Partner for Future Technology

Calibration and compensation of **INGUN RF probes**

Contents

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1. Abbreviations

VNA	Abbreviation for Vector Network Analyzer
DUT	Commonly used abbreviation for device under test
Single ended	The simplest and most commonly used method of signalling and transmission whereby one pin (in coaxial probe, the inner conductor) carries a varying voltage that represents the signal, while the other pin (outer conductor for a coaxial probe) is connected to a reference voltage, usually ground. See differential for comparison.
Differential	A method for transmitting information using two complementary signals. In the case of RF probes, this is a pair of inner conductors for each of the differential lines. There can also be one or more ground pins in addition to the shield which is typically connected to ground. See single-ended for comparison.
In-situ	A Latin phrase which means in the original place. Here it refers to the method of the DUT being calibrated in its operating position.
Non-In-Situ	Refers to a scenario where the DUT must be taken out of its operating position for calibration. Also see in-situ.
SOL	Abbreviation for Short Open Load – a calibration technique which makes use of a calibration kit with Short, Open and Load standards.
SOLT	Abbreviation for Short Open Load Thru – a calibration technique which makes use of these four calibration kits.
Manual contacting	Refers to contact between the RF probe and the DUT which is generated manually by the test operator. See automatic contacting for comparison.
Automatic contacting	Refers contact between the RF probe and the DUT which is automatically generated. See manual contacting for comparison.
Cal kit	Short for calibration kit. A kit consists of known RF terminations such as open, short, load, thru and sliding load. In many cases these terminations will take place electronically, in which case the cal kit is referred to as e-cal kit.
Test fixture	A mechanical unit where the DUT is placed to be tested.
SMA	Abbreviation for sub miniature A
Compensation	Refers to the subtraction of offsets created by the measurement accessories such as cables and RF probes.

2. Why we need calibration and compensation?

Determining the effect of RF probes and their corresponding adapters and/or cables in measurements is a crucial part of RF testing. In doing so, INGUN customers can measure their DUTs without interference from the inherent properties of the RF probes and cables.

Challenges

- The RF probe tip (where the calibration takes place) should be accessible in a way that does not hinder the placement and connection of components required for the calibration/compensation.
- RF probe tips have a wide range of form factors that differ from those of the components used for calibration/compensation. If these differ from the form factors in the test system, adapters are needed.
- The operating stroke of the RF probe should be maintained during calibration/compensation.

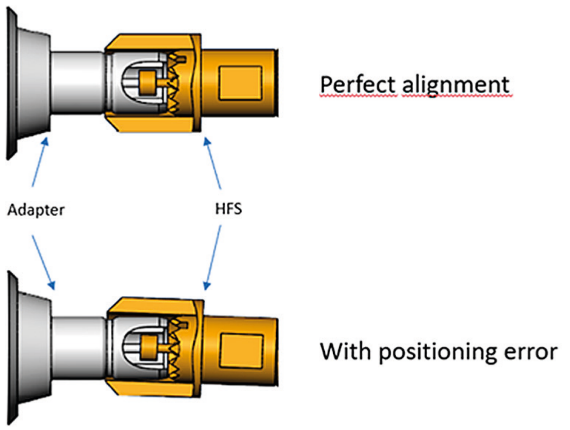
Figures of merit

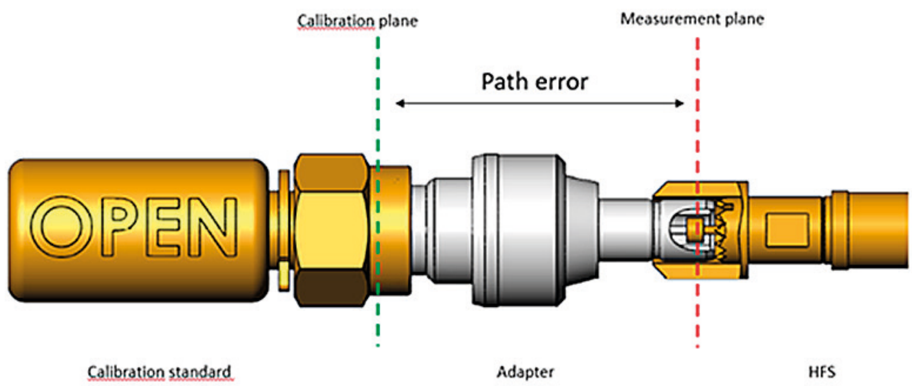
INGUN's ultimate goal is to provide our customers with virtually error-free testing while maintaining the quick, simple, and cost-effective testing. Based on these figures of merit, customers can decide which calibration/compensation method best serves their intended application.

Errors associated with calibration/ compensation

In addition to errors that arise due to the shortcomings of commonly used calibration kits, there are two main errors that typically arise when calibrating an RF probe:

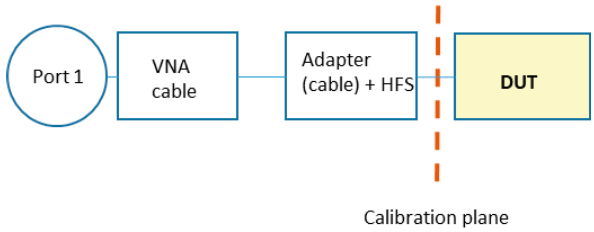
- **Positioning error:** this error arises when the RF probe is not accurately aligned with its counterpart.
- **Calibration path error:** this error arises when extensions are added or removed after the calibration has already been performed.

