FUNCTION AND DESIGN OF COAXIAL CONNECTORS

Thomas Robok – Technical Academy

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Agenda

- Coaxial Systems
- Basic RF-Engineering
- Overview PCB Structures
- Combination Connector & PCB

Coaxial Systems

- *Types*
- *Mechanic*

Coaxial Systems: Types

Würth Elektronik Product range


NEW
UMRF Connectors


SMP Connectors


EXTENDED
SMA Connectors


EXTENDED
Reverse Polarity SMA Connectors


MCX Connectors


MMCX Connectors


SMB Connectors


EXTENDED
Cable Assemblies


EXTENDED
Adaptor


NEW
RF Tools

Coaxial Systems: Types

Main Models

- Plug: active part of coupling system
- Jack: complementary part of the coupling system

Cable Connector

PCB Connector

Adaptor

Connected between 2 cable assemblies

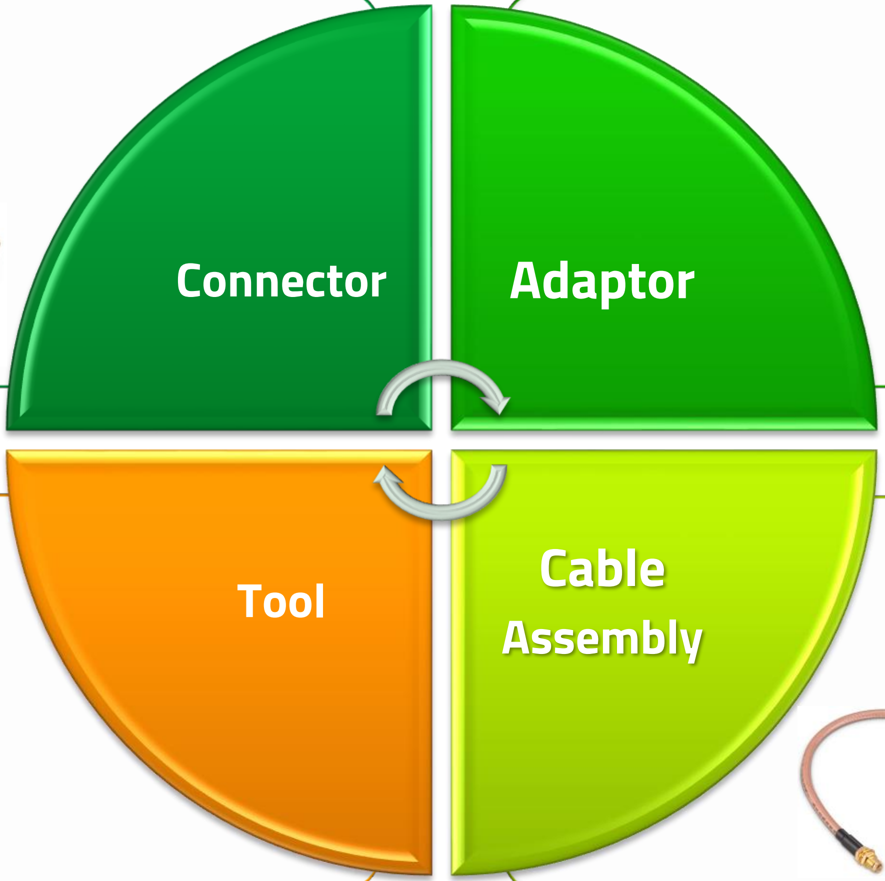
Panel Connector

Soldered to a wire, PCB, or fixed on a micro electronic box or on a microwave box according to its back shape design.

Coaxial Systems: Types

WE Product Range

- PCB Connector
- Panel Connector



- Configuration:
  - Jack to Jack
  - Plug to Plug
  - Jack to Plug

- Torque Wrench

- Cable Type:
  - Flexible
  - Hand-Formable

Coaxial Systems: Types

PCB Connector

- Very popular
- Fixed PCB thickness
- Flat tab & round post pin

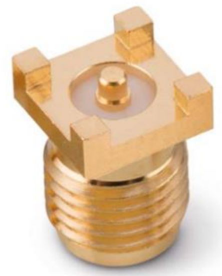
End Launch

Through Hole

- Good retention on PCB
- Wider range of PCB thickness
- Available with SMT signal pin

- Full SMT
- PCB mid mount

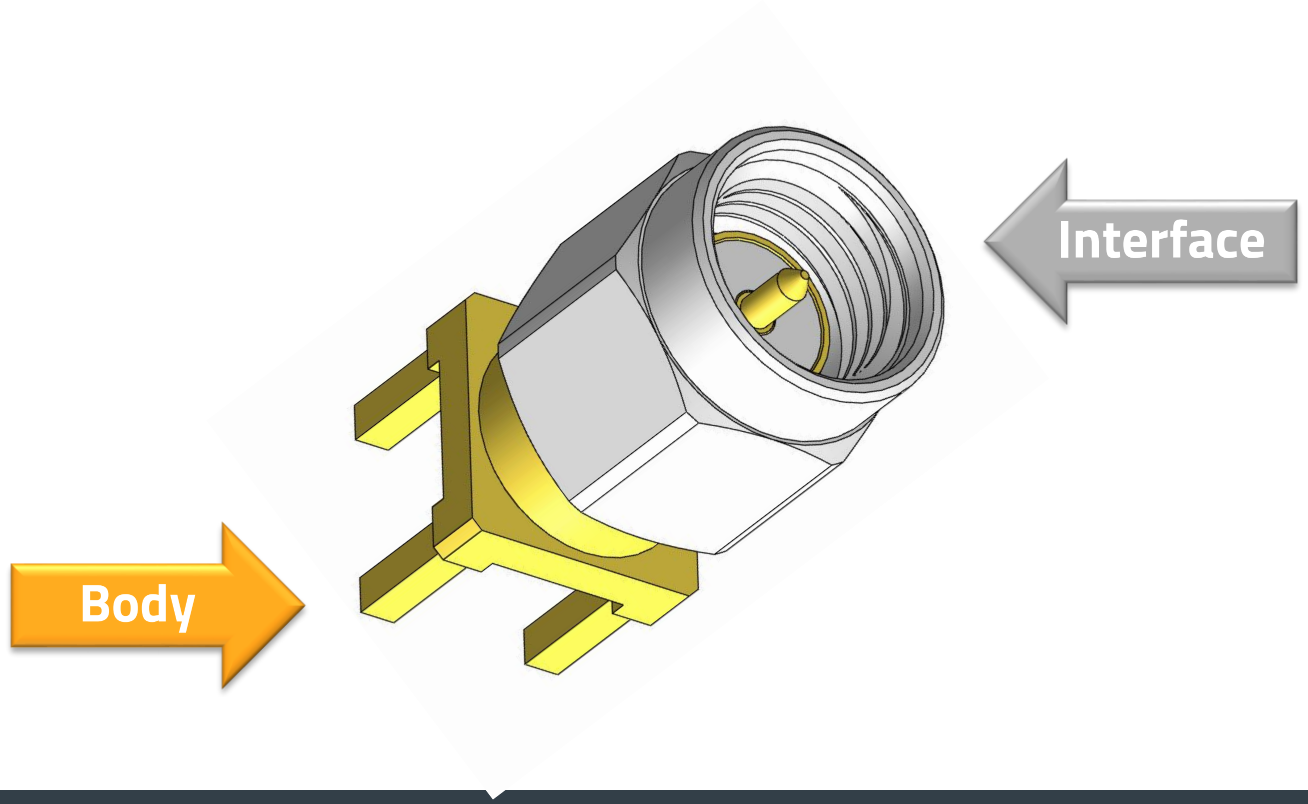
Surface Mount



Surface Mount

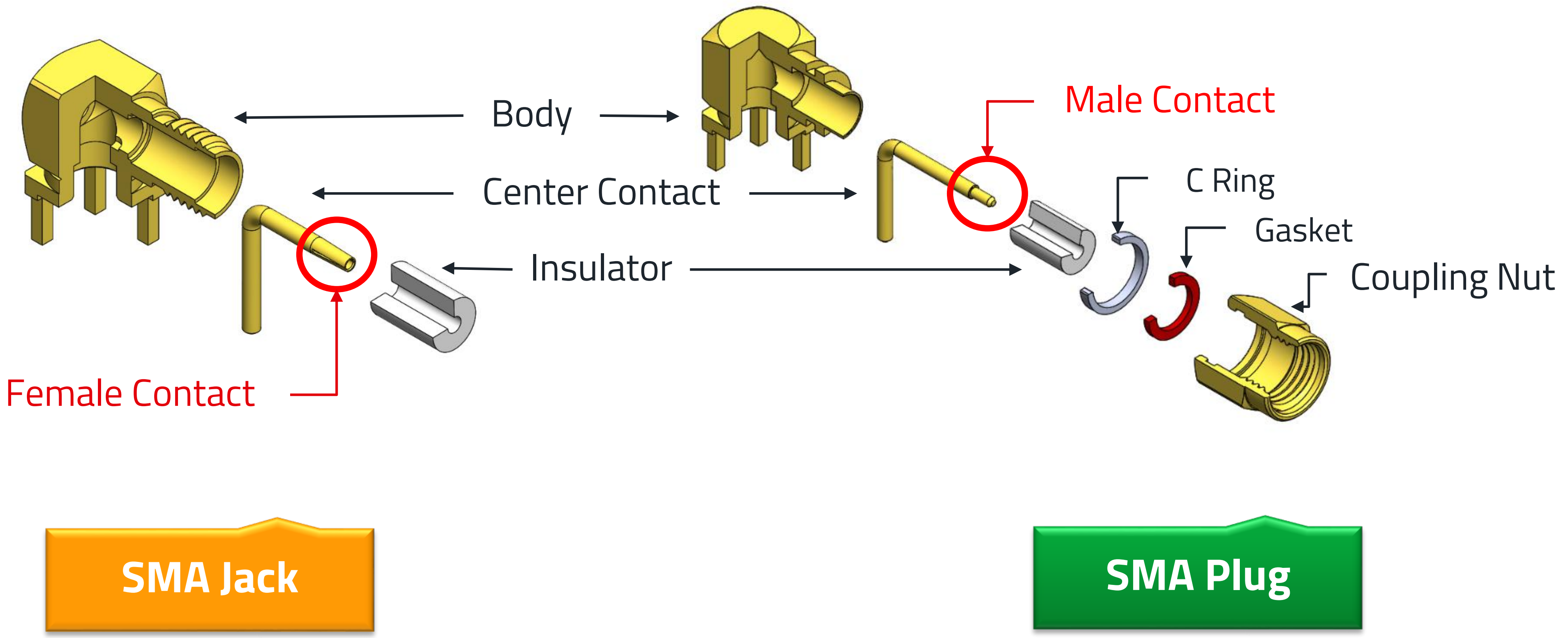
- Full SMT

Coaxial Systems: Mechanic



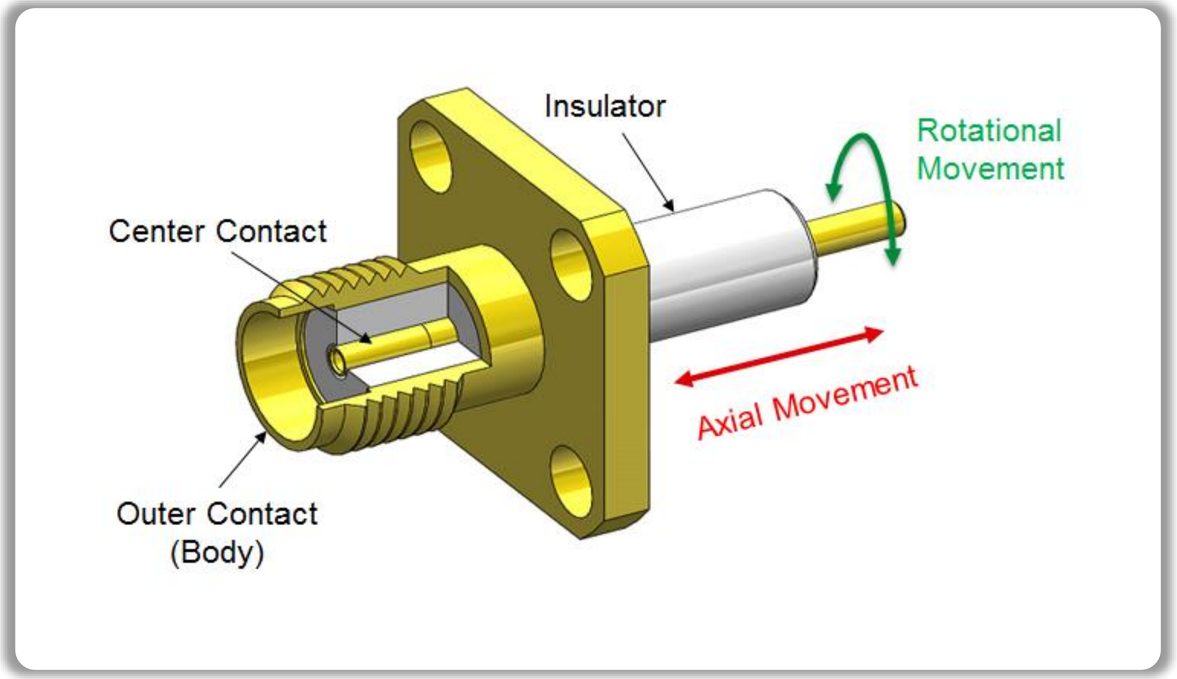
Coaxial Systems: Mechanic

Constructive Parts



Coaxial Systems: Mechanic
Captivation

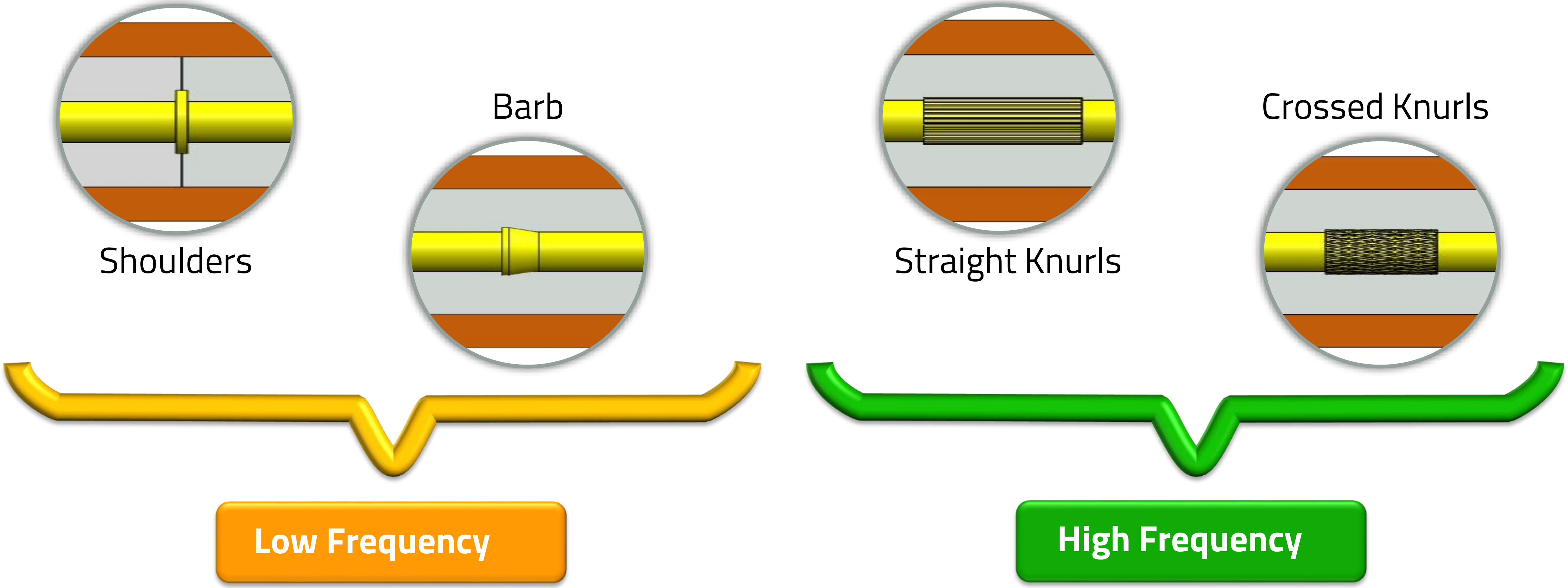
- **Capture mechanism for Rotation & Axial Movement**



- **Captivated center contact**
  - Stabilizes rotational & axial movement
- **Captivated dielectric**
  - Positioning and isolation of center & outer contact

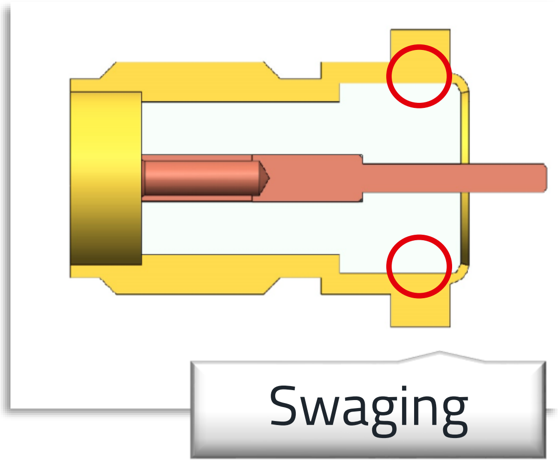
Coaxial Systems: Mechanic

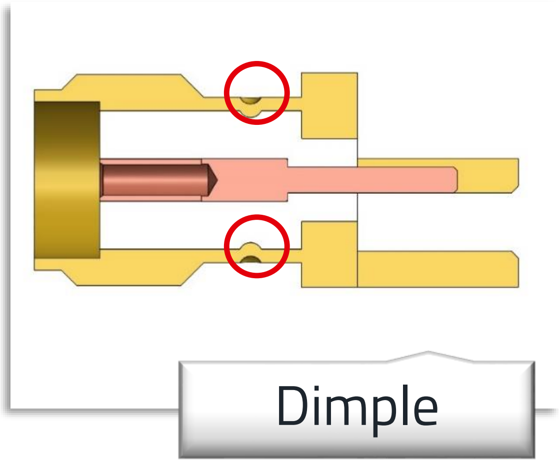
Contact Captivation

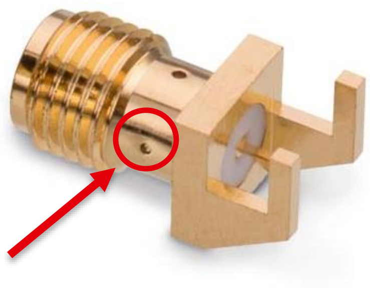


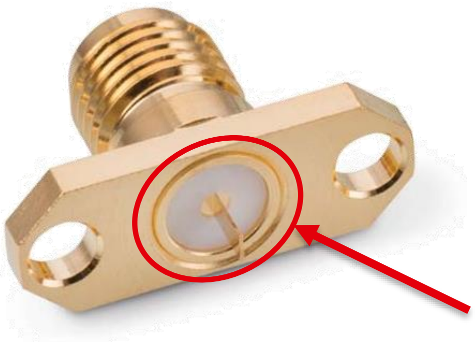
Coaxial Systems: Mechanic

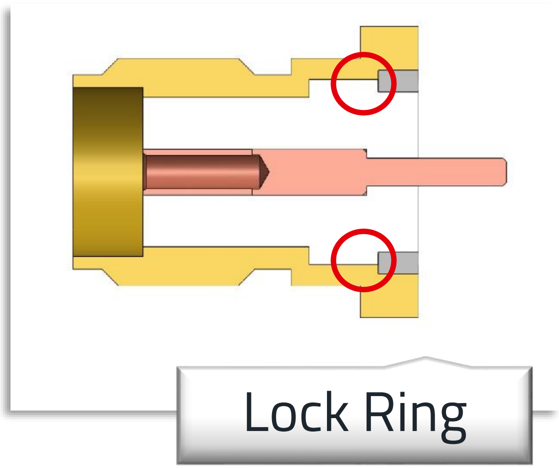
Dielectric Captivation Technologies

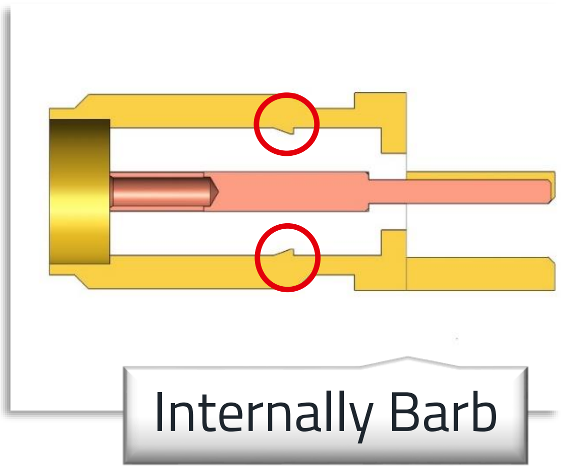






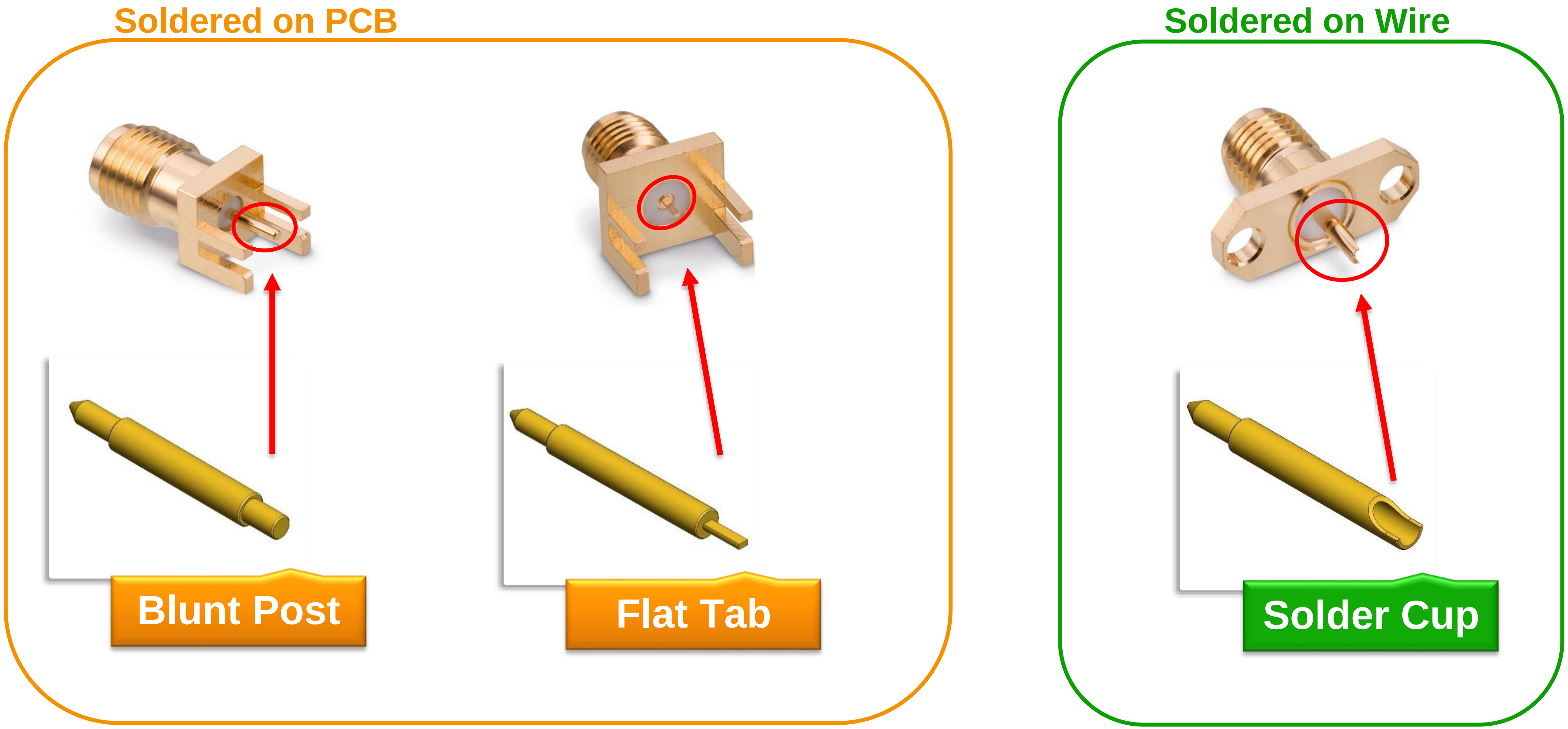






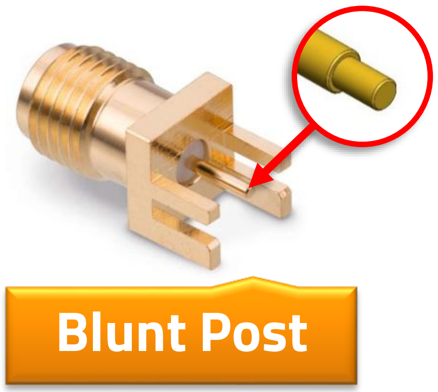
Coaxial Systems: Mechanic

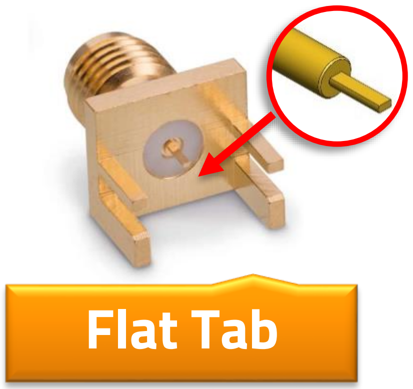
Center Contact Back Shape (1)



Coaxial Systems: Mechanic

Center Contact Back Shape (2)

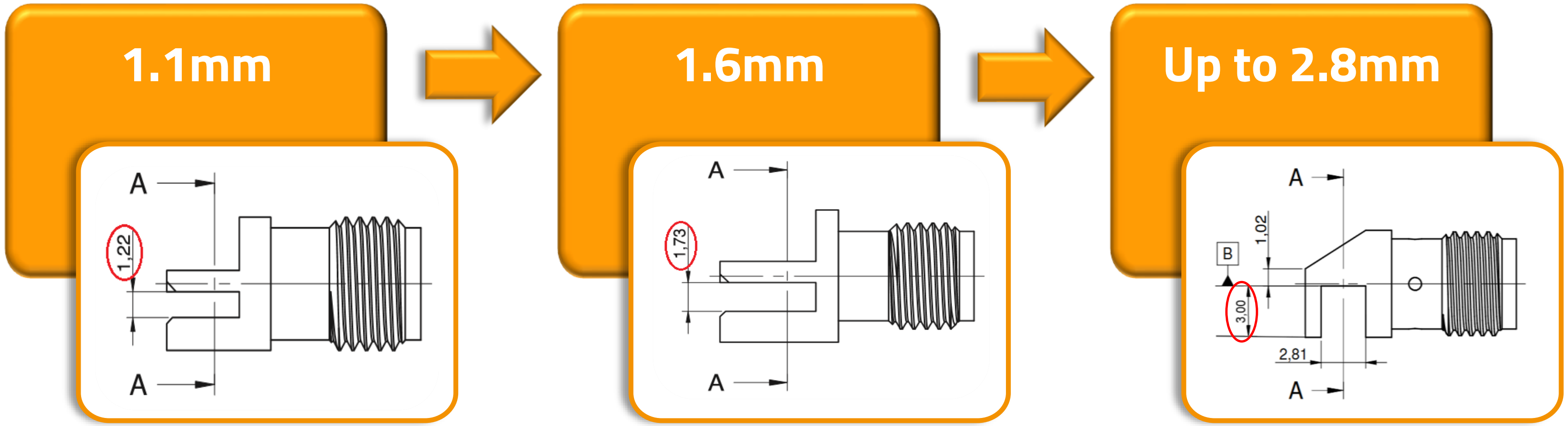




Feature	Round Post	Flat Tab
Mechanical Contact with PCB	++	+
Transmission Line Design	+	++
Frequency Range	+	++

Coaxial Systems: Mechanic
End Launch - PCB Thickness

- **PCB-Thickness varies from chosen type**



- **Determined either by slide-in thickness or max. pin length**

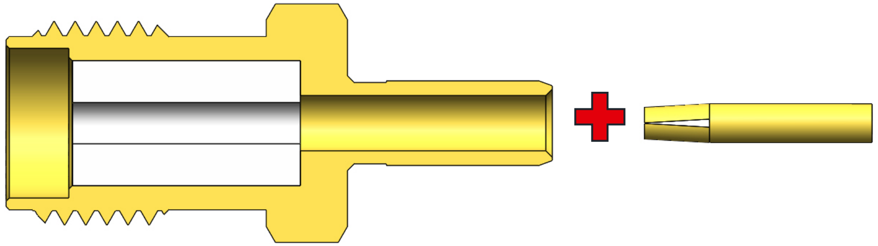
Coaxial Systems: Mechanic

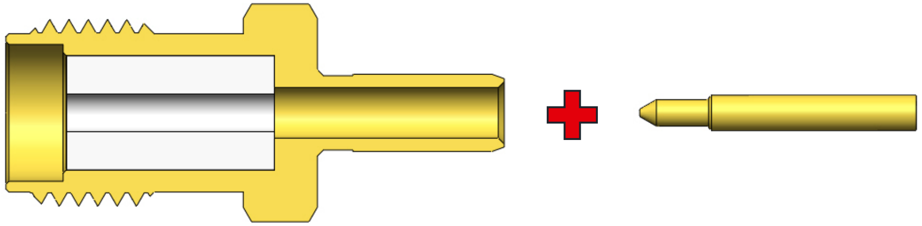
Jack: Standard vs. Reverse Polarity

Standard

Female body

female center contact





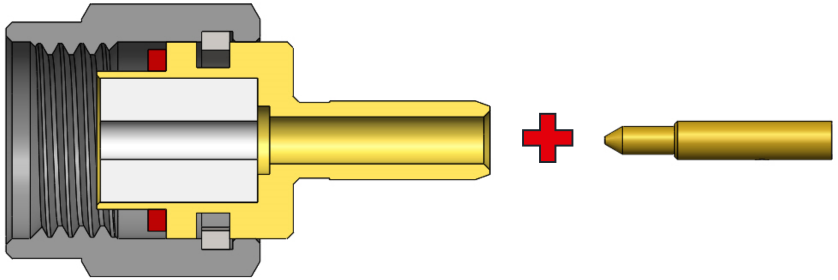
Reverse Polarity

Female body

male center contact

Coaxial Systems: Mechanic

Plug: Standard vs. Reverse Polarity



Standard

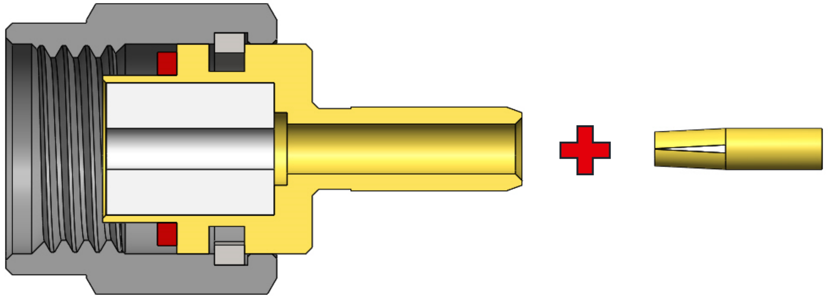
Male body

male center contact

Reverse Polarity

Male body

female center contact



Coaxial Systems: Properties

General Information

- Operating Temp.: -65 up to +165 °C

Mechanical Properties

- Mating Cycle: 500 Cycles

Electrical Properties

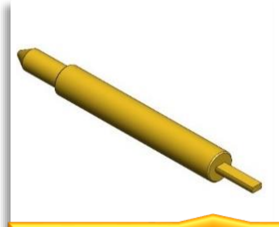
- Frequency band: DC ~ 18 GHz

Coaxial Systems: Summary

Center Contact Back Shape

Blunt Post

- Good contact
- Low frequency



Flat Tab

- Easy PCB design
- High frequency

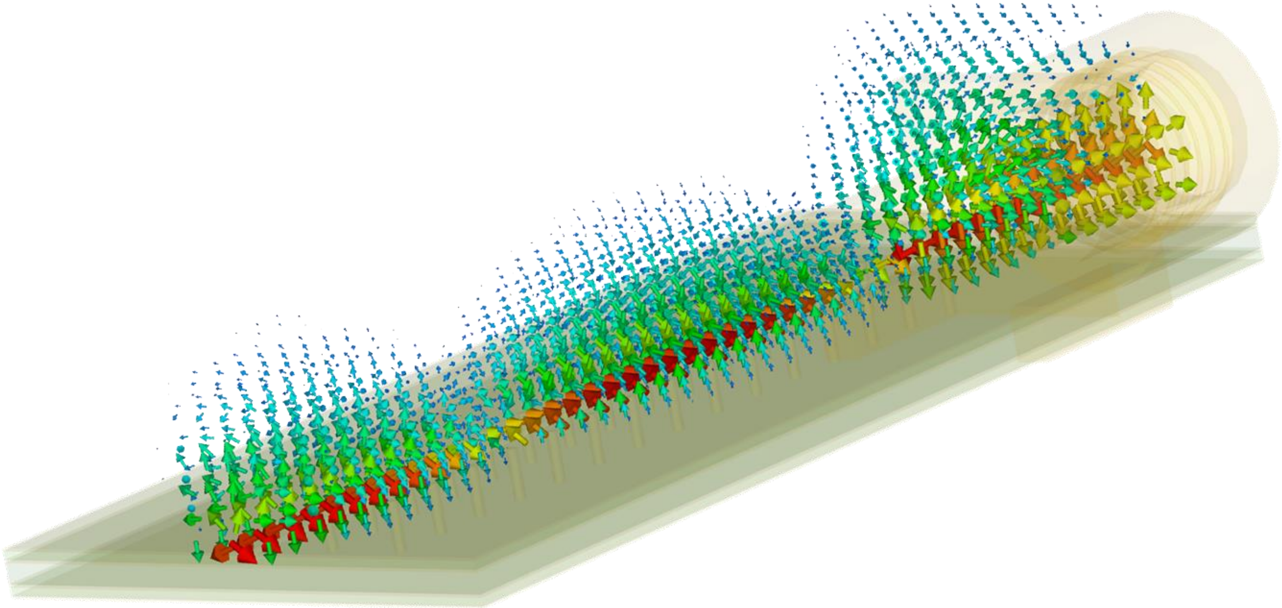
PCB Thickness

→ 1.1mm & 1.6mm

→ Up to 2.8mm

- **Basic RF-Engineering**
  - *Wave Characteristic*
  - *Reflection & Attenuation*
  - *S-Parameter & VSWR*
  - *Discontinuity & TDR*

