AutoKal

Automatic Calibration
of
Vector Network Analyzer
ZVR

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Application Note 1EZ30_2E

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Products:

ZVR incl. Option ZVR-B1
ZVRE incl. Option ZVR-B1

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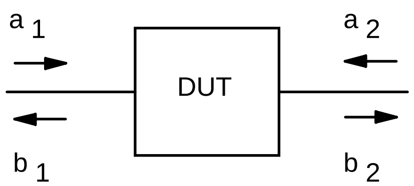
Contents

1. Introduction

Vector network analyzers are used in high frequency applications to measure the complex scattering parameters of an unknown device-under-test (DUT). In general, the DUT characteristics can be evaluated by using electromagnetic waves. The correlation between the incident, reflected and transmitted wave quantities at the DUT is defined by its scattering matrix **S**.



$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Figure 1: Scattering parameter description of a two-port device.

For a two-port DUT (Fig. 1), the scattering parameters have the following meaning:

S_{11}: Reflection at port 1 with port 2 matched
S_{21}: Forward transmission with port 2 matched
S_{12}: Reverse transmission with port 1 matched
S_{22}: Reflection at port 2 with port 1 matched

Since network analyzers which measure the wave quantities a_i, b_i (i = 1, 2) are no ideal measuring instruments, the determination of the required scattering parameters is subject to errors. A significant enhancement of measurement accuracy, however, is possible by utilizing appropriate mathematical system error correction procedures. Therefore the non-ideal characteristics of the network analyzer must be known. The determination of these non-ideal characteristics can be performed by using a calibration procedure.

1.1 Error Model of Network Analyzers

A block diagram of a vector network analyzer equipped with four receiver channels, e.g. ZVR, is shown in Fig. 2.

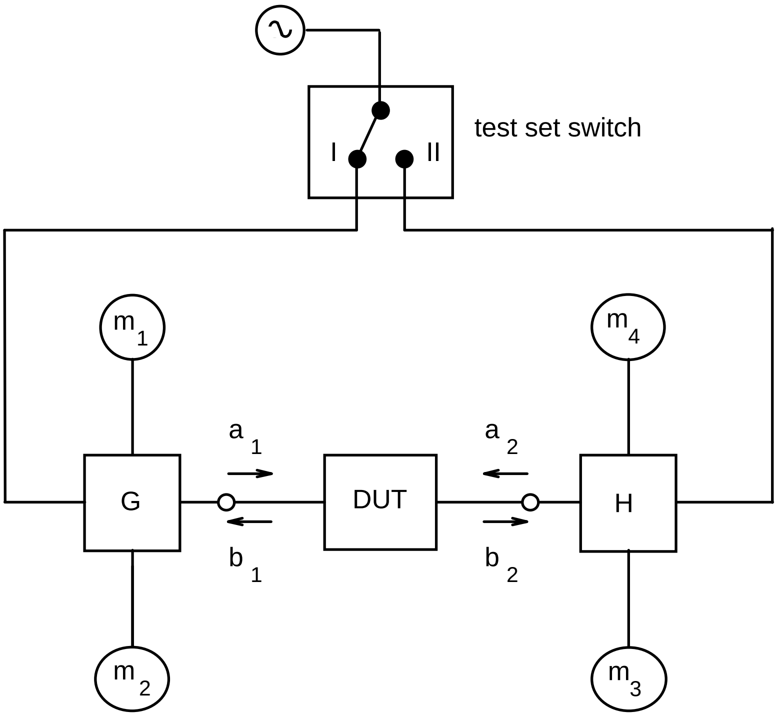


Figure 2: Block diagram of a vector network analyzer, e.g. ZVR

The analyzer consists of a test set switch (SPDT switch) and two reflectometers *G* and *H* as well as four receiver channels m_i (i = 1...4). The block *DUT* represents a device-under-test located between the two test ports.

The correlation between the wave quantities a_i, b_i at the test ports and the measurement values m_i is given by two error two-ports as described by the matrices **G** and **H** (Eq. 1) according to a four-port / two-port reduction [1]. The calculation of these two matrices is the task of the calibration procedure.

$$\begin{pmatrix} b_1 \\ a_1 \end{pmatrix} = \begin{pmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{pmatrix} \begin{pmatrix} m_1 \\ m_2 \end{pmatrix} \quad ; \quad \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} = \begin{pmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{pmatrix} \begin{pmatrix} m_3 \\ m_4 \end{pmatrix} \quad . \tag{1}$$

Besides the description of a DUT by scattering parameters, characterization with transmission matrices is also possible. The transmission matrix **N** is defined by a linear combination of the transmitted and reflected waves, however, in a different relationship. For a two-port, Eq. 2 is valid.

$$\begin{pmatrix} b_1 \\ a_1 \end{pmatrix} = \begin{pmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{pmatrix} \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} \quad ; \quad \mathbf{N} = \frac{1}{S_{21}} \begin{pmatrix} -det(\mathbf{S}) & S_{11} \\ -S_{22} & 1 \end{pmatrix} \quad . \tag{2}$$

A combination of Eq. 1 and Eq. 2 leads to the expression:

$$\begin{pmatrix} m_1 \\ m_2 \end{pmatrix} = \mathbf{G}^{-1} \, \mathbf{N} \, \mathbf{H} \begin{pmatrix} m_3 \\ m_4 \end{pmatrix} \tag{3}$$

The block diagram of Fig. 2 reduces to a cascaded network consisting of two error two-ports and the DUT.

