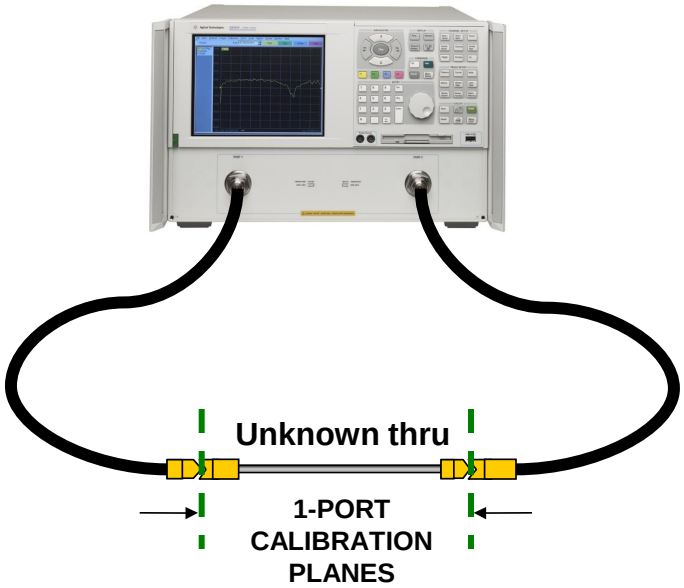
Advanced Calibration Techniques for Vector Network Analyzers

Presented by:

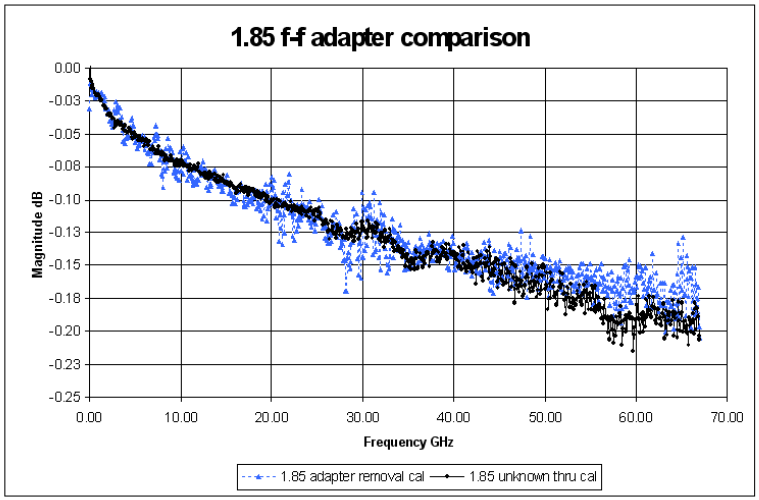
Agilent Technologies

Objectives

- Provide insight into some of the latest **calibration techniques** that improve **accuracy** and make calibration **easier**
- Look at performance **improvements** using the advanced techniques compared to more traditional methods



Comparing Unknown Thru and Adapter Removal

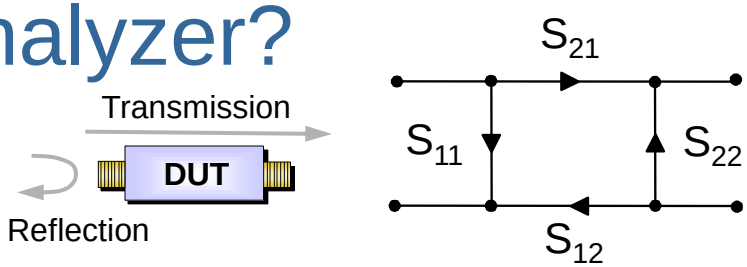


Agenda

- **Overview of Calibration**
- **Advanced Calibration Techniques**
  - “Unknown Thru” Calibration
  - Data-Based Calibration-Standard Definitions
  - Expanded (Weighted Least Squares) Calibration

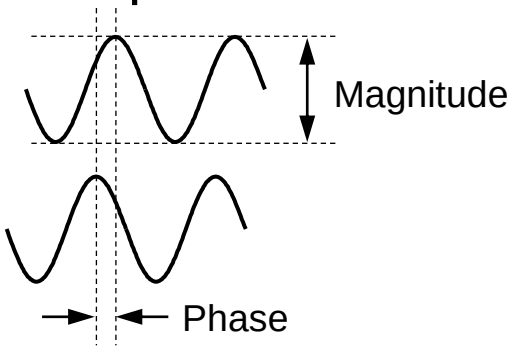
- **Fixture And Probe Techniques**
  - Automatic Port Extensions
  - Embedding/De-embedding
  - Measuring Fixtures/Probes
- **Electronic Calibration**

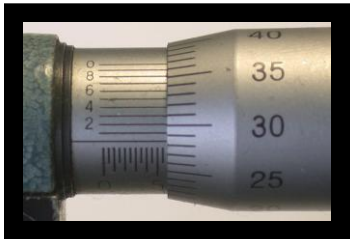
What is a Vector Network Analyzer?

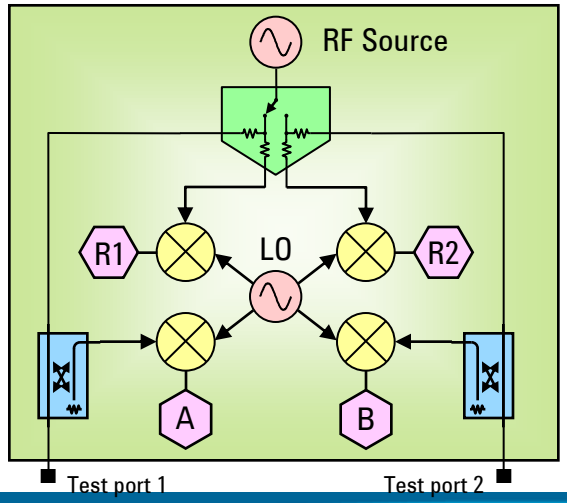


Vector network analyzers (VNAs)…

- Are stimulus-response test systems
- Characterize forward and reverse reflection and transmission responses (S-parameters) of RF and microwave components
- Quantify linear magnitude and phase
- Are very fast for swept measurements
- Provide the highest level of measurement accuracy







The Need for Calibration

How do we get accuracy?

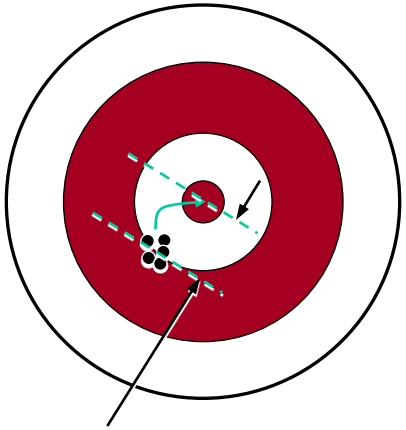
- With vector-error-corrected calibration
- Not the same as the yearly instrument calibration

Why do we have to calibrate?

- It is impossible to make perfect hardware
- It would be extremely difficult and expensive to make hardware good enough to entirely eliminate the need for error correction

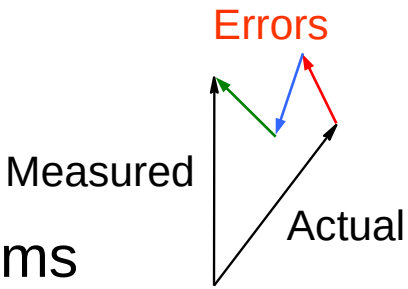
What does calibration do for us?

- Removes the largest contributor to measurement uncertainty: systematic errors
- Provides best picture of true performance of DUT



Systematic error

What is Vector-Error Correction?



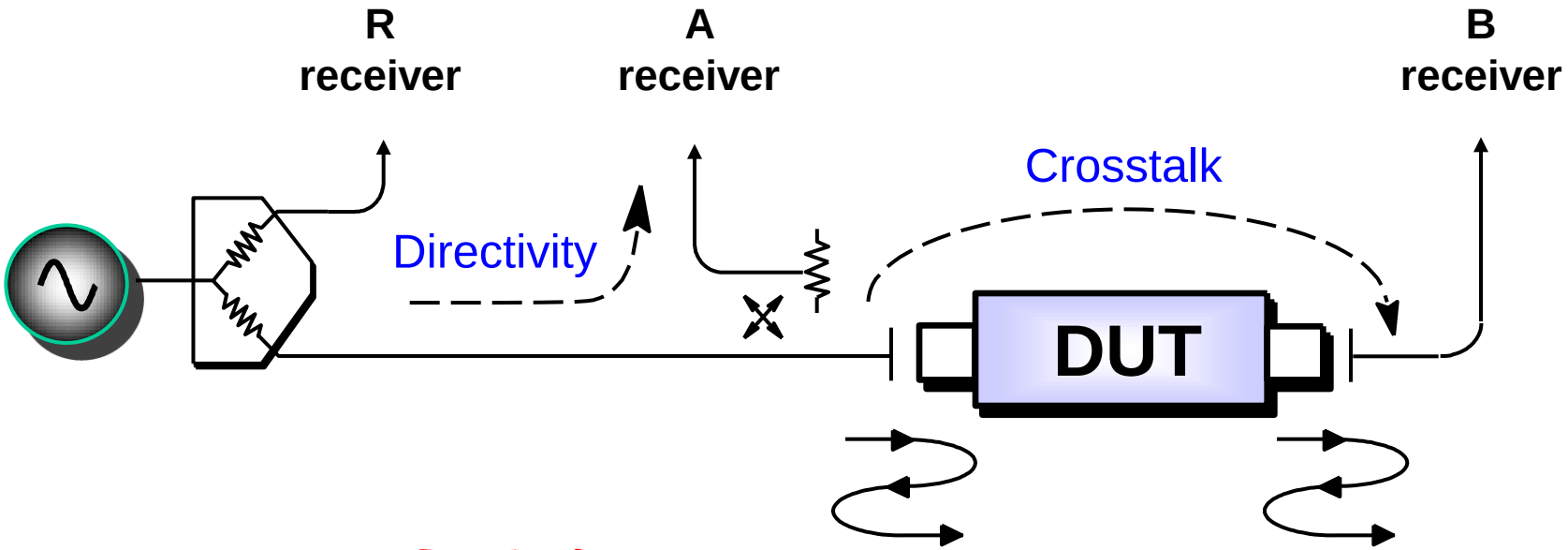
Vector-error correction…

- Is a process for characterizing systematic error terms
- Measures known electrical standards
- Removes effects of error terms from subsequent measurements

Electrical standards…

- Can be mechanical or electronic
- Are often an open, short, load, and thru, but can be arbitrary impedances as well

Systematic Measurement Errors



Frequency response

- reflection tracking (A/R)
- transmission tracking (B/R)

Six forward and six reverse error terms yields 12 error terms for two-port devices

Performing the Calibration: SOLT

- Two most common types of calibration: SOLT and TRL
  - Both types remove all the systematic error terms
  - Type and definition of calibration standards are different
- SOLT
  - Basic form uses short, open, load, and known-thru standards
  - Advanced forms use multiple shorts and loads, unknown thru, arbitrary impedances (ECal)
  - Uses the 12-term error model
- Advantages:
  - Easy to perform
  - Applicable to a variety of environments (coaxial, fixture, waveguide…)
  - Provides a broadband calibration

Performing the Calibration: TRL

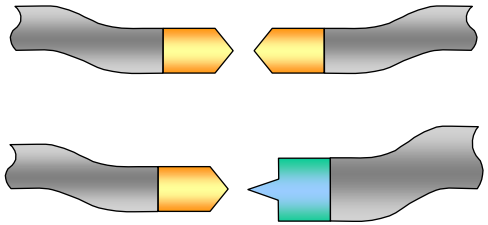
- Basic form: thru, reflect, line standards
- Advanced forms: TRM, LRM, LRL, LRRL…
- Uses a 10-term error model

- Advantages
  - Uses standards that are easy to fabricate and have simpler definitions than SOLT
    - Only need transmission lines and high-reflect standards
    - Required to know impedance and approximate electrical length of line standards
    - Reflect standards can be any high-reflection standards like shorts or opens
    - Load not required; capacitance and inductance terms not required
  - Potential for most accurate calibration (depends on quality of transmission lines)
  - Commonly used for in-fixture and on-wafer environments

Component Measurement Challenges

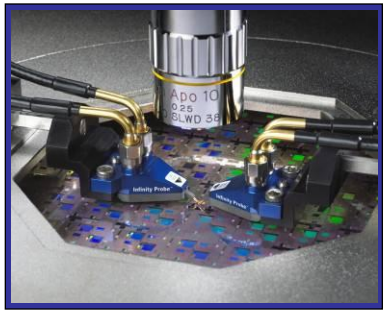
Non-insertable coaxial devices

- Same sex connectors (e.g., SMA females)
- Mixed connectors (e.g., SMA and Type-N)



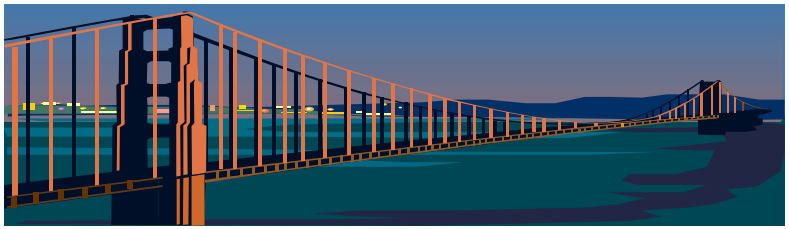
Devices without coaxial connectors

- Surface-mount devices
- Devices on wafer
- Devices with waveguide ports



Mechanically difficult situations

- Physically long devices
- Fixed test-port positions
- Non-in-line connectors

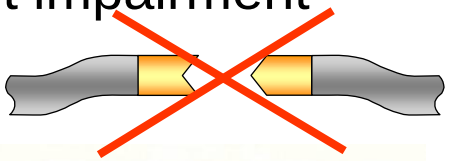


Multiport (>4 port) devices

Unknown Thru Calibration

The "Unknown Thru" technique is…

- Used when a "flush" (zero-length or mate-able) thru cannot be used or when using a flush thru would cause measurement impairment
- A refinement of SOLT calibration
- Also called short-open-load-reciprocal-thru (SOLR)



Unknown Thru technique eliminates need for…

- Matched or characterized thru adapters
- Moving or bending test cables

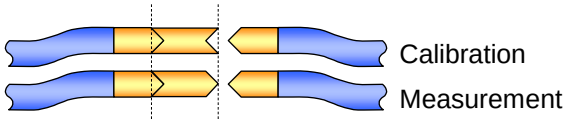
Works great for many component measurement challenges…

- Non-insertable devices
- Mechanically difficult situations
- Multiport devices

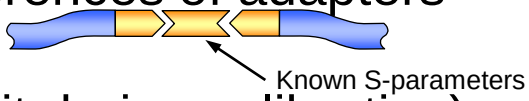
Non-Insertable ECal Modules

ECal resolves many, but not all non-insertable

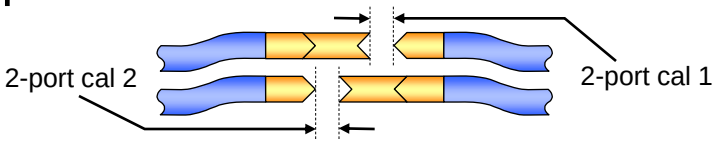
Compromises of Traditional Non-Insertable Methods



- **Swap equal adapters**
  - Need phase matched adapters of different sexes (e.g., f-f, m-f)
  - Errors introduced from loss and mismatch differences of adapters

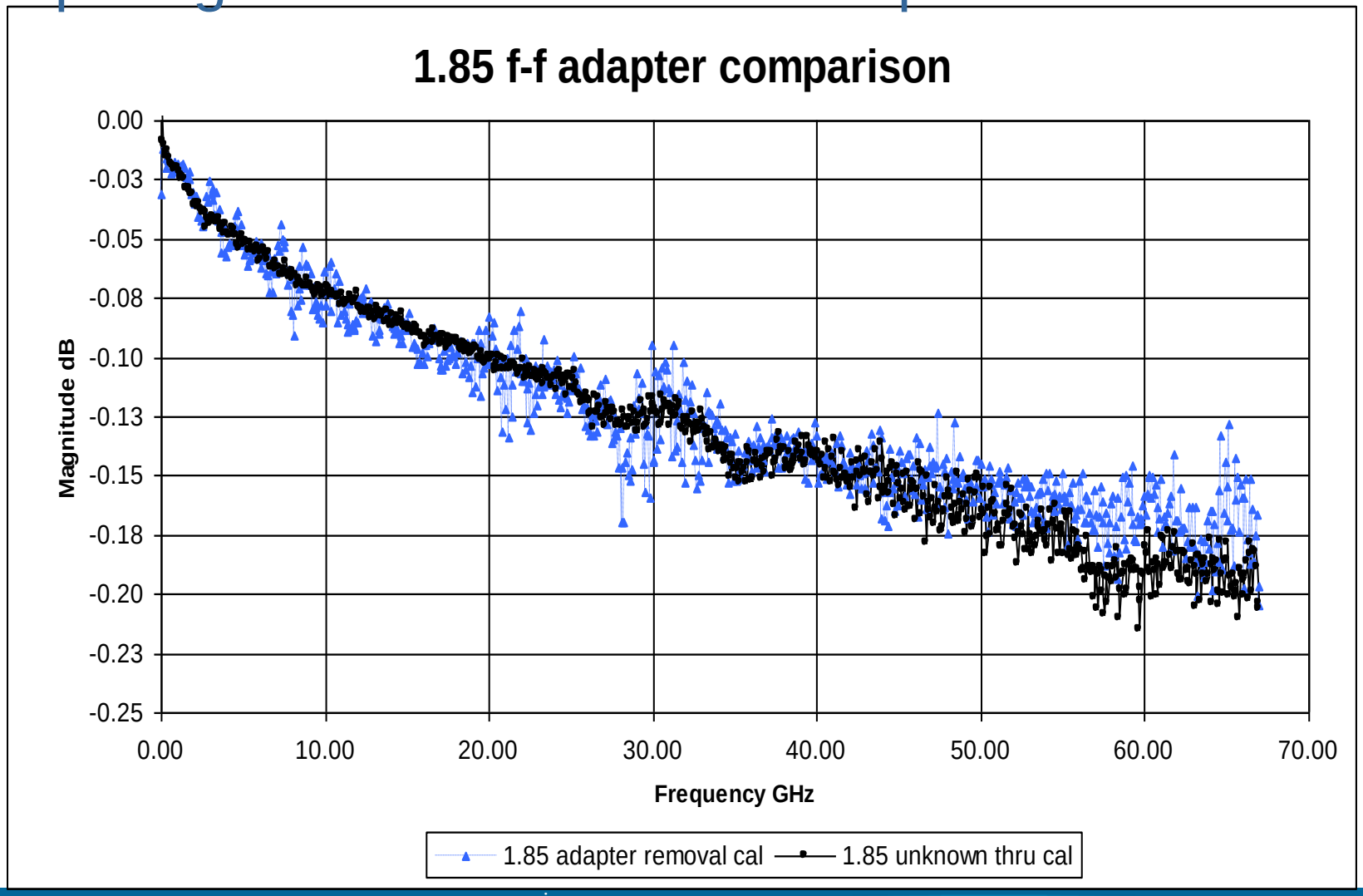


- **Use characterized thru**
  - Two-step process (characterize thru, then use it during calibration)
  - Need a non-insertable cal to measure S-parameters of characterized thru



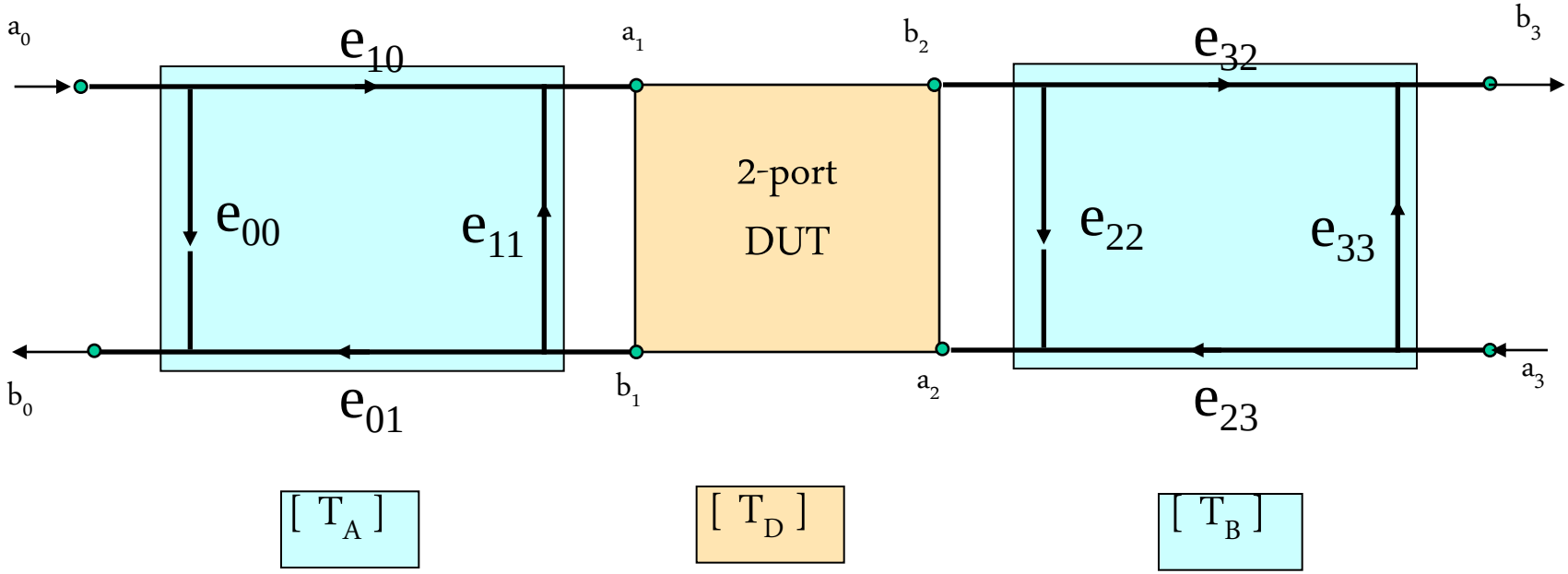
- **Perform adapter removal cal**
  - Accurate but many steps in calibration (need to do two 2-port calibrations)
- **Add adapters after cal, then, during measurement…**
  - Use port extensions – doesn't remove adapter mismatch effects
  - De-embed adapters (S-parameters known) – similar to characterized thru

Comparing Unknown Thru and Adapter Removal



Unknown Thru Algorithm

Unknown thru algorithm uses same 8-term error model as TRL



$$[T_m] = \left(\frac{1}{e_{10}e_{32}}\right)\begin{bmatrix} e_{10}e_{01} - e_{00}e_{11} & e_{00} \\ -e_{11} & 1 \end{bmatrix}[T_D]\begin{bmatrix} e_{32}e_{23} - e_{22}e_{33} & e_{22} \\ -e_{33} & 1 \end{bmatrix}$$

Only 7 error terms need to be determined

Unknown Thru Calibration Requirements

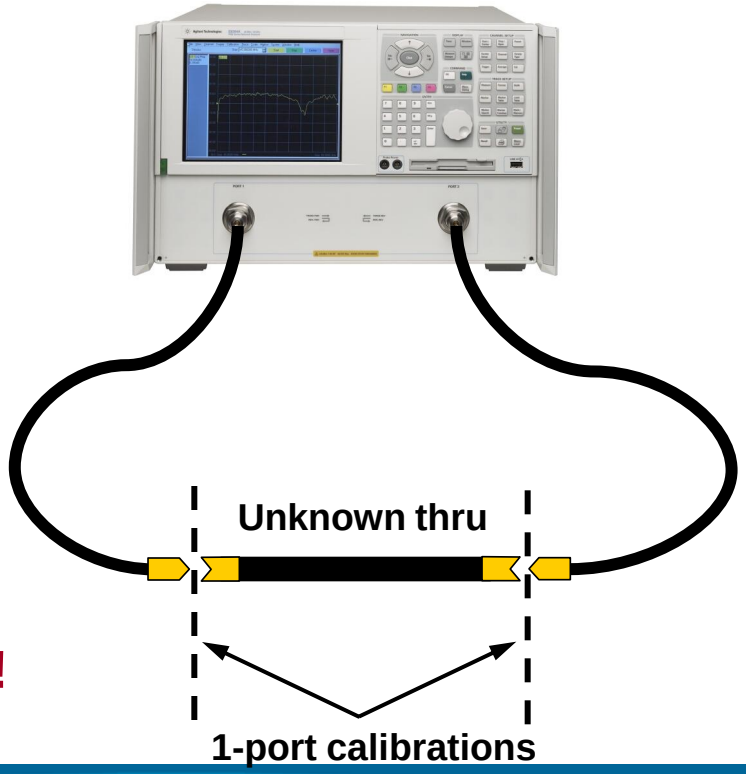
- Systematic errors of all test ports (directivity, source match, reflection tracking) can be completely characterized (6 terms)
- "Unknown thru" calibration standard (7th term):
  - Must be reciprocal (i.e., $S_{21} = S_{12}$)
  - Must know phase to within a quarter wavelength
- VNA signal-path switch errors can be quantified
  - Same restriction as TRL calibration
  - Requires dual reflectometers on all ports or equivalent (e.g., a 2-port 4-receiver VNA)

    <u>OR</u>
  - Requires characterization of switch correction terms via a two-tier calibration

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \underbrace{\begin{bmatrix} \frac{b_{11}}{a_{11}} & \frac{b_{12}}{a_{22}} \\ \frac{b_{21}}{a_{11}} & \frac{b_{22}}{a_{22}} \end{bmatrix}}_{\text{Ideal S-parameters}} \bullet \underbrace{\begin{bmatrix} 1 & \frac{a_{12}}{a_{22}} \\ \frac{a_{21}}{a_{11}} & 1 \end{bmatrix}^{-1}}_{\text{Switch correction}}$$

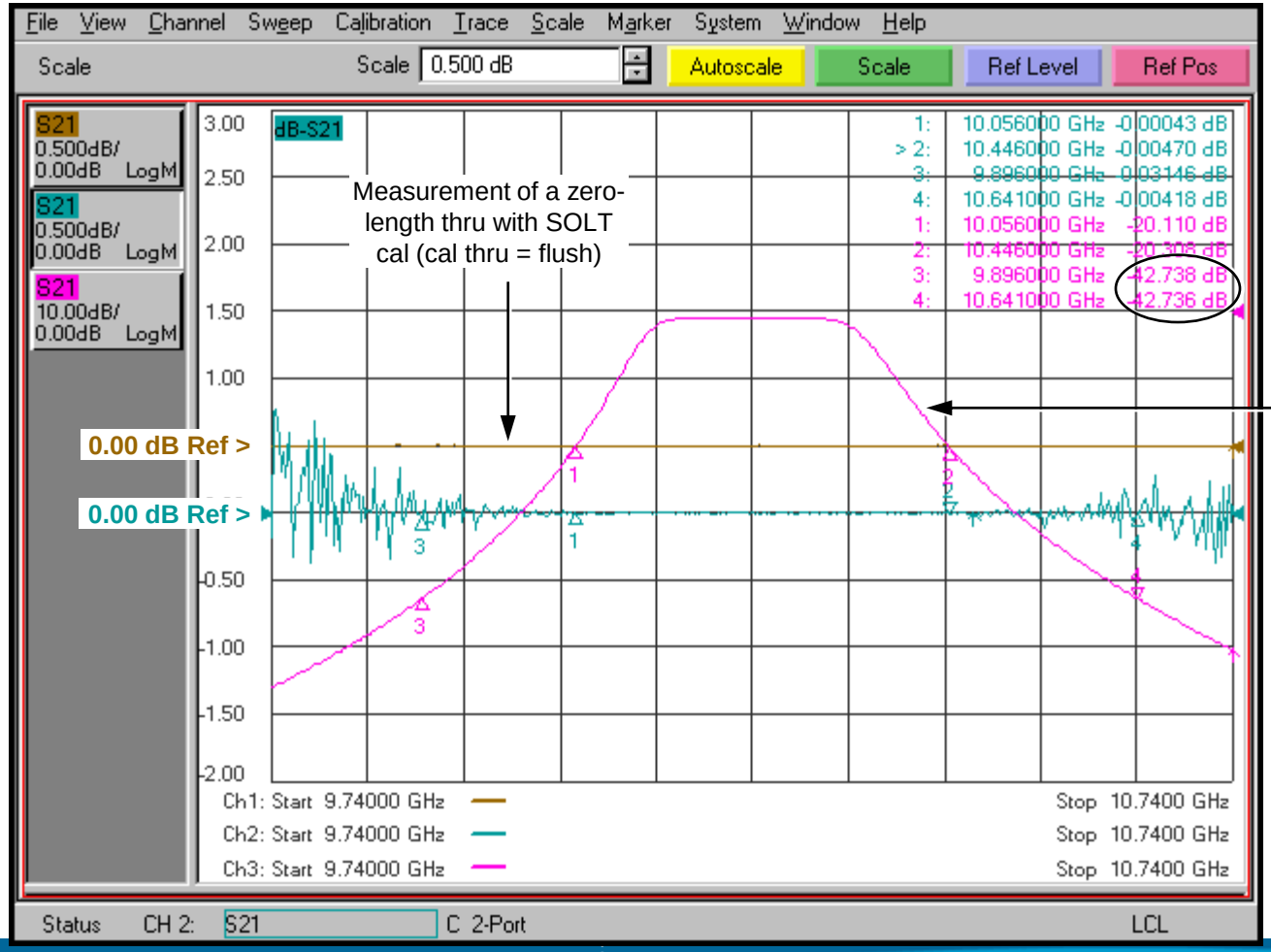
Two-Port Unknown Thru Calibration Sequence

1. Measure open, short, load on port 1 (e_{00}, e_{11}, $e_{10}e_{01}$)
2. Measure open, short, load on port 2 (e_{22}, e_{33}, $e_{32}e_{23}$)
3. Measure insertable adapter (unknown thru) between ports 1 and 2 ($e_{10}e_{32}$)
4. Confirm estimated electrical delay of unknown thru



Unknown Thru calibration is as simple as performing a "flush thru" 2-port calibration!