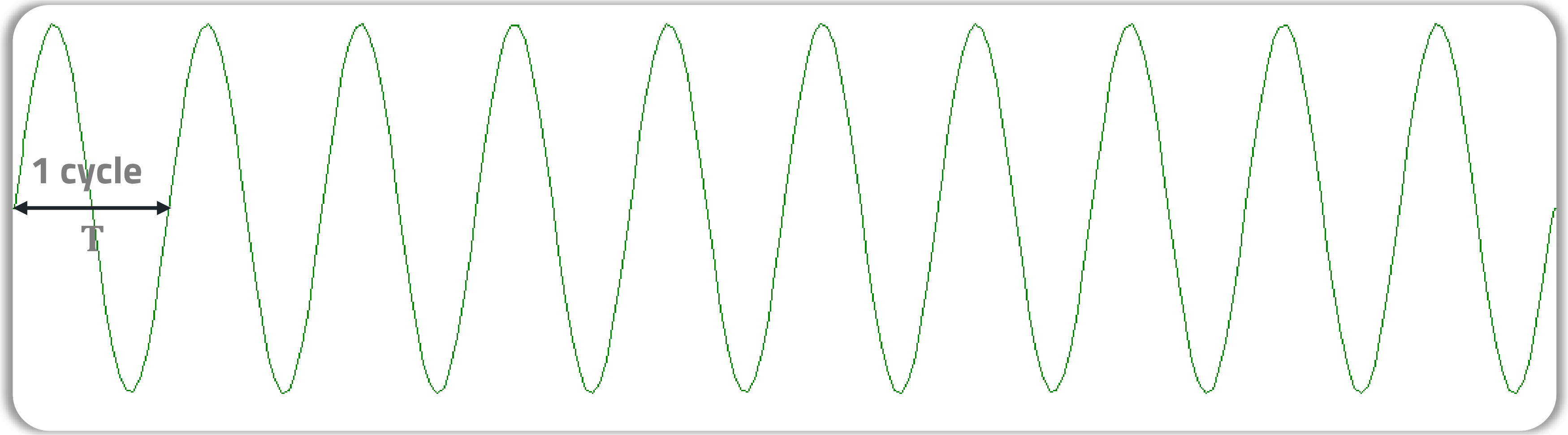
Basic RF-Engineering: Wave Characteristic



Basic RF-Engineering: Wave Characteristic

Frequency

- **Number of cycles per second =** ***f*** (Hertz = Hz)



10 complete cycles in one second ➔ f = 10Hz

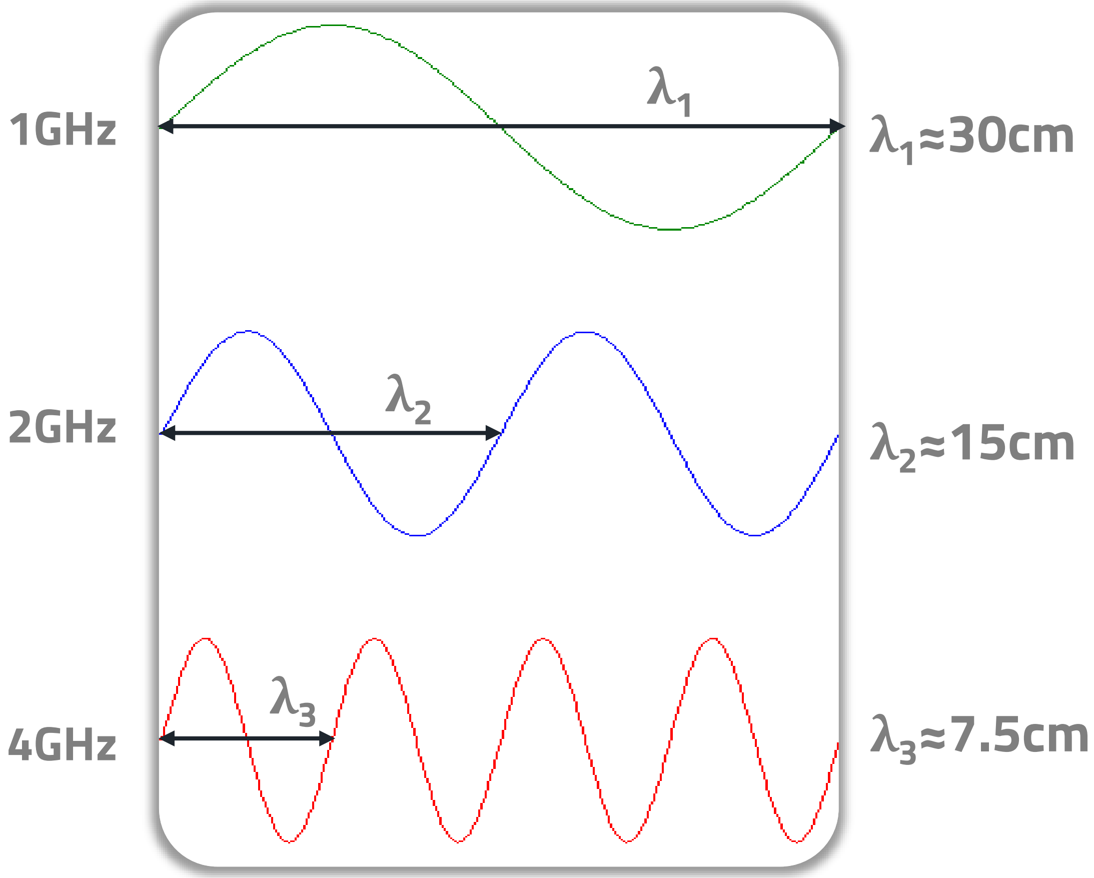
Basic RF-Engineering: Wave Characteristic

Wavelength

- Relates on frequency and propagation velocity:

$$\lambda = \frac{c}{f}$$

- The shorter the wavelength, the higher the frequency.



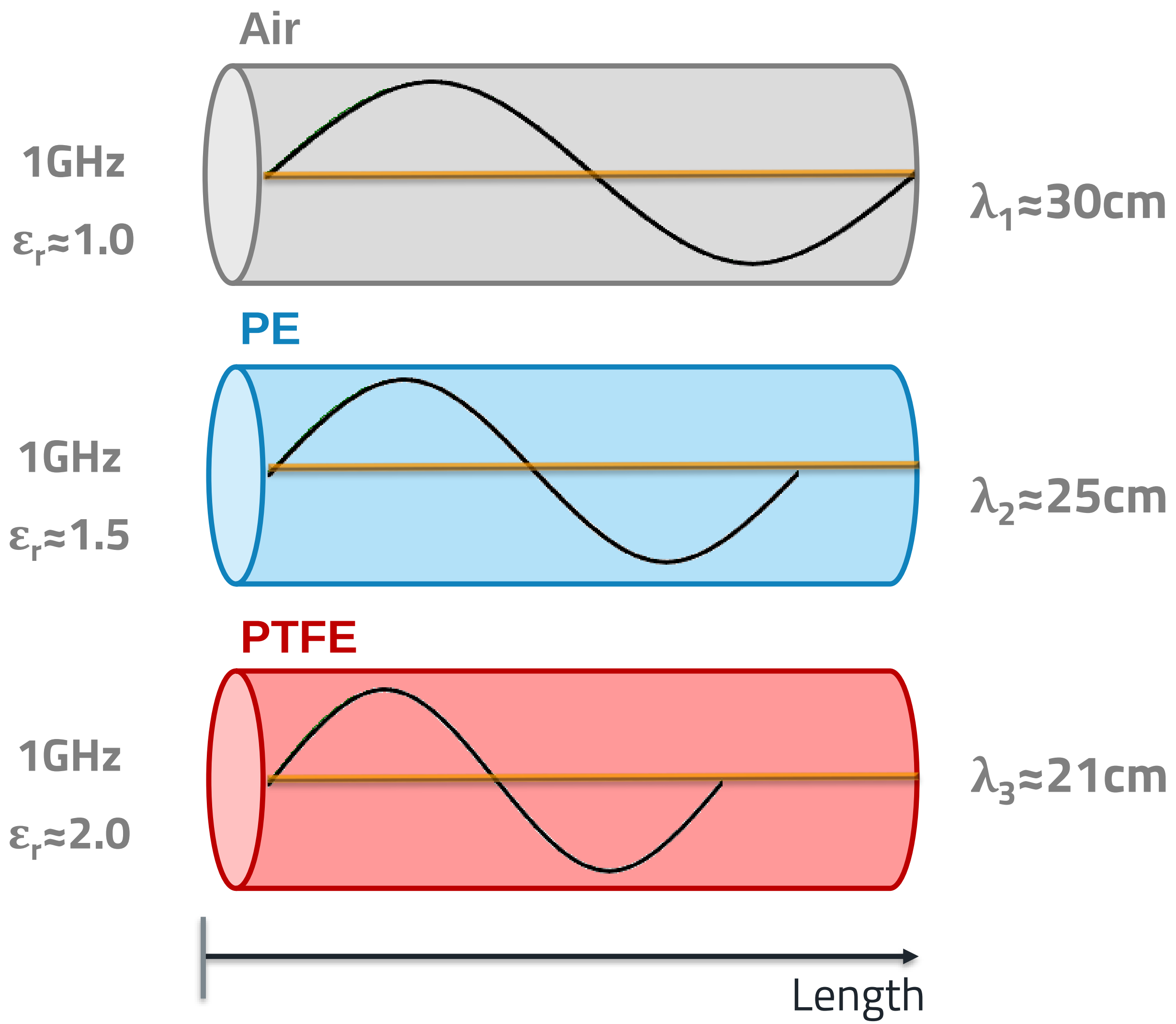
Basic RF-Engineering: Wave Characteristic

Influence of Dielectric Material

- Insulation materials influence velocity of propagation and wavelength:

$$\lambda = \frac{v_p}{f}\,, \qquad v_p = \frac{c}{\sqrt{\varepsilon_r \mu_r}}$$

- Both effects increase along with the dielectric constant

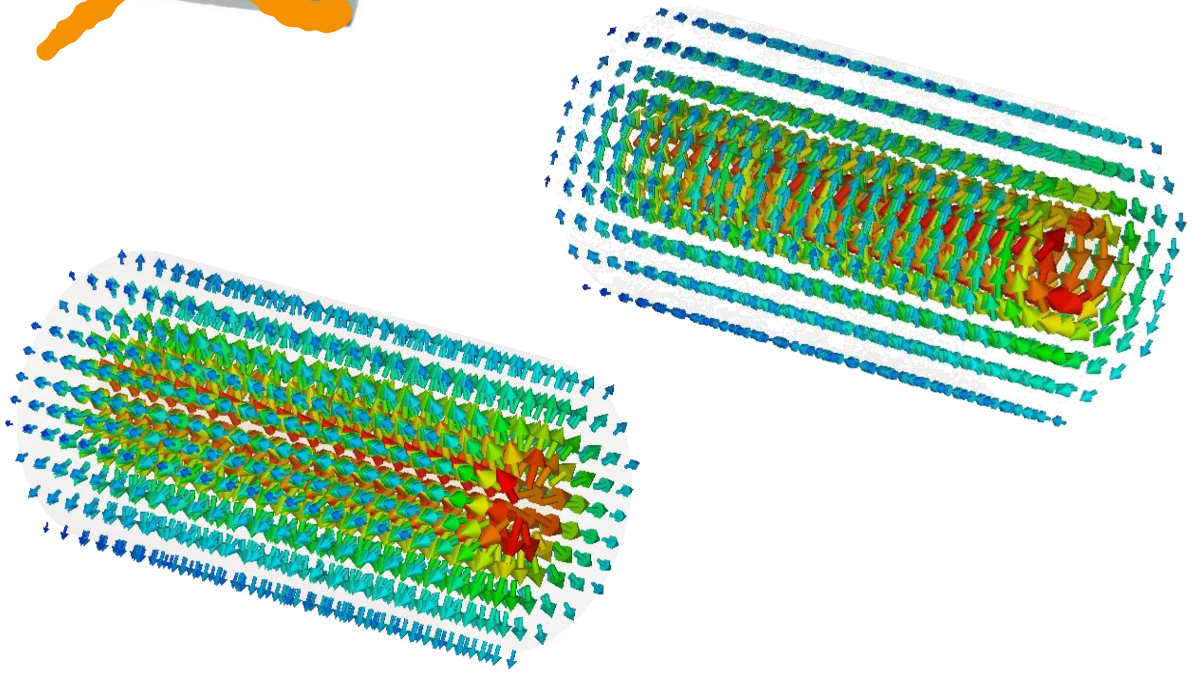


Basic RF-Engineering: Wave Characteristic

Wave Impedance

- **Different from the electrical impedance!**
  - It's the impedance of the traveling wave

- **Defined by the electric and magnetic field**
  - Effected by environmental parameters μ_r , ε_r

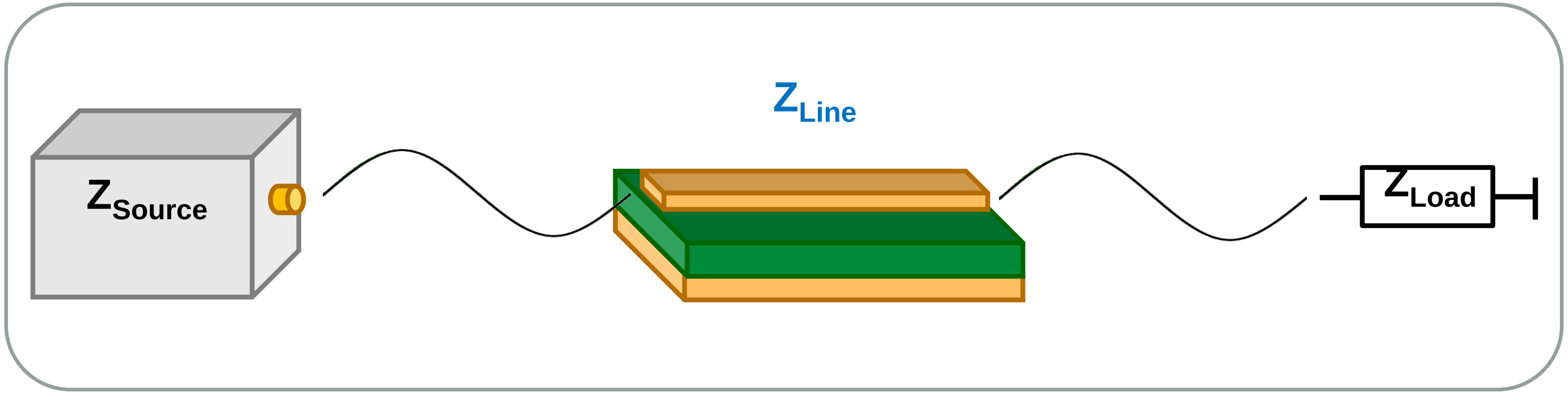


- **Typically**: **50Ω!**

Basic RF-Engineering: Wave Characteristic

Line Impedance

- Property of a line to transmit electromagnetic wave → **Wave impedance of a line**
- **Line impedance depends on**:
  - Material parameter
  - Geometry



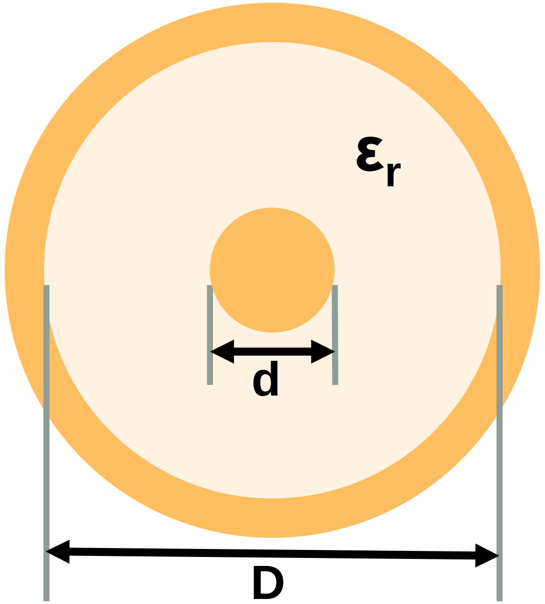
Z_{source}: El. impedance

Z_{load}: El. impedance

Z_{line}: Wave impedance

Basic RF-Engineering: Wave Characteristic

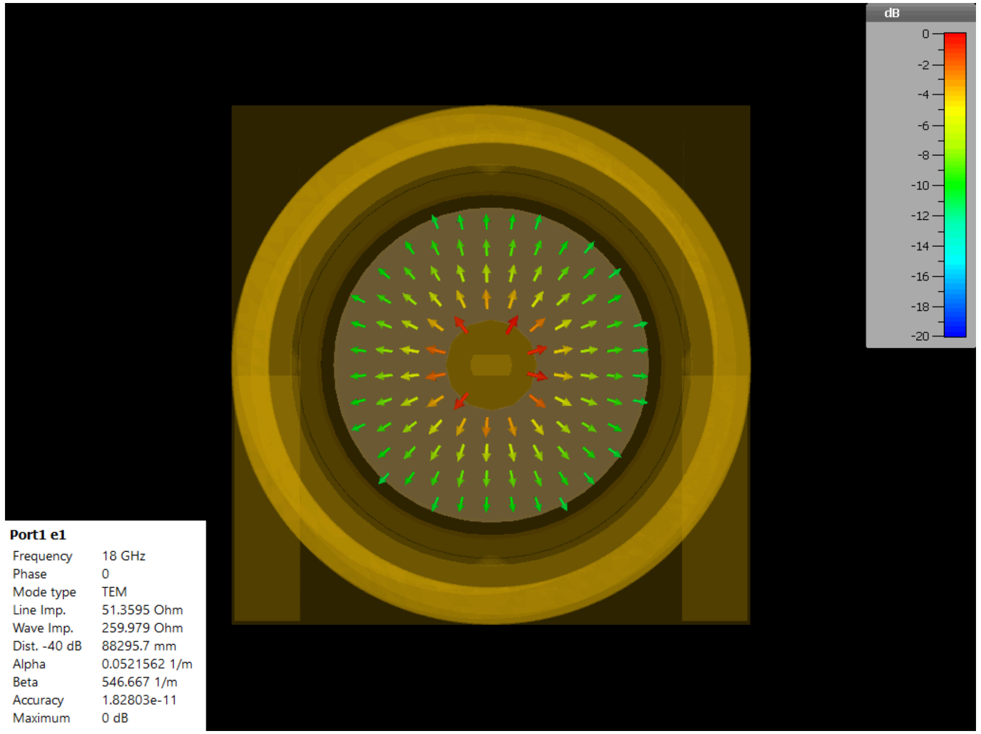
Line Impedance - Example



$$Z_c = \frac{138\Omega}{\sqrt{\varepsilon_r}} \times \log\frac{D}{d}$$

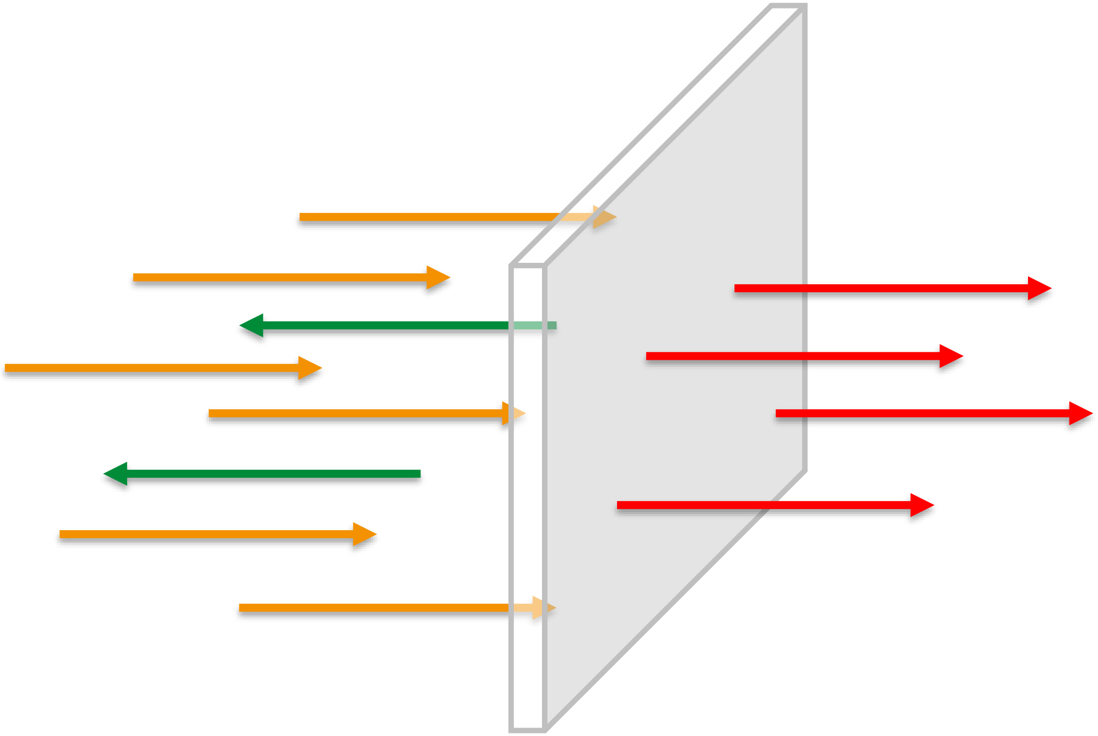
$$\max Z_c = 377\Omega$$

Impedance of free space



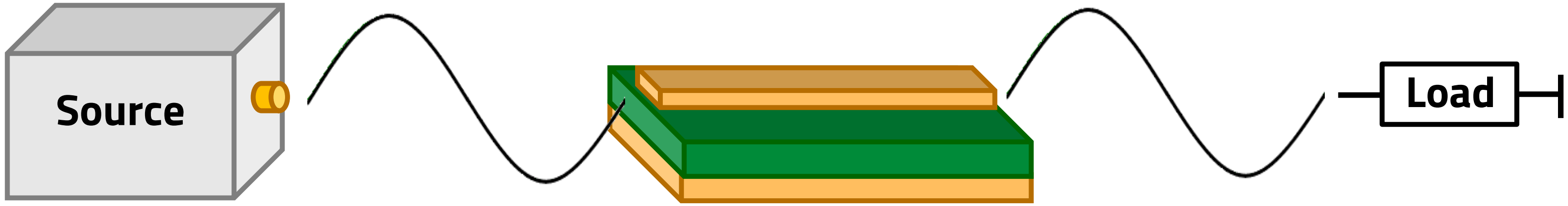
- **d** = Diameter of the inner conductor
- **D** = Inside diameter of the outer conductor
- **ε_r** = Dielectric constant of the insulation material

Basic RF-Engineering: Reflection & Attenuation

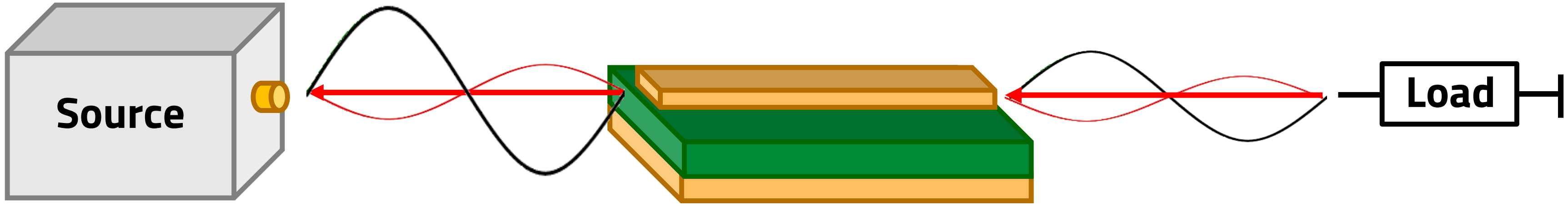


Basic RF-Engineering: Reflection
Overview

- **Perfect match:** $Z_{source} = Z_{line} = Z_{load}$ *normally 50Ω*

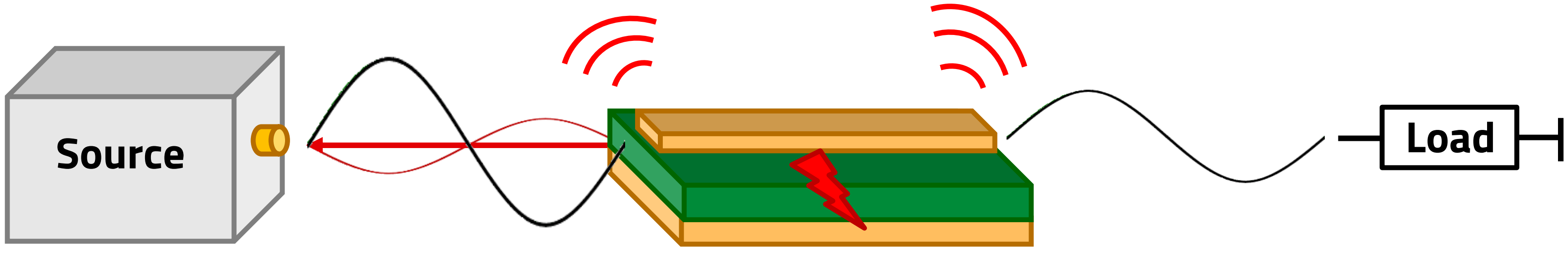


- **Reflection (mismatch):** $Z_{source} \neq Z_{line} \neq Z_{Load}$



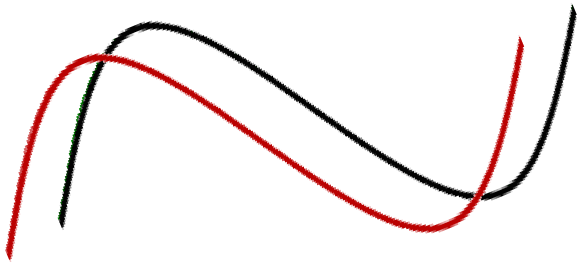
Basic RF-Engineering: Attenuation
Overview

- **Signal loss over transmission path**



- **Sum over:**
  - Absorption *(in the dielectric)*
  - Heat loss *(joule effect in the conductor)*
  - Radiation loss *(leakage in the environment)*
  - Reflection loss *(variations of Z_{Line})*

Basic RF-Engineering: S-Parameter & VSWR

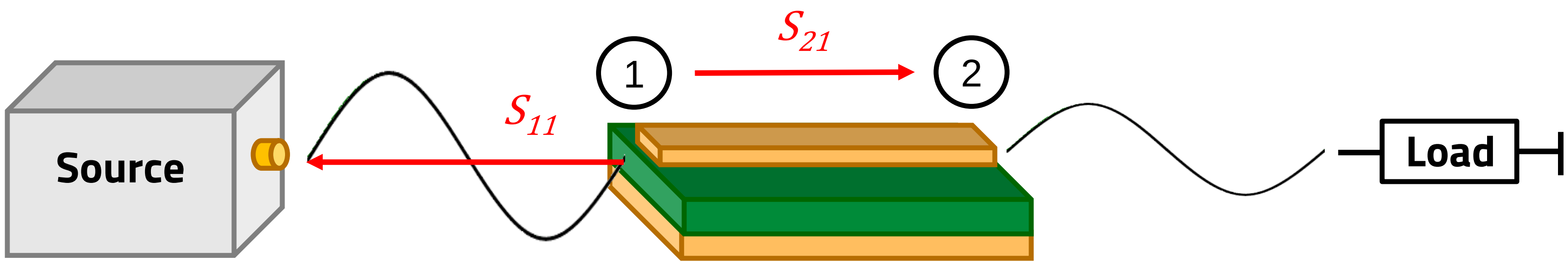


$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

Basic RF-Engineering: S-Parameter

Basics

- **Factor of reflection and throughput:**



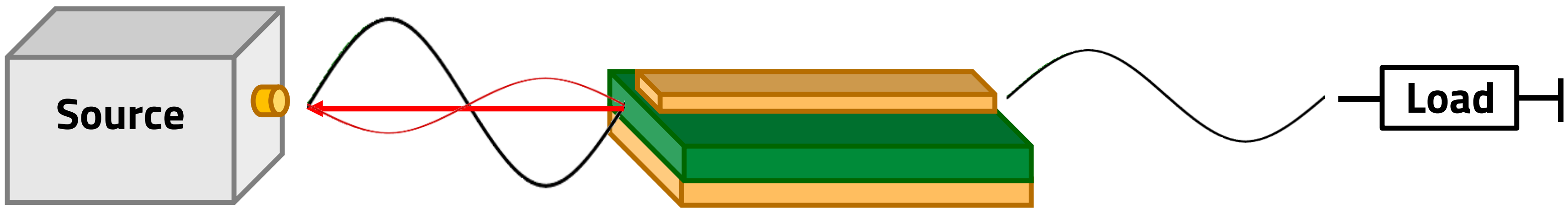
- **S-Matrix:**
  - S_{ii}: Reflection at Port i
  - S_{ji}: Throughput from Port i to Port j
- **Power domain!**

- **Mostly given in dB:**
  - $S[dB] = 10 \times \log(S);$
  - $\text{e.g. } -3dB = 10 \times \log(0.5)$
- **Calculation:**
  - $1.000mW \times 0.5 = 500mW$
  - $30dBm - 3dB = 27dBm$

Basic RF-Engineering: VSWR

Basics

- **Voltage standing wave ratio (VSWR):**



- **Only reflection/return loss:**

$$R_L = 20\log\frac{U_{forward}}{U_{reflected}}\ [dB]$$

- **Voltage domain!**

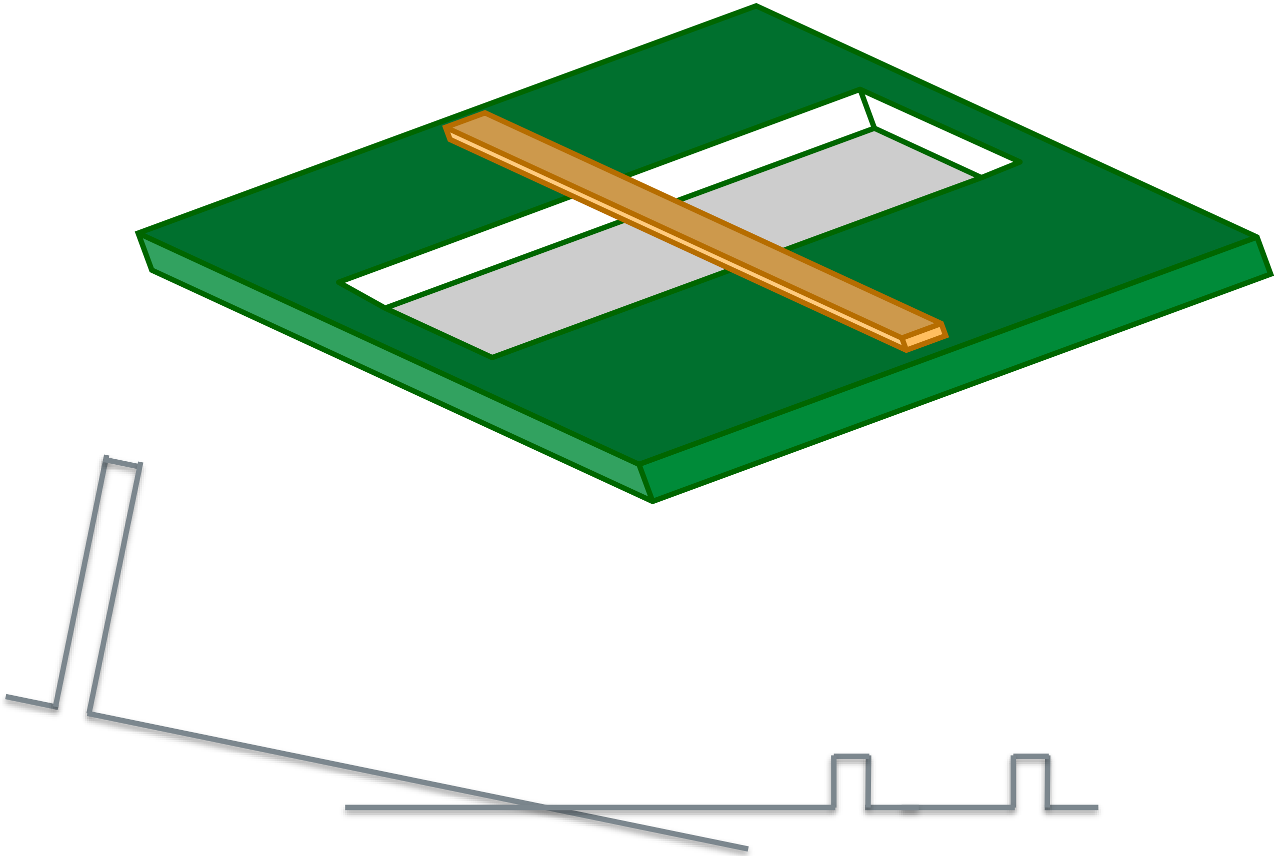
Basic RF-Engineering: S-Parameter & VSWR

Comparison

VSWR	Return Loss	
1.0	∞	Very well matched
1.02	40.1 dB	
1.03	35.3 dB	
1.1	26.4 dB	Well matched
1.12	24.9 dB	
1.15	23.1 dB	
1.2	20.8 dB	Matched
1.3	17.7 dB	
1.4	15.6 dB	
1.5	14.0 dB	Poorly matched
1.7	11.7 dB	
1.8	10.9 dB	
2.0	9.5 dB	Not matched