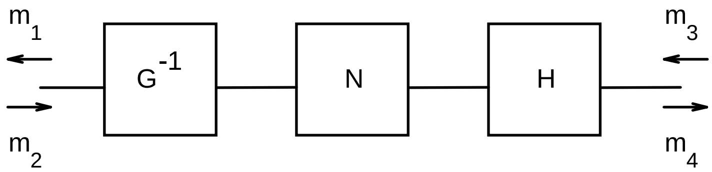


Figure 3: Cascaded network of two error two-ports and the device-under-test.

The elimination of the waves a_i, b_i (i = 1, 2) in Eq. 1 by application of the scattering parameters yields the vector equation:

$$\begin{pmatrix} G_{11} m_1 + G_{12} m_2 \\ H_{21} m_3 + H_{22} m_4 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} G_{21} m_1 + G_{22} m_2 \\ H_{11} m_3 + H_{12} m_4 \end{pmatrix} \tag{4}$$

A second vector expression is derived for the second position of the test set switch. If the measurement values of the second switch position are defined by m'_i (i = 1...4), a combination of the two vector equations yields the matrix expression:

$$\mathbf{S} = \begin{pmatrix} G_{11} m_1 + G_{12} m_2 & G_{11} m'_1 + G_{12} m'_2 \\ H_{21} m_3 + H_{22} m_4 & H_{21} m'_3 + H_{22} m'_4 \end{pmatrix} \begin{pmatrix} G_{21} m_1 + G_{22} m_2 & G_{21} m'_1 + G_{22} m'_2 \\ H_{11} m_3 + H_{12} m_4 & H_{11} m'_3 + H_{12} m'_4 \end{pmatrix}^{-1} \tag{5}$$

This expression can be used during calibration of the network analyzer. Moreover, the transformation of Eq. 5 for a known scattering matrix **S** results in four linear, independent equations which are useful during the calculation of the error parameters contained in the matrices **G** and **H**.

A determination of the scattering matrix for an unknown DUT can also be performed with Eq. 5 if the system errors of the network analyzer are known.

1.2 Manual Calibration Procedures

Commonly used procedures for the calibration of vector network analyzers, e. g. TOM or TRM [2] (T = Through, M = Match, O = Open, R = Reflect) are based upon the measurement of various known or partially unknown calibration standards. Depending upon the type of procedure, the individual calibration standards must be manually connected to the test ports of the network analyzer in order to perform a measurement of the calibration standards.

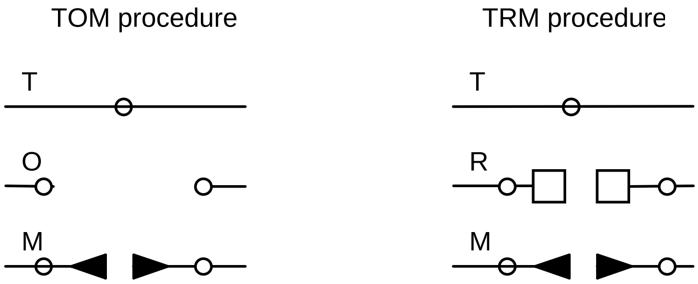


Figure 4: Manual calibration techniques.

The parameters found by manual calibration procedures have the hidden risk of being in error because of possible contact problems which may occur when the standards are frequently connected to the test ports. The consequence is an erroneous system error correction.

At the conclusion of a correctly completed calibration procedure, the non-ideal characteristics of the measuring instrument are known. Unavoidable changes in electrical characteristics due to temperature instability or to other drifts in the network analyzer, which occur after the calibration, lead to errors in the measurement results. On the other hand, the characteristics of mechanical components (lines, connectors, etc.) are highly reproducible and change only slightly over long periods of time.

The specified measurement accuracy requirements dictate the interval between two calibrations. This interval may be from one to several days, but may also be just a matter of hours. Hence, the calibration effort (connection of standards) can be considerable. In an industrial measurement environment, the repetition of a calibration is often very difficult and expensive since on-going production may have to be interrupted or even the analyzer system may have to be dismantled.

2. The AutoKal Procedure

The *AutoKal* (Automatic Calibration) procedure is based upon the application of an automated, passive switching unit controlled by the network analyzer. For purposes of calibration, the switching unit must be able to take on three independent, reproducible switching states.

