USB 3.1

REFERENT: KLEMENS BEHR (FAE)
AUTOR: Robert Schillinger
Field Application Engineer

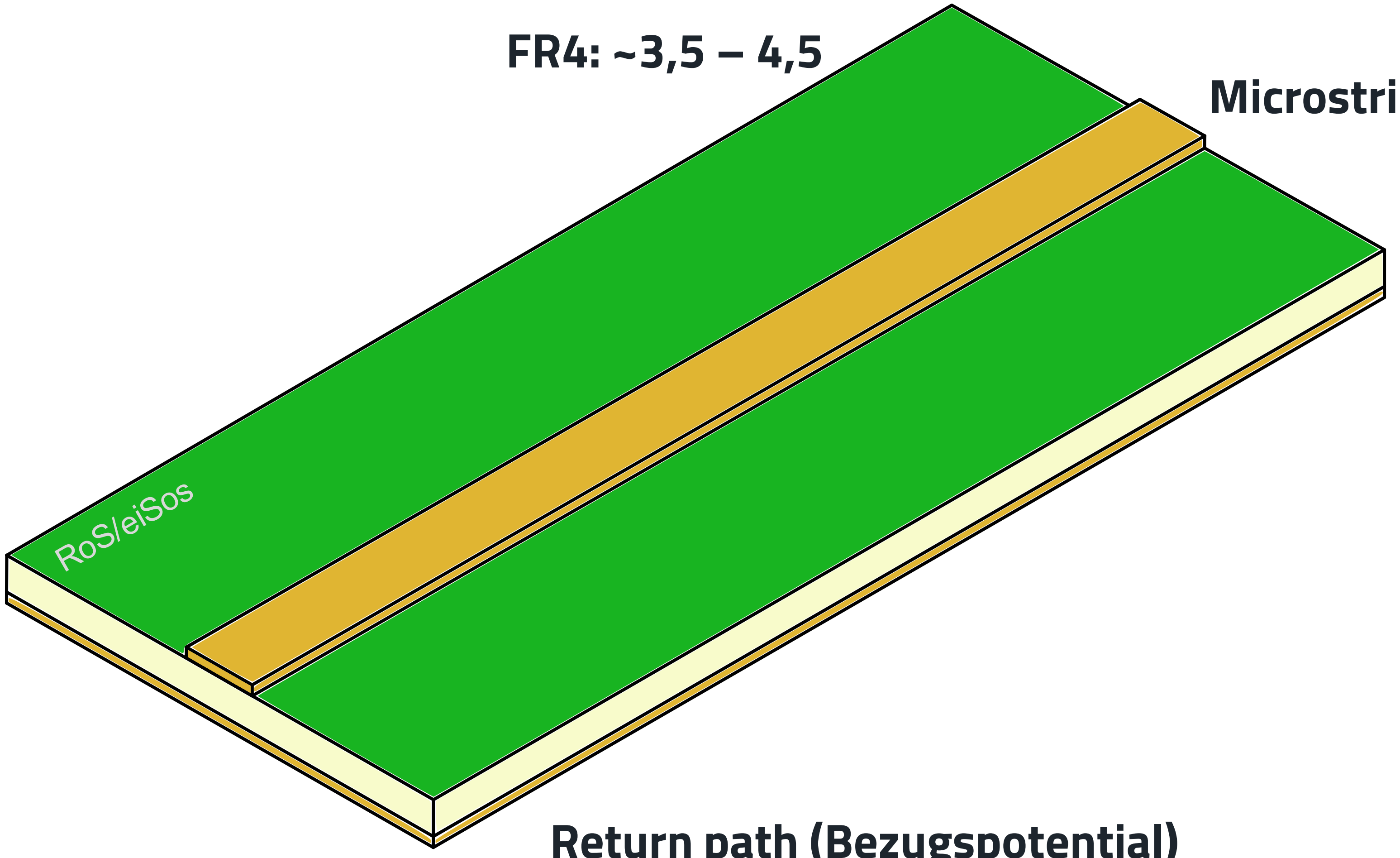
WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

- Grundlegende Betrachtungsweisen
  - Was ist eine Übertragungsleitung?
  - Was ist die charakteristische Impedanz?
  - Impedanz der Microstrip Line
- PCB-Aufbau
- Auswahl der Schutzkomponenten
- Type-C Filterboard
  - Blockdiagram
  - Leiterbahnführung (unterbrochene Bezugslage, Vias, ...)
- Einfluss der Schutzkomponenten auf die Signalqualität

GRUNDLAGEN

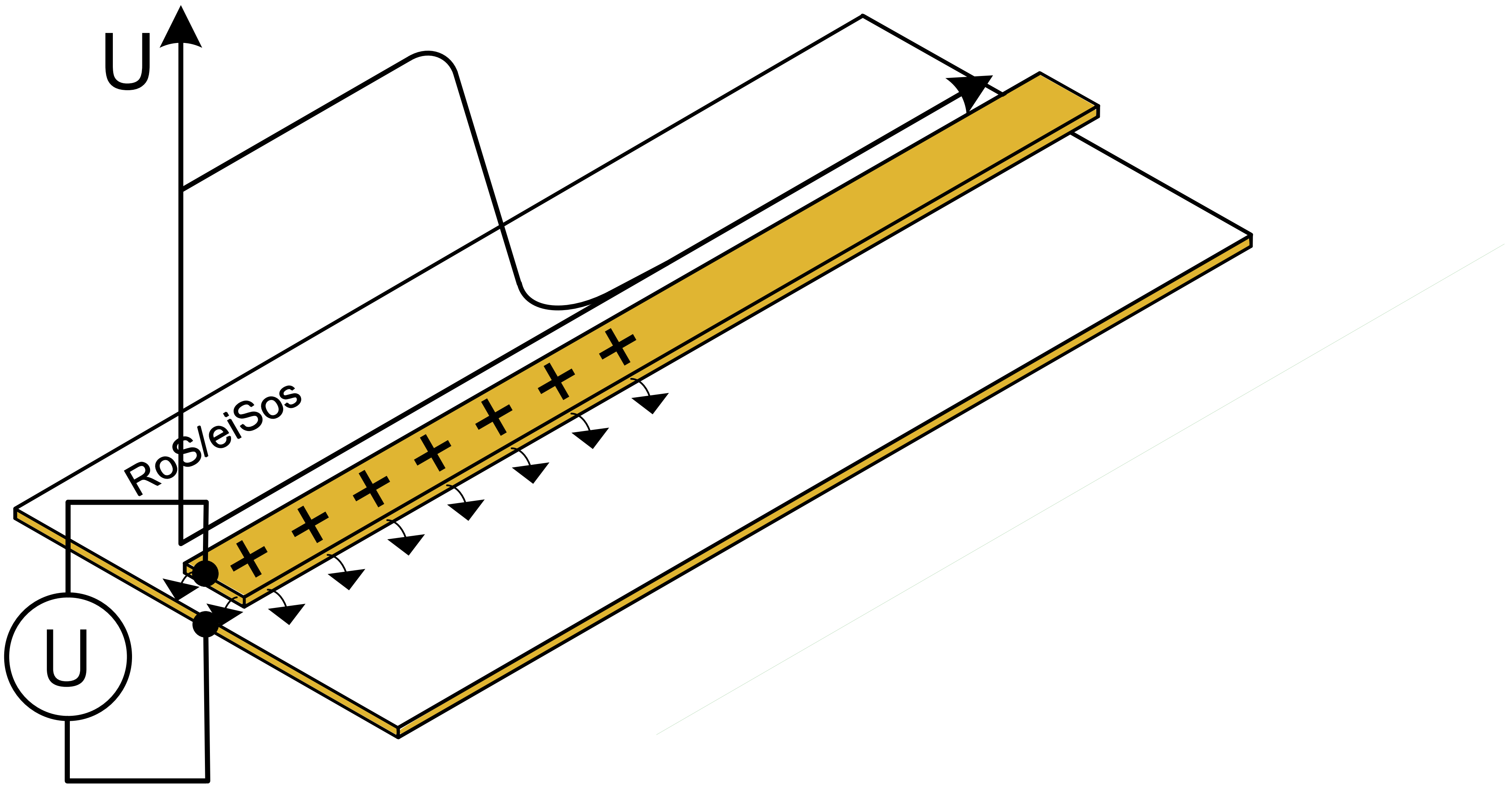
Grundlagen

Was ist eine Übertragungsleitung?



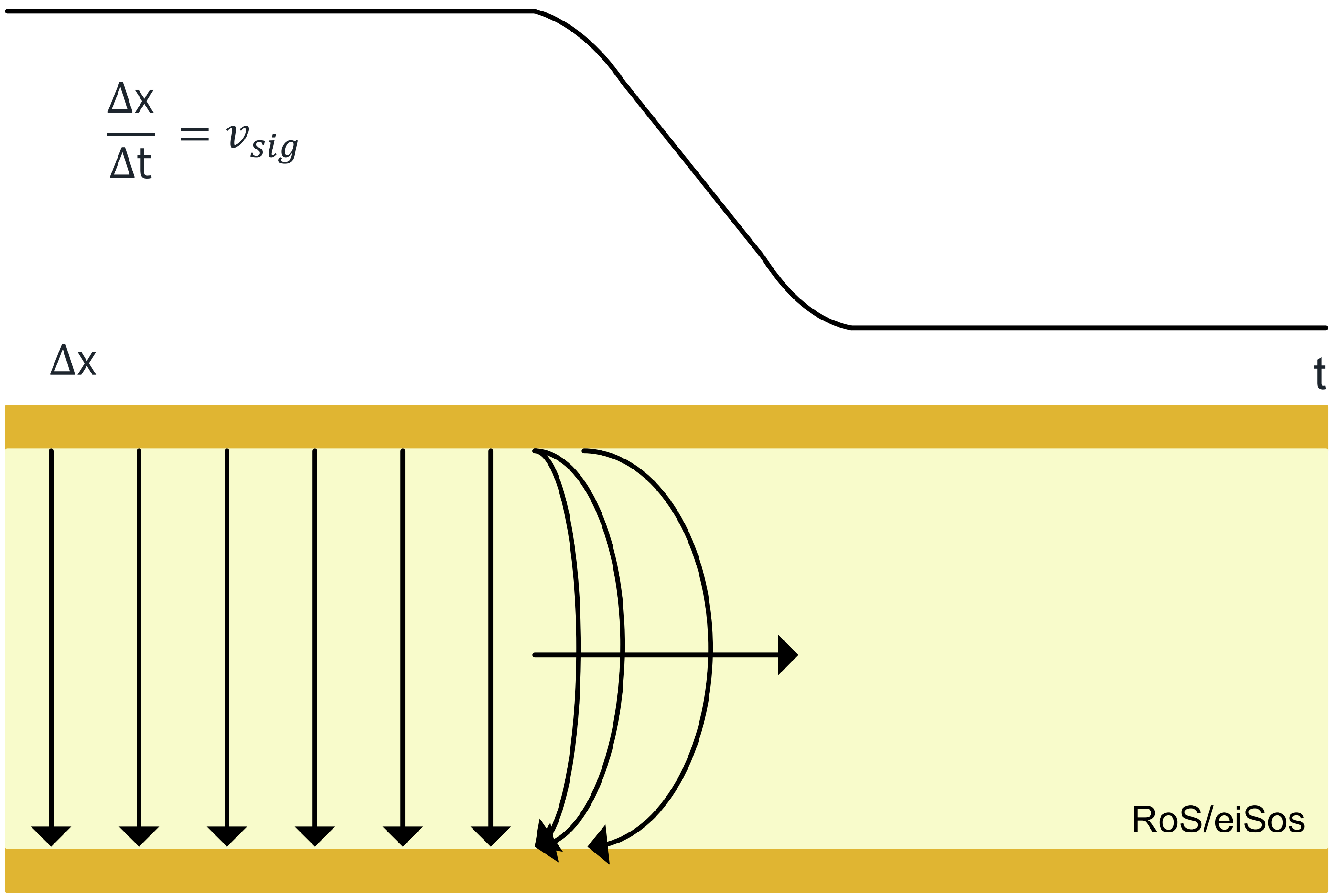
Grundlagen

Was ist eine Übertragungsleitung?



Grundlagen

Signalgeschwindigkeit



Grundlagen

Signalgeschwindigkeit

$$v_{sig} = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0} \cdot \sqrt{\varepsilon_r \cdot \mu_r}} = \frac{c_0}{\sqrt{\varepsilon_r \cdot \mu_r}}$$

$$v_{sig} = c_0 \approx 30 \frac{cm}{ns}$$

Annahme für FR4: $\varepsilon_r = 4$

$$v_{sig} = \frac{c_0}{\sqrt{\varepsilon_r \cdot \mu_r}} \approx 15 \frac{cm}{ns}$$

Grundlagen

Signalverzögerung

$$\text{Signallaufzeit} = \frac{1}{v_{sig}} = \frac{1}{15\,\frac{cm}{ns}} = 66{,}67 \cdot 10^{-3}\,\frac{ns}{cm} = 66{,}67\,\frac{ps}{cm}$$

$$\text{Twisted Pair Signallaufzeit} \sim 5\frac{ns}{m} \Rightarrow \varepsilon_r = 2$$

Grundlagen

Transitional Electrical Length

TEL = (RT or FT) · Signalgeschwindigkeit

z. B. RT of 30ps

TEL = 0,03ns · $15\frac{\text{cm}}{\text{ns}} = 0{,}45\text{cm}$

Ab einer Leitungslänge von etwa 20% von TEL spricht man von einer Übertragungsleitung und bekommt auch relevante Reflexionen!

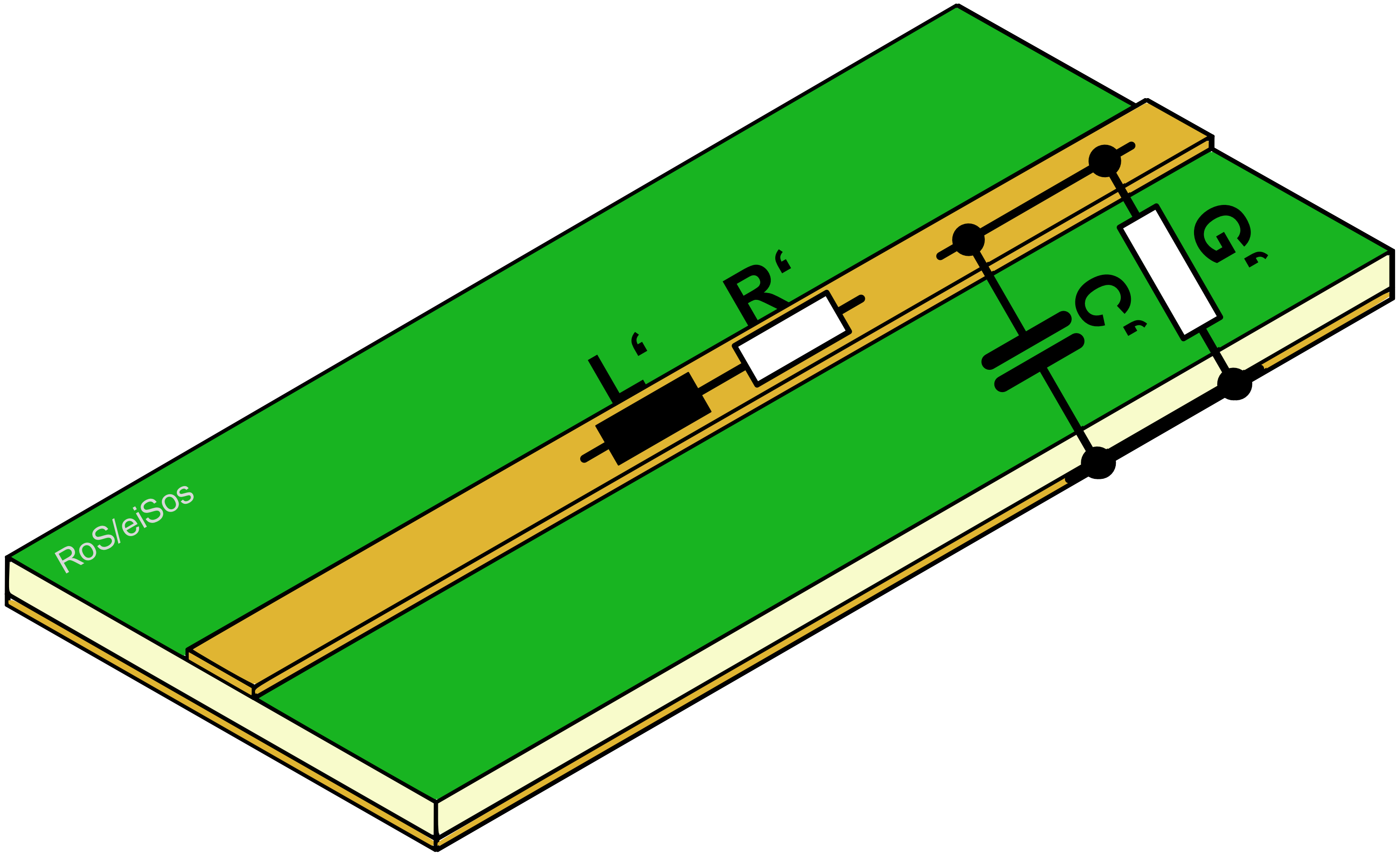
Grundlagen

Was ist die charakteristische Impedanz?

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

f -> 0: $Z_0 = \sqrt{\frac{R'}{G'}}$

f -> ∞: $Z_0 = \sqrt{\frac{L'}{C'}}$



Grundlagen

Charakteristische Impedanz

Ansatz: $Z = \frac{U}{I}$

für $I = \frac{\Delta Q}{\Delta t}$ mit $\Delta Q = \Delta C \cdot U$ und $\Delta C = C' \cdot v \cdot \Delta t$

$$I = \frac{C' \cdot v \cdot \Delta t \cdot U}{\Delta t} = C' \cdot v \cdot U$$

$$Z = \frac{U}{I} = \frac{U}{C' \cdot v \cdot U} = \frac{1}{C' \cdot v}$$

Ergebnis: $C' = \frac{1}{Z_0 \cdot v_{sig}}$

Annahme für FR4: $\varepsilon_r = 4$

$$C' = \frac{1}{87\Omega \cdot 15\frac{cm}{ns}} = 766\frac{pF}{m} = 7{,}7\frac{pF}{cm}$$

$$L' = 580\frac{nH}{m} = 5{,}8\frac{nH}{cm}$$

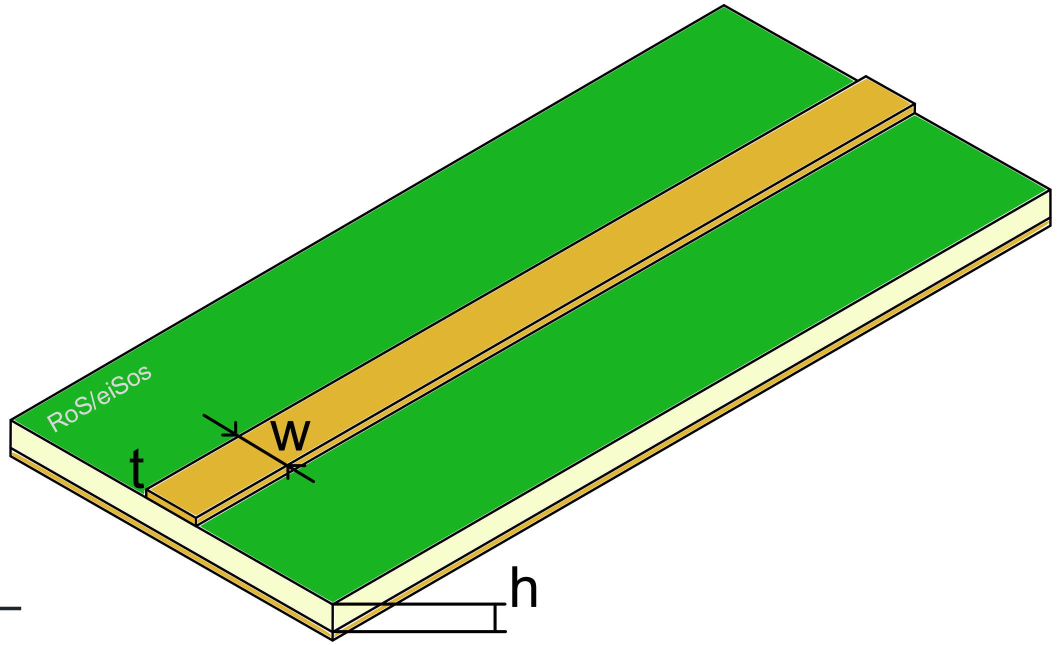
Grundlagen

Impedanz der Microstrip Leitung

$$L = L' \cdot l \cdot \ln\left(\frac{5{,}98 \cdot h}{0{,}8 \cdot w + t}\right)$$

$$C = C' \cdot l \cdot \frac{(\varepsilon_r + 1{,}41)}{\ln(\frac{5{,}98 \cdot h}{0{,}8 \cdot w + t})}$$

$$Z = \sqrt{\frac{L'}{C'}} \cdot \sqrt{\frac{x^2}{\varepsilon_r + 1{,}41}} = Z_0 \cdot \sqrt{\frac{1}{\varepsilon_r + 1{,}41}} \cdot x$$



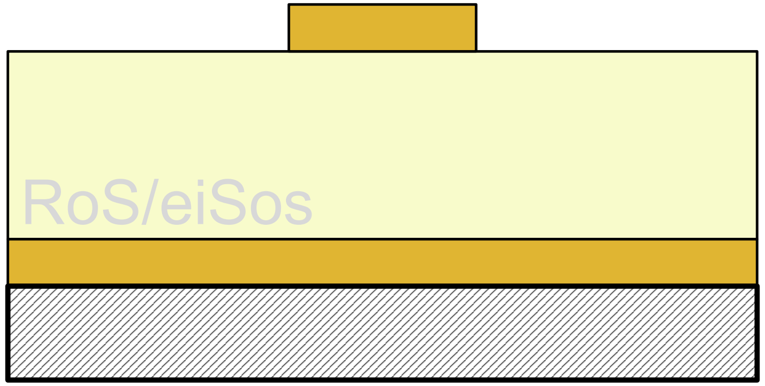
=> h ↑ ▶ *Z* ↑

=> w ↑ ▶ *Z* ↓

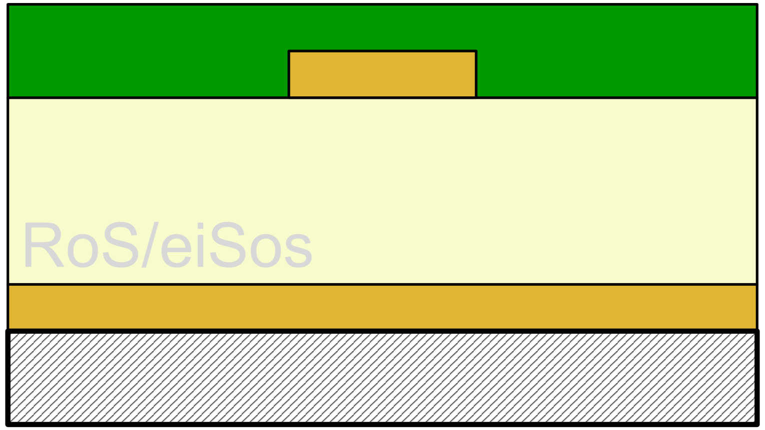
PCB-AUFBAU

PCB-Aufbau

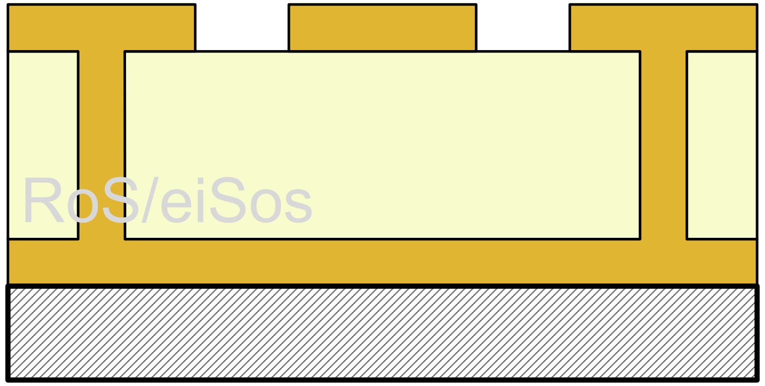
Single-Ended builds – Microstrip



Surface Microstrip



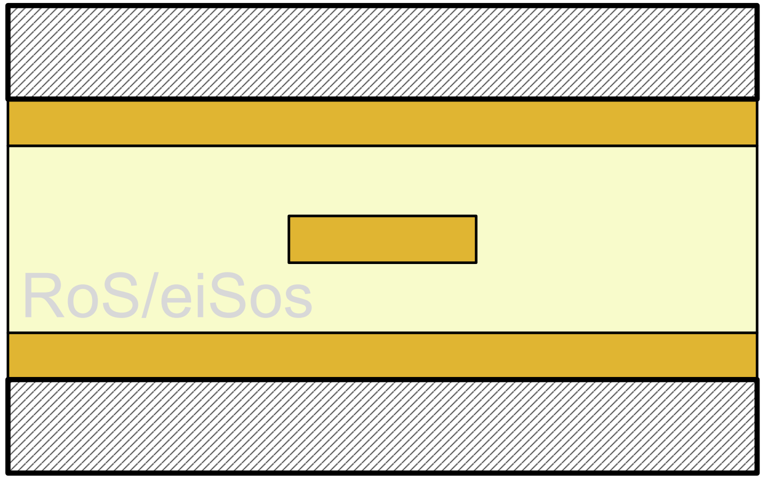
Coated Microstrip



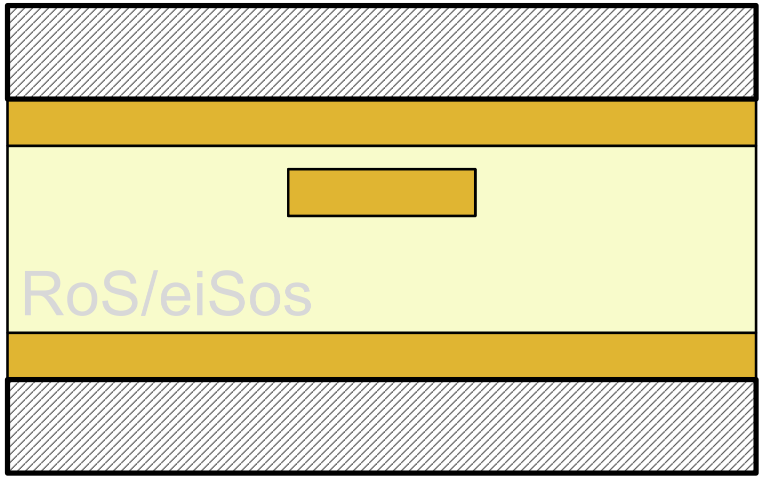
Grounded coplanar waveguide

PCB-Aufbau

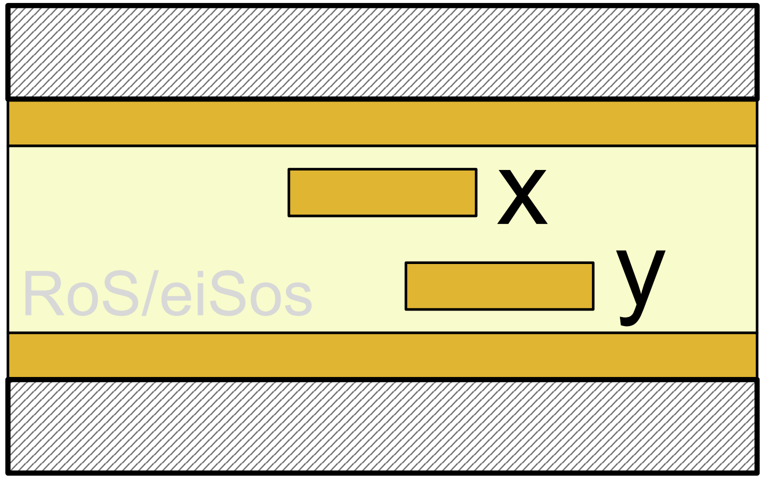
Single-Ended builds – Stripline



Symetric



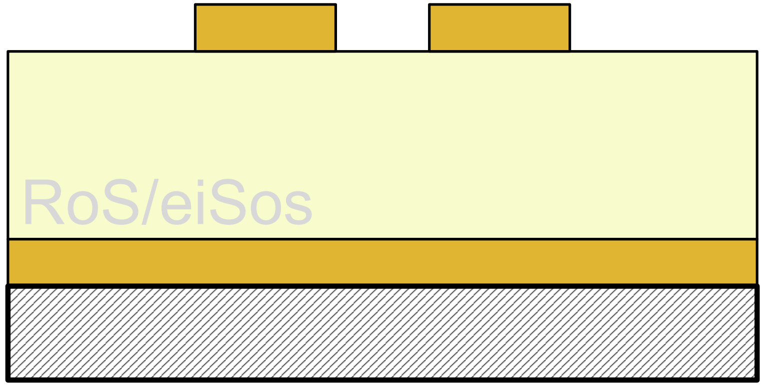
Asymetric



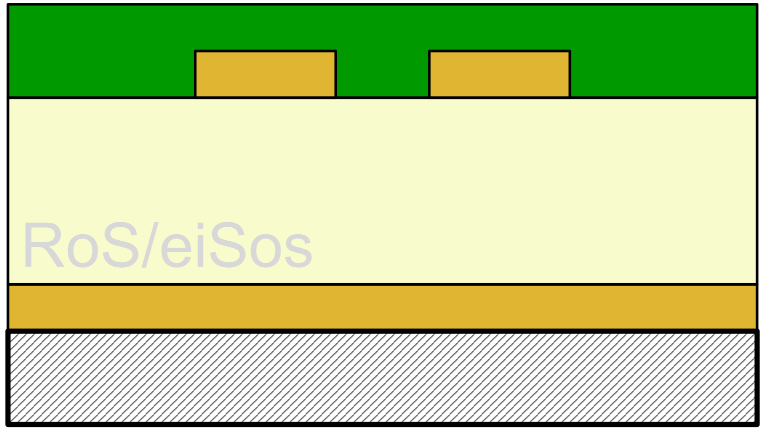
Dual
(x-y orientation)