- **Return loss example:**
  - 15dB: 97% Insertion & 3% Reflection
  - 10dB: 90% Insertion & 10% Reflection
  - 6dB: 75% Insertion & 25% Reflection

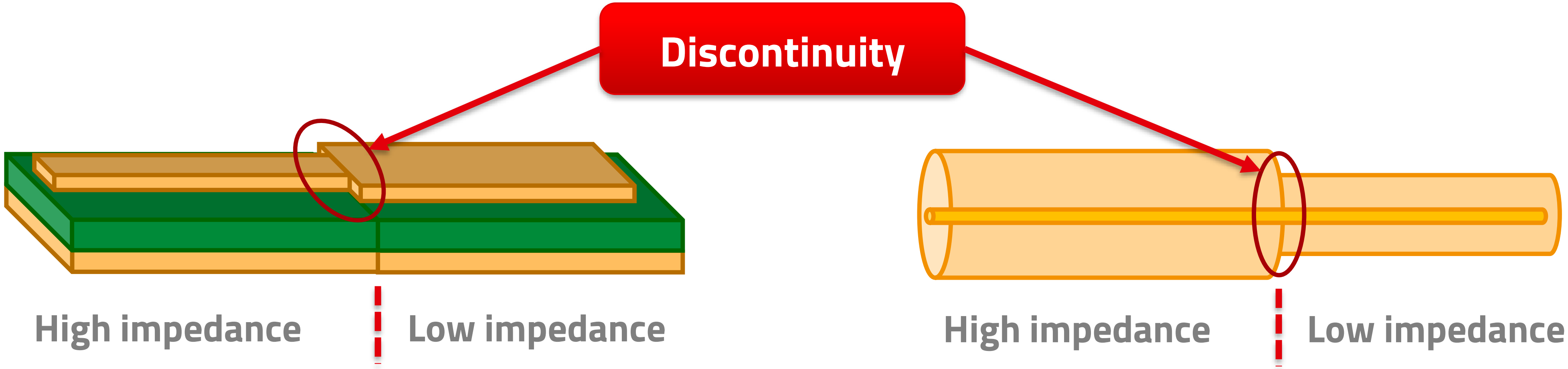
Basic RF-Engineering: Discontinuity & TDR



Basic RF-Engineering: Discontinuity

Impact

- **Impedance variation on RF-path**

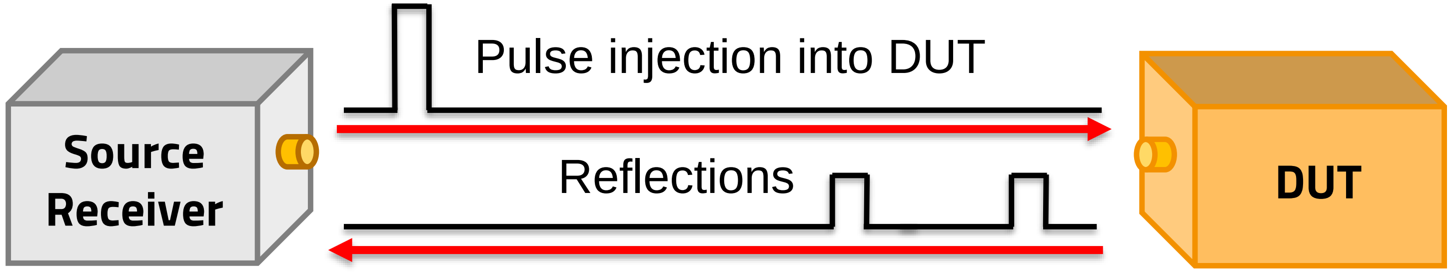


- **Causes:**
  - Reflection
  - Field conversion

Basic RF-Engineering: Time Domain Reflectometry

Functionality

- **Wave impedance measurement through a system**

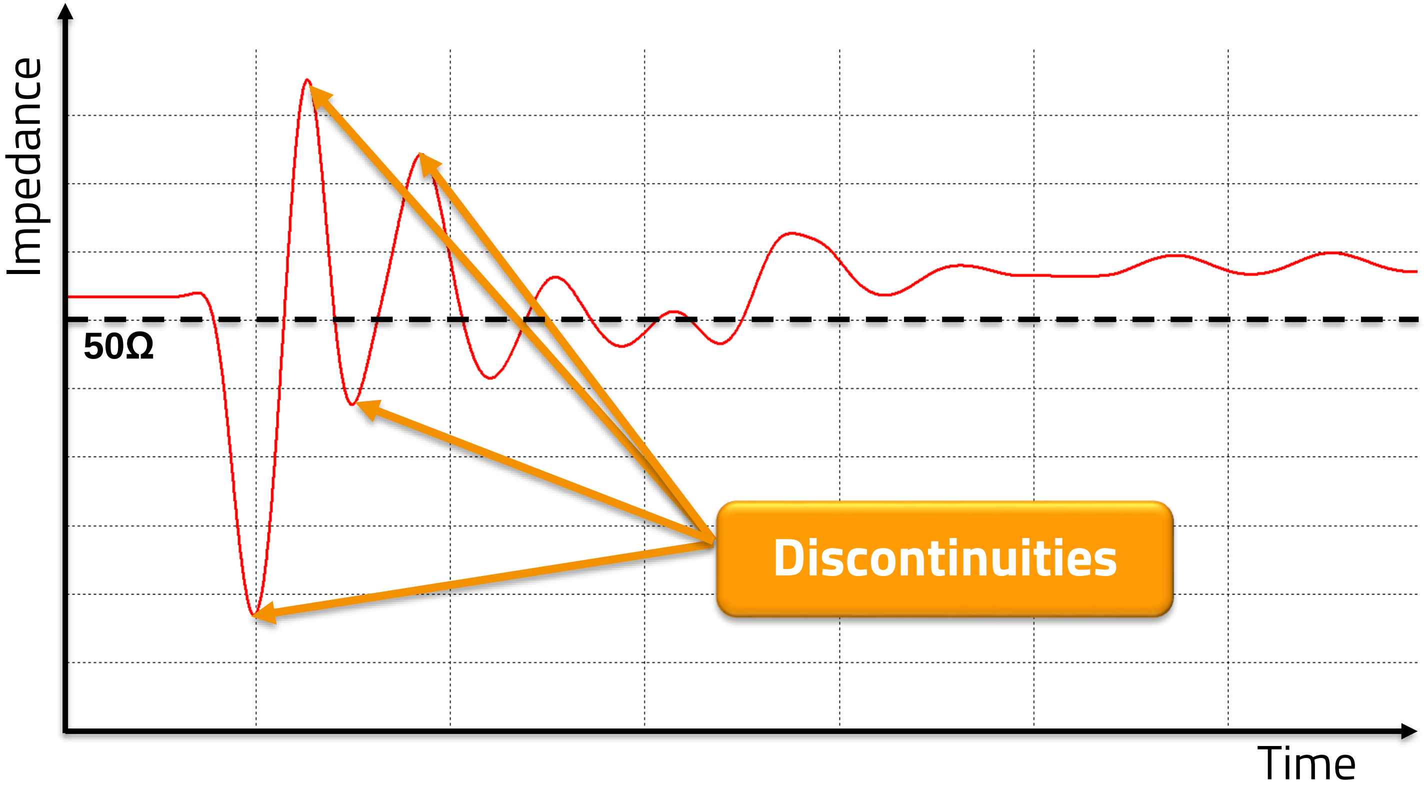


- **Measurement of reflections**
  - Amplitude
  - Time

- **Impedance over time**

Basic RF-Engineering: Time Domain Reflectometry

Example



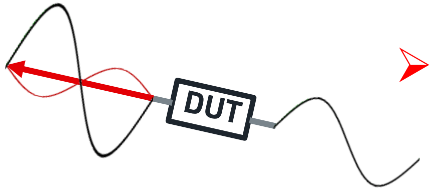
- **Time ~ Length :** $$L = \frac{c}{\sqrt{\varepsilon_r \mu_r}} \times t$$

Basic RF-Engineering : Summary

Wave Impedance

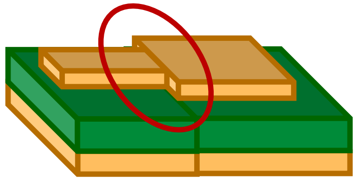
- **Depends on:**
  - E- & H-Field
  - μ_r , ε_r
- **Typically: 50Ω!**

S-Parameter



- **S_{ii}** *(S_{11},S_{22},..)*
  - Reflection
- **S_{ij}** *(S_{12},S_{21}..)*
  - Throughput

Discontinuity



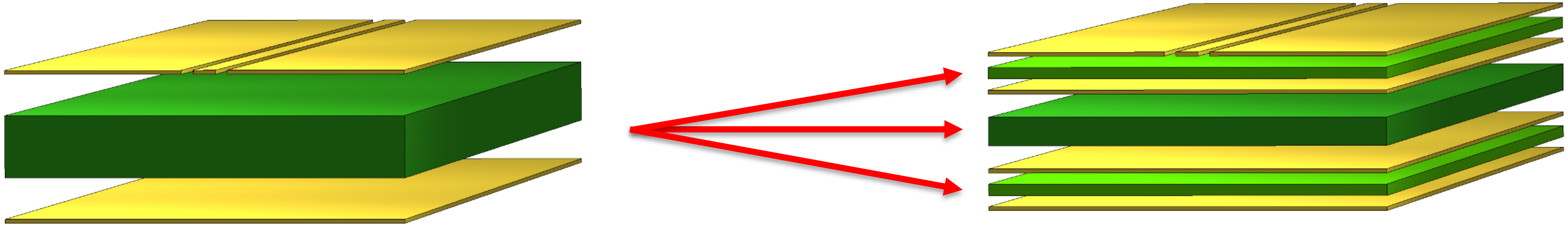
- **Causes**
  - Reflection
- **Measured with**
  - TDR

- **Overview PCB Structures**
  - *Typical Layer Setup*
  - *Planar Transmission Lines*
  - *Tips & Tricks*

Overview PCB Structures: Typical Layer Setup

Overview PCB Structures: Typical Layer Setup

Definition



2-Layer	
Height	1.55 mm
Prepreg	None
Core	FR4

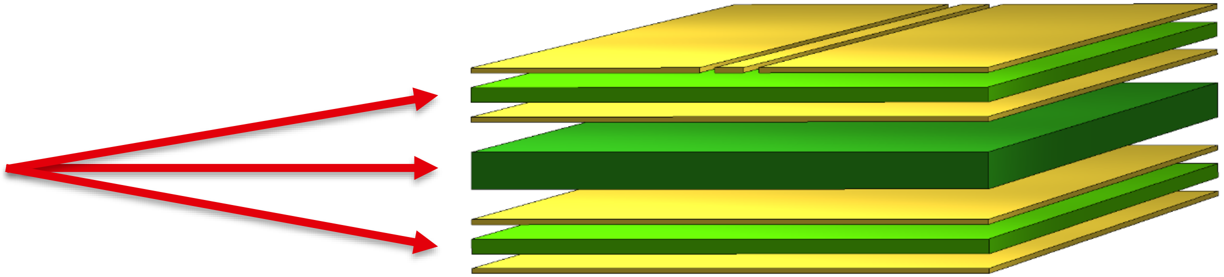
- **Low production cost**
  - Mostly no separate GND-Plane

4-Layer	
Height	1.55 mm
Prepreg	FR4
Core	FR4

- **Good for RF-Designs**
  - Separate GND-Plane
  - Dielectric differs

Overview PCB Structures: Typical Layer Setup
Dielectric

- **FR4 core and prepreg made up of:**
  - Woven glass fabric
  - Resin



- **Differs on dielectric and loss tangent:**
  - Glass & Resin combination
  - Fabrication enviroment

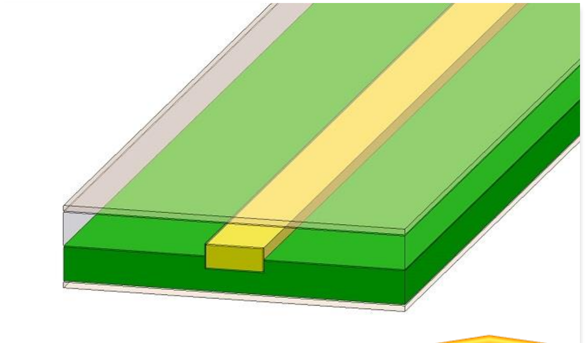
→ **Different RF-Characterisitc!**

  - Changes over frequency

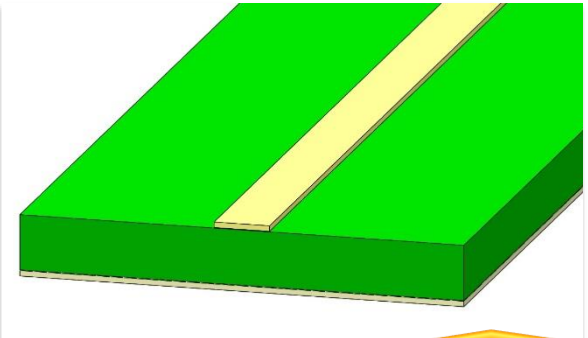
Overview PCB Structures: Planar Transmission Lines

Overview PCB Structures: Planar Transmission Lines

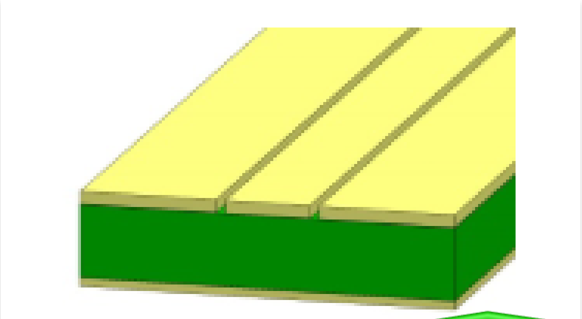
Various Types



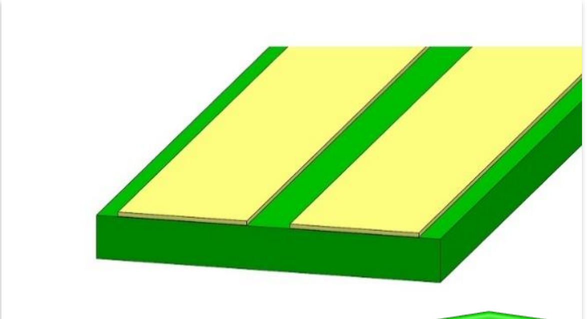
Stripline



Microstrip



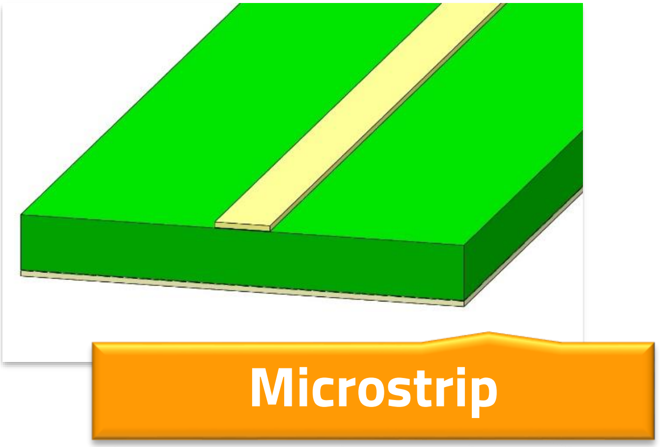
Grounded Coplanar

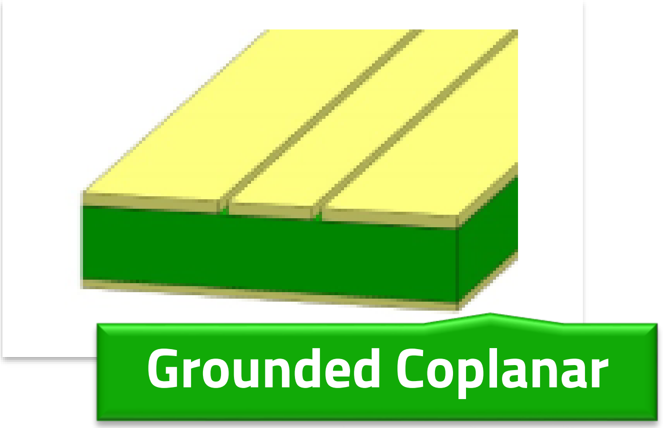


Slot line

Overview PCB Structures: Planar Transmission Lines

Generally Used Types





Microstrip

- Wider line width
- Antenna fed-line
- No Ground on RF-Layer

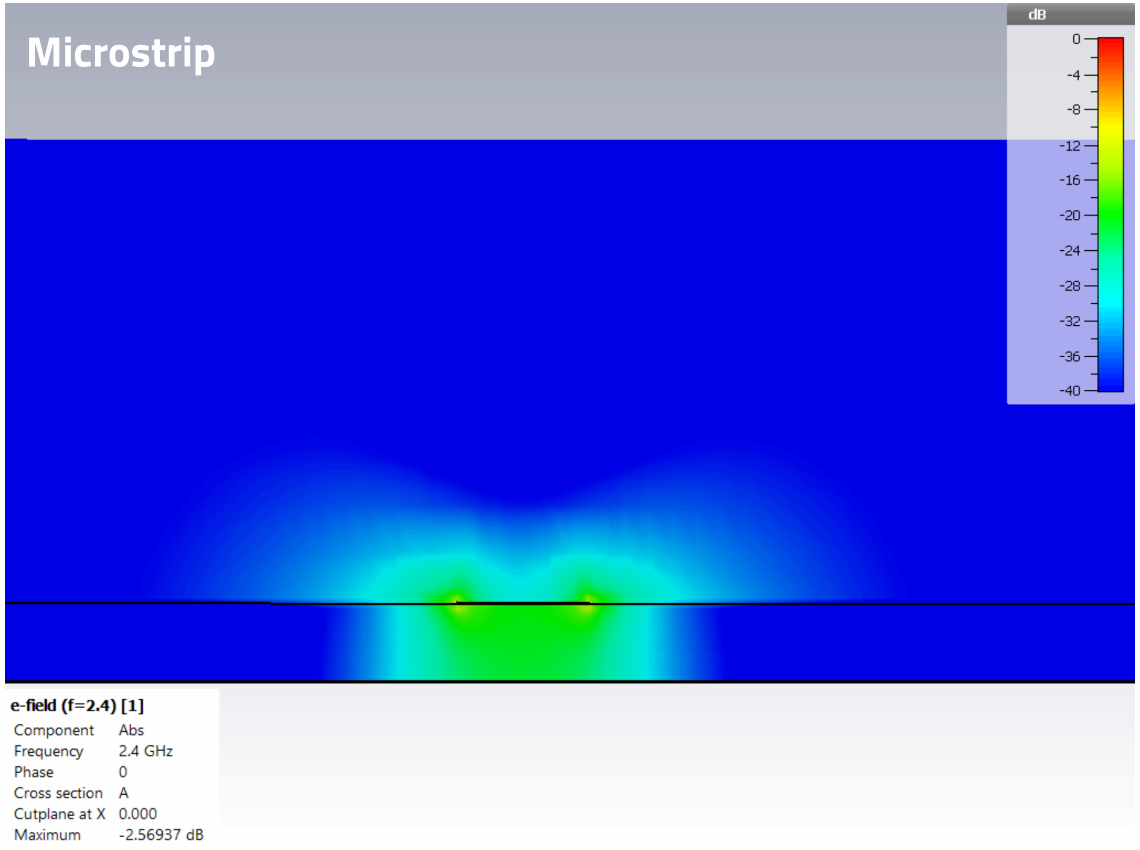
- Line width depends on substrate height and ε_r

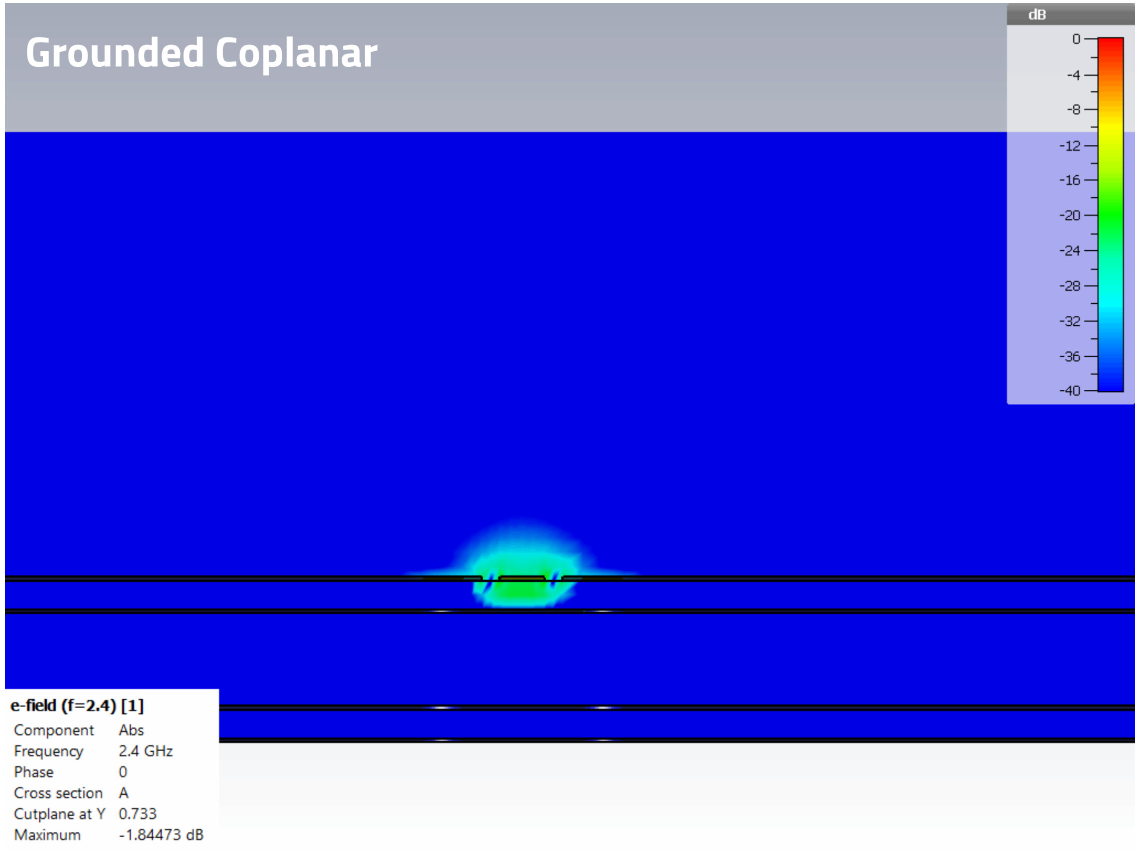
Grounded Coplanar

- Smaller line width
- Ground connection to components
- Various planar matching designs

- Line width depends on substrate height, ε_r and gap width

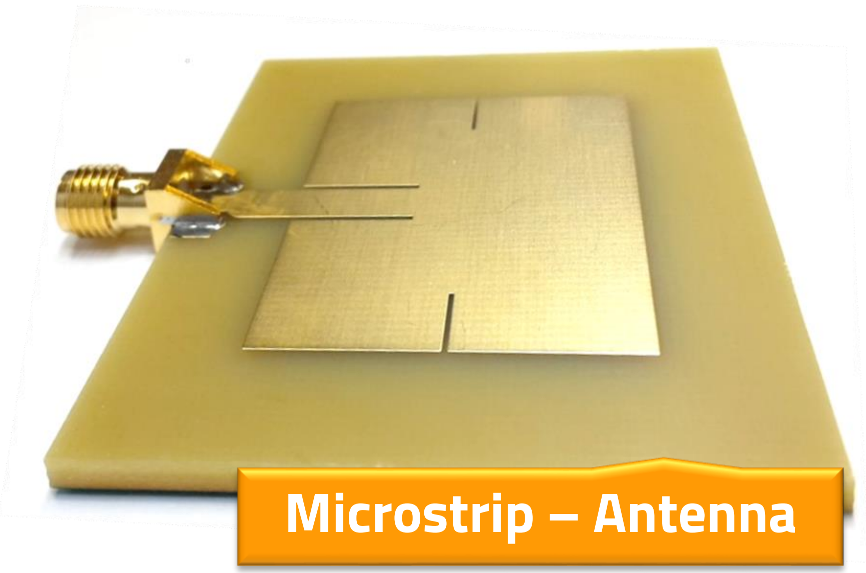
Overview PCB Structures: Planar Transmission Lines
Field Distribution

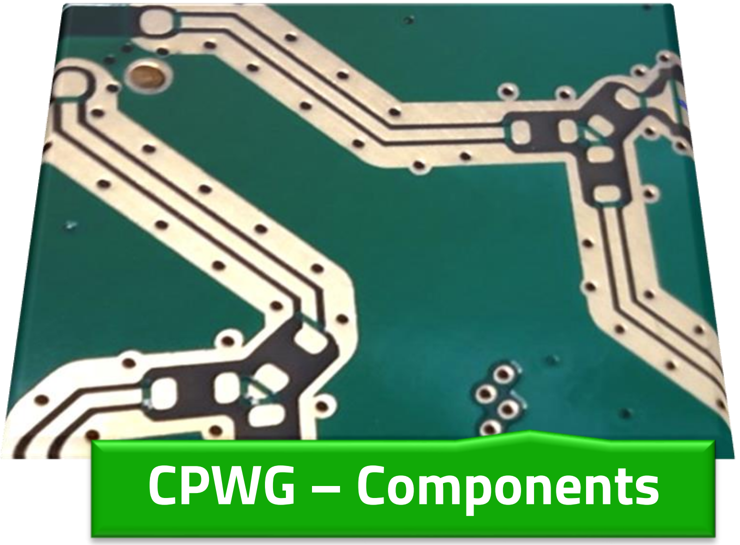




Overview PCB Structures: Planar Transmission Lines

Generally Used Types - Applications

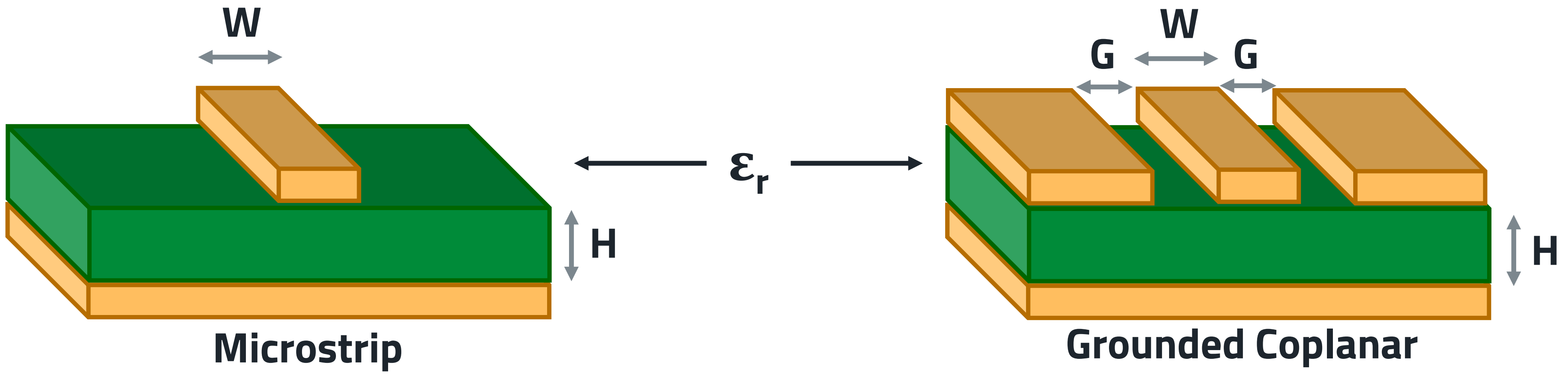




Overview PCB Structures: Planar Transmission Lines

Generally Used Types – Line Impedance

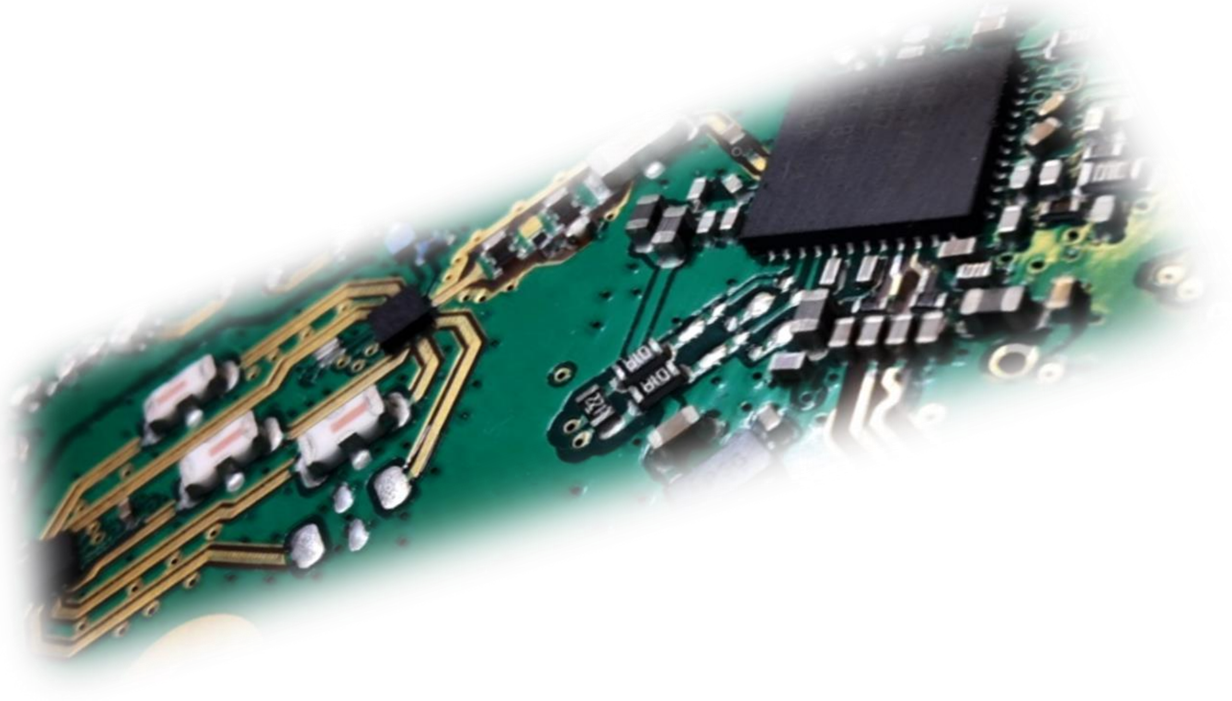
- **Line impedance depends on**:



- **W** = Trace width
- **ε_r** = Dielectric constant of the core/prepreg
- **G** = Gap between trace and ground
- **H** = Height of the core/prepreg

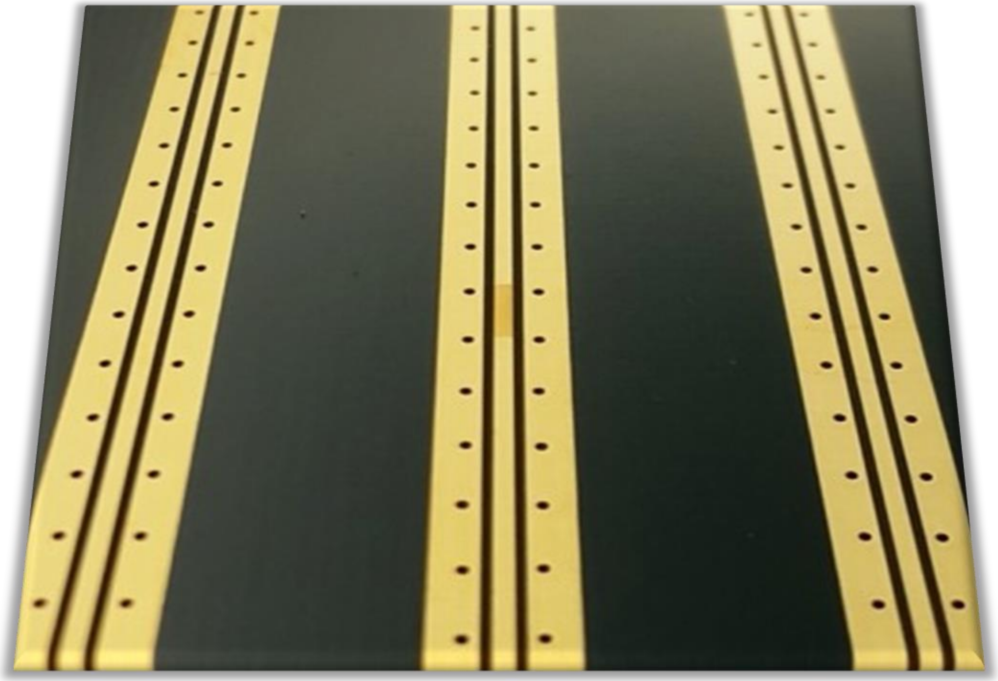
↑ **W** ⇨ ↓Z_{Line}
↑ **ε_r** ⇨ ↓Z_{Line}
↑ **G** ⇨ ↑Z_{Line}
↑ **H** ⇨ ↑Z_{Line}

