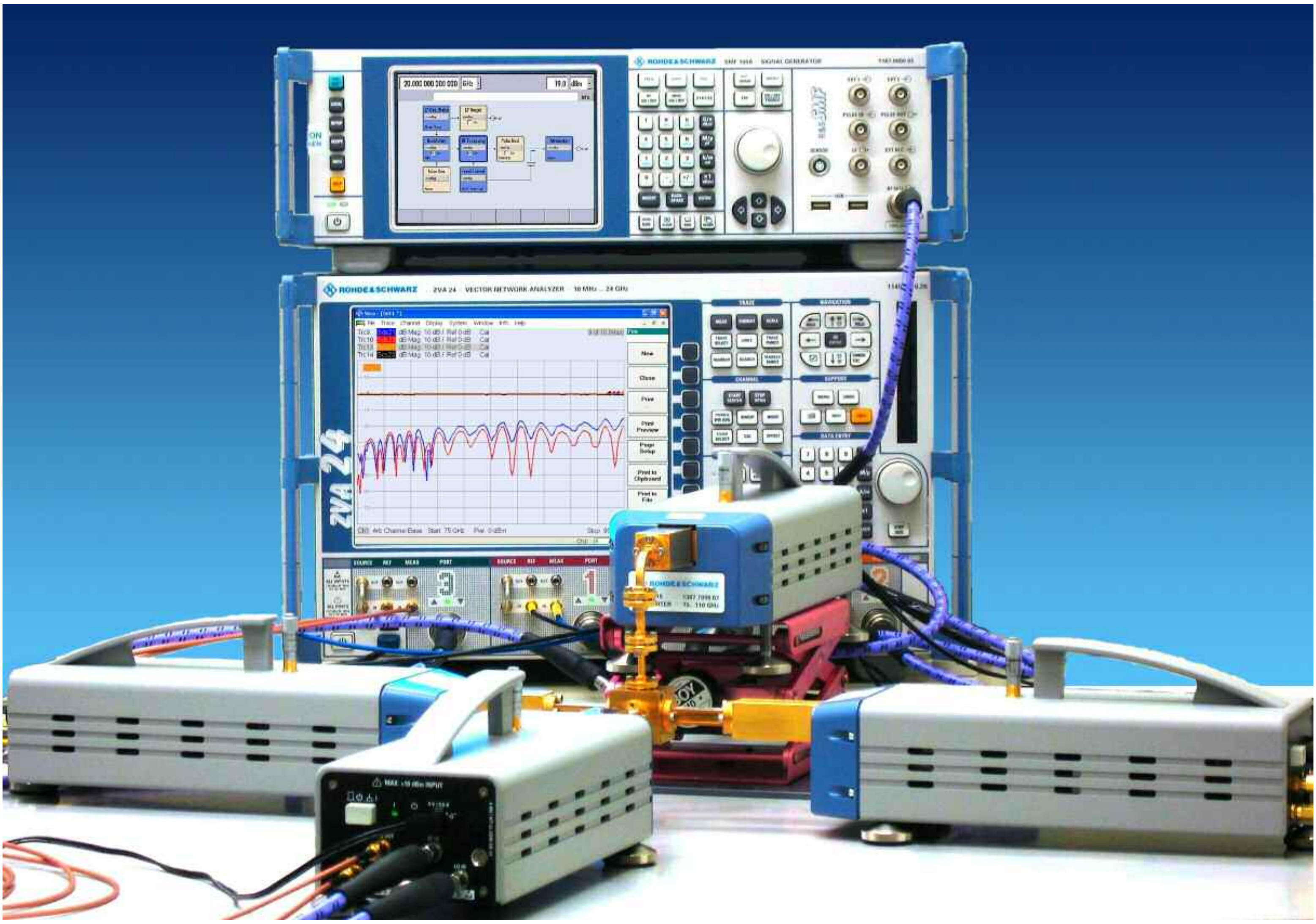


Products: R&S®ZVA-Z110, R&S®ZVA24, R&S®ZVA40, R&S®ZVT20, R&S®SMF100A

Multiport Millimeter-Wave Measurements Using Converters of the R&S®ZVA-Family

Application Note 1EZ56

The R&S®ZVA-Z110 converters offered for the R&S®ZVA family enable network analysis in the W band (75 GHz to 110 GHz). In this Application Note, measurements with three or four converters will be discussed. Test configurations for such measurements have so far been implemented only with coaxial connector systems for a frequency range up to approx. 40 GHz. The term "multiport measurements" was created for this type of measurements.

ROHDE&SCHWARZ

Subject to change - Michael Hiebel, 09.2007 - 1EZ56_0E

Contents

1. Features

The R&S®ZVA and R&S®ZVT20 vector network analyzers are ideal for use in conjunction with the R&S®ZVA-Z110 converters. The R&S®ZVT20 allows the user to perform millimeter-wave measurements with up to six ports. Together with the analyzers, the converter provide the following features:

- The converters feature an integrated attenuator (power adjusting screw) by which the output power of the waveguide test port can be controlled manually.
- Using a suitable waveguide power sensor, you can perform power calibration of the analyzer's reference and measurement receivers. You can then carry out calibrated measurements of wave quantities by means of these receivers. Compared with a direct measurement using a power meter, the measurement performed with the analyzer offers wider dynamic range and higher measurement speed.
- By combining the above two features, you can accurately set the power of the stimulus signal by manual control.
- The converters are shaped so that the screw-connected flange joints are easily accessible.
- The converters come with two exchangeable test port adapters, which makes them compatible with a variety of waveguides.
- The converters can be set up on four or three feet, or using no feet at all, depending on requirements. Using three feet greatly facilitates alignment of the test port flange.
- The converters are of compact design, which facilitates their use in wafer probers and with other applications where space is at a premium.
- The converters are cooled passively, i.e. without using a fan. This is of advantage in particle-sensitive environments; plus, it ensures silent operation.
- The converters come with a storage box to protect them during periods of non-use.
- A special converter control software option available for the R&S®ZVA and R&S®ZVT20 allows the fast and easy configuration of typical measurement tasks. After you have selected the converter type and the cabling scheme, the unit performs all other settings automatically, including all frequency conversion ratios as well as the selection of the test port type (e.g. WR10) and the calibration kit.
- The converters can be operated below their specified minimum frequency, i.e. their operating range can be extended into the next lower band. In other words, R&S®ZVA-Z110 converters can also perform measurements outside the W band operating on frequencies of 60 GHz or higher. In this case, compliance with specified data cannot be fully ensured; this applies in particular when the waveguide is operated in the vicinity of its cutoff frequency.
- The converters come with a universal input AC adaptor including four different AC plugs for nearly all conventional mains sockets.

2. Key Specifications

Key specifications of the R&S®ZVA-Z110 converters[1]:

Frequency range	75 GHz to 110 GHz
Test port output power	+2 dBm with +7 dBm at *RF IN*
Accuracy of output power	< 4 dB (with 0 dB power attenuation)
Manual power attenuation	0 dB to 25 dB
Dynamic range	95 dB (typ. 110 dB)
Input power at *RF IN*, *LO IN*	+5 dBm to +10 dBm (ideally +7 dBm)
Plug-in power supply	100 V to 240 V, 47 Hz to 63 Hz

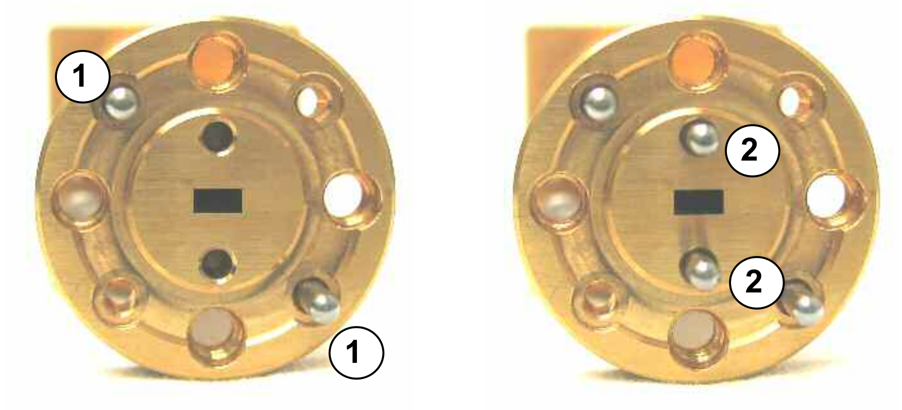


Fig. 2.1: UG-387 precision anti-cocking flange without and with indexing pins

For waveguides above 50 GHz, the UG-387 flange is most commonly used. The converters are compatible with this flange. In accordance with the MIL specification, the UG-387 flange is to be used with alignment pins (Fig. 2.1 ①) with a diameter of 1.565 mm (0.0615 in) [2]. This diameter is supported by numerous manufacturers (e.g. Aerowave, Inc., Custom Microwave, Inc., M/A-COM/Tyco Electronics Ltd., and Flann Microwave Ltd.). Alignment pins with other diameters are also commonly used; an important manufacturer is Agilent Technologies, Inc., offering pins with a diameter of 1.605 mm (0.0630 in). To ensure compatibility also with this variant of the UG-387 flange, the converters come with two different variants of test port adapter (Fig. 2.2). One of the adapters is designed for use with 1.565 mm alignment pins. It makes highly accurate contact even without using indexing pins in addition (Fig. 2.1 ②). The second adapter is designed for use with alignment pins of both 1.565 mm and 1.605 mm in diameter. To achieve contacting as accurate as possible, it is advisable to use indexing pins in addition. Indexing pins are available for both test port adapters (precision flanges). The test port adapters have an outer rim that is designed to prevent cocking of the flanges relative to each other (anti-cocking flanges). It is also possible to connect DUTs with standard flanges (i.e. flanges not featuring the anti-cocking or precision characteristics mentioned above) to the test port adapters.

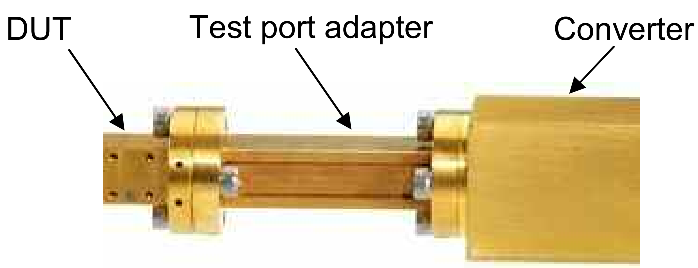


Fig. 2.2: Recommended configuration for connecting a DUT to a converter

1 For binding data sheet specifications refer to the latest version of reference [1].

3. General Requirements and Operating Principle

For the purpose of this Application Note, it is assumed that an R&S®ZVA or R&S®ZVT network analyzer with a suitable upper frequency limit of at least 20 GHz is used. The direct generator/receiver access option (R&S®ZVA-B16 or R&S®ZVT-B16) and the converter control option (R&S®ZVA-K8) must be installed.