Unknown Thru Example Using a Bandpass Filter

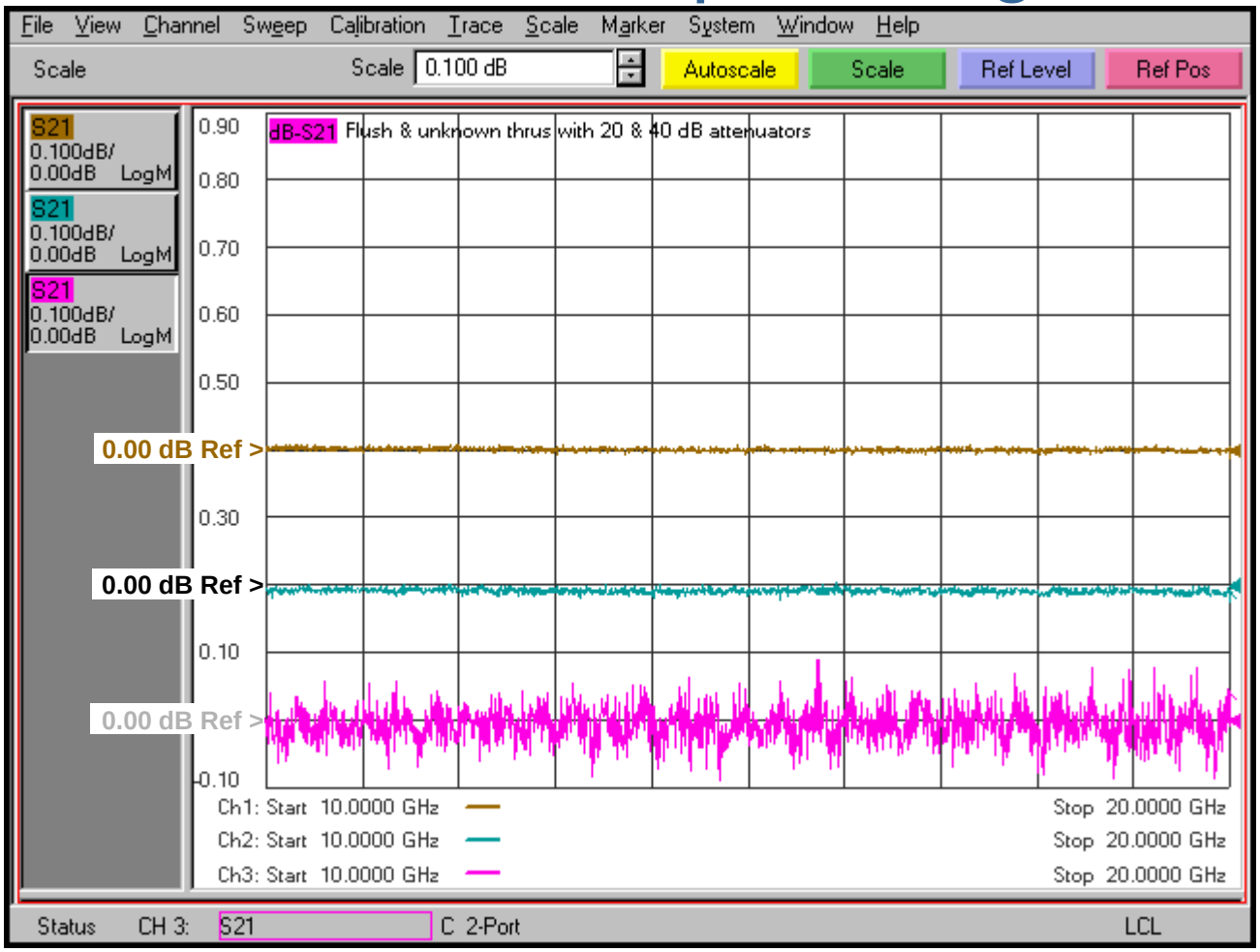


BPF used during thru-calibration step

Measurement of a zero-length thru with unknown thru cal (cal thru = BPF)

0.5 dB/div

Unknown Thru Example Using Attenuators



0.1 dB/div

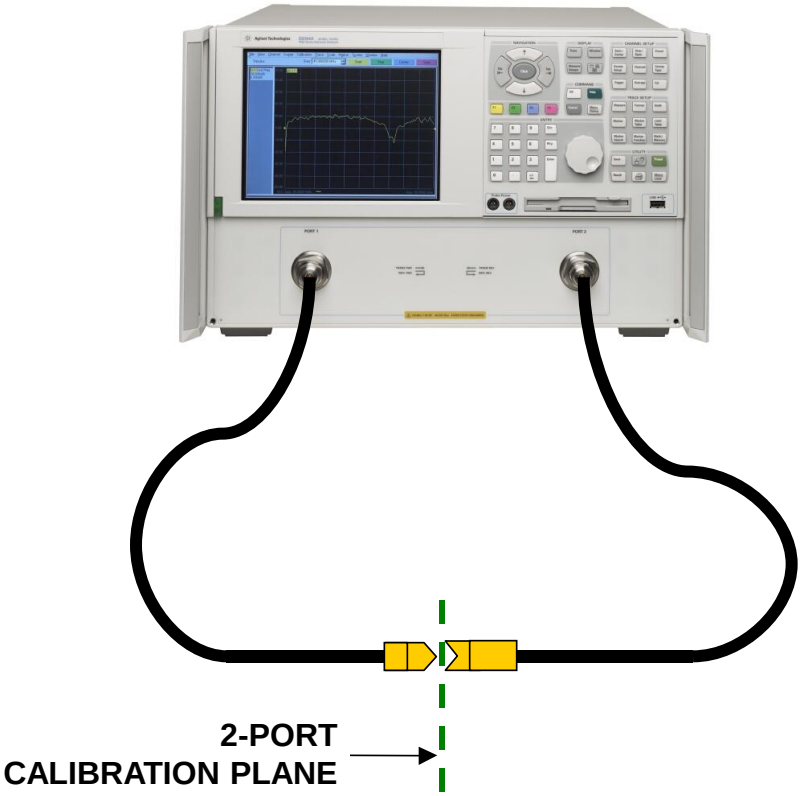
Thrus:

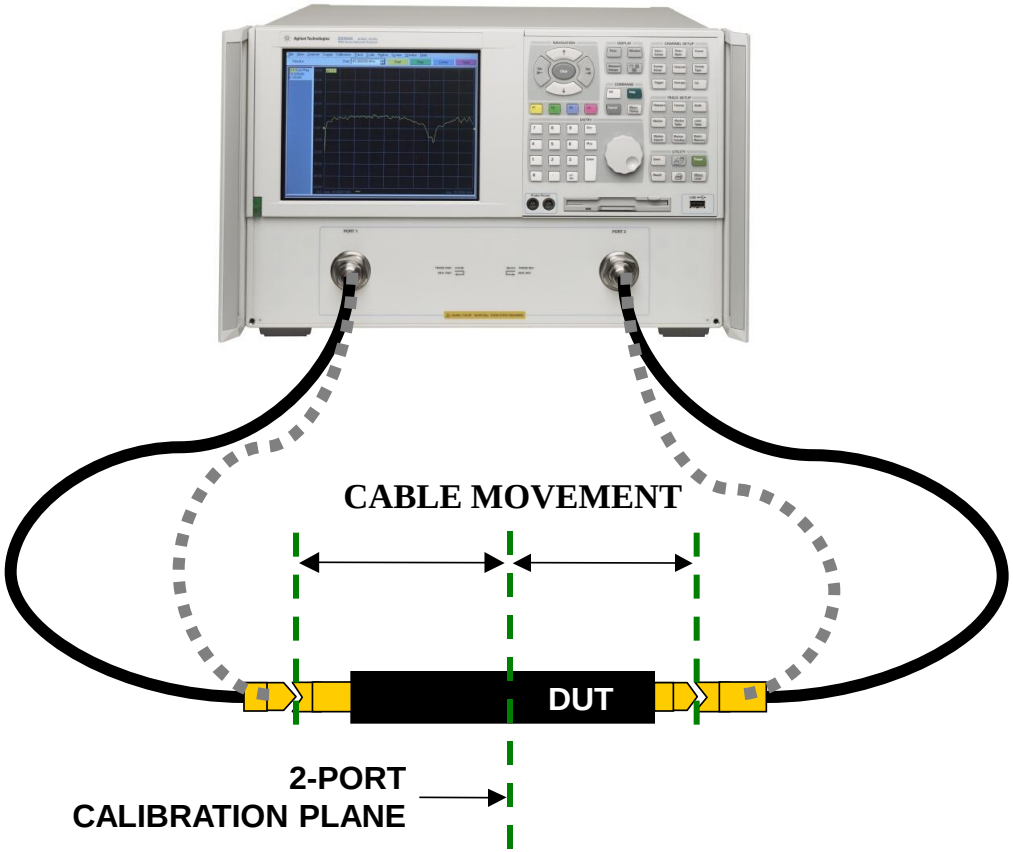
- Zero-length
- 20 dB attenuator
- 40 dB attenuator

IF BW = 1kHz

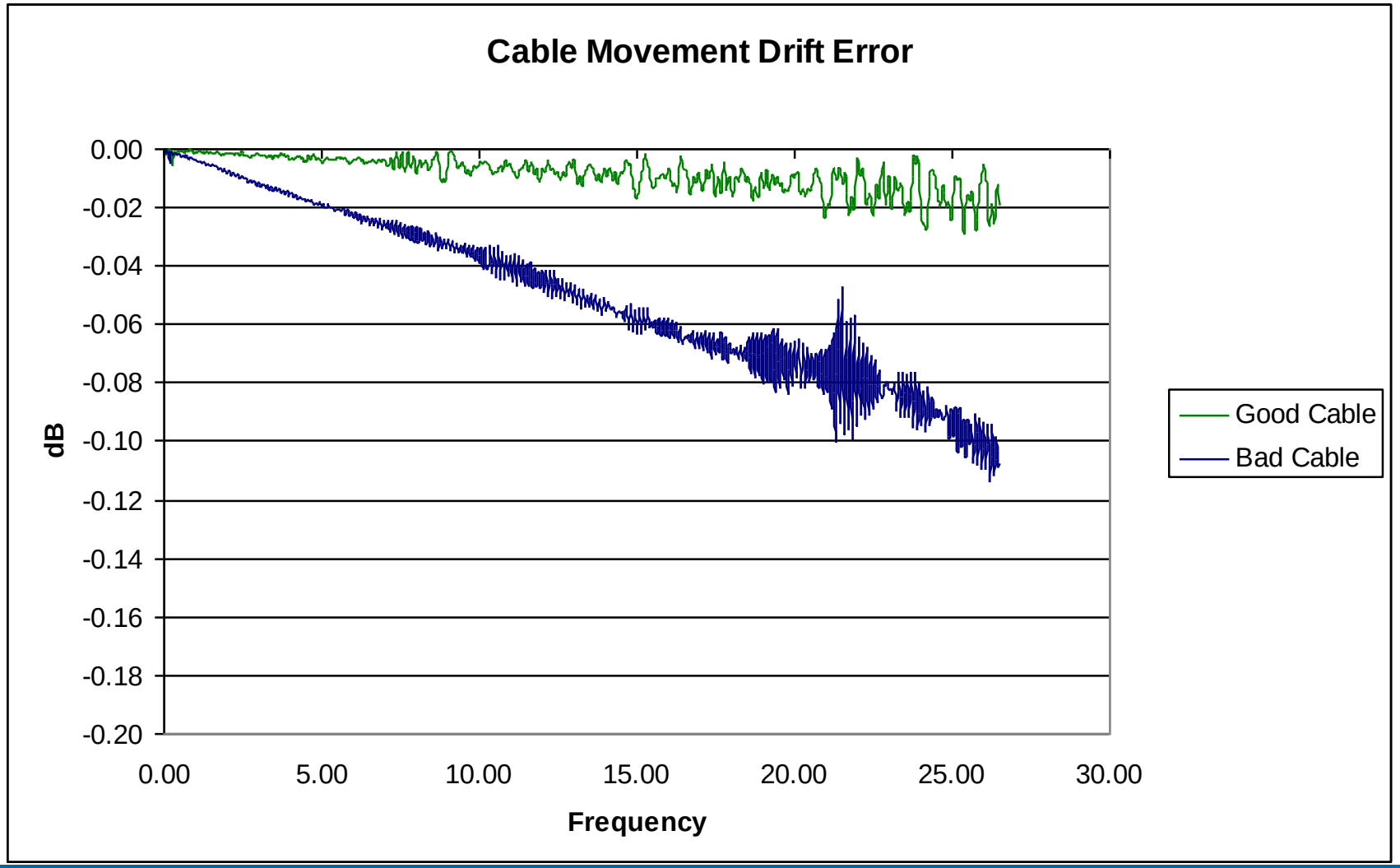
DUT is a zero-length thru

Measuring Physically Long Devices (Usual Way)

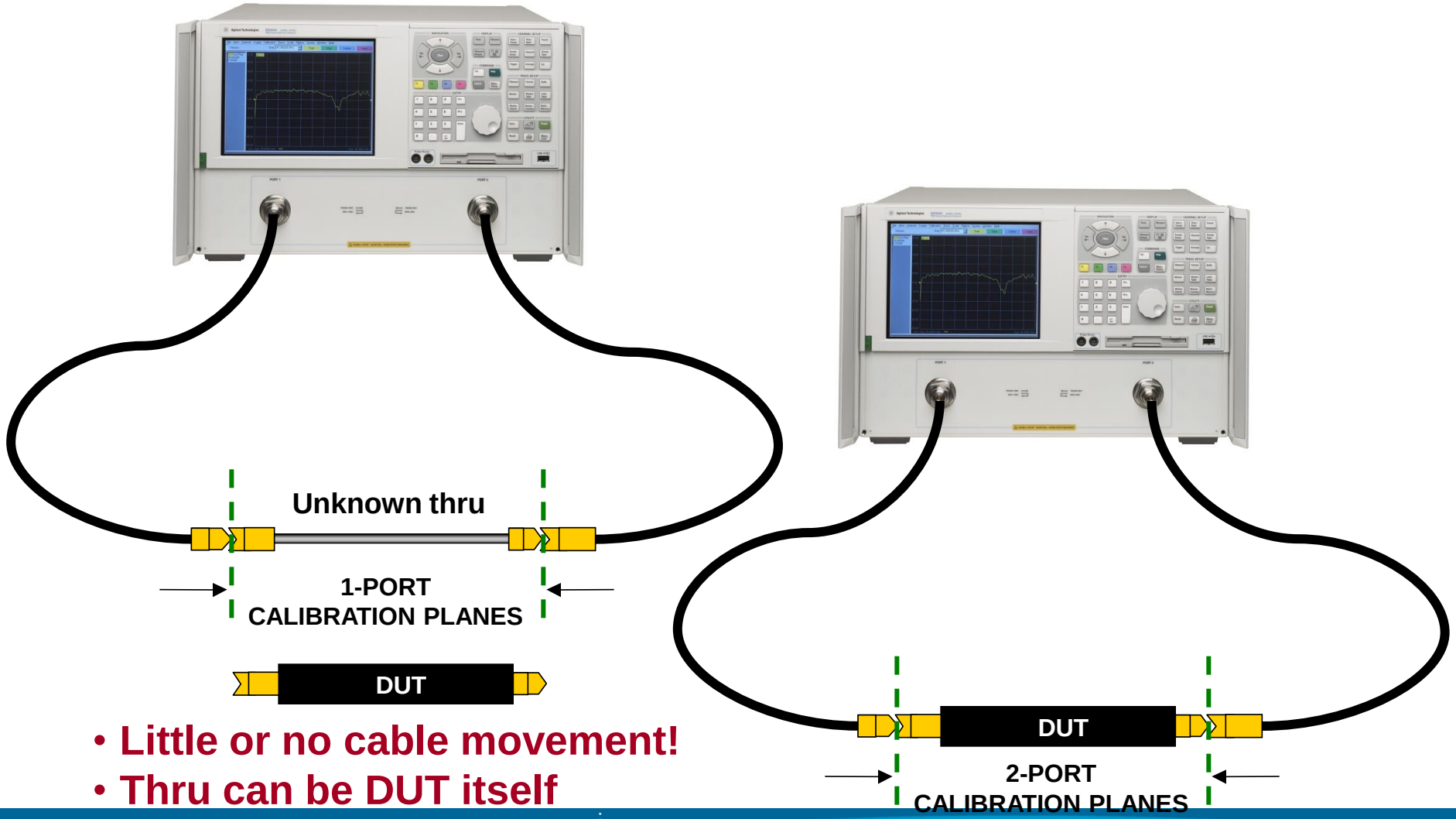




Cable Movement Error

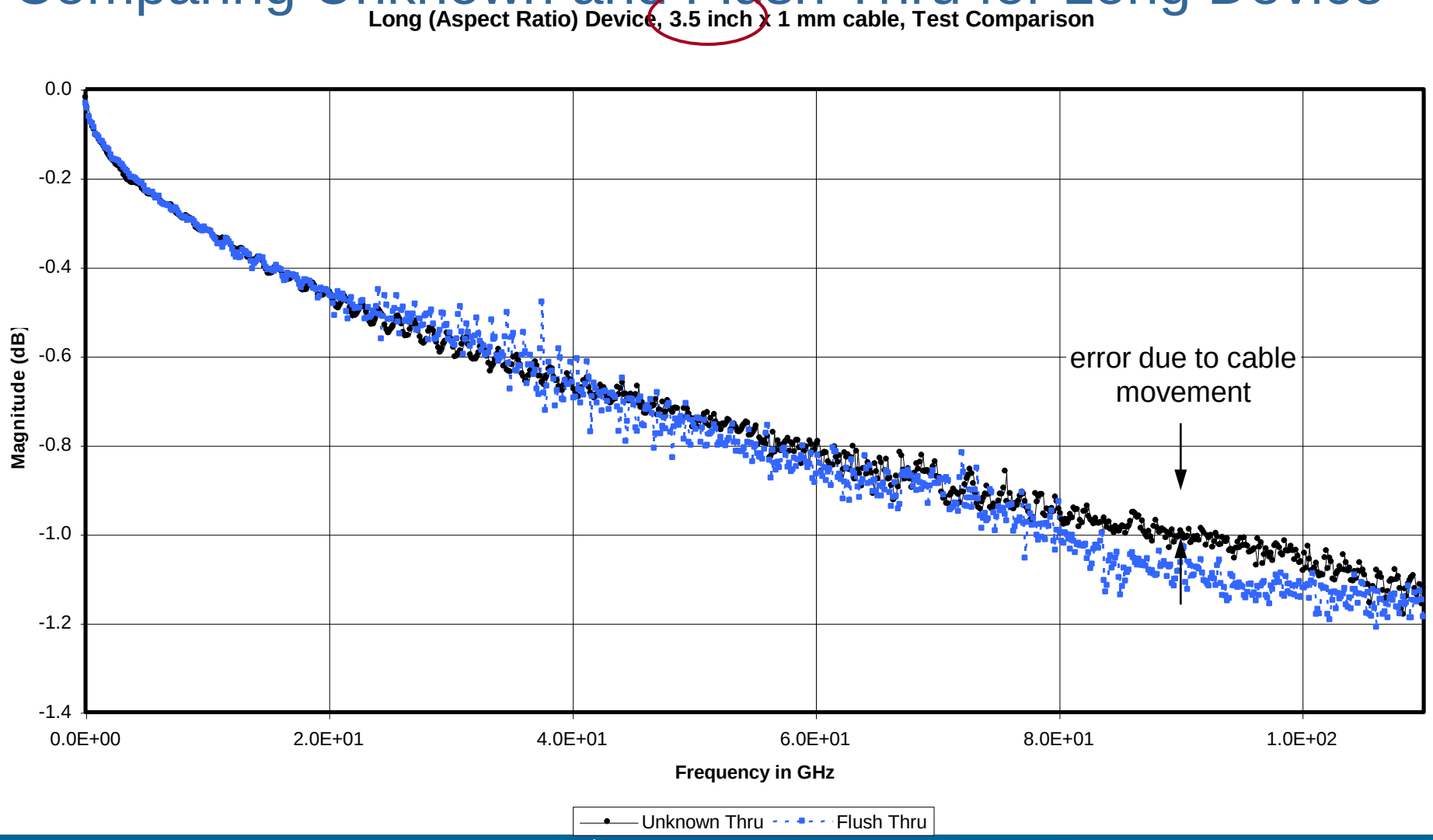


Measuring Physically Long Devices (Unknown Thru)

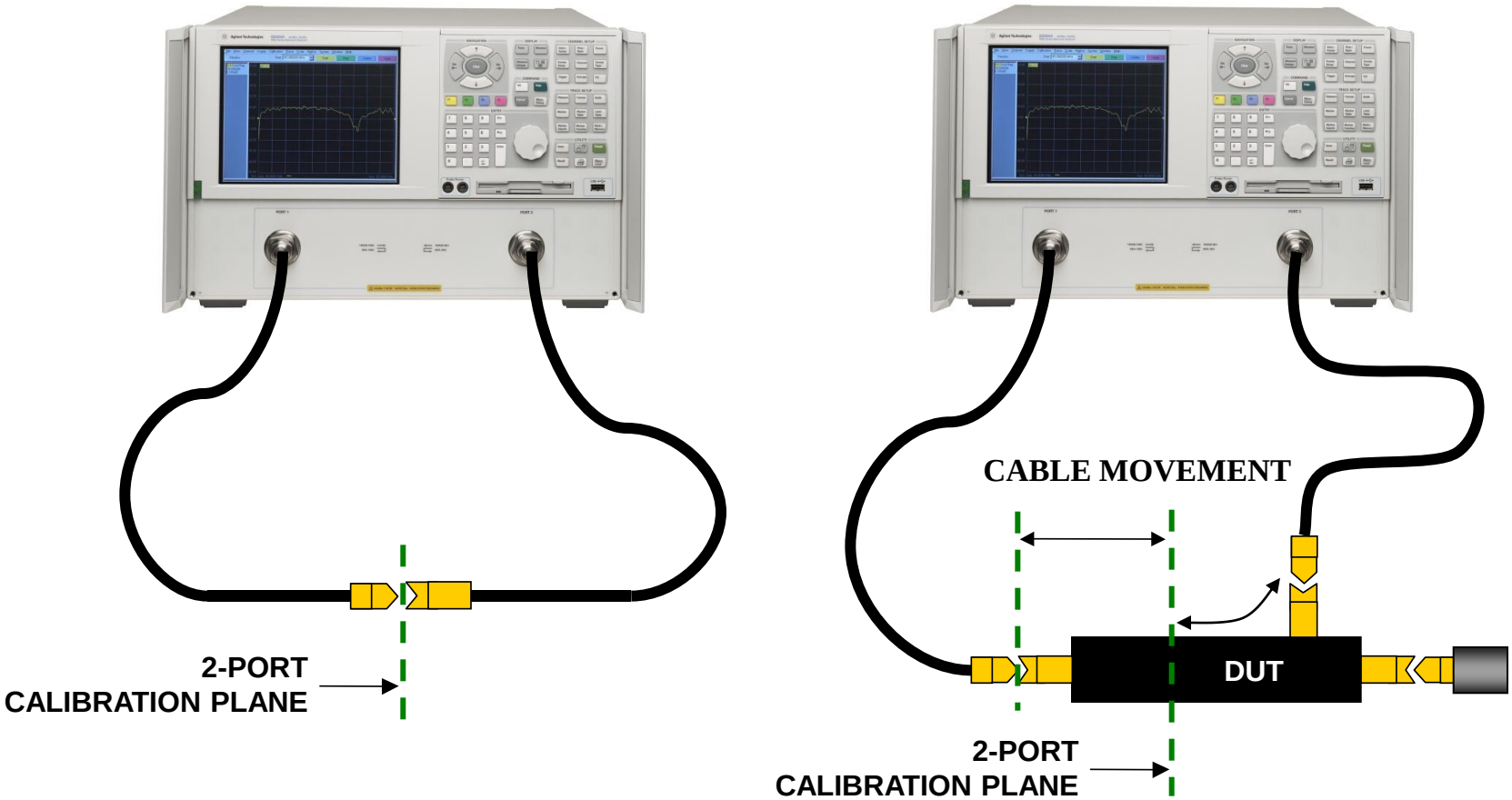


- **Little or no cable movement!**
- **Thru can be DUT itself**

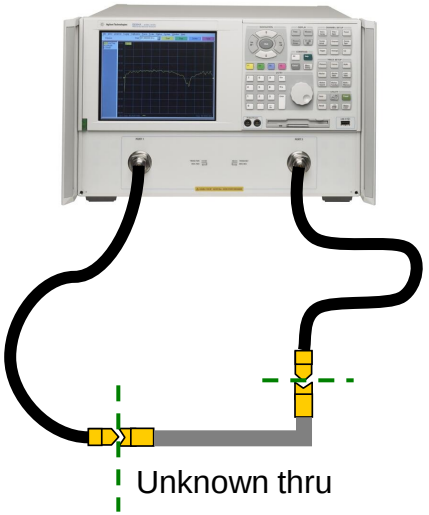
Comparing Unknown and Flush Thru for Long Device



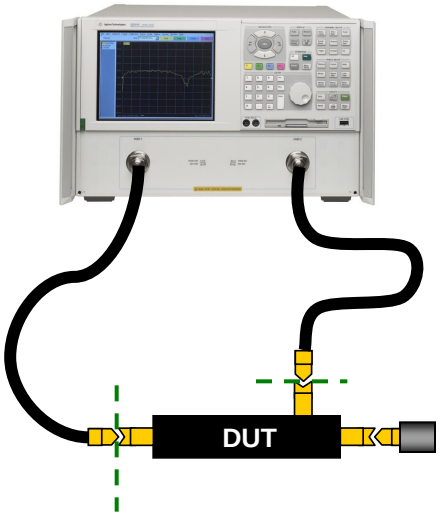
Measuring Devices with Non-Aligned Ports (Usual Way)



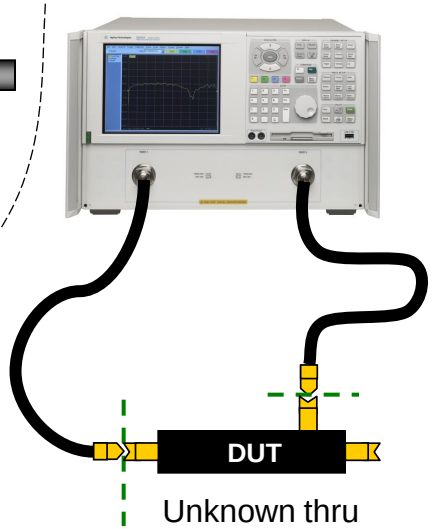
Measuring Devices with Non-Aligned Ports (Unknown Thru)