As shown in Fig. 5, the network analyzer is modified at a test port (e.g. port *2*) by the extension of the switching unit *E*. The switching unit is a permanent part of the analyzer and will not be removed after completion of the calibration procedure. An additional transmission network T_N represents the interconnection between the switching unit *E* and port *2'*.

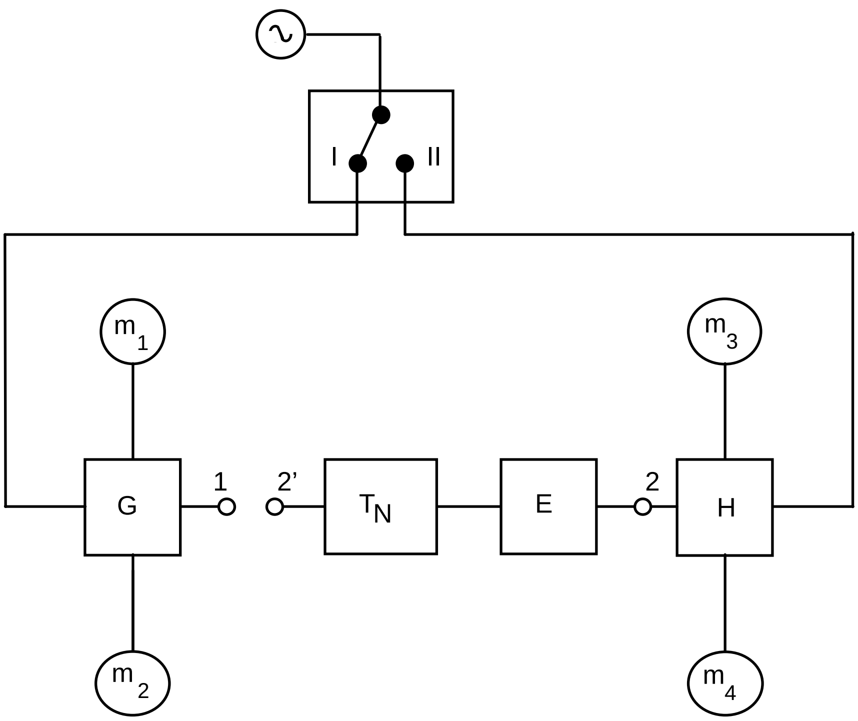


Figure 5: Configuration of the network analyzer.

The *AutoKal* calibration is divided into two procedural steps, fundamental calibration and automatic (transfer) calibration.

Fundamental Calibration:

In order to characterize the switching unit, it is necessary to perform a manual calibration. Since the switching unit is a passive, very stable component, it is only necessary to carry out a fundamental calibration at intervals of several months. Another possible reason for repeating the fundamental calibration is a change in the transmission network, e.g. a change of the connector type at a test port 2'.

Automatic (transfer) Calibration:

The automatic (transfer) calibration is the actual calibration procedure which leads to the determination of the error parameters of the network analyzer.

The transfer calibration is performed automatically by the network analyzer. The user is only required to provide the interconnection between the two test ports and simply press the AutoKal softkey in the CAL menu. In comparison to manual calibration procedures, the *AutoKal* calibration leads to a considerable simplification in the handling of calibration standards.

2.1 Theoretical Description

The starting point of the description of the procedure is the equivalent circuit of a network analyzer as derived in Section 1.1 by the application of the four-port/two-port reduction method. Fig. 6 illustrates the configuration of the cascaded two-ports with the analyzer being extended by the switching unit *E* and the transmission network T_N. The block *N* represents a two-port located between the test ports.

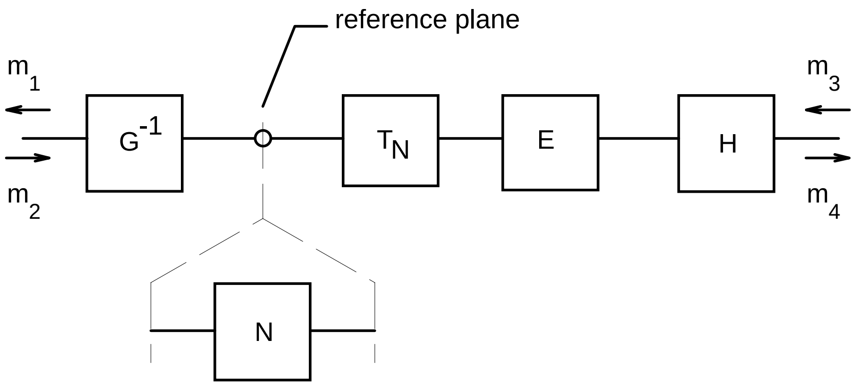


Figure 6: Realization of virtual calibration standards.