The righthand part of Fig. 3.1 shows a block diagram of the R&S®ZVA-Z110 converter. It has the following main function blocks:

① **Source multiplier**, which produces the stimulus signal with *f* = 75 GHz to 110 GHz from the *RF IN* signal by frequency multiplication

② **Waveguide attenuator** with a screw for setting the output power of the waveguide test port

③ **Directional coupler** to separate the measurement and the reference channel

④ Two **harmonics mixers** for converting the measurement and the reference channel to a fixed IF of 279 MHz. The two harmonics mixers use the eighth harmonic of the *LO IN* signal.

To make the signals easier to identify, the color coding used in Fig. 3.1 for the *LO IN*, *MEAS OUT*, *REF OUT*, and *RF IN* signals will be maintained in other figures below.

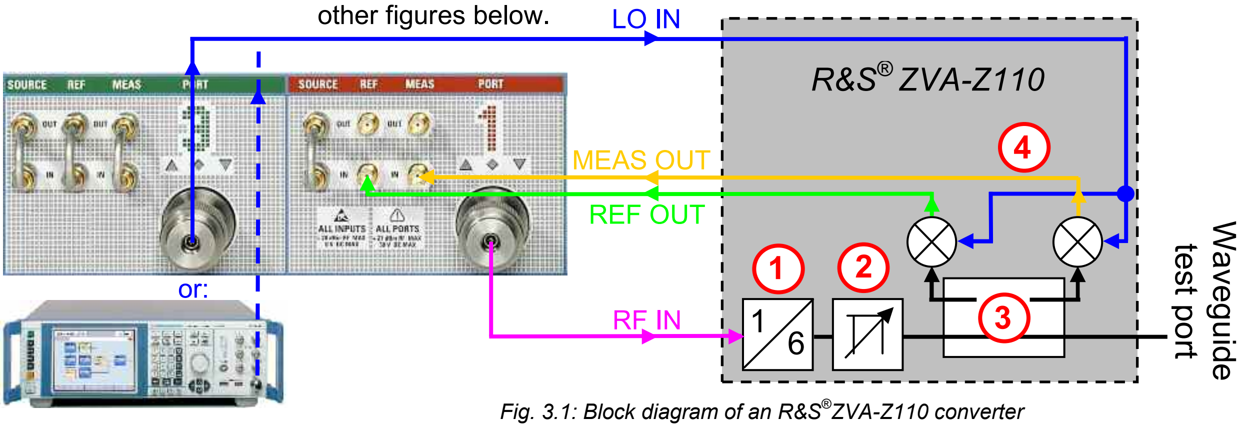


Fig. 3.1: Block diagram of an R&S®ZVA-Z110 converter

The lefthand part of Fig. 3.1 shows how a converter is connected to the network analyzer. Each converter is assigned to a network analyzer test port that supplies the converter with the *RF IN* signal and, in turn, accepts the *REF OUT* and *MEAS OUT* IF signals from the converter via its external receiver inputs. The converter thus replaces the internal test set of the network analyzer at that specific port (e.g. S_{11} for the return loss measured at the waveguide test port shown in Fig. 3.1). The converter's waveguide test port takes the place of the analyzer's test port, and measured quantities are assigned to this port (port 1 in this case). Another test port (port 3 in this case) is needed to provide the converter with the *LO IN* signal. The *LO IN* and the *RF IN* signals have a fixed frequency relationship relative to each other. While the *RF IN* signal is switched on and off depending on the measurement direction, the *LO IN* signal must be permanently switched on. The test port (port 3) supplying the *LO IN* signal is therefore not available for other purposes. Optionally, an external signal generator can be used instead of the test port to deliver the *LO IN* signal. All converters included in a test setup must be supplied with the *LO IN* signal from one and the same oscillator. With an external signal generator, a power splitter is used to distribute the *LO IN* signal. If the *LO IN* signal is delivered by the network analyzer, two test ports are as a rule available, which derive the LO signal from one internal oscillator in the network analyzer. If two test ports are not sufficient, each port can be extended by connecting an external Wilkinson divider.

4. Measurement Examples

When configuring a millimeter-wave test setup, some basic rules have to be observed. For more detailed information, refer to section 5.1 of the attachment. Since applications with three or four converters are discussed here, the test setups presented in this Application Note are relatively complex. To get familiarized with this topic, see reference [5], which focuses on one- and two-port measurements using the R&S®ZVA-Z110 converters.

Overview of measurement examples:

Measurement example, section 4.1:

- Test setup without an external generator
- S-parameter measurement with three (four) waveguide test ports
- Typical application of UOSM calibration with waveguides
- Calculation of directivity of device under test (DUT) (three-port directional coupler in this case)

Measurement example, section 4.2:

- Test setup with an external signal generator to deliver the *LO IN* signal
- Configuration and control of external signal generator from network analyzer
- S-parameter measurement with four waveguide test ports
- Taking into account the direction of polarization when calibrating waveguide test ports
- Display of balanced S-parameters as a mixed mode S-parameter

What test setup should preferably be used?

Whether you use a test setup with or without an external signal generator will in many cases depend on your existing pool of test equipment. Apart from this, the advantages offered by a test setup without an external signal generator should be taken into account, i.e.:

- Higher sweep speed
- Highly compact test setup

Other applications

It is also possible to implement a test setup with up to six R&S®ZVA-Z110 converters. This is done by using an R&S®ZVT20 six-port network analyzer together with an external signal generator and a suitable LO distribution network.

Other applications of the R&S®ZVT20 six-port network analyzer in conjunction with the converters are measurements on frequency-converting waveguide DUTs. In the measurement example in section 4.1, Fig. 4.4., the RF stimulus signals for waveguide test ports 1 and 3 are delivered by different oscillators of the R&S®ZVT20. It is thus also possible to apply the stimulus signals to the waveguide test ports with a frequency offset in a convenient manner.

4.1 Directivity Measurement from 75 GHz to 110 GHz

Measurement task:

A test setup for measuring waveguide directional couplers is to be created and configured. All important S-parameters as well as directivity are to be measured in a single test sequence. The devices under test (DUTs) are three-port directional couplers, i.e. one of the four ports of the directional coupler is terminated with a match inside the coupler. A six-port R&S®ZVT20 is used as a network analyzer. Three converters are provided for the three waveguide test ports needed in this case. The test setup can easily be expanded by a fourth converter, for example to perform a full measurement of a four-port directional coupler by means of four test ports in a single test sequence.

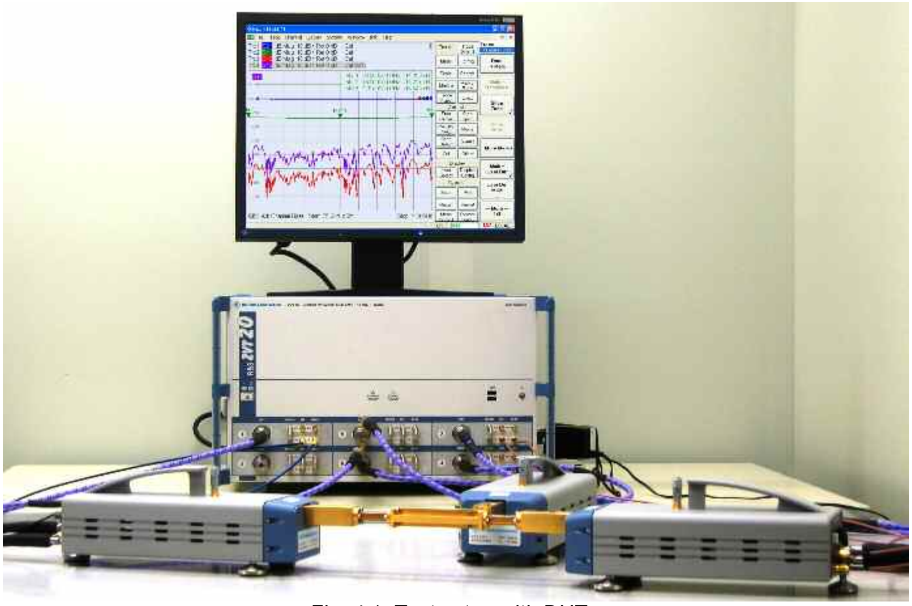


Fig. 4.1: Test setup with DUT

Step 1: Configuring the converters

Select the converter type (*ZVA-Z110* in this case) and the cabling scheme (internal RF, internal LO (*RF intern*, *LO intern*) in this case). Activate the setting with *Apply* and terminate the dialog with *Close*.

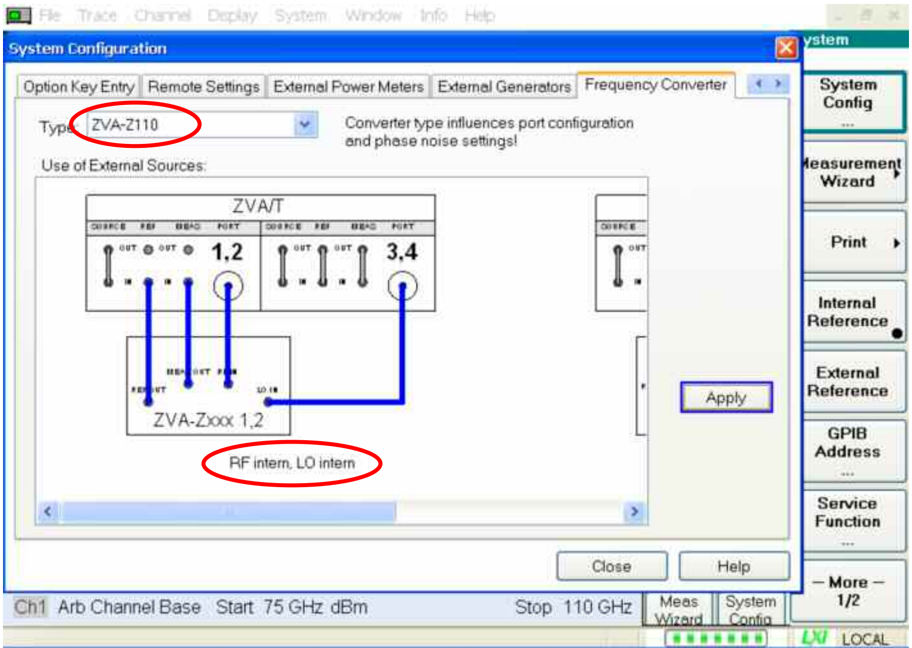


Fig. 4.2: Configuring the converters on the R&S®ZVT20

The network analyzer is now basically configured for operation with the converters. This becomes first obvious by the stimulus axis at the bottom of Fig. 4.2 changing to the range of 75 GHz to 110 GHz. Other settings are influenced as well, for example the test port type (important for calibration). The six test ports of the R&S®ZVT20 allow a variety of cabling schemes to be implemented. Moreover, the R&S®ZVT20 network analyzer is available in various configurations with two to six test ports. The converter configuration shown in Fig. 4.2, for example, applies to a four-port R&S®ZVT20 model. For the measurement described here, therefore, the test port assignment has to be modified. The test port configuration can be accessed under *Mode* | *Port Config* on the network analyzer. Fig. 4.3 shows the modified settings.

