FCT for RF/High Speed Applications with Test Probes. Strategies, Pitfalls and How to Avoid Those.

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What we will cover today...

01 **FCT of PCBA assemblies**
What is a test probe and why do we need to use those?

02 **The problems start as the frequency goes up!**
Impedance, impedance matching influence of mechanical properties on electrical behavior

03 **Test targets**
RF connectors, test points on boards and “makeshift” test points

04 **Types of RF and high-speed tests**
Power level, filter characteristics, constellation diagrams, TDR

05 **Calibration considerations**
Why is calibration necessary? Probe tip calibration: SOL(T), thru-calibration

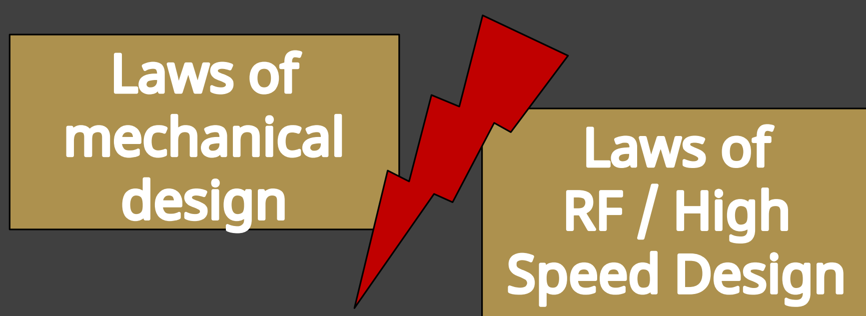
06 **More applications with RF (and other) probes**
Continuity, pin position test, high voltage (hi pot), high power

07 **EMC & Shielding Considerations**
With or without use of RF Probes, shielding maybe a necessity

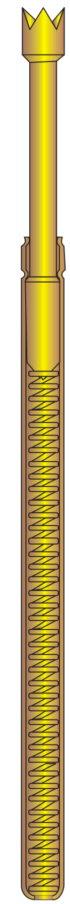
Key message / theme:

“To avoid any pitfalls, the laws of mechanical design needs to be aligned with the laws of RF / High Speed”

(sometimes those 2 clash)



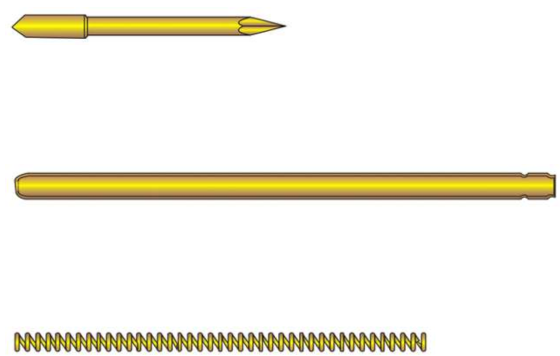
1. What is a Test Probe and why do we need those?



- Mechanical device to establish **temporary** electrical contact
- Mostly **spring-loaded** components
- Highly repeatable & **many mating cycles**
- For production test of **PCBA’s / electronic modules / batteries** etc.

Easiest probe =

1. Plunger
2. Barrel
3. Spring



Needless to say, it’s a bit more complex for RF or we would not fill an hour ☺

1. Varieties of Spring-Probes

Main categories:

1. Standard test probes
- Single ended
- Double ended

2. 4 wire test probes
- Two probes in one for Kelvin testing
- Center and outer conductor

3. RF and high-speed digital
- Coaxial
- Board to board
- Differential
- Contacting modules

4. Probes with SPST switch

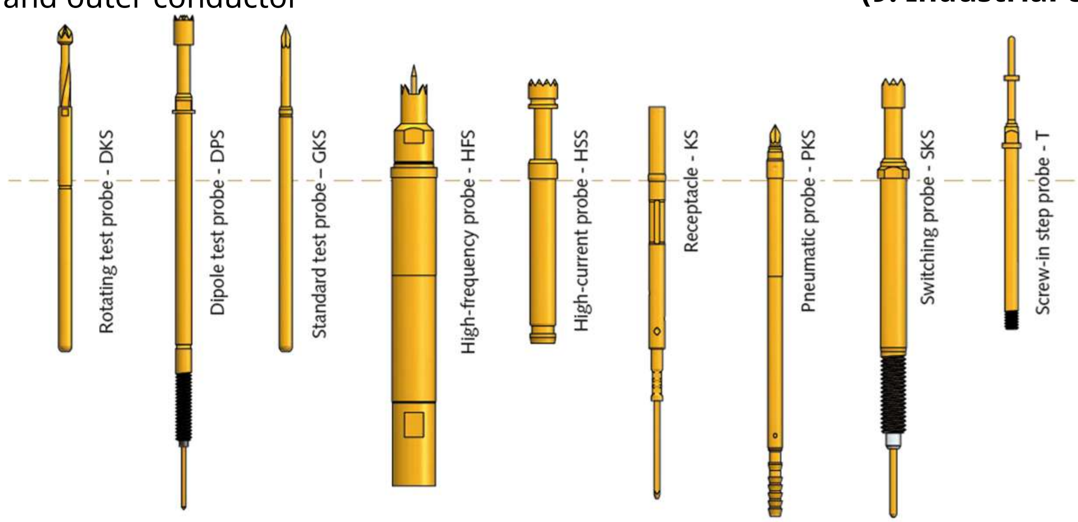
5. Threaded probes
- Cable harness testing
- High vibration
- Fast actuation

6. Pneumatic probes

7. Rotating probes

8. High current probes

(9. Industrial contacts)



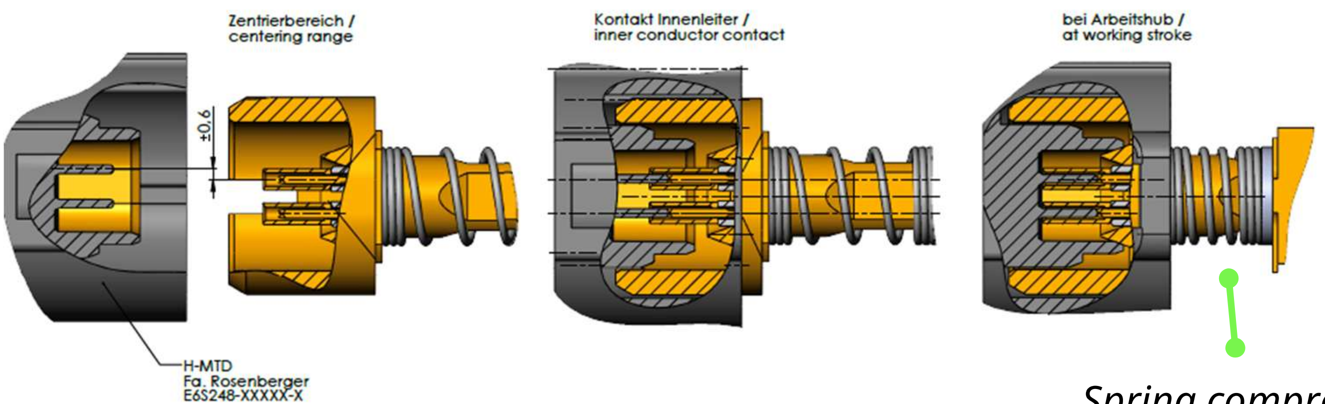
1. Making contact with a connector

It’s all about longevity! → Mating connector sometimes down to 5 matings / probe up to **30,000…100,000**

- A spring-probe provides a **temporary** connection between a *PCBA or module* and a *test system* . Almost never is the probe used as a permanently installed component.

- Purposes are: **Quick connect and disconnect** while allowing **high-mating** cycles which surpass those of a mating connector. All geared towards production test.

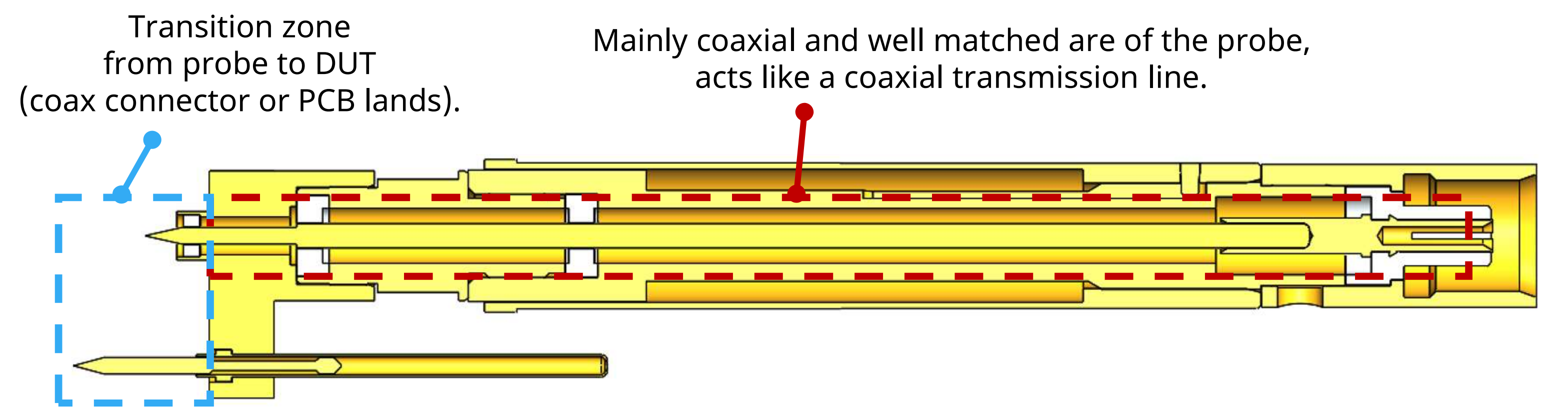
- Spring-probes typically come in *coaxial* or *differential variations,* with 50 Ohm, 75 or 100 Ohm impedance.



Spring compression

1. Coaxial RF probes are very complex!

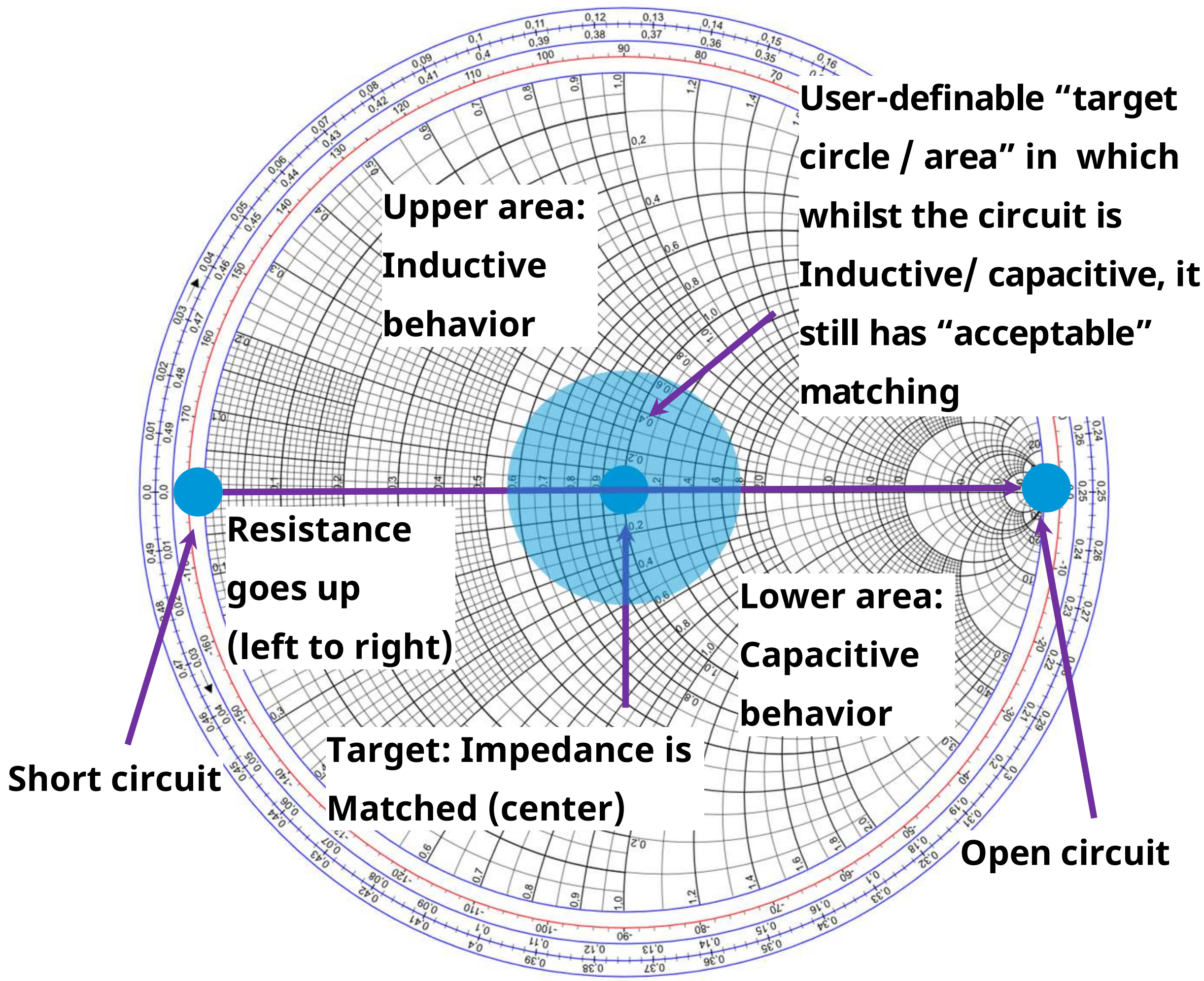
Up to <u>thirty components</u> for some versions - many of the interior components must be impedance-matched



- Dashed areas are critical for impedance matching.
- RF “magic” happens here (and it’s the manufacturer’s trade secret how to achieve it)
- Simulations tools and experience needed to keep notches out, to keep insertion loss low and matching high and close to the nominal impedance.

2. Impedance matching

- **Impedance** in laymen’s terms is similar to **resistance**, but at high frequencies
- Adds **inductive** and **capacitive** elements.
- **Maximum power transfer** only possible if impedance is “matched”
- Right side: So-called **“Smith Chart”**

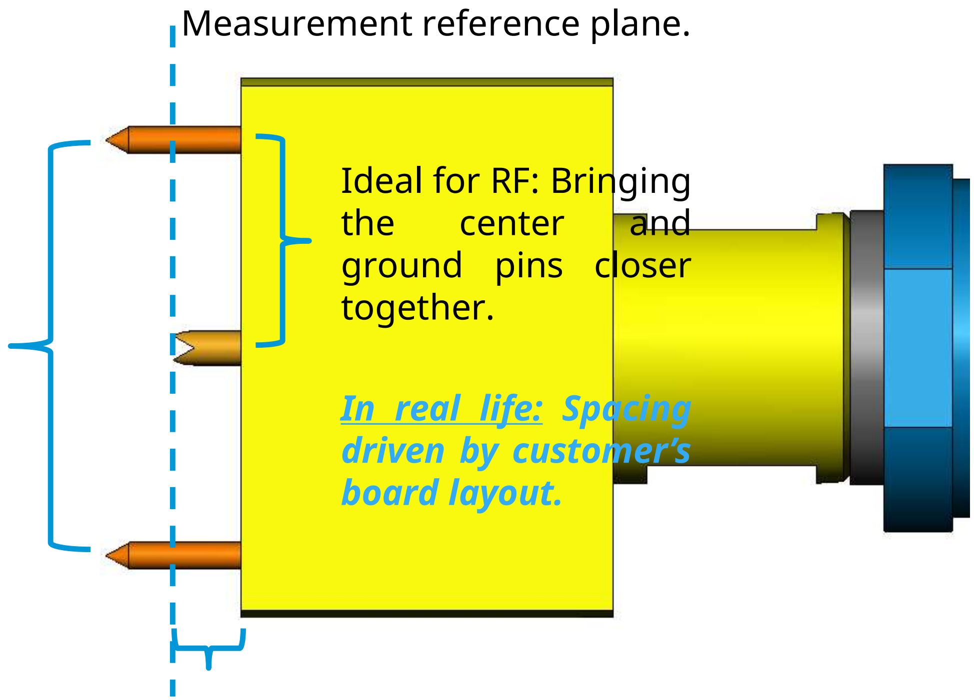


2. Impedance matching – effects for probe design

Tip styles:

For RF, “softer” tips, such as flat ones or hemispherical (round) ones .

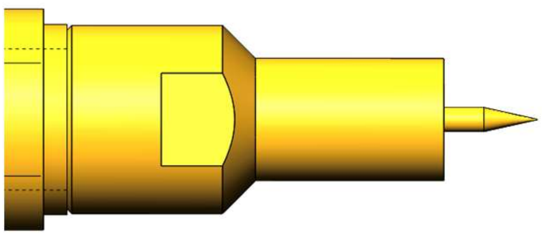
<u>In real life:</u> Contaminated (no clean) boards etc. dictate the use of aggressive tips.



RF: Overhang should be kept as short as possible.

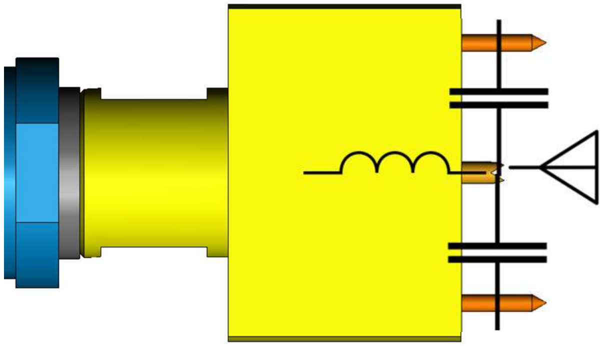
<u>Real life:</u> Overhang driven by customer’s board design.