PCB-Aufbau

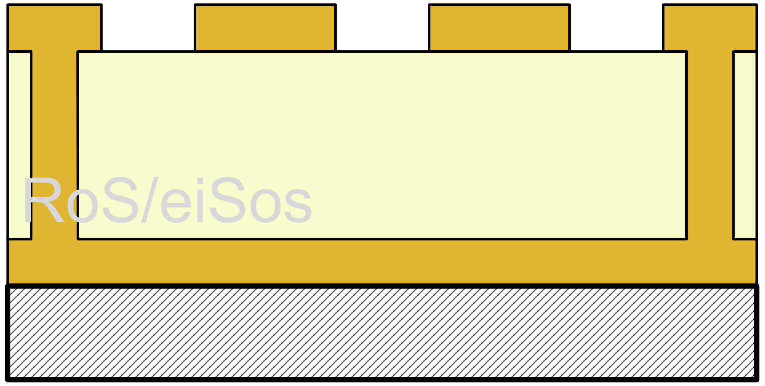
Differential builds – Microstrip



Edge-coupled



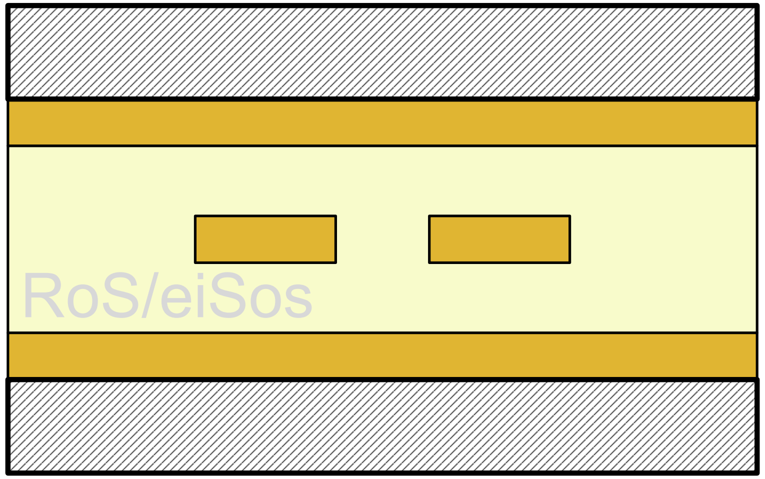
Edge-coupled
with coating



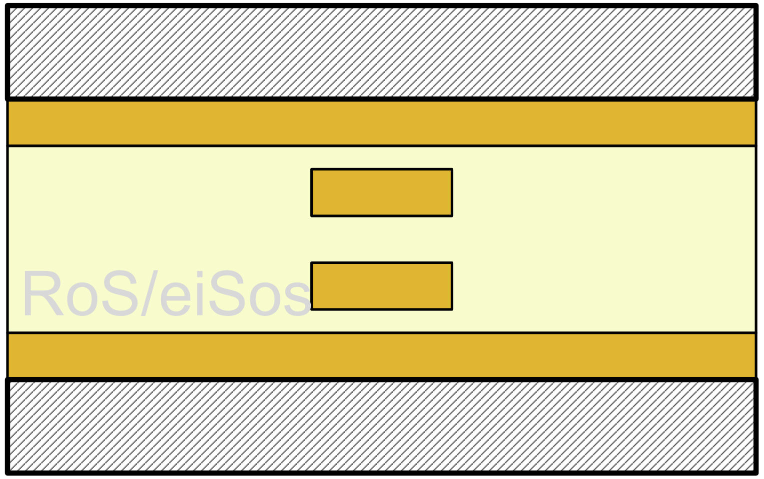
Grounded coplanar waveguide

PCB-Aufbau

Differential builds – Stripline



Edge-coupled



Broadside-coupled

PCB-Aufbau

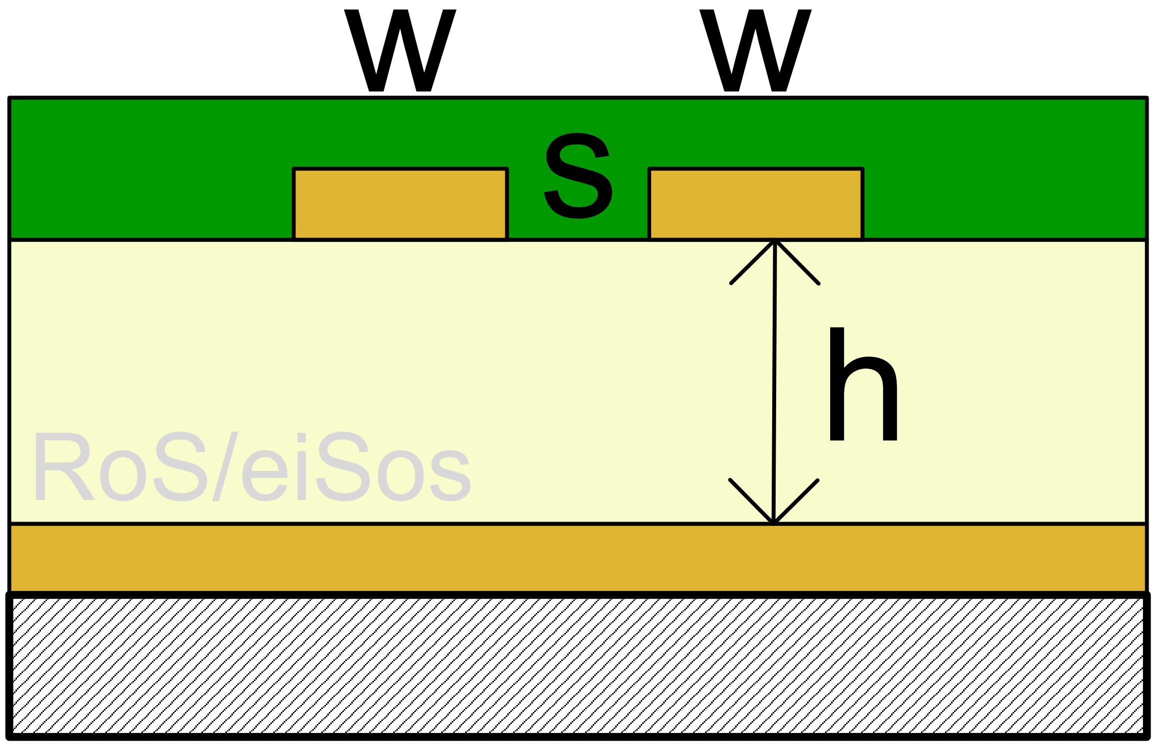
Zusammenhänge

$$Z_{diff} = 2 \cdot Z \cdot \left[1 - 0{,}48 \cdot e^{\left(-0{,}96 \cdot \frac{s}{h}\right)}\right]$$

[ ] ≈ 0,8

$$=> Z_{diff} \approx 1{,}6 \cdot Z$$

=> h ↑ ▶ Z ↑
=> w ↑ ▶ Z ↓
=> s ↑ ▶ Z ↑



PCB-Aufbau

Zusammenfassung

- Viele verschiedene Aufbaumöglichkeiten
- Viele Parameter, die verändert werden können

- Um gute Ergebnisse zu erhalten sollten bereits vor dem Design Gespräche mit dem Leiterplattenhersteller bezüglich Layerstack und Materialien geführt werden.

- Für genaue Ergebnisse der Impedanzberechnung spielen sehr viele Parameter eine Rolle. Hier helfen Softwaretools (2D/3D-Solver), die sehr genaue Berechnungen liefern können.

BAUTEILAUSWAHL

Bauteilauswahl

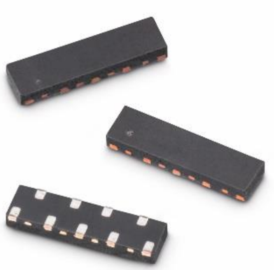
- Störungsunterdrückung auf den diff. Paaren
  - CMC für USB2.0
  - CMC für USB3.x


744231091

7442335600


748020024


- Schutz vor Überspannung durch elektrostatische Entladung
  - TVS Diode für Controls und USB2.0
  - TVS Diode für USB3.x
  - TVS Diode für Spannungsversorgung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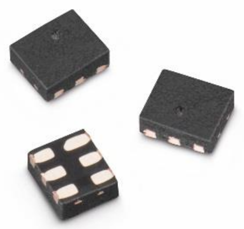
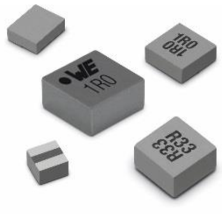

824012823


824045810

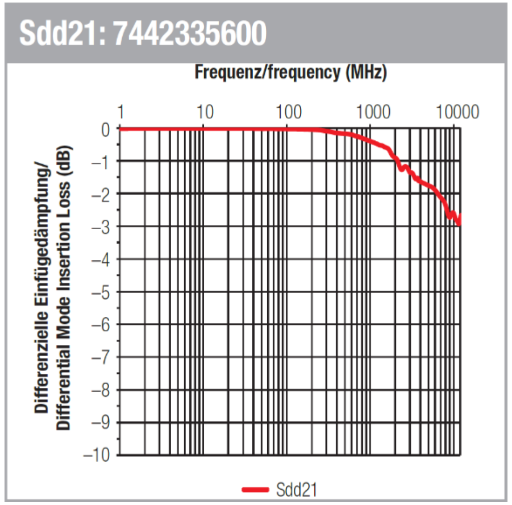
- Filterung der Versorgungsspannung
  - HF/NF Kombination mit Chip-Bead und Induktivität

74279226101

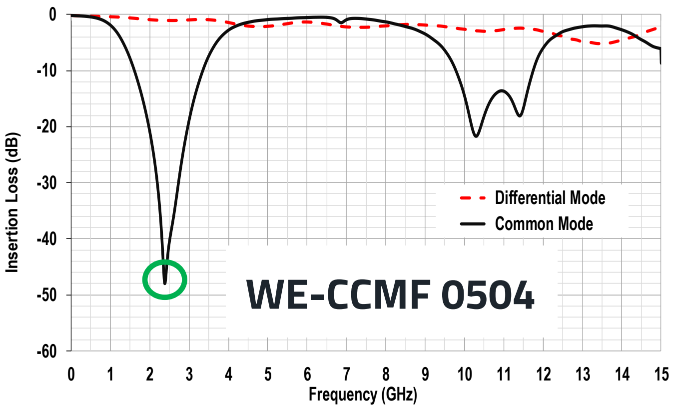

885012107018


74438356012


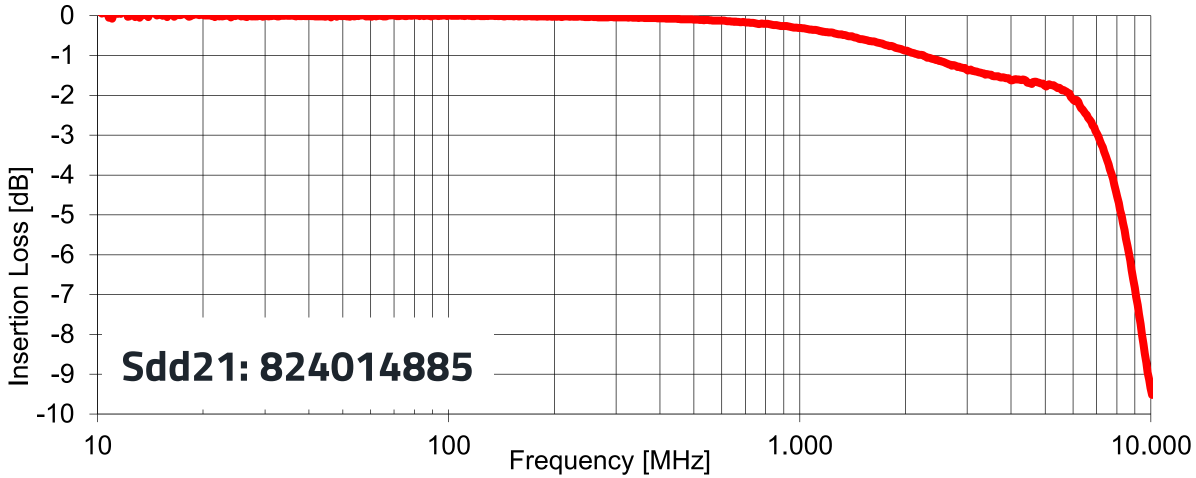
Bauteilauswahl

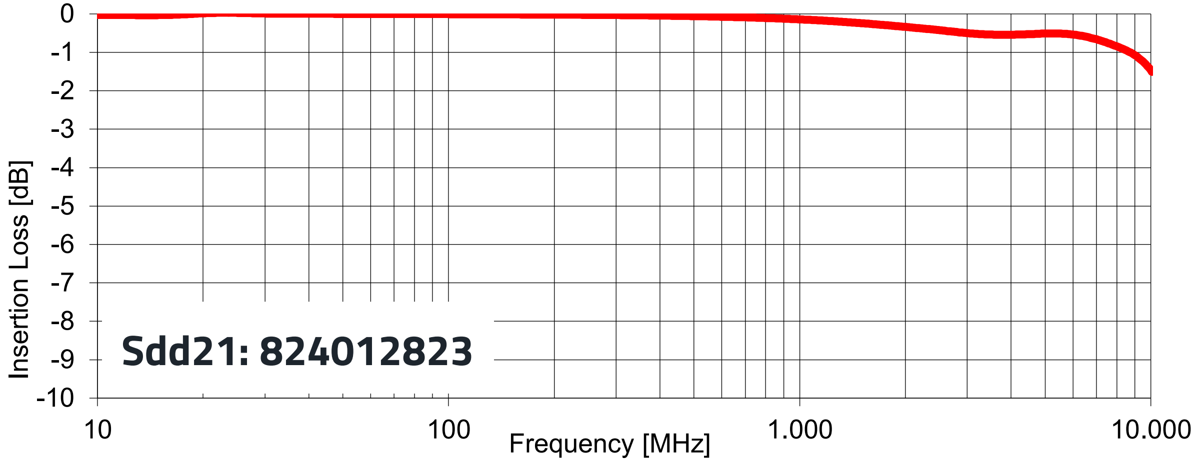


WE-CNSW HF 0504



WE-CCMF 0504

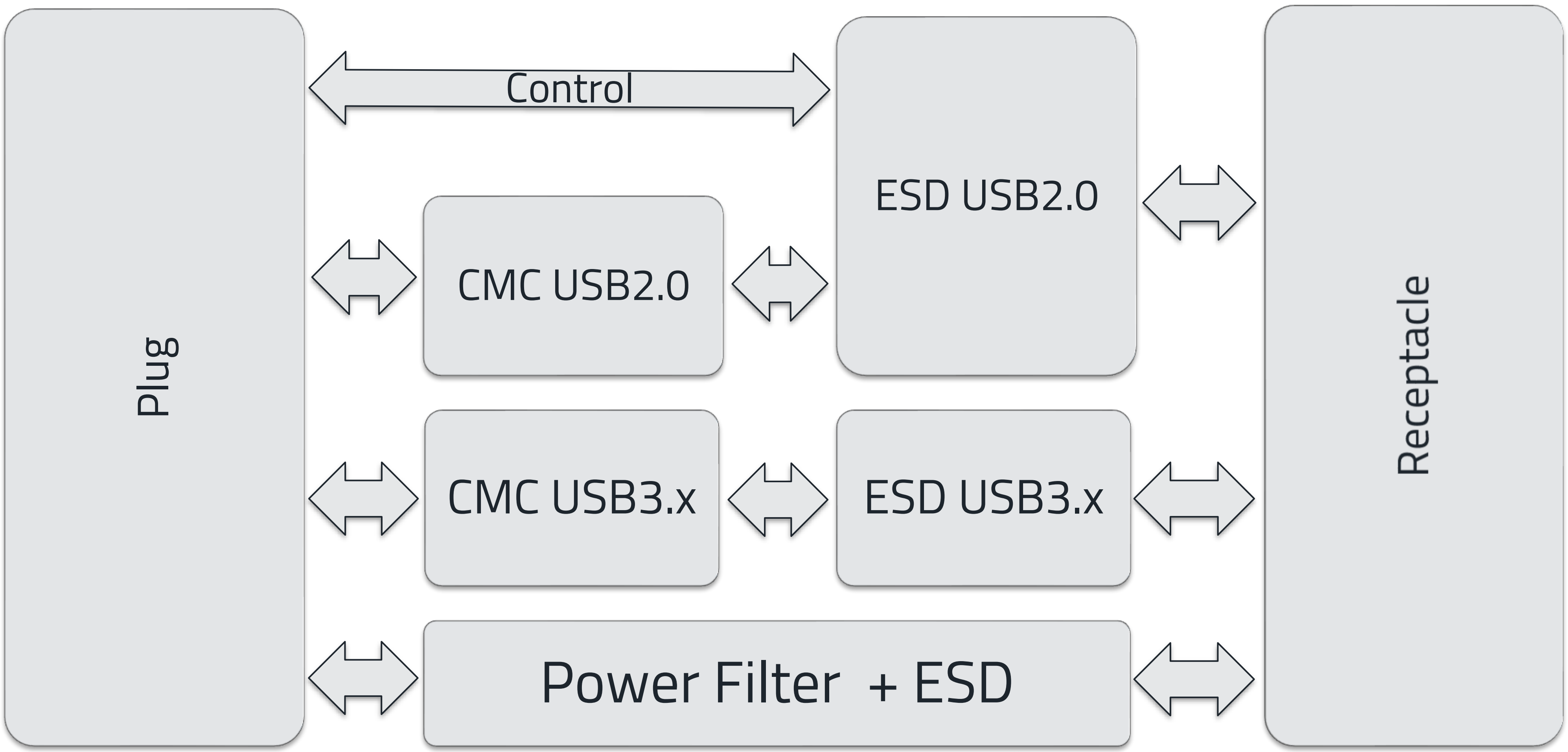




TYPE-C FILTERBOARD

Type-C Filterboard

Blockdiagramm



Type-C Filterboard

Übersicht

WE-CNSW HF
0504 60 Ohm
7442335600

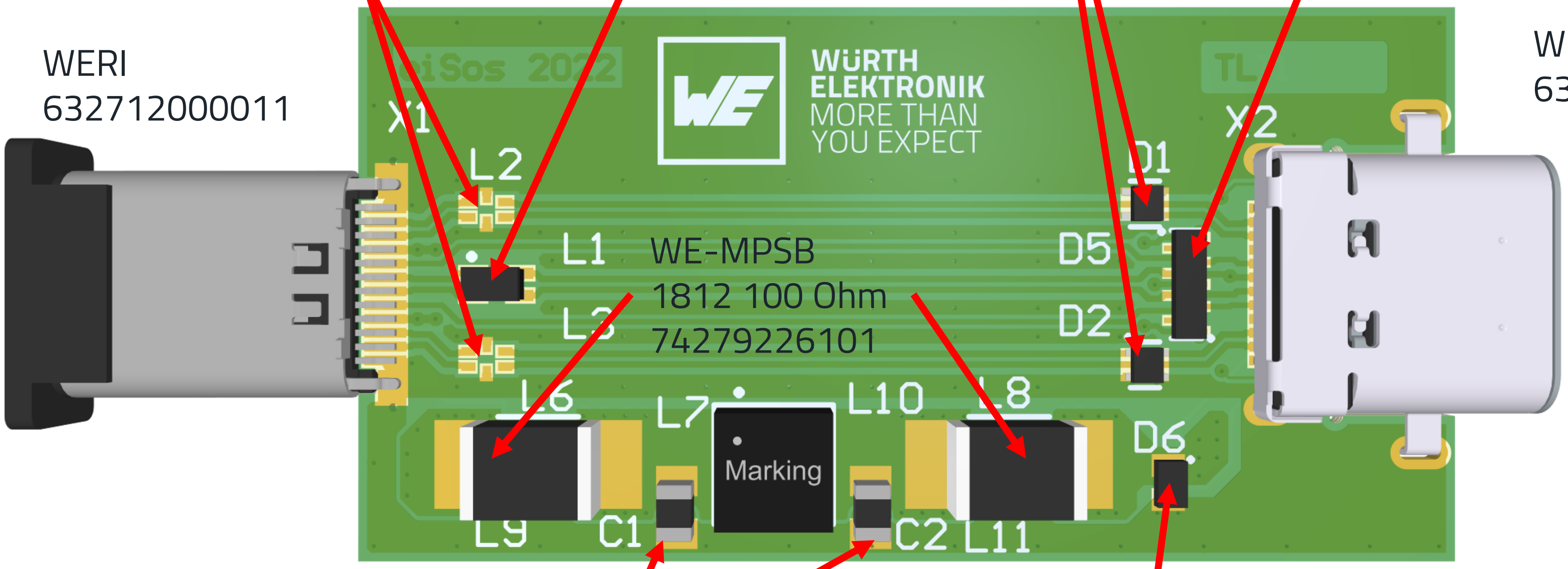
WE-CNSW
0805 90 Ohm
744231091

WE-TVS
DFN1210
824012823

WE-TVS
DFN3810
824014885

WERI
632712000011

WERI
632723130112



WE-MPSB
1812 100 Ohm
74279226101

WCAP-CSGP
0805 4,7µF/25V
885012107018

WE-MAPI
4020 1,2µH
74438356012

WE-TVS
DFN1610
824045810

Type-C Filterboard

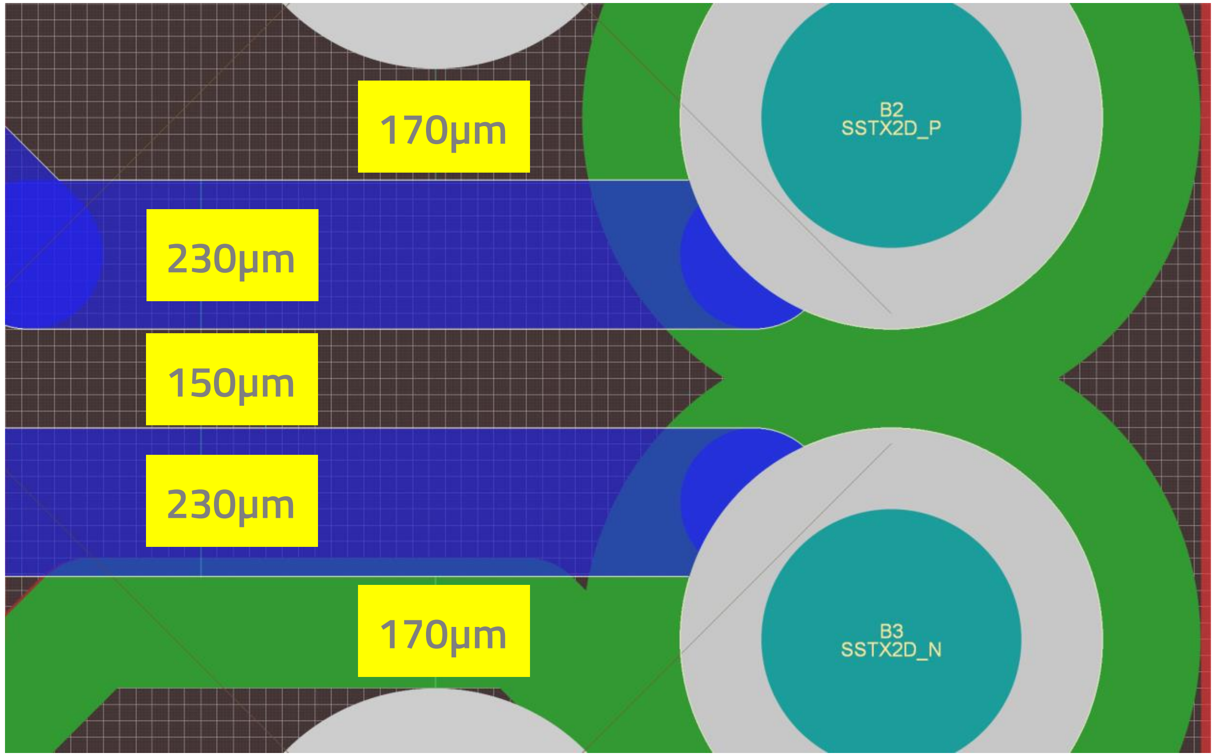
Bestellnummern

- Stick mit 60W PD: 82931060
- Mustertüte mit allen Komponenten für 60W: 82931061