A mathematical description of the two-port configuration yields:

$$\begin{pmatrix} m_1 \\ m_2 \end{pmatrix} = \mathbf{G}^{-1}\,\mathbf{N}\,\mathbf{T_N}\,\mathbf{E}\,\mathbf{H}\begin{pmatrix} m_3 \\ m_4 \end{pmatrix} \quad . \tag{6}$$

The switching unit must take on three different switching states. Table 1 indicates the transmission matrix for these three states.

Switching State	Transmission Matrix **E**
0	$\mathbf{E} = \mathbf{E_0}$
1	$\mathbf{E} = \mathbf{E_1} \bullet \mathbf{E_0}$
2	$\mathbf{E} = \mathbf{E_2} \bullet \mathbf{E_0}$

Table 1: Transmission matrix **E** for three switching states.

$\mathbf{E_0}$ represents the transmission matrix of the initial state. $\mathbf{E_1}$ and $\mathbf{E_2}$ include the changes of the switching network for the second and third positions.

The basis of the *AutoKal* procedure is a ***virtual transformation*** of the switching network standards into the reference plane. The network standards are realized via three states of the switching unit. Since both test ports of the analyzer must present an exact through-connection during the automatic (transfer) calibration, the initial state of the switching unit is converted to a through-connection.

$$\mathbf{E_0} \longrightarrow \mathbf{N} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \tag{7}$$

The transformation of the two switching states which deviate from the initial position is shown in Eq. 8.

$$\begin{aligned} \mathbf{E_1}\ \mathbf{E_0} &\longrightarrow \tilde{\mathbf{E}}_1 \\ \mathbf{E_2}\ \mathbf{E_0} &\longrightarrow \tilde{\mathbf{E}}_2 \end{aligned} \tag{8}$$

If the switching unit is in its second state, the deviation from the initial position $\mathbf{E_1}$ is transformed to a modified $\tilde{\mathbf{E}}_1$ which is virtually located between the reference planes.

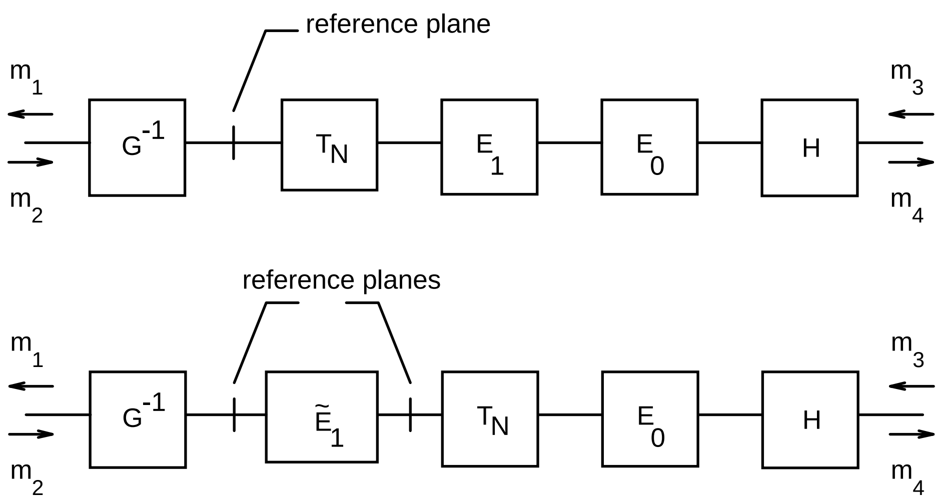


Figure 7: Transformation of network standards.

In view of the transformation (Eq. 8), the effect of the two two-port configurations of Fig. 7 must be identical. Mathematically, this yields:

$$\mathbf{G}^{-1}\ \mathbf{T_N}\ \mathbf{E_1}\mathbf{E_0}\mathbf{H} \quad = \quad \mathbf{G}^{-1}\ \tilde{\mathbf{E}}_1\mathbf{T_N}\ \mathbf{E_0}\mathbf{H} \tag{9}$$

Rearranging this equation, $\tilde{\mathbf{E}}_1$ is the result of a similarity transformation, that is, a virtual transformation of the deviation $\mathbf{E_1}$ into the reference plane.

$$\tilde{\mathbf{E}}_1 \quad = \quad \mathbf{T_N}\ \mathbf{E_1}\mathbf{T_N}^{-1} \tag{10}$$

As can be seen from Eq. 10, it is not necessary to know the initial state $\mathbf{E_0}$ of the switching unit. For calibration purposes, only the virtual changes must be known. In addition, Eq. 10 also clarifies the technical requirements imposed upon the switching unit. The transmission network and any changes of the switching unit need not be known, only a high degree of reproducibility is required.

2.1.1 Fundamental Calibration

The purpose of the fundamental calibration is the calculation of the scattering matrices $\tilde{\mathbf{S}}_1$ and $\tilde{\mathbf{S}}_2$ of the virtual calibration standards $\tilde{E}_1$ and $\tilde{E}_2$.

