Products: R&S ZVM, R&S ZVK

Measurement Method for Determining the Equivalent Reflection Coefficient of Directional Couplers and Power Splitters

Application Note

A measurement method presented by John R. Juroshek (NIST) in conjunction with the Vector Network Analyzers R&S ZVM or R&S ZVK from Rohde & Schwarz allows fast and accurate determination of the equivalent reflection coefficient of power splitters or directional couplers. If the magnitude and phase of reflection coefficients of source (e.g. power splitter) and sink (e.g. power meter) are known, a mathematical correction of the measurement error caused by mismatch is possible. This measurement uncertainty content can thus normally be reduced by one order of magnitude, which is beneficial during the calibration of power meters, for example.

ROHDE&SCHWARZ

Contents

1 Overview

Resistive power splitters or directional couplers are frequently used for the calibration of power meters. An example is provided in the following figure.

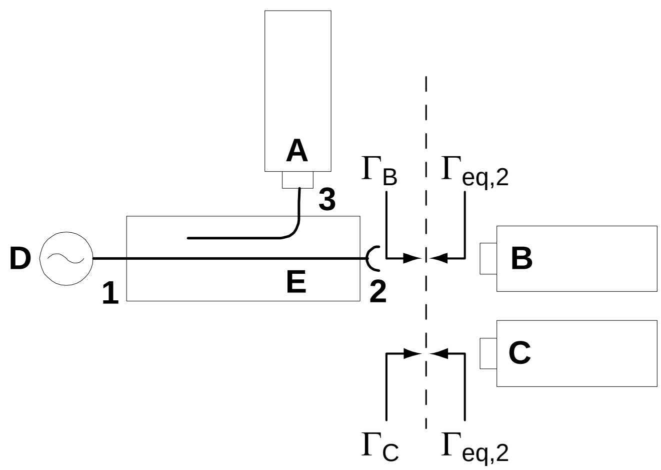


Fig. 1 Calibration of power meter

With

A	Incident Power Detector
B	Reference | Transfer Standard
C	Device under Test | Calibration Item
D	Source | Signal Generator
E	Directional Coupler or Power-Splitter

The measurement uncertainty occurring during the calibration of the calibration item mainly consists of two components:

1 the calibration uncertainty of the reference standard,

2 the uncertainty caused by mismatch of

a) power splitter or directional coupler <> reference standard

b) power splitter or directional coupler <> calibration item.

If, for example, a power sensor with the reflection coefficient Γ_C is calibrated according to a setup described in Fig. 1, the incident power will deviate by the following factor as compared to the measurement using the reference standard with the reflection coefficient Γ_B:

$$\frac{1}{Q} = \frac{\left|1-\Gamma_{eq}\Gamma_B\right|^2}{\left|1-\Gamma_{eq}\Gamma_C\right|^2} \quad [7]$$

If values of 0.13 are assumed for the magnitudes of all three reflection coefficients, which is quite realistic in the frequency range up to 40 GHz, Q can be in the range from 0.93 to 1.07.

In general, such deviations (max. 7%) cannot be tolerated for the calibration of power meters.

It should be noted that this uncertainty content is only caused by mismatch and that it is purely systematic.

The calibration uncertainty of the reference standard can only be reduced by choosing a calibration laboratory accredited for a lower measurement uncertainty. The calibration uncertainty during the recalibration of the reference power meter is thus principally limited by national and international institutions (PTB, NIST, etc.).

However, the user can directly influence measurement uncertainty caused by mismatch by doing either of the following:

- Using a power splitter with a low equivalent source match (what is generally recommended).
- Correcting the measured values mathematically. The mathematical correction of measured values is also called Γ correction. The true value of the incident power can quite accurately be determined (i.e. the incident power can be determined with a much smaller measurement uncertainty) by means of this method.

If the vector Γ correction is to be performed in the broadband and at a large number of frequency points, some methods for determining the equivalent reflection coefficient of a power splitter are not suitable for use in practice.

This is due to the fact that a lot of time would be required for the calibration of a power splitter. And it is also due to the fact that various methods are limited to certain discrete frequency points.

Methods based on vector network analyzers are suitable for use since the alignment of the DUT regarding magnitude and phase must be measured with a vector network analyzer, i.e. this measuring instrument and the corresponding accessories are always required anyway.

The method proposed by John R. Juroshek in conjunction with a Vector Network Analyzer R&S ZVM or R&S ZVK from Rohde & Schwarz can be used to determine the equivalent reflection coefficient of a power splitter in complex form and at up to 2001 frequency points within only a few minutes.

The time required to determine the equivalent reflection coefficient of a power splitter port corresponds to a full two-port calibration of a network analyzer.

2 Description of Measurement Method

Vector network analysis is based on the idea that errors of this kind of measuring instruments and/or of the complete test setup can be determined and therefore corrected. However, only time-invariant, systematic and linear influences can be eliminated. The errors of the vector network analyzer are determined by measuring different well known calibration standards to the test port (or the test ports). A set of correction values is calculated based on these measurements. This set is used to correct the "raw measured values" measured at a later time.

The most widely known method for one-port calibration is the OSM method (**O**pen **S**hort **M**atch).

These three standards are connected one after the other to the test port (reference plane) and the relations occurring for wave-quantities a1 to b1 are determined.

The behaviour of the individual standards is assumed to be known. The corresponding descriptive models are stored in the vector network analyzer.

Based on the three relations obtained, the three unknown quantities, i.e. the three characteristic system data items *source match*, *directivity* and *reflection tracking*, can be calculated using the following formula:

$$\Gamma = \frac{\Gamma_M - e_{00}}{e_{11}(\Gamma_M - e_{00}) + e_{01}} \quad [1]$$

where

Γ = measured value after the correction, which is defined by the models of the calibration standards

Γ_M = raw, uncorrected measured value; relation of wave-quantities

e_{00} = directivity in forward direction

e_{11} = source match in forward direction

e_{01} = reflection tracking in forward direction.

