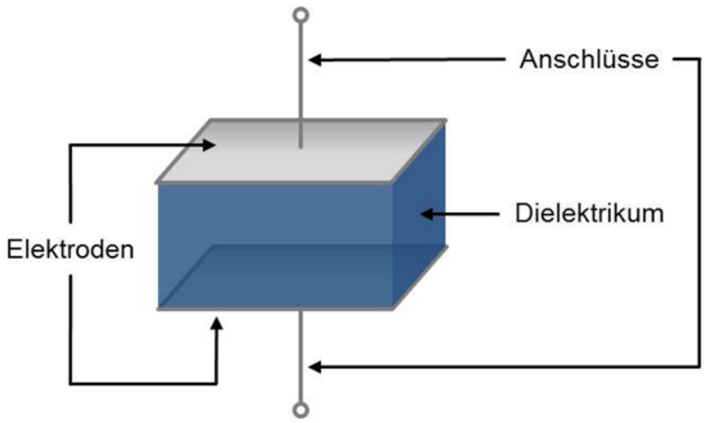
Coupling effects

Minimize crosstalk



- Insert a track or area between the lines which is connected to GND by vias like a shield between the tracks
- Space between vias: smaller than $\lambda/10$ of the highest noise frequency

Plate capacitor



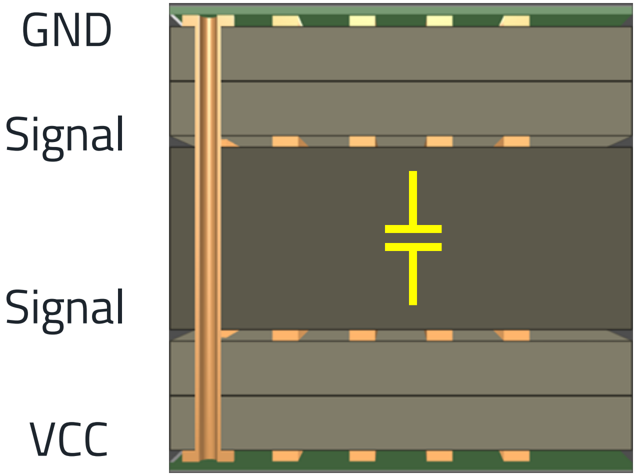
- Relevant parameters of a plate capacitor:
  - $C = \varepsilon * \frac{A}{d} = \varepsilon_0 * \varepsilon_r * \frac{A}{d}$
- C – Capacity [F]
- A – Area
- d – Distance
- ε_0 – Absolute permitivity: $8{,}85 \times 10^{-12} \frac{As}{Vm}$
- ε_r – Relative permitivity: FR4 ca. 4.2

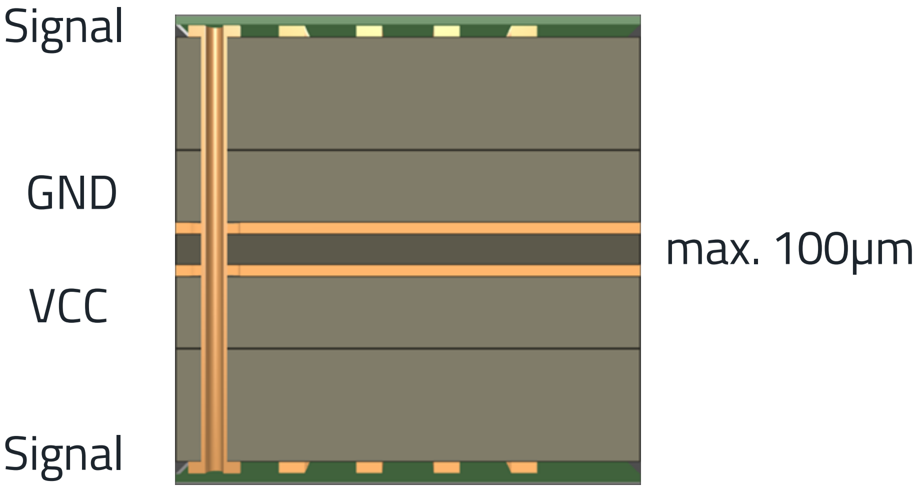
- e.g. Eurocard 160x100mm (d=100µm):

- $C = \frac{0{,}016m^2}{100\times10^{-6}m} \times 8{,}85x10^{-12} \times 4.2 = 6nF$

GND reference

- Higher interference signal levels on the power supply link to the signal layer (capacitive coupling).
- Small plate spacing between VCC and GND and large area results in a low characteristic impedance up to a few hundred MHz and a low impedance.





Shielding

Through shielding one trys to protect electronic devices from influencing electro magnetic fields either from the outside or from the inside

Shielding

Theoretical aspects of shielding

Reducing coupling effects

The usage of shielding in connectors

Shielding materials

Shielding

Theoretical aspects of shielding

- Shielding efficiency SE_{dB} by Schelkunoff
- Absorption
- Reflection
- Apertures

EMC

Permeability

$$\textbf{Permeability}: \mu = \mu_0 \mu_r$$

Permeability of vacuum $\mu_0 = 4\pi * 10 - 7\ Hm^{-1}$

$$\textbf{Conductivity}: \sigma = \sigma_r \sigma_0$$

Conductivity of copper $\sigma_0 = 5{,}98 * 10^7\ Sm^{-1}$

Material	Relative Leitfähigkeit σr
Copper	1
Bronze	0,3
Aluminium	0,6
Steel	0,1
Stainless steel	0,05
Nickel	0,2
Tin	0,15

Material	Relative Permeabilität μr
Copper	1
Bronze	1
Aluminium	1
Steel	1000
Stainless steel	500
Nickel	100
Tin	1

Shielding

The cage of Faraday

Protection of external electromagnetic disturbances

Global shielding efficency in dB:

- 2 kinds of losses:
  1. Reflection
  2. Absorption

$$SE_{dB} = 20\log\left(\frac{Ei}{Et}\right)$$

$$SE_{dB} = 20\,log\left(\frac{Hi}{Ht}\right)$$

Shielding

The cage of Faraday

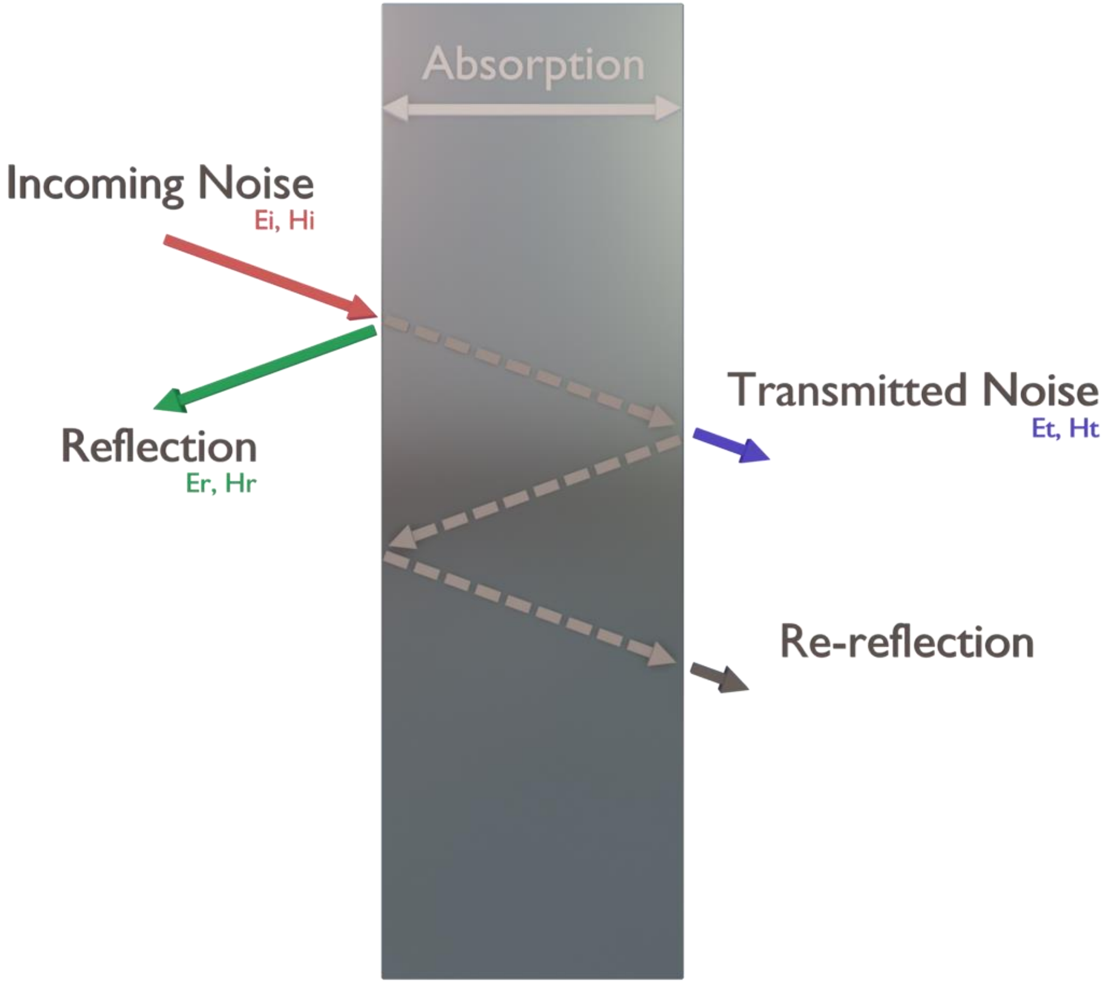
Protection of external electromagnetic disturbances

Global shielding efficency in dB:

- 2 kinds of losses:
  1. Reflection
  2. Absorption

$$SE_{dB} = 20\log\left(\frac{Ei}{Et}\right)$$

$$SE_{dB} = 20\,log\left(\frac{Hi}{Ht}\right)$$



Shielding efficiency SE_{dB} by Sergey Alexandrovich Schelkunov

Formula

- A_{dB} : Absorption
- R_{dB} : Reflection
- B_{dB} : Rereflection

$$SE_{dB} = A_{dB} + R_{dB} + B_{dB}$$

Rereflection

- Negligible, when the shielding material has a sufficient thickness

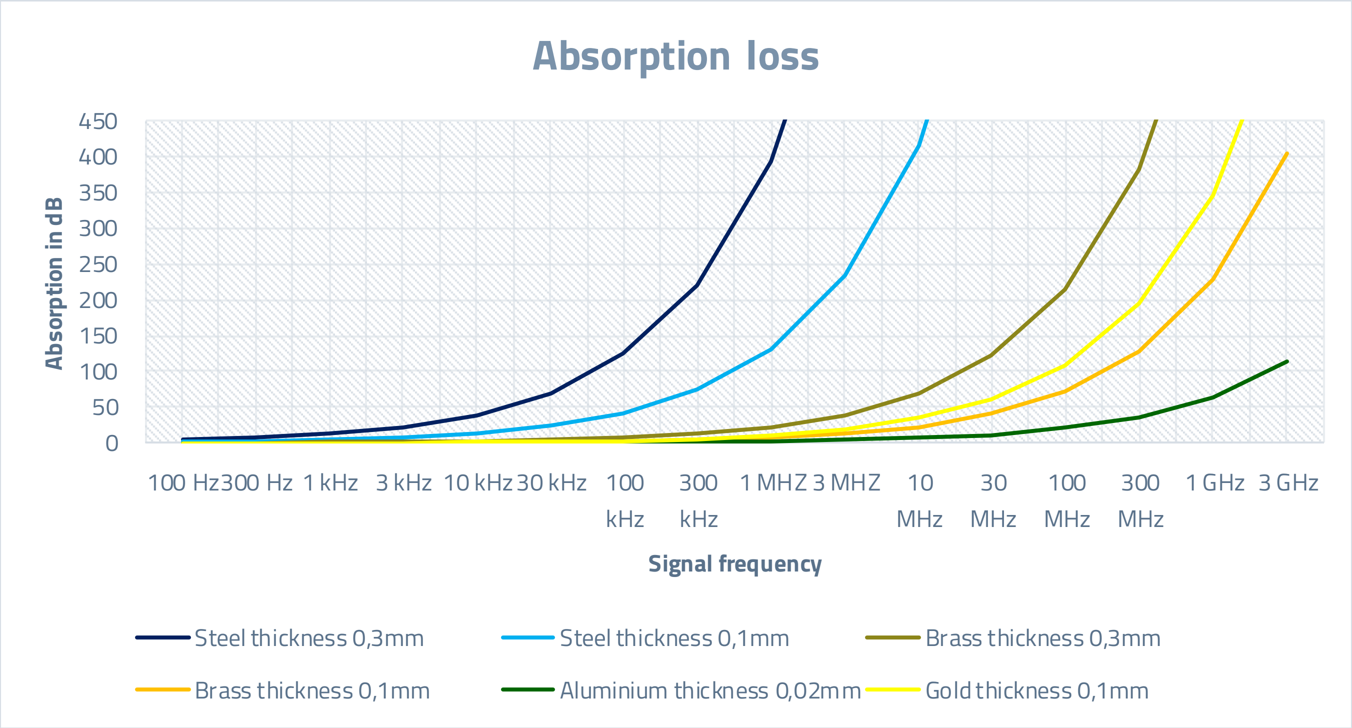
Absorption

Formula

- **Absorption loss**
- in dB:

$$A_{dB} = 1314 * t_{cm} * \sqrt{(f_{MHz} * \sigma r * \mu r)}$$

- t : Material thickness (cm)
- f : Frequency (MHz)
- σr : Relative conductivity
- μr : Relative permeability