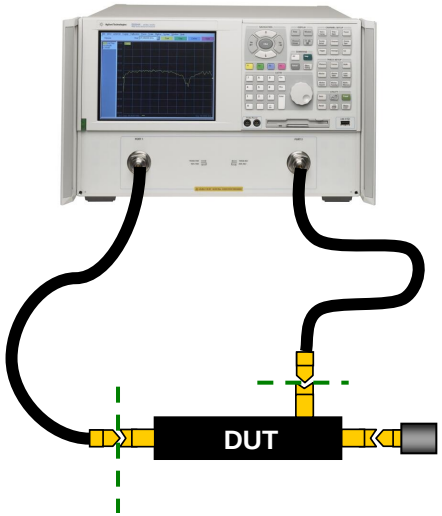
Calibration



Measurement

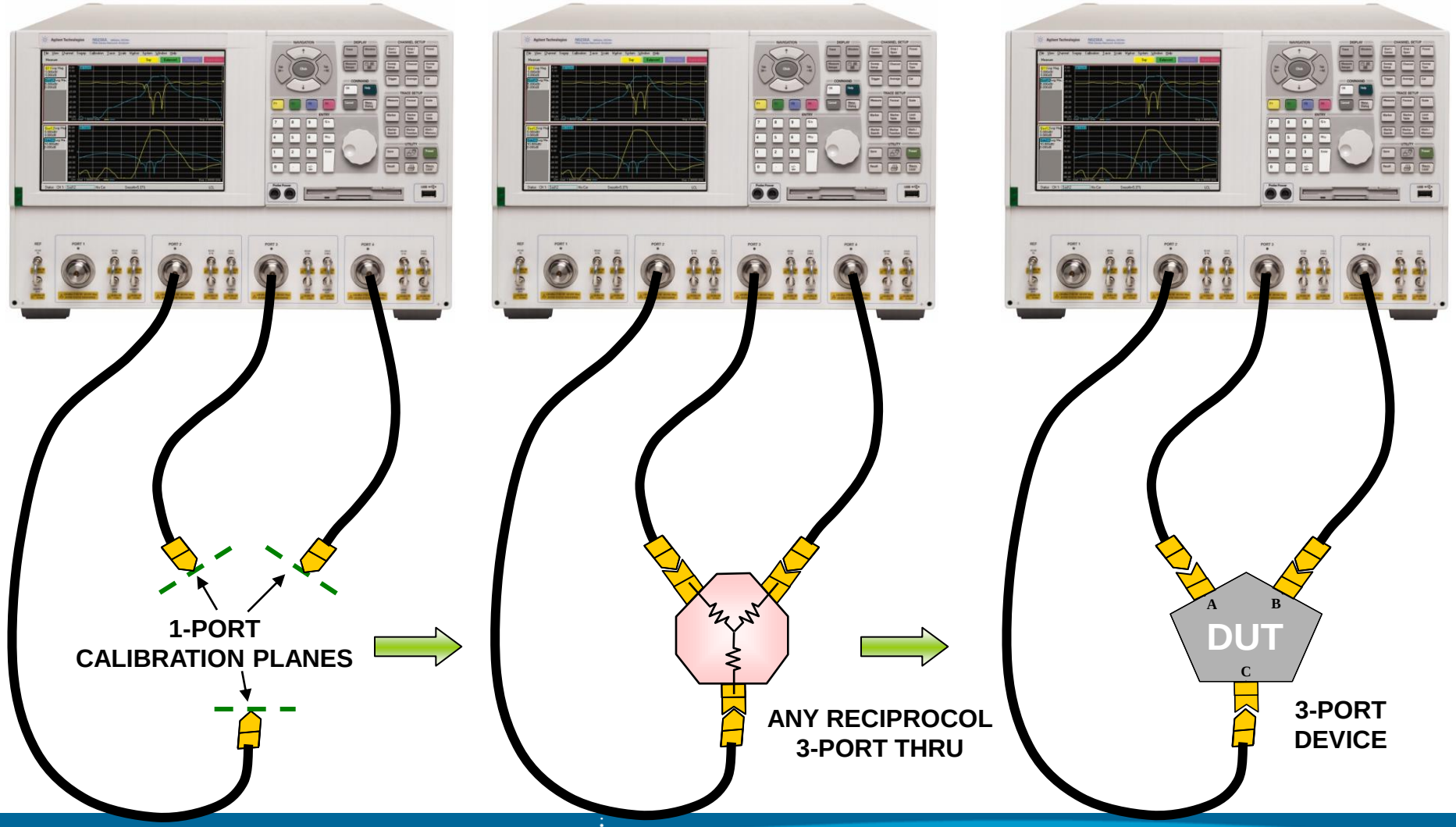


Calibration



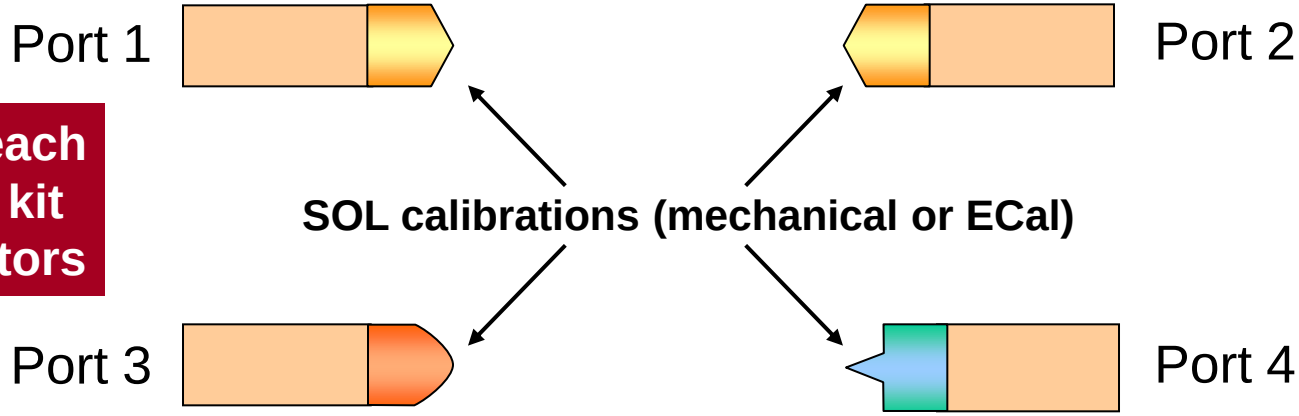
Measurement

Multiport Case (Unknown Thru)

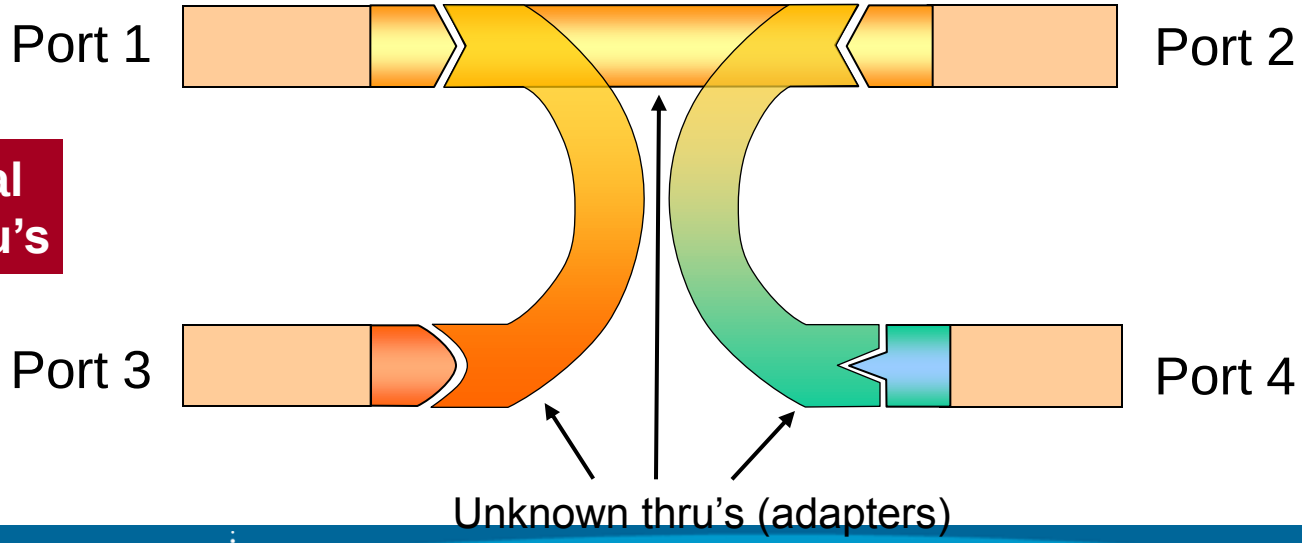


4-Port Unknown Thru with Different Connectors

Perform SOL cal on each test port using a cal kit that matches connectors

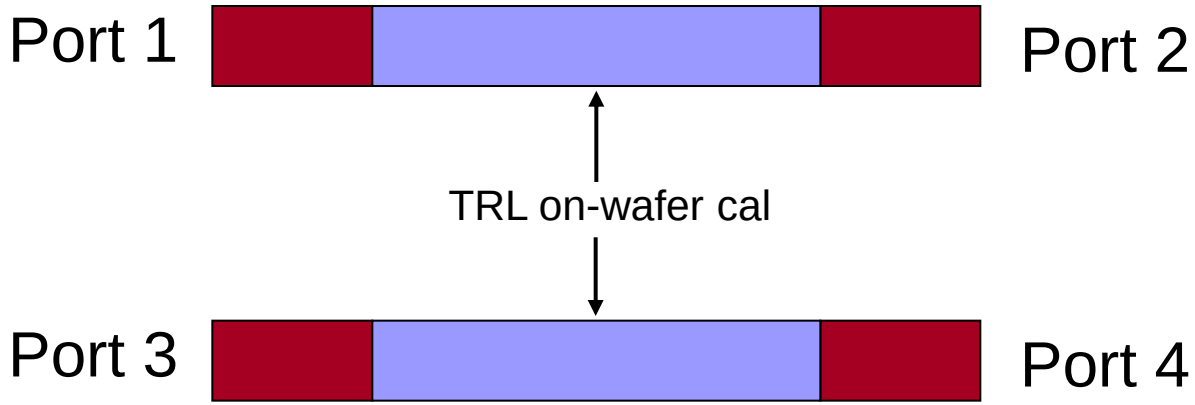


Finish multiport cal using unknown thru's



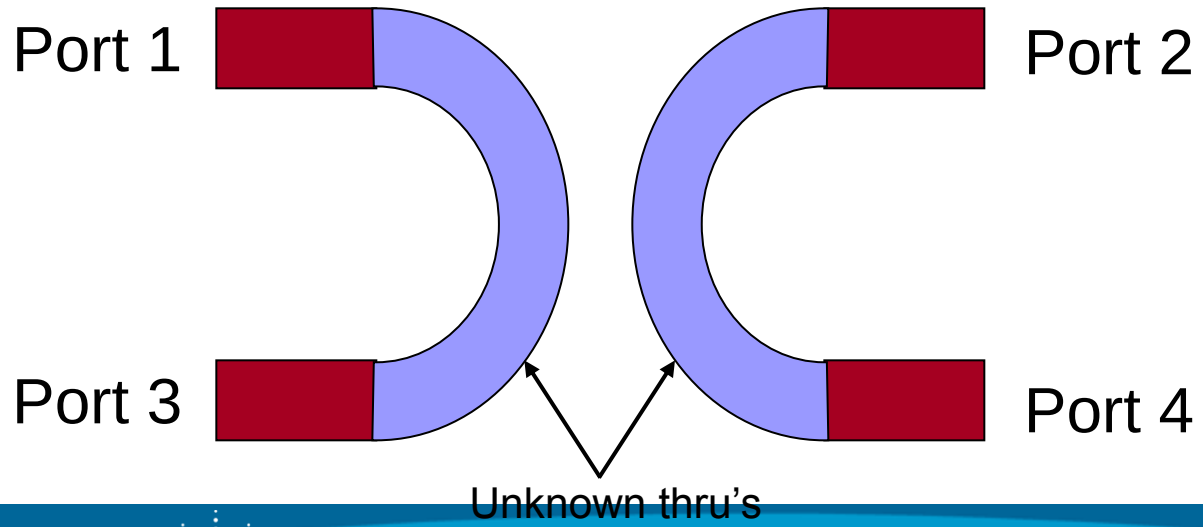
On-Wafer Calibrations Using Unknown Thru's

Straight thru's



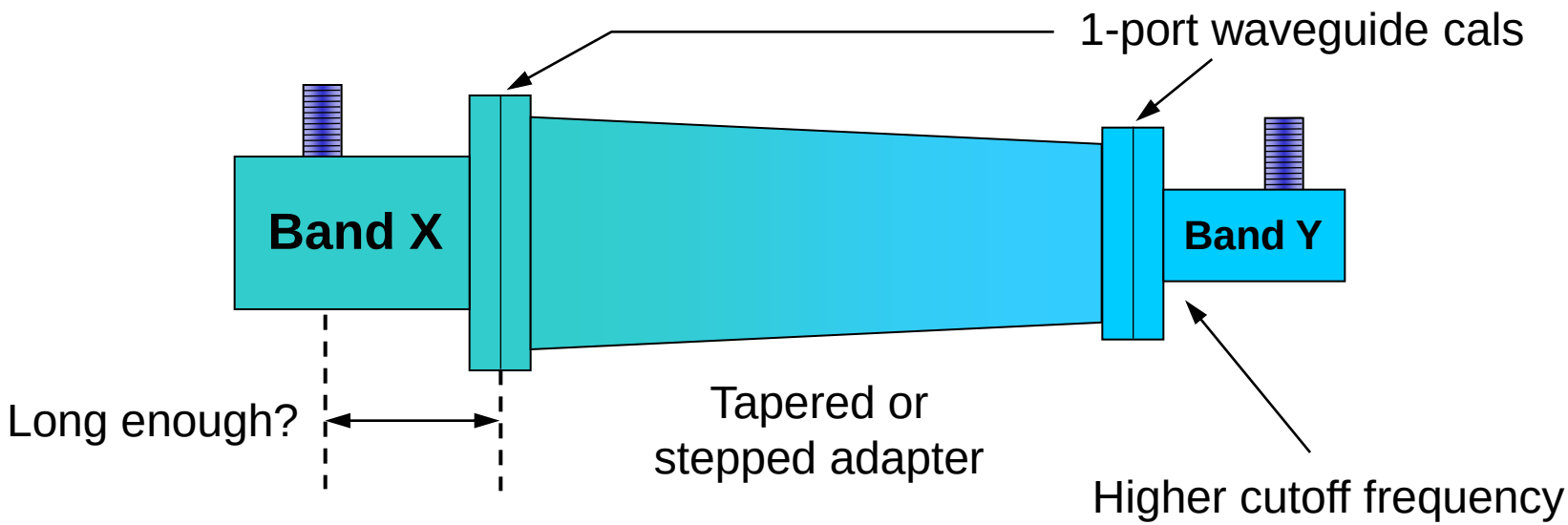
and/or

Imperfect thru's

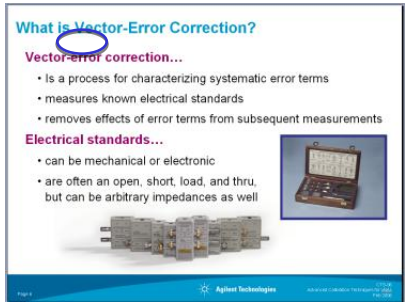


Unknown Thru for Different Waveguide Bands

- Calibrate each waveguide adapter with appropriate waveguide cal kit
- Watch out for these potential problems:
  - Non-overlapping waveguide bands
  - Attenuation near cutoff may be too high for thru calibration
  - Undesired higher-order modes
    (longer adapters provide better attenuation for higher-order modes)

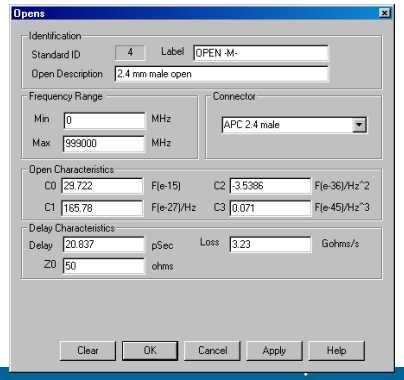


Defining Calibration Standards

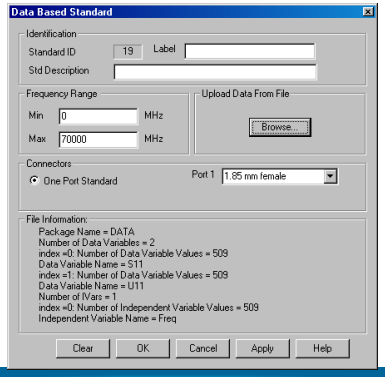


- VNA calibration requires a known electrical standard
- Several approaches for "knowing" electrical performance
  - **Nominal models** based on nominal physical dimensions
  - **Characterized models** based on individually measured physical dimensions
  - **Characterized models or data** based on individually measured electrical quantities
- Models can be polynomial based or data based
  - Polynomial example: C_0, C_1, C_2, C_3 for capacitance of open
  - Data-based example: CITIFILE with magnitude and phase data versus frequency

Polynomial definition

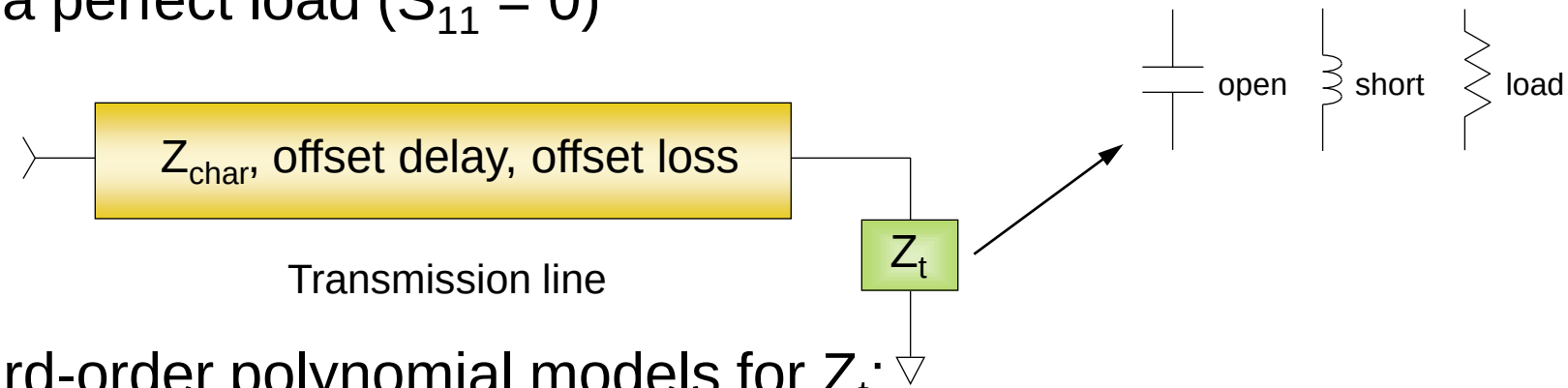


Data-based definition



Traditional Polynomial-Based Models

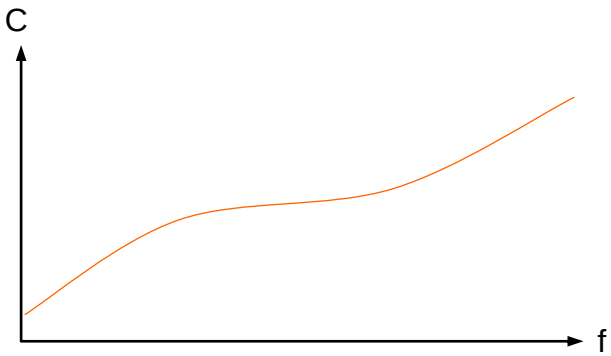
- Lossy transmission line terminated with either…
  - a frequency-dependant impedance for opens and shorts
  - a perfect load ($S_{11} = 0$)



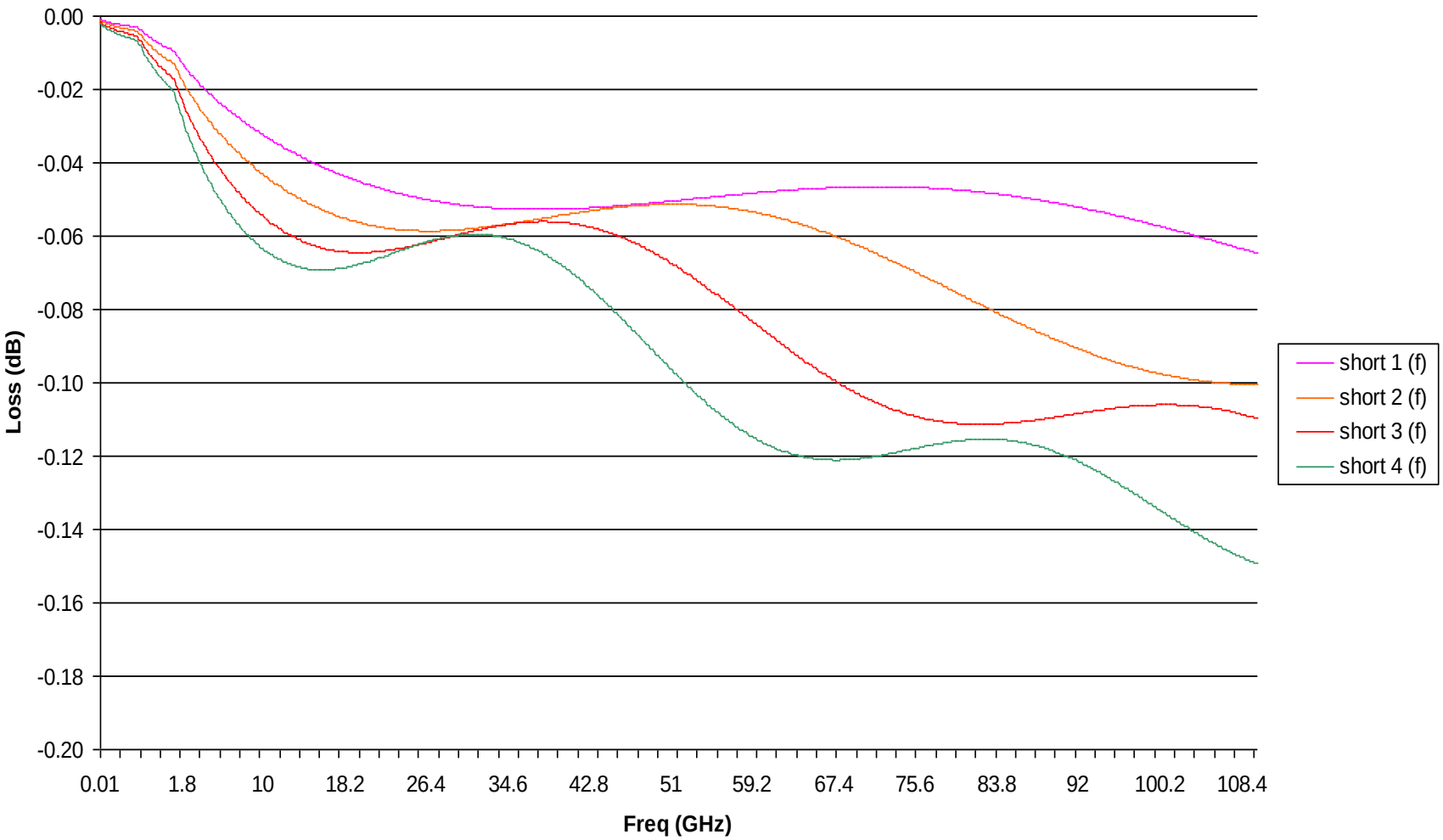
- Third-order polynomial models for Z_t:
  - Open capacitance:

    $$C(f) = C_0 + C_1*f + C_2*f^2 + C_3*f^3$$
  - Short inductance:

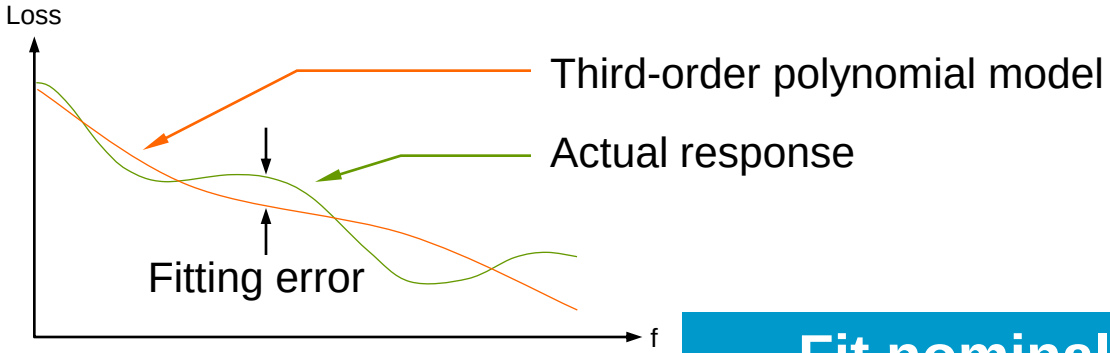
    $$L(f) = L_0 + L_1*f + L_2*f^2 + L_3*f^3$$

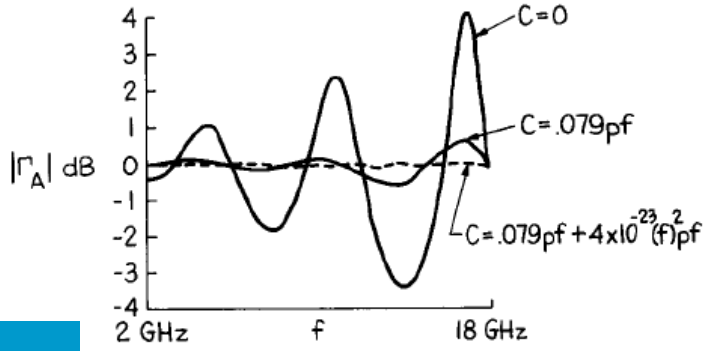


Data-Based Values - 85059A 1.0 mm Calibration Kit



Calibration Standard Modeling Process





Fit nominal response to polynomial model

Compute nominal response from nominal dimensions

Nominal polynomial model: offset loss, delay, Zo, Co, Ls
(includes fitting errors)

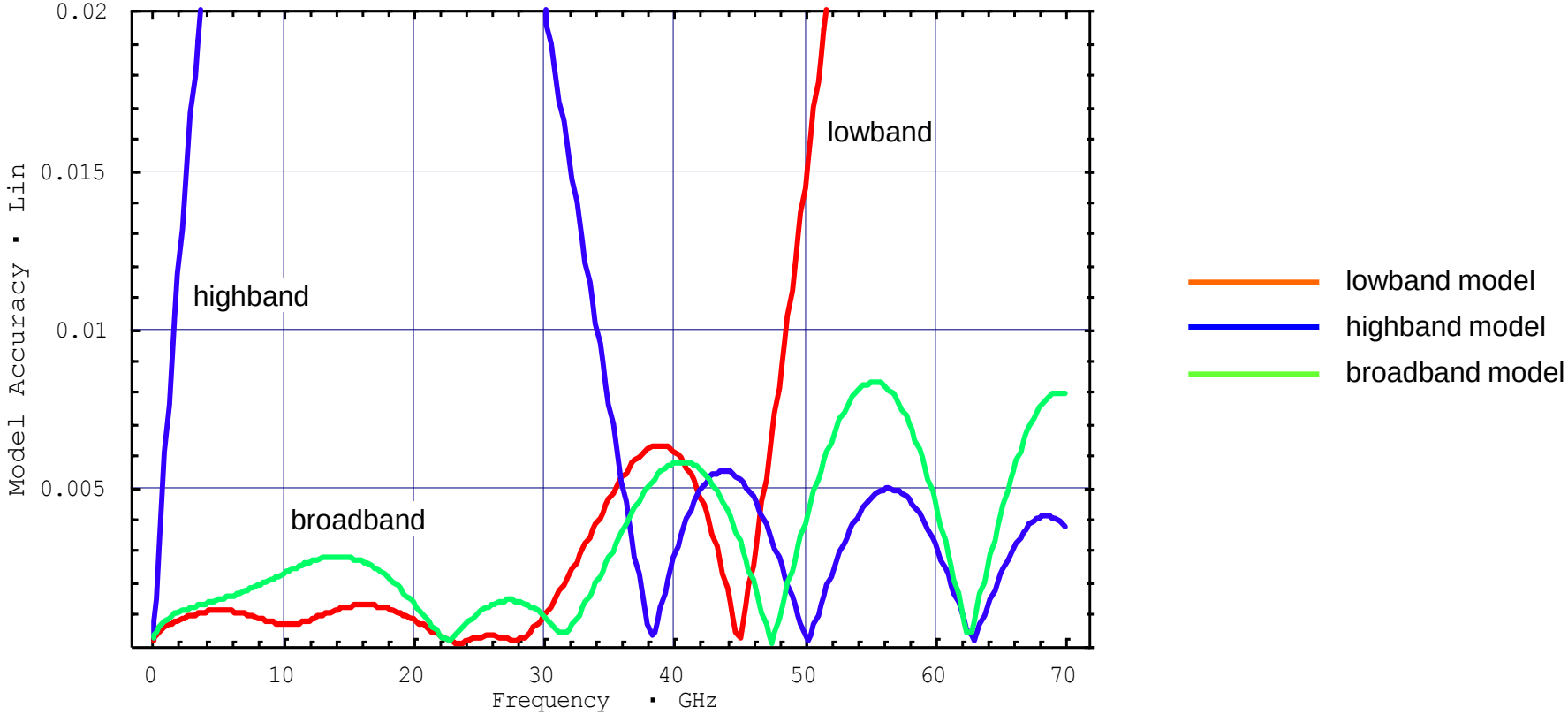
Nominal data-based model
(eliminates fitting errors)

Fitting errors typically get worse as frequency increases

Fitting Errors

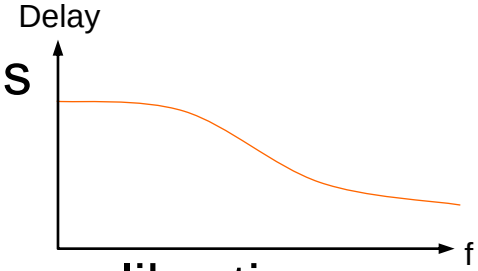
- A given standard can have more than one polynomial model
- Optimized, multi-band models often used to improve accuracy at high frequencies

Comparison of polynomial models for 1.85 mm short 1 (5.4 mm offset)



Benefits of Data-Based Standards

- Increased accuracy of calibration compared to using polynomial models, especially for frequencies > 50 GHz
- Eliminates the necessity of fitting the calibration standard's response to a limited set of low-order models
  - Not restricted to "coax" or "waveguide" models
  - Account for any type of dispersion
  - Great for on-wafer, microstrip, coplanar, etc.