Overview PCB Structures: Tips & Tricks



Overview PCB Structures: Tips & Tricks

Solder-Resist free

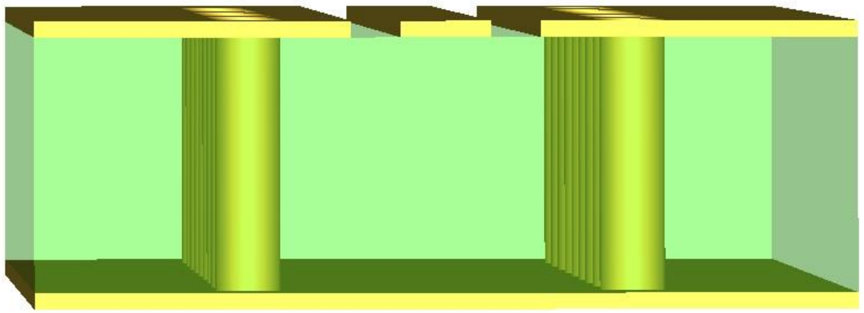


- **Solder resist:**
  - Increases loss
  - Adds dielectric

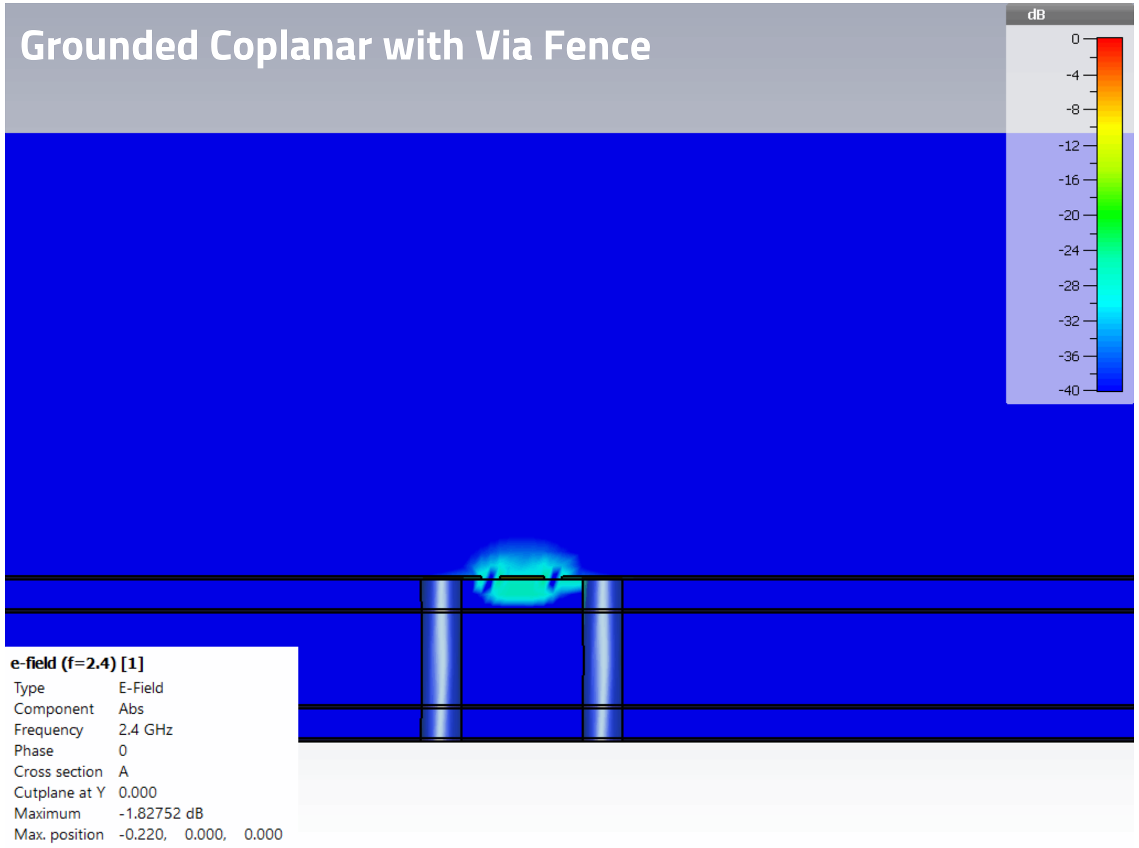
- **Remove solder resist from:**
  - RF-Line and
  - Near Ground-Plane

Overview PCB Structures: Tips & Tricks

Via Fence

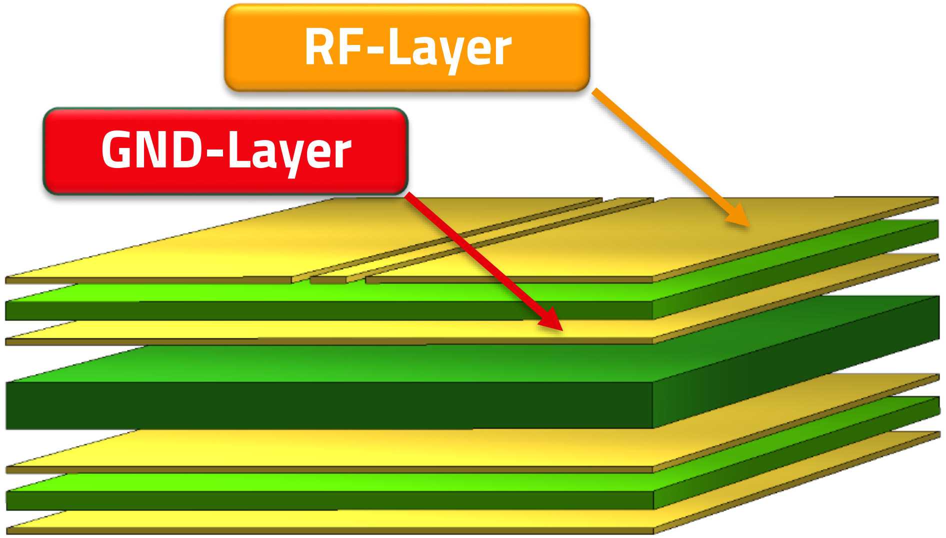


- **Field captured between GND**
  - Reduces coupling
  - Less loss
- **Stabilized ground planes**



Overview PCB Structures: Tips & Tricks

Layers

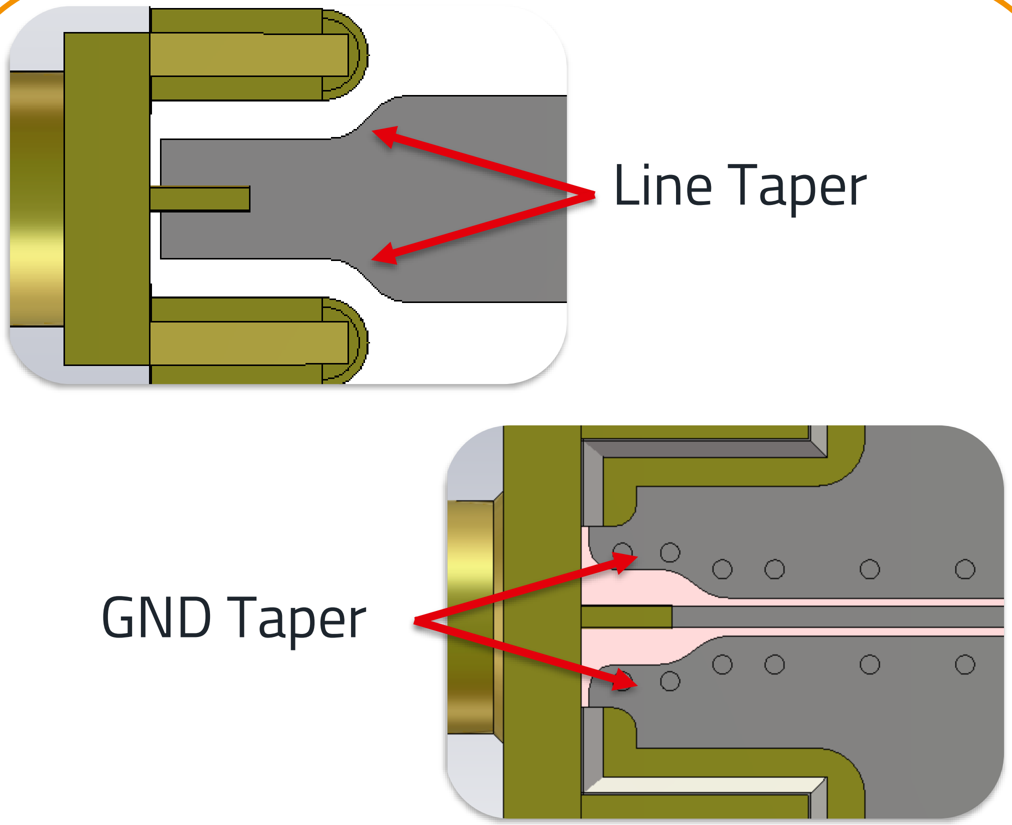


- **Top & Bottom as RF-Layer**
  - Reduced loss
  - No Vias inside trace → Mismatch!
- **Seperate ground-layer underneath RF**
  - Decreases discontinuities
  - Good connection to RF-Layer GND needed!

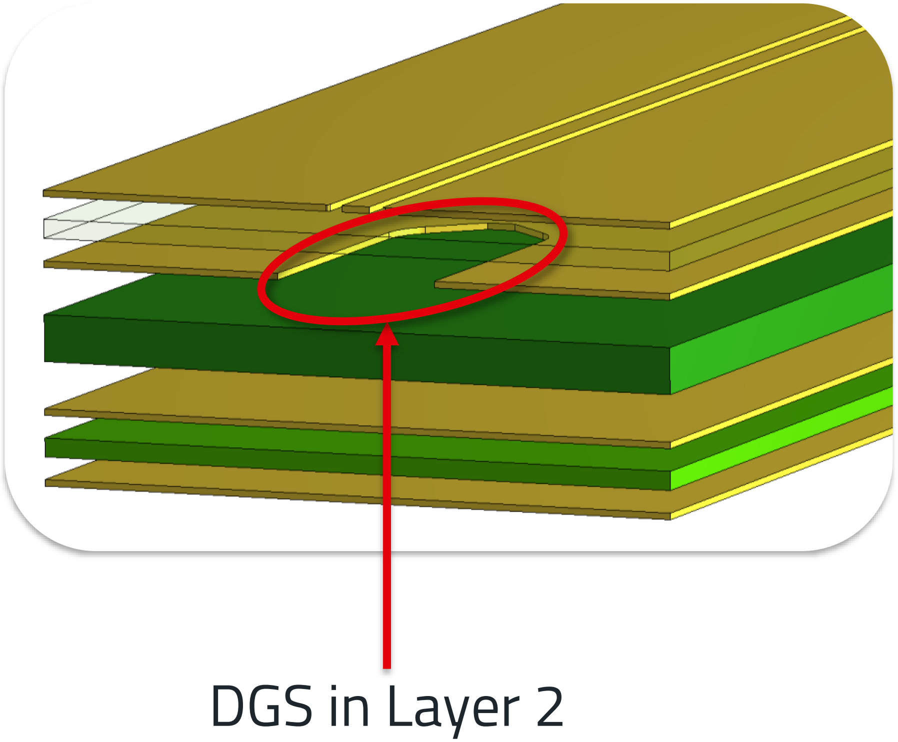
Overview PCB Structures: Tips & Tricks

Planar Impedance Matching

Taper Structures

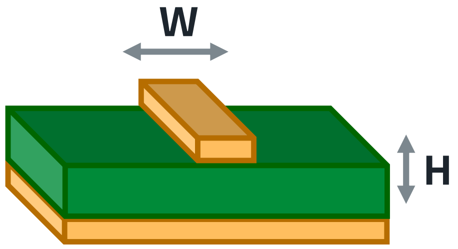


Defective Ground Structure (DGS)

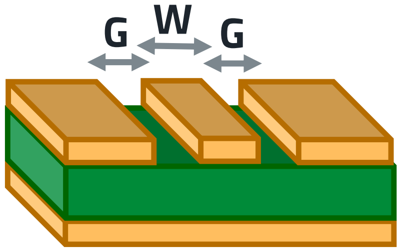


Overview PCB Structures: Summary

Line Impedance



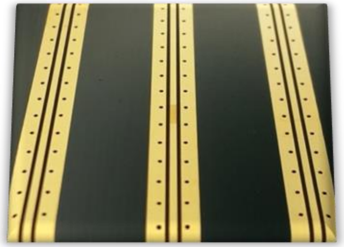
$\longleftarrow \varepsilon_r \longrightarrow$

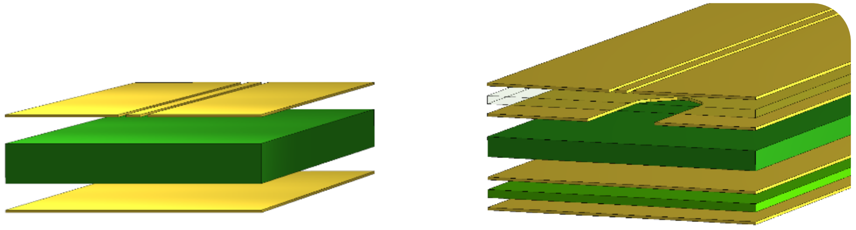


- $\uparrow Z_{Line} : \uparrow G , \uparrow H$
- $\downarrow Z_{Line} : \uparrow \varepsilon_r , \uparrow W$

Tips

- Solder resist free & Vias



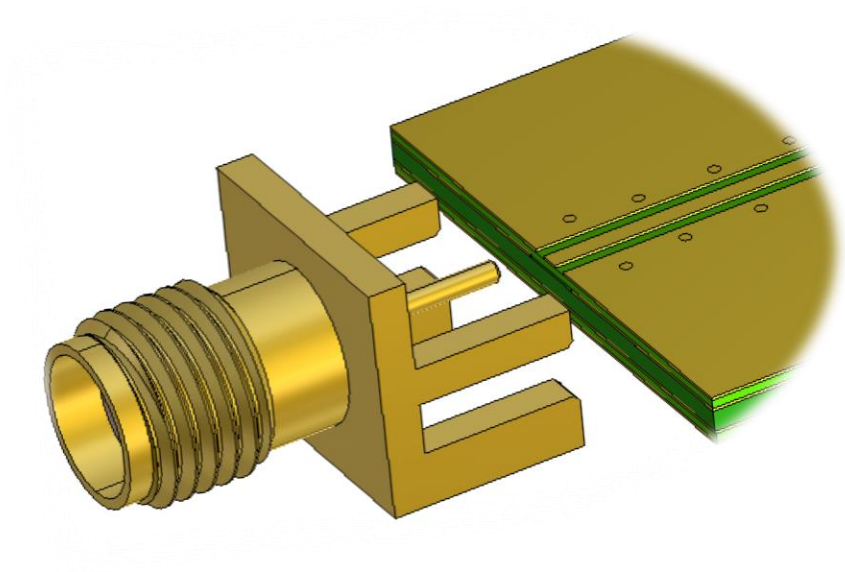


- RF & GND-Layer
- Taper & DGS

Combination Connector & PCB

- *Suitable Combinations*
- *Occuring RF-Effects*
- *Various Examples*

Combination Connector & PCB: Suitable Combinations



Combination Connector & PCB: Suitable Combinations

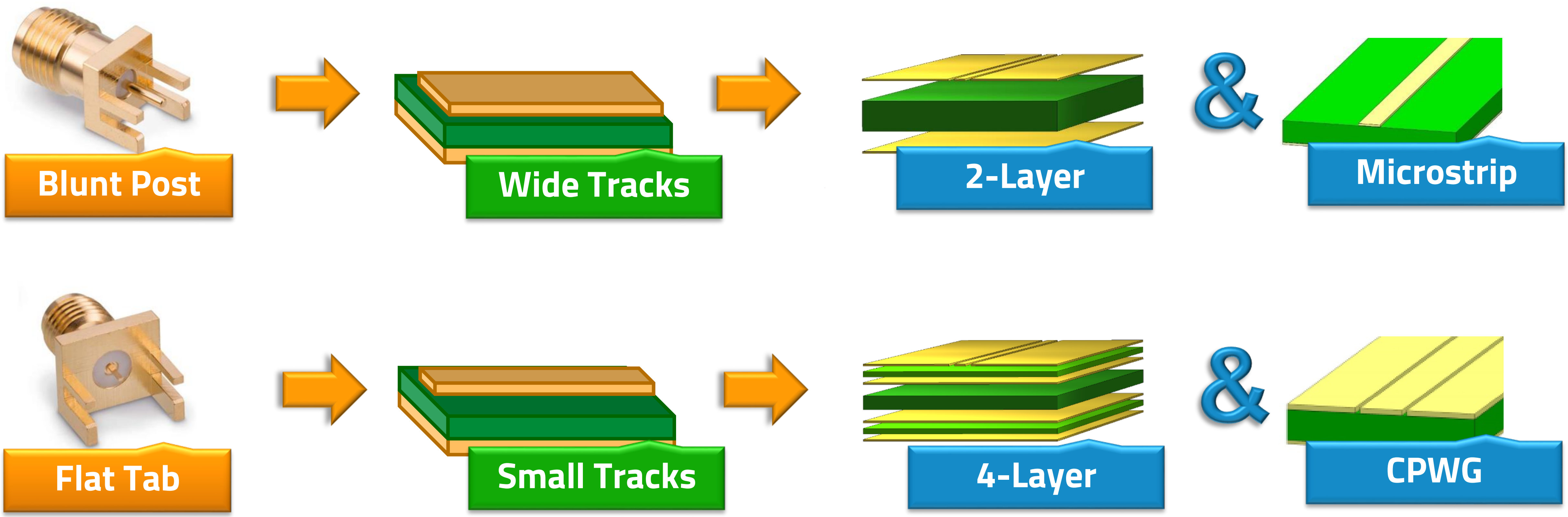
Short Guide - Frequency

Blunt Post → Low Frequency

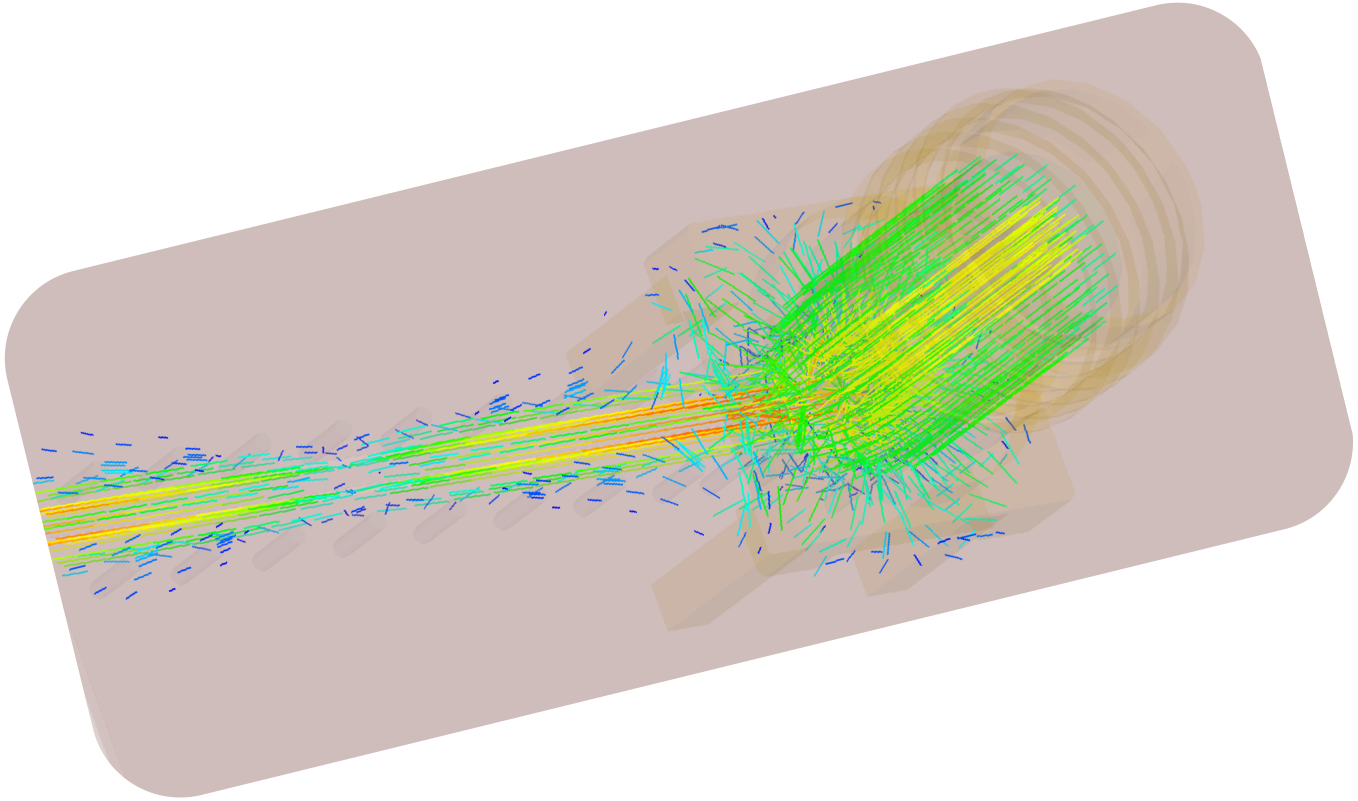
Flat Tab → High Frequency

Combination Connector & PCB: Suitable Combinations

Short Guide - PCB



Combination Connector & PCB: RF-Effects



Combination Connector & PCB: RF-Effects

Discontinuities

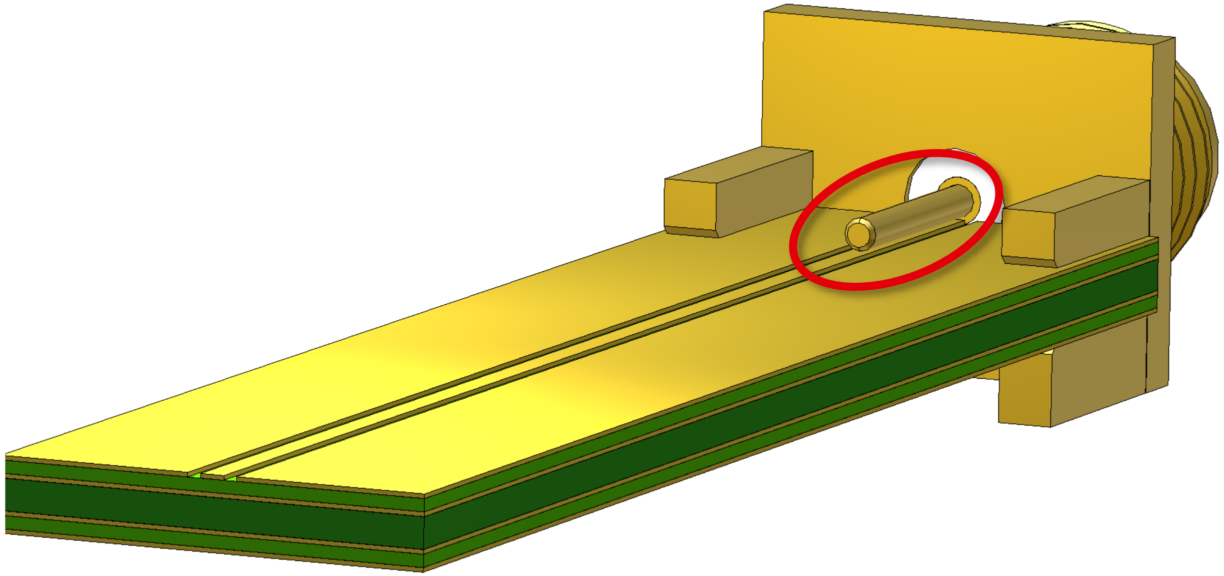
- **Discontinuity at connection point**
  - Change in line impedance
  - Field conversion

↓

- **Huge Mismatch and Reflection!**

↓

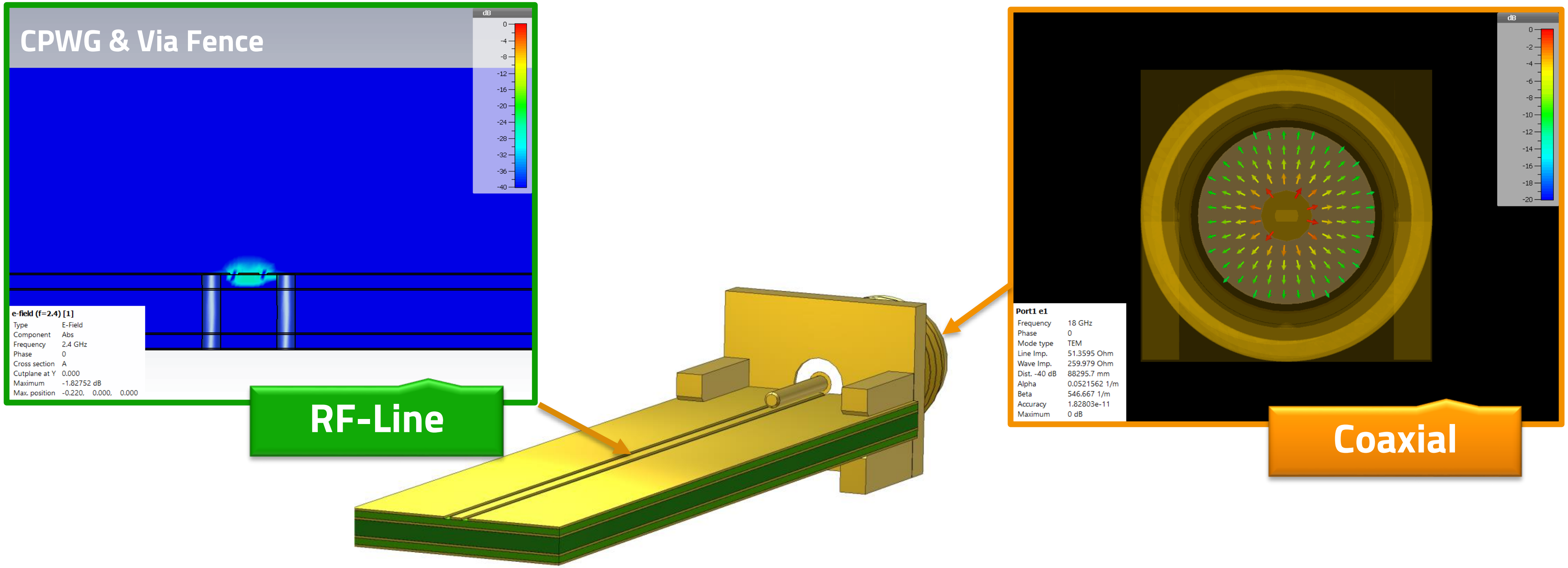
- **Planar matching circuit needed**



Combination Connector & PCB: RF-Effects

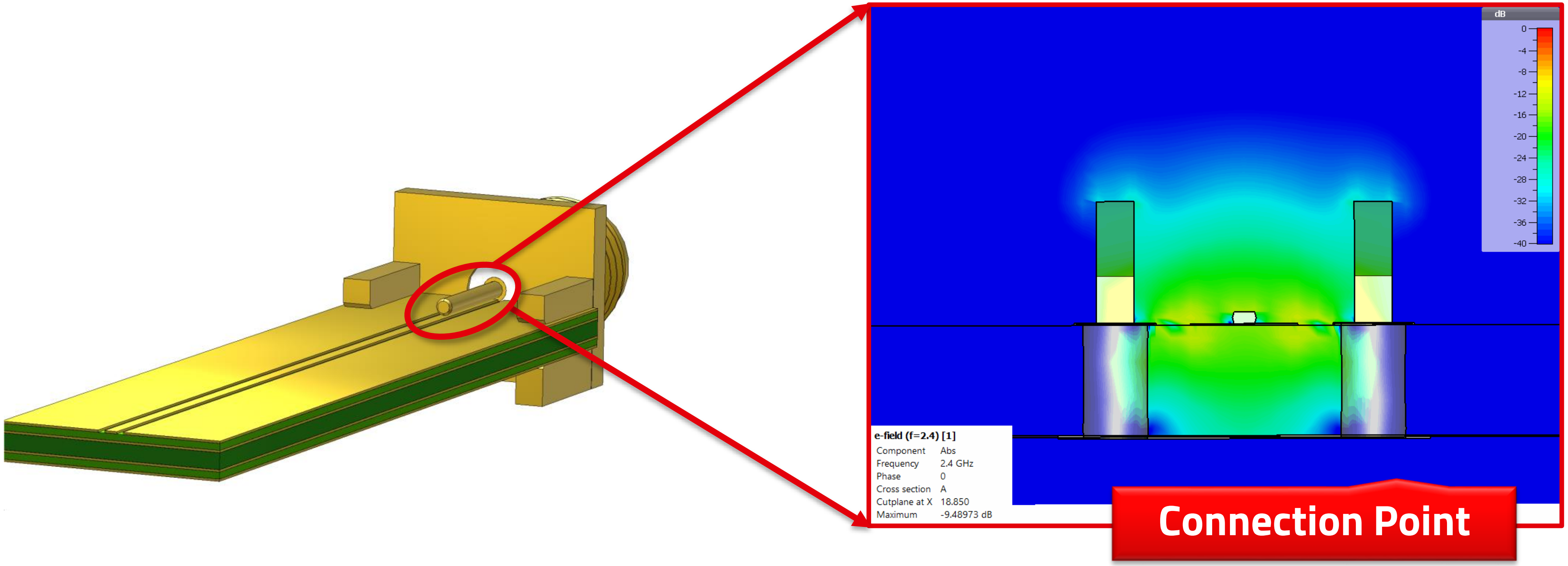
Field conversion (1)

- **Geometry of field changes at connection point**

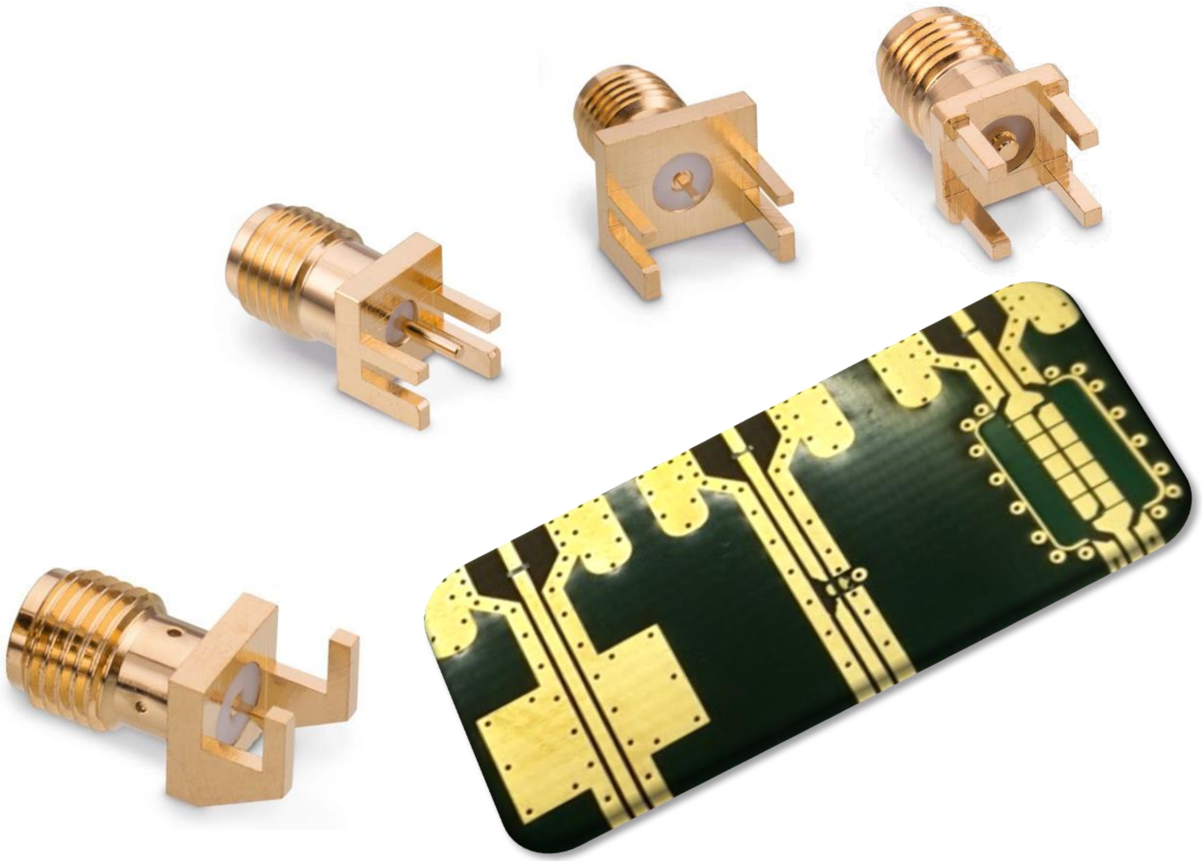


Combination Connector & PCB: RF-Effects

Field conversion (2)



Combination Connector & PCB: Examples



Combination Connector & PCB: Examples

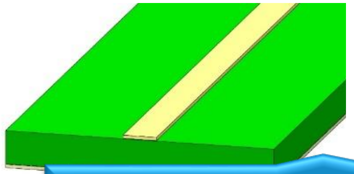
Chosen Combinations (1)

- **Simulation from DC to 18GHz**

Flat Tab

&

2-Layer

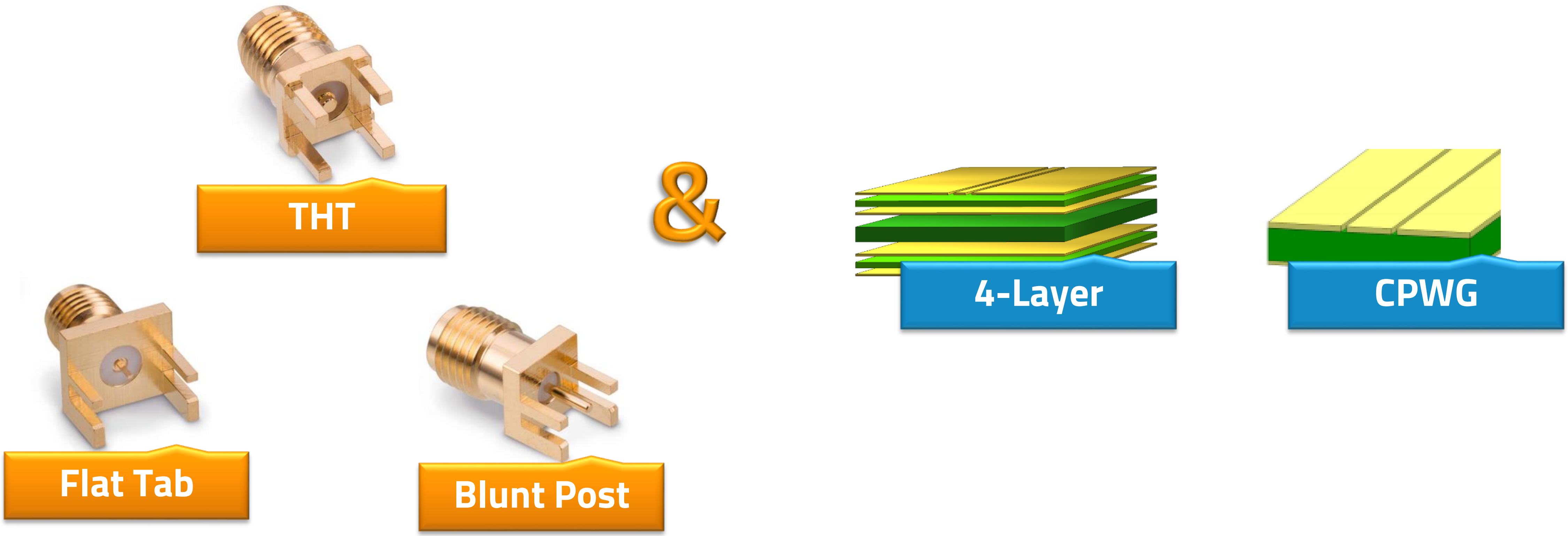


Microstrip

Combination Connector & PCB: Examples

Chosen Combinations (2)

