# Frequently Asked Questions about Vector Network Analyzer ZVR

Application Note 1EZ38_3E

Subject to change

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Products:

**ZVR**

**ZVRE**

**ZVRL**

ROHDE&SCHWARZ

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# Frequently asked questions…

# …on measurements with the analyzer:

### 1. Can frequency range, the number of test points or the measurement bandwidth be varied without the calibration being lost?

Yes. Vector Network Analyzers ZVR and ZVRL allow to vary the **measurement bandwidth (IFBW) any time** without the calibration becoming invalid, as the measurements will be carried out at the same frequency points at which the calibration was performed. The CAL enhancement label signals that the calibration is valid. By the way, during calibration the bandwidth is automatically reduced to 1 kHz when a larger bandwidth was used before. This reduces the effect of noise without affecting the calibration speed. After termination of the calibration the original IF bandwidth is automatically restored.

By contrast, **changing the frequency range or the number of measurement points** means in most cases that the analyzer measures at other than the calibrated frequencies. In this case **calibration data have to be interpolated**. This can be done by selecting the CAL INTERPOL function. Measurements can then be carried out in any subrange within the previously calibrated frequency range and with any number of measurement points. Of course, calibration cannot be extrapolated to ranges outside the previously calibrated range. To identify calibration interpolation the enhancement label changes from CAL to CAI.

### 2. What is the maximum IF bandwidth?

The maximum selectable measurement bandwidth **is 26.5 kHz**. It may be reduced from 10 kHz to 1 Hz in half-decade steps. After PRESET the IF bandwidth is 10 kHz so that a high measurement speed is ensured. Even in the case of large bandwidths the dynamic range is more than 80 dB.

### 3. What about aging and temperature drift?

The stability and reproducibility of measurements is a key feature of all quality network analyzers. In the development of the ZVR network analyzer family particular emphasis was placed on these characteristics and a number of measures concerning concept, construction and electrical characteristics were taken to reduce temperature drift to a minimum. This also applies to the ventilation used which ensures a uniform temperature in all receiver channels particularly for critical modules such as the front end. In addition, scattering parameters are always derived from the vector ratio of measurement-channel and reference-channel parameters, the RF cabling in the analyzer test set being such that the measurement and reference channels have the same electrical length. Phase variations caused by temperature drift are compensated for by the calculation of vector ratios. Moreover, a thin coaxial compensation line for the reference channels is provided together with the balun which is housed in SWR bridges. The coaxial cable for the baluns and the compensation lines in the two bridges are taken from the same cable. This ist the reason why the SWR bridges for ZVRE and ZVR can only be ordered in pairs.

Furthermore, all instruments are subjected to **pre-aging** in the test shop to minimize the drift. Due to these measures, it is sufficient to calibrate only once as long as the test setup is not changed whatever the application. A calibration is typically valid for months. For instance, after normalization, switching off and complete cooling down the analyzer and **switching the cold unit on again** a few minutes later typical values for analyzer **stability** are **<0.02 dB** and **<0.5°** for transmission measurements**.** For reflection measurements the **stability of the effective directivity** is **typically >60 dB.** With higher stability requirements, it is advisable to give the instrument one hour to warm up. After that time the typical difference to a measurement the day before with the instrument switched off overnight is <0.005 dB, and <0.1°. If higher stability is required, the network analyzer should be operated under constant ambient conditions in an air-conditioned room and after a warm-up of at least two hours. For the most stringent requirements it is necessary to carry out a calibration immediately before each measurement. In all other cases, previously determined calibration data sets can be used as long as the test setup is not significantly changed.

