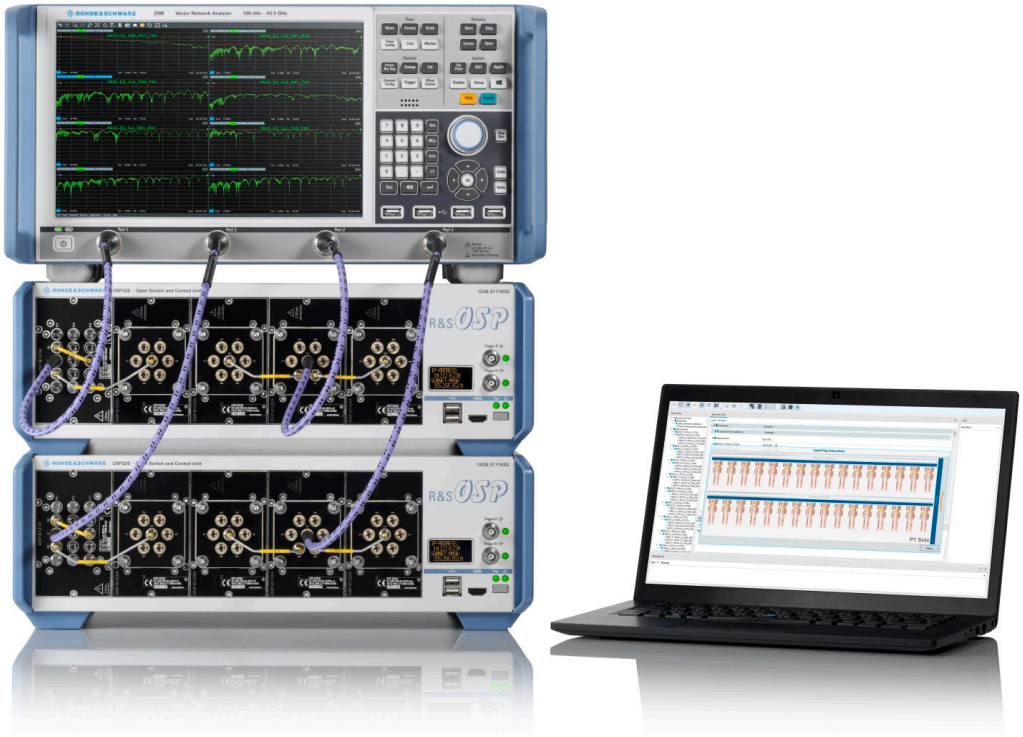
# R&S®ZNrun-K4xx
# Compliance Test Automation for High Speed Digital Interfaces with R&S®ZNrun V2.90
# User Manual



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Version 06

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Make ideas real

This document describes the following R&S®ZNRUN-Kxx options:

- R&S®ZNRUN-K410 "Compliance test automation for high-speed Ethernet IEEE 802.3bj/by/cd" (1332.6010.02)
- R&S®ZNRUN-K411 "Compliance test automation for high-speed Ethernet IEEE 802.3ck" (1332.6026.02)
- R&S®ZNRUN-K440 "Compliance test automation for PCIe 5.0 and 6.0 cable assemblies" (1332.5965.02)

Options R&S®ZNRUN-K4xx are available as **local licenses** (suffix **.02**, as stated above) and **floating licenses** (suffix **.51**).

Each of these options includes software maintenance for the first year after purchase. Dedicated maintenance options prolong the maintenance period for additional flexibility:

- R&S®ZNRUNMK410 "Software maintenance for R&S®ZNRUN-K410" (1332.6061.81)
- R&S®ZNRUNMK411 "Software maintenance for R&S®ZNRUN-K411" (1332.6078.81)
- R&S®ZNRUNMK440 "Software maintenance for R&S®ZNRUN-K440" (1332.5965.81)

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Muehldorfstr. 15, 81671 Muenchen, Germany
Phone: +49 89 41 29 - 0
Email: info@rohde-schwarz.com
Internet: www.rohde-schwarz.com
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1179.6350.02 | Version 06 | R&S®ZNrun-K4xx

Throughout this manual, products from Rohde & Schwarz are indicated without the ® symbol, e.g. R&S®ZNrun is indicated as R&S ZNrun.

# 1 System overview

Testing high-speed cable assemblies for data centers or consumer electronics, requires high frequencies and a multi-port setup. Characterizing the cable under test with a 4-port vector network analyzers is a time-consuming process: Executing different characterization tests for every lane (or combination of lanes) in a cable assembly, requires many cable reconnections, with many chances for human errors.

Options R&S ZNrun-K4xx enable precise and time-saving compliance tests of high-speed cable assemblies (and connectors), in line with the relevant standards. Each compliance test defines three simple steps for the test procedure: Setup, calibrate and measure. The automated measurement step is time-optimized and ensures reproducibility of results.

The multi-port setup, based on the R&S OSP open switch and control platform, enables up to 256 ports switching without manual port reconnection. This setup reduces the typical test time drastically. For example, the test time for a high-speed Ethernet cable with 8 lanes in line with IEEE 802.3cd, is reduced to one hour compared to one day with manual testing.

Starting with version 2.80, the ZNrun Server automatically configures the required R&S OSP paths when executing one of the predefined compliance test projects.

The implemented calibration algorithms are optimized for maximum speed and minimum number of reconnections. This optimization reduces user's effort and allows time saving. For example, the calibration of the 48-port setup for IEEE 802.3cd cables with 8 lanes, takes maximally 45 minutes instead of several hours. User guidance during calibration and measurement minimizes the risk of human error and increases the confidence in the test results.

The full compliance test automatically executes all required measurement steps and post-processes the measured data according to the standard. It exports both raw and processed measurement data and generates a comprehensive test report, including the measurement results and the overall pass/fail verdict. The exported measurement data allow you to do further analysis and custom postprocessing.

**Development and precompliance testing**

Since R&S ZNrun V2.90 it is possible to select and configure the test cases to be executed. You can now customize the tests according to your needs for development purposes and precompliance testing.

# 2 R&S ZNrun

## 2.1 Introduction

R&S ZNrun is a PC-based software suite for the definition, configuration and execution of automated VNA tests. It controls the involved measurement devices (VNAs, switch matrices, calibration units) and supports many Rohde & Schwarz instruments. A plug-in interface is provided to control additional measurement equipment and devices under test via custom remote control connections.

R&S ZNrun stands for modularity, extensibility, compatibility and optimized speed of measurement execution. Therefore it is ideal for use in high volume production of multiport devices requiring control during test, e.g. for testing the RF properties in various operating states.

Setting up R&S ZNrun for testing is as simple as describing the test setup (test equipment, DUTs) and defining the test sequence. Configurations are modular and reusable and therefore minimize your configuration time. Based on the configuration, R&S ZNrun calculates a connection plan, which is optimized for both quality and measurement speed. It also calculates an initialization sequence, calibration plan and a speed-optimized test plan. At execution time, R&S ZNrun verifies that the measurement can be performed with the connected measurement equipment.

R&S ZNrun comes with the following applications:

- **ZNrun Server**
  The core of the software suite. Runs and manages Measurement Execution Units (MEUs). A plug-in interface enables user-defined extensions, such as custom devices and post processors.
- **ZNrun Workbench**
  The main graphical user interface (GUI) of R&S ZNrun. Allows you to develop, test and tune a MEU, before it is used in the production field. Can deploy the MEU to a ZNrun Server and communicate with the server during MEU execution. Integrates or gives access to the other R&S ZNrun applications (ZNrun Calibration Client, ZNrun Measurement Client, ZNrun Visualization Client).
- **ZNrun Calibration Client**
  The ZNrun Calibration Client guides a technician through all the steps of the calibration process. For laboratory use, it offers a more advanced interface, which allows definition of user-defined calibration tasks. It is available as a stand-alone application and integrated in the ZNrun Workbench.
- **ZNrun Measurement Client**
  An application for controlling the execution of a MEU on a ZNrun Server. Provides a graphical and a remote control interface (SCPI commands). A plug-in interface enables user-defined extensions, such as the creation of custom log files and reports.
- **ZNrun Visualization Client**

The ZNrun Visualization Client allows you to visualize and document measurement results. It is available as a stand-alone application and integrated in the ZNrun Workbench.

- **ZNrun Cable Test Client**
  The ZNrun Cable Test Client allows even more streamlined measurements with predefined MEUs. This client is particularly useful if the user has to measure a multitude of DUTs (e.g. cables), where standard measurements and appropriate calibrations are requested.

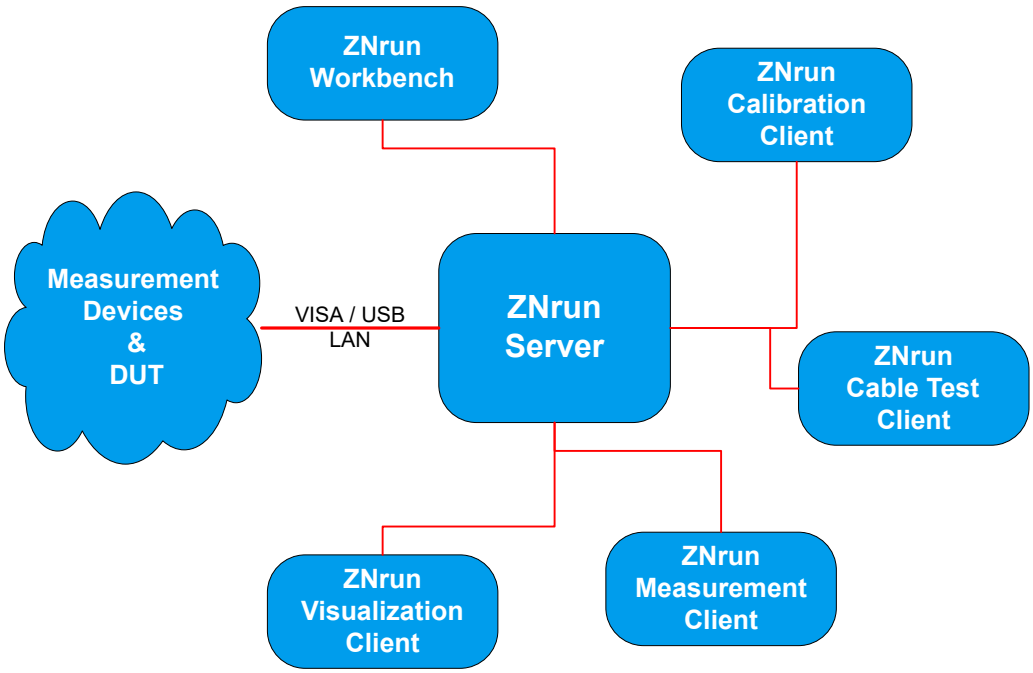



*Figure 2-1: R&S ZNrun*

## 2.2 Required software and licenses

**Basic requirements**

You can download the R&S ZNrun software suite free of charge from the Rohde & Schwarz website. Without purchasing any licenses, you can use the ZNrun Workbench application to:

- Create or modify existing R&S ZNrun measurement projects (defining ports, stimuli, VNA devices etc.)
- Save your work and share it with your colleagues

To execute a measurement project, you need at least license R&S ZNrun-K1 on the ZNrun Server.


**Licenses for automated cable tests**

Currently, the following licenses are available:

- R&S ZNrun-K410 "Compliance test automation for high-speed Ethernet according to IEEE 802.3bj, 802.3by and 802.3cd"
- R&S ZNrun-K411 "Compliance test automation for high-speed Ethernet according to IEEE 802.3ck"
- R&S ZNrun-K440 "Compliance test automation for PCIe 5.0 and 6.0 cable assemblies"

# 3 Test equipment

## 3.1 Vector network analyzer

At the heart of the test setup, there is a network analyzer of the R&S ZNB or R&S ZNA family.

### R&S ZNB

The R&S ZNB is ideal for developing, producing and servicing RF components such as cables, filters, mixers and amplifiers. Its model-specific frequency ranges of 9 kHz to 4.5/8.5 GHz and 100 kHz to 20/26.5/40/43.5 GHz are designed for mobile radio, electronic goods as well as aerospace and defense applications. The R&S ZNB can also be used in aerospace and defense applications, and for high-speed printed circuit board design.


For more information, see the R&S ZNB product pages at https://www.rohde-schwarz.com/product/znb.

### R&S ZNA

The R&S ZNA vector network analyzers are the high-end series of the R&S VNA portfolio: excellent RF-performance is combined with a wide range of software features and a unique hardware concept. The touch-only operation together with the DUT-centric approach makes the R&S ZNA to a powerful, universal and compact measurement system for characterizing both passive and active devices.

For more information, see the R&S ZNA product pages at https://www.rohde-schwarz.com/product/zna.

### 3.1.1 Recommended / supported models for R&S ZNrun-K41x

All predefined R&S ZNrun projects for IEEE 802.3 cable conformance tests require a **4-port VNA**. The recommended VNA model was selected according to the frequency range to be covered.

For the recommended instruments, Rohde&Schwarz offers suitable connection cables between VNA and switch matrix.

Compared to manual compliance testing, for automated tests using R&S ZNrun-K41x the following R&S ZNB and R&S ZNA models are supported.

***Table 3-1: R&S ZNrun-K41x automated IEEE 802.3 cable assembly tests – supported VNAs***

| | **R&S ZNrun-K410**<br>**IEEE 802.3bj-2014, IEEE 802.3by-2016** | **R&S ZNrun-K410**<br>**IEEE P802.3cd-2018** | **R&S ZNrun-K411**<br>**IEEE P802.3ck-2022** |
|---|---|---|---|
| | **compliance** | **compliance** | **compliance / precompliance** |
| **R&S ZNB26**<br>4 ports 2.92 mm (m)<br>100 kHz to 26.5 GHz<br>order no. 1334.3330.65 | ✓ (recommended) | ✓ (recommended) | – / – |
| **R&S ZNB40**<br>4 ports 2.92 mm (m)<br>100 kHz to 40 GHz<br>order no. 1334.3330.84 | ✓ | ✓ | – / – |

| | R&S ZNrun-K410<br>IEEE 802.3bj-2014, IEEE 802.3by-2016 | R&S ZNrun-K410<br>IEEE P802.3cd-2018 | R&S ZNrun-K411<br>IEEE P802.3ck-2022 |
|---|---|---|---|
| | **compliance** | **compliance** | **compliance / precompliance** |
| **R&S ZNB43**<br>4 ports 2.92 mm (m)<br>100 kHz to 43.5 GHz<br>order no. 1334.3330.94 | ✓ | ✓ | – / ✓ (recommended) |
| **R&S ZNA50**<br>4 ports 2.4 mm (m)<br>10 MHz to 43.5 GHz<br>order no. 1332.4500.54 | – | – | ✓ (recommended) / – |
| **R&S ZNA67**<br>4 ports 1.85 mm (m)<br>10 MHz to 43.5 GHz<br>order no. 1332.4500.64 | – | – | ✓ / – |

- R&S ZNB and R&S ZNA models that are not mentioned in this table cannot be used with the predefined R&S ZNrun projects for IEEE P802.3 compliance or pre-compliance testing.
- For R&S ZNrun-K411 compliance tests on 8-lane cables, the paging file size of the R&S ZNA must be set to 50 GB.

### 3.1.2 Recommended / supported models for R&S ZNrun-K440

All predefined R&S ZNrun projects for PCIe cable conformance tests require a **4-port VNA**. According to the PCIe standard specification, the conformance tests must cover frequencies up to 24 GHz. In addition, the specification requires an accurate deembedding of the test fixtures, which, from the experience of Rohde & Schwarz and other industry experts, requires frequencies above 26.5 GHz. For this reason, the recommended VNA for PCIe cable conformance tests is a 4-port R&S ZNB43.

The following R&S ZNB and R&S ZNA models are supported.

- **R&S ZNB43** (recommended)
  4 ports 2.92 mm (m), 100 kHz to 43.5 GHz, order no. 1334.3330.94
- **R&S ZNB40**
  4 ports 2.92 mm (m), 100 kHz to 40 GHz, order no. 1334.3330.84
- **R&S ZNB26**
  4 ports 2.92 mm (m), 100 kHz to 26.5 GHz, order no. 1334.3330.65
- **R&S ZNA**
  All 4-port models (see https://www.rohde-schwarz.com/product/zna#models)

- For the recommended 4-port R&S ZNB43, Rohde & Schwarz offers suitable connection cables between VNA and switch matrix.
- R&S ZNB models that are not mentioned above cannot be used with the predefined R&S ZNrun projects for PCIe compliance testing.

## 3.2 Switch matrix R&S OSP

The modular R&S OSP open switch and control platform can be used to perform RF switch and control tasks quickly and easily. All R&S OSP models can be remotely operated via Ethernet.

### 3.2.1 Base unit R&S OSP320

The R&S OSP320 base unit (order no. 1528.3111K02) that is used for the automated cable tests, is 3 rack units high. It can accommodate up to 10 switch modules, 5 on the front and 5 on the rear side.

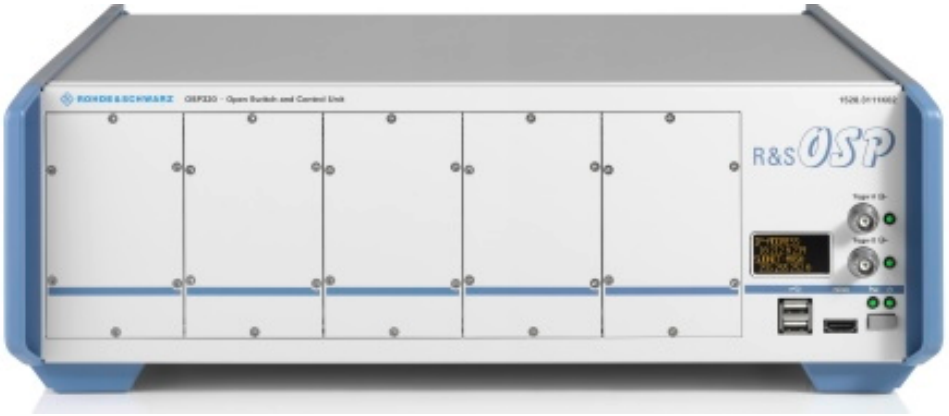



*Figure 3-1: R&S OSP320 base unit, front panel*

For the predefined automated cable tests, we only use the front side module slots.

