
Virtual Embedding Networks for Vector Network Analyzer ZVR

Application Note 1EZ45_0E

Subject to change

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Products:

ZVR with Options ZVR-B15 and ZVR-K9

ZVC with Options ZVR-B15 and ZVR-K9



ROHDE & SCHWARZ

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1 ABSTRACT

When measuring scattering parameters with a vector network analyzer ZVR or ZVC, software option ZVR-K9 allows one to take **virtual embedding networks** into account. With this tool, **embedding** and **de-embedding** measurement tasks can be solved. In a production environment, for example, various test fixtures with different matching networks may be replaced by a combination of a single standard fixture with stable and easily manageable virtual networks. Another typical application is **shifting the reference plane**. Furthermore, ZVR-K9 allows the **measurement of embedding networks** as well as their import and export for **data exchange with CAD applications**.

2 INTRODUCTION

In standard configuration, most modern vector network analyzers (VNAs) are equipped with two coaxial test ports, to which the coaxial test cables are connected. Usually the reference plane of the connectors corresponds to the plane of system error calibration and thus of the measured S-parameters. In most cases the reference impedance is $50\ \Omega$ or $75\ \Omega$.

If one wishes to use such a network analyzer for measuring a device under test (DUT) that has a non-coaxial reference plane or ports with a deviating reference impedance, a transformation or embedding network (EN) must be inserted. A transistor may serve as a typical example of a non-coaxial DUT. In order to contact this device, a test fixture is required.

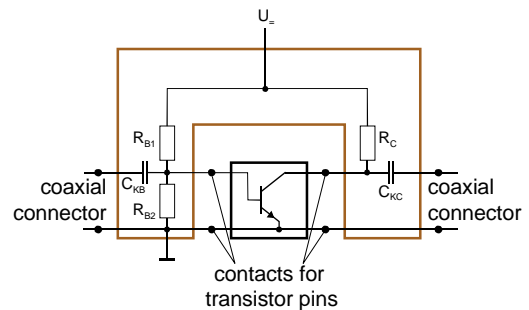


Fig. 1: Bipolar transistor in a test fixture

Fig. 1 shows a grounded-emitter bipolar transistor in a simple test fixture. The fixture contacts are adapted to the transistor case. Base and collector are linked to coaxial connectors, e.g. SMA sockets, via blocking capacitors C_{KB} and C_{KC} . The emitter is grounded. In order to make clear how the device terminals are related to the input and output ports of the transistor, the emitter has been split in Fig. 1. Furthermore, the fixture contains a bias network consisting of a base potential divider R_{B1} and R_{B2} and a collector resistance R_C . Some fixtures incorporate additional matching elements (not shown in Fig. 1) in order to transform the input and output impedance of the transistor to the reference impedance of the network analyzer.

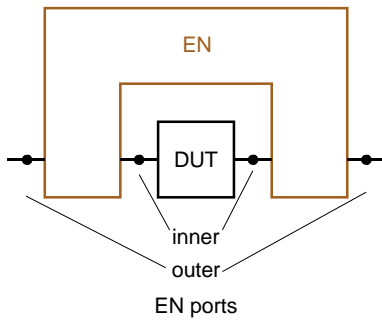


Fig. 2: Equivalent circuit for a transistor in a test fixture

Fig. 2 is structurally equivalent to the test setup of Fig. 1; the DUT corresponding to the transistor and the EN to the fixture. The ports connected to the DUT are called "inner", the ones connected to the network analyzer "outer" ports. Assuming that each port of the DUT is accessible from the exterior via the EN, a general EN has twice as many ports as the device under test.

The question arises where the reference plane of the measured S-parameters is located. If the EN is simply connected to the network analyzer, which is calibrated at the test cable connectors, then the joint network consisting of EN and DUT is measured. This may be useful if in an application the DUT is operated only together with the EN, thus requiring the joint network data for system design.

If, however, the S-parameters of the DUT alone are interesting, either a system error calibration at the inner EN ports must be performed or the EN must be computationally isolated from measurement data of the joint network (DUT + EN), which refer to the outer EN ports. The latter procedure is also known as "de-embedding". The S-parameters of the EN are assumed to be known.

In some cases the measurement task that is complementary to de-embedding may be interesting, too. That is measuring a DUT as if it was embedded into an EN, though this EN does not physically exist. By that one can, for example, investigate the influence of virtual impedance transformers onto a really existing DUT and optimize the transformers before they are actually realized in hardware (Fig. 3).

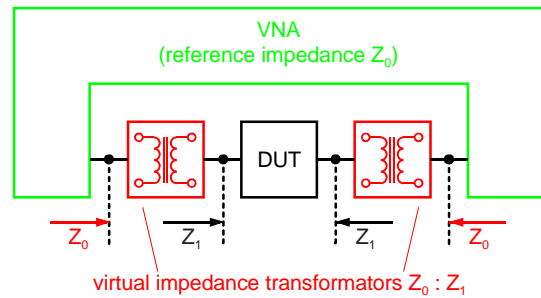


Fig. 3: Impedance transformation using virtual matching networks

Measurements of that kind are generally addressed as "embedding". Here, too, the EN must be a priori known.

