a LIGHTWAVE® LiveWebcast

New Test Requirements for 40/100 GbE Transceivers

2nd March 2010

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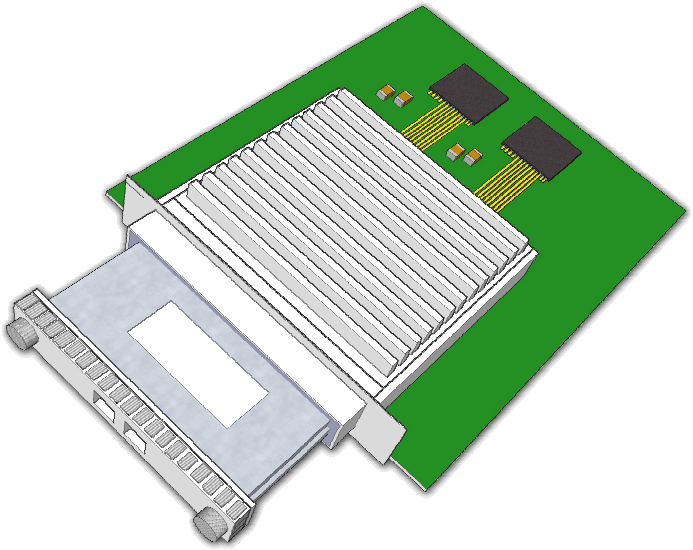
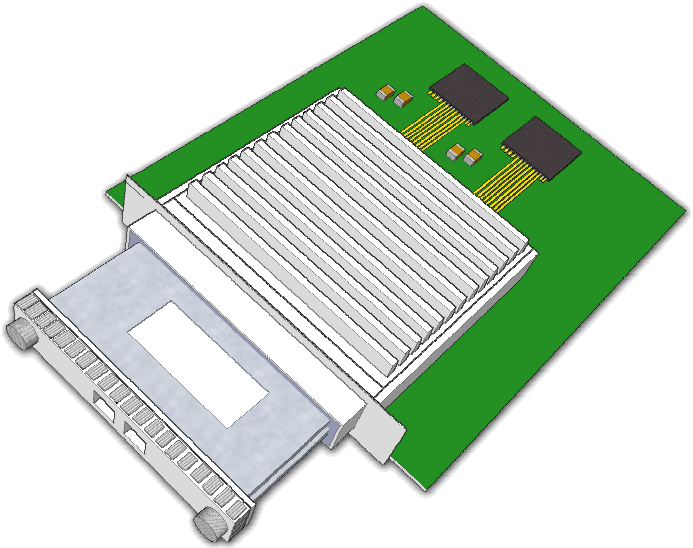
Agenda



- Introduction
- Transmitter Testing
- Receiver Testing
- Interconnect Testing
- Summary

Introduction



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100Gb/s Communications

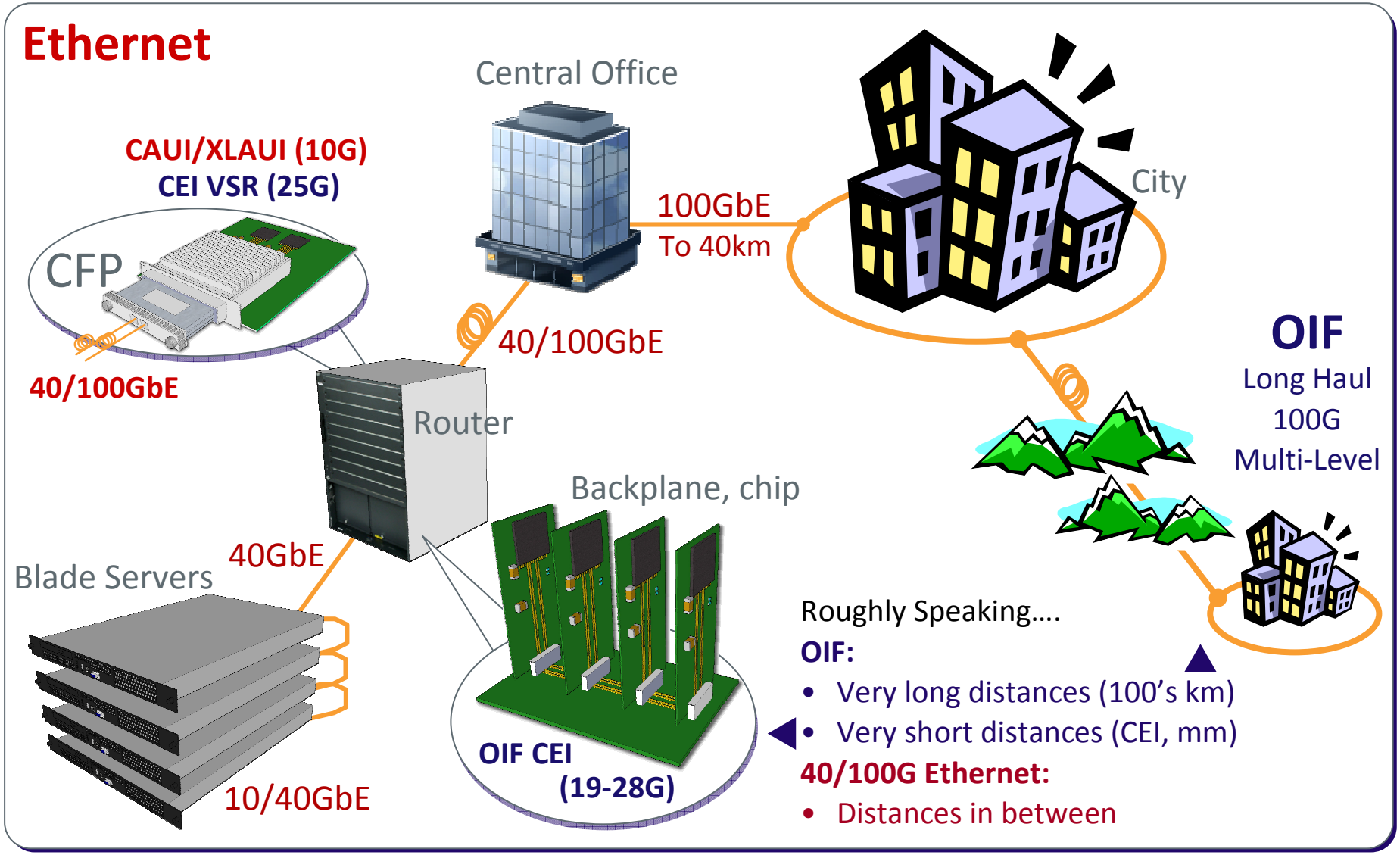
Two worlds:

1. **Ethernet**: 100 and 40Gb/s with traditional NRZ signaling:
   Low cost LAN and Metro networks, based on existing technology.
   Multi-lane 10Gb/s and 25Gb/s (**802.3ba**) and 40Gb/s (**803.bg**)
2. Long haul 100 and 40Gb/s with new, complex signaling:
   OIF standardizing complex optical signaling (DP-QPSK, aka PM QPSK)

We are addressing **Ethernet** today.