- Stick mit 100W PD: 82931100
- Mustertüte mit allen Komponenten für 100W: 82931101

Type-C Filterboard

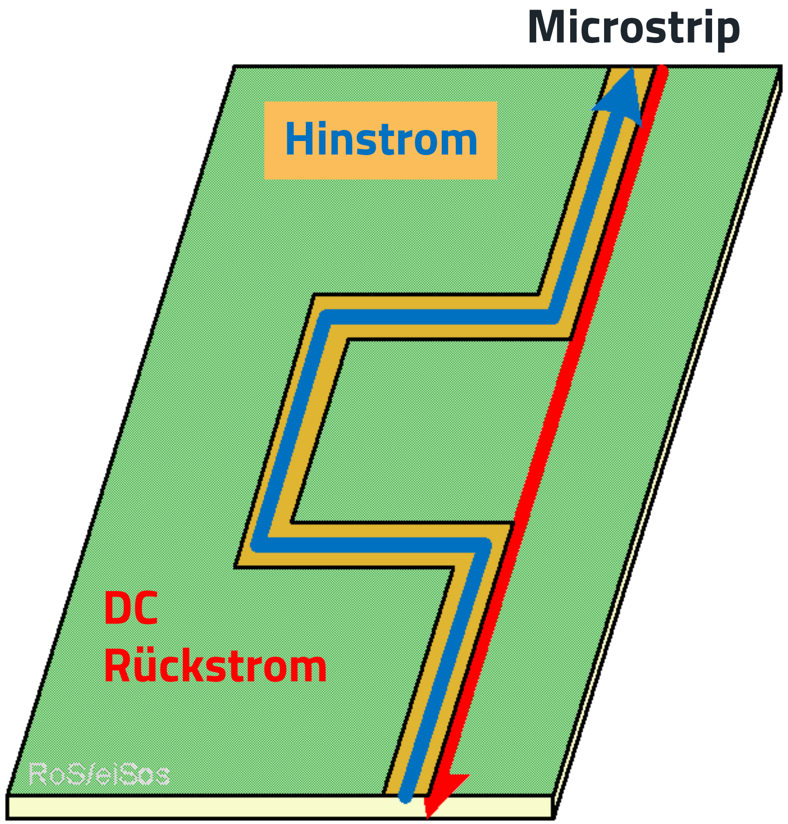
PCB Aufbau



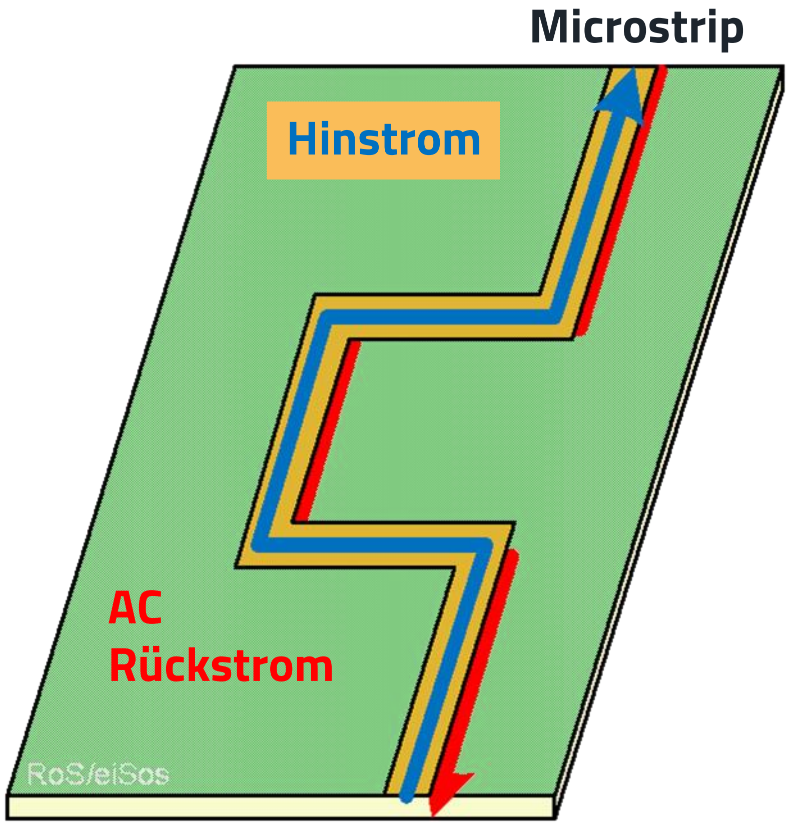
#	Name	Material	Type	Weight	Thickness	Dk	Df
	Top Overlay		Overlay				
	Top Solder	SM-001	Solder Mask		0.03mm	3.5	0.03
1	Top Side	CF-004	Signal	1oz	0.035mm		
	Dielectric 2	PP-010	Prepreg		0.177mm	4	0.02
2	Ref Ground TS	CF-004	Plane	1oz	0.035mm		
	Dielectric 3	Core-028	Core		0.25mm	4.1	0.02
3	Ref Ground BS	CF-004	Plane	1oz	0.035mm		
	Dielectric 5	PP-010	Prepreg		0.177mm	4	0.02
4	Bottom Side	CF-004	Signal	1oz	0.035mm		
	Bottom Solder	SM-001	Solder Mask		0.03mm	3.5	0.03
	Bottom Overlay		Overlay				

Type-C Filterboard

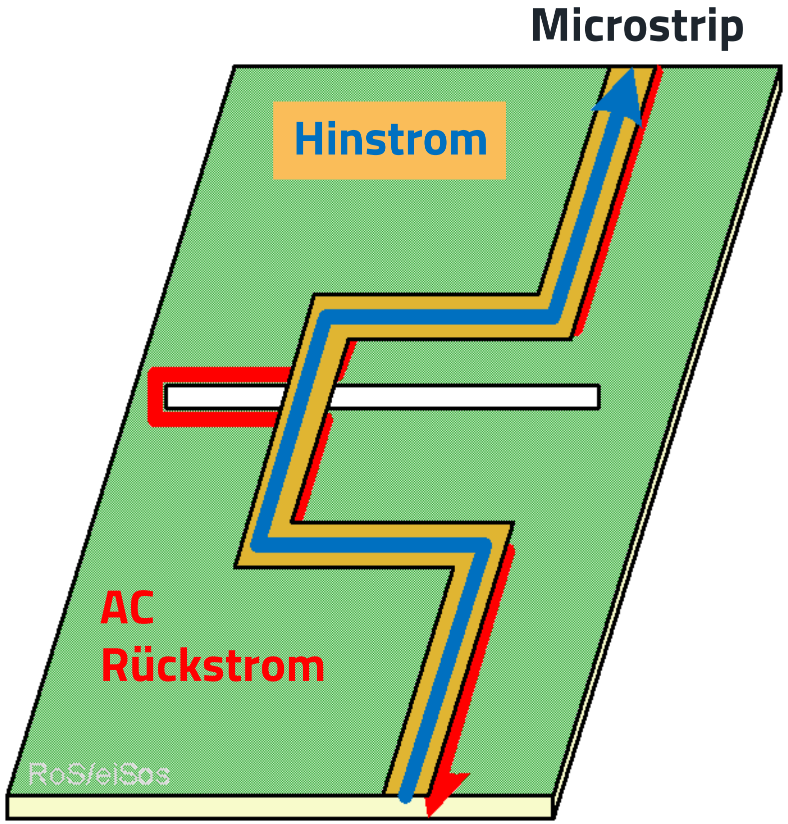
Rückstrom sucht die geringste Impedanz



Rückleiter



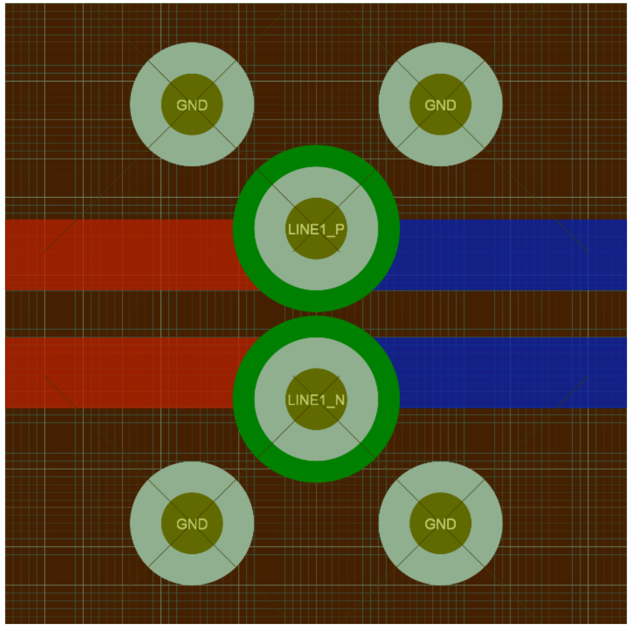
Rückleiter

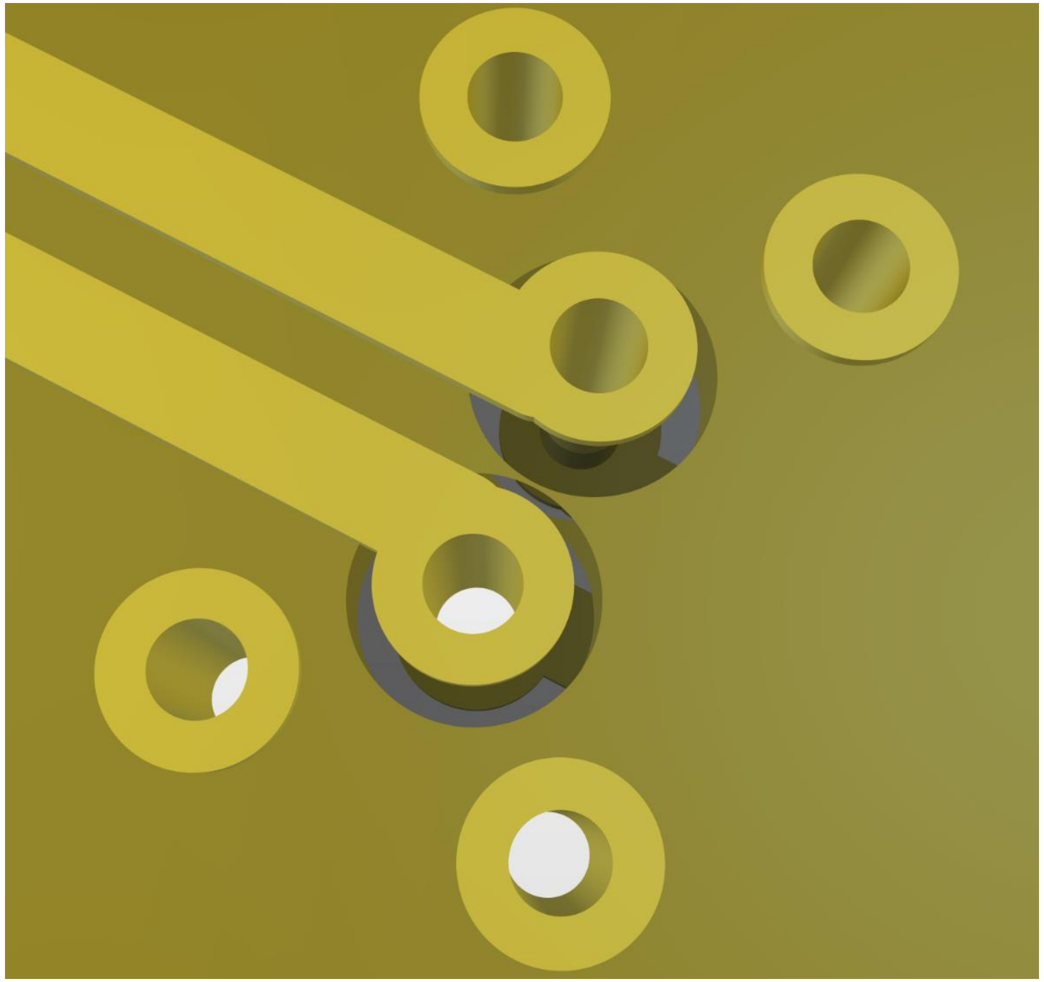


Rückleiter geschlitzt

Type-C Filterboard

Designregeln





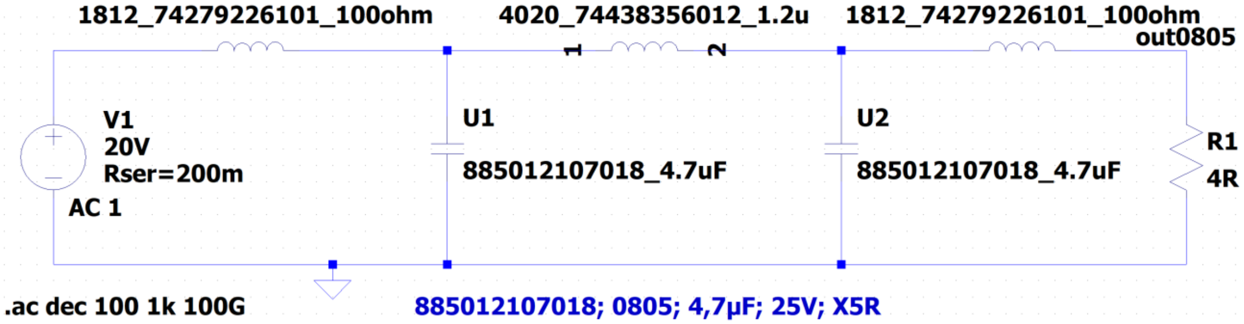
Type-C Filterboard

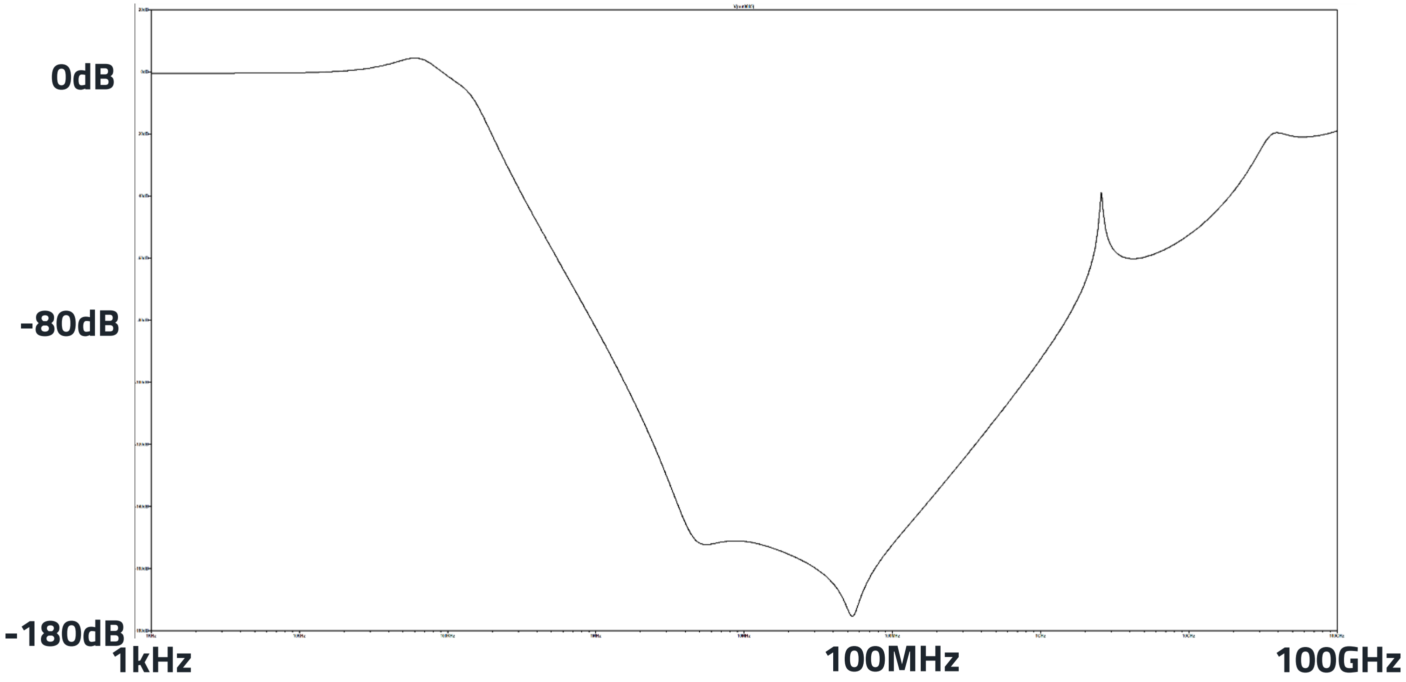
PD Filter

- Breitbandfilter für den PD Pfad
- Ausgelegt für 100W

- Temperaturen an L4 bei:
  - 5V/1,5A: 24,3°C
  - 5V/3A: 35,1°C
  - 20V/5A: 64,9°C

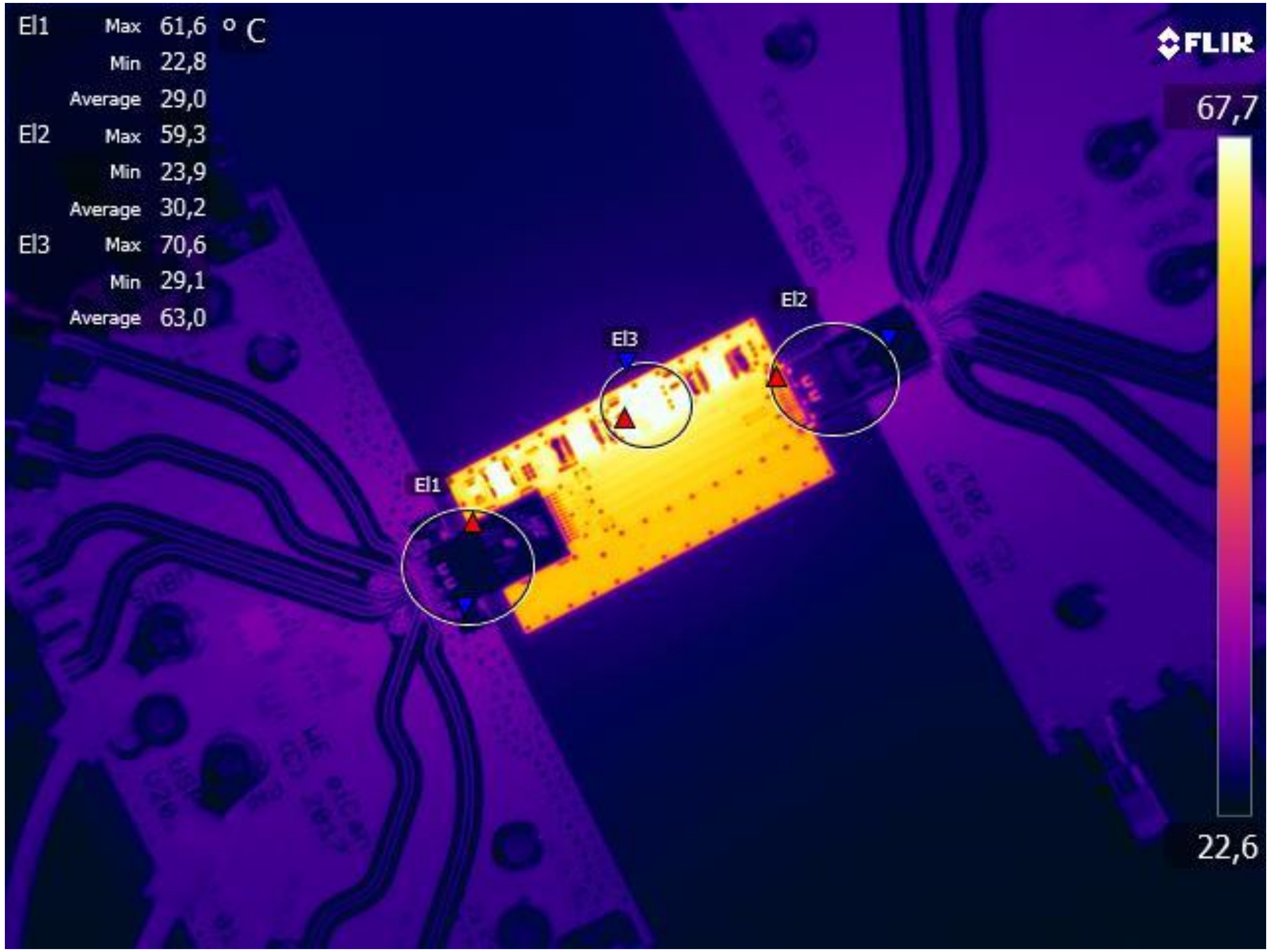
- Spannungsabfall über Filter:
  - @1,5A: 40mV
  - @3A: 89mV
  - @5A: 156mV