## 4. How can PCBs be tested up to around 2 GHz?

There are different solutions to this problem, depending on whether the measurements are carried out in 50 Ω or 75 Ω systems or whether a high-impedance measurement is required. With low-impedance measurements on a few interfaces only, PCBs may be fitted into **test fixtures**. The inner conductor and the ground line of the normally planar, in many cases microstrip or coplanar connectors of the PCB are contacted by the test fixture and the coaxial connector of the network analyzer is connected via an adapter. If PCB interfaces cannot be contacted in this way, eg because they are not located at the edge of the board but somewhere inside, special test adapters with suitable **coaxial probes** for contacting the testpoints may be used. For high-impedance measurements, special **high-impedance RF probes** are available. They comprise a sensitive RF preamplifier and may be connected to any point of the DUT. The advantage is that the DUT is virtually unloaded, ie the voltages measured are the same as with no high-impedance probe connected. The operating voltage for the RF preamplifier can be supplied from the network analyzer. To this end two connectors PROBE 1 and PROBE 2 are provided on the front panel of ZVR to which commercial RF probes can be connected.

## 5. Can balanced-to-ground measurements up to 100 MHz be carried out with the ZVR?

This depends on the available test adapter and particularly on the **balun** which is required as an external component for transforming the applied balanced signals into unbalanced signals. Thus basically all network analyzers of the ZVR family are able to carry out balanced measurements in the full frequency range up to 4 GHz. The ultra wideband balun used in the internal SWR bridges of the passive test set comprises three pairs of ferrite-core circuits and covers the frequency range from 9 kHz to 4 GHz. Baluns for instance for the **frequency range 10 kHz to 125 MHz** are commercially available.

## 6. Is it also possible to measure very low impedances below 1 Ω?

Yes, and in this case a simple normalization calibration is generally sufficient, where the DUT is replaced by a short. Thanks to its excellent basic characteristics (test port matching etc.) and thermal stability, Network Analyzer ZVR is able to measure impedances near 0 Ω with an impressive accuracy. For instance, a **560 mΩ mini-resistor** was measured up to 100 MHz with an **uncertainty of typically less than 40 mΩ.** With the aid of more suitable calibration techniques like TRM the measurement accuracy can be further improved. For measurements at high frequencies it is very important for the electrical length of the DUT to be taken into account to avoid phase shift of the reflection coefficient which increases the impedance of the DUT.

## 7. How much faster is Network Analyzer ZVR than other analyzers in surface acoustic wave (SAW) filter measurement?

The measurement speed of any network analyzer is limited by the chosen measurement bandwidth (IF bandwidth). The measurement bandwidth is determined by the internal IF filter used for filtering the test signal that has been down-converted in the receiver. Same as in most state-of-the-art network analyzers, this filter is digitally realized in ZVR with the aid of a digital signal processor (DSP). The narrower the selected IF bandwidth, the lower the effect of noise and the greater the dynamic range but also the longer the measurement time. The latter corresponds to approx. the reciprocal of the measurement bandwidth irrespective of whether an analog or a digital filter is used. The speed can be slightly improved at the expense of the filter quality. Conversely, extremely steep-edged IF filters with high stop-band attenuation lengthen the measurement time.

An advantage of Network Analyzer ZVR is that it allows wider measurement bandwidths to be used. The maximum IF bandwidth setting "Full" in analyzers of the ZVR family is 26.5 kHz, that of other network analyzers is 3 kHz. Thanks to the wider bandwidth in conjunction with a slightly more speed-optimized IF filter characteristic of the ZVR, the measurement speed of the ZVR is somewhat more than 10 times higher compared to other analyzers.

ZVR also offers a special measurement mode, the "fast mode" with reduced dynamic range and accuracy. This mode allows less time for the settling of the internal generator and receiver, and does not switch the internal IF amplifiers in front of the A/D converters. This speeds up the measurement again by a factor of 1.5

However, the minimum settling time of the DUT must always be taken into account. For example, measuring a narrowband crystal filter at the highest measurement speed is not useful since the filter is not able to settle within the brief period of the stimulus signal which can be seen at times as a tilting of the trace. This problem can be solved with the aid of a special characteristic of the ZVR, ie by linking two measurements. In one measurement the test frequency is swept as usual from low to high frequencies (forward sweep) and in the second the sweep direction is reversed (reverse sweep). The sum of the two fast measurements is approximately the result that would be obtained in a sufficiently slow sweep.