2. Impedance matching – “parasitics” with a test probe



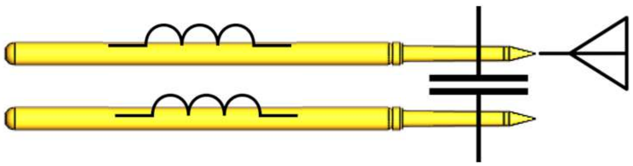
Ideal:

A coaxial structure throughout, even in the transition area. Well impedance-defined and shielded.



Compromise for GS, GSG etc.:

Certain parts, such as the overhang could act like antennas, capacitors and inductances. Probe impedance defined inside but sometimes not in transition area.

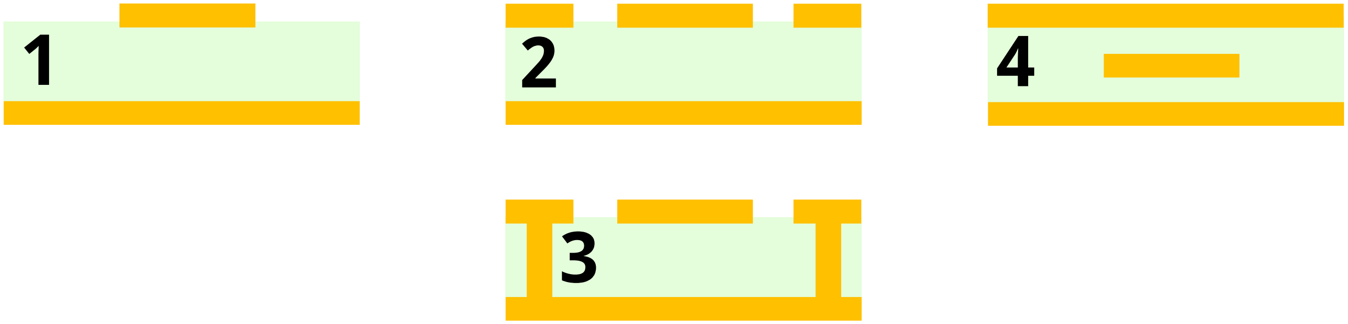


If DC probes are used: Probes need to be installed in a certain way, to avoid parasitic bahavior.

2. Impedance matching – proper board design

Planar transmission-line technologies (e.g. for 50 Ohm or other impedances)

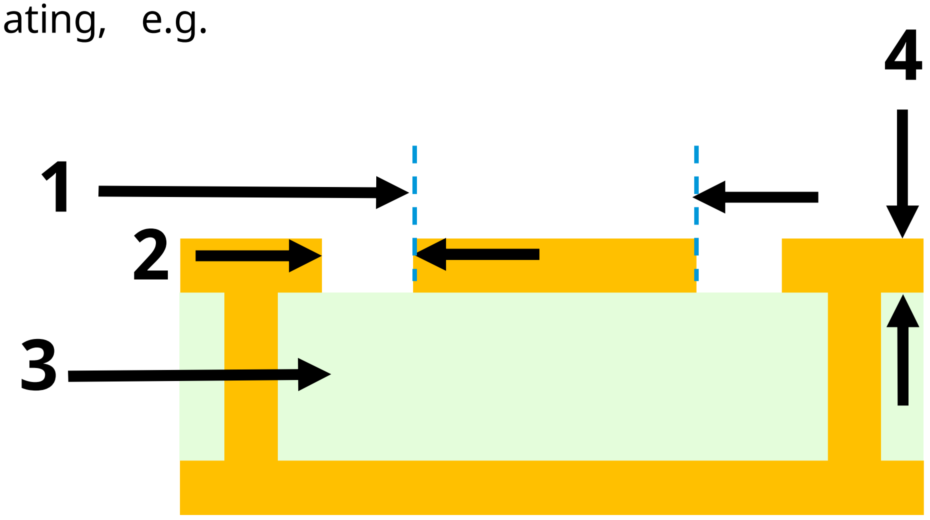
- Microstrip **(1)**
- Coplanar Waveguide (CPW) **(2)**
- Grounded Coplanar Waveguide (GCPW) **(3)**
- Stripline **(4)**



2. Impedance-matching (board design) - variables

Impedance-defining parameters on an RF board, GCPW

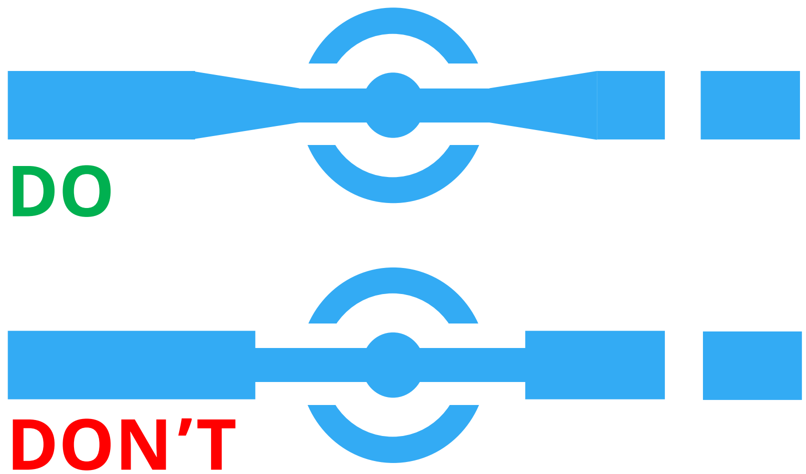
- Trace width **(1)**
- GS-gap width **(2)**
- Dielectric properties of the RF substrate & loss tangent **(3)**
- Trace height **(4)**
- Not shown: Plating, Dielectric layer over plating, e.g. conformal coating etc., spacing of ground vias



2. Impedance-matching - transmission line / test points

Narrowing of the PCB trace to accomodate RF probes

- Use tapering methods on either side of the transmission line
- Do not use ”sharp” (abrupt) steps

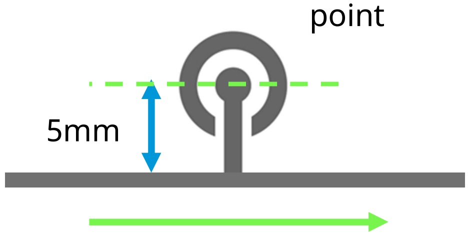


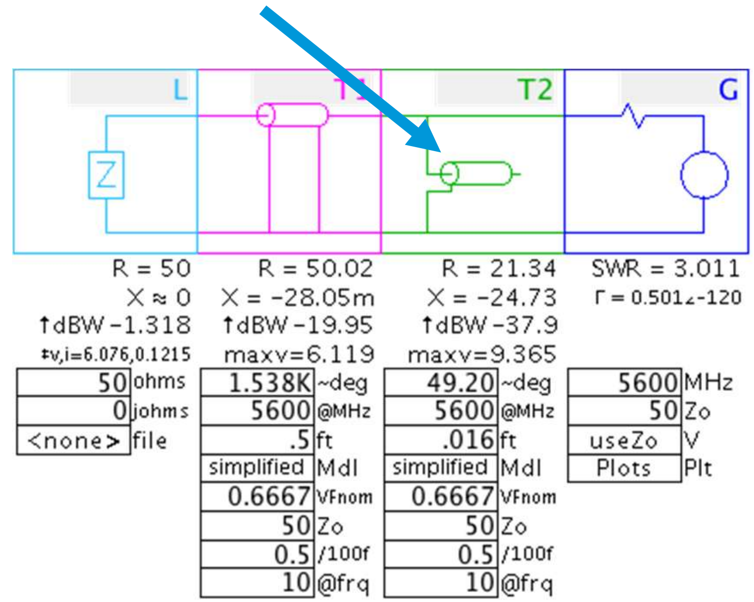
2. Impedance-matching

Above a certain frequency , usually in the GHz range, mechanical properties of the device under test and the probing structure interfere with the electrical characteristics of the whole system and thus the performance.

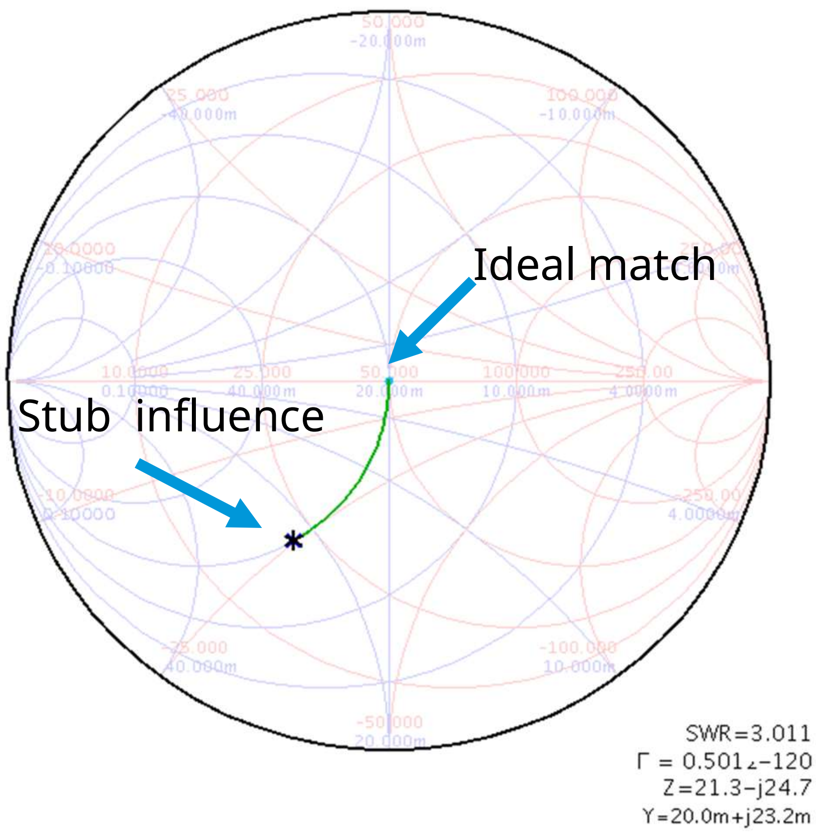
Example: A transmission-line stub

~5 mm stub
15 cm transmission line
50 Ohms impedance
f=100 MHz, 2.4 GHz and 5.6 GHz WiFi





2. Impedance-matching



“Testability”

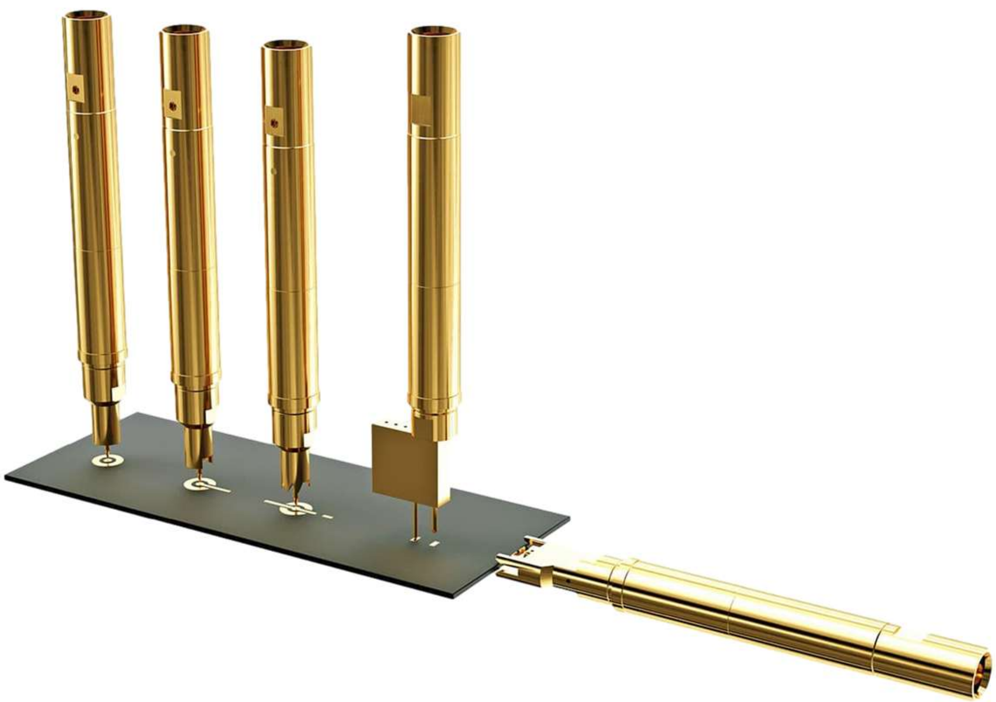
- **At 100 MHz** – no problem
- **At 2.4 GHz** (WiFi) – signal degradation
- **At 5.6 GHz** (WiFi) – not testable anymore

Circuit has capacitive behavior which does not Show up when doing a lower frequency Measurement!

→ Compensation features necessary!
→ RF simulation suggested to do circuit analysis. Important for proper DFT!

3. Test targets – PCBA test points

Challenge – impedance matching of the TP



Stripline

Signal in inner layer

Microstrip

Careful with stubs!

Microstrip

Careful: Impedance “split”

Grounded coplanar waveguide

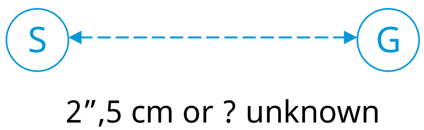
Good option for high performance

Ground - Signal

Lacks second ground contact, compromise

3. Test targets – test points, use of standard pins for test

Effect on the coverable frequency range / data rate

		Frequency range / data rate
	**“Uncontrolled”** Use for low -peed clock signals only or other low frequency signals.	Low
	**“Better”controlled** Not as well “shielded”, but GSG is a Good architecture	Higher
	**Well controlled** • Proper DFT & “shielding” • Proper material choice • Proper probe choice • Simulations done GHz signals are possible!	GHz range

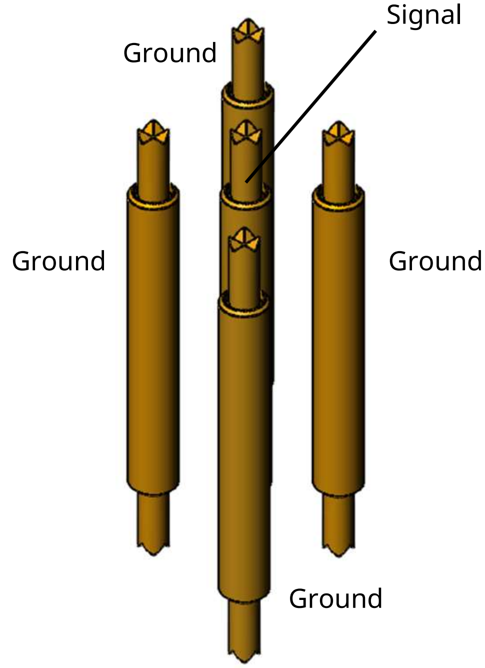
3. Test targets – test points, use of standard pins for test

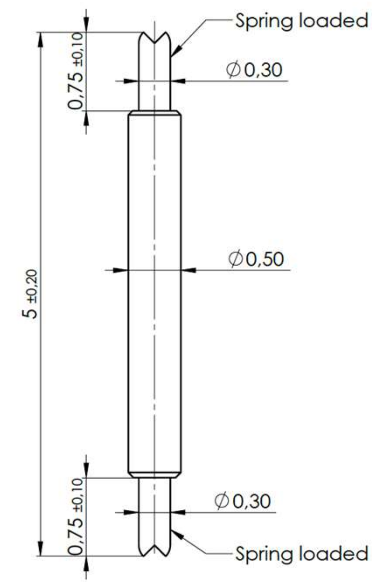
It is preferred to have a probe that is as **short as possible** to allow higher frequencies and to have these arranged similar to a **test socket architecture**

Fine pitch probes:

In use for multi-pin / board to board Connector probes

(along with electroformed blade pins)





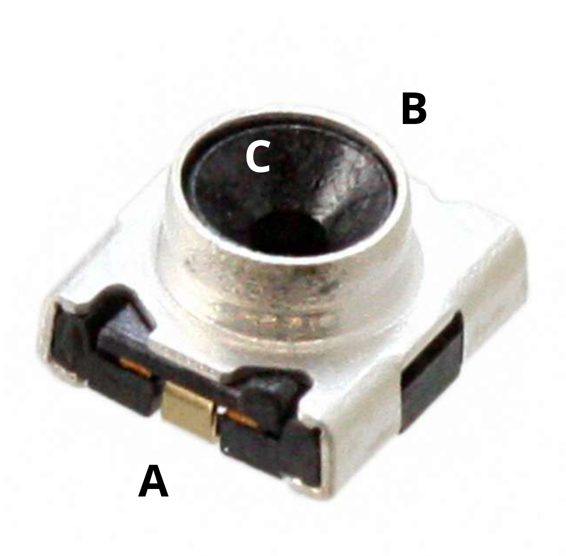
Maximaler Hub: 1,5 mm Empfohlener Arbeitshub: 1,0 mm Federkraft bei Arbeitshub: 0,2 N ± 15%
Maximum stroke: 1.5 mm Recommended working stroke: 1.0 mm Spring force at working stroke: 0.2 N ± 15%