Reflection – Far field

Formula

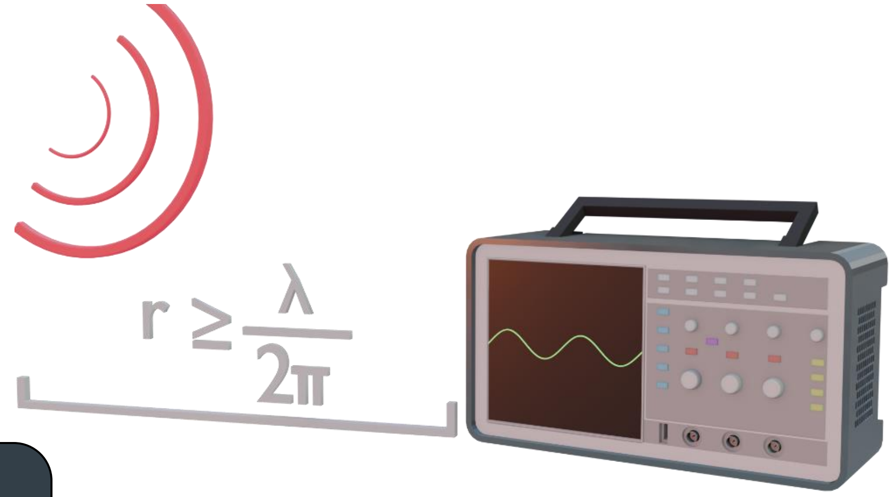
Reflection loss

for the far field

- **Intrinsic impedance of a material:**

$$Z_m = 369\sqrt{\frac{\mu_r f_{MHz}}{\sigma_r}} * 10^{-6}$$

$$t > 3\delta$$



- **Reflection loss in dB:**

$$R_{dB} = 20\log\left(\frac{Z_w}{4Z_m}\right)$$

$$R_{dB} = 168 + 10\log\left(\frac{\sigma_r}{f * \mu_r}\right)$$

$$Z_w = \sqrt{\frac{\mu}{\varepsilon}} = 377\,\Omega \quad \textit{Disturbance source } r \geq \frac{\lambda}{2\pi}$$

Reflection – Near field

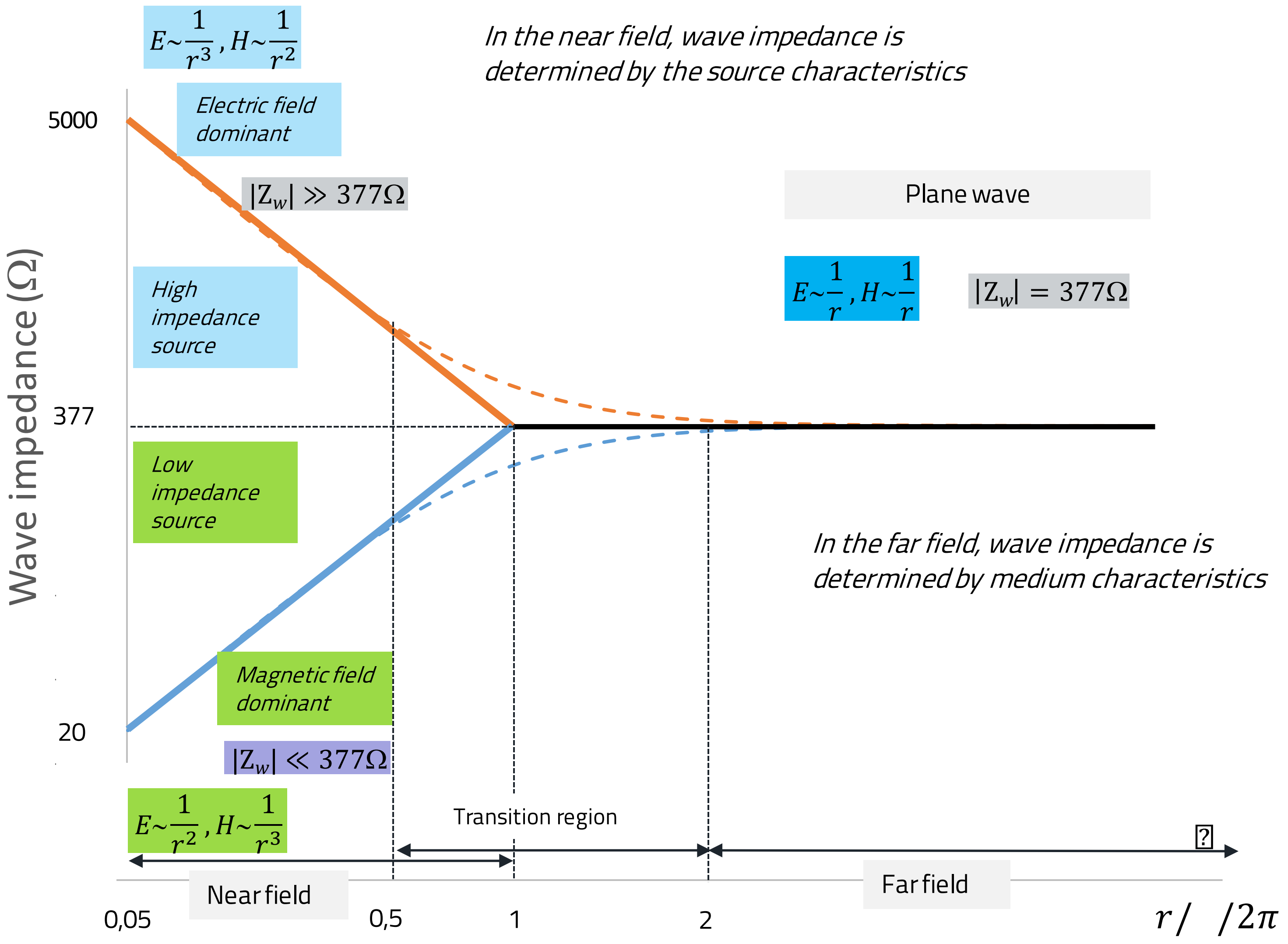
Reflection diagram

Reflection – Far field

$$R_{E,dB} = 322 + 10log(\frac{\sigma_r}{\mu_r * f^3{}_{Hz} * r^2{}_m})$$

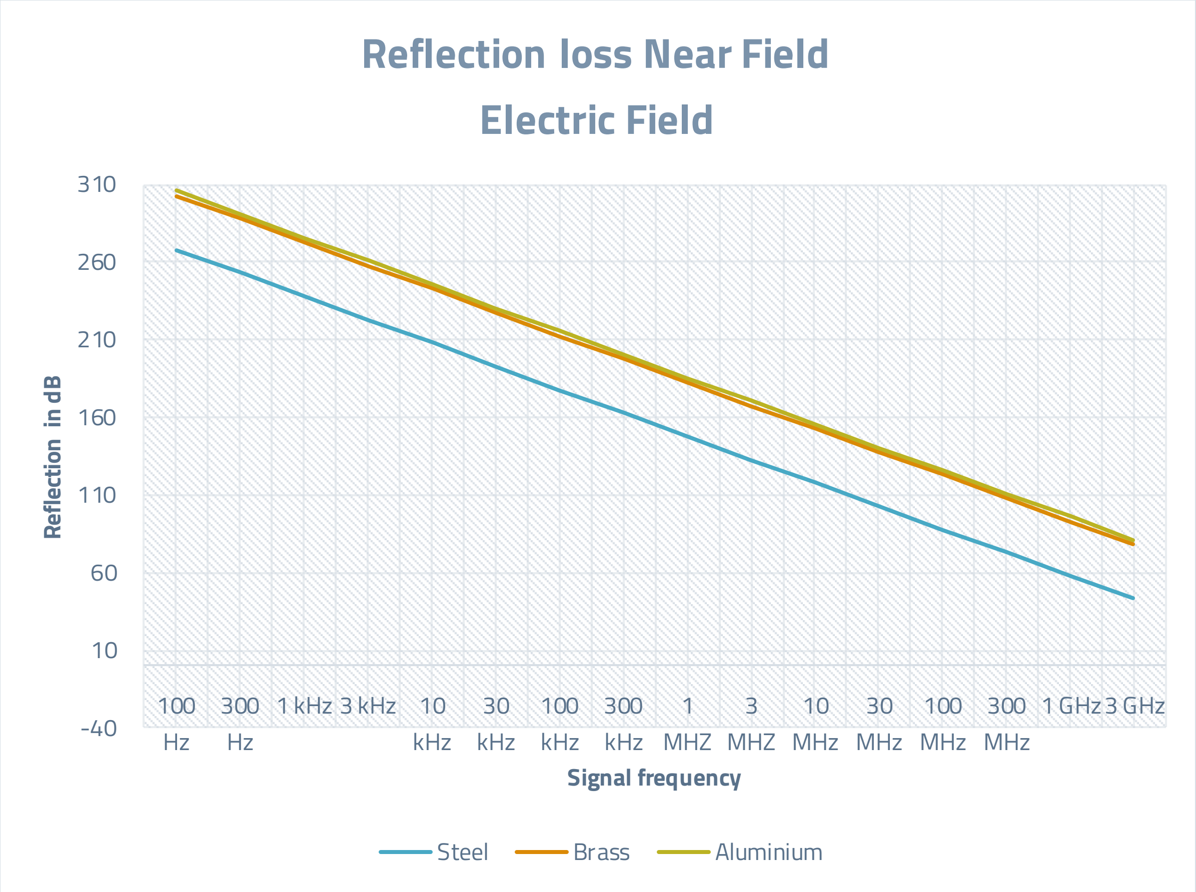
$$R_{M,dB} = 14,57 + 10log(\frac{f_{Hz} * \sigma_r * r^2{}_m}{\mu_r})$$

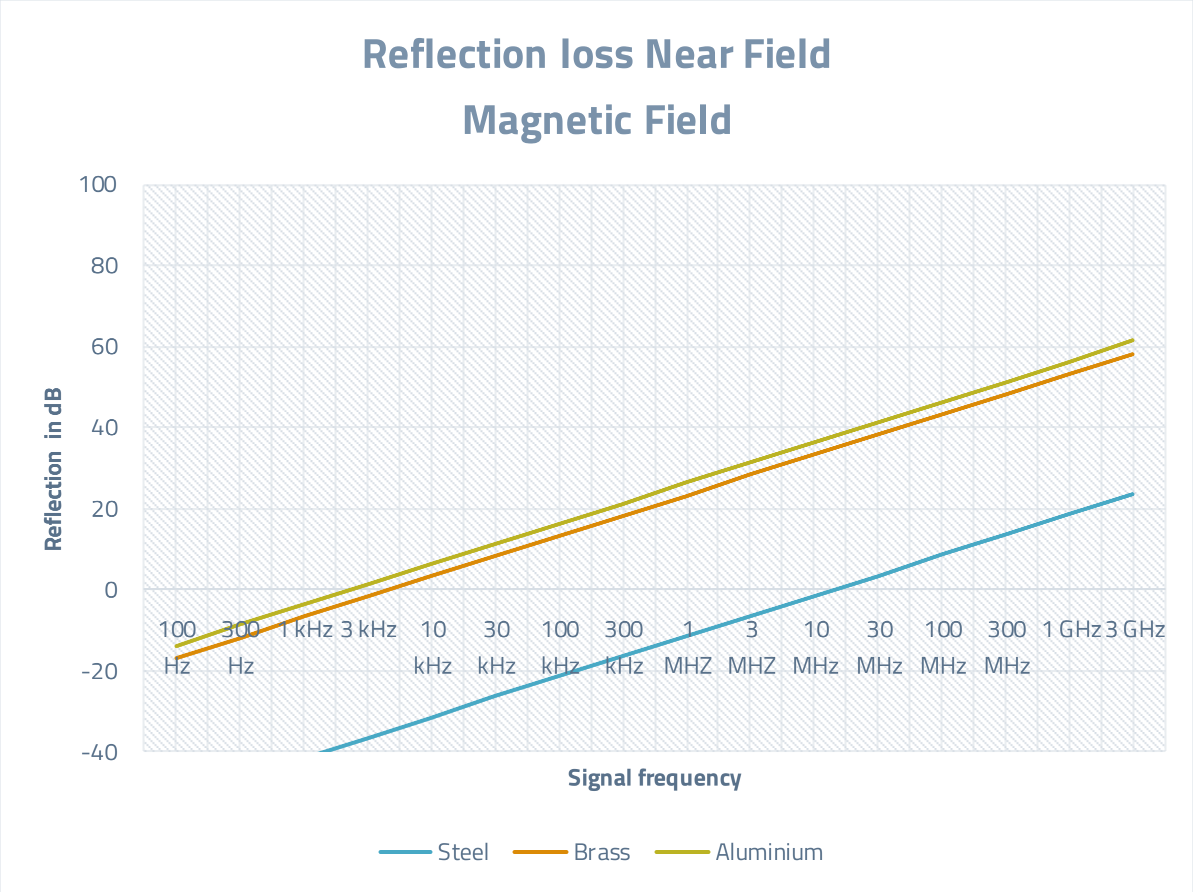
- r : Material thickness (m)
- f : Frequency (Hz)
- σr : Relative conductivity
- μr : Relative permeability