- Makes it easy to use characterized devices during calibration
  - No longer need to assume perfect standards (like a broadband load)
  - Use of a characterized load retains ease-of-use of a broadband-load SOLT calibration while significantly improving accuracy
- Can include accuracy data for expanded math

Data-based Standards: Nominal or Characterized Models

Model

Compute nominal response from nominal dimensions → **Nominal data-based model (valid for a particular part number)**

Approach currently used for Agilent's commercial 1.85 and 1.0 mm cal kits

Measure

Characterize actual response for a particular standard (for example, a fixed load) → **Characterized data-based model (valid for a particular standard)**

Often used in metrology labs

Data-Based Standard File

```
CITIFILE A.01.01
#PNA Rev A.01.00
#PNA STDTYPE DATABASED
COMMENT MODEL: 85058-60101
COMMENT SERIAL NUMBER: NOMINAL
#PNA STDREV Rev A.01.00
#PNA STDLABEL "SHORT 1 -M-"
#PNA STDDESC "1.85 mm male [SHORT 1]"
#PNA STDFRQMIN 0
#PNA STDFRQMAX 70000000000
#PNA STDNUMPORTS 1
COMMENT "1.85 mm" known so #PNA DEFINECONNECTOR statement non needed
COMMENT #PNA DEFINECONNECTOR "1.85 mm" 0 70000000000 COAX
#PNA CONNECTOR 1 "1.85 mm" MALE
COMMENT PINDEPTH is optional, only applies to coax devices
#PNA PINDEPTH 1 0.007 0.007

NAME DATA
COMMENT This section describes the s parameter data and weighting
COMMENT factor for the calibration standard
COMMENT COVERAGEFACTOR is used to scale the weighting factor
COMMENT S[i,j] is sij for the standard. Supported formats: RI
COMMENT U[i,j] is the weighting factor for sij.
COMMENT Supported U[i,j] formats: RI, MAG
#PNA COVERAGEFACTOR 2
```

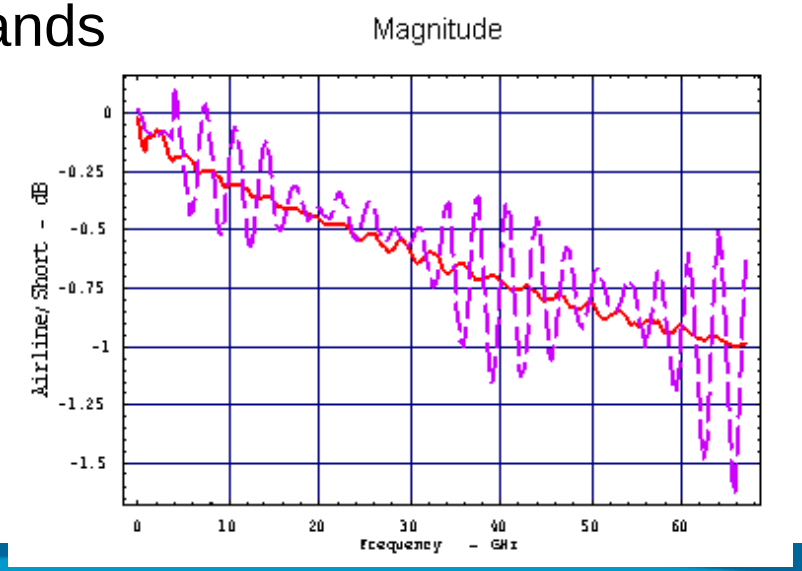
```
COMMENT note number of points is 509 below
VAR Freq MAG 509
DATA S[1,1] RI
DATA U[1,1] MAG
VAR_LIST_BEGIN
0
10000000
15000000
...
70000000000
VAR_LIST_END
BEGIN
-1,0
-0.99976354927,0.00249289367
-0.99970950119,0.00367766097
...
0.9772034982,-0.14575300423
END
BEGIN
0.00028
0.00028
0.00028
...
0.005
END
```

Ignored when not used with expanded calibration

What is Expanded (Weighted-Least-Squares) Cal?

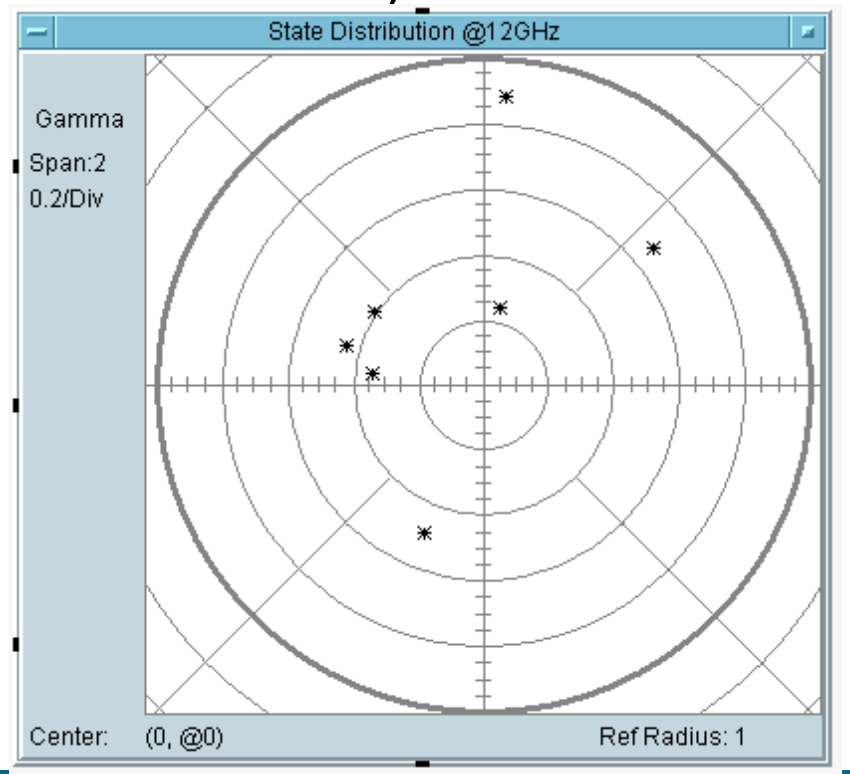
- Measures multiple (>3) standards at each frequency to provide over-determined solution to reflection error terms of SOL cal
- Uses weighted-least-squares fit to calculate error coefficients
- Weighting factor is a function of frequency and is a combination of calibration-standard accuracy and proximity to other standards
- Eliminates discontinuities due to abrupt changes in calibration standards for different frequency bands

Result: higher accuracy!



Advantage of Measuring More Than 3 Standards

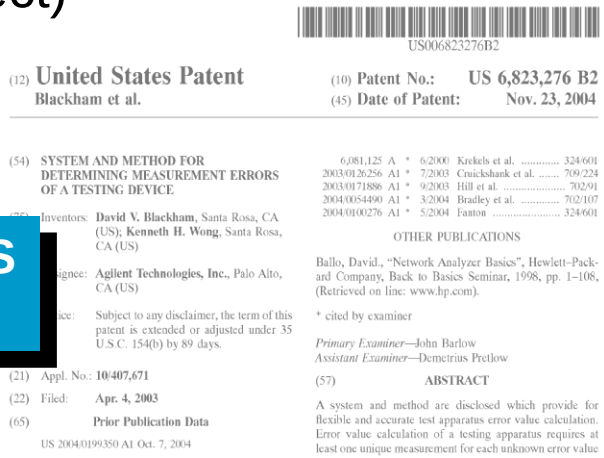
- Similar to trace averaging – the more data, the better the results
- Reduces residual errors after calibration
- Used in Agilent's ECal (electronic calibration) modules to improve accuracy



Why “Weighted” Least Squares?

- Weighted least squares (WLS) beneficial when calibration standards are known with different levels of accuracy
  - Fixed loads are more accurate at low frequencies
  - Sliding loads are generally more accurate at higher frequencies
  - Shorts are more accurate than opens
- Less weighting is assigned to calibration standards that are bunched together (proximity effect)

Patented WLS algorithm



US006823276B2

(12) **United States Patent**
Blackham et al.

(10) **Patent No.: US 6,823,276 B2**
(45) **Date of Patent: Nov. 23, 2004**

(54) **SYSTEM AND METHOD FOR DETERMINING MEASUREMENT ERRORS OF A TESTING DEVICE**

(75) Inventors: **David V. Blackham**, Santa Rosa, CA (US); **Kenneth H. Wong**, Santa Rosa, CA (US)

(73) Assignee: **Agilent Technologies, Inc.**, Palo Alto, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 89 days.

(21) Appl. No.: **10/407,671**

(22) Filed: **Apr. 4, 2003**

(65) **Prior Publication Data**

US 2004/0199350 A1 Oct. 7, 2004

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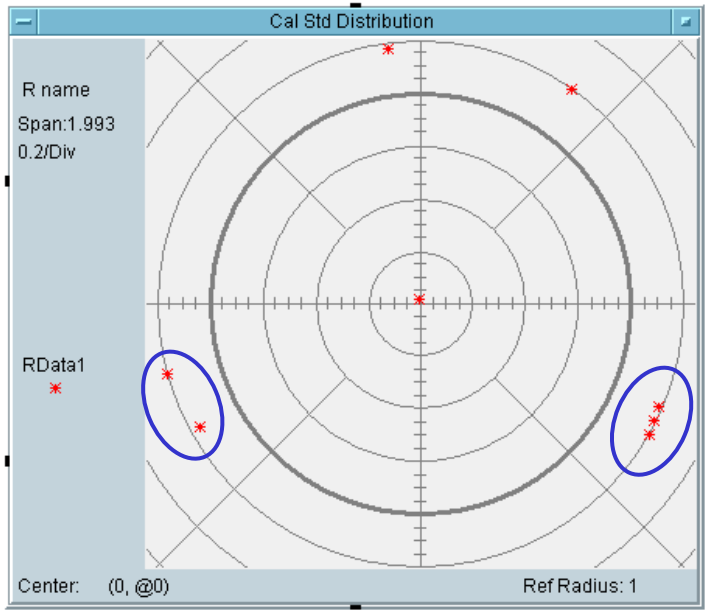
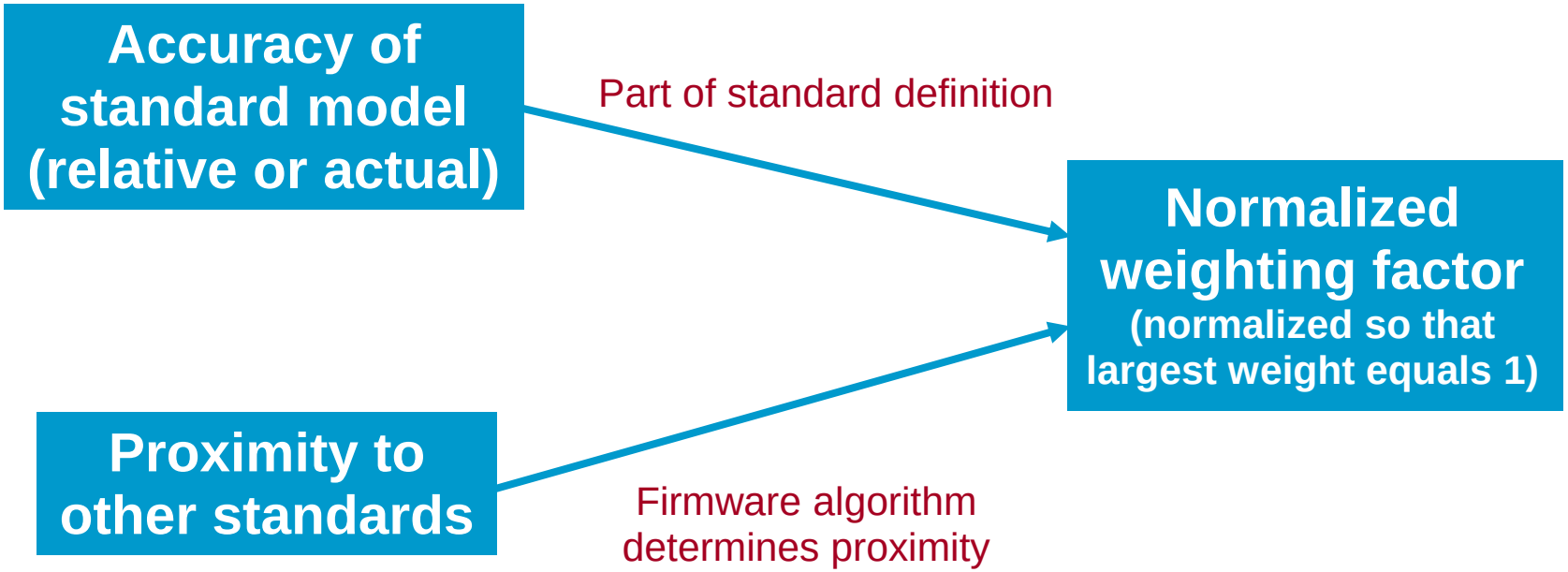
Primary Examiner—John Barlow
Assistant Examiner—Demetrius Pretlow

(57) **ABSTRACT**

A system and method are disclosed which provide for flexible and accurate test apparatus error value calculation. Error value calculation of a testing apparatus requires at least one unique measurement for each unknown error value



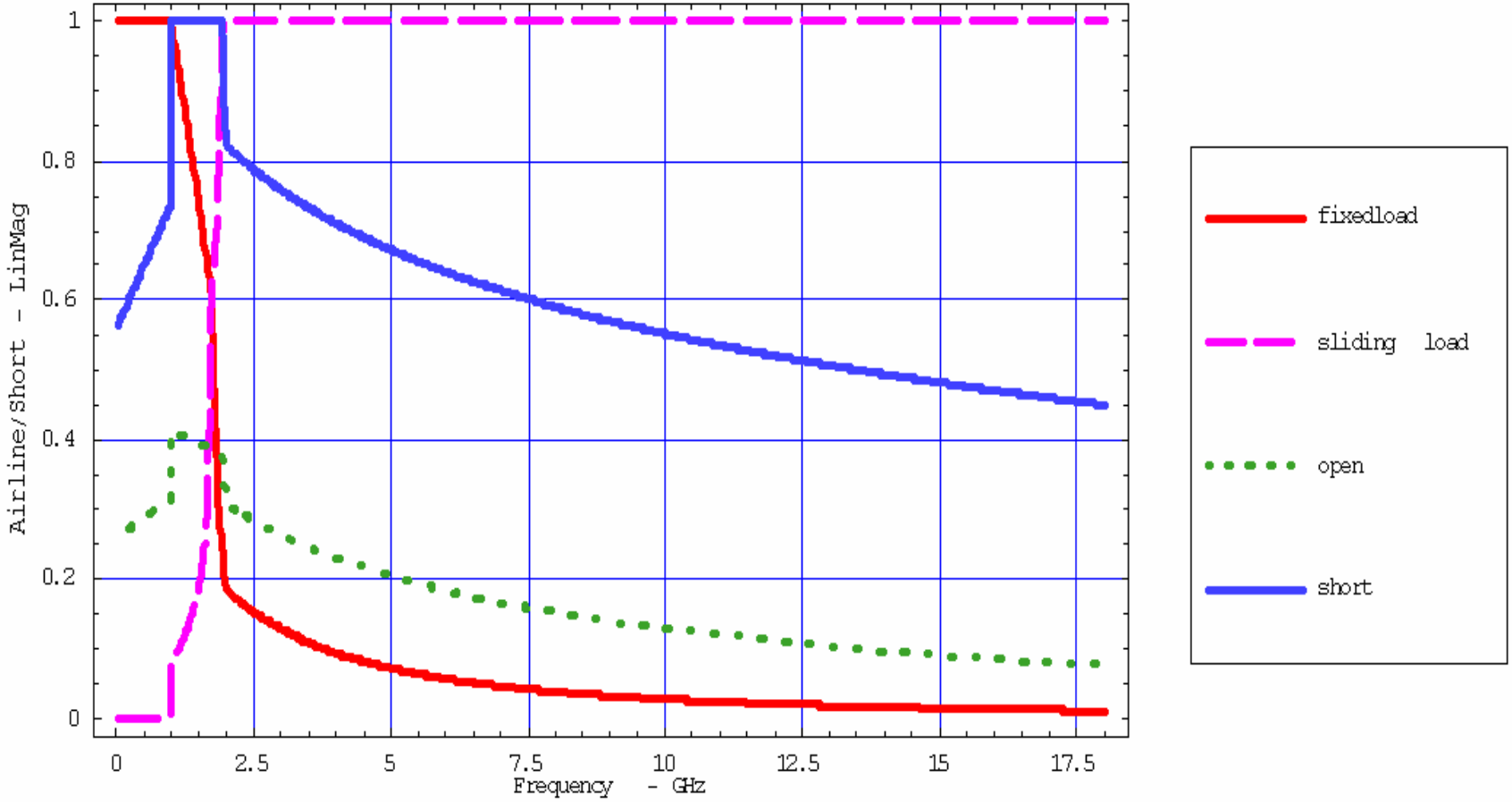
Factors That Contribute to Weighting



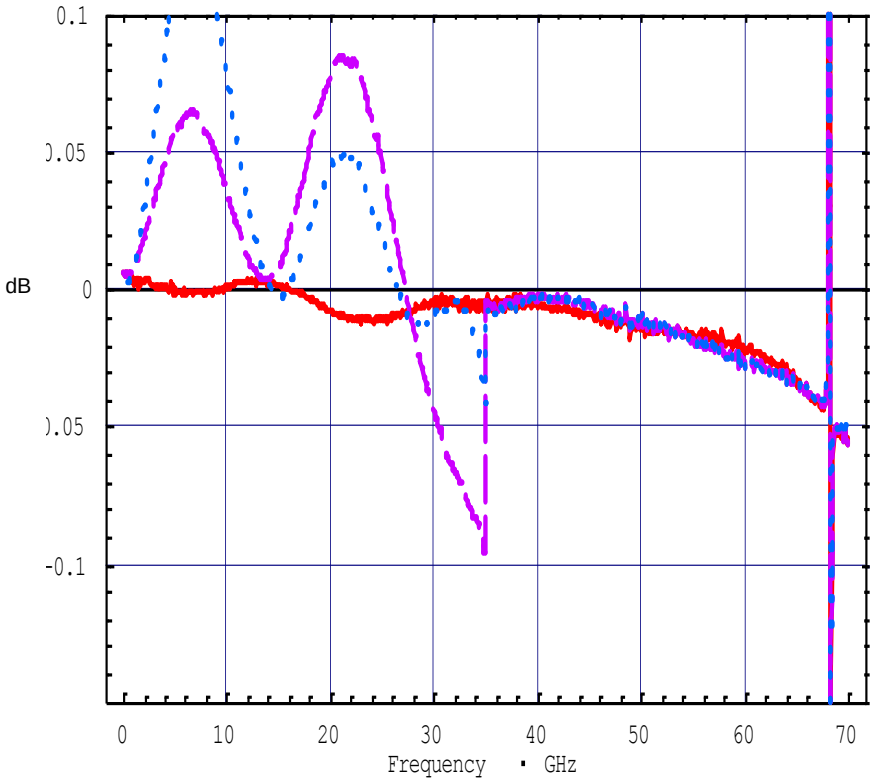
- Data-based standards use actual reported accuracy
- Polynomial standards use relative accuracy model, defined over full frequency range of the connector
- Mixing actual and relative accuracy within a particular calibration kit may lead to less-than-optimal results

Example of Relative (Normalized) Weighting

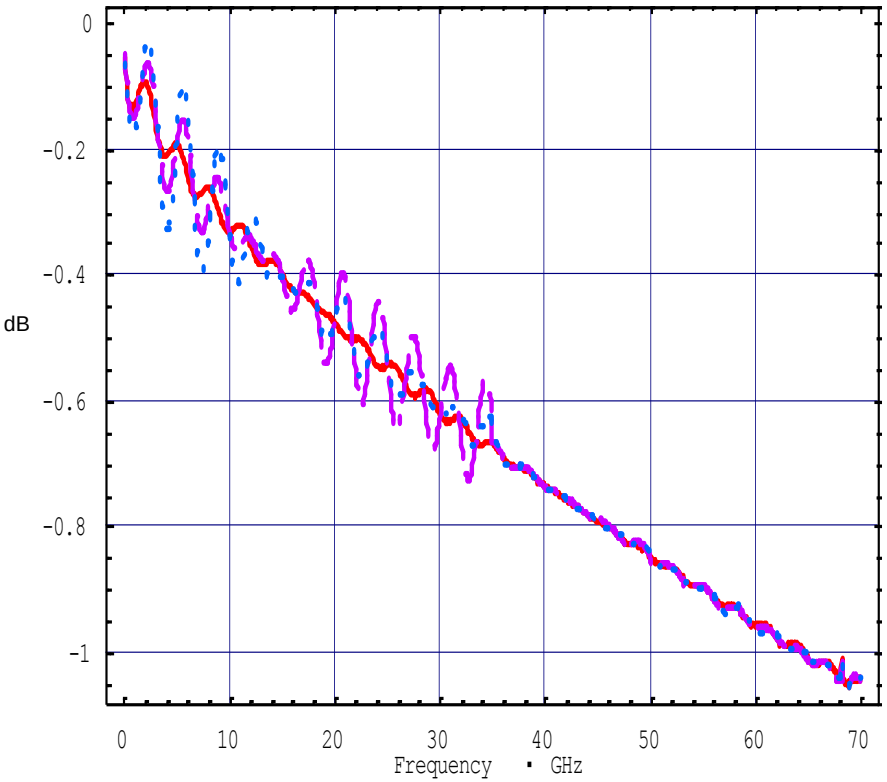
Weights for each standard versus frequency for a weighted-least squares calibration using an 85050B (a non-data-based) 7mm cal kit



Measurements Comparing Three Calibrations



Flush short



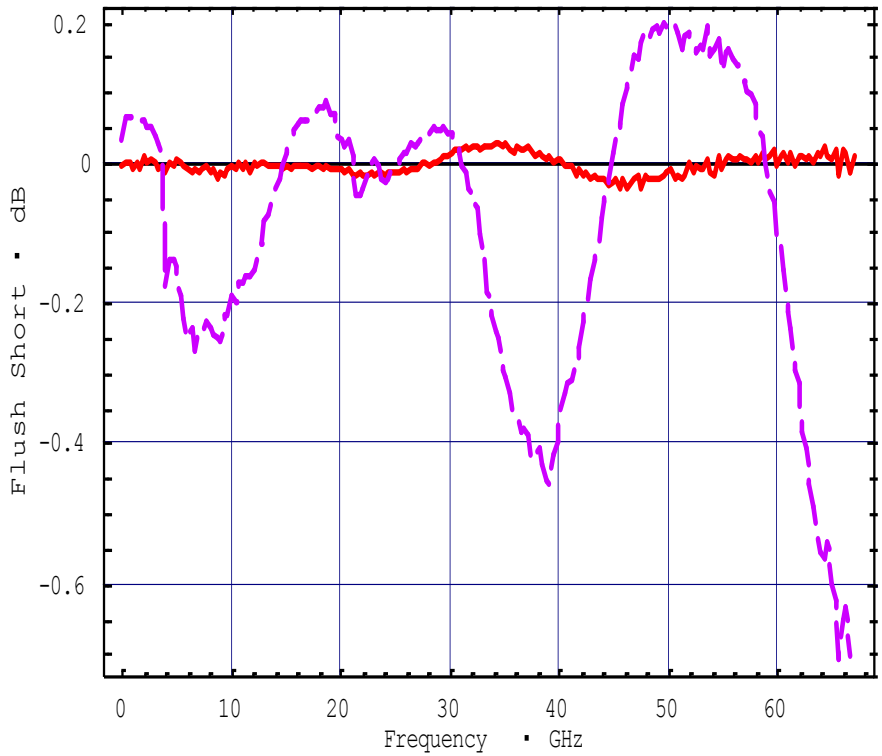
5 cm airline + short

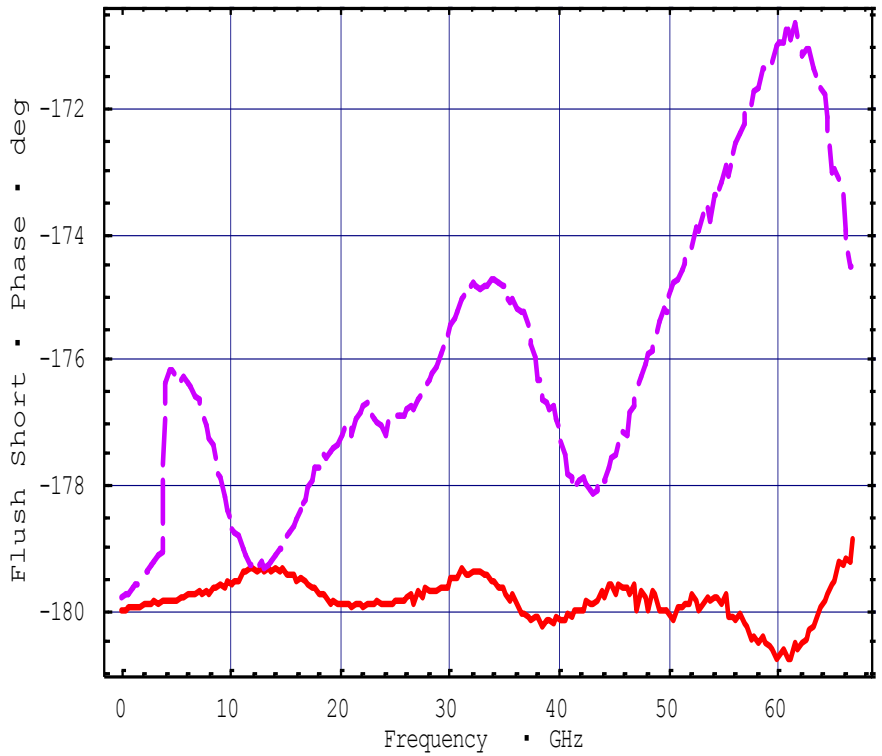
data-based expanded cal (WLS)

3-standard data based

polynomial (banded)