802.3ba™ is a trade mark of IEEE. www.ieee.org

High Speed Networks & Standards



IEEE 802.3ba™
New High Speed Interfaces

	Interface	Type	Data Rate	Chan.	Range	Notes
1.**	100G**BASE**-ER4	Optical, *1310nm SM*	**25**.78125 Gb/s	4	40 km	Module (transceiver) transmission side interfaces (designated by '**BASE**' in the name)
2.**	100G**BASE**-LR4	Optical, *1310nm SM*	**25**.78125 Gb/s	4	10 km	
3.**	40G**BASE**-LR4	Optical, *1310nm SM*	**10**.3125 Gb/s	4	10 km	
4.**	100G**BASE**-SR10	Optical, *850nm MM*	**10**.3125 Gb/s	10	100 m	
5.**	40G**BASE**-SR4	Optical, *850nm MM*	**10**.3125 Gb/s	4	100 m	
6.	100G**BASE**-CR10	Electrical, *Cu cable*	**10**.3125 Gb/s	10	7 m	
7.	40G**BASE**-CR4	Electrical, *Cu cable*	**10**.3125 Gb/s	4	7 m	
8.**	40G**BASE**-KR4	Electrical, *backplane*	**10**.3125 Gb/s	4	1 m	
9.**	CAUI	Electrical	**10**.3125 Gb/s	10	25 cm	Chip to module, re-timed ("nAUI")
10.	XLAUI	Electrical	**10**.3125 Gb/s	4	25 cm	
11.	CPPI	Electrical	**10**.3125 Gb/s	10	25 cm	Chip to module, non-re-timed (like SFP+) ("nPPI")
12.	XLPPI	Electrical	**10**.3125 Gb/s	4	25 cm	

Distance →

** *Aspects of these variants will be covered in this presentation*

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Common Transceiver Types

Type	Chip to module side (electrical)		Transmission side (BASE)
CFP 40GbE	4x 10G 'XLAUI' (or maybe XLPPI for SR4)	4 / 4 CFP	4x 10G: 1310nm WDM (LR4) 850nm ribbon (SR4) Copper (CR4, KR4)
CFP 100GbE	10 x10G 'CAUI' (or maybe CPPI for SR10)	10 / 10 CFP	10x 10G: 850nm ribbon (SR10) Copper (CR10) 4x 25G: **1310nm WDM (LR4, ER4)**
Future 100GbE	4x 25G (new OIF CEI VSR effort)	4 / 4 "CFP2"	4x 25G: 1310nm WDM (LR4, ER4)
CXP	10x 10G	10 / 10 CXP 10 / 10	10 fiber ribbon cable (12 fibers for Infiniband applications) Module is smaller than CXP for higher port density (like XFP)

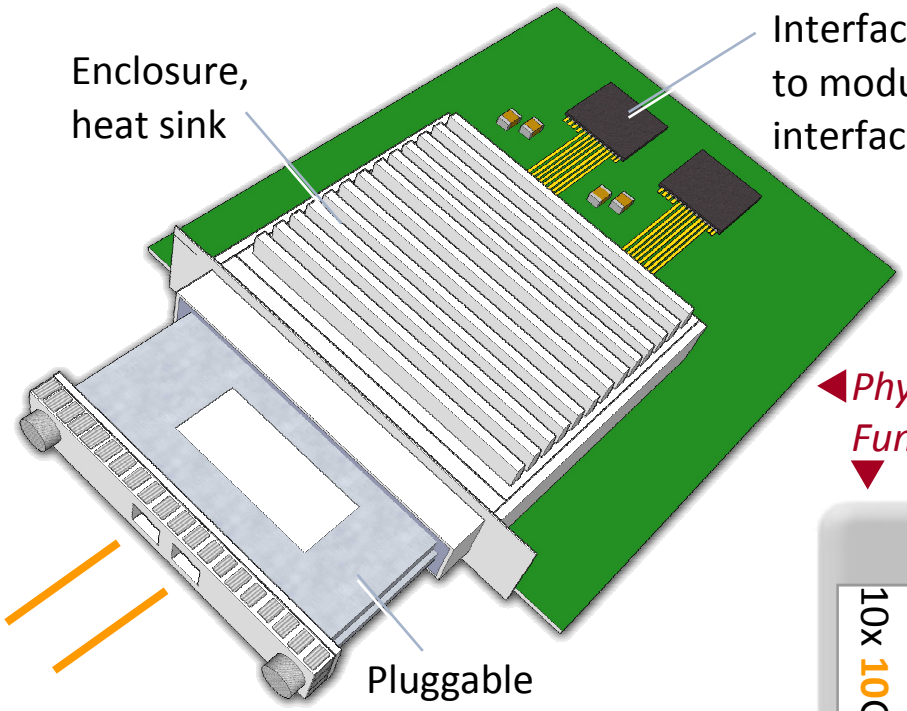
Main focus today

Anatomy of a CFP – Example 100GBASE-LR4/ER4

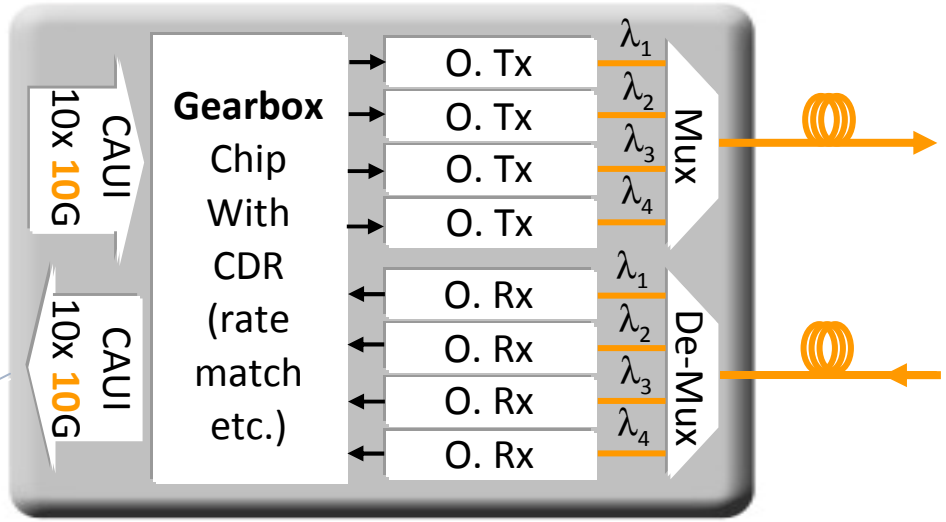
- ✓ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ❑ CAUI

