Signal Integrity Measurement Systems

By
Chaitanya Sreerama (Intel Labs)
Outline

• Purpose
• Time Domain vs. Frequency domain
• Time Domain Reflectometry (TDR)
• Vector Network Analyzer (VNA)
• Q & A
Why do we need measurements?

To identify and quantify

Clean, open, logical 1 & 0 at launch from transmitter

Logical 1 & 0 can be hard to distinguish at end of long interconnects; (this is often called a "closed eye")

Fast, sharp, edges at transmitter launch

Smeared edges at end of long interconnect.
Tighter geometry in Multiple Lanes Result in Crosstalk

Serial data can be a single differential signal...

...but generally there are multiple "lanes" of serial data running side by side; these can CROSSTALK with each other.
Time Domain: is the domain for analysis of mathematical functions or signals with respect to time

An oscilloscope is a tool commonly used to visualize real-world signals in the time domain.

Frequency Domain: is the domain for analysis of mathematical functions or signals with respect to frequency.

A spectrum analyzer is the tool commonly used to visualize real-world signals in the frequency domain.

A time-domain graph shows how a signal changes with time, whereas a frequency-domain graph shows how much of the signal lies within each given frequency band over a range of frequencies.
One can use a Fourier transform and inverse Fourier transform to convert a given function or signal between the time and frequency domains.
Time Domain Reflectometry (TDR)
Time Domain TDR/TDT

Time Domain Through/Transmission

Time Domain Reflectometer
**Time Domain TDR/TDT**

**What information do you get?**
- Characteristic impedance of the system
- Resistive, inductive, and capacitive nature of each
- Discontinuity
- Types of losses (series or shunt)

**What is it used for?**
- Cable maintenance/repair
- Phone line maintenance/repair
- PWB trace characterization
- Silicon characterization
- Connector characterization

\[
\rho = \frac{V_{\text{reflected}}}{V_{\text{incident}}}
\]
\[
\rho = \frac{Z_L - Z_{\text{ref}}}{Z_L + Z_{\text{ref}}}
\]
\[
Z = Z_{\text{ref}} \frac{1 + \rho}{1 - \rho}
\]

\[V_{\text{settled}} = V_{\text{incident}} + V_{\text{reflected}}\]

\[
\rho = 0 \text{ at } Z = Z_0
\]
\[
\rho = -1 \text{ for a Short}
\]
\[
\rho = 1 \text{ for an Open}
\]
Basic TDR Oscilloscope Equivalent Circuit

\[ R_{\text{source}} = 50 \, \Omega \]

\[ Z_0 = 50 \, \Omega \]

then \[ V_{\text{incident}} = \frac{1}{2} V \]

Basic TDR Equations

\[ Z_{\text{load}} = Z_0 \cdot \frac{1+\rho}{1-\rho} = Z_0 \cdot \frac{V_{\text{settled}}}{2 \cdot V_{\text{incident}} - V_{\text{settled}}} \]

\[ \rho = \frac{V_{\text{reflected}}}{V_{\text{incident}}} = \frac{Z_{\text{load}} - Z_0}{Z_{\text{load}} + Z_0} \]

Source: http://www.gigaprobestek.com/images/tdr_iconnect_quick_guide.PDF
Reflection coefficient for:

- **Short Circuit:**
  \[ \rho = \frac{V_{\text{reflected}}}{V_{\text{incident}}} = \frac{-V}{V} = -1 \]

- **Open Circuit**
  \[ \rho = \frac{V_{\text{reflected}}}{V_{\text{incident}}} = \frac{V}{V} = 1 \]

- **Matched Load**
  \[ \rho = \frac{V_{\text{reflected}}}{V_{\text{incident}}} = \frac{0}{V} = 0 \]

Time Domain TDR Simple Lumped Element Behavior

**Shunt Capacitance**

\[ \tau = \frac{1}{2} Z_0 C \]

\[ C = \frac{-2}{Z_0} \int_{-t}^{t} \rho dt \]

\[ C = \frac{-2}{Z_0} \text{Area} \]

**Series Inductance**

\[ \tau = \frac{L}{2Z_0} \]

\[ L = 2Z_0 \int_{-t}^{t} \rho dt \]

\[ L = 2Z_0 \text{Area} \]