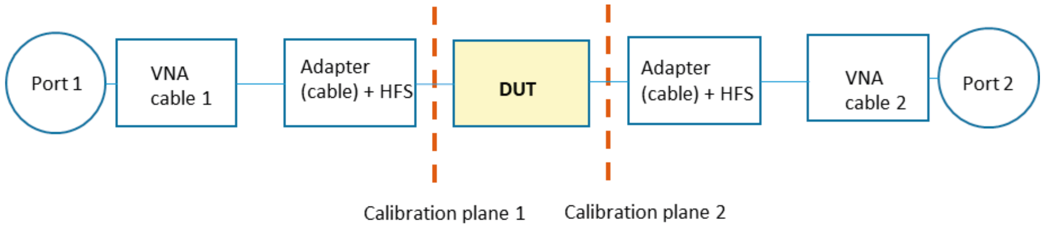




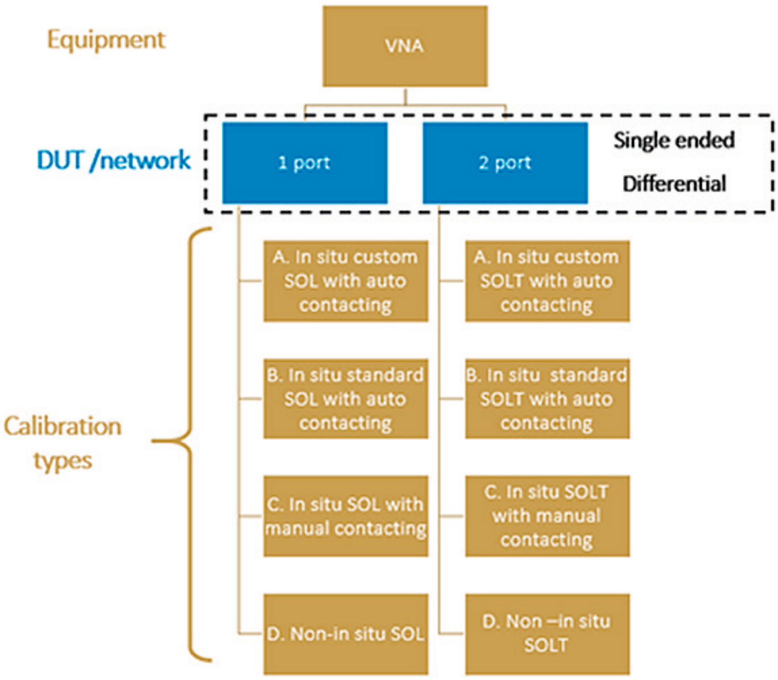
3. Calibration in VNA testing when the RF probe is inside the calibration plane

The following two block diagrams show the calibration setups for 1-port and 2-port testing respectively, when the RF probe is included in the calibration.





These two setups can be broken down into several different scenarios. An overview of some of the most common scenarios and their recommended calibrations are summarised in the following diagram.



VNA testing and calibration scenarios

Required components, procedures, merits and demerits of each of these calibration types are provided on the subsequent pages. In the subsequent sections the required components, procedure, advantages and disadvantages of 1-port single-ended calibrations is described first, followed by descriptions of 2-port calibrations in the same format. A brief overview of differential tests is also provided. Similar procedures to that of 2-port calibration can be followed for multiport calibration, because multiport calibration can be seen as an extension of 2-port calibration.

The ZVA67 vector network analyzer (VNA) from Rhode & Schwarz was used to show the steps in the following set-up descriptions. Similar steps can be followed with other VNAs.

I.

Calibration of 1-port, single-ended testing using VNA

As stated in the previous section, four methods of calibration are possible in single port VNA testing.

A. In-situ custom SOL with auto contacting

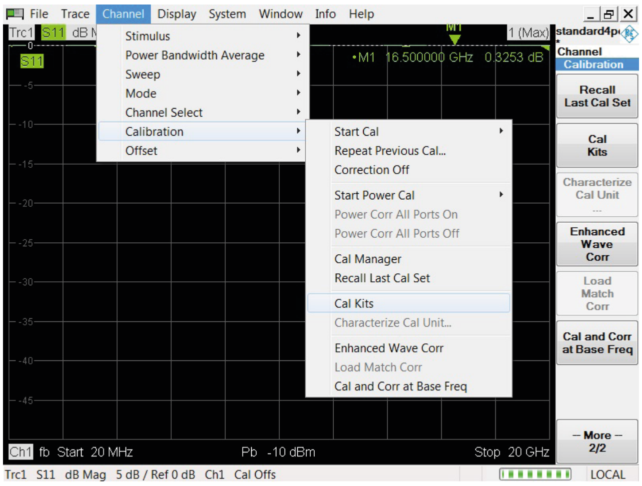
This method uses custom SOL kits that mimic the outline shape of the DUT to perform the calibration.

Required components:

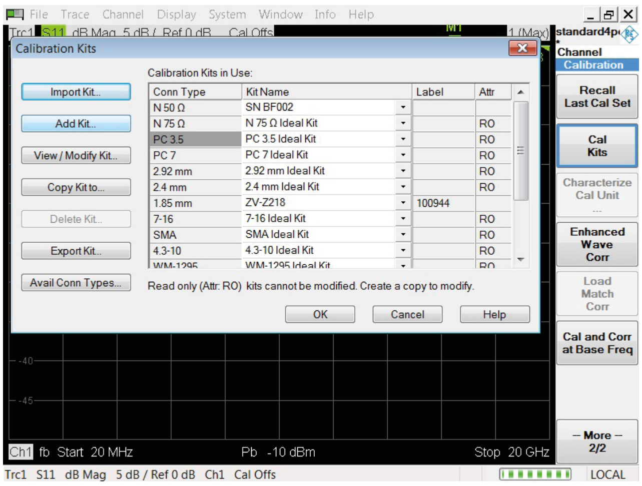
Custom-made SOL kits with calibration parameters.

Procedure:

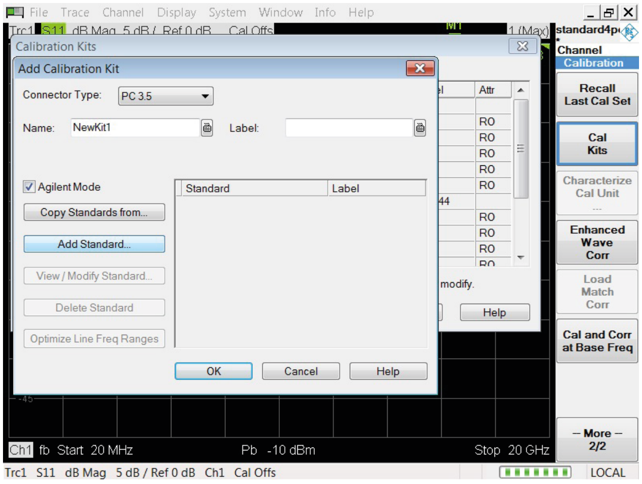
1. Open the **Calibration** toolbox in the VNA software. Load the calibration parameters for the custom calibration standard, by clicking **Cal Kits**.