### 3.2.2 Switch modules

The predefined configurations for automated cable tests use the following switch modules.

**R&S OSP-B121**

- **H**igh frequency variant R&S OSP-B121**H**,
  **3 × SPDT**, terminated, DC to 40 GHz, 2.92 mm, order no. 1515.5504.40
- **U**ltra-high frequency variant R&S OSP-B121**U**,

**2 × SPDT**, terminated, DC to 50 GHz, 2.4 mm, order no. 1515.5504.52

**R&S OSP-B122**

- 1 × SP6T, terminated
- **H**igh frequency variant R&S OSP-B122**H**,
  DC to 40 GHz, 2.92 mm, order no. 1528.1525.02
- **U**ltra-high frequency model R&S OSP-B122**U**,
  DC to 50 GHz, 2.4 mm, order no. 1528.1525.51

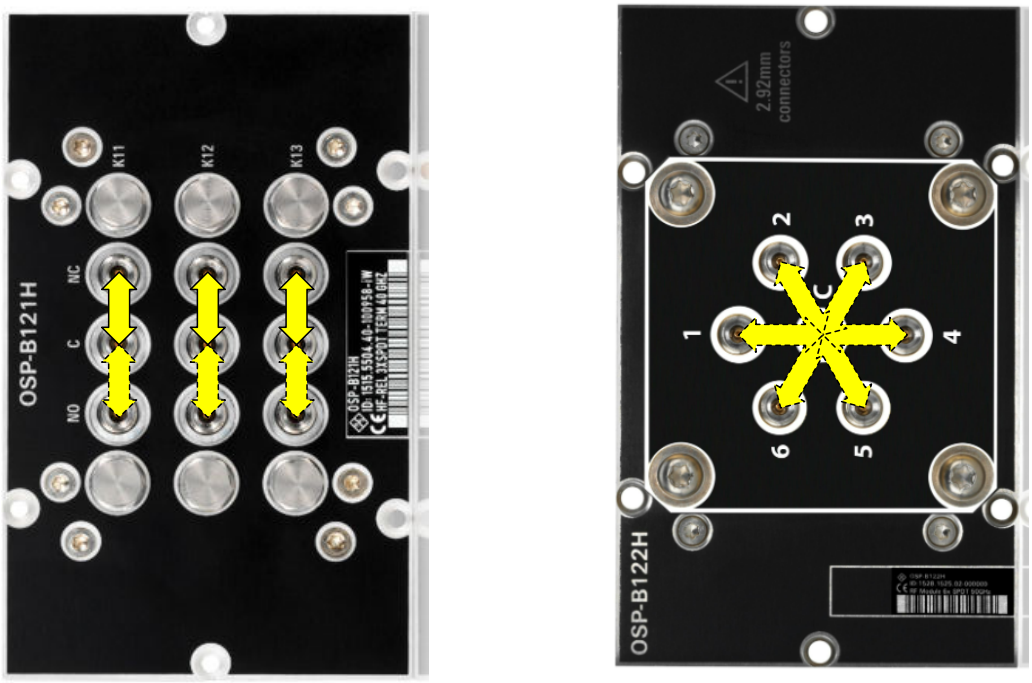



*Figure 3-2: R&S OSP-B121H (left) and R&S OSP-B122H (right) with connectivity*

- For the R&S OSP-B121U variant with 2 x SPDT, the rightmost port group is not available. The connectivity of the other two is identical to the R&S OSP-B121H.
- The appearance and connectivity of R&S OSP-B122H and B122U are similar.

For easier assembly of RF cables, we recommend using an R&S SMA-WRENCH, order no. 1528.1590.02.

### 3.2.3 Combined 1:n switches

By combining several switch modules using external cables, it is possible to connect one source port to 8 or more destination ports:

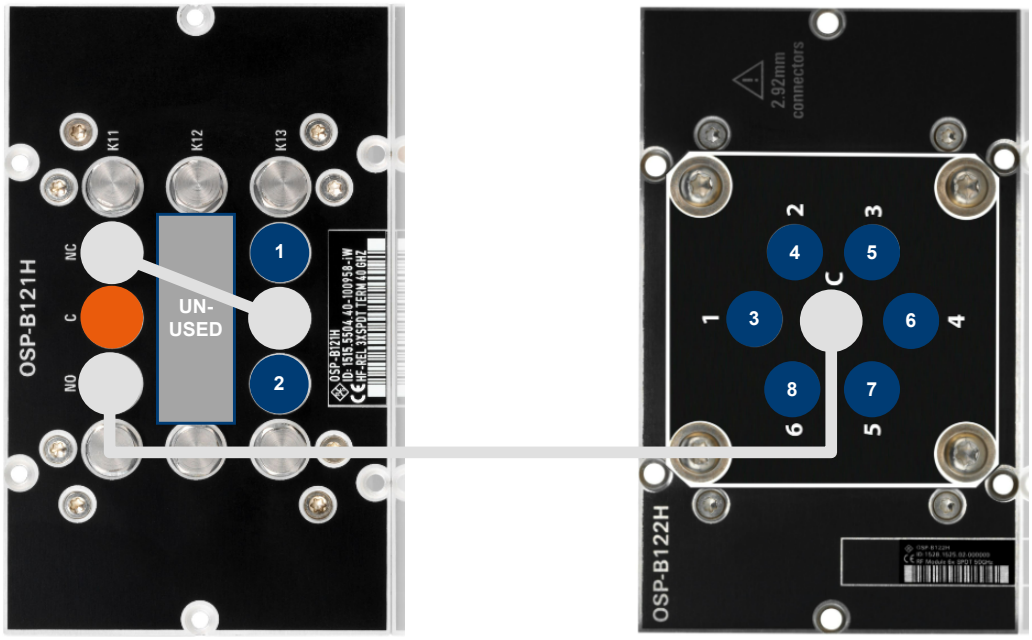



*Figure 3-3: Combined 1:8 switch (single R&S OSP320)*

Left = R&S OSP-B121H/U
Right = R&S OSP-B122H/U

For the R&S OSP-B121U variant with 2 x SPDT, the rightmost port group is not available. For this variant, the port group in the middle takes the role of the rightmost port group in the drawing above.

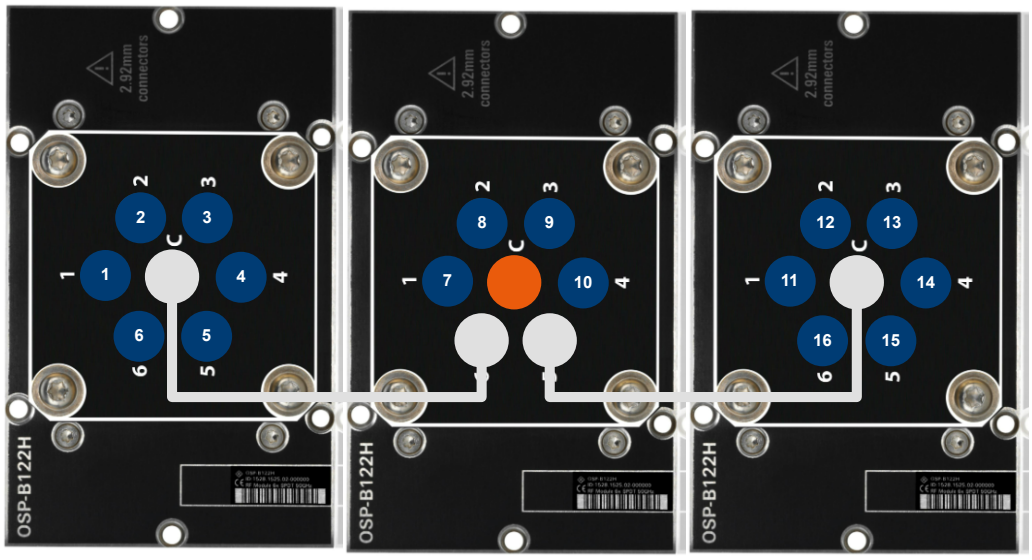



*Figure 3-4: Combined 1:16 switch (single R&S OSP320)*

A 1:n switch can also be combined from switch modules residing in different base units:

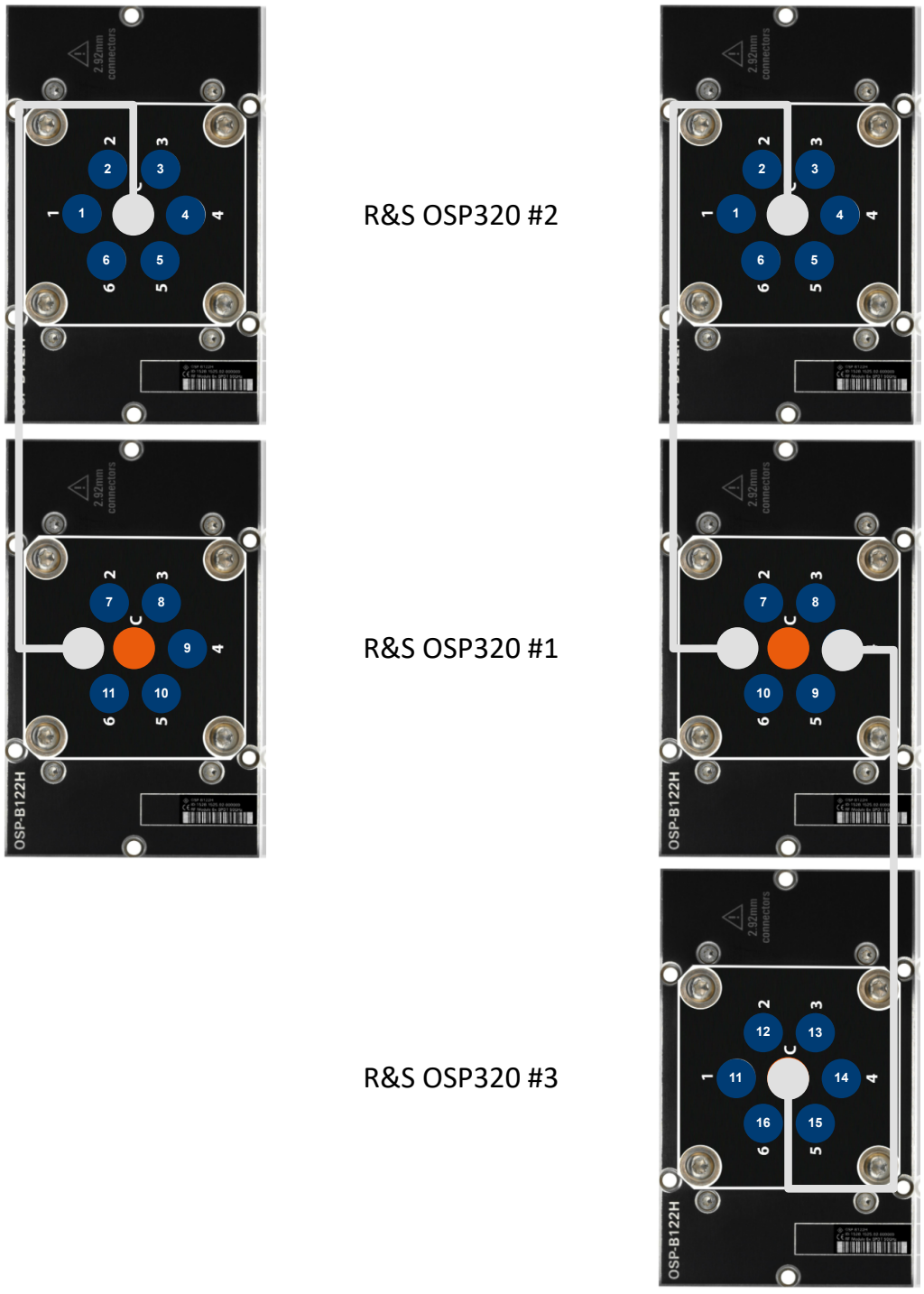



***Figure 3-5: Other combined switches (multiple R&S OSP320)***

Left = 1:11 (2 x R&S OSP320)
Right = 1:16 (3 x R&S OSP320)

### 3.2.4 Multiport solutions for automated cable testing

The multiport solutions for automated cable tests comprise predefined switch matrices, based on 1, 2 or 3 R&S OSP320. Each of these R&S OSP320 is equipped with certain switch modules and/or combined 1:n switches at particular front slots.

#### 8-port solution

The 8-port solution consists of a single 4:8 switch matrix:


***Figure 3-6: 8-port solution based on 1 x R&S OSP320***

Front slots 1 and 4 = Switch modules R&S OSP-B121

#### 24-port solution

The 24-port solution consists of two 2:12 switch matrices:

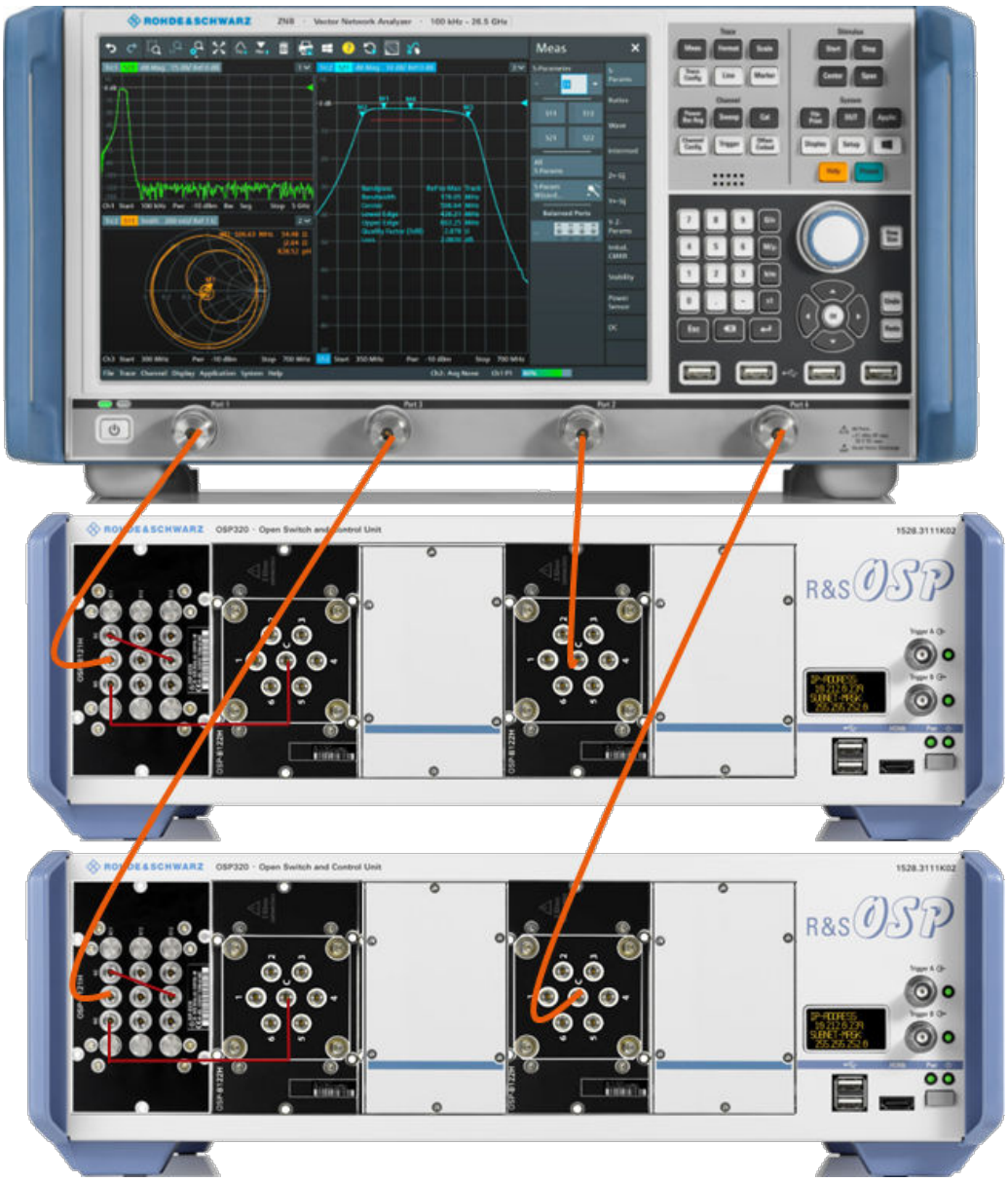



***Figure 3-7: 24-port solution based on 2 x R&S OSP320***

Front slots 1 and 2 = Combined 1:8 switches
Front slot 4 = Switch modules R&S OSP-B122

The 40 GHz variant uses the **H** switch modules, the 40 GHz variant the **U** switch modules. Dedicated sets of semi-rigid cables for the 2 combined 1:8 switches are available as R&S ZV-Z40CR4 and R&S ZV-Z50CR4, respectively (see Chapter 3.2.5, "Semi-rigid cable sets", on page 19).