More details here:
www.cfp-msa.org/

Note: Both 40GbE & 100GbE use 1310nm WDM, but channel λ's different so 40Gbe & 100GbE can be used on same fiber.



Physical
Functional



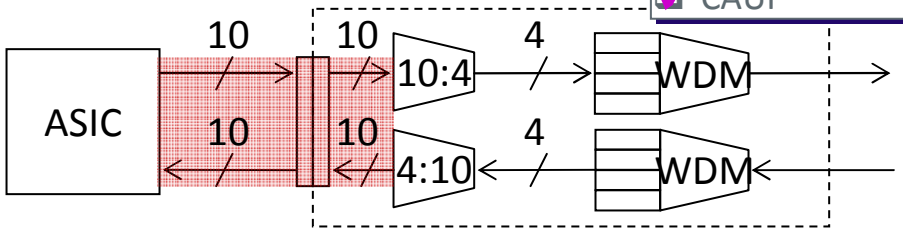
(20 lines each as differential, 40 inc Rx & Tx)

Electrical interfaces for 40/100 Gb/s Ethernet

- ❑ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ✓ 40GBASE-KR4
- ✓ CAUI

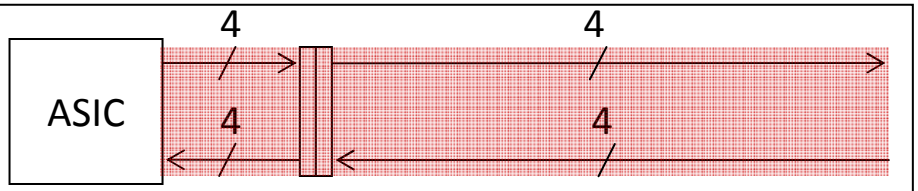
XLAUI (40 Gb/s) and CAUI (100 Gb/s)

- Chip-to-chip (not shown)
- Chip-to-module (retimed)
  - showing here LR4/ER4



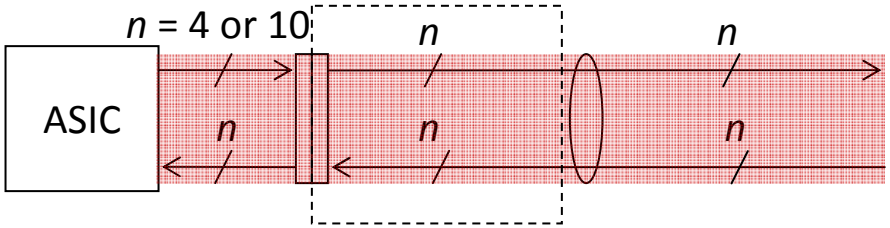
40 Gb/s Backplane Ethernet

- Up to 1 m and 2 connectors
- 40GBASE-KR4



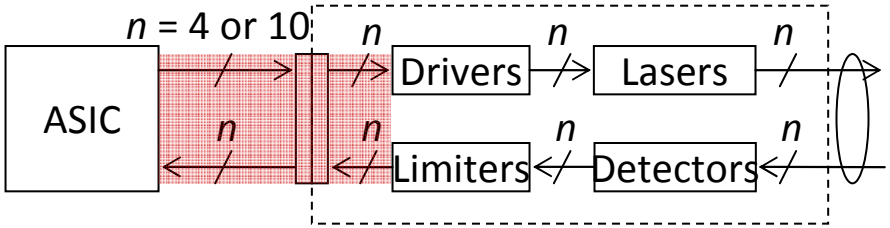
Copper cable assembly

- Up to 10 m
- 40GBASE-CR4 (40 Gb/s)
- 100GBASE-CR10 (100 Gb/s)



Parallel Physical Interface (PPI)

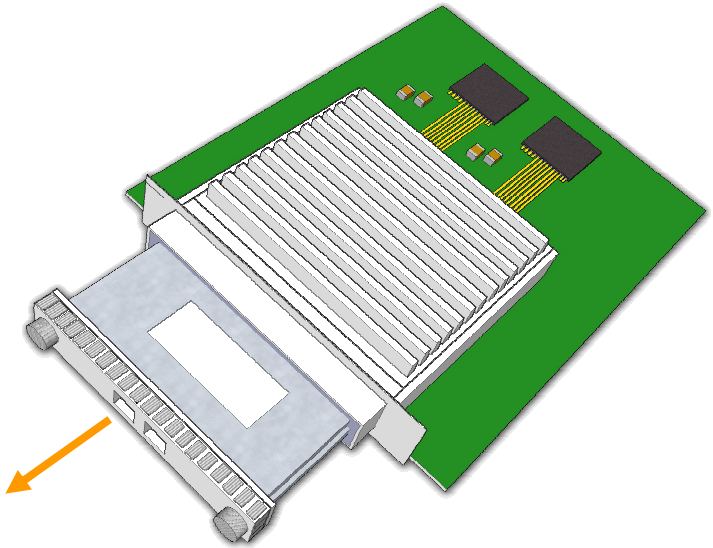
- Chip-to-module (limiting)
- 40 and 100 Gb/s



Interfaces consist of an aggregation of 10 Gb/s serial lanes

Adapted from DesignCon 2009 Panel "Design Challenges for Next Generation, High Speed Ethernet: 40 and 100 GbE" by Adam Healy, LSI Logic