It is also possible that the measurement of the EN, which is required as an auxiliary function for embedding and de-embedding, constitutes the very measurement task. This is called "unterminating". Generally, the transmission line types of inner and outer ports are different, so that this measurement problem cannot be solved with a conventional two-port network analyzer.

Software option ZVR-K9 adds the functions embedding, de-embedding and four-port EN measurement to a network analyzer ZVR or ZVC. A simple EN for demonstration of these functions consists of coaxial insertion adapters ZPV-Z1, which are connected to both ports of the DUT. Originally, these adapters were designed to accommodate probes of the vector voltmeter ZPV. Without a probe inserted, they exhibit resonances with more than 4 dB transmission loss and a reflection coefficient of 0.9 in the frequency range up to 4 GHz. The EN can be measured using the function *Measure Network* of ZVR-K9. In order to illustrate the *Embedding* function, some measured results of a through-connection, embedded in a physical EN as well as in a virtual one, are shown for comparison in Fig. 4.

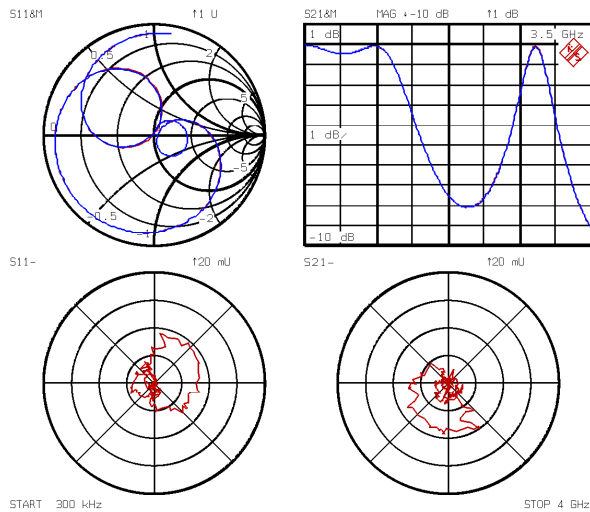


Fig. 4: Forward scattering parameters of a through-connection, embedded into two insertion adapters ZPV-Z1. Upper diagrams: traces with physical and with virtual EN. Below each diagram, the vector difference of the two curves.

The measured DUT, which consists of through-connection and EN, is essentially a series circuit of two ZPV-Z1. From the two upper diagrams the forward scattering parameters S_{11} and S_{21} can be seen. The traces measured with a physical EN and with a virtual one are almost perfectly congruent. Therefore their vector difference is shown below, respectively. Note the large magnification of the lower diagrams, which show that the values do not differ by more than 0.01 from each other.

For the measurement of non-coaxial DUTs some sort of test fixture is needed anyway. Thus a physically existing fixture for non-coaxial DUTs, which contains integrated transformation elements, cannot be completely replaced by a virtual EN. In such a case the task is to determine the EN as the "difference" between two fixtures. Software ZVR-K9 provides a solution to this task, too.

In addition to the measurement functions mentioned, ZVR-K9 offers the ability to read EN from external files stored in the output format of the CAD applications Serenade[®] (formerly Super-Compact[®]) and Series IV (formerly Touchstone[®]) or to export the S-parameters of measured EN in these formats.

Finally the software contains useful tools for the administration of the EN and of system error correction data.

3 THEORETICAL FUNDAMENTALS

The following chapter covers the fundamentals of the system theory the software option ZVR-K9 is based upon. However, those who are interested especially in applications may skip this chapter.

Embedding and de-embedding with ZVR software option K9 are founded on a modification of system error correction data. A real network analyzer can be thought of as consisting of an ideal analyzer and an EN that represents the system errors. Fig. 5 shows this model by means of a two-port network analyzer.

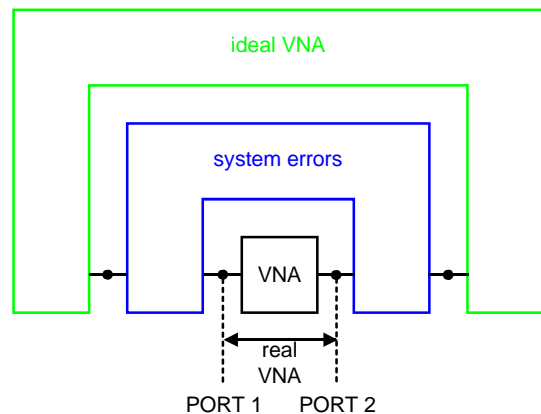


Fig. 5: Real network analyzer, separated into an ideal analyzer and a system error network.

Comparing Fig. 5 and Fig. 2, one recognizes that system error correction may also be understood as a de-embedding of a DUT that is embedded into the system error EN. The reference plane for the scattering parameters is shifted from the outer ports of the system error network to the inner ones. Conversely, this means that for de-embedding the same mathematical procedure may be applied as for system error correction. When system error correction is to be applied along with de-embedding, it is not necessary to pass through the correction algorithm twice. It is more advantageous to combine system error network and EN first, resulting in a modified system error network, and then to use these new parameters for correction calculations.