### 32-port solution

The 32-port solution consists of 4 combined 1:11 switches, each of them distributed over 2 R&S OSP320 base units:

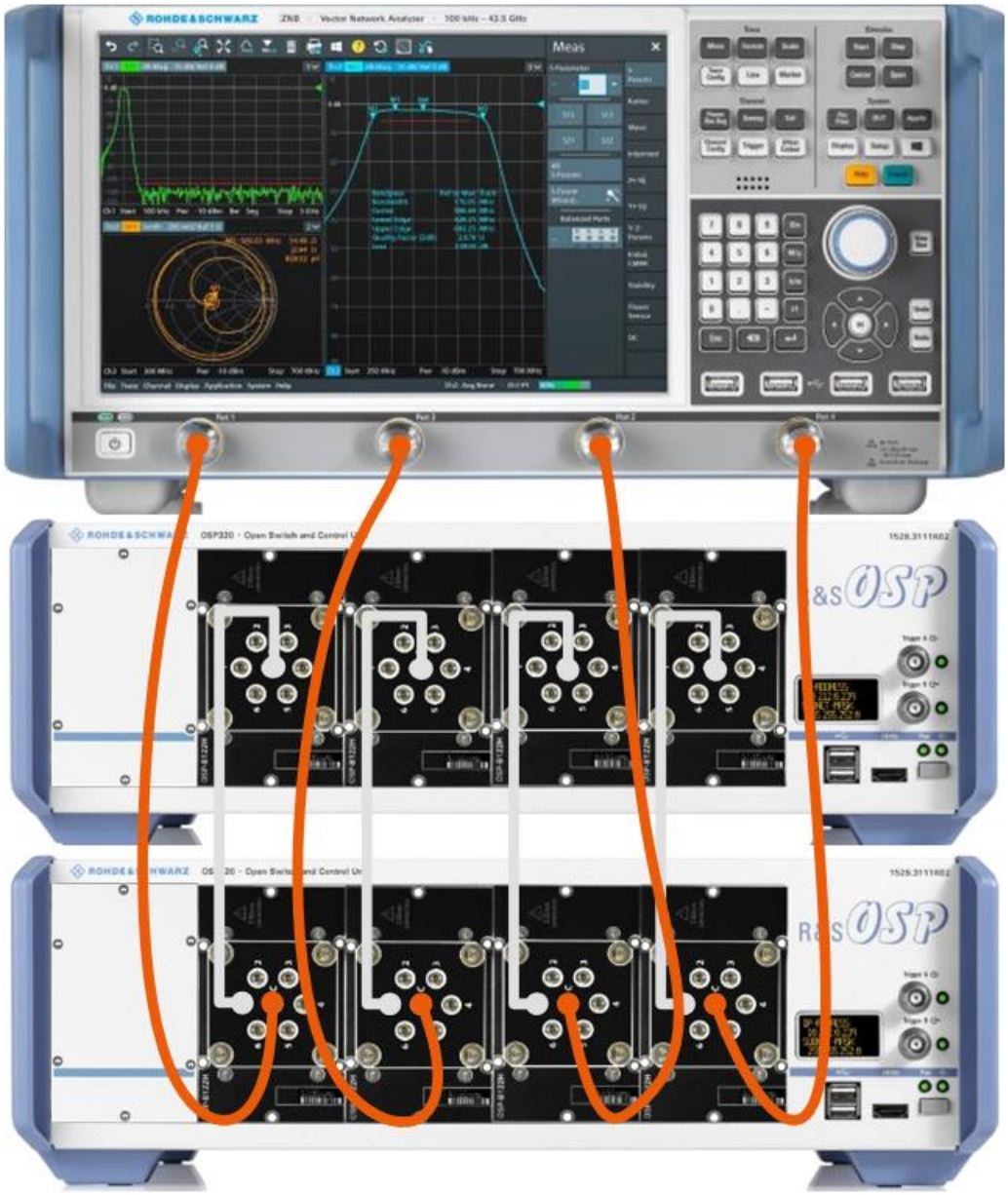


*Figure 3-8: 32-port solution based on 2 x R&S OSP320*

Front slots 1 to 4 = 4 combined 1:8 switches

Currently Rohde & Schwarz only offers a 40 GHz variant with switch modules R&S OSP-B122**H**. A dedicated set of semi-rigid cables for the 4 combined 1:8 switches is available as R&S ZV-Z40x4 (see Chapter 3.2.5, "Semi-rigid cable sets", on page 19).

### 48-port solution

The 48-port solution consists of two 2:24 switch matrices:

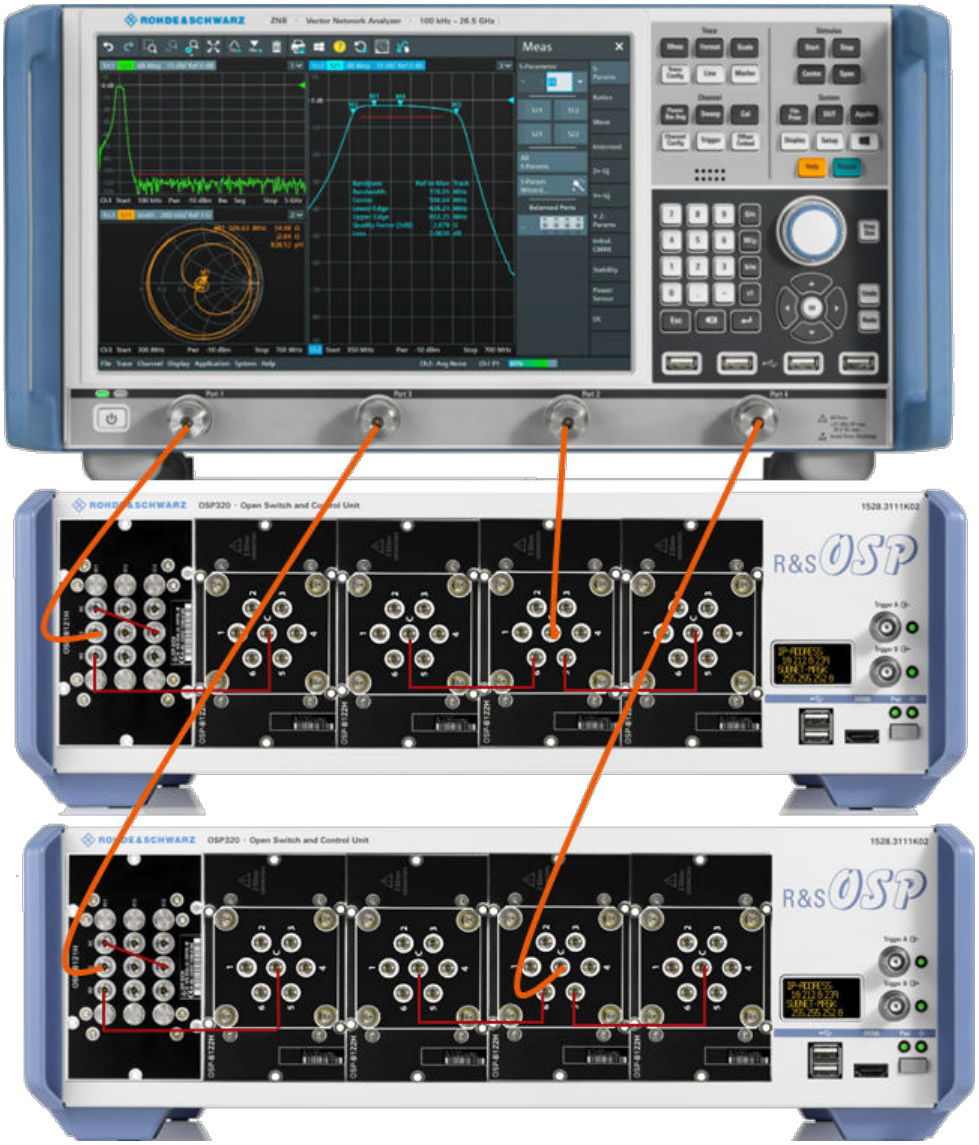


*Figure 3-9: 48-port solution based on 2 x R&S OSP320*

Slots 1 and 2 = Combined 1:8 switch (single R&S OSP320)
Slots 3 to 5 = Combined 1:16 switch (single R&S OSP320)

The 40 GHz variant uses the **H** switch modules, the 40 GHz variant the **U** switch modules. Dedicated sets of semi-rigid cables for the 2 combined 1:8 switches are available as R&S ZV-Z40CR8 and R&S ZV-Z50CR8, respectively (see Chapter 3.2.5, "Semi-rigid cable sets", on page 19).

### 64-port solution

The 64-port solution consists of 4 combined 1:16 switches, each of them distributed over 3 R&S OSP320 base units:

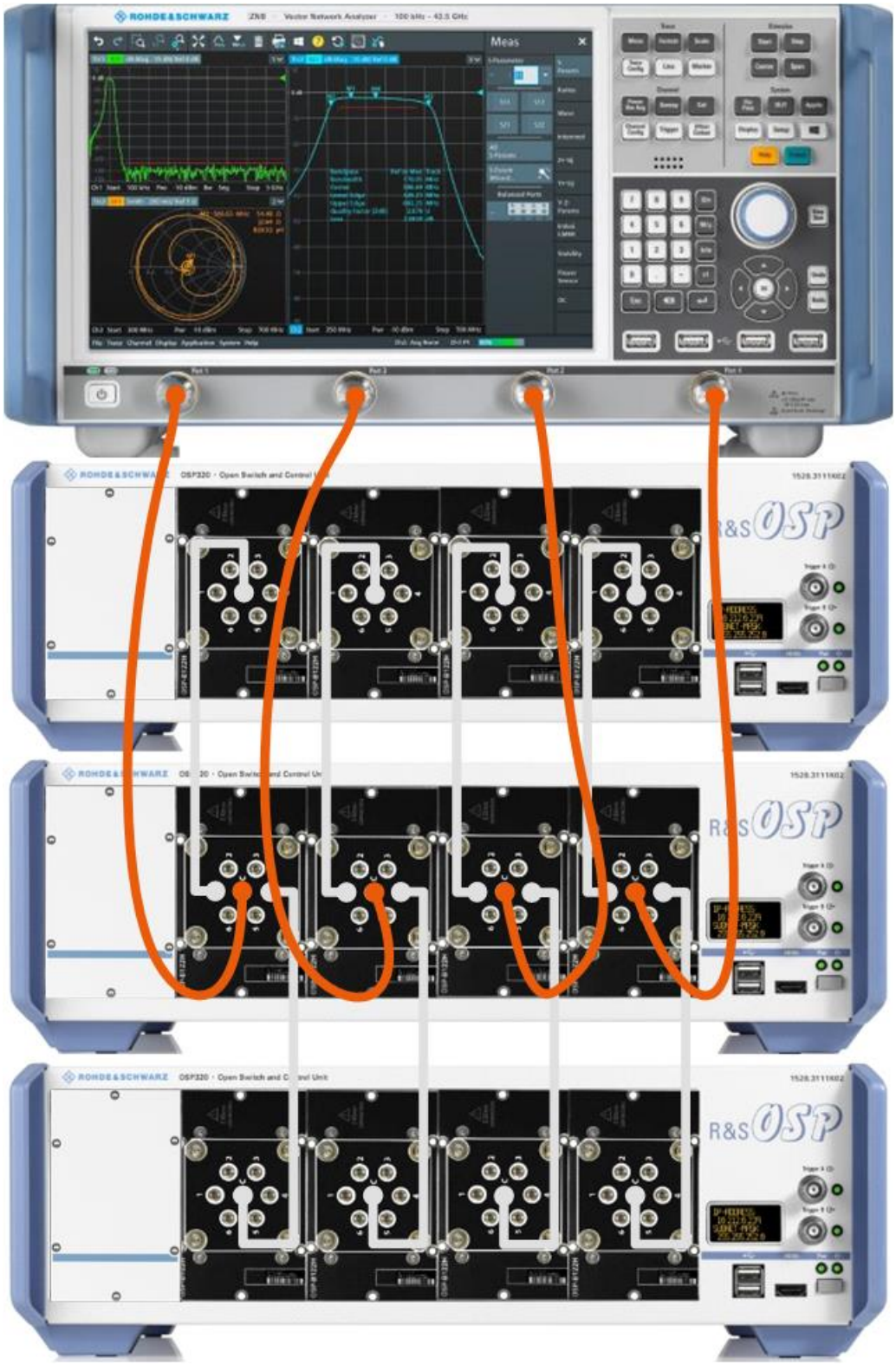



*Figure 3-10: 64-port solution based on 3 x R&S OSP320*

Front slots 1 to 4 = 4 combined 1:16 switches

Currently Rohde & Schwarz only offers a 40 GHz variant with switch modules R&S OSP-B122**H**. A dedicated set of semi-rigid cables for the 4 combined 1:16 switches is available as R&S ZV-Z40x8 (see Chapter 3.2.5, "Semi-rigid cable sets", on page 19).

**Demo setup 24-ports**

For demonstration purposes, you can use a 4:24 matrix setup, based on a single R&S OSP320 and 4 switch modules R&S OSP-B122H or -B122U.

***Figure 3-11: 24-port setup based on 1 x R&S OSP320 (for demonstration purposes only)***

### 3.2.5 Semi-rigid cable sets

For predefined multiport setups comprising combined 1:n switches, dedicated sets of semi-rigid cables are available.

| Multiport setup | Cable set | Frequency range | Connector type | Description |
|---|---|---|---|---|
| 24-port solution | R&S ZV-Z40CR4 | DC to 40 GHz | 2.92 mm (m) | 4 semi-rigid cables |
| 32-port solution | R&S ZV-Z40X4 | | | |
| 48-port solution | R&S ZV-Z40CR8 | | | 8 semi-rigid cables |
| 64-port solution | R&S ZV-Z40X8 | | | |

## 3.3 Connection cables between VNA and switch matrix

Rohde&Schwarz offers various connection cables, suitable for different connector types and frequency ranges. The following cables are recommended for automated cable testing.

| R&S cable | Connector type | Freq. range | Length | Order no. |
|---|---|---|---|---|
| R&S ZV-Z193 | 3.5 mm (f) – 3.5 mm (m) | 0 Hz to 26.5 GHz | 610 mm (24 in) | 1306.4520.24 |
| R&S ZV-Z195 | 2.92 mm (f) - 2.92 mm (m) | 0 Hz to 40 GHz | | 1306.4536.24 |
| R&S ZV-Z197 | 2.4 mm (f) - 2.4 mm (m) | 0 Hz to 50 GHz | | 1306.4571.24 |

## 3.4 Calibration units

Rohde&Schwarz offers various automatic calibration units, with different connector types and frequency ranges. The following 2-port calibration units are recommended for automated cable testing.

| R&S calibration unit | Connector type | Freq. range | Order no. |
|---|---|---|---|
| R&S ZN-Z53 | 3.5 mm (f) | 100 kHz to 26.5 GHZ | 1335.7046.32 |
| R&S ZN-Z54 | 2.92 mm (f) | 9 kHz to 40 GHZ | 1335.7117.92 |
| R&S ZN-Z55 | 2.4 mm (f) | 9 kHz to 50 GHZ | 1335.7181.42 |
| R&S ZN-Z156 Var. 03 | 1.85 mm (f) | 10 MHz to 67 GHz | 1332.7239.03 |

# 4 IEEE 802.3 compliance tests

## 4.1 Method of implementation

Rohde & Schwarzprovides a Method of implementation (MOI) for IEEE up to 100 Gbps interface channel test, which was created in close cooperation with the University of New Hampshire Interoperability Laboratory (UNH-IOL).

The MOI describes precise and error-free compliance testing of high-speed cables and backplanes according to IEEE 802.3 standards, using a VNA from Rohde & Schwarz. The purpose of this document is to provide a step-by-step guideline on how to perform compliance testing for cable assembly and channel characteristics as defined in the following IEEE 802.3 serial interface specifications:

| Specification | | PHY Type | Typical Connector Type |
|---|---|---|---|
| **IEEE 802.3bj-2014** | Clause 92 | 100GBASE-CR4 | QSFP28 |
| | Clause 93 | 100GBASE-KR4 | 2.92 mm, 2.4 mm connector |
| **IEEE 802.3by-2016** | Clause 110 | 25GBASE-CR | SFP28, SFP56 |
| | Clause 111 | 25GBASE-KR | 2.92 mm, 2.4 mm connector |
| **IEEE 802.3cd-2018** | Clause 136 | 50GBASE-CR1, 100GBASE-CR2, 200GBASE-CR4 | SFP28, SFP56, QSFP28, QSFP56 |
| | Clause 137 | 50GBASE-KR1, 100GBASE-KR2, 200GBASE-KR4 | 2.92 mm, 2.4 mm connector |
| **IEEE 802.3ck-2022** | Clause 162 | 100GBASE-CR1, 200GBASE-CR2, 400GBASE-CR4 | SFP112, QSFP112, QSFP-DD112, OSFP112 |
| | Clause 163 | 100GBASE-KR1, 200GBASE-KR2, 400GBASE-KR4 | 2.4 mm, 1.85 mm connector |

As described in the MOI, you could do the compliance tests with a single 4-port VNA, successively connecting each balanced TX port to every balanced RX port and measuring the balanced transmission S-parameters. For cables with a single lane (2xTX, 2xRX) this test can be done fast and reliably. With more lanes, however, numerous reconnections must be done, and the procedure becomes time-consuming and error-prone.

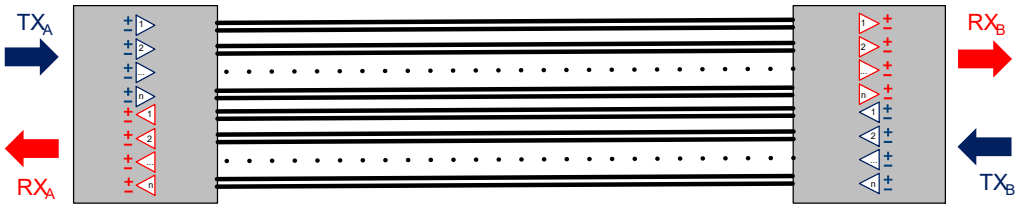



*Figure 4-1: n balanced lanes*

### Multi-port setup

A multiport setup can reduce the measurement time from hours to minutes. The R&S ZNrun implementation focuses on multi-port setups that do not require reconnecting test ports and fixture ports during the measurement phase.