Type-C Filterboard

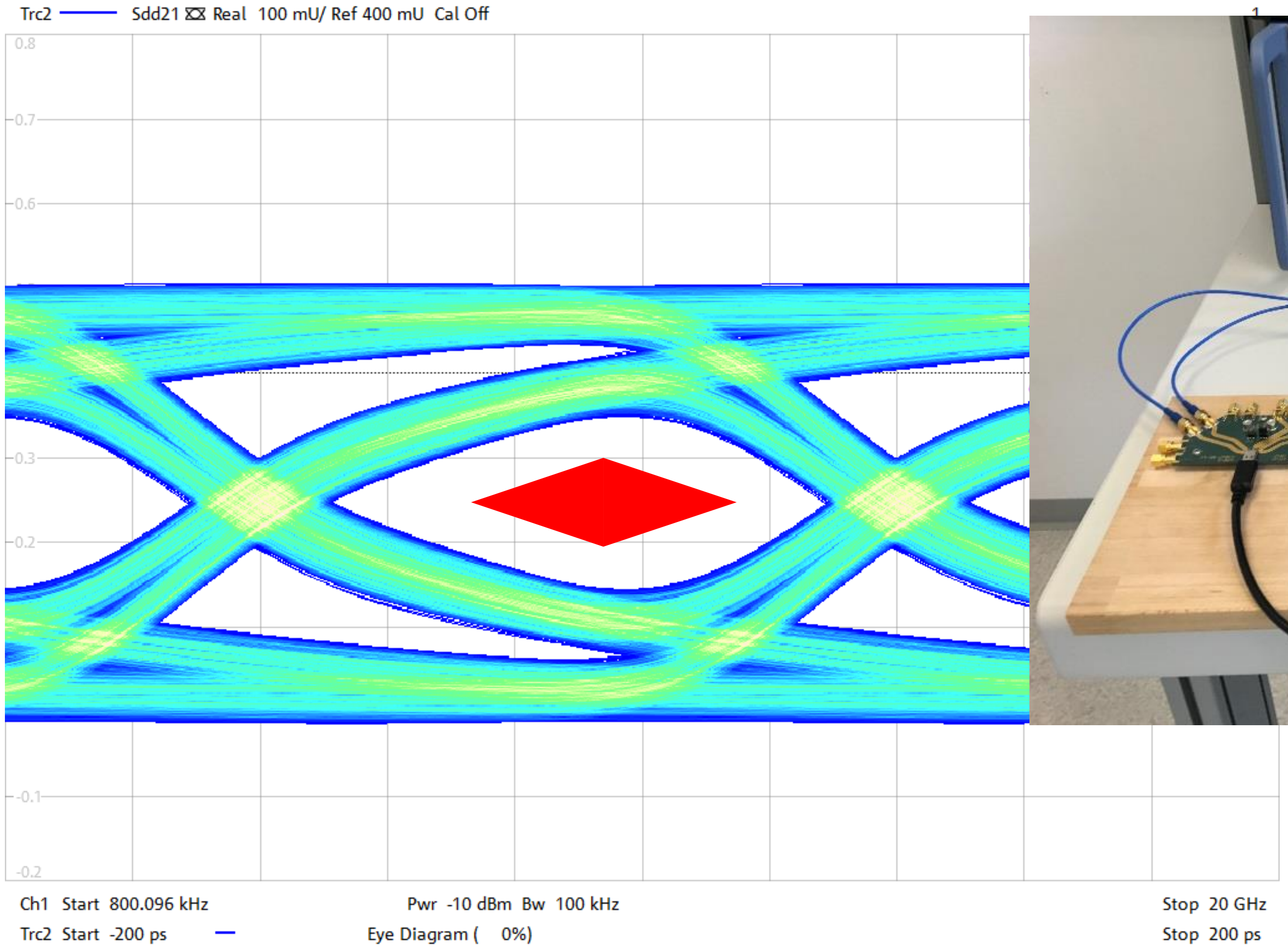
Erwärmung

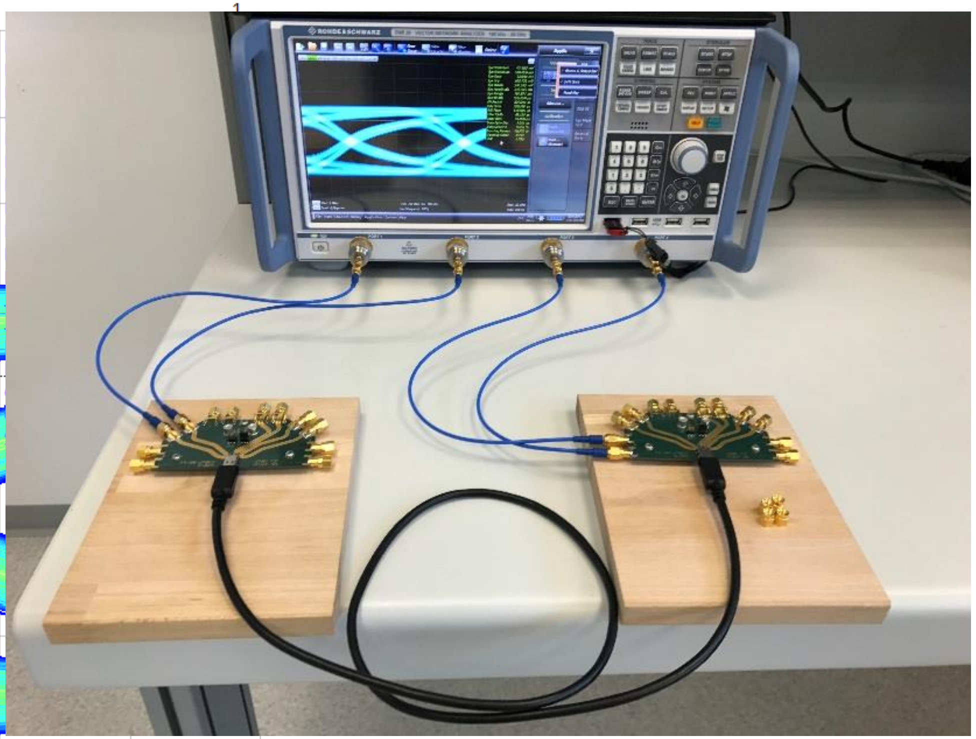


MESSUNGEN

Messungen

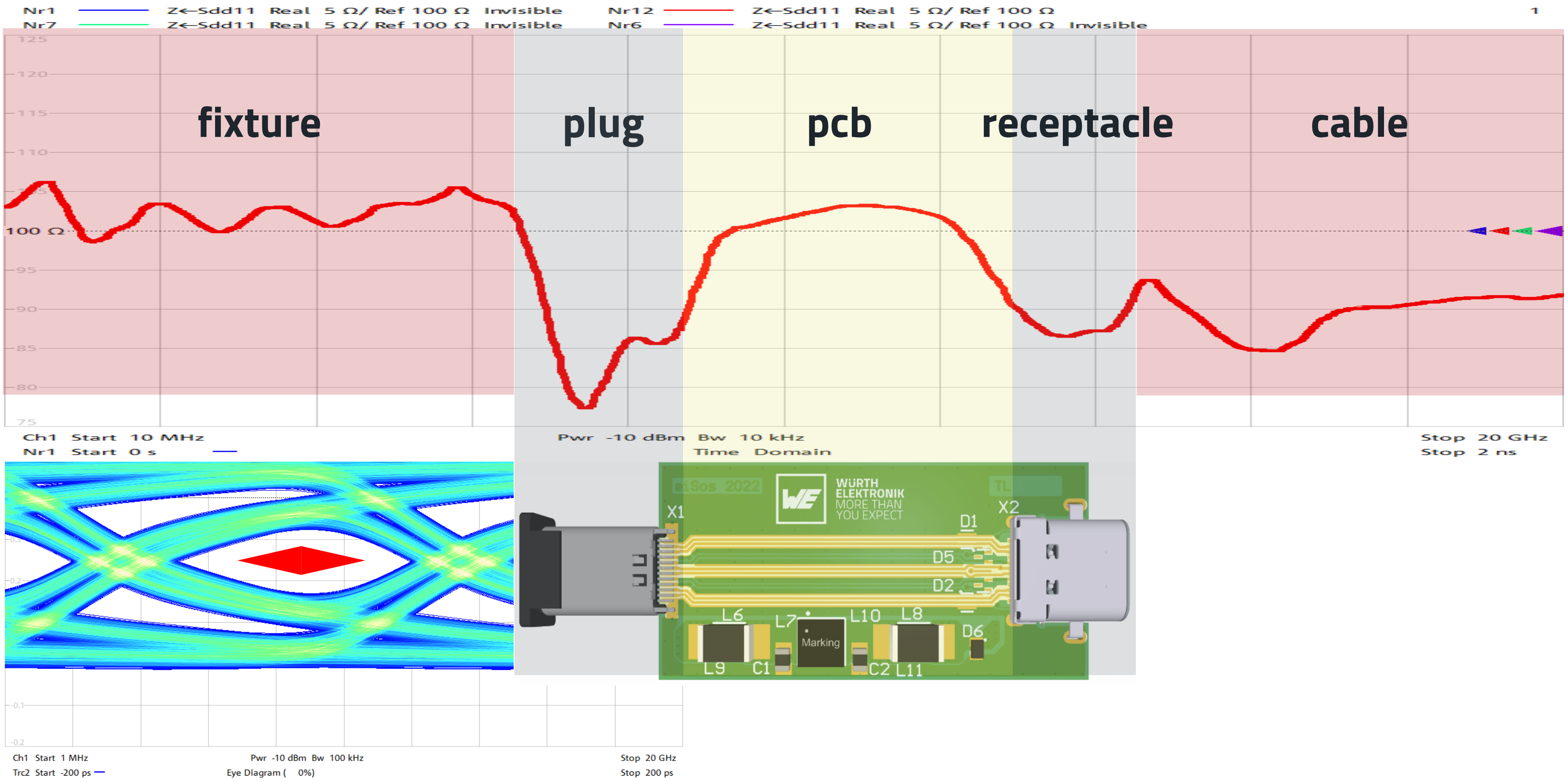
Messaufbau





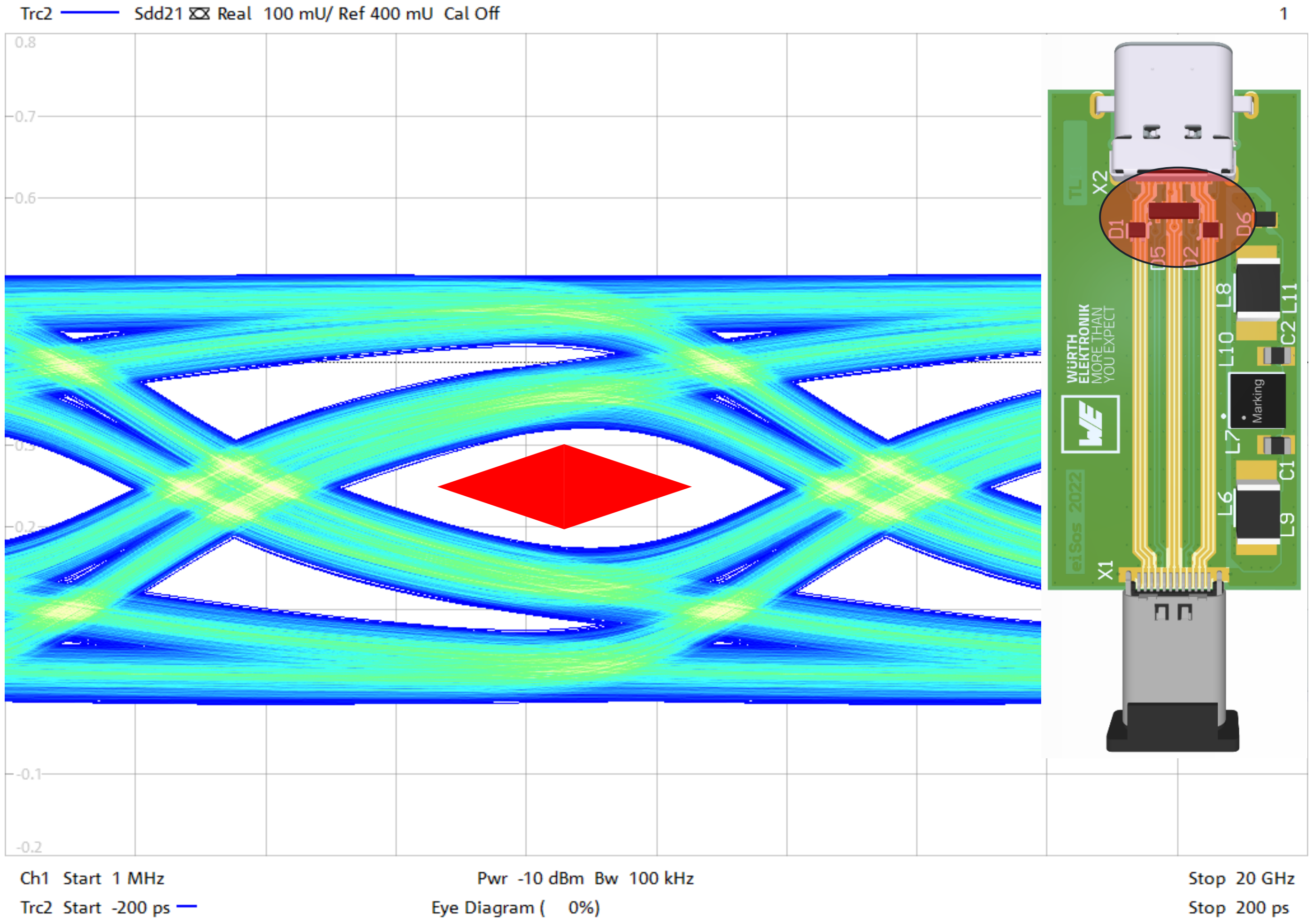
Messungen

Filteradapter – leer



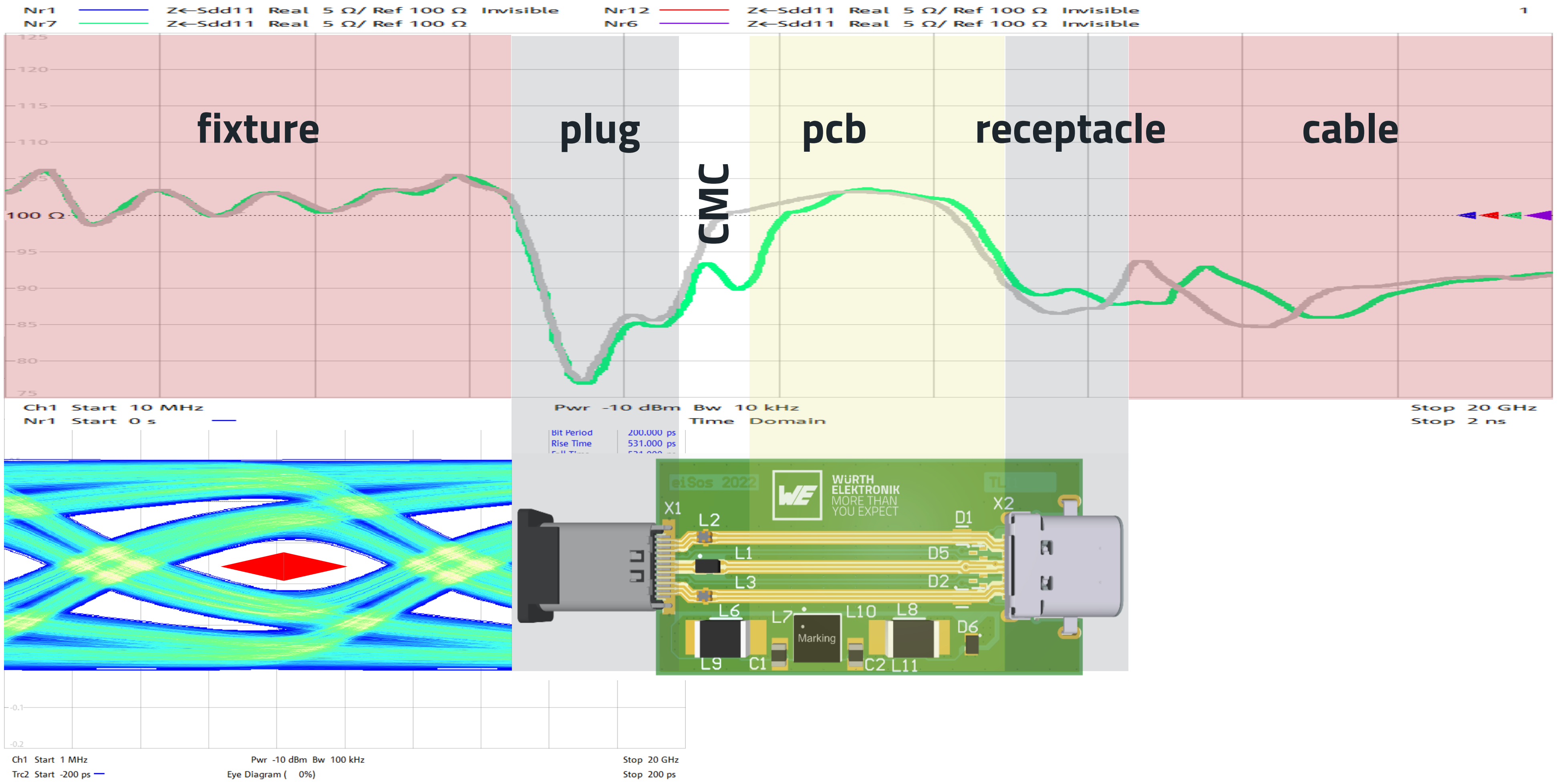
Messungen

Filteradapter – ESD



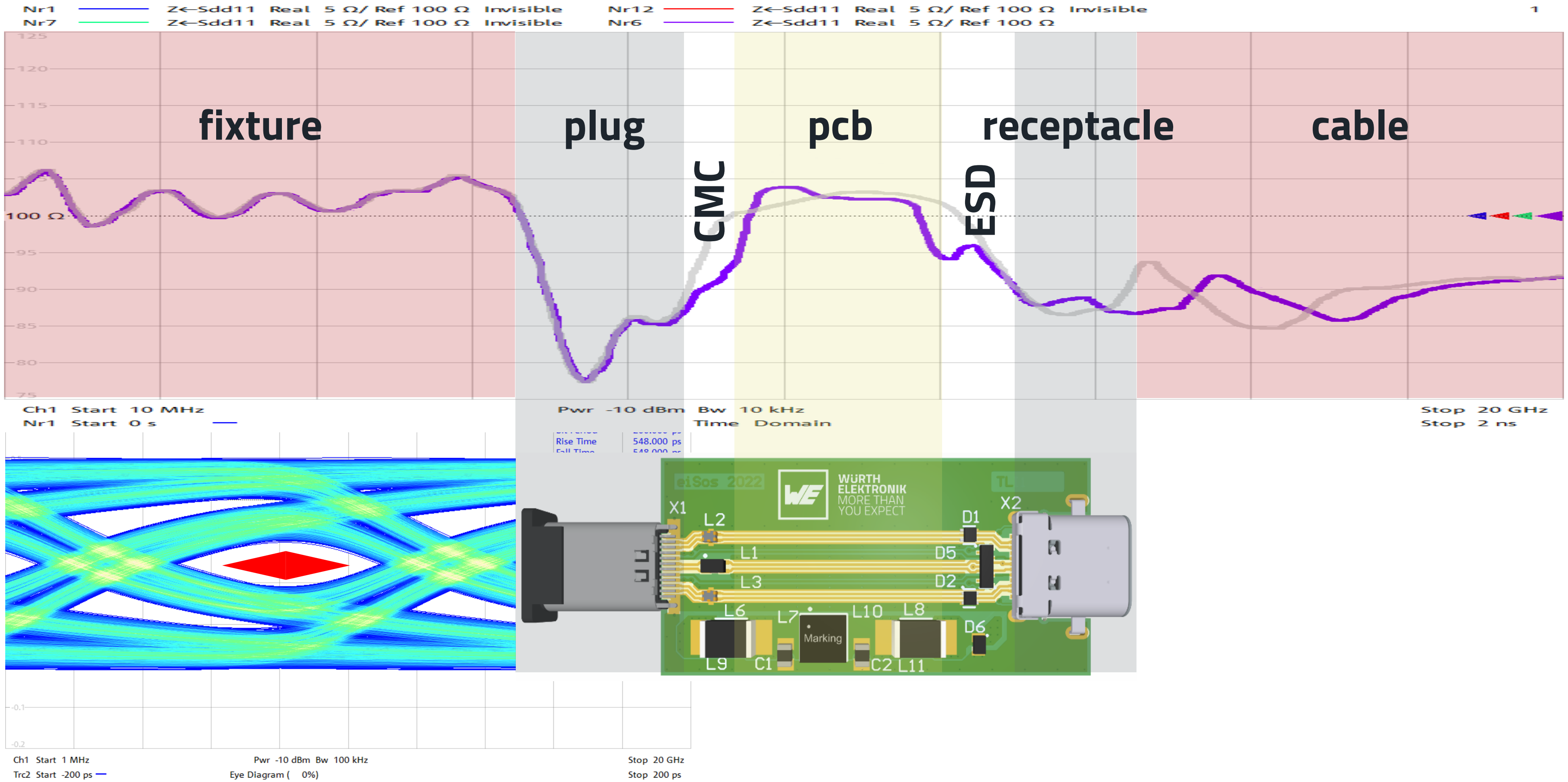
Messungen

Filteradapter – CMC



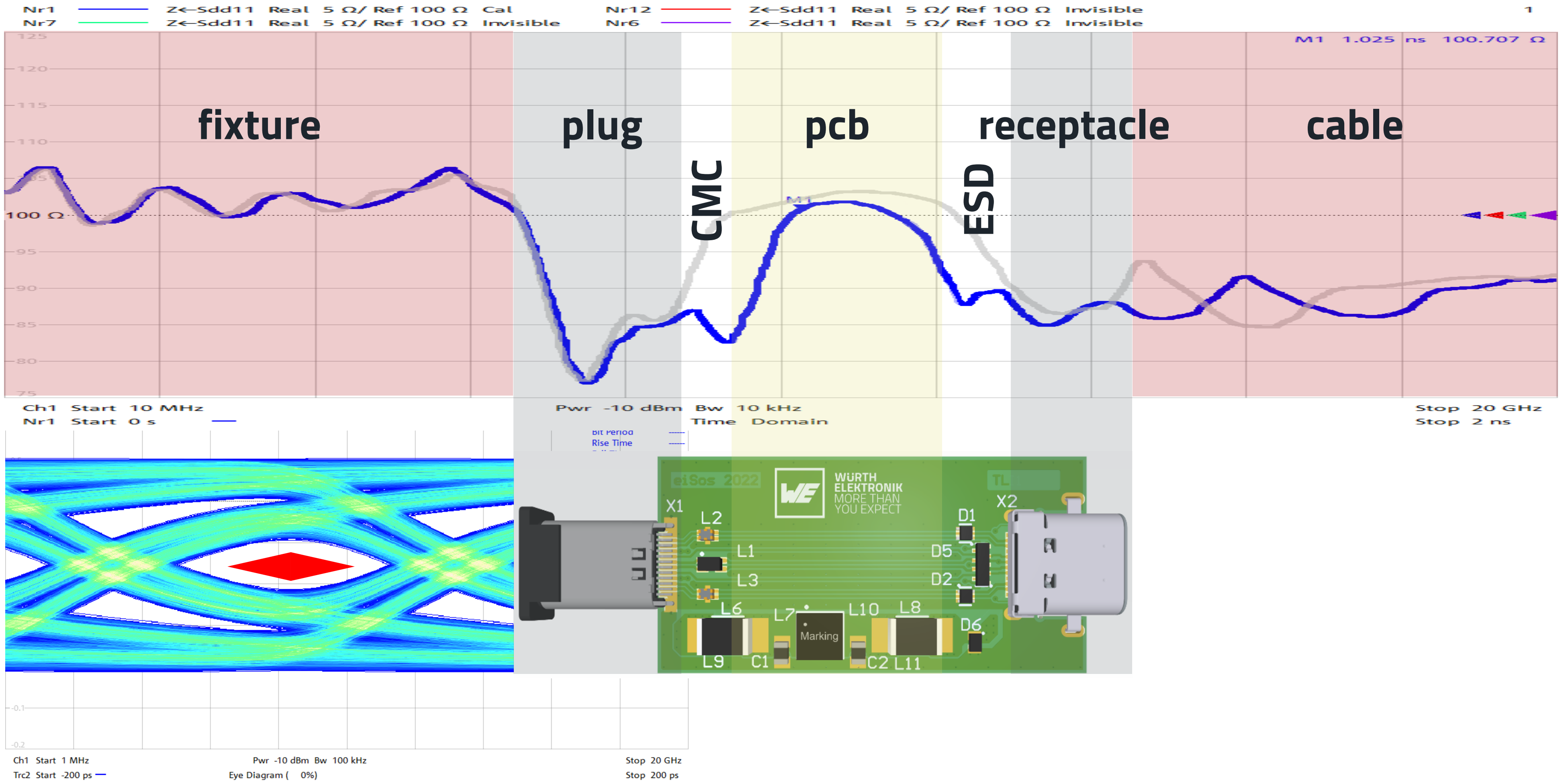
Messungen

Filteradapter – CMC/ESD



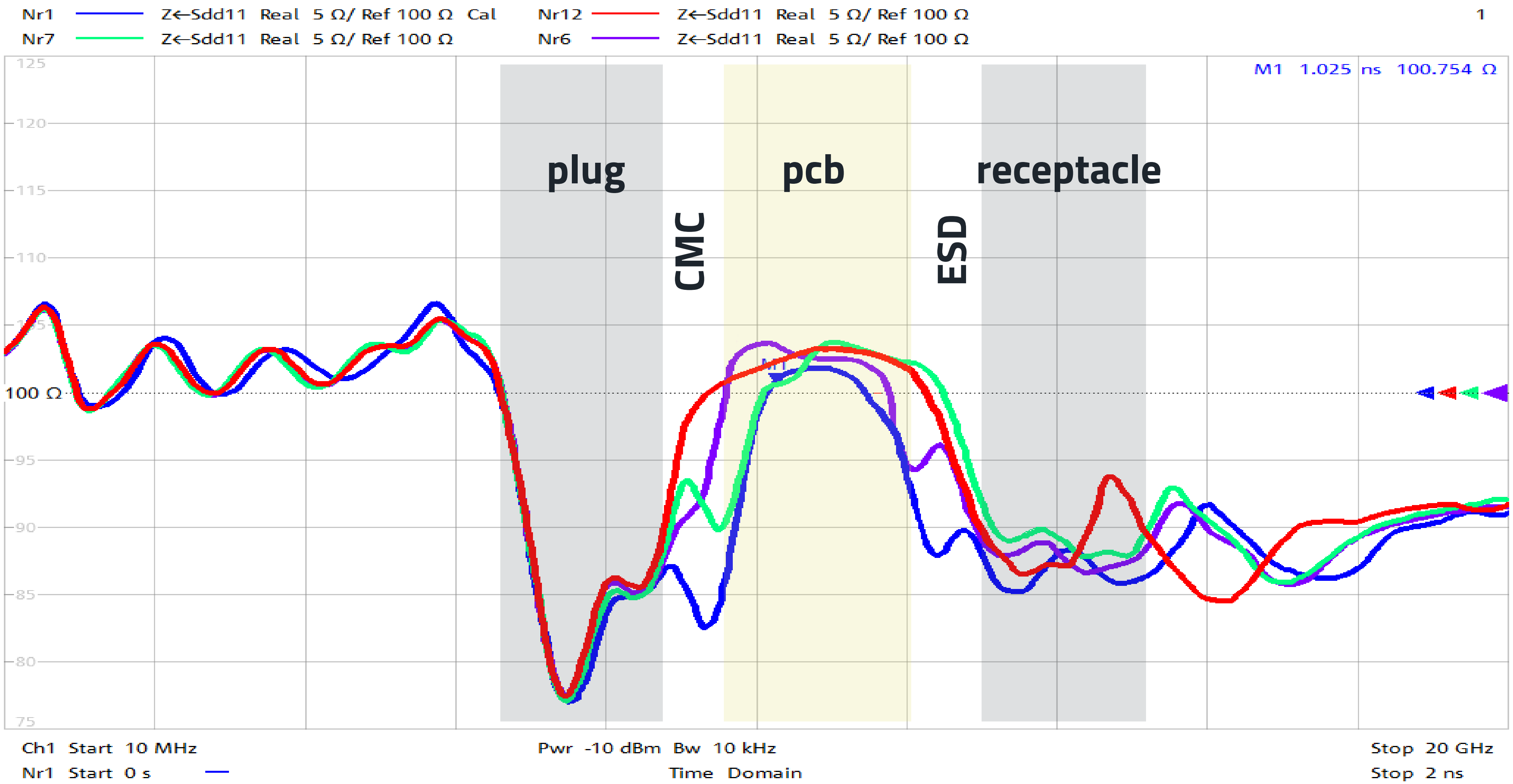
Messungen

Filteradapter – CMC/ESD mit Lötstopp



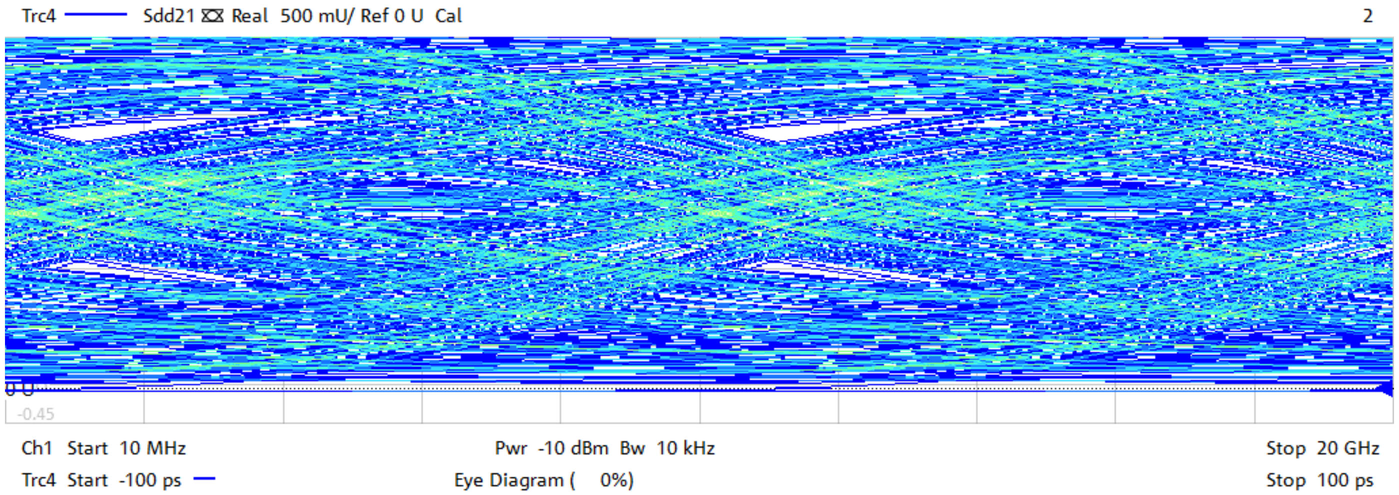
Messungen

Zusammenfassung – Impedanz



Messungen

Augendiagramm 10GBit/s



Literatur

- Signalintegrität – Manfred Schmidt – Vogel – ISBN 978-3-8343-3256-1
- Pocket Reference – Art Kay, Tim Green – TI – www.ti.com/analogrefguide
- Signal and Power Integrity – Eric Bogatin – Prentice Hall – ISBN 978-0-13-234979-6