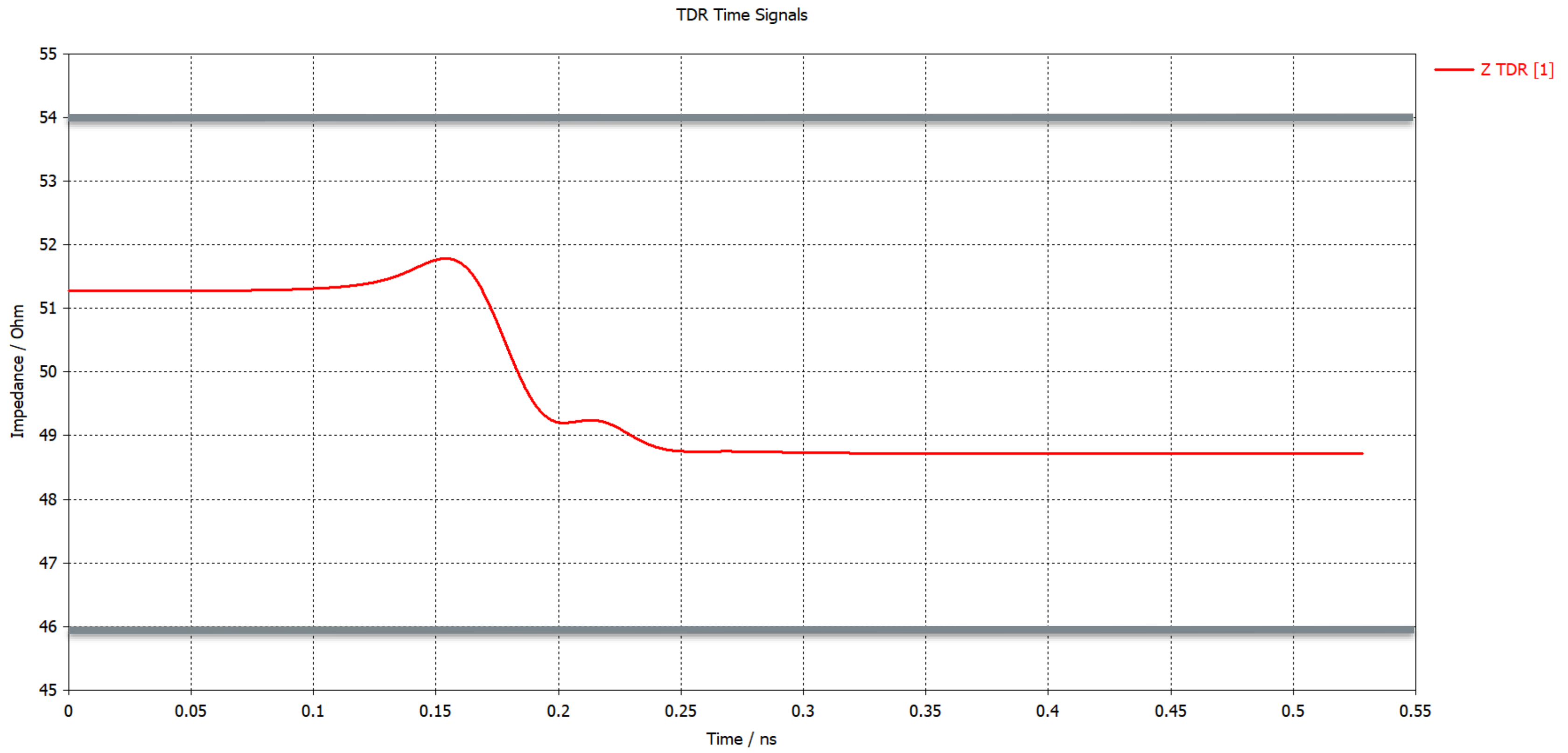
- **Simulation from DC to 18GHz**



Combination Connector & PCB: Examples

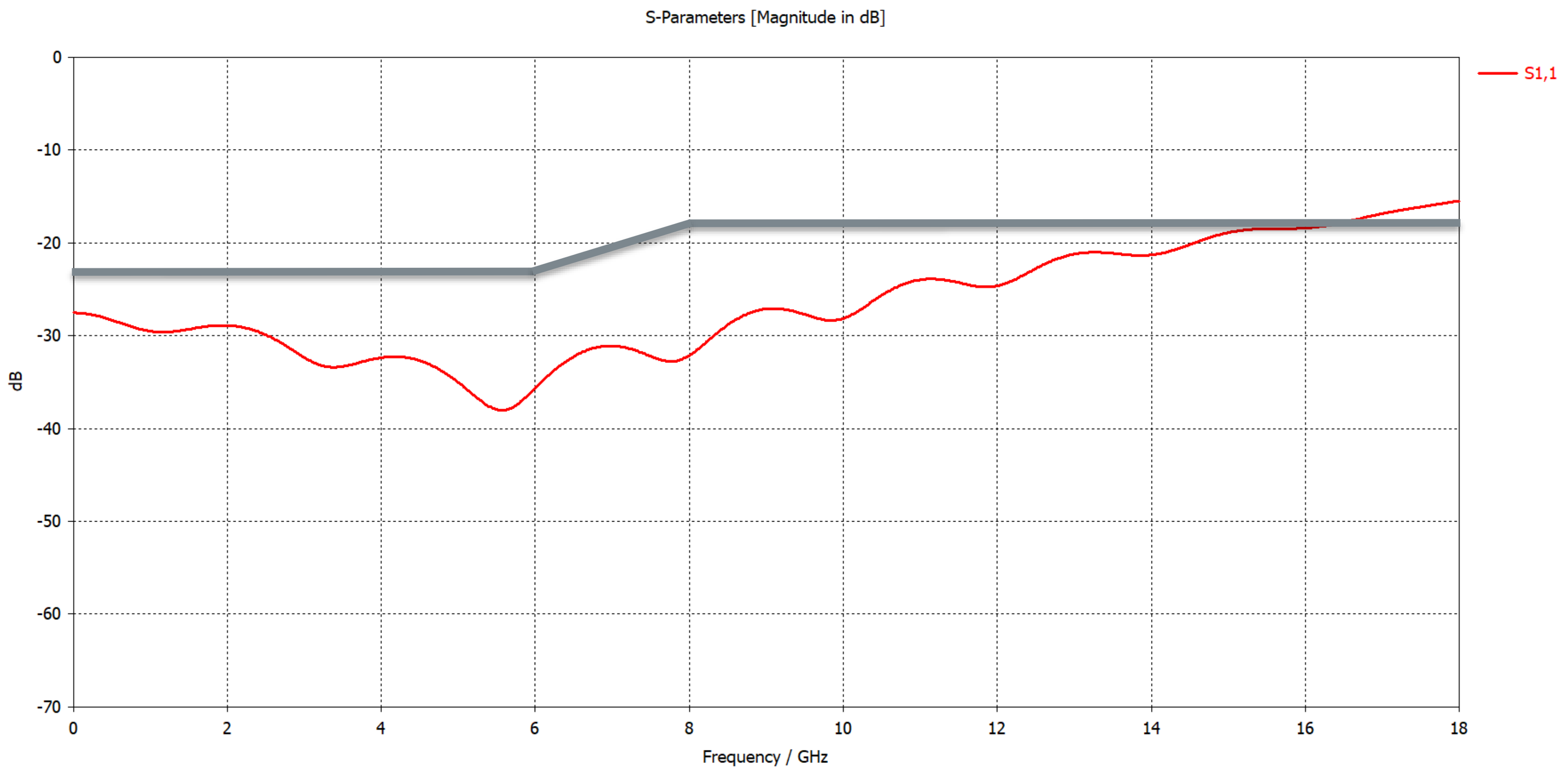
Properties

- **Goal: minimal reflection & mismatch**



Combination Connector & PCB: Examples
Properties

- **Goal: minimal reflection & mismatch**



Combination Connector & PCB: Examples

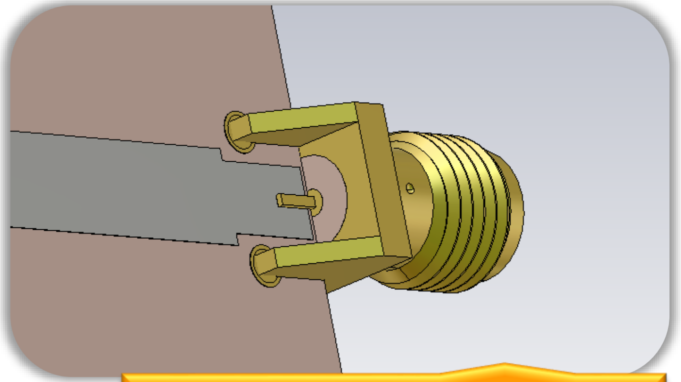
Microstrip: Overview

- **Given Task:**
  - Flat Tab **60312202114511**
  - 2.8mm PCB
  - 2 Layers – FR4 Core
  - Microstripline
- **Application: Patch Antenna**

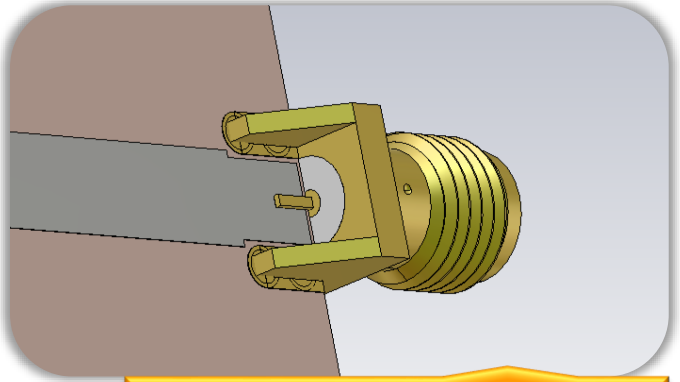
Combination Connector & PCB: Examples

Microstrip: Design suggestions

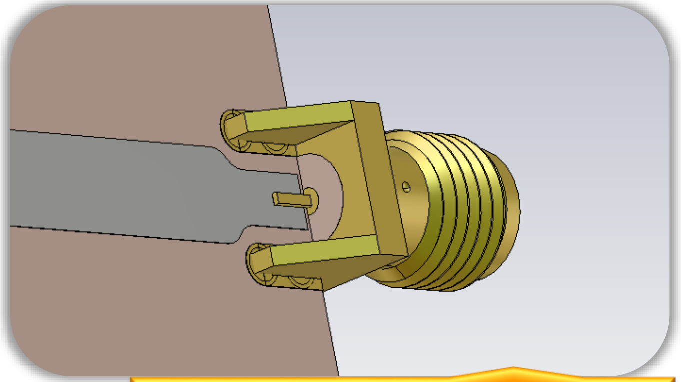
- **Analysis of 3 different designs**



1: Data Sheet



2: Worst-Case

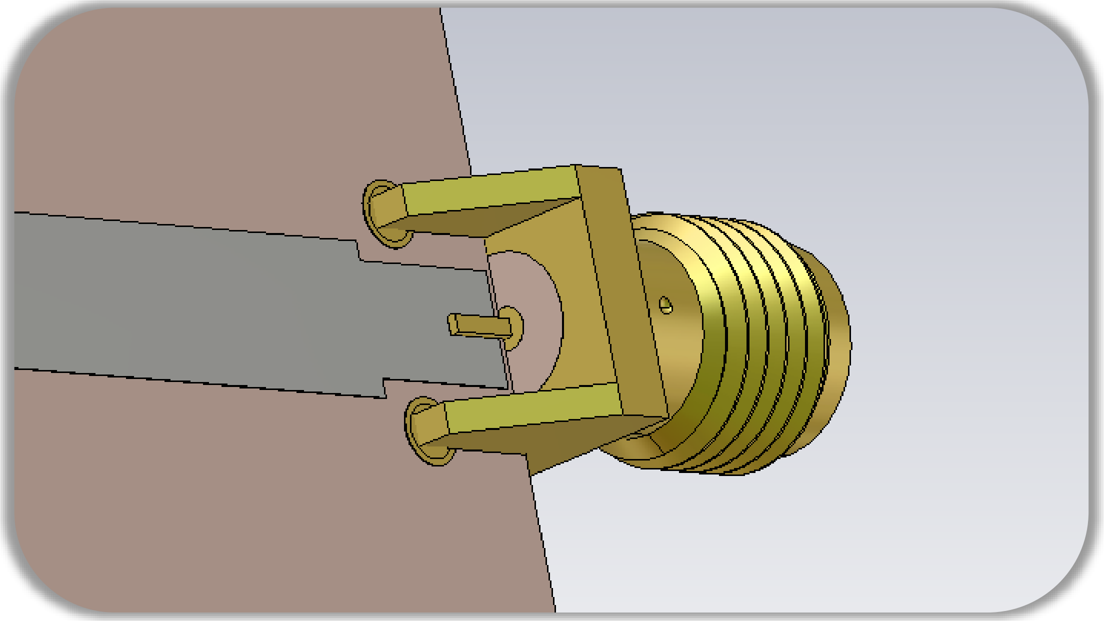


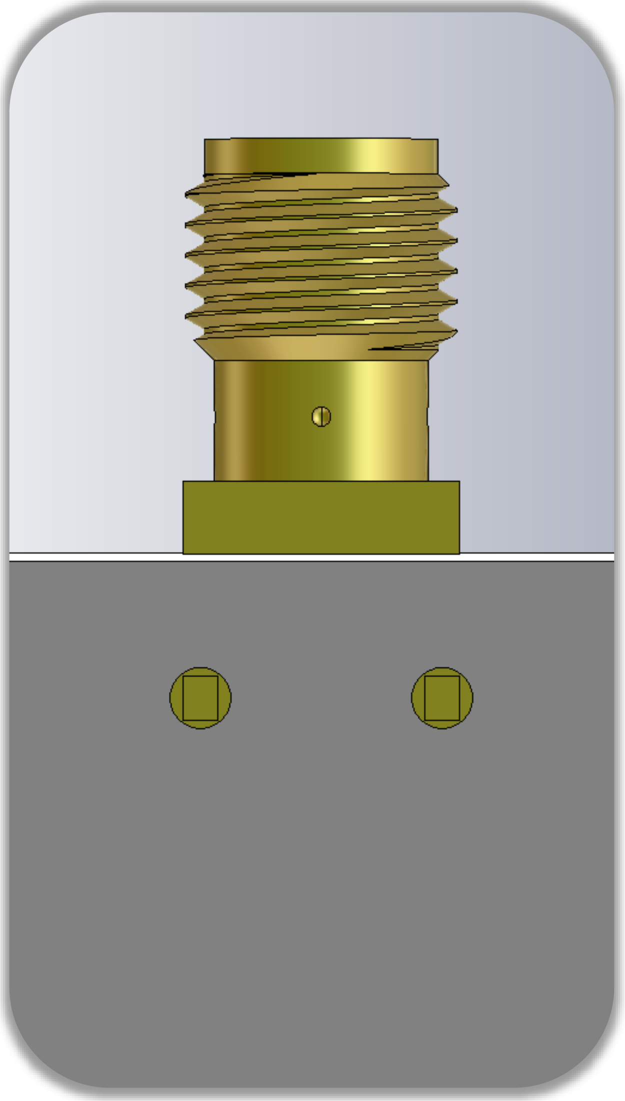
3: Optimized

Combination Connector & PCB: Examples

Microstrip: Data Sheet Design

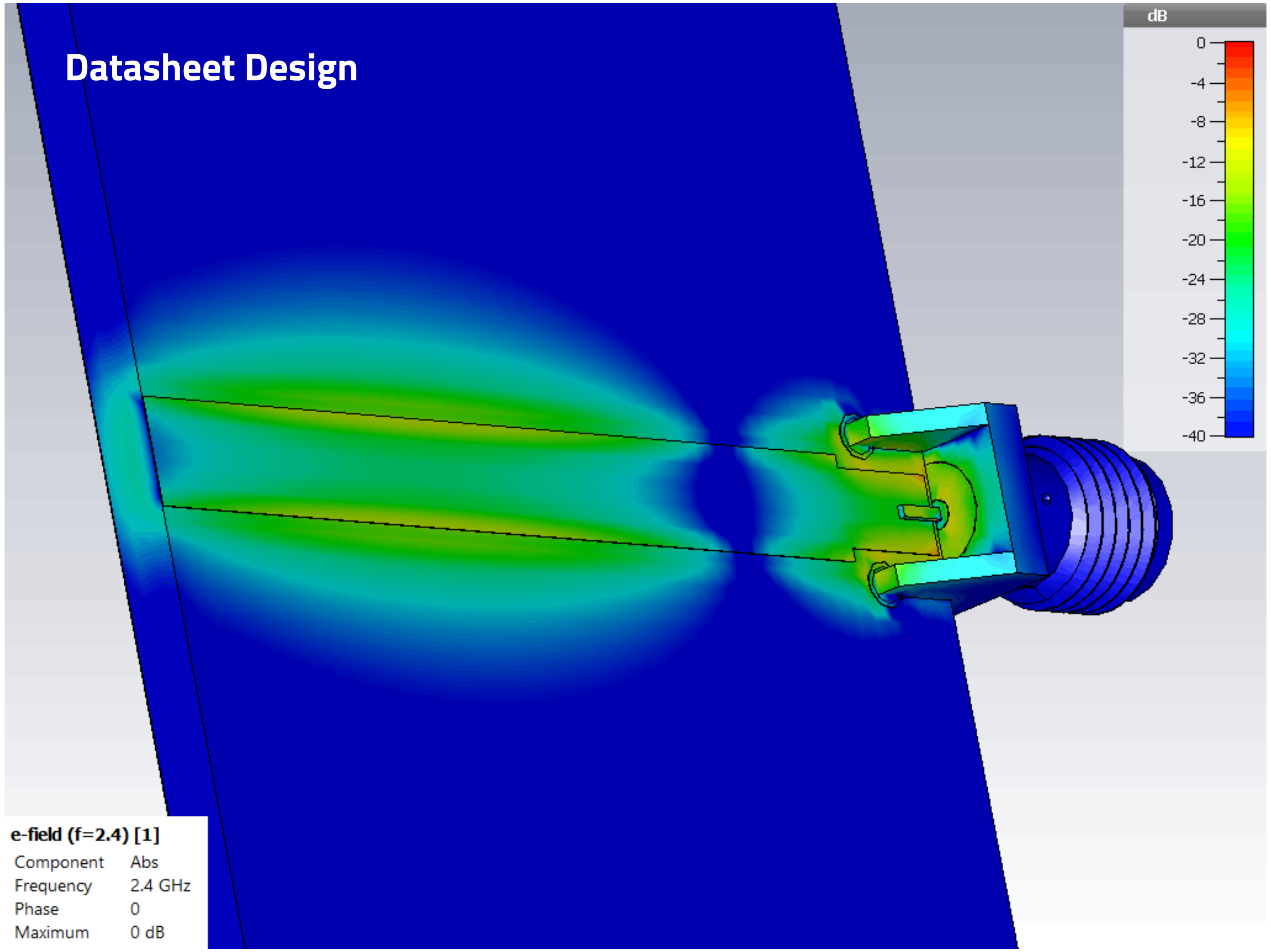
- Only 2 Vias for chassis pins
- No further GND connection
- Arbitrary RF-Line





Combination Connector & PCB: Examples

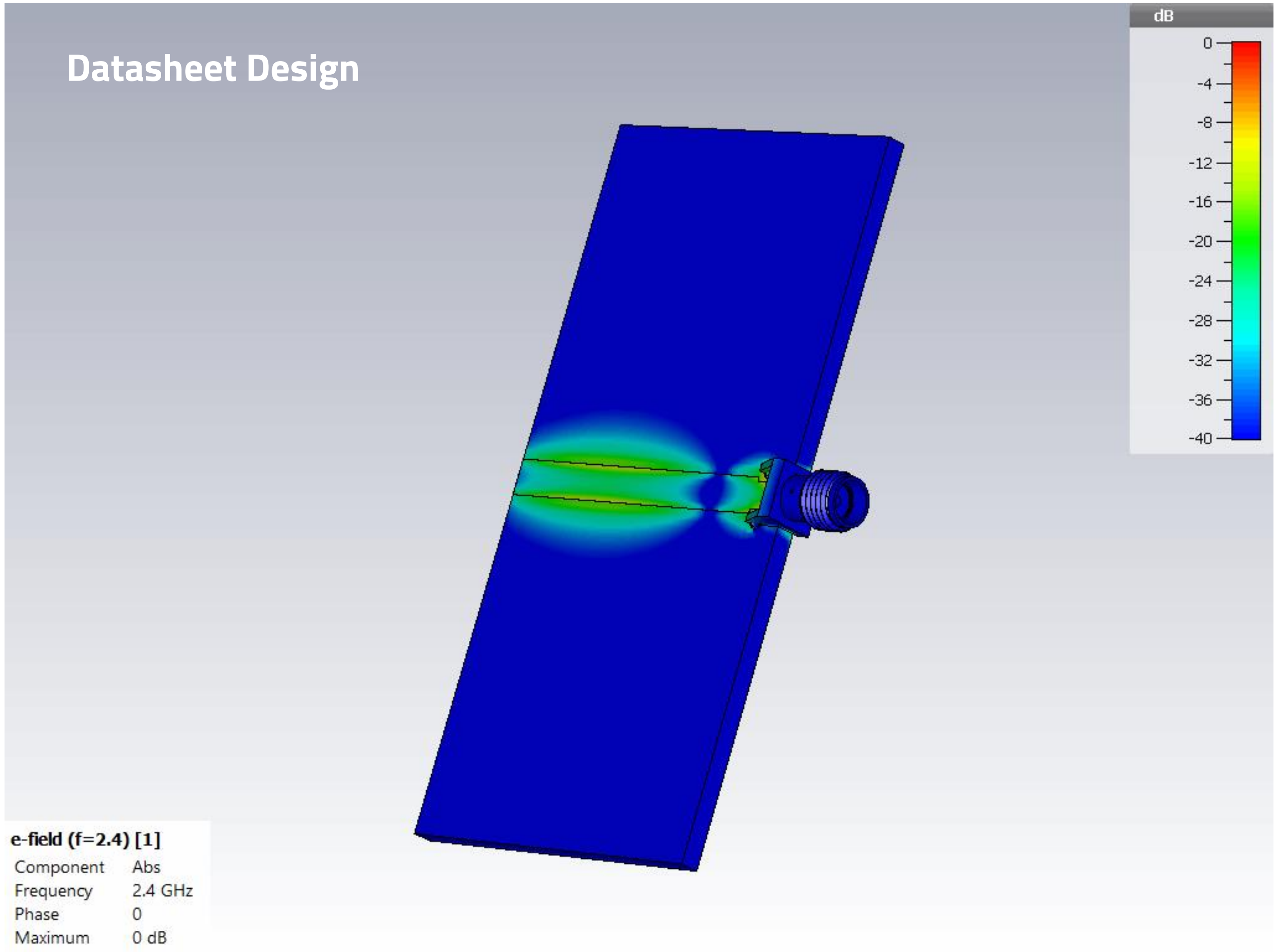
Microstrip: Data Sheet Design – Simulation (1)



Combination Connector & PCB: Examples

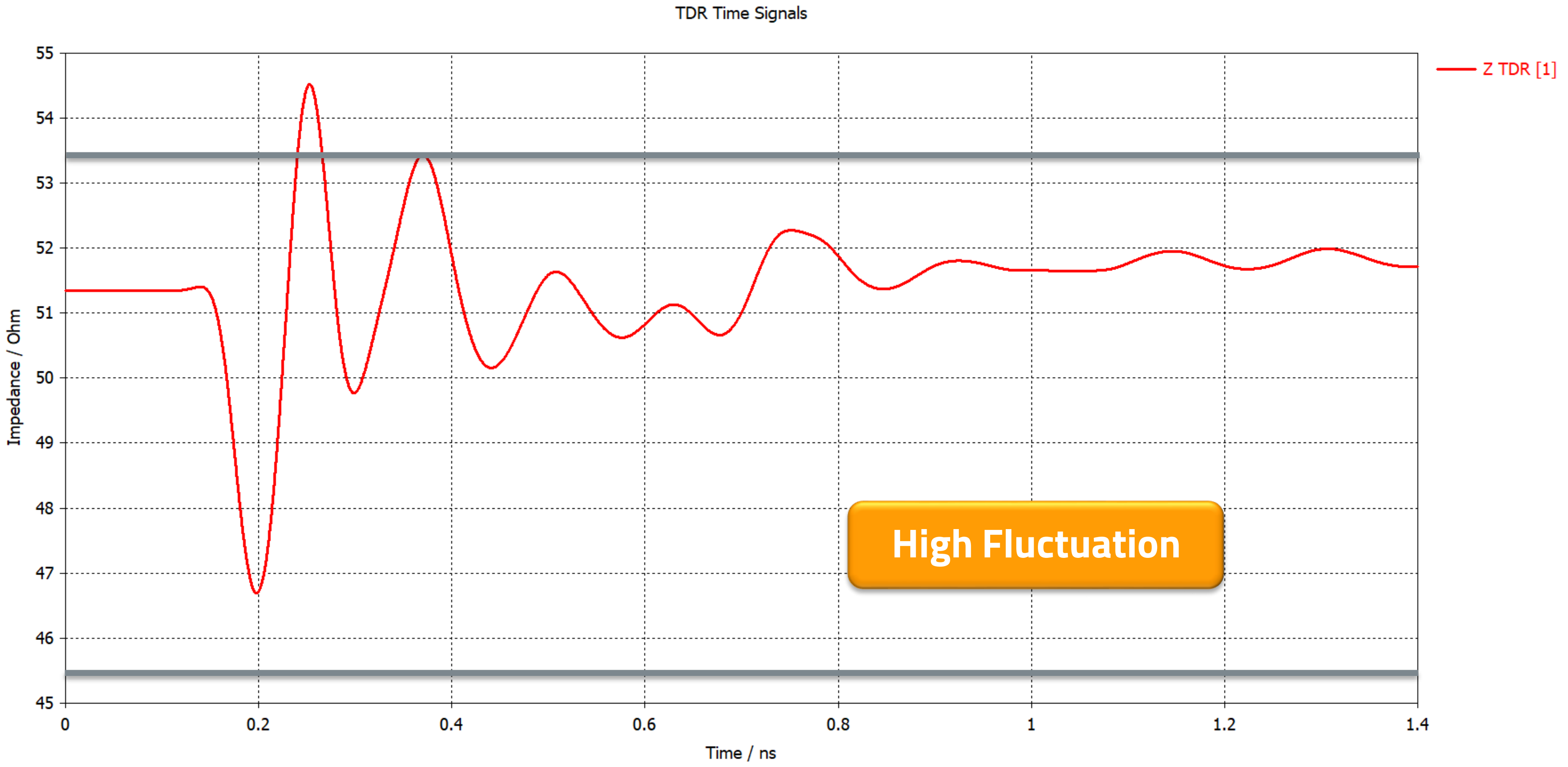
Microstrip: Data Sheet Design – Simulation (2)

- **No Solderpads**
- **Slot antenna**
  - Radiation
  - EMI Problems!



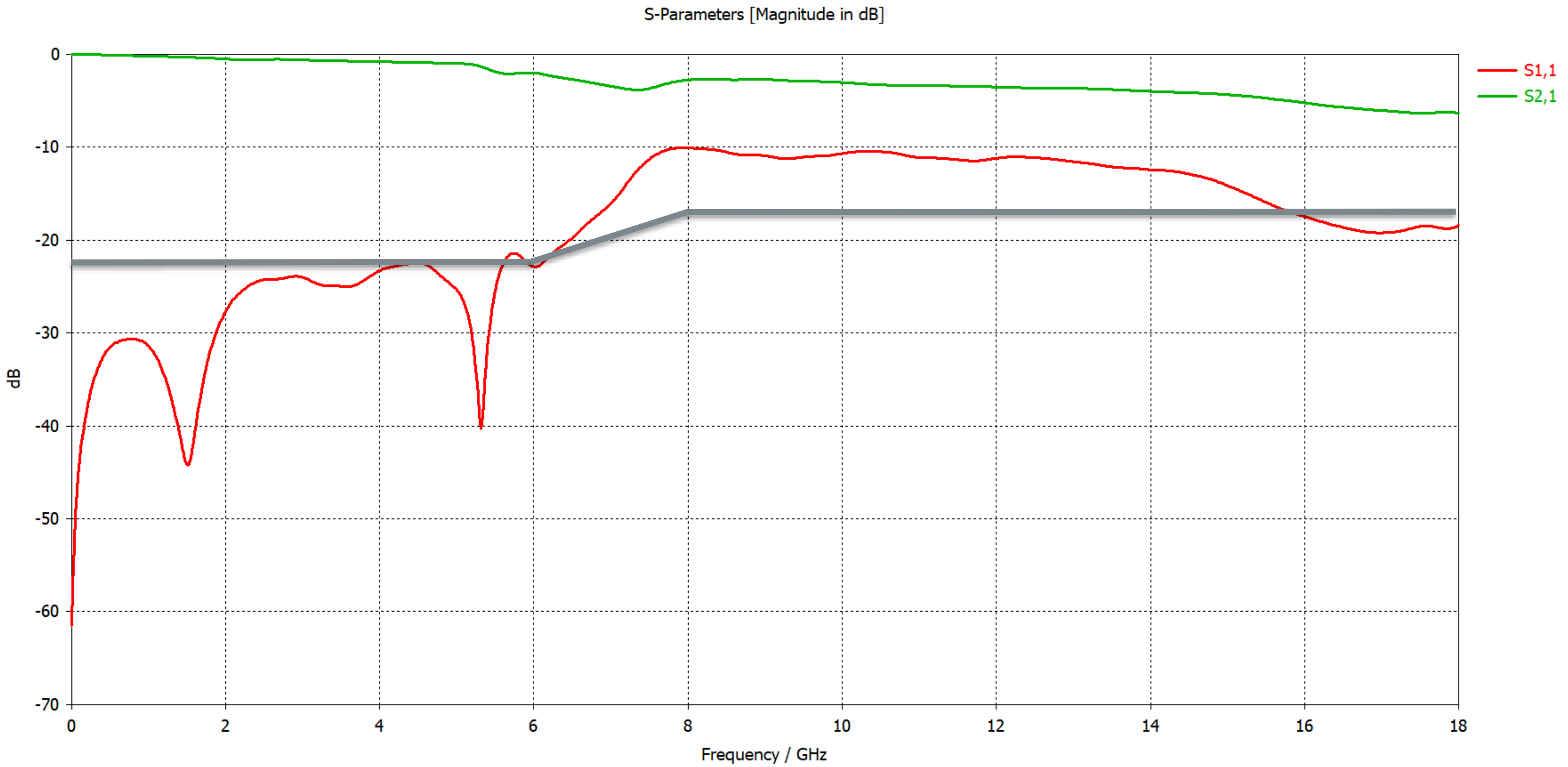
Combination Connector & PCB: Examples

Microstrip: Data Sheet Design – TDR



Combination Connector & PCB: Examples

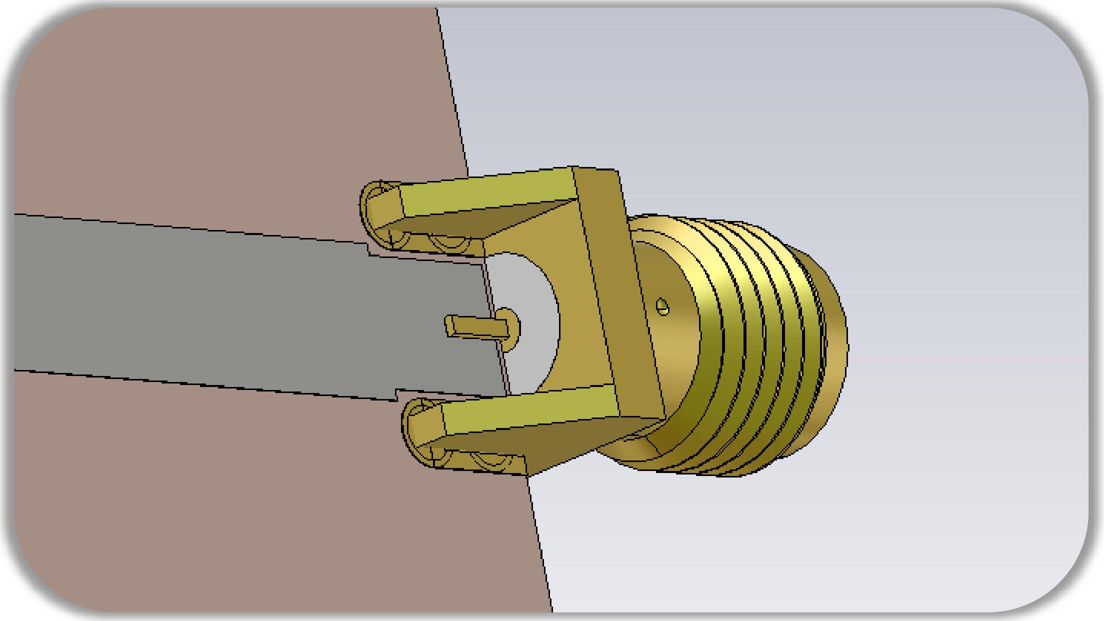
Microstrip: Data Sheet Design – S-Parameter