For SAW filters these limitations are mostly not observed. In this case the full measurement speed of ZVR can be utilized which **is approximately 15 times greater in the fastest mode** than that of comparable network analyzers.

## 8. What possibilities and references are available for component tests?

**Suitable adapters** play a key role in the testing of components not provided with common coaxial connectors. The range of test adapters is as wide as the variety of components. R&S supports the user in many ways in the selection of suitable adapters for components tests and **optimum calibration and measurement procedures.** Thus tailor-made adapters can be fabricated for the components to be tested and suitable references or calibration standards can be implemented for the customer. Many application problems can be elegantly solved with the aid of the highly suitable R&S calibration procedure TNA which comes as standard for all four-channel network analyzers ZVR. In addition, the new Virtual Embedding Networks ZVR-K9 for which a patent is pending, allows component tests to be carried out without the use of matching networks whose production, maintenance and variety often prove to be problematical. The matching networks are replaced by a sophisticated numerical technique as part of the system error correction which has to be carried out in any case (see questions on virtual transformation networks, page 10).

## 9. How can the advantages of the VXI bus be utilized for the DC control circuits in the system?

Network analyzers of the ZVR family **are not able to** control system components via the VXI bus. Conversely, the network analyzer cannot be controlled via the VXI bus. For system application of any kind the IEC/IEEE bus is recommended. Of course, IEC/IEEE-bus-compatible DC voltage sources may also be controlled via this bus.

Network analyzers ZVR may comprise up to **three independent IEC/IEEE-bus interfaces,** one being standard equipment for universal applications. The second, the so-called system bus, serves for fast control of external generators as may be required, for instance, as local oscillators for measurements on frequency-converting DUTs, with the ZVR acting as a system controller. The third (optional) IEC/IEEE-bus interface is used in conjunction with the Computer Function Option ZVR-B15 for controlling any test setups by the PC-compatible computer in the ZVR.

## 10. What happens to the open path in three-port operation?

When the 3-Port Adapter Option ZVR-B8 is used, PORT1 of the network analyzer is extended to two ports, ie PORT1 and PORT3 by means of an electronic FET switch (SPDT). This allows seven of the altogether nine S-parameters of an arbitrary three-port DUT to be directly measured. Controlled by the network analyzer the measurement path from PORT1 to PORT2 or the path from PORT3 to PORT2 are alternately switched on. The unused port of the open path is **terminated with a low-reflection** 50 Ω resistor integrated in the 3-Port Adapter.

The following Application Notes are available for further information on three-port measurements: 3-Port Measurements (1EZ26_0E) and Multiport Measurements using Vector Network Analyzer ZVR (1EZ37_0E).

## 11. Can also 4-port measurements be performed?

This can be done in several ways. A direct solution is by using the optional 4-Port Adapter ZVR-B14. This adapter comprises two electronic switches and thus extends the two ports PORT1 and PORT2 of the network analyzer to a total of four ports PORT1 to PORT4. These ports are then activated in pairs depending on the network analyzer channel currently active so that different transmissions and all reflections of a 4-port DUT can be determined.

The 4-port adapter is available in two different models, ie .02 and .03. The first model has two single pole double throw switches (2 x SPDT) and is thus especially suitable for DUTs with two inputs and two outputs such as directional couplers or double pole double throw switches (DPDT). The following S-parameters of the DUT can be determined: **S11, S22, S33, S44, S21, S12, S32, S23, S41, S14, S43 and S34.**

The second model on the contrary has a single pole triple throw switch (SP3T) and is more suitable for DUTs with one input and three outputs or vice versa such as filter banks or power dividers. It allows the measurement of the following 4-port S-parameters: **S11, S22, S33, S44, S21, S12, S31, S13, S41 and S14.**

Application Note Multiport Measurements using Vector Network Analyzer ZVR (1EZ37_0E) provides further detailed information.