In the **Calibration Kit** field, click **Add Kit**.

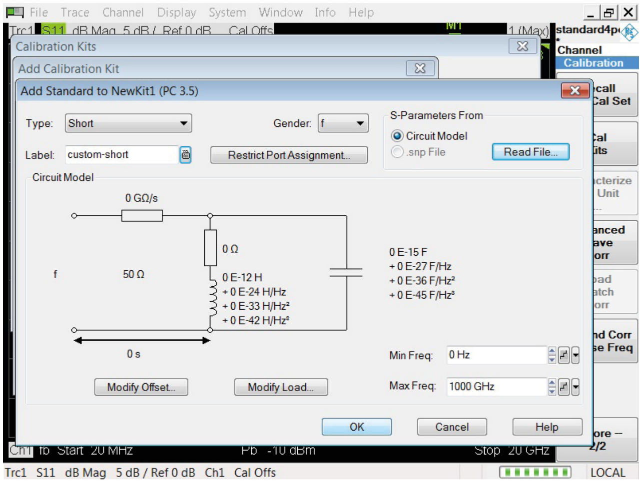


In the **Add Calibration Kit** field, click **Add Standards**.

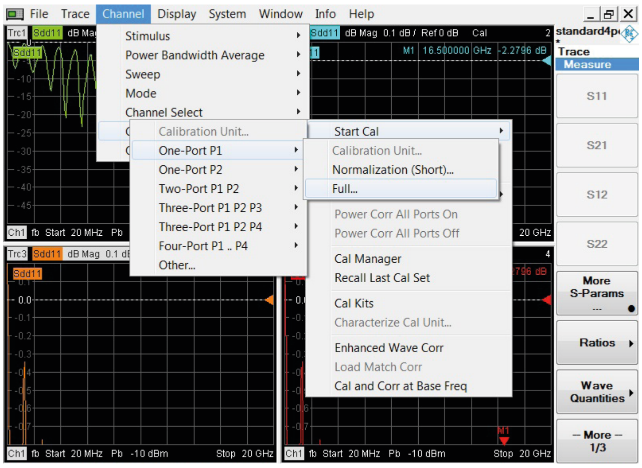


For **Type**, select **Short** from the drop down menu.

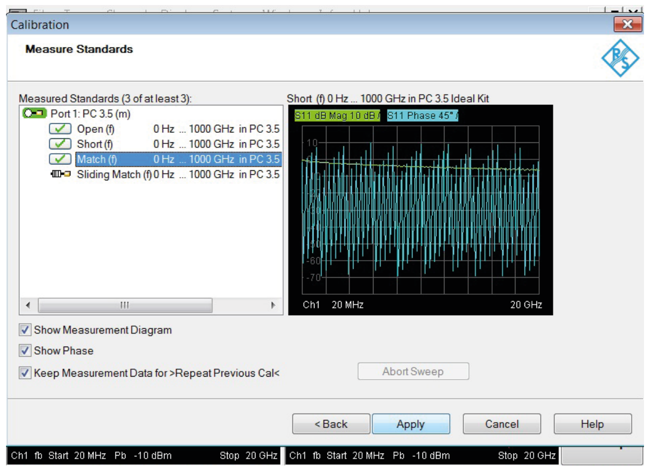
Next, insert the calibration parameters for **Short** and save by clicking **Ok**. Then, repeat the above steps for **Open** and **Load**. The calibration kit is now ready to be used. The following steps describe how to use these kits in calibration.



2. Insert the **custom-short** kit.
3. Close the test fixture (or activate the unit that guides the RF probe to its contacting position).
4. Perform the calibration for the chosen calibration kit by selecting **One Port P1**, then **Full** as shown below. Then click on **Short(f)** for the system.

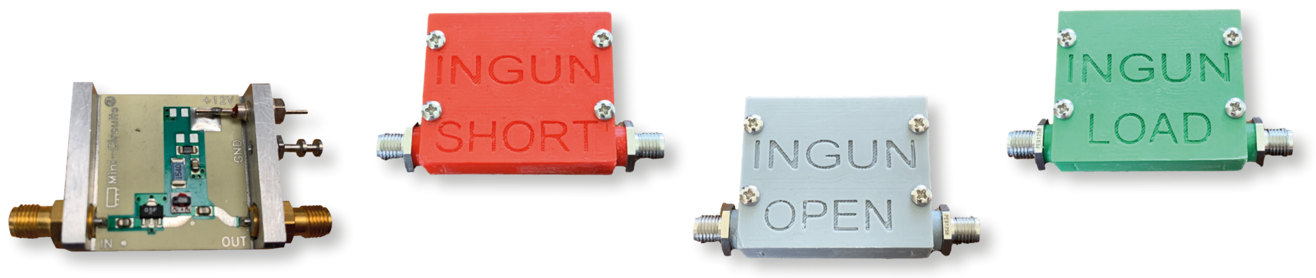


5. Repeat steps 2-4 for **Open** and **Load** kits.
6. Click **Apply** to save the measurement results and complete the calibration.



Example:

1-port testing of DUT where the SMA at the left side is contacted as shown in the figure below. Exact mechanical SOL replicas of this DUT will be placed in the test fixture instead of the DUT so that the calibration can be completed.



DUT (left) and SOL kit that mimic it (Short, Open and Load, left to right)

Advantages:

- Risk of positioning errors is low.
- No calibration path errors
- Quick and easy to operate

Disadvantages:

- Making custom-made SOL kits can be extremely complex and expensive.
- Custom-made SOL kits may not achieve the RF performance of other commercially available calibration kits.

B. In-situ standard SOL with automatic contacting

This method utilises a custom-made mounting unit to maintain the probe's contact with the standard calibration components.

Required components:

- Custom-made adapters to connect RF probe tip to calibration kit
- Standard SOL calibration kits
- Custom-made automatic contacting units

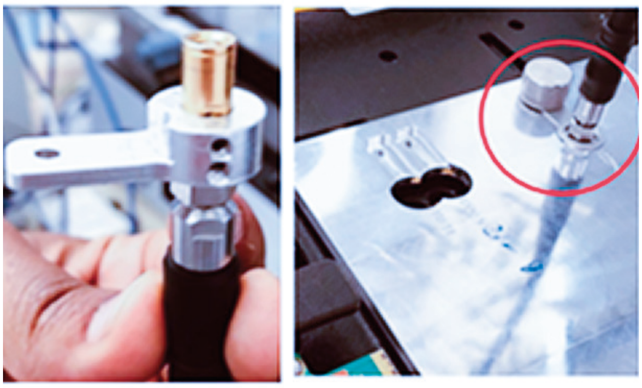
Procedure:

The procedure may vary depending on the nature of the custom-made contacting mechanism.