USB 3.1

Robert Schillinger
Field Application Engineer

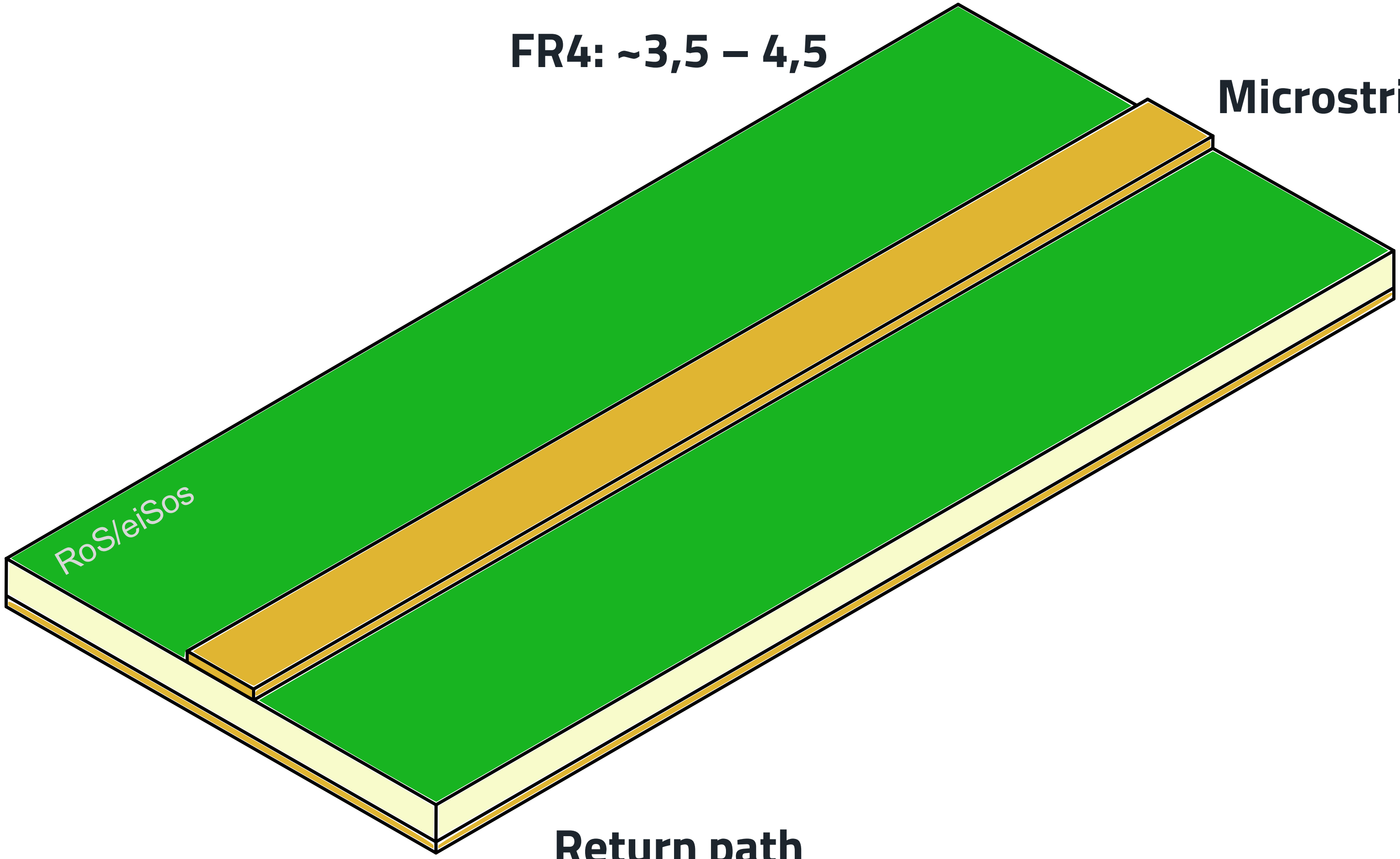
WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

- Basics
  - What is a transmission line?
  - Characteristic impedance
  - Impedance of a microstrip line
- PCB Stackups
- Selection of EMI components
- Type-C Stick
  - Blockdiagram
  - Routing
- Influence in impedance (measurements)

BASICS

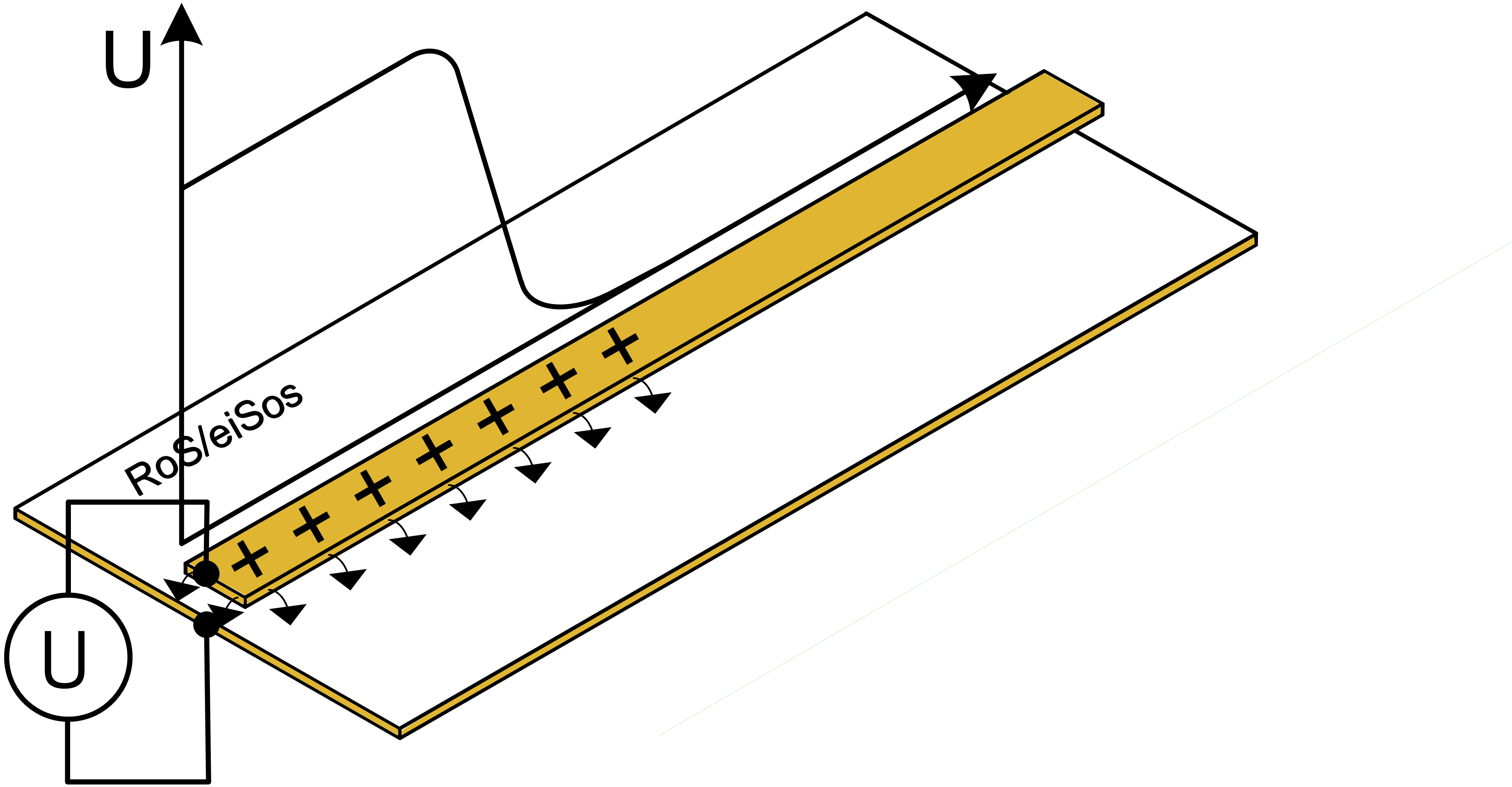
Basics

What is a transmission line?



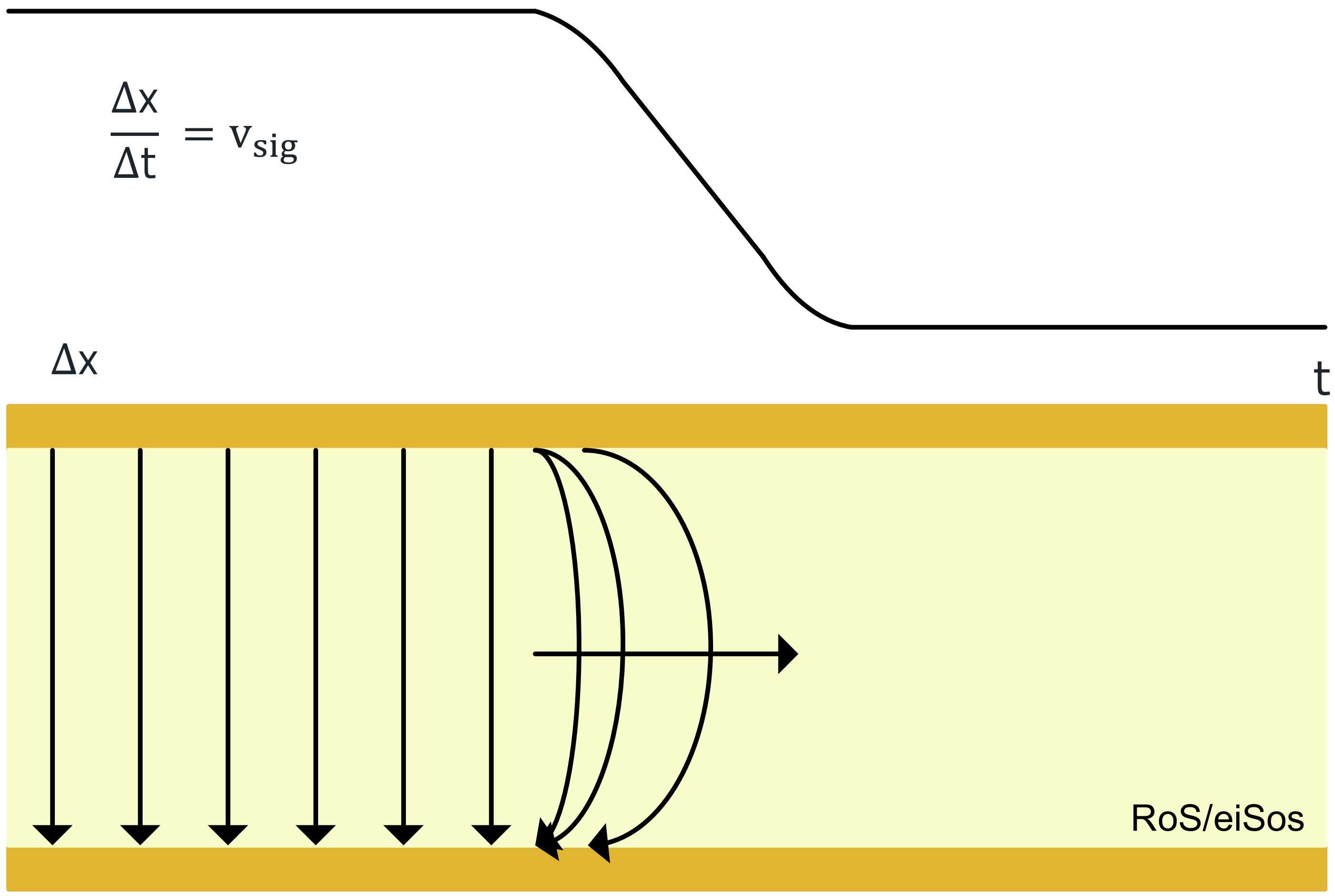
Basics

What is a transmission line?



Basics

Signal speed



Basics

Signal speed

$$v_{sig} = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0} \cdot \sqrt{\varepsilon_r \cdot \mu_r}} = \frac{c_0}{\sqrt{\varepsilon_r \cdot \mu_r}}$$

$$v_{sig} = c_0 \approx 30 \frac{cm}{ns}$$

approach for FR4: $\varepsilon_r = 4$

$$v_{sig} = \frac{c_0}{\sqrt{\varepsilon_r \cdot \mu_r}} \approx 15 \frac{cm}{ns}$$

Basics

Wiring delay

$$\text{wiring delay} = \frac{1}{v_{sig}} = \frac{1}{15\,\frac{cm}{ns}} = 66{,}67 \cdot 10^{-3}\,\frac{ns}{cm} = 66{,}67\,\frac{ps}{cm}$$

Twisted Pair wiring delay ~ $5\frac{ns}{m}$ => $\varepsilon_r = 2$

Basics

Transitional Electrical Length

TEL = (RT or FT) · signal speed

e.g. RT of 30ps

TEL = 0,03ns · $15\frac{\text{cm}}{\text{ns}} = 0{,}45\text{cm}$

From a length of arround 20% of TEL we have a transmission line together with relevant reflections!

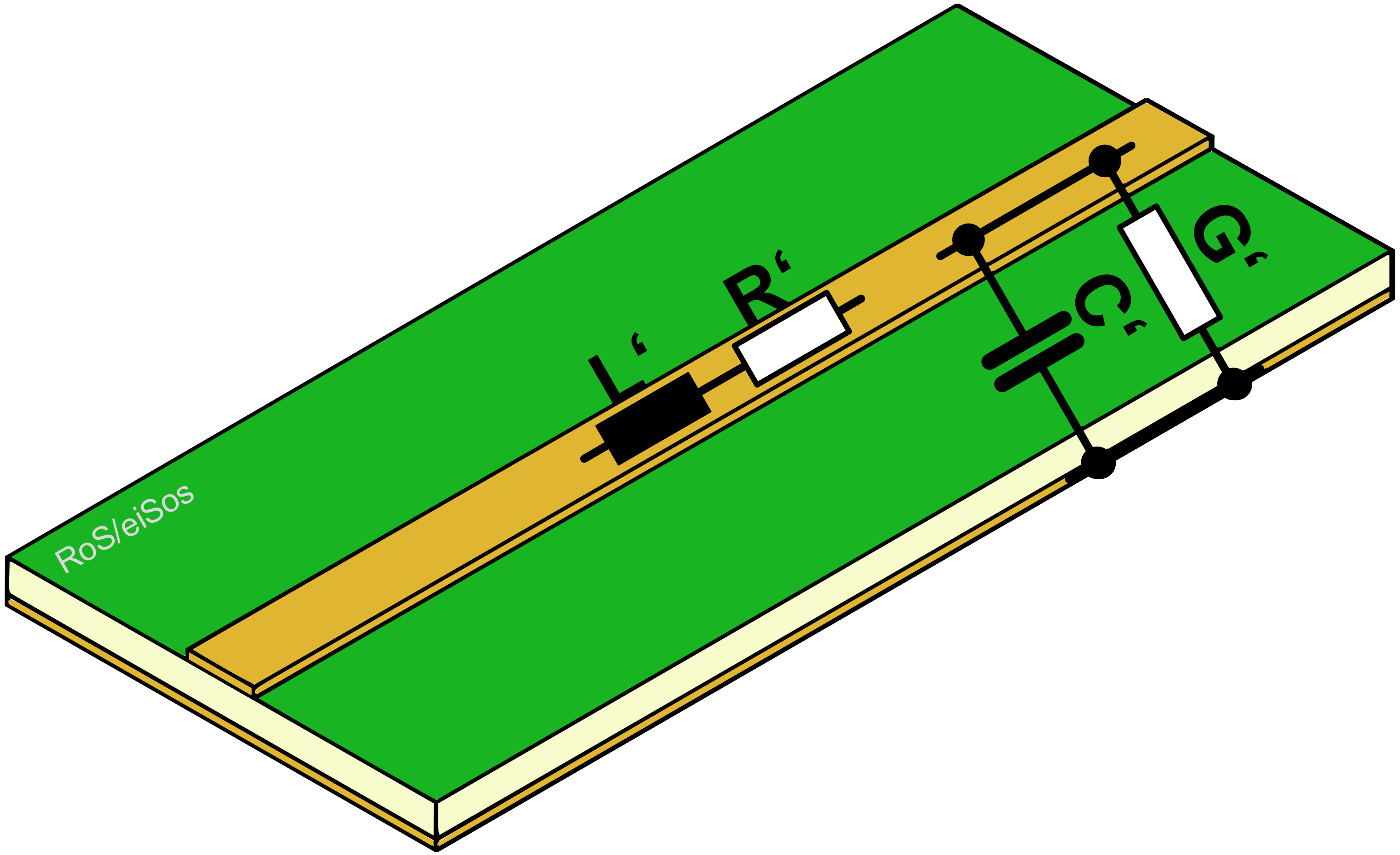
Basics

Characteristic impedance

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

f -> 0: $Z_0 = \sqrt{\frac{R'}{G'}}$

f -> ∞: $Z_0 = \sqrt{\frac{L'}{C'}}$



Basics

Characteristic impedance

approach: $Z = \frac{dU}{dI}$

for $I = \frac{\Delta Q}{\Delta t}$ with $\Delta Q = \Delta C \cdot U$ and $\Delta C = C' \cdot v \cdot \Delta t$

$$I = \frac{C' \cdot v \cdot \Delta t \cdot U}{\Delta t} = C' \cdot v \cdot U$$

$$Z = \frac{U}{I} = \frac{U}{C' \cdot v \cdot U} = \frac{1}{C' \cdot v}$$

result: $C' = \frac{1}{Z_0 \cdot v_{sig}}$

for FR4: $\varepsilon_r = 4$

$$C' = \frac{1}{87\Omega \cdot 15\frac{cm}{ns}} = 766\frac{pF}{m} = 7{,}7\frac{pF}{cm}$$

$$L' = 580\frac{nH}{m} = 5{,}8\frac{nH}{cm}$$

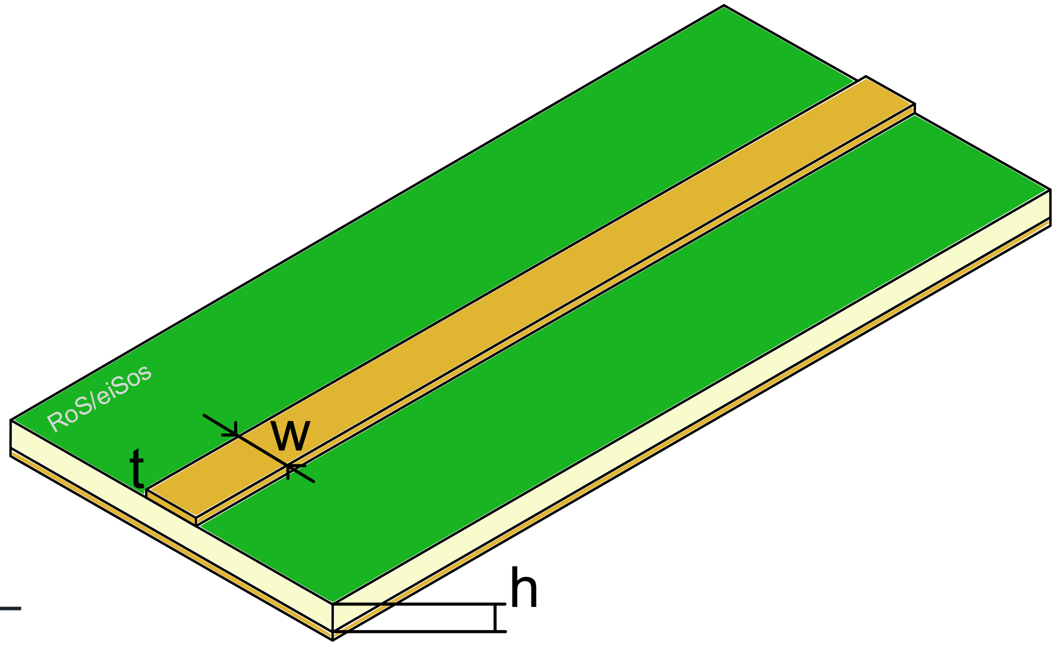
Basics

Impedance Microstrip Line

$$L = L' \cdot l \cdot \ln\left(\frac{5{,}98 \cdot h}{0{,}8 \cdot w + t}\right)$$

$$C = C' \cdot l \cdot \frac{(\varepsilon_r + 1{,}41)}{\ln\left(\frac{5{,}98 \cdot h}{0{,}8 \cdot w + t}\right)}$$

$$Z = \sqrt{\frac{L'}{C'}} \cdot \sqrt{\frac{x^2}{\varepsilon_r + 1{,}41}} = Z_0 \cdot \sqrt{\frac{1}{\varepsilon_r + 1{,}41}} \cdot x$$



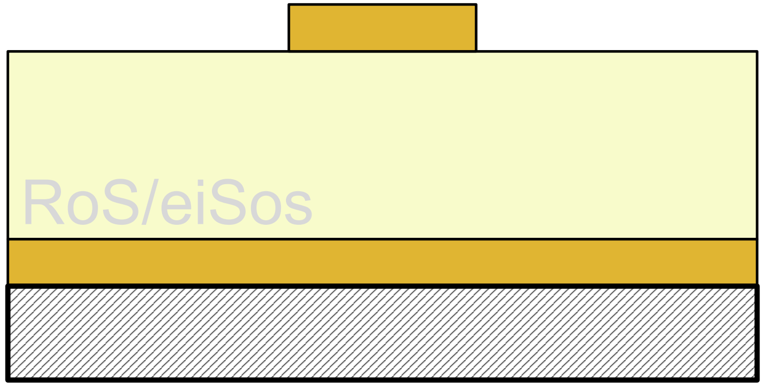
=> h ↑ ▶ *Z* ↑

=> w ↑ ▶ *Z* ↓

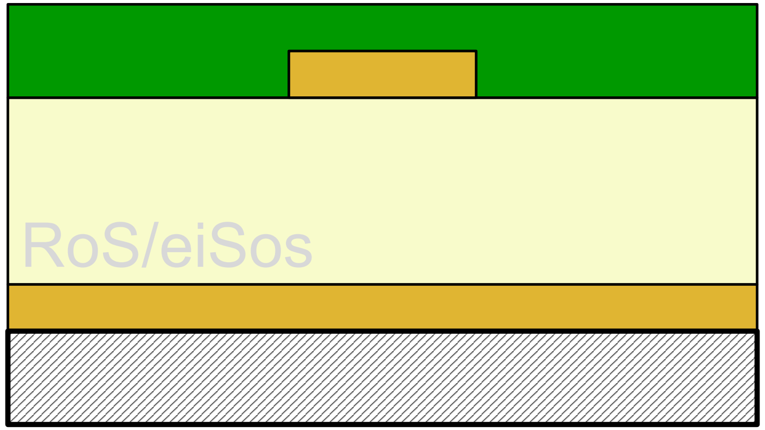
PCB-STACKUPS

PCB-Stackups

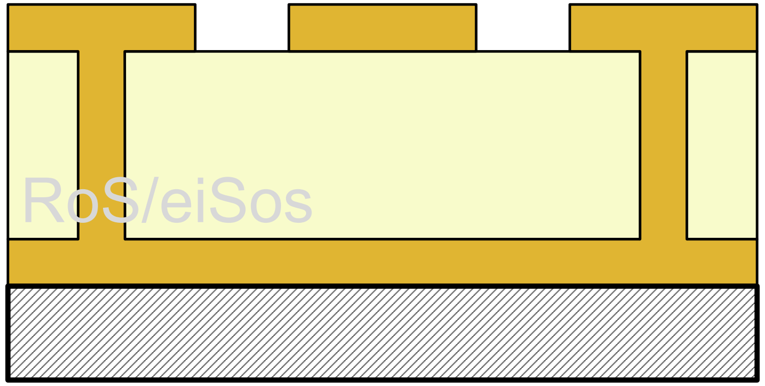
Single-Ended builds – Microstrip



Surface Microstrip



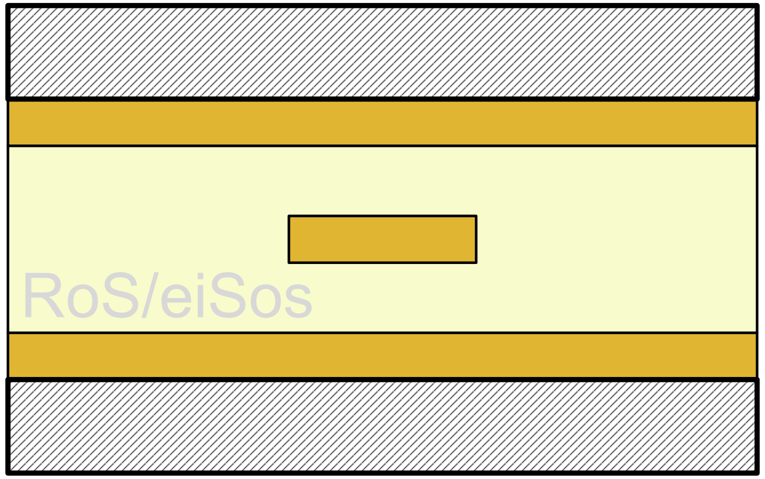
Coated Microstrip

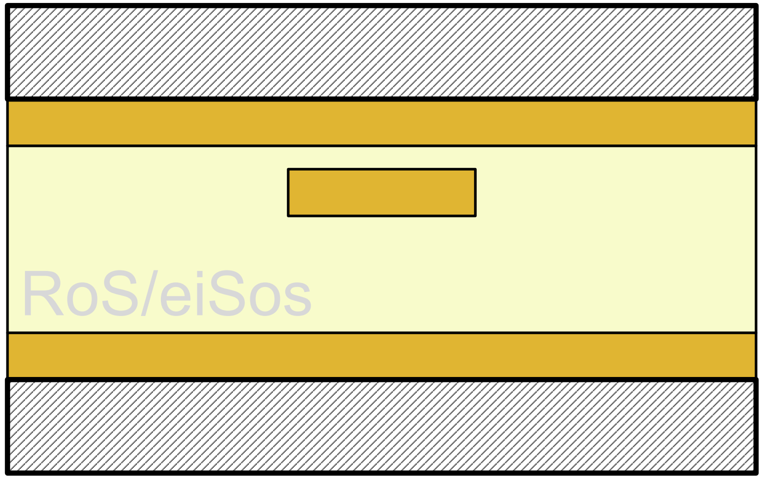


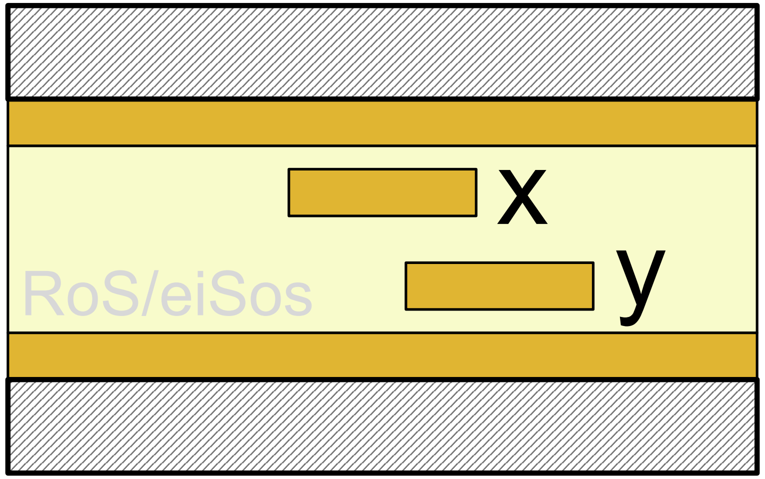
Grounded coplanar waveguide

PCB-Stackups

Single-Ended builds – Stripline







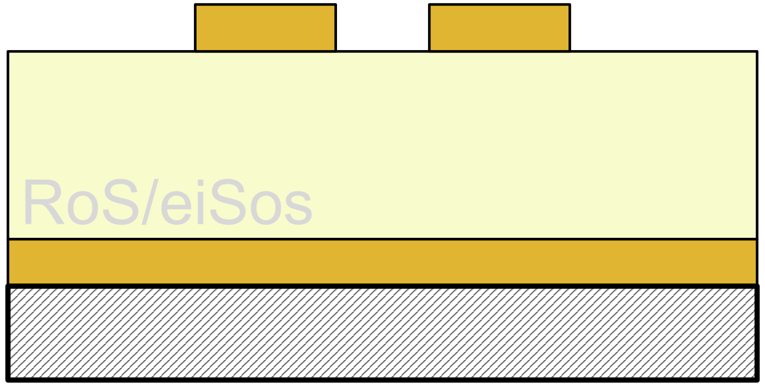
Symetric

Asymetric

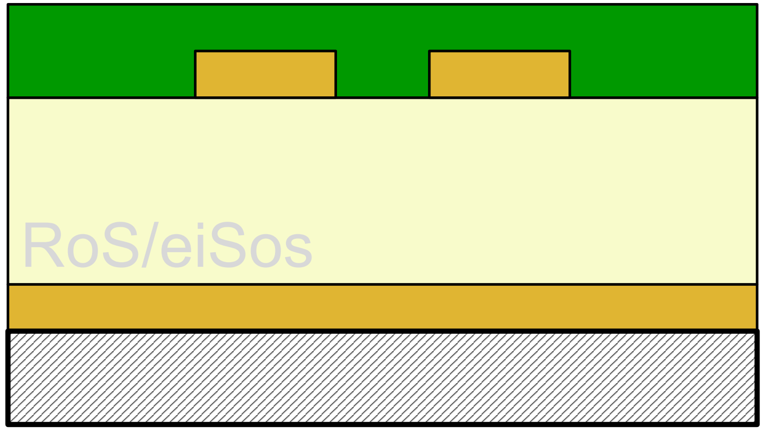
Dual
(x-y orientation)