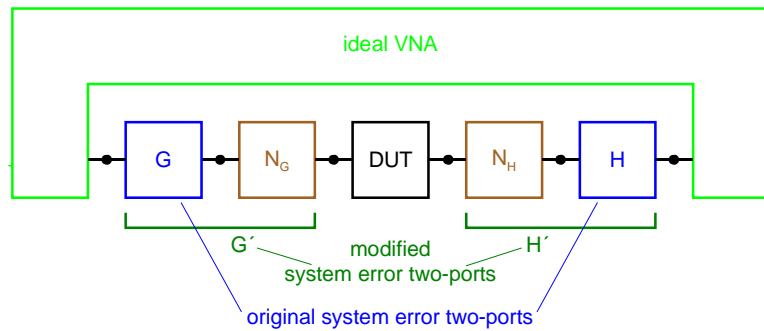


Fig. 6: De-embedding of a two-port DUT by modification of the 7-term system error two-ports

Software option ZVR-K9 allows the modification of system error correction data that have been recorded using one of the 7-term calibration procedures TOM, TRM TRL or TNA. Therefore, it can only be run on network analyzer models ZVR and ZVC, since they are the only ones that have 7-term calibration procedures implemented. In contrast to the general error model of Fig. 5, the 7-term error model does not take crosstalk errors between the test ports into account. This restriction, however, does not compromise measurement accuracy for nearly all coaxial and for many non-coaxial DUTs. Fig. 6 shows the de-embedding of a two-port DUT using 7-term correction. The general system error four-port is reduced to two two-ports G and H , the transformation network consists of the two-ports N_G and N_H . The modified system error two-port G' is created by the series connection of G and N_G , H and N_H are combined resulting in H' .

Embedding is the inverse procedure of de-embedding. Therefore the assumption is near at hand that the modified system error correction data consist of the original data plus the inverse EN. This can be regarded as if a neutral network, consisting of the desired EN and its inverse, was inserted at the test ports of Fig. 5. As shown in Fig. 7, EN and DUT are combined to form a new DUT, and the addition of original system error correction data and inverse EN results in modified correction data.

The unterminating problem with different connec-

tor types (or more general: with different modes) at inner and outer ports is also resolved in ZVR-K9 by means of system error calibrations. Here it has to be assumed that the connectors of the inner and outer ports are of the same type. The system error EN G' and H' are the result of a calibration performed on the inner ports, whereas G and H stem from the outer ones (Fig. 6). Now one can calculate the desired partial EN N_G and N_H by "subtracting" the outer error two-ports G and H from the inner G' and H' . In this context "subtraction" is only used for reasons of illustration. Actually some matrix calculations are carried out.

As mentioned earlier, ZVR-K9 is based upon 7-term calibration methods. Since an unambiguous description of the two system error two-ports would require 8 terms, the individual transmission factors of N_G and N_H remain indefinite. This is not important for embedding and de-embedding, because here just the invariable products of two transmission factors enter into the final result. Unambiguous unterminating requires additional conditions, e.g. reciprocity, for the transmission of the two-ports to be known.

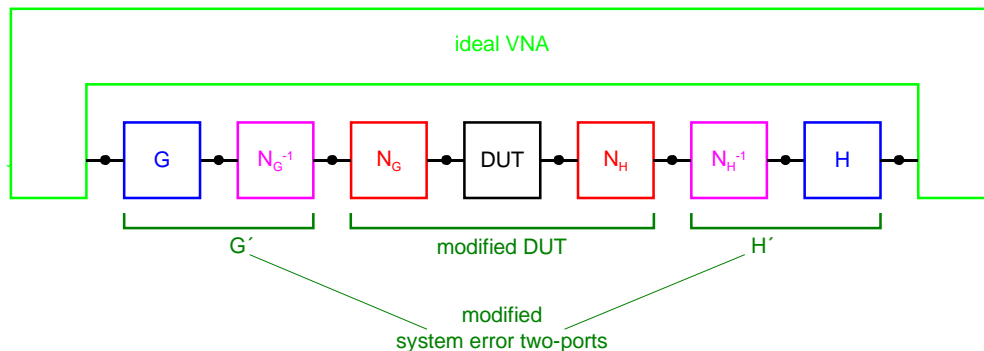


Fig. 7: Embedding of a two-port DUT by modification of the 7-term system error two-ports

4 APPLICATION EXAMPLES

4.1 SAW FILTER TEST FIXTURE

The first application example is a test fixture for surface acoustic wave (SAW) filters with an integrated impedance matching network. This fixture is to be replaced by a simplified version without matching components. Through this measure, one can reduce the measurement uncertainty caused by spread, temperature dependence and aging of the matching elements (resistors, coils and capacitors). If, in a production environment, there are several test fixtures with equal pinout, but different matching networks, these can be replaced by a combination of a standard fixture with different virtual EN. Thus the expenditure in handling different fixtures is significantly reduced.