Reflection – Near Field

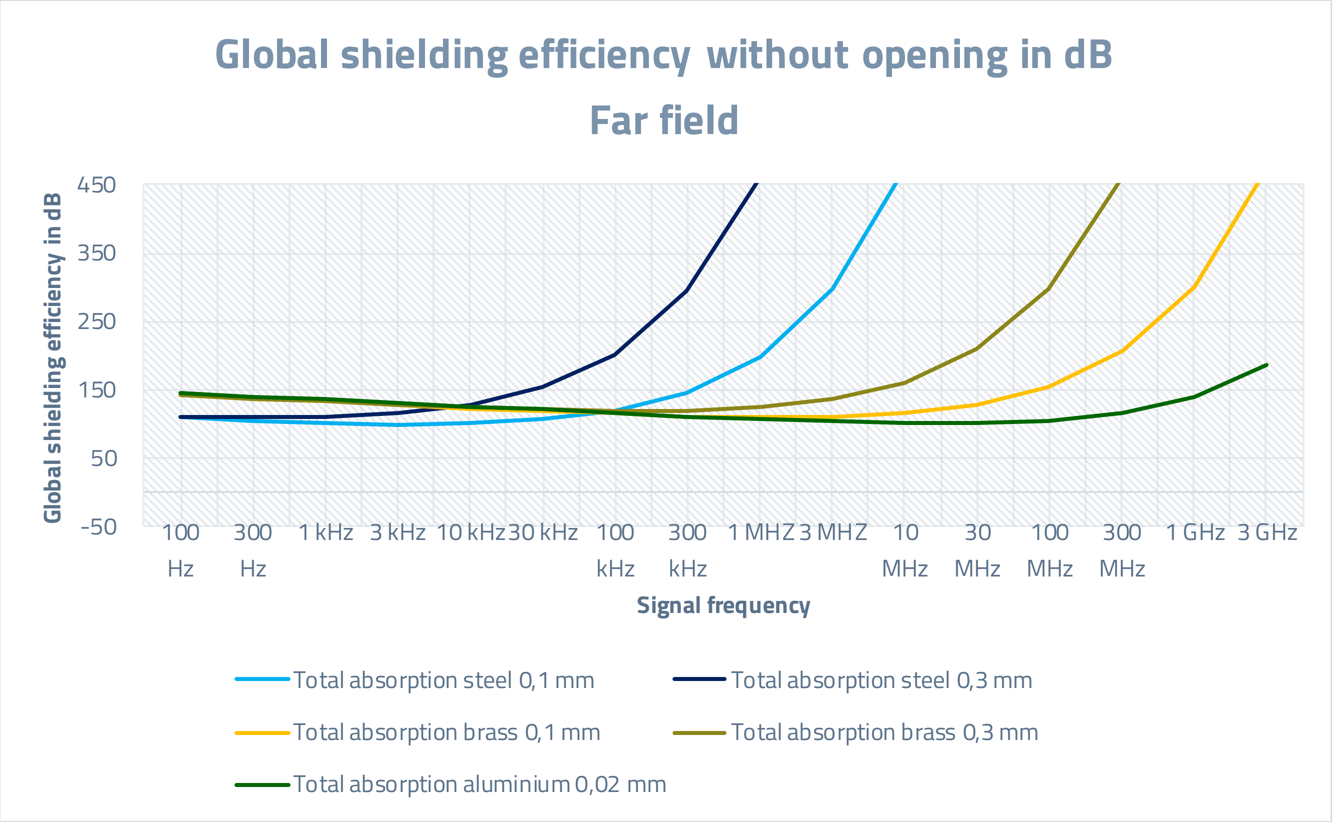
Difference between electric and magnetic field

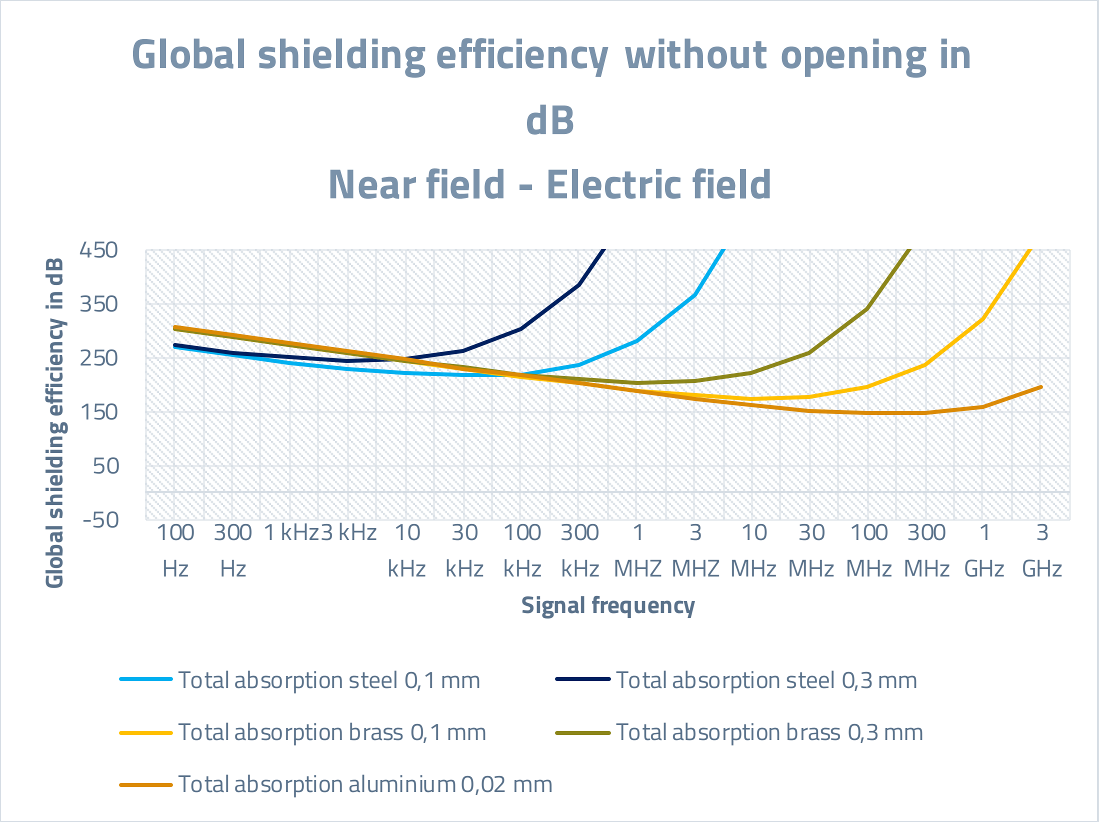




Shielding efficiency SE_{dB} by Sergey Alexandrovich Schelkunov

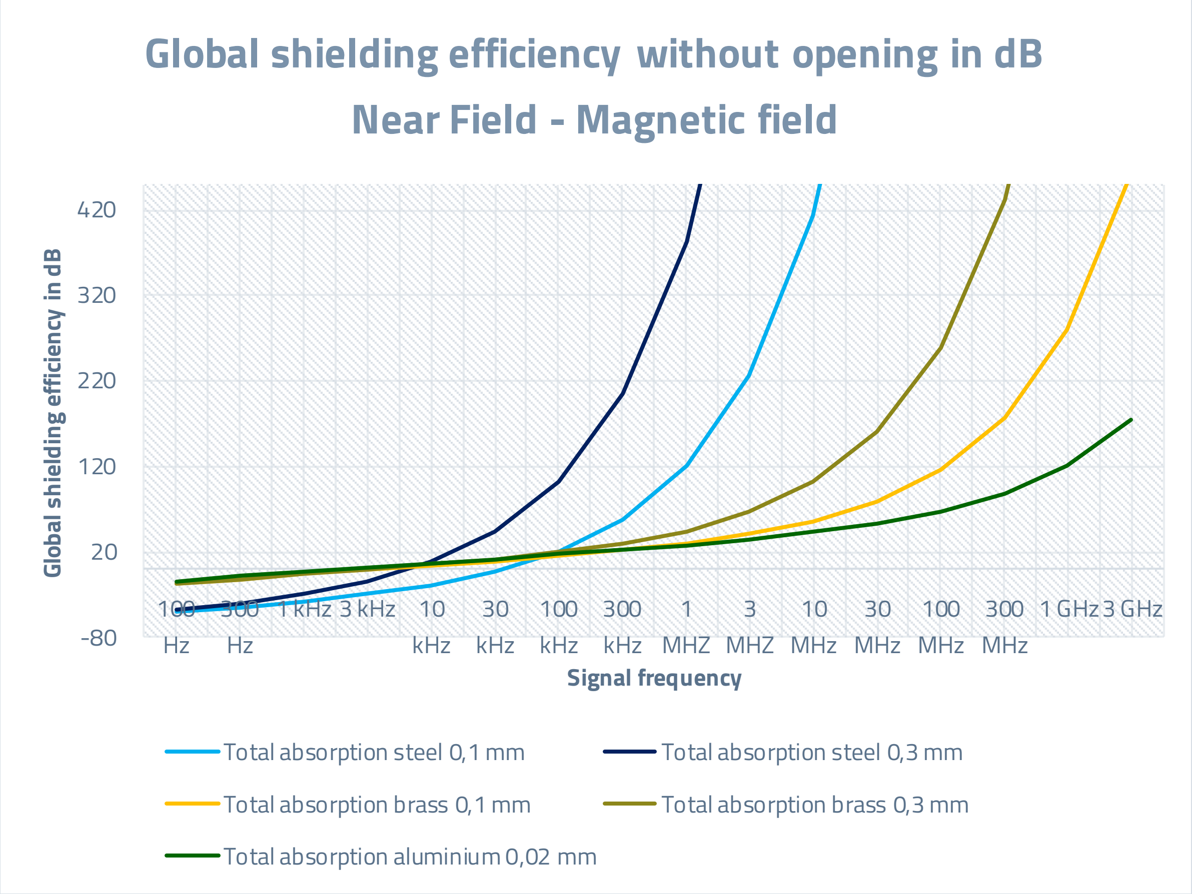
Far field and Near field electric field shielding efficiency





Shielding efficiency SE_{dB} by Sergey Alexandrovich Schelkunov

Near field shielding efficiency



Shielding

Reminder - Galvanic corrosion

Metal A / Metal B	Platine	Gold	Stainless steel	Silver	Nickel	Copper	Brass	Tin	Lead	Steel	Aluminium	Iron	Chrome	Zinc
Platine	0	0,13	0,25	0,35	0,43	0,57	0,65	0,8	0,84	1	1,09	1,11	1,2	1,4
Gold	0,13	0	0,11	0,22	0,3	0,44	0,52	0,67	0,71	0,87	0,96	0,98	1,07	1,27
St. steel	0,25	0,11	0	0,1	0,18	0,32	0,4	0,55	0,59	0,75	0,84	0,86	0,95	1,15
Silver	0,35	0,22	0,1	0	0,08	0,22	0,3	0,45	0,49	0,65	0,74	0,76	0,85	1,05
Nickel	0,43	0,3	0,18	0,08	0	0,14	0,22	0,37	0,41	0,57	0,66	0,67	0,77	0,97
Copper	0,57	0,44	0,32	0,22	0,14	0	0,08	0,23	0,27	0,43	0,52	0,54	0,63	0,83
Brass	0,65	0,52	0,4	0,3	0,22	0,08	0	0,15	0,19	0,35	0,44	0,47	0,55	0,75
Tin	0,8	0,67	0,55	0,45	0,37	0,23	0,15	0	0,04	0,2	0,29	0,31	0,4	0,6
Lead	0,84	0,71	0,59	0,49	0,41	0,27	0,19	0,04	0	0,16	0,25	0,27	0,36	0,56
Steel	1	0,87	0,75	0,65	0,57	0,43	0,35	0,2	0,16	0	0,09	0,11	0,2	0,4
Al	1,09	0,96	0,84	0,74	0,66	0,52	0,44	0,29	0,25	0,09	0	0,05	0,11	0,4
Iron	1,11	0,98	0,86	0,76	0,67	0,54	0,47	0,31	0,27	0,11	0,05	0	0,1	0,3
Chrome	1,2	1,07	0,95	0,85	0,77	0,63	0,55	0,4	0,36	0,2	0,11	0,1	0	0,2
Zinc	1,4	1,27	1,15	1,05	0,97	0,83	0,75	0,6	0,56	0,4	0,4	0,3	0,2	0