PCB-Stackups

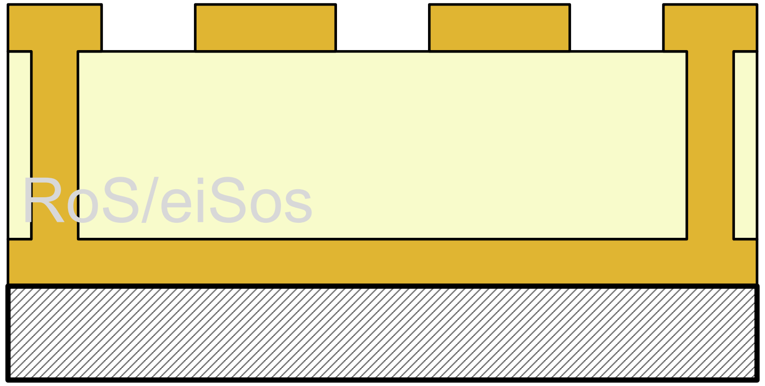
Differential builds – Microstrip



Edge-coupled



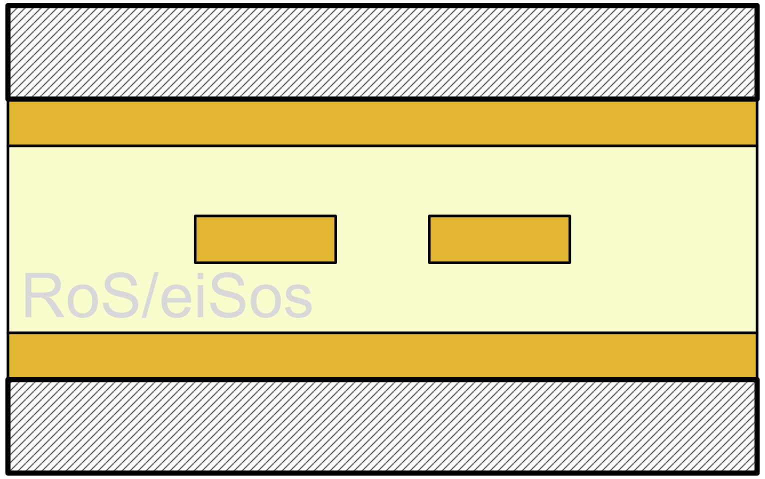
Edge-coupled
with coating

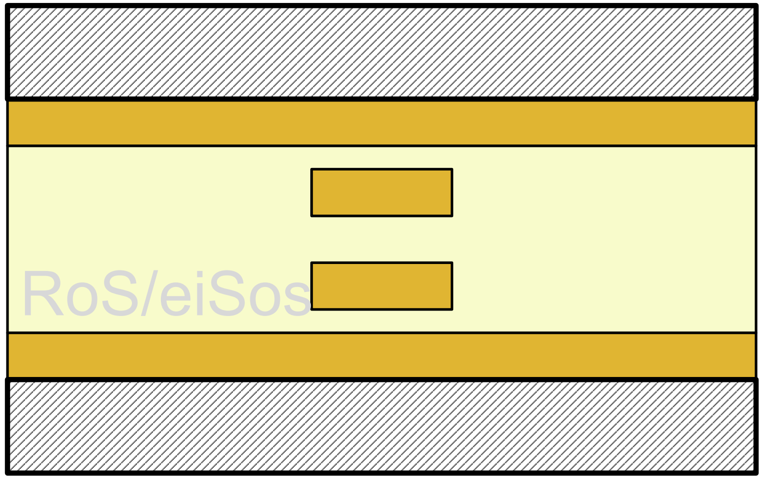


Grounded coplanar waveguide

PCB-Stackups

Differential builds – Stripline





Edge-coupled **Broadside-coupled**

PCB-Stackups

Relationships

$$Z_{diff} = 2 \cdot Z \cdot \left[1 - 0,48 \cdot e^{\left(-0,96 \cdot \frac{s}{h}\right)}\right]$$

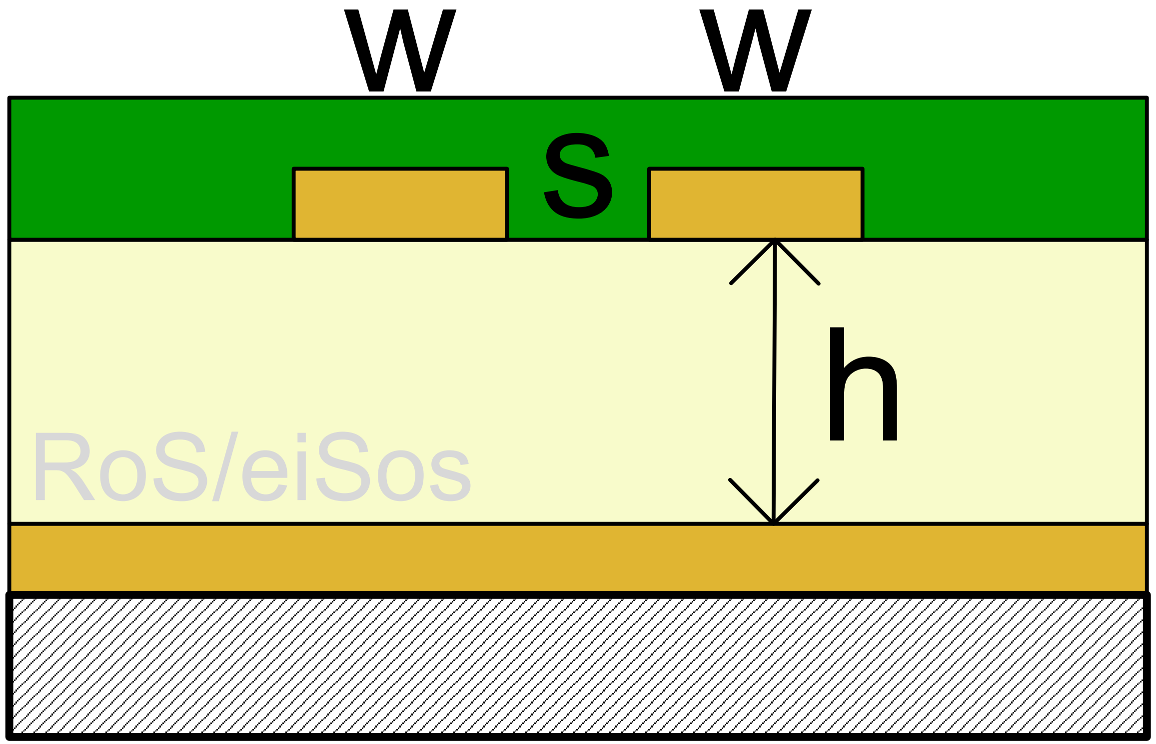
[ ] ≈ 0,8

$$=> Z_{diff} \approx 1,6 \cdot Z$$

=> h ↑ ▶ Z ↑

=> w ↑ ▶ Z ↓

=> s ↑ ▶ Z ↑



PCB-Stackups

Conclusion

- Several possibilities to get the right impedance together with a lot of parameters are variing
- To reach acceptable results it is important to talk to the pcb-manufacturer about possible layerstacks and materials before the design starts
- For an exact calculation of impedance a lot of parameters take effects. To get precise results use softwaretools (2D/3D-Solver).

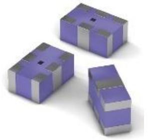
COMPONENT SELECTION

Component selection

- Attenuation of noise on diff. pairs
  - CMC for USB2.0
  - CMC for USB3.x
- Overvoltage protection against ESD
  - TVS Diode for Controls and USB2.0
  - TVS Diode for USB3.x
  - TVS Diode for power distribution
- Filtering of power distribution
  - RF/NF combination with chip-bead and inductor


744231091

7442335600


748020024
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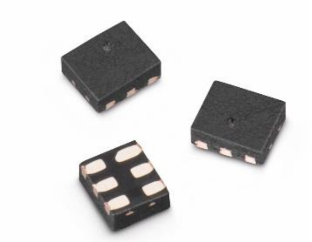
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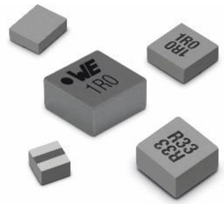
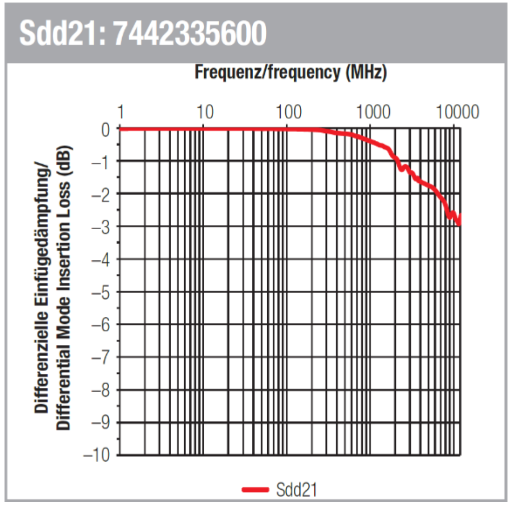
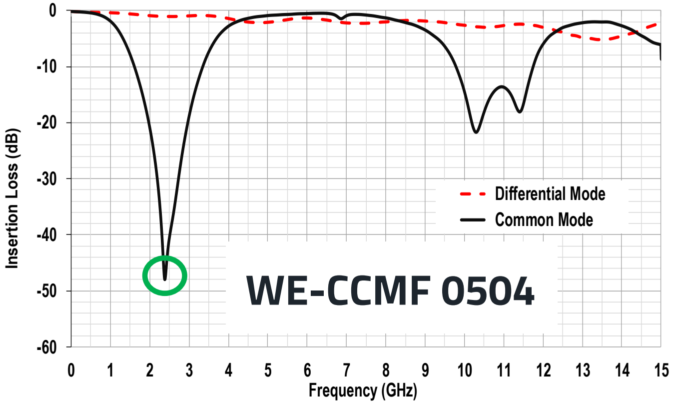
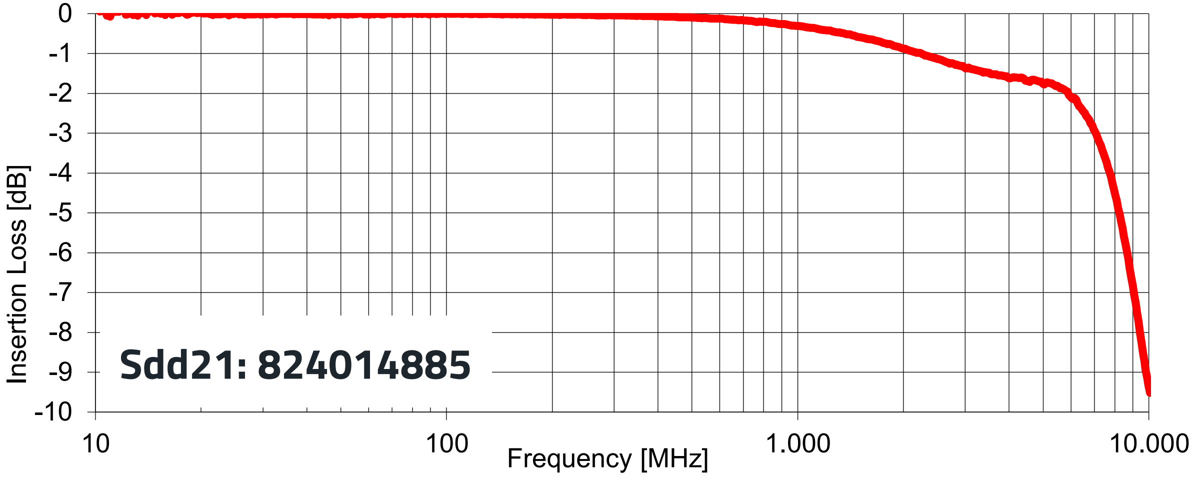


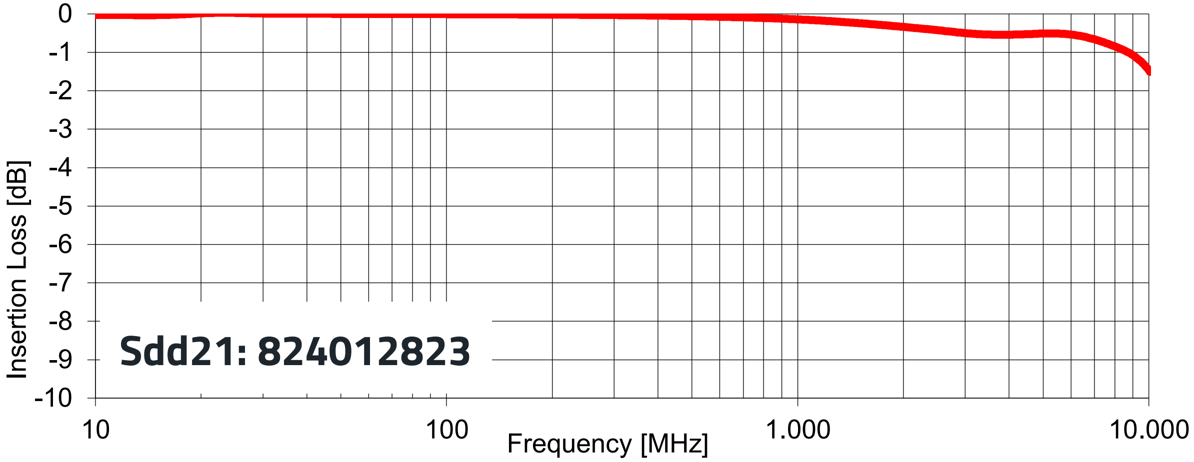
Component selection



WE-CNSW HF 0504



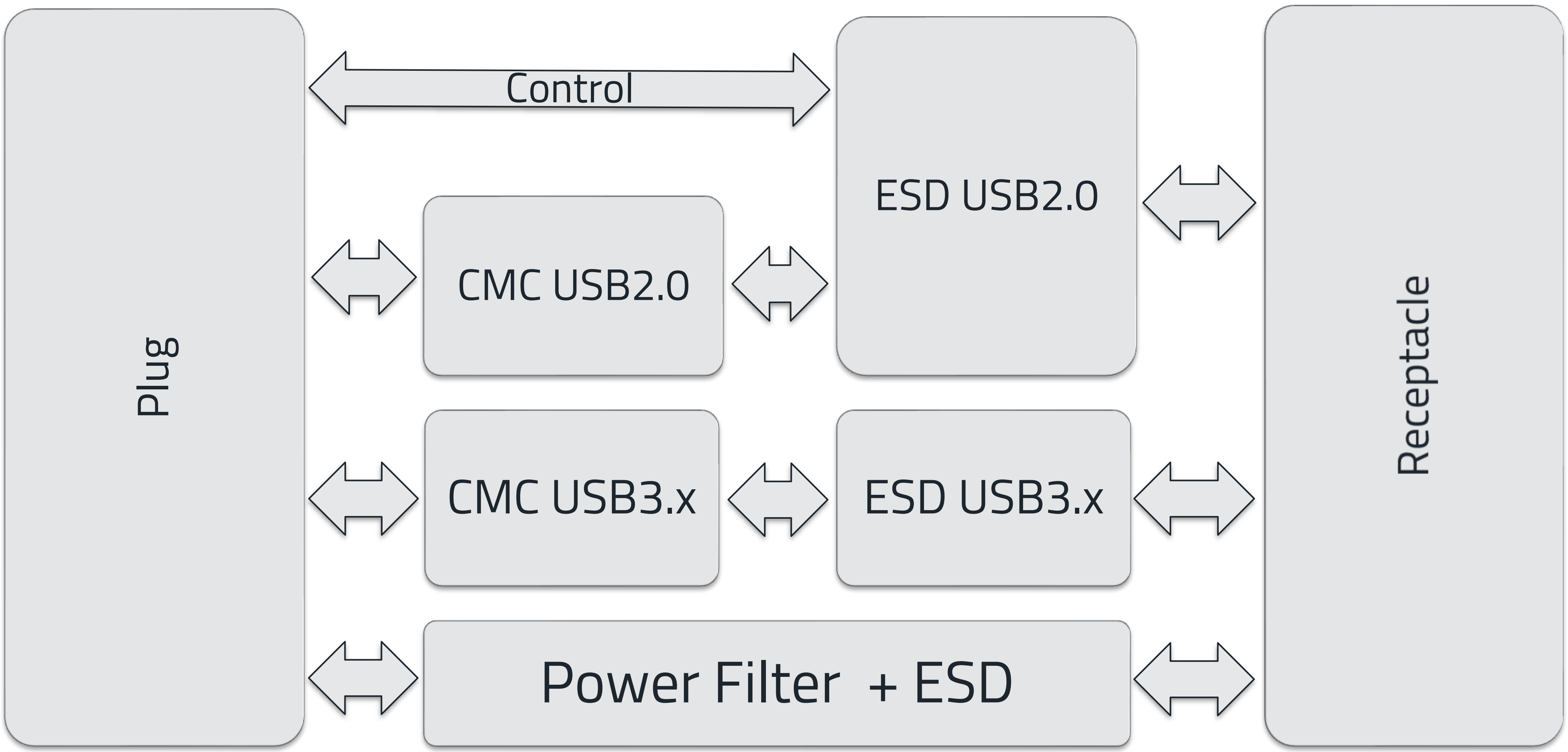




TYPE-C-STICK

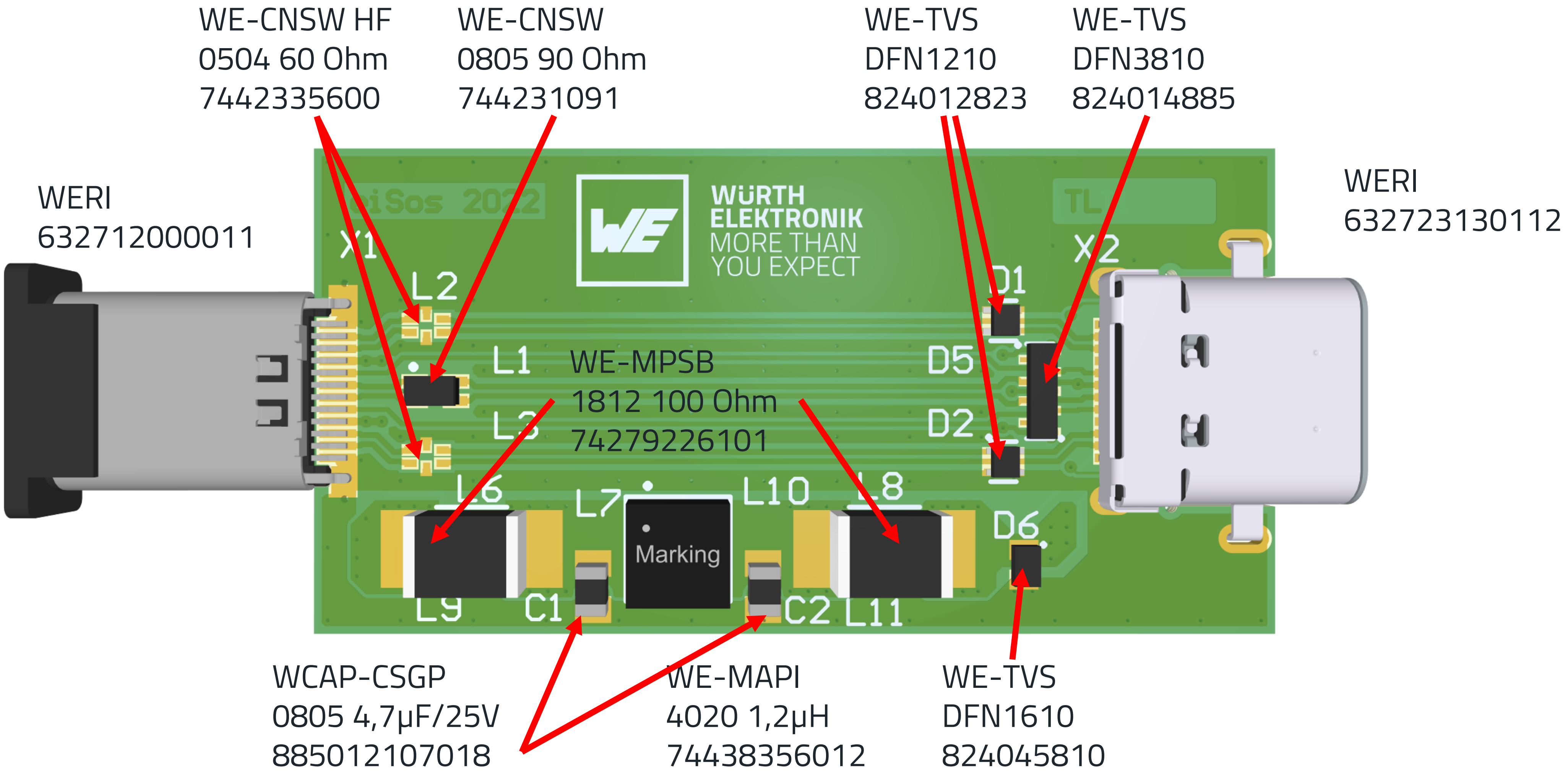
Type-C-Stick

Signal flow



Type-C-Stick

Overview



Type-C-Stick

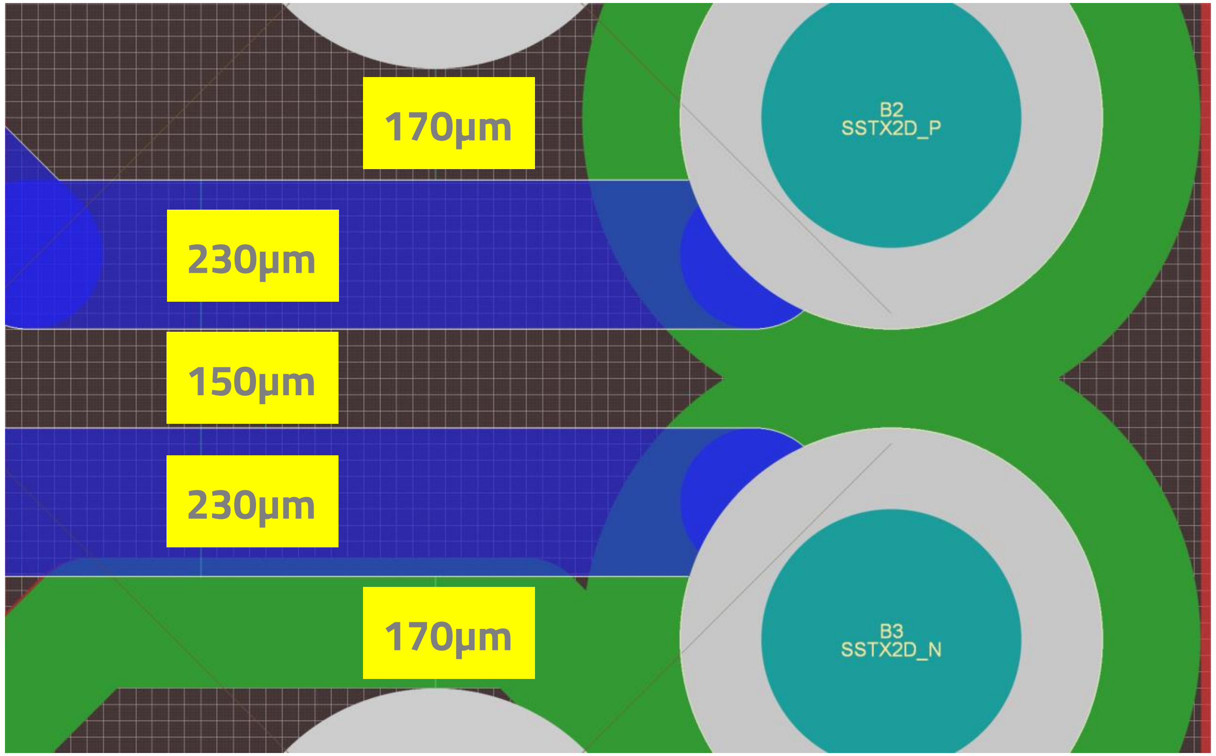
Order codes

- Stick with 60W PD: 82931060
- Sample bag with all components for 60W: 82931061

- Stick with 100W PD: 82931100
- Sample bag with all components for 100W: 82931101