With *n* balanced lanes, 4*n* balanced ports = 8*n* test ports would be required to connect all fixture ports. For symmetrical CR*n* cables and *n* > 1, it suffices to connect the *2n* balanced TX ports (on the left and right) to the balanced RX ports on the left, measure, flip the cable under test, and repeat the measurement. This trick limits the number of required test ports to 6*n*.

### S-parameter measurements

According to the MOI, for each RX ("victim") and every TX ("aggressor"), the balanced transmission S-parameters from TX to RX must be measured. For associated RX and TX, these parameters are called THRU parameters. For RX and TX on the same cable end, these parameters are called NEXT parameters. For RX and TX on opposite cable ends, these parameters are called FEXT parameters.

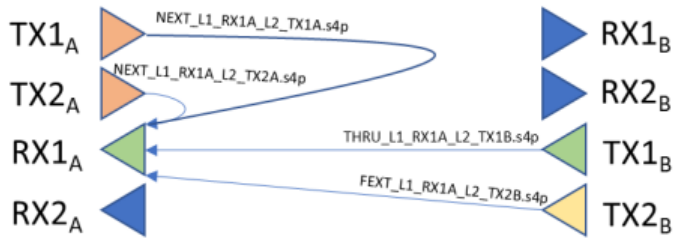



***Figure 4-2: Connections to RX1A victim for 2 lanes***

In total, $2n \cdot 2n = 4n^2$ `s4p` Touchstone files are generated:

- 2*n* files with THRU parameters
- $2n^2$ files with NEXT parameters
- 2*n* (*n*-1) files with FEXT parameters

Slightly differing from the MOI, the R&S ZNrun solution uses the following naming convention for the generated `s4p` Touchstone files:

| *Measurement Type* | *Receiver Lane under Test ("Victim Lane")* | *Agressor Lane* |
|---|---|---|
| `\|-> THRU` | `\|-> [RX1A_pos,RX1A_neg]` | `\|-> [TX1B_pos,TX1B_neg]` |
| `\|-> NEXT` | `\|-> ...` | `\|-> ...` |
| `\|-> FEXT` | `\|-> [RX8B_pos,RX8B_neg]` | `\|-> [TX8A_pos,TX8A_neg]` |

***Figure 4-3: Naming convention for measurement result files (8 lanes)***

For example, the name of the RX1A THRU touchstone file (i.e. the s4p file containing the differential insertion loss and differential return loss of receiver RX1A) is `THRU_[RX1A_pos,RX1A_neg]_[TX1B_pos,TX1B_neg].s4p`.

**S-parameter validation**

The IEEE 802.3 standards require the THRU parameters to be within certain masks or limits. The validation can be done by the VNA, directly from the measurement results.

With 2 and 1 denoting the logical port numbers of the RX and TX port, respectively, the following differential S-parameters are covered by the compliance test specifications:

- Differential-mode insertion loss – SDD21
- Differential return loss – SDD11, SDD22
- Differential to common mode return loss – SCD11, SCD22
- Differential to common mode conversion loss – SCD21
- Common mode to common mode return loss – SCC11, SCC22

See the MOI for details.

**Additional figures of merit: COM and ERL**

In addition to the validation of the THRU parameters, the following metrics are calculated from the s4p Touchstone files using MATLAB® scripts provided by IEEE:

- **Channel operating margin (COM)**
  Basically, COM is the delta (magnitude) between insertion loss and isolation, which can be loosely described as a signal-to-noise ratio or SNR. Isolation is comparable to crosstalk, in the sense that leakage between lanes (NEXT, FEXT) is recorded.
- **Effective return loss (ERL)**
  ERL incorporates an aggregate of mismatches within the channel. Unlike standard return loss, which is only a function of impedance mismatches within the channel, ERL incorporates return loss with the effects of equalization, transmitter noise and receiver frequency response into a signal-to-noise-like figure of merit.

For each receiver RX<i>A or RX<j>B, both COM and ERL can be calculated based from the THRU, NEXT and FEXT s4p files collected for this receiver. See "S-parameter measurements" on page 22. IEEE 802.3 standards require COM and ERL to be within certain limits.

The MATLAB scripts are shipped with the R&S ZNrun installer. However, the MATLAB runtime that is required to run them, has to be installed manually. Download version 9.10 or higher from the MathWorks® internet pages (https://www.mathworks.com/products/compiler/matlab-runtime.html).

## 4.2 Test setup for 1-lane copper cables

The proposed setup for 1-lane cable tests consists of a 4-port Rohde&Schwarz VNA, a 4:8 switch matrix, and the cables connecting them.

- Compliance tests for 100GBASE-CR1 cables (specified in IEEE 802.3ck-2022) require frequencies above 43 GHz, and hence a R&S ZNA50 must be used (see Table 4-1). For precompliance tests, where fast and cost efficient measurements typically overweigh utmost accuracy, you can also use a R&S ZNB43.
  See Chapter 3.1, "Vector network analyzer", on page 7.
- Use a calibration unit that covers the required frequency range.

### 4.2.1 Required equipment

*Table 4-1: Multiport VNA/OSP setup for 1-lane cable tests*

| IEEE standard and cable definition | Recommended VNA and calibration unit | Required switch matrix configuration | Recommended connection cables VNA ⇔ Switch matrix |
|---|---|---|---|
| 802.3by-2016<br>25GBASE-CR<br>CA-25G-L/N/S | R&S ZNB26<br>and<br>R&S ZN-Z53 | • 1 x R&S OSP320<br>• 2 x R&S OSP-B121H<br>in front slots 1 and 4 | 4 x R&S ZV-Z195 |
| 802.3cd-2018<br>50GBASE-CR1 | | | |
| 802.3ck-2022<br>100GBASE-CR1<br>**precompliance** | R&S ZNB43<br>and<br>R&S ZN-Z54 | | |
| 802.3ck-2022<br>100GBASE-CR1<br>**compliance** | R&S ZNA50<br>and<br>R&S ZN-Z55 | • 1 x R&S OSP320<br>• 2 x R&S OSP-B121U (variant 52 with **2 x SPDT**)<br>in front slots 1 and 4 | 4 x R&S ZV-Z197 |

For recommended test fixtures, see Chapter 4.6, "Test fixtures and connection cables", on page 31.

### 4.2.2 Connection plan

The following connections must be established:

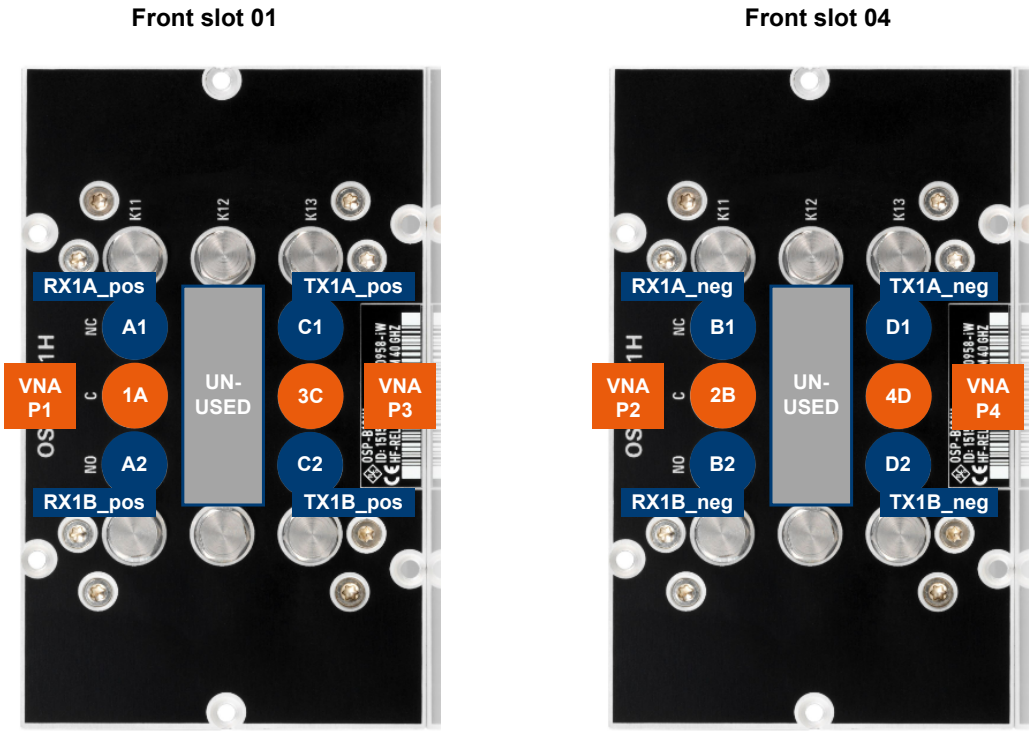



***Figure 4-4: R&S ZNrun connection plan for 1-lane tests (VNA + 1 x R&S OSP320)***

Front slots 01 and 04 = R&S OSP-B121H
1A, ..., 4D = Matrix VNA port names
P1, ..., P4 = VNA ports to be connected
A1, ..., D8 = Matrix test port names
RX1A_pos, ..., TX1B_neg = Fixture ports to be connected (MOI naming)

For the R&S OSP-B121U variant 52 with **2 x SPDT**, the rightmost port group is not available. In the drawing above, for both modules the port group in the middle takes the role of the rightmost port group.

## 4.3 Test setup for 4-lane copper cables

The proposed setup for 4-lane cable tests consists of a 4-port Rohde&Schwarz VNA, a 4:24 switch matrix, and the cables connecting them.

Compliance tests for 400GBASE-CR4 cables (specified in IEEE 802.3ck-2022 require frequencies above 43 GHz, and hence a R&S ZNA50 must be used (see Table 4-1). For precompliance tests, where fast and cost efficient measurements typically over-weigh utmost accuracy, you can also use a R&S ZNB43.

See Chapter 3.1, "Vector network analyzer", on page 7.

### 4.3.1 Required equipment

*Table 4-2: Multiport VNA/OSP setup for 4-lane cable tests*

| IEEE standard and cable definition | Recommended VNA and calibration unit | Required switch matrix configuration | Recommended connection cables VNA ⇔ Switch matrix |
|---|---|---|---|
| 802.3bj-2014<br>100GBASE-CR4 | R&S ZNB26<br>and<br>R&S ZN-Z53 | • 2 x R&S OSP320<br>• 2 x R&S OSP-B121H<br>in front slot 1 of each R&S OSP<br>• 4 x R&S OSP-B122H<br>in front slots 2 and 4 of each R&S OSP<br>• 1 x R&S ZV-Z40CR4<br>semi-rigid cables for both R&S OSP | 4 x R&S ZV-Z195 |
| 802.3cd-2018<br>200GBASE-CR4 | | | |
| 802.3ck-2022<br>400GBASE-CR4<br>**precompliance** | R&S ZNB43<br>and<br>R&S ZN-Z54 | | |
| P802.3ck-2022<br>400GBASE-CR4<br>**compliance** | R&S ZNA50<br>and<br>R&S ZN-Z55 | • 2 x R&S OSP320<br>• 2 x R&S OSP-B121U (variant 52 with **2 x SPDT**)<br>in front slot 1 of each R&S OSP<br>• 4 x R&S OSP-B122U<br>in front slots 2 and 4 of each R&S OSP | 4 x R&S ZV-Z197 |

For recommended test fixtures, see Chapter 4.6, "Test fixtures and connection cables", on page 31.

### 4.3.2 Connection plan

For both R&S OSP:

- Front slots 1 and 2 are combined to a 1:8 submatrix A (See Figure 3-3)
- Front slot 4 is used as a 1:4 submatrix B

The following connections must be established:

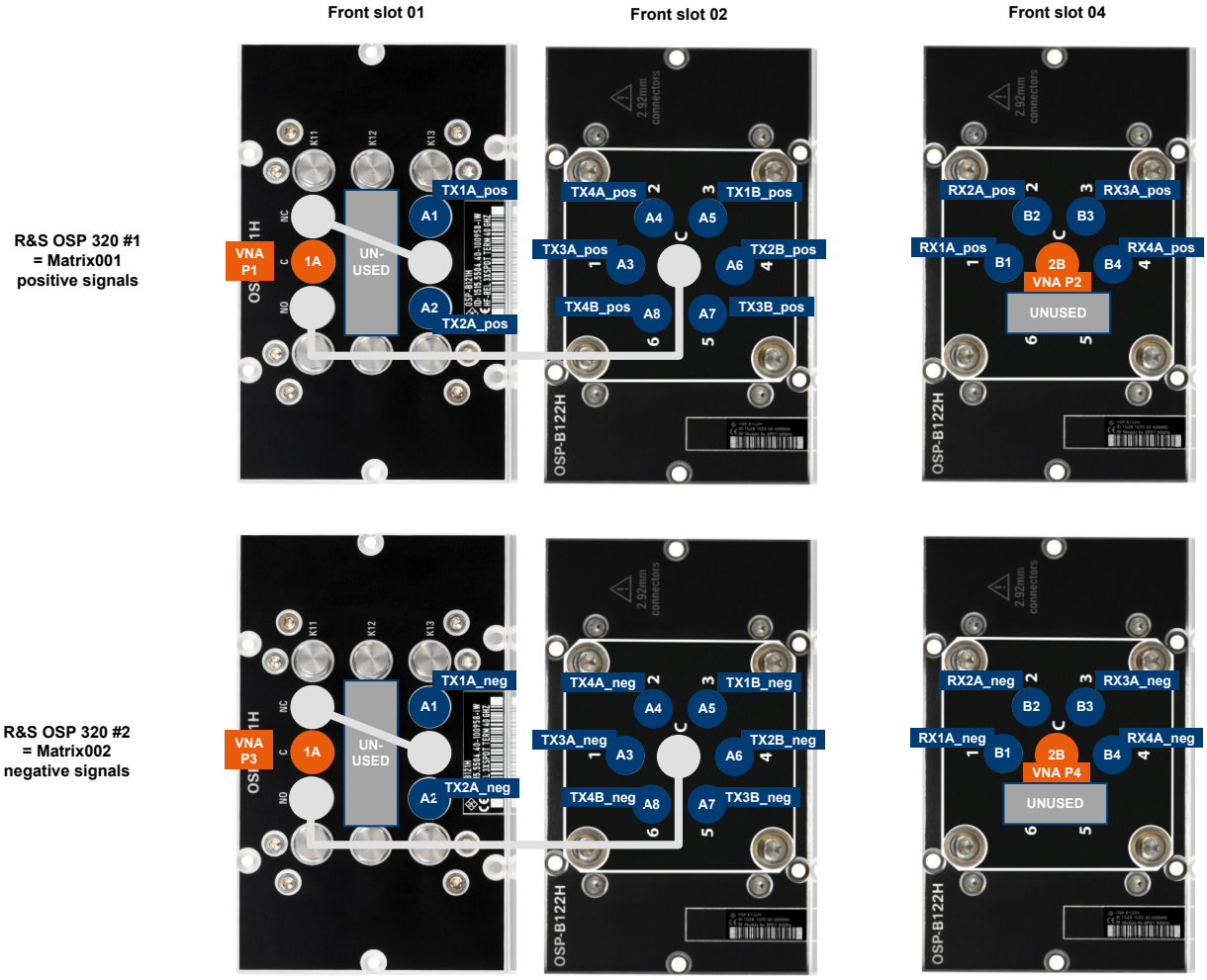



*Figure 4-5: R&S ZNrun connection plan for 4-lane tests (VNA + 2 x R&S OSP320)*

| | |
|---|---|
| Top R&S OSP | = Matrix 001 ("plus" matrix) |
| Bottom R&S OSP | = Matrix 002 ("minus" matrix) |
| Front slot 01 | = R&S OSP-B121H/U |
| Front slots 02 and 04 | = R&S OSP-B122H/U |
| 1A, ..., 2B | = Matrix VNA port names |
| P1, ..., P4 | = VNA ports to be connected |
| A1, ..., A8, B1, ..., B4 | = Matrix test port names |
| RX1A_pos, ..., TX4B_neg | = Fixture ports to be connected (MOI naming) |
| Grey lines | = Semi-rigid cables |

- For the R&S OSP-B121U variant 52 with **2 x SPDT**, the rightmost port group is not available. For this variant, the port group in the middle takes the role of the rightmost port group in front slot 01.
- Instead of connecting the RX ports of the B-side fixture to the R&S OSP, which would require a setup with 32 test ports, the cable under test is flipped once during the measurement (see "Multi-port setup" on page 22).
  (Note that the 4x24 switch matrix that was presented as "Demo setup 24-ports" on page 19, does **not** offer the required connectivity for 4-lane conformance tests.)
- The (unused) RX ports of the B-side fixture must be terminated during the measurement.

## 4.4 Test setup for 8-lane copper cables

The proposed setup for 8-lane cable tests consists of a Rohde&Schwarz VNA, a 4:48 switch matrix, and the cables connecting them.

Compliance tests for 800GBASE-CR8 cables (specified in IEEE 802.3ck-2022 require frequencies above 43 GHz, and hence a R&S ZNA50 must be used (see Table 4-1). For precompliance tests, where fast and cost efficient measurements typically overweigh utmost accuracy, you can also use a R&S ZNB43.

See Chapter 3.1, "Vector network analyzer", on page 7.

### 4.4.1 Required equipment

*Table 4-3: Multiport VNA/OSP setup for 8-lane cable tests*

| IEEE standard and cable definition | Recommended VNA and calibration unit | Required switch matrix configuration | Recommended connection cables VNA ⇔ Switch matrix |
|---|---|---|---|
| 802.3bj-2014<br>200GBASE-CR8 | R&S ZNB26<br>and<br>R&S ZN-Z53 | • 2 x R&S OSP320<br>• 2 x R&S OSP-B121H<br>in front slot 1 of each R&S OSP<br>• 8 x R&S OSP-B122H<br>in front slots 2 to 5 of each R&S OSP<br>• 1 x R&S ZV-Z40CR8<br>semi-rigid cables for both R&S OSP | 4 x R&S ZV-Z193 |
| 802.3ck-2022<br>400GBASE-CR8<br>**precompliance** | R&S ZNB43<br>and<br>R&S ZN-Z54 | | 4 x R&S ZV-Z195 |
| 802.3ck-2022<br>800GBASE-CR8<br>**compliance** | R&S ZNA50<br>and<br>R&S ZN-Z55 | • 2 x R&S OSP320<br>• 2 x R&S OSP-B121U (variant 52 with **2 x SPDT**)<br>in front slot 1 of each R&S OSP<br>• 8 x R&S OSP-B122U<br>in front slots 2 to 5 of each R&S OSP | 4 x R&S ZV-Z197 |

For recommended test fixtures, see Chapter 4.6, "Test fixtures and connection cables", on page 31.