First, it is necessary to calibrate the network analyzer using a manual calibration procedure, e.g. TOM. Here, the switching unit *E* is in the initial state (Fig. 8).

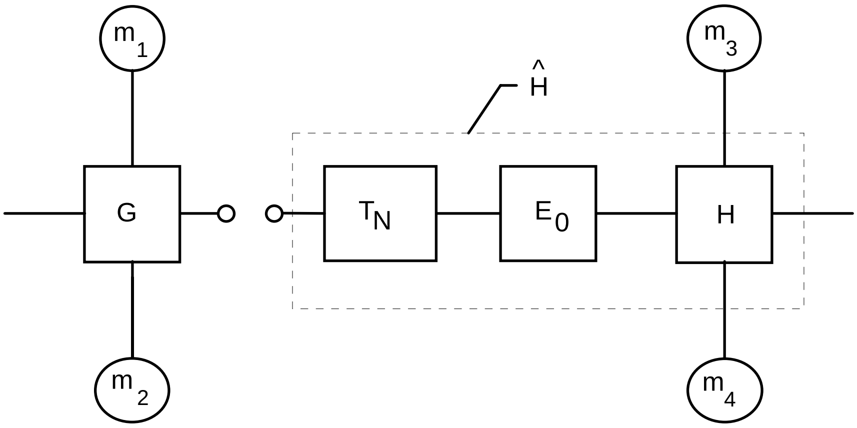


Figure 8: Initial state of the network analyzer

The calibration, e.g. TOM, yields the system error matrices **G** and $\hat{\mathbf{H}}$ which describe the reflectometers *G* and $\hat{H}$.

In the next step, the test ports are combined to form an exact through-connection and the switching unit is switched to its second state so that the virtual standard $\tilde{E}_1$ is realized. An analyzer measurement under these conditions generates the desired virtual scattering parameters when Eq. 5 is applied.

$$\tilde{\mathbf{S}}_1 = \begin{pmatrix} G_{11} m_1 + G_{12} m_2 & G_{11} m'_1 + G_{12} m'_2 \\ \hat{H}_{21} m_3 + \hat{H}_{22} m_4 & \hat{H}_{21} m'_3 + \hat{H}_{22} m'_4 \end{pmatrix} * \begin{pmatrix} G_{21} m_1 + G_{22} m_2 & G_{21} m'_1 + G_{22} m'_2 \\ \hat{H}_{11} m_3 + \hat{H}_{12} m_4 & \hat{H}_{11} m'_3 + \hat{H}_{12} m'_4 \end{pmatrix}^{-1} \quad (11)$$

In a similar way, $\tilde{\mathbf{S}}_2$ can be determined after setting the switching device to the third state. Once the matrices $\tilde{\mathbf{S}}_1$ and $\tilde{\mathbf{S}}_2$ have been found, the task of the fundamental calibration is completed.

A fundamental calibration requires a total of five analyzer measurements. The individual measurements with the corresponding calibration standard and the required state of the switching unit are summarized in Table 2.

Measurement	DUT	Switching state
1	T	0
2	T	1
3	T	2
4	O	0
5	M	0

Table 2: Measurements for fundamental calibration using TOM

Since the AutoKal switching unit *E* is a mechanical, passive device and has very stable electrical characteristics, it is usually only necessary to perform a fundamental calibration at intervals of several months.

2.1.2 Automatic Calibration

The frequently performed transfer calibration AutoKal for the determination of the currently valid error matrices **G** and $\hat{\mathbf{H}}$ takes place automatically. Here, it is only necessary to provide a through-connection of the two test ports.

During this automatically controlled calibration, the network analyzer performs three measurements at the three states of the switching unit. The results of the measurements yield the following equations:

$$\begin{aligned} \mathbf{M1} &= \mathbf{G}^{-1}\,\hat{\mathbf{H}}, \\ \mathbf{M2} &= \mathbf{G}^{-1}\,\tilde{\mathbf{E}}_1\,\hat{\mathbf{H}}, \\ \mathbf{M3} &= \mathbf{G}^{-1}\,\tilde{\mathbf{E}}_2\,\hat{\mathbf{H}}, \end{aligned} \tag{12}$$

where

$$\mathbf{M}_i = \begin{pmatrix} m_1 & m'_1 \\ m_2 & m'_2 \end{pmatrix} \begin{pmatrix} m_3 & m'_3 \\ m_4 & m'_4 \end{pmatrix}^{-1} \quad , \quad (i = 1 \ldots 3) \quad . \tag{13}$$

With a knowledge of the measurement matrices $\mathbf{M}_i$ (i = 1...3) as well as the transmission matrices of the virtual network standards determined during the fundamental calibration, the desired system matrices **G** and $\hat{\mathbf{H}}$ can be found.

