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Maury Microwave
Your Calibration, Measurement & Modeling Solutions Partner!

# How to improve accuracy and quantify uncertainty of your RF measurement

# What makes your measurement more accurate



**1 | Operator**

- Achieving repeatable connections

**2 | Components**

- Best practices
- Impact of pin depth and concentricity
- Connector compatibility
- Choosing the right cables and adapters

**3 | Instrumentation**

- VNA calibration and verification techniques
- Identifying VNA noise floor and drift

**4 | Quantifying measurement uncertainty**

# 1 | Operator

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# Achieving repeatable connections



Apply the ***specific*** force for accurate connections

| Connector | Frequency | Required Torque |
|---|---|---|
| 1mm | DC – 110 GHz | 4 in-lbs |
| 1.85mm | DC – 67 GHz | 8 in-lbs |
| 2.4mm | DC – 50 GHz | 8 in-lbs |
| 2.92mm | DC – 40 GHz | 8 in-lbs |
| 3.5mm | DC – 26.5 GHz | 8 in-lbs |
| SMA | DC – 26.5 GHz<br>DC – 18 GHz | 5 or 8 in-lbs |
| 7mm | DC – 18 GHz | 12 in-lbs |
| Type N | DC – 18 GHz | 12 in-lbs |
| 7/16 | DC – 18 GHz | 20 in-lbs |

# Achieving repeatable connections

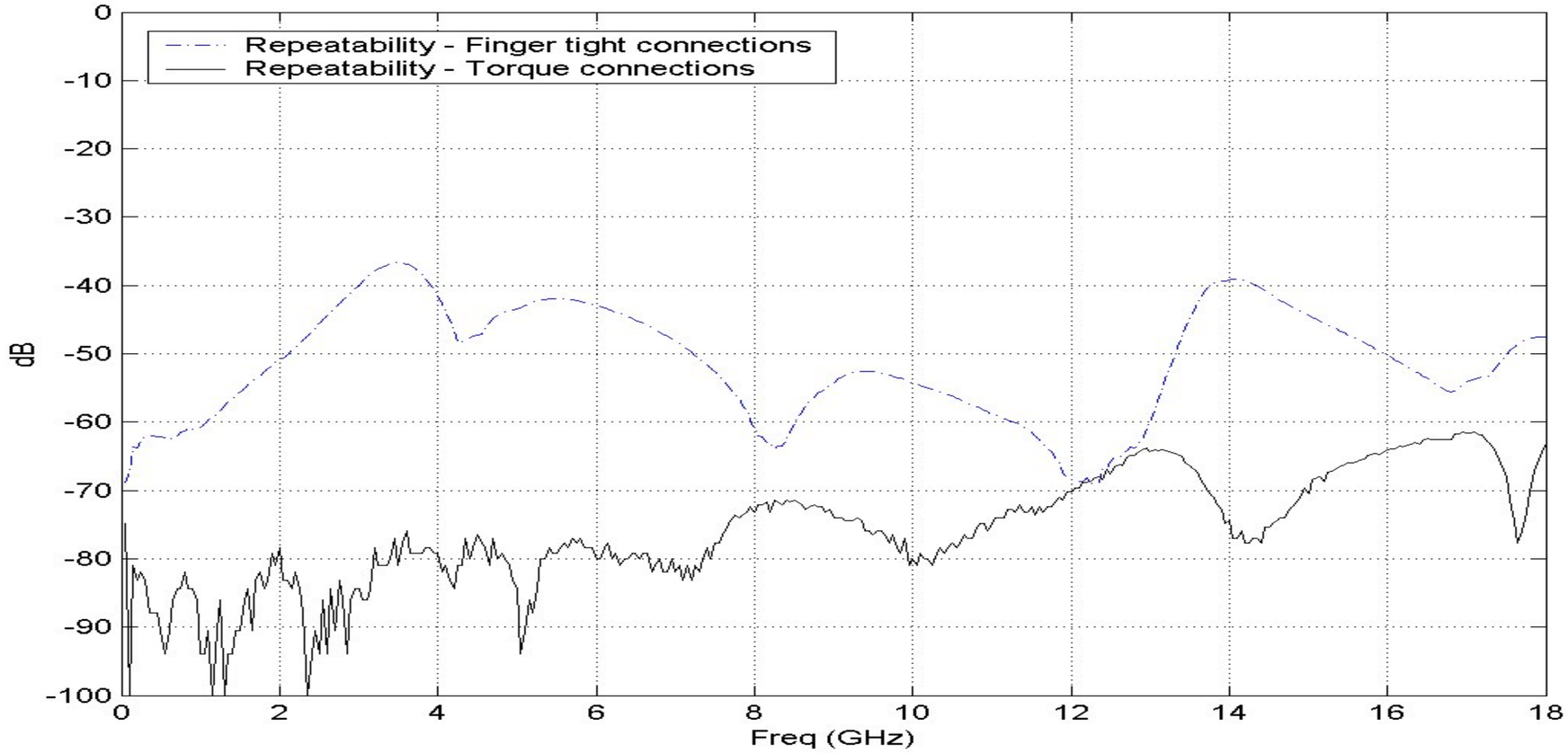



*TIP: always use a **torque wrench** for accurate and repeatable connections!*

# Achieving repeatable connections



Apply the ***same force*** for repeatable connections

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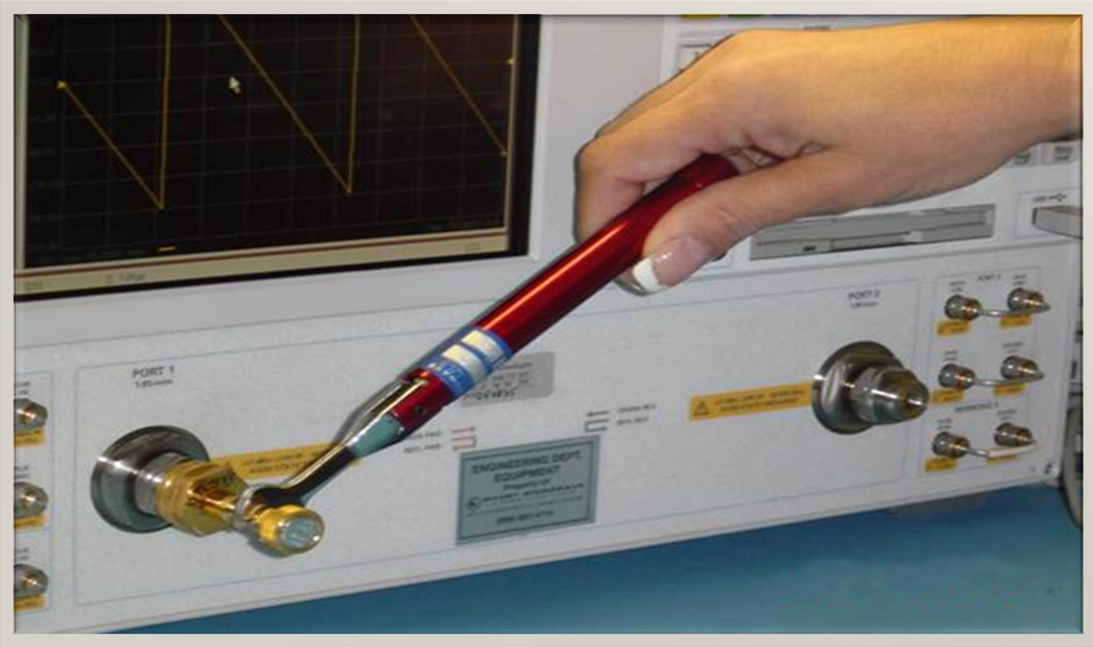
# Achieving accurate and repeatable connections