The simple fixture must provide an electrical connection between the coaxial test cables of the network analyzer and the contacts of the filter's SMD case. Fig. 8 shows the system model. Since in the application circuit the SAW filter is always

tual network must be thought of as separated from the simple test fixture and connected to its outer ports.

ZVR-K9 can determine the virtual network via the function *Measure Network: Indirect Measurement*. For that, three 7-term calibrations must be performed: One at the coaxial reference plane and one at the inner ports of the original test fixture and of the simplified fixture. The latter two calibrations require special standards that must be pin compatible to the SAW filters. For the inner calibrations, it is recommended to choose a procedure with not fully known standards, since these are easier to manufacture. For the determination of the network that represents the difference between the test fixtures it is not important whether the standards are in the same case as the filter. In both test fixtures, however, the same standards must be used. Note that for de-embedding problems this point is quite important: If standards with well-known characteristics, which can be entered via *Modify Calkit*, are inserted into a case corresponding to the DUT, then the reference plane

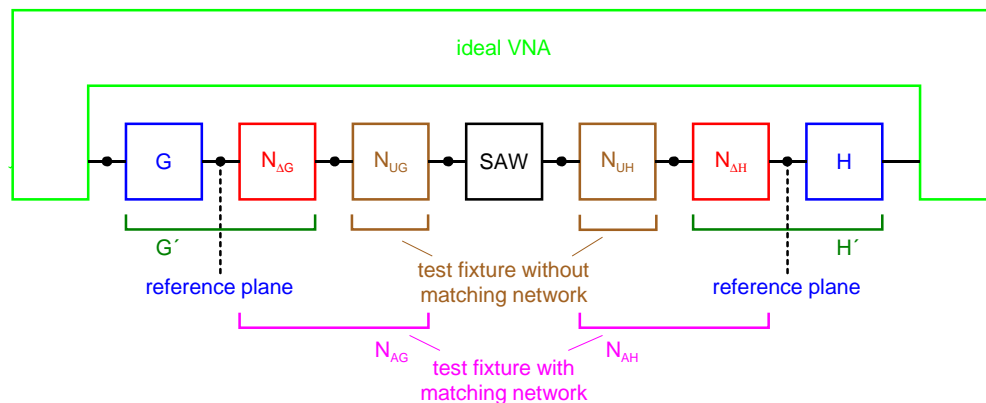


Fig. 8: Test fixture for SAW filters with a virtual matching network: system model

operated together with matching elements, its specifications also refer to this case. The reference plane of the S-parameters to be measured is located in the coaxial connectors of the test cables. So the complete DUT consists of the SAW filter and the embedding test fixture with matching network (N_{AG} and N_{AH}). As shown in chapter 3 the real two-port network analyzer can be represented by an ideal analyzer and the system error two-ports G and H . Now the problem is to find a virtual EN, consisting of N_{AG} and N_{AH} , which exhibits, in combination with the simplified fixture N_{UG} and N_{UH} , the same electrical behaviour as the matched test fixture (N_{AG} , N_{AH}). In this interconnection model the virtual network must be arranged at the outer (coaxial) ports of the test fixture, in order to allow for its inclusion into the system error correction data during embedding. Note that such a virtual network is generally not electrically equivalent to the real matching circuit. The latter is integrated anywhere inside the test fixture, whereas the vir-

after de-embedding is at the inner ports of the case. If, however, the standards are without case, the s-parameters after de-embedding refer to the outer case ports.

The calibration standards shown in Fig. 9 were manufactured in thin-film technology on ceramic substrates and are pin-compatible to a surface-mountable SAW filter. At the upper left one can see the bottom side of a substrate with its contact pads, where the upper and the lower contact pair each form a port. The vias leading to the top side can also be seen.

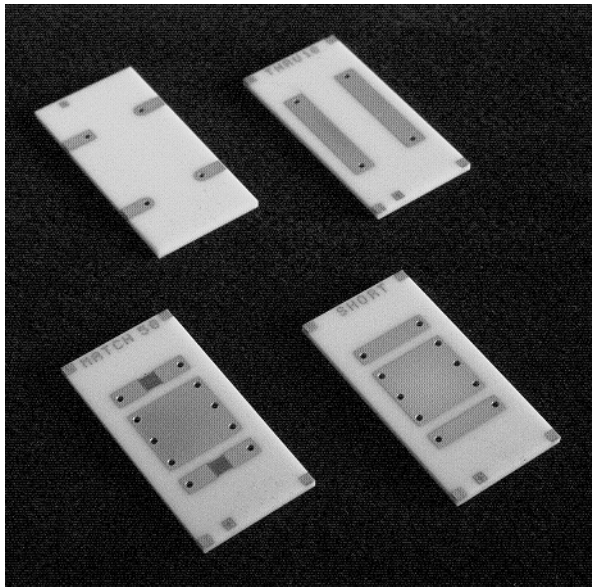


Fig. 9: TRM / TNA calibration standards for SAW filter

The THROUGH connection (above at the right) has been designed as a coplanar stripline with a characteristic impedance of $50\ \Omega$. Below left there is a $50\ \Omega$ double MATCH, which can also be used as an ATTENUATION, and below right a double SHORT, which may also serve as a double REFLECT or a NETWORK. The central ground area reduces crosstalk. With these standards a TRM- (THROUGH-REFLECT-MATCH) or TNA- (THROUGH-NETWORK-ATTENUATION) calibration can be performed.