### 4.4.2 Connection plan

For both R&S OSP:

- Front slots 1 and 2 are combined to a 1:8 submatrix A
- Front slots 3 to 5 are combined to a 1:16 submatrix B

See Chapter 3.2.3, "Combined 1:n switches", on page 11.

The following connections must be established:

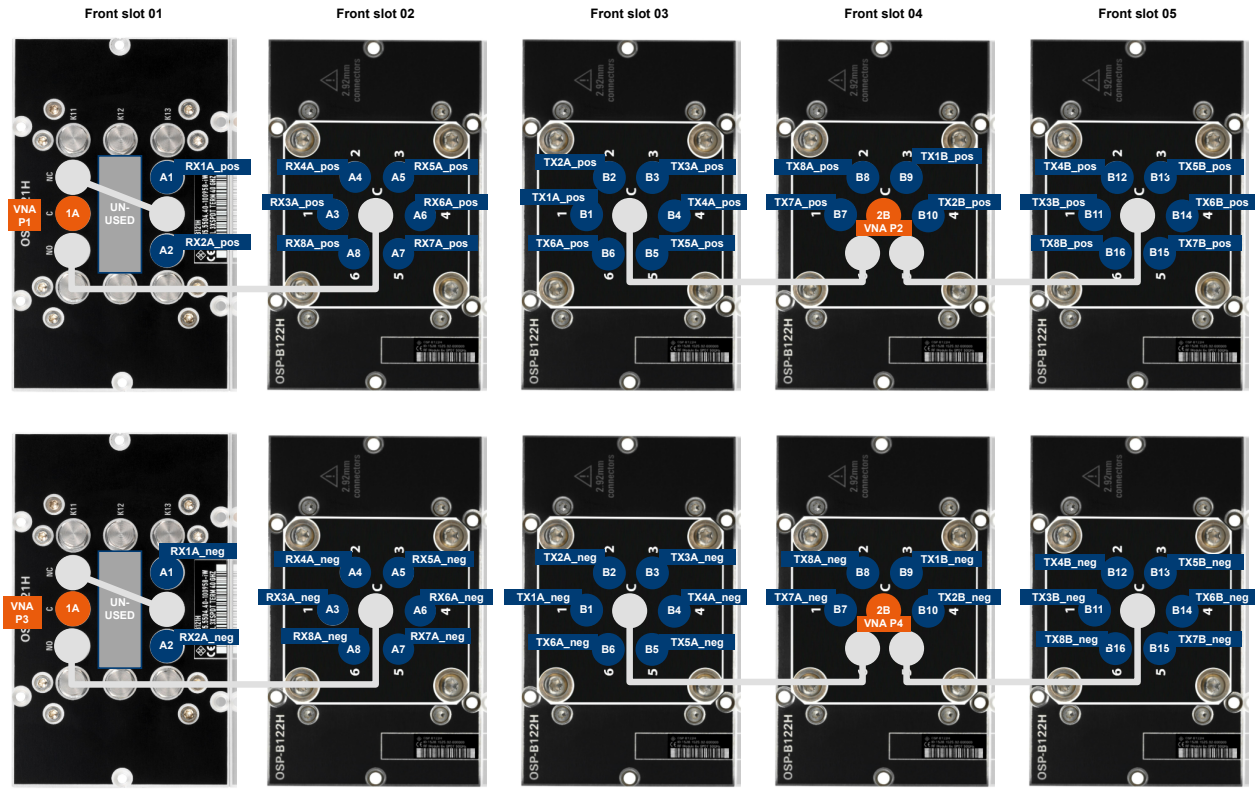



*Figure 4-6: R&S ZNrun connection plan for 8-lane tests (VNA + 2 x R&S OSP320)*

| | |
|---|---|
| Top R&S OSP | = Matrix 001 ("plus" matrix) |
| Bottom R&S OSP | = Matrix 002 ("minus" matrix) |
| 1A, 2B | = Matrix VNA port names |
| P1, ..., P4 | = VNA ports to be connected |
| A1, ..., A8, B1, ..., B16 | = Matrix test port names |
| RX1A_pos, ..., TX8B_neg | = Fixture ports to be connected (MOI naming) |
| Grey lines | = Semi-rigid cables |

- Instead of connecting the RX ports of the B-side fixture to the R&S OSP, which would require a setup with 64 test ports, the cable under test is flipped once during the measurement.
- The (unused) RX ports of the B-side fixture must be terminated during the measurement.

## 4.5 R&S OSP path definitions

Before you can use one of the predefined test setups, suitable path definitions must be installed on each R&S OSP.

Since version 2.82, the R&S ZNrun does this automatically and manual installation via R&S OSP web GUI is no longer supported. However, it is still possible to install the path definitions via SCPI.

Preconfigured SCPI command files (`*.cmd`) are located in the folder `C:\ProgramData\Rohde-Schwarz\ZNrun\2.9x\Resources\DeviceConfig\matrix_routes` on the ZNrun Server.

| Cable type | Cable under test | File name |
|---|---|---|
| 1-lane | 25GBASE-CR, CA-25G-L/N/S (802.3by-2016)<br>50GBASE-CR1 (802.3cd-2018) | `route_4_8_40GHz.cmd` |
| | 100GBASE-CR1 (802.3ck-2022) | `route_4_8_50GHz` |
| 4-lane | 100GBASE-CR4 (802.3by-2016)<br>200GBASE-CR4 (802.3cd-2018) | `route_2_12_40GHz.cmd` * |
| | 400GBASE-CR4 (802.3ck-2022) | `route_2_12_50GHz.cmd` * |
| 8-lane | 200GBASE-CR8 (802.3cd-2018) | `route_2_24_40GHz.cmd` * |
| | 800GBASE-CR8 (802.3ck-2022) | `route_2_24_50GHz.cmd` * |
| * on both R&S OSP | | |

`route_2_12_40GHz.cmd` *

`route_2_12_50GHz.cmd` *

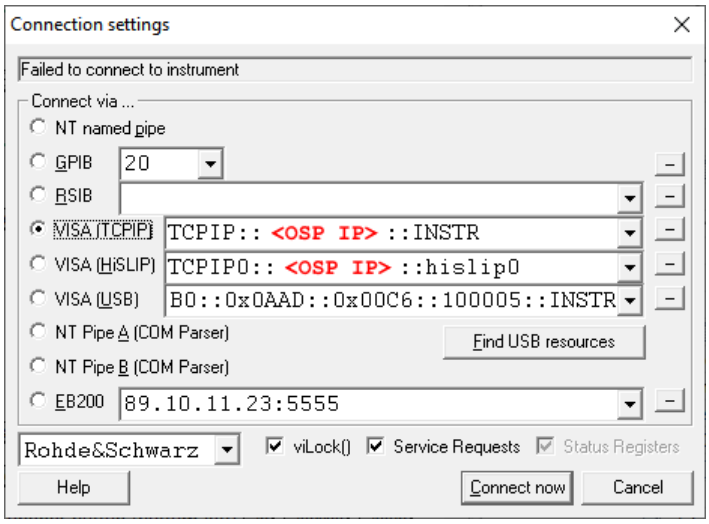
**Path setup via SCPI**

Use your favorite SCPI execution tool to run the path setup commands against the involved R&S OSP. For example, you can use the "GPIB Explorer" (a.k.a. IECWIN32) that is installed with the VNA firmware or firmware simulation.

For general information on remote control of Rohde & Schwarz products via SCPI, see Remote control via SCPI.

To install the preconfigured path definitions:

1. Copy the required path definition file or files (`*.cmd`) to a USB drive
2. Attach the USB drive to the PC (or VNA) with your SCPI execution tool.
3. In the tool, execute the SCPI commands for path creation:
   a) Establish a VISA IP connection to your R&S OSP.
   The "GPIB Explorer", for example, prompts you to select a suitable interface and specify the required connection parameters on startup:




   b) Load the `*.cmd` file into your tool, or copy its content into the tool's command execution environment.
   c) Run the script, or execute all its commands in the given order.

## 4.6 Test fixtures and connection cables

Leading test fixture makers for IEEE 802.3 high-speed cables:

- Wilder Technologies (https://www.wilder-tech.com/en/products)
- PHY-SI (https://phy-si.com/)

For standard-specific recommendations, see Method of implementation (MOI) for IEEE up to 100 Gbps interface channel test.

As connection cables between OSP and test fixtures we recommend:

- Johnson™ 2.92 mm 40 GHz Test Cable Assemblies
- Mini-Circuits® T50-2FT-VMVM+ (2.4mm, 50GHz)

## 4.7 R&S ZNrun compliance and precompliance test projects

Options R&S ZNrun-K41x enable using the predefined R&S ZNrun projects for compliance and precompliance testing.

During installation, these projects are copied to a directory tree below the root directory `C:\ProgramData\Rohde-Schwarz\ZNrun\2.9x\Resources\MOI\IEEE-802-3` on the ZNrun Server.

Since R&S ZNRUN V2.90, the predefined MOI projects are read-only.

To modify such a project, open it in the ZNrun Workbench, make your changes, and save it to a different location. Or copy the project to a different location and remove the read-only flag before opening it in the ZNrun Workbench.

### Option R&S ZNrun-K410

IEEE 802.3bj-2014 and IEEE 802.3by-2016

- `<root directory>\IEEE8023bj, by\25GBASE-CR1\`
  - `L-ZNB26-OSP320-8port.znrun`
  - `N-ZNB26-OSP320-8port.znrun`
  - `S-ZNB26-OSP320-8port.znrun`
- `<root directory>\IEEE8023bj, by\100GBASE-CR4\`
  - `ZNB26-OSP320-24port.znrun`
- `<root directory>\IEEE8023bj, by\200GBASE-CR8\`
  - `ZNB26-OSP320-48port.znrun`

IEEE 802.3cd-2018

- `<root directory>\IEEE8023cd\50GBASE-CR1`
  - `ZNB26-OSP320-8port.znrun`
- `<root directory>\IEEE8023cd\200GBASE-CR4`
  - `ZNB26-OSP320-24port.znrun`
- `<root directory>\IEEE8023cd\400GBASE-CR8`
  - `ZNB26-OSP320-48port.znrun`

### Option R&S ZNrun-K411

IEEE 802.3ck-2022

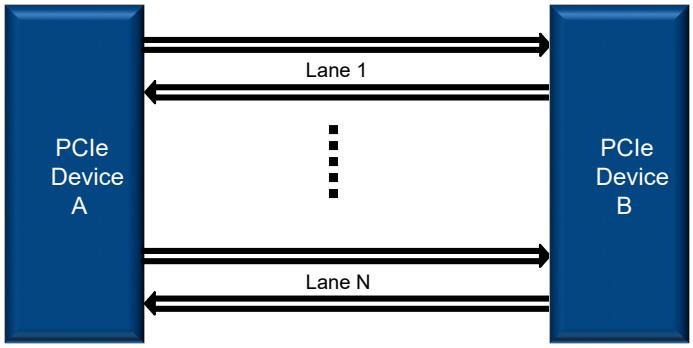
- `<MOI folder>\ieee-802-3\IEEE8023ck\100GBASE-CR1\`
  - `ZNA50-OSP320-8port.znrun`
  - `ZNB43-OSP320-8port.znrun` (precompliance)
- `<MOI folder>\ieee-802-3\IEEE8023ck\400GBASE-CR4\`
  - `ZNA50-OSP320-24port.znrun`
  - `ZNB43-OSP320-24port.znrun` (precompliance)

- <MOI folder>\ieee-802-3\IEEE8023ck\800GBASE-CR84\
  - ZNA50-OSP320-48port.znrun
  - ZNB43-OSP320-48port.znrun (precompliance)

# 5 PCI Express compliance tests

Rohde & Schwarz does not offer its own method of implementation (MOI) for compliance testing of PCI Express (PCIe) cables. However, the automated test solution implemented with software option R&S ZNrun-K440 closely follows the External Cable Specification for PCI Express 5.0 and 6.0, created by PCI-SIG®.

A PCIe link is made up of one or more full duplex lanes, each consisting of 1 differential Tx pair and 1 differential Rx pair.




R&S ZNrun-K440 focuses on x4 and x8 mated cable assemblies, i.e. cable assemblies with 4 or 8 lanes.

| PCIe Revision | Year | Transfer Rate | Encoding | Modulation | Lanes | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | x1 | x2 | x4 | x8 | x16 |
| | | GT/s | | | GB/s | GB/s | GB/s | GB/s | GB/s |
| **1.0** | 2003 | 2.5 | 8b/10b | NRZ | 0.25 | 0.50 | 1.0 | 2.0 | 4.0 |
| **2.0** | 2007 | 5.0 | 8b/10b | NRZ | 0.50 | 1.0 | 2.0 | 4.0 | 8.0 |
| **3.0** | 2010 | 8.0 | 128b/130b | NRZ | 0.98 | 1.97 | 3.94 | 7.88 | 15.8 |
| **4.0** | 2017 | 16.0 | 128b/130b | NRZ | 1.97 | 3.94 | 7.88 | 15.8 | 31.5 |
| **5.0** | 2019 | 32.0 | 128b/130b | NRZ | 3.94 | 7.88 | 15.8 | 31.5 | 63.0 |
| **6.0** | 2021 | 64.0 | 1b/1b | PAM4 | 8.0 | 16.0 | 32.0 | 64.0 | 128.0 |

In general, you could do the compliance tests with a single 4-port VNA, successively connecting each balanced TX port to every balanced RX port and measuring the differential S-parameters. However, for a cable with multiple lanes numerous reconnections must be done, and the procedure becomes time-consuming and error-prone.

## 5.1 Measurements and evaluations

To get the full picture, all differential S-parameters between any pair of TX and RX ports must be measured.

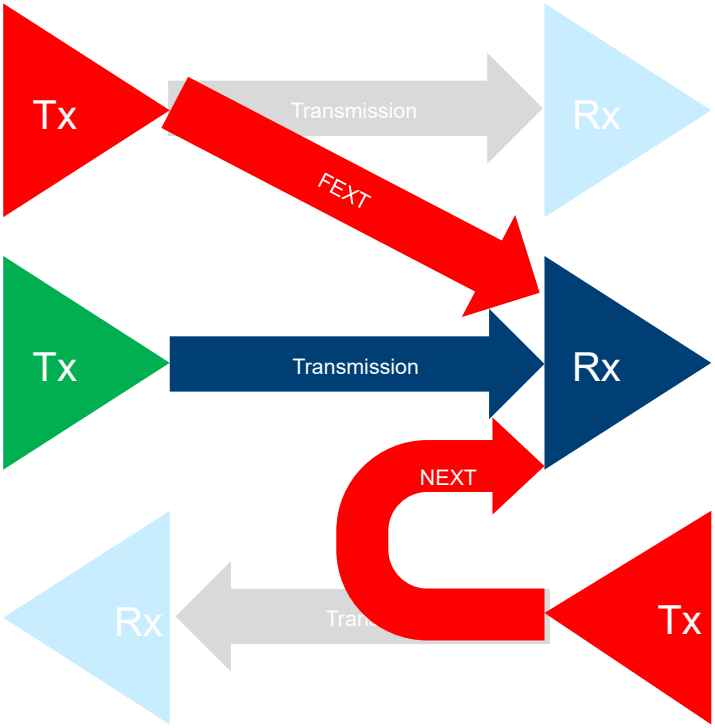



*Table 5-1: S-parameter measurements*

| **Measurement** | **Measured quantity**<br>**0 GHz to 24 GHz, 10 MHz grid** | **Limit**<br>**0 GHz to 24 GHz** |
|---|---|---|
| Differential insertion loss | $Sdd_{21}$ for each lane and both transmission directions | Segmented upper limit line (continuous and piecewise linear) |
| Differential return loss | $Sdd_{11}$ and $Sdd_{22}$ for each lane and both transmission directions | |
| Near-end crosstalk NEXT | Sdd between a victim RX port, and an aggressing TX port on the same side of the DUT | Linear upper limit line on PSNEXT curve (see table below) |
| Far-end crosstalk FEXT | Sdd between a victim RX port, and an aggressing TX port on the other side of the DUT | Linear upper limit line on PSFEXT curve (see table below) |

For n lanes, in total $2n \cdot 2n = 4n^2$ `s4p` Touchstone files are generated:

- $2n$ files with THRU parameters
- $2n^2$ files with NEXT parameters
- $2n$ ($n$-1) files with FEXT parameters

In addition to the measured S-parameter data, the following metrics are calculated and evaluated against specified limits or limit lines.

*Table 5-2: Evaluations*

| Evaluation | Definition | Limit |
|---|---|---|
| Integrated return loss (iRL) | Integration of averaged differential return loss after a power weighting filter | If a return loss S-parameter violates its limit line, then the corresponding iRL must be below a specified value. |
| Differential power sum near-end crosstalk (psNEXT) | Power sum per victim, summed over all NEXT aggressors | Linear limit lines<br>0 GHz to 24 |
| Differential power sum far-end crosstalk (psFEXT) | Power sum per victim, summed over all NEXT aggressors | |
| Differential crosstalk (psXT) | Power sum per victim, summed over all NEXT and FEXT aggressors | n.a. |
| Component contribution to integrated crosstalk noise for NEXT (ccICN-NEXT) | Calculated from PSNEXT values, integrated per victim | If some PSNEXT violates its limit line, then the corresponding ccICN must be below a specified value. |
| Component contribution to integrated crosstalk noise ccICNNEXT | Calculated from PSFEXT values, integrated per victim | If some PSFEXT violates its limit line, then the corresponding ccICN must be below a specified value. |
| Effective intra-pair skew (EIPS) | Calculated from the measured S-parameter data | Must be less than the specified number of picoseconds. |
| Inter-pair skew (lane-to-lane) | Difference in transit times between two differential pairs | Must be less than the specified number of picoseconds. |

For the corresponding formulas and limits, see the PCI-SIG® External Cable Specification for PCI Express 5.0 and 6.0.