**Terminating Capacitance**

\[ \tau = Z_0 C \]

\[ L = \frac{Z_0}{2} \int_{-t}^{t} \rho dt \]

\[ L = \frac{Z_0}{2} \text{Area} \]

**Terminating Inductance**

\[ \tau = \frac{L}{Z_0} \]

\[ C = \frac{1}{-2Z_0} \int_{-t}^{t} \rho dt \]

\[ C = \frac{1}{-2Z_0} \text{Area} \]
Capacitive – Inductive terminations

- Capacitor Load Termination
- Inductor Load Termination
- Shunt Capacitance Discontinuity
- Series Inductance Discontinuity

Identify the type of load termination/discontinuity

- Capacitor Load Termination
  ![Capacitor Load Termination Diagram]
- Inductor Load Termination
  ![Inductor Load Termination Diagram]
- Shunt Capacitance Discontinuity
  ![Shunt Capacitance Discontinuity Diagram]
- Series Inductance Discontinuity
  ![Series Inductance Discontinuity Diagram]

Capacitive – Inductive discontinuities
Time Domain TDR of a transmission line with capacitive and inductive discontinuities

Coupled transmission lines

With two conductors plus ground there are two modes of propagation.

Instead of $Z_0$ we have

$$[Z] = \begin{bmatrix} Z_{dd} & Z_{dc} \\ Z_{cd} & Z_{cc} \end{bmatrix} \quad \begin{bmatrix} V_d \\ V_c \end{bmatrix} = \begin{bmatrix} Z_{dd} & Z_{dc} \\ Z_{cd} & Z_{cc} \end{bmatrix} \begin{bmatrix} i_d \\ i_c \end{bmatrix}$$

If the lines are symmetric the modes are pure differential and common modes

$$[Z] = \begin{bmatrix} Z_{dd} & 0 \\ 0 & Z_{cc} \end{bmatrix} \quad V_d = Z_{dd}i_d \quad V_c = Z_{cc}i_c$$

The physical significance of a mode is that the signal propagates with a single velocity. The velocity of the two modes might not be the same.
Differential TDR Measurements

All of the single-ended TDR measurement concepts apply to differential transmission lines.

- The odd mode impedance is defined as the impedance measured by observing one line, while the other line is driven by a complementary signal.
- The differential impedance is the impedance measured across the two lines with the pair driven differentially.
  \[ Z_{\text{differential}} = 2 \cdot Z_{\text{odd}} \]
- The even mode impedance is defined as the impedance measured by observing one line, while the other line is driven by an equivalent signal as the first.
- The common mode impedance is the impedance of the lines connected together in parallel
  \[ Z_{\text{common}} = \frac{Z_{\text{even}}}{2} \]

Advantages of Differential Signaling

Provides higher noise immunity for critical signals in a high-speed digital design.

- Allows transmission of signals where a clean, reliable common ground between the driver and the receiver is not available.
- Provides increased immunity to the common-mode noise in the system, because the receiver only sees relative (differential) voltage between the two transmission lines in the differential pair.
- In addition, because the fields radiated by each signal are of opposite polarity, they cancel out to significantly reduce the radiated energy, the main cause for electromagnetic interference (EMI) between devices.
- Differential signals are also less sensitive to the attenuation of the signal in the transmission medium, because the receiver design typically allows sufficient gain to reproduce the original signal.

Typical applications of differential signals are low-voltage differential signaling (LVDS), PCIe etc.
**Differential Mode**

Assuming Balanced steps and cables

\[
\rho_{\text{cc}} = \frac{V_1 + V_2}{V_{\text{inc1}} + V_{\text{inc2}}} = \frac{1}{2} \left( \frac{V_1}{V_{\text{inc}}} + \frac{V_2}{V_{\text{inc}}} \right) = \frac{\rho_1 + \rho_2}{2}
\]

\[
Z_{\text{cc}} = \sqrt{Z_1 + Z_2}
\]

If the test device is not balanced, differential to common mode voltage reflection coefficient is:

\[
\rho_{\text{cd}} = \frac{V_1 - V_2}{V_{\text{inc1}} - V_{\text{inc2}}} = \left( \frac{\rho_1 - \rho_2}{4} \right)
\]

**Common Mode**

If the test device is not balanced, common to differential voltage reflection coefficient is:

\[
\rho_{\text{cd}} = \frac{\sqrt{V_1 - V_2}}{V_{\text{inc1}} + V_{\text{inc2}}} = \left( \frac{\rho_1 - \rho_2}{4} \right)
\]
Vector Network Analyzer (VNA)
Vector Network Analyzer (VNA)

A PNA or a Precision Network Analyzer (also known as a VNA – Vector Network Analyzer) is a high frequency broadband measurement system providing a fast sweep speeds, wide dynamic range & low trace noise.