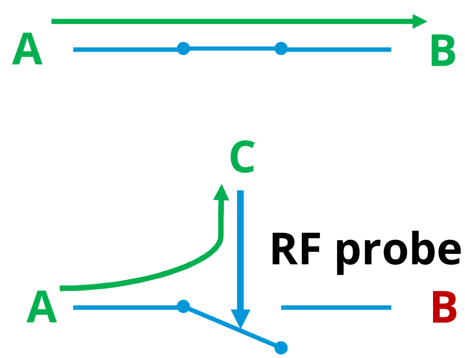
15:1

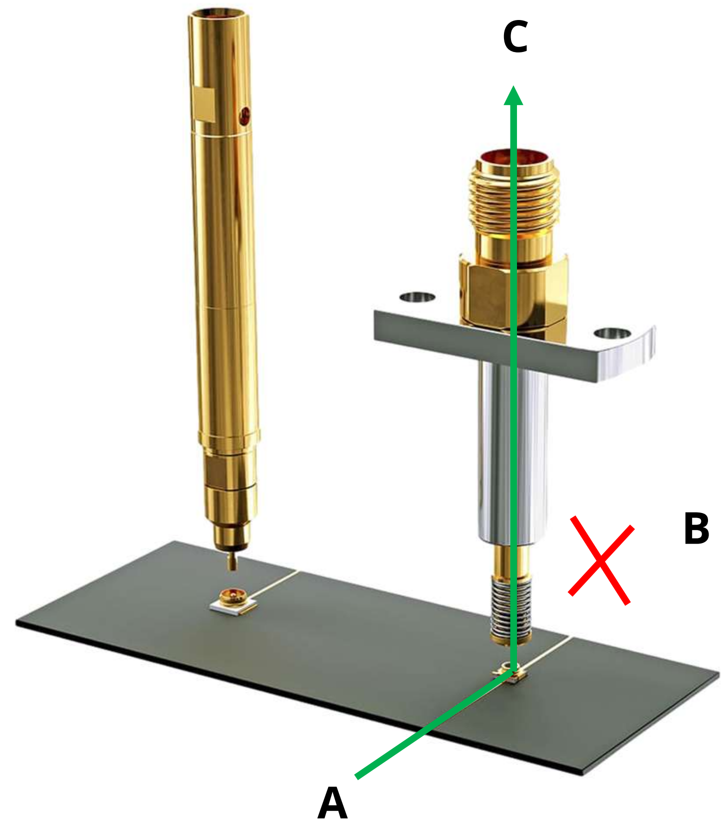
GKS-309 304 030 A 0200 L50

3. Test targets – small board connectors (antennas / switches)

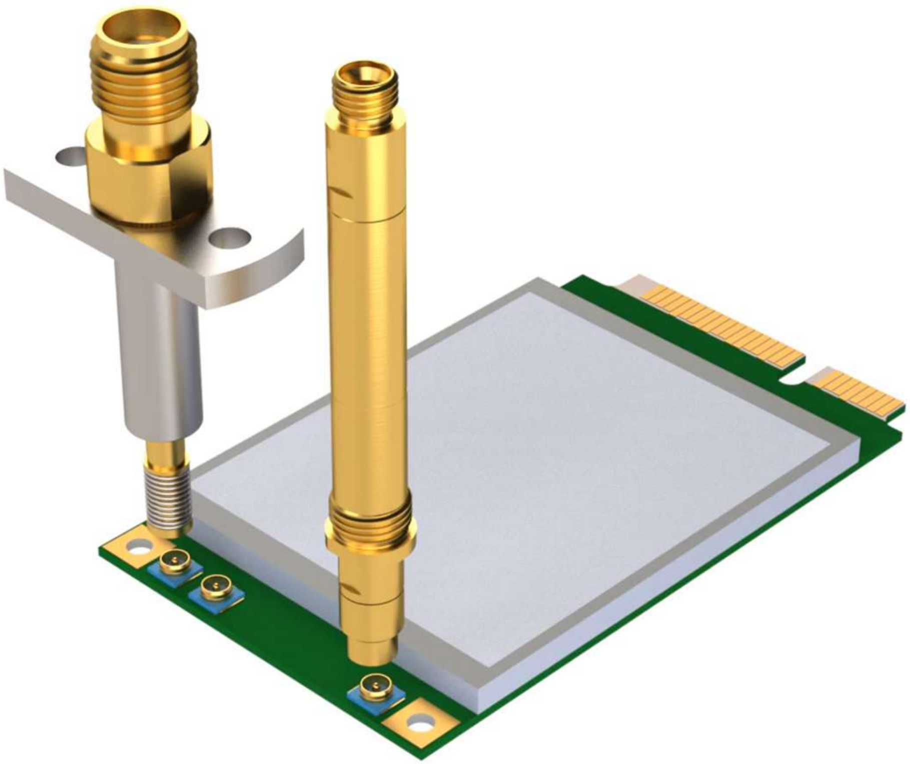
Switches “reroute” the signal (no impedance mismatch)







3. Video: RF module testing



Flange-mounted coaxial RF probes quite often have a self-alignment mechanism. Receptacle-mounted probes series should be mounted in a floating plate or in a receptacle (socket) that has such a self-alignment system.

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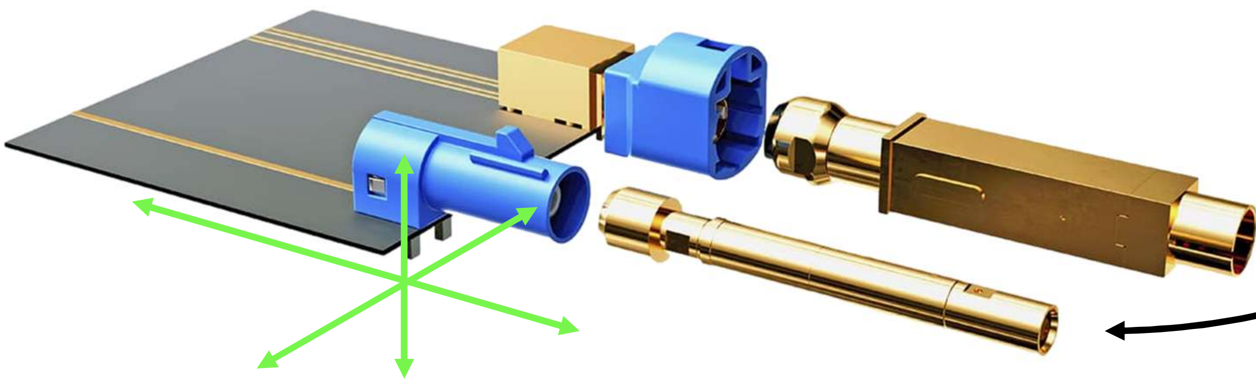
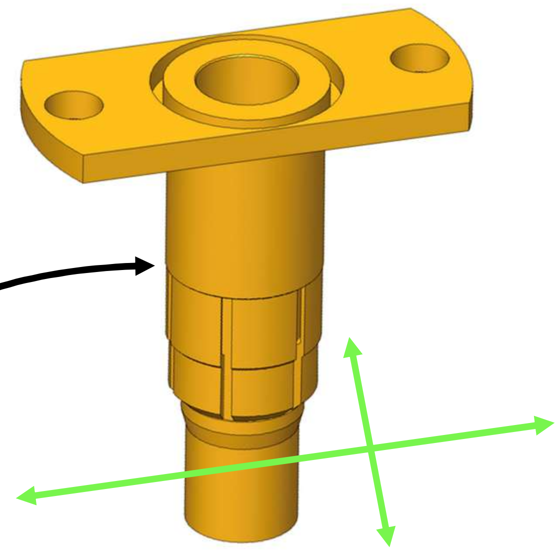
3. Test targets – larger board connectors

Challenge: Tolerancing / positioning of the connectors & catching it with the probe



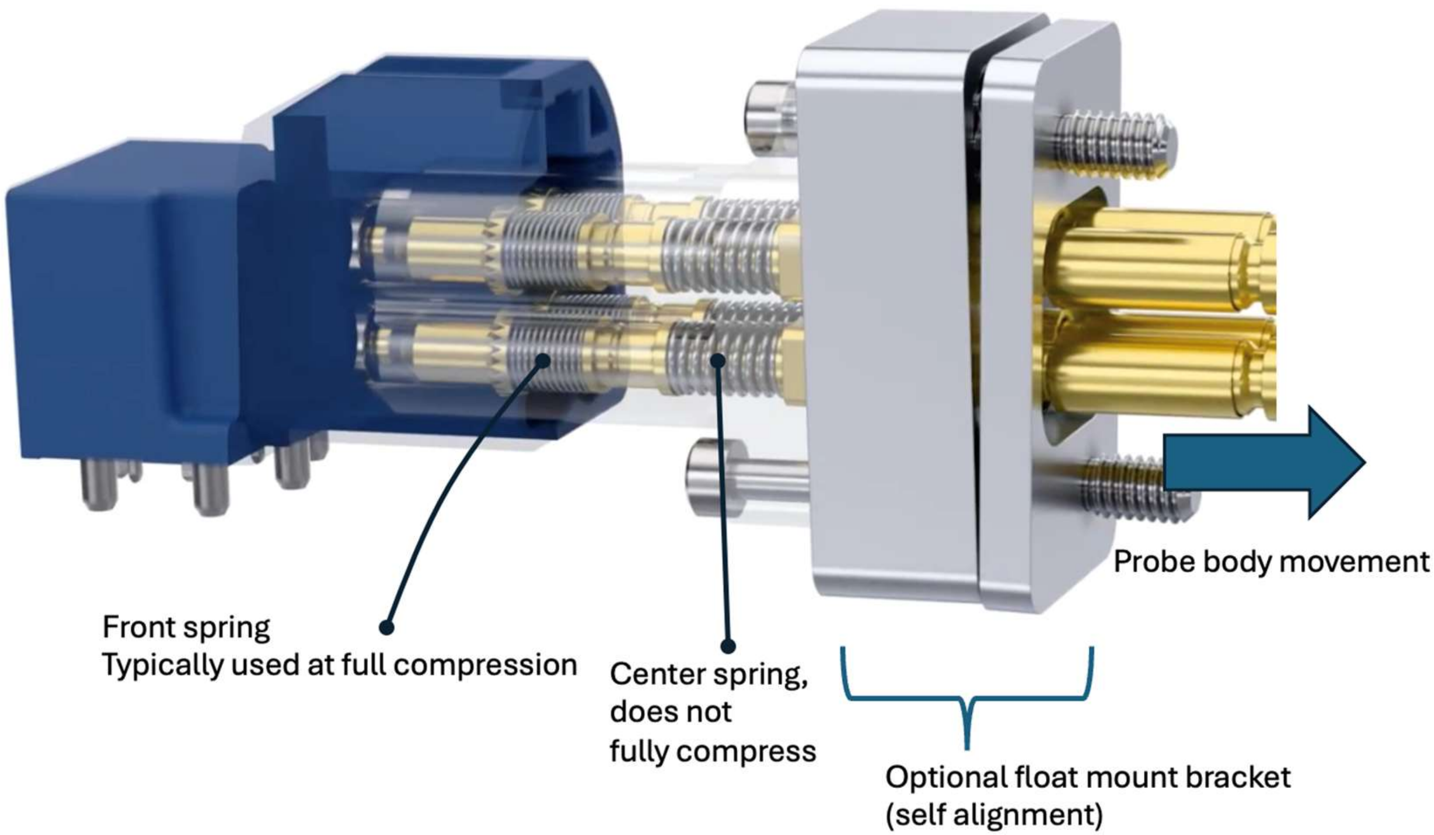
X / Y / Z tolerancing stackup



Pair probes with **float mount socket** (provides self-alignment)

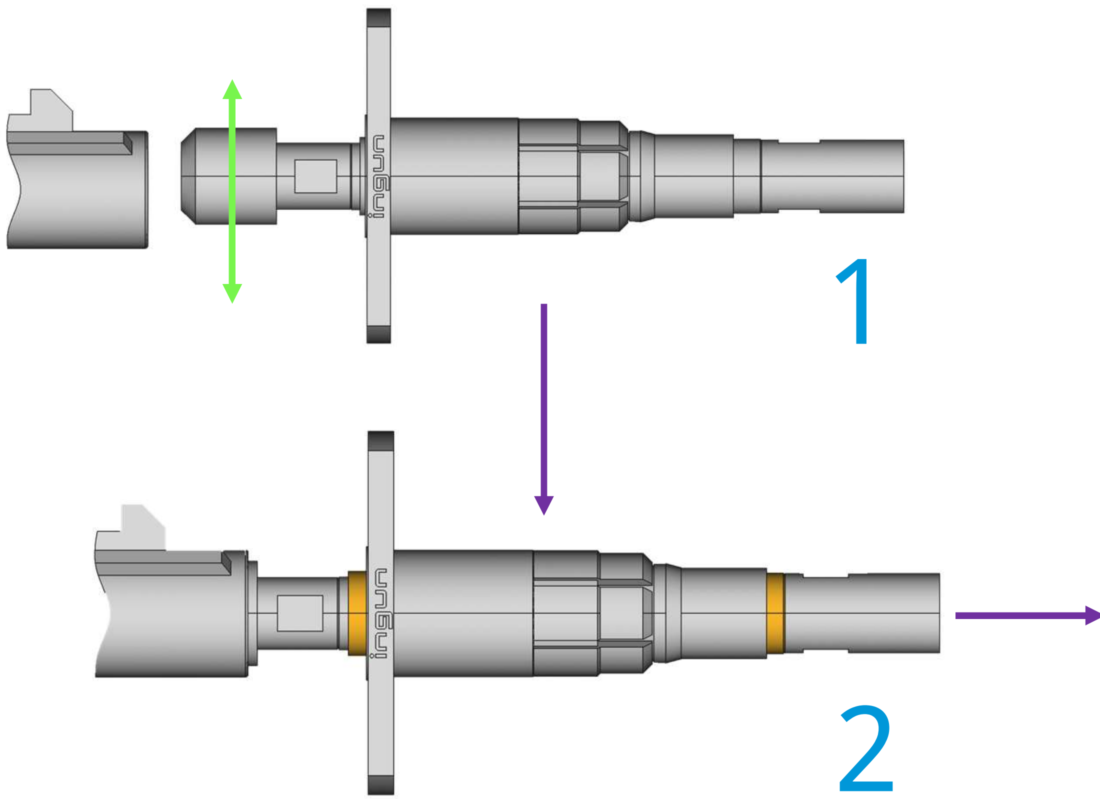
3. Test targets

For connector test, self-aligning receptacles (mounting brackets) are recommended



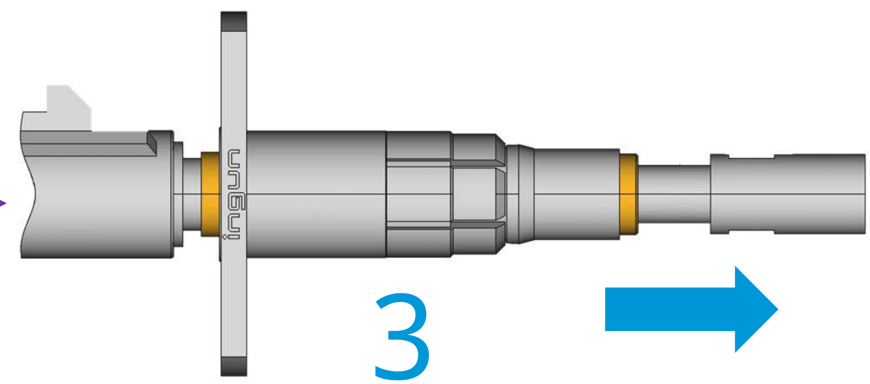
3. Test targets

For connector test, self-aligning receptacles (mounting brackets) are recommended

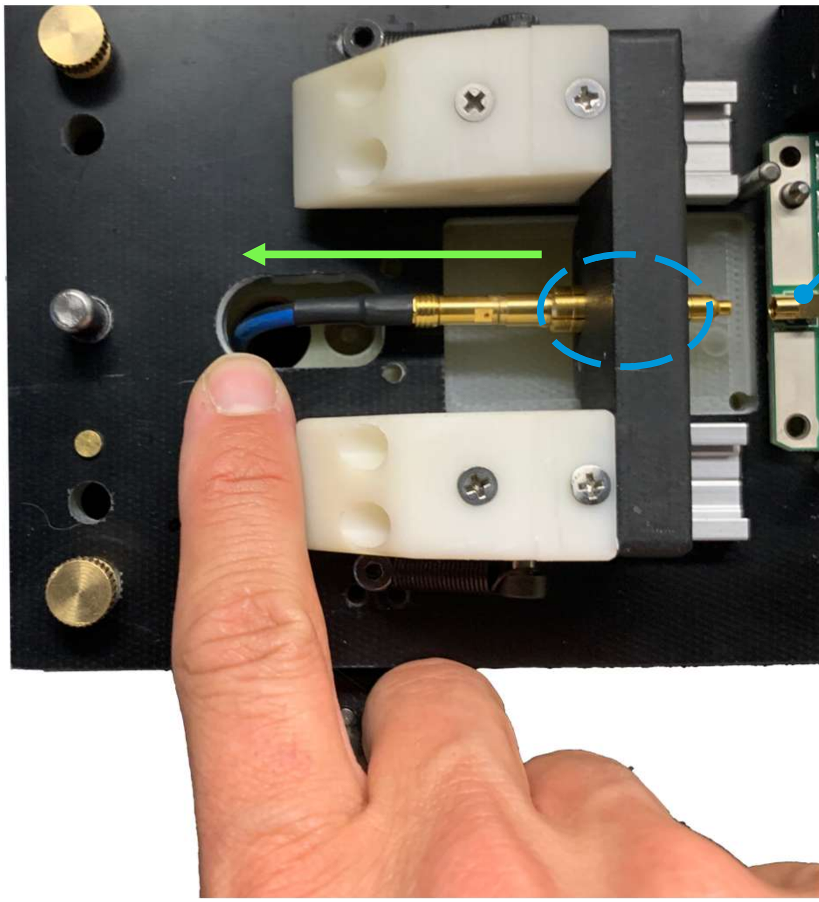


Mating with a FAKRA connector in three steps:

1. XY alignment done with float receptacle.
2. Connector engagement.
3. Applying force to center and outer conductor.



3. Test targets – wiring considerations (probe tail)

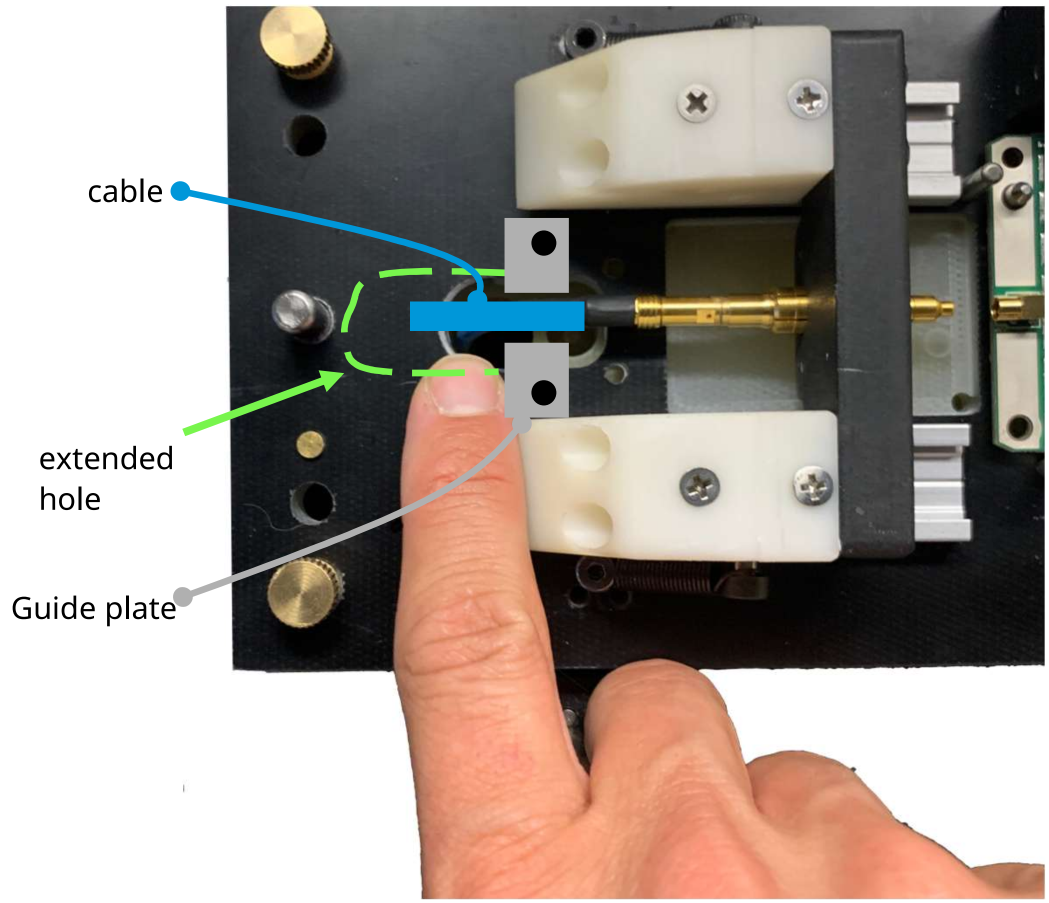


DUT (here: MMCX connector)

- Probe needs to move in y-axis during compression but can’t retract because the hole is too small
- **Cable weight** in combination with a **float receptacle** can lead to drag and bring probe out of position
- A guide plate is needed for this side-contacting example.

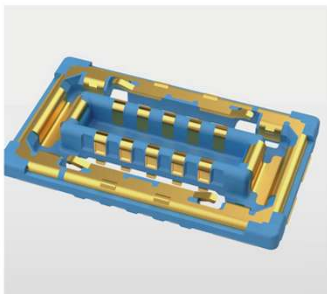
3. Test targets – wiring considerations (probe tail)

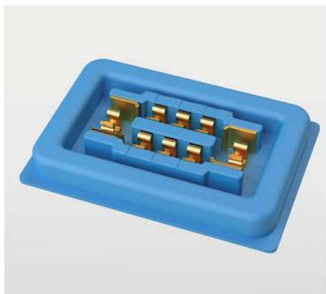
- A cable guide is used to keep cabling centered. Important when using a **float receptacle**
- Feedthru hole is extended
- Probe will now self-center onto the DUT without any issues.



3. Test targets – board to board connectors

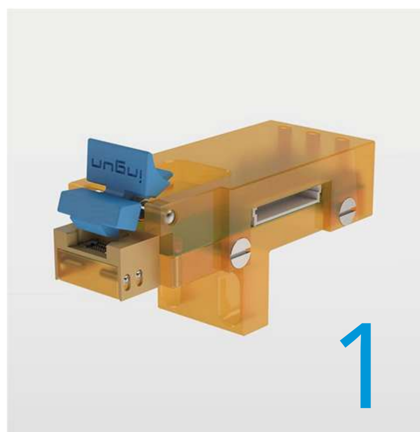
.35 mm pitch (traditional), .175 mm (quad row)

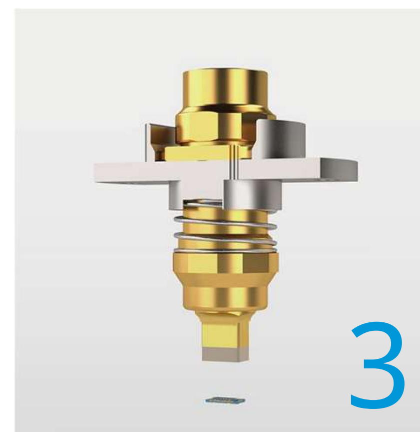




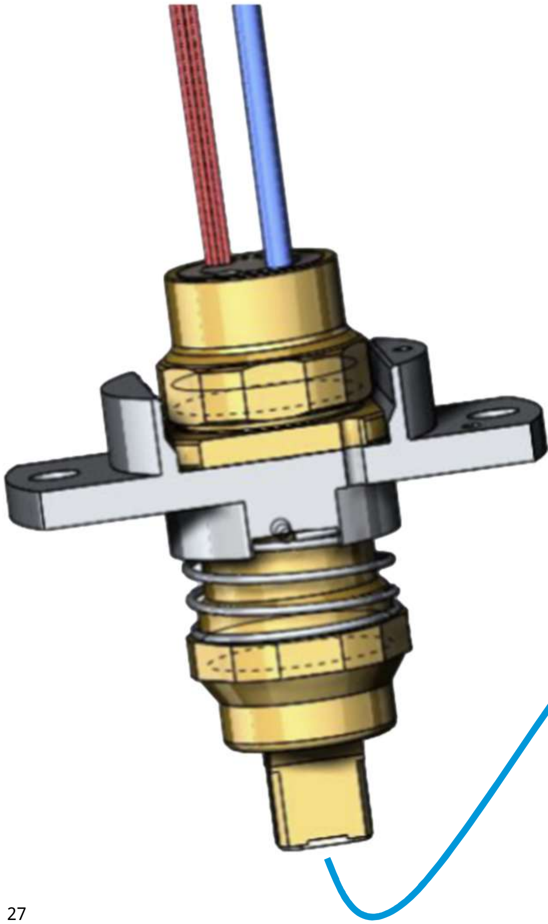
Smartphones / tablets / laptops

Probing solutions
1. Interposer / hand clamp
2. Socket contacting module
3. Traditional probe



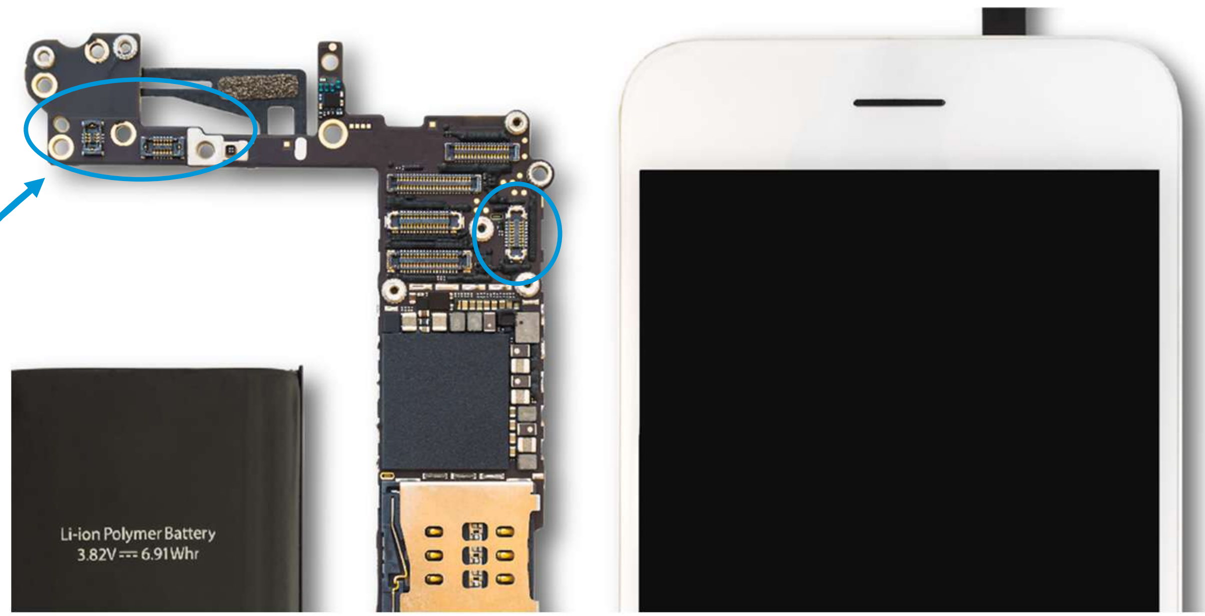


3. Test targets – board to board connectors



Pin technologies used for such probes:

- Blade–pin technology
- Fine-pitch probe technology



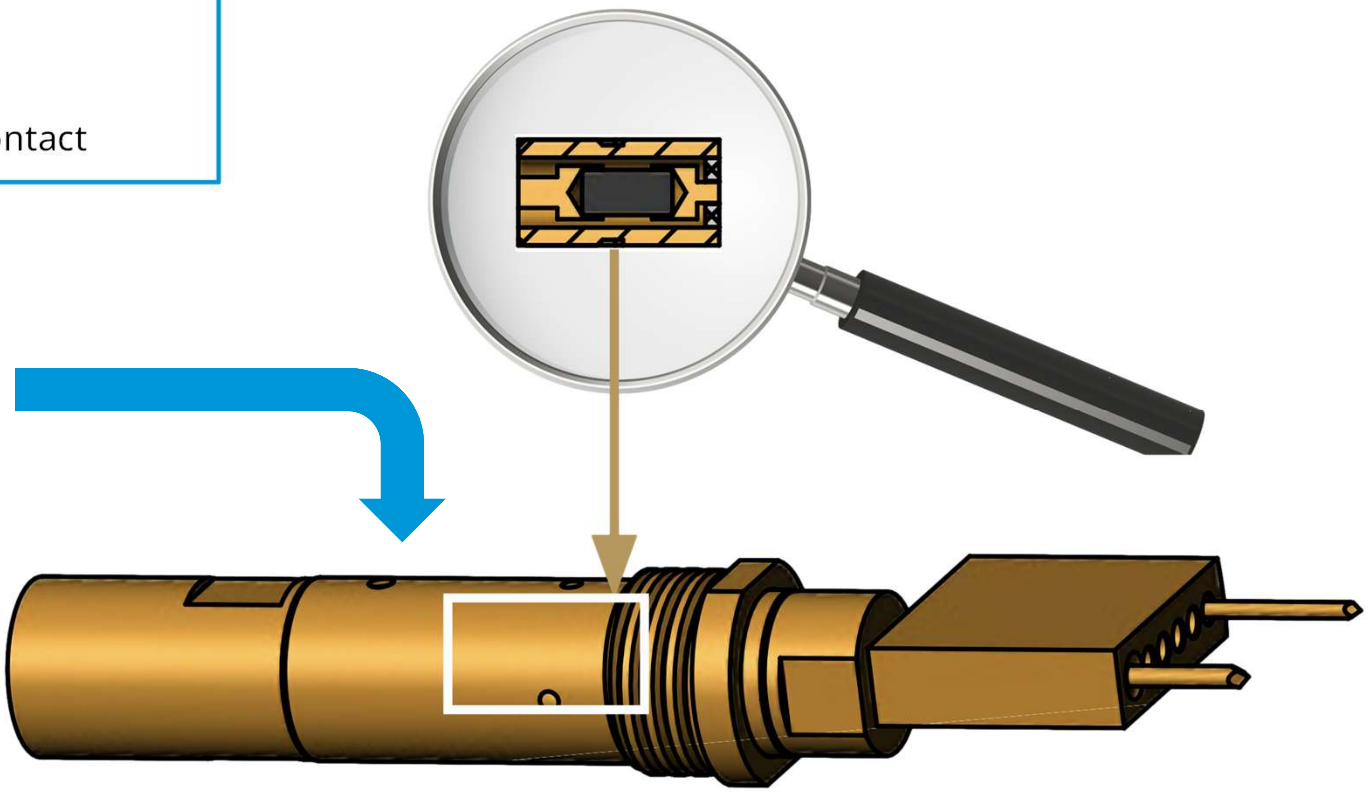
Source: Shutterstuck

3. Test targets – “makeshift” test points

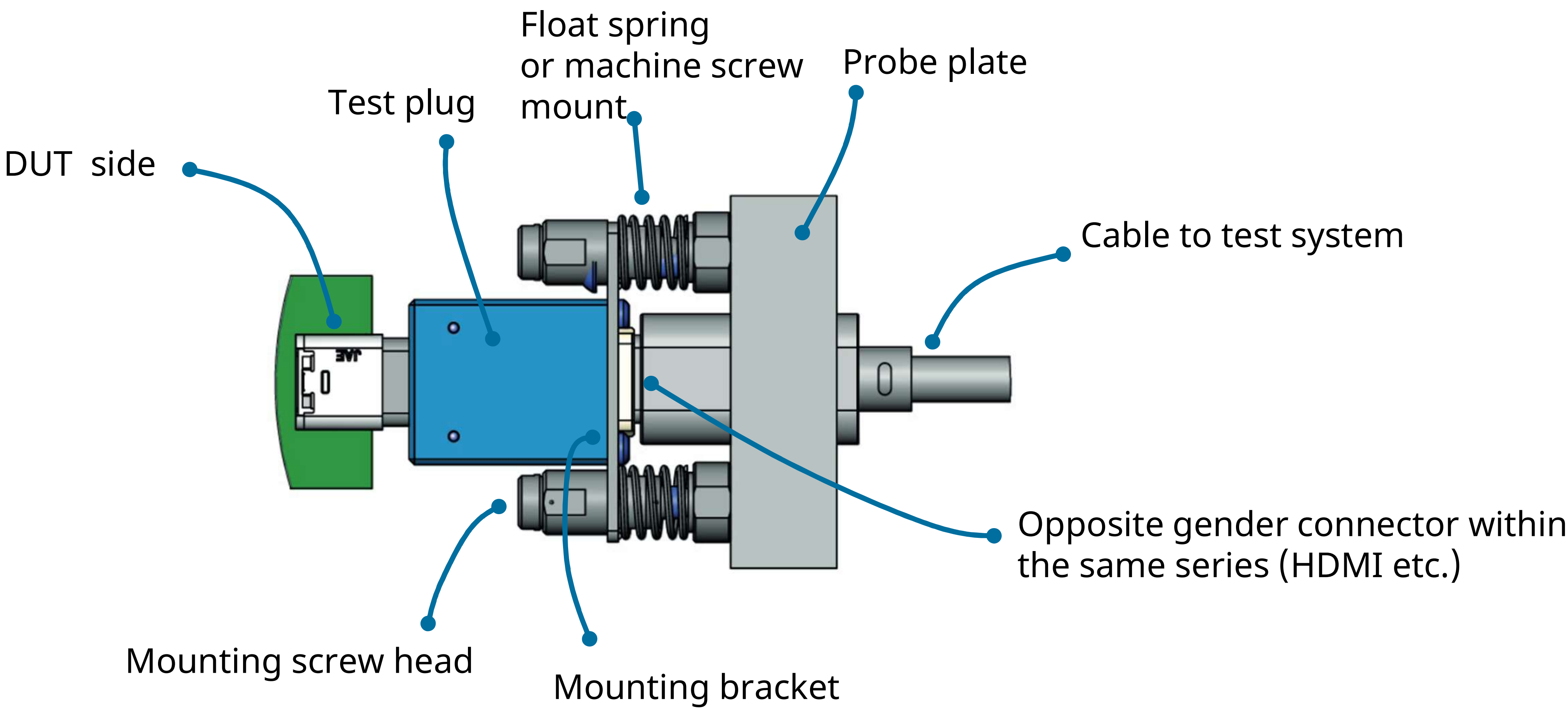
Be aware of impedance mismatch issues!