An alternative solution is to operate two 3-Port Adapters ZVR-B8 together at the optional MULTIPORT ADAPTER socket on the rear panel using a simple Y cable, PORT1 and PORT2 of the network analyzer are then extended to two ports each. The second 3-Port Adapter is configured so that it does not switch synchronously to the even or odd channels as usual, but is in the setting PORT1 for channels CH1 and CH2 and setting PORT3 for channels CH3 and CH4. The 4-port DUT is now connected to the four available ports. Depending on the selected channels CH1 to CH4, **the 4-port S-parameters S31, S13, S32, S23, S41, S14, S42 and S24** can be measured like with model .02 of the 4-port adapter in addition to transmission S-parameters **S21** and **S12** and all reflection coefficients **S11 to S44**.

Application Note Multiport Measurements (1EZ37_0E) mentioned above provides further detailed information.

Another way of carrying out 4-port measurements is to use the Extra Inputs 4-Port Option ZVR-B26. The two optional inputs INPUT b1 and INPUT b2 are used as PORT3 and PORT4 supplementing the test ports PORT1 and PORT2. Fast switchover between the four ports is ensured by two additional electronic switches integrated in the test set. This configuration permits the **4-port S-parameters S11, S22, S21, S12, S31, S32, S41 and S42** to be measured without the need for 3-port or 4-port adapters. Application Notes 4-Port Measurements (1EZ25_0E) and Multiport Measurements (1EZ37_0E) provide further information on this solution.

# …regarding calibration:

## 12. Is full system error correction also valid in the case of 4-port measurements?

The mathematical routines implemented in the analyzers of the ZVR family for system error correction apply to 1-port and 2-port measurements. They are based on different, partly simplified models (normalization, One Path Two Port, TOSM, TOM, TNA, etc.) through to the full model (TOM-X), which detects and numerically eliminates any coupling between the two measurement channels and the reference channels.

Because of the enormous amount of calculations involved, full models are **not** implemented at present **for 3-port and 4-port measurements.** Simplified models are used instead. For instance, in the case of 3-port measurements, a full 2-port calibration is performed for each of the two available paths, PORT1 to PORT2 and PORT3 to PORT2.

If 4-port measurements are performed with the aid of two 3-Port Adapters ZVR-B8 or one 4-Port Adapter ZVR-B14, up to four separate 2-port calibrations can be carried out. If 4-port DUTs are measured with the aid of the modified Extra Input 4-Port Option ZVR-B26, full 2-port calibration is only possible for PORT1 and PORT2 and a simple normalization calibration is carried out for the paths to PORT3 and to PORT4.

## 13. Are calibration data lost when the instrument is switched off?

**No**. After a calibration, **the calibration data are stored** automatically on the internal hard disk **and activated when the instrument is switched on again.** In addition, the user may store any calibration data on the hard disk or on floppies to be able to call them up later to suit the test setup used. The only limitation on the number of calibration records that can be stored is the memory size of the disks.

## 14. Can a DUT be used for calibration?

A DUT may be used instead of a calibration standard for normalizing the test setup. The characteristics of all subsequently measured DUTs are then compared with this **golden device** which is used as a reference**.** This procedure corresponds to a normalization calibration, eg transmission normalization with a through-connection selected in the CAL menu of the network analyzer. This procedure is ideal for the determination of the identity of two DUTs. However, due to the non-specified measurement accuracy it should not be used for accurate quantitative measurements of the differences of two DUTs.

## 15. Have any measurements been made with this calibration?

Measurements with a golden device being used as a reference have been carried out with the ZVR **frequently and without any problems.** For such measurements, the reference DUT, eg a bandpass filter, is connected first and then the filter to be measured or adjusted is connected to the same terminals. This allows the characteristics of the two DUTs to be compared. An interesting variation is the use of two synchronously switched 3-Port Adapters ZVR-B8 or a 4-Port Adapter ZVR-B14. They permit the reference device and the DUT to be measured simultaneously which considerably simplifies a comparison of temperature and drift effects.