The PNA allows the quantification of the reflection and transmission characteristics of a DUT in Frequency Domain.
Frequency Domain Analysis

- Time Domain signals on T-lines lines are hard to analyze
  - Many properties, which can dominate performance, are frequency dependent, and difficult to directly observe in the time domain
  - Skin effect, Dielectric losses, dispersion, resonance

- Frequency Domain Analysis allows discrete characterization of a linear network at each frequency
  - Characterization at a single frequency is much easier

- Frequency Analysis is beneficial for three reasons
  - Ease and accuracy of measurement at high frequencies
  - Simplified mathematics
  - Allows separation of electrical phenomena (loss, resonance … etc)
Frequency Domain Vector Network Analyzer (VNA)

Unlike TDR the reflected wave is measured separately from the incident wave.

\[ S_{jk} = \frac{\text{sine wave out from port } j}{\text{sine wave into port } k} \]

\[ \text{Mag}(S_{jk}) = \frac{\text{Amp}(\sqrt{\text{Power}_j})}{\text{Amp}(\sqrt{\text{Power}_k})} \]
\[ \text{Phase}(S_{jk}) = \text{Phase}(\sqrt{\text{Power}_j}) - \text{Phase}(\sqrt{\text{Power}_k}) \]

\[ S_{11} = \text{Return Loss} \]
\[ S_{21} = \text{Insertion Loss} \]
What is Return Loss and Insertion Loss

**Return Loss (S11)**
1. Reflected wave from the DUT
2. Relates to impedance match of the interconnect
3. Exhibits periodic effects due to the standing waves
4. For Ideal DUT which is perfectly matched $S_{11}= 0 = -\infty$ (dB)

**Insertion Loss (S21)**
1. Transmitted wave through the DUT
2. Relates to reflections, coupling, and losses
3. For Ideal DUT $S_{21}= 1 = 0$ (dB)

**Loss free networks**
1. For a loss free network, the total power exiting the N ports must equal the total incident power
2. Since $s$-parameters are the square root of power ratios, the following is true for loss-free networks

$$\left(S_{11}\right)^2 + \left(S_{21}\right)^2 = 1$$
Single ended 4 port S-parameters

Port 1  Port 2

Mixed mode or differential S-parameters

Drive the ports with differential and common mode stimulus

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<tr>
<th>Differential</th>
<th>Common</th>
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<td>$S_{DD11}$</td>
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<td>$S_{CC22}$</td>
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Another good way to visualize the VNA data specially calibration is:

- Smith Chart

References:
http://en.wikipedia.org/wiki/Smith_chart
http://www.fourier-series.com/rf-concepts/smithchart.html
The 4 Ports N5230A 20 GHz PNA

- 3.5 mm connectors = 26.5 GHz
- Internal switches and couplers limit bandwidth to 20 GHz
- Channel setup (for Calibration)
Dynamic range = Highest power that the VNA can measure – VNA noise floor
Sufficient Dynamic Range can be reached by reducing the IF bandwidth.

Recommend an IF Bandwidth of 100-500 Hz achieves a balance between speed & validity of Calibration and Dynamic Range
An Ideal PNA Setup

- Perfectly Matched Ports
- Ideal Calibration Standards
- Ideal Connectors & Probes
- Zero Crosstalk between Ports
- No Variation in Cables
- Stable Environment (Temperature / Humidity)
Measurement Errors

**Systematic Errors**
- Caused by imperfections in test setup
- Characterized through Calibration & mathematically removed before the measurement process.

6 types of systematic errors
- Unmatched ports
- Imperfect Calibration Standards
- Imperfect Connectors & Probes

**Random Errors**
- Caused by instrument noise (IF noise floor & repeatability).
- Switch Repeatability
- Connector Repeatability
- Vary randomly wrt time

Noise errors can be reduced by
- increasing source power,
- narrowing the IF bandwidth,
- using trace averaging over multiple sweeps.