Test ports 1 to 4 of the R&S®ZVT20 (lines 1 to 4 of the *Port Configuration* table) are configured as ports for generating the *RF IN* signal. The base frequency f_b range corresponds to the frequency axis (75 GHz to 110 GHz), and is generated by the converter by way of sixfold multiplication. The source frequency supplied by the R&S®ZVT20 is therefore defined as $f_b/6$ (see Fig. 4.3 ①). The receiver frequency for the *REF* and *MEAS* IF signals (i.e. the frequency at which these IF signals have to be applied to the analyzer) is set to a fixed value of 279 MHz (see Fig. 4.3 ②).

Test ports 5 and 6 deliver the LO signal, whose frequency is obtained as follows: (f_b – 279 MHz) / 8 (see Fig. 4.3③).

For the *RF IN* and *LO IN* signals, a power of +7 dBm is optimal. The values in the *Power* column (Fig. 4.3 ④) are set accordingly. Test port 5 is extended by means of an external Wilkinson divider so that it supplies two converters with the LO signal (see Fig. 4.4 on next page). The Wilkinson divider connected to test port 5 causes a 3 dB insertion loss; therefore, the power has to be set to 10 dBm for this test port.

The checkmarks in the *Gen* column (Fig. 4.3 ⑤) indicate that test ports 5 and 6 are permanently operated as active ports independently of the measurement direction. This is because the LO signal is needed at all converters independently of the measurement direction.

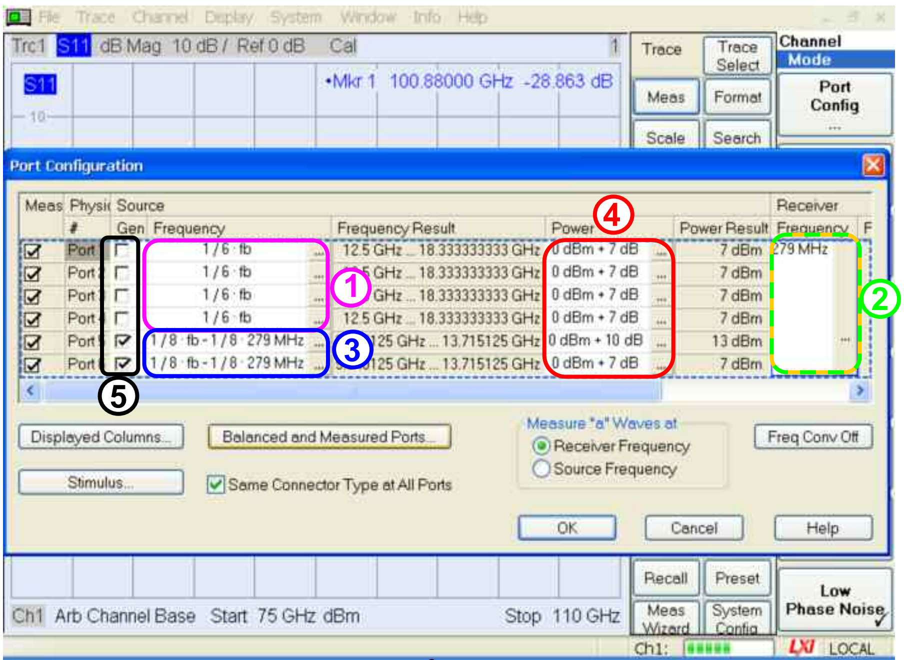


Fig. 4.3: Modifying the R&S®ZVT20 test port configuration

Step 2: Connecting the converters

Fig. 4.4 below shows the cabling scheme in detail, as well as the internal R&S®ZVT20 stimulus oscillators. The LO signal (blue) is provided by a common oscillator (stimulus oscillator 3) and is then distributed as required. It is thus ensured that the IF signals (*MEAS*, *REF*) are phase-coherent relative to one another. This is necessary in order to determine the measured S-parameters unambiguously in terms of phase (complex S-parameters).[1]

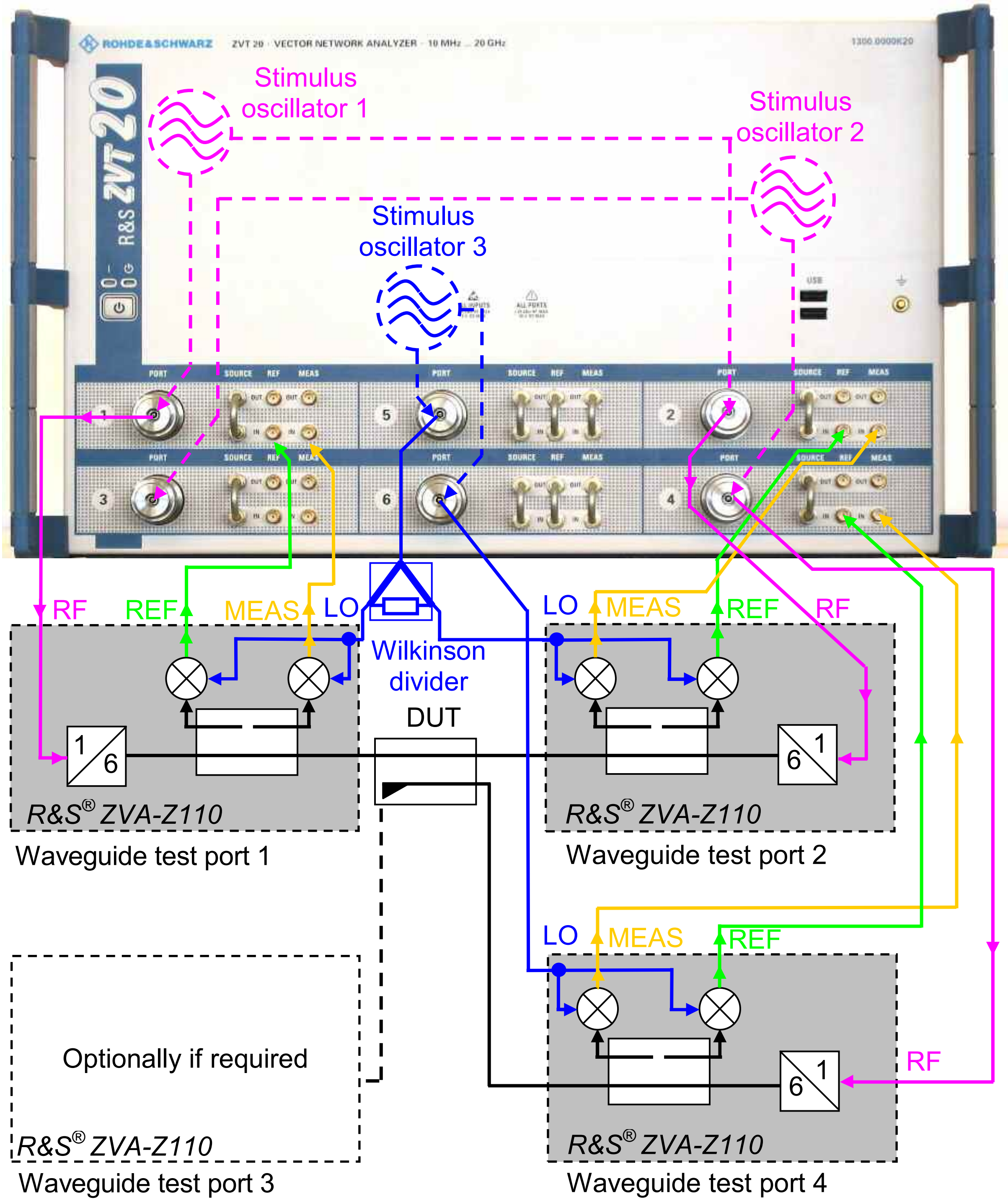


Fig. 4.4: Cabling scheme for three (four) converters and a six-port R&S®ZVT without an external generator

Step 3: Preparatory operations for waveguide measurement
In our example, a measurement bandwidth of 1 kHz is to be set on the R&S®ZVT20. The R&S®ZVA-Z110 converters contain an adjusting screw for setting the test port output power (see Fig. 4.5 ①). Since compression effects can be excluded for the passive DUT to be measured here, the

[1] With measurements on frequency-converting DUTs, the phase information is often not needed. In such cases, it may also be appropriate to use various oscillators – which may even operate at different frequencies – to provide the LO signal.

maximum test port output power will be used. Maximum output power is obtained for all settings > 2 mm of the power adjusting screw. Set all three converters to maximum output power.

System error correction is a vital prerequisite for obtaining correct results. Once calibration is carried out (Step 4), the R&S®ZVT20 performs system error correction automatically. It is advisable to determine the appropriate geometrical orientation of the test ports already before calibration. Any significant modification to the test port orientation after calibration may cause an (avoidable) loss in accuracy. The optimal test port orientation can be determined, for example, by means of a trial setup including the DUT as shown in Fig. 4.5. Especially with multiport measurements, it is helpful to try different trial setups and evaluate them according to the following criteria:

- accessibility of the screw-connected flange joints
- short cable lengths for RF and LO signal transmission
- mechanical stability of the RF and LO cabling

