AN 002

S-Parameter Measurements with Non-Metrology Connector Interfaces

Adapter Calibration Kits

Application Note

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1 Introduction

Precise S-parameter measurements (e.g. return loss, insertion loss) can be achieved by correcting the errors caused by the measurement equipment (vector network analyzer (VNA) and test port cables) with the help of a calibration process. Rosenberger has therefore developed calibration kits for the most common metrology connector interfaces for example RPC-N, RPC-3.5 mm or RPC-2.92 mm.

After performing the calibration of the VNA, one can measure the S-parameters of a device under test (DUT) by simply connecting it to the calibrated VNA test ports as long as the corresponding connector interfaces are mechanically compatible to each other. If this is not the case, coaxial adapters are usually applied to ensure mechanical compatibility. Unfortunately, such adapters are not perfect and thus they induce measurement errors in the S-parameters obtained after calibration.

To overcome this issue so-called non-metrology calibration kits have been made commercially available. They are used similar to the metrology calibration kits, and the result is a calibrated reference plane at the non-metrology interface. However, these non-metrology calibration kits are usually not traceable to SI units and also not very cost-effective.

For this reason, Rosenberger has recently introduced ***Calibration Kits - Adapter Version*** (in the following referred to as '*Adapter Calibration Kits*') for some connector types for example QMA, SnapN, 4.3-10 or BMA. They consist of adapters with their related data and are used in combination with an appropriate metrology calibration kit. They are a cost-saving alternative to the non-metrology calibration kit, if an appropriate metrology calibration kit is already available. An overview of the use of adapter calibration kits is given in section 2. You might as well consult your adapter calibration kit manual.

Question: What is the accuracy of the obtained measurement results if an adapter calibration kit is applied instead of a conventional non-metrology calibration kit?

Results: This application note demonstrates that the measurement results achieved with the use of a type 4.3-10 adapter calibration kit are comparable to those achieved with a non-metrology calibration kit.

The following diagram shows different calibration kit types (4.3-10) and how they can be rated in terms of price and precision of measurement.

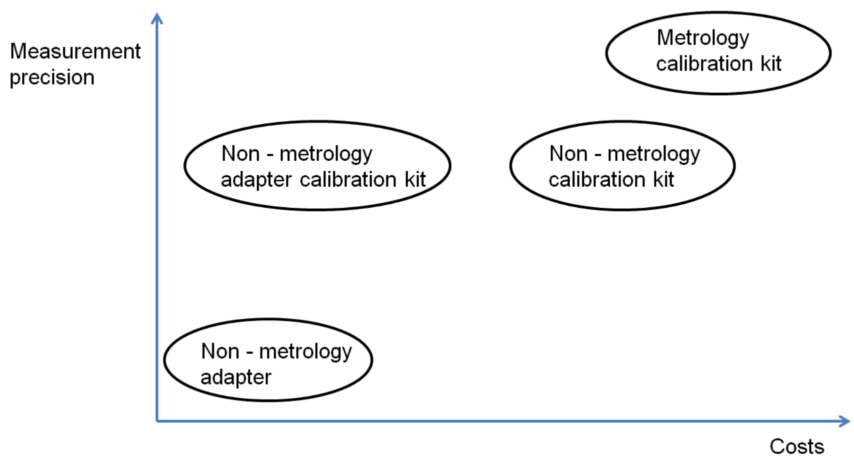


Figure 1. Measurement precision vs. costs

An overview of the different methods is given in section 3, a detailed description of the calibration procedures is given in section 4, followed by the comparison of the measurement results in section 5. A glossary of key terms is provided in section 6 and a list of references can be found in section 7 for further reading.

2 Rosenberger's Adapter Calibration Kit

As already mentioned, an adapter calibration kit consists of adapters and their associated S-parameter data. It allows you to calibrate your VNA for measurements of components with a so-called 'non-metrology' interface. In order to do so, the VNA has to be calibrated with a metrology calibration kit using either modified standard definitions or the de-embedding function of the VNA. The modified standard definitions are only valid for use with the related metrology calibration kit.

Both methods are designed to shift the reference plane to the non-metrology interface. After calibration, the metrology-to-non-metrology adapters (included in your adapter calibration kit) have to be connected to the calibrated ports. At this point the VNA is ready to measure DUTs with a non-metrology interface without the necessity for a non-metrology calibration kit.

NOTE:

The Rosenberger product name for 'Adapter Calibration Kit' is 'Calibration Kit', for example:

4.3-10 Calibration Kit
Adapter Version.

The term 'Adapter Calibration Kit' is used here to distinguish it clearly from 'Metrology Calibration Kit'.

Removing adapter errors:

When an adapter is applied its influence (errors) can be either removed or ignored. In Fig. 2 different ways of dealing with the influence of an adapter are illustrated. Ignoring an adapter means it is part of the DUT and its influence will not be removed. This case is only shown in Fig. 2 for the sake of completeness.