1. Connect the RF probe with the adapter using the custom-made automatic contacting unit.
2. Screw the **Short** standard calibration kit from the SOL calibration kit on the adapter.
3. Perform the calibration for the **Short** standard calibration kit using the **Calibration** toolbox in the VNA software as shown in section A, step 4.
4. Repeat the procedure for **Open** and **Load** standard calibration kits.

Example:

The following picture shows a contacting mechanism where the coaxial adapter (that connects the RF probe tip with standard SOL calibration kit) is equipped with a drilled extension component (left) that can be contacted with the RF probe tip by screwing it on the metal plate (right).



An example of in-situ standard SOL with automatic contacting.

Advantages:

- Risk of positioning errors is low.
- Depending on the design of the custom unit, it can be quick and easy to operate.

Disadvantages:

- The fixing units are usually specific to the intended application and must be designed accordingly
- A certain degree of error is to be expected when the calibration path is not compensated.

C. In-situ standard SOL with manual contacting

This method involves contacting the calibration components with the installed RF probe manually.

Required components:

- Standard adapters (RF probe tip to calibration kit)
- Standard SOL calibration kits

Procedure:

1. Screw the Short standard from the SOL calibration kit on the standard adapter.
2. Manually contact the installed RF probe with the adapter.
3. Perform the calibration for the Short standard using the Calibration toolbox in the VNA software as shown in section A, step 4.
4. Repeat the procedure for Open and Load standards

Advantages:

- Inexpensive as custom-made units are not required.
- The probe remains installed in the test fixture.

Disadvantages:

- Reduced accuracy: errors due to both incorrect probe positioning and uncompensated calibration path.
- Depending on the set-up, two operators are needed to operate the measurement device while contacting the RF probe at its operating stroke.

D. Non in-situ standard SOL

This method is employed when calibration is not possible with the RF probe in its original testing position and it has to be uninstalled, i.e., not in-situ. Contacting the RF probe with the adapter can be realised either manually or with the help of some kind of contacting unit.

Required components:

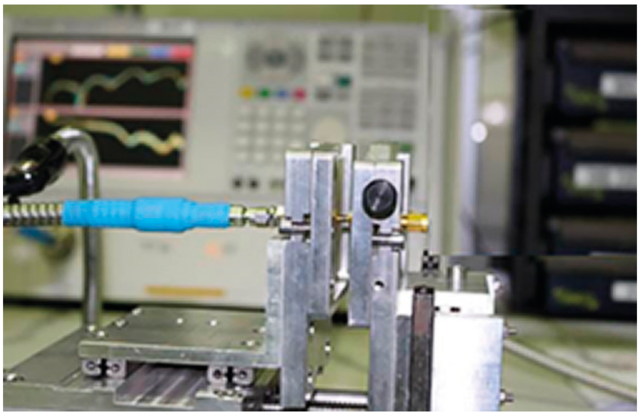
- Standard adapters (RF probe tip to calibration kit)
- Standard SOL calibration kits
- Optional: contacting units (unless manual contacting is preferred)

Procedure:

1. Remove the RF probe from the test set-up.
2. Screw the **Short** standard from the SOL calibration kit on the standard adapter.
3. Manually contact the uninstalled RF probe with the adapter.
4. Perform the calibration for the **Short** standard using the **Calibration** toolbox in the VNA software as shown in section A step 4.
5. Repeat the procedure for **Open** and **Load** standards.

Example:

The picture below shows a mechanical unit connecting the coaxial adapter with the uninstalled RF probe and cable.



Advantages:

- Inexpensive as custom-made calibration kits are not required.

Disadvantages:

- A certain degree of error is to be expected when the calibration path is not compensated.
- Unsuitable if calibration has to be done frequently.
- If no such mounting units, as shown in picture above, are used, positioning errors will also occur.
- Depending on the set-up, two operators may be needed to operate the measurement device while maintaining the adapter at operating stroke.

II.
Calibration of 2-port, single-ended testing using VNA

For the majority of 2-port calibration cases, SOLT calibration technique is preferred to TRL/M. This manual is also written taking SOLT into account. However, similar steps can be followed for TRM/L too.

A. In-situ custom SOLT with auto contacting

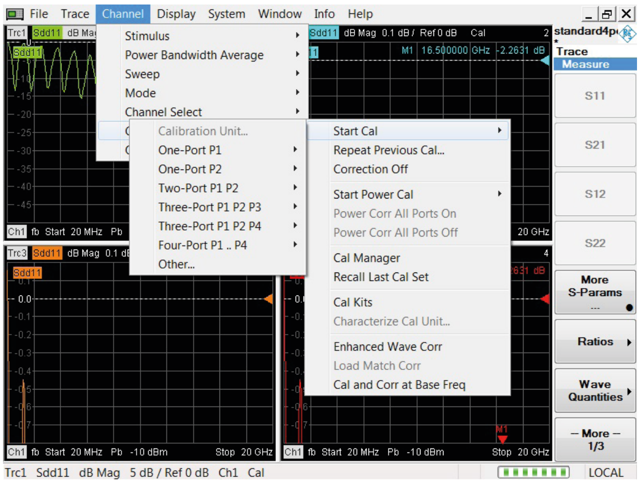
In this scenario, as with the SOL kits in section 1.A, SOLT kits that mimic the outline of the DUT are used.

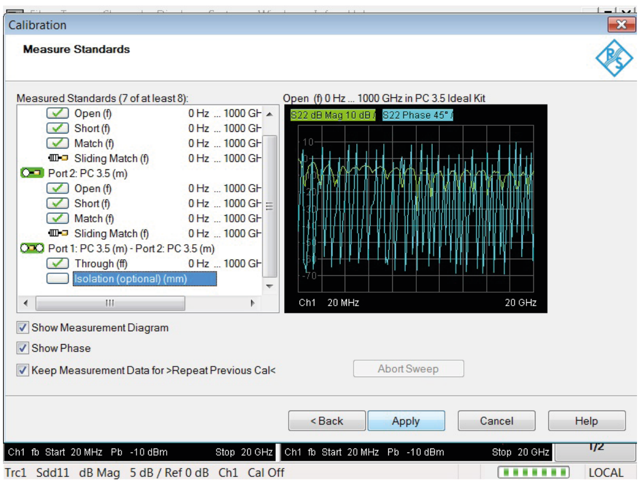
Required components:

Custom SOLT calibration kits with calibration parameters.