**Drift Errors**
- Caused by unstable environment such as temperature variation.
- Cause degradation in system’s performance after a calibration
- Removed by additional Calibration

Drift errors can be minimized
- By constructing a stable test environment with ambient temperature (68 – 86 F)
What Is Measurement Calibration?

- Calibration removes one or more of the systematic errors using an equation called an error model. Measurement of high quality standards (for example, a short, open, load, and thru) allows the analyzer to solve for the error terms in the error model.

- The accuracy of the calibrated measurements is dependent on the quality of the standards in the calibration kit and how accurately the standards are modeled (defined) in the calibration kit definition file. The calibration-kit definition file is stored in the analyzer. In order to make accurate measurements, the calibration kit definition must match the actual calibration kit used.
Conditions Where Calibration Is Suggested

Generally, you should calibrate for making a measurement under the following circumstances:

1) You want the best accuracy possible.
2) You are adapting to a different connector type or impedance.
3) You are connecting a cable between the test device and an analyzer test port.
4) You are measuring across a wide frequency span or an electrically long device.
5) You are connecting an attenuator or other such device on the input or output of the test device.

If your test setup meets any of the conditions above, the following system characteristics may be affected:

1) Amplitude at device input
2) Frequency Response Accuracy
3) Directivity
4) Crosstalk (Isolation)
5) Source Match
6) Load Match
Measuring Short, Open and Load at each Port allows for 6 equations to solve for 6 unknown residual errors.

4 Residual Errors in the Forward Direction

- Matched Ports, Ideal Calibration Standards, Ideal connectors & probes

4 Residual Errors in the Reverse Direction

- Matched Ports, Ideal Calibration Standards, Ideal connectors & probes

8 Terms Error Model

The Thru between Port 1 & 2 solves for the 2 residual transmission errors.

Frequency response errors → reflection & transmission tracking within test receivers
Source & load impedance mismatches → reflections
Directivity & crosstalk → signal leakage
In the 12-Terms Error Model,
Isolation and Switch Errors are considered.
PNA accessories and Quotes

- 50 GHz 4 port PNA with an Economic Cal kit
- PLTS (Platform Layer Physical System) – software for 4 ports calibration
- Test Port Adapters
- Gore Cables
- Probe Station
- Probe positioners
- Probes
PNA Accessories

Test port savers (Adapters)

Lint-free swabs and alcohol for cleaning probe tips

Contact substrate to test planarity of probe landings

Cal substrate for Differential probing

Cal substrate for Single Ended probing

GORE Picoprobe

GORE Cable

SOLT Cal kits for coaxial connectors
TRL Coaxial Cal Kit
7960S14A (Maury Microwave)

- Open F/Open M
- Short F/Short M
- Load F/Load M
- Thru F to F
- Thru M to M
- Adapters (M/M, M/F, F/F)
- Open End Wrench
- Disk with Cal definitions

SOLT Coaxial Cal Kit
85056A (Agilent)

- Open F/Open M
- Short F/Short M
- Broadband Load F/Load M
- Low band loads F/M
- Thru F to F
- Thru M to M
- Sliding loads
- Adapters (M/M, M/F, F/F)
- Wrench (Open End & Torque)
- Disk with Cal definitions
Ground (G) to signal (S) tip spacing are specified in Microns from 50 to 1250 microns. For standard GSG probes, the two spacings are equal.

Single-ended/Differential Probing

Differential/Dual Probes

Single ended Probes (typically 250 microns)

Calibration Substrate
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Quote Net Total: $56,514.71

Quote Price Total: USD $56,514.71
## PLTS – 4 port Agilent software License

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**Test Port Adapter from Maury Microwave**

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0Z = Internally Ruggedized cable, based on 0.140" O. D., Solid Center Conductor with enhanced phase stability.
0CJ = 2.4mm Straight Pin (male)
Maximum operating frequency (GHz) = 50
Assembly length 48 inches

**PRICES QUOTED ARE SUBJECT TO ACCEPTANCE WITHIN 30 DAYS FROM DATE OF QUOTATION, and may be changed by Seller thereafter without notice.**