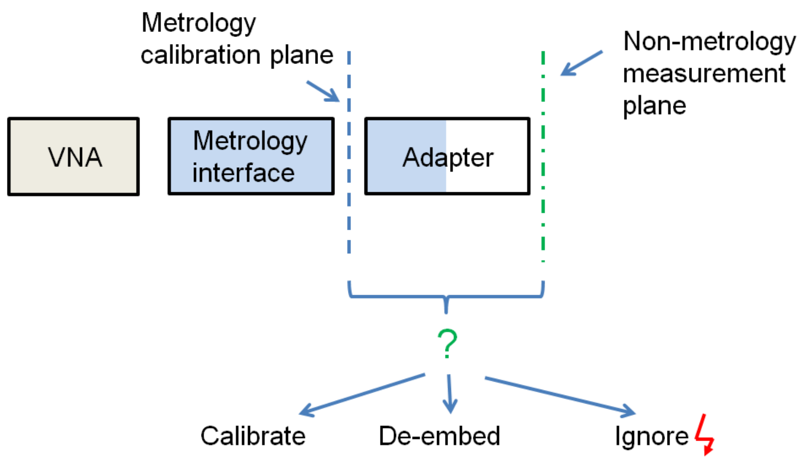
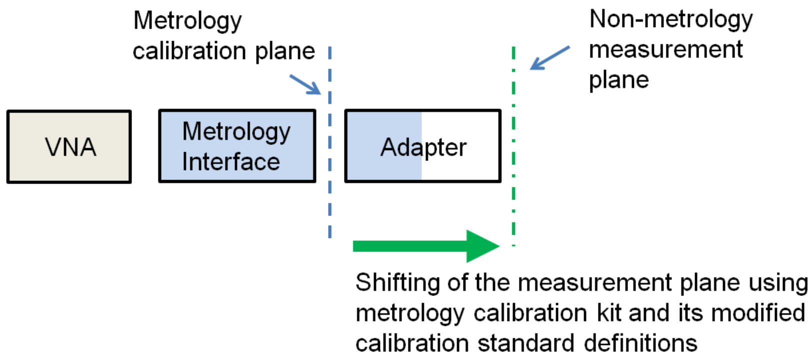


Figure 2. Different ways of using an adapter

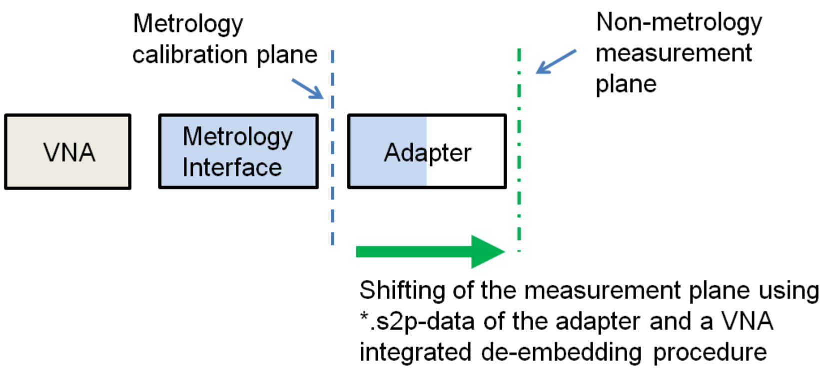
3 Overview and Description of Methods

The charts below provide a brief overview of three different calibration methods. In addition to the adapter kit methods (method 1 and method 2), the conventional VNA calibration with a non-metrology calibration kit is also shown (method 3).

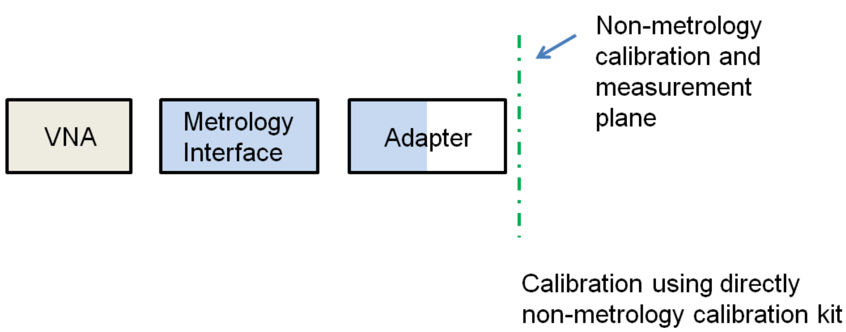
Method 1: Using modified standard definitions



Method 2: Using de-embedding function



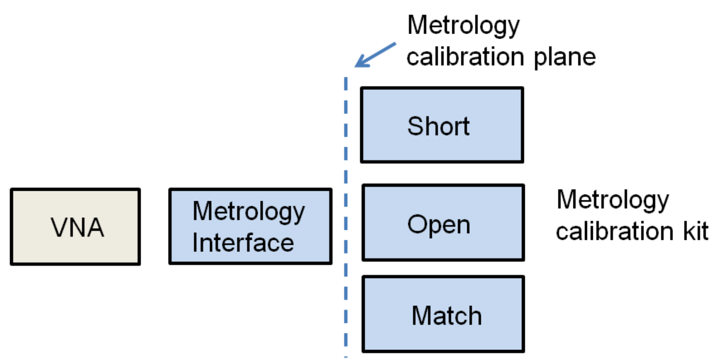
Method 3: Calibration using non-metrology calibration kit



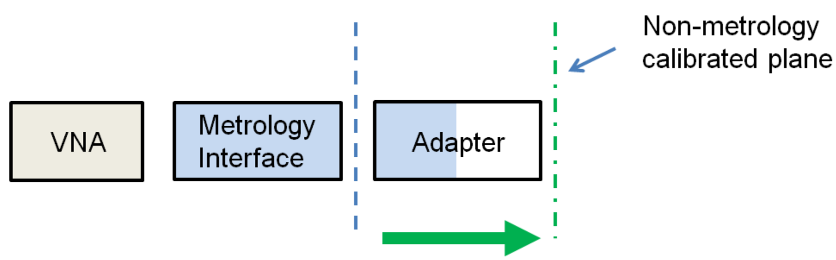
3.1 Method 1: Using modified standard definitions

This method is a little more complicated than method 2 but applicable to almost every instrument following the steps below:

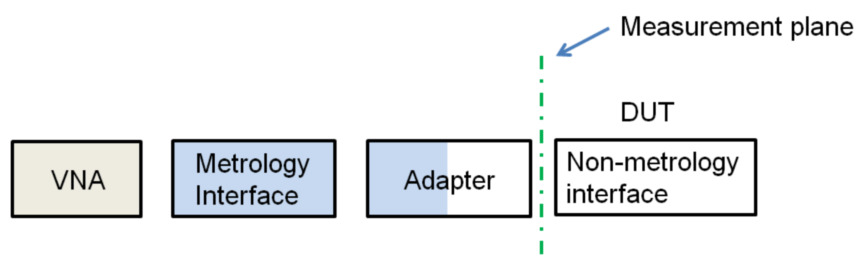
1. Load the modified standard definitions into the VNA
2. Calibrate the VNA using the metrology calibration kit



3. Mount the adapter



4. Measure the DUT

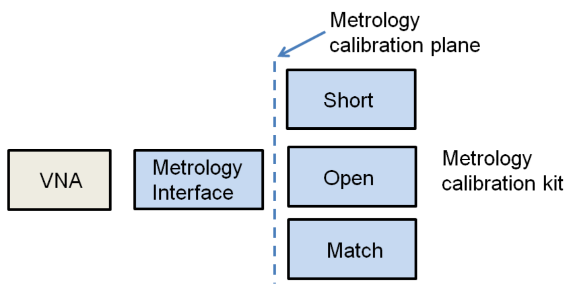


3.2 Method 2: Using de-embedding function

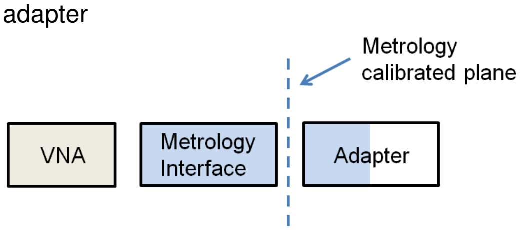
This method is applicable to instruments with integrated "Adapter de-embedding function" considering the following steps:

1. Load the metrology standard definitions into the VNA

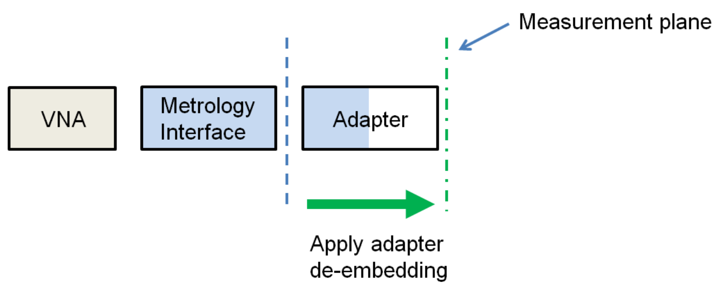
2. Calibrate the VNA using the metrology calibration kit



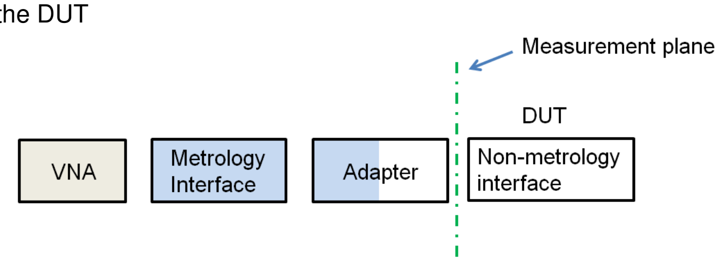
3. Mount the adapter



4. Activate the adapter de-embedding function using the uploaded s2p-file of the adapter



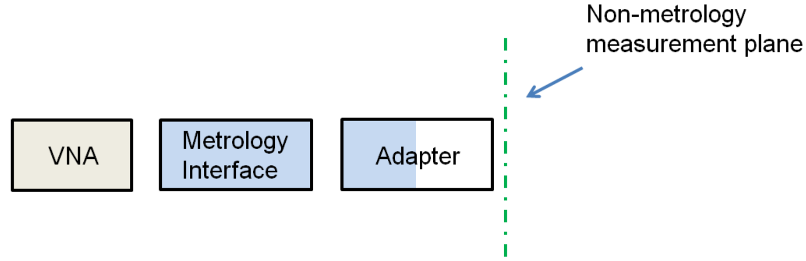
5. Measure the DUT



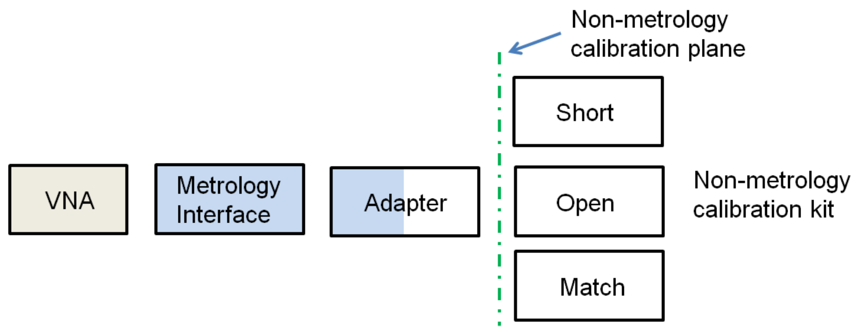
3.3 Method 3: Calibration using non-metrology calibration kit

This method is applicable if a non-metrology calibration kit is available where the following steps have to be taken:

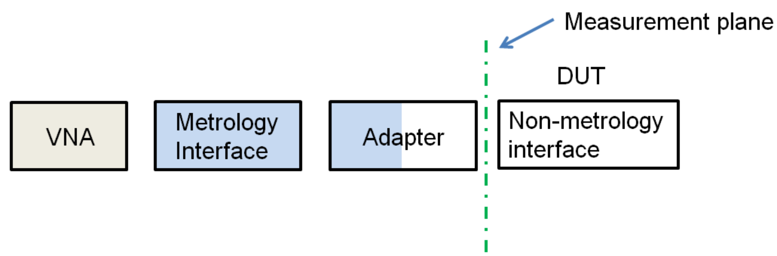
1. Load the non-metrology standard definitions into the VNA
2. Mount the adapter



3. Calibrate the VNA using the non-metrology calibration kit



4. Measure the DUT



4 Applying the Adapter Calibration Kit Methods

The following examples illustrate how to perform a VNA calibration with the use of an adapter calibration kit for a DUT which has 4.3-10 connectors. Afterwards, measurement results are compared and evaluated in terms of accuracy.