Use a ***torque wrench*** correctly



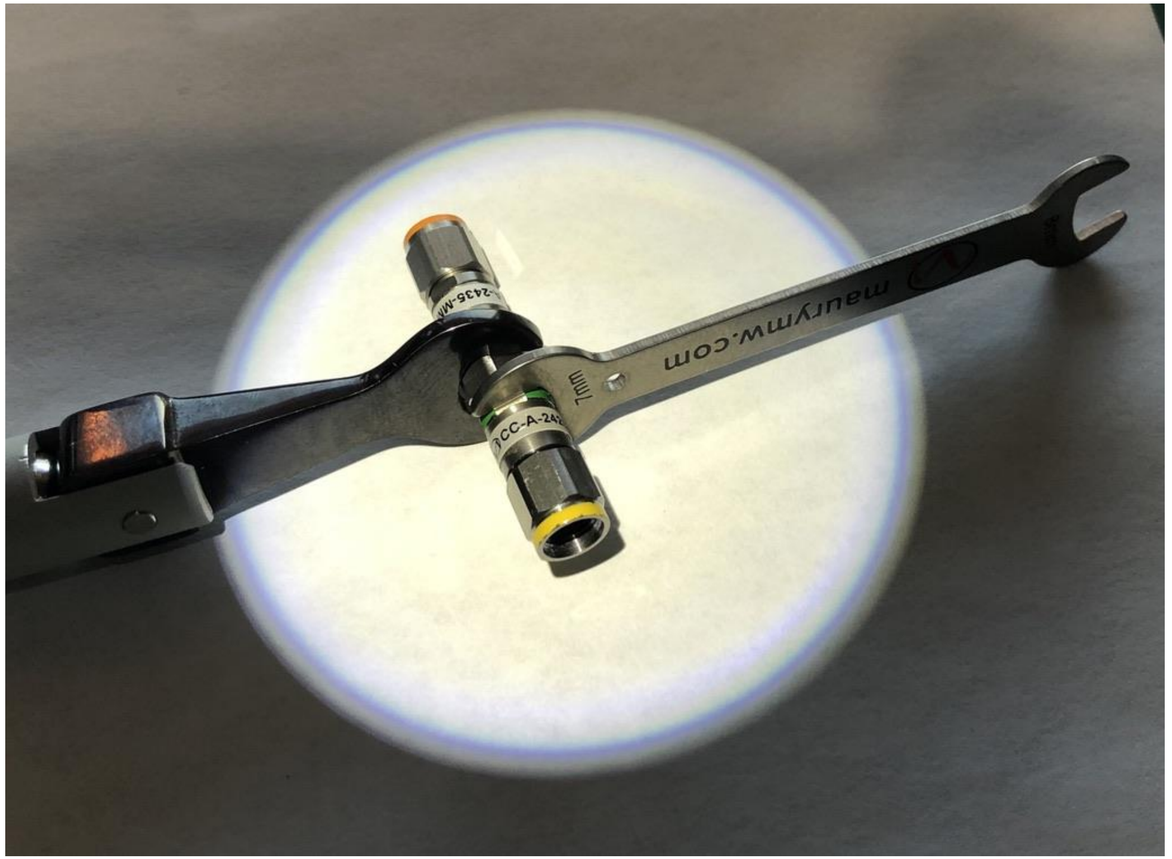


*Which is right?*

# Achieving accurate and repeatable connections



Use a ***torque wrench*** correctly




*TIP:* ***don't twist*** *the female connector!*

# 2 | Components

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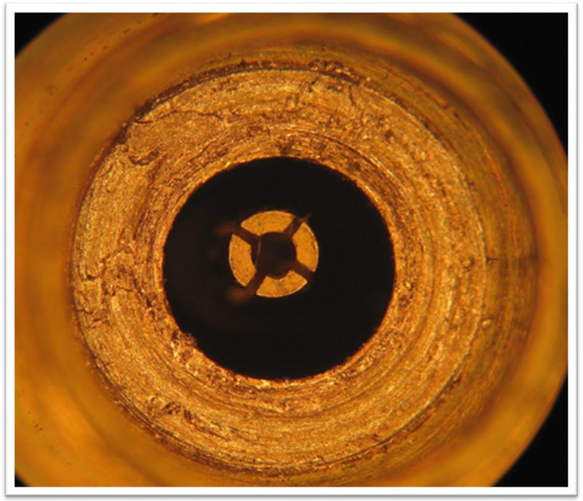
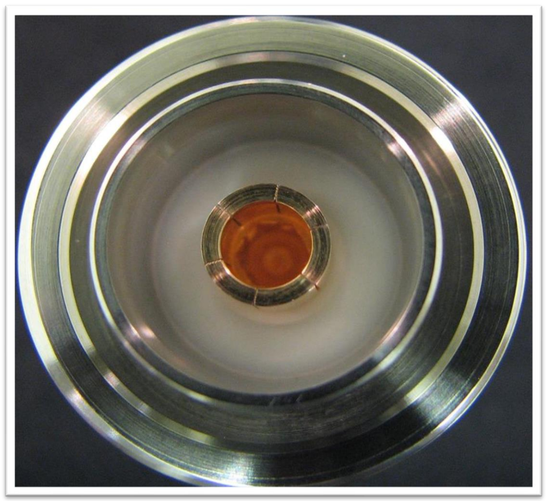
# Best practices





*Do any of these look good?*

*TIP:* ***always inspect*** *connectors before use!*

# Best practices



- Use Low-pressure air to remove loose particles

- Use Industrial lint-free cotton or foam swabs  (no Q-Tips)

- Lightly moisten
  (do not saturate)


*TIP:* ***always clean*** *before using connectors!*

# Best practices



Which one looks right?


*TIP: always **store your components** properly to avoid damage!*

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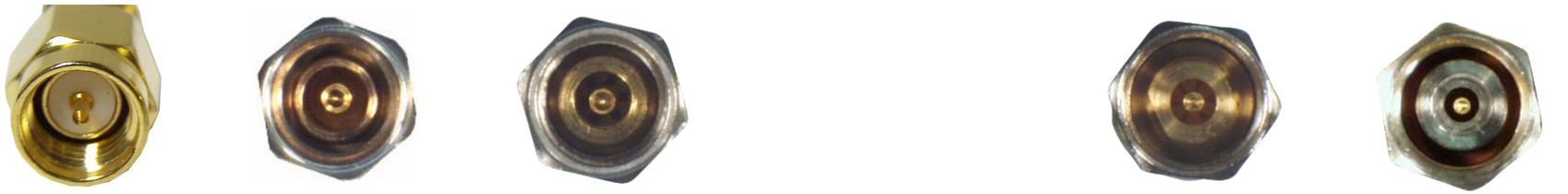
# Connector compatibility