**Port impedances and de-embedding**

The specified limit lines are based on 85 Ω differential reference impedance. The impact of test fixtures must be de-embedded from the measured data. All masks are length independent but maximum length of 2 m is assumed for insertion loss.

Let <TX|RX><l>_<L|R> denote the transmit|receive port at the left|right side of lane number <l> = 1, ..., N.

## 5.2 Test setup for x4 cables and connectors

The proposed setup for 4-lane PCIe 5.0 and 6.0 cable and connector tests consists of a 4-port R&S ZNB43, a 4:32 switch matrix, and the cables connecting them.

According to the PCIe 5.0 and 6.0 external cable specification, the conformance tests must cover frequencies up to 24 GHz, so a R&S ZNB26 would be sufficient. However, the specification requires an accurate de-embedding of the test fixtures, which, from the experience of Rohde & Schwarz and other industry experts, requires frequencies above 26.5 GHz. For this reason, the recommended VNA for PCIe cable conformance tests is a 4-port R&S ZNB43.

### 5.2.1 Recommended equipment

*Table 5-3: Multiport VNA/OSP setup for 4-lane cable tests (x4)*

| PCIe revision | Recommended VNA and calibration unit | Required switch matrix configuration | Recommended connection cables VNA ⇔ Switch matrix |
|---|---|---|---|
| 5.0<br>6.0 | R&S ZNB43<br>and<br>R&S ZN-Z54 | • 2 x R&S OSP320<br>• 8 x R&S OSP-B122H in front slots 2 to 5 of both frames<br>• 1 x R&S ZV-Z40X4 semi-rigid cable set | 4 x R&S ZV-Z195 |

For recommended test fixtures, see Chapter 5.7, "Test fixtures and connection cables", on page 43.

### 5.2.2 Connection plan

The switches at front slot 2 of the two R&S OSP320 are combined to a 1:11 submatrix, with submatrix ports 9 to 11 unused. See Figure 3-5. Same for front slots 3 to 5.

The following connections must be established:

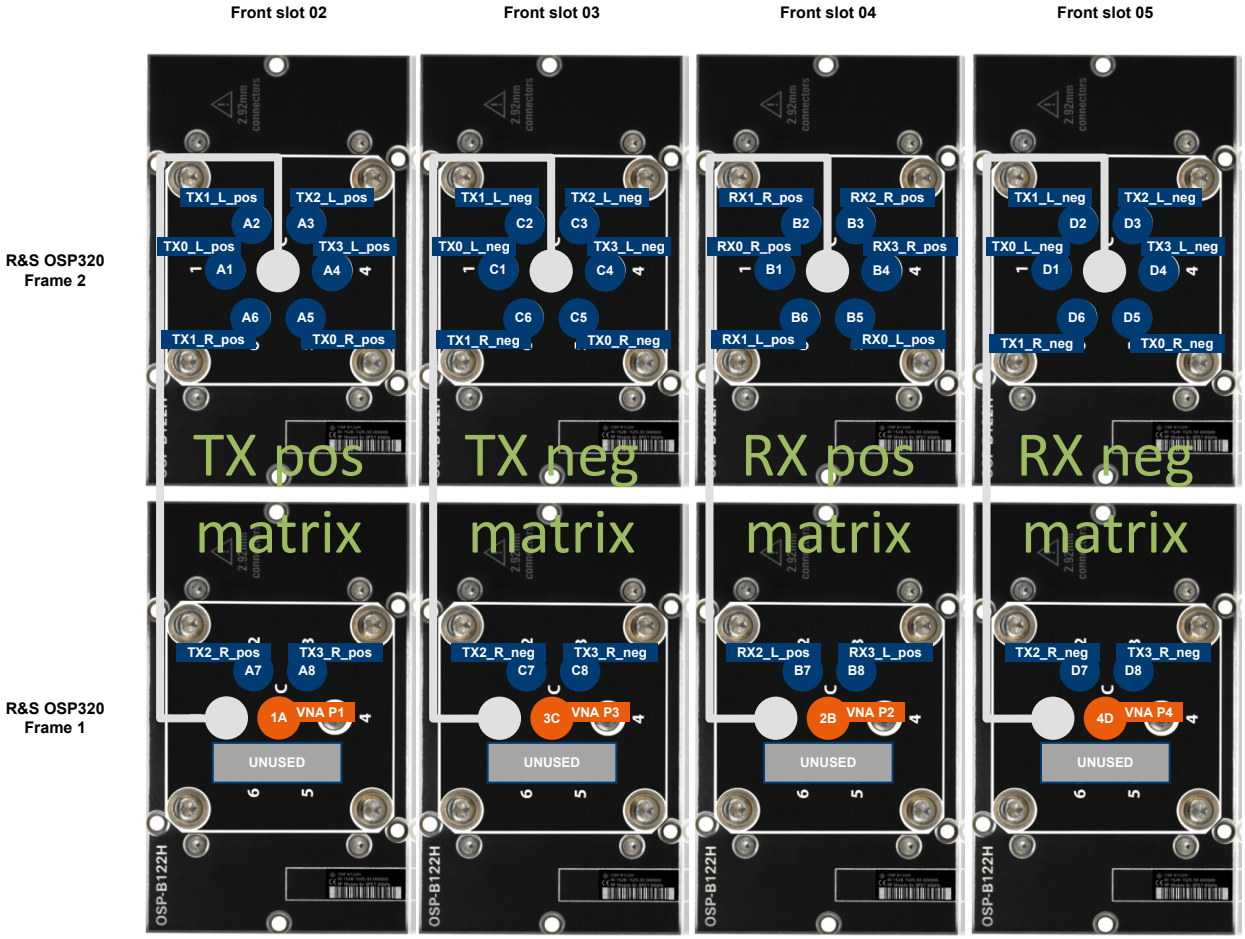



*Figure 5-1: R&S ZNrun connection plan for x4 cable tests (VNA + 2 x R&S OSP320)*

Front slots 02 to 05 = R&S OSP-B122H
1A, ..., 4D = Matrix VNA port names
P1, ..., P4 = VNA ports to be connected
A1, ..., D8 = Matrix test port names
RX1_L_pos, ..., TX1_R_neg = Fixture ports to be connected (L: left; R: right)
Grey lines = Semi-rigid cables

## 5.3 Test setup for x8 cables and connectors

The proposed setup for 8-lane PCIe 5.0 and 6.0 cable and connector tests consists of a 4-port R&S ZNB43, a 4:64 switch matrix, and the cables connecting them.

According to the PCIe 5.0 and 6.0 external cable specification, the conformance tests must cover frequencies up to 24 GHz, so a R&S ZNB26 would be sufficient. However, the specification requires an accurate de-embedding of the test fixtures, which, from the experience of Rohde & Schwarz and other industry experts, requires frequencies above 26.5 GHz. For this reason, the recommended VNA for PCIe cable conformance tests is a 4-port R&S ZNB43.

### 5.3.1 Recommended equipment

*Table 5-4: Multiport VNA/OSP setup for 8-lane cable tests (x8)*

| PCIe revision | Recommended VNA and calibration unit | Required switch matrix configuration | Recommended connection cables VNA ⇔ Switch matrix |
|---|---|---|---|
| 5.0<br>6.0 | R&S ZNB43<br>and<br>R&S ZN-Z54 | • 3 x R&S OSP320<br>• 12 x R&S OSP-B122H in front slots 2 to 5 of all frames<br>• 1 x R&S ZV-Z40X8 semi-rigid cable set | 4 x R&S ZV-Z195 |

For recommended test fixtures, see Chapter 4.6, "Test fixtures and connection cables", on page 31.

### 5.3.2 Connection plan

The switches at front slot 2 of the three R&S OSP320 are combined to a 1:16 submatrix. See Figure 3-5. Same for front slots 3 to 5.

The following connections must be established:

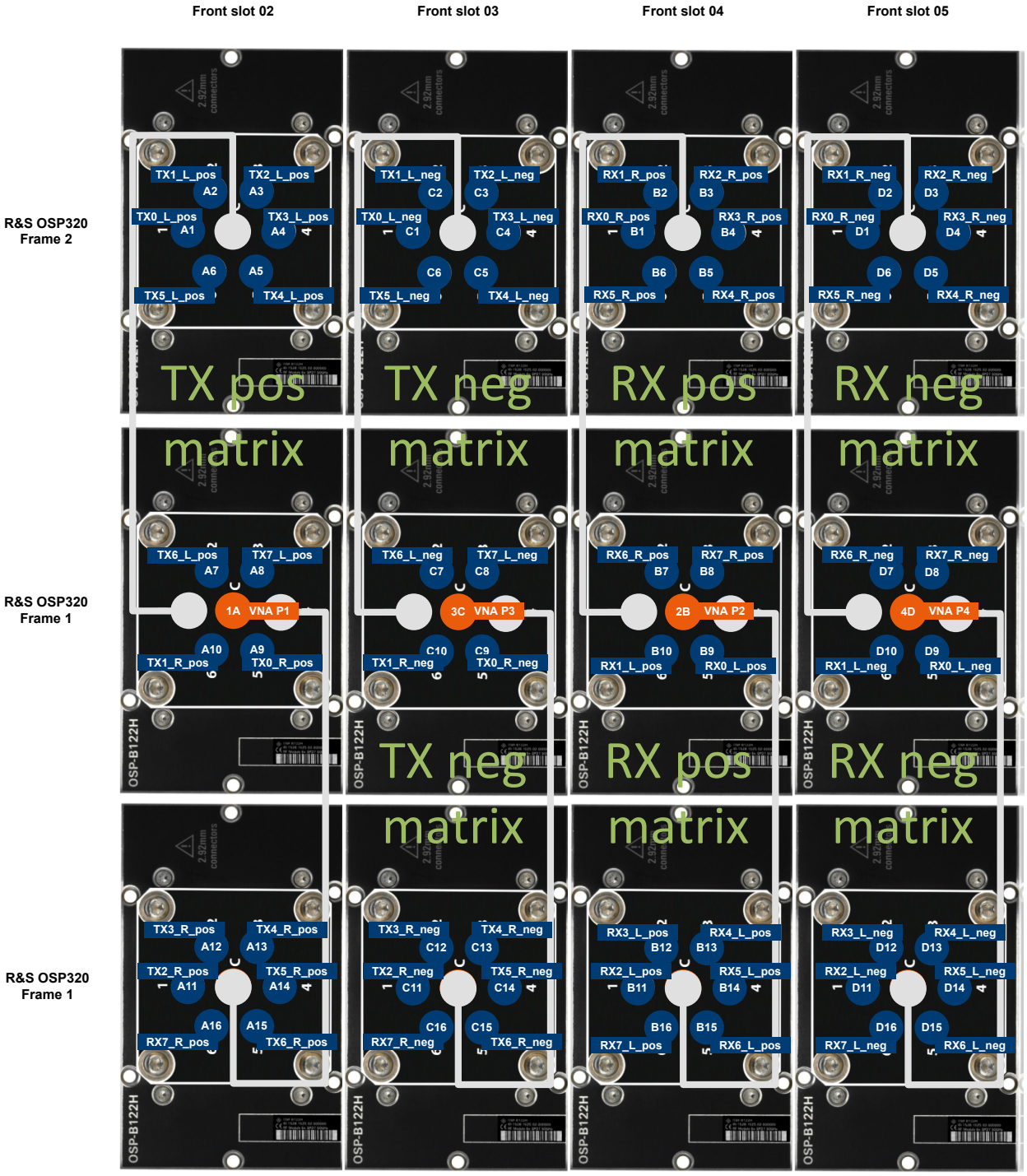
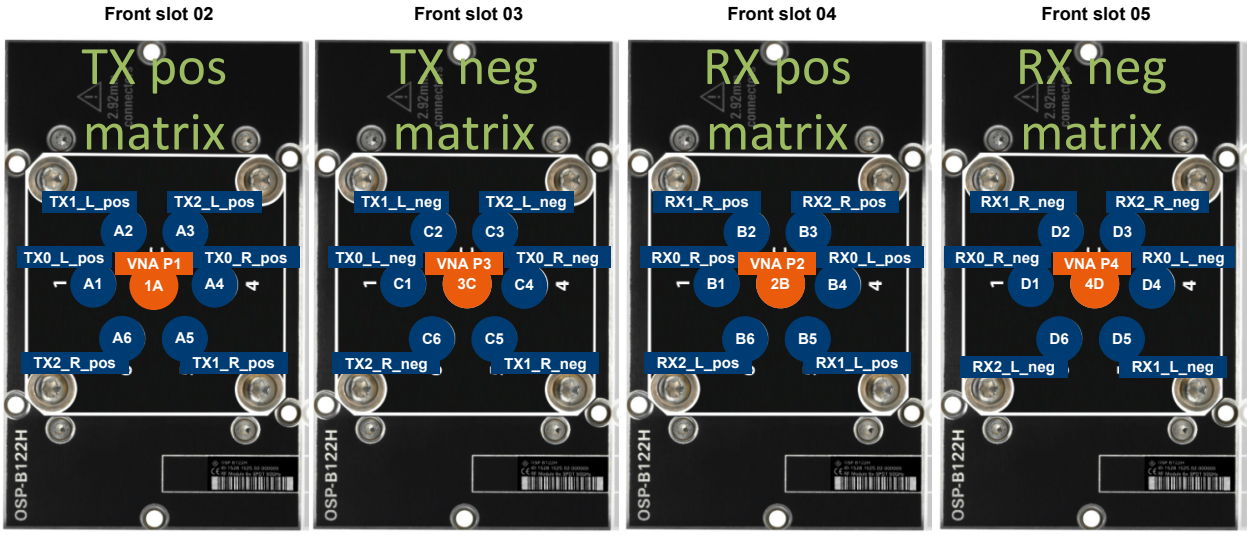



*Figure 5-2: R&S ZNrun connection plan for x8 cable tests (VNA + 2 x R&S OSP320)*

Front slots 02 to 05 = R&S OSP-B122H
1A, ..., 4D = Matrix VNA port names
P1, ..., P4 = VNA ports to be connected
A1, ..., A16, ..., D1, ..., D16 = Matrix test port names
RX1_L_pos, ..., TX8_R_neg = Fixture ports to be connected (L: left; R: right)
Grey lines = Semi-rigid cables

## 5.4 Demo setup

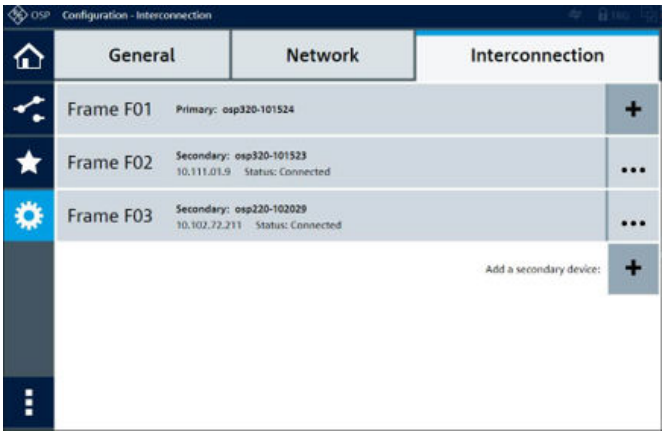
Option R&S ZNrun-K440 enables a set of demo projects `<...>-ZNx-OSP320-24port.znrun` that allow you to test "3 out of *n* lanes" (3 x TX, 3 x RX) of a PCIe x*n* cable. These projects use a single R&S OSP320, equipped and configured as a 4:24 matrix with the following connection plan:




## 5.5 OSP interconnections

To configure the paths and control the switching on 2 or 3 interconnected R&S OSP, the controlling R&S ZNrun or VNA only talks to the primary R&S OSP (frame 01 in the connection plans).

To make the primary R&S OSP aware to the secondary ones, use the "Settings > Interconnection" menu of its web GUI to configure the additional frames' IP addresses.



All OSPs must have the same FW version installed.

## 5.6 R&S OSP path definitions

Before you can use one of the predefined test setups, suitable path definitions must be installed on each R&S OSP.

The R&S ZNrun does this automatically, but path setup via SCPI is also possible. Pre-configured SCPI command files (`*.cmd`) are located in the folder `C:\ProgramData\Rohde-Schwarz\ZNrun\2.9x\Resources\DeviceConfig\matrix_routes` on the ZNrun Server.

| Cable type | File name |
|---|---|
| x4 (4 balanced full duplex lanes) | `route_4_32.cmd`* |
| x8 (8 balanced full duplex lanes) | `route_4_64.cmd`* |
| Demo setup (3 balanced full duplex lanes) | `route_4_24.cmd` |
| * on the primary R&S OSP320 | |

### Path setup via SCPI

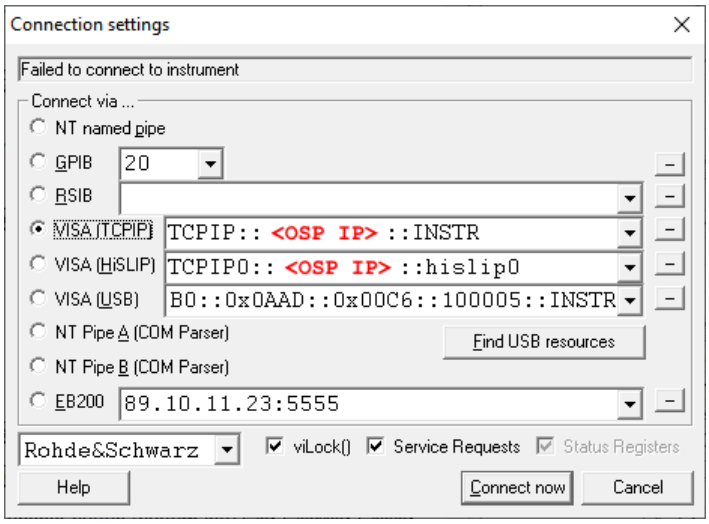
Use your favorite SCPI execution tool to run the path setup commands against the involved R&S OSP. For example, you can use the "GPIB Explorer" (a.k.a. IECWIN32) that is installed with the VNA firmware or firmware simulation.