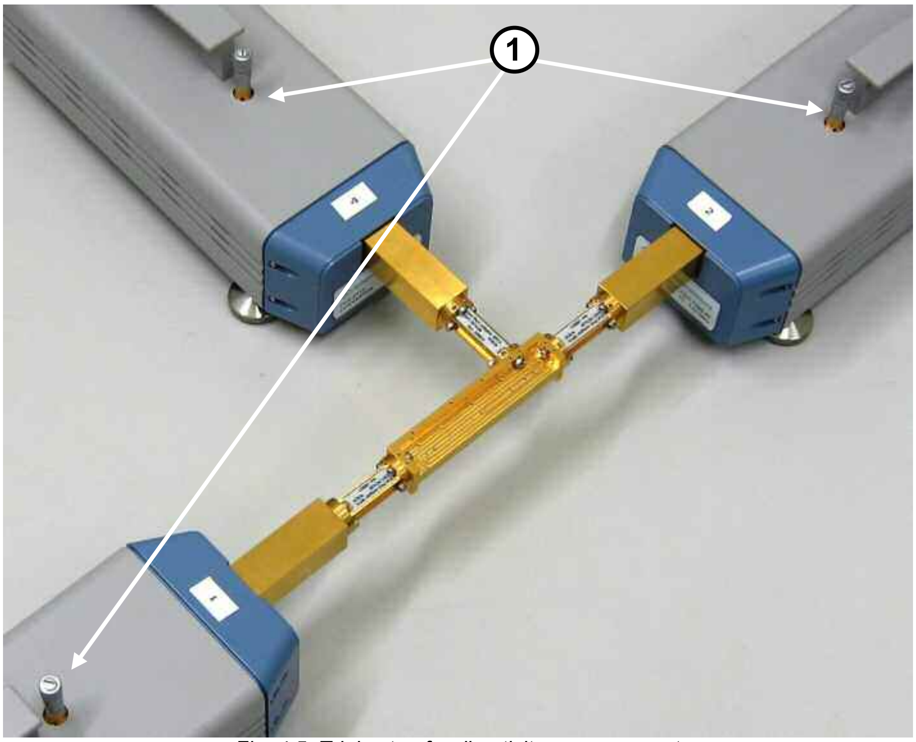


Fig. 4.5: Trial setup for directivity measurement

Due to the nature of *Through* standards, the orientation of the test ports relative to one another is more or less fixed. The UOSM *(**U**nknown Through, **O**pen, **S**hort, **M**atch)* calibration technique would therefore be the preferred choice. It is similar to the TOSM (***T**hrough, **O**pen, **S**hort, **M**atch)* technique. In contrast to a *Through*, an *Unknown Through* has to fulfill only one requirement, i.e. reciprocity. The *Unknown Through*, therefore, need not feature good matching or low loss. Even low-priced waveguide sections with standard flanges meet the reciprocity requirement and can therefore be used as *Unknown Throughs*. Such waveguide sections are available in various shapes (see section 5.2, table 5.1, lefthand column). They can be used to bridge the required distances without necessitating any significant changes to the converter positions.

Step 4: Calibration
Select the *Cal* | *Start Cal* | *Other* dialog in the network analyzer firmware. The analyzer automatically proposes the WR10 test port type. The analyzer also proposes a calibration kit (R&S®ZV-WR10 in this case), and all you

have to do is check whether the correct kit has been proposed.[1] In the dialog shown below, you can configure the calibration in detail. Only test ports 1, 2, and 4 of the R&S®ZVT20 are used as waveguide test ports. Consequently, you have to select only these test ports and assign the UOSM calibration technique to these ports (see Fig. 4.6).

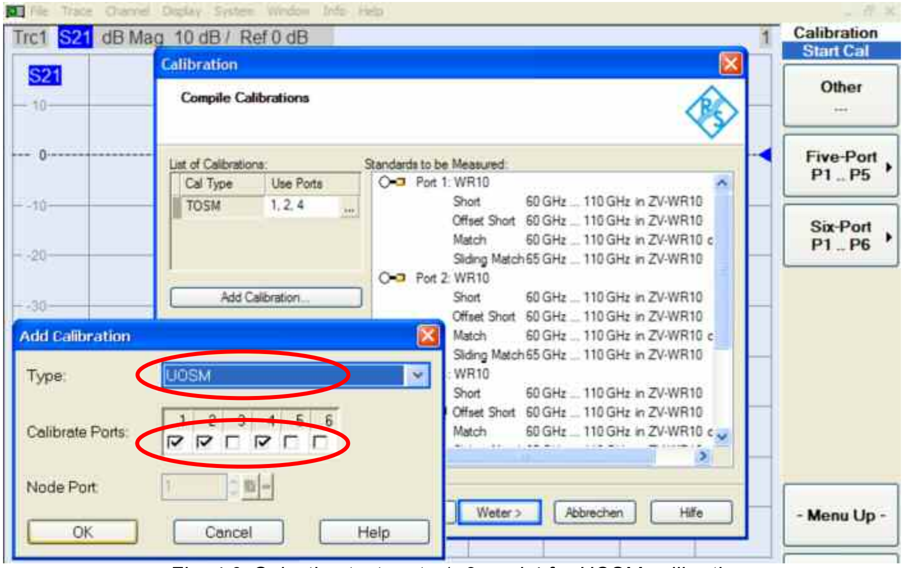


Fig. 4.6: Selecting test ports 1, 2, and 4 for UOSM calibration

Mount the one-port calibration standards shown in Fig. 4.7 to each of the three test ports one at a time and measure them. The one-port standards include a *Short*, an *Offset Short* (made up of a *Short* and a *Shim*[2]), and a *Fixed Match*. When mounting the calibration standards, make sure to evenly tighten the connecting screws on the waveguide flanges.[3]

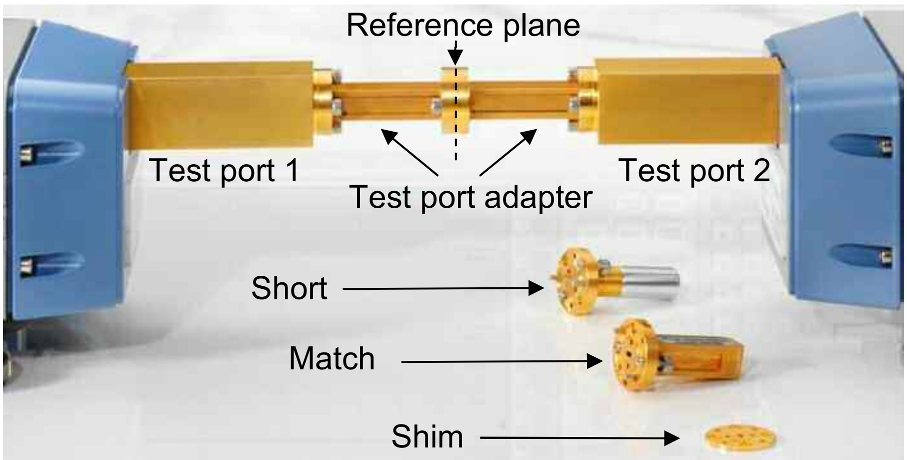


Fig. 4.7: (Direct) Through between waveguide test ports 1 and 2, and one-port calibration standards used for the measurement

The *Through* between waveguide test ports 1 and 2 is established by directly screwing together the two test ports (see Fig. 4.7 above). The *Through* standards between waveguide test ports 1 and 4, and 2 and 4, are realized

[1] We recommend that you use the R&S® ZV-WR10 calibration kit. You can also define a waveguide calibration kit of your own. To do this, refer to the interactive help function of the R&S®ZVT / R&S®ZVA.

[2] An *Open* standard cannot be implemented in configurations based on waveguide technology because of the radiation losses occurring at an open end of the waveguide. To obtain an additional reflection standard, a *Short* is used that is appropriately transformed by means of a small waveguide section referred to as a *Shim*.

[3] To further enhance accuracy, you can use the additional indexing pins (see Fig. 2.1 ②) to fix the standards of the R&S®ZV-WR10 calibration kit.

by using an H-plane bend so as to maintain the test port orientation determined before (see Step 3).

Fig. 4.8a: Unknown Through standard between waveguide test ports 1 and 4

Fig. 4.8b: Unknown Through standard between waveguide test ports 2 and 4

The UOSM technique involves an inherent 180° phase ambiguity. With typical coaxial *Through* standards, a phase of 0° would be obtained at 0 Hz. For such standards, the network analyzer would automatically extrapolate the results of the calibration measurement to 0 Hz, thus eliminating phase ambiguity. By contrast, with dispersive line systems such as waveguides, phase ambiguity cannot be eliminated automatically. Therefore, you have to activate *Dispersive* in the *Unknown Through Characteristics* dialog (see Fig. 4.9), which comes up after all calibration measurements have been completed.

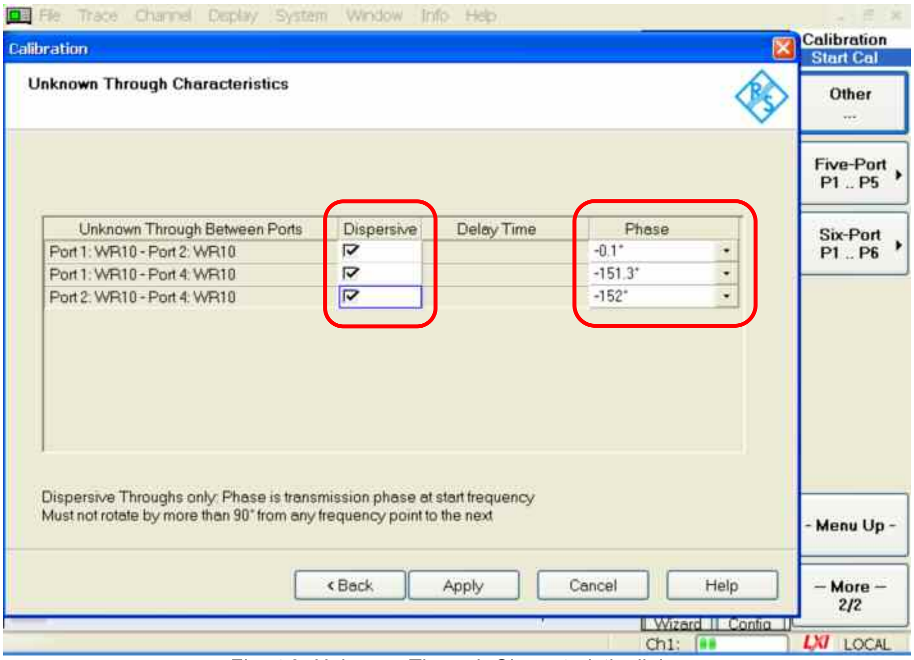


Fig. 4.9: Unknown Through Characteristic dialog

The phase values offered for the *Unknown Through* standrads may be changed by 180° (the network analyzer offers two approximated phase values for each *Unknown Through* standard). In a preliminary measurement, a phase value of –151.5° was measured at 75 GHz for the H-plane bend. For the direct *Through* shown in Fig. 4.7, a phase value of 0° can be assumed. In the dialog in Fig. 4.9, the phase values have been selected accordingly.

Step 5: Connecting the DUT and performing the measurement
Connect the DUT as shown in Fig. 4.5. An important test parameter is the return loss at each of the DUT's waveguide ports. The results obtained for the return loss are displayed on the R&S®ZVT20 by means of three traces (S_{11}, S_{22}, and S_{44}, see Fig. 4.10). Results can be automatically checked for compliance with predefined limits using the *Limit Lines* function (read line inserted at 26 dB in this case).