*Please refer to the Quote # above when placing an order.*
Cascade Probe Station

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</tbody>
</table>

This is a BTS2000 package plus the following: (1) mount and low power focus mechanism for video scope (similar to SQ-133-588-01). (2) two kits to mount an Agilent PNA head to one positioner gantry of an R1000 station. It will provide mounting and also tie the two positioner plates on one gantry into one unit for synergistic motion of the PNA and the positioner holding the probe. Does NOT INCLUDE PNA or Positioner. Provides for mounts on both East & West positioner gantry's of the station. The PNA will be oriented in a North-South attitude. (3) chuck assembly that will mount to the base of an R1000 station. The chuck surface is large enough to hold an 18 by 24 inch circuit board utilizing vacuum based board clamps and bullet supports. The chuck will have an adjustment of 3 inches nominal. It will have a vacuum base to hold it in position on the base plate of the station and adjustable support posts under the edge of the chuck for additional stability. No Vacuum zones on this chuck assembly. (4) Includes a fixed position instrument tray that can be mounted on top of the scope gantry. Order separately SQ-115-331-01 (Board Clamp) and SQ-115-331-02 (Bullet Support) if needed.
# GGB Probe positioner

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Product</th>
<th>Description</th>
<th>Price</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>02</td>
<td>GTL101-110W</td>
<td>Fine Position Probe Positioner - vacuum base w/ East/West Nose</td>
<td>$3,600</td>
<td>7,200</td>
</tr>
<tr>
<td>02</td>
<td>02</td>
<td>GTL102-110V</td>
<td>Fine Position Probe Positioner - vacuum base w/ East/West Nose</td>
<td>$3,600</td>
<td>7,200</td>
</tr>
<tr>
<td>03</td>
<td>04</td>
<td>GTL101-115</td>
<td>90-degree rotational adapter plate for positioners</td>
<td>$150</td>
<td>600</td>
</tr>
<tr>
<td>04</td>
<td>01</td>
<td>GTL101-121</td>
<td>Thin film substrate vacuum holder</td>
<td>$450</td>
<td>450</td>
</tr>
<tr>
<td>05</td>
<td>01</td>
<td>GTL-101-151</td>
<td>Vacuum Manifold 7-position</td>
<td>$600</td>
<td>600</td>
</tr>
<tr>
<td>06</td>
<td>01</td>
<td>GTL-101-521</td>
<td>CCD video camera, power supply, zoom-optics, halogen-ring illumination system, S-video cable, and mounting kit</td>
<td>$5,799</td>
<td>5,799</td>
</tr>
</tbody>
</table>

**TOTALS**: $21,949
Ground (G) to signal (S) tip spacing are specified in Microns from 50 to 1250 microns.
For standard GSG probes, the two spacings are equal. ~ S975

Single ended Probes (typically 250 microns)

Contact substrate to test planarity of probe landings
$450

Cal substrate for Differential probing
$975

Cal substrate for Single Ended probing
$975

$1995
PERFORMING A 2 PORT CALIBRATION
USING THE N5230A 20 GHz PNA

Content:
Connections for a 2 port setting
Ensuring that the PNA is ready for its 2 Port Cal
Inputting in the Cal kit- containing the definition of the Calibration Standards for your 2 Ports Cal
Performing a 2 Port Calibration
Connections for a 2 Port Setting

1. Connect the AC power cable.

2. Turn the analyzer on by pressing the front panel On/Off switch. When the analyzer is turned on, the On/Off switch changes color from yellow to green.

Only the 2 port box E8364B (option 014 is not needed e.g. option 014 is only important to talk to the 4 port box e.g. the N4421B) PNA works as a stand alone PC and no extra software is needed.
Setting up the PNA for a 2 port Cal

Ensure that BOTH the 2 port and the 4 port boxes are ON

The PNA stands alone and works like a PC

Always Press “Preset” before starting any new Calibration

Ensure that the correct cables with correct connector size are being used e.g.

<table>
<thead>
<tr>
<th>Connector Size</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 mm</td>
<td>26.5 GHz</td>
</tr>
<tr>
<td>2.4 mm</td>
<td>50 GHz</td>
</tr>
<tr>
<td>1.85 mm</td>
<td>67 GHz</td>
</tr>
<tr>
<td>1 mm</td>
<td>110 GHz</td>
</tr>
</tbody>
</table>

- The Cables should be correctly torqued to each port of the PNA
- The required Cal kit is installed in the PNA
Calibration kits

A calibration kit is a set of physical devices called standards. Each standard has a precisely known or predictable magnitude and phase response as a function of frequency.