The method described by John R. Juroshek makes use of the fact that a vector network analyzer determines its own errors and forms - together with the DUT - an "enhanced network analyzer".

The DUT is connected between the two test ports of the vector network analyzer. The DUT port of interest remains "open". It forms the reference plane and is the "new" port of the enhanced network analyzer.

The OSM calibration (including sliding loads) will now be performed step by step and the resulting relations of the wave-quantities will be determined.

After completion of the measurements, the system error correction can externally be simulated and the required parameter (the equivalent source match) can be determined.

The most obvious approach would ostensibly be to use the vector network analyzer to perform this calculation since these algorithms for evaluation must be implemented in the vector network analyzer anyway. This would reduce the time required for measuring the equivalent reflection coefficient (especially when a sliding load is used as usually required for high-frequency measurements) and would also reduce potential error sources to a considerable extent.
Unfortunately, characteristic system data cannot be output with most of the vector network analyzers, which makes the implementation of the method according to John R. Juroshek difficult.

But with a vector network analyzer of the ZVx family from Rohde & Schwarz, these parameters can now very easily be output: by entering a service function, the desired term can be displayed and stored in any usual form on a storage medium.

Other functions of the vector network analyzer are of course also available in this mode, which allows the insertion of limit lines (and "limit checks"), for example.

The measurement results can be displayed on screen in the most common formats (SWR, reflection coefficient, return loss, ...), output to a commercial printer or saved to a storage medium.

3 Further Measuring Methods in Brief

Different methods were presented in the technical literature [1, 2, 3, 4, 5, 7]. Three of these methods will be discussed in the following.

1 Determination of the equivalent reflection coefficient based on the S-parameters of the power splitter according to the following equation

$$\Gamma_{eq} = S_{22} - S_{32} \cdot \frac{S_{21}}{S_{31}} \quad \text{[1-7].}$$

2 Determination of the equivalent reflection coefficient according to a method developed by Rohde & Schwarz [7]. This method is based on a swept power measurement by using an air line, where evaluation is performed by means of digital signal processing methods.

3 Direct measurement of equivalent reflection coefficient at port 2 or 3 by applying a virtual ground at the junction point of the two resistors by passive or active means on port 1 (AOC and POC technique [3]).

Although method 1) is discussed sufficiently in the technical literature, some important facts should be pointed out here since they reduce the suitability of the method or limit measurement uncertainty. Normally, a power splitter has three connectors of the same type and gender, i.e. the network analyzer has to be configured and calibrated to determine the S-parameters of non-insertable DUTs.

In the microwave range, the adapter removal calibration of the vector network analyzer is thus indispensable.

Unfortunately, this method is very time-consuming and requires twice the effort of a full two-port calibration. Also the measurement uncertainty is slightly higher than that obtained with a calibration for insertable DUTs.

The S-parameters must be measured via a measurement cable. The measurement cables largely contribute to measurement uncertainty since the position of the cables largely differs from the position used during the calibration of the vector network analyzer.

Moreover, the DUT's test port not included in the measurement has to be terminated with its characteristic reference impedance. In the broadband range (e.g. to 40 GHz) this is usually not possible within the desired quality. The accuracy can be improved to a large extent by using a sliding load for the higher frequency range but this is accompanied by a very time-consuming measurement and calculation.

The method 2) [7] makes use of the fact that the symmetry of power splitting depends on the load match.

A longer air line terminated with an mismatched power sensor is connected to port 2 (port under test) of the power splitter. The end of the air line connected to port 2 of the power splitter is thus characterized by a relatively high reflection coefficient whose phase angle quickly changes with the frequency. Due to interactions with the equivalent reflection coefficient to be determined for the power splitter, the ratio of the powers output at ports 2 and 3 changes and thus also the ratio of measured values at the power meters. The amplitude of the ripple is proportional to the magnitudes of the reflection coefficient being determined and the reflection coefficient at the input of the air line. If the complex reflection coefficient is also known at the input of the air line, the parameter in question, i.e. the equivalent reflection coefficient of the test port, can be calculated by digital signal processing.

This method offers determination of the equivalent reflection coefficient with only slight uncertainties. Since the method is very convenient and simple (the port to be tested must be connected only once per measurement), it is of great importance for use in practice (e.g. production).

As a specially mismatched sensor is required for this method, its general use is restricted.

The method was developed for the measurement of power reference standard and is used by Rohde & Schwarz in this field of application. An important advantage of this method, especially for this purpose, is the fact that the power reference (consisting of a power splitter with a fixed power sensor) does not have to be disassembled to determine the equivalent reflection coefficient.

The method presented in [7] was implemented up to 40 GHz at Rohde & Schwarz and was used here as a comparison or reference method.

Remarks regarding 3): The POC method (**P**assive **O**pen **C**ircuit) allows measurements only at discrete frequencies. The attainable measurement accuracy depends on the attenuation between node and port 1. Therefore, accurate measurements are only possible for the lower GHz range.

The AOC method (**A**ctive **O**pen **C**ircuit) prevents the influence of attenuation by applying a correction signal at port 1. Therefore, the method is very accurate. However, this method is difficult to automate since the phase shifter and the attenuator have to be set individually for each frequency.

4 Practical Implementation of Measurement Method using Vector Network Analyzer R&S ZVM or R&S ZVK

If an R&S ZVM or R&S ZVK is used for measuring the equivalent reflection coefficient, only a microwave cable, a 50 Ω termination and a 10 dB or 20 dB attenuator is required in addition to the corresponding calibration kit.