For the measurement and the calculation of an unknown DUT, the switching unit must be in its initial state.

2.2 AutoKal for Analyzers with three Receiver Channels

The application of *AutoKal* procedure is not limited to network analyzers with four receiver channels, as ZVR. It can be shown in the following that the configuration for an automatic calibration can also be implemented on uni- or bi-directional network analyzers with only three receiver channels, e.g. ZVRE.

A bi-directional network analyzer with three receiver channels is shown in Fig. 9 on the next page.

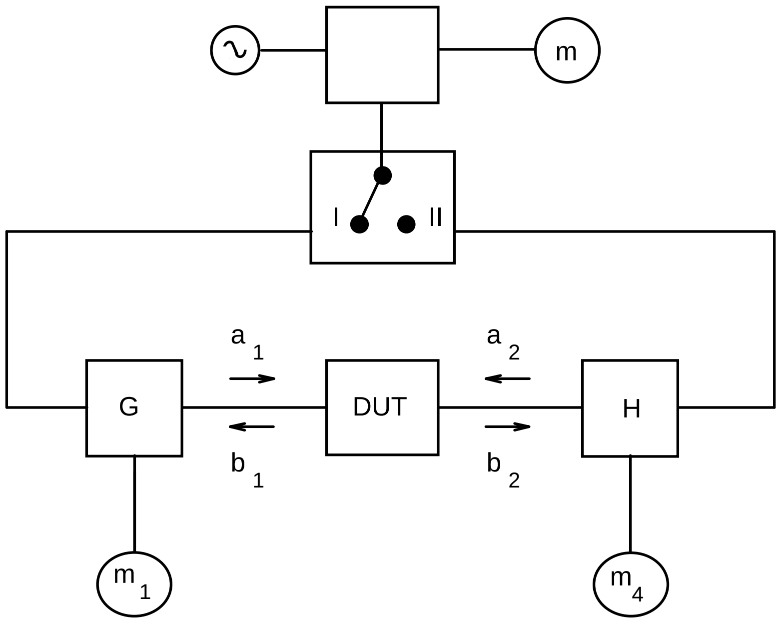


Figure 9: Block diagram of a vector network analyzer with three receiver channels, e.g. ZVRE

The two reflectometers *G* and *H* are each connected to one receiver channel. The third receiver channel is fed between the RF source and the test set switch. The information provided by the third receiver channel *m* is a measure of the incident wave transmitted to the DUT. With reference to the algebra of Section 1.1, *m* represents the coefficient m_2 for the first position and the coefficient m'_3 for the second position of the test set switch.

Due to configuration of the third receiver channel *m* the test set switch must be included in the error model of the network analyzer. Consequently, there are different system errors for each test set switch position:

Position I:	**G**	**H**
Position II:	**G'**	**H'**

For the first test set switch position, Eq. 14 describes the relationship between the measurement coefficients m, m_i (i = 1, 4) and the waves a_j, b_j (j = 1, 2) at the two test ports.

$$\begin{pmatrix} b_1 \\ a_1 \end{pmatrix} = \begin{pmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{pmatrix} \begin{pmatrix} m_1 \\ m \end{pmatrix} \quad ; \quad \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} = \begin{pmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{pmatrix} \begin{pmatrix} 0 \\ m_4 \end{pmatrix} \quad . \qquad (14)$$

Eq. 15 is valid for the second position of the switch.

$$\begin{pmatrix} b_1 \\ a_1 \end{pmatrix} = \begin{pmatrix} G'_{11} & G'_{12} \\ G'_{21} & G'_{22} \end{pmatrix} \begin{pmatrix} m'_1 \\ 0 \end{pmatrix} \quad ; \quad \begin{pmatrix} a_2 \\ b_2 \end{pmatrix} = \begin{pmatrix} H'_{11} & H'_{12} \\ H'_{21} & H'_{22} \end{pmatrix} \begin{pmatrix} m' \\ m'_4 \end{pmatrix} \quad . \qquad (15)$$

The combination of expressions Eq. 14 and Eq. 15 and the application of the scattering parameters yields Eq. 16.

$$\mathbf{S} = \begin{pmatrix} G_{11} m_1 + G_{12} m & G'_{11} m'_1 \\ H_{22} m_4 & H'_{21} m' + H'_{22} m'_4 \end{pmatrix} \begin{pmatrix} G_{21} m_1 + G_{22} m & G'_{21} m'_1 \\ H_{12} m_4 & H'_{11} m' + H'_{12} m'_4 \end{pmatrix}^{-1} \qquad (16)$$

In view of this correlation, the application of the *AutoKal* procedure to analyzers with three receiver channels is similar to that of analyzers with four receiver channels.

A well-known calibration technique for determining the virtual calibration standards during the *AutoKal* fundamental calibration for analyzers with three receiver channels is the 12-term procedure TOSM.