Fig. 10 shows the corresponding measured results. In the upper two diagrams the forward parameters S_{11} and S_{21} of the filter can be seen. They were measured in the original test fixture as well as in the simplified version with a virtual embedding network. Again, the traces are practically identical, despite the 100 times magnification of the S_{11} diagram and the large overall attenuation of more than 40 dB. Also in the two lower diagrams measurements with both fixtures are depicted, but for the simplified fixture no virtual EN was included into the coaxial system error correction data. So one can see how the SAW filter behaves without EN (reflection: trace with marker 2, transmission: upper trace). The difference with respect to the traces of the original test fixture illustrates the strong transformation effect and the high attenuation of the matching circuit.

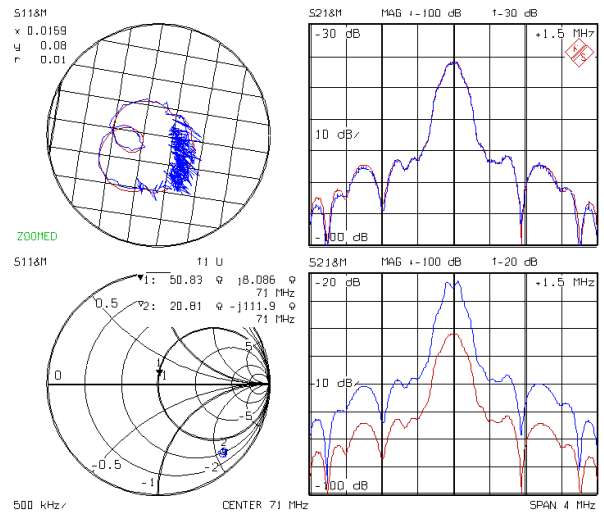


Fig. 10: Forward S-parameters of the SAW filter:
 upper diagrams: original test fixture with coaxial calibration, simplified fixture with virtual EN
 lower diagrams: both fixtures with coaxial calibration

4.2 SHIFTING THE REFERENCE PLANE AFTER AN AUTOMATIC CALIBRATION

Virtual EN may also be used to shift the reference plane of system error calibration. With option ZVR-B1, for example, a measurement setup can be calibrated at a plane that is located on the test port side of the automatic transfer standard (AutoKal box). If the transfer standard is subsequently removed, the reference plane must be shifted to the ports of the ZVR, which are then accessible (Fig. 11).

In this case, the EN consists of the two two-ports N_G and N_H , which are situated between the original and the new reference planes. Via the ZVR-K9 function *Measure Network (Direct Measurement)*, this network can be determined from the difference between two coaxial calibrations. In the next step an automatic calibration (AutoKal) is performed in the usual way. The AutoKal procedure that has been implemented in ZVR and ZVC is a 7-term procedure, therefore an EN can basically be included in the correction data.

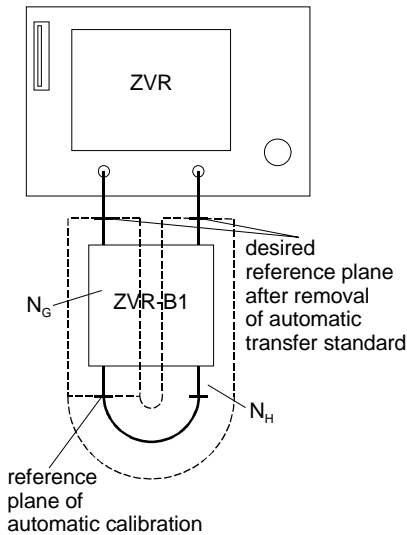


Fig. 11: Shifting the reference plane after an automatic calibration

The question arises, however, whether the embedding or the de-embedding procedure need to be applied here. This can be answered by means of the model shown in Fig. 12. For simplicity, only one half is depicted, which belongs to PORT 1. At port 2 the situation is mirror-imaged.

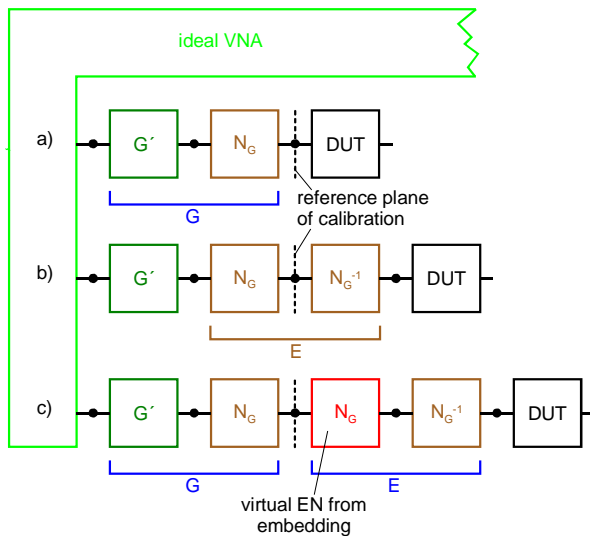


Fig. 12: Compensation of the automatic transfer standard
 a) situation after an automatic calibration
 b) transfer standard removed
 c) embedding into virtual transfer standard