Fig. 4.10: Automatic limit check of return loss for all ports of the directional coupler

Further quantities to be measured are the insertion loss, the coupling loss, and the isolation of the directional coupler. The insertion loss (S_{21}) expresses the loss occurring on the direct signal path of the directional coupler (Fig. 4.11 ①); the coupling loss (S_{41}) expresses the loss on the coupling path (Fig. 4.11 ②). In addition to the (wanted) coupling effect, there is also unwanted crosstalk (Fig. 4.11 ③), which is described by S_{42}. For the crosstalk path, isolation should be as high as possible.

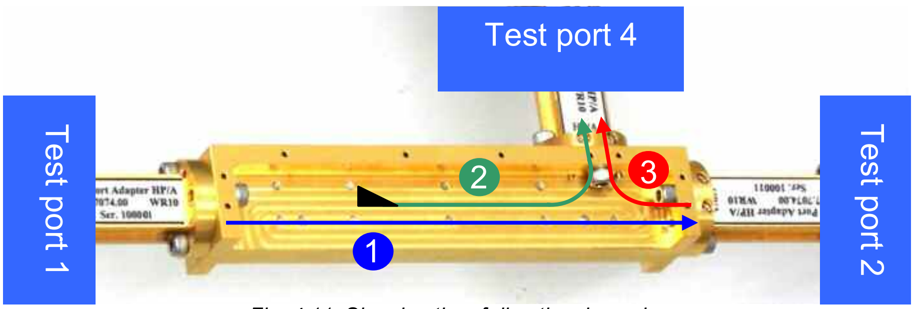


Fig. 4.11: Signal paths of directional coupler

To enable a more conclusive comparison of the isolation characteristics of directional couplers with different coupling loss, the directivity (D) was introduced. It describes the ratio of the (unwanted) crosstalk (S_{42}) to the (wanted) coupling effect (S_{41}). Using trace mathematics, this ratio can be calculated from the Trc3 and Trc2 traces shown in Fig. 4.12. Limit lines were not used in this diagram, as otherwise it would have become too crowded. The coupling effect (Fig. 4.11 ②) is actually narrowband. To extend it across the entire bandwidth of the waveguide, a special design of the directional coupler is required. This has been implemented in the DUT, where the coupling effect occurs across the entire waveguide band with a variation of less than 1 dB (see marker values in Fig. 4.12).

Fig. 4.12: Insertion loss, coupling loss, isolation, and directivity of DUT

4.2 S-Parameter Measurement on a Magic Tee

Measurement task:

For the second measurement task, an R&S®ZVA24 four-port network analyzer, an R&S®SMF100A signal generator, and four R&S®ZVA-Z110 converters are used (see cover picture of this Application Note). Alternatively, the test setup described in section 4.1 could be used for this measurement. The DUT is a four-port magic tee. It operates in the frequency range 75 GHz to 95 GHz and can be used as a combiner, for example. Its operating principle can be discussed by considering the E-field:

- If an E-field is applied to the *Ph. 2* and *Ph. 4* physical ports with equal phase (Fig. 4.13a), the E-field vectors superimpose on each other constructively at the waveguide junction of port 3, i.e. maximum signal power is present at port 3. At the output of port 1, on the other hand, the difference vector formed by the two E-field vectors is obtained. Assuming that equal power is present at Ph. 2 and Ph. 4, the two vectors cancel each other out, i.e. no output power is present at port 1.
- If an E-field is applied to the *Ph. 2* and *Ph. 4* physical ports with opposite phase and equal power (Fig. 4.13 b), the E-field vectors superimpose on each other destructively, i.e. there is no output signal at port 3, and the maximum possible difference vector (i.e. the maximum signal power) is obtained at port 1.
- Because of these characteristics, ports 1 and 3 are also referred to as Δ or Σ ports, respectively.

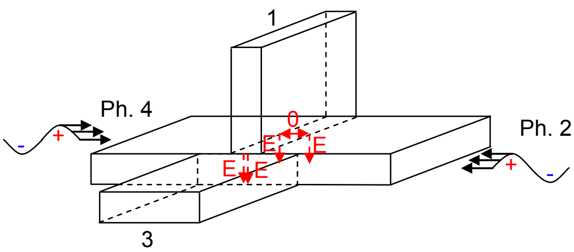


Fig. 4.13a: Magic tee with common-mode stimulation

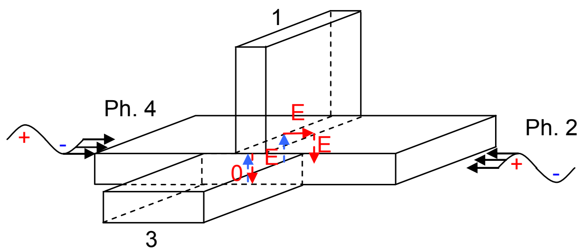


Fig. 4.13b: Magic tee with differential-mode stimulation

If we imagine the physical ports *Ph. 2* and *Ph. 4* as being combined to form a balanced port, the common-mode component of the balanced pair of ports *Ph. 2* and *Ph. 4* is present at port 1, and the differential-mode component is present at port 3. The described behavior of the magic tee is to be verified by means of this measurement.

Step 1: Synchronization and remote control of external generator
Synchronize the R&S®ZVA24 to the 10 MHz reference of the R&S®SMF100A generator. Since the LO frequency has to be tracked during the measurement, a remote connection between the generator (providing the LO frequency of the converters) and the network analyzer is required. In this example, a remote connection is established via the IEC/GPIB bus, using the options R&S®ZVAB-B44 (USB-to-IEC/GPIB adapter) and R&S®SMF-B83 (removable GPIB).[1] After making the connection, you can detect the generator on the network analyzer under *System* | *System Config* | *External Generators* by means of *Refresh Tables*, and add it to the list of configured generators (*Configured:*) by means of *Add v*.

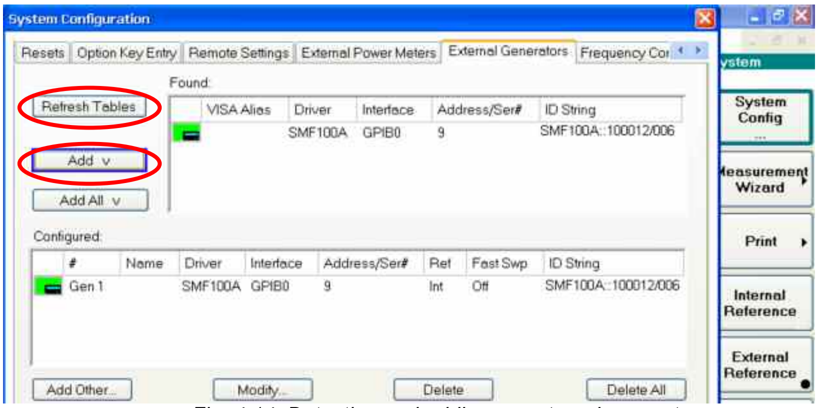


Fig. 4.14: Detecting and adding an external generator

Step 2: Configuring the converters
The converters are configured under *System* | *System Config* | *Frequency Converter* (Fig. 4.15). Select the converter type (*ZVA-Z110* in this case) and the cabling scheme (internal RF, external LO (*RF intern*, *LO extern*) in this case). Activate the setting with *Apply* and terminate the dialog with *Close*.

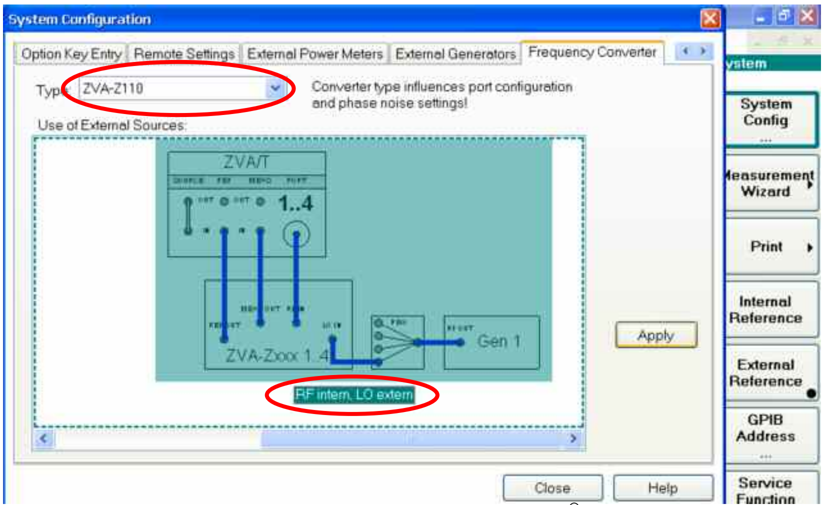


Fig. 4.15: Configuring the converters on the R&S® ZVA

[1] Instead of an IEC/GPIB connection, a LAN connection can be used to link up the generator to the network analyzer. The R&S®ZVAB-B44 and R&S®SMF-B83 options will not be needed in this case. Controlling an external generator takes more time than controlling an internal generator of the network analyzer. To accelerate generator tracking during frequency sweeps, the *TRIGGER* and *BLANK* handshake signals of the generator can be applied to the R&S®ZVA USER CONTROL port in addition to an existing remote-control connection. This makes it possible to use the *List* function to perform sweeps. When this function is used, the network analyzer transfers all frequency points to the generator via the remote connection (GPIB or LAN) prior to the start of the sweep. During the frequency sweep (or repeated frequency sweeps), the handshake signals are used exclusively to switch to the next frequency point.

Step 3: Connecting the converters
The generator delivers the LO signal, which is distributed to all converters as *LO IN* via a four-way power splitter. Test ports 1 to 4 of the network analyzer deliver the RF stimulus signal for the converters, in such a manner that the RF stimulus signal is applied to the converters one at a time, depending on the measurement direction. The IF signals from the converters are fed to the eight direct receiver inputs (4x *REF IN*, 4x *MEAS IN*) of the R&S®ZVA24.

