R&S High Speed Digital Cable Testing Solution

데이터 센터 용 고속 케이블과 커넥터에 대한 자동화 컴플라이언스 테스트 솔루션을 소개합니다!

Jaehyun Lee

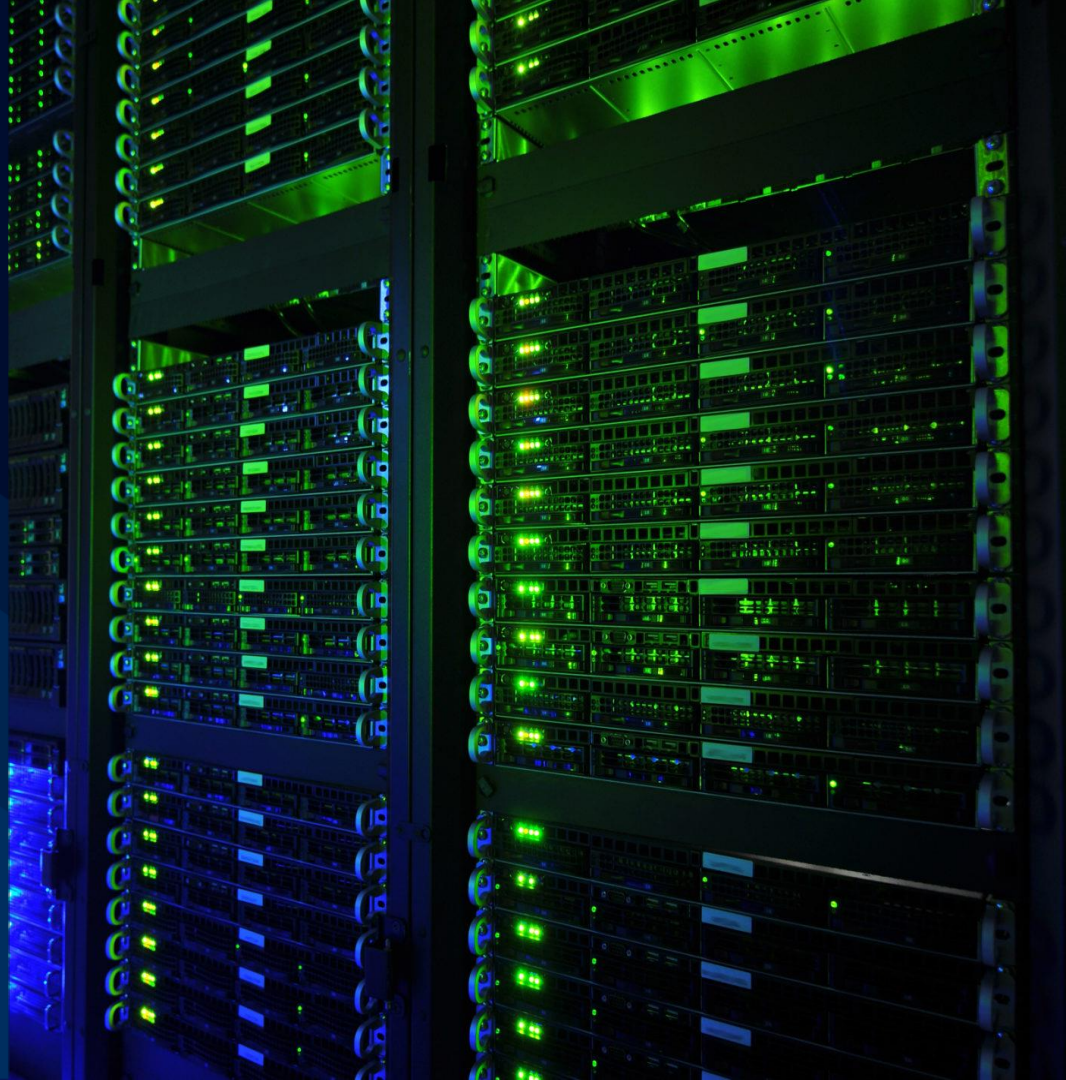
Application Engineer / Product Manager
Jan, 2025

ROHDE&SCHWARZ

Make ideas real

AGENDA

- IEEE Ethernet evolution and Demand for Cables
- Channel Testing with VNA
- Ethernet specification and QSFP Cable Examples
- R&S automated VNA solution



Challenges for AI-driven Data Centers For 800G / 1.6 T b/s Networking

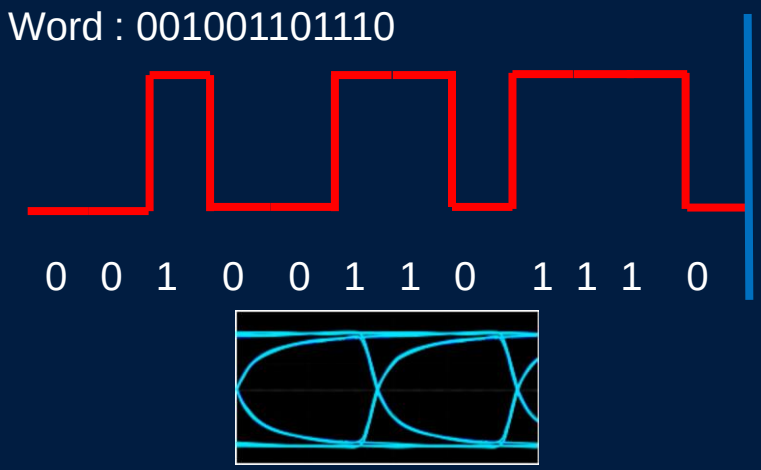
Source : EthernetRoadmap 2023-Side1-Final-Feb1- (ethernetalliance.org)