4.1 Test Equipment and VNA Settings

All VNA measurements were carried out on the Agilent PNA E8361C Vector Network Analyzer.

Sweep Settings:

Sweep Properties	Value
Start	50 MHz
Stop	12 GHz
Points	240
IF Bandwidth	100 Hz
Power	-15 dBm

VNA Configuration:

The DUTs in the following measurement examples had 4.3-10 male/male connectors. Therefore, the adapters N 50 Ω female to 4.3-10 female from the adapter calibration kit had to be used. Consequently, the test port cables connected to ports 1 and 2 of the VNA had N male connectors at the other end (Figures 3 and 4).

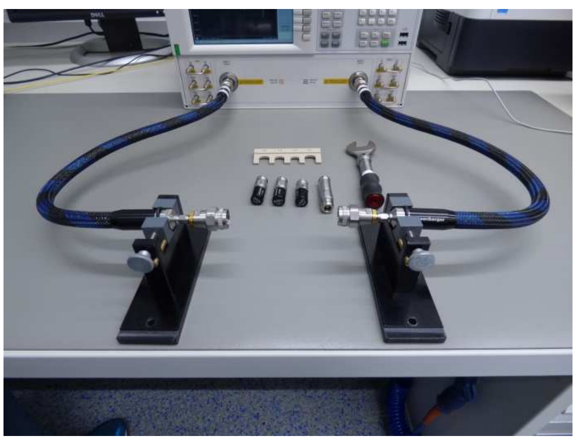


Figure 3. VNA setup

Figure 4. Calibration plane N 50 Ω (m)

4.2 Calibration Kits

The calibration kits below were used to calibrate the VNA:

- Rosenberger Calibration Kit RPC-N Industrial Version, model number 05CK010-150 (metrology)
- Rosenberger Calibration Kit Adapter Version, model number 64CK070-150 (non-metrology)
- Rosenberger Calibration Kit 4.3-10 Industrial Version, model number 64CK010-150 [(1)]

1. Normally, a calibration kit with a non-metrology interface calibrated by an NMI is not available. For our measurements we used a specially designed 4.3-10 calibration kit which was calibrated by the Swiss Federal Office of Metrology and Accreditation (METAS). For that reason, the 4.3-10 calibration kit can be regarded as a metrology calibration kit.

Figure 5. Calibration Kit, RPC-N Industrial Version

Figure 6a. 4.3-10 Calibration Kit, Adapter Version

Figure 6b. Adapters N 50 Ω to 4.3-10

Figure 7a. 4.3-10 Calibration Kit

Figure 7b. METAS Calibration Label

4.2.1 Devices under test (DUTs)

The following two devices were measured:

1. Cable 4.3-10 (m/m) 2 m, (see Figure 11)
2. Adapter configuration 4.3-10 (m/m), (see Figure 8a)

2 = <u>Adapter 4.3-10 (m) to N 50 Ω (m)</u> + <u>Adapter N 50 Ω (f/f)</u> + <u>Adapter N 50 Ω (m) to 4.3-10 (m)</u>

Figure 8a. Adapter configuration

Figure 8b. Calibrated 4.3-10 ports

4.3 VNA Preparation

Modified Standard Definitions

4.3-10 Calibration Kit

64CK070-150 (+05CK DB Standards)

SN XXXXX (+BH005) Date: 2017-06-22

Standard	Open (m)	Open (f)	Load (m)	Load (f)	Unit
Ser. No.					-
Min. Freq.	0	0	0	0	GHz
Max. Freq.	12	12	12	12	GHz
Offset Z0	50	50	50	50	Ω
Offset Delay	-101.0556	-101.0556	-151.4224	-151.4224	ps
Offset Loss	2.25	2.25	1.80	1.80	GΩ/s
C0	7.9928	-4.5349	---	---	10^{-15} F
C1	1099.89	2599.98	---	---	10^{-27} F/Hz
C2	-284.96	-416.89	---	---	10^{-36} F/Hz^2
C3	9.39	13.54	---	---	10^{-45} F/Hz^3

Keysight/Agilent format

Figure 9. Example of a Standard Definitions Card

The modified standard definitions have to be entered into the VNA to prepare it for the calibration process. For more details, please refer to the adapter kit manual.

De-embedding

First of all, a model of the two-port network (in our case an adapter) to be de-embedded is needed. The model can be either the S-parameter data e.g. in Touchstone® format (s2p-file) or a circuit model. For more detailed information, please consult your VNA manual.

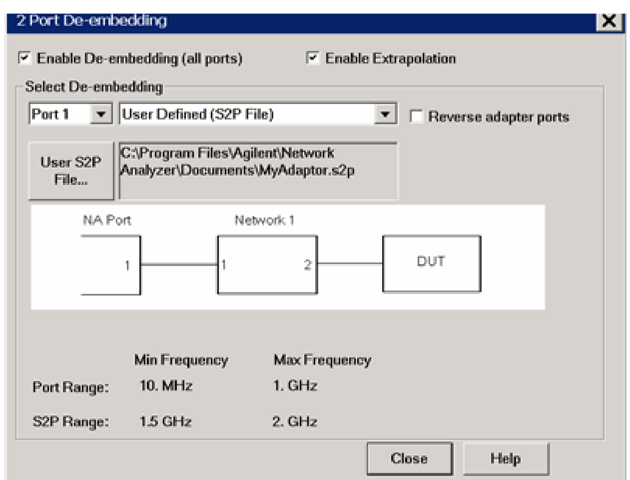


Figure 10. Typical 2-port de-embedding dialog box on the Agilent PNA

4.4 VNA Calibration

In principle, network analyzer calibration is the determination of the systematic VNA error terms by measuring a set of known reference standards (calibration kit) and applying the error correction to obtain a corrected result.