Metal A is attacked

Metal B is attacked

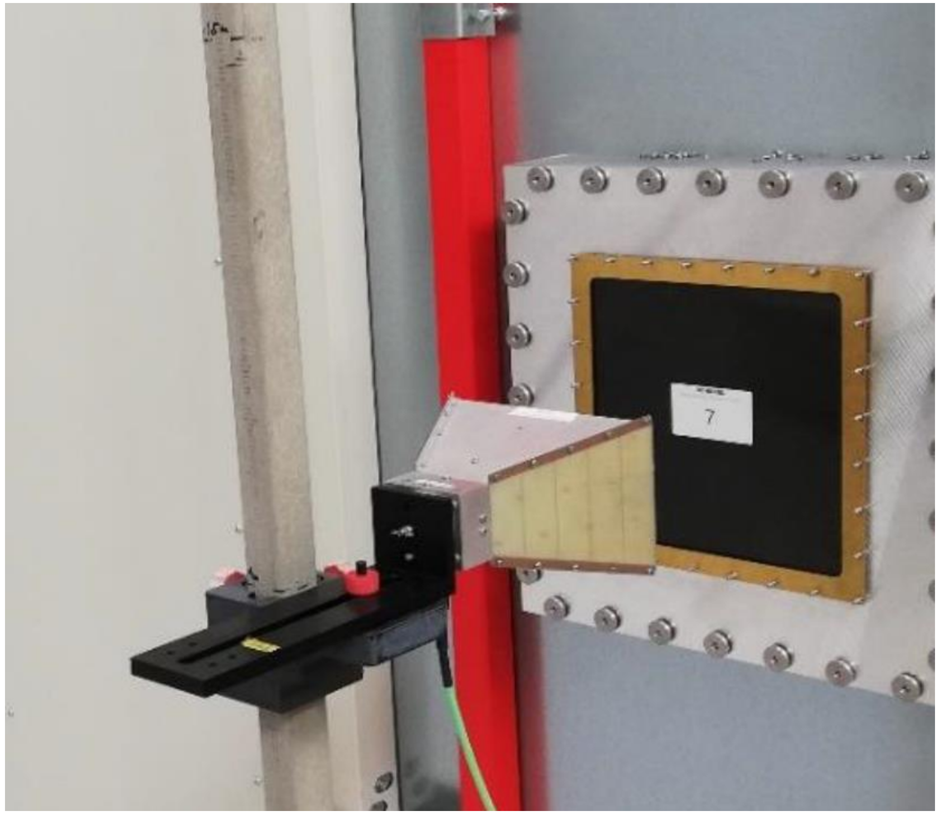
Risk of galvanic corrosion

No galvanic corrosion

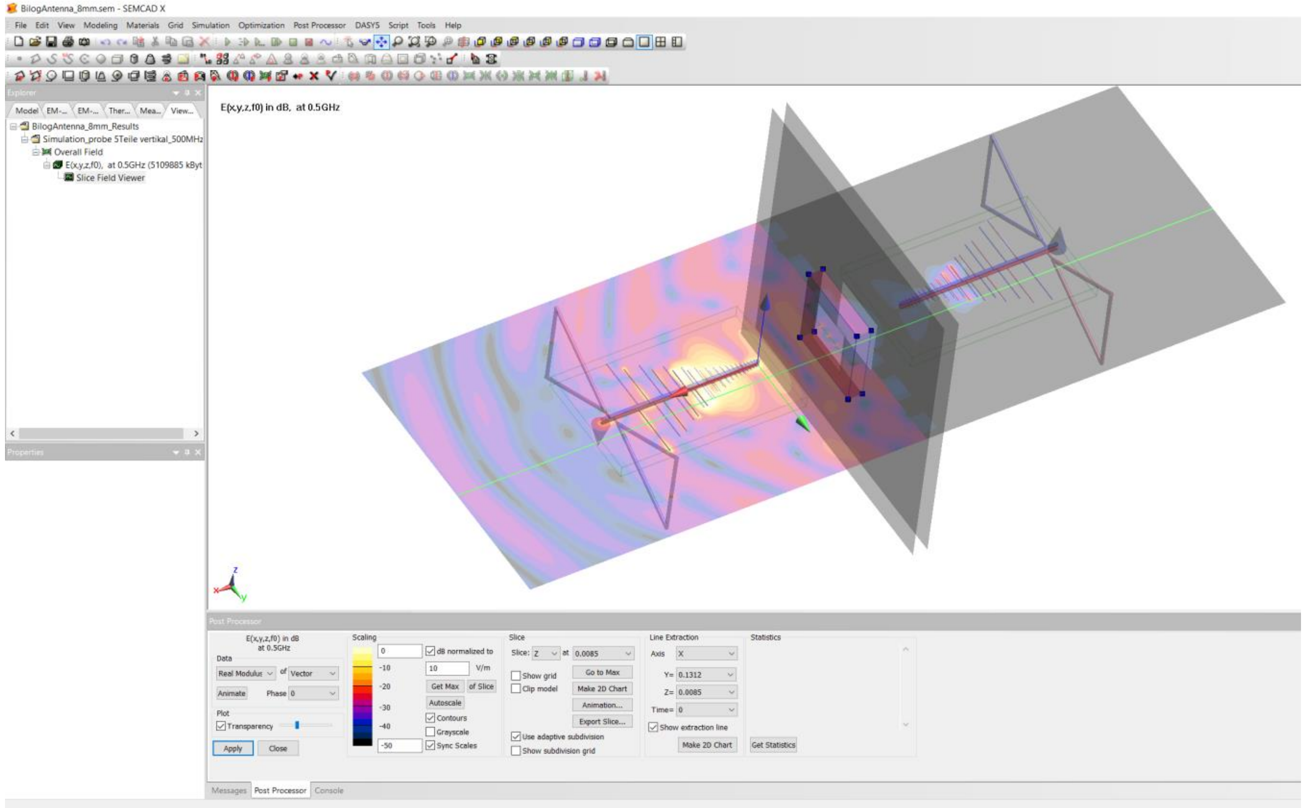
Shielding efficiency

Simulation in Sim4Life

SEIBERSDORF LABORATORIES



Material sample 343mm

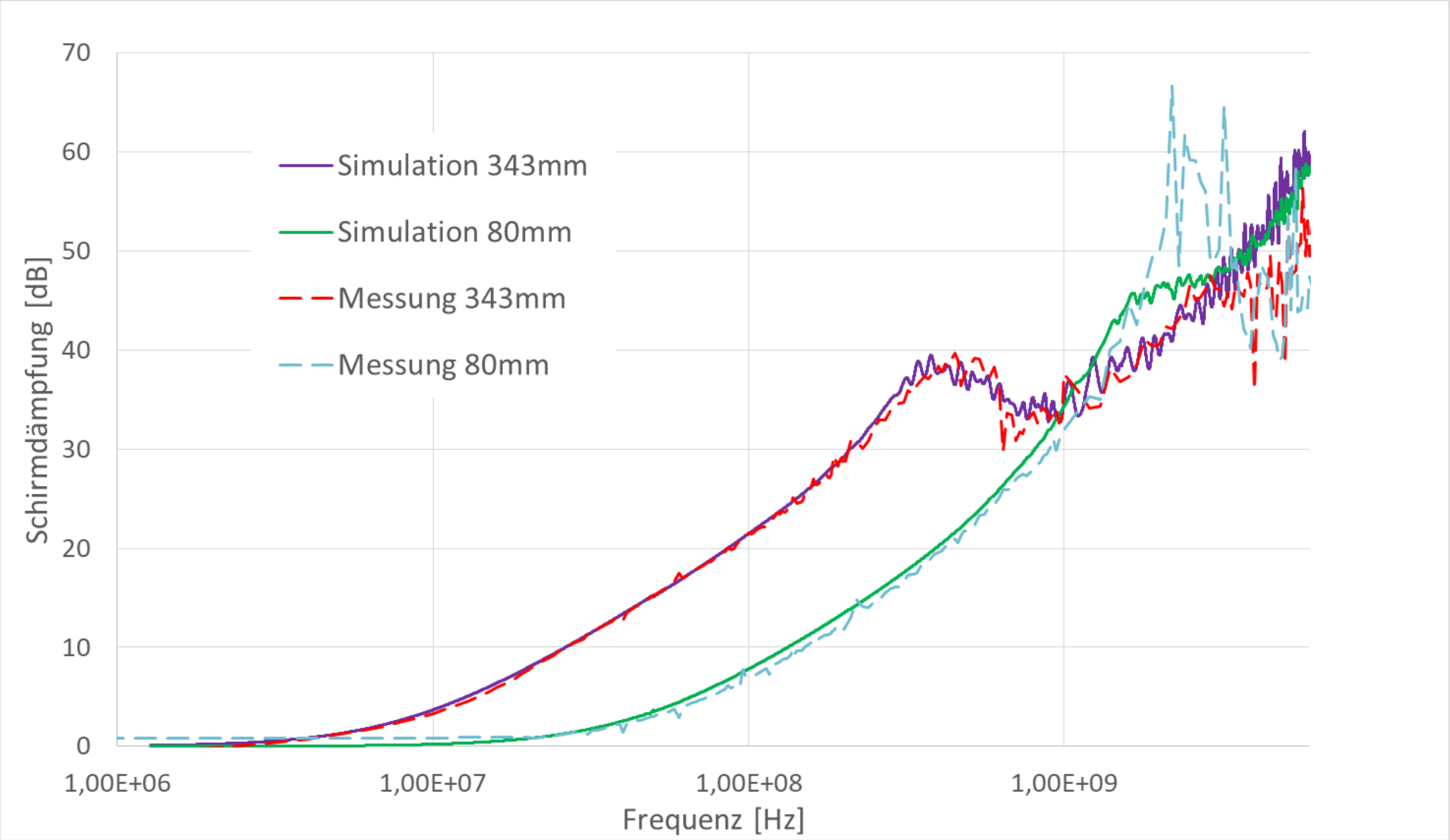


Simulation in Sim4Life

Shielding efficiency

Simulation in Sim4Life

SEIBERSDORF LABORATORIES



Shielding

WE shielding materials







Produkt	Shielding Material
USB 2.0	Brass + Sn Brass + Ni
USB 3.0	Brass + Sn Stainless steel + Ni
USB3.1	Steel + Ni
USB3.1 type C	Steel + Ni
Fire wire	Brass + Ni
HDMI	Brass + Sn
MJ	Brass + Ni
DSUB	Steel + Sn Steel + Ni
DC power jack	Brass + Ni

Shielding

Apertures

The maximal length of an apertures is defined by the frequency

If $l \geq \frac{\lambda}{2}$ then your shielding is useless

Rule of thumb for critical length of apertures:

Industrial applications: $l < \frac{\lambda min}{20}$

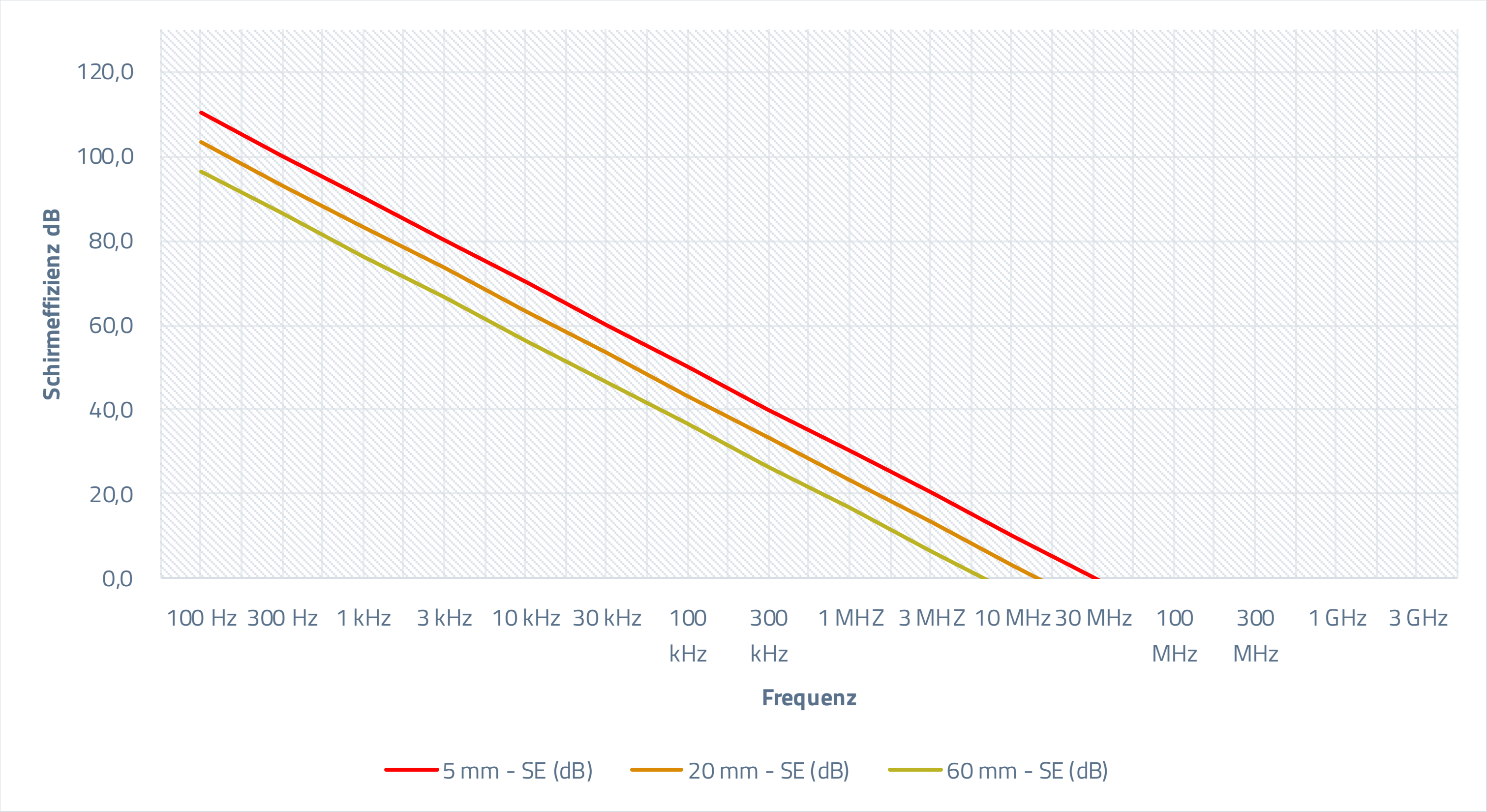
Military applications: $l < \frac{\lambda min}{50}$

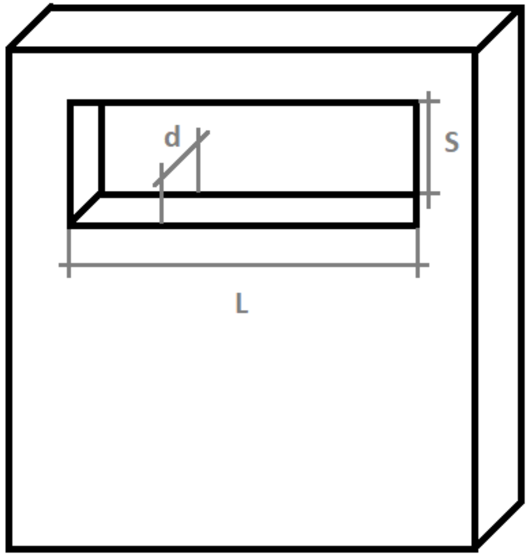
Shielding

Shielding efficiency when using different long apertures

$$SE_{dB} = 97 - 20\log(Lf_{MHz}) + 20\log\left(1 + \ln\left(\frac{L_{mm}}{S_{mm}}\right)\right) + SE_{shad} + 30 * \left(\frac{d_{mm}}{L_{mm}}\right)$$