After an automatic calibration one faces situation a): The system error two-port G comprises the internal errors G' of the network analyzer as well as the part N_G of the automatic transfer standard that is related to PORT 1. In order to maintain the calibrated measurement plane, the removal of the transfer standard is modelled in b) by embedding the DUT into a virtual EN N_G^{-1} that cancels N_G . In step c) this virtual network is compensated by

embedding it into another virtual network N_G introduced by the ZVR-K9 software. With respect to the (unchanged) reference plane, the original DUT is obtained again, since the new N_G and N_G^{-1} complement each other to the neutral unity network E .

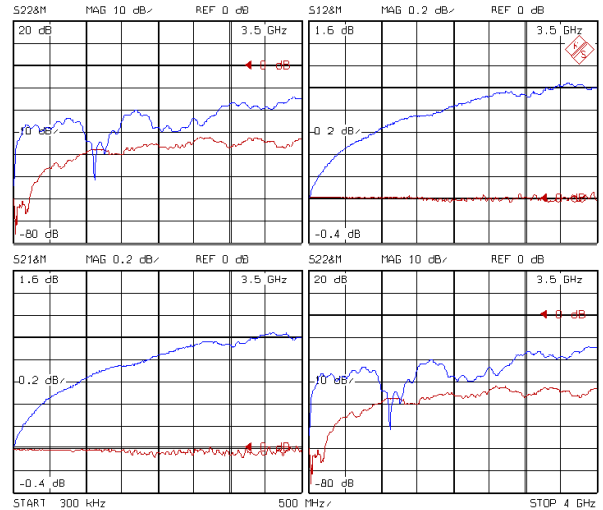


Fig. 13: S-parameters of a through-connection after an automatic calibration and the removal of the transfer standard. In all four diagrams, the upper traces represent the result before, the lower ones after the embedding of the transfer standard

Fig. 13 shows the S-parameters of a through-connection after the removal of the automatic transfer standard. The upper curves were measured without modifying the automatically taken system error correction data, the lower ones after introducing the transfer standard as a virtual embedding network. Without virtual compensation, the through seems to have 1 dB gain. This is because the correction data still take the attenuation of the transfer standard into account, which is no longer connected. Furthermore, the effective test port match reduces to 15 dB at 4 GHz. With virtual embedding, the transmission loss is again 0 dB, test port match improves to more than 30 dB.

Shifting the reference plane can be advantageously applied in multipoint measurements, too. The measurement setup of Fig. 14 is intended for the fully error-corrected measurement of three-port devices using a two-port network analyzer. Both test ports of the network analyzer are connected through to two of the three test ports of the test switch matrix. The ports of the test switch matrix that are not connected through must be matched by the actual S-parameter reference impedance.

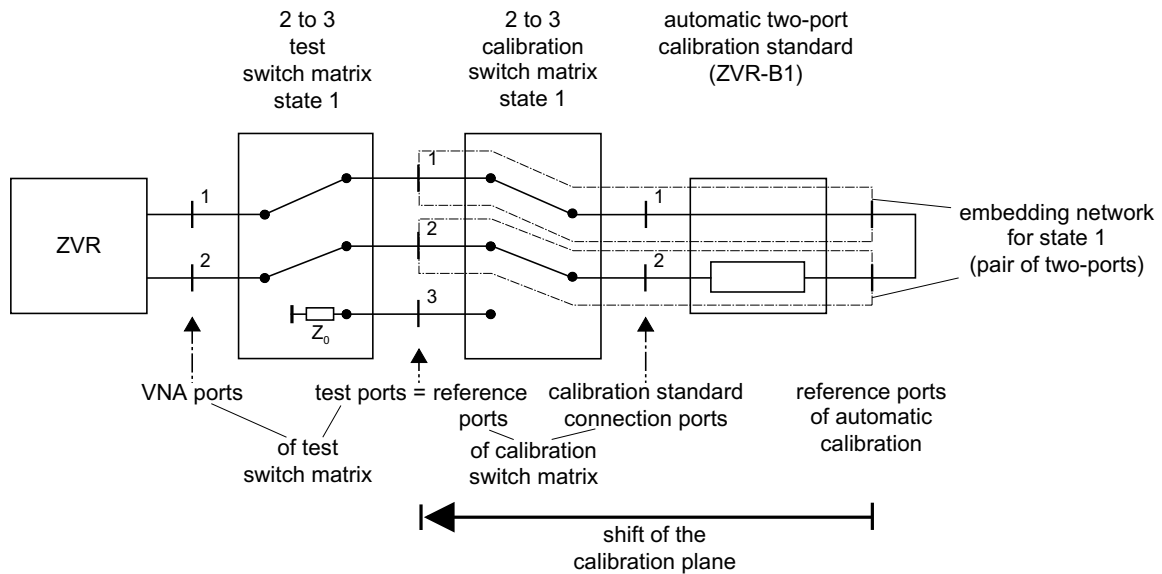


Fig. 14: Shift of the calibration plane after an automatic calibration, applied to a three-port measurement