## 16. Why are there no points in the Smith chart on reconnecting the OPEN or SHORT after calibration?

For measurements with **SHORTs** the calibrated network analyzer does not display a short point (r = -1) in the Smith chart as might be expected. A trace is shown instead which, at low frequencies, starts at the short circuit point and, at high frequencies, runs along the unity circle of the Smith chart and passes, starting from 180°, phase values up to 35° at 4 GHz, for instance and thus comes even close to the open circuit point (r = +1).

This behaviour is fully correct and can be explained by the **electrical length** of the SHORT. For reasons of mechanical design the short plane is generally not in the reference plane, which is defined by the outer edge of the outer conductor, but 15.1 mm behind the reference plane as is the case for the standards of Calibration Kit ZV-Z21. Since the network analyzer measures and displays the reflection coefficient referred to the reference plane, the correct reflection coefficient of the SHORT is displayed that is obtained by transformation of its short plane via a 15.1 mm line that is connected ahead. If another SHORT with a different electrical length between its short plane and the reference plane is measured instead of the calibration short as DUT, the analyzer indicates its reflection coefficient correctly as expected from a correctly measuring network analyzer. With a long length between the short plane and the reference plane, the open circuit point is passed. This is exactly the case for the frequency at which the electrical length of the standard is a quarter of the wavelength. If the length of the standard is 0 however, the expected short circuit point is obtained in the Smith chart over the complete span.

Since such a short of the length 0 is normally not available (an exception is the calibration standard SHORT (F) of Calibration Kit ZCAN), a circular arc rather than a point is usually obtained whose length is determined by the product of the frequency range (SPAN) and the electrical length of the calibration standard (LENGTH).

The position of the reference plane can be mathematically shifted after calibration with the aid of operating function OFFSET. With the length of the standard selected as offset, ie 15.1 mm as used in the example (ELECTRICAL LENGTH), the network analyzer indicates the measured phase in the short plane of the standard. This phase is accurately 180° and the measured curve lies at the short circuit point of the Smith chart.

Similar conditions apply to **OPENs** but a further effect occurs: the so-called fringing capacitance of the open line end. In contrast to SHORTs which can be produced practically ideally (apart from the electrical length to be taken into account), OPENs have a significant stray capacitance of the open line end amounting to several tenths of femtofarad and depending on the frequency. The fringing capacitance of the calibration standards used for ZVR is accurately known and is taken into account during calibration so that no additional measurement uncertainties have to be coped with. With an OPEN used as the DUT, the fringing capacitance causes a phase shift which in turn results in the trace not being coincident with the open point after mathematical correction of electrical length (OFFSET). This does not mean, however that the network analyzer performs an inaccurate measurement but is a correct representation of the real capacitance of the OPEN. If an ideal OPEN could be made whose reflection coefficient were exactly +1 over the complete span, ie with the magnitude 1 and the phase 0°, the analyzer (provided that such a standard is connected) would measure a point as data trace at the open circuit point (at the right edge of the unity circle of the Smith chart).

## 17. How often should a calibration be repeated in production applications?

The answer to this question depends on the stability of the network analyzer (see question 3 concerning aging and temperature drift) but also on the stability of the appropriate user-specific test setup and on the required accuracy of the particular measurement. For many applications involving measurements carried out either directly or via short test cables (eg ZV-Z11) at the test ports of the network analyzer and moderate accuracy requirement, the network analyzer need **not be calibrated at all.** In this uncalibrated state (CAL enhancement label off) measurements are automatically corrected via factory calibration in which a TOM calibration (for ZVR) between PORT1 and the end of a Test Cable ZV-Z11 connected to PORT2 is performed. Thanks to the excellent stability of the analyzer, this factory calibration is fully sufficient for a great number of applications.

If the user has a different and more elaborate test setup with, for instance, adapters or long cables, which also comprises frequency- or even temperature- or time-dependent components, **a calibration of the test setup is indispensable.** For these cases Vector Network Analyzer ZVR offers a great variety of partly worldwide new and exclusive calibration methods that offer distinct advantages (see: "Die ZVR-Familie“ in Elektronik-Praxis No. 3/96 of 9.2.96, pp 116-119).