3. Practical Realization and Application of the AutoKal Procedure

3.1 Realization of the Switching Unit

The switching unit, necessary for the performance of automatic transfer calibration, must exhibit three independent switching states. For defining the switching states, simple resistor configurations with non-precision specifications can be used. The resistive networks used must possess stable, long-term characteristics.

A matched pi-attenuator is a simple, well-known circuit for the realization of a switching unit which guarantees a well-matched test port. The pi-network shown in Fig. 10 contains two additional switches which allow the three different switching states (Fig. 11) to be realized. The switches may be electro-mechanical and, therefore, automatically controlled.

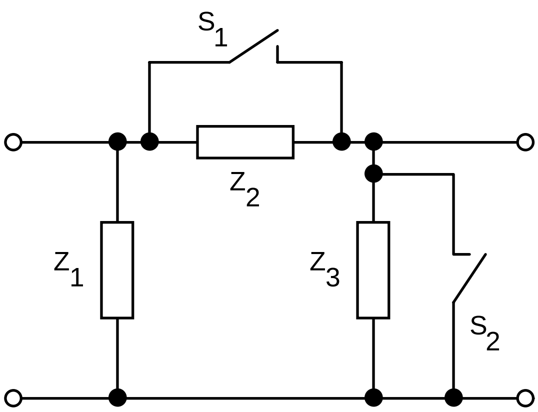


Figure 10: Switching unit realization.

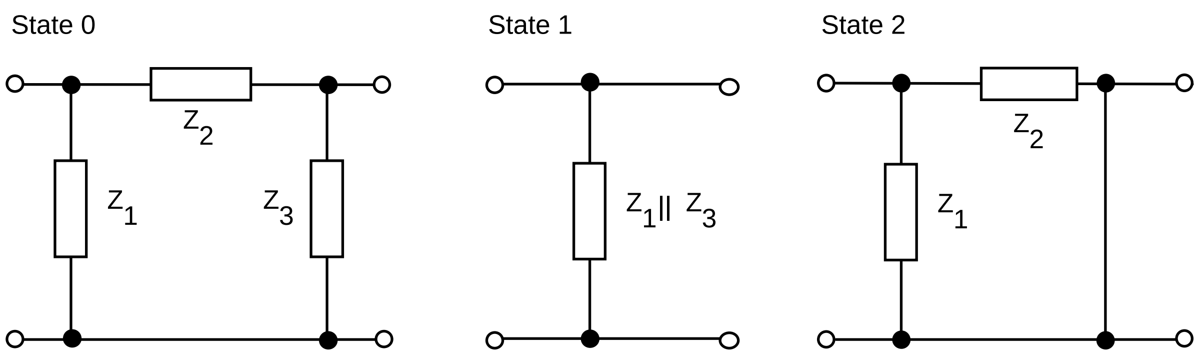


Figure 11: Switching states of the pi-network

Another version of a switching unit is shown in Fig. 12. Here, the networks *NW1* and *NW2* are switched into the signal path during the second and third states as a function of position of the synchronously operating switches *S1* and *S2.*

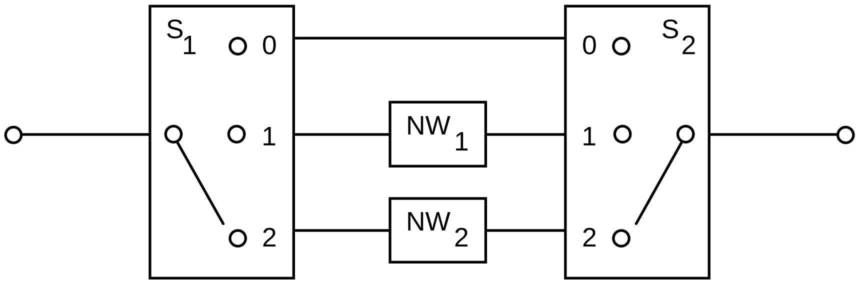


Figure 12: Realization of the switching network.

3.2 Implementation of the AutoKal Procedure

The implementation of the AutoKal procedure is accomplished by modifying a network analyzer to include a control unit and a switching device. The control unit may be contained either within the analyzer chassis itself or located remotely with a connection to the network analyzer interface. The switching device, realized here as module ZVR-B1, is connected to the test ports of the analyzer. The test ports of the AutoKal unit are the actual test ports at which the fundamental calibration and all measurements of unknown DUTs are carried out. A control cable connects the AutoKal module to the control unit, which is a part of the ZVR vector network analyzer.

The internal switching device is inserted between one test port pair, i.e. PORT1 (male) and PORT1 (female), within the AutoKal unit ZVR-B1. The connection between the other test port pair, i.e. PORT2 (male) and PORT2 (female), is realized by a direct through line.