Such as but not limited to
- PCB pin headers
- Castellated plated holes
- Signal trace + faraway ground contact

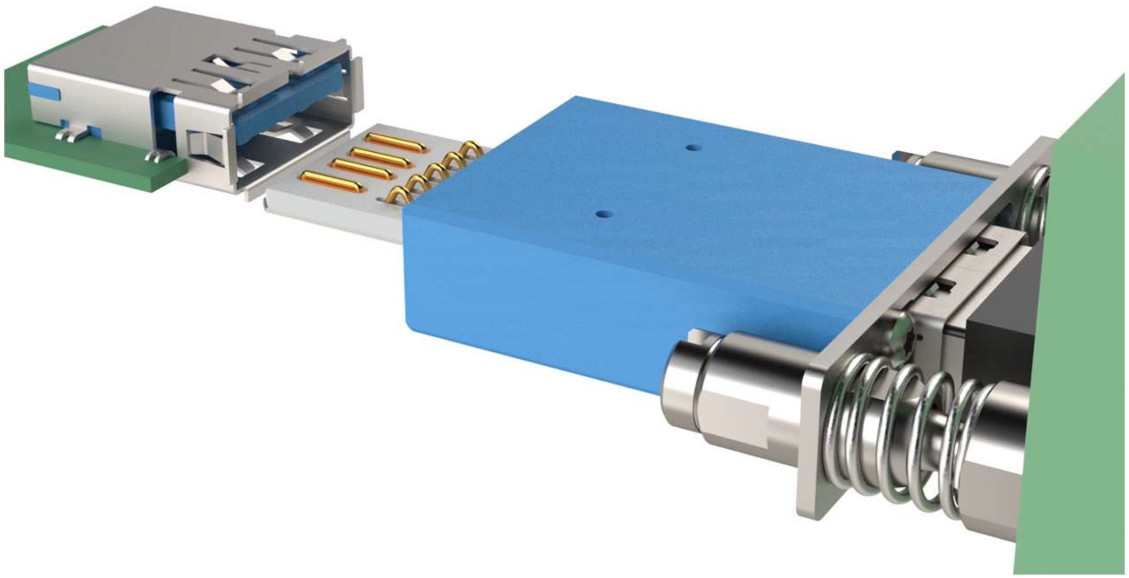
Picking up a signal straight from the trace: Allow the signal to be attenuated, but don’t interfere with the signal flow on the board = high impedance probe (voltage divider)

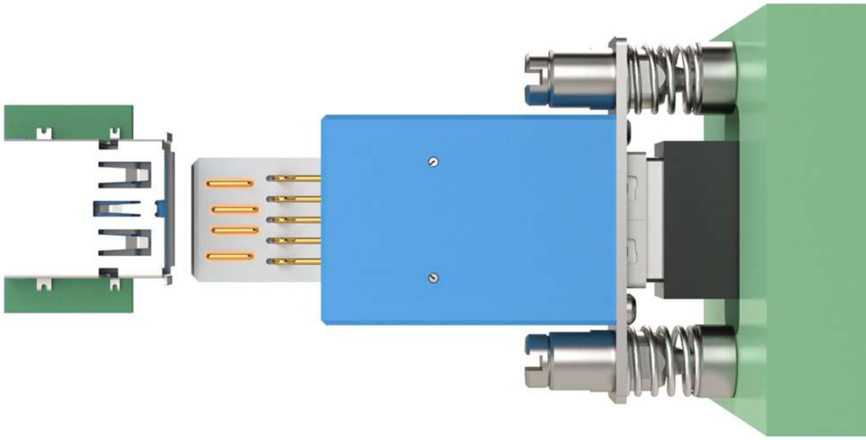


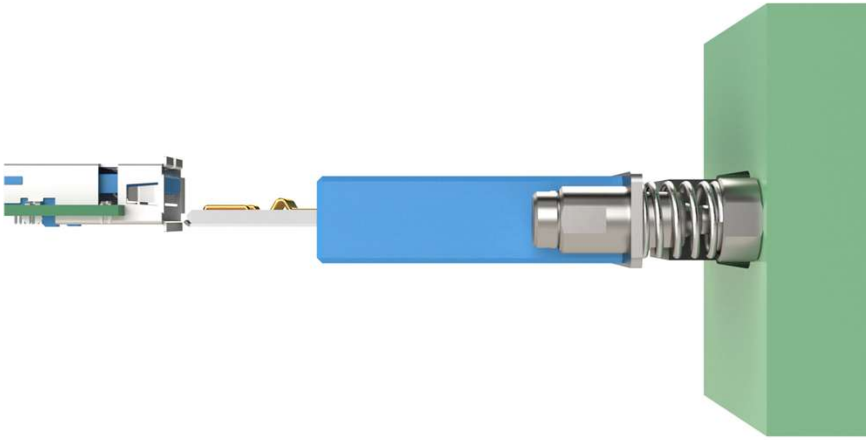
3. Test targets - high speed connectors (USB & co.)



3. Test targets - high speed connectors

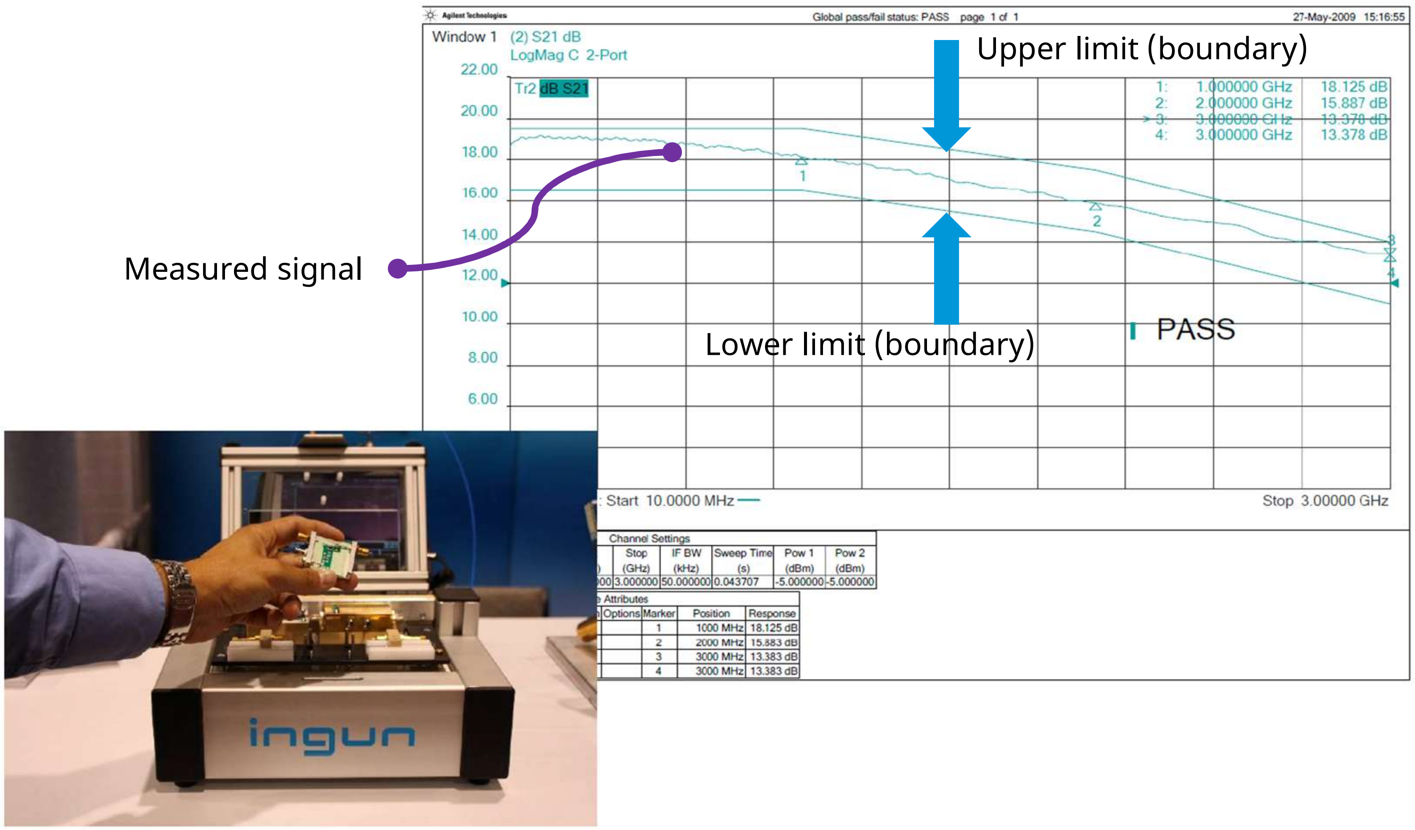




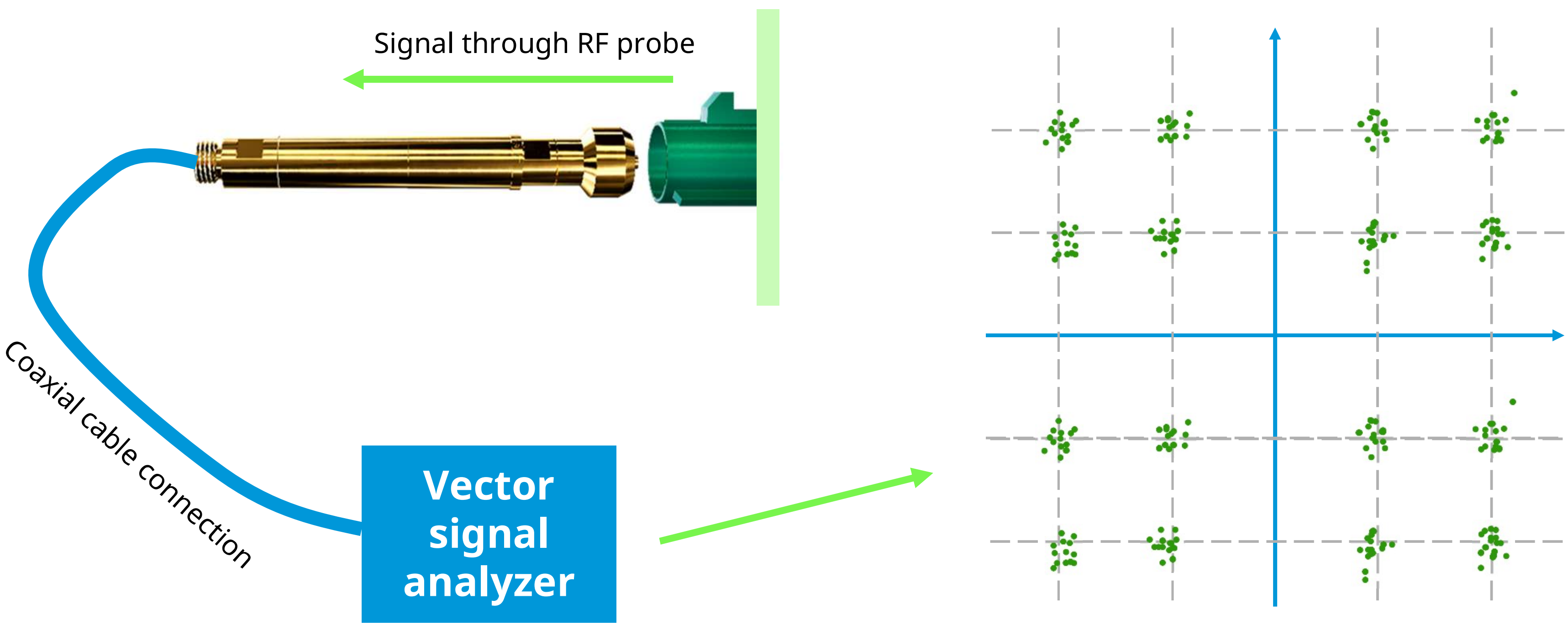


4. Types of RF test – amplifier output measurement

Relatively “easy” to do, but there’s still “one catch” – don’t forget to compensate for losses of the cable / probe (see calibration chapter)

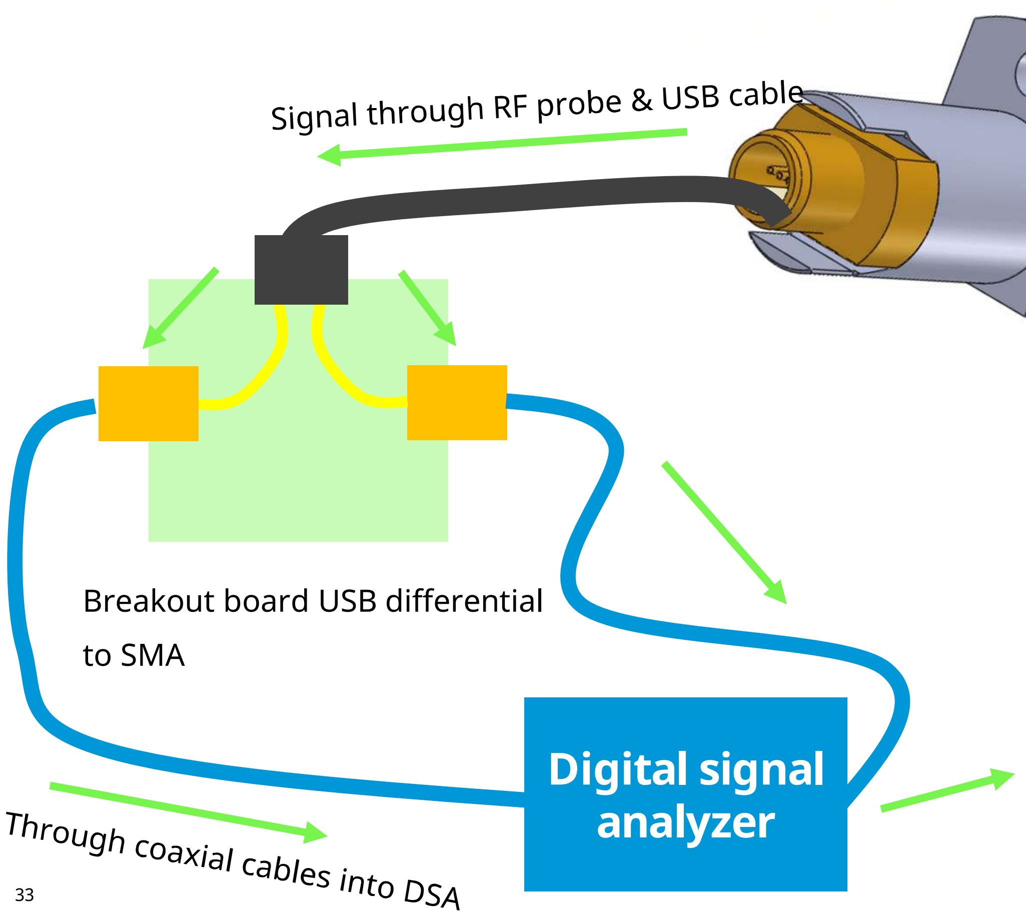


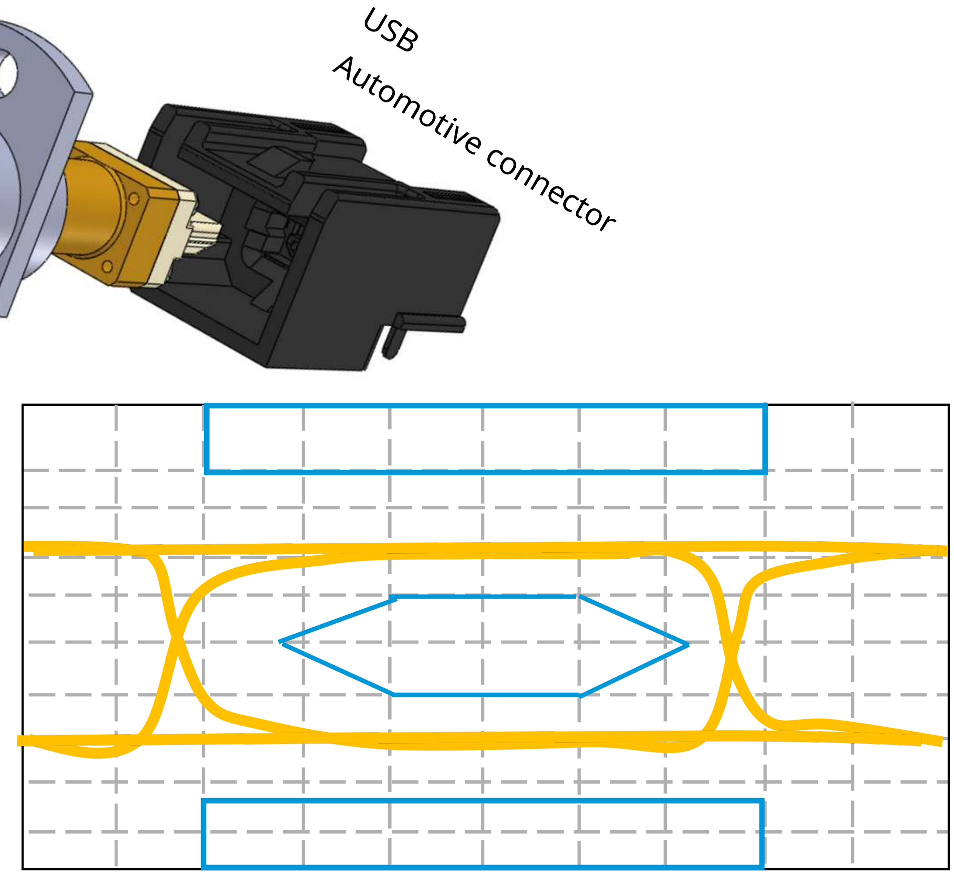
4. High speed measurements – constellation diagrams / EVM