For general information on remote control of Rohde & Schwarz products via SCPI, see Remote control via SCPI.

To install the preconfigured path definitions:

1. Copy the required path definition file or files (`*.cmd`) to a USB drive
2. Attach the USB drive to the PC (or VNA) with your SCPI execution tool.
3. In the tool, execute the SCPI commands for path creation:

a) Establish a VISA IP connection to your primary R&S OSP320.
The "GPIB Explorer", for example, prompts you to select a suitable interface and specify the required connection parameters on startup:




b) Load the `*.cmd` file into your tool, or copy its content into the tool's command execution environment.
c) Run the script, or execute all its commands in the given order.

## 5.7 Test fixtures and connection cables

Leading test fixture makers for PCIe 5.0 and 6.0 mated cable assemblies:

- Allion Labs (https://www.allion.com/fixtures/)
- Samtec (https://www.samtec.com/kits/si-eval-cable/si-fly-flyover/)

As connection cables between OSP and test fixtures we recommend:

- Johnson™ 2.92 mm 40 GHz Test Cable Assemblies

## 5.8 R&S ZNrun compliance test projects

Option R&S ZNrun-K440 enable using the predefined R&S ZNrun projects for compliance tests on PCIe mated cable and connector assemblies.

During installation, these projects are copied to a directory tree below the root directory `C:\ProgramData\Rohde-Schwarz\ZNrun\2.9x\Resources\MOI\pci-sig\PCIe 5.0 and 6.0 - CopperLink External Cable\Rev 0.9` on the ZNrun Server.

Since R&S ZNRUN V2.90, the predefined MOI projects are read-only.

To modify such a project, open it in the ZNrun Workbench, make your changes, and save it to a different location. Or copy the project to a different location and remove the read-only flag before opening it in the ZNrun Workbench.

PCIe rev. 5.0

- Test setup for x4 cables and connectors

  `<root directory>\x4\`
  - `32GTs-matedcable-ZNx-OSP320-32port.znrun`
  - `32GTs-matedconnector-ZNx-OSP320-32port`
- Test setup for x8 cables and connectors

  `<root directory>\x8\`
  - `32GTs-matedcable-ZNx-OSP320-64port.znrun`
  - `32GTs-matedconnector-ZNx-OSP320-64port`
- Demo setup

  `<root directory>\x3\`
  - `32GTs-matedcable-ZNx-OSP320-24port.znrun`
  - `32GTs-matedconnector-ZNx-OSP320-24port`

PCIe rev. 6.0

- Test setup for x4 cables and connectors

  `<root directory>\x4\`
  - `64GTs-matedcable-ZNx-OSP320-32port.znrun`
  - `64GTs-matedconnector-ZNx-OSP320-32port`
- Test setup for x8 cables and connectors

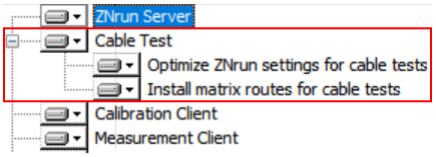
  `<root directory>\x8\`
  - `64GTs-matedcable-ZNx-OSP320-64port.znrun`
  - `64GTs-matedconnector-ZNx-OSP320-64port`
- Demo setup

  `<root directory>\x3\`
  - `64GTs-matedcable-ZNx-OSP320-24port.znrun`
  - `64GTs-matedconnector-ZNx-OSP320-24port`

# 6 Operation

Use the ZNrun Cable Test Client to perform cable compliance tests. Since R&S ZNrun V2.90 the predefined cable test projects are automatically installed with the ZNrun Cable Test Client. However, they cannot be opened without the appropriate license option.

Make sure to install the ZNrun Cable Test Client with the desired features on the ZNrun Server PC:




E.g., select "Install matrix routes for cable tests" if you want to create the routes on the proposed R&S OSP matrix setups via SCPI.

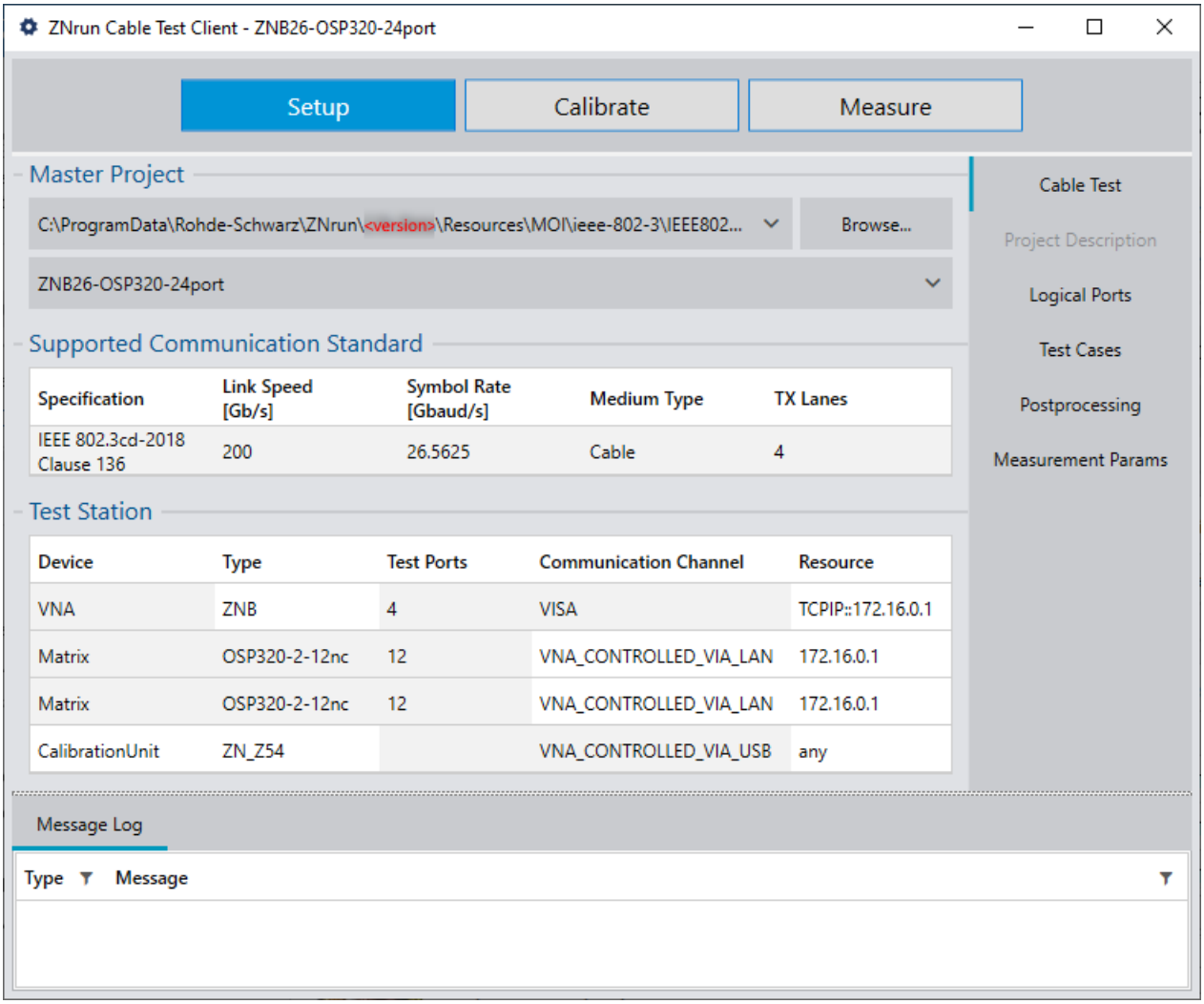
## 6.1 Performing cable tests

**ZNrun Cable Test Client: Program start**

► On the ZNrun Server PC, run the ZNrun Cable Test Client from the windows Start menu.

### 6.1.1 Measurement setup

The ZNrun Cable Test Client always starts in "Setup" mode. If you have run it before, it restores the setup of the previous session.




**"Cable Test"**

In the "Cable Test" panel, you can select the cable test to be performed, and the test equipment to be used. See the screenshot above.

1. Activate "Setup">"Cable Test"
2. Select the "Master Project":
   a) Browse to the directory containig your cable test projects.
   At first program start, browsing begins at the installation directory of the predefined cable test projects.
   b) Select the suitable project.
   For predefined IEEE 802.3, refer to Chapter 4.7, "R&S ZNrun compliance and precompliance test projects", on page 32.
   For predefined PCIe 5.0 and 6.0 projects, refer to see Chapter 5.8, "R&S ZNrun compliance test projects", on page 43.
3. Specify the IP address of the VNA that you want to use for testing.

4. For each of the listed R&S OSP switch matrices:

   a) Select "VNA_CONTROLLED_VIA_LAN" as "Communication Channel"
   b) Specify its IP address

   **Note:**
   - Make sure that IP connections between ZNrun Server, VNA and switch matrices can be established.
   - Before you can run a PCIe x4 or x8 test, you have to configure the OSP interconnections. R&S ZNrun and the VNA only communicate to the "primary" R&S OSP320.

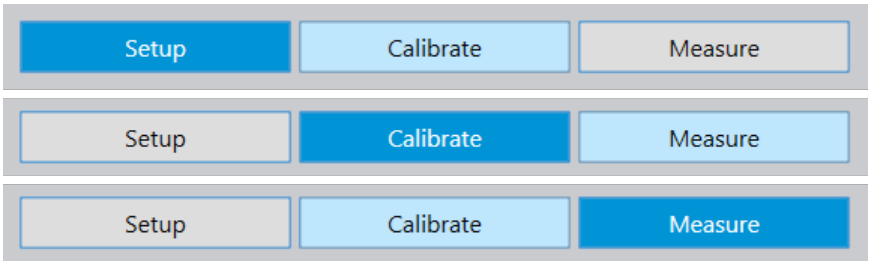
5. If you want to calibrate the test setup:

   a) Choose the "Type" of the calibration unit
   b) Select or specify the appropriate "Communication Channel" and "Resource" ("VNA_CONTROLLED_VIA_US" and "any" for the recommended calibration units)

6. Proceed with Calibrate or Measure.

   **Tip:** If the ZNrun Server finds applicable calibrations in its calibration database and in the cal pool of the selected VNA, it automatically selects the one to be used according to its calibration settings (ZNrun Settings app).

   To check that everything is set up correctly, try to switch to "Calibrate" and then to "Measure".




### Logical ports

In the "Logical Ports" panel, you can de-embed the test fixtures and specify the balanced reference impedances of the links (cable + test fixtures).