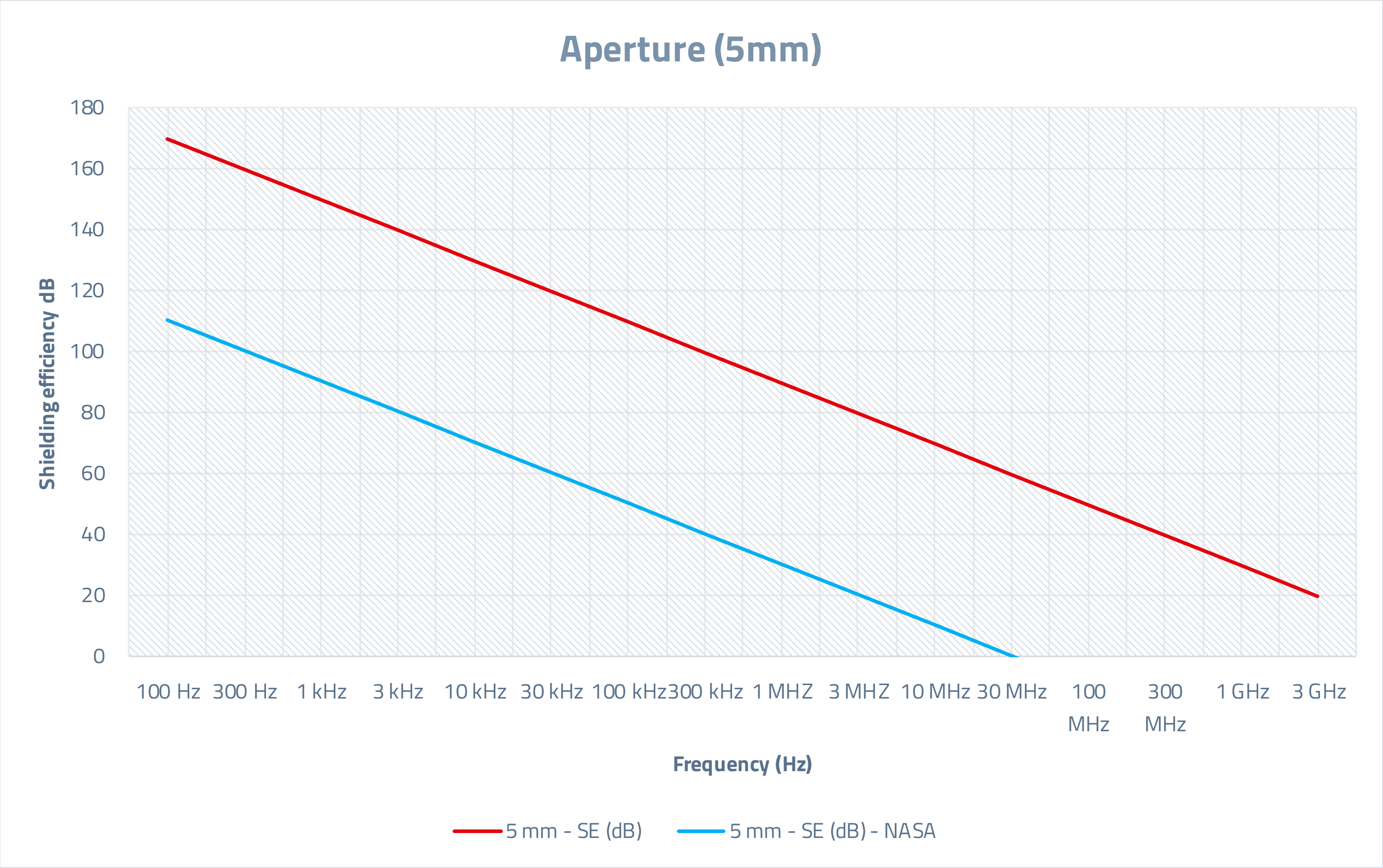
NASA - Design Guidelines for Shielding Effectiveness, Current Carrying Capability, and the Enhancement of Conductivity of Composite Materials





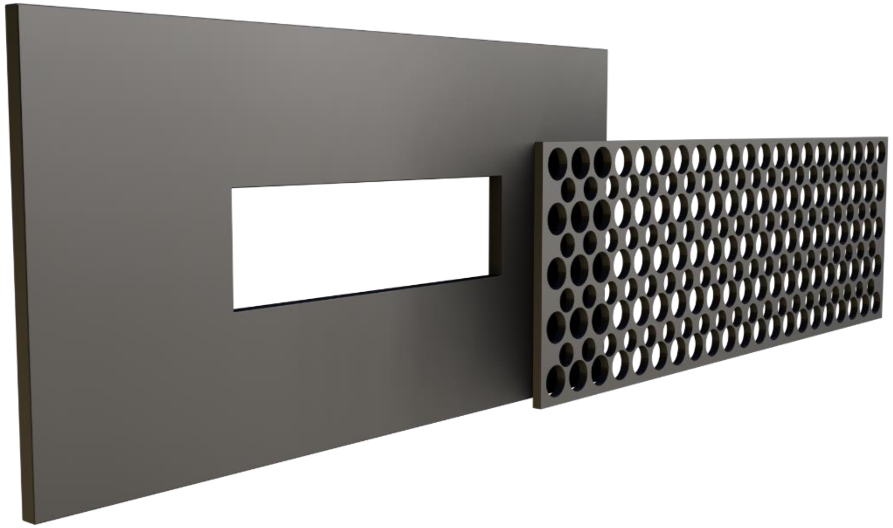
Shielding

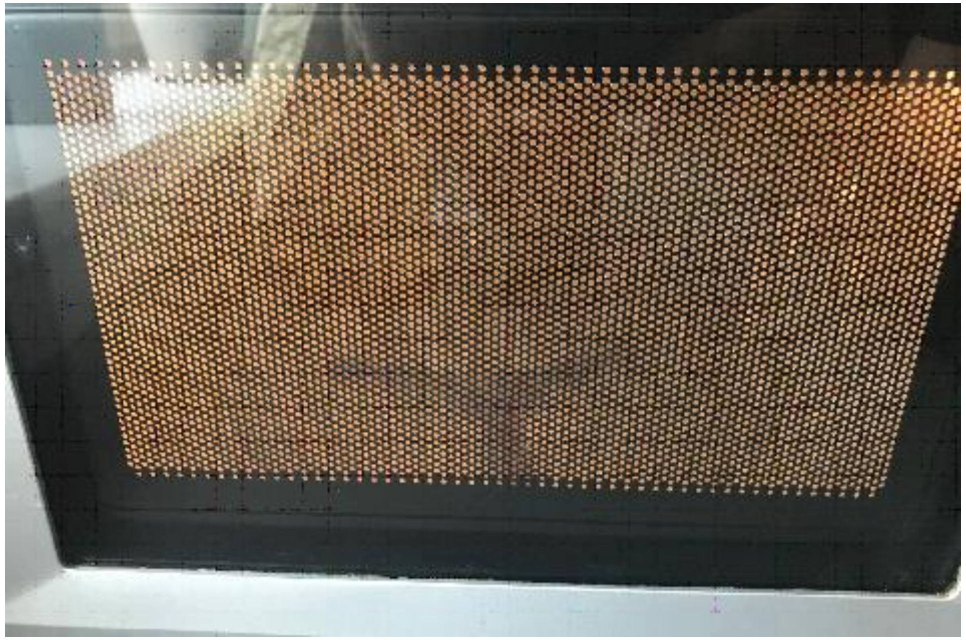
Comparing both formulas



Shielding

How can we increase the aperture size?

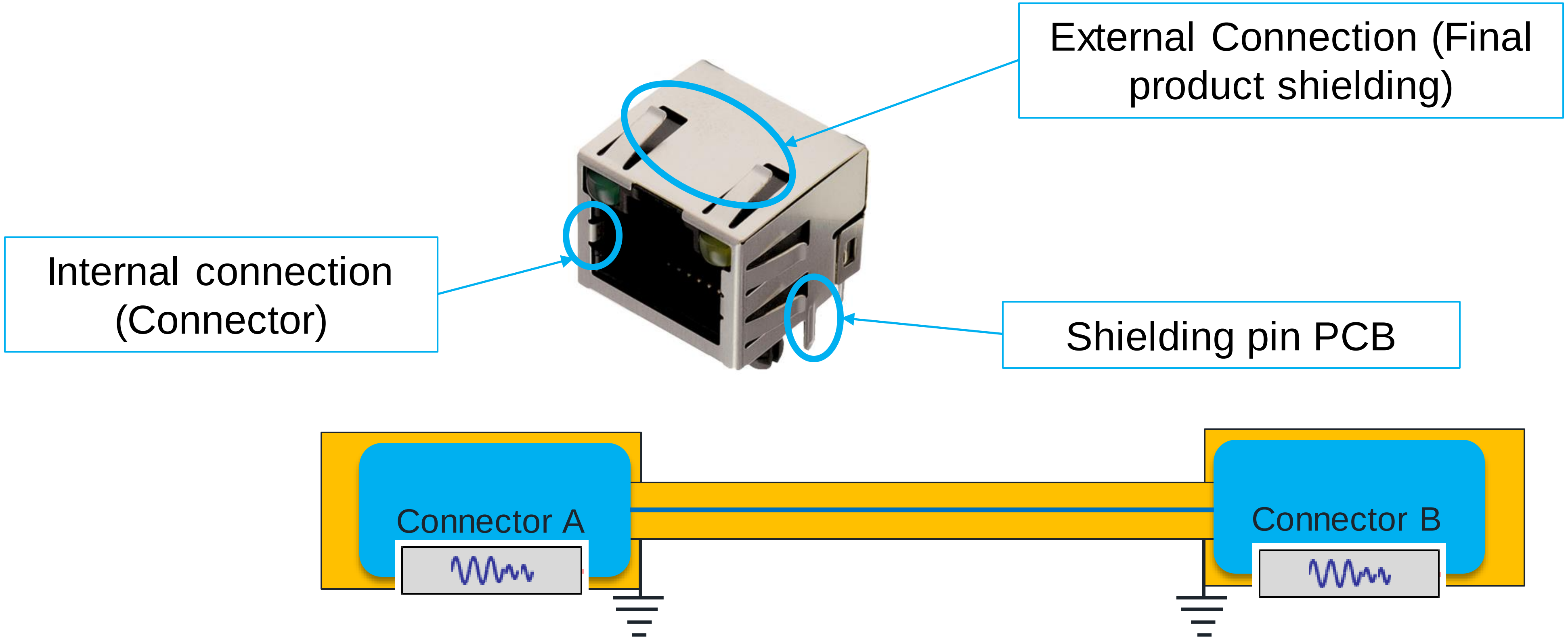




Shielding

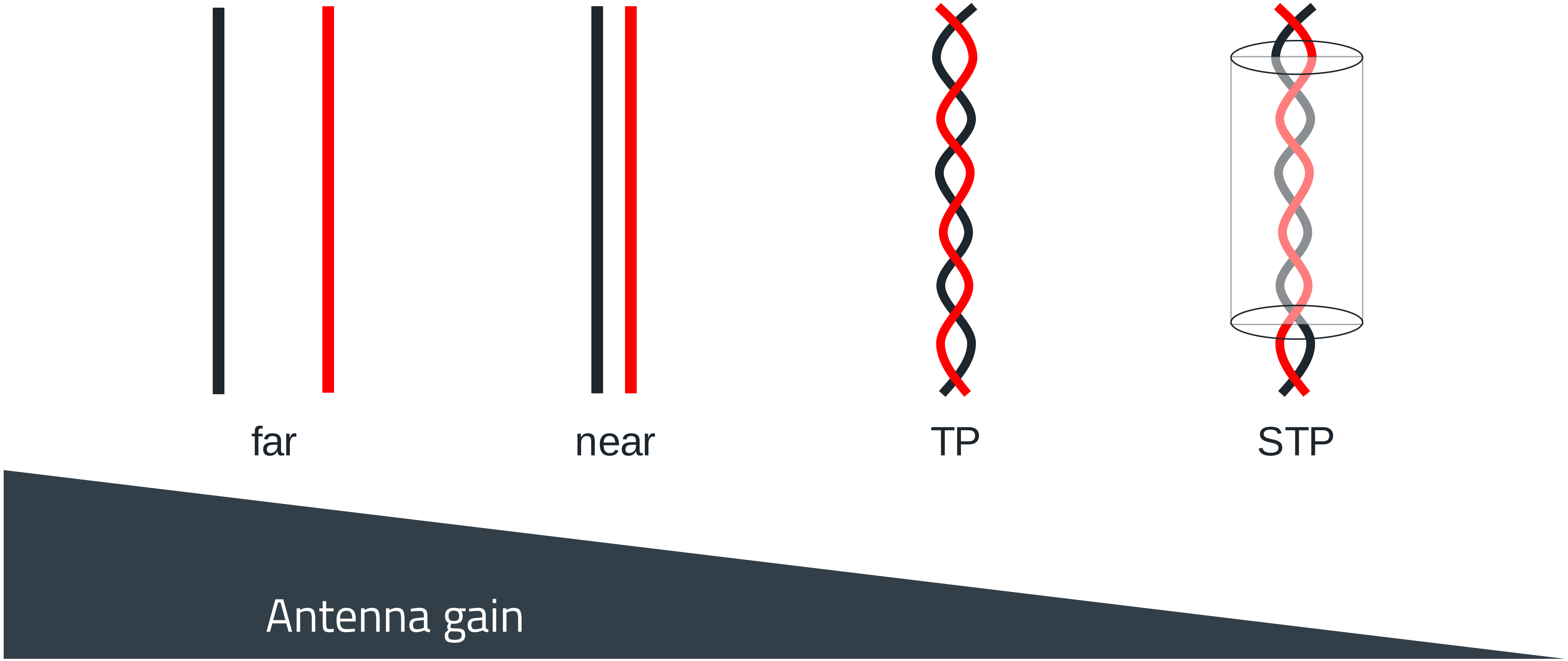
Return path of high frequency current

Shielding continuity (Electrical connection)