Mechanically compatible

Mechanically compatible



SMA 3.5mm 2.92mm 2.4mm 1.85mm

*While mechanically compatible, mixing connectors may cause resonances*

*TIP: **don't try** and connect incompatible connectors!*

# Identifying connectors



3.5mm 2.92mm 2.4mm 1.85mm

3.5mm 2.92mm 2.4mm 1.85mm

*What are the benefits of properly identifying connectors?*

*TIP: save time and money and eliminate damage **using color-coded** connectors!*

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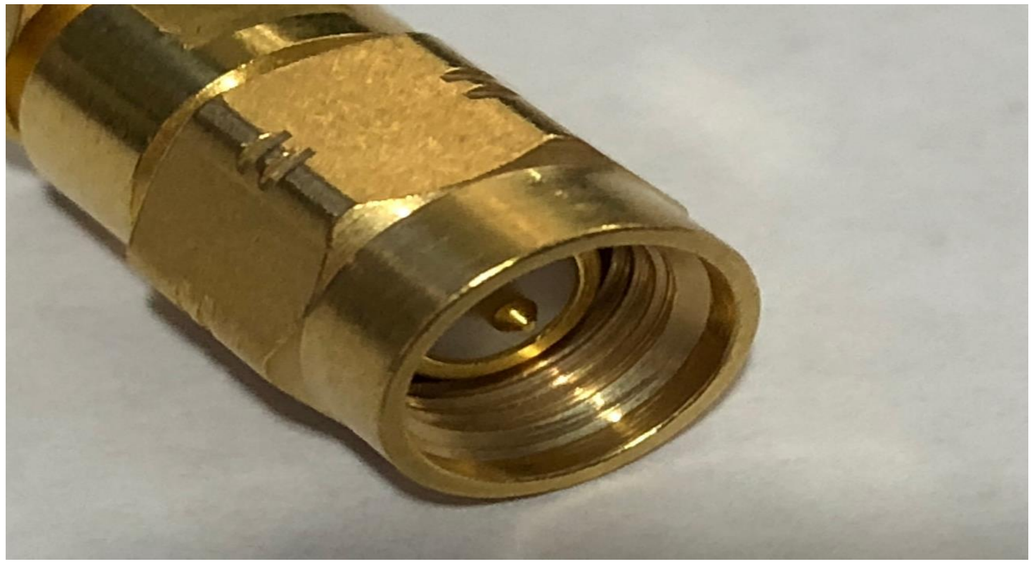
# Impact of pin depth and concentricity



Protruding pin
*Damages connectors*



Recessed pin
*Improper connection*

*TIP: **gage** before using connectors!*

# Choosing the right cables



VNA test port

Phase-stable
armored

Phase-stable
low-profile

General purpose

*What characteristics are important to you?*
*VSWR, phase-stability, flexibility, price…*

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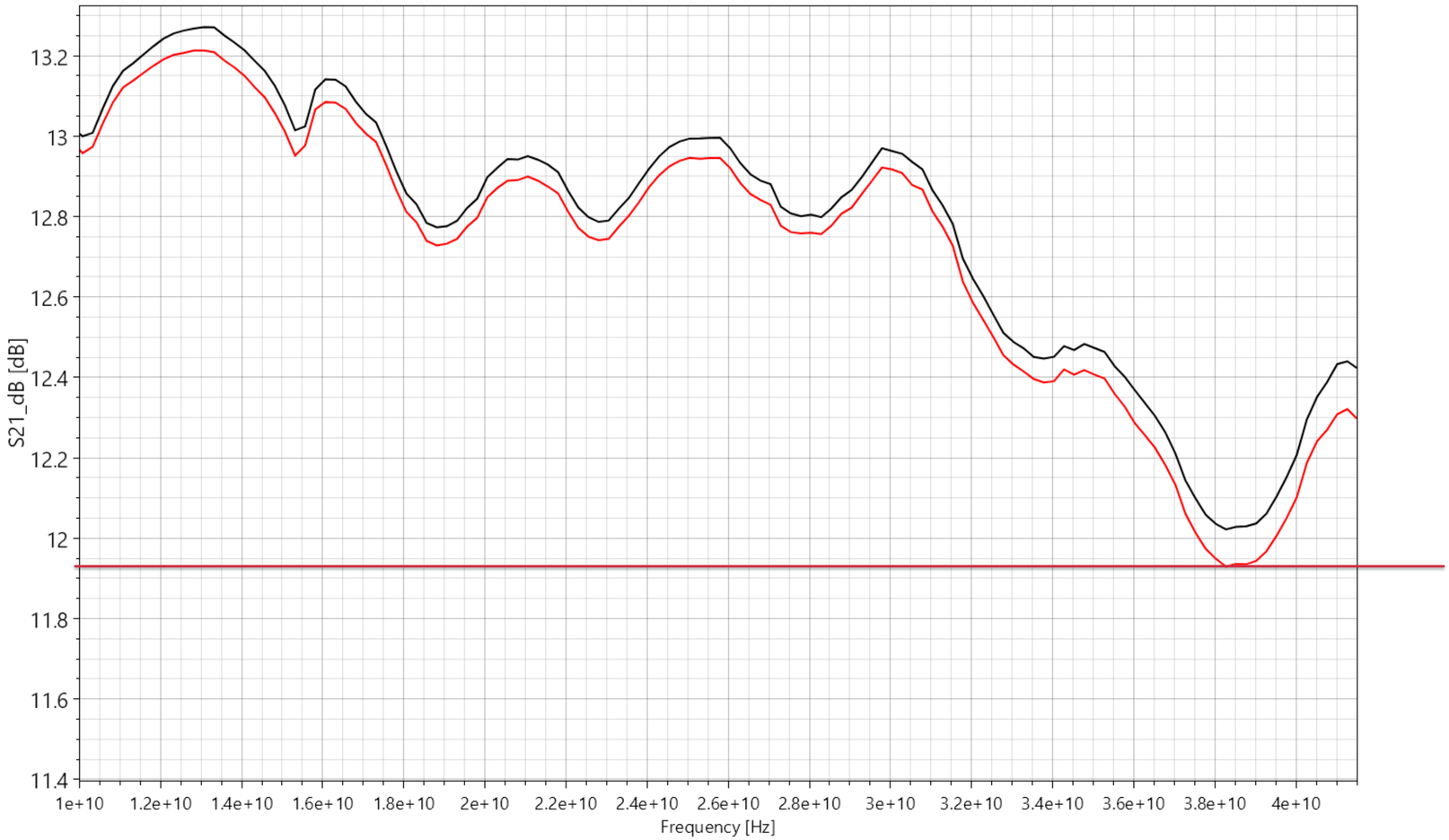
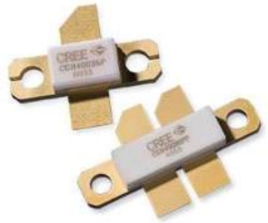
# Importance of amplitude stability





*TIP: use **amplitude-stable** with flexure cable assemblies to minimize inconsistencies!*