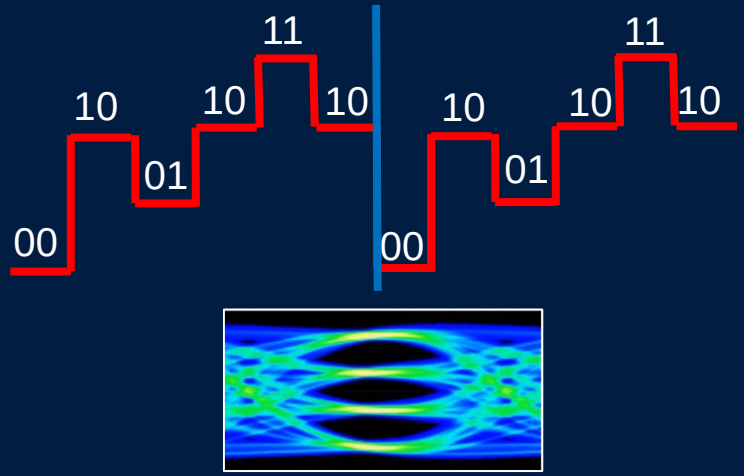
Evolution of High-Speed Ethernet Standard

IEEE specification	Copper cables	Data rate (per Lane)	Modulation	Symbol rate (per Lane)
802.3bj-2014 802.3by-2016	25GBASE-CR 100GBASE-CR4	25Gbps	NRZ	f_b = 25.785 Gbd
802.3cd-2018	50GBASE-CR1 100GBASE-CR2 200GBASE-CR4	50Gbps	**PAM4**	f_b = 26.565 Gbd
802.3ck-2022	100GBASE-CR1 200GBASE-CR2 400GBASE-CR4	100Gbps	**PAM4**	f_b = 53.125 Gbd
802.3df-2023	**800GBASE-CR8**	**100Gbps**	**PAM4**	f_b = 53.125 Gbd
802.3dj draft	200GBASE-CR1 400GBASE-CR2 **800GBASE-CR4** **1.6TBASE-CR8**	**200Gbps**	**PAM4**	f_b = 106.25 Gbd

Moving from NRZ to PAM4 : More sensitive to Noise

- **PAM4** is implemented instead of NRZ to increase data rates. PAM4 transfers **twice the content** in the same amount of time.
- This means PAM4 requires **half the BW** compared to NRZ.
- However, **SNR drops by 9.5db** which makes PAM4 more sensitive to Noise and Crosstalk



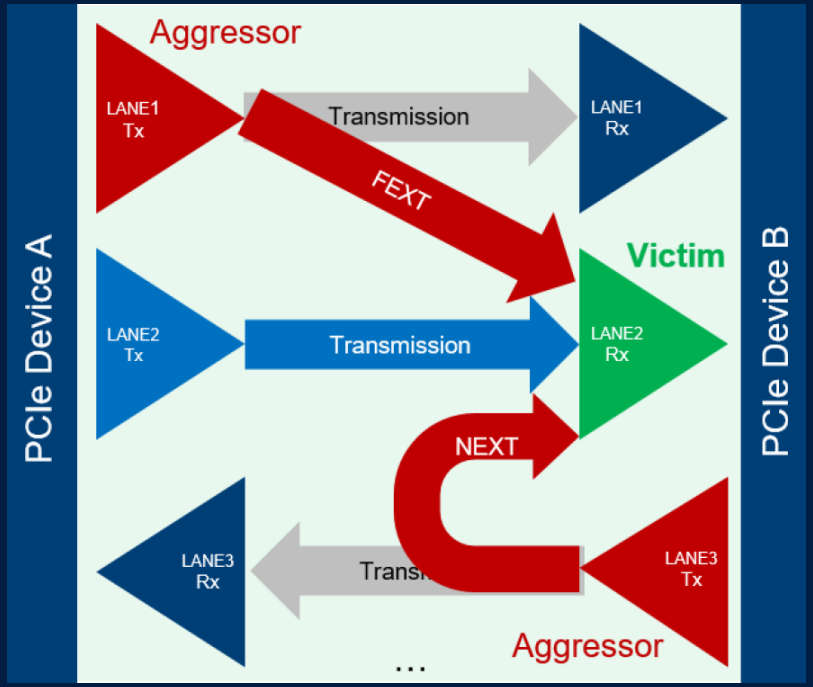


Moving from NRZ to PAM4 : More sensitive to Crosstalk

Multiple aggressors and higher crosstalk

- Crosstalk:
  - Near end crosstalk: **NEXT**
  - Far end crosstalk: **FEXT**

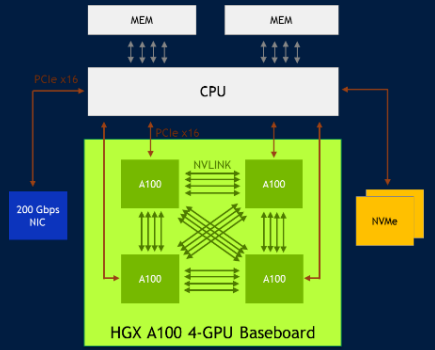
- Multiple aggressors: power sum
  - power sum NEXT: **PSNEXT**
    or Multi-disturber NEXT: **MDNEXT**
  - Power sum FEXT: **PSFEXT**
    or Multi-disturber FEXT: **MDFEXT**



Why choose cable for high speed?

- Improved Signal Loss
- Less Crosstalk
- Lower EMI
- Fewer PCB Layers
- Thermal Management
- Better head dissipation compared to PCB traces

- Flexibility in design
- Easy to replace/upgrades
- Scalability and Future-Proofing
- Simplified Routing
- Reduces PCB Complexity