The method for test port 1 of the vector network analyzer is described as follows (the case is similar for port 2):

Example:

The equivalent reflection coefficient of port 2 of a power splitter (connectors 3 x 2.92 mm female) is to be determined up to 40 GHz by means of an R&S ZVK (frequency range 100 MHz to 40 GHz, 100 MHz intervals):

The input of the power splitter is connected to port 1 of the vector network analyzer. Port 3 of the power splitter is connected to the "R1 CH IN" input via a cable. The insertion of an adapter does not affect the measurement accuracy. To prevent the reference channel from being overdriven, it is recommended to interconnect an attenuator of approx. 10 dB to 20 dB (see Fig. 2).

The "R1 CH OUT" output is terminated with a 50 Ω load.

Port 2 of the power splitter is now the "new" port 1 of the vector network analyzer. A "full one-port" calibration (OSM) would be sufficient to determine the equivalent source match.

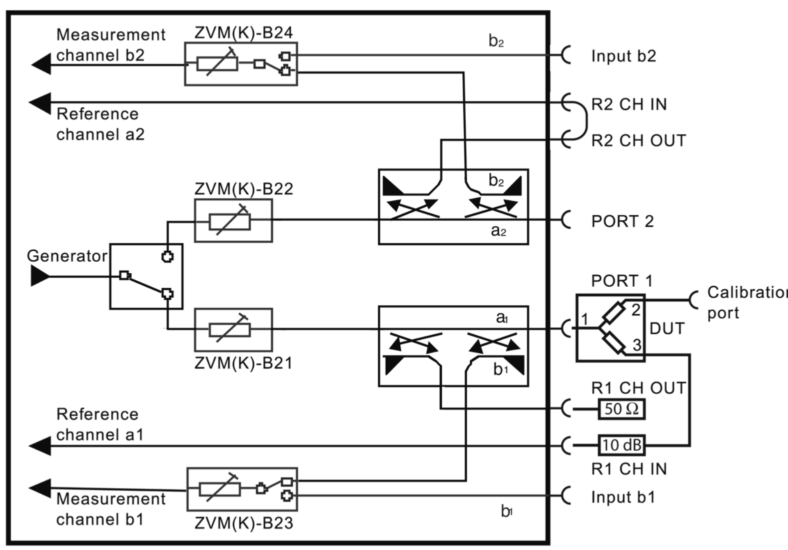


Fig. 2 Test setup with R&S ZVM or R&S ZVK

Since only "full two-port" methods (e.g. TOSM) currently offer direct output of system errors, such a method has to be used. But only the calibration steps relevant for port 1 have to be performed. The remaining calibration steps can be performed without having to connect the corresponding standards.

Settings on the R&S ZVK:

PRESET

START 100 MHz

STOP 40 GHz

SWEEP > NUMBER OF POINTS > 400

AVG > IF BW > 100 Hz

FORMAT > MAGNITUDE > SWR

CAL > START NEW CAL > FULL TWO PORT

PORT 1 CONNECTOR > 2.92 mm FEMALE

Note: PORT 1 CONNECTOR refers to the connector system and gender used by the test port of the vector network analyzer. If the equivalent reflection coefficient of a port at a power splitter is to be determined, the system or gender of the port to be measured is relevant since this port represents the test port of the corresponding vector network analyzer port.

PORT 2 CONNECTOR > 2.92 mm MALE or FEMALE

Here, the gender of the connector is irrelevant for measuring the equivalent reflection coefficient since the measurements at port 2 of the vector network analyzer do not affect the measurement result of interest.

CAL > START NEW CAL > FULL TWO PORT > TOSM > TOSM CAL MEAS

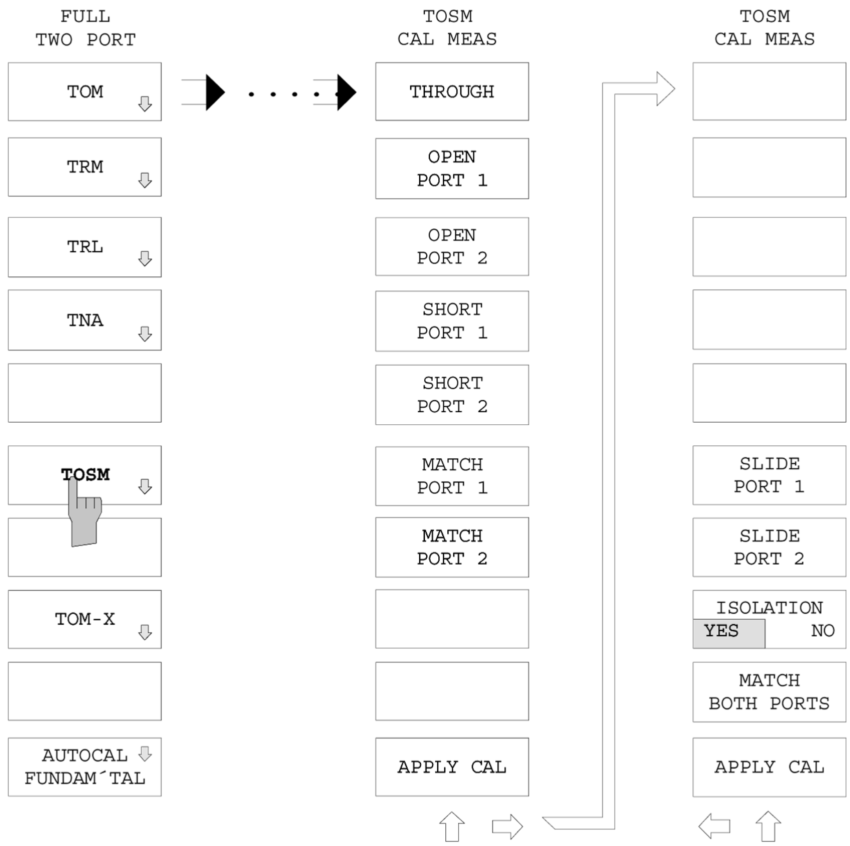


Fig. 3 Calibration steps for the TOSM method

THROUGH

It is not necessary to connect a standard or to establish a connection.