Transmitter Testing



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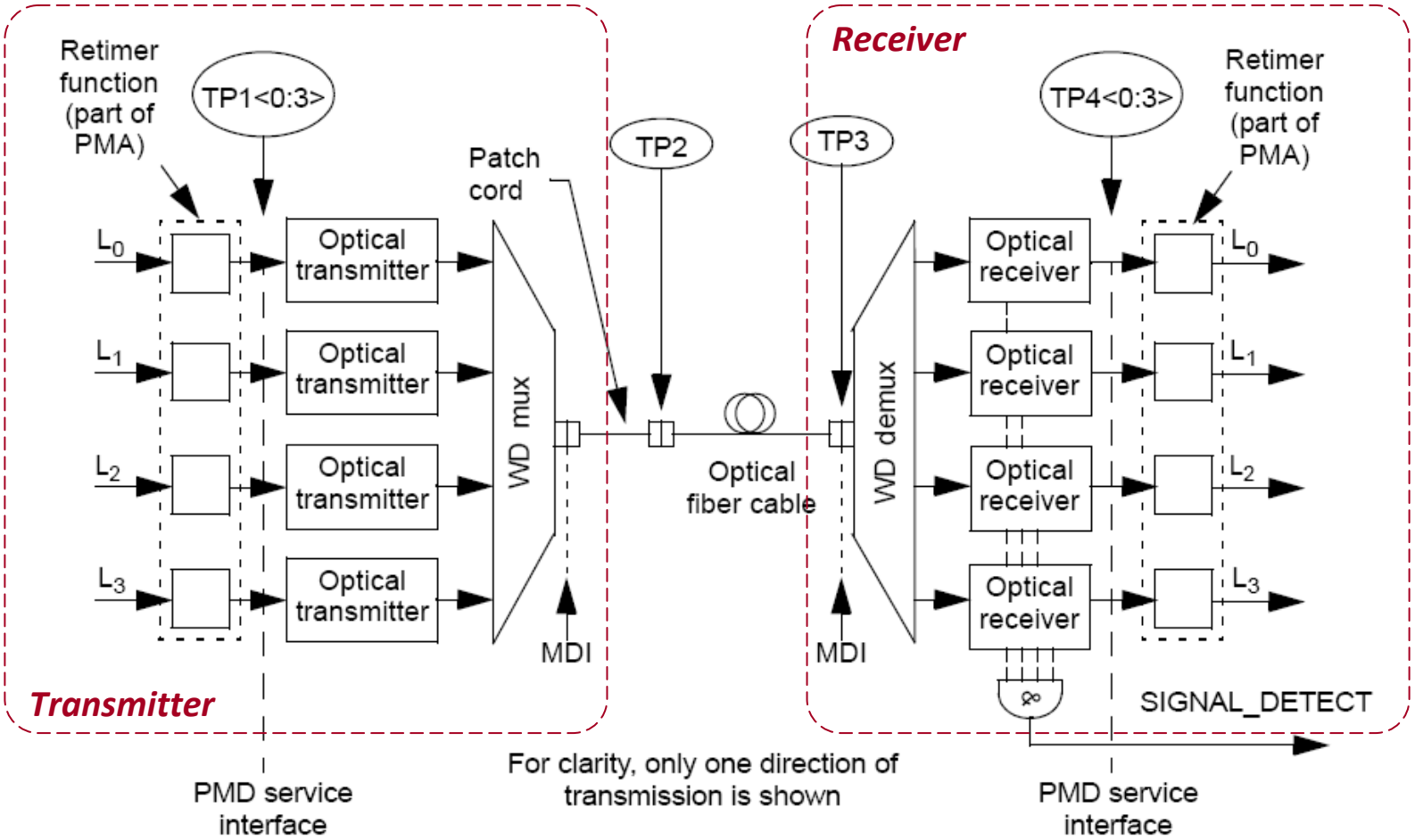
Testing 100GBASE–LR4/ER4 - Transmitter

- ✓ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ❑ CAUI

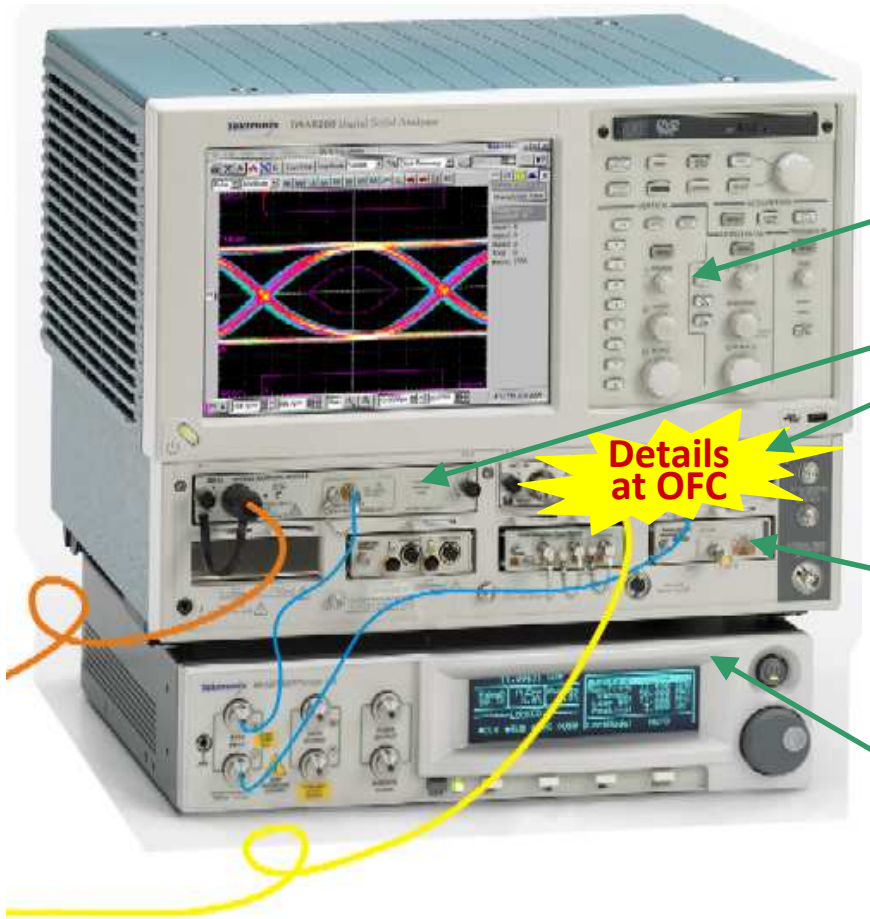


©IEEE

Taken from IEEE P802.3ba™D3.0, Figure 88–2, p340.