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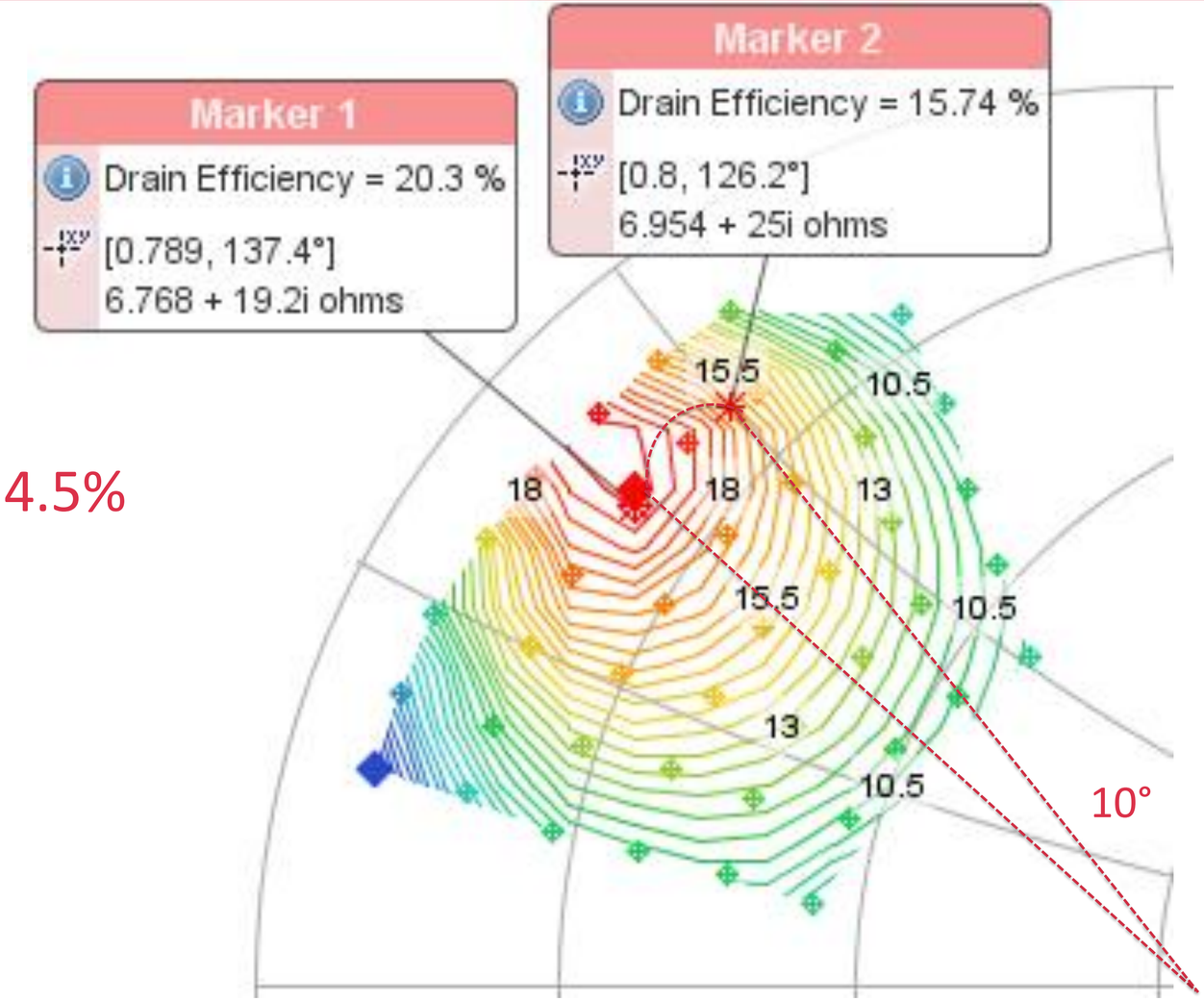
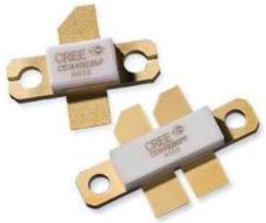
# Importance of phase stability






Drain Eff +/- 4.5%



*TIP: use **phase-stable** with flexure cable assemblies to minimize inconsistencies!*

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# Choosing the right adapters



Calibration/
metrology

Precision/
color-coded

Lab-grade/
general purpose

*What characteristics are important to you?*
*VSWR, materials, ease-of-identification, price…*

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# Importance of VSWR



Components with high VSWR impact:

- Power transfer
- Resolution of the calibration


$\Gamma_{adap}$ $\Gamma_{adap}$

**Example (Power transfer):**

Power available from amplifier → 1W

- Components A → VSWR 1.17:1 (50 GHz) → Power reduction < 1%
- Component B → VSWR 1.6:1 (50 GHz) → Power reduction is around 7%

*Calibration does not eliminate impact of VSWR mismatch*

*TIP: use **low-VSWR** components to reduce mismatch!*

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# 3 | Instrumentation

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# VNA noise floor and drift



VNA characteristics that impact S-parameter measurements

Noise floor

The lowest possible signal level that a VNA can measure.