4. References

[1] SCHIEK, B., Meßsysteme der Hochfrequenztechnik, Hüthig-Verlag, Heidelberg 1984

[2] EUL, H.-J., SCHIEK, B., A Generalized Theory and New Calibration Procedures for Network Analyzer Self-Calibration, IEEE-MTT, Vol. 39, April 1991, pp 724-731.

[3] KREKELS, H.-G., SCHIEK, B., Ein Netzwerkanalysator Kalibrierverfahren für eine redundante Anzahl an Kalibrierstandards, Proceedings of the national URSI conference 1993, Kleinheubach (Germany), vol. 37 , pp 117-126.

[4] KREKELS, H.-G., SCHIEK, B., An Automatic Procedure for a Calibration of a Network Analyzer, Proceedings of the Conference on Precision Electromagnetic Measurements 1994 (CPEM), Boulder, USA, pp 123-124.

[5] KREKELS, H.-G., Verfahren zur Kalibrierung und Etablierung von vektoriellen Netzwerkanalysatoren mit Anwendung auf Doppelsechstor-Anordnungen, Shaker-Verlag, Aachen 1996

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30 August 1996

5 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: Zeitbereichsmessungen mit dem Netzwerkanalysator ZVR, Appl. Note 1EZ44_1D.

6 Ordering Information

Order designation	Type	Frequency range	Order No.
Vector Network Analyzers (test sets included) *			
3-channel, unidirectional, 50 Ω, passive	ZVRL	9 kHz to 4 GHz	1043.0009.41
3-channel, bidirectional, 50 Ω, passive	ZVRE	9 kHz to 4 GHz	1043.0009.51
3-channel, bidirectional, 50 Ω, active	ZVRE	300 kHz to 4 GHz	1043.0009.52
4-channel, bidirectional, 50 Ω, passive	ZVR	9 kHz to 4 GHz	1043.0009.61
4-channel, bidirectional, 50 Ω, active	ZVR	300 kHz to 4 GHz	1043.0009.62
3-channel, bidirectional, 50 Ω, active	ZVCE	20 kHz to 8 GHz	1106.9020.50
4-channel, bidirectional, 50 Ω, active	ZVC	20 kHz to 8 GHz	1106.9020.60
Alternative Test Sets *			
75 Ω SWR Bridge for ZVRL (instead of 50 Ω) [1]			
75 Ω, passive	ZVR-A71	9 kHz to 4 GHz	1043.7690.18
75 Ω SWR Bridge Pairs for ZVRE and ZVR (instead of 50 Ω) [1]			
75 Ω, passive	ZVR-A75	9 kHz to 4 GHz	1043.7755.28
75 Ω, active	ZVR-A76	300 kHz to 4 GHz	1043.7755.29
Options			
AutoKal	ZVR-B1	0 to 8 GHz	1044.0625.02
Time Domain	ZVR-B2	same as analyzer	1044.1009.02
Mixer Measurements [2]	ZVR-B4	same as analyzer	1044.1215.02
Reference Channel Ports	ZVR-B6	same as analyzer	1044.1415.02
Power Calibration [3]	ZVR-B7	same as analyzer	1044.1544.02
3-Port Adapter	ZVR-B8	0 to 4 GHz	1086.0000.02
Virtual Embedding Networks [4]	ZVR-K9	same as analyzer	1106.8830.02
4-Port Adapter (2xSPDT)	ZVR-B14	0 to 4 GHz	1106.7510.02
4-Port Adapter (SP3T)	ZVR-B14	0 to 4 GHz	1106.7510.03
Controller (German) [5]	ZVR-B15	-	1044.0290.02
Controller (English) [5]	ZVR-B15	-	1044.0290.03
Ethernet BNC for ZVR-B15	FSE-B16	-	1073.5973.02
Ethernet AUI for ZVR-B15	FSE-B16	-	1073.5973.03
IEC/IEEE-Bus Interface for ZVR-B15	FSE-B17	-	1066.4017.02
Generator Step Attenuator PORT 1	ZVR-B21	same as analyzer	1044.0025.11
Generator Step Attenuator PORT 2 [6]	ZVR-B22	same as analyzer	1044.0025.21
Receiver Step Attenuator PORT 1	ZVR-B23	same as analyzer	1044.0025.12
Receiver Step Attenuator PORT 2	ZVR-B24	same as analyzer	1044.0025.22
External Measurements, 50 Ω [7]	ZVR-B25	10 Hz to 4 GHz (ZVR/E/L) 20 kHz to 8 GHz (ZVC/E)	1044.0460.02

[1] To be ordered together with the analyzer.
[2] Harmonics measurements included.
[3] Power meter and sensor required.
[4] Only for ZVR or ZVC with ZVR-B15.
[5] DOS, Windows 3.11, keyboard and mouse included.
[6] For ZVR or ZVC only.
[7] Step attenuators required.

*** Note:**
Active test sets, in contrast to passive test sets, comprise internal bias networks, eg to supply DUTs.