Constellation diagram of 16QAM signal / for EVM analysis

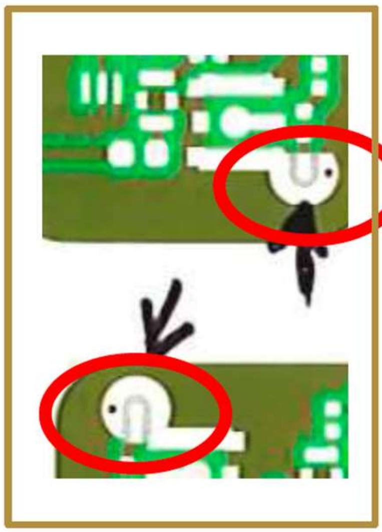
4. High speed measurements – constellation diagrams / EVM

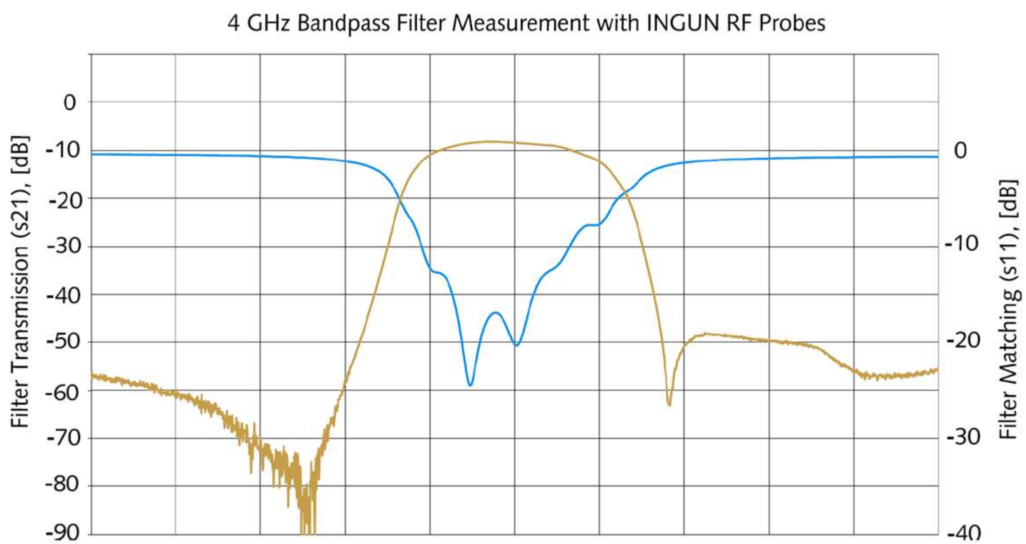




Acquisition of eye pattern diagrams

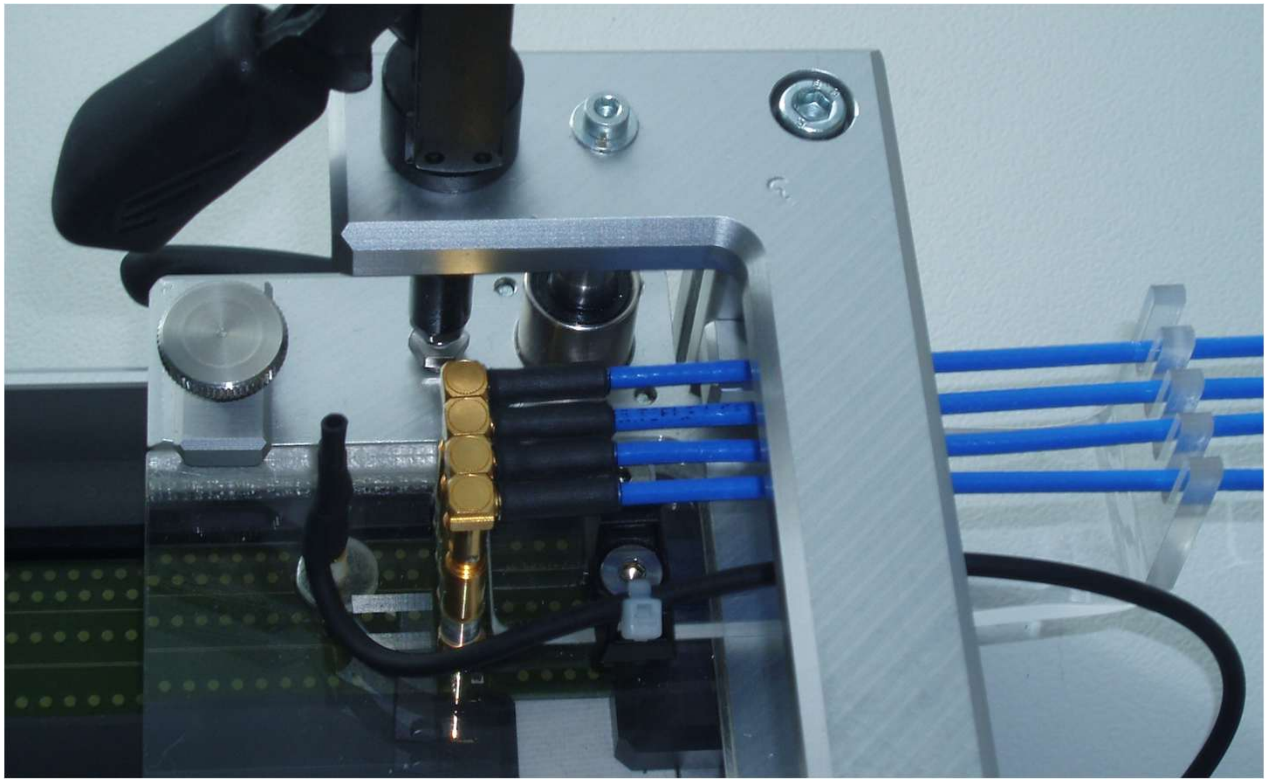
4. Filter curve measurements





- Measurement of a 4 GHz bandpass filter with RF probes
- Transmission (filter curve) and return loss is shown

4. Types of RF test – TDR on test coupons



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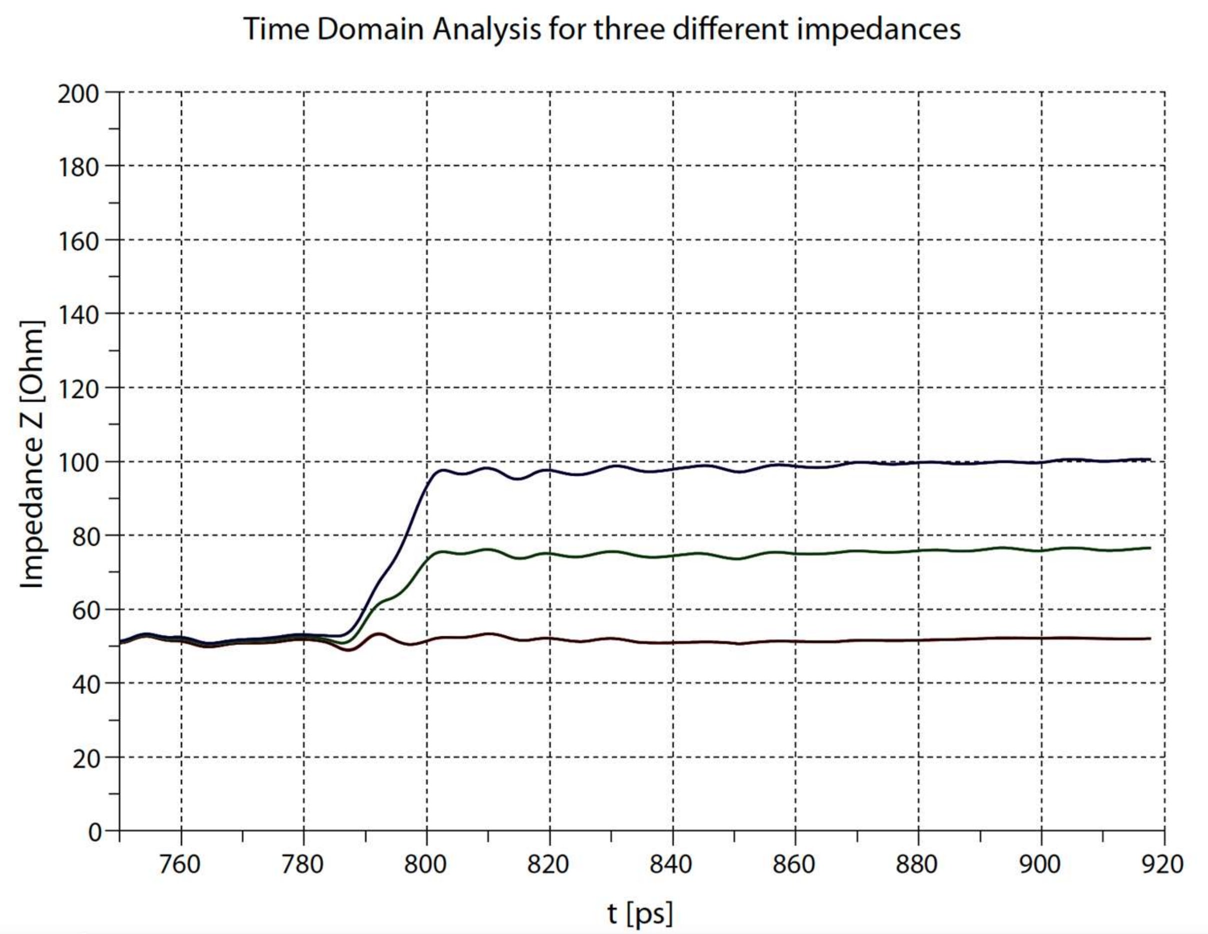
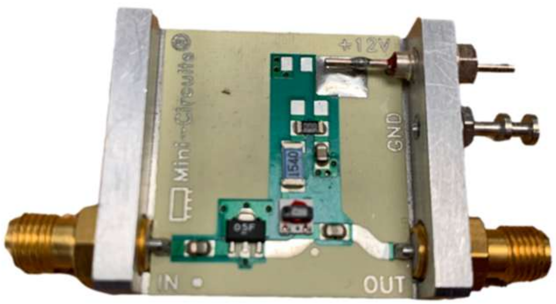


5. Calibration considerations – "probe tip calibration"

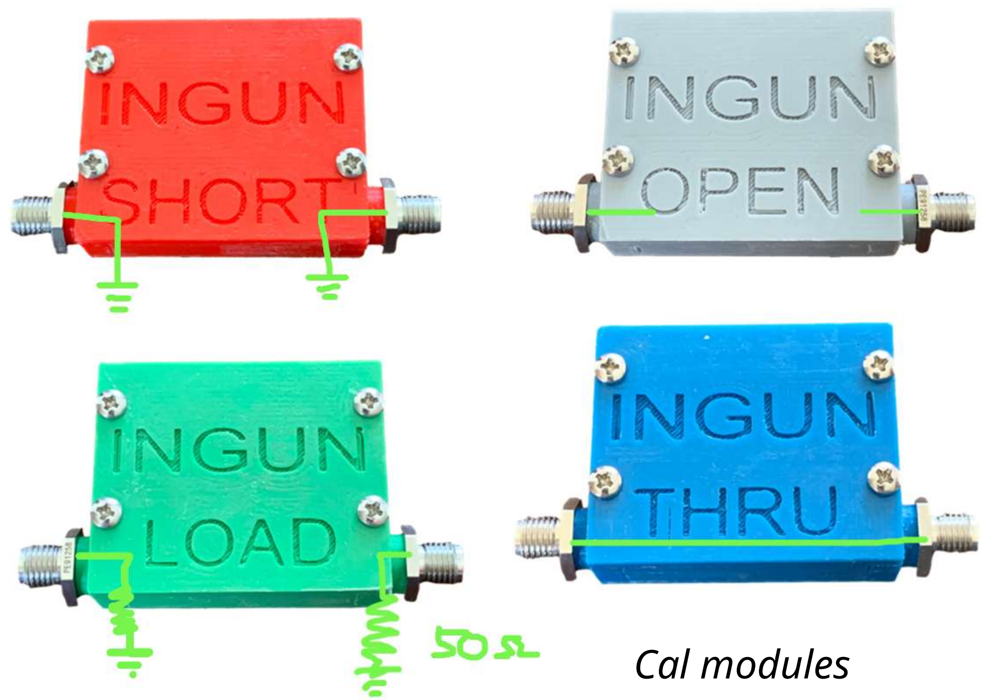
Typically done with application-specific in-situ modules for SOLT cal or similar technology.

RF test port
#1
SMA female



RF test port
#2
SMA female

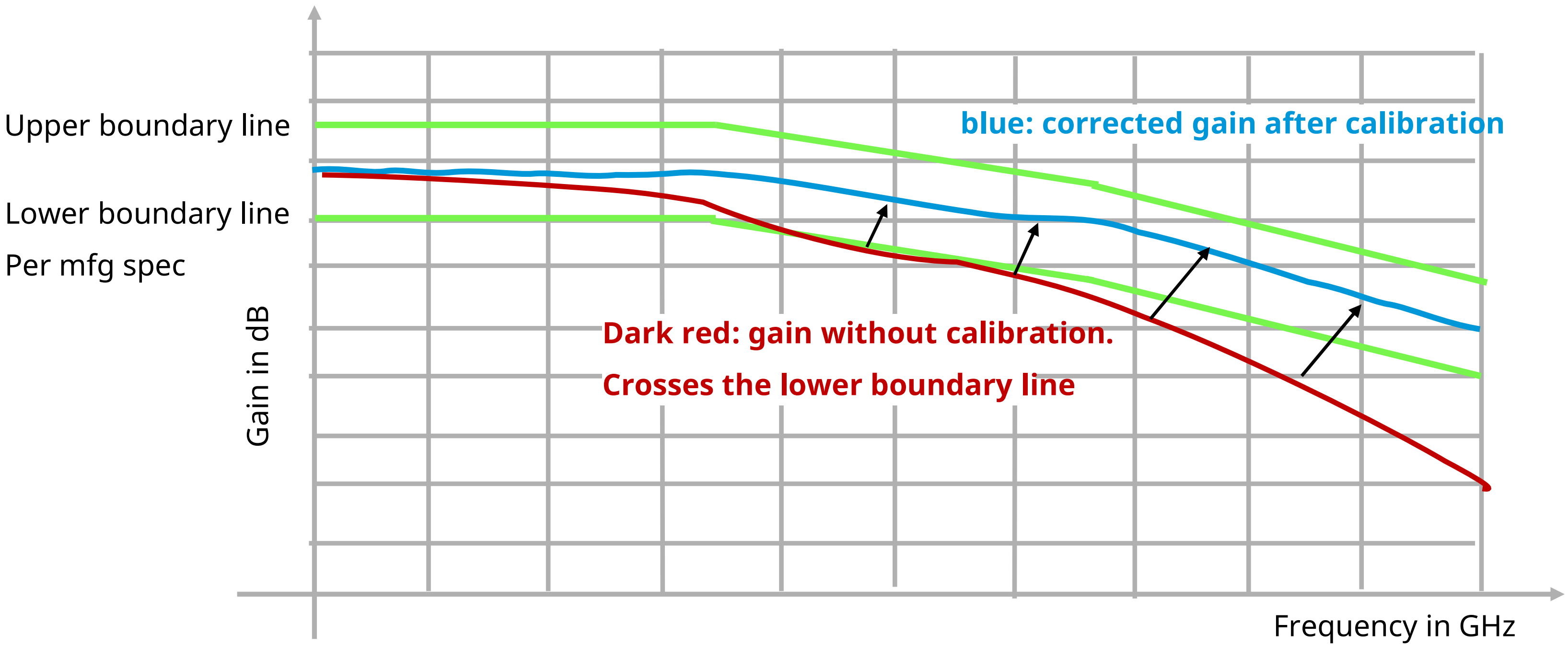
Device under test



Cal modules

5. Calibration considerations – “probe tip calibration”

Remember the amplifier measurement from chapter 4?



5. Calibration considerations – “probe tip calibration”

With a calibration, you “characterize” the setup

Probe tip **cablibration with special calibration adaptors** helps to correct the increasing insertion loss vs. number of contacting cycles.