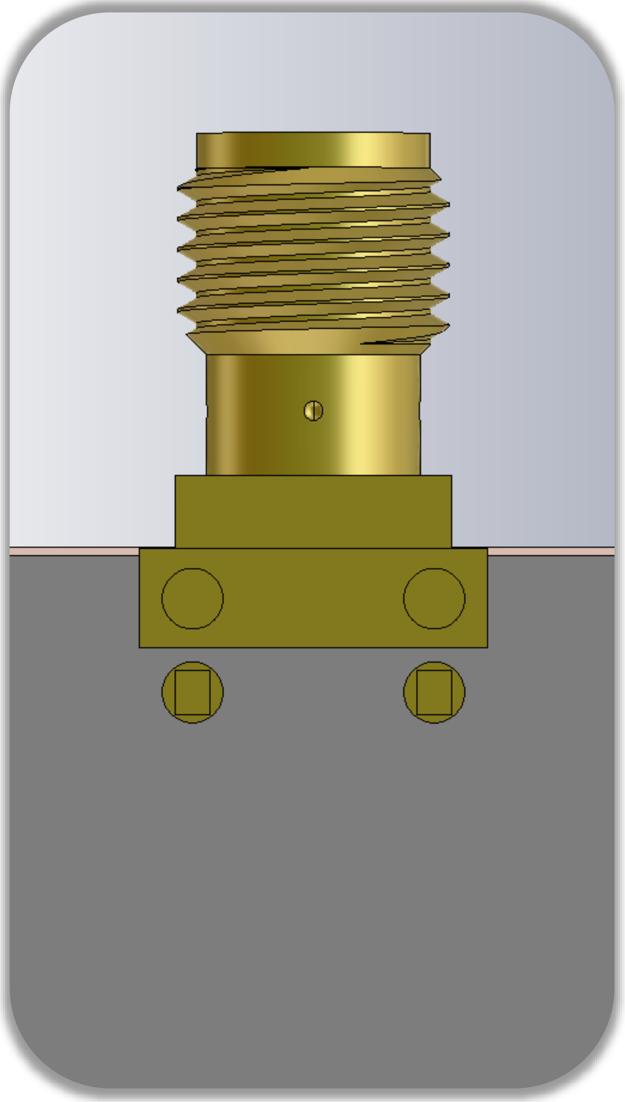


Combination Connector & PCB: Examples

Microstrip: Worst-Case Design

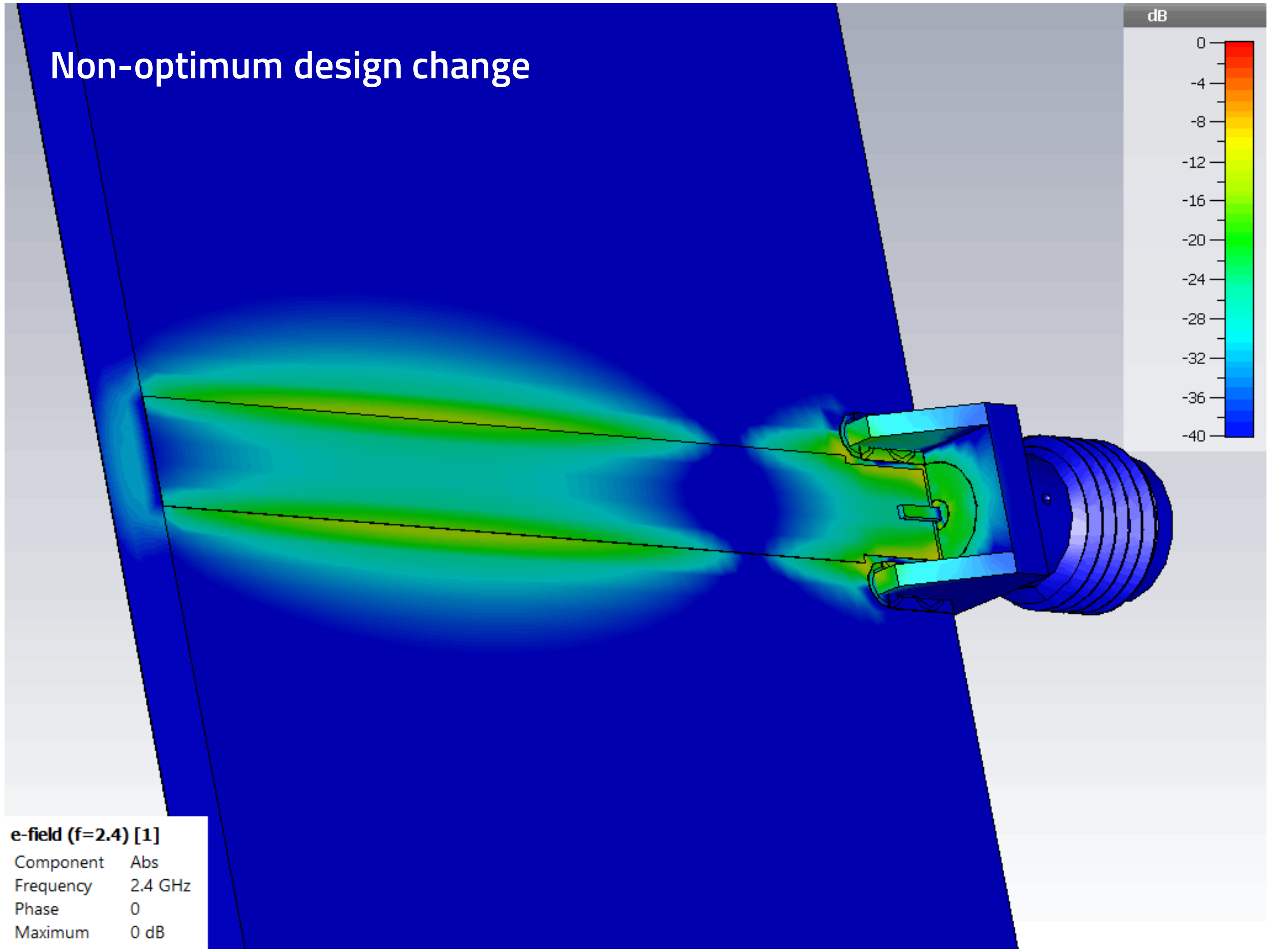
- 4 Vias for chassis
- Good GND connection
- Wide RF-Line at connection point





Combination Connector & PCB: Examples

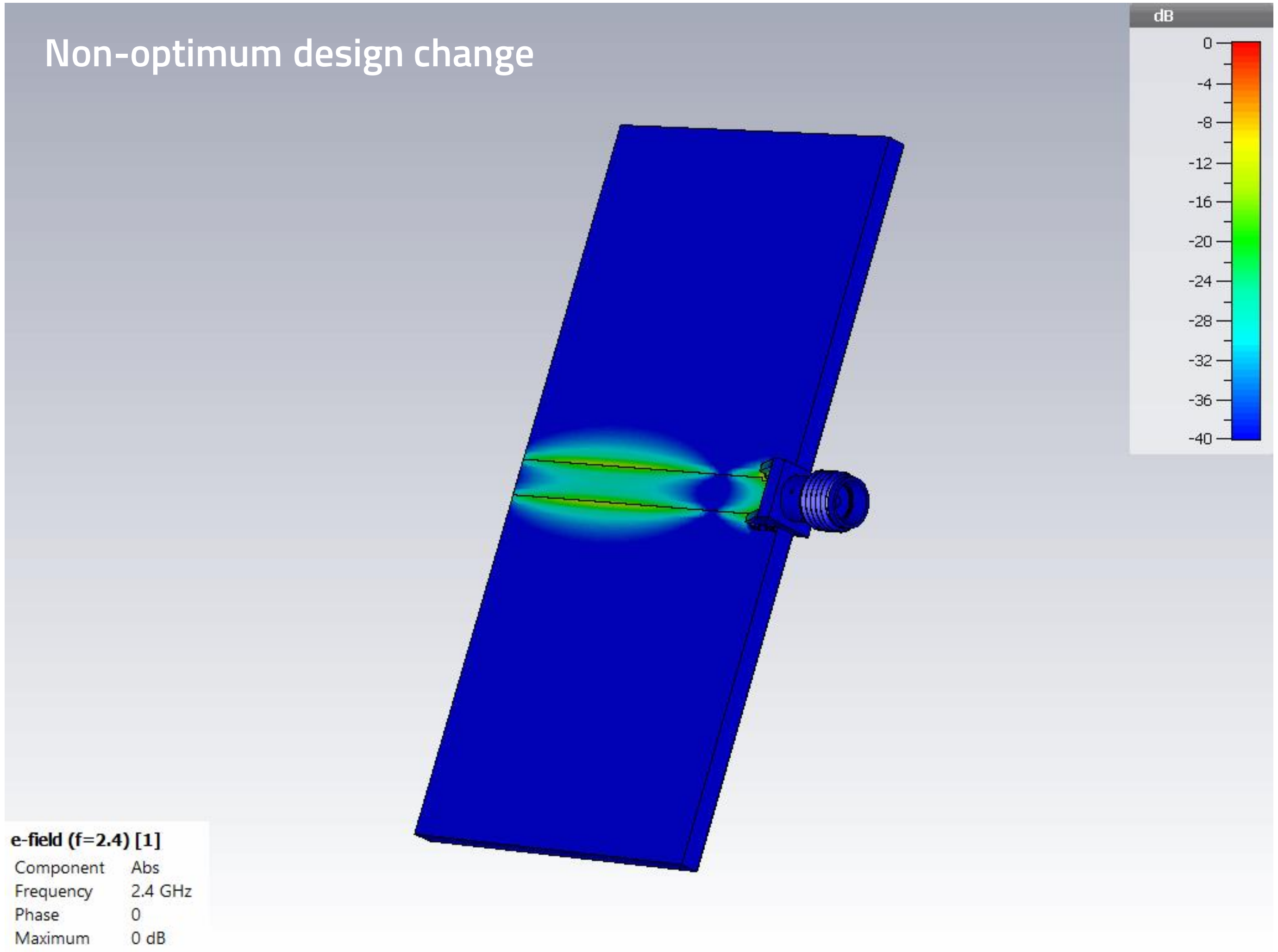
Microstrip: Worst-Case Design – Simulation (1)



Combination Connector & PCB: Examples

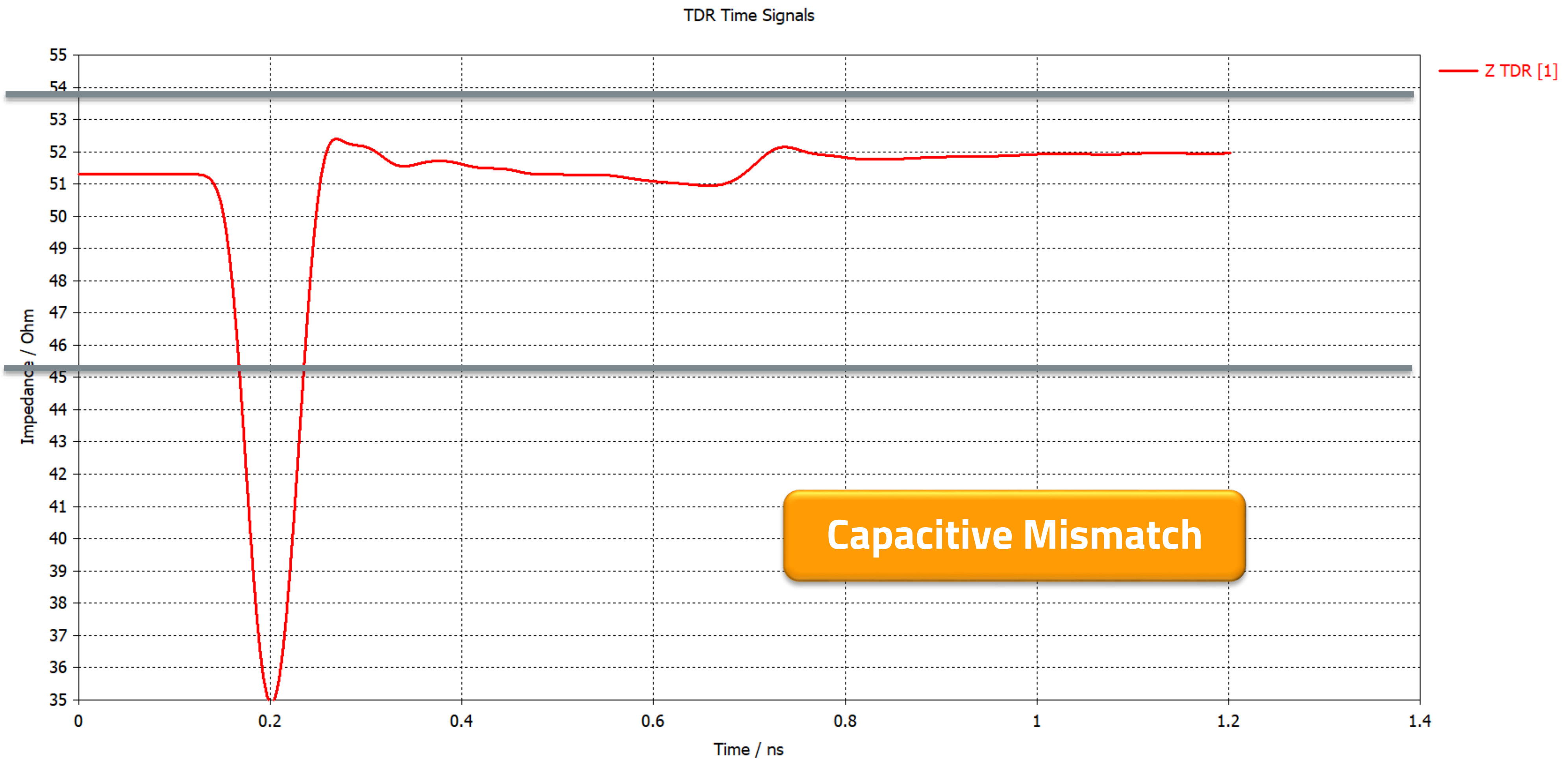
Microstrip: Worst-Case Design – Simulation (2)

- **Solderpads on:**
  - Top
  - Bottom
- **No radiation**



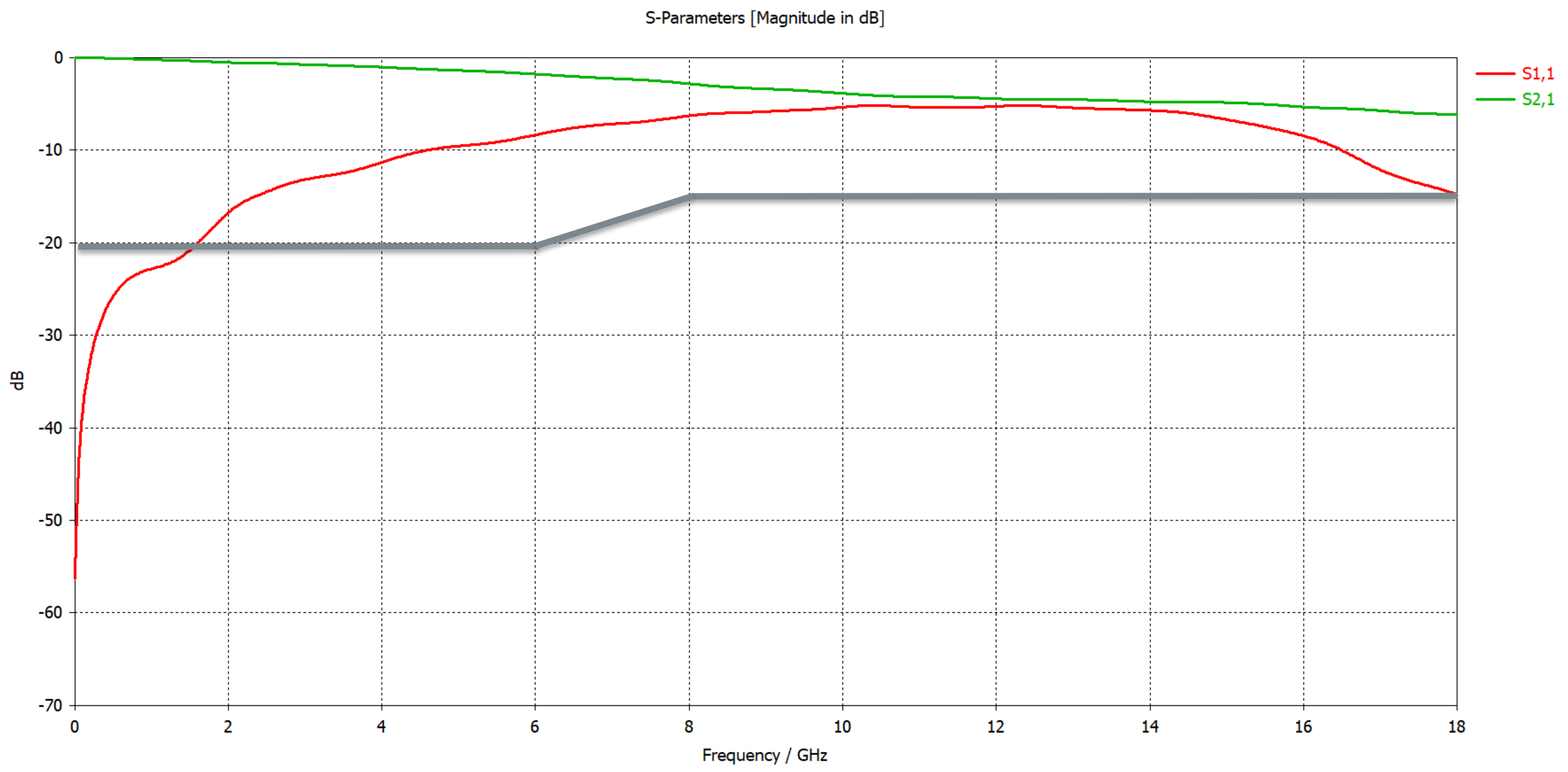
Combination Connector & PCB: Examples

Microstrip: Worst-Case Design – TDR



Combination Connector & PCB: Examples

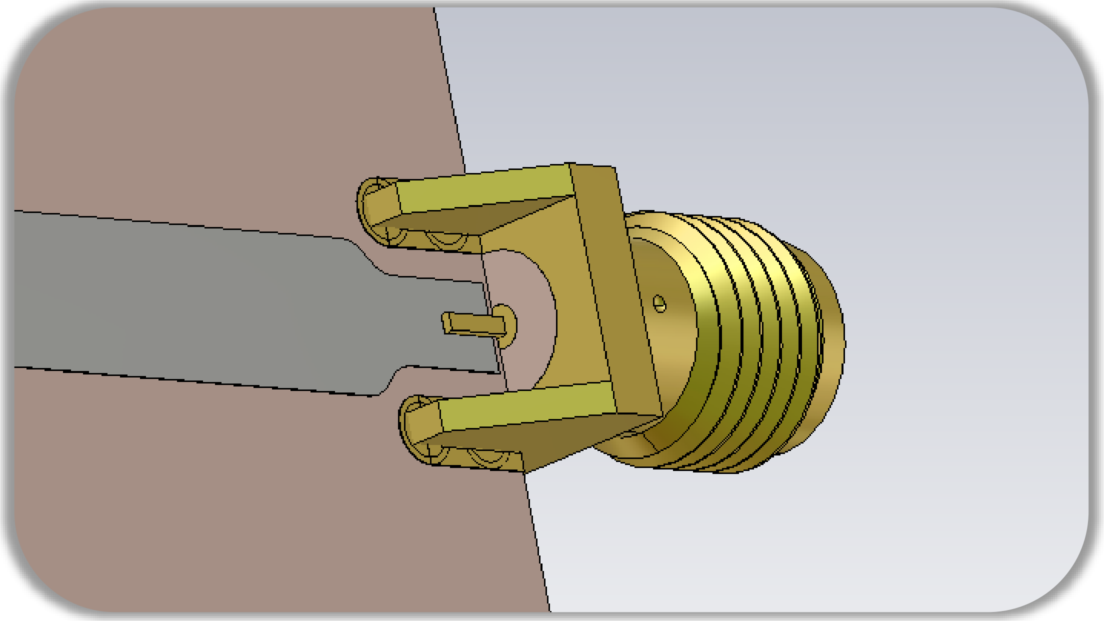
Microstrip: Worst-Case Design – S-Parameter

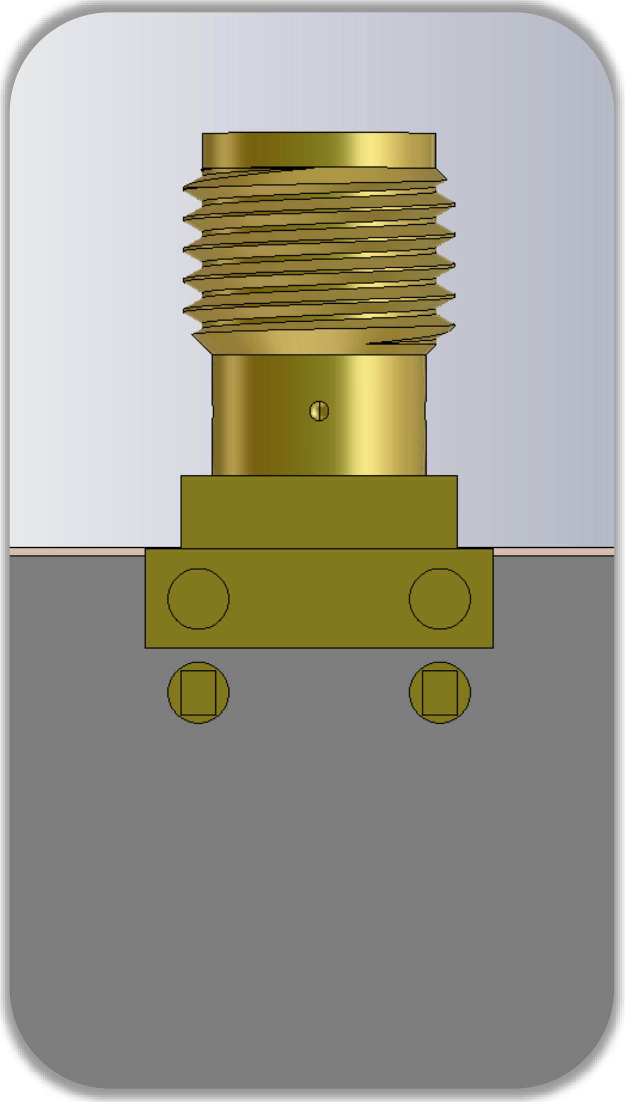


Combination Connector & PCB: Examples

Microstrip: Optimized Design

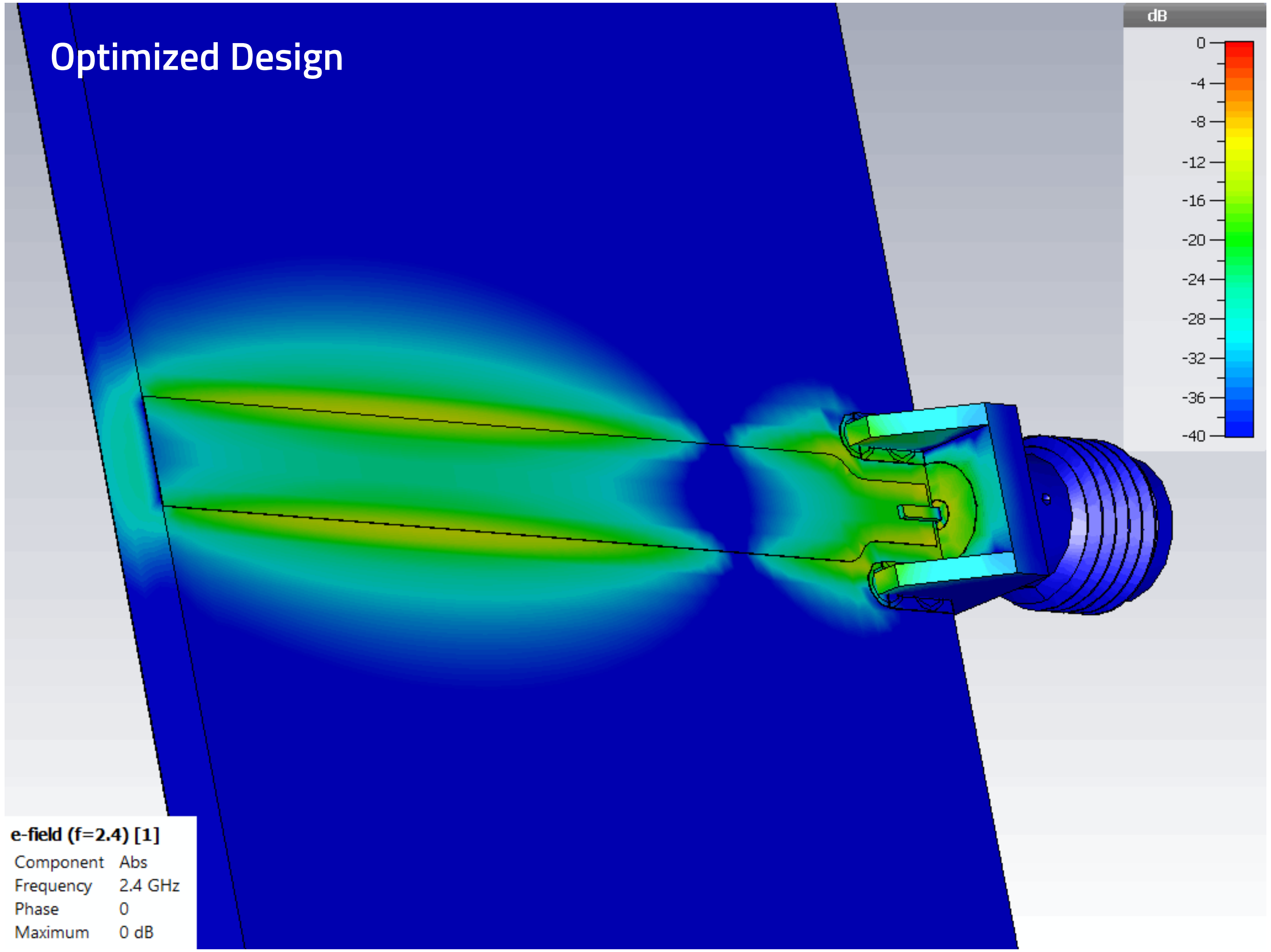
- 4 Vias for chassis
- Good GND connection
- Optimized RF-Line with taper





Combination Connector & PCB: Examples

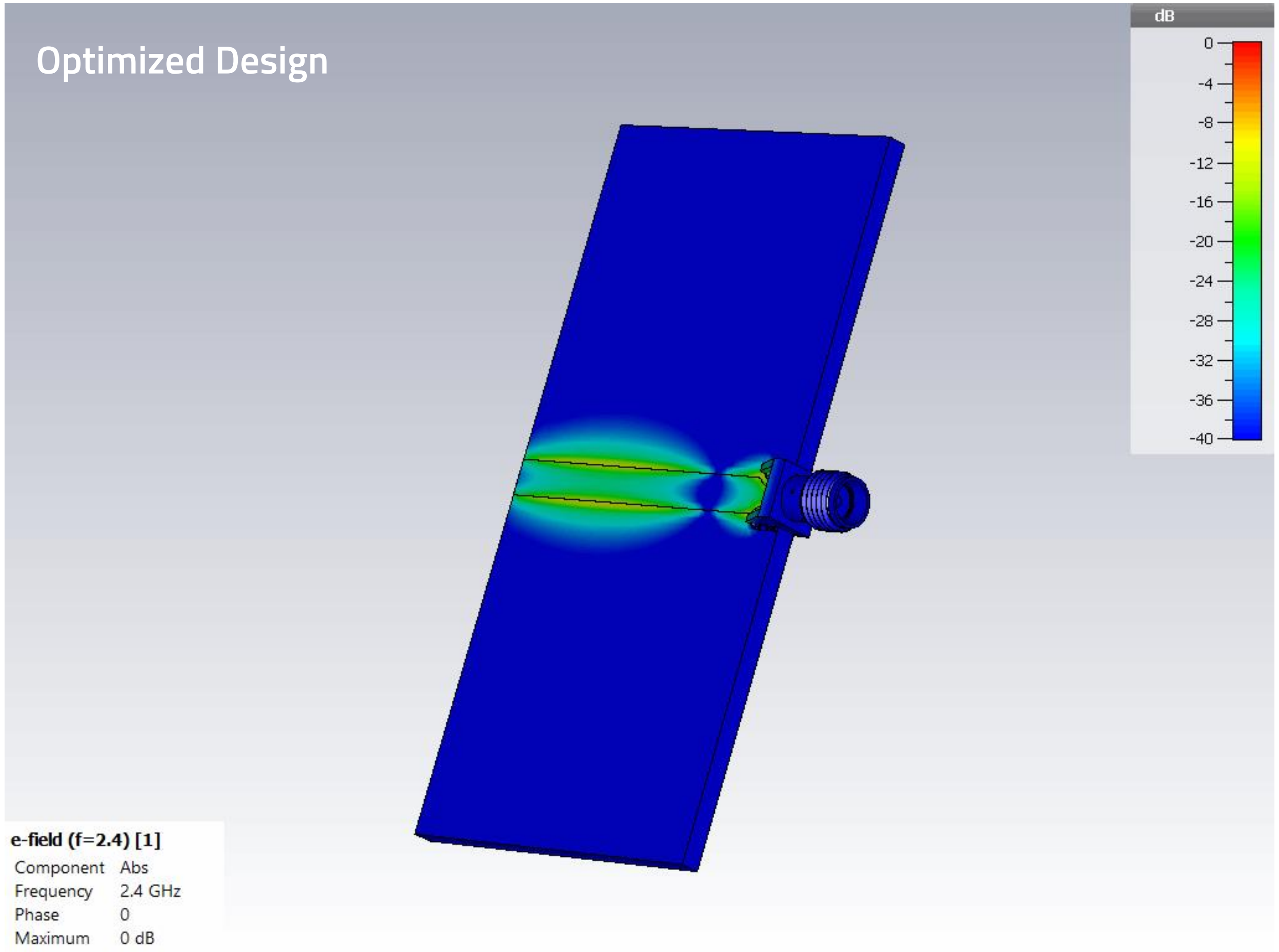
Microstrip: Optimized Design – Simulation (1)



Combination Connector & PCB: Examples

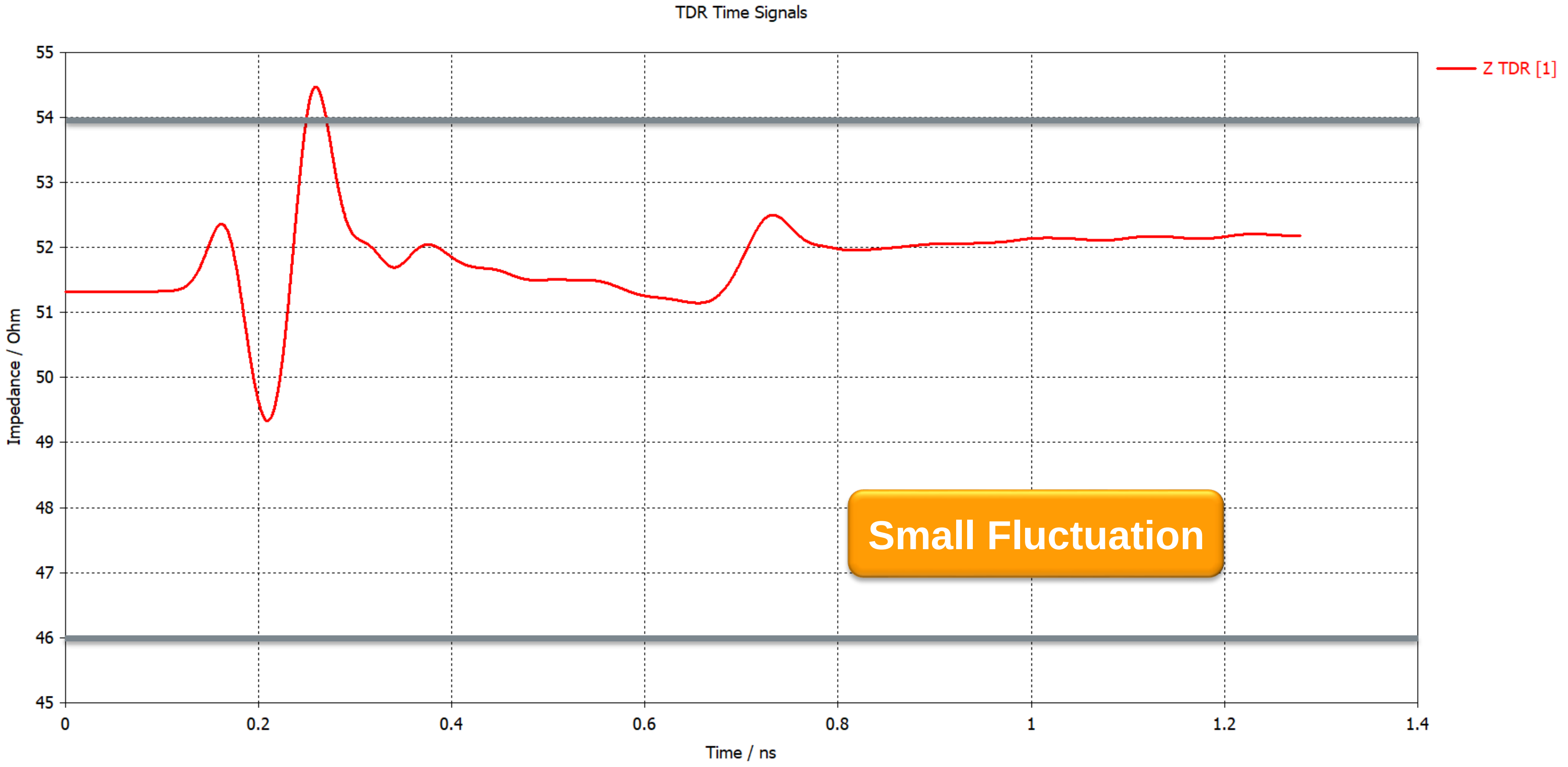
Microstrip: Optimized Design – Simulation (2)