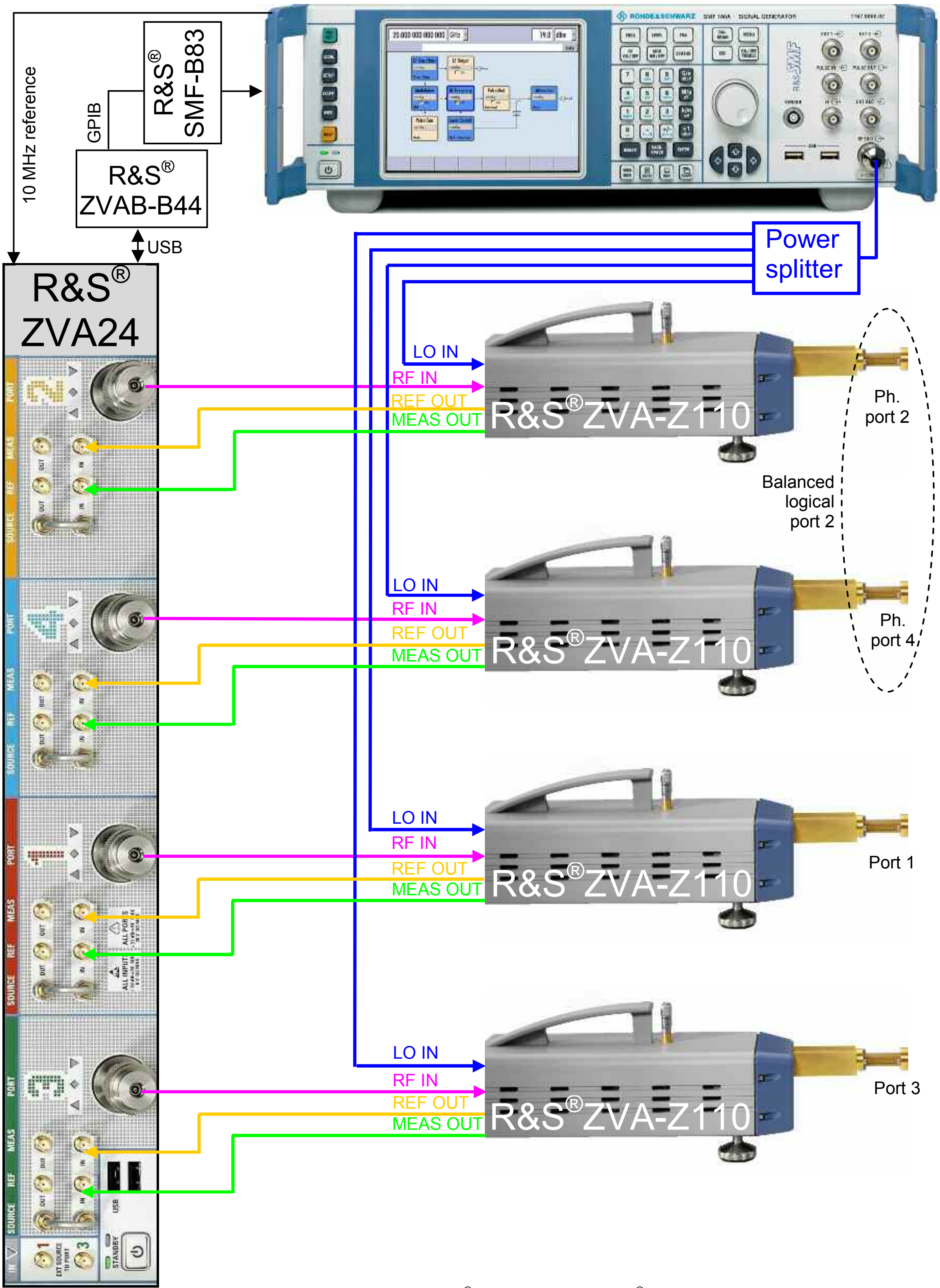


Fig. 4.16: Cabling scheme for an R&S®ZVA24 with four R&S®ZVA-Z110 converters

Step 4: Making the power settings
The optimal LO input power for an R&S®ZVA-Z110 converter is 7 dBm. Since test setups including only one converter – and therefore no power splitter – are also possible, the generator output power is automatically set to 7 dBm in Step 2. In the four-converter configuration discussed here, however, an insertion loss of 12 dB is to be assumed for the four-way power splitter. This means that the generator output power must be increased to 19 dBm. This can be done under *Mode* | *Port Config* on the R&S®ZVA.[1]

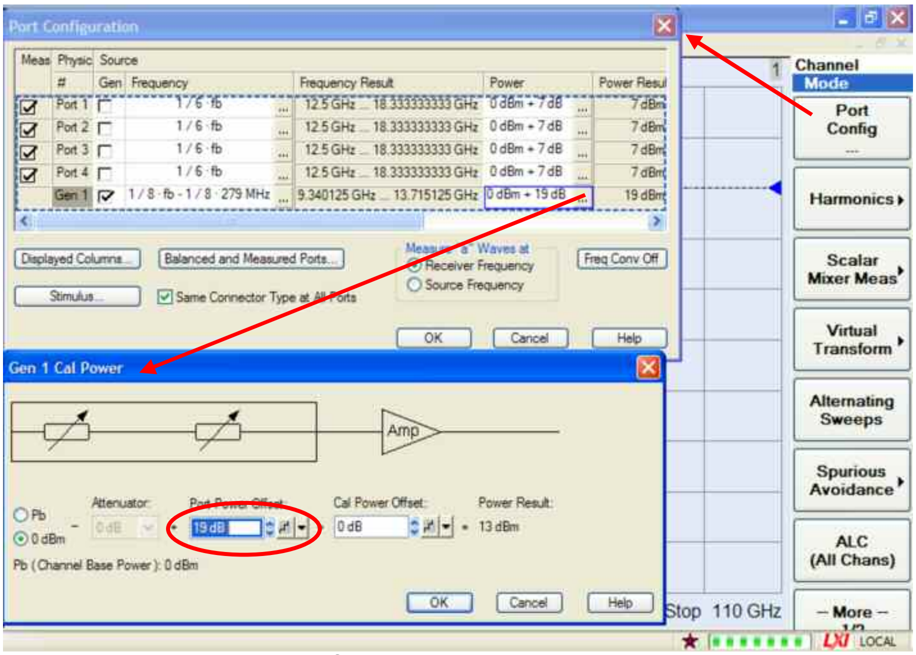


Fig. 4.17: Changing the generator output power

In addition to the generator output power, the output power of the waveguide test ports (on the converters) has to be set. This is done by means of the power adjusting screw provided on each converter (Fig. 4.18). Since compression effects can be excluded for the passive DUT to be measured here, the maximum test port output power will be used. Maximum output power is obtained for all settings > 2 mm of the power adjusting screw. Set all four converters to maximum output power.


Fig. 4.18: Power adjusting screw

Select a measurement bandwidth of 1 kHz or 100 Hz on the R&S®ZVA24.

Step 5: Configuring the test ports for mixed-mode measurements
With the configuration made so far, the four waveguide test ports will be treated as single-ended ports (unbalanced ports). To combine the physical ports 2 and 4 into a balanced logical port, go to the *Balanced and Measured Ports* dialog (Fig. 4.19). It can be accessed as follows: *Meas* | *More S-Params* | *Balanced and Measured Ports*.

[1] The generator output power may be increased to the above value only if a power splitter with the stated insertion loss is used. If a Wilkinson divider, which has a lower insertion loss, is used for distributing the generator LO signal, a lower power value has to be selected to avoid damage to the converters caused by high input power.

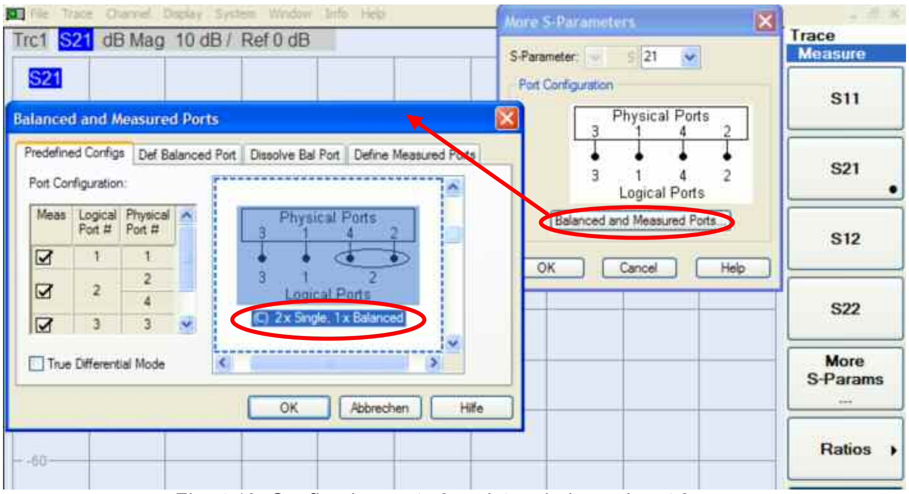


Fig. 4.19: Configuring ports 2 and 4 as balanced port 2

Under *Predefined Configs*, select the configuration shown in Fig. 4.19. The measurements are carried out in virtual differential mode. In this mode, the network analyzer actually performs single-ended measurements of the S-parameters. Advantageously, calibration (Step 6) can therefore be carried out using the familiar waveguide calibration standards. The S-parameters are converted to balanced quantities only for the display of results. Select the S_{sd12}, S_{sc12}, S_{sd32}, and S_{sc32} S-parameters as measured quantities. If necessary, create traces for these parameters by means of *Trace Select | Add Trace*.

Step 6: Calibration

To ensure that system errors are eliminated when performing the S-parameter measurements, the test setup is to be calibrated. This is done using the R&S®ZV-WR10 calibration kit. Open the dialog shown in Fig. 4.6 (page 11). Under *Calibrate Ports*, select test ports 1 to 4. Select UOSM as the calibration technique – reasons for this are given in section 4.1, Step 3 (page 10, last paragraph). Mount the one-port calibration standards shown in Fig. 4.7 to each of the four test ports one at a time and measure them. The one-port standards include a *Short*, an *Offset Short* (made up of a *Short* and a *Shim*), and a *Fixed Match*.

The direct *Through* between the physical test ports 2 and 4 is established by directly screwing together the two waveguide test ports (see Fig. 4.7).

The *Through* standard between the physical test ports 4 and 3, and 3 and 2, can be established by using an H-plane bend, similar as shown in Fig. 4.8a/b.

The *Through* standard between the physical test ports 4 and 1, and 2 and 1, is established by means of an E-plane bend. From the red arrows in Figs 4.20a and 4.20b below it can be seen that the two *Through* standards are not equivalent. The E-plane bend involves a rotation of the polarization of the E-field by +90° and –90°, respectively. The polarization directions obtained at test port 1, therefore, differ by 180°. However, in addition to a fixed reference plane that has to be observed for all standards in a test setup, waveguide calibration standards also must fulfill the requirement of a uniform polarization direction[1].

[1] By example: Coaxial calibration standards, implicitly meet the requirement of uniform polarization direction because of their radially symmetric fields. This requirement is, therefore, unknown with coaxial standards.