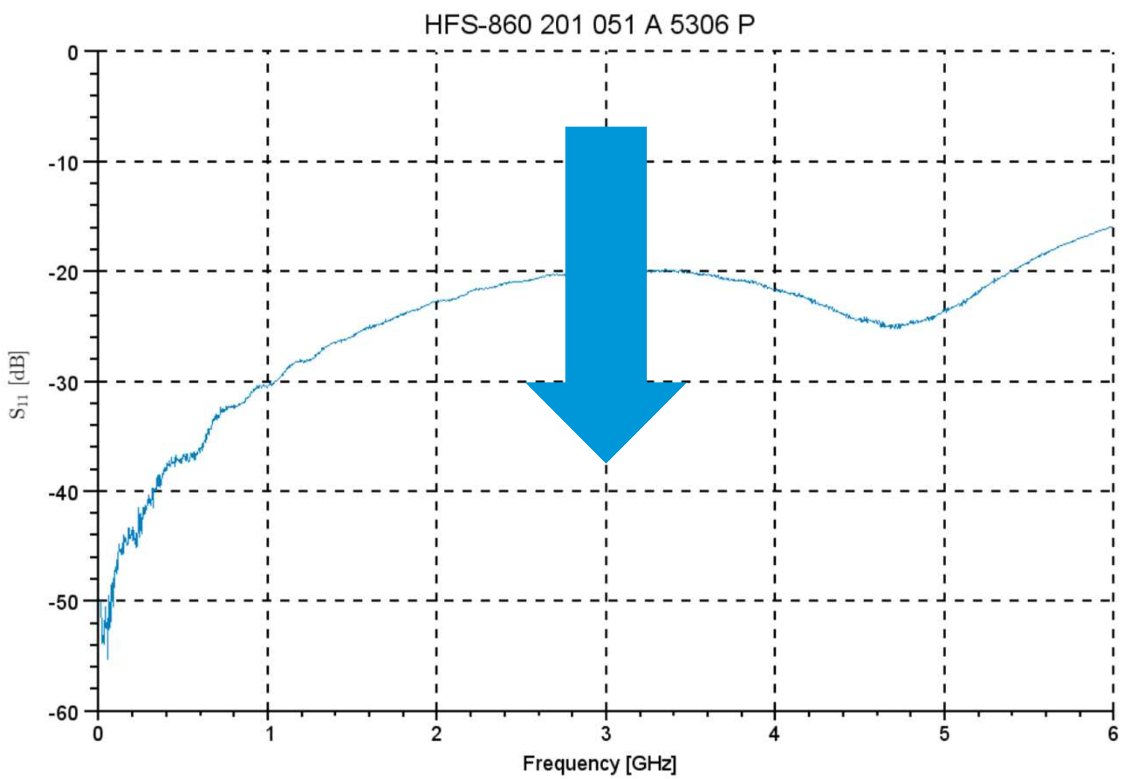
- Use an adaptor that can be installed in the probe plate of the fixture

-or-

- An **in-situ cal board** that mimics the features (meachnial outline) of the DUT

5. Calibration considerations – “probe tip calibration”

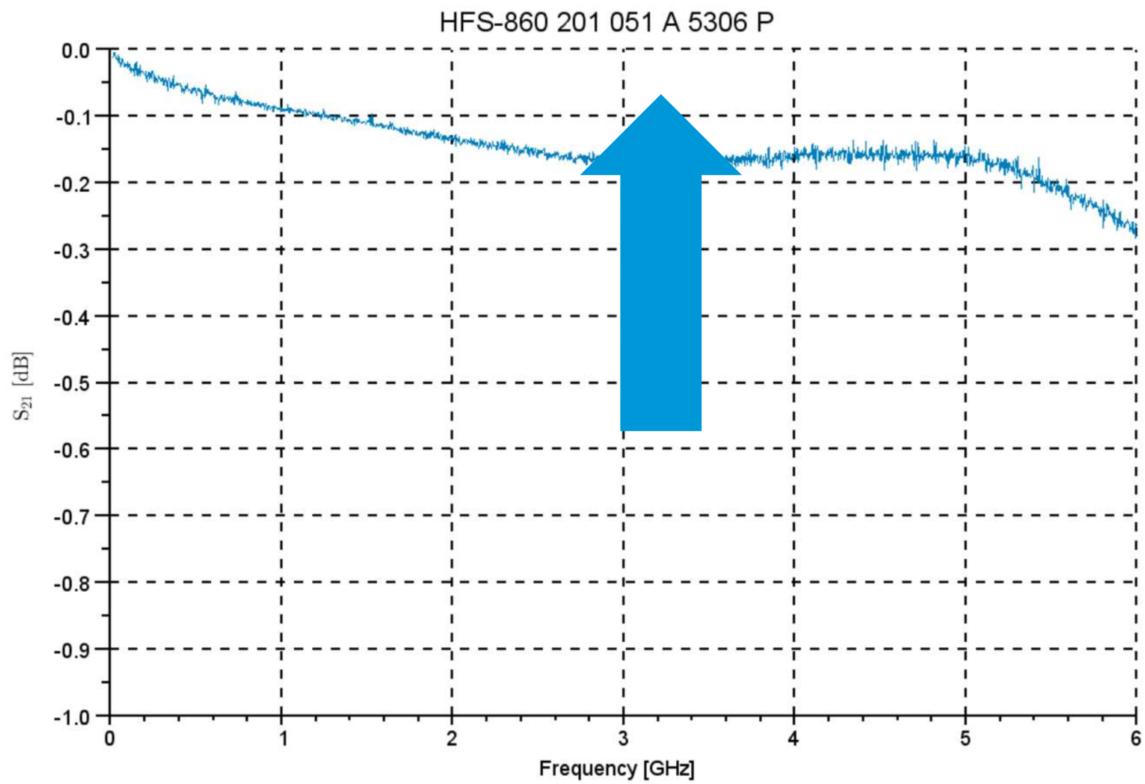
With a calibration, you “characterize” the setup



- Keep return loss low to minimize reflectiond

5. Calibration considerations – “probe tip calibration”

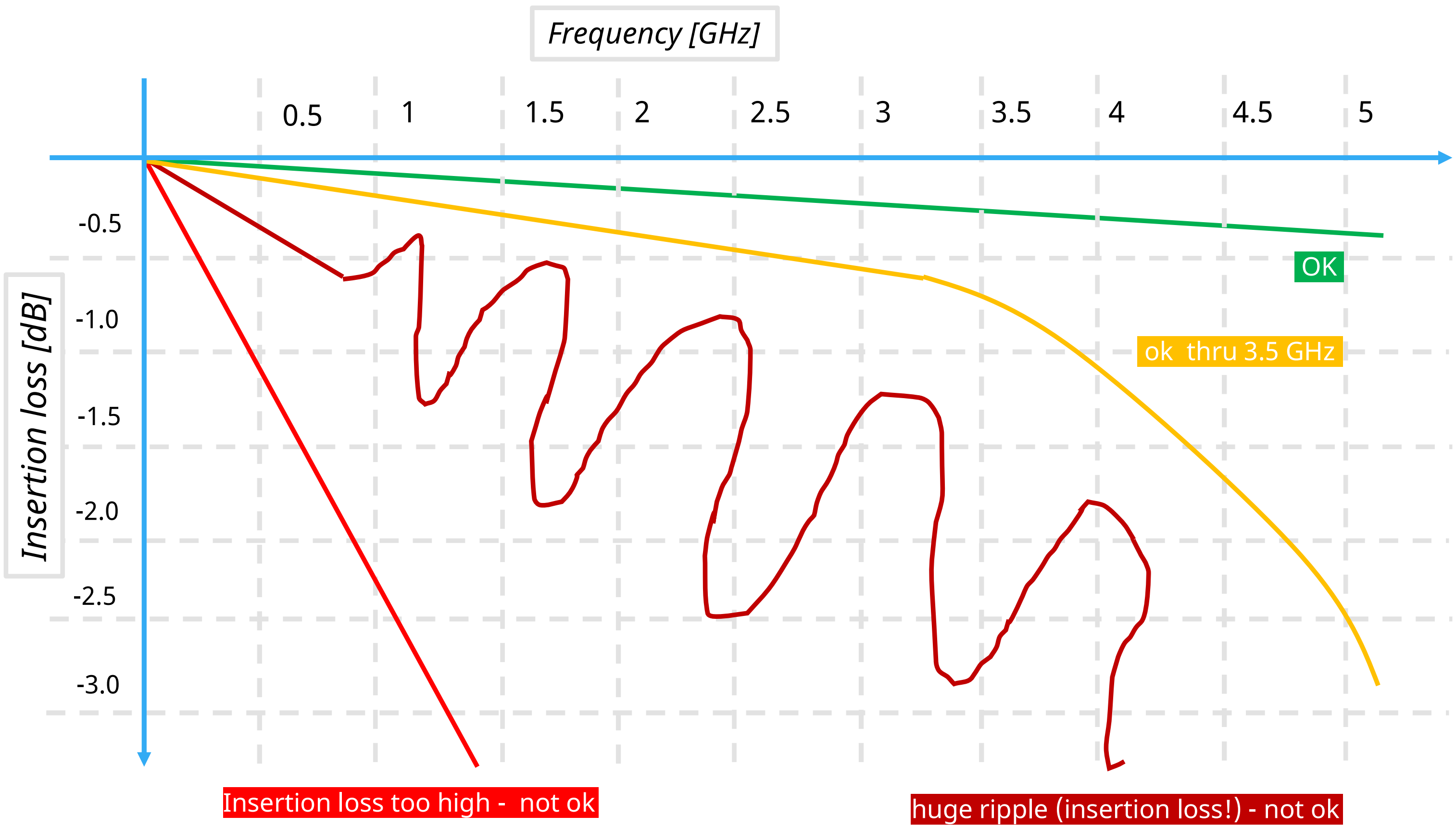
With a calibration, you “characterize” the setup



- Keep insertion loss low to minimize loss from A to B

5. Measurements – insertion loss – acceptance criteria

Insertion loss graphs for a test probe measurement (without cabling attached).



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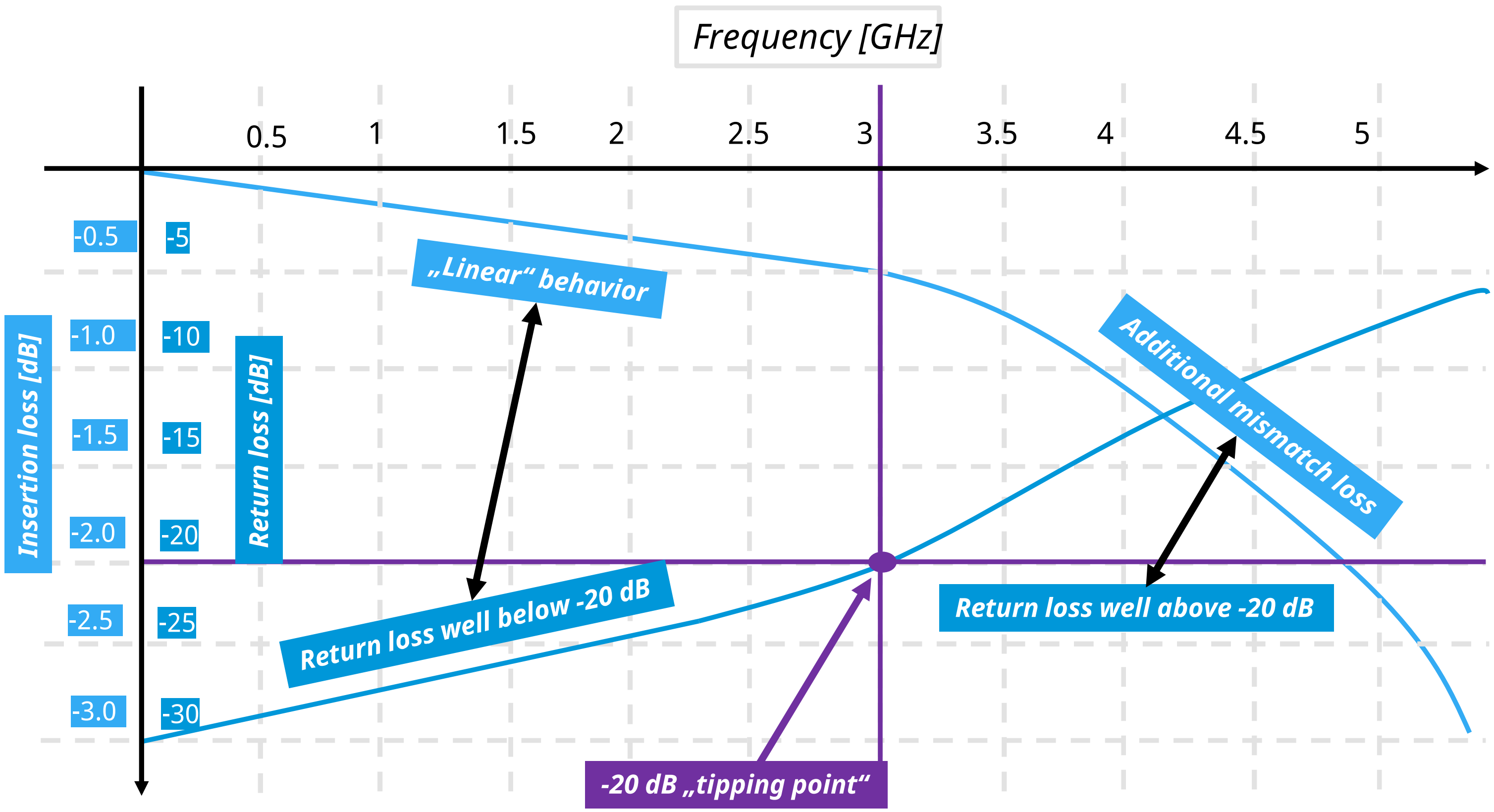
5. Measurements – return loss – acceptance criteria

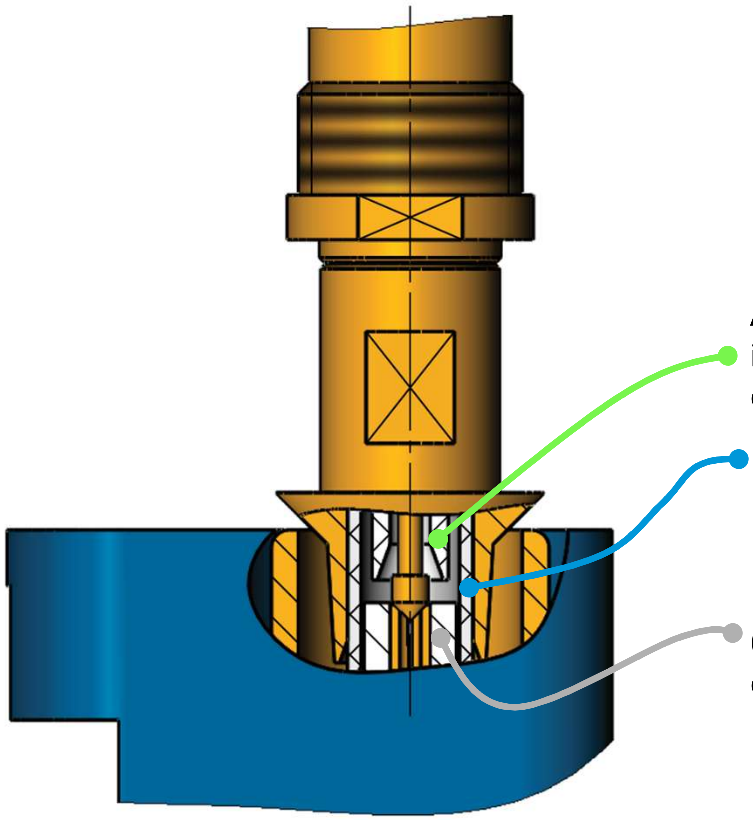


This graph is for the **return loss (matching)** – but in addition we also show the correlation between the return loss and the insertion loss.

Above the “tipping point” one can typically see additional mismatch losses.

That happens roughly when the -20 dB line is crossed, however circuits typically **still can be used at -15 or even -10 dB return loss.**

6. More applications with coax probes: Hi pot



Hi pot probes typically require additional insulation to prevent arcing at high voltages.