In order to calibrate the three-port analyzer, made up of the two-port analyzer and the test switch matrix, a setup that consists of a calibration switch matrix (identical to the test switch matrix) and an automatic two-port transfer standard ZVR-B1 is used. The switching state of the calibration switch matrix is always equal to that of the test switch matrix, so the ports of the network analyzer are in all switching states connected to the automatic transfer standard.

It must be guaranteed that in all three switching states of the matrices individual system error correction data are applied. The most simple way to accomplish this is to decouple the display channels in a quad channel display and to control the switching matrices via the channel-dependent TTL signals on the MULTIPORT ADAPTER rear-panel connector of the ZVR and an appropriate logic circuit. This connector is part of the options ZVR-B8 (three-port adapter) and ZVR-B14 (four-port adapter).

For measuring all 9 scattering parameters of a three-port it is necessary to determine the two-port S-parameters in three different states of the switching matrices. This implies that each reflection factor is measured twice. To be able to shift the reference plane from the output of the transfer standard to the input of the calibration switch matrix, the corresponding EN of each switching state must be determined first. This is accomplished as before by means of calibrations at the inner (output of the transfer standard) and outer (input of the calibration switch matrix) EN ports.

Then for each switching state of the setup of Fig. 14 an automatic calibration must be performed. After that, the calibration switch matrix and the

transfer standard can be removed. Finally, the three previously determined EN are included in the pertinent correction data file via the embedding procedure. Now the three-port network analyzer is calibrated with respect to the three ports of the test switch matrix.

This procedure can be generalized for n-port measurements. If more than four switching states are necessary, control of the switching matrices and management of the correction data files must be performed by a DOS or Windows® application running on the ZVR or on an external computer.

4.3 MEASUREMENT OF A TRANSITION FROM PRINTED CIRCUIT BOARD TO CERAMIC SUBSTRATE

In the applications of ZVR-K9 hitherto presented the measurement of the EN was a subtask. But, like in the following example, it may also be the very measuring problem to determine and display the S-parameters of the EN.

In modern microwave circuits, it is endeavoured to use more and more planar transmission lines without coaxial interfaces. For example several microwave modules that have been designed on ceramic substrates could be integrated as an assembly on one epoxy carrier board, which only contains RF lines and low frequency circuits. The RF transitions from the printed circuit board to the ceramic substrates should exhibit as low reflection and attenuation as possible.

If the transition is regarded as an EN, it can be determined by means of an "outer" calibration on the circuit board and an "inner" one on the ce-

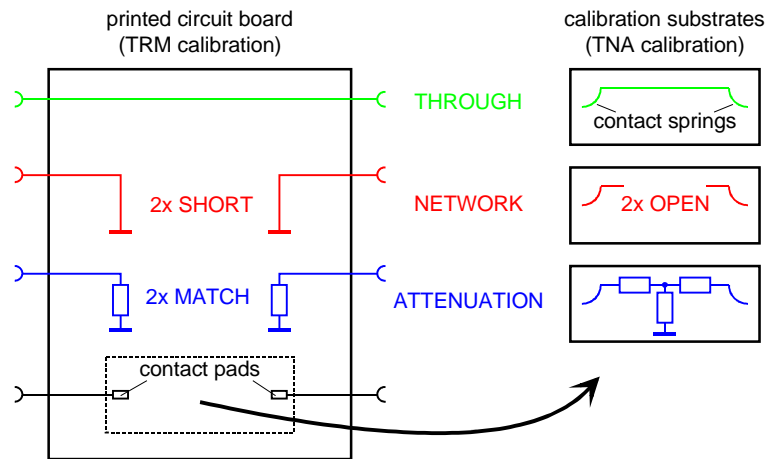


Fig. 15: Calibration standards for the measurement of a transition from printed circuit board to ceramic substrate

ramic substrate. It is convenient to calibrate using the TRM or TNA procedure.

The calibration standards that have been manufactured for such a measurement are shown schematically in Fig. 15.

By means of the command *Measure Network*, the S-parameters of the transition can be determined and saved as an EN. To make them visible, the network can be exported in a CAD data bank format and imported into the appropriate CAD software as a black box element. Fig. 16 shows the measured S-parameters of a transition from an epoxy board to a ceramic substrate.

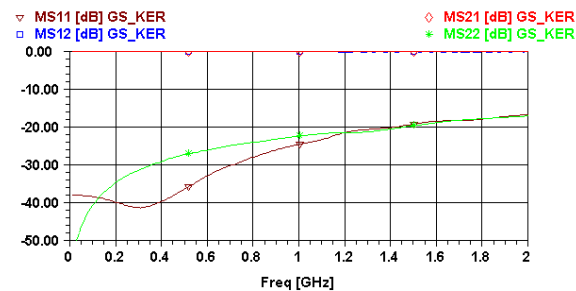


Fig. 16: S-parameters of a transition from epoxy board to ceramic substrate

With the aid of the CAD program, of course, it is then also possible to investigate the behaviour of the transition in a simulated circuit environment or to fit a model to the measured data by optimizing the parameters.