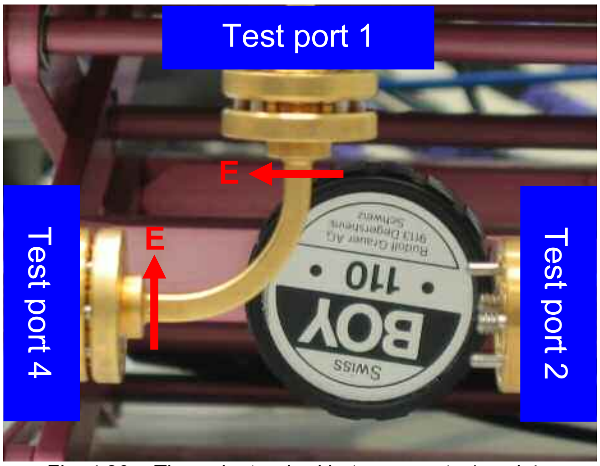


Fig. 4.20a: Through standard between ports 1 and 4

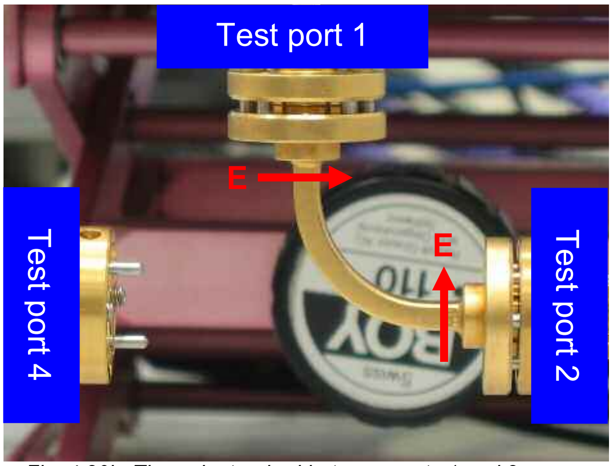


Fig. 4.20b: Through standard between ports 1 and 2

The *Through* standards shown in Figs 4.20a and 4.20b violate the requirement of uniform polarization direction. To remedy this, there are basically three approaches:

- Turn test port 2 by 180°, meaning that the top of the related R&S®ZVA-Z110 converter has to be situated downwards
- Complementing the *Through* standard in Fig. 4.20b by a 180° twist
- Taking into account the polarization rotation as a frequency-independent 180° phase offset when evaluating the error terms from the calibration measurement.

The first two approaches will not work for mechanical reasons. The use of the UOSM technique for waveguide calibration involves an inherent 180° phase ambiguity as discussed in section 4.1, Step 4. Therefore, you have to activate *Dispersive* for all *Through* standards listed in the dialog in Fig. 4.21 (for reasons see text accompanying Fig. 4.9, page 12). The dialog comes up after all calibration measurements have been completed.

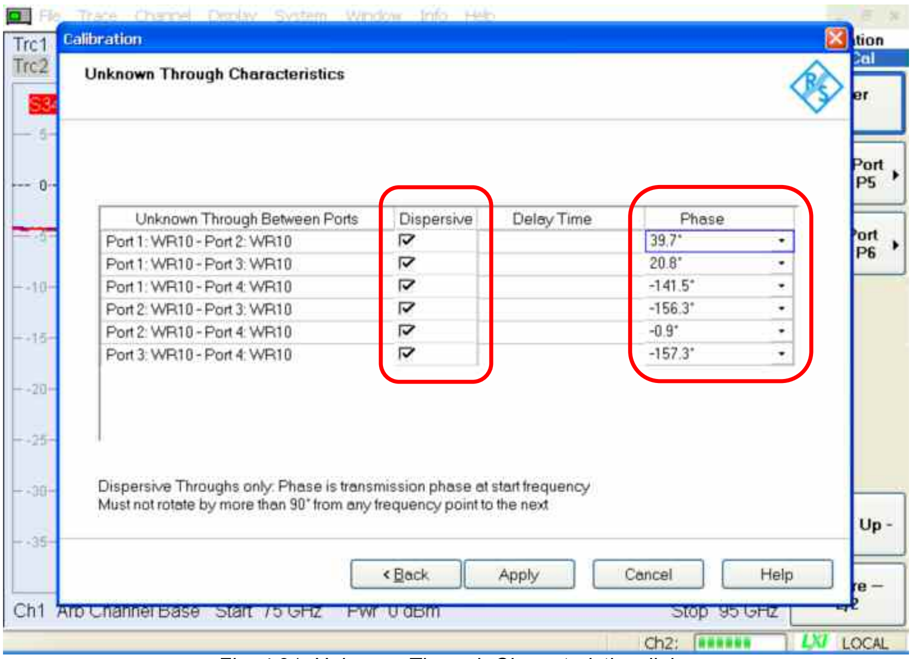


Fig. 4.21: Unknown Through Characteristics dialog

For each *Unknown Through*, select the appropriate phase value from the two values offered. In a preliminary measurement using a calibrated two-port test setup, the following phase values were obtained at 75 GHz: 20° for *Through* 1-3, –140° for *Through* 1-4, and 157° for *Through* 2-3. Some values can also be derived by way of conclusion: For the direct *Through* between ports 2 and 4 (Fig. 4.7), for example, the phase value is 0°. For the *Through* standards between ports 1 and 4, and 1 and 2, a 180° phase difference should be obtained because of the polarization rotation discussed above. For the *Through* standards between ports 2 and 3, and 3 and 4, identical phase values should be obtained.

Step 7: Connecting the DUT

Mount the magic tee between the configured and calibrated test ports as shown in Fig. 4.22.

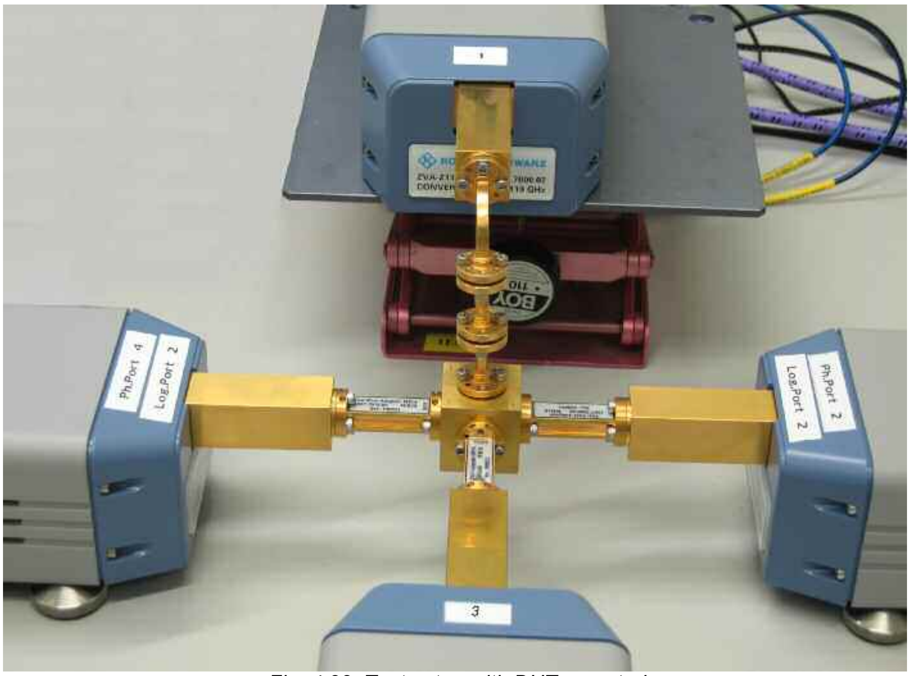


Fig. 4.22: Test setup with DUT mounted

The results obtained for the S_{sd12}, S_{sc12}, S_{sd32}, and S_{sc32} mixed-mode S-parameters largely substantiate the expected behavior.

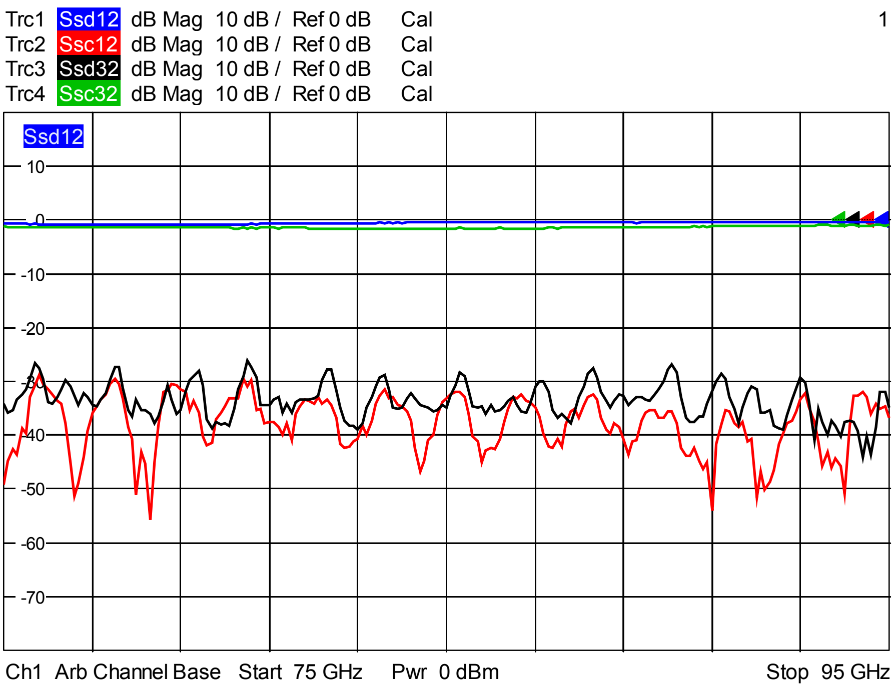


Fig. 4.23: Results obtained for the S_{sd12}, S_{sc12}, S_{sd32}, and S_{sc32} mixed-mode S-parameters

It becomes obvious that a magic tee cannot be implemented 100% lossless (a loss of ≈ 1 dB is obtained for S_{sd12} and S_{sc32}), and that the (unwanted) S_{sd32} and S_{sc32} quantities obtained after mode conversion can be suppressed only to a limited extent. In addition to the mixed-mode parameters, S-parameters based on single-ended measurements are also of interest, e.g. the isolation between the unbalanced ports 1 and 3, or the return loss at each of the unbalanced ports 1 and 3.