In order for the analyzer to use the standards of a calibration kit, the response of each standard must be mathematically defined and then organized into standard classes that correspond to the error models used by the analyzer.

To be able to use a particular calibration kit, the known characteristics from each standard in the kit must be entered into analyzer memory or recalled from a default list of calibration kits stored in the analyzer.
Before any calibration can be performed, the required Cal Kit must be installed in the PNA. The Cal kit contains the Cal Standards definitions. e.g. Capacitance value for an Open, Inductance value for a Short
In order to import a new Cal kit (or just to verify that the required Cal kit has already been imported), Click on Calibration from the top menu, then select Advance Modify Cal kit
Select the Cal Kit to be verified
If a new Cal kit will be inserted, click on Import Kit from the Menu then search for your Cal kit file. PNA Cal kit files end with the .ckt extension.
Performing a 2 Port Calibration

Under Channel Setup on the menu on the top right on the PNA, Press on Start/Set to set the Start Frequency (10 MHz, the lower end of the 50 GHz PNA).
No Cor means that the PNA is not calibrated right now
Next, under Channel Setup on the menu on the top right on the PNA, Press on Power to set the Power Level. This sets the Signal Power and the typical number used is -17 dBm. This is a low power value recommended by Agilent to ensure the lifetime of the switches inside your PNA.
Then, Under Channel Setup on the menu on the top right on the PNA, Press on Sweet Setup to set the IF Bandwidth. An IF Bandwidth between 100-500 Hz e.g. 300 Hz achieves a balance between speed & validity of Calibration and Dynamic Range.
Under the same menu, set up the number of points that you would like collected, typically 5000 points for a frequency range of 10 MHz-50GHz.
Under Channel Setup on the menu on the top right of the PNA, select Average. Setting the Average Factor to 3, for example, will collect data 3 times and makes an average of these 3 collected data before saving the S parameters. The Signal to Noise Ratio (S/N) is improved by 3 dB for every factor-of-2 increase in averages. This is an optional step. Usually the average factor is left to 1.
We are now ready to start the calibration. Select Cal under the Channel Setup And click on Cal Wizard.
On the screen that pops up, press on “Unguided Calibration: Use Mechanical Standards”. It is called an Unguided Calibration because the Electronic Calibration option is not being used. Make sure that “Create new Cal set” is selected. Then press Next
After pressing Next, select “Full SOLT 2-port(1,2) in order to perform a fresh 2 port Cal. Make sure “View or Select Cal kit” is selected. Usually for a 2 port, “Omit Isolation” is selected. The error caused by crosstalk is so insignificant for a 2 port Cal, that it is more accurate to “Omit Isolation”.
After Next is selected, the Cal kit to be used is selected e.g. for a 2 port 2.4 mm Calibration, 85056D : 2.4mm Calibration Kit is selected, for a 2 port coaxial Cal.
2.4 mm Coaxial Cal Kit:  
85056A or 85056D?

The 85056A 2.4 mm SOLT Coaxial Calibration Kit contains:
1. A low band load (M & F)
2. A broad band load (M & F)
3. And a sliding load (M & F)

The 85056D 2.4 mm SOLT Coaxial Calibration Kit contains a broadband load (M & F).

For a broadband SOLT (Short Open Load Thru) Coaxial Calibration, either 2.4 mm Cal kit can be used as the load used during calibration is the broadband load to cover the broadband frequency ranges.