WLS and Sliding-Load* Calibration Comparison – Flush Short



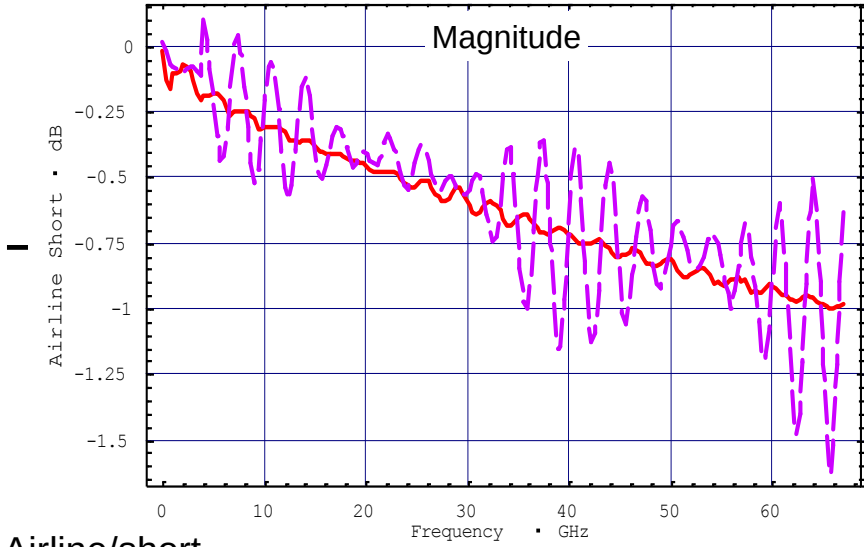


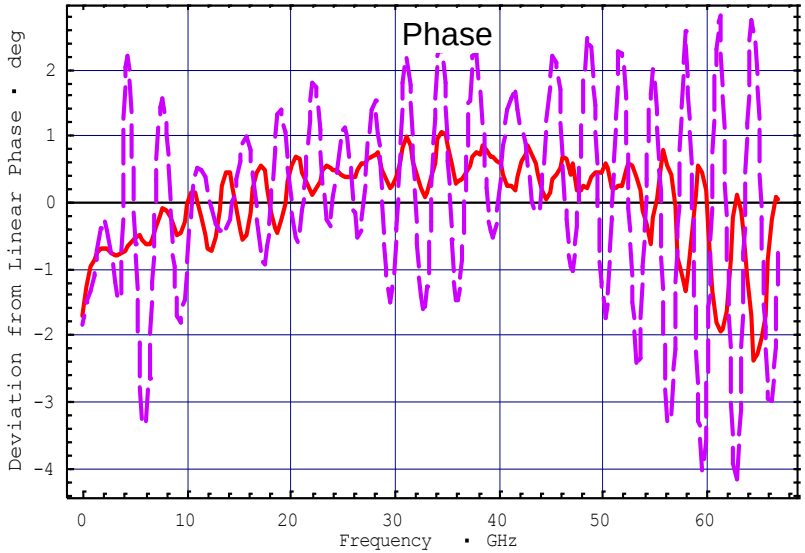
data-based expanded cal (WLS)

sliding-load cal

* Commercially available (non-Agilent) sliding-load cal kit

WLS and Sliding-Load* Calibration Comparison – 5 cm Airline With Flush Short / Fixed Load



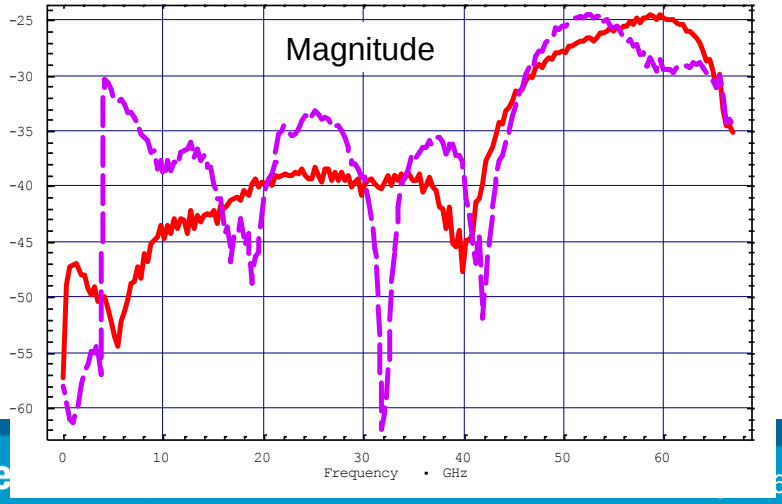


Airline/short

data-based expanded cal (WLS)

sliding-load cal

Load

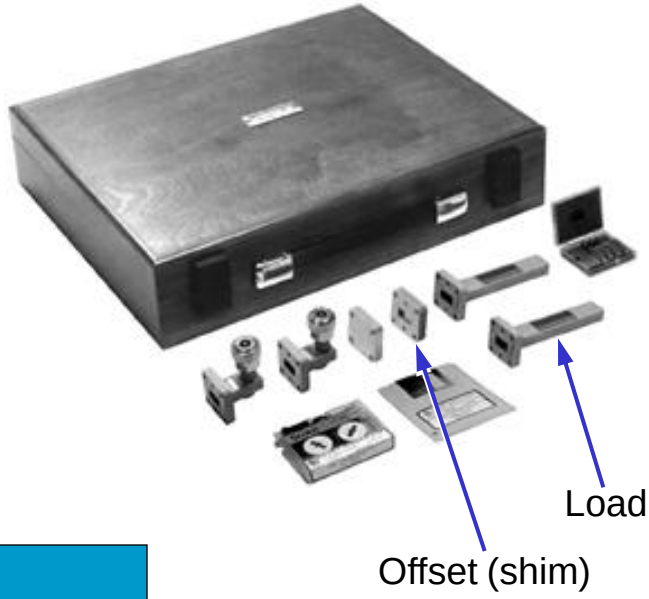


Data-based calibration with expanded math yields much lower measurement errors compared to conventional sliding-load cal

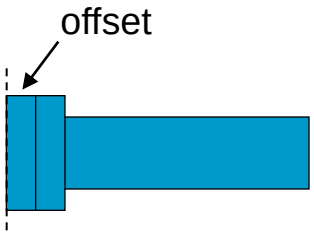
* Commercially available (non-Agilent) sliding-load cal kit

Offset Load Calibration Overview

- Offset-load calibration originated with 8510
- Offset load is a compound standard – load is connected multiple times with different offsets
- In simplest and most common form, there are just two connections: the load by itself, and the load with an offset
- Similar to a sliding load standard, except offsets are set by a known, precise transmission line (e.g., a waveguide section)
- Not the same as a load standard with defined delay, which is a single standard



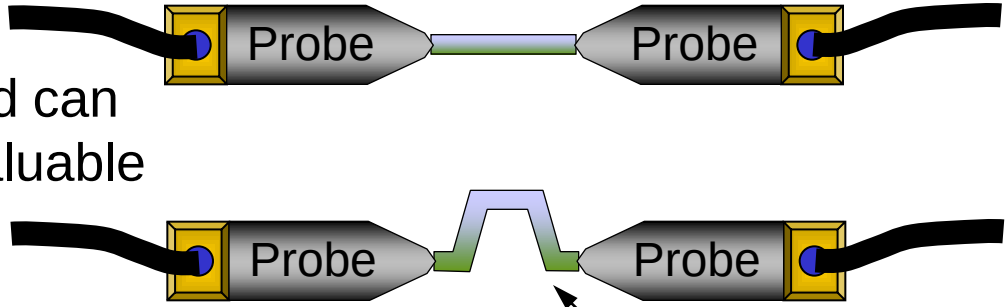
1. Measure load by itself



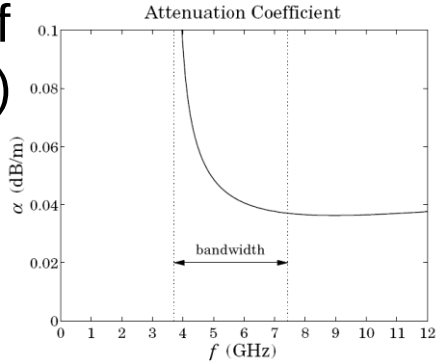
2. Measure load plus offset

Offset Load Calibration Advantages

- Provides higher directivity and load match accuracy when the definition of the offset is better known than the load definition
- Does not require a dual reflectometer VNA as it uses SOLT error model instead of TRL error model
- Ideal for 1-port calibrations
- Also helpful in situations where calibration planes cannot physically move, such as fixed probe or waveguide positions, where TRL calibrations are difficult
- Waveguide offset-load standard can include loss term (especially valuable near cutoff frequency)



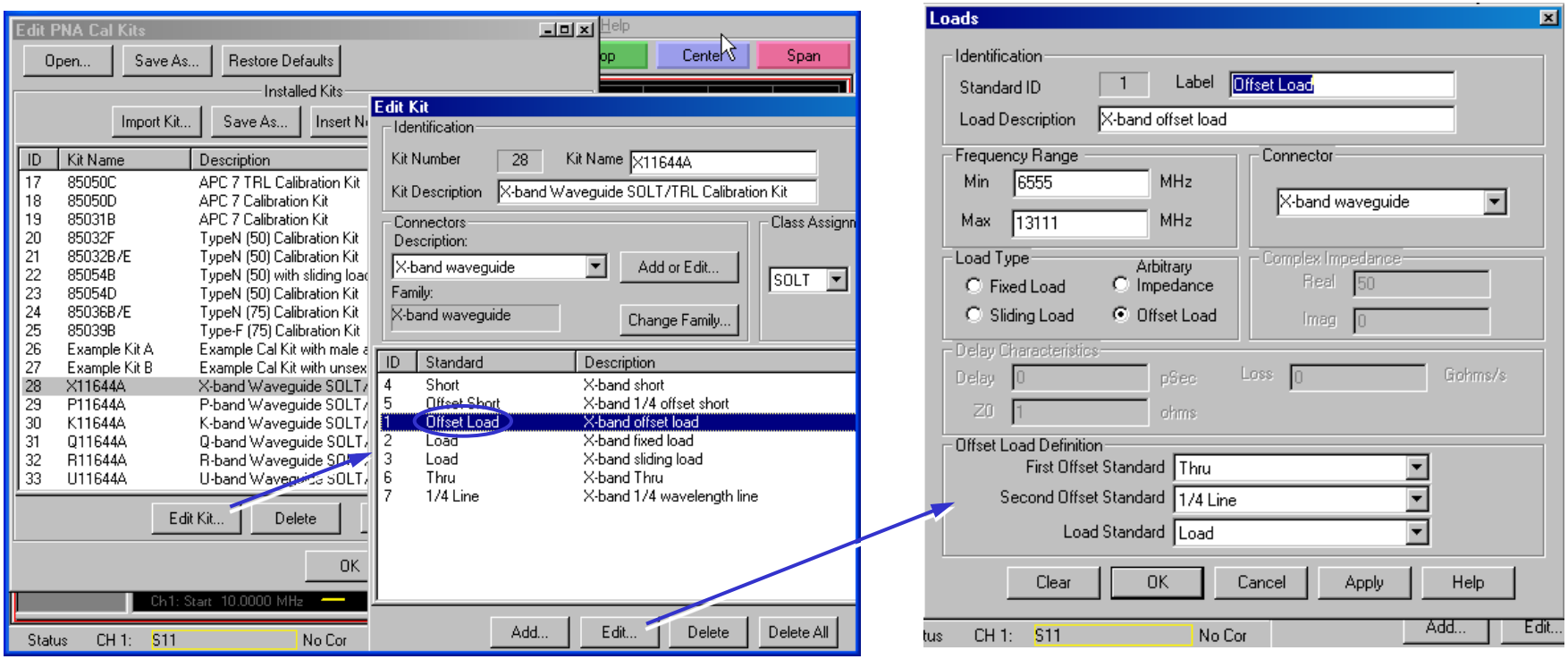
Not a good TRL standard



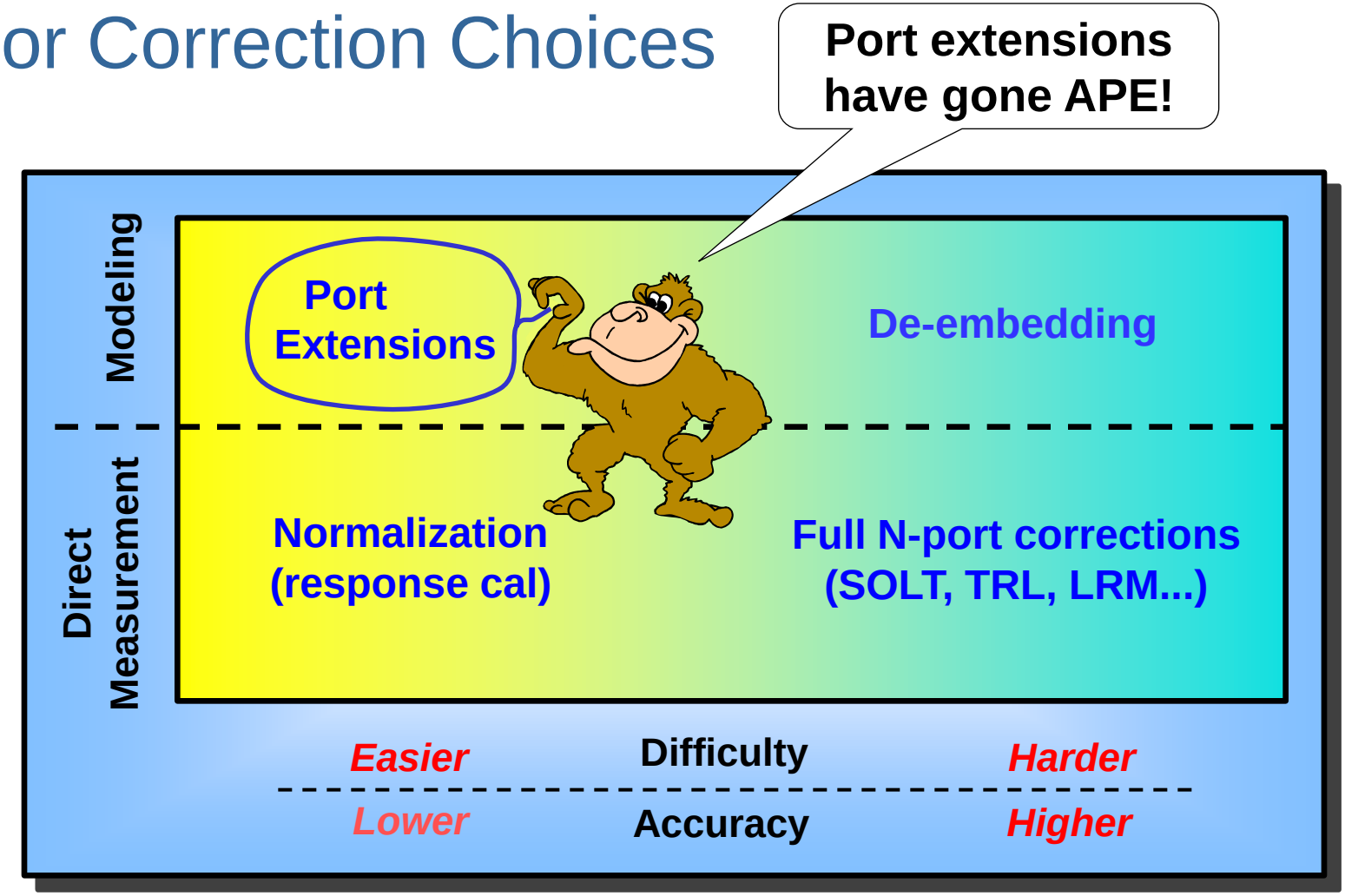
Attenuation constant in WR-159 waveguide

Offset Load Definition

- Only available in PNA guided calibration (SmartCal)
- Math is enhanced over what 8510 did
- Offset load definitions are included in Agilent waveguide cal kits



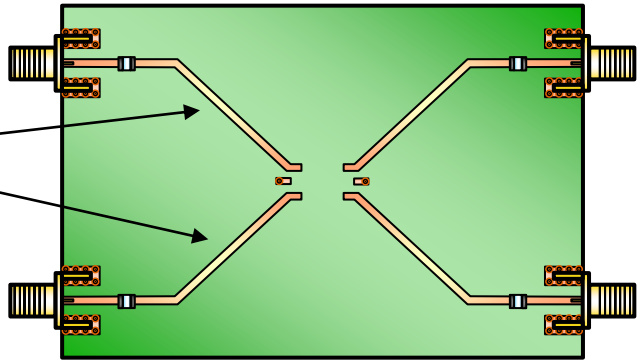
Error Correction Choices



APE = Automatic Port Extensions

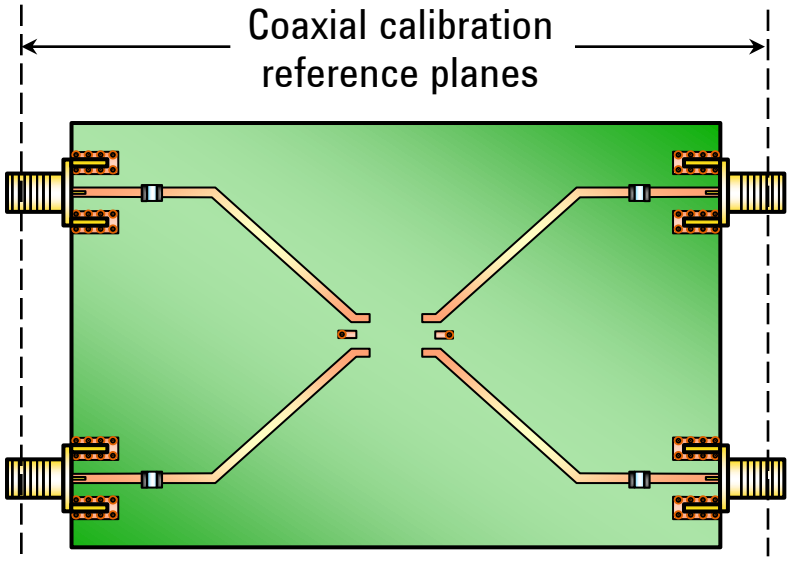
- First solution to apply both electrical delay and insertion loss to enhance port extensions
- First approach to give reasonable alternative to building in-fixture calibration standards or de-embedding fixture
- Recommended procedure: perform a two-step calibration
  - Step 1: Perform a full two-port coaxial calibration (includes network analyzer, test cables, and adapters)
  - Step 2: Perform a response calibration of test fixture

APE accounts for loss and phase of fixture transmission lines



Automatic Port Extensions – Step 1

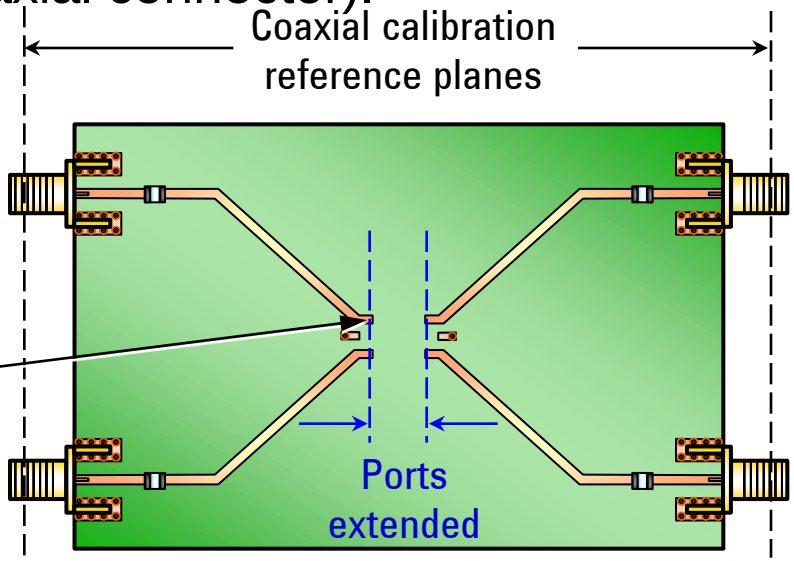
- First, perform coaxial calibration at fixture connectors to remove errors due to VNA and test cables
- At this point, only the fixture loss, delay and fixture mismatch remain as sources of error.



Automatic Port Extensions – Step 2

- After coaxial calibration, connect an open or short to the portion of fixture being measured (will be repeated for all ports of text fixture)
- Perform APE: algorithm measures each portion of fixture and computes insertion loss and electrical delay
- Values calculated by APE are entered into port extension feature
- Now, only fixture mismatch remains as source of error (dominated by coaxial connector).

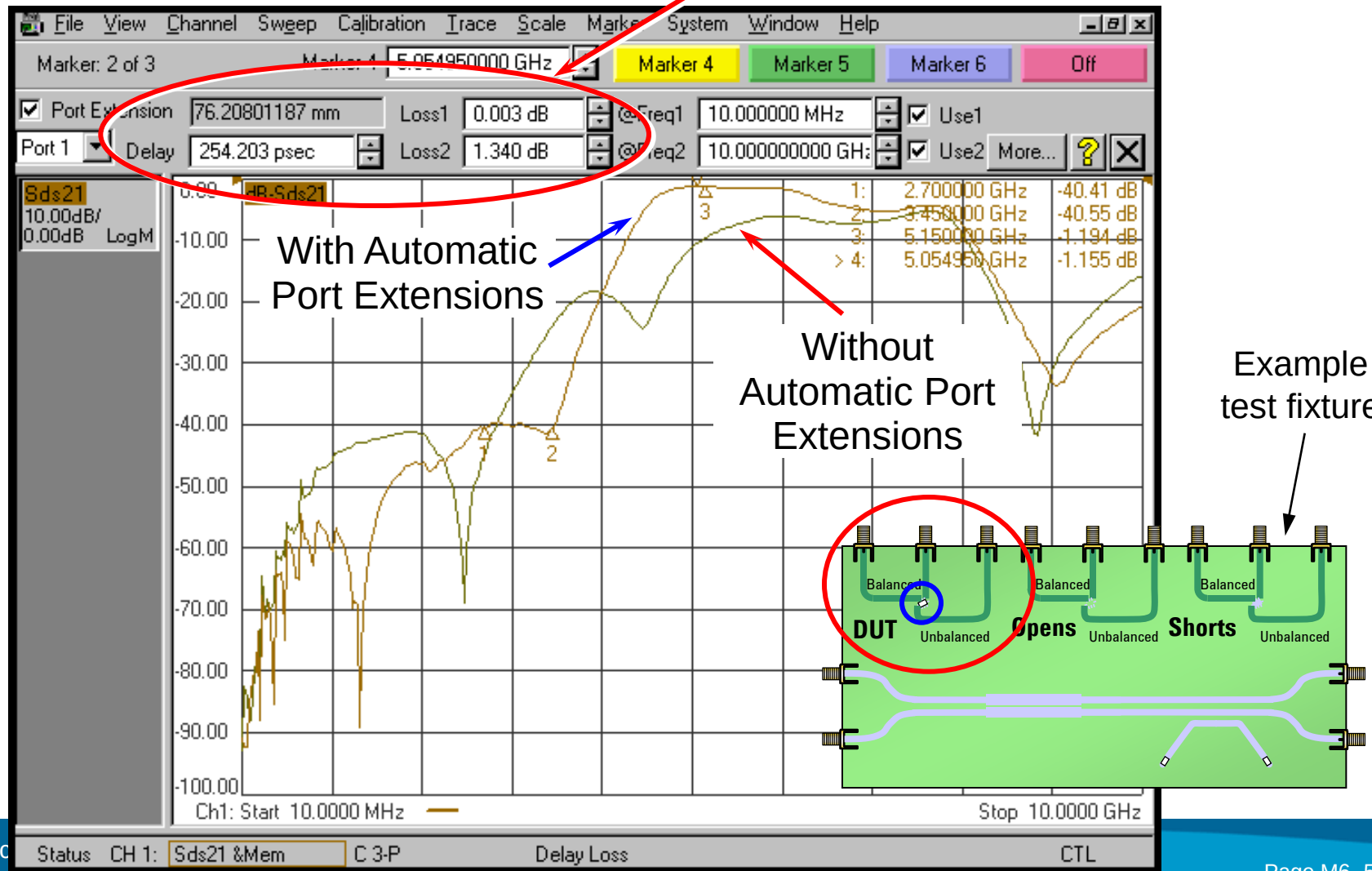
Open or short placed at end of each transmission line



Port extensions with loss and delay provide a response calibration of the test fixture

Measurement Results

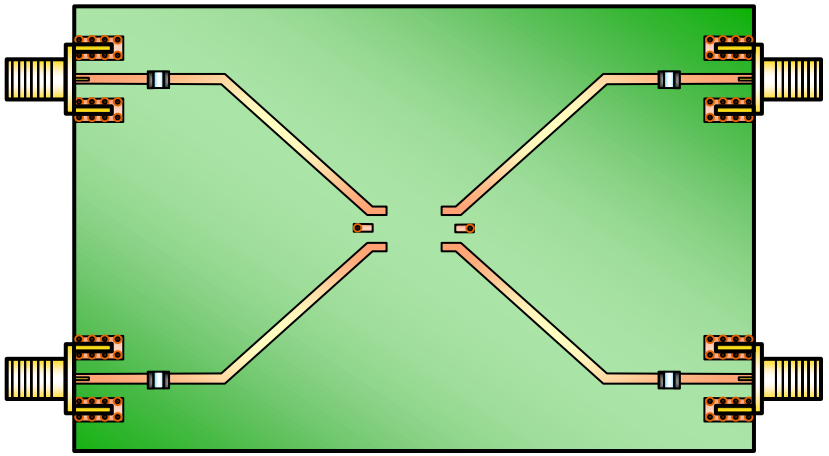
Delay and loss compensation values computed by APE



Automatic Port Extensions – Implementation

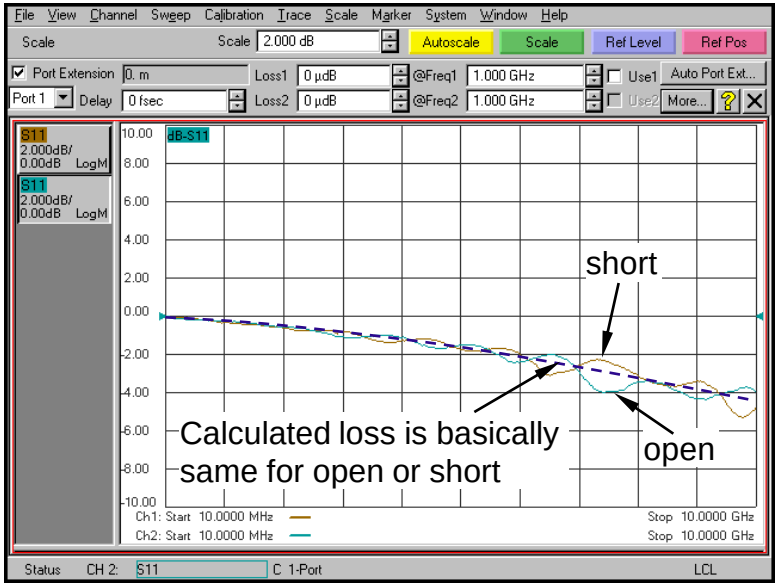
- Measures S_{ii} (reflection) of each port
- Uses ideal open or short models
- Computes electrical delay using best-fit straight-line model
- Computes insertion loss using a best-fit coaxial (one frequency point) or dielectric (two frequency points) loss model
- Computed delay and loss values are automatically displayed via a port-extension tool bar
- Values saved as part of instrument state

Measure reflection of each test port with open or short



Which Standards Should I Use?