Type-C-Stick

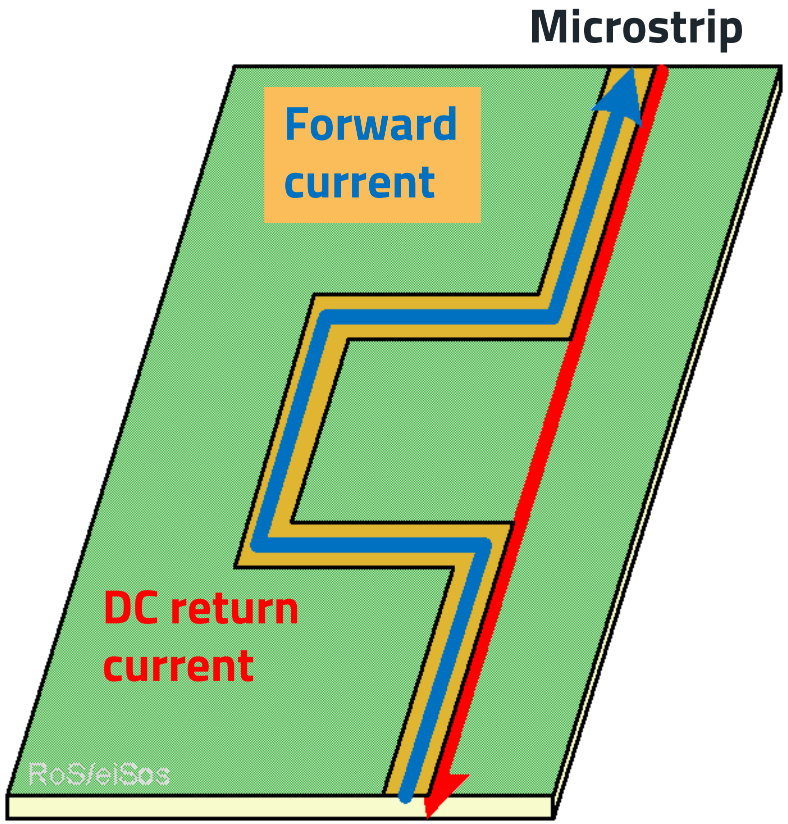
PCB stackup



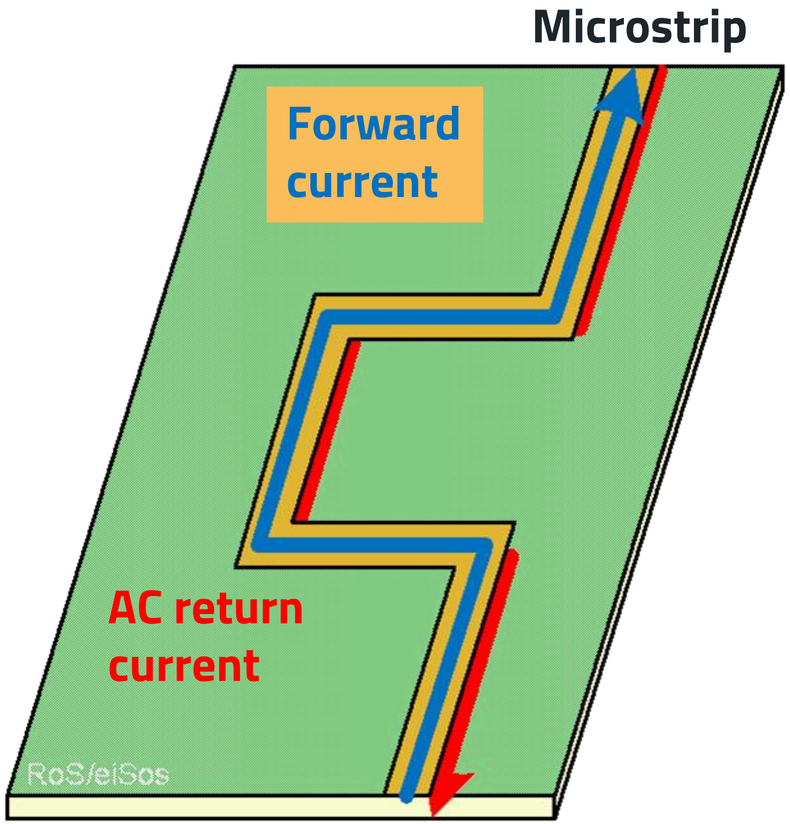
#	Name	Material	Type	Weight	Thickness	Dk	Df
	Top Overlay		Overlay				
	Top Solder	SM-001	Solder Mask		0.03mm	3.5	0.03
1	Top Side	CF-004	Signal	1oz	0.035mm		
	Dielectric 2	PP-010	Prepreg		0.177mm	4	0.02
2	Ref Ground TS	CF-004	Plane	1oz	0.035mm		
	Dielectric 3	Core-028	Core		0.25mm	4.1	0.02
3	Ref Ground BS	CF-004	Plane	1oz	0.035mm		
	Dielectric 5	PP-010	Prepreg		0.177mm	4	0.02
4	Bottom Side	CF-004	Signal	1oz	0.035mm		
	Bottom Solder	SM-001	Solder Mask		0.03mm	3.5	0.03
	Bottom Overlay		Overlay				

Type-C-Stick

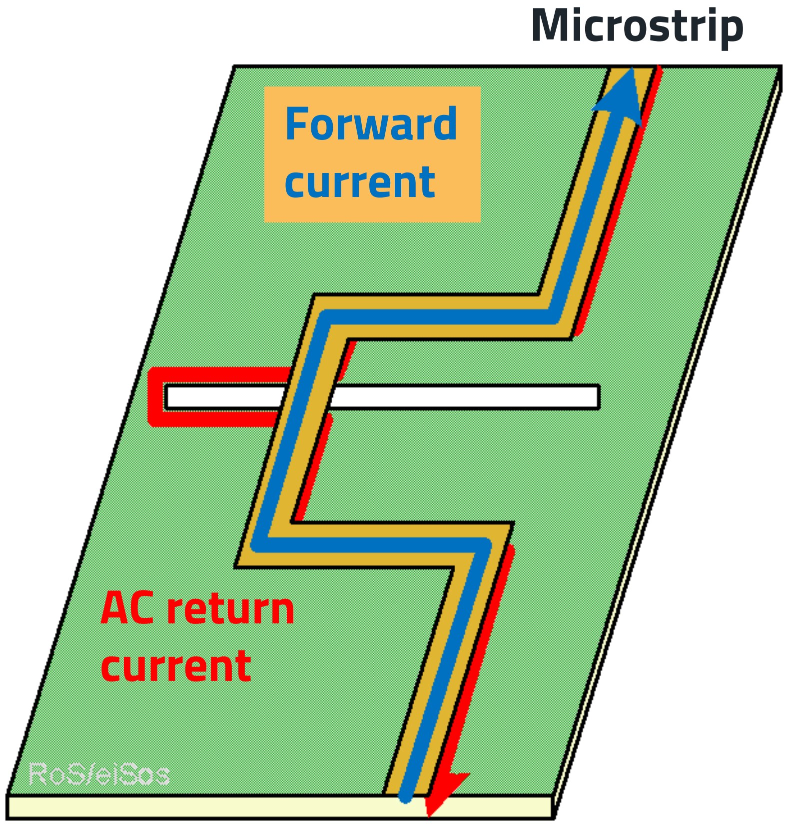
Path of least impedance



Return path



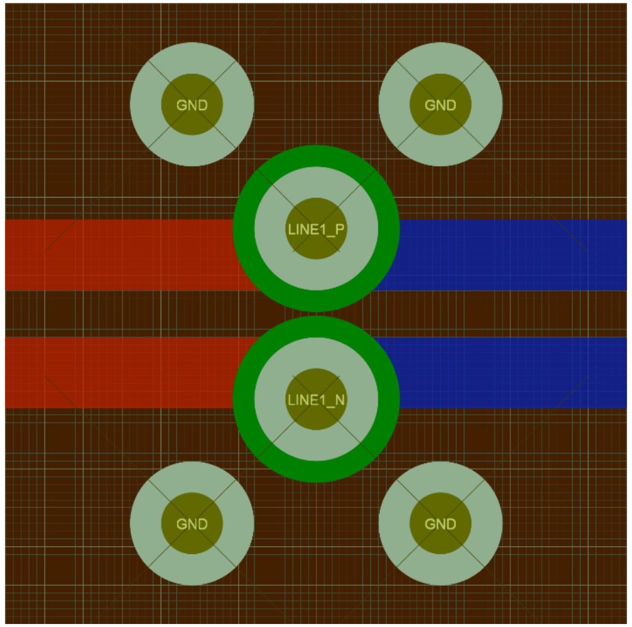
Return path

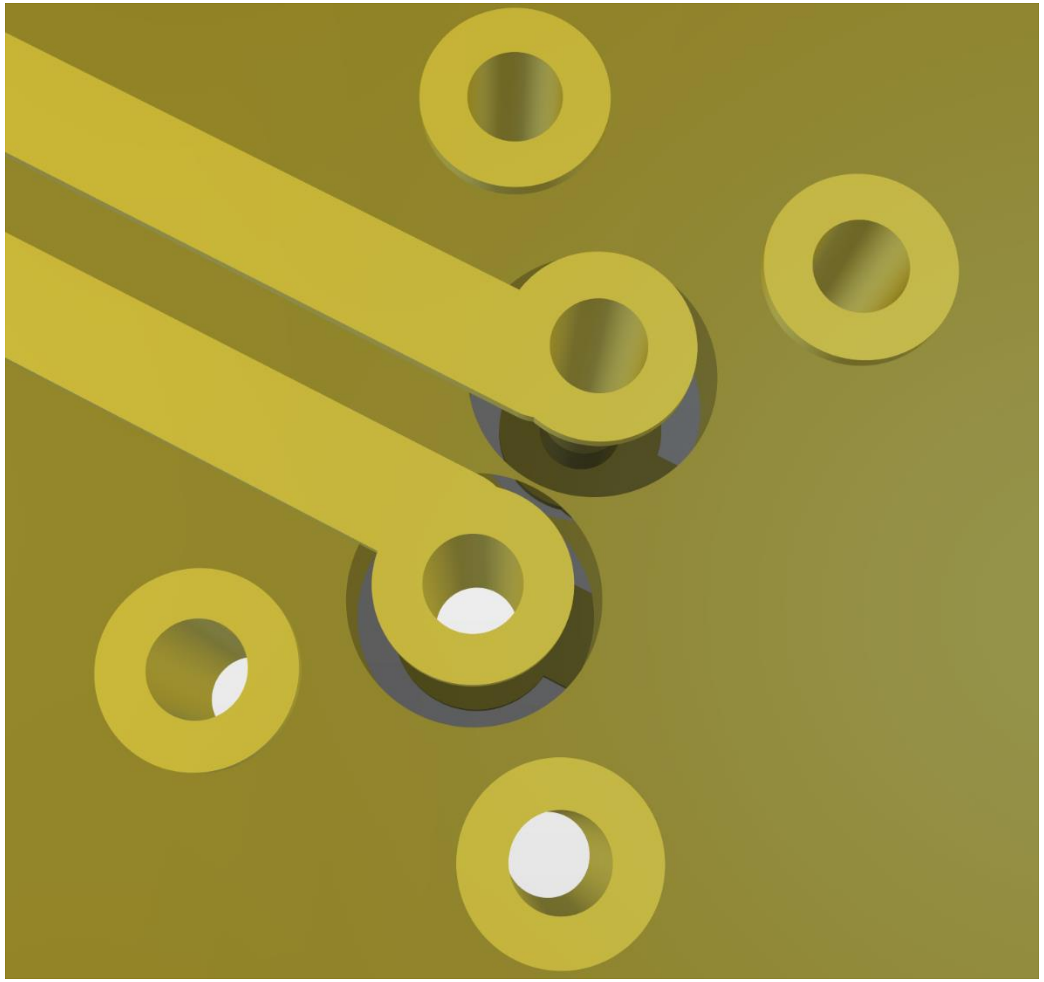


Slotted return path

Type-C-Stick

Designrules





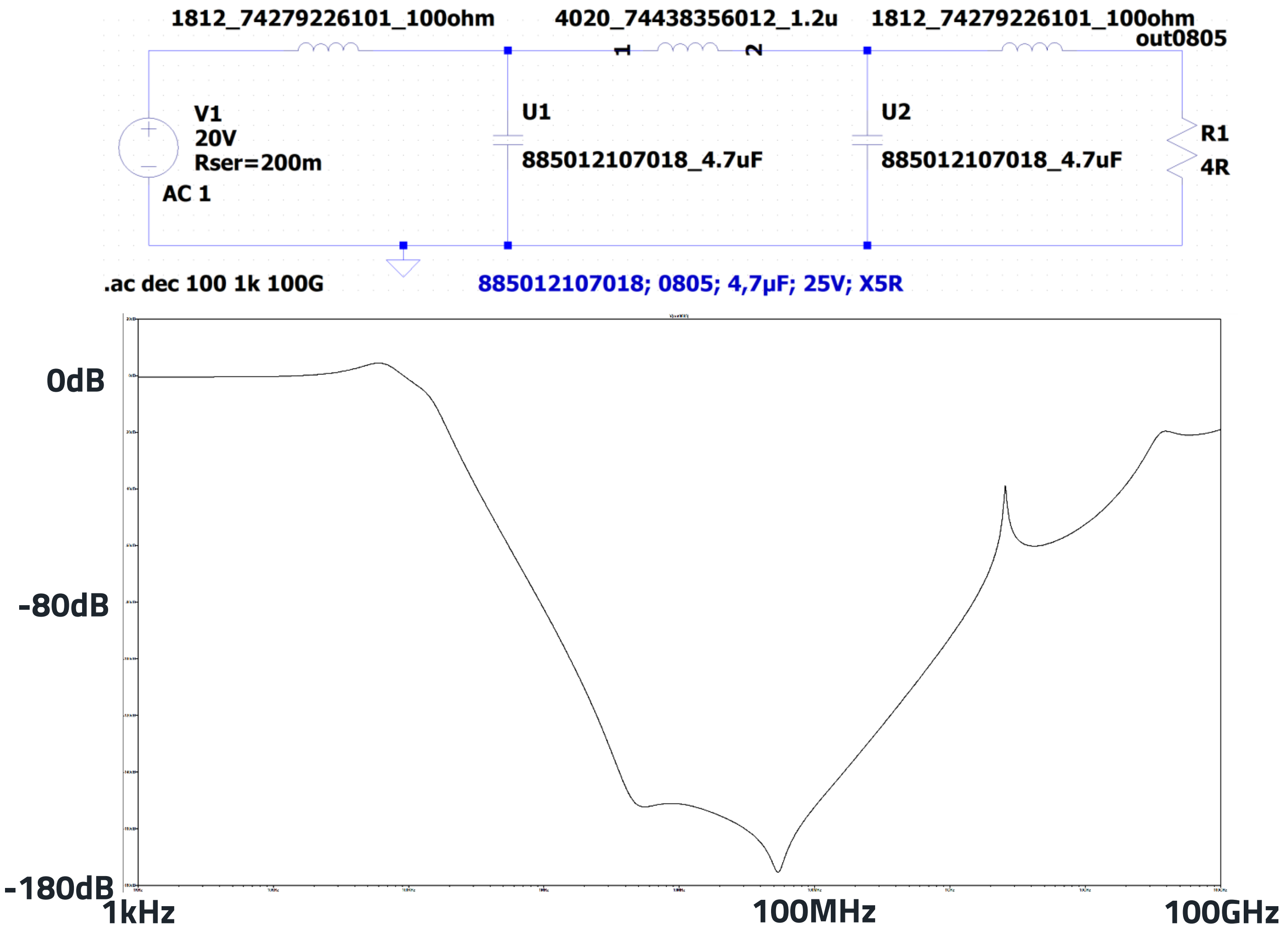
Type-C-Stick

PD filter

- Wideband filter for PD path
- Designed for 100W

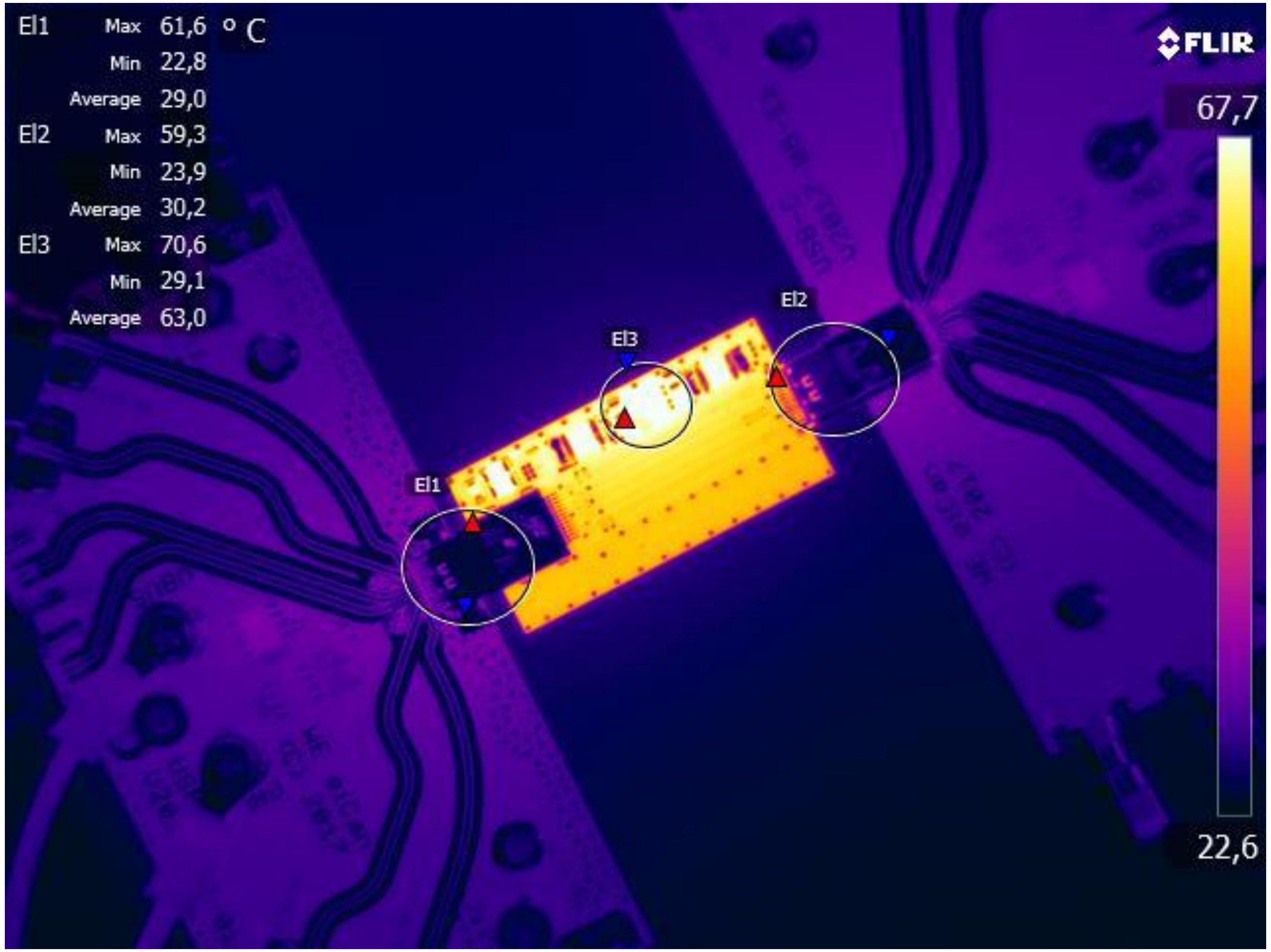
- Temperature at L4:
  - 5V/1,5A: 24,3°C
  - 5V/3A: 35,1°C
  - 20V/5A: 64,9°C