As long as the external test setup is stable in its characteristics, a calibration carried out with the ZVR can be used for months for all measurements tolerating an inaccuracy of a few tenths of dB or a few degrees although the operating temperature of the instrument has an important influence. Let us assume the instrument is calibrated when completely warmed up and is then switched off overnight. The cold instrument directly after power-up will show a deviation of typically 0.05 dB and 2° which continuously decreases to typically 0.005 dB and 0.1° as the instrument is allowed to warm up for something like an hour to attain thermal equilibrium. For measurements for which this stability is acceptable, a recalibration is only required when some changes have taken place with the test setup. In all other cases stored calibration data may be used for many months.

If higher accuracy is required, the network analyzer should be operated under constant ambient conditions in an air-conditioned room and be given at least two hours to warm up. Only for the most stringent accuracy requirements will it be necessary to carry out **a calibration immediately before each measurement.**

## 18. Can a 50 Ω line be used for verification?

Yes. A known **50 Ω line is one of the best standards for verifying** the measurement accuracy of a network analyzer. For coaxial systems so-called air lines are used. Air lines are high-precision coaxial lines without dielectric supports. The space between the inner and outer conductor is filled with air over the whole length of the line. This allows an exact description of the field distribution and consequently precise assessment of the characteristic impedance. A typical 50 Ω air line with N connectors has an outer conductor of nominally 7 mm diameter and a 3.0396 mm inner conductor, production tolerances being approx. 2 µm. The accuracy of the characteristic impedance is influenced by the line dimensions and the deviations of the coaxial tubes from the ideal cylindrical shape. The accuracy also depends on the eccentricity of the tubes and the field penetration, which is frequency-dependent because of the skin effect and thus changes the effective line diameter, and finally on the roughness of the conductor surfaces. In practice the characteristic impedance can be specified to a maximum accuracy of 0.1 Ω which corresponds to a return loss of between 0 dB and 60 dB.

To verify an important system characteristic of the network analyzer, eg test port matching (source match), scattering parameter S11 is selected and the air line connected to PORT1 of the network analyzer. A short-circuit at the other end of the line causes a total reflection. A perfect network analyzer should now yield a measured broadband return loss of exactly 0 dB, the low loss of the air line being neglected. Because of the finite source match of a real network analyzer, the whole of the signal reflected by the short circuit is not received. Part of the reflected signal, eg 10%, is reflected back by the port to the shorted end via the air line. Here it is reflected again and superimposed at the test port onto the direct signal. Neglecting multi-reflections, two signals are superimposed in the receiver of the analyzer, one approaching the correct magnitude of 1, the other with a magnitude of approx. 0.1 because of the assumed 10% reflection at the test port. Superposition of the two signals is not scalar but vectorial and because of the length of the air line (typically 300 mm) the phase of the second signal varies against that of the first as a function of frequency. The two extreme values are obtained through the addition and subtraction of the signals depending on the frequency and this is shown as a ripple of ±10% in the linear representation of the trace. Therefore, the ripple of the trace corresponds to an important system characteristic of the analyzer, ie the source match to be verified.

This method may be used in the same way for verifying the so-called **effective source match** which is obtained after system error calibration and correction. Values of 1% corresponding to 40 dB are typical for analyzers of the ZVR family.

### 19. How can a calibration be performed in 3-port operation?

The 3-Port Adapter option ZVR-B8 is controlled by the analyzer via a rear-panel connector. The path from PORT1 to PORT2 is through-connected for the two odd channels CH1 and CH3 and the path from PORT3 to PORT2 for the two even channels CH2 and CH4. Three-port calibration is then performed **as two independent 2-port calibrations** for each of the two paths. Any calibration method, eg TOM, may be used for the measurements between PORT1 and PORT2 with the channel CH1 active and between PORT3 and PORT2 with channel CH2 active.

With the 3-port DUT connected and parameter S21 displayed in channels CH1 and CH2 in the DUAL CHANNEL SPLIT mode, S-parameter S21 of the 3-port DUT is measured in CH1 and S-parameter S23 in CH2 as the 3-Port Adapter is controlled as described above.