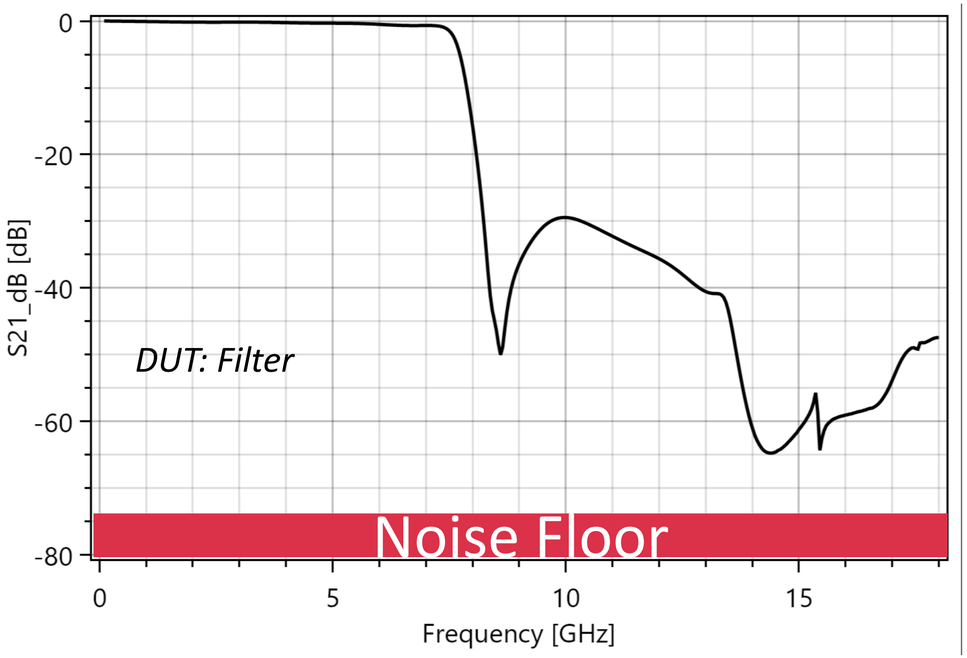
Drift

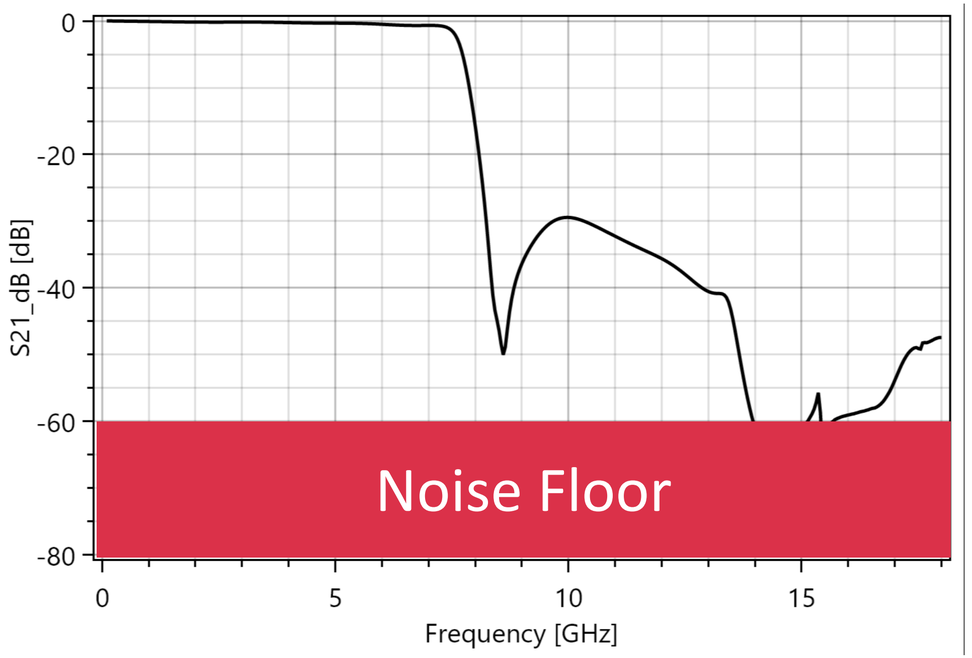
The change in measurements over time.

*What does that mean to your measurements?*

# Impact of VNA noise floor





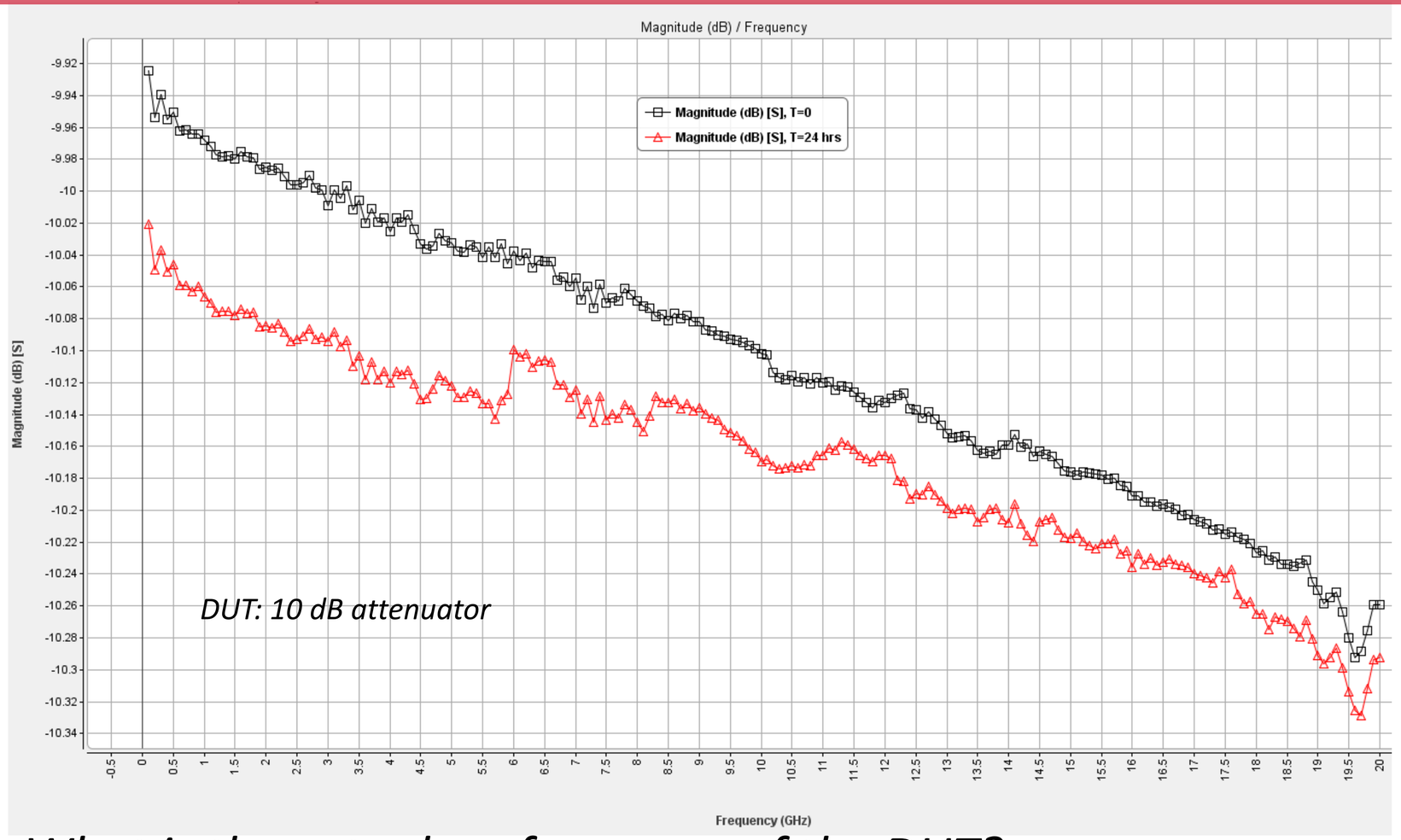




*What is the actual performance of the DUT?*

*TIP: make sure your measurements are **above the noise floor**!*

# Impact of VNA drift






*What is the actual performance of the DUT?*

*TIP: make sure to **recalibrate before drift** occurs or choose better instrument!*

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# VNA calibration techniques



Common 2-port VNA calibration techniques

SOLT with polynomial coefficients
Short, open, load, thru - based on generalized polynomial coefficients.

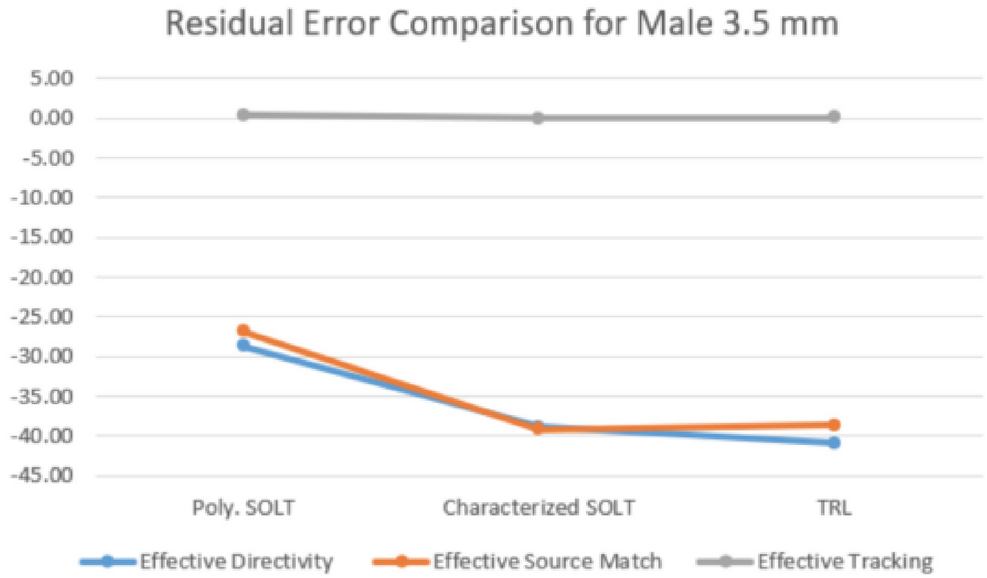
SOLT with characterization
Short, open, load, thru - uses individually characterized standards.