OPEN PORT 1

Connect OPEN 2.92 mm male to port 2 of power splitter.

OPEN PORT 2

It is not necessary to connect a standard.

SHORT PORT 1

Connect SHORT 2.92 mm male to port 2 of power splitter.

SHORT PORT 2

It is not necessary to connect a standard.

MATCH PORT 1

Connect MATCH 2.92 mm male to port 2 of power splitter.

MATCH PORT 2

It is not necessary to connect a standard.

The following measurements with a sliding load are optional but they considerably contribute to higher accuracy.

SLIDE PORT 1

Connect sliding load 2.92 mm male to port 2 of power splitter.

The sliding load is measured at 5 positions.

SLIDE PORT 2

This step is not required if the broadband termination (MATCH PORT 2) is defined in the kit definition up to the stop frequency (i.e.: 40 GHz). If this is not the case, this measurement must be performed but it is not required to connect a standard.

APPLY CAL

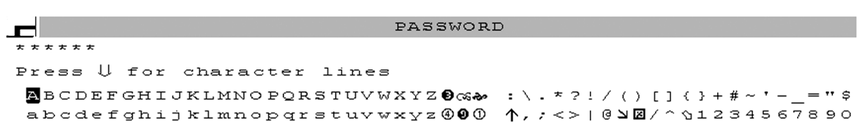
The measurements are completed by pressing this softkey. The correction data for the vector network analyzer will be determined.

The desired parameter, the equivalent reflection coefficient of port 2 of the power splitter, can be read by means of a service function.

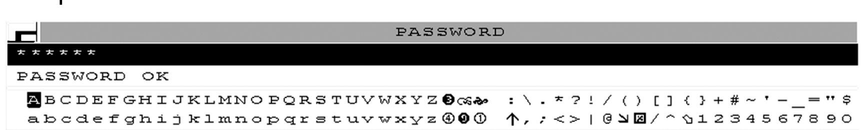
The service password must be entered first:

SETUP > SERVICE > ENTER PASSWORD

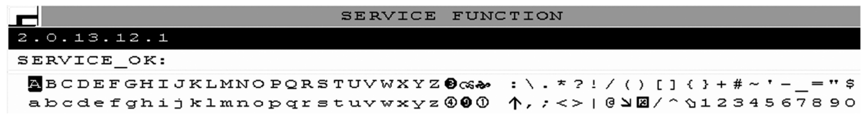
Entry of the following password: 894129



The password is confirmed with "X1 / Enter".



The vector network analyzer is now in the service mode. After entry of the service function 2.0.13.12.1, which is confirmed by the ENTER (X1) key, the equivalent reflection coefficient will be displayed.



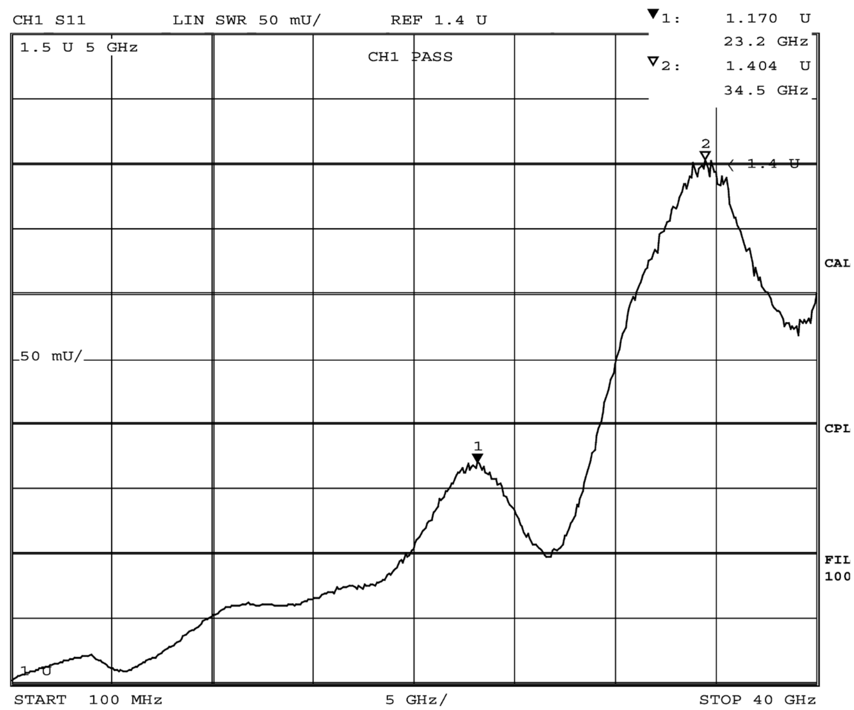


Fig. 4 Equivalent reflection coefficient of DUT displayed by the R&S ZVK. Representation in 'SWR' format with limit lines and limit check displayed.

The measurement result can now be displayed in the desired format (e.g. SWR, reflection coefficient, return loss) on the vector network analyzer. The result can be printed and stored (e.g. in the ASCII or Touchstone format) for documentation purposes and/or further processing. The usual functions of the vector network analyzer are of course available for this purpose.

The service function can be deactivated by entering the service function 2.0.13.0.

Short summary of important service functions:

Password to access the service menu: **894129**

Service function to display the source match at port 1 of the vector network analyzer: **2.0.13.12.1**

Service function to display the source match at port 2 of the vector network analyzer: **2.0.13.22.1**

Service function to switch off the above service functions: **2.0.13.0** or **2.0.13.0.0**

Service function to deactivate all service functions with subsequent PRESET: **0.0.0**

5 Measurement Uncertainty

When measuring the equivalent reflection coefficient, the accuracy is mainly determined by the specific calibration kit used. The residual system port impedance match (better known as “Effective Source Match” of the calibration - kit) more or less corresponds to the measurement uncertainty.