Note that the Open, Short, and Thru standards have the same definitions in both the 85056A and the 85056D 2.4 mm SOLT Coaxial Cal kit.
Next is selected and we are now ready to measure the standards. **Open** is the first standard highlighted. Click on the highlighted **Open**
The system will prompt you to connect the Open standard to Port 1. Connect **Open** ensuring it is correctly torqued to your cable and press ok.
The end of the 2.4 mm Gore cable is a 2.4 mm male. So any standard to be connected should be a 2.4 mm female. Here, click on 2.4 mm female open. Data will be acquired and a tick will follow on the box and the OK button will be available when done. Click on Ok when done.
Notice that a tick is now present on top of the first Open and the short is highlighted. Press on Short and after removing the Open from the cable end, connect a 2.4 mm female short and press ok to proceed.
Again, since the end of the 2.4 mm Coax cable is a 2.4 mm male, any standard to be connected should be a 2.4 mm female. Here, click on 2.4 mm female Short. Data will be acquired and a tick will follow on the box and the OK button will be available when done. Click on Ok when done.
Notice that a tick is now present on top of the first Short as well and that Loads is now highlighted. Press on Loads and after removing the Short Standard from the cable end,
Here, click on 2.4 mm female broadband load. Data will be acquired and a tick will follow on the box and the OK button will be
Thru can now be measured. Connect a **Thru** between Port 1 and Port 2 and press ok.
The Thru data will be acquired in the same fashion. Proceed on to the next Open Standard connecting a female open to Port 2 and repeated the steps for Port 2 for
After all data using these 7 connections have been made, ticks are present on top of all the standards.
Next is selected and the system will prompt you to save an instrument state at this stage.

Congratulations! You have just completed a 2 port Calibration of the 50 GHz PNA.
Port 1 & Port 2 Thru

Calibration Substrate

GSG

GSG

GSG

GSG

2 Ports SOLT Picoprobing

Chaitanya Sree & Dr. Paul G. Huray
This indicated that you now have a Calibrated 2 Port SOLT Cal on your PNA. Two windows are present on this screen. To add in more windows, Click on Window (From the top menu bar), then New.
To change the format of the S parameters displayed on the window, right click on the grey area and select your desired format.
To add in another S parameter display to any window, click on the window, then click on Trace from the Top Menu and select the New Trace that you would like to be displayed.
To verify reflection measurements, perform the following steps:

Connect either an OPEN or SHORT standard to port 1. The magnitude of S11 should be close to 0 dB (within a few tenths of a dB).

Connect a load calibration standard to port 1. The magnitude of S11 should be less than the specified calibrated directivity of the analyzer (typically less than -30 dB).

To verify transmission measurements:

Connect a THRU cable (or known device representative of your measurement) from port 1 to port 2. Verify the loss characteristics are equivalent to the known performance of the cable or device.

To verify S21 isolation, connect two loads: one on port 1 and one on port 2. Measure the magnitude of S21 and verify that it is less than the specified isolation (typically less than -80 dB).
Backup Slides
Random Errors:
Switch & Connector Repeatability Errors

Switch Repeatability Errors

Mechanical RF switches are used in the analyzer to switch the source attenuator settings.

Sometimes when mechanical RF switches are activated, the contacts close differently from when they were previously activated. When this occurs inside of the analyzer, it can adversely affect the accuracy of a measurement.

You can reduce the effects of switch repeatability errors by avoiding switching attenuator settings during a critical measurement.

Connector Repeatability Errors

Connector wear causes changes in electrical performance. You can reduce connector repeatability errors by practicing good connector care methods.
There are several situations that can cause unstable measurements, preventing repeatability in measurements e.g.

1) Temperature Drift
2) Frequency Drift
3) Inaccurate Measurement Calibrations
4) Device Connections
Temperature Drift
Thermal expansion and contraction changes the electrical characteristics of the following components:
A) Devices within the analyzer
B) Calibration kit standards
C) Test devices
D) Cables
E) Adapters

To reduce the effects of temperature drift on your measurements:
1. Switch on the analyzer 1/2 hour before performing a measurement calibration or making a device measurement.
2. One hour before you perform a measurement calibration, open the case of the calibration kit and take the standards out of the protective foam.
3. Use a temperature-controlled environment. All specifications and characteristics apply over a 25 °C ±5 °C range (unless otherwise stated).
4. Ensure the temperature stability of the calibration kit devices.
5. Avoid handling the calibration kit devices unnecessarily during the calibration procedure.
6. Ensure the ambient temperature is ±1°C of the measurement calibration temperature.
Frequency Drift
The analyzer frequency accuracy is based on an internal 10 MHz frequency oscillator. If better frequency accuracy and stability are required for any measurement applications, the internal frequency standard can be overrode and the user’s own high-stability external frequency source can be used.