### 20. Can AutoKal be used with a test fixture in a planar environment?

Yes. Generally, calibrations are performed to improve the measurement accuracy of the whole network analyzer system, in other words the ZVR including cables, adapters and all other components of the test setup. The calibration method also determines the reference planes for the vector measurements of complex S-parameters of DUTs, irrespective of whether calibration is carried out in a coaxial or planar environment. The essential criterion is that the contacts to the calibration standards and later on to the DUT are reliable, reproducible and of good quality and that the calibration standards feature the required characteristics. In this respect there is no difference between AutoKal and the other calibration methods. The difference and an advantage of the AutoKal technique is that a complete 2-port calibration can be performed with only one calibration standard, namely a through-connection T. AutoKal needs a single fundamental calibration prior to its first use to determine the characteristics of the transfer standards within the AutoKal unit. TOM is the recommended method for this fundamental calibration which requires, in addition to the through-connection T, an open-circuit O and a matched load M. Whether AutoKal can be used for planar connectors or not depends on whether the standards required for a TOM calibration are available in planar form. Basically, AutoKal can also be linked to the TNA technique for fundamental calibration. AutoKal can then be used reliably for nearly all planar applications. This is not yet possible in the ZVR but can be implemented, if required.

### 21. Can the case capacitance $C_0$ of a one-port resonator be eliminated in a TOM-X calibration?

Yes. To do this, the calibration standards should be fitted into the empty case of the resonator, eg into the case of a crystal. What is essential is good reproducibility, ie the case capacitance for calibration and DUT measurements should be the same. If this criterion is met to a sufficient degree, the calibration method TOM-X, which is particularly suitable for eliminating X = crosstalk by calculation, takes the case capacitance as a source for the crosstalk. If the capacitance is constant in the calibration and DUT measurements and is not DUT-dependent, the **case capacitance $C_0$** is **eliminated particular effectively** due to the full calibration model used in the **TOM-X calibration.**

## …regarding virtual transformation networks:

### 22. What does "measuring in a customer-specific environment" mean?

The Virtual Embedding Networks Option ZVR-K9 allows **any** customized **circuit environment,** eg a matching network or PCB to which the DUT will be fitted later on, to be **virtually integrated** into the test fixture of an automatic test system.

The function of a whole module, which may only be theoretically known or does not exist at all, can be tested in this way and yet only one critical component needs to be measured. Thus an overall function check can be made at an early development stage and the suitability of a component for the environment for which it is intended can be guaranteed. Should a component have to be changed on the PCB, the interplay with the DUT can be tested immediately and the number of rejects in production can thus be considerably reduced.

## 23. Where do the data for the virtual transformation network come from?

The virtual transformation network can be determined **directly by measuring S-parameters**, for instance when an existing matching transformer should be replaced later on by a virtual transformer with the aid of the option ZVR-K9. Another possibility is **to synthesize** a network **with the aid of a simulation program** and to transfer the measured S-parameters to the network analyzer, ie to implement the virtual network.

The new calibration technique TNA (R&S patent) allows the implementation and use of virtual networks also in planar circuit environments where conventional calibration techniques often fail. The latter require calibration standards of accurate and known characteristics, which in practice often cannot be realized with sufficient quality. The calibration technique TNA, on the contrary, places low demands on the characteristics of the calibration standards. It permits almost any unknown calibration standards to be used and an accurate calibration to be performed at the reference plane of the DUT within the test fixture and at the coaxial interfaces of the DUT. Thus, the networks between these interfaces can also be determined and considered in the calculation or, the other way round, the network can be calculated as a difference and eliminated.