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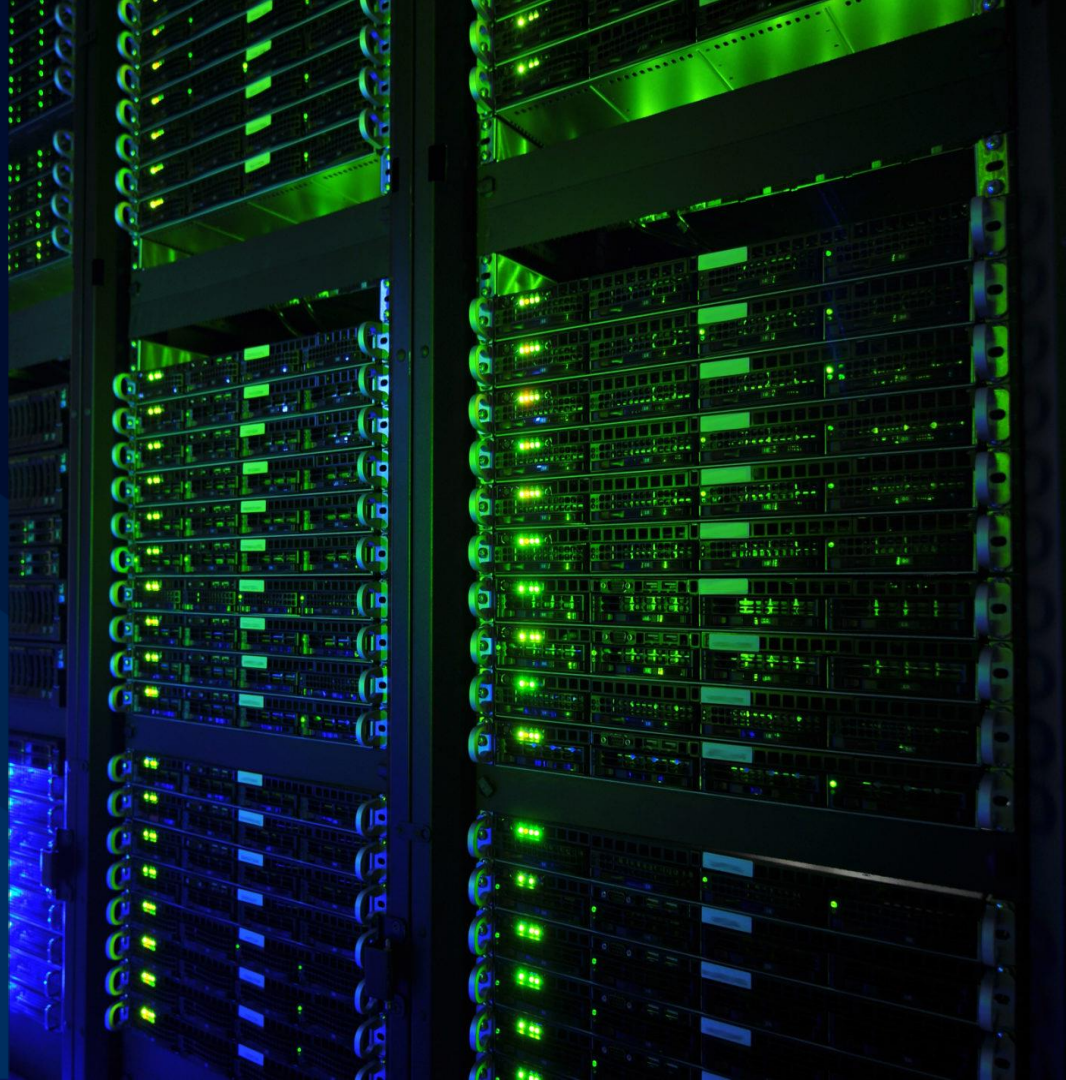
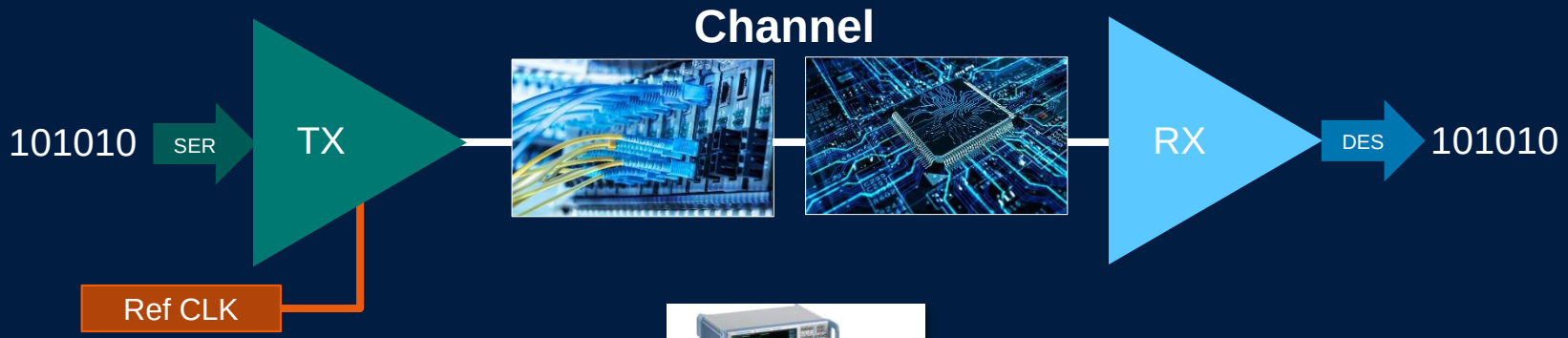
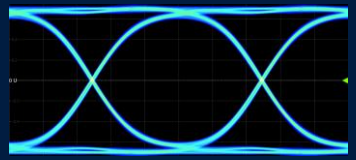
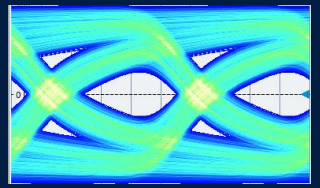


Channel Testing Simplified





VNAs are almost exclusively used for characterizing the channel



R&S Vector Network Analyzer(VNA)
Channel Test: PCBs and Interconnects

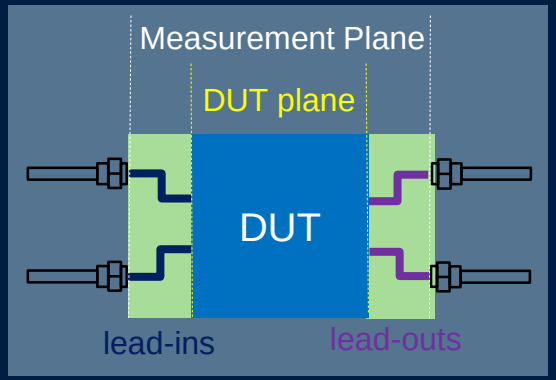
Channel Test Cases with R&S ZNB Vector Network Analyzer