Modified Standard Definitions

A one-port or two-port calibration on the metrology connectors has to be performed using the modified standard definitions and the metrology calibration kit.

De-embedding

The VNA has to be calibrated using a metrology calibration kit and its original standard definitions.

4.5 Final Steps

Modified Standard Definitions

The non-metrology adapters have to be connected to the metrology interface. The VNA is now ready for measurements on DUTs with a non-metrology interface. Due to the modified standard definitions, the measurement reference plane is set at the non-metrology interface.

De-embedding

The non-metrology adapters have to be connected to the metrology interface. At this point, the adapters are part of the DUT and therefore have to be mathematically removed by using the de-embedding function of the VNA. The de-embedding function uses the model of the two-port network and has to be switched on (activated) for your measurements. The VNA is now ready for measurements on DUTs with non-metrology interface.

NOTE: Remember to deactivate the de-embedding function for measurements on metrology grade DUTs without the use of the adapters.

5 Comparison of measurement results

5.1 DUTs

1. Cable 4.3-10 (m/m), 2m (see Figure 11)
2. Adapter configuration 4.3-10 (m/m), (see Figure 12)

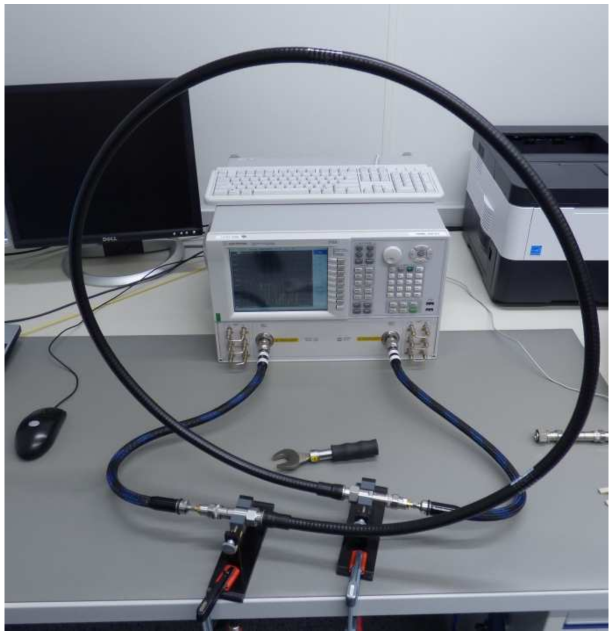


Figure 11. Measurement of the cable

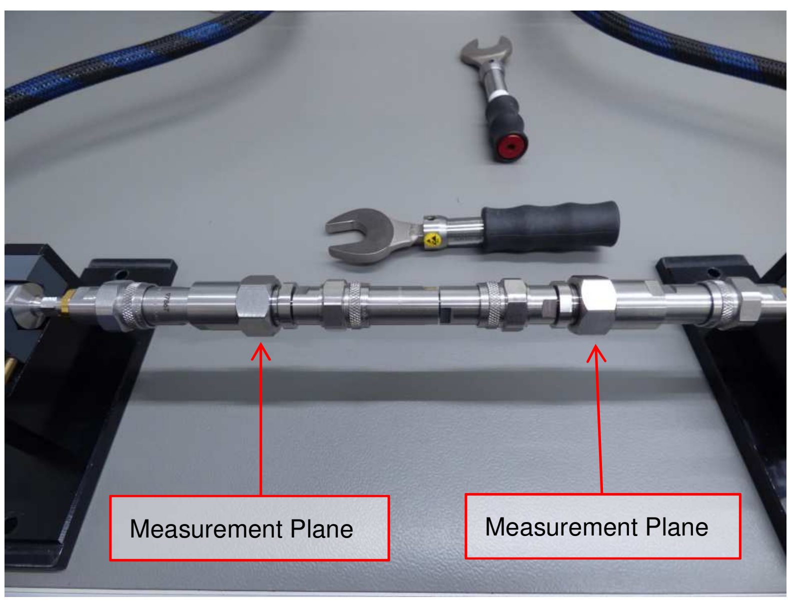


Figure 12. Measurement of the adapter configuration

5.2 Compared Methods

Both DUTs were measured with 4 different calibration methods as follows:

a) 4.3-10 adapter calibration kit (using modified standard definitions)
b) 4.3-10 adapter calibration kit (using de-embedding)
c) 4.3-10 calibration kit (non-metrology kit)
d) 4.3-10 calibration kit (calibrated by METAS and taken as reference value)

NOTE:

As pointed out earlier in section 2.2, the 4.3-10 calibration kit was SI traceably characterized by METAS and can therefore be regarded as metrology calibration kit. Because of the low uncertainties the measurement results obtained with this kit (curve d) were taken as reference value.