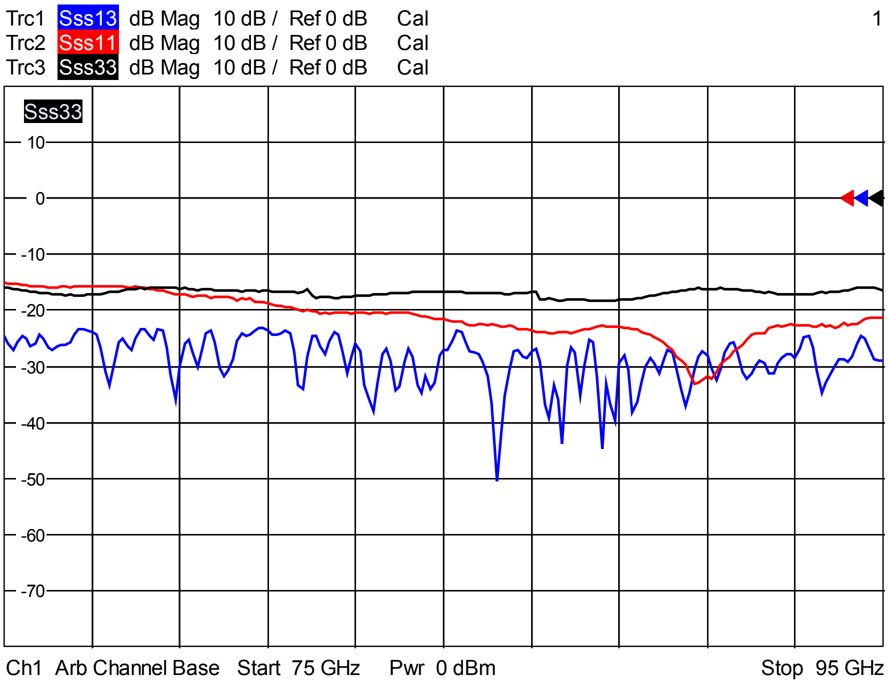


Fig. 4.24: Results of selected unbalanced measurements: isolation between ports 1 and 3, matching at ports 1 and 3

5. Attachment

5.1 General Information

The information given in the following is meant to help you reproduce the discussed measurement examples as accurately as possible and to avoid errors. It is not meant to replace the relevant instrument documentation.

- Waveguide flanges are high-precision mechanical components that may be damaged by improper handling, for example by cocking of the flanges relative to each other. Make sure, therefore, to set up the test equipment on an even and stable surface. Flanges must be properly aligned relative to each other before they are mounted.
- Do not operate the converters above their maximum permissible input power otherwise they may be damaged. Therefore, prior to making the RF and LO connections to the converters, make sure that their maximum specified input power *i*s not exceeded. Prior to connecting the converters, you should always select the correct converter type and cabling scheme in the *Frequency Converter* configuration dialog (see Fig. 4.2), and activate the setting with *Apply*.
- The converters operate on the principle of frequency multiplication. Along with the frequencies of the RF and the LO signal, any phase errors of these signals will be multiplied, too. Phase errors may result, for example, from the use of unsuitable cables for the RF and LO connections. By contrast, the IF signals, which have a frequency of approx. 300 MHz, can be considered uncritical in this respect.

- Another avoidable cause of phase errors is the improper mounting of coaxial connectors. A suitable torque wrench should therefore be used for mounting the connectors.
- Temperature fluctuations inevitably lead to phase drift due to the longitudinal expansion of the coaxial cables (RF, LO) and waveguide components. High temperature stability is therefore a vital prerequisite for performing high-accuracy millimeter-wave measurements.

5.2 Typical Waveguide Sections

The following table shows some typical waveguide sections and typical waveguide components.

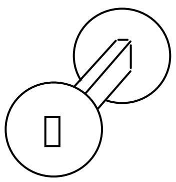
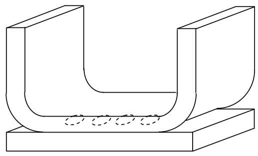
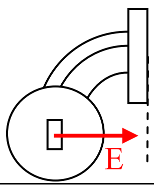
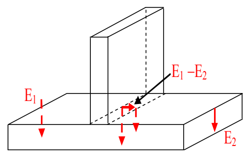
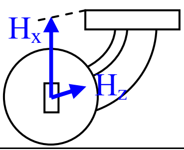
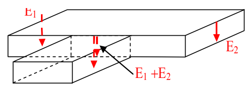
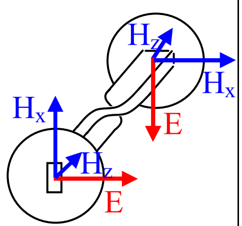
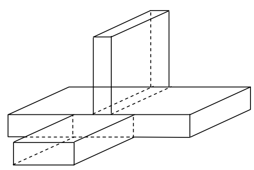
Two-port		Multiport	
Designation / drawing	Explanation	Designation / drawing	Explanation
Straight section 	Typical are lengths in integer inch numbers, e.g. 1 in (25.4 mm), 2 in (50.8 mm), etc	Directional coupler 	In waveguide technology, directional couplers can be implemented as multihole couplers, for example. Other forms, e.g. crossguide couplers, are also commonly found in waveguide technology.
E-plane bend, 90° 	An E-plane bend is bent along its wide side.	E-plane tee 	With an E-plane tee, the signal is coupled out on the wide side of the waveguide.
H-plane bend, 90° 	An H-plane bend is bent along its narrow side.	H-plane tee 	With an H-plane tee, the signal is coupled out on the narrow side of the waveguide.
Twist, 90° 	A twist involves a rotation of the waveguide cross section, e.g. by 90°. Along with the cross section, the electromagnetic field components inside the waveguide are rotated.	Magic tee 	The magic tee is a combination of an E-plane tee and an H-plane tee (see also measurement example in section 4.2).

Table 5.1: Typical waveguide sections

The designations "E-plane bend / tee" and "H-plane bend / tee" are based on the orientation of the electric field (E-field) or the magnetic field (H-field) inside a waveguide. To illustrate this, a few selected electric and magnetic field lines have been entered as arrows in the drawings. These field lines are meant as examples only, since the E- and the H-field vary as a function of locus and time. Moreover, it is assumed that the waveguides operate in their intended frequency bands. The characteristics of the E- and the H-plane tee can be explained based on the E-field. The E-plane tee thus corresponds to a series connection, and the H-plane tee to a parallel connection. Because of these characteristics, the E-plane tee, the H-plane tee, and the magic tee shown in the table would normally exhibit mismatch at their ports. The mismatch can be reduced by using a modified waveguide design.

6. References

[1] "R&S®ZVA-Z110 Converter WR10 Specifications", Rev. 01.00, Rohde & Schwarz GmbH & Co. KG, June 2007

[2] Kerr, A. R., Wollack, E., and Horner, N.: "ALMA Memo No. 278: Waveguide Flanges for ALMA Instrumentation"; ALMA/National Radio Astronomy Observatory, Nov. 1999

[3] "Quick Start Guide: R&S®ZVA-Z110 Converter WR10", Rev. 1.0, Rohde & Schwarz GmbH & Co. KG, June 2007

[4] Hiebel, Michael: "Fundamentals of Vector Network Analysis", Rohde & Schwarz GmbH & Co. KG, 2nd Edition, 2007, ISBN 978-3-939837-06-0

[5] Hiebel, Michael: "Application Note 1EZ55: Millimeter-Wave Measurements Using Converters of the R&S®ZVA Family", Rohde & Schwarz GmbH & Co. KG, 2007

7. Ordering information

Measurement example, section 4.1

3	Converters WR10	R&S®ZVA-Z110	75 GHz to 110 GHz	1307.7000.02
6	Test Port Cables, 965 mm, 3.5 mm (f)/3.5 mm (m)	R&S®ZV-Z193	0 Hz to 26.5 GHz	1306.4520.36
1	Waveguide Calibration Kit WR10	R&S®ZVA-WR10	without Sliding Match	1307.7100.10
1	Vector Network Analyzer, 20 GHz, 2 ports	R&S®ZVT20		1300.0000.20
1	Additional Port 3 for R&S®ZVT20 (option)	R&S®ZVT20-B63		1300.1606.03
1	Additional Port 4 for R&S®ZVT20 (option)	R&S®ZVT20-B64		1300.1606.04
1	Additional Port 5 for R&S®ZVT20 (option)	R&S®ZVT20-B65		1300.1606.05
1	Additional Port 6 for R&S®ZVT20 (option)	R&S®ZVT20-B66		1300.1606.06
1	Direct Generator/Receiver Access for port 1 (option)	R&S®ZVT20-B16		1300.1635.11
1	Direct Generator/Receiver Access for port 2 (option)	R&S®ZVT20-B16		1300.1635.12
1	Direct Generator/Receiver Access for port 3 (option)	R&S®ZVT20-B16		1300.1635.13
1	Direct Generator/Receiver Access for port 4 (option)	R&S®ZVT20-B16		1300.1635.14
1	Converter Control Software (option)	R&S®ZVA-K8		1307.7022.02

Additional equipment required:

Wilkinson divider, SMA/3.5 mm, frequency range min. 9 GHz to 14 GHz (e.g. MECA Electronics model 802-2-10.500-M01, or MECA Electronics model 802-2-11.500-M01, or a similar product)

Measurement example, section 4.2

4	Converters WR10	R&S®ZVA-Z110	75 GHz to 110 GHz	1307.7000.02
8	Test Port Cables, 965 mm, 3.5 mm (f)/3.5 mm (m)	R&S®ZV-Z193	0 Hz to 26.5 GHz	1306.4520.36
1	Waveguide Calibration Kit WR10	R&S®ZVA-WR10	without Sliding Match	1307.7100.10
1	Vector Network Analyzer, 24 GHz, 4 ports	R&S®ZVA24	10 MHz to 24 GHz	1145.1110.26
1	Direct Generator/Receiver Access (option)	R&S®ZVA24-B16		1164.0209.26
1	Converter Control Software (option)	R&S®ZVA-K8		1307.7022.02
1	USB-to-IEC/GPIB Adapter (option)	R&S®ZVAB-B44		1302.5544.02
1	Microwave Signal Generator	R&S®SMF100A		1167.0000.02
1	Frequency Range 1 GHz to 22 GHz (option)	R&S®SMF-B122	1 GHz to 22 GHz	1167.7004.02
1	High Output Power 1 GHz to 22 GHz (option)	R&S®SMF-B31	1 GHz to 22 GHz	1167.7404.02
1	Removable GPIB (option)	R&S®SMF-B83		1167.6408.02

Additional equipment required:

Four-way power divider, SMA/3.5 mm (e.g. Weinschel/Aeroflex model 1594A) or, alternatively, three two-port power splitters (e.g. 3x Weinschel/Aeroflex model 1579), which are to be cascaded so that the two outputs of the first power splitter feed the other two power splitters.

For all ordering information please note:

Cables with ruggedized connectors (e.g. R&S®ZV93, 1301.7595) cannot be used for connecting the R&S® ZVA to the R&S®ZVA-Z110 converters because of the large dimensions of these connectors.

ROHDE & SCHWARZ GmbH & Co. KG · Mühldorfstraße 15 · D-81671 München · P.O.B 80 14 69 · D-81614 München ·
Telephone +49 89 4129 -0 · Fax +49 89 4129 - 13777 · Internet: http://www.rohde-schwarz.com