Procedure:

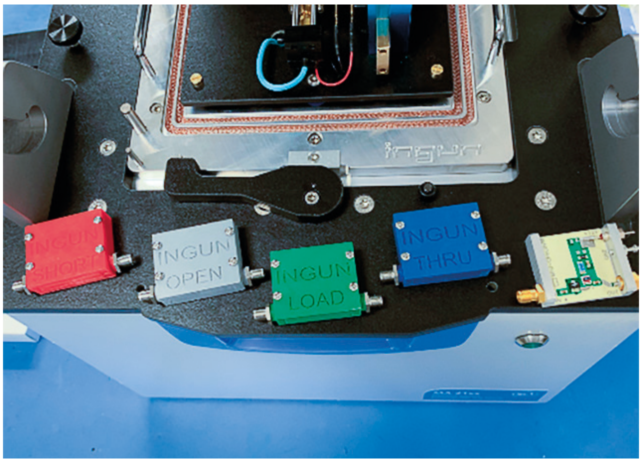
1. Load the calibration parameters for the custom calibration standard as shown in section 1.A (the only difference here is that parameters for the **Thru** standard will also be added).
2. Insert the **Short** calibration kit in test set-up.
3. Close the fixture (or activate the unit that guides the RF probe to its contacting position).
4. Select **Two-Port P1 P2** calibration in the calibration tool. Then, perform the calibration for both ports of the kit inserted (as shown below).
5. With the calibration tool open, repeat steps 2-3 for **Open, Load** and **Thru**.
6. Click **Apply** to save the measurement results.





Example:

2-port testing where the SMA on the right and left side of the DUT are contacted as shown in the figure below. Exact mechanical SOLT replicas of this DUT will be placed in the test fixture in lieu of the DUT and the calibration can be completed.



Advantages:

- Risk of positioning errors is low.
- No calibration path errors.
- Quick and easy to operate.

Disadvantages:

- Making custom-made SOLT kits can be extremel complex and expensive.
- Custom-made SOLT kits might not achieve the RF performance of other commercial kits.

B. In-situ standard SOLT with auto contacting

This method utilises a custom-made mounting unit to maintain the RF probe's contact with the standard calibration components.

Required components:

- 2 x calibration kit adapters for each of the RF probe tips
- Standard SOLT calibration kits
- Custom-made automatic contact units

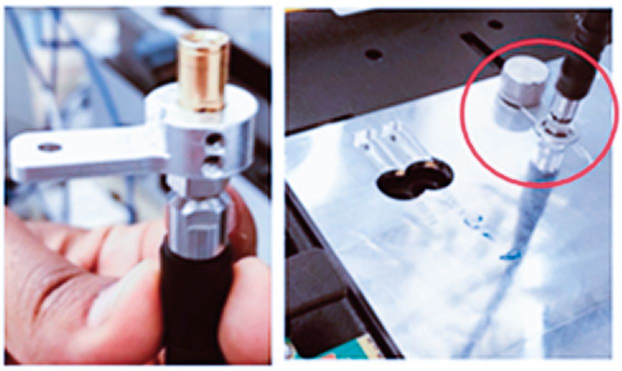
Procedure:

The exact procedure may vary depending on the nature of the custom-made contacting mechanism used.

1. Connect the RF probes to the adapters using the custom-made automatic contacting unit.
2. Screw the **Short** standard from the SOLT calibration kit on one of the adapters.
3. Perform the calibration for the **Short** standard using the **calibration** toolbox as shown in step 3 of section 2A.
4. Perform steps 2 & 3 for **Open** and **Load** standards.
5. Perform steps 2 & 3 also for **Thru** standard. In most cases, the two probes that are being calibrated in 2-port calibration could be located where a standard **Thru** kit would not fit. If that is the case, an unknown **Thru** kit should be used.

Example:

The following picture shows a contacting mechanism where the coaxial adapter (that connects the RF probe tip with standard SOLT calibration kit) is equipped with a drilled extension component (left) that can be contacted with the RF probe tip by screwing it on the metal plate (right).



Advantages:

- Risk of positioning errors is low.
- Depending on the design of the custom unit, it can be quick and easy to operate.

Disadvantages:

- The fixing units are typically specific to the intended application and must be designed accordingly.
- A certain degree of error is to be expected when the calibration path is not compensated.

C. In-situ standard SOLT with manual contacting

This method involves contacting the calibration components with the installed RF probe manually.

Required components:

- 2 x calibration kit adapters for each of the RF probe tips
- Standard SOLT calibration kits

Procedure:

1. Screw the **Short** standard from the SOLT calibration kit on one of the adapters.
2. Manually contact the RF probe with the adapter.
3. Perform the calibration for the **Short** standard using the calibration toolbox as shown in step 3 of section 2A.
4. Perform steps 2&3 for **Open** and **Load** standards.
5. Perform steps 2&3 also for **Thru** standard. In most cases, the two probes that are being calibrated in 2-port calibration could be located where a standard **Thru** kit would not fit. If that is the case, an unknown **Thru** kit should be used.

Advantages:

- Inexpensive as custom-made units are not required.
- The probe remains installed in the test fixture.

Disadvantages:

- Reduced accuracy: errors due to both incorrect probe positioning and uncompensated calibration path.
- Depending on the set-up, two operators are needed to operate the measurement device while contacting the RF probe at its operating stroke.

D. Non in-situ standard SOLT

This method is employed when calibration is not possible with the RF probe in its original testing position and it has to be uninstalled, i.e., not in-situ. Contacting the RF probe with the adapter can be realised either manually or with the help of some kind of contacting unit.