Signal Integrity Analysis of Channel

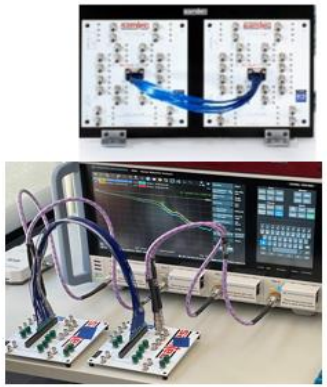
- Frequency Domain Analysis
  - Insertion Loss and Return Loss
  - Differential S-parameter / Crosstalk for Multilane
  - Delta-L 4.0 for PCB Characterization
  - Advanced De-embedding
- Time Domain analysis
  - TDR(Impedance) / Eye Diagram / Skew

De-embedding Requirements

- Easy and accurate test fixture characterization and de-embedding
- Guidance through “De-embedding Assistant”



PCIe 5.0 / 6.0 Cables compliance test case with De-embedding according to PCIe Specification



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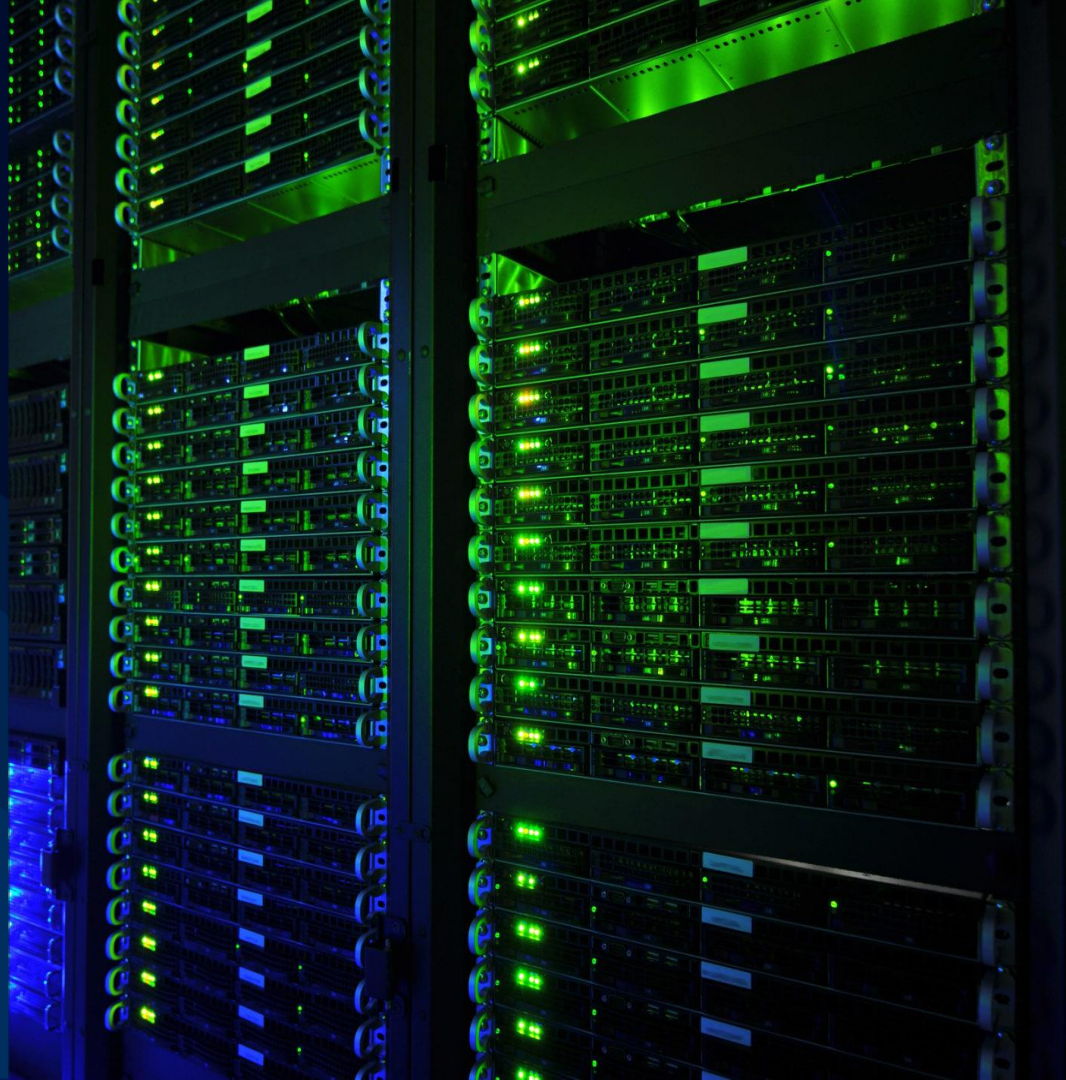
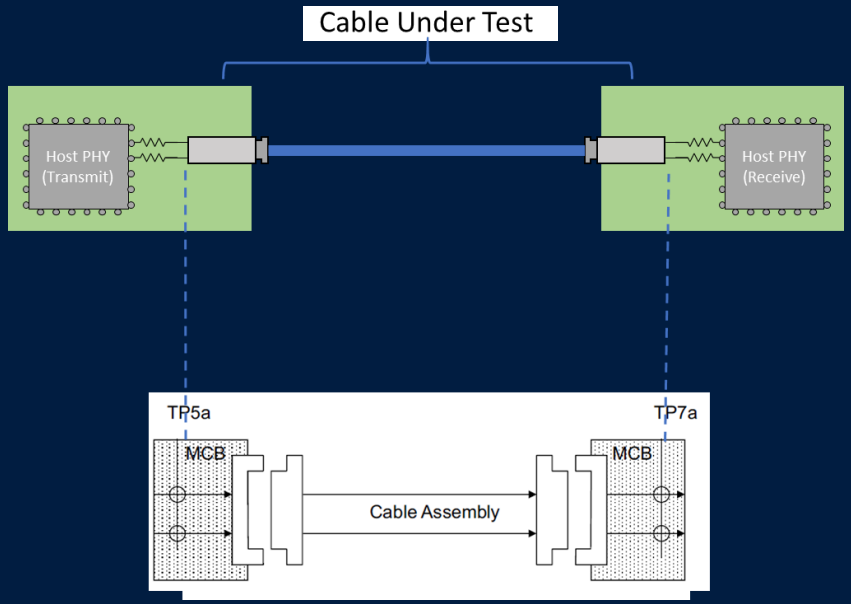