TRL
Thru, reflect, line – only requires well-defined characteristic impedance of Thru.

# VNA calibration techniques



| Performance | Poly. SOLT | CD SOLT | TRL |
|---|---|---|---|
| Accuracy | - | + | + |
| Repeatability | + | + | - |
| Bandwidth | + | + | - |
| Ease-of-use | + | + | - |
| One-port calibration | + | + | - |




*TIP: characterized SOLT offers TRL-like accuracy with SOLT ease-of-use*

# VNA calibration validation techniques



Common VNA calibration validation techniques

## Airline and short

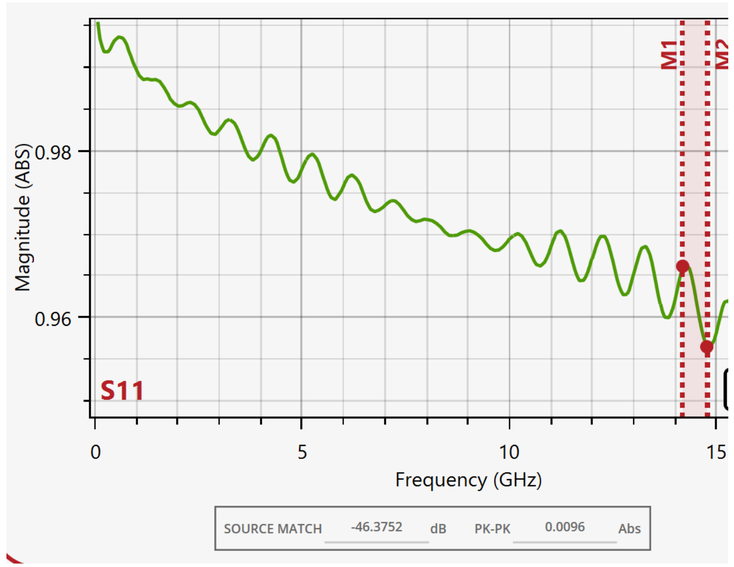
Post-calibration onsite measurement of airline connected with short circuit termination.

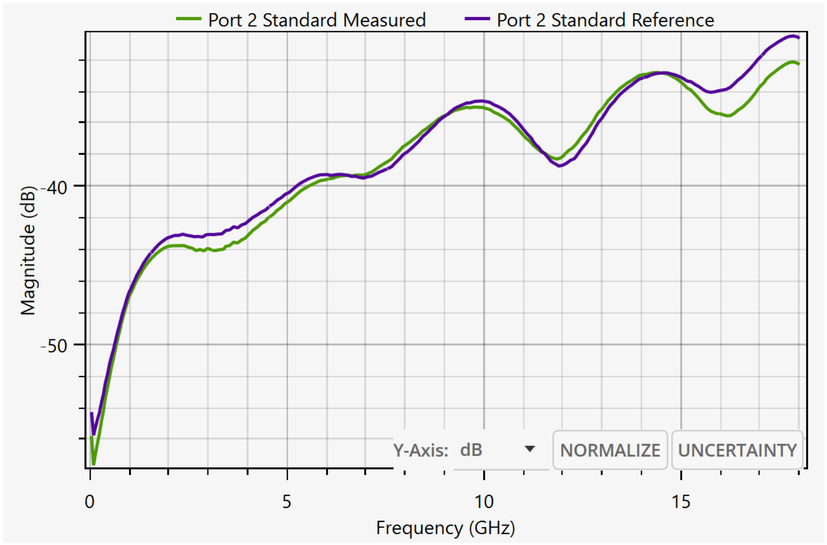
## Characterized/golden device

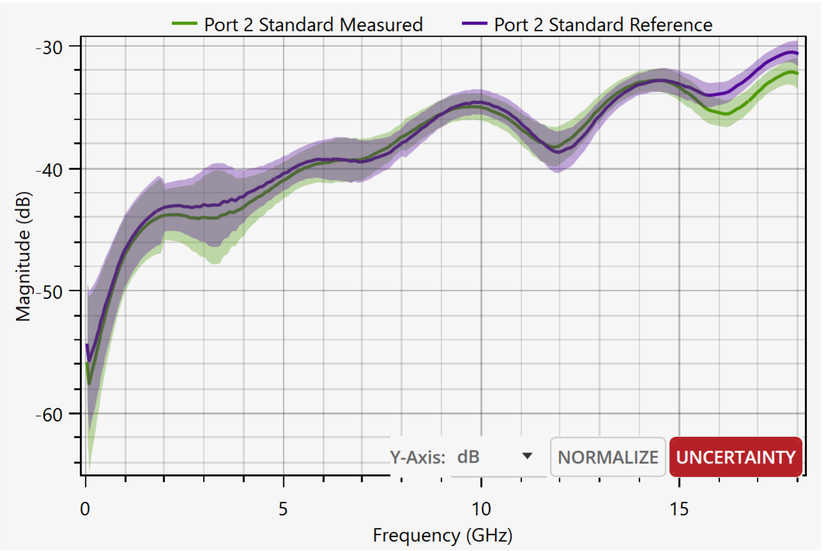
Post-calibration onsite measurement of characterized/golden device is compared with factory measurements.
Measurements can be compared without or with measurement uncertainty.

# VNA calibration validation techniques





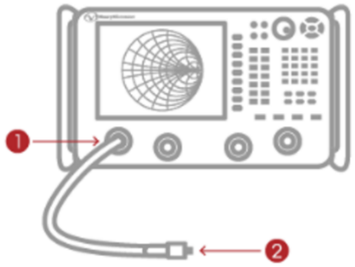

*Which one identifies a valid calibration?*

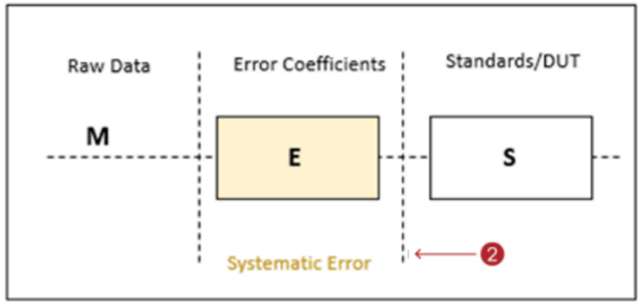
*TIP: use verification devices with measured uncertainty to validate calibrations!*