The tools used, e.g. test cables, attenuators and adapters, do not affect the measurement uncertainty. They only have to be suitable for the frequency range of interest to avoid any phase discontinuities caused by higher propagation modes.

Moreover, the measurement accuracy is limited by effects resulting from

a) the DUT

b) the network analyzer

Remarks regarding a): Vector Γ correction is only useful if the power splitter has stable electronic data. A precondition for this are precision connectors, for example.

Depending on the connector system, different factors regarding the reproducibility of the connection have to be considered in the calculation.

Remarks regarding b): The network analyzer can contribute the following to measurement uncertainty:

- linearity of the receiver
- stability of the receiver
- noise

A drift of the network analyzer is negligible since the measured values are recorded during calibration. The time required for one measurement is approx. 5 minutes.

Example:

Measurement uncertainty occurring when determining the equivalent reflection coefficient of a 2.92 mm power splitter. Since the equivalent reflection coefficient is a complex parameter, the measurement uncertainty is calculated as the magnitude of an error vector (radius of the “uncertainty circle”). As can be shown very easily, the vector uncertainty is expressed only to a minor extent in the magnitude of the measurand, i.e. a magnitude uncertainty of approx. 0.7 times the vector uncertainty is expected (if the equivalent reflection coefficient is greater than the vector uncertainty).

Measuring equipment:

Vector Network Analyzer	R&S ZVK
2.92 mm Calibration Kit with Sliding Loads	R&S ZV-Z35
Test Cables 2.92 mm	R&S ZV-Z15
Attenuators 10 dB, 2.92 mm	

The residual system port impedance match of the 2.92 mm Calibration Kit R&S ZV-Z35 can be described by approximation with the following equation

$$\Gamma_{q,eff,ZV-Z35} \approx 0.005 + 0.00025 \cdot \frac{f}{GHz}$$ (see Fig. 5)

R&S ZV-Z35 specification:

DC to 20 GHz min. 40 dB residual system port impedance match (0.01 linear).

20 to 40 GHz min. 35 dB residual system port impedance match (0.018 linear).

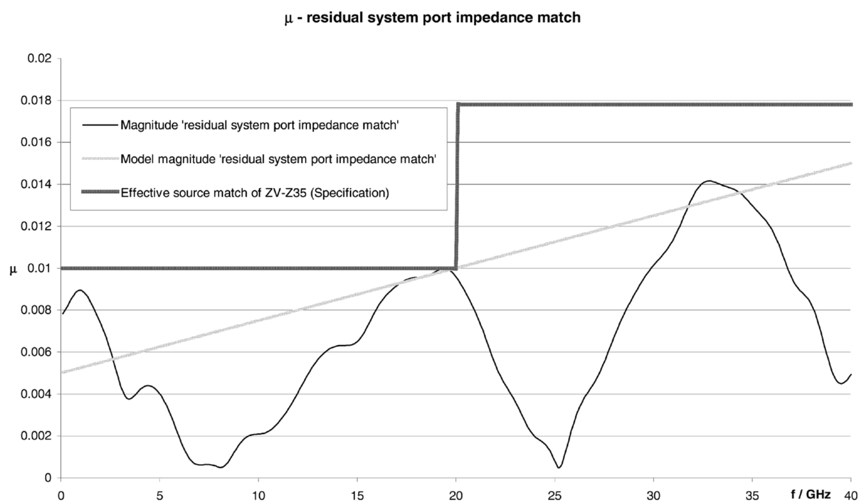


Fig. 5 μ residual system port impedance match of 2.92 mm Calibration Kit R&S ZV-Z35

The residual system port impedance match in Fig. 5 was determined by means of a method that made use of an air line.

Due to the skin effect, the impedance of the air line deviates from the nominal value towards lower frequencies. This deviation is purely systematic and can be corrected. This correction has not been made (see Fig. 12) which is why the residual system port impedance match below approx. 3 GHz has increased.

Parameter	**Standard uncertainty**
Residual system port impedance match with used calibration kit	0.0025+0.000125*f/GHz
Reproducibility of measurements (noise, repeatability of connections)	0.0005+0.00005*f/GHz
Linearity deviation of vector network analyzer	0.0005
Combined uncertainty (1σ)	**0.0027+0.00013*f/GHz**

With a coverage factor of k=2, corresponding to a confidence level of approx. 95%, a combined uncertainty of approx. 0.0054 + 0.00026*f/GHz is obtained.

If only the magnitude of the equivalent reflection coefficient is of interest, this value can be reduced by a factor of $\sqrt{2}$ which corresponds to a combined measurement uncertainty of approx. 0.0038 + 0.00018*f/GHz.

6 Experimental Results Check – Comparison with Other Measurement Methods

The accuracy of the method described can be shown by comparisons with other methods at 2 power splitters.

a Power splitter N, DC to 18 GHz, Weinschel model 1870A

The power splitter was kindly provided by PTB. Measured values obtained by using the AOC method [3] and method [7] ('Ripple method') were already available for this power splitter. The measurements using the AOC method were performed in the DKD laboratory 401 of DASA in the city of Ulm (Germany).

When comparing the three measurement methods, it should also be noted that several years had elapsed between the different measurement results and that the power splitter has meanwhile been used.