If desired, this model can be reimported as a virtual EN into ZVR-K9.

4.4 IMPORT AND EXPORT OF A TRANSFORMATION NETWORK

Virtual EN need not necessarily be derived from real existing EN by measurement, like in the preceding examples. One can also work with hypothetical networks, the S-parameters of which have been calculated by a CAD program. For this purpose ZVR-K9 offers the possibility of importing four-port scattering parameters in the data bank output formats of the CAD applications Serenade® (Super Compact) from Ansoft and Series IV® (Touchstone) from HP-EEsof.

The 8th order Butterworth bandpass shown in Fig. 17 was dimensioned for a passband range from 1.2 GHz to 1.5 GHz. This filter represents the two-port N_G of an EN according to Fig. 18.

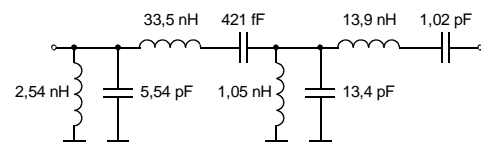


Fig. 17: Butterworth bandpass filter 1.2 GHz to 1.5 GHz

N_H is a through-connection. The four-port scattering parameters of this EN have been calculated with Serenade® and saved as a *.flp file. As a demonstration example (*getstart.flp*), this file is contained in the ZVR-K9 software package. Note that the port numbering must be according to Fig. 18, in order to ensure that the data are correctly interpreted by ZVR-K9.

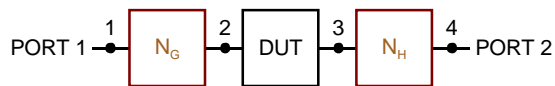


Fig. 18: Numbering of the four EN ports for data import

The *Import File* instruction in the *File* menu reads a *.flp file (or a *.s4p file in HP-EEsof format) and saves it as a virtual EN. The frequency point grid must be linear or logarithmic, which is checked during import. All valid frequency units and data formats are accepted, like real and imaginary, linear magnitude and phase, dB magnitude and phase. A comment may be attached to the EN, it appears later in the list of the saved EN.

Fig. 19 shows the measured scattering parameters of a through-connection that has been embedded into the virtual bandpass EN described above. So one gets the scattering parameters of the filter, which correspond to those of the CAD simulation.

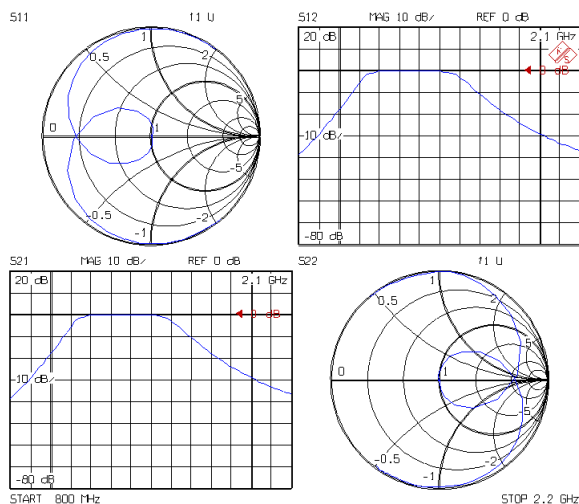


Fig. 19: S-parameters of a through-connection embedded into a virtual bandpass filter

All EN saved by ZVR-K9 can be exported as a *.flp or *.s4p file. Here, too, all data formats that are valid for the chosen file type may be selected. Exporting a measured EN makes sense, for example, if minor modifications or tuning can be more easily performed on the virtual EN than on the real one. Finally the modified EN must be re-imported back into ZVR-K9.

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23 September 1998

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- [11] O. Ostwald: Group and Phase Delay Measurements with Vector Network Analyzer ZVR, Appl. Note 1EZ35_1E.
- [12] O. Ostwald: Multiport Measurements using Vector Network Analyzer, Appl. Note 1EZ37_1E.
- [13] O. Ostwald: Frequently Asked Questions about Vector Network Analyzer ZVR, Appl. Note 1EZ38_3E.
- [14] A. Gleißner: Internal Data Transfer between Windows 3.1 / Excel and Vector Network Analyzer ZVR, Appl. Note 1EZ39_1E.
- [15] A. Gleißner: Power Calibration of Vector Network Analyzer ZVR, Appl. Note 1EZ41_2E
- [16] O. Ostwald: Pulsed Measurements on GSM Amplifier SMD ICs with Vector Analyzer ZVR, Appl. Note 1EZ42_1E.
- [17] O. Ostwald: Time Domain Measurements using Vector Network Analyzer ZVR, Appl. Note 1EZ44_1E.

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.