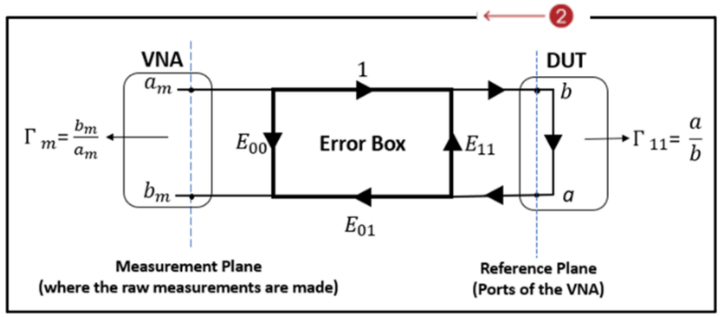
# 4 | Quantifying *uncertainty*

# Errors that impact measurements

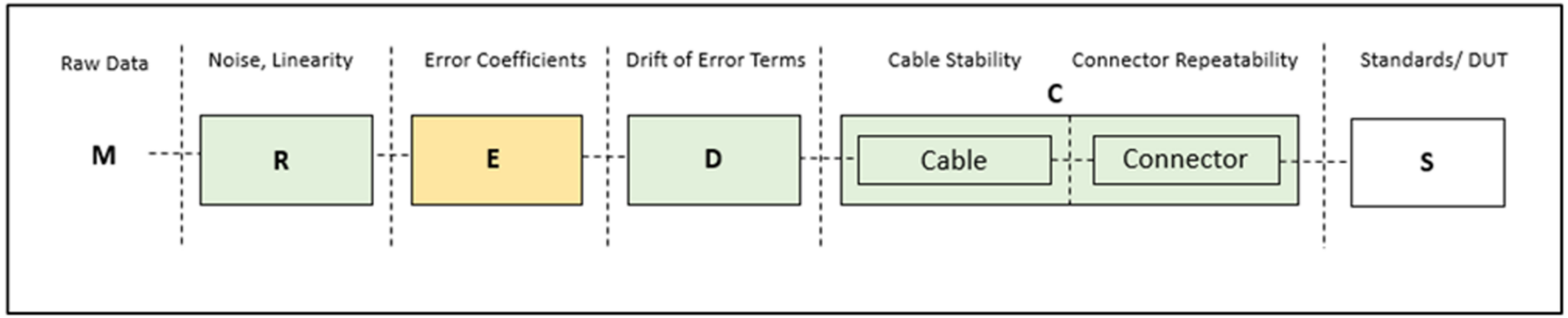




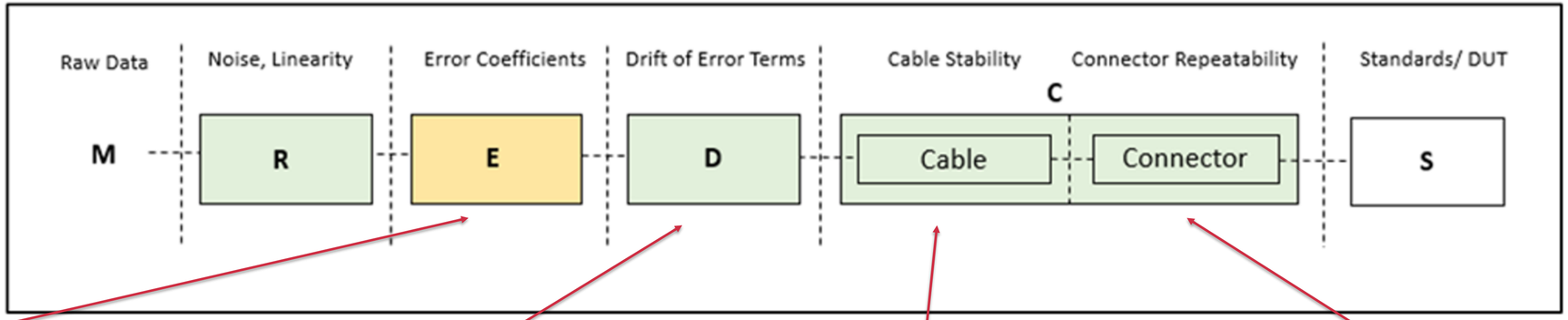

*What you do today when you calibrate a VNA to measure S-parameters*

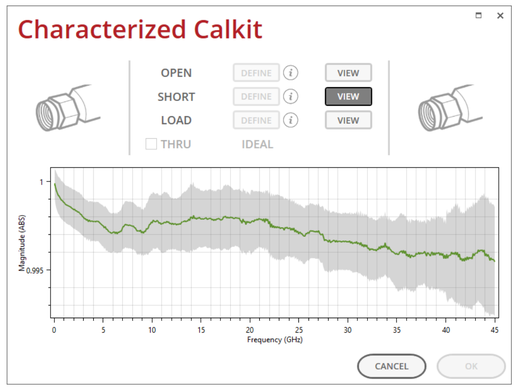


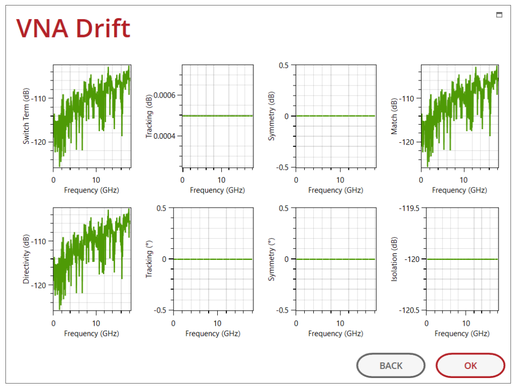

*Expanding calibration model to include additional sources of real-life error (including cables)*

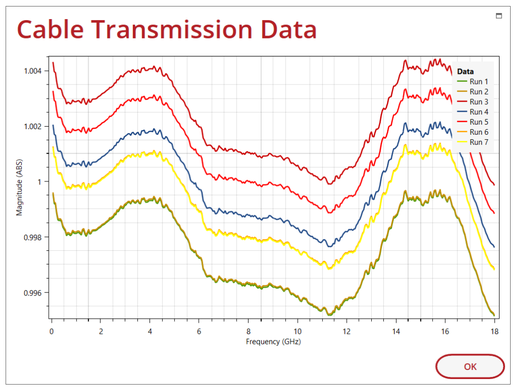
# Quantifying the sources of error

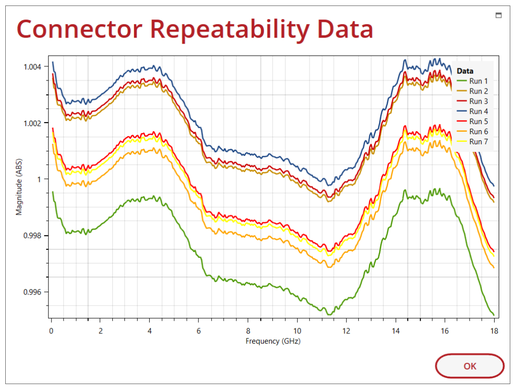





| Influence | 2 GHz |
|---|---|
| VNA Noise Floor | 0.002 % |
| VNA Noise Trace | 0.004 % |
| VNA Linearity | 2.7 % |
| VNA Drift Directivity | 0.001 % |
| VNA Drift Tracking | 0.007 % |
| VNA Drift Match | 0.001 % |
| VNA Drift Symmetry | 0 % |
| Cable Transmission | 44.6 % |
| Cable Reflection | 42.1 % |
| Connector Reflection | 0.6 % |
| Cal Kit | 9.9 % |