Inaccurate Measurement Calibrations
If a measurement calibration is inaccurate, the true response of a device under test will not be measured. Calibration standards that match the definitions should be used in the calibration process. Note that connectors should always be inspected and cleaned if needed before use.

Device Connections
Good connections are necessary for repeatable measurements. The following will ensure good connections:
1) Inspect and clean the connectors for all of the components in the measurement setup.
2) Use proper connection techniques.
3) Avoid moving the cables during a measurement.
### PNA Correction Level

The correction level provides information about the accuracy of the active measurement. Correction level notation is displayed on the status bar for different calibration types like response, full 2-port, TRL or power calibration.

<table>
<thead>
<tr>
<th>Correction Levels:</th>
<th>Accuracy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full C</td>
<td>Highest</td>
<td>Full Correction level is displayed immediately after a calibration is performed or when a valid calibration is recalled from memory. For optimum accuracy, avoid adjusting analyzer settings after calibration so that measurement remains at this level.</td>
</tr>
<tr>
<td>Interpolated C*</td>
<td>Uncertain</td>
<td>An interpolated measurement is indicated by (C*) in the status bar. Interpolation occurs when you any of the following settings is changed: Sweep time, Frequency (subset of Start/Stop), IF Bandwidth, Port power, Stepped sweep enabled/disabled, Number of points.</td>
</tr>
<tr>
<td>No Correction</td>
<td>Lowest</td>
<td>If the frequency span is increased outside the original start/stop frequency, or sweep type is changed, the current calibration becomes invalid and error correction is turned OFF. The analyzer indicates a no-correction status with No Cor on the status bar.</td>
</tr>
<tr>
<td><strong>Do</strong></td>
<td><strong>Connector Care</strong></td>
<td><strong>Do Not</strong></td>
</tr>
<tr>
<td>--------</td>
<td>--------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Handling and Storing Connectors</td>
<td></td>
<td>Touch mating-plane surfaces Set connectors contact-end down Store connectors contact-end down</td>
</tr>
<tr>
<td>Keep connectors clean Protect connectors with plastic end caps Keep connector temperature same as analyzer</td>
<td></td>
<td>Set connectors contact-end down Store connectors contact-end down in box or drawer</td>
</tr>
<tr>
<td>Visual Inspection</td>
<td></td>
<td>Use a connector with a bent or broken center conductor Use a connector with deformed threads</td>
</tr>
<tr>
<td>Inspect connectors with magnifying glass. Look for metal debris, deep scratches or dents</td>
<td></td>
<td>Use any abrasives Allow alcohol into connector support beads Apply lateral force to center conductor</td>
</tr>
<tr>
<td>Cleaning Connectors</td>
<td></td>
<td>Use an out of specification connector Hold connector gage by the dial</td>
</tr>
<tr>
<td>Clean surfaces first with clean, dry compressed air Use lint-free swab or brush Use minimum amount of alcohol Clean outer conductor mating surface and threads Use high pressure air (&gt;60 psi)</td>
<td></td>
<td>Use an out of specification connector Hold connector gage by the dial</td>
</tr>
<tr>
<td>Gaging Connectors</td>
<td></td>
<td>Use an out of specification connector Hold connector gage by the dial</td>
</tr>
<tr>
<td>Inspect and clean gage, gage master and device tested Use correct torque wrench zero gage before use. Use multiple measurements and keep record of readings</td>
<td></td>
<td>Use an out of specification connector Hold connector gage by the dial</td>
</tr>
<tr>
<td>Making Connections</td>
<td></td>
<td>Cross thread the connection Twist connector body to make connection Mate different connector types</td>
</tr>
<tr>
<td>Align connectors first Rotate only the connector nut Use correct torque wrench</td>
<td></td>
<td>Cross thread the connection Twist connector body to make connection Mate different connector types</td>
</tr>
</tbody>
</table>

**Cleaning Connectors**
- Clean surfaces first with clean, dry compressed air
- Use lint-free swab or brush
- Use minimum amount of alcohol
- Clean outer conductor mating surface and threads
- Use high pressure air (>60 psi)

**Gaging Connectors**
- Inspect and clean gage, gage master and device tested
- Use correct torque wrench zero gage before use.
- Use multiple measurements and keep record of readings

**Making Connections**
- Align connectors first
- Rotate only the connector nut
- Use correct torque wrench