25, 28, and 40 Gb/s Capable Test Equipment: Optical Test for 40/100 GbE

- ✓ 100GBASE-ER4/LR4
- ✓ 100GBASE-SR10
- ✓ 40GBASE-SR4
- ✓ 40GBASE-LR4
- ✓ 40GBASE-KR4
- ✓ CAUI



- Single DSA mainframe is capable of handling all bit-rates of the standard.

Digital Sampling Oscilloscope:
- Tektronix DSA8200

Optical Modules:
- 80C12-10G or 80C08C for 10 Gb/s signaling
- 80C10B-F1* for 25, 28 and 40 Gb/s signaling (40 Gb/s is part of the upcoming 802.3bg)

Recommended above 10 Gb/s:
- 82A04 Phase Reference module for high accuracy/ low jitter

Clock Recovery
- Tek 80A07/ BERTScope CRHS28000A up to 28.6 Gb/s

** Note: 80C10B CR pickoff is a product concept only. Come to Tektronix booth at OFC for details.*

Transmitter Test for LR and ER

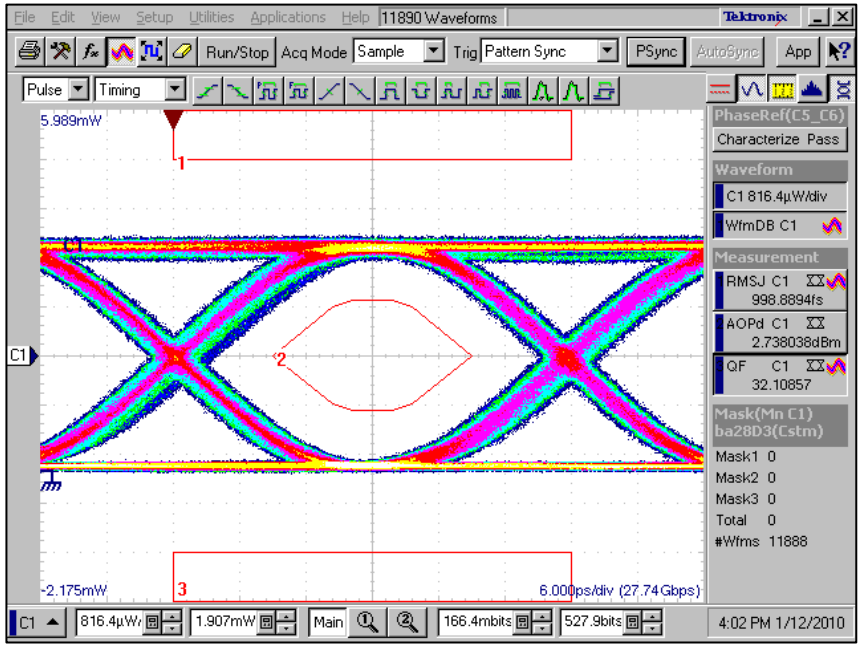
- ☑ 100GBASE-ER4/LR4
- ☐ 100GBASE-SR10
- ☐ 40GBASE-SR4
- ☐ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI

- Most of the Transmitter Test measurements are **similar to the tests** in the original, 10 Gb/s **802.3ae** document (ratified in 2002).
- We will look at several measurements on the 25 Gb/s signal

TX Test – Measurements for 40GBASE-LR4, 100GBASE-LR4/ER4

- ☑ 100GBASE-ER4/LR4
- ☐ 100GBASE-SR10
- ☐ 40GBASE-SR4
- ☑ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI

- Similar to **10GBASE** single-mode optical
- Newly defined aspects are:
  - Optical **Reference Receiver** at 7.5 or **19.34 GHz**; Clock Recovery at 4 or **10 MHz PLL LBW**
  - **Masks** – scaled version of 802.3ae. **New masks for 25 and 28 Gb/s** available as files from Tektronix
  - Masks – **hit ratio** of 0.005%; **calculation in oscilloscope math** (contact Tektronix for details)
  - **OMA measurement** now possible on PRBS-9
  - **TDP**, Transmitter Dispersion Penalty: **similar to 802.3ae**



LR4 Mask Test Using DSA8200 & 80C10B-F1 Reference Receiver

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New Jitter Measurements

- ☑ 100GBASE-ER4/LR4
- ☑ 100GBASE-SR10
- ☑ 40GBASE-SR4
- ☑ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI

- The standard uses **new J2** and **J9** jitter measurements.
- The measurements are used for the definition of **Stressed Eyes**, and for measurement on **nPPI**
- A discussion of these measurements follows.

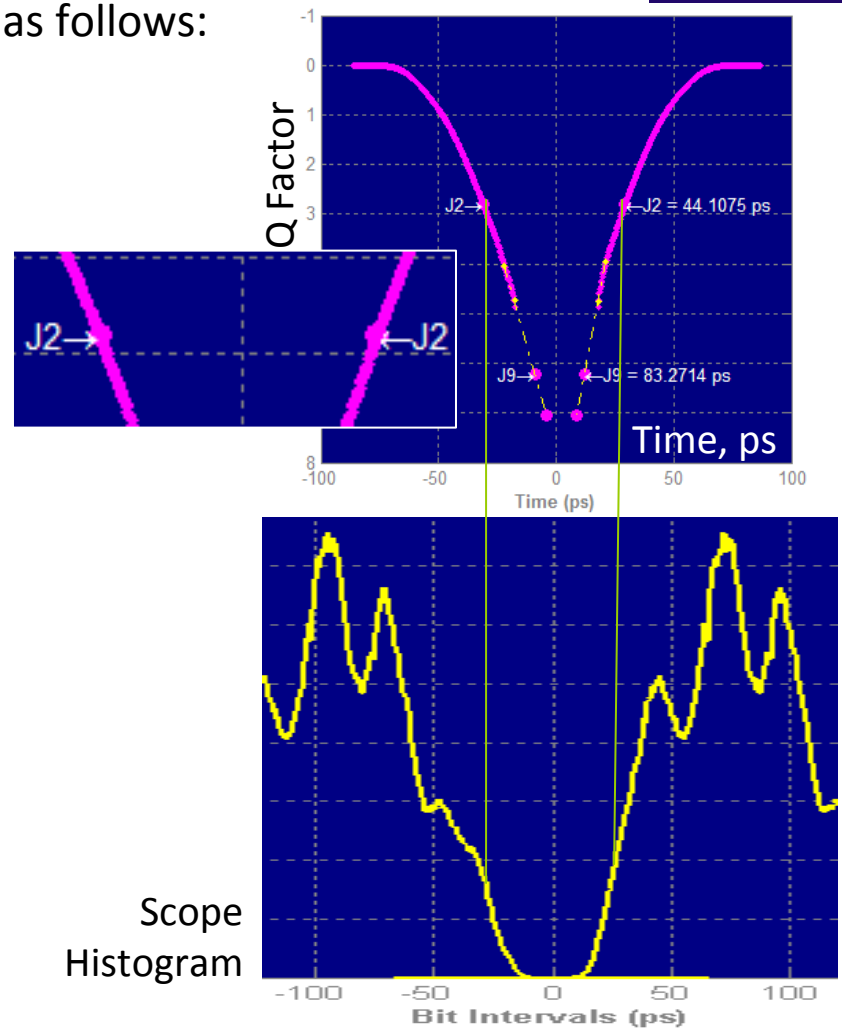
Jitter Methodology J2 and J9 Jitter – **J2**