Measuring equipment used:

Vector Network Analyzer	R&S ZVK
Calibration Kit "N" with Sliding Loads	Agilent 85054B
Test Cable "N"	R&S ZV-Z11

Attenuator 10 dB, various adapters

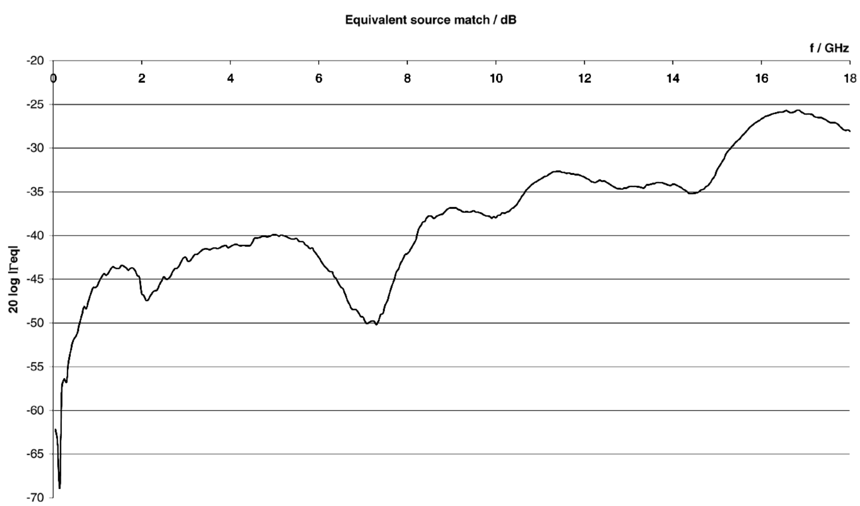


Fig. 6 Equivalent source match of power splitter Weinschel model 1870A using the method from John R. Juroshek [1]

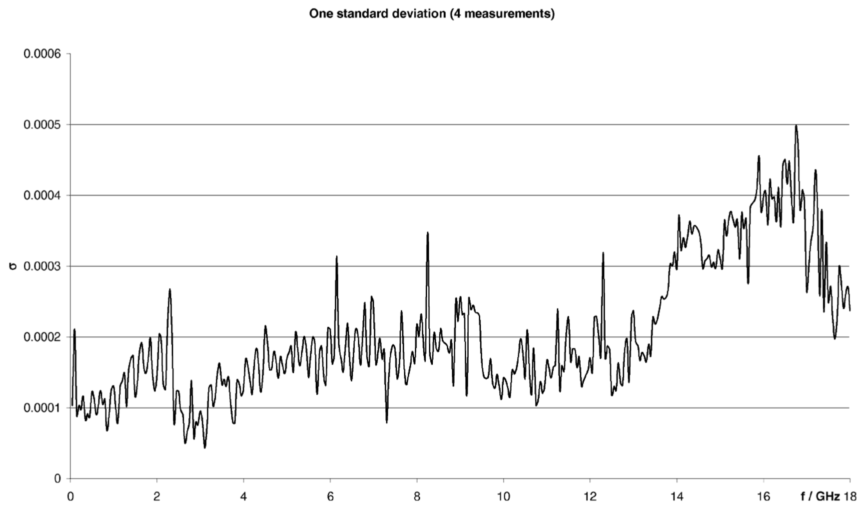


Fig. 7 One standard deviation (σ) based on 4 measurements. Measurement according to [1]

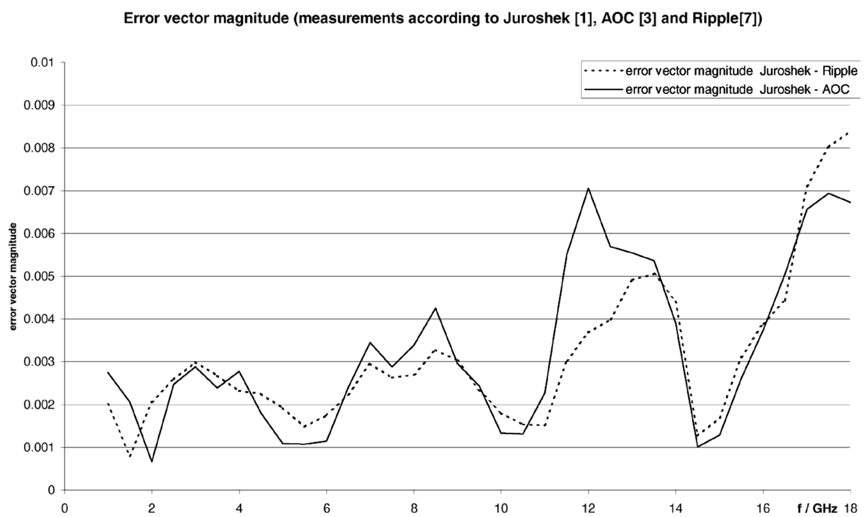


Fig. 8 Error vector magnitude of results according to Juroshek [1] compared with AOC method [3] and Ripple method [7] (35 points)

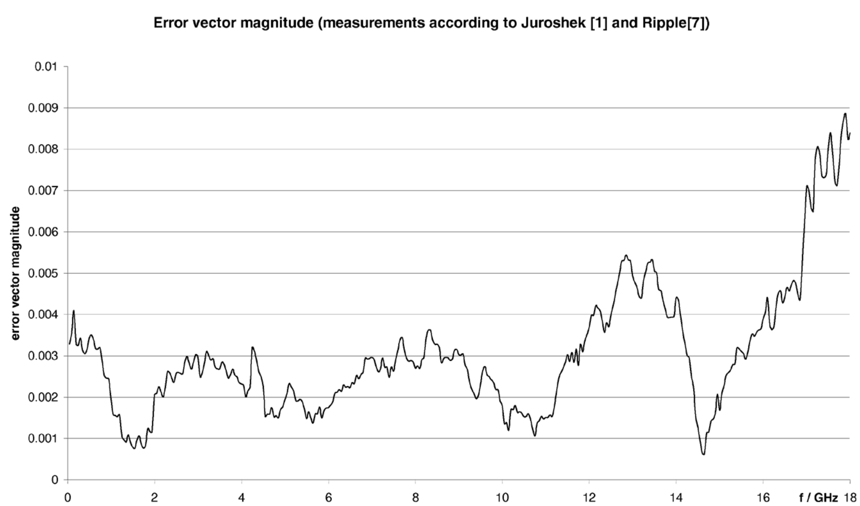


Fig. 9 Error vector magnitude of results according to Juroshek [1] compared with Ripple method [7] (360 test points)

Remarks regarding Figs. 8 and 9: The measured values obtained using the AOC method occurred only in a very coarse grid (500 MHz) which is why the comparison with the Ripple method in the 50 MHz grid is again given in Fig. 9.