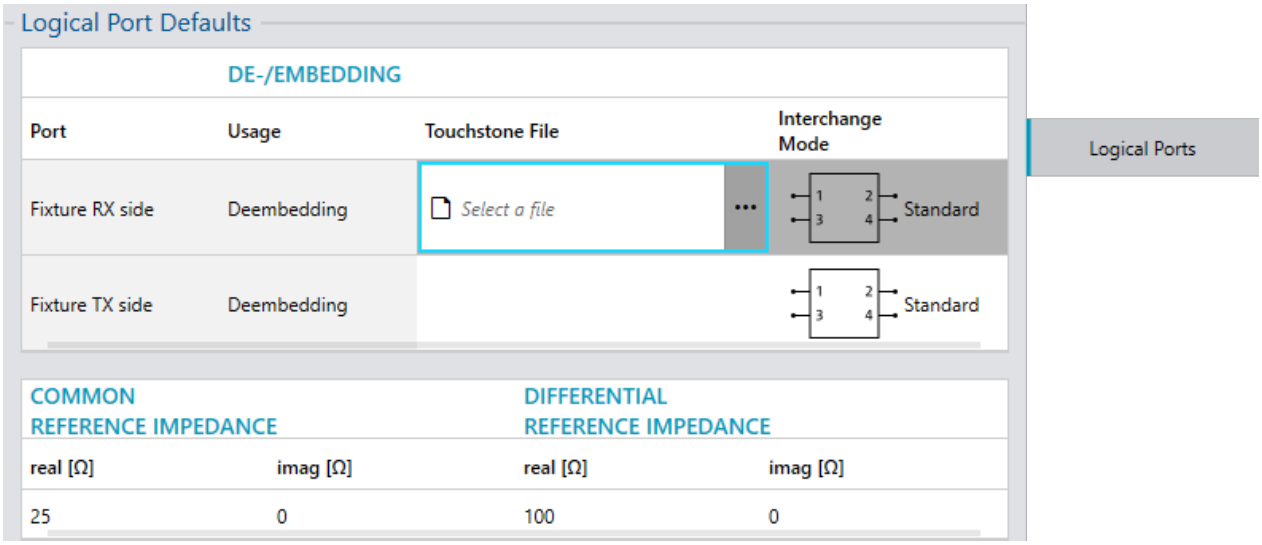



*Figure 6-1: Logical ports configuration R&S ZNRUN-K41x*

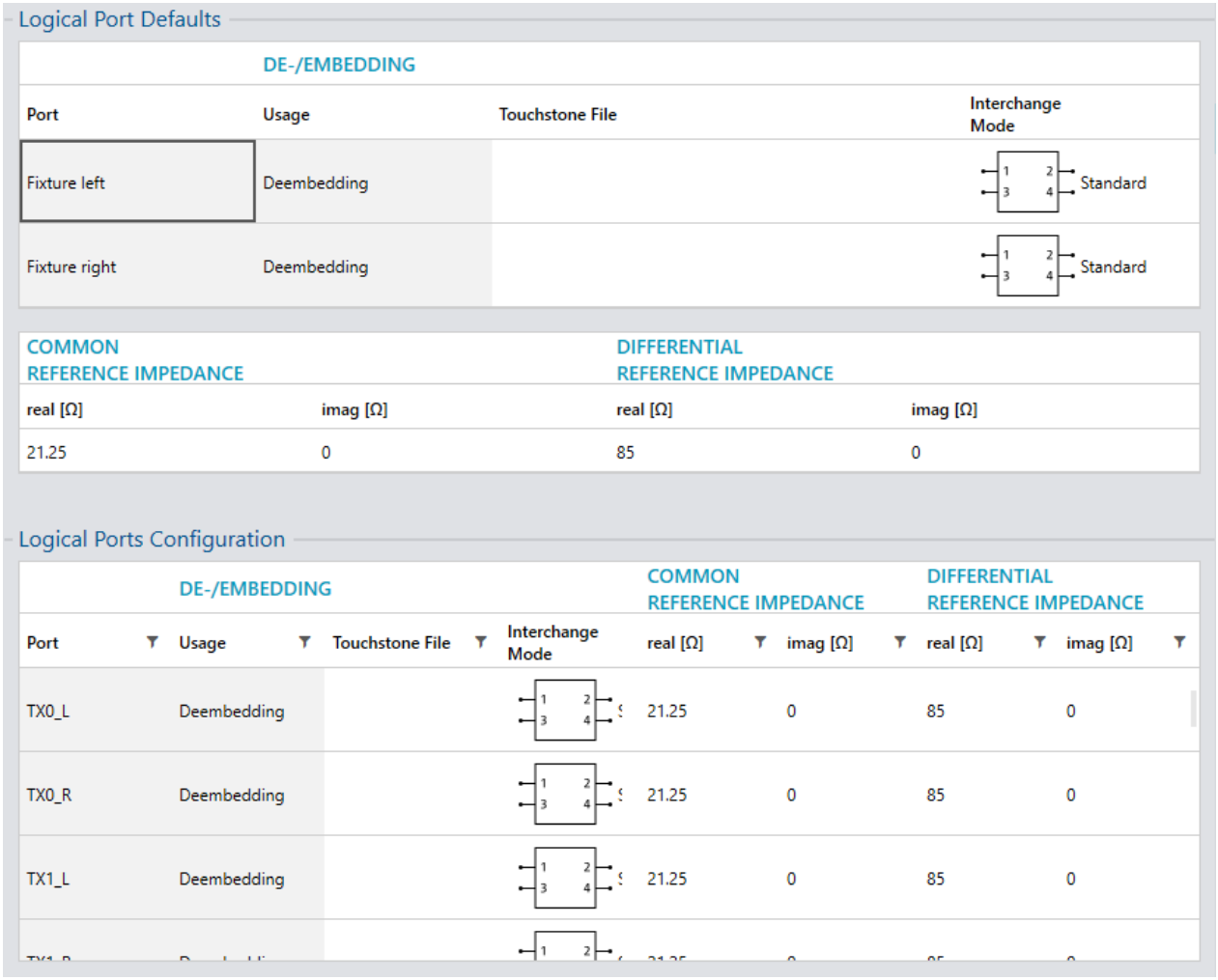


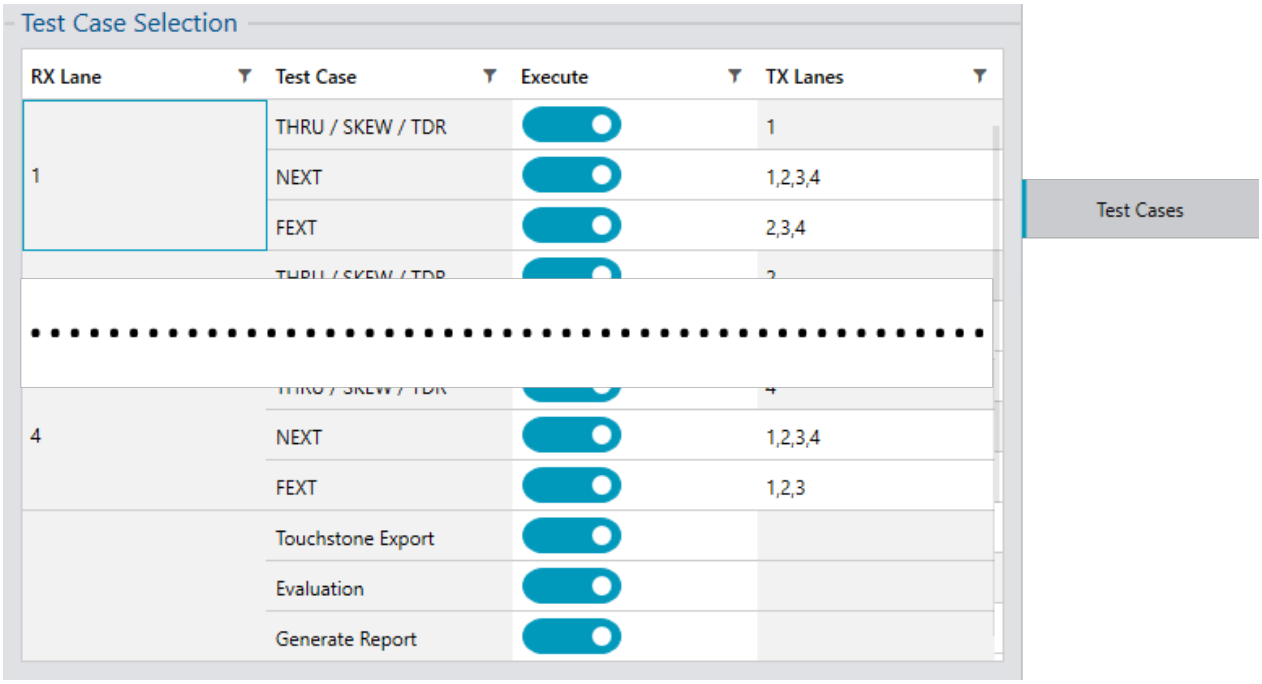

***Figure 6-2: Logical ports configuration R&S ZNRUN-K440***

1. Select the "Touchstone Files" you want to use for deembedding the test fixtures. To create these s4p files, we recommend using the deembedding assistant of the R&S ZNA/ZNB firmware.
2. If the port order within a deembedding file is non-standard, select the correct "Interchange Mode"
3. Specify the common and differential mode reference impedances.
   For PCIe cables and connectors, the limits defined in the specification are based on a differential reference impedance of 85 Ω.

   Your modifications are persisted in the user-specific ZNrun Cable Test Client settings.

**"Test Cases"**

In the "Test Cases" panel, you can select the lanes and directions to be measured, and the subsequent actions (Touchstone export, calculation of additional figures of merit, reporting).

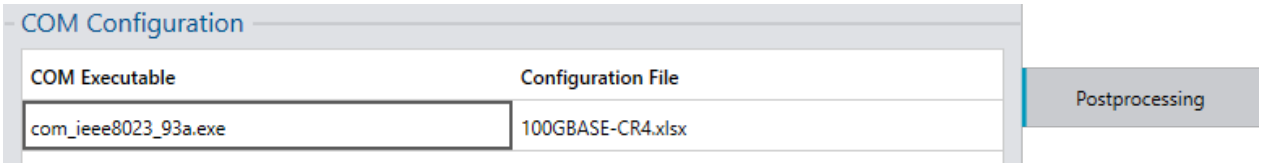



1. In the "Execute" column, select the test cases to be performed.
2. In the "TX lanes" column of each measurement test case (THRU, NEXT, FEXT lines), select the TX lanes "agressing" the respective "victim" RX.

   Your selection is persisted in the user-specific ZNrun Cable Test Client settings.

### Postprocessing

The encrypted R&S ZNrun-K41x projects allow you to select the IEEE COM executable and related configuration file to be used for postprocessing. See "Additional figures of merit: COM and ERL" on page 23.




Modified postprocessing settings are persisted in the selected master project (see ""Cable Test"" on page 46).

### Measurement Params

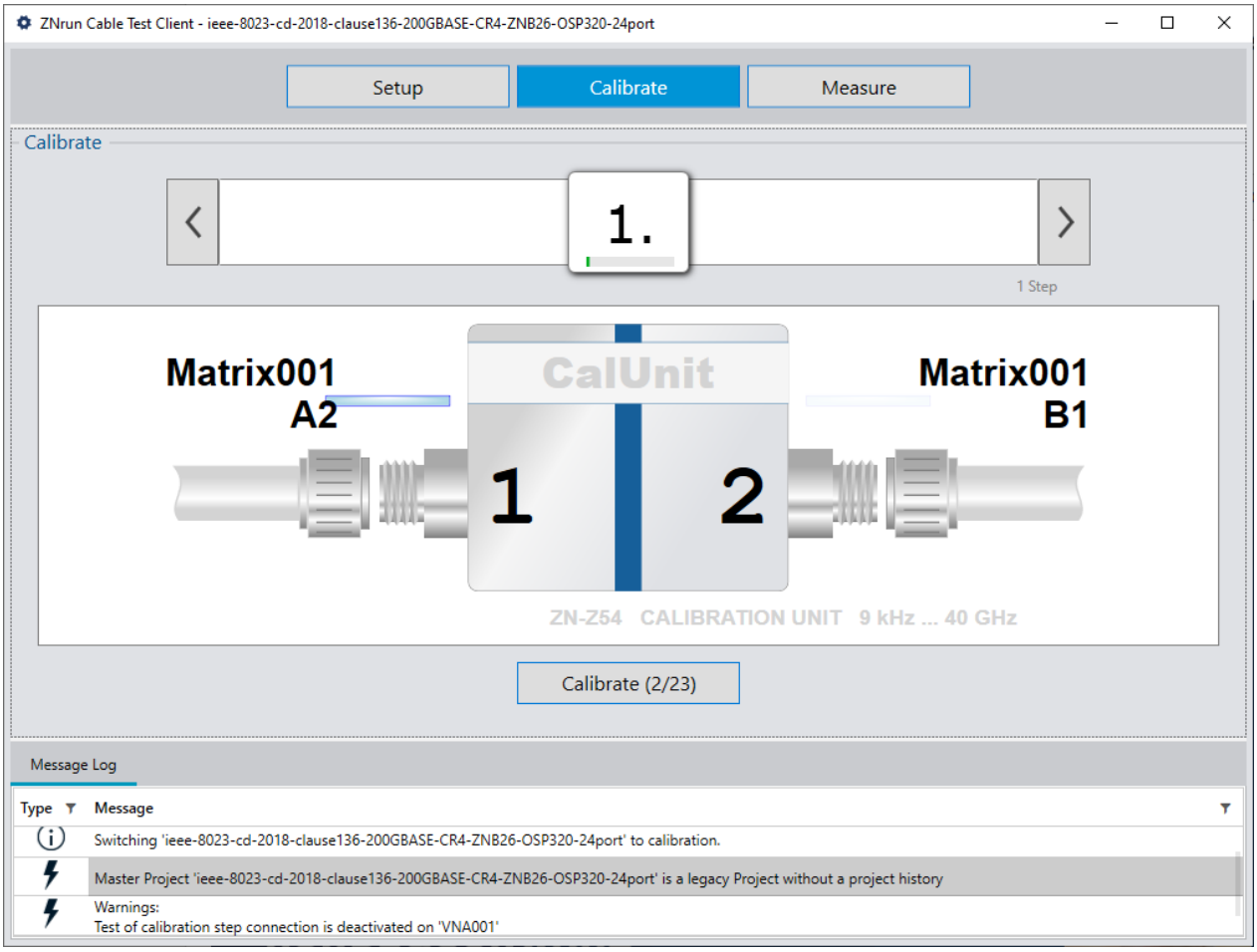
Allows you to edit certain measurement parameters. Runs the ZNrun Workbench and opens the appropriate workspaces.


Running the ZNrun Workbench from the ZNrun Cable Test Client is not possible for read-only projects, such as the predefined ones since R&S ZNRUN V2.90.

To modify a predefined project, open it directly in the ZNrun Workbench (not via the ZNrun Cable Test Client), make your changes, and save it to a different location. Or copy the project to a different location and remove the read-only flag before opening it in the ZNrun Workbench or ZNrun Cable Test Client.

### 6.1.2 Calibrate

After you have completed the "Cable Test", you can activate "Calibrate".




1. Follow the on-screen instructions on how to connect the cal unit

   Reconnect the calibration unit as displayed in the calibration wizard. Ports that have to be reconnected are marked with a blue bar. Locate them using the suitable connection plan:

   - R&S ZNRUN-K41x IEEE 802.3:
     - Chapter 4.2.2, "Connection plan", on page 24
     - Figure 4-5
     - Figure 4-6

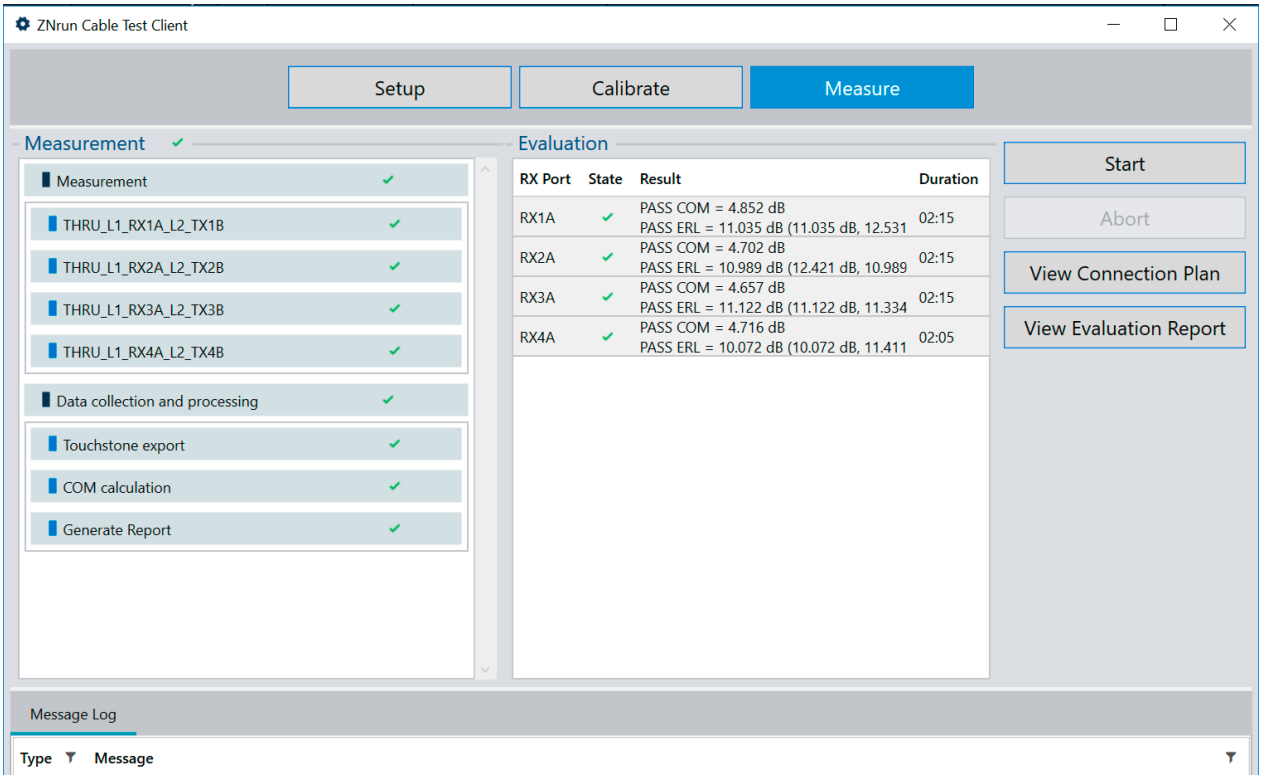
     R&S ZNRUN-K440 PCIe 5.0 and 6.0:
     - Figure 5-1
     - Figure 5-2

2. Select "Calibrate (x/y)" to proceed with the calibration.
3. Go back to step 1 until the calibration is complete.

   A completed calibration is added to the calibration pool of the VNA and to the calibration database of the ZNrun Server.

### 6.1.3 Measure

After you have completed the "Cable Test", you can activate "Measure".



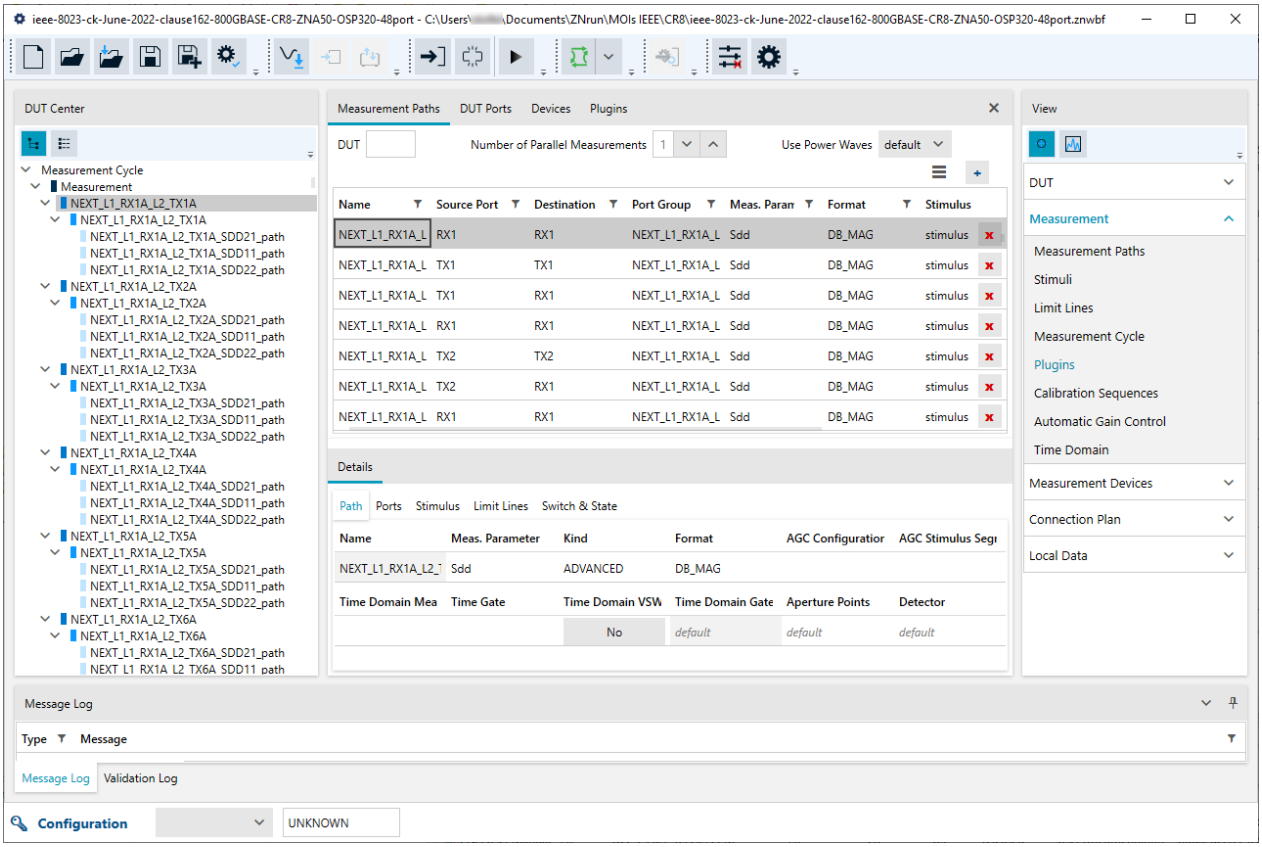

1. Connect the test fixture to the matrix as depicted in the applicable connection plan:
   - Chapter 4.2.2, "Connection plan", on page 24
   - Figure 4-5
   - Figure 4-6
2. Select "Start".

   The ZNrun Server performs the THRU, NEXT and FEXT measurements described in the MOI. For each measurement, a separate setup is generated on the VNA.
3. If prompted to do so, flip the cable under test, and select "Continue".

   After the VNA has finished the measurements, the ZNrun Server enters the "Data collection and processing phase", i.e.
   - It saves the selected measurement results and exports to a directory `ZNrun\<MOI name>\<Timestamp>` of your user documents directory (typically `C:\Users\<username>\Documents\`).
   - It performs the selected evaluations
   - If selected, it generates a PDF report summarizing the test results.
   - It saves the measurement results, other selected exports and the report to a directory `ZNrun\<MOI name>\<Timestamp>` of your user documents directory (typically `C:\Users\<username>\Documents\`).

## 6.2 Beyond compliance

The ZNrun Workbench allows you to debug the setups or DUT. By setting breakpoints or using step-by-step execution, you can analyze non-passing measurements. By modifying the test parameters (stimuli, limits, etc.) you can execute first plausibility measurements before starting the full compliance test.




The protected R&S ZNrun-K4xx remain protected when edited and saved. They can be executed on a ZNrun Server with suitable K4xx option, but cannot be rolled out. Furthermore, the ZNrun Server runs them exclusively (see "Exclusive measurement execution" on page 54).

### Exclusive measurement execution

The ZNrun Server runs the protected R&S ZNrun-K4xx projects as exclusive measurement execution units, i.e.:

- Only the executing client (ZNrun Cable Test Client or ZNrun Workbench) has access to the MEU. Other clients cannot connect to it.
- During execution, the MEU and registered plugins have only limited access to the properties of the ZNrun project.
- The ZNrun Server unloads the MEU when execution stops.