IEEE 802.3 Specification Requirements



- **Compliance Parameters include:**
  - Impedance Mask
  - Insertion Loss
  - Return Loss
  - Near-End Crosstalk (NEXT)
  - Far-End Crosstalk (FEXT)
  - Conversion Loss
  - Channel Operating Margin (COM)
  - Effective Return Loss (ERL)

Testing Ethernet: Typical Module Form Factors

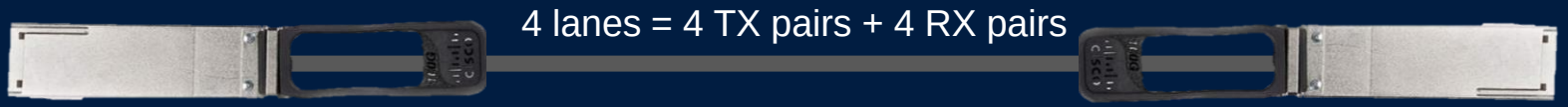
<table>
<tr><th>1x lane</th><th>4x lane</th><th colspan="2">8x lane</th></tr>
<tr><td>SFP+</td><td>QSFP(+/28/56)</td><td>QSFP-DD</td><td>OSFP</td></tr>
<tr><td>  </td><td>  </td><td>  </td><td>  </td></tr>
<tr><td>1 TX / 1 RX Lane

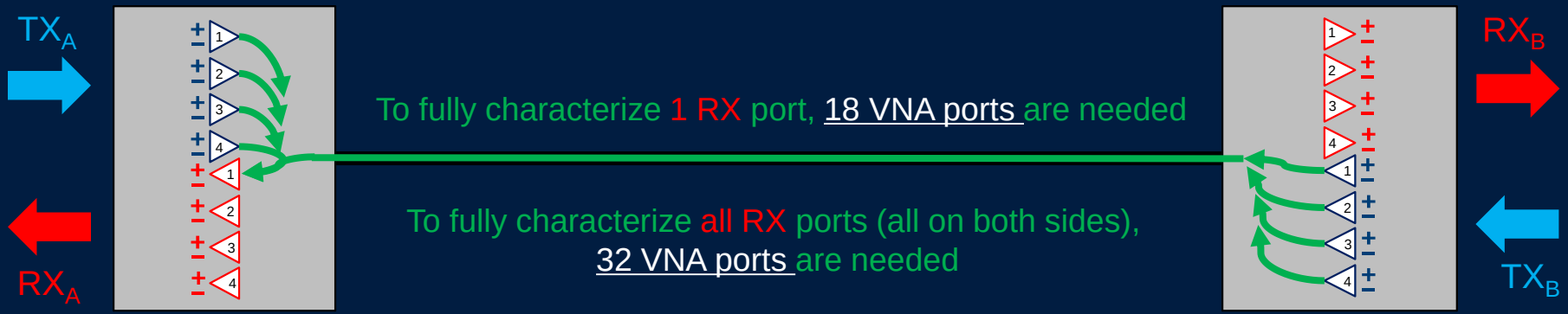
10 Gbps</td><td>4 TX / 4 RX Lanes

<table><tr><th></th><th>Per Lane Rates</th></tr><tr><td>QSFP+</td><td>10 Gbps</td></tr><tr><td>QSFP28</td><td>25 Gbps</td></tr><tr><td>QSFP56</td><td>50 Gbps</td></tr></table></td><td colspan="2">8 TX / 8 RX Lanes

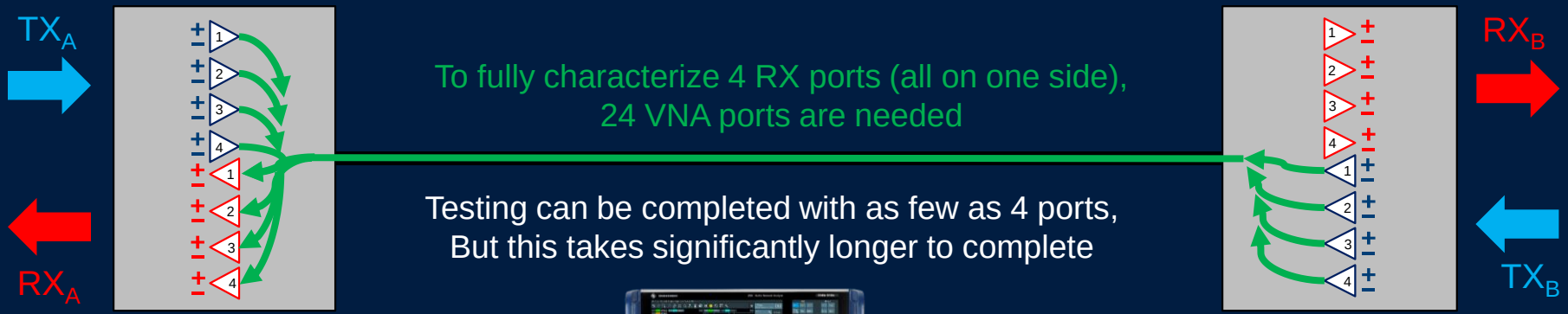
Being deployed for 802.3dj designs
(200 Gbps per lane)</td></tr>
</table>

Example: Testing a QSFP Cable





Example: Testing a QSFP Cable



Testing IEEE802.3 cables with VNA

Required Measurements:

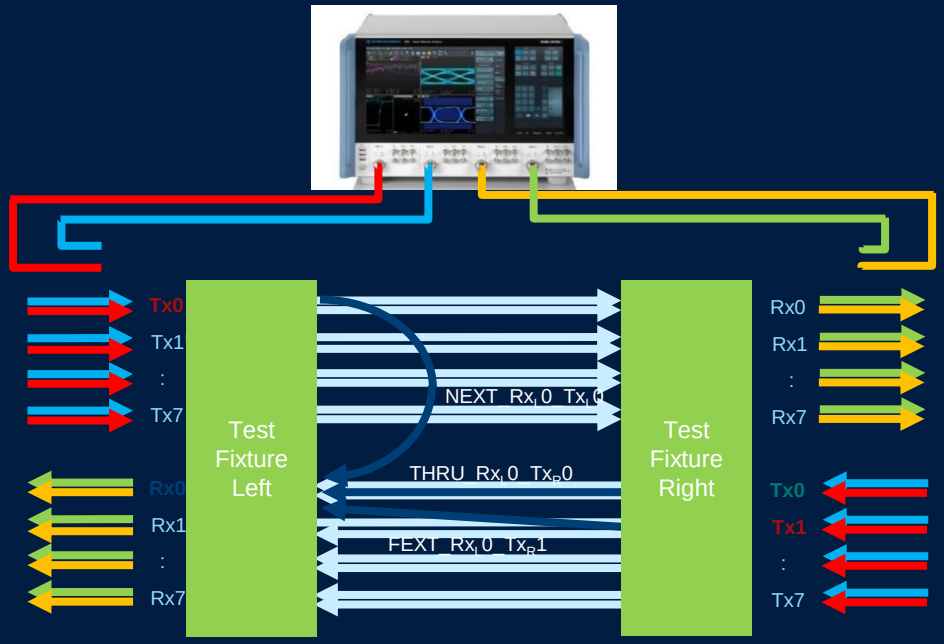
- Insertion loss Sdd21
- Return loss Sdd11 and Sdd22
- NEXT
- FEXT

Testing with 4 port VNA:

- Multiple 4-port measurements

Postprocessing:

- COM (Channel Operating Margin)
- ERL (Effective Return Loss)



Example IEEE802.3 CR8 cable

High-Speed Cable Test: IEEE802.3
Cable Types – DAC and AOL

Direct Attach Copper Cables (DAC): short distances, very economic

- purpose: connect switches, servers, and storage inside racks in data centers
- 2 types:
  - **passive DAC cables** (without signal conditioning): no re-timer in connector paddle card
    → can be tested w. VNAs

  - active DAC cables (with signal conditioning): re-timer in connector paddle card
    → cannot be tested with VNAs

Active Optical Cables (AOL): longer distances

- purpose: link switches, servers, and storage between different racks inside data centers

High-Speed Cable test: IEEE802.3 Symmetric cables

Symmetric Cable: e.g. **QSFP-DD (CR8)** to **QSFP-DD (CR8)**:

- Majority of cables are symmetric
- Allows simplified test setup for THRU, NEXT, FEXT by flipping the cable once:
  - Connection #1: cable side A – fixture A
    cable side B – fixture B

  - Connection #2: cable side B – fixture A
    cable side A – fixture B

→ **Reduced number of ports: 16 + 32 = 48**

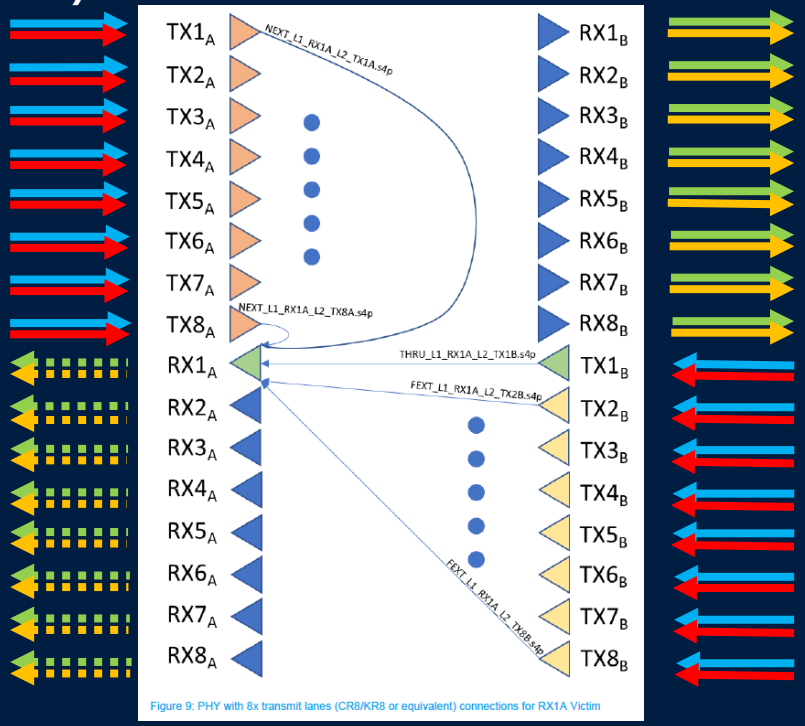


Figure 9: PHY with 8x transmit lanes (CR8/KR8 or equivalent) connections for RX1A Victim