- For broadband applications, shorts or opens work equally well
- Choose the most convenient standard (often an open) – this is a key benefit of Automatic Port Extensions
- Will using both an open and a short improve accuracy?
  - Using two standards makes little difference for broadband measurements, as many ripples occur and calculated loss is the same for open or short
  - Using two standards improves accuracy for narrowband measurements, where a full ripple cycle does not occur

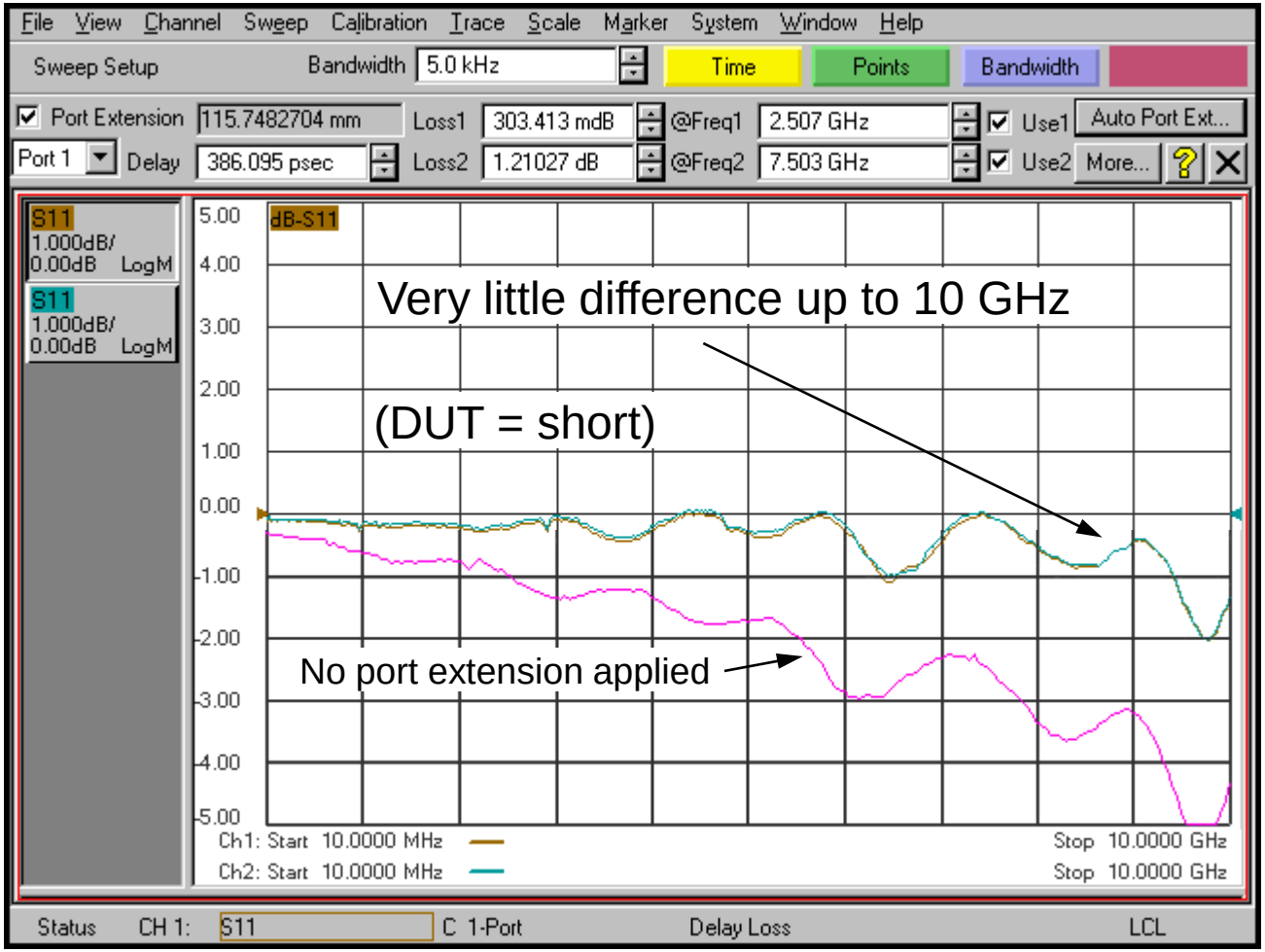


Broadband

Broadband APE Example

APE with short

APE with open

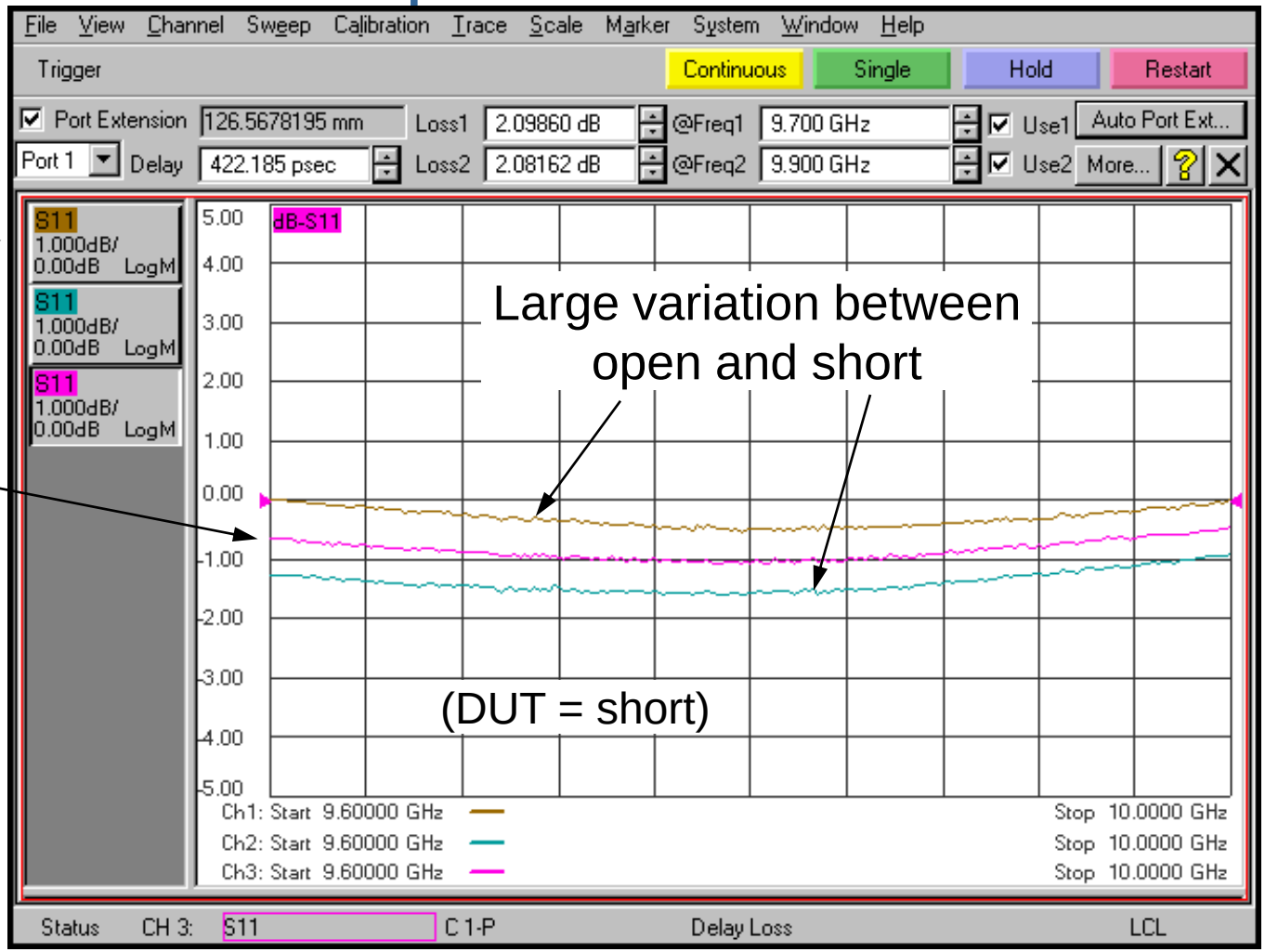


Narrowband APE Example

APE with short

APE with open

APE with both open and short



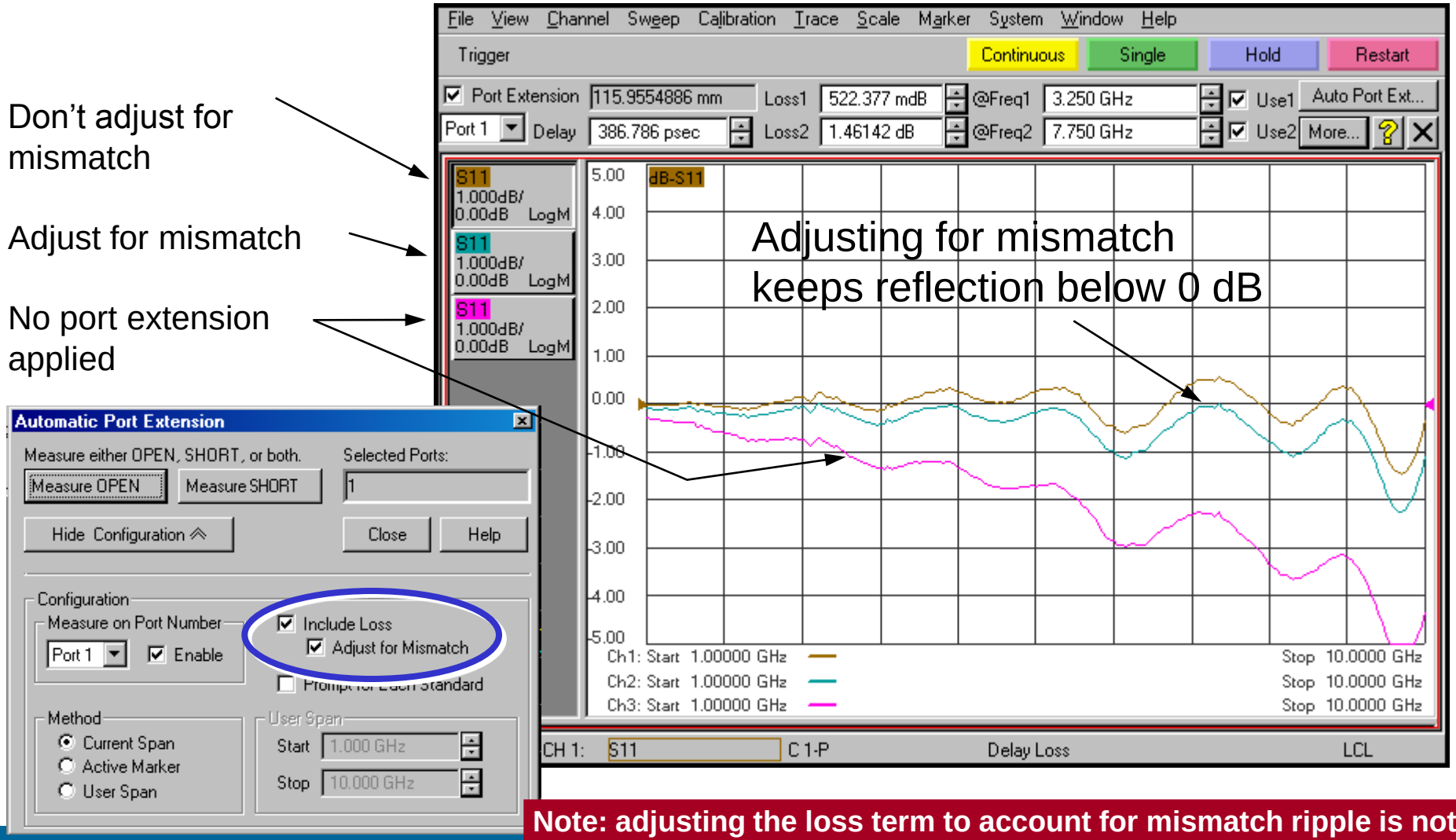
400 MHz span

Adjusting for Mismatch Ripple

Don't adjust for mismatch

Adjust for mismatch

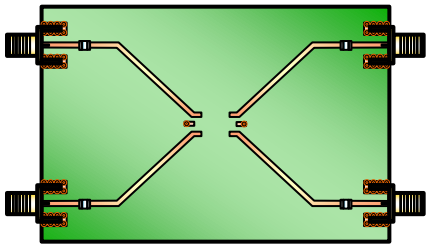
No port extension applied



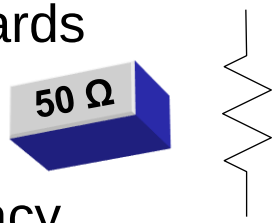
Adjusting for mismatch keeps reflection below 0 dB

Note: adjusting the loss term to account for mismatch ripple is not the same as removing the mismatch with vector-error correction

Summary of Automatic Port Extensions

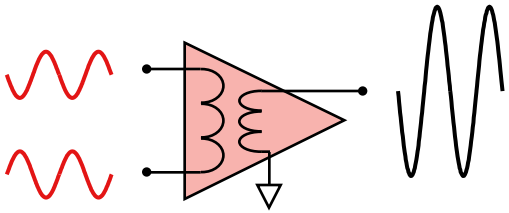


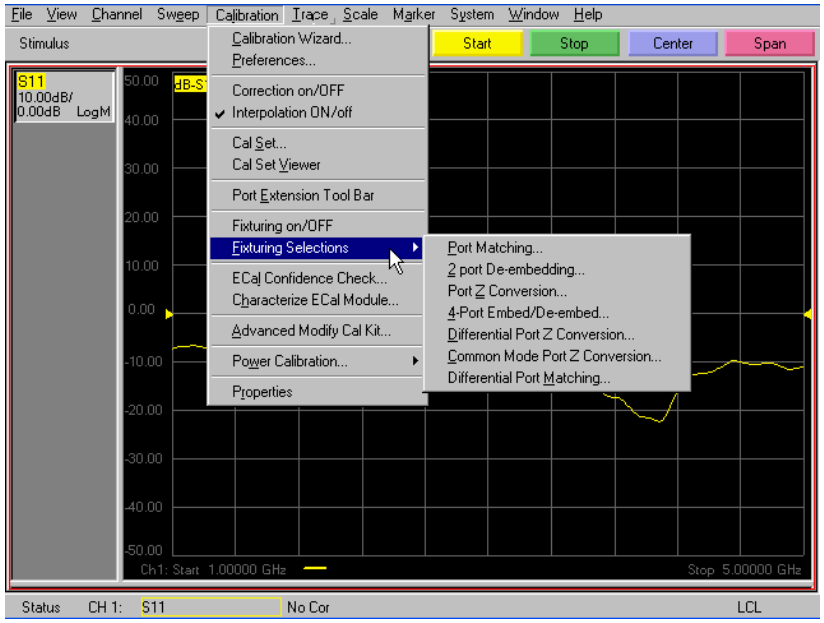
- Especially useful for in-fixture applications where complete calibration standards are not available
- Eliminates the need to design and build difficult load standards
- Applicable to a wide range of fixture designs
- Works with probes too
- Easy to use and provides quick results with medium accuracy



Virtual Fixturing Using Software Tools in VNA

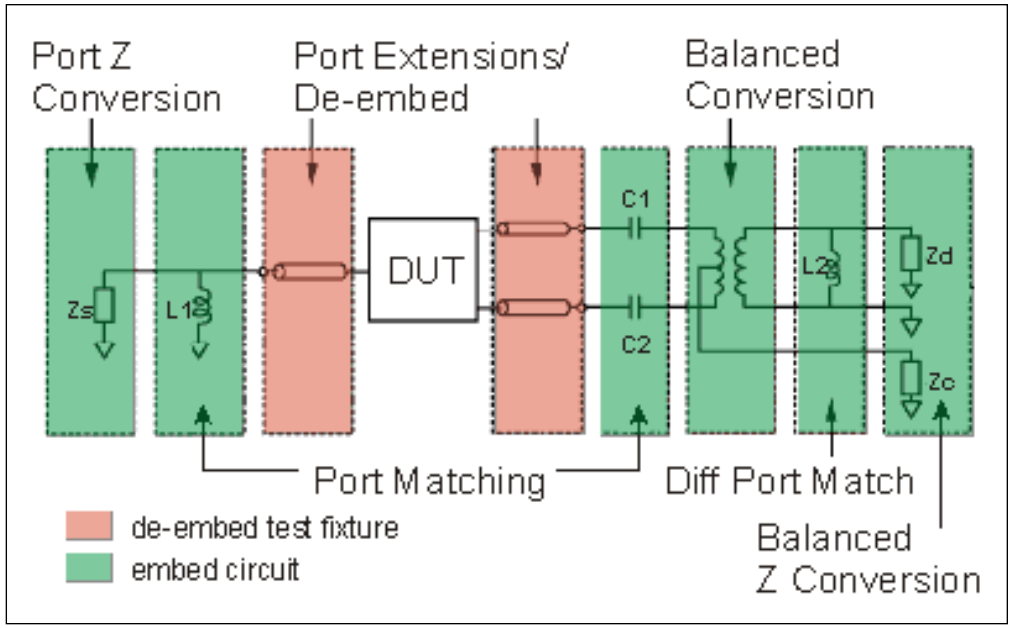
- Software-fixture tools recalculate single-ended S-parameter data to…
  - Change test port impedances
  - De-embed test fixtures, probes, adapters, cables, etc.
  - Embed matching circuits
  - Calculate mixed-mode (differential / common mode) S-parameters
- Fixturing features are common to PNA and ENA families and Physical Layer Test Software (PLTS)
- Especially useful for single-ended-to-balanced or fully balanced devices





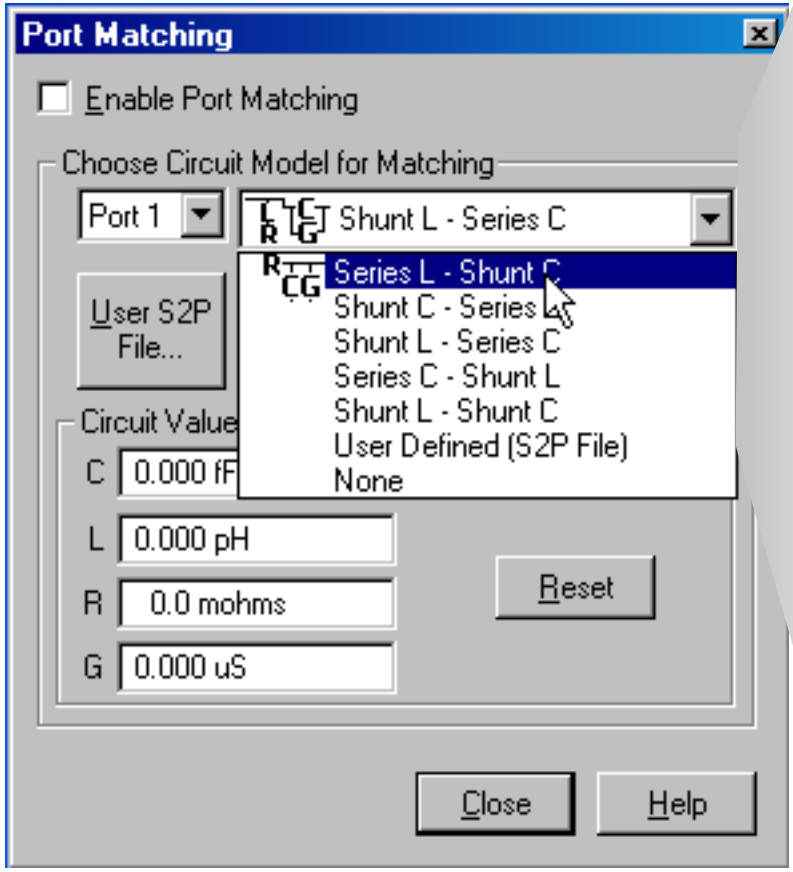
Order of Fixturing Operations

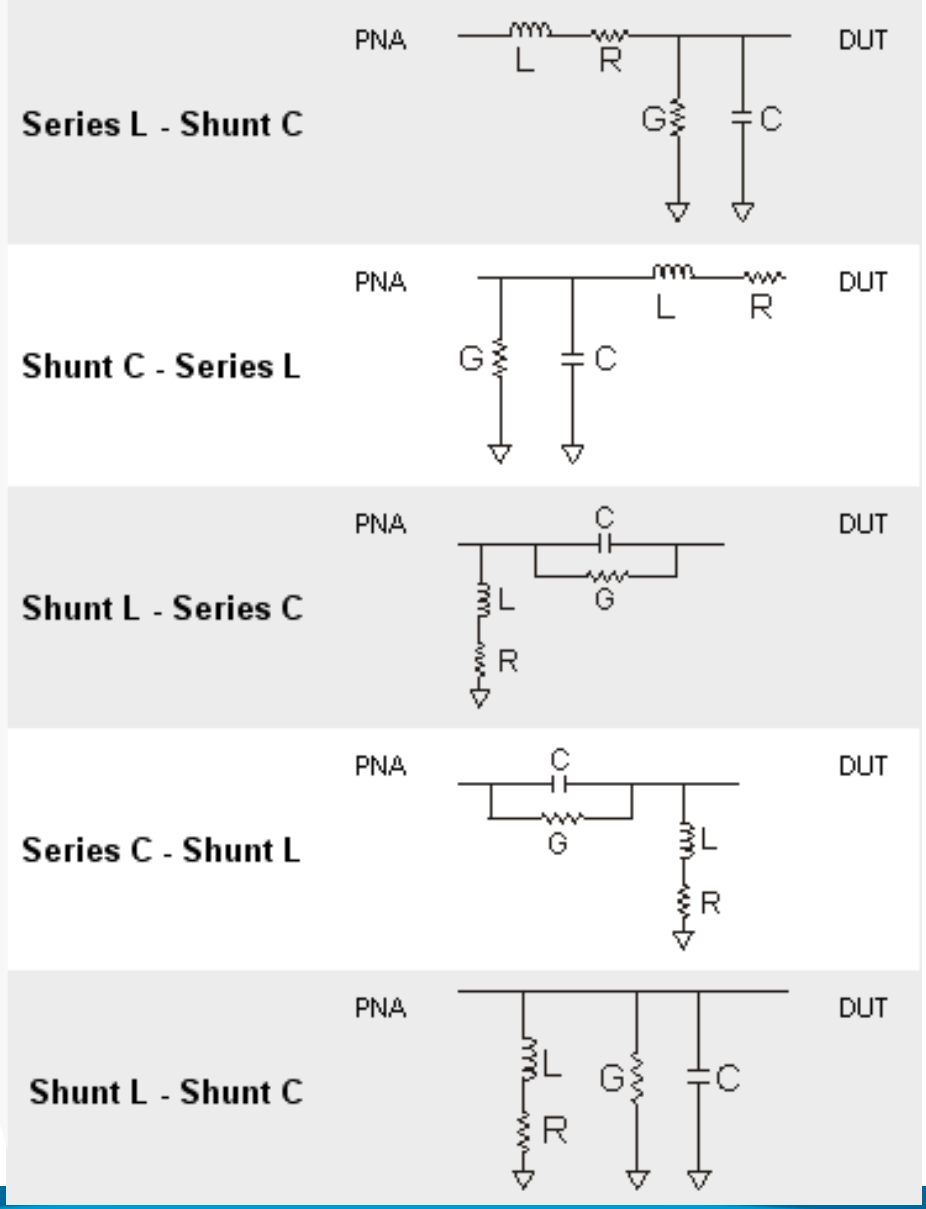
- **First, single-ended functions are processed in this order:**
  - Port extensions
  - 2-port de-embedding
  - Port Z (impedance) conversion
  - Port matching / circuit embedding
  - 4-port network embed/de-embed
- **Then, balanced functions are processed in this order:**
  - Balanced conversion
  - Differential- / common-mode port Z conversion
  - Differential matching / circuit embedding



Example circuit simulation

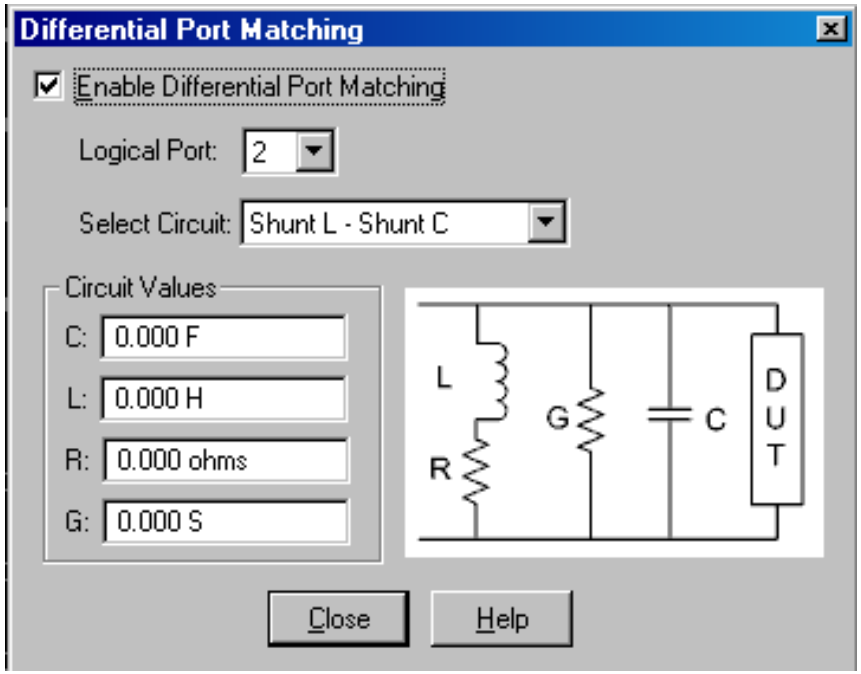
Port Matching

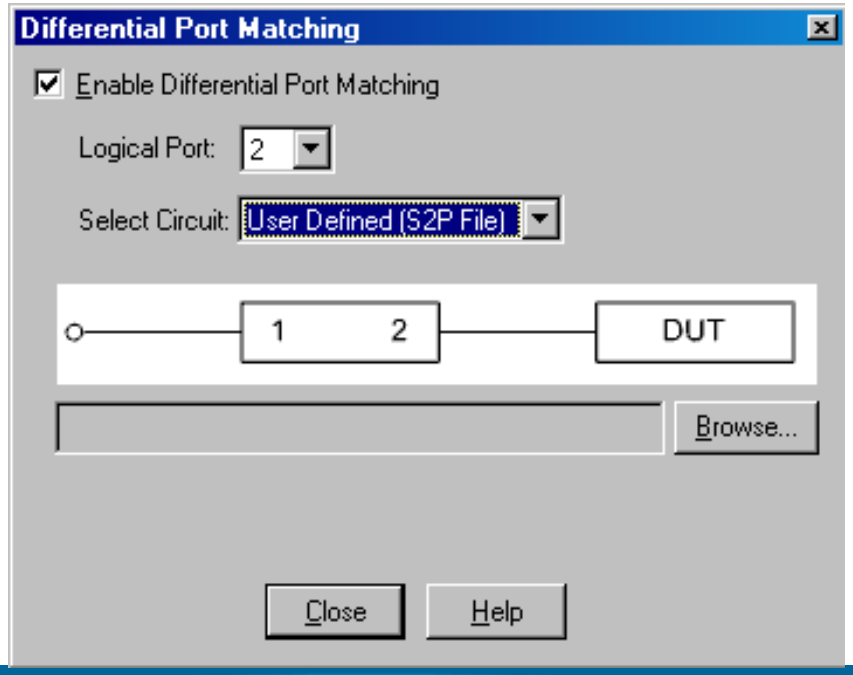




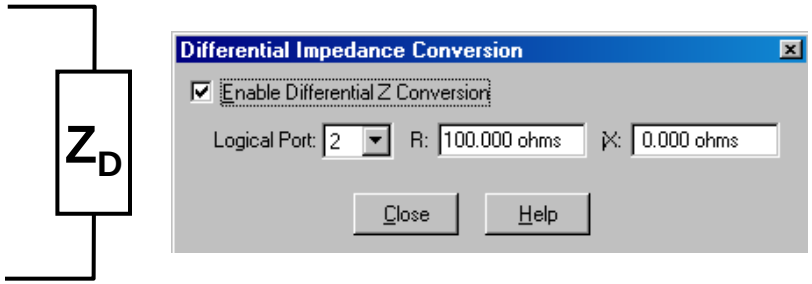
Port matching feature
is same as embedding