## 24. How can it be guaranteed that TNA standards have the desired characteristic impedance?

Compared with other calibration techniques, the TNA technique is the least demanding with regard to having to know the characteristics of the calibration standards. However, a few characteristics of the standards have to be known or represented as exactly as possible. This is for one the electrical length of the through-connection T (Through) which determines the reference plane for phase measurements in reflection and transmission. In addition, the input impedance at both ends of the A standard (Attenuator) and the characteristic impedance of the through-connection T should be of the same value as both together determine the reference characteristic impedance. If the impedances are different or if one of them or both do not comply with the desired reference impedance, measurement errors will occur resulting in a reduced effective directivity of the test setup.

In coaxial test setups these problems can be easily mastered, but here the TNA technique will hardly ever be necessary. TNA is of more interest in planar structures using microstrip lines, for instance. In this case **the same rules** should be observed when **dimensioning** the through standard T as are used for calculating the lines around the DUT in the real circuit. Thus the **characteristic impedance obtained per definition** is ideal. Dispersion will not be disturbing, on the contrary it is desirable that the through standard shows the same dispersion as the environment to which the DUT has to be matched with low reflection.

Care should also be taken that the impedance of the A standard matches the characteristic impedance of the T standard as accurately as required, but this depends on how the A standard has been realized. For instance, the A standard may be made up of two concentrated resistors, which unlike the line have almost no dispersion. The standard may also be implemented in the form of a line like the T standard, with a tapered absorbing rubber used for attenuation.

## 25. Are TNA standards traceable?

This question concerns the T (Through) and A (Attenuator) standards since apart from reflection symmetry no special demands are placed on the N (Network) standard which is realized in most cases by open test terminals, ie by simply disconnecting the DUT. The decisive characteristics of the T and A standards have been discussed in the previous section on the characteristic impedance. Whether the standards can be traced to national or international standards depends on the type of line of the calibration standards. As far as coaxial calibration standards are concerned, the answer is clearly yes.

In the case of planar structures, standards are **often only indirectly** traceable. Theoretically, even the most exotic structure can be traced back to a primary standard. If required, this is checked individually and performed with the aid of the R&S calibration laboratory.

## 26. Can a dummy be used so that calibration can be performed within and outside the housing?

When performing a calibration for measurements on housed components, the connectors both on the inside and outside of the housing may be used as reference planes. If a calibration is to be performed at the connectors inside, **empty housings (dummies) can be modified** - by using calibration substrates, for instance - **such that they can be employed as calibration standards**. If the housings are well matched and have a low loss, these standards can also be used for calibration on the connectors on the outside of the housing. The TNA calibration technique (R&S patent) is especially suitable as it comprises only the easy-to-realize calibration standards T = Through, N = Network and A = Attenuator. For T a direct through-connection may be used instead of the DUT, N can be realized with any unknown network featuring reflection symmetry and is best obtained by simply disconnecting the DUT, ie by leaving the terminals open (for calibration outside the housing) or by an empty housing (for calibration within the housing). Standard A is characterized by matching at both ends, any unknown crosstalk between the test ports being acceptable. For many applications, the mentioned standards can be set up in the form of the housing or be fitted into the empty DUT case. This has the additional advantage that in automatic test stations both the calibration standards and the DUTs can be connected automatically to the test fixture.

## 27. Does embedding/ deembedding reduce the measurement speed?

No. The data required for virtual transformation networks are first mathematically linked to the calibration data of the network analyzer via a modification of the system error matrices. During the measurement the modified matrices are used instead of the original system error matrices. Therefore, **no additional calculations are required** during the measurement beyond the usual, high-speed calculations for system error correction. The **measurement speed is as high** as with conventional system- error-corrected measurements without the use of virtual networks.

## 28. Can the virtual transformation network be determined by measurements only or can it also be synthesized?

Yes, the virtual transformation network may be designed and simulated, for instance, **with the aid of a common simulation program like SuperCompact.** The simulation calculation may be carried out with the network analyzer using the optional Computer Function ZVR-B15. The S-parameters of the virtual transformation network are transferred to the network analyzer in the form of an FLP file (S-parameter data set for multiports), combined with the system error correction matrices so that modified matrices are obtained which are then used in the subsequent DUT measurement.

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Rohde & Schwarz
19 January 1998

# 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 ne tworks, eg to supply DUTs.