- **Solderpads on:**
  - Top
  - Bottom
- **No radiation**



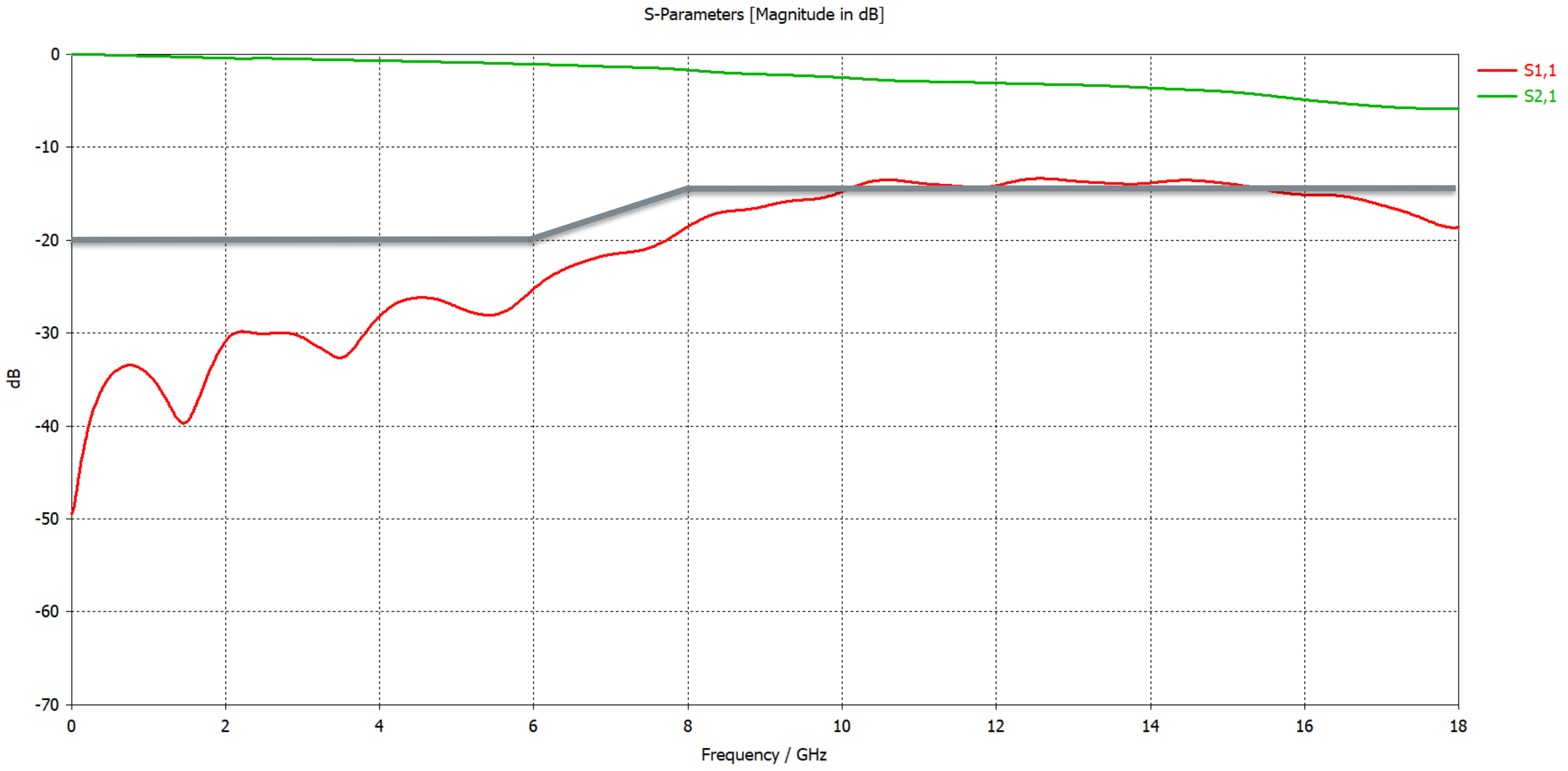
Combination Connector & PCB: Examples

Microstrip: Optimized Design – S-Parameter



Combination Connector & PCB: Examples

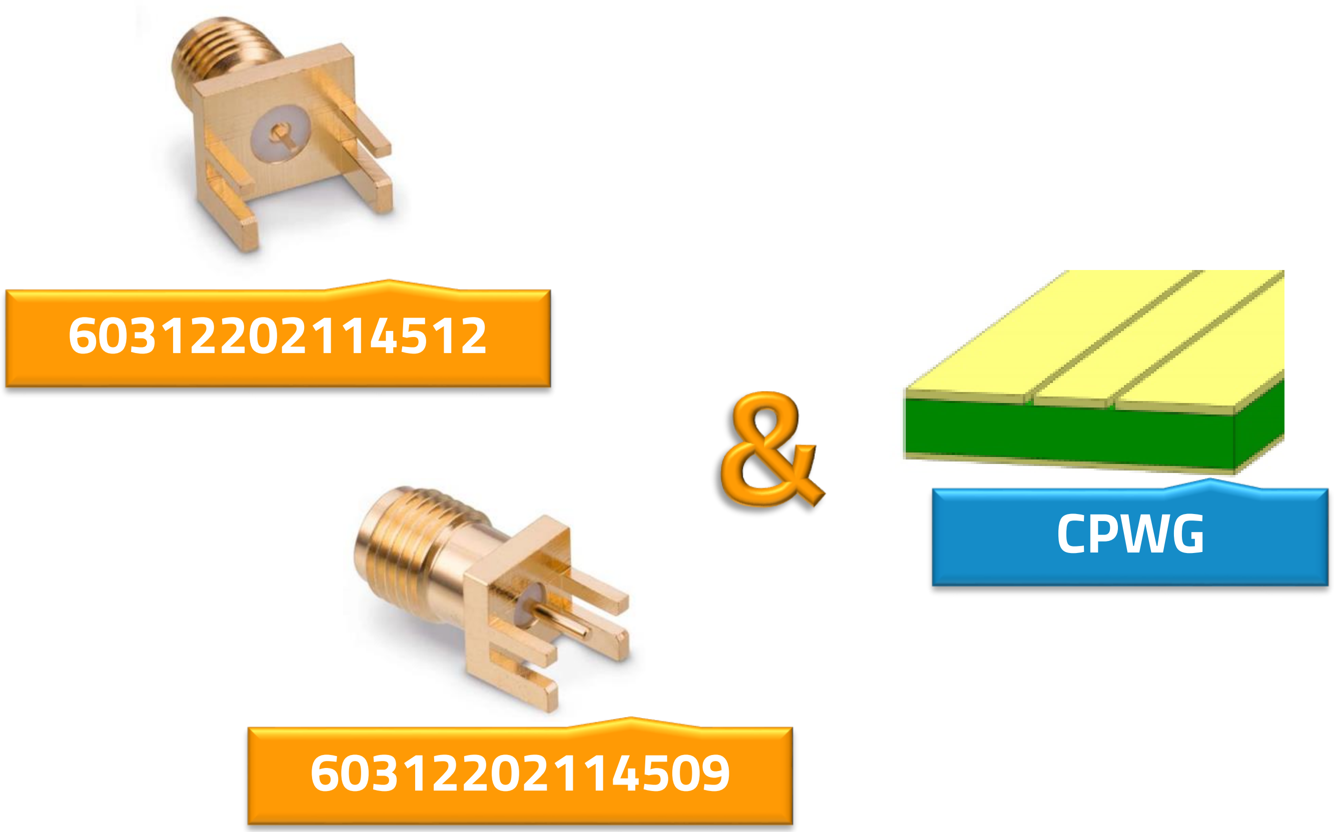
Microstrip: Optimized Design – TDR



Combination Connector & PCB: Examples

CPWG: Design suggestions

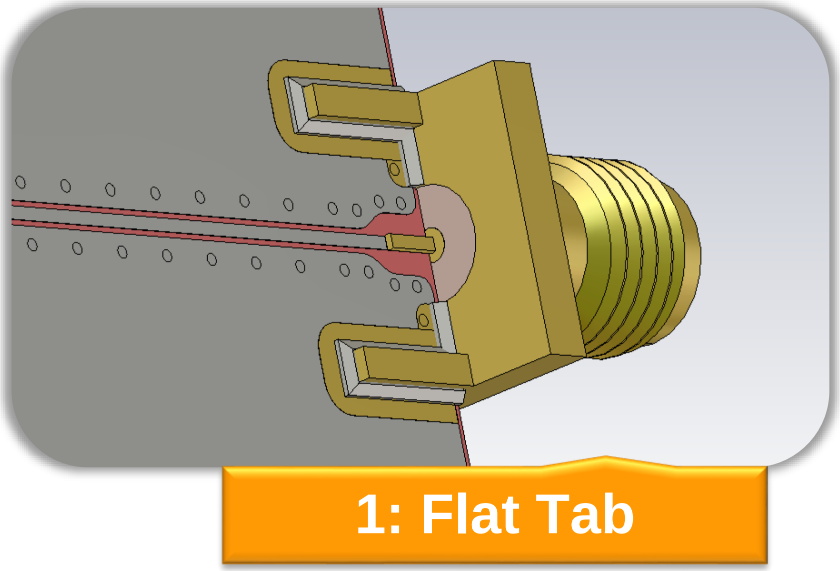
- **Given Task:**
  - Flat Tab **60312202114512**
  - Blunt Post **60312202114509**
  - 1.55 mm PCB
  - 4 Layers – FR4 Core & Prepreg
  - CPWG
- **Application: Circuit design**

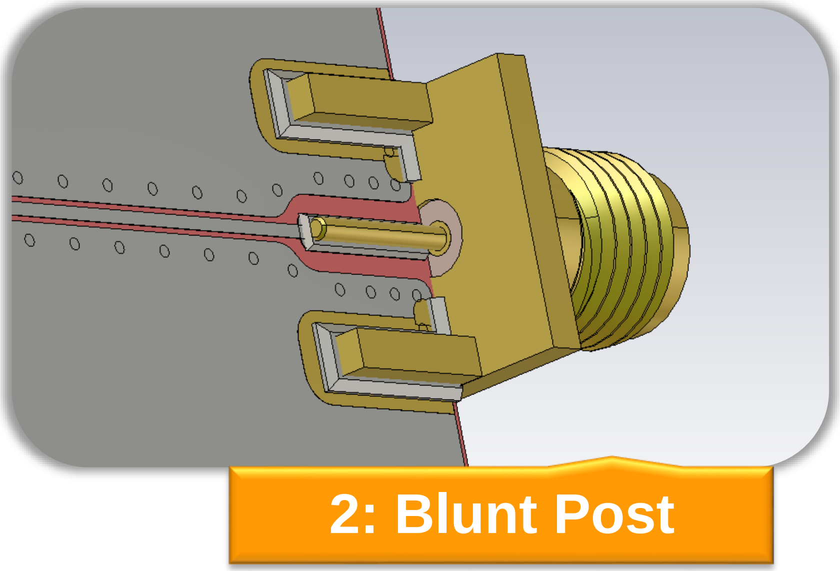


Combination Connector & PCB: Examples

CPWG - Round vs Flat: Overview

- **Analysis of 2 different designs**





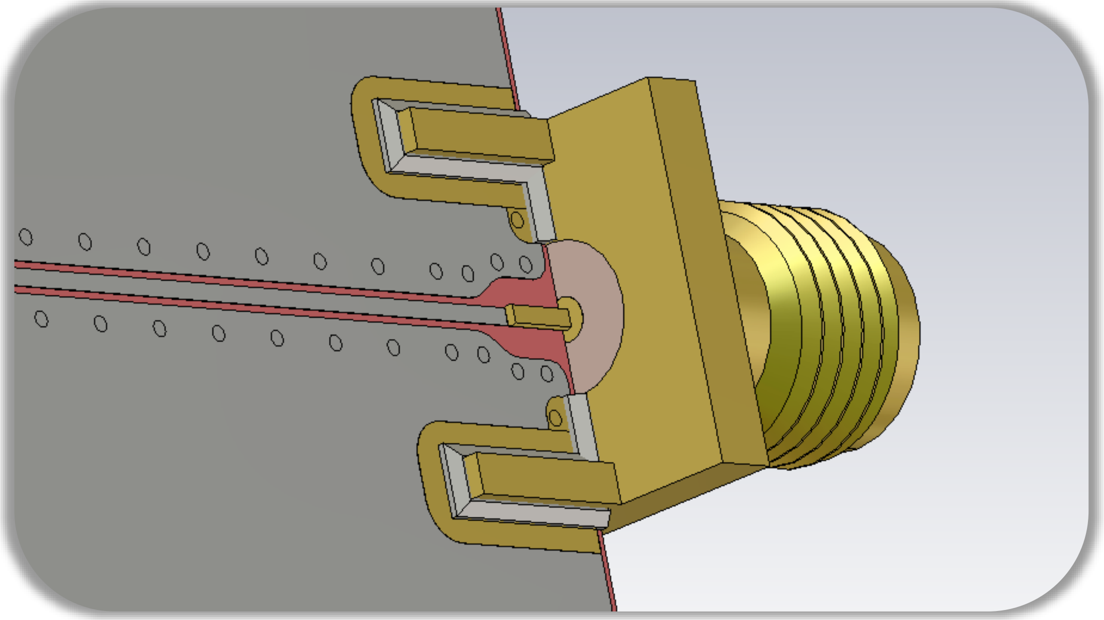
- **Fits to small traces**
  - Easy design
  - Difficult to solder

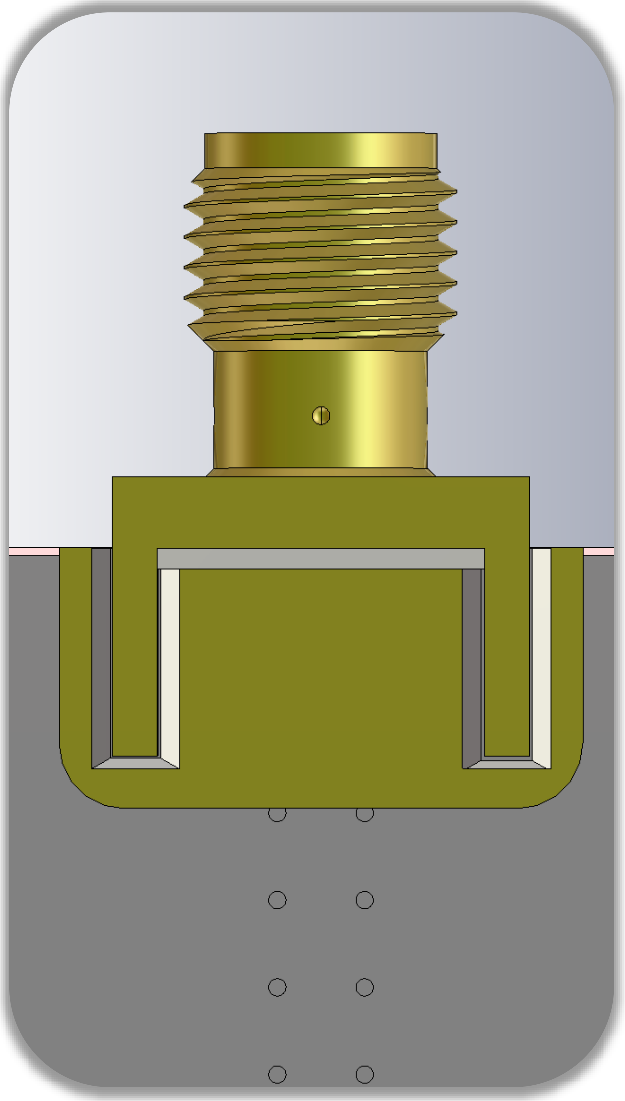
- **Needs extra solder pad**
  - Difficult design
  - Easy to solder

Combination Connector & PCB: Examples

CPWG - Flat: Design

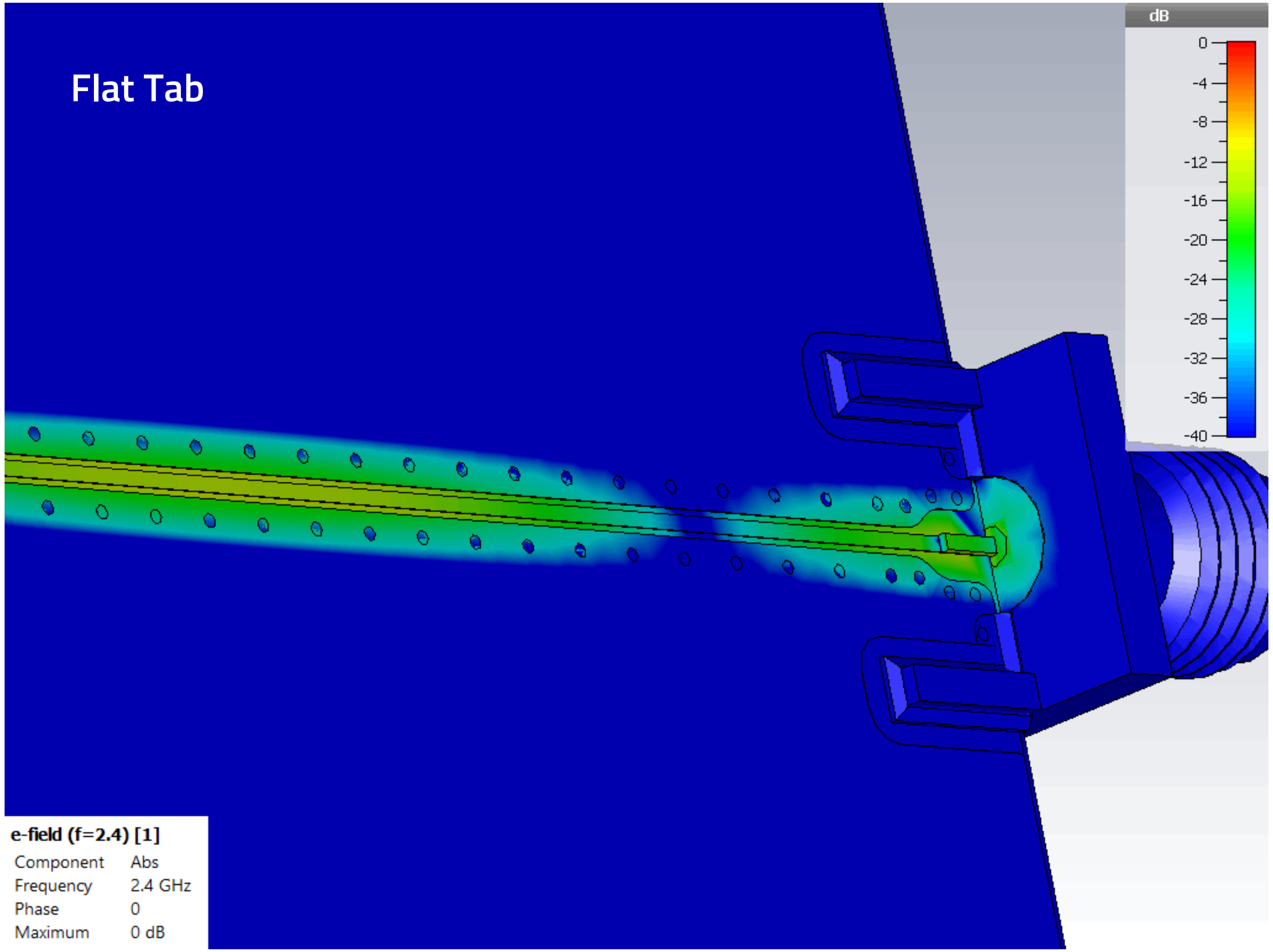
- Solder pads & several vias
- Very good GND connection
- Optimized RF-Line with taper





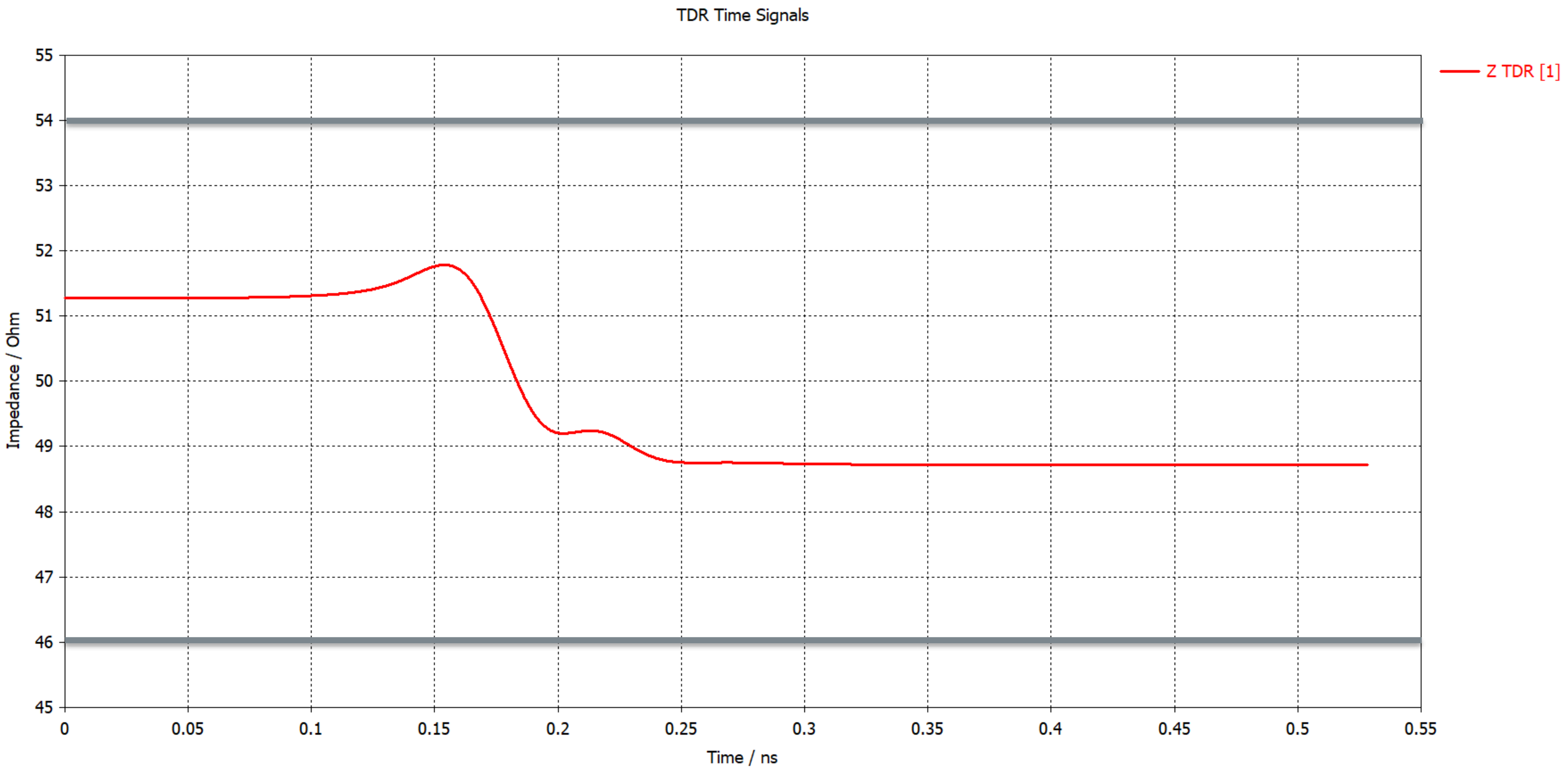
Combination Connector & PCB: Examples

CPWG - Flat: Simulation



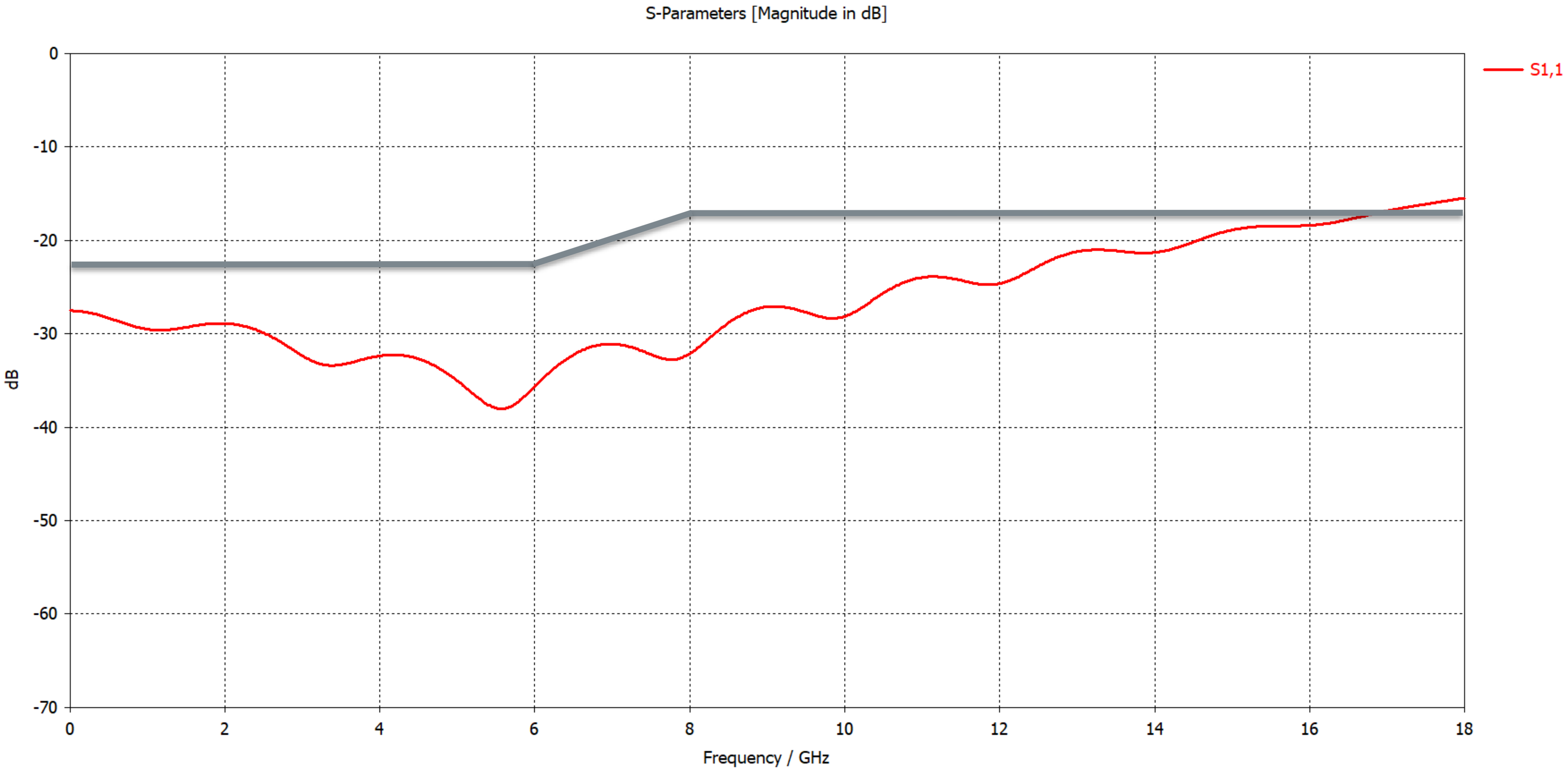
Combination Connector & PCB: Examples

CPWG - Flat: TDR



Combination Connector & PCB: Examples

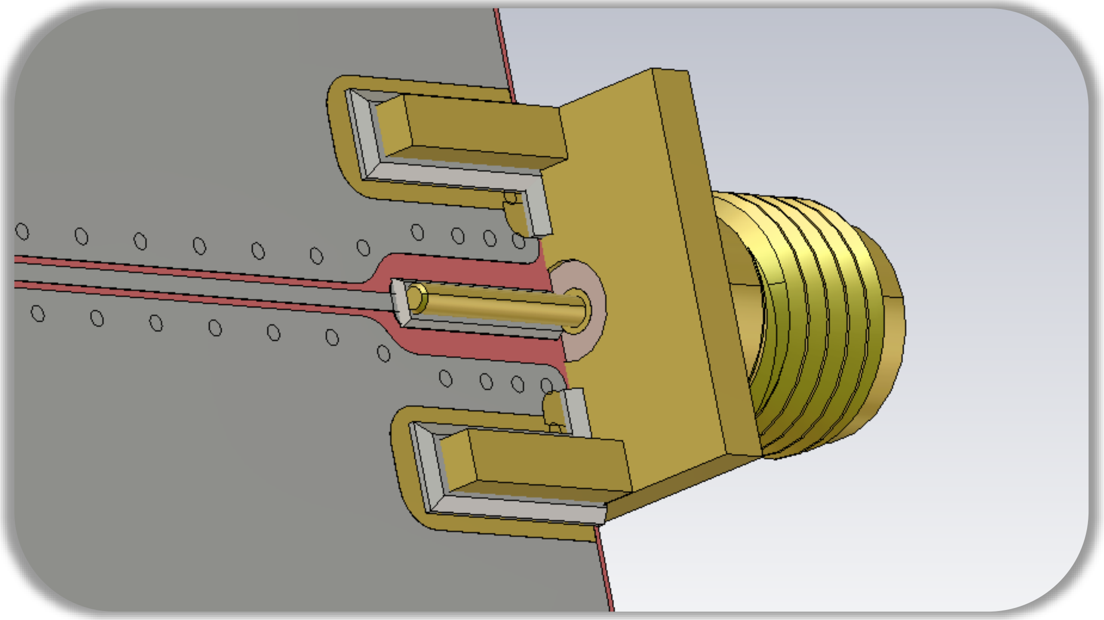
CPWG - Flat: S-Parameter

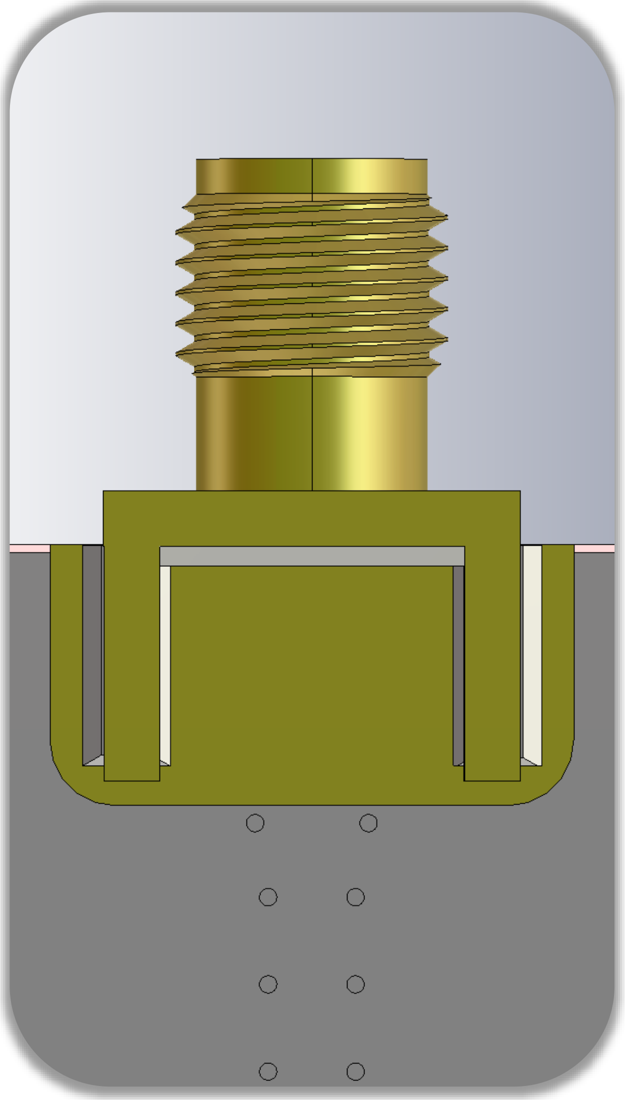


Combination Connector & PCB: Examples

CPWG - Round: Design

- Solder pads & several vias
- Very good GND connection
- Optimized RF-Line with tapers