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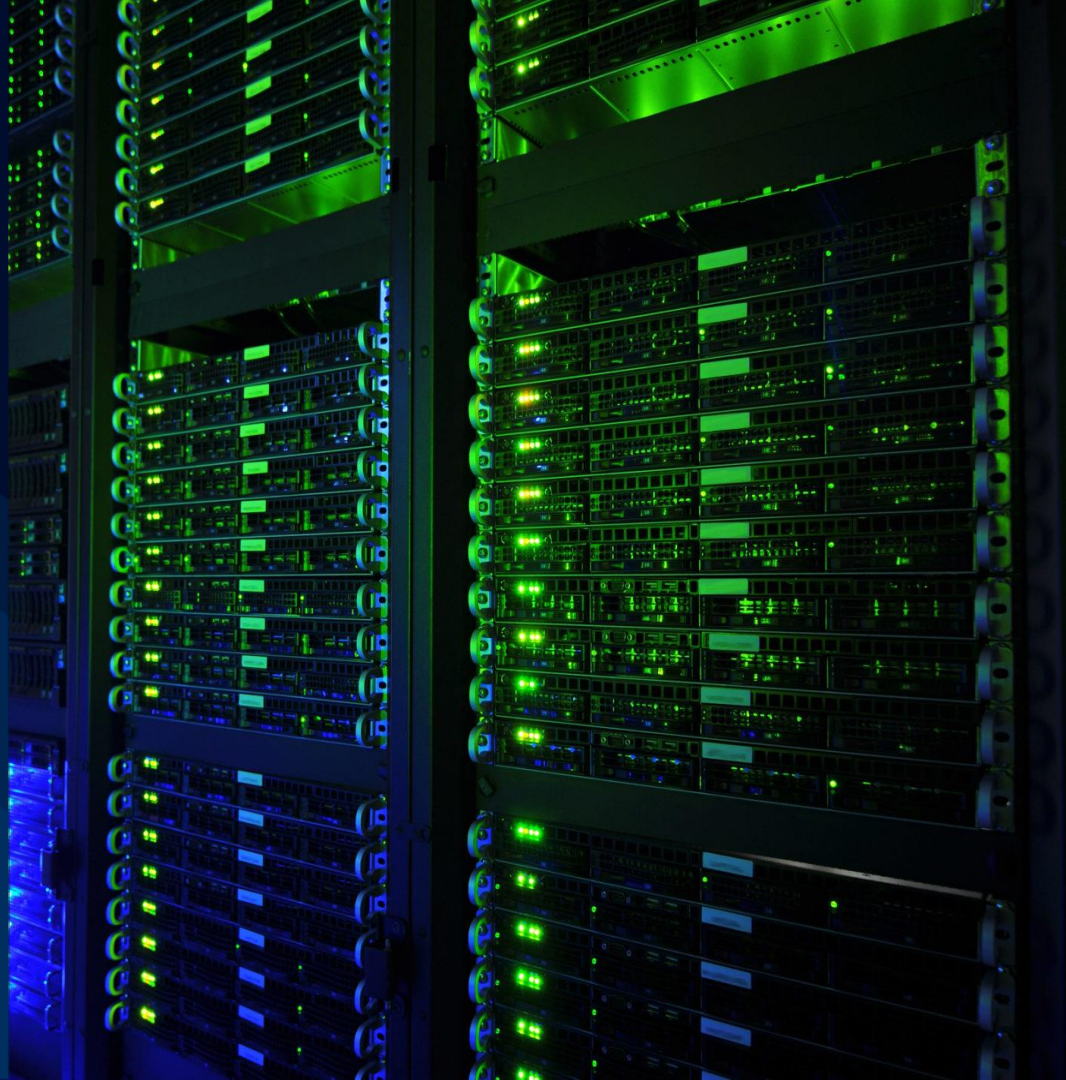


Recommended Multiport Configuration For IEEE802.3 CR8 and CR4 cables

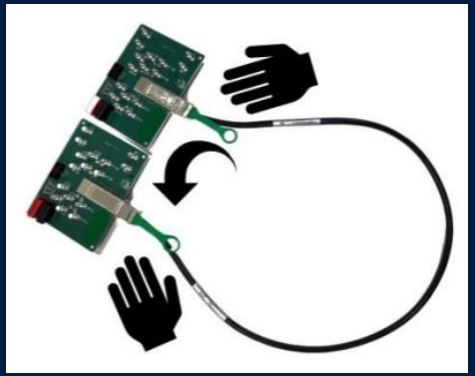
Cable under test		R&S®OSP
Form factor	Number of lanes	Number of ports
QSFP-DD to QSFP-DD, QSFP to QSFP	8 × TX/RX (CR8)	48
QSFP to QSFP	4 × TX/RX (CR4)	24

- Test port requirement
  - CR4 → 32 test ports
  - CR8 → 64 test ports.

- **Reduced test port** method
  - For high-speed cables with the same form factor on both sides, **some test ports can be reused, resulting in a reduced total number of required ports.**

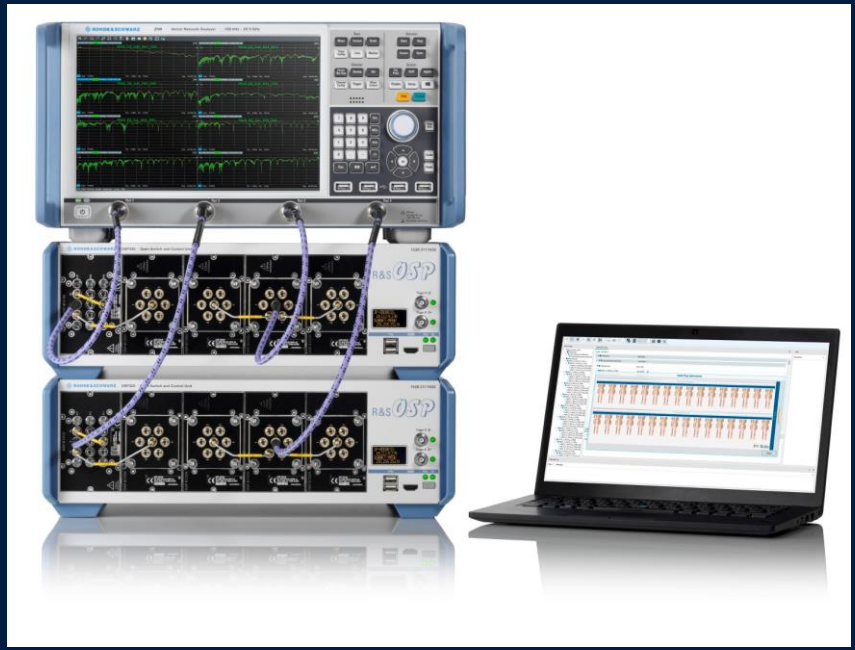
- **Efficient test setup**
  - **The user only needs to unplug the cable under test** once, flip it, and re-plug it into the test fixtures, eliminating the need for multiple coaxial cable re-connections during measurement.