Required components:

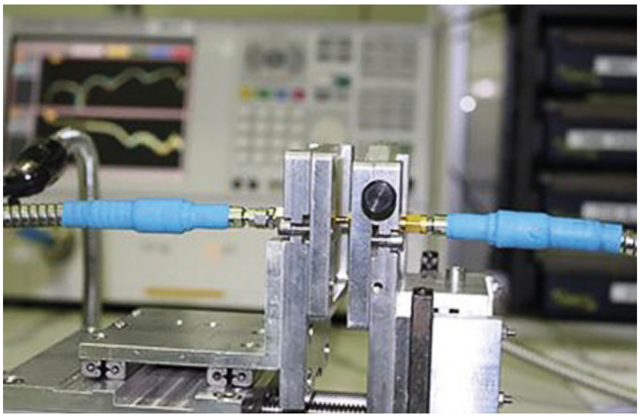
- 2 x calibration kit adapters for each of the RF probe tips
- Standard SOLT calibration kits
- Optional: contacting units (unless hand contacts are preferred)

Procedure:

1. Remove the RF probe from the test set-up.
2. Screw the **Short** standard from the SOL calibration kit on the standard adapter.
3. Manually contact the uninstalled RF probe with the adapter.
4. Perform the calibration for the **Short** standard using the **Calibration** toolbox in the VNA software as shown in section A step 4.
5. Repeat the procedure for **Open** and **Load** standards.

Example:

The picture below shows a mechanical unit connecting the coaxial adapter with the uninstalled RF probe and cable.



Advantages:

- Inexpensive as custom-made units are not required

Disadvantages:

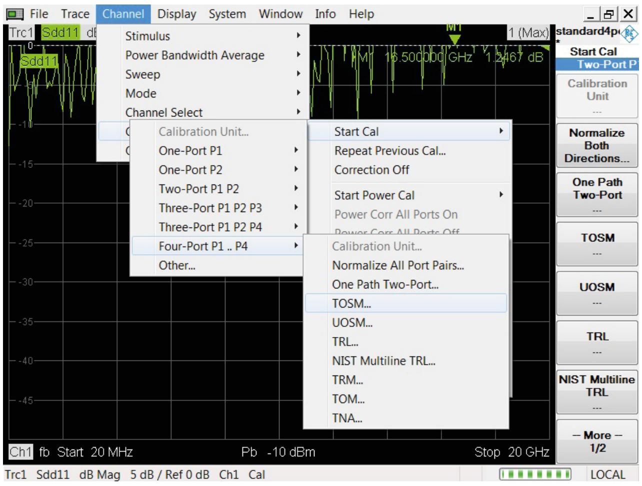
- A certain degree of error is to be expected when the calibration path is not compensated.
- If no such mounting units, as shown in figure above, are used, positioning errors will also occur.
- Depending on the set-up, two operators may be needed to operate the measurement device while maintaining the adapter at operating stroke.

III.
Calibration of differential testing using VNA

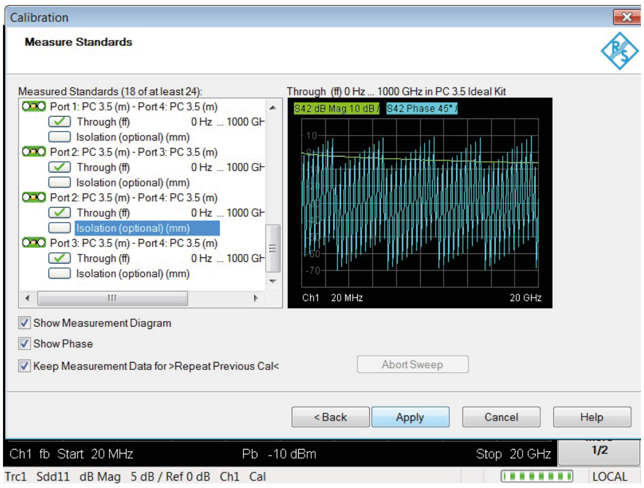
Single port differential calibration can be first calibrated using the same method as for 2-port single-ended – as shown in section II. As previously stated, the calibration kits used can be custom-made or standard kits, and contacting may be automatic or manual. Once the calibration is complete, balanced logical ports can be defined.

Furthermore, 2-port differential calibration can be calibrated using the same method as for 4-port single-ended calibration. An illustration of a calibration using the ZVA67 VNA is given below.

1. Open the **Calibration** toolbox in the VNA software. Select **Four-Port P1**, then **TOSM** (SOLT) calibration

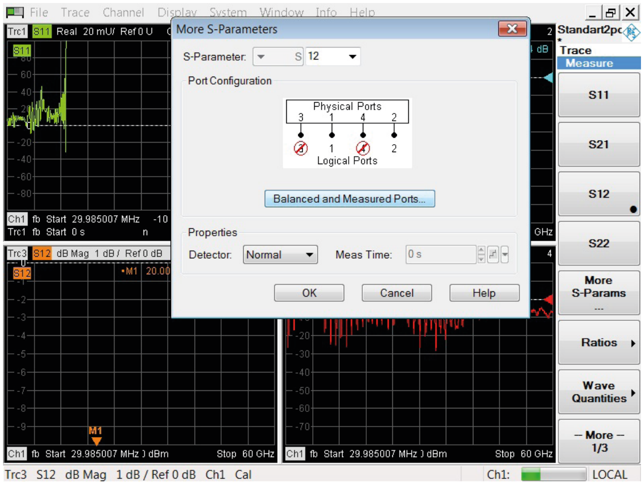


2. Connect and calibrate each of the standard kits, then click **Apply** to save the measurement results.

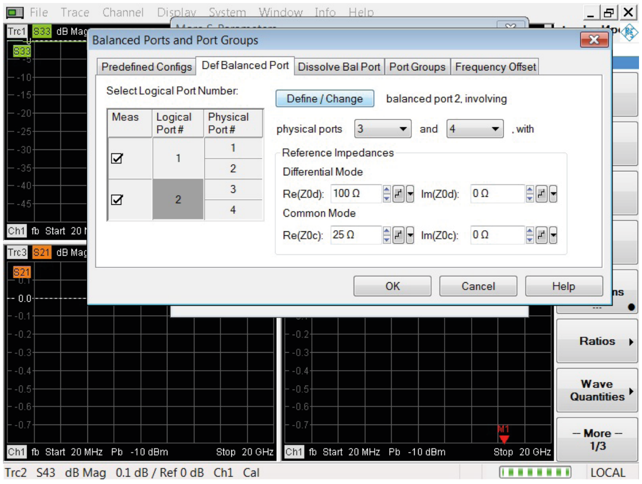


3. Once the 4-port, single-ended calibration is completed, logical ports can be defined to transform these four ports to two differential ports.