- ☑ 100GBASE-ER4/LR4
- ☑ 100GBASE-SR10
- ☑ 40GBASE-SR4
- ☑ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI

- IEEE 802.3ba requires J2 and J9 jitter measurements, and defines J2 and J9 as follows:

- **IEEE 802.3ba 86.8.3.3.1 J2 Jitter**

  J2 Jitter is defined as the time interval that includes all but **10^{-2}** of the jitter distribution, which is the time interval from the 0.5th to the 99.5th percentile of the jitter histogram. This may be measured using an oscilloscope, or if measured by plotting BER vs. decision time, J2 is the time interval between the two points with a **BER of 2.5×10^{-3}**. Oscilloscope histograms should include at least 10,000 hits, and should be taken over about 1% of the signal amplitude. Test Patterns are **PRBS31**, Scrambled Idle, or live traffic.

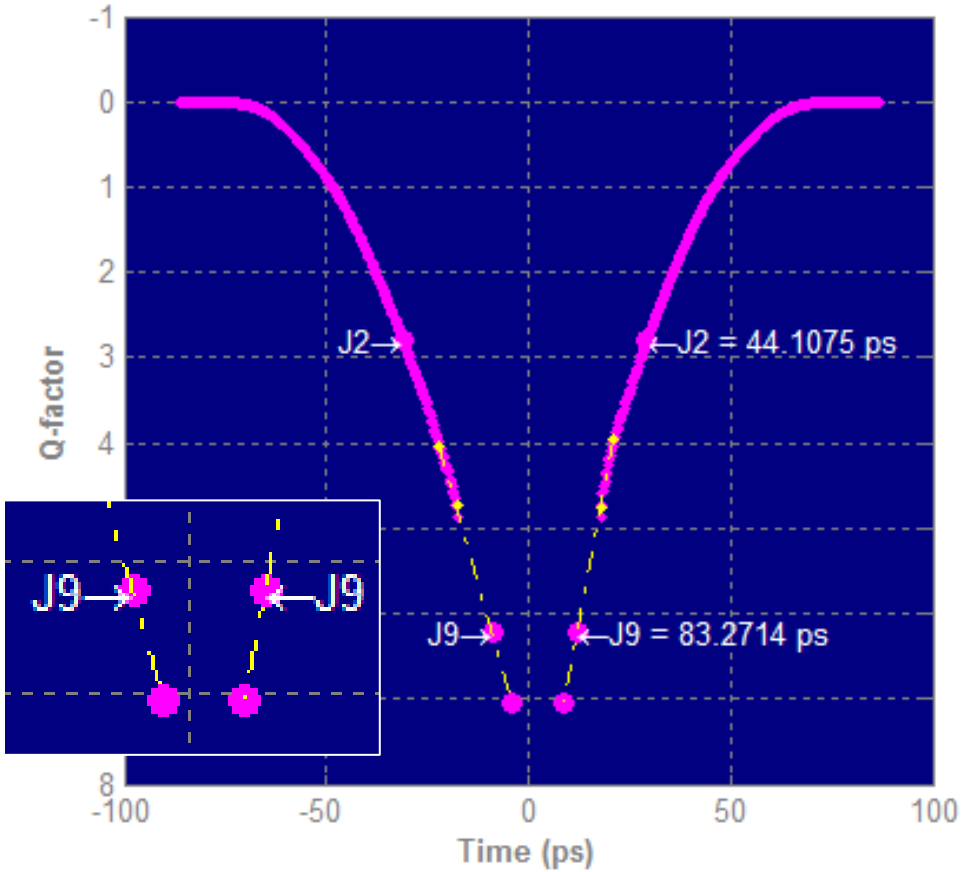


Jitter Methodology J2 and J9 Jitter – **J9**

- ☑ 100GBASE-ER4/LR4
- ☑ 100GBASE-SR10
- ☑ 40GBASE-SR4
- ☑ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI

- **IEEE 802.3ba 86.8.3.3.2 J9 Jitter**

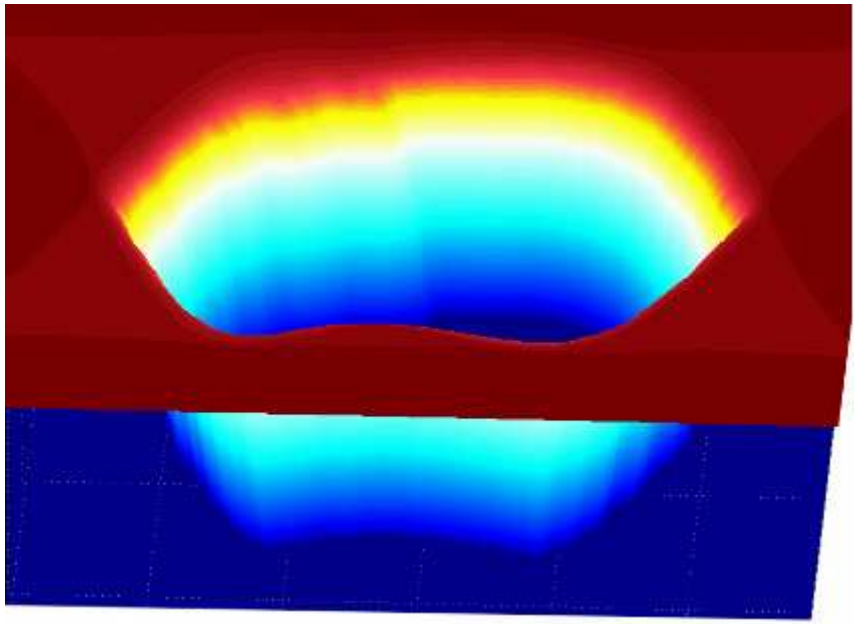
  J9 Jitter is defined as the time interval that includes all but **10^{-9}** of the jitter distribution. If measured by plotting BER vs. decision time, it is the time interval between the two points with a BER of **2.5×10^{-10}**. Test Patterns are **PRBS31** or Scrambled Idle.