5.2.1 Cable 4.3-10 (m/m), 2 m

Measured S-Parameters

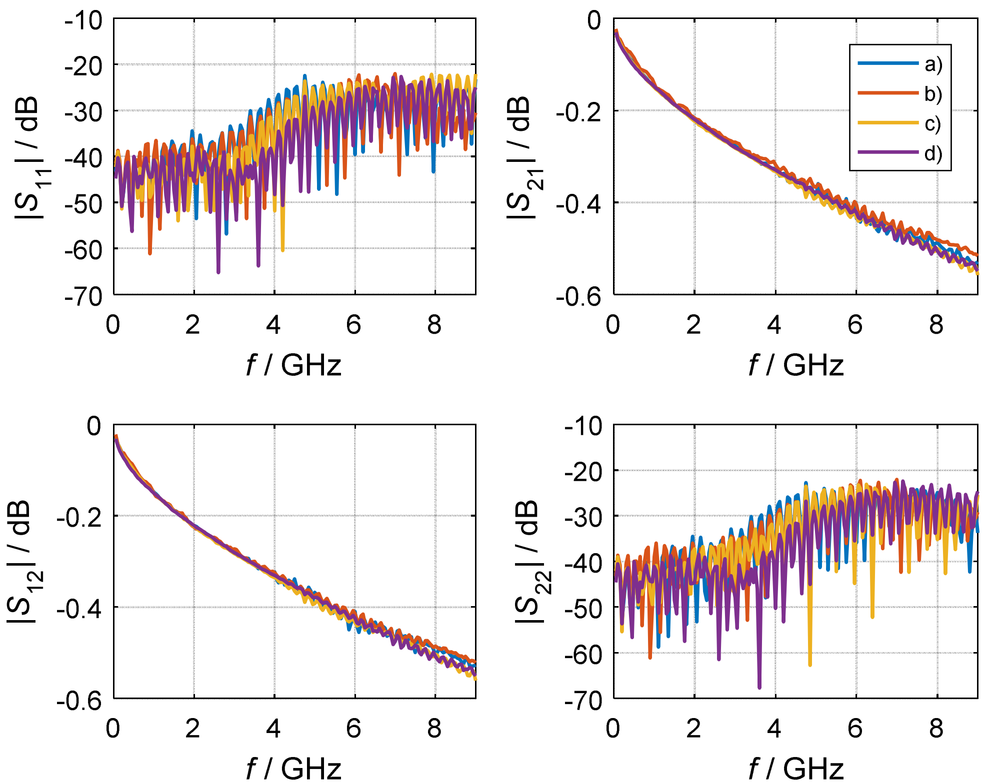


Figure 13. S-parameters (Mag) of the measured cable

S-Parameter deviation (normalized to reference value)