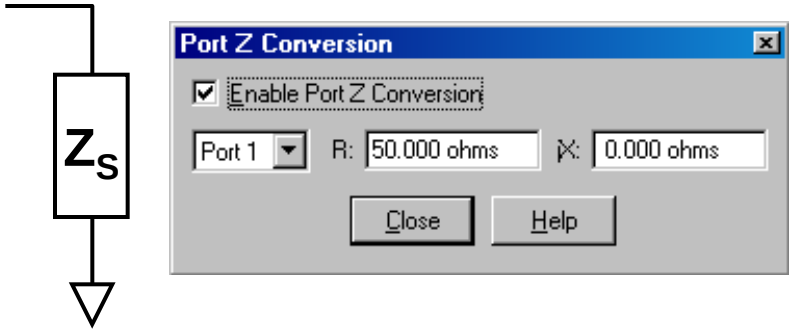
Differential Port Matching

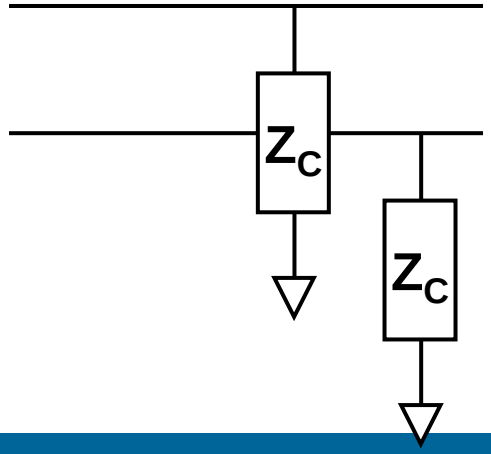


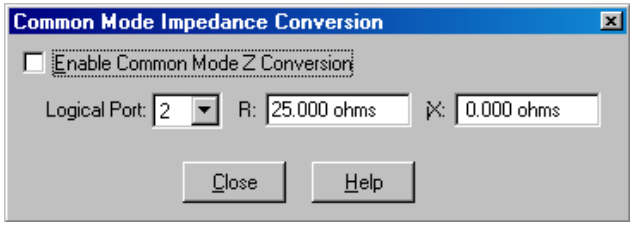


Single-Ended and Differential Port Z (Impedance) Conversion

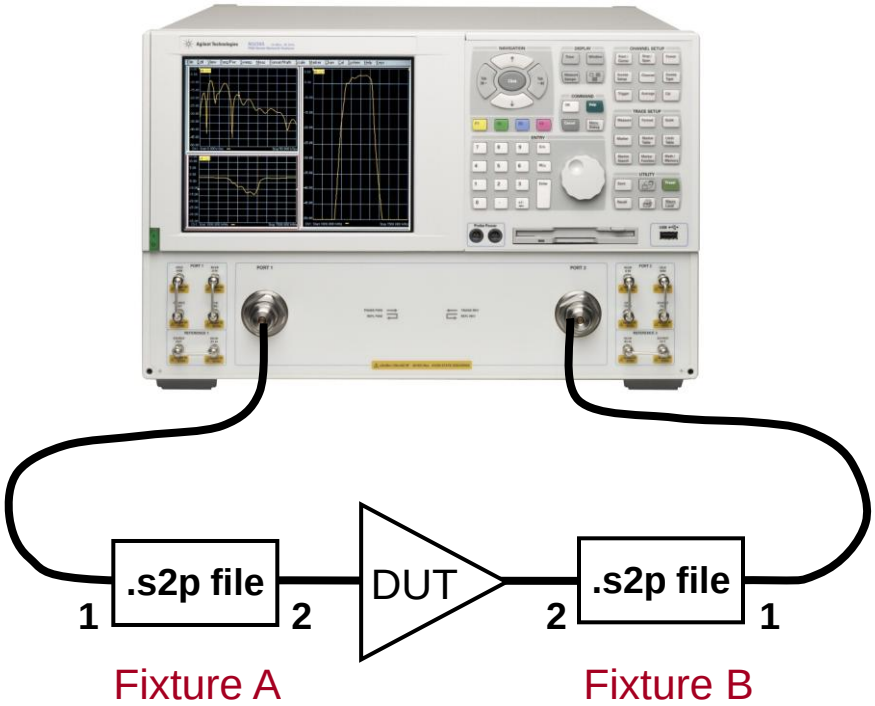


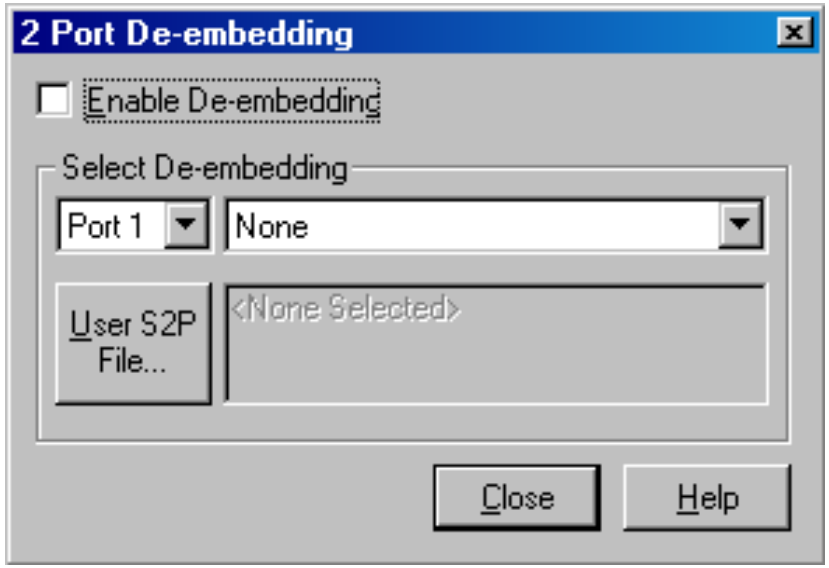






Two-Port De-Embedding

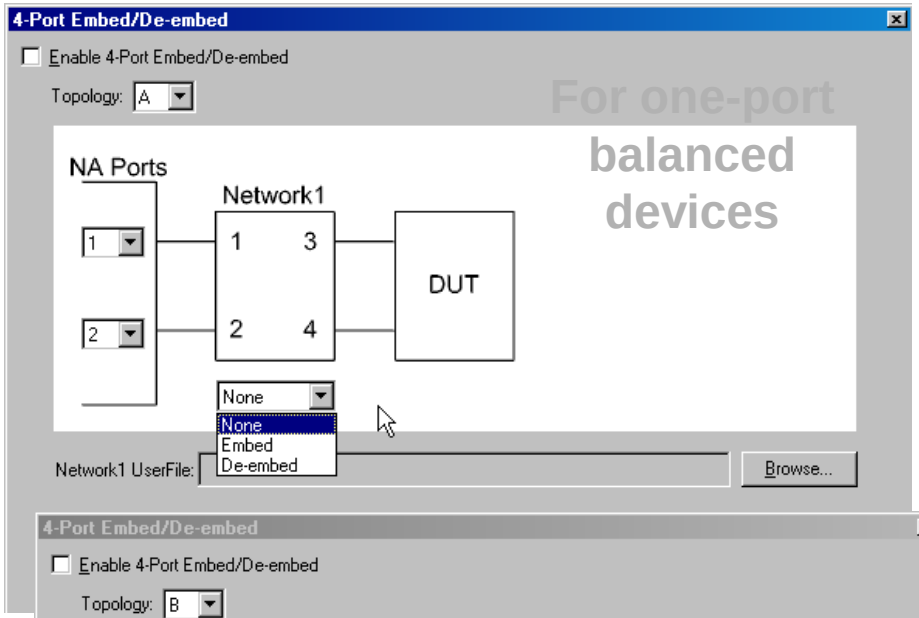




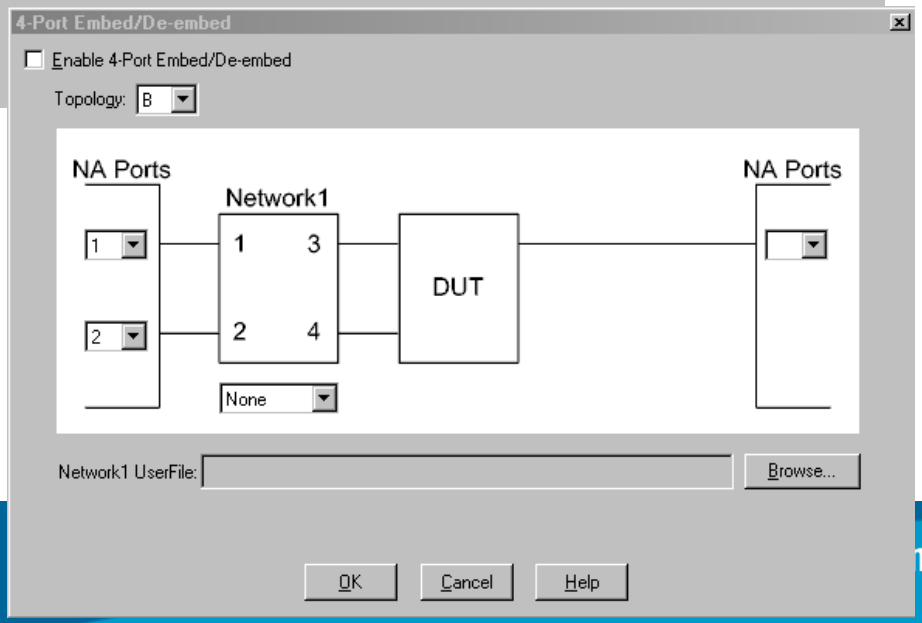
PNA uses this file definition for ports:

- **Port 1 of the fixture is connected to the PNA**
- **Port 2 of the fixture is connected to the DUT**

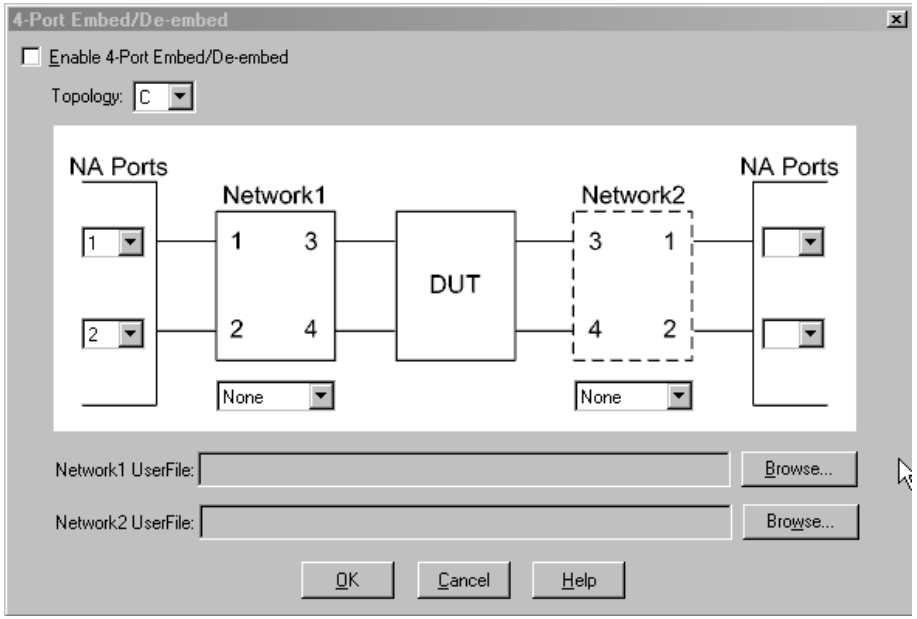
Four-Port Embedding/De-Embedding



For one-port balanced devices



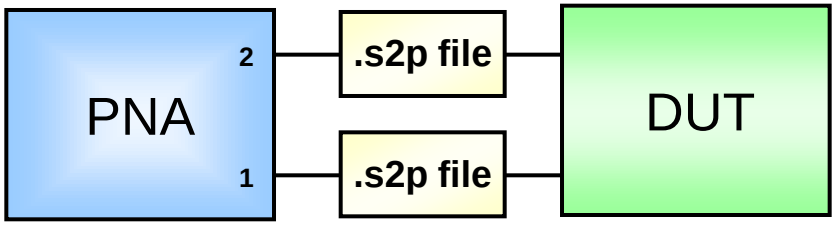
For two-port balanced devices



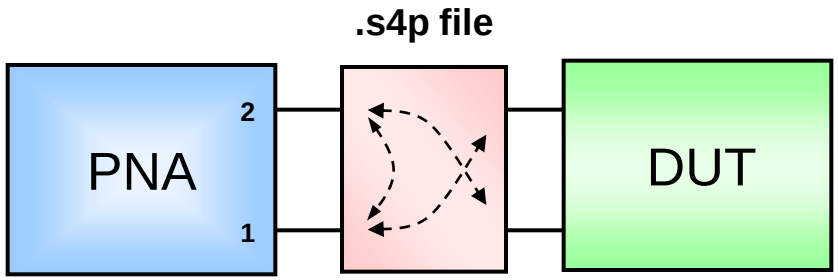
For balanced to single-ended devices

Two Versus Four Port Embedding / De-Embedding

- Question: On a balanced port, what is the difference between:
  - Two .s2p embedding/de-embedding files?
  - One .s4p embedding/de-embedding files?
- Answer: Crosstalk terms!



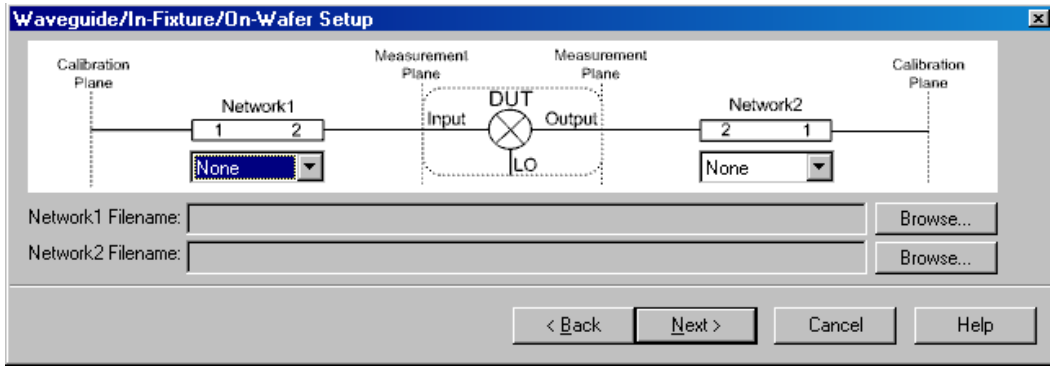
Cannot simulate fixture crosstalk between PNA ports 1 and 2

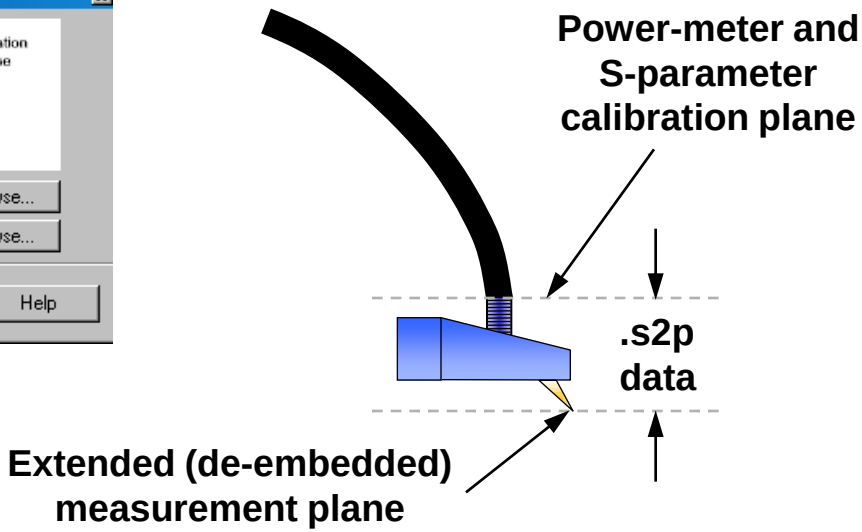


Can use full "leaky" model to simulate fixture crosstalk

On-Wafer Mixer Measurements Using FCA

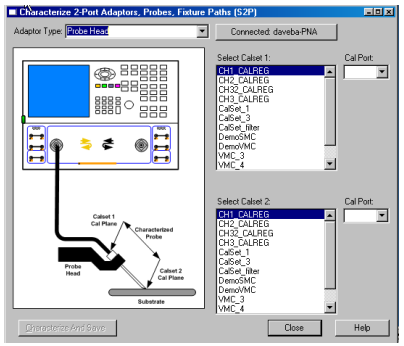
- Previous versions of the Frequency Converter Application (FCA) did not allow on-wafer measurements using Scalar- or Vector-Mixer Cals
- A.06.0x allows embedding of probe data files during FCA calibration
- Perform S-parameter, power-meter, & cal-mixer calibrations in coax
- After coax calibrations, reference plane is at probe tip

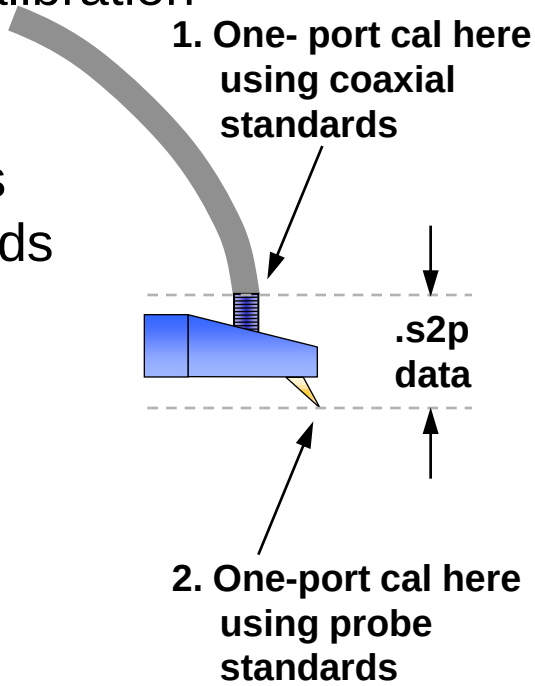




How Do I Get My Probe De-Embedding Data?

- Three techniques to measure S-parameter data of probes…
  - Easiest: use PNA or ENA macro that performs two one-port calibrations
  - Measure a thru and then do an adapter-removal calibration
  - Measure a thru and then do an unknown thru calibration
- Using two one-port calibrations…
  - Assumes probe is reciprocal (S21 = S12)
  - First one-port calibration uses coaxial standards
  - Second one-port calibration uses probe standards
  - Macro extracts .s2p data of probe using the two one-port calibrations

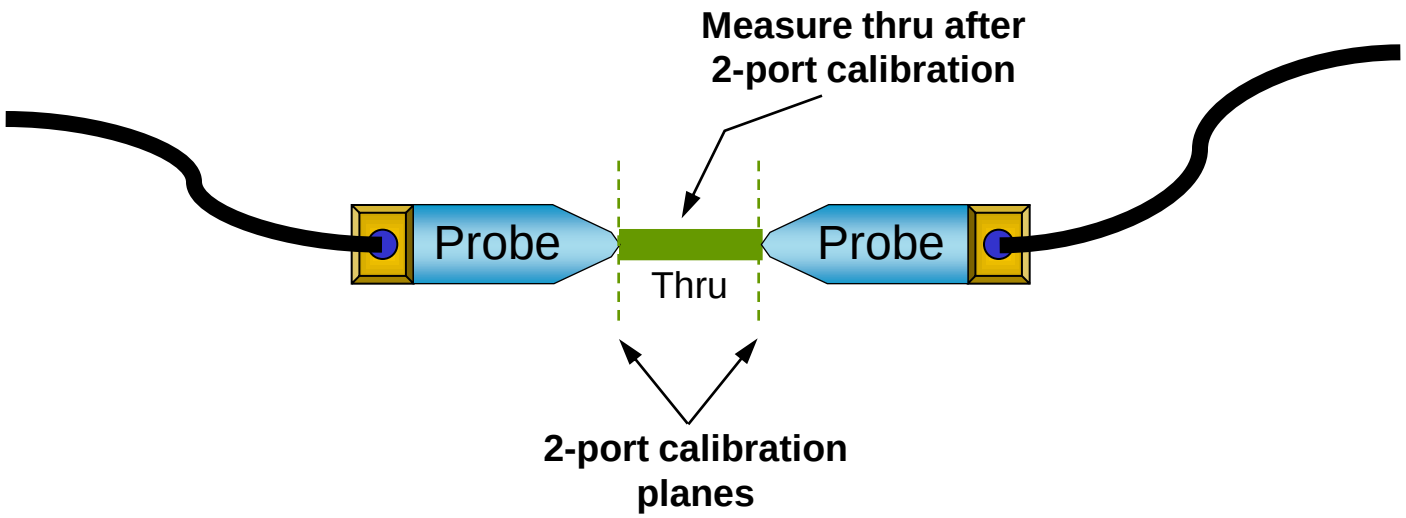




Measuring Probes Using Adapter Removal or Unknown Thru Calibration

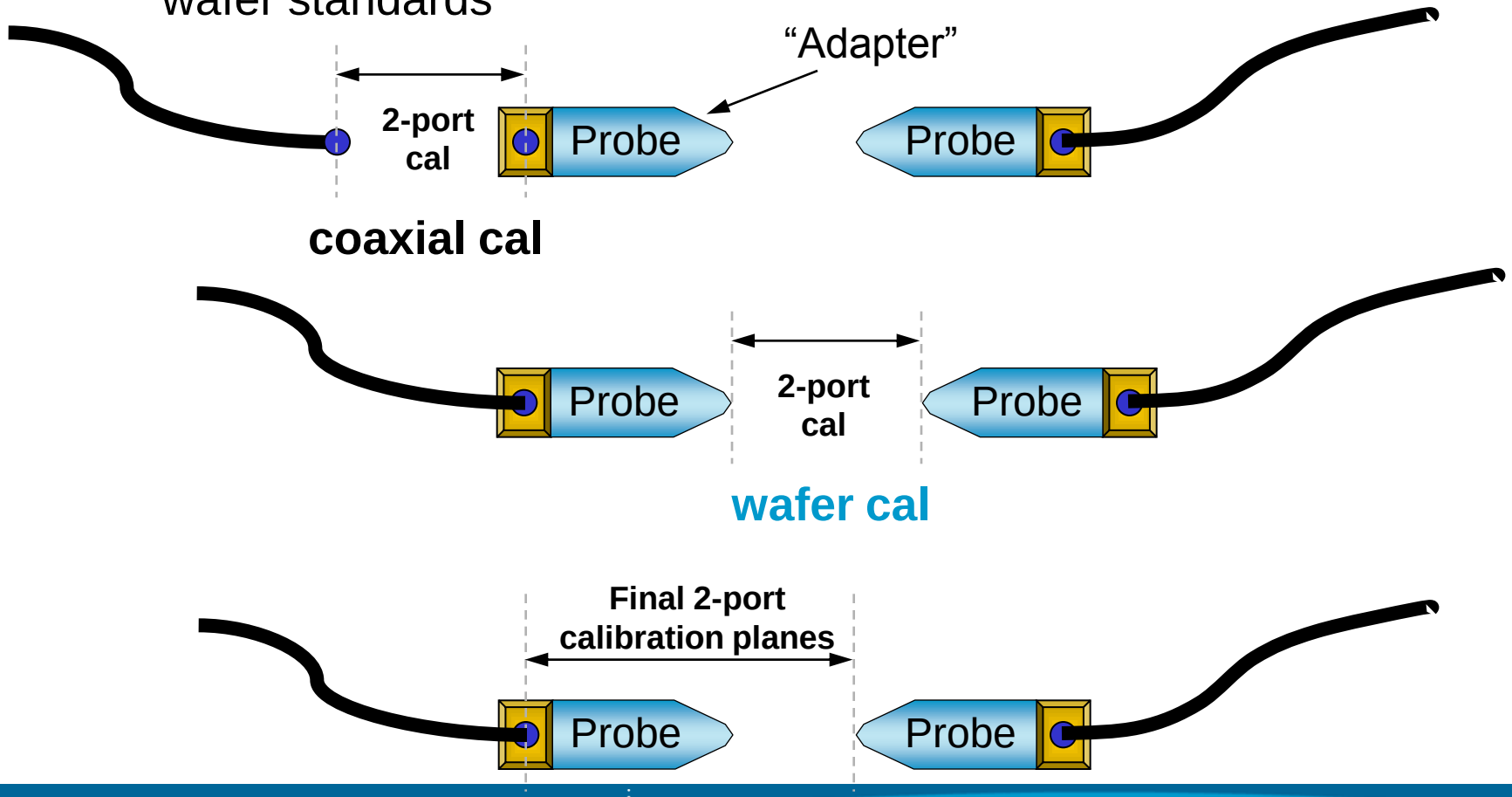
In either case, start by measuring a thru standard:

1. Perform an SOLT or TRL cal using wafer probes
2. Measure thru device and save data in .s2p file for de-embedding in a later step



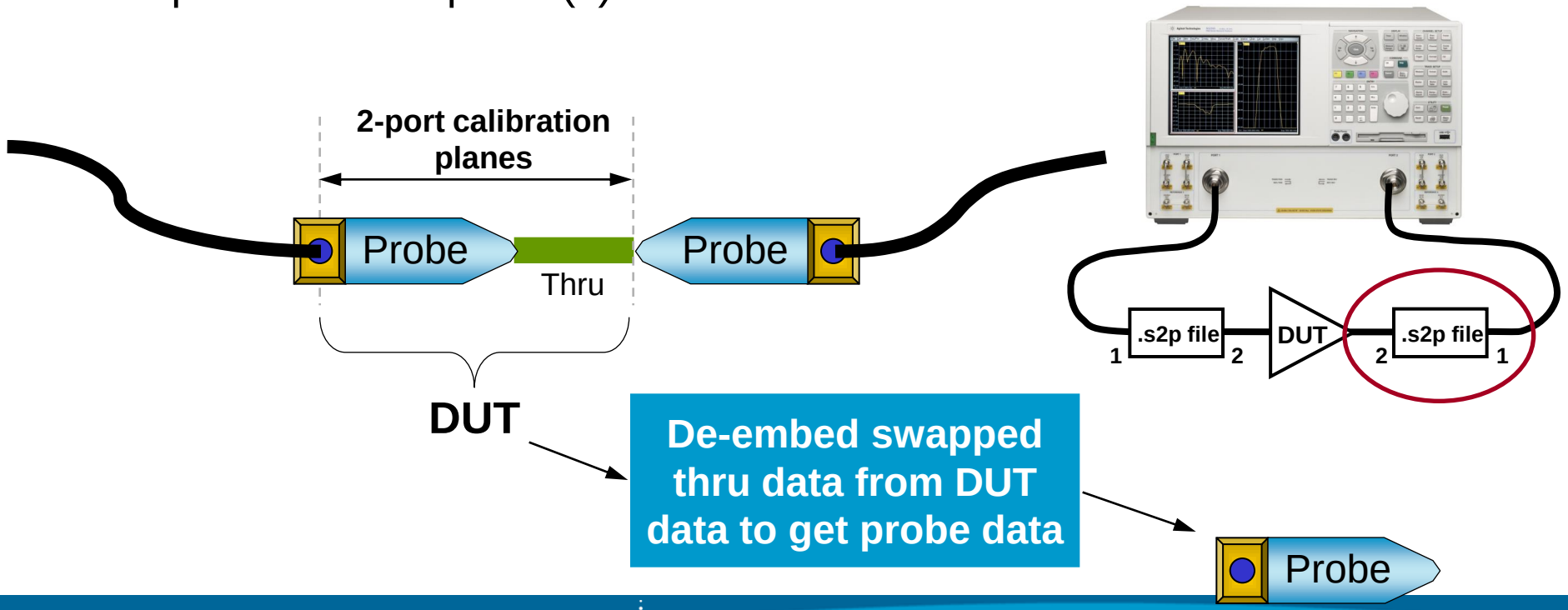
Measuring Probes Using Adapter-Removal Cal

3. Perform an adapter removal calibration using coaxial and on-wafer standards



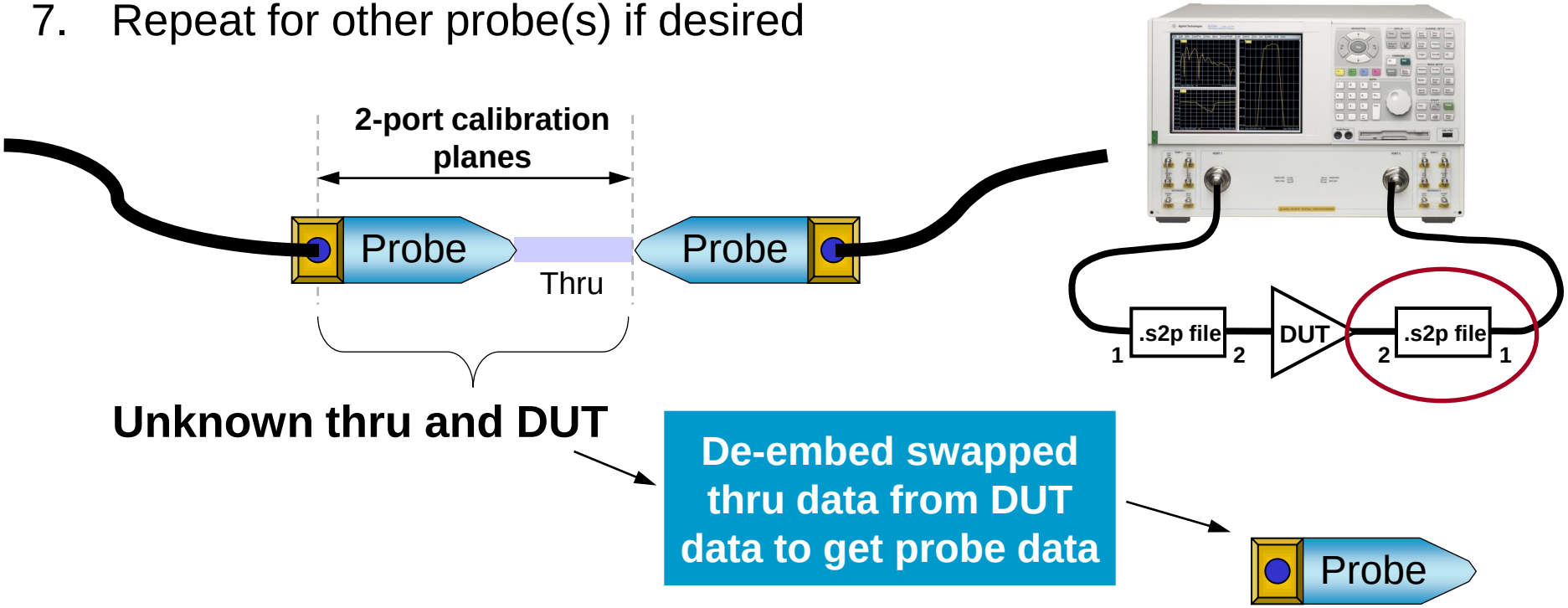
Measuring Probes Using Adapter-Removal Cal (cont)