Jitter Methodology J2 and J9 Jitter Oscilloscope Measurement Tools

- ☑ 100GBASE-ER4/LR4
- ☑ 100GBASE-SR10
- ☑ 40GBASE-SR4
- ☑ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI

- **80SJNB**, the premium jitter tool for sampling oscilloscopes, can measure and **decompose jitter** with great results thanks to the sampling oscilloscope's **low noise and jitter floor**.
- **All** of PJ, RJ, DDJ, DCD, Dual Dirac model, PWS, TJ, ***and* J2, J9**, as well as a **breakdown for Noise** are available … but such complete analysis relies on relatively **short, repeatable** pattern of data being analyzed.
- Such patterns are not provided for J2 and J9 measurements
- A **different methodology** is needed



Analysis in 80SJNB:
Premium jitter tool; pattern is required

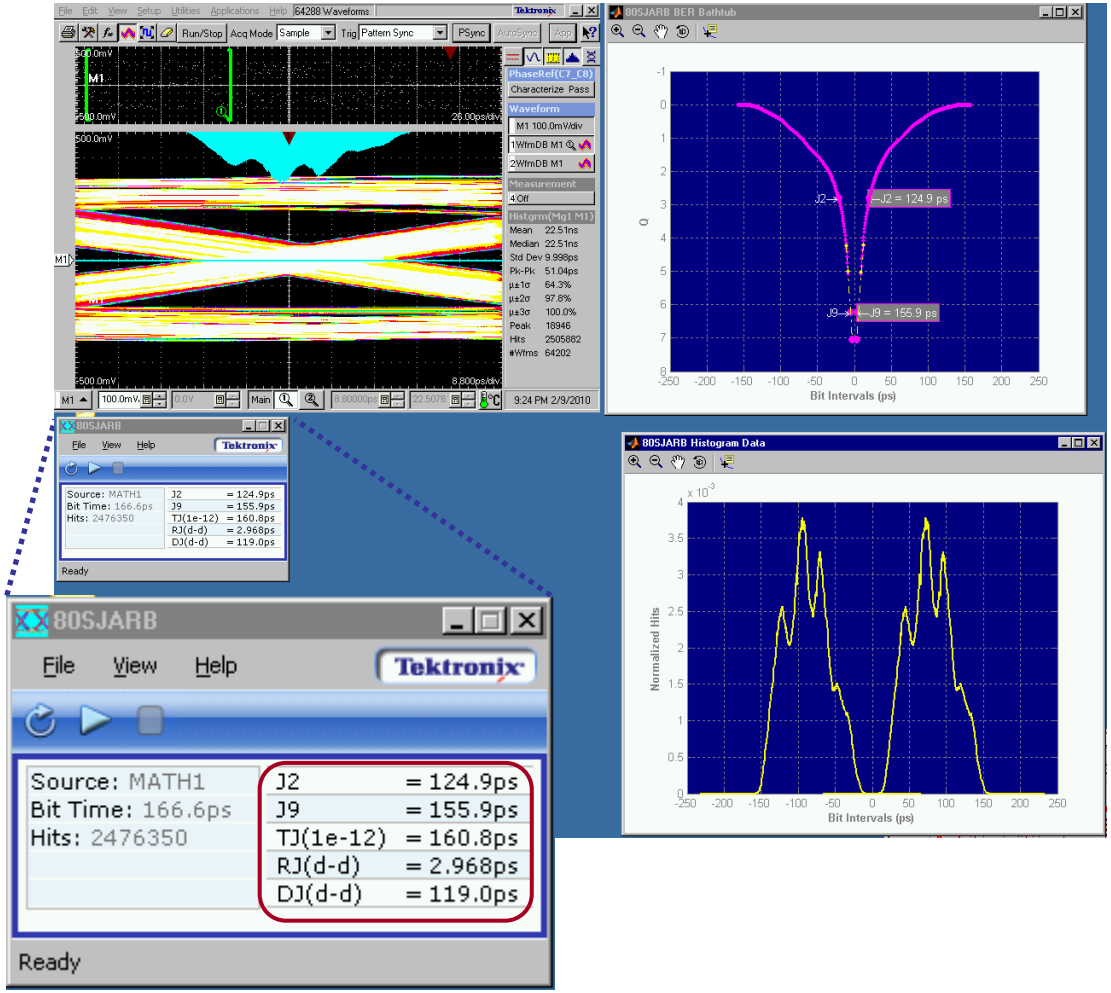
80SJARB: Sampling Jitter Tool for PRBS31, Random Data, and J2 and J9 Jitter

- ☑ 100GBASE-ER4/LR4
- ☑ 100GBASE-SR10
- ☑ 40GBASE-SR4
- ☑ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI

- **80SJARB Application**

80SJARB **measures jitter on random data** as well as long patterns (e.g. **PRBS31**), and reports:

- **J2**
- **J9**
- $DJ_{\delta\delta}$, $RJ_{\delta\delta}$, (Dual Dirac)
- TJ at BER= 10^{-12} jitter.



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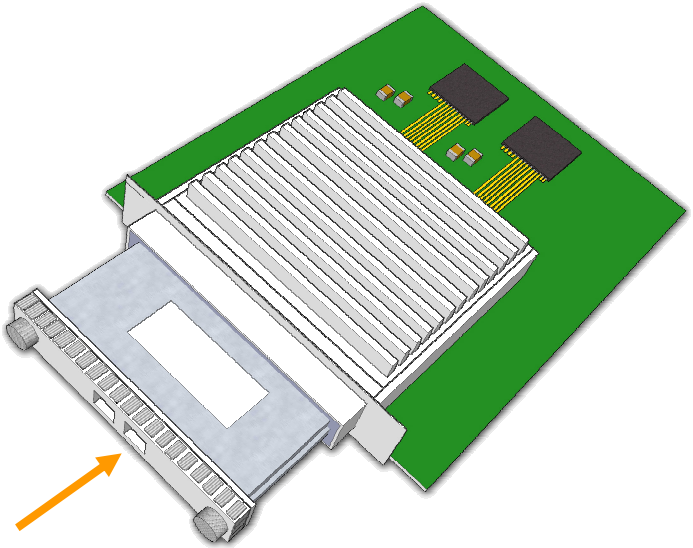
Receiver Testing