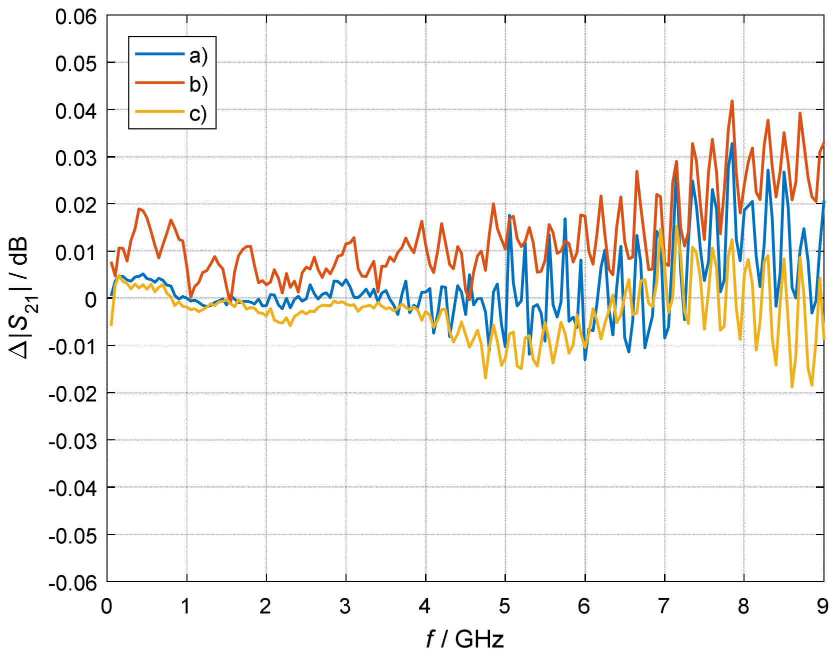


Figure 14. Normalized S21 (Mag log) Cable

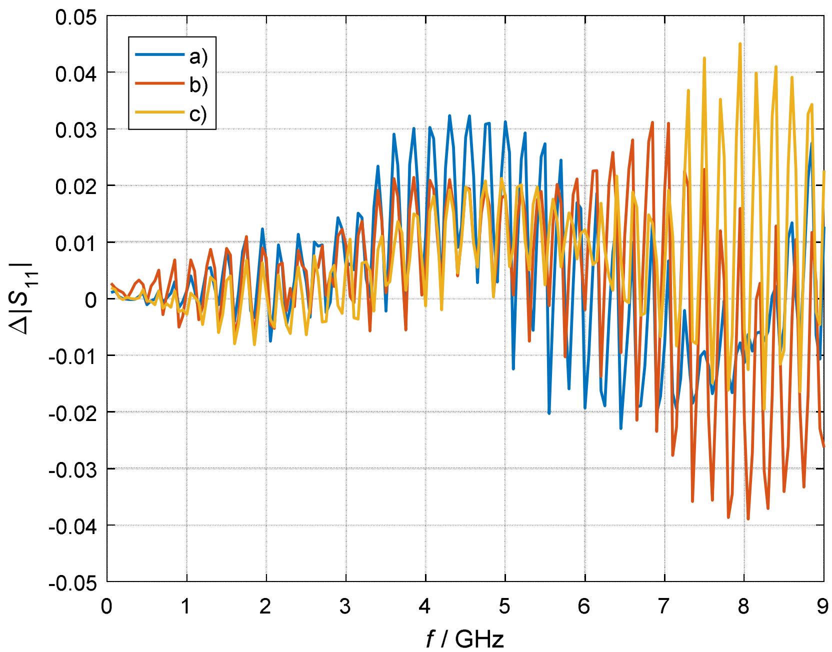


Figure 15. Normalized S11 (Mag lin) Cable

5.2.2 Adapter Configuration 4.3-10 (m/m)

Measured S-Parameters

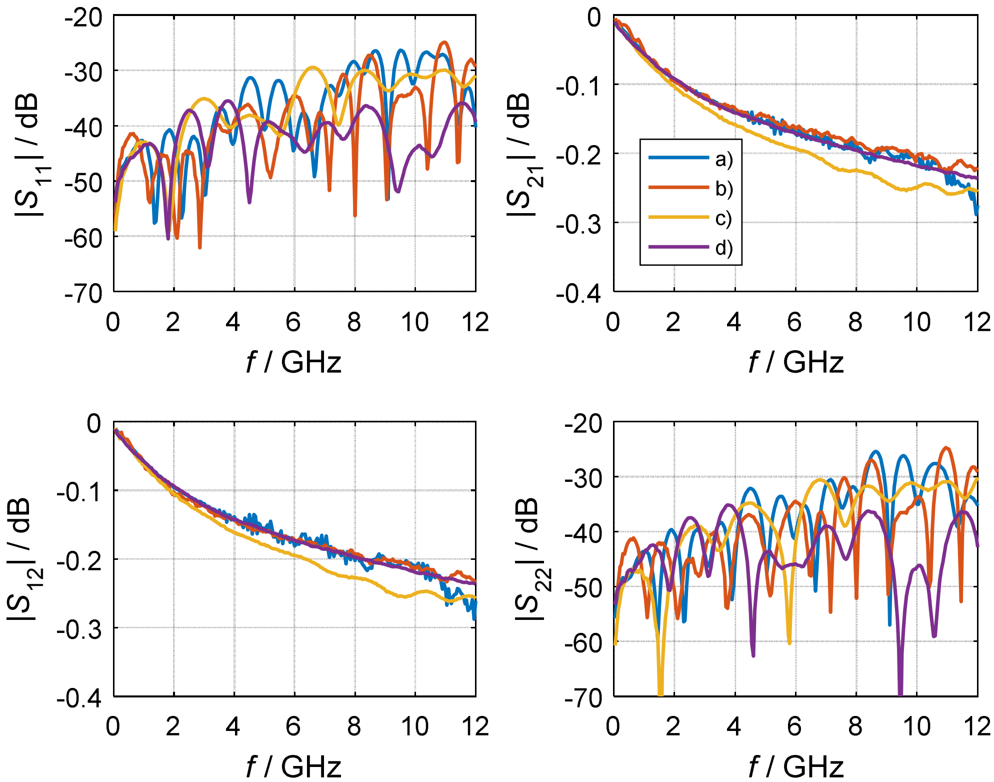


Figure 16. S-parameters (Mag) of the measured adapter configuration

S-Parameter deviation (normalized to reference value)