Shielding

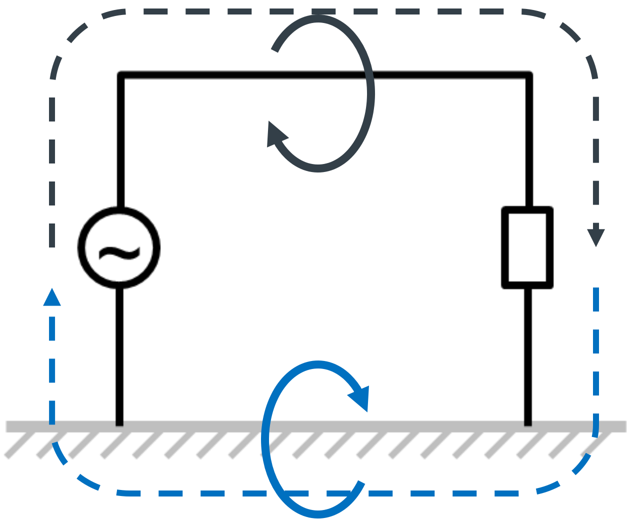
Cable as antenna



Shielding

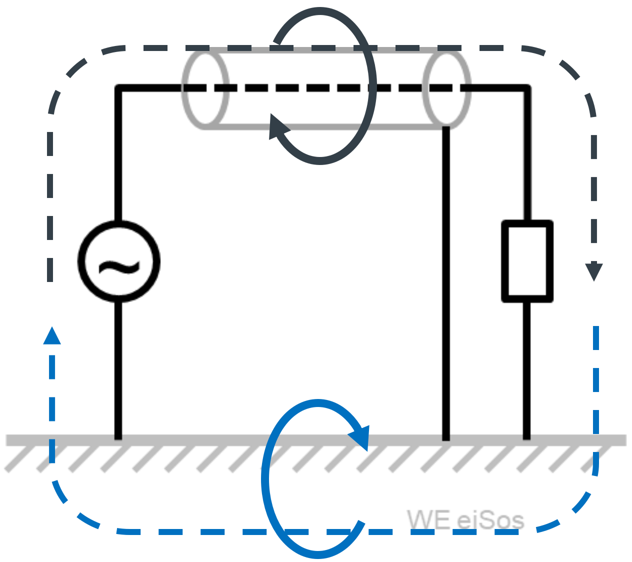
Cable shielding

RADIATED NOISE



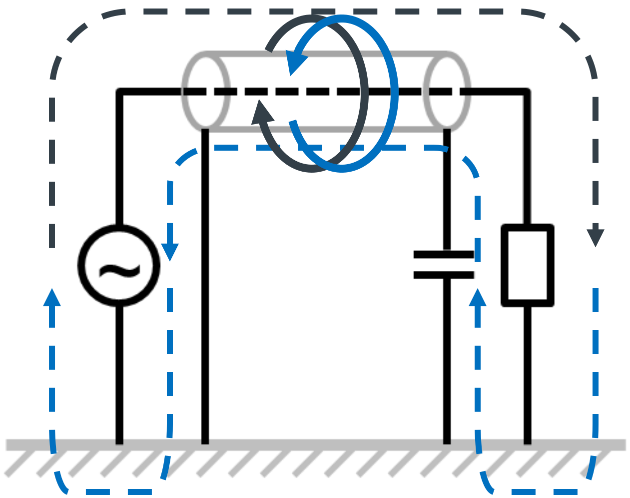
Without shielding, big enclosed current loop surface

Shielded E-field
uncompensated H-field



Added shielding, **one** end grounded, big current loop surface

Shielded E-field
compensated H-field

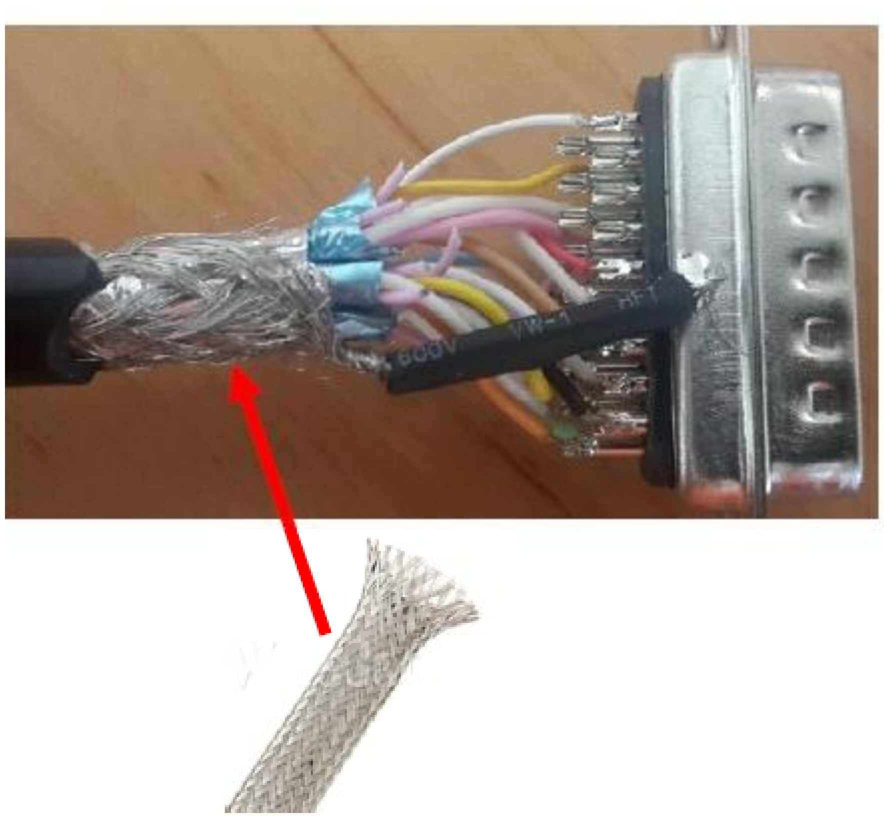


Added shielding, **both** ends grounded, **reduced** current loop surface

Shielding

Cable shielding examples

Area coverage of the braided shielding > 85%

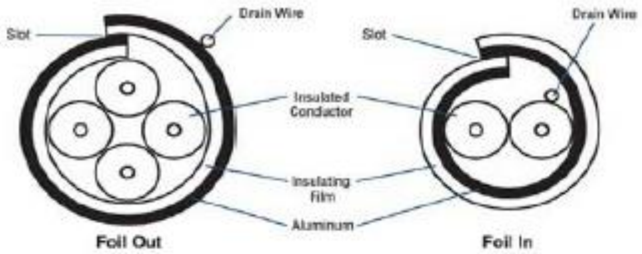


Every twisted pair should be shielded seperatly

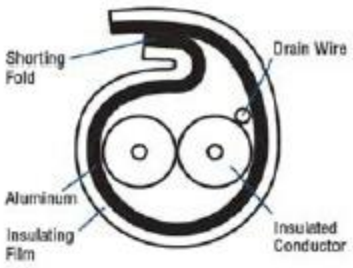
Shielding

Cable shielding examples

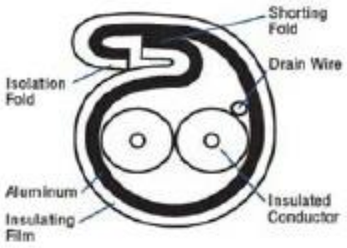
Don't



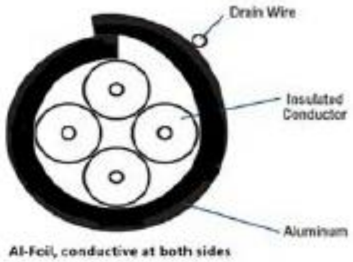
Good



Better



Best



Shielding

Example USB 3.1

100MHz and a aperture length of 5mm

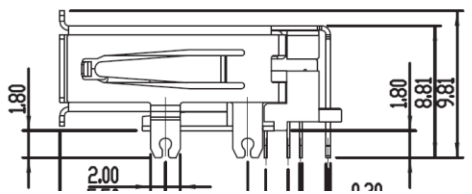
1GHz and a aperture length of 5mm

5GHz and a aperture length of 5mm

$$SE_{@100MHz} = 20\log\left(\frac{\lambda}{2L}\right) = 49{,}5\ dB$$

$$SE_{@1GHz} = 20\log\left(\frac{\lambda}{2L}\right) = 29{,}5\ \text{dB}$$

$$SE_{@5GHz} = 20\log\left(\frac{\lambda}{2L}\right) = 15{,}5\ \text{dB}$$



Shielding

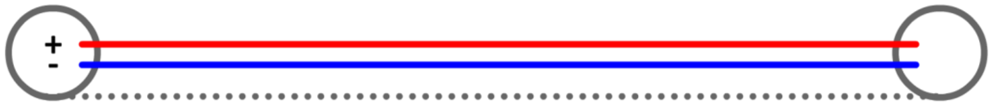
Interconnecting cable and shielding

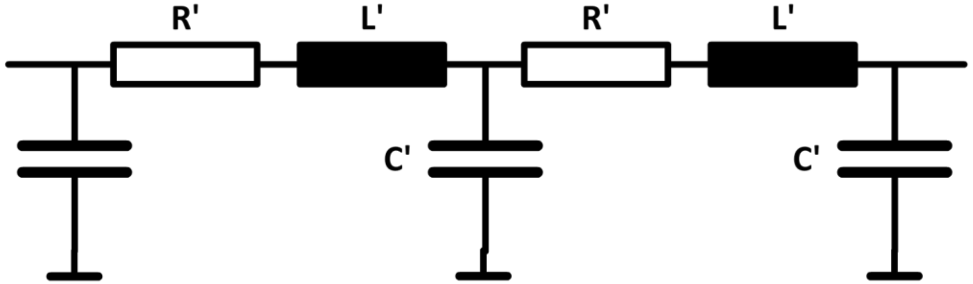
Interconnecting cable

R ↓ C ↓ L ↑ ➔ $Z_{Conductor}$ 50 … 100Ω

Shielding

R ↑ C ↑ L ↓ ➔ $Z_{Shielding}$ 1 … 5Ω





$$Z_0 = \sqrt{\frac{R' + j\omega L'}{G' + j\omega C'}}$$

f → 0: $Z_0 = \sqrt{\frac{R'}{G'}}$

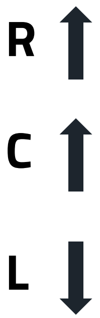
f → ∞: $Z_0 = \sqrt{\frac{L'}{C'}}$

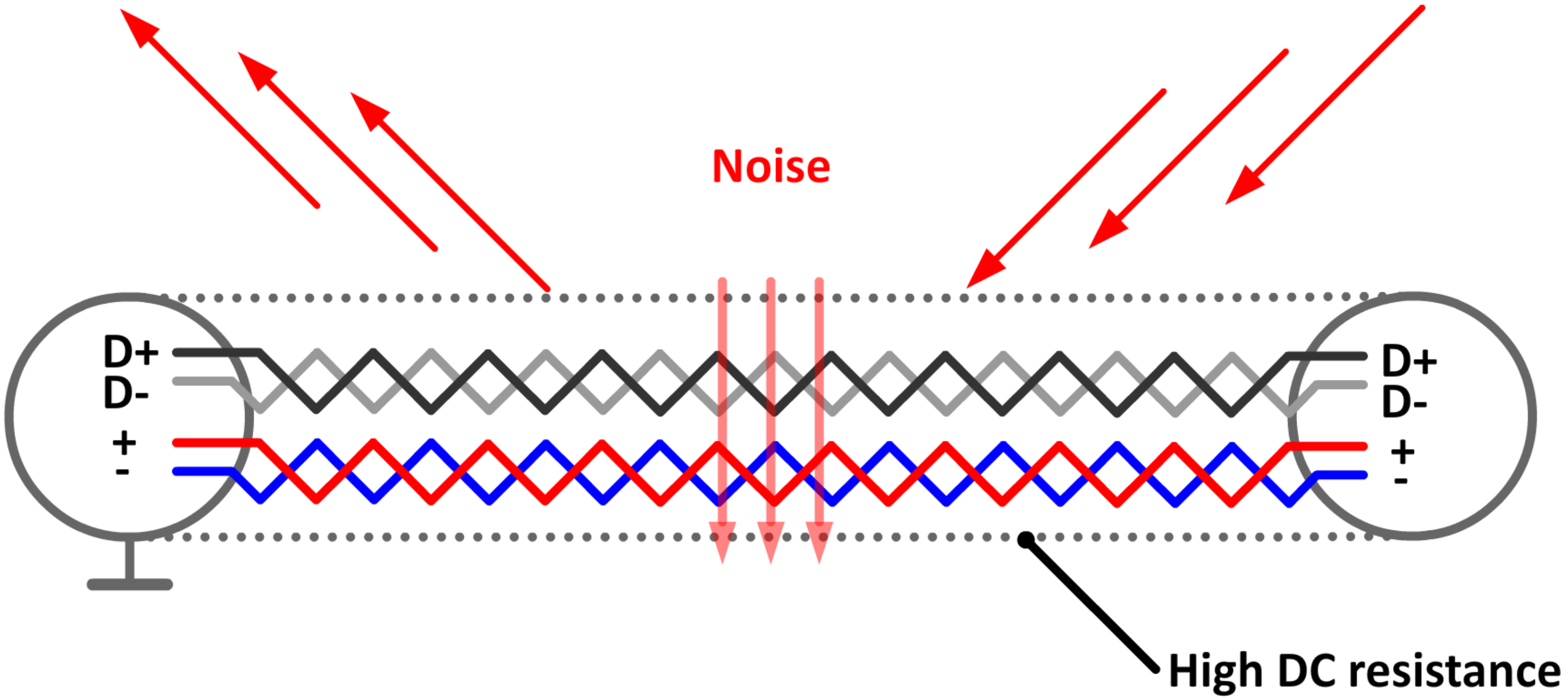
$\omega = 2\pi f$

Shielding

Interconnecting cable and shielding USB cable

Shielding

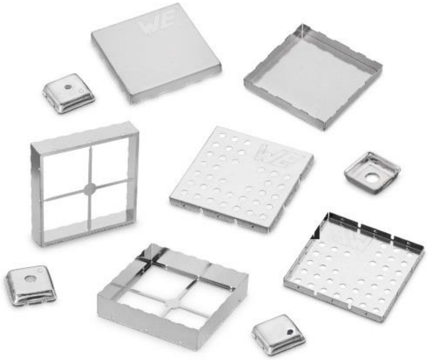




Shielding

Options to reduce the capacitive coupling

- Reducing the interference voltage by decreasing the switching frequency or by applying low-pass filters
- Reducing the capacitive coupling through
  - Reducing the length of coupled conductors
  - Increasing the distance between conductors with different electric circuits
  - Avoid parallel conductor paths
  - Electrical shielding (Cable, circuit board, housing)