Fig. 8 clearly shows that the deviation to both other methods is nearly the same, i.e. that the deviation is systematic. The deviation is mainly determined by the calibration kit used, i.e. by the deviation of the calibration standards from their mathematical models (e.g. coefficients of the open standards).

This represents the limit of the method according to Juroshek. If this error component, the 'residual system port impedance match', were known, the measurement result of the equivalent reflection coefficient could be corrected accordingly with this value and the measurement uncertainty could thus be reduced.

b Power splitter 2.92mm, DC to 40 GHz, Weinschel model 1534

Measured values (up to 26.5 GHz) of the magnitude of the equivalent reflection coefficient were provided for this power splitter by the manufacturer. For this reason, a vectorial comparison is not useful. The power splitter was measured using the Ripple method [7] and reveals that the two methods correspond very well with each other up to 40 GHz.

Measuring equipment used:

Vector Network Analyzer	R&S ZVK
2.92 mm Calibration Kit with Sliding Loads	R&S ZV-Z35
Test Cable 2.92 mm	R&S ZV-Z15

Attenuator 10 dB, various adapters

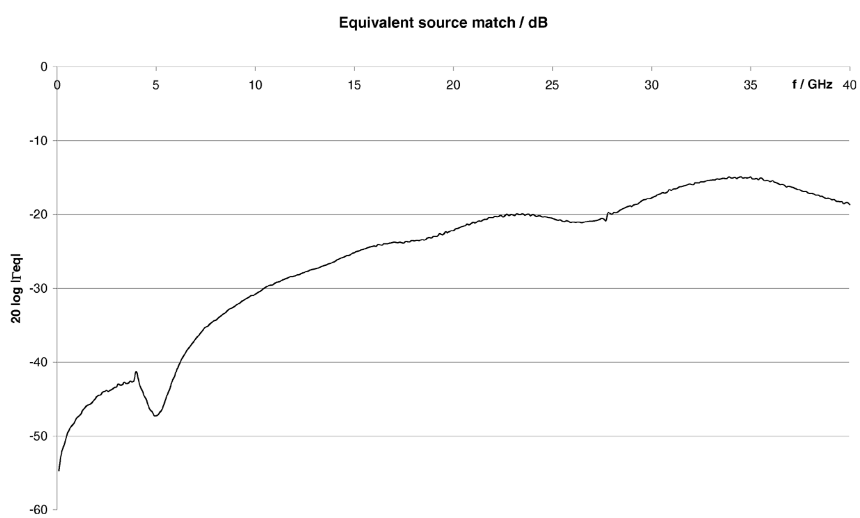


Fig. 10 Equivalent source match of power splitter Weinschel model 1534 using the method from John R. Juroshek [1]

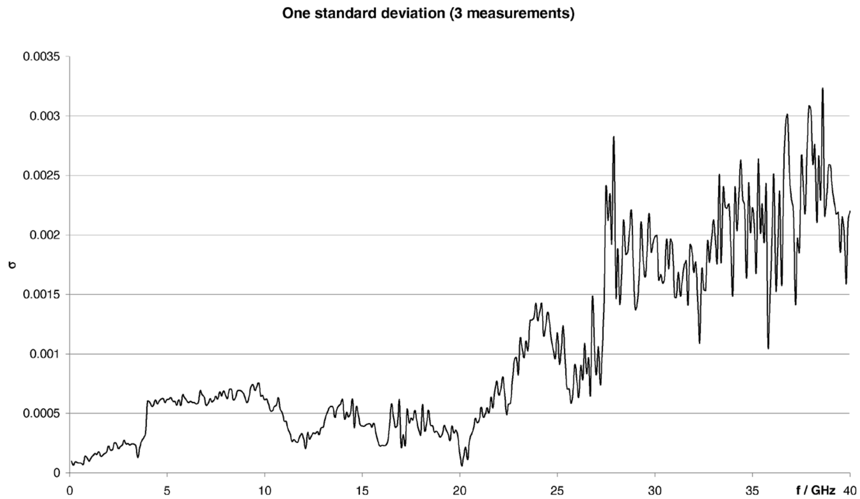


Fig. 11 One standard deviation (σ) based on 3 measurements. Measurement according to [1]

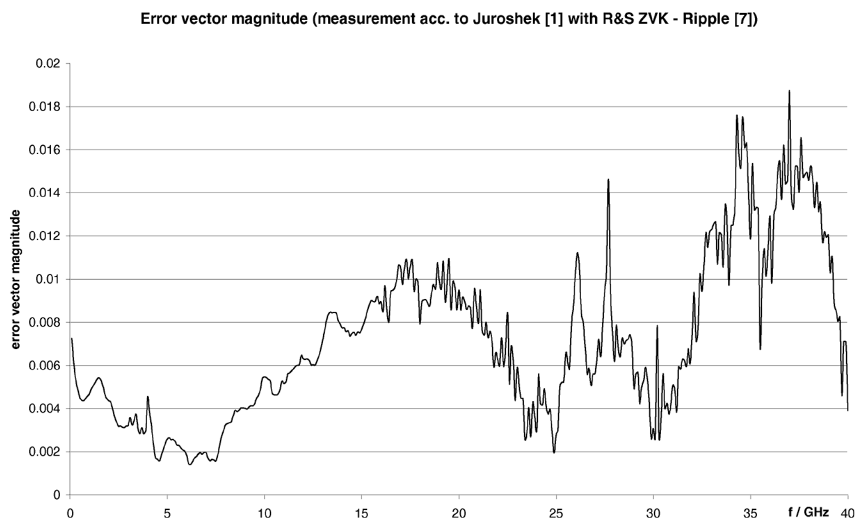


Fig. 12 Error vector magnitude of results according to Juroshek [1] compared with Ripple method [7] (400 test points)

Remarks regarding Figs. 10 and 11:

These two figures clearly show the discontinuity at 4 GHz. A passive power splitter cannot cause such a hop. The reason for the hop is the use of different components as terminations during the measurement: fixed termination up to 4 GHz and sliding load for frequency range from 4 GHz to 40 GHz.