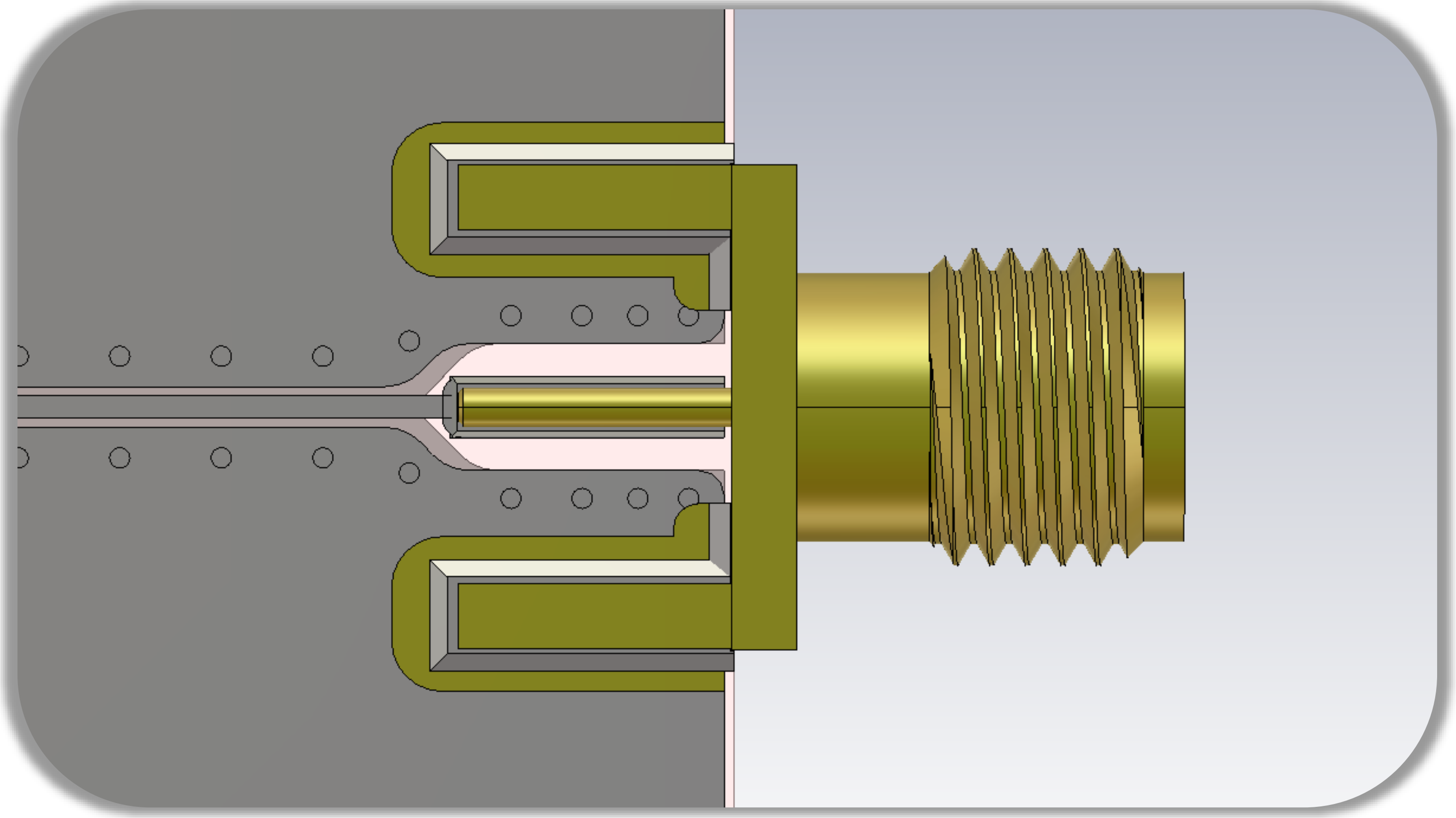




Combination Connector & PCB: Examples

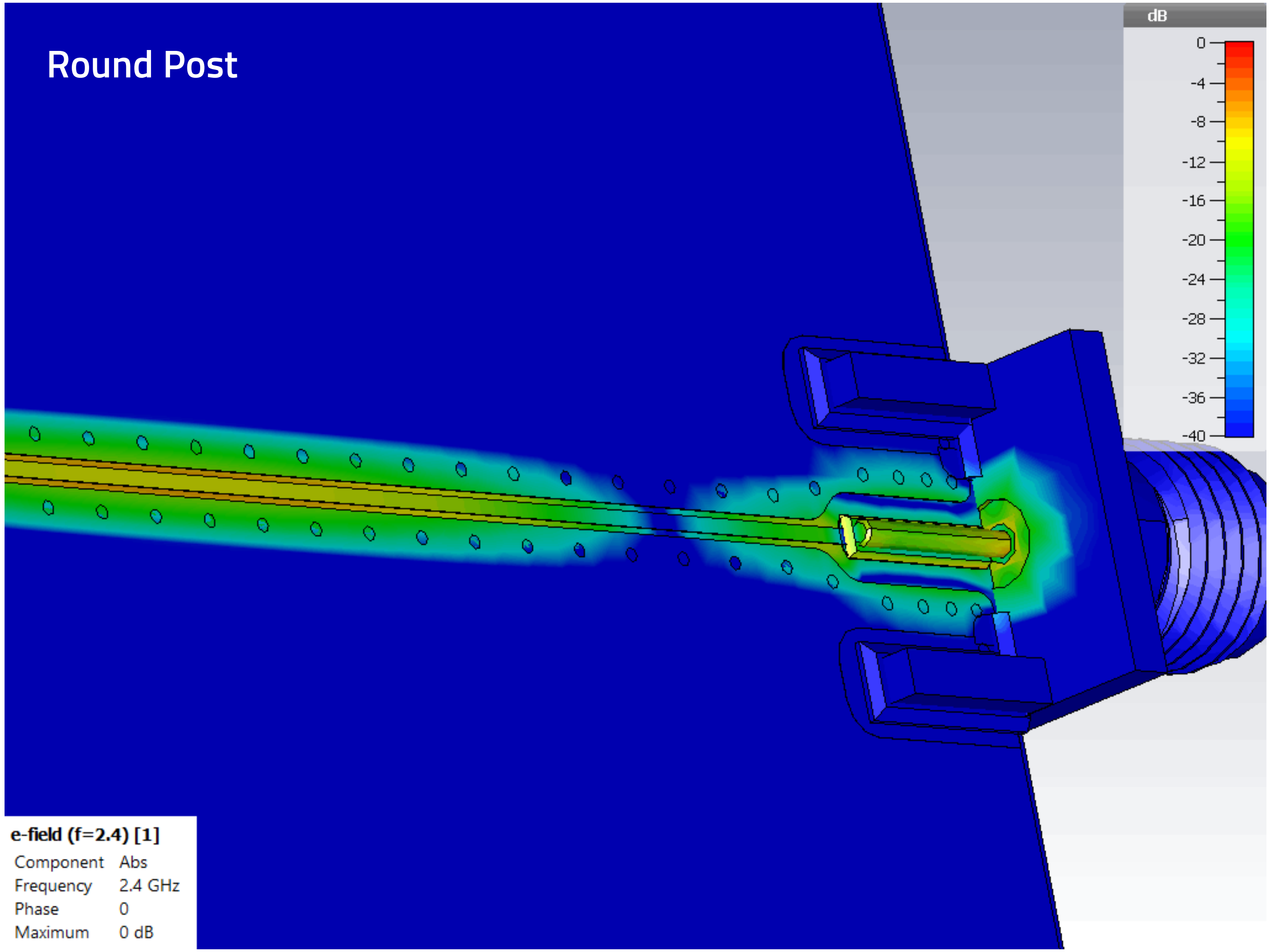
CPWG - Round: Design - DGS

- Defective Ground Structure: matching structure → decreases parasitic capacitance



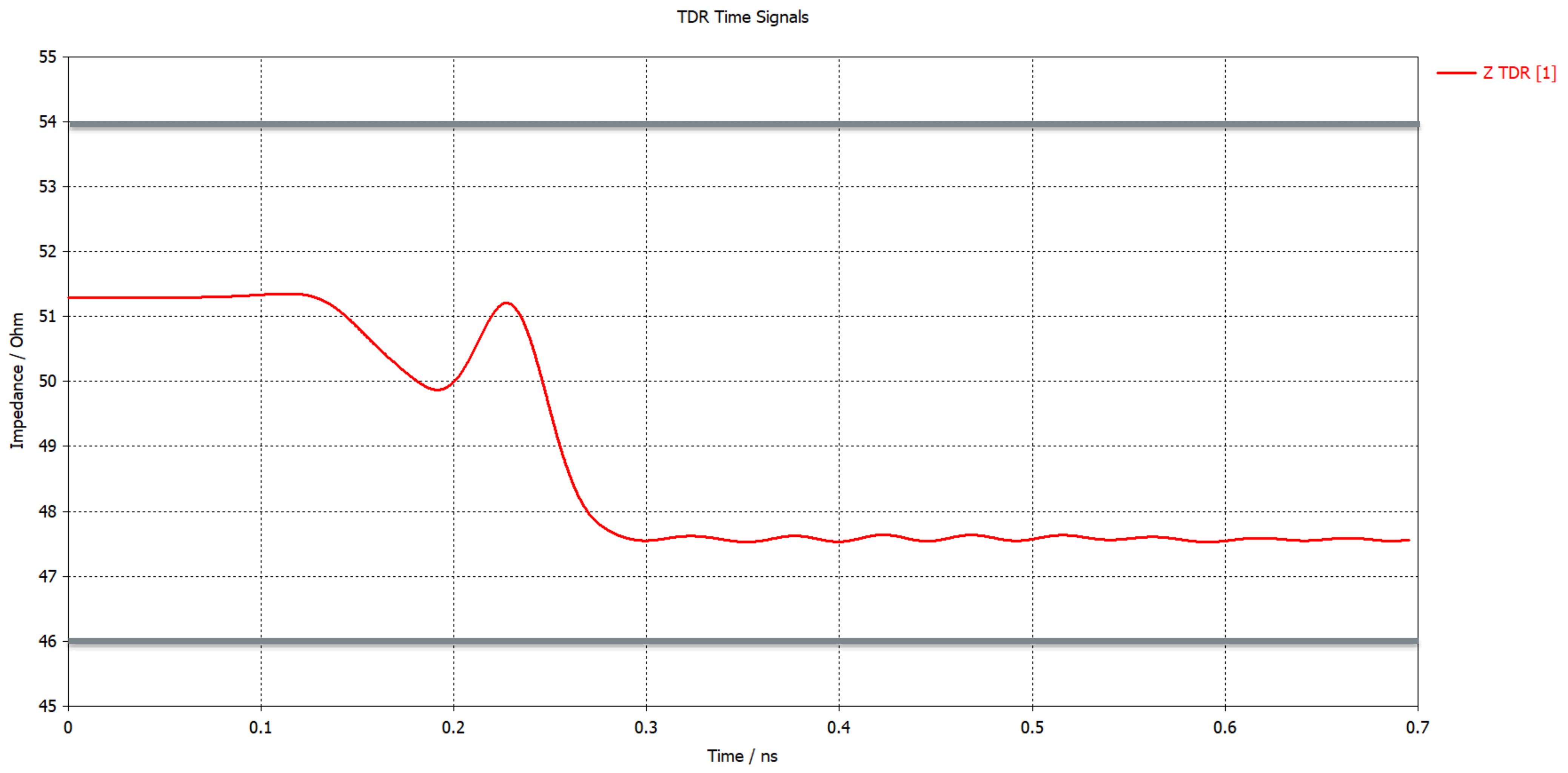
Combination Connector & PCB: Examples

CPWG - Round: Simulation



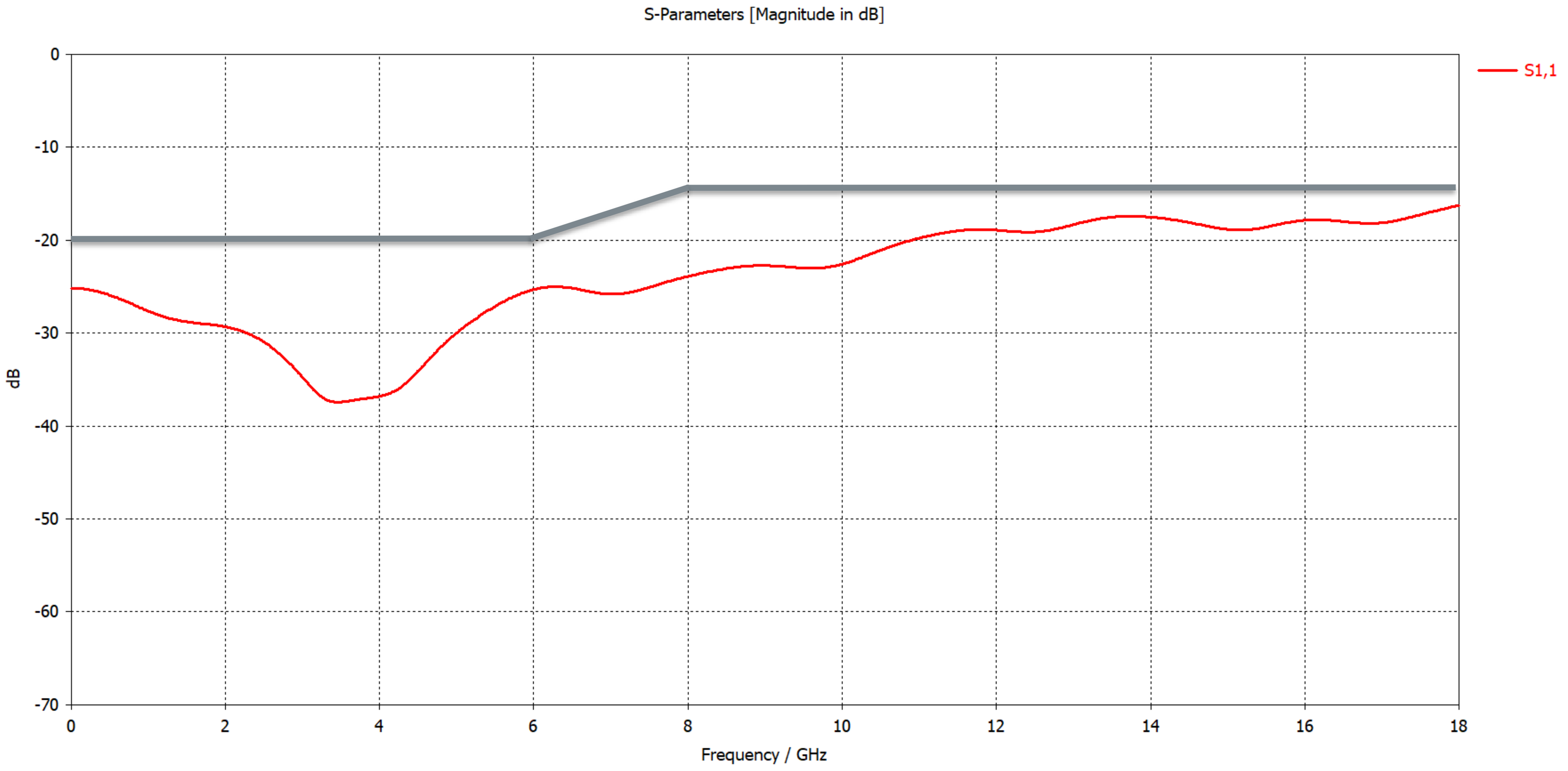
Combination Connector & PCB: Examples

CPWG - Round: TDR



Combination Connector & PCB: Examples

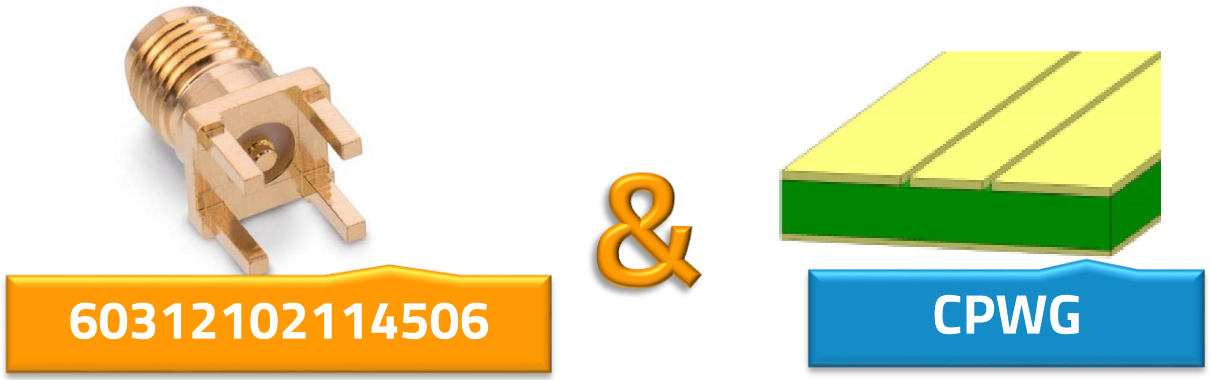
CPWG - Round: S-Parameter



Combination Connector & PCB: Examples

CPWG - THT: Overview

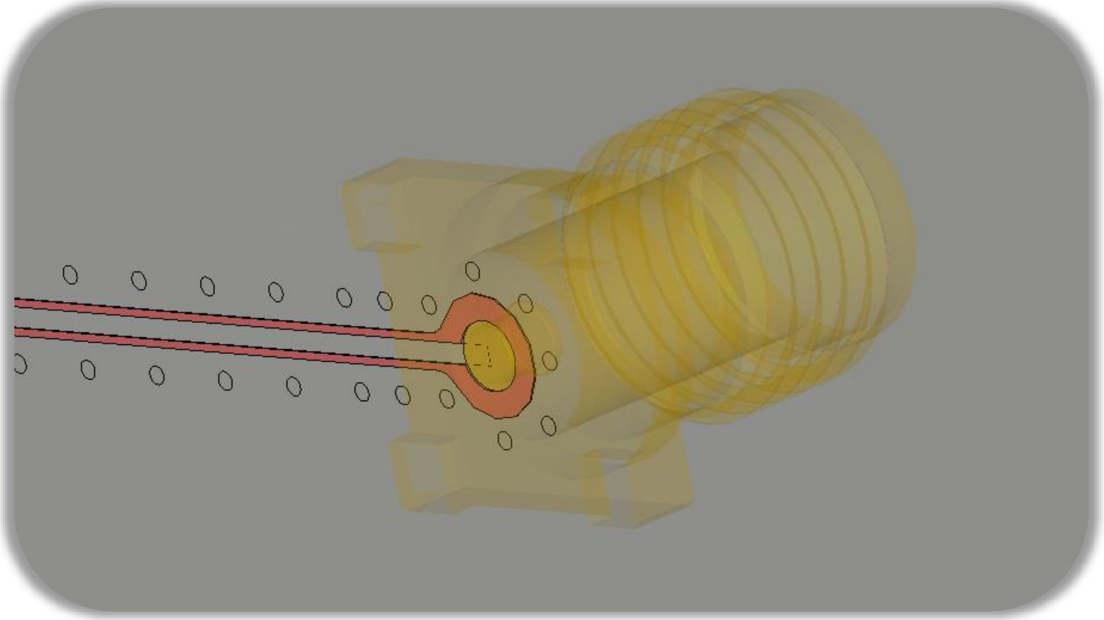
- **Given Task:**
  - THT **60312102114506**
  - 1.55 mm PCB
  - 4 Layers – FR4 Core & Prepreg
  - CPWG
- **Application: Circuit design**

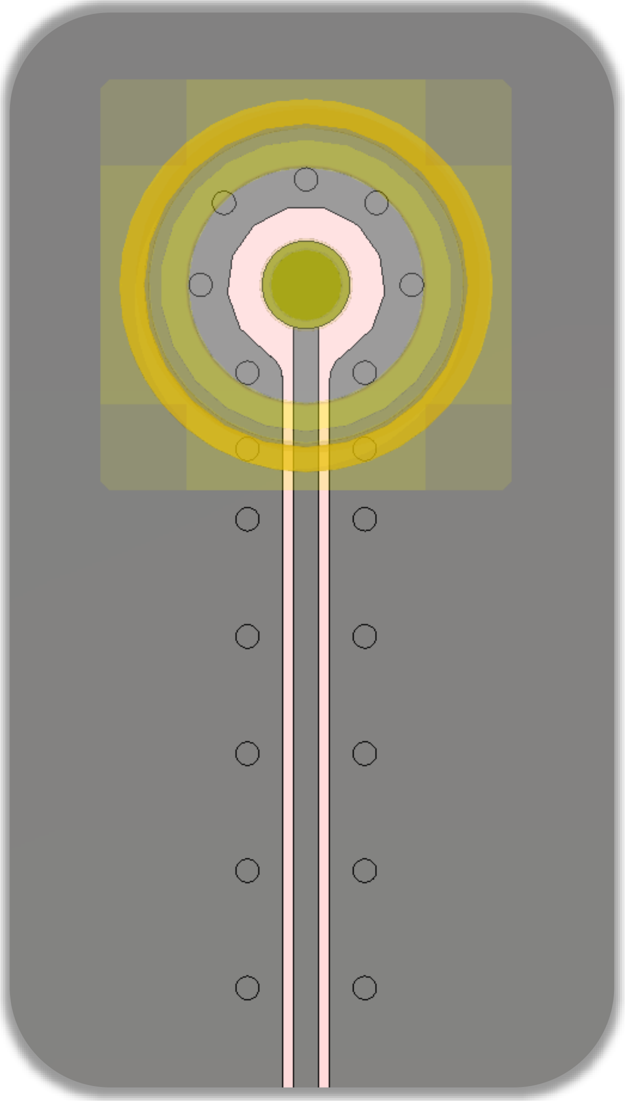


Combination Connector & PCB: Examples

CPWG - THT: Design

- **Solderpad & several vias**
- **Very good GND connection**

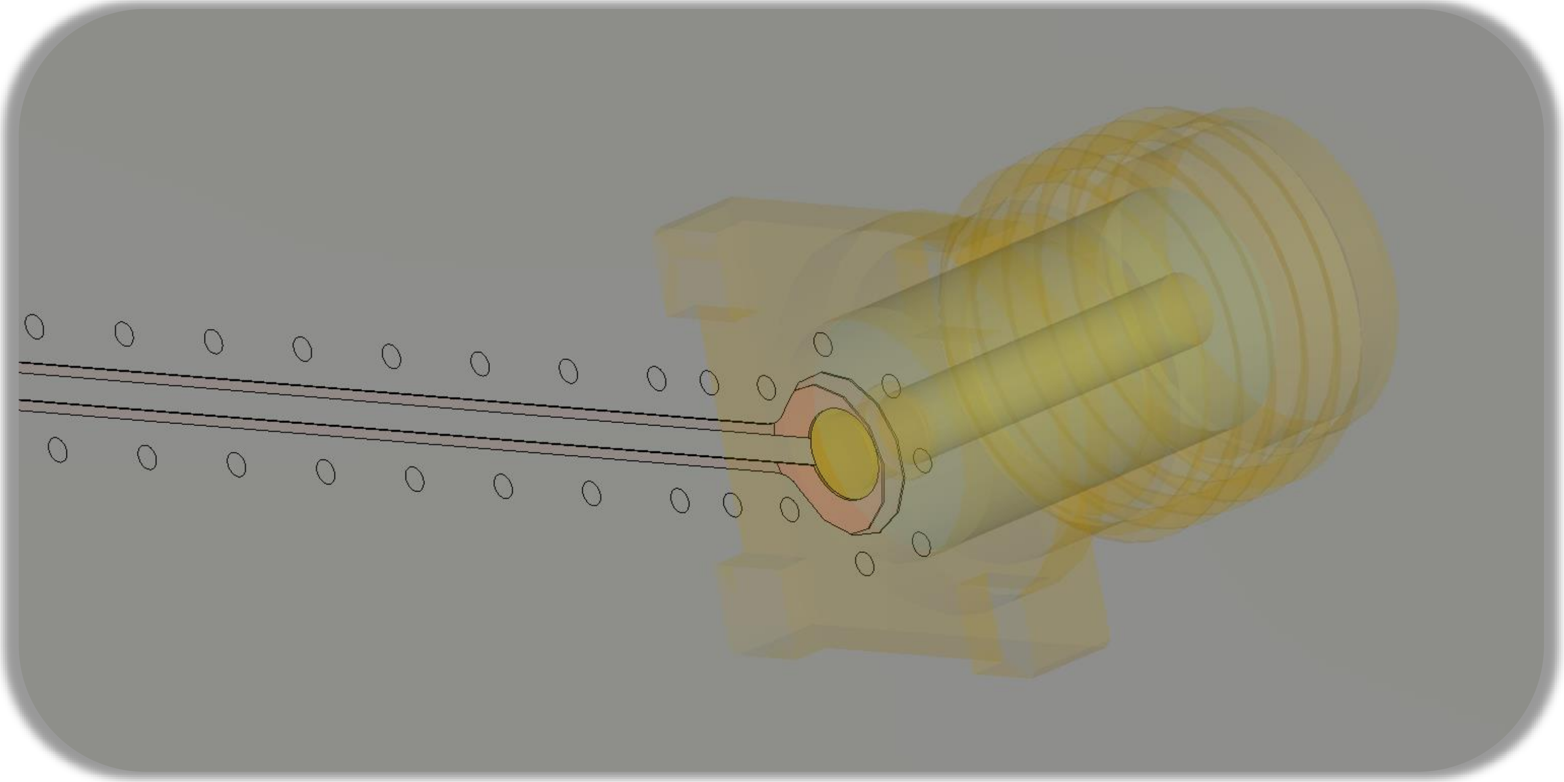




Combination Connector & PCB: Examples

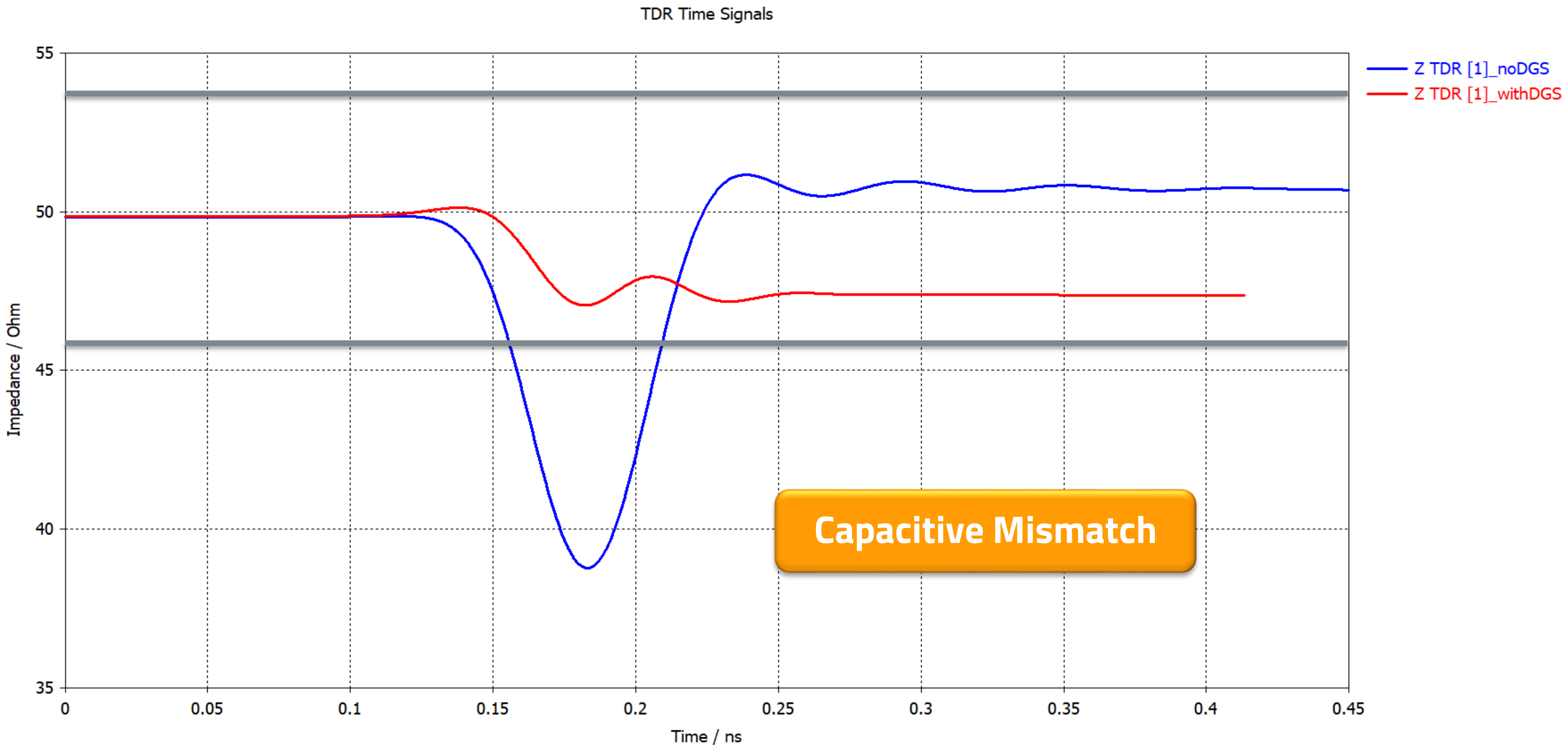
CPWG - THT: Design - DGS

- **Defective Ground Structure: matching structure → decreases parasitic capacitance**



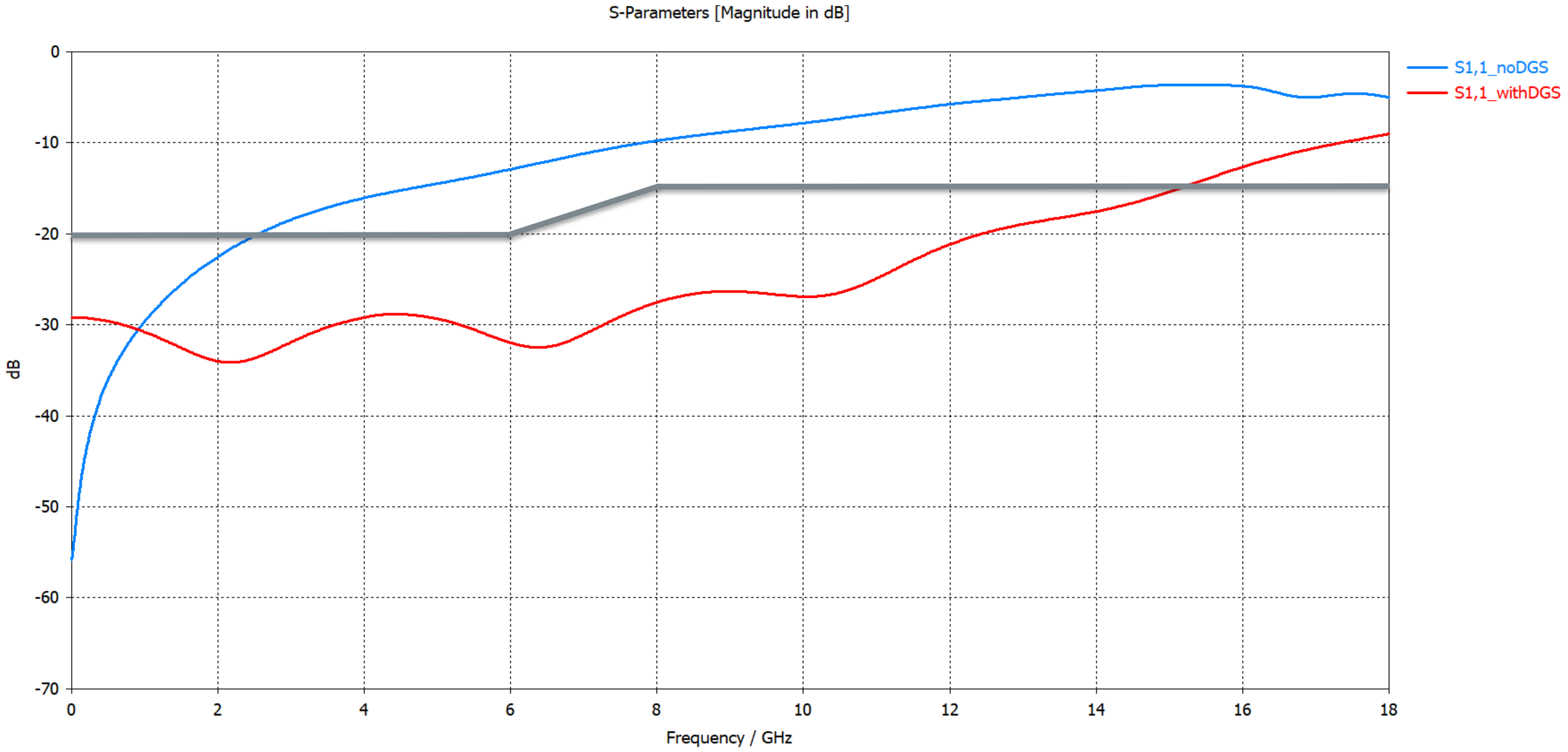
Combination Connector & PCB: Examples

CPWG - THT: TDR



Combination Connector & PCB: Examples

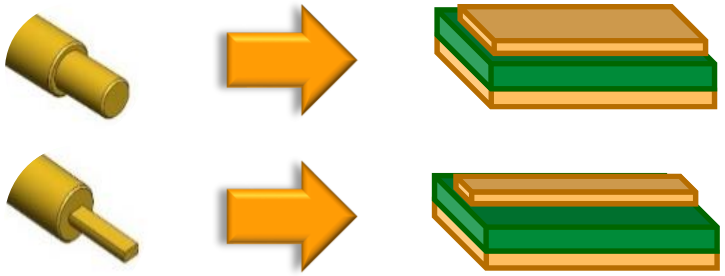
CPWG - THT: S-Parameter



Combination Connector & PCB: Summary

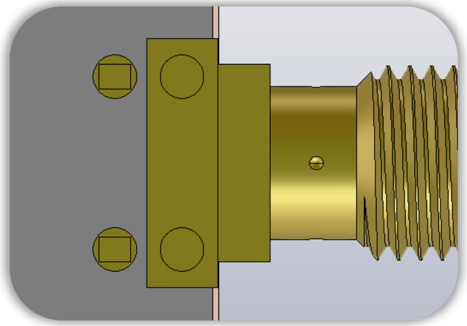
Combination Guide

- **Chose SMA-Post from:**
  - Frequency range
  - Line structure

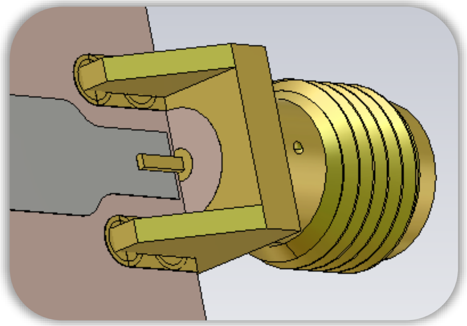


Design

- **Good GND connection**
  - Avoid slot-antenna!



- **Optimize RF-Line**
  - Taper & DGS



Reminder of Training Keypoints

Choose SMA Type based on:

- **mechanical conditions**
- **Electrical values**
- **Electrical design**
  - Line structure
  - PCB-layer setup

Be aware of your design:

- **Good GND connection**
  - Don't only look on the connector layout, but optimize the whole connection area !
- **Use the right tools:**
  - Line- and GND-Tapers
  - DBS-structures
  - Via Fence

  } to compensate parasitics

Summary

- **Choose SMA-Type from:**
  - Mechanical conditions
  - Electrical values
  - Electrical design:
    - Linestructure
    - PCB-Layer setup

- **Be aware of your design**
  - Don’t only change the connector layout – optimize the whole connection area
  - Use the right tools
    - Line- and GND-taper
    - DGS
    - Via fence

    to compensate parasitics