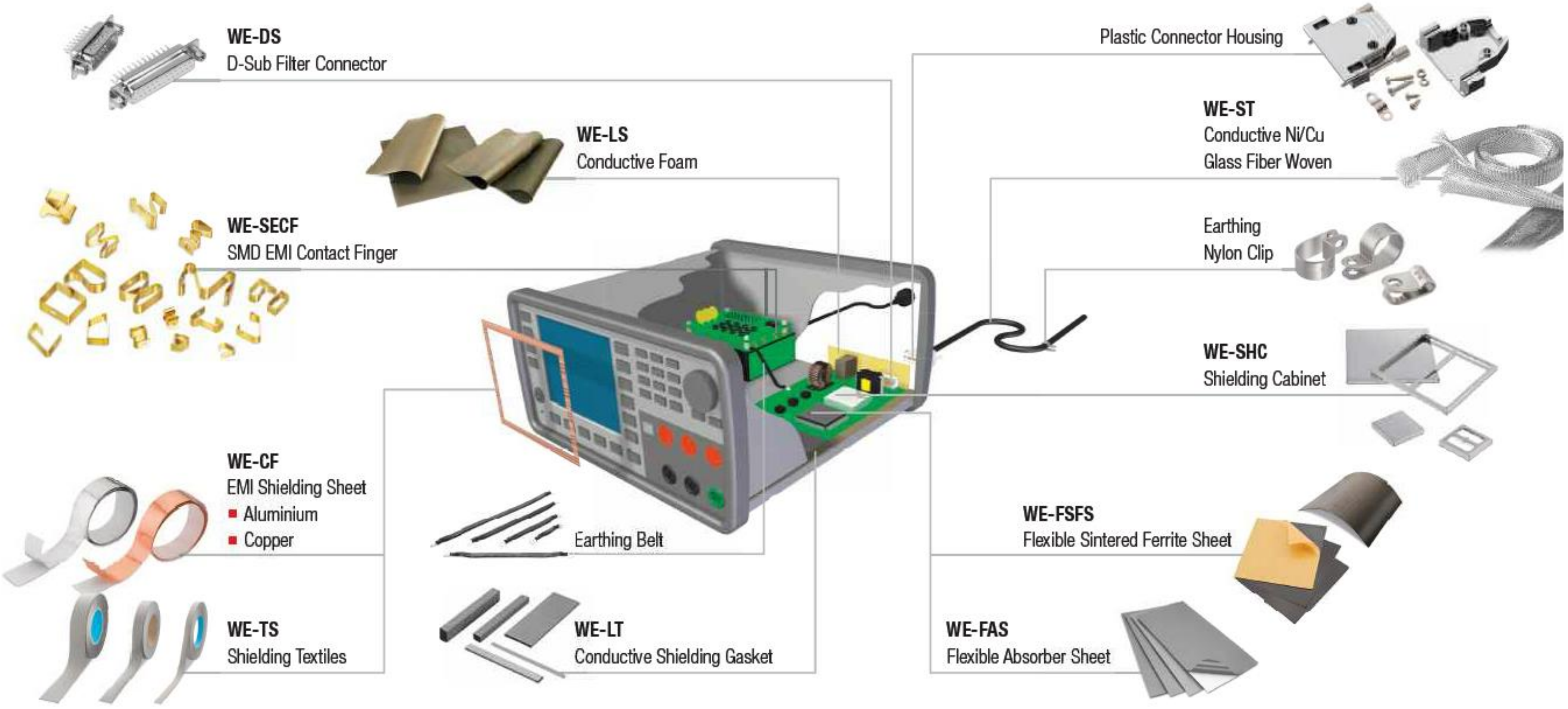
Shielding

Options to reduce the capacitive coupling

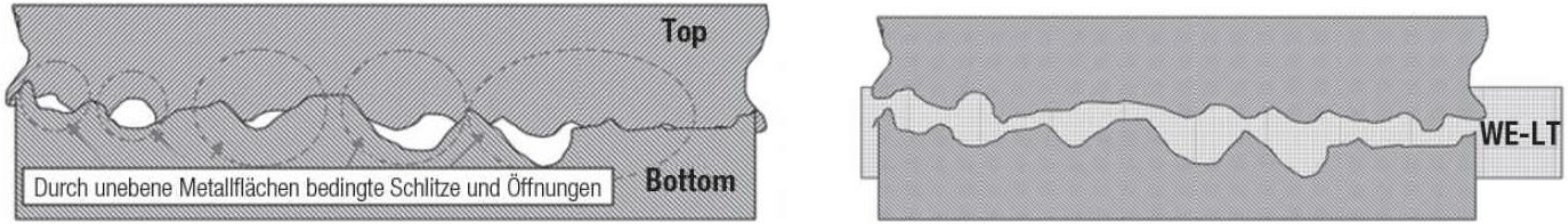
- Reducing the interference voltage by decreasing the switching frequency or by applying low-pass filters
- Reducing the capacitive coupling through
  - Reducing the loop surface of coupled electrical circuits
  - Increasing the distance between conductors with different electric circuits
  - Twisting the forward and return-conductor (Cable)
  - Magnetic shielding with soft magnetic ferrite material (big μ_r)

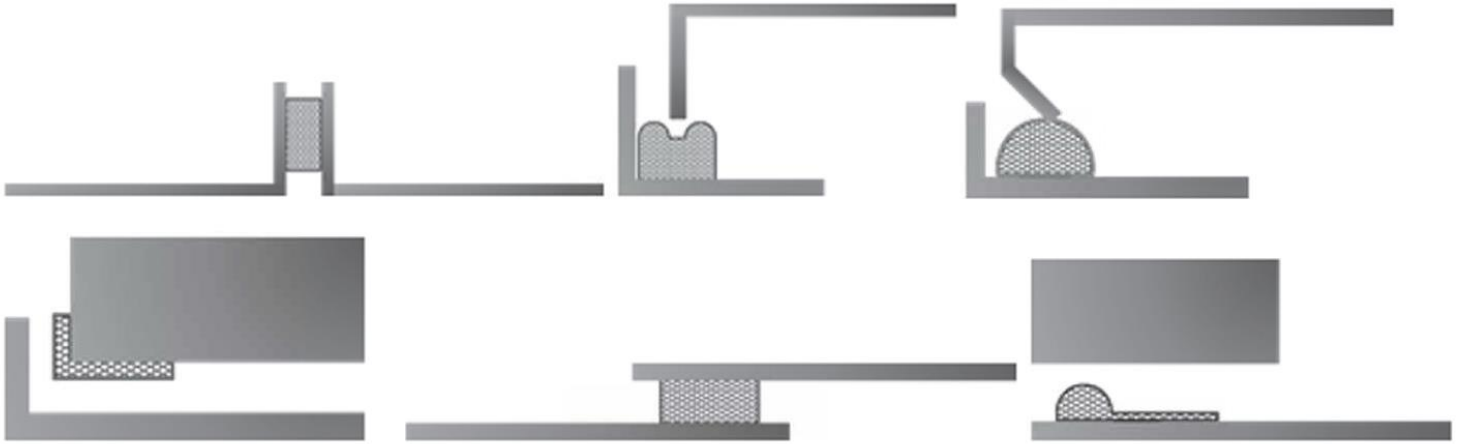
Abschirmmaterialien

Koaxialschirmanbindung



WE-LT

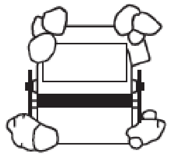
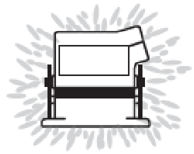

Top
Durch unebene Metallflächen bedingte Schlitze und Öffnungen
Bottom
WE-LT



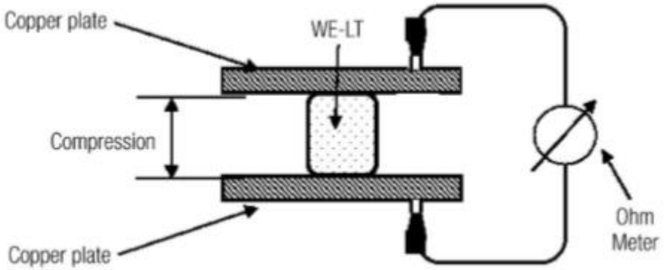
WE-LT

- Kann applikationsbedingt eine IP 54 Schutzklasse erreichen

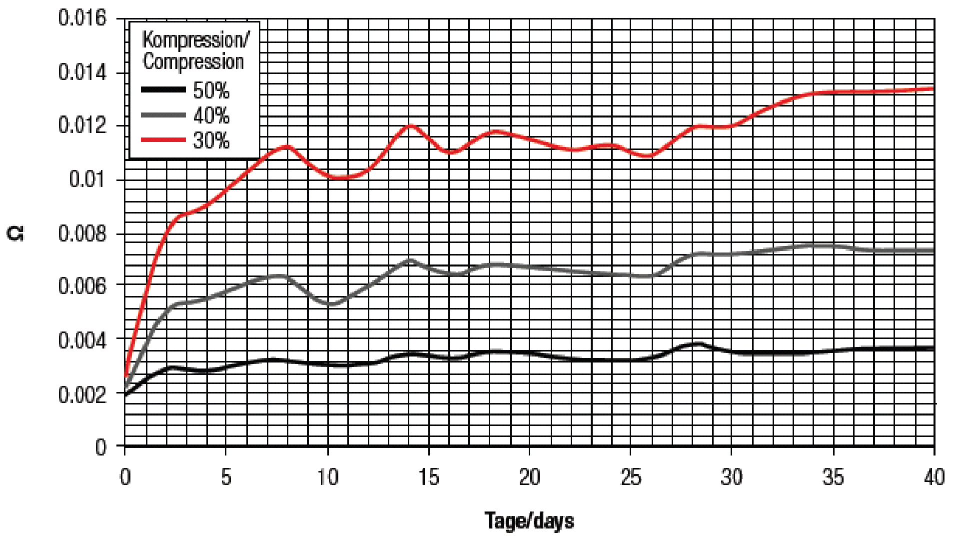
Schutzarten nach DIN EN 60529 (IEC 529/VDE 047 T1)

5		Schutz gegen Berührung, Schutz gegen Staubablagerung im Inneren	4		Schutz gegen Spritzwasser aus allen Richtungen

- Langzeitverlauf Oberflächenwiderstand vs. Kompression



Langzeitverlauf Oberflächenwiderstand vs. Kompression



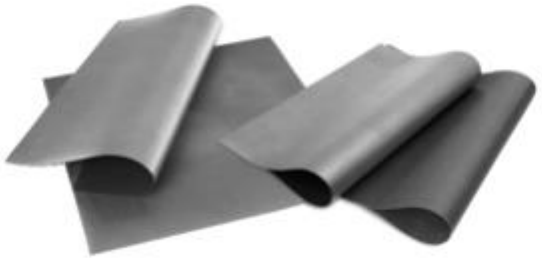
WE-LS

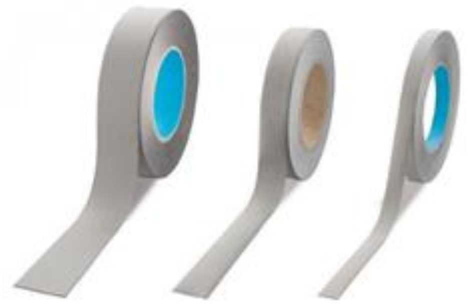
Conductive foam

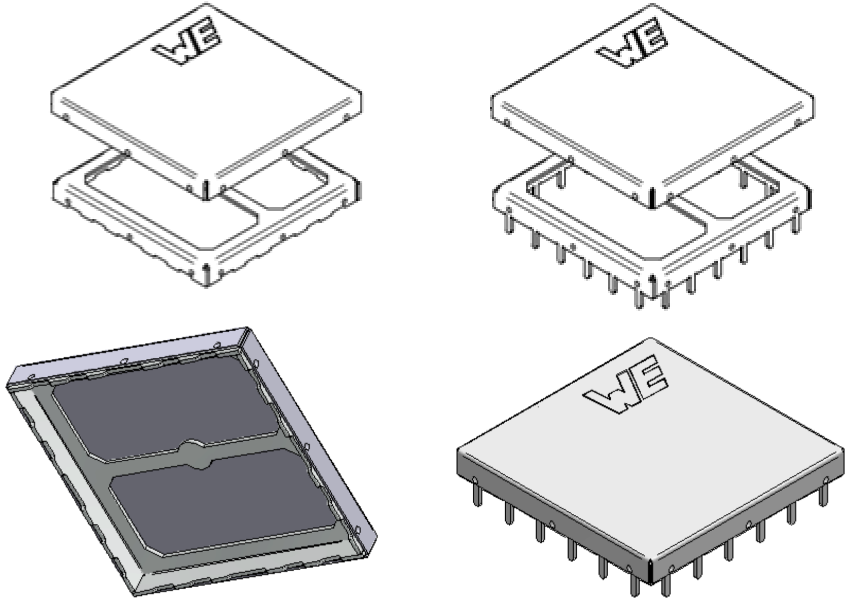
Conductive foils and tapes

Shielding cabinets

Shielding textiles







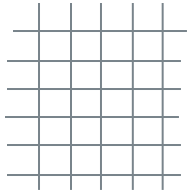
WE-FSFS

- Aufbau WE-FSFS

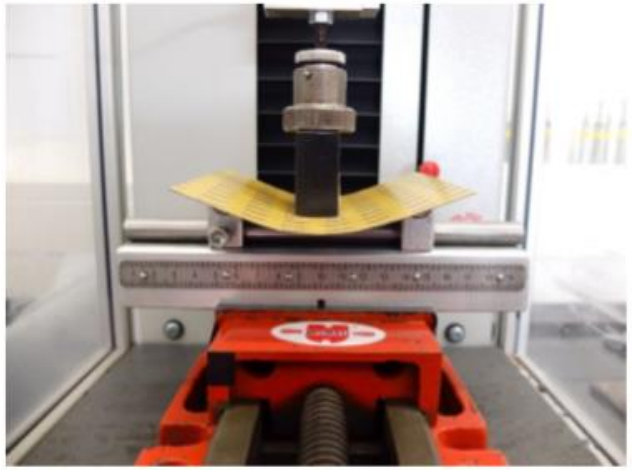
  - PET Schutzfolie: hoher Oberflächenwiderstand mit starker Haftfestigkeit, um die Ferritschicht zu schützen

  - Ferritschicht mit hoher Permeabilität
    (wird mittels Laserschnitt unterteilt, damit sie flexibel wird)

  - Klebefolie: Schutz für die Ferritschicht + Klebefolie zum Anbringen des Produkts