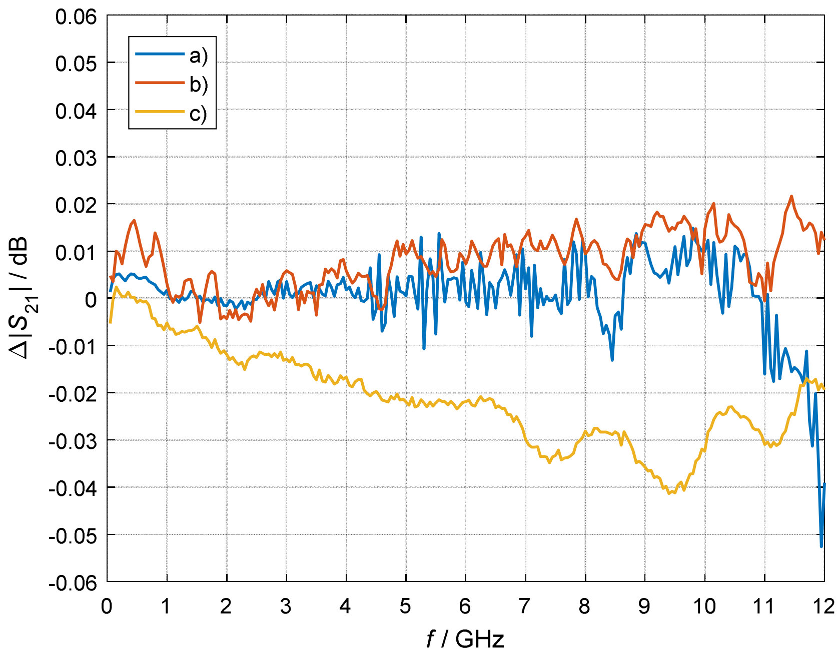


Figure 17. Normalized S21 (Mag log) Adapter Configuration

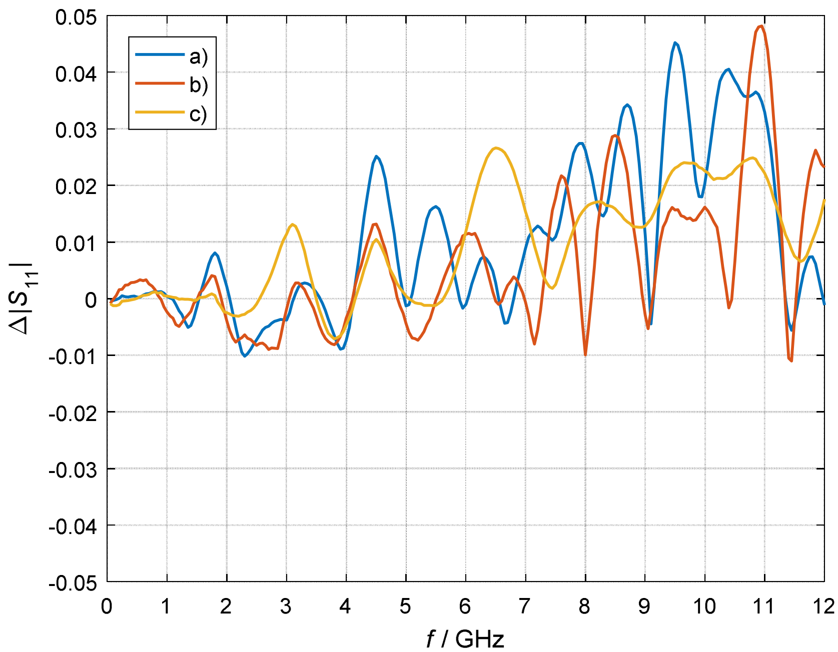


Figure 18. Normalized S11 (Mag lin) Adapter Configuration

5.3 Conclusion

Comparison of adapter methods

The achieved results indicate a good agreement between the different methods of calibration, particularly for the lower frequency range.

Non-metrology calibration kit

The measured S-parameters using the non-metrology calibration kit are similar compared to the results achieved with the adapter calibration kit.

NOTE:

The measurements were conducted with great care but only once. The results can therefore be seen as a snapshot of a specific situation. A detailed statistical analysis was not the intention of this investigation and would be very time-consuming.

5.4 Summary

We may summarize the findings in a few words:

- Measured S-parameters showed good agreement between the compared calibration methods.
- An adapter kit can be a cost-saving alternative to the conventional MSO or TMSO non-metrology calibration kit with minimum quality loss. Typically, a metrology calibration kit is already available and can be used.
- As regards operation, adapter kits can be different from the usual handling. Handling and calibration procedure are a bit more complex.

The table below evaluates the main characteristics of adapter calibration kit and non-metrology kit.

Table 4.4. Summary of main characteristics for different calibration kits.

Aspect	Adapter calibration kit	Non-metrology kit
Accuracy	++	++
Handling	+	++
Price	++	+

Comments:

The 4.3-10 connector interface is comparatively well-defined in terms of reference plane position and dielectric at the mating plane. Its connector repeatability is similar to that of metrology interfaces. This is not always the case when dealing with other non-metrology interfaces for example SMP, TNC or MCX. The obtained results are not necessarily applicable to other non-metrology interfaces.

6 Glossary

The following table provides simple definitions of the terms used in this document. Many terms used in VNA measurement and metrology, are rooted in history and are not coherent with contemporary terminology commonly used in metrology. The terms may have different meanings in other documents.

Adapter calibration kit	An adapter calibration kit is a set of adapters used in conjunction with a metrology calibration kit. It allows you to calibrate a VNA for measurements on devices with a non-metrology interface.
DUT	Device under test.
VNA	A vector network analyzer (VNA) is an instrument that measures the network parameters (usually S-parameters) of electrical networks.
S-parameters	S-parameters or scattering parameters describe the electrical behavior of linear electrical networks.
SI	The International System of Units, universally abbreviated SI, is the modern form of the metric system, and is the most widely used system of measurement.
OSL	VNA one port calibration based on open, short and (matched) load standards. Sometimes also called OSM or SOL calibration.
OSLT	VNA two port calibration based on open, short, (matched) load standards and the measurement of a thru connection. Sometimes also called SOLT or OSMT calibration.
NMI	National Metrology Institute.
Metrology interface	Interface with traceability to international standards, e.g. N50 Ω, 3.5 mm, 2.92 mm, etc. Traceability provided by an NMI or accredited lab.
Non-metrology interface	Interface without direct traceability to international standards, e.g. BMA, SMP, SMA, TNC, etc.
Metrology calibration kit	A set of VNA calibration standards with metrology interface used to perform a VNA calibration to measure DUTs with metrology interfaces.
Non-metrology calibration kit	A set of VNA calibration standards with non-metrology interface used to perform a VNA calibration to measure DUTs with non-metrology interfaces.
Standard definitions	Standard definitions describe the electrical performance of a calibration standard. The definition can be either based on nominal physical dimensions or based on actual measurements as a frequency dependent list of reference values (data-based).
De-embedding	De-embedding is a mathematical process that removes the effects of unwanted portions of a two-port network that are embedded in the measured data by subtracting their contribution. Modern VNAs provide this additional functionality and therefore are able to remove unwanted effects of a two-port or adapter.
VNA calibration	Determination of the systematic VNA error terms by measuring a set of known reference standards and applying the error correction to obtain a corrected result.
VNA calibration standards	Characterized measurement standards, which are used during the VNA calibration procedure.

7 References

[1] V. Teppati, A. Ferrero, and M. Sayed, editors. Modern RF and Microwave Measurement Techniques. Cambridge University Press, 2013. ISBN 978-1-107-03641-3.

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[5] Agilent Technologies, Specifying Calibration Standards and Kits for Agilent Vector Network Analyzers, Application Note 1287-11, Online: http://cp.literature.agilent.com/litweb/pdf/5989-4840EN.pdf, March 2011.

[6] D. M. Pozar, Microwave Engineering, 4th Edition, John Wiley and Sons, 2012.

[7] Rytting, Doug. "Network analyzer error models and calibration methods." White Paper, September (1998).

8 Additional Information

This Application Note is updated from time to time. Please visit the Rosenberger website http://www.rosenberger.com/de/index.php to download the latest versions.

9 Revision History

Revision Number / Date	Description	Author
V1.0 / 11.10.2017	Final Review	R. Oppelt, J. Schubert, M. Kotzev