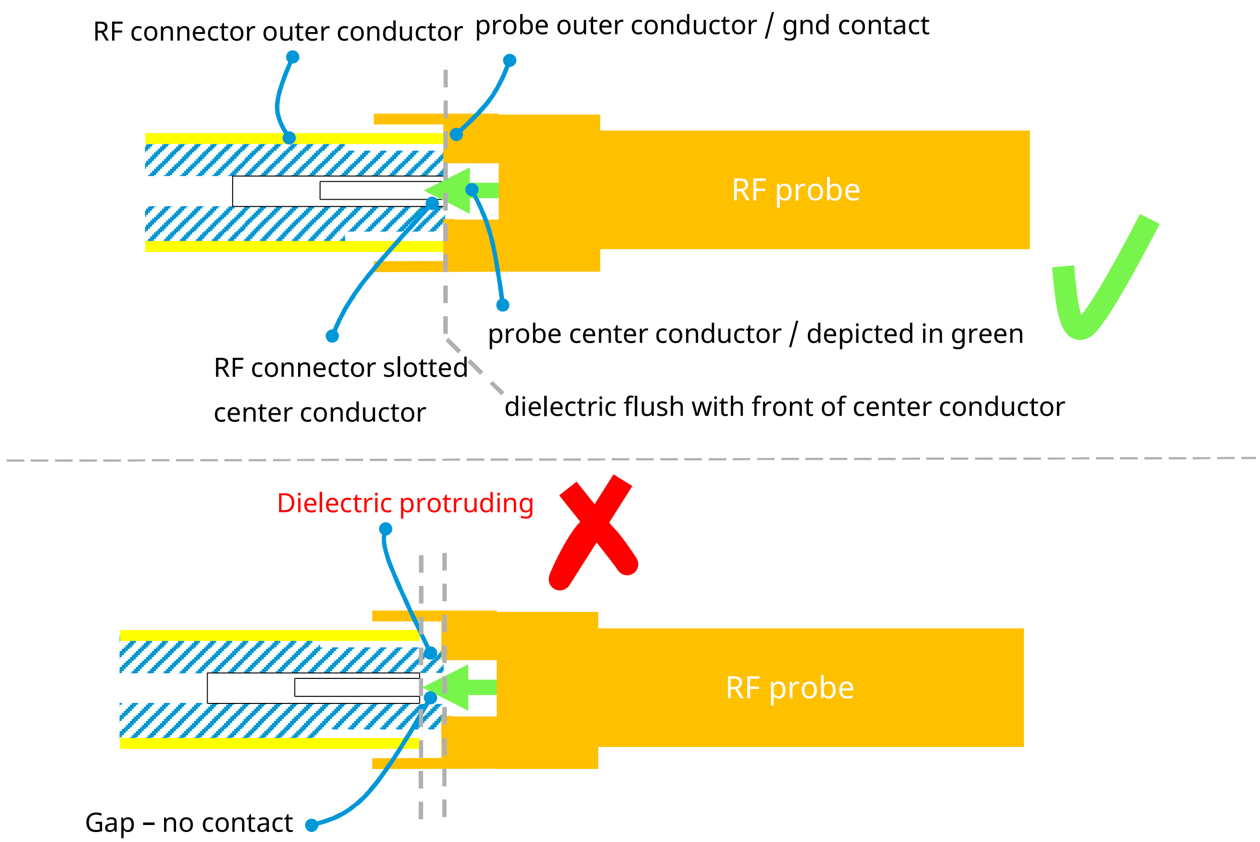
Combining RF & hi pot with one probe not recommended (impedance mismatch)

6. More applications with coax probes: Continuity

Application:
- Test if dielectric is protruded (faulty RF connector)

Reason:
- Some stamped and formed connectors have poor tolerances

Test method:
- Coaxial probe, made for that connector type
- Continuity tester to check if center conductor makes contact.
- If contact is made, dielectric is flush or within tolerance.



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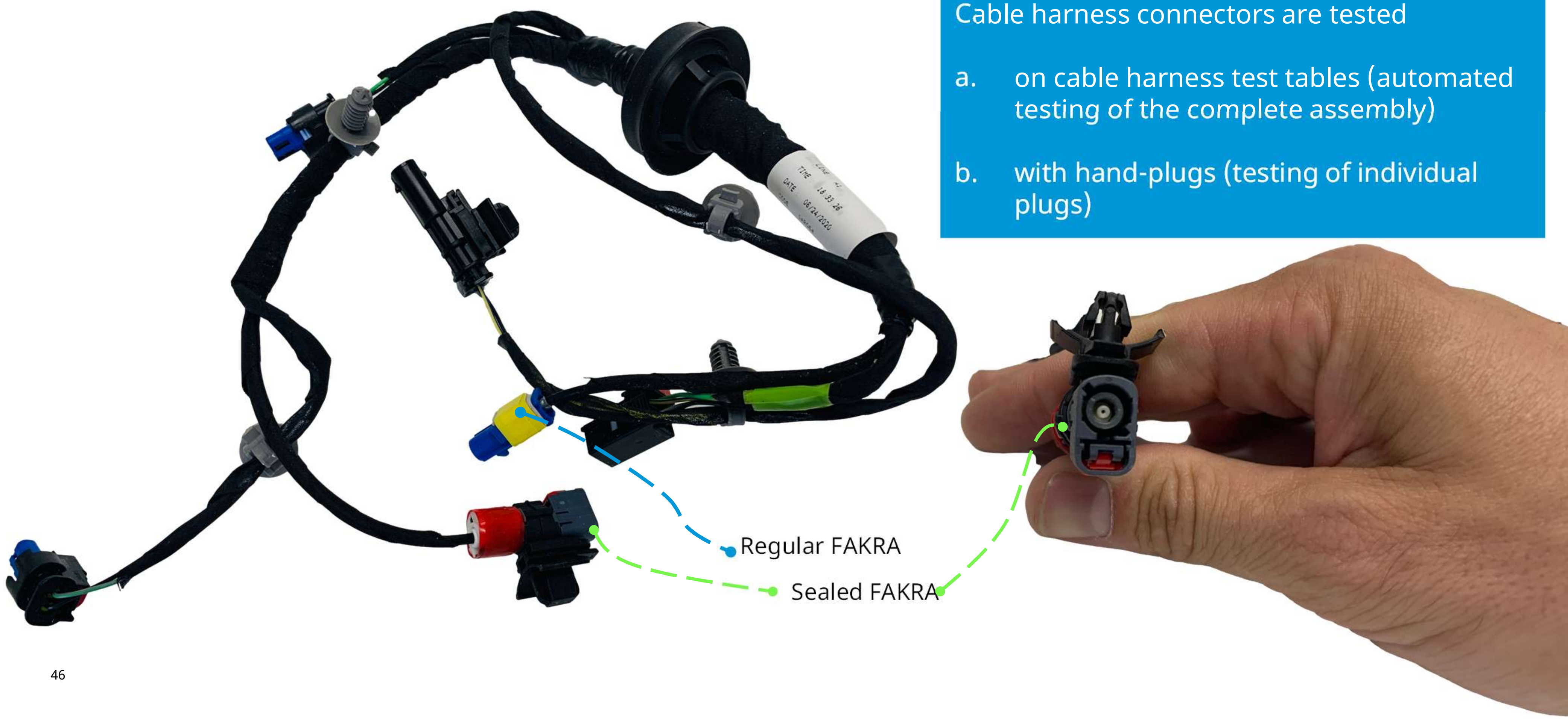
6. More applications with coax probes: Continuity

Cable harness connectors are tested

a. on cable harness test tables (automated testing of the complete assembly)

b. with hand-plugs (testing of individual plugs)



6. More applications: High power

- Power handling vs. frequency for RF probes is a VERY complex subject
- However, it can be estimated with some equations, without guarantee for utmost precision / correctness.
- The following are the equations for peak power (NOT frequency dependent)

$$V_{\text{peak,max}} = E_d \frac{d}{2} \ln \frac{D}{d}$$

$$Z_0 = \frac{\ln \frac{D}{d}}{2\pi} \frac{\delta_0}{\sqrt{\epsilon r}}$$

$$P_{\text{peak,max}} = \frac{V_{\text{peak,max}}}{2Z_0}$$

$$P_{\text{peak,max}} = \frac{\pi E_d^2 \left(\frac{d}{2}\right)^2 \ln\left(\frac{D}{d}\right)}{\delta_0}$$

https://www.microwaves101.com/encyclopedias/coax-power-handling
http://mpd.southwestmicrowave.com/static/appendix.pdf

6. More applications: High power

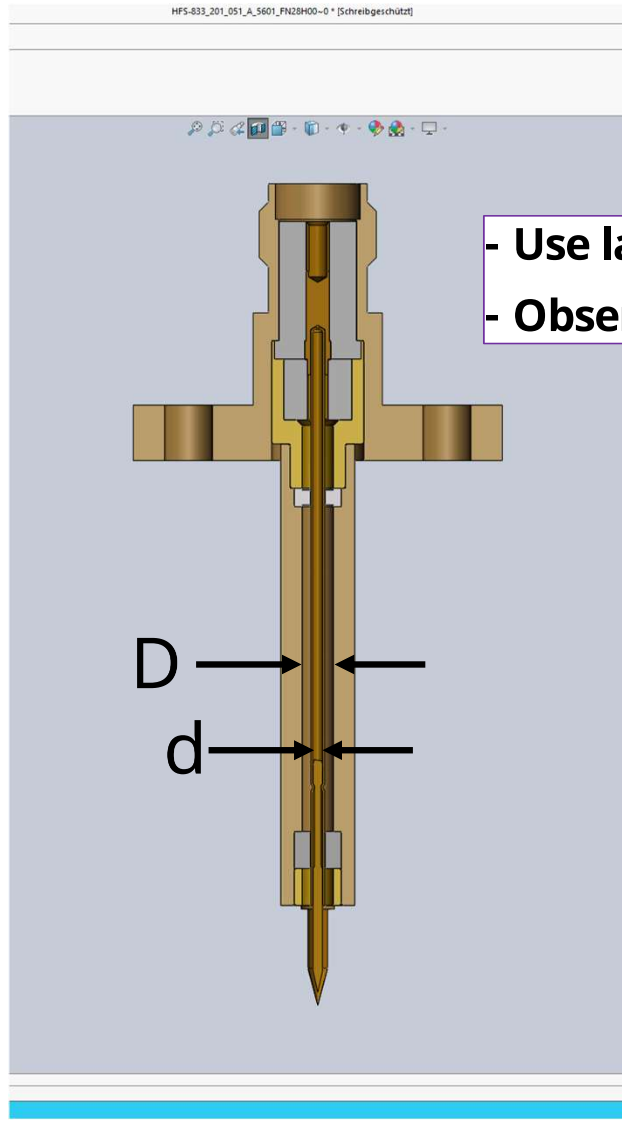
$P_{peak,max}$ = 958.93 Watts (static, peak power, at **ideal matching**)

Compensation for extremely low return loss (short or open): Voltage could double, add 6 dB safety margin

958.93 W = 60 dBm
60 dBm – 6 dB = 54 dBm
54 dBm = 250 W

Start linear power **de-rating curves** for avg. power vs. frequency from there (958.93 W and 250 W, for these two boundary conditions).

INGUN HFS-833 architecture
long airline structures



- **Use larger versions**
- **Observe heatup**

$$E_d \approx 1 \frac{MV}{m}$$

$$Z_0 = 50\Omega$$

$$d = .75mm$$

$$D = 1.7mm$$

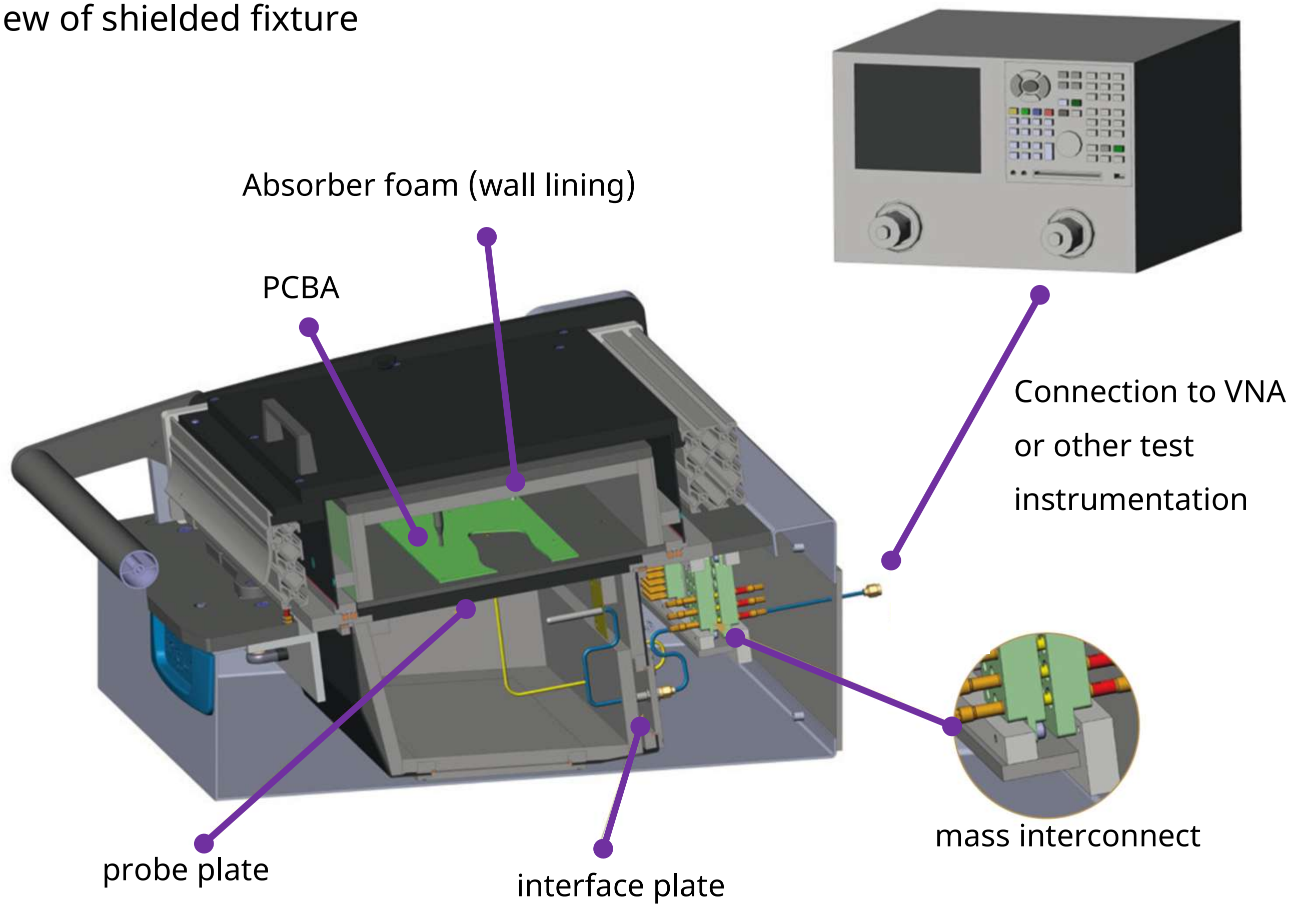
$$\epsilon_r = 1$$

7. EMC / shielding considerations

Shielded test fixture inserts for “noisy” environments

7. EMC / shielding considerations

Cutplane view of shielded fixture



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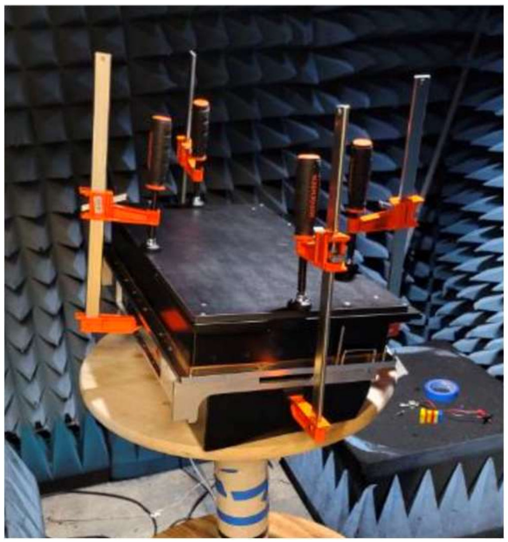
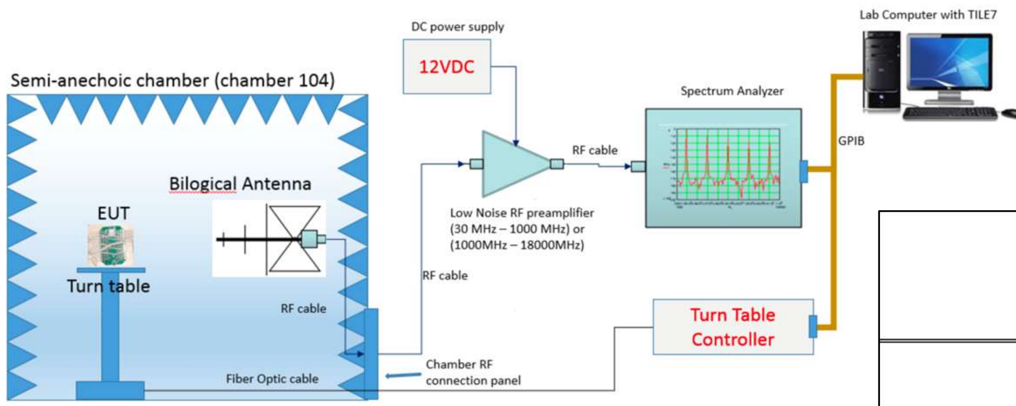
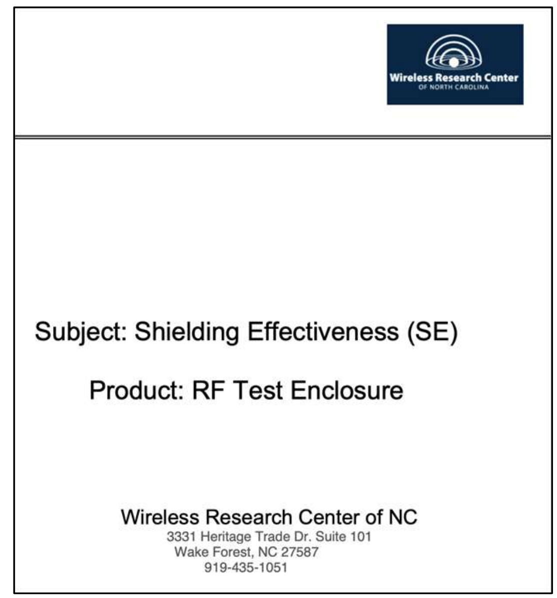
7. EMC / shielding considerations

It is suggested to measure a test fixture AFTER customization.






Wireless Research Center OF NORTH CAROLINA

Subject: Shielding Effectiveness (SE)

Product: RF Test Enclosure

Wireless Research Center of NC
3331 Heritage Trade Dr. Suite 101
Wake Forest, NC 27587
919-435-1051

Left photo: Study in anechoic chamber of how the closing force affects the shielding effectiveness.

Right side: Lab measurements & reports are vital to show what happens to shielding integrity after parts are added to the test fixture.

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