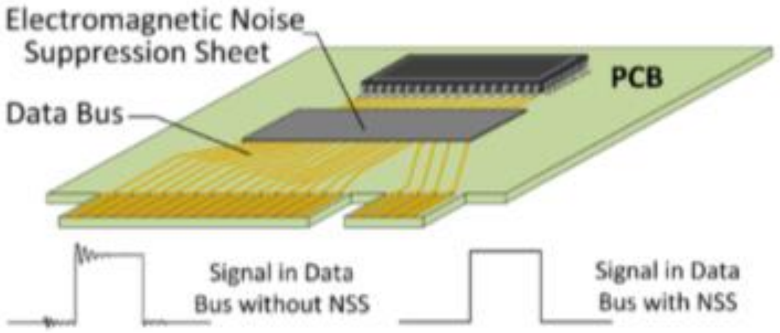


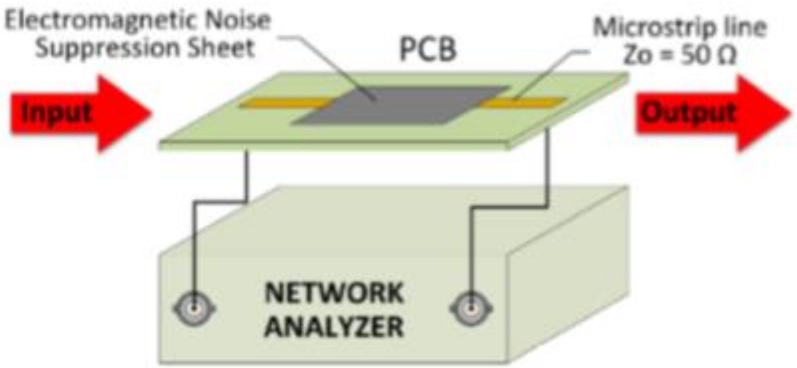
- Flexibilität
  - Biegetests, um die elektromagnetischen Eigenschaften sicherzustellen

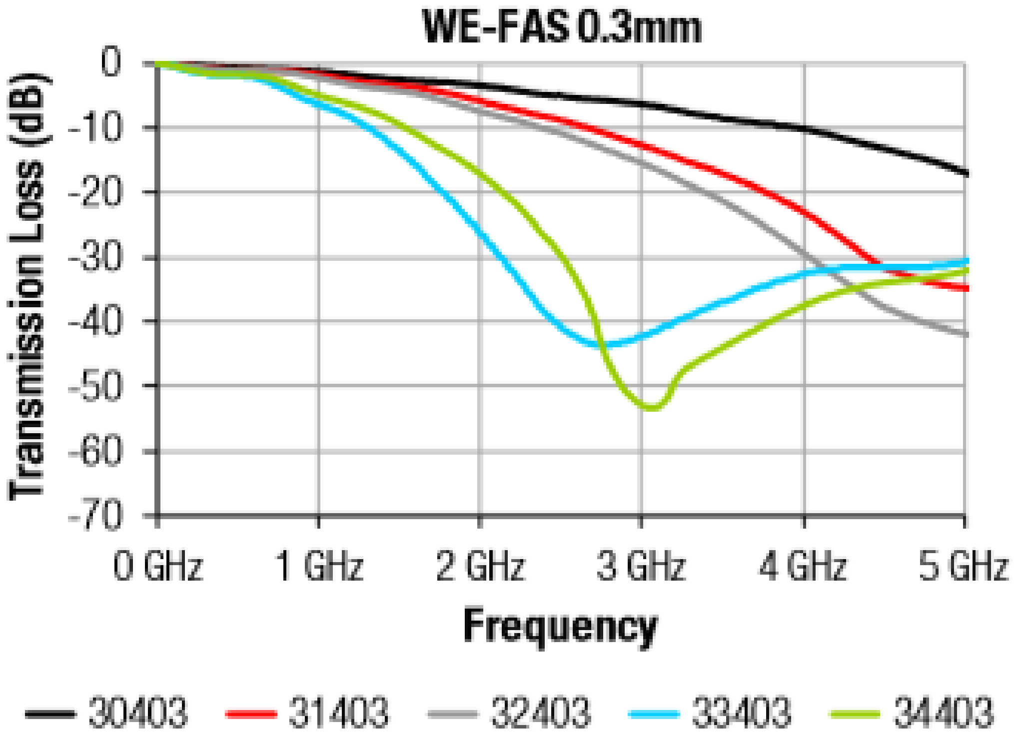


WE-FAS und WE-FSFS

- Messmethoden
  - Mikrostreifenleitungsmethode (MSL)



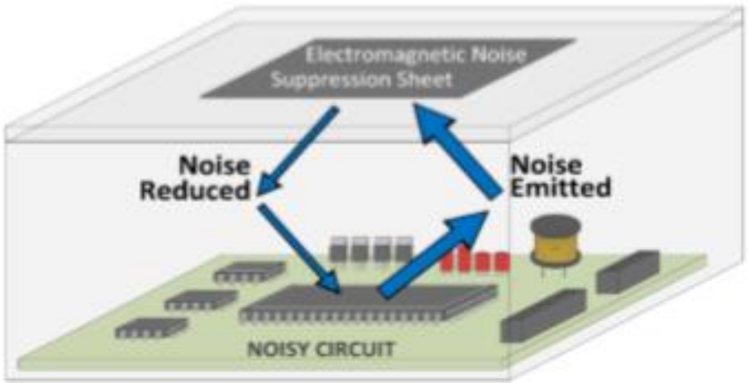


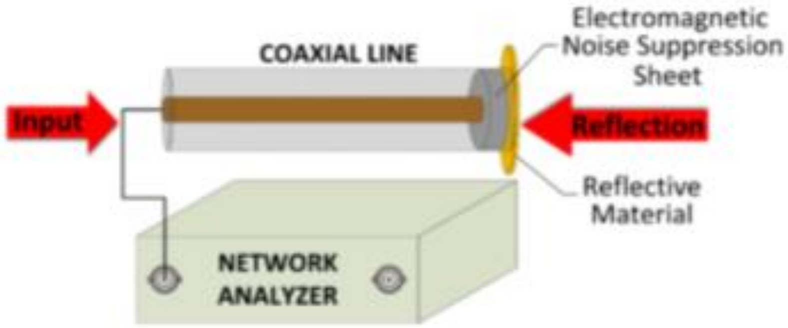


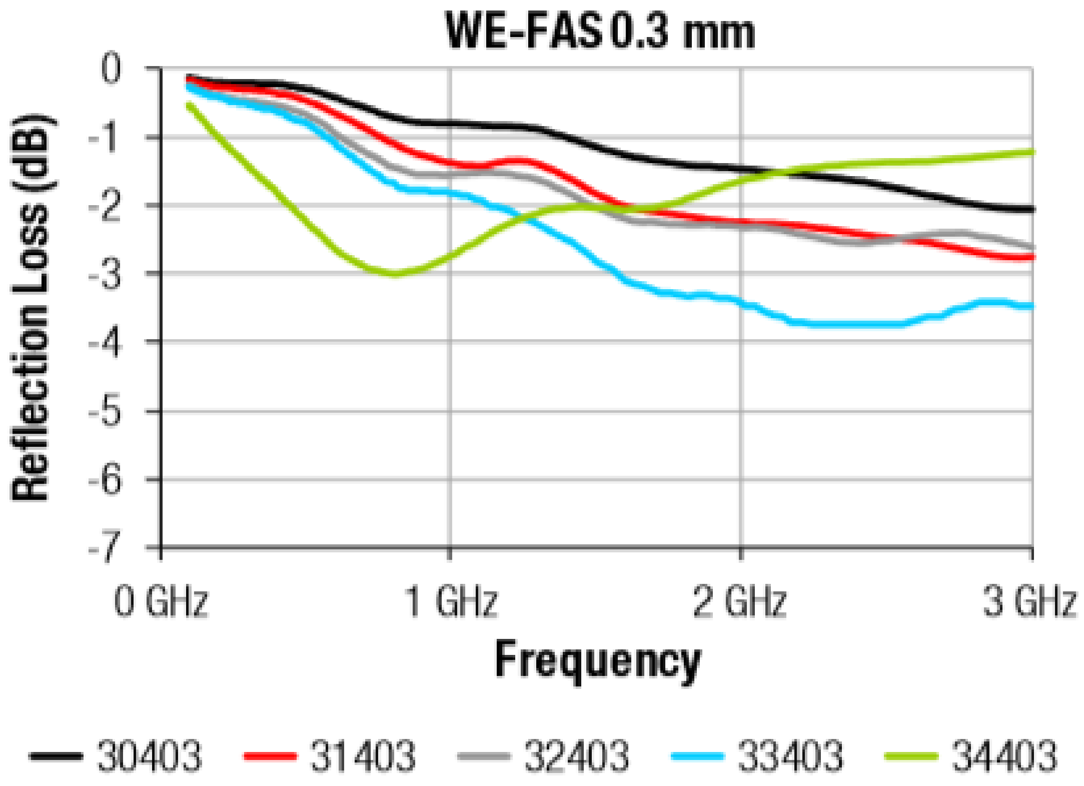
Übertragungsdämpfung als Funktion unterschiedlicher Materialien

WE-FAS und WE-FSFS

- Messmethoden
  - Koaxialleitungsmethode



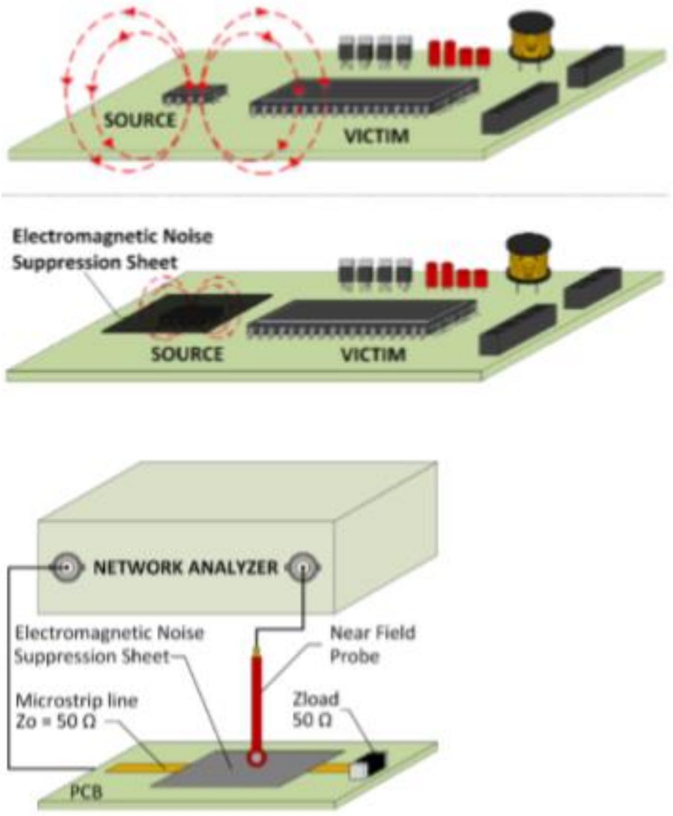


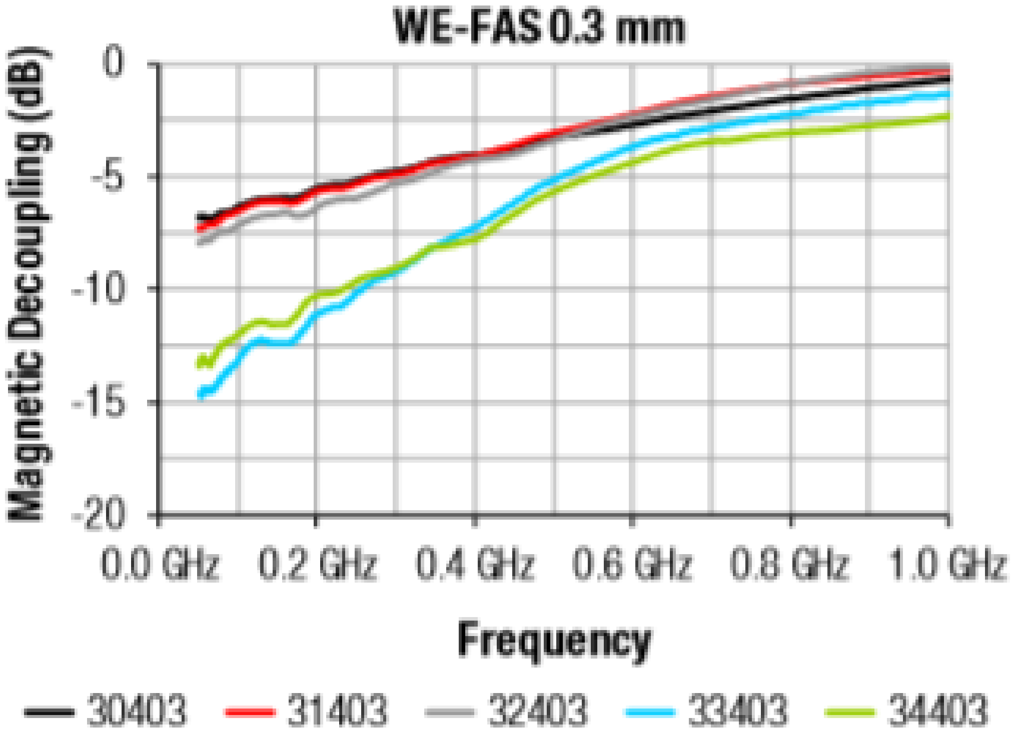


Reflexionsdämpfung als Funktion unterschiedlicher Materialien

WE-FAS und WE-FSFS

- Messmethoden
  - Magnetische Entkopplungsmethode





Magnetische Entkopplung als Funktion unterschiedlicher Materialien

Shielding

More informations

- Application Notes unter: https://www.we-online.com/web/en/electronic_components/produkte_pb/application_notes/Application_Notes.php

  - ANP016: Going Wireless with Magnetic Shielding
  - ANP022: Selection and Characteristics of WE-FSFS
  - ANP059: Characterization Methods for Flexible Absorber Sheets WE-FAS

- Literature:
  - Electromagnetic Compatibility Engineering - Henry Ott