Recommended R&S®OSP open switch and control platform for 48, 24 ports



R&S Solution For Compliance and Verification For IEEE802.3 bJ, by, cd, ck, df, dj

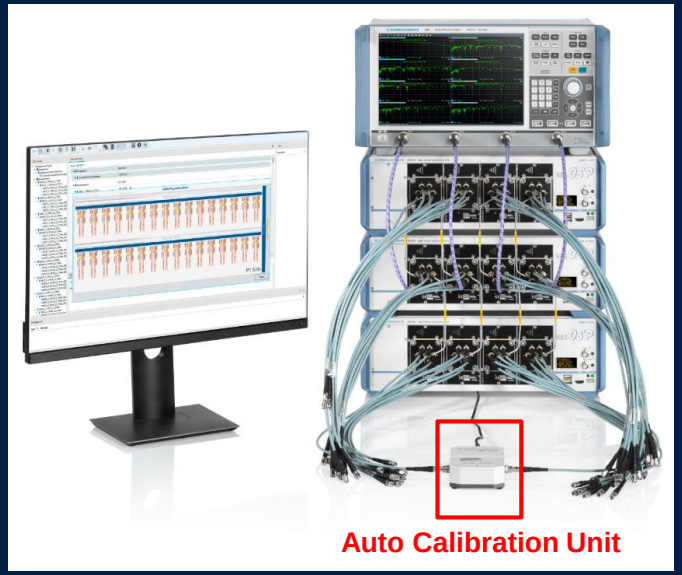
- Supported Cables
  - IEEE802.3 symmetrical cables: **CR8 (8 lanes)**, **CR4 (4 lanes)**, and **CR1 (1 lane)**
- Automation Features
  - **R&S VNA** and **R&S OSP** controlled by **ZNrun** for automated measurements
  - Automated post-processing according to **IEEE802.3 metric**
- Automated Measurement and Reporting
  - S-parameter measurement: **Through**, **FEXT**, and **NEXT**
  - Post-processing: **COM**, **ERL**, and **Report generation** with overall verdict and detailed results

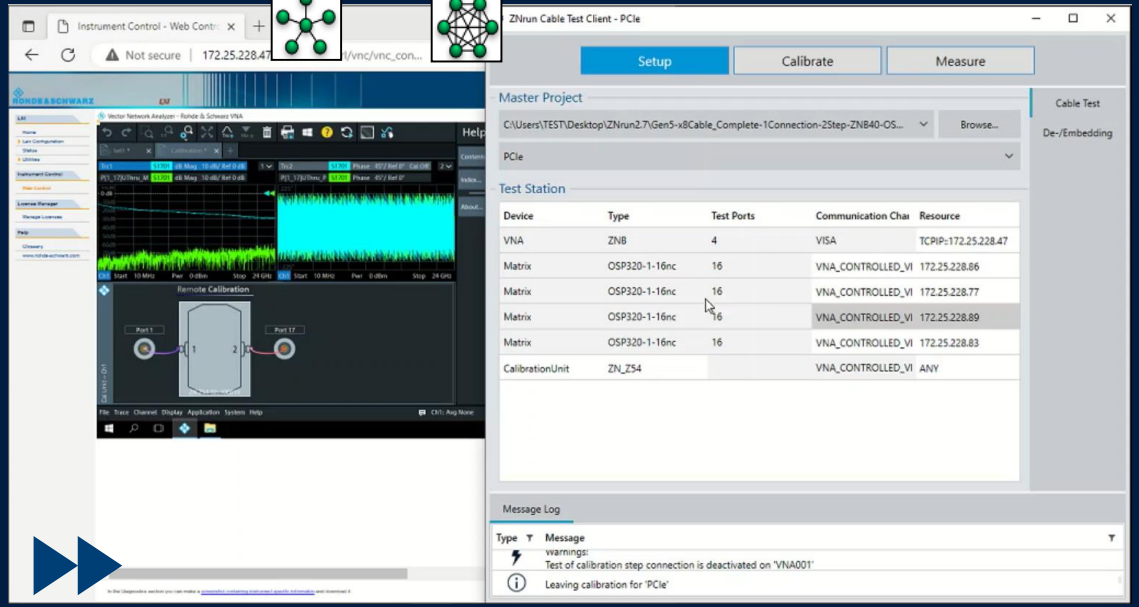


Patented Time Efficient Calibration Algorithm
ex. 64-port Calibration

< 1hr

connections: 63 vs. 768





Demo Video

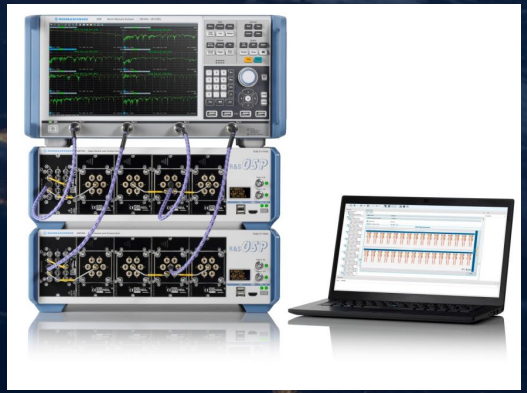
R&S ZNrun and VNA for compliance test

IEEE specification	ZNrun technology-based option	Copper cables	Data rate (per Lane)	Modulation	Symbol rate (per Lane)	VNA BW requirement (PCBs / Cable Assemblies)
802.3bj-2014 802.3by-2016	**R&S®ZNrun-K410**	25GBASE-CR 100GBASE-CR4	25Gbps	NRZ	f_b = 25.785 Gbd	**25 GHz**
802.3cd-2018	**R&S®ZNrun-K410**	50GBASE-CR1 100GBASE-CR2 200GBASE-CR4	50Gbps	PAM4	f_b = 26.565 Gbd	**25 GHz**
802.3ck-2022	**R&S®ZNrun-K411**	100GBASE-CR1 200GBASE-CR2 400GBASE-CR4	100Gbps	PAM4	f_b = 53.125 Gbd	**50 GHz**
802.3df-2023	**R&S®ZNrun-K411**	**800GBASE-CR8**	100Gbps	PAM4	f_b = 53.125 Gbd	**50 GHz**
802.3dj draft	**R&S®ZNrun-K412**	200GBASE-CR1 400GBASE-CR2 **800GBASE-CR4** **1.6TBASE-CR8**	200Gbps	PAM4	f_b = 106.25 Gbd	**60 GHz**

Summary

- Data Center, Service Providers need **800G / 1.6 T b/s** Networking for AI
  - Increase IEEE802.3 Ethernet, PCIe cable demands

- R&S Compliance Test Solution
  - IEEE802.3 & PCIe automation compliance test of Cables and Connectors
  - Predefined topology for multi-lane setup
  - Test cases selection
  - Efficient calibration
  - Reduction in testing time
  - Report generation
  - Time domain(TDR) / De-embedding



Q&A

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