4. Measure thru plus probe
5. De-embed *swapped* thru data to obtain probe data
6. Save probe data in .s2p file for later use in measuring DUTs
7. Repeat for other probe(s) if desired



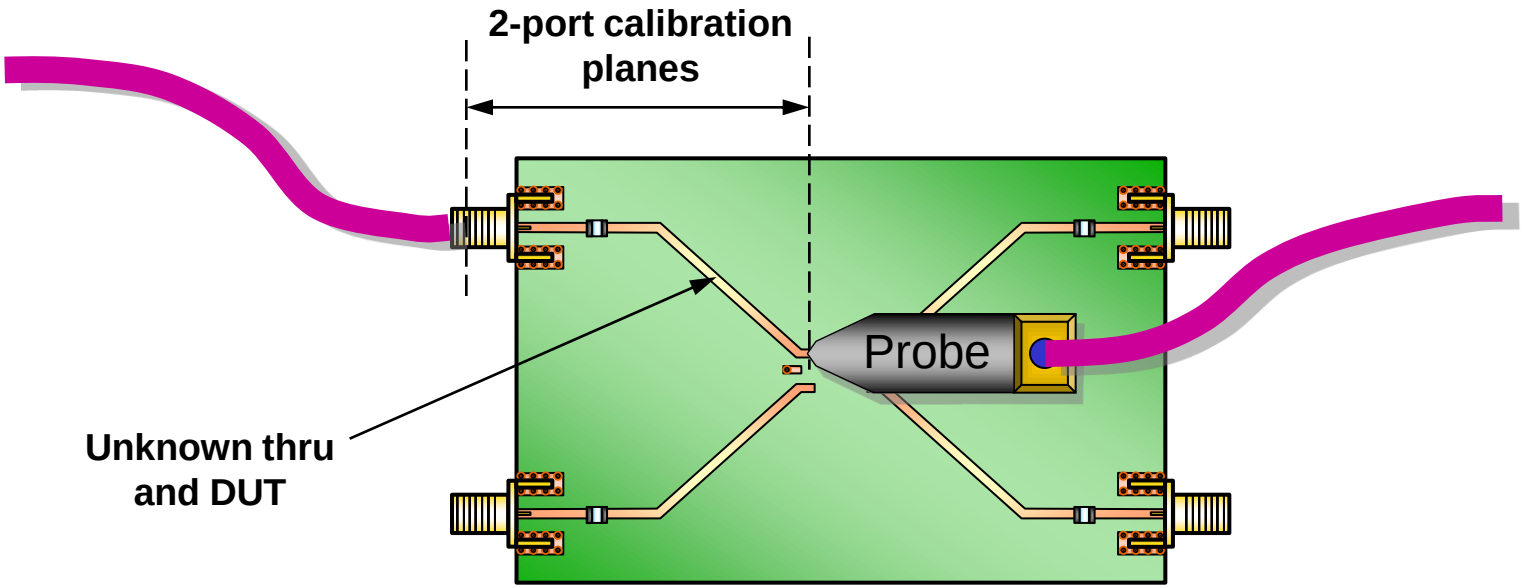
Measuring Probes Using Unknown Thru Cal

3. Perform unknown thru cal in coax and with probe
4. Measure thru plus probe
5. De-embed *swapped* thru data to obtain probe data
6. Save probe data in .s2p file for later use in measuring DUTs
7. Repeat for other probe(s) if desired



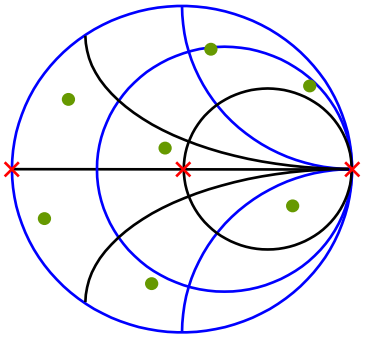
How Do I Get My Fixture De-Embedding Data?

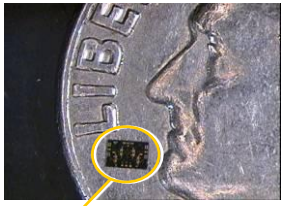
1. Perform an unknown thru cal using coax on one side, a probe on the other side, and the fixture itself for the unknown thru
2. Measure the fixture section and save data as .s2p file
3. Repeat for each section of fixture

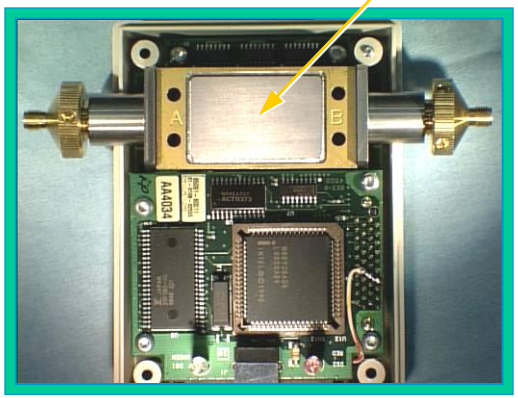


What is Electronic Calibration?

- Calibration using standards that are electronically switched known impedances, instead of shorts, opens and loads
- Impedance standards are spread out on the Smith chart
- Impedances known by measurements at factory using individually characterized coaxial airlines and TRL cals
- Impedances are very repeatable due to:
  - Hermetically sealed “ECal on a chip” microcircuit
  - Internal electric heater
  - Low thermal mass of microcircuit
  - Low thermal conductivity between microcircuit and outside world
  - Mechanically rugged connectors

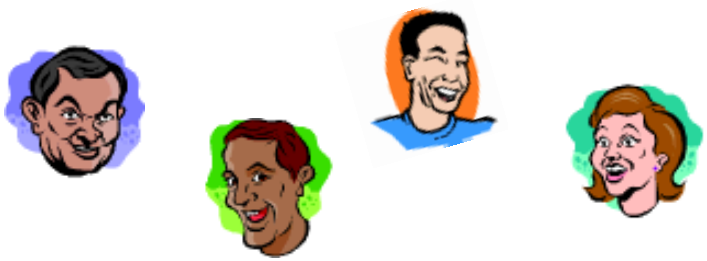


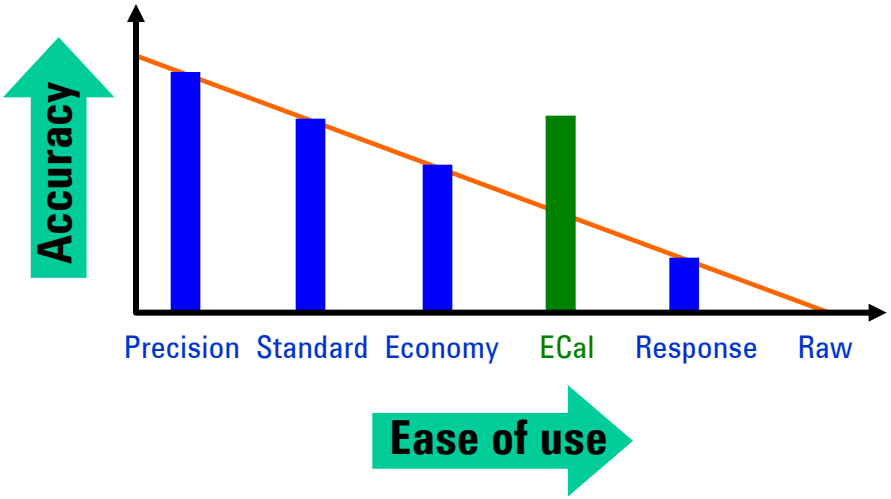




Benefits of Electronic Calibration

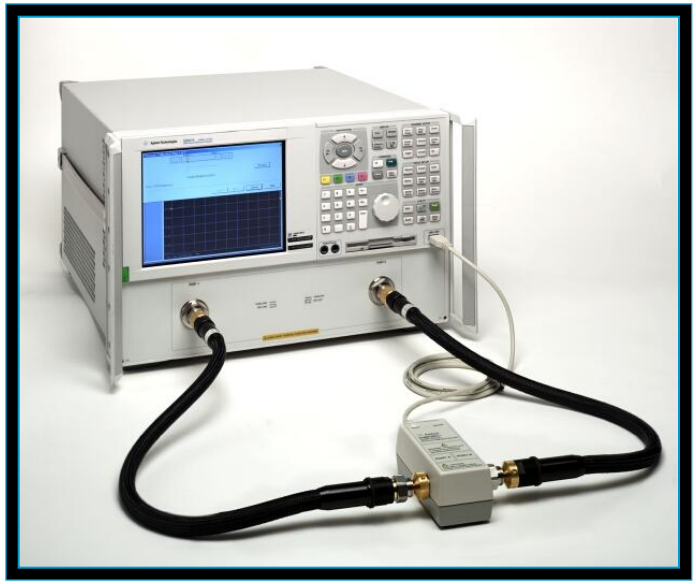
- Provides fast AND accurate calibration
  - Typical calibration takes **20 to 60 seconds** with ECal versus several to many minutes when using mechanical standards
  - Accuracy equivalent to a **short-open-sliding-load** calibration
- No risk of connecting the wrong mechanical standard
- Lowers wear and tear on connectors and standards
- Lowers chances of repetitive-motion injuries of users, especially for test systems with a large number of test ports





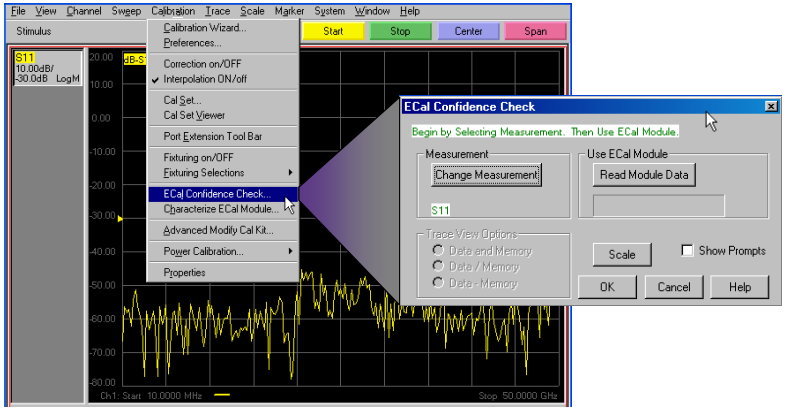
Agilent's "ECal" Line of Electronic Calibration

- Frequency coverage from 300 kHz to 67 GHz in many connector types (7/16, Type F, N, and 7, 3.5, 2.4, 2.92, 1.85 mm)
- Two and four port modules, with mixed connector sexes and types
- User characterization of modules lets you add adapters, use different connectors, de-embed fixtures and probes, and do yearly re-certification
- Easy connection with USB



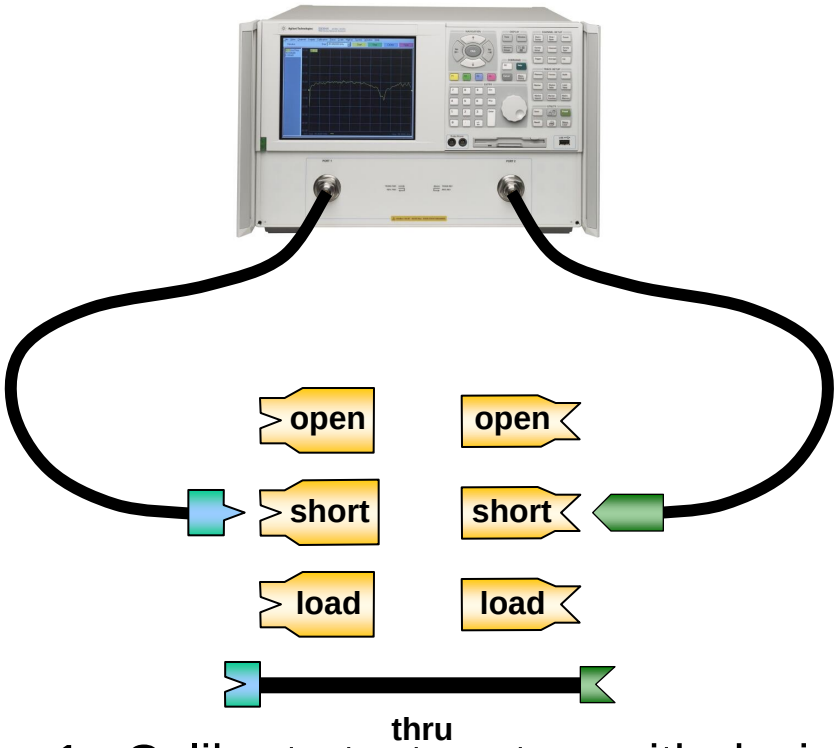
Details of User Characterization

- Add up to 5 user-measured data sets to flash memory of module
- Easy to perform:
  - Define frequency range and number of points
  - Calibrate network analyzer with mechanical standards (quality of user characterization depends on this calibration)
  - Follow calibration wizard to characterize each port of ECal module
- User-characterized ECal is used just like a standard factory-characterized ECal
- Confidence check tells you when to characterize again

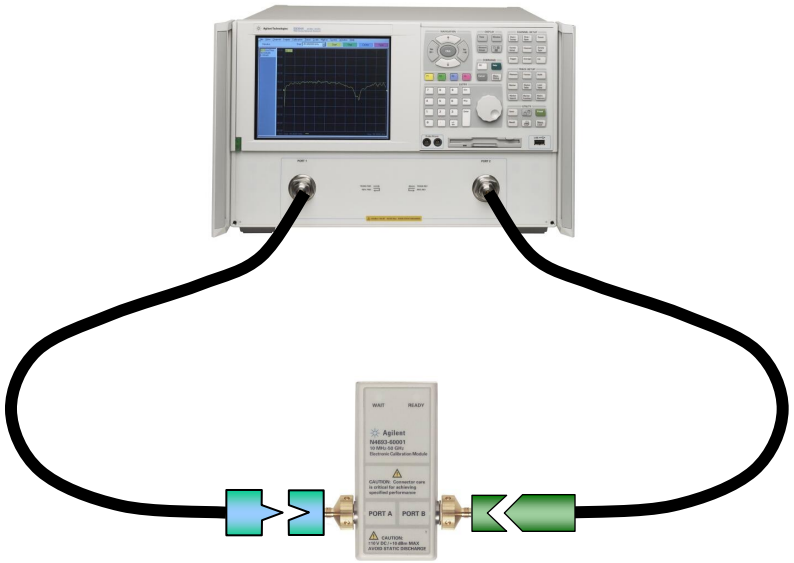


User Characterization: Using Adapters

Step 1



Steps 2,3

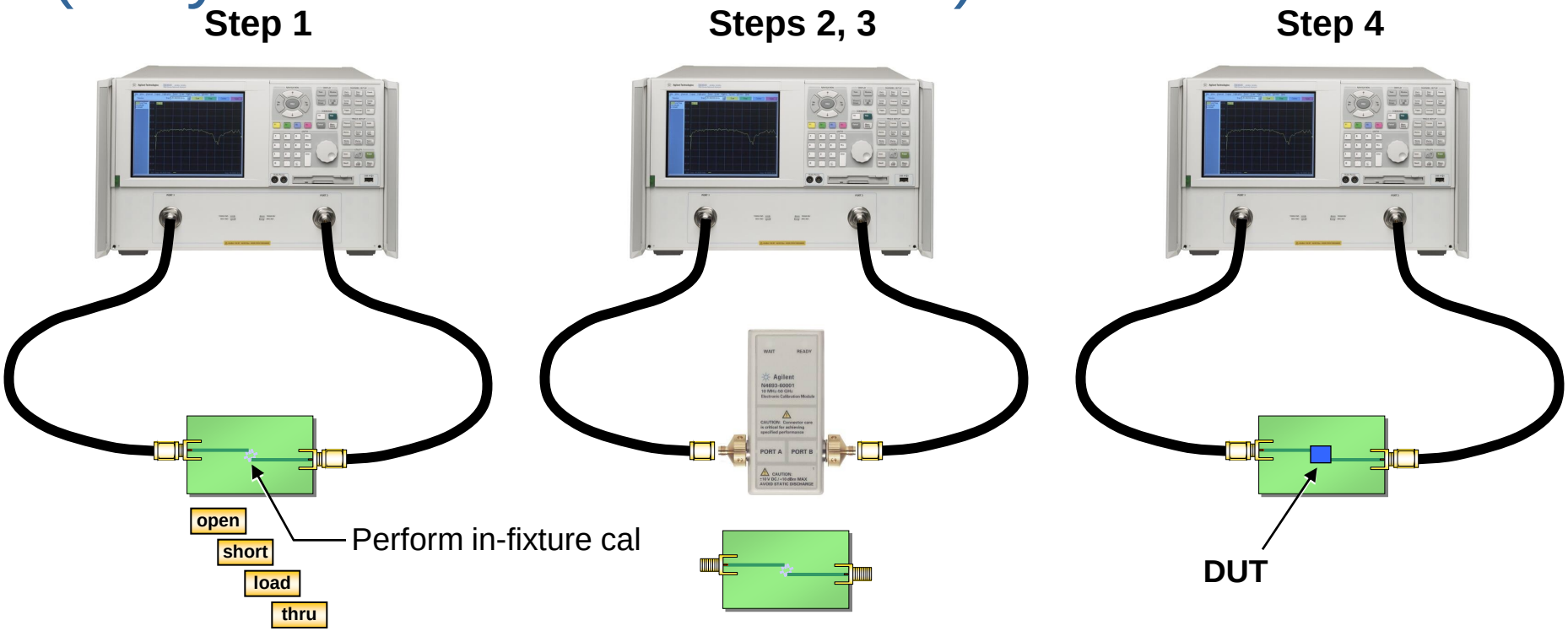


Step 1: Calibrate test system with desired connectors using any calibration method (SOLT, SOLR, TRL)

Step 2: Connect ECal module with adapters to analyzer

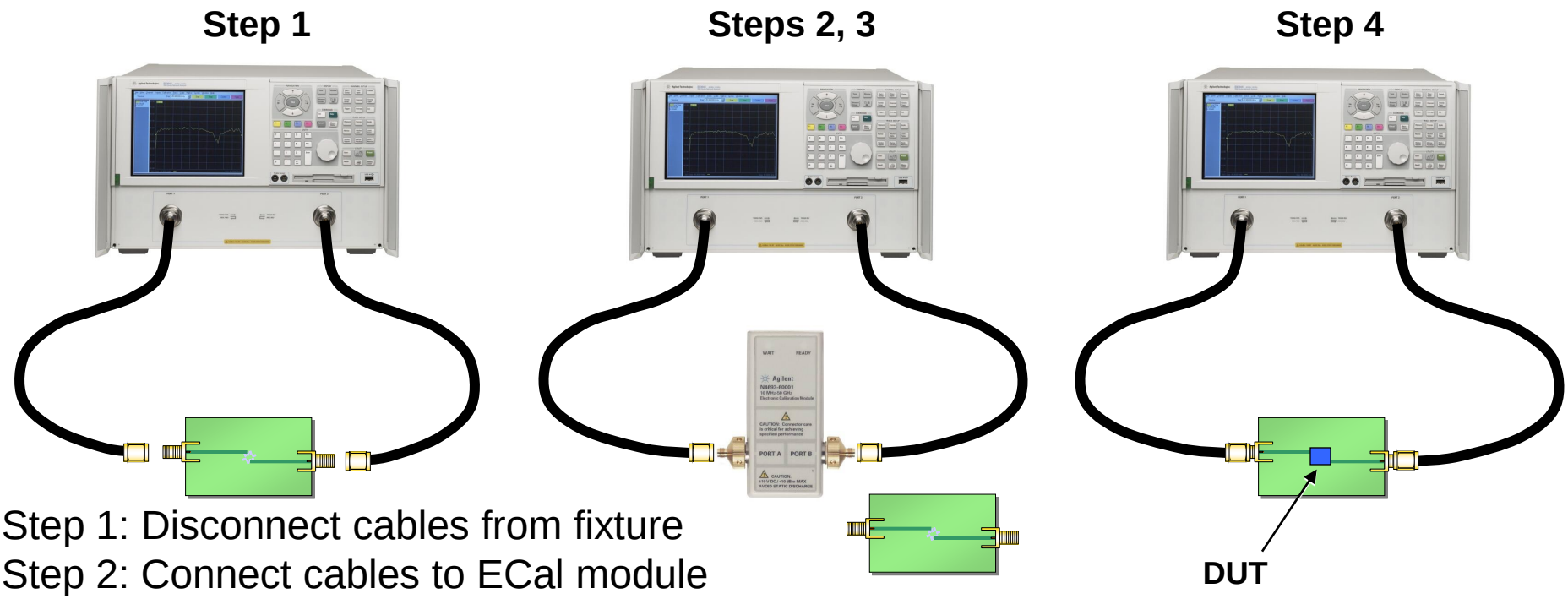
Step 3: Perform user characterization of ECal module using calibrated test system

User Characterization: Embedding Fixture Data (Only Need to Do This Once)



Step 1: Calibrate test system & fixture using any calibration method (SOLT, TRL, …)
Step 2: Disconnect cables from fixture and connect them to ECal module
Step 3: Perform user characterization of ECal module (fixture data is embedded)
Step 4: Disconnect cables from ECal module and reconnect to fixture

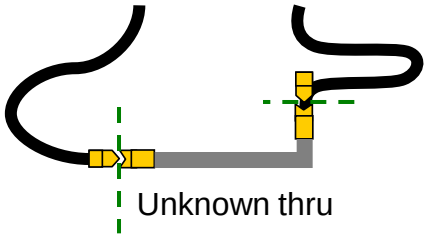
User Characterization: Applying Fixture Cal (Simple! Does Not Require In-Fixture Cal)



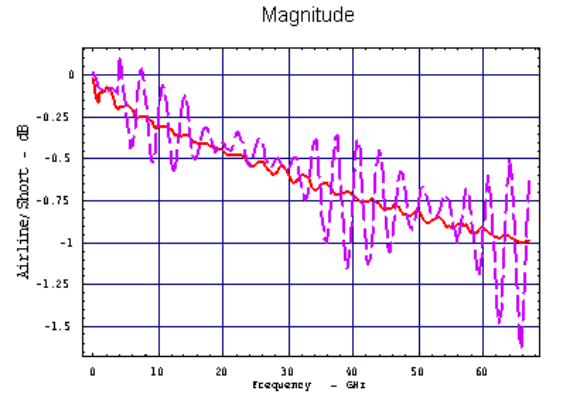
Step 1: Disconnect cables from fixture
Step 2: Connect cables to ECal module
Step 3: Perform “User-Defined ECal Calibration” of test system
Step 4: Disconnect cables from ECal module and re-connect them to fixture with DUT
Step 5: Start measuring! (Fixture data is de-embedded from the measurement)

Summary

- **Calibration** is a key part of accurate measurements using vector network analyzers
- Many **new techniques** increase accuracy or make calibration easier to perform, especially for fixtured or on-wafer measurements
- The **"Unknown Thru" calibration** eliminates cable movement and simplifies non-insertable calibrations



- **Data-based-standard definitions** and **expanded calibration** using weighted-least-squares math greatly impr 67 GHz and 110 GHz measurements
- Testing multiport devices is easier and more accurate than ever due to **N-port calibration** and **reduced-standard calibrations**

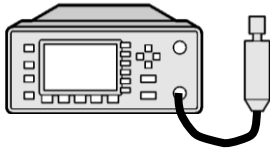


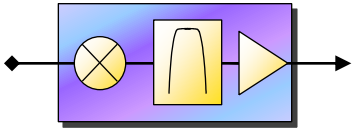
Summary (continued)

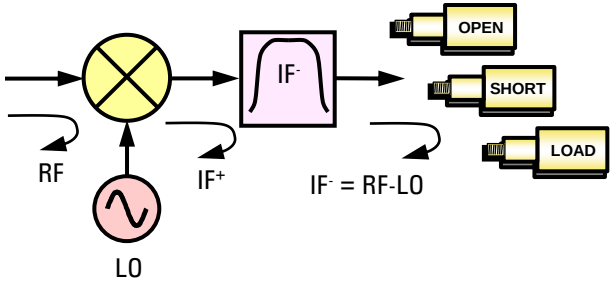
- **Two-tier TRL calibration** allows single-receiver VNAs like Agilent's 4-port PNA-L take advantage of TRL, LRM, LRL cals for fixtures & probes

- **Offset-load calibration** increases accuracy for one-port waveguide cals with compound load standard and accurate waveguide loss model

- Advanced **mixer/converter calibrations** yield the highest accuracy for measuring conversion loss and absolute group delay

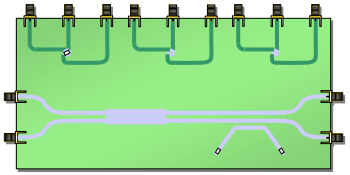




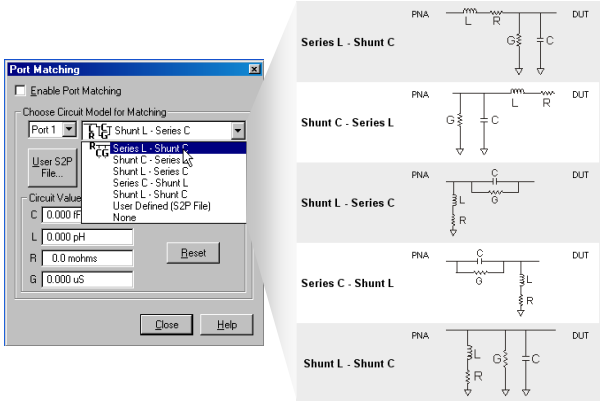


Summary (continued)

- **Automatic-port extensions** are simple to perform for medium-accuracy measurements of fixtured components



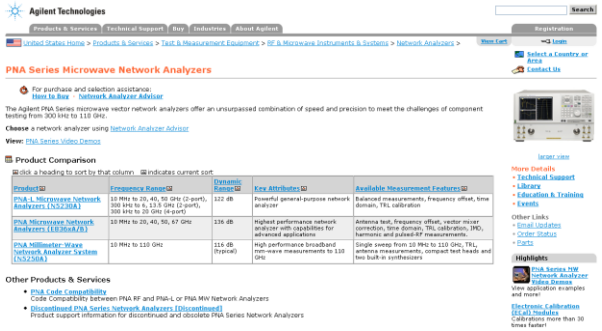
- **Software fixture tools** allow port-impedance conversions, embedding, de-embedding, and mixed-mode S-parameter measurements of single-ended and balanced devices

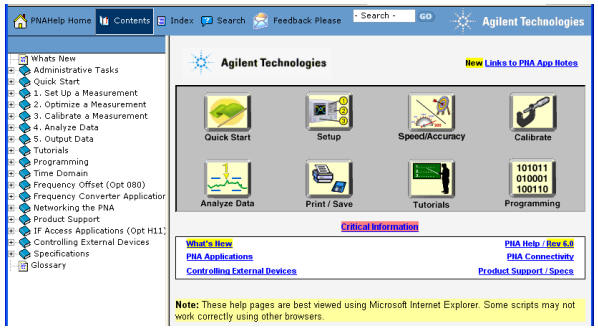


- **Electronic calibration** is a simple, fast and accurate way to calibrate network analyzers in a variety of applications

Additional Resources

- **Application note** 1287-11 “Specifying Calibration Standards and Kits for Agilent Vector Network Analyzers”, 5989-4840EN
- **Magazine article** *“Latest Advances in VNA Accuracy Enhancements”*, Dave Blackham, Ken Wong, Microwave Journal, July, 2005
- **Agilent Web links**:
  - –Network analyzer calibration: www.agilent.com/find/nacal
  - –PNA network analyzers: www.agilent.com/find/pna
  - –PNA-L network analyzers: www.agilent.com/find/pnal
  - –ECal electronic cal modules: www.agilent.com/find/ecal
  - –PNA Help Online: na.tm.agilent.com/pna/help/PNAWebHelp/help.htm
  - –Cal kit definitions: na.tm.agilent.com/pna/caldefs/stddefs.html





Network Analyzer Forum

www.agilent.com/find/agilent_naforum

- Learn more about calibration, applications, general usage, and remote operation
- Get answers from the factory
- Have peer-to-peer discussions

Dedicated section for calibration and error correction issues