- Voltage drop over filter:
  - @1,5A: 40mV
  - @3A: 89mV
  - @5A: 156mV



Type-C-Stick

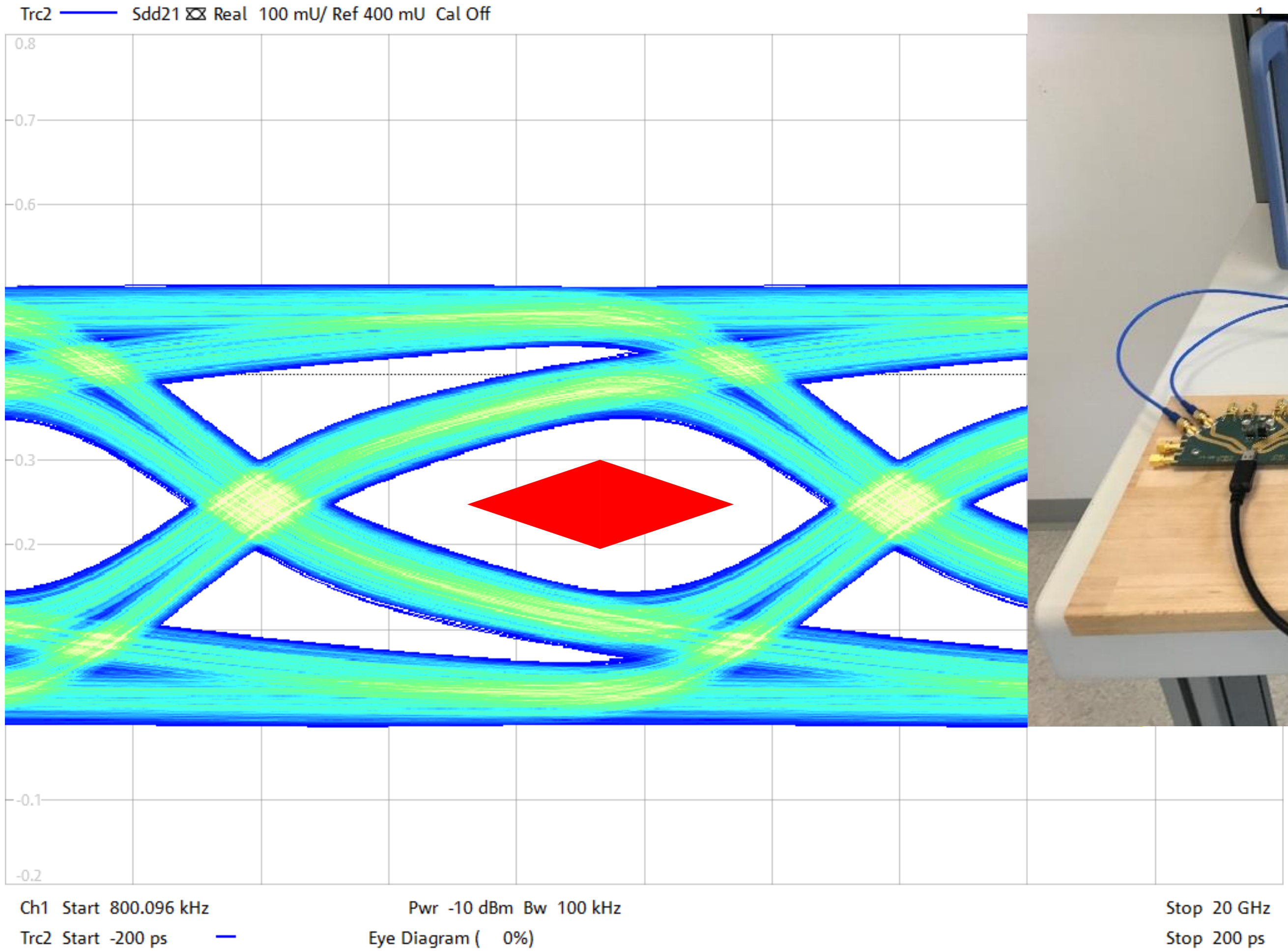
Heating

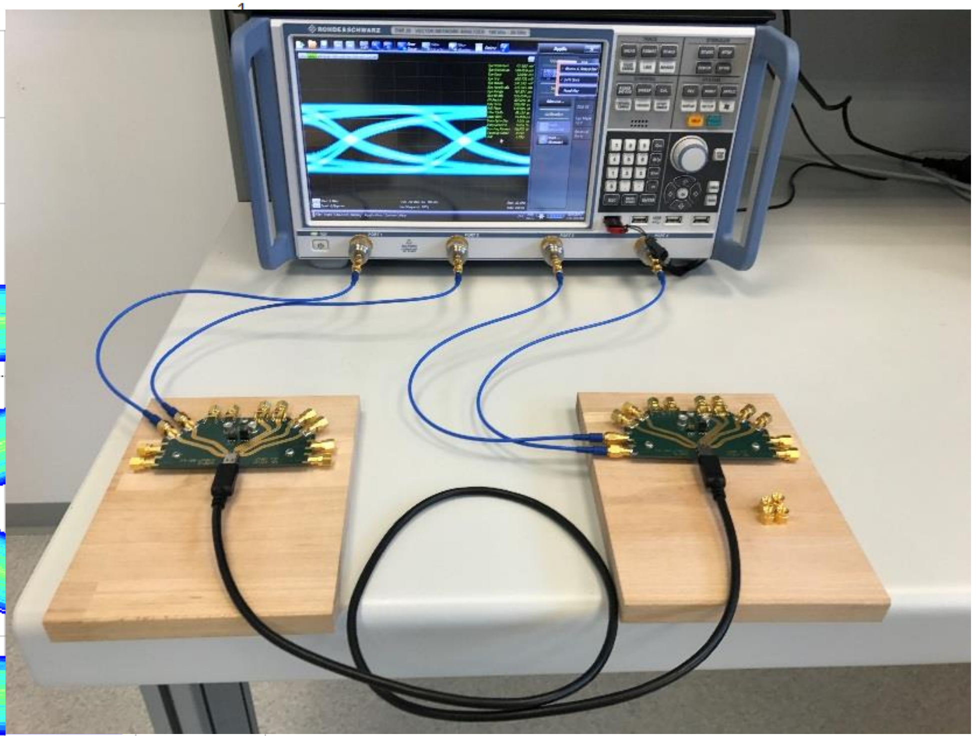


MEASUREMENTS

Measurements

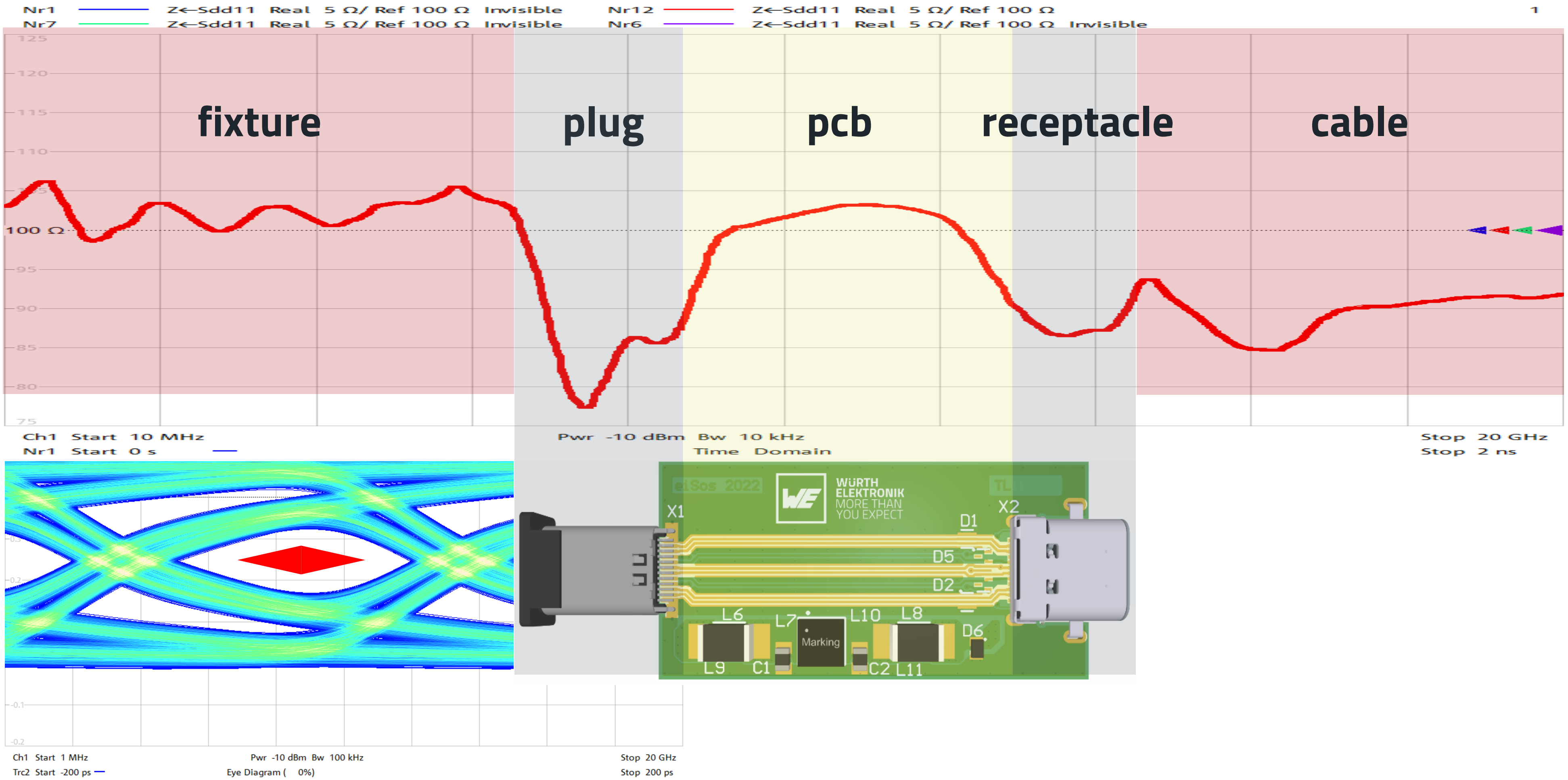
Test equipment





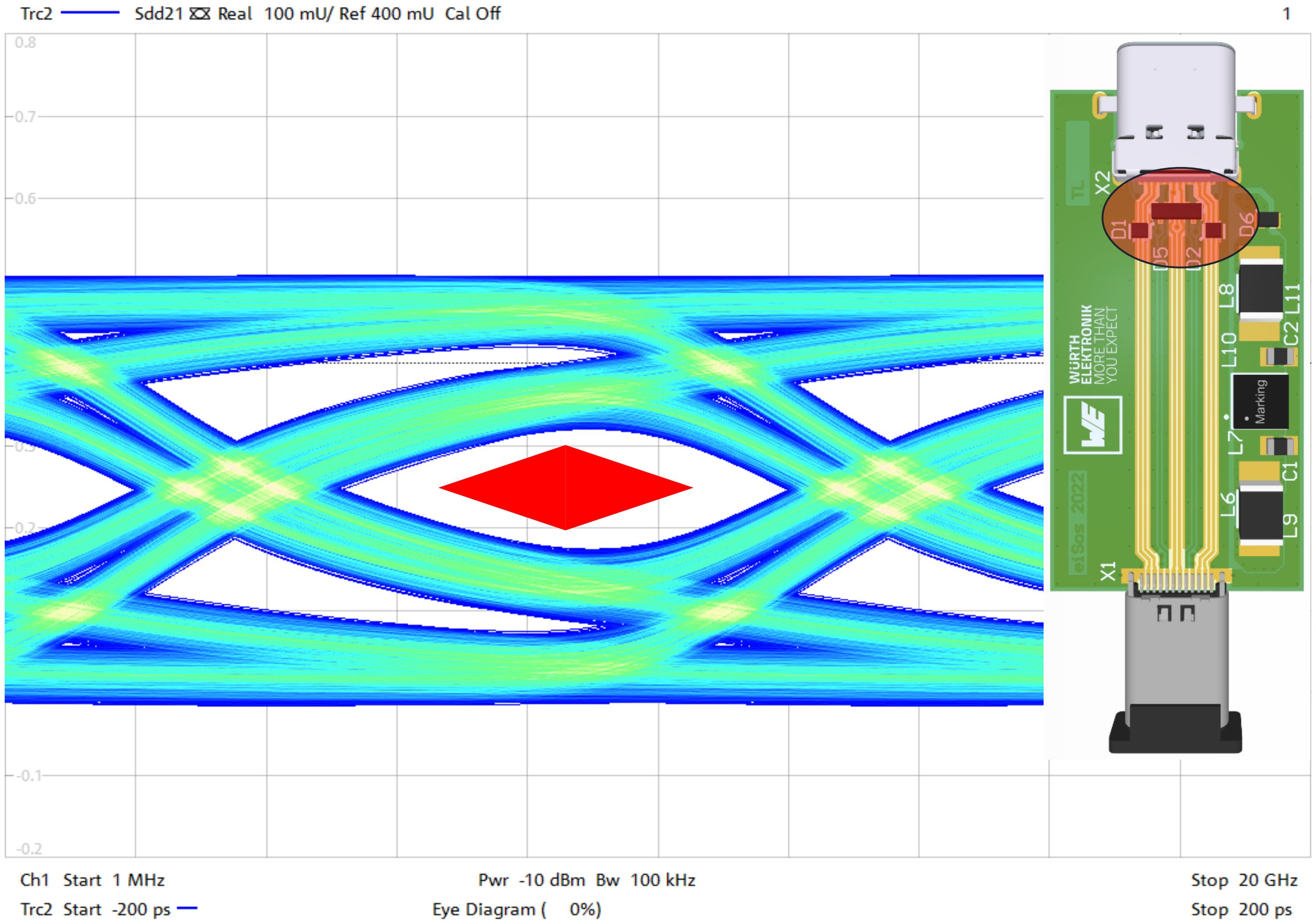
Measurements

Filteradapter – without components



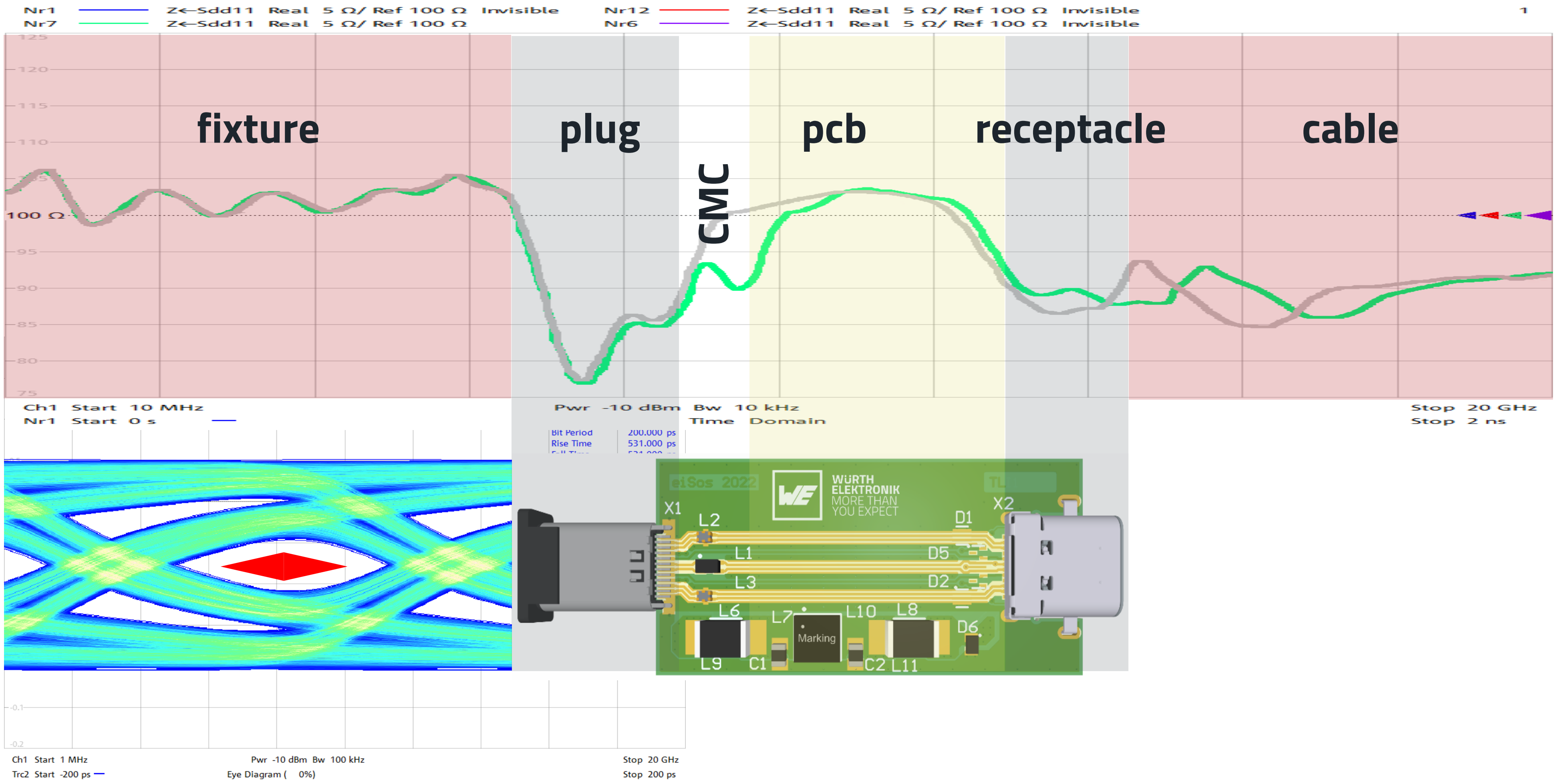
Measurements

Filteradapter – ESD



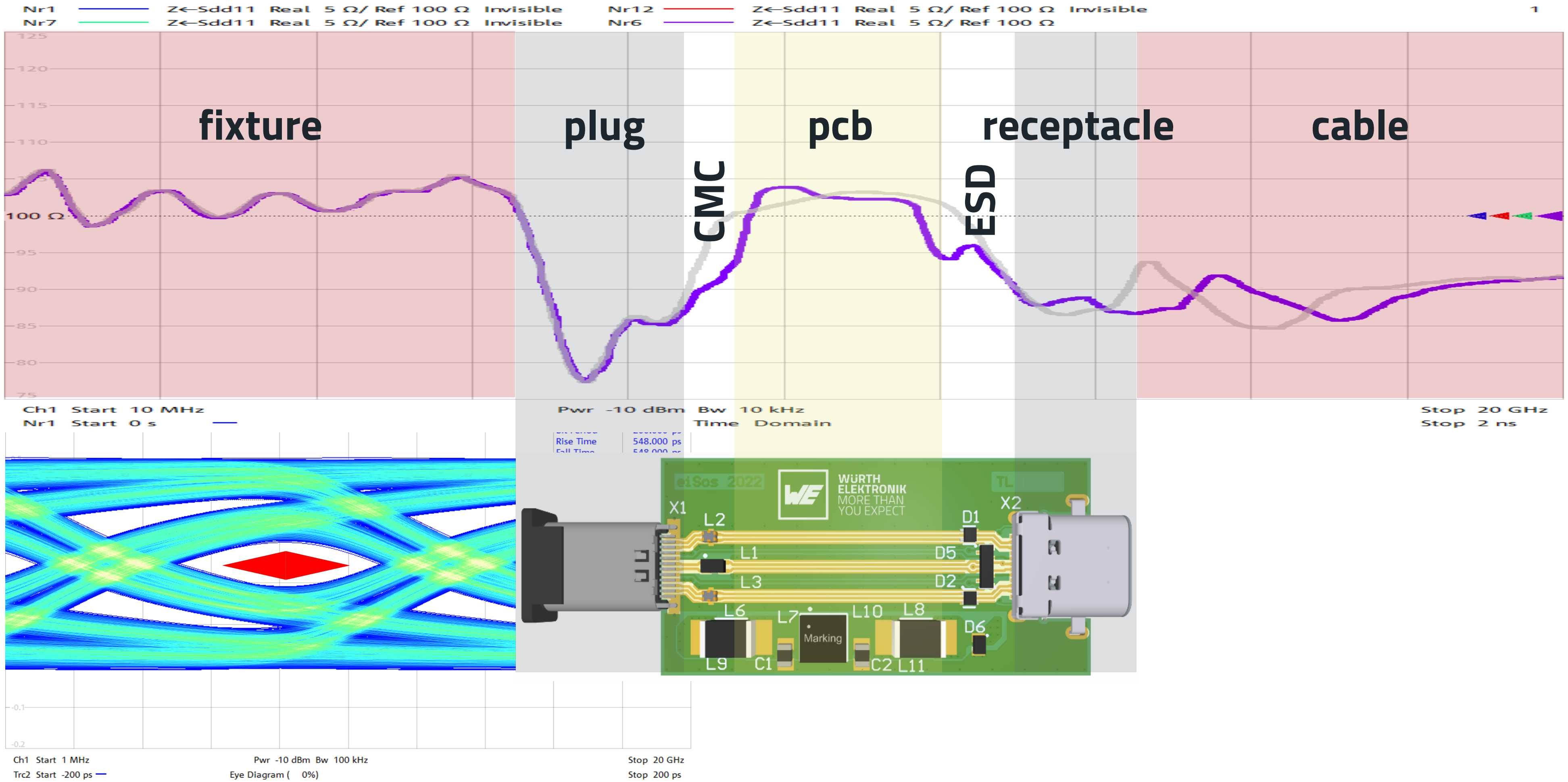
Measurements

Filteradapter – CMC



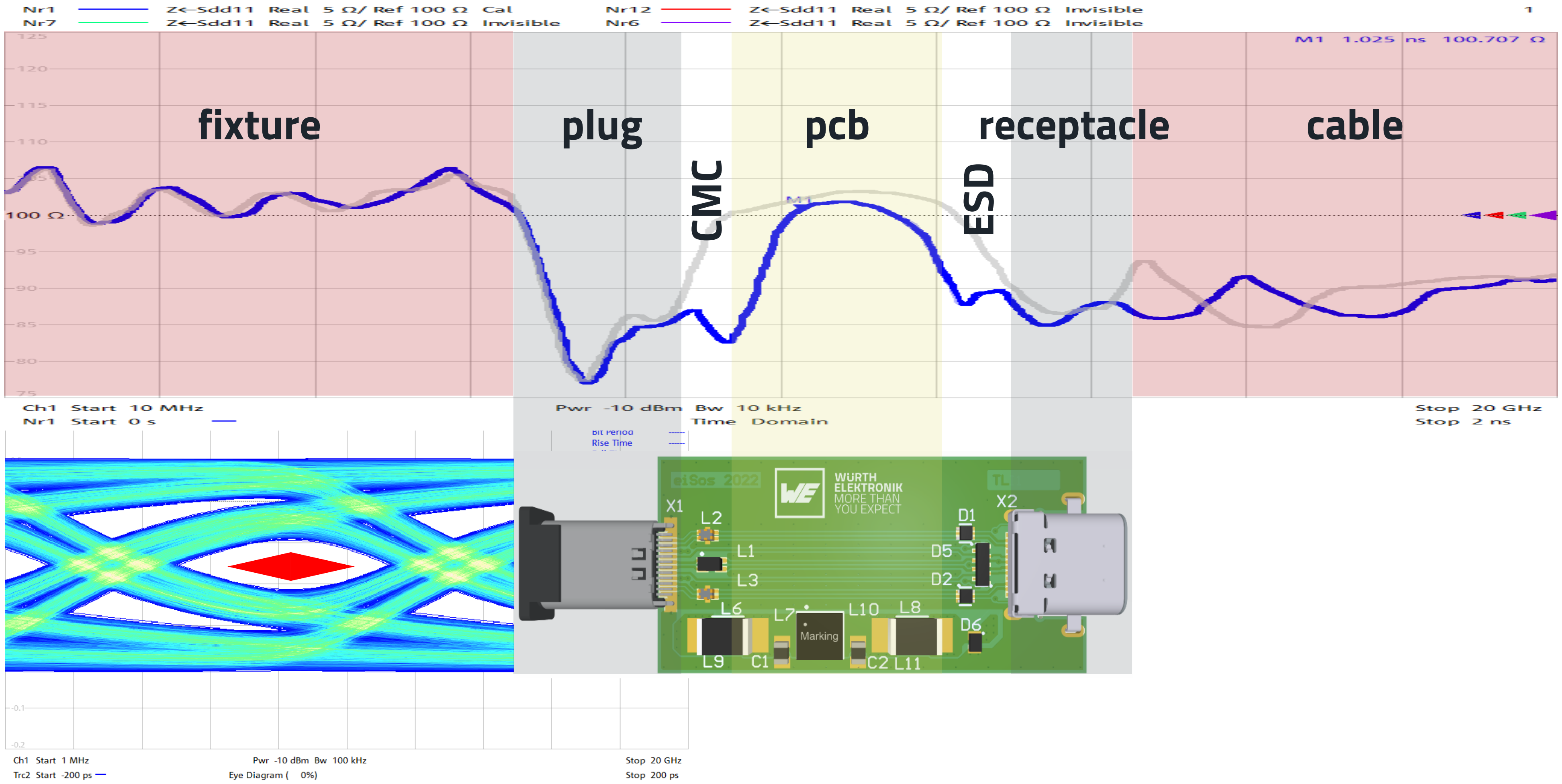
Measurements

Filteradapter – CMC/ESD



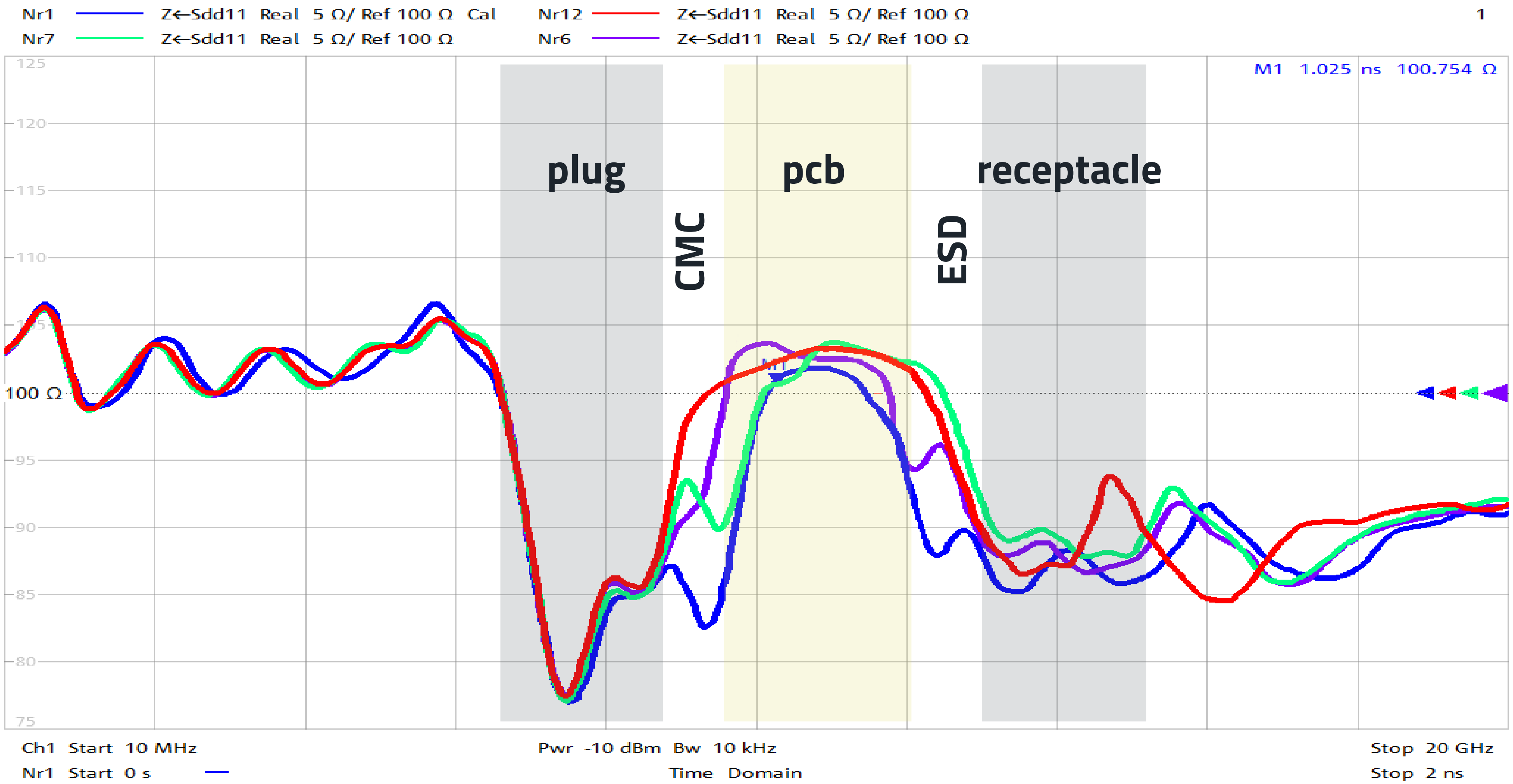
Measurements

Filteradapter – CMC/ESD with coating



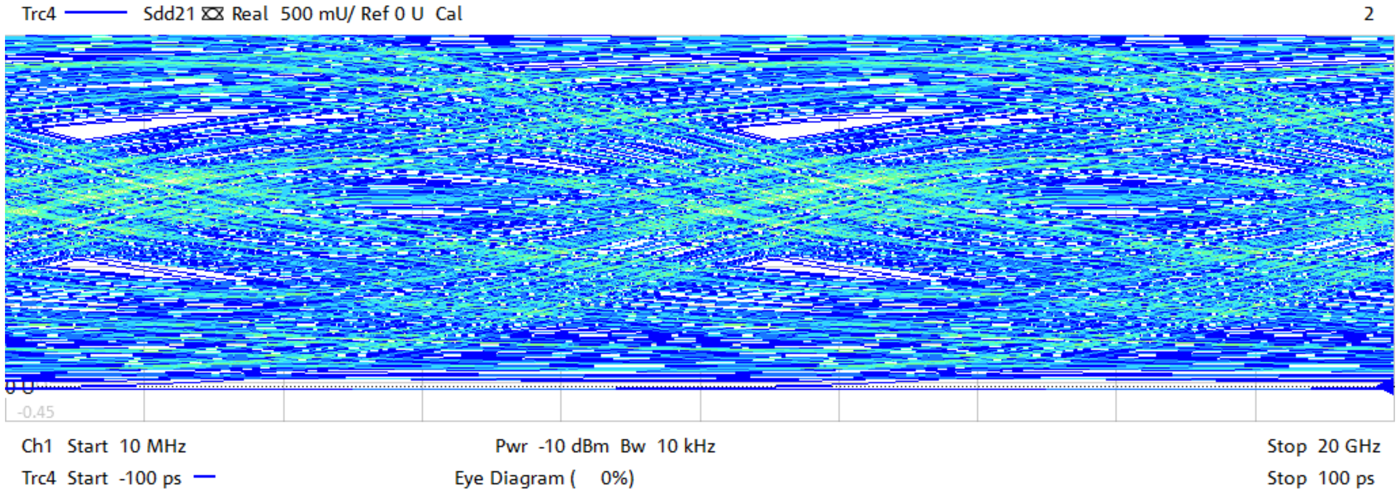
Measurements

Summery – Impedance



Measurements

Eye diagram 10GBit/s



Literature

- Signalintegrität – Manfred Schmidt – Vogel – ISBN 978-3-8343-3256-1
- Pocket Reference – Art Kay, Tim Green – TI – www.ti.com/analogrefguide
- Signal and Power Integrity – Eric Bogatin – Prentice Hall – ISBN 978-0-13-234979-6

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THANKS FOR YOUR VALUABLE TIME!

Robert Schillinger
Field Application Engineer

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