4. In the **More S-Parameters** window, select **Balanced and Measured Ports**.



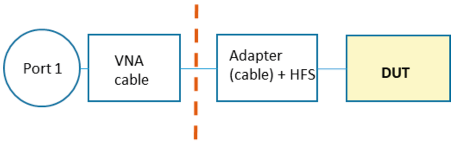
5. Go to the **Def Balanced Port** tab, group the ports as shown below and click **Define/Change**.

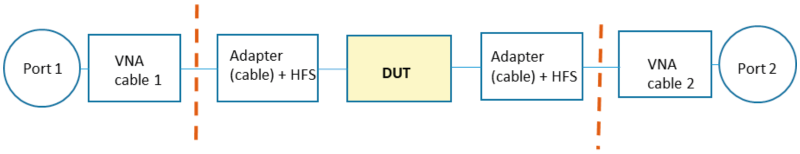


4. Calibration in VNAs where the RF probe lies outside the calibration plane

In many of the cases of VNA testing, customers may wish to remove the effect of the RF probes from their calibration to reduce complexity. Therefore, once the calibration is done, the offset can be subtracted in one of the built-in tools that VNAs provide.

The following two diagrams show the calibration setups for 1-port and 2-port testing respectively.





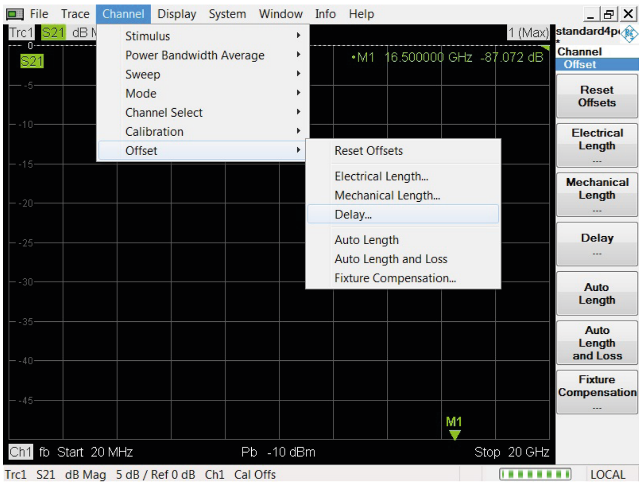
In the case of 2-port testing that involves probing from only one side, the HFS probe on either side will be omitted.

As can be seen from the set-ups, there will be an adapter or cable plus RF probe outside the calibration plane, it is then the customer's decision to either consider this offset ideal, or to use the built-in tools in the VNA software to exclude them.

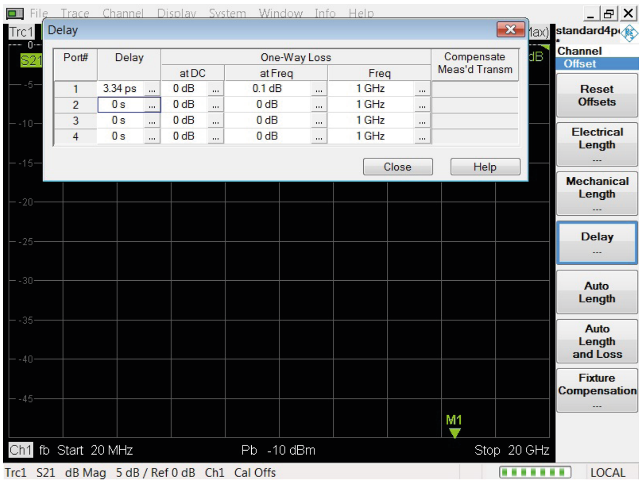
There are different offset options. For instance, the various compensation options that R&S ZVA67 offers are shown below.

Option 1:
Inserting compensation values manually

To insert the compensation values manually, select **Offset** option from the **Channel** menu. Click **Delay**.

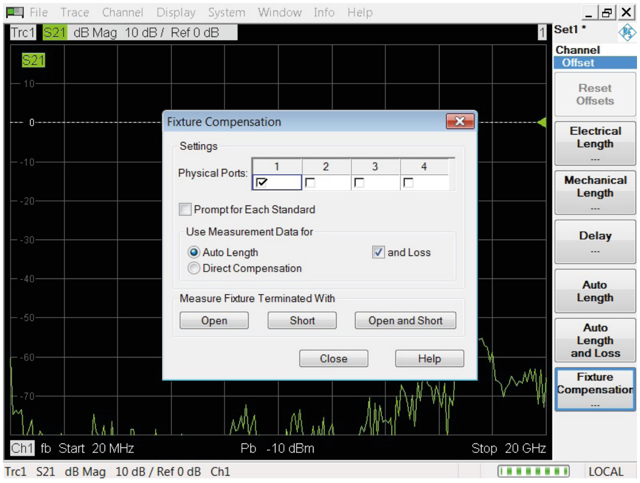


Manually insert **Delay** and loss both **at DC** and **Freq** as well as **Freq** for target frequency.



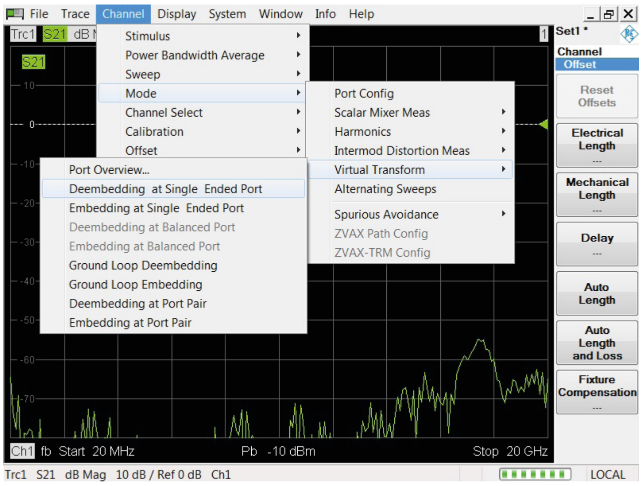
Option 2:
Automatic compensation

For automatic compensation, select the **Offset** option from the **Channel** menu and click on **auto length and loss**. Then select the **Physical ports** you required to perform auto length and loss measurement and check **Auto length and Loss**. Then click **Open**.