Uncertainty supplied by vendor

Repetitive measurements over time

Measurement change with cable flexure

Measurement change with connect/disconnect cycles

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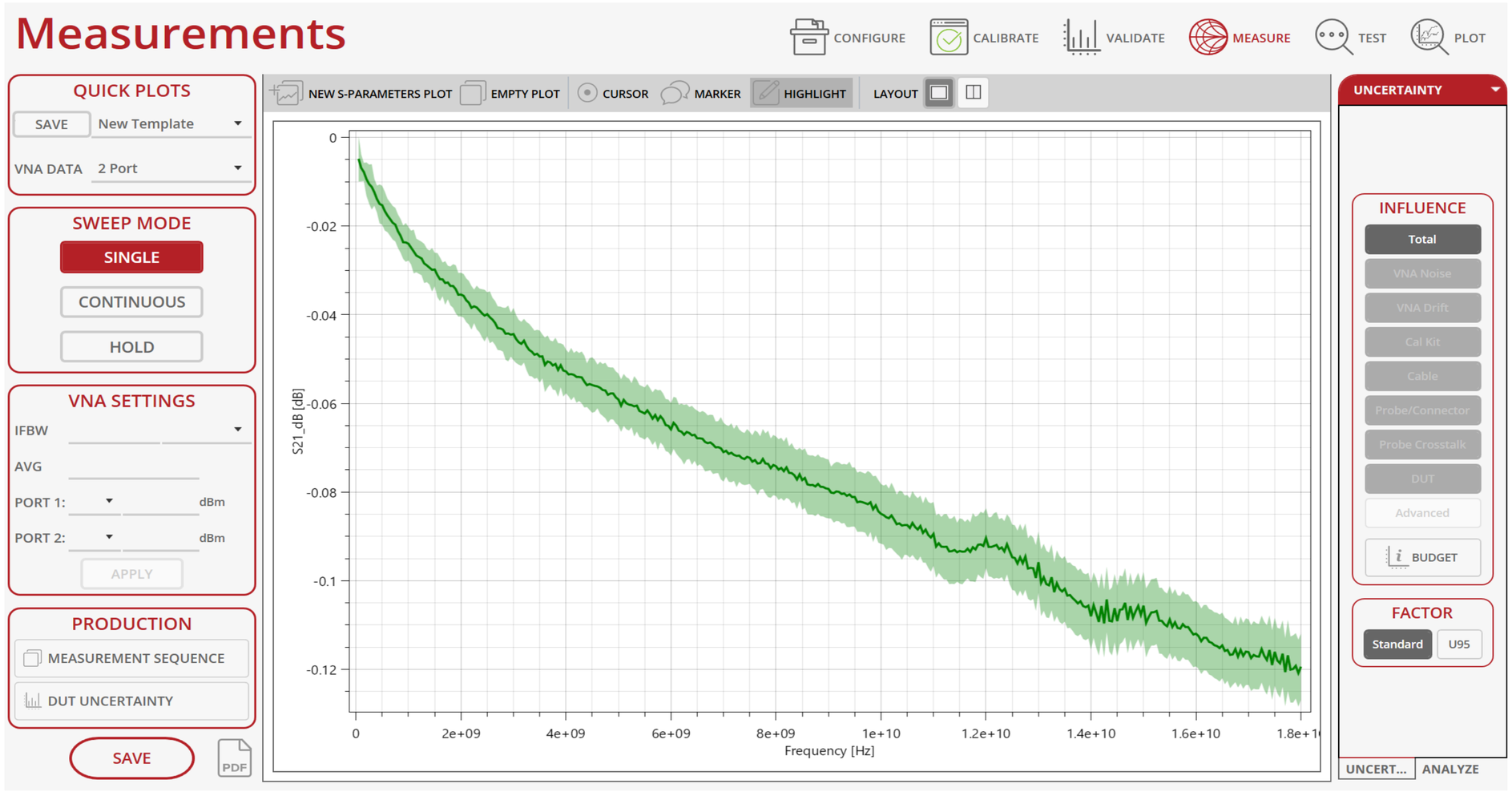
# S-parameters measurements with uncertainty






*TIP: follow recommendations to improve measurement accuracy!*

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# Summary of tips

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# Summary of tips



## Operator

- always use a torque wrench for accurate and repeatable connections
- don’t twist the female connector

## Components

- always inspect connectors before use
- always clean before using connectors
- always store your components properly to avoid damage
- gage before using connectors
- don’t try and connect incompatible connectors
- low-VSWR components to reduce mismatch
- use amplitude-stable with flexure cable assemblies to minimize inconsistencies
- use phase-stable with flexure cable assemblies to minimize inconsistencies
- save time and money and eliminate damage using color-coded connectors

## Instrumentation

- make sure your measurements are above the noise floor
- make sure to recalibrate before drift occurs or choose better instrument
- characterized SOLT offers TRL-like accuracy with SOLT ease-of-use
- use verification devices with measured uncertainty to validate calibrations

## Quantifying measurement uncertainty

- follow recommendations to improve measurement accuracy

# About Maury Microwave

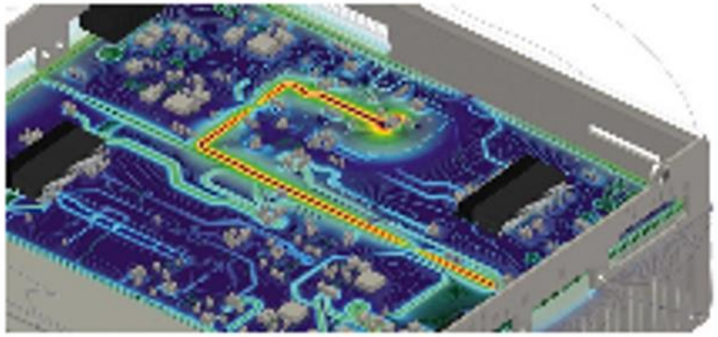


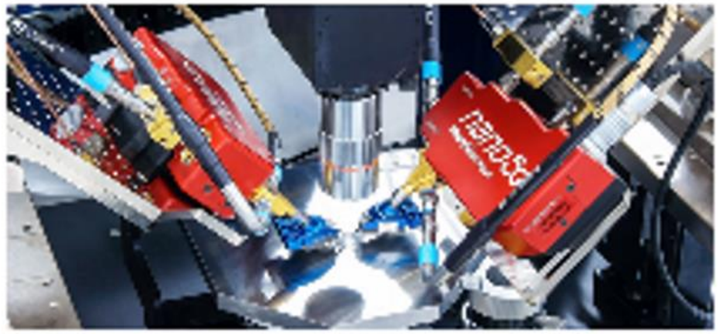
- 66 year experience with calibration kits and standards.
- +40 years making test systems for RF Device Characterization (Load Pull, Impedance Matching, Noise Measurements).
- Their measurement systems require a high level of measurement accuracy which resulted in the launch of their own RF interconnect portfolio such as RF Cable Assemblies and Adapters.
- Their StabillityPlus flexure cables have the best phase stability in the industry!
- Maury Microwave have adopted the ColorConnect coding of IEEE.
- Products with 7mm, TNCA, N-Connector, 2.92mm (K), 3.5mm, 2.4mm, 1.85mm, NMD, SMA, Waveguide.


# About HI-TECH



- 35 years experience in RF & Microwave.
- Not just Sales but also Demonstrations, Installations, Training, Servicing, Technical Assistance.
- Support RF community with:
  - RF Components
  - RF EDA Software
  - RF Interconnect + Lab Components
  - RF / Thermal Test & Measurement Instruments + Systems
  - RF Services & Consultancy





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Modelithics · Werlatone · Microsanj · Holzworth · Z~Communications, Inc. · Noisecom

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# Questions?



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# *Thank you.*