Remarks regarding Fig. 12:

The Ripple method is based on the evaluation of a ripple caused by mismatch using an air line.

Since the impedance of the air line strongly varies towards lower frequencies due to the skin effect, the Ripple method would have to be corrected accordingly in order to work properly for very low frequencies (with small uncertainties).

Since this correction has not been performed, the “very large” difference of the two methods between 100 MHz and approx. 3 GHz occurs.

7 Special Technical Features

The measurement method proposed by John R. Juroshek for determining the equivalent reflection coefficient of a power splitter can basically be implemented with any vector network analyzer. However, the transmission and conversion of measurement data as well as the calculation (especially when a sliding load is used) is relatively time-consuming and error prone.

Hardware requirements:

If the method is to be implemented using the Vector Network Analyzer R&S ZVR/E or R&S ZVC/E from Rohde & Schwarz, option R&S ZVR-B6 is required. This option allows direct access to reference channel a1.

Depending on the type of model used, the equivalent reflection coefficient can be measured in the frequency range from 9 kHz (R&S ZVR Var. 61and R&S ZVR-B6) up to 40 GHz (R&S ZVK).

8 Summary

The method described allows fast, accurate and elegant determination of the equivalent reflection coefficient of a power splitter.

The user can thus very easily apply vector Γ correction, e.g. during the calibration of power meters, and can consequently profit from a considerable increase in measurement accuracy.

Once the Γ correction has been implemented, these advantages in the calibration of power meters can be verified without increasing the DUT measurement time and without incurring additional costs for expensive hardware.

9 References

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10 Further Application Notes

[1] O. Ostwald: 3-Port Measurements with Vector Network Analyzer ZVR, Appl. Note 1EZ26_1E.

[2] H.-G. Krekels: Automatic Calibration of Vector Network Analyzer ZVR, Appl. Note 1EZ30_1E.

[3] O. Ostwald: 4-Port Measurements with Vector Network Analyzer ZVR, Appl. Note 1EZ25_1E.

[4] T. Bednorz: Measurement Uncertainties for Vector Network Analysis, Appl. Note 1EZ29_1E.

[5] P. Kraus: Measurements on Frequency-Converting DUTs using Vector Network Analyzer ZVR, Appl. Note 1EZ32_1E.

[6] J. Ganzert: Accessing Measurement Data and Controlling the Vector Network Analyzer via DDE, Appl. Note 1EZ33_1E.

[7] J. Ganzert: File Transfer between Analyzers FSE or ZVR and PC using MS-DOS Interlink, Appl. Note 1EZ34_1E.

[8] O. Ostwald: Group and Phase Delay Measurements with Vector Network Analyzer ZVR, Appl. Note 1EZ35_1E.

[9] O. Ostwald: Multiport Measurements using Vector Network Analyzer, Appl. Note 1EZ37_1E.

[10] O. Ostwald: Frequently Asked Questions about Vector Network Analyzer ZVR, Appl. Note 1EZ38_3E.

[11] A. Gleißner: Internal Data Transfer between Windows 3.1 / Excel and Vector Network Analyzer ZVR, Appl. Note 1EZ39_1E.

[12] A. Gleißner: Power Calibration of Vector Network Analyzer ZVR, Appl. Note 1EZ41_2E

[13] O. Ostwald: Pulsed Measurements on GSM Amplifier SMD ICs with Vector Analyzer ZVR, Appl. Note 1EZ42_1E.

[14] O. Ostwald: Time Domain Measurements using Vector Network Analyzer ZVR, Appl. Note 1EZ44_0E.

[15] J. Simon: Virtual Embedding Networks for ZVR and ZVC Network Analyzers, Appl. Note 1EZ45_0E.

[16] J. Ganzert: Controlling External Generators and Power Meters with Vector Network Analyzer ZVR, Appl. Note 1EZ46_0E.

[17] A. Gleißner: Using the Frequency Conversion Mode of Vector Network Analyzer ZVR, Appl. Note 1EZ47_0E.

[18] O. Ostwald: Measurement Accuracy of Vector Network Analyzer ZVK, Appl. Note 1EZ48_0E.

[19] J. Simon: Reading and Modifying the Correction Data for System Errors and Power of a ZVR Vector Network Analyzer, Appl. Note 1EZ47_0E.

[20] T. Bednorz: Conversion Gain Measurements on Mixers with different Input and Output Impedances, Appl. Note 1EZ50_0E.

11 Ordering Information

Vector Network Analyzer		
R&S ZVM	10 MHz to 20 GHz	1127.8500.60
R&S ZVK	10 MHz to 40 GHz	1127.8651.00
Test Cables		
R&S ZV-Z11	0 Hz to 18 GHz	1085.6505.03
R&S ZV-Z14	0 Hz to 26.5 GHz	1134.4093.02
R&S ZV-Z15	0 Hz to 40 GHz	1134.4193.02
Calibration Kit		
R&S ZV-Z21	0 Hz to 18 GHz	1085.7099.02
R&S ZV-Z33	0 Hz to 26.5 GHz	1128.3518.02
R&S ZV-Z35	0 Hz to 40 GHz	1128.3547.02

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