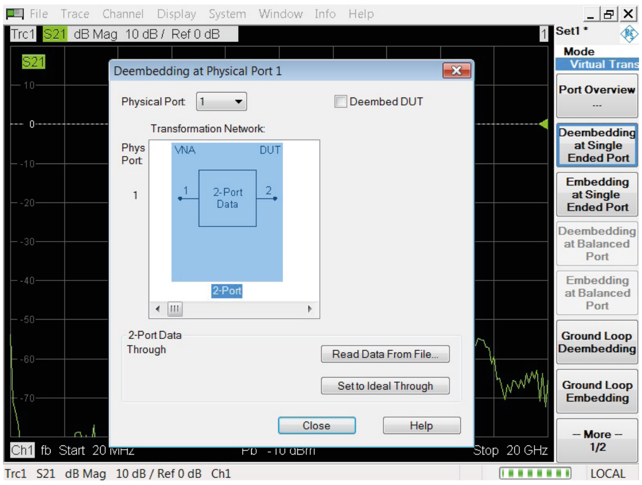


Option 3:
Deembedding

From the Channel menu, select the Mode option, then click on Virtual Transform followed by Deembedding at Single Ended Port.



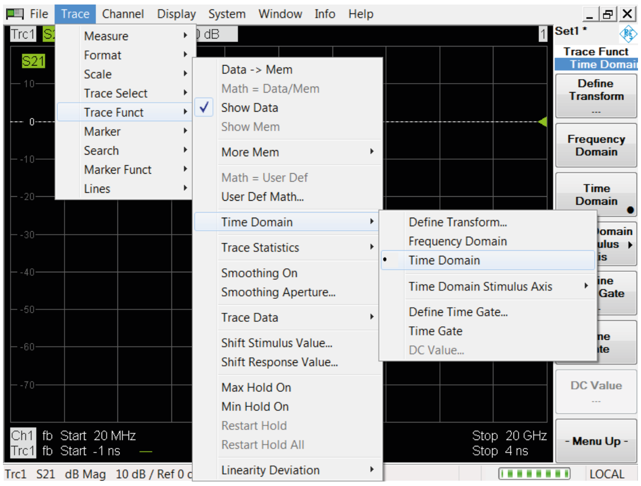
Click Read Data From File to import an S2P file for the part that should be de-embedded. Finish by checking the Deembed DUT box.



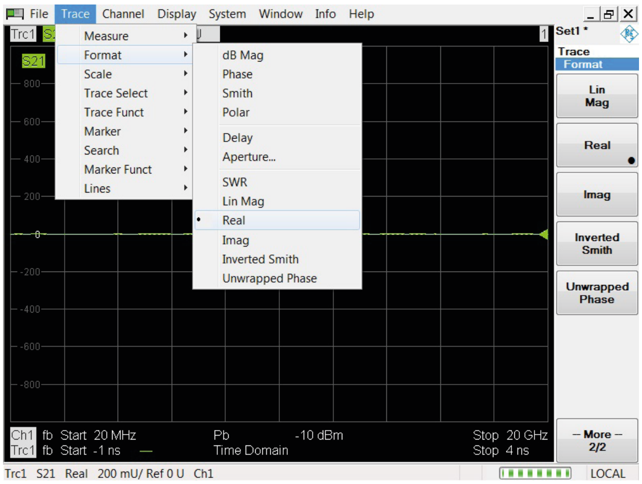
Option 4:
Time domain gating

If the VNA has a time domain option, time domain gating can be used as an alternative offset option. In this case, the influence of the radio frequency test probe is eliminated by setting a time domain (gate).

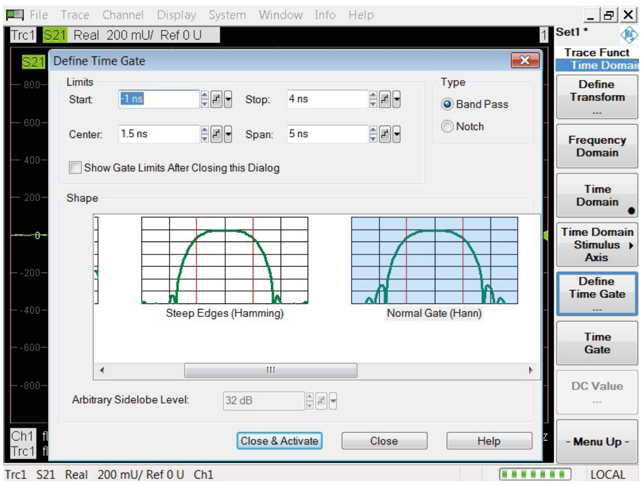
From the **Trace menu**, select **Trace Funct**, then **Time Domain** followed by **Time Domain**.



Go back to the **trace** menu and select **Format**, then **Real**.



From the **Trace menu**, select **Trace Funct**, then **Time Domain** and then **Define Time Gate**. Then set the window parameters such as **Start, Stop, Center, Span** and **Type**. Then click on **Close & Activate**.



5. Compensation in equipment other than VNA

RF probes can also be used in other set-ups that include equipment other than VNAs. Some of these are oscilloscopes, spectrum analysers, power meters as well as others.

Additionally, RF probes can be part of communication systems with the sole purpose of providing a smooth connection between the DUT and the test system. The test parameters, in this case, are defined by the customer to suit their testing needs. These could be lower layer testing such as determining Bit Error Rate (BER) or Packet Error Ratio (PER). Alternatively, higher layer testing such as measuring net data rate (bits/s), or compliance test of certain standards such as Wi-Fi, Bluetooth, USB, HDMI, etc. may be required. Another test could be sending a video file and checking for image quality.

The effect of the RF probes and their adapters and/or cables should be determined on a regular basis. As there are a wide range of applications, the exact offset compensation mechanism cannot be given here. INGUN recommends using a known or reference DUT to calibrate or determine the characteristics of the RF probe regularly. After that, the probe can either be considered ideal, or its effect can be compensated. Upon request, touchstone files of the probes with their corresponding cable assembly are available.

Partner for Future Technology

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