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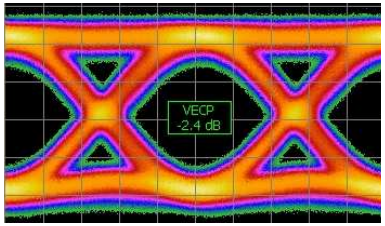
Optical SRS Testing (40GBASE-SR4, 100GBASE-SR10)

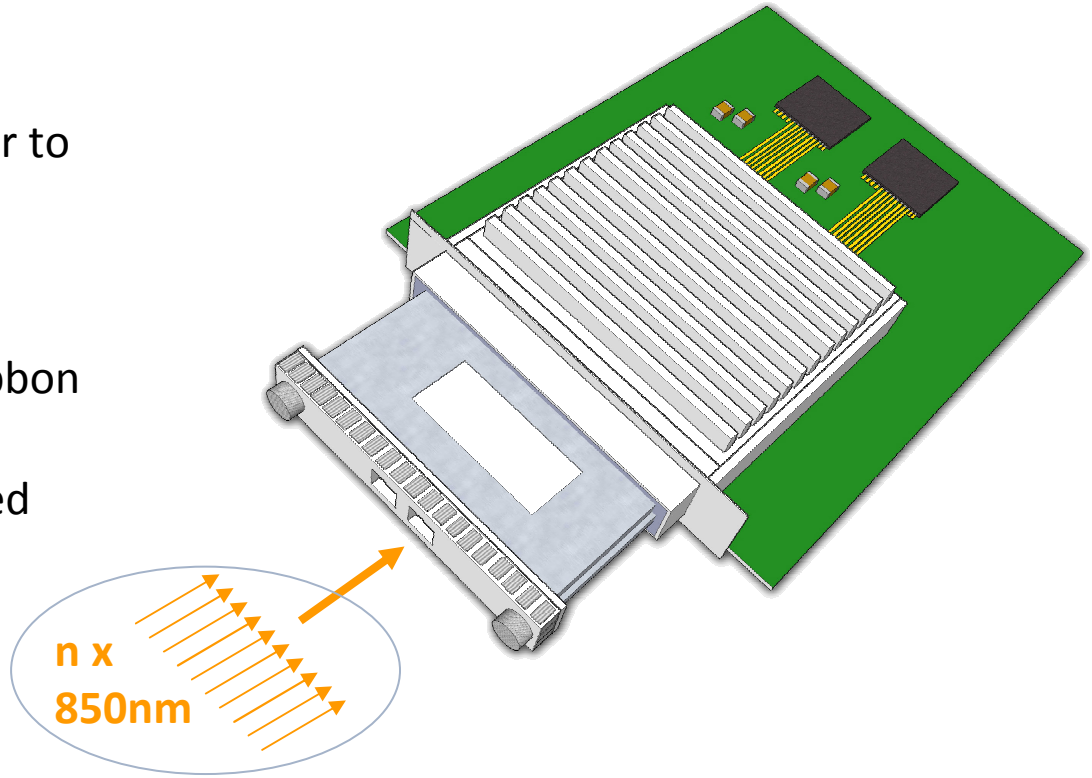
- ❑ 100GBASE-ER4/LR4
- ✓ 100GBASE-SR10
- ✓ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ❑ CAUI

1. Regular **10GbE** (10GBASE-SR & 10GBASE-LR) optical stressed eye testing is well established
   1. **Single channel** test setup



(SRS = Stressed Receiver Sensitivity)

2. SRS testing of 40GBASE-SR4 & 100GBASE-SR10 are very similar to 10GBASE-SR (850 nm, 10.3125 Gb/s) (refer to [2]).
   Major differences:
   1. **4 or 10 parallel lanes** in ribbon fiber (all active)
   2. Use **RI** (random noise-based interference) **instead of SI** (sinusoidal interference) to set VECP



(VECP = Vertical Eye Closure Penalty)

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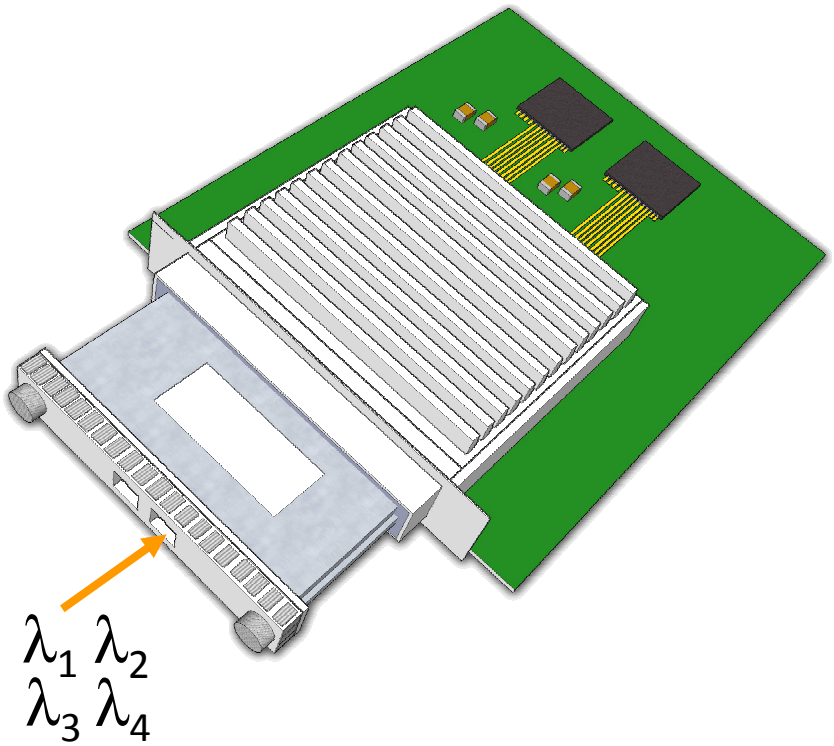
Optical SRS Testing (40GBASE-LR4, 100GBASE-LR4, ER4)

- ✓ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ✓ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ❑ CAUI

1. SRS testing of 40GBASE-LR4 and 100GBASE-ER4/LR4 testing is on **four separate 1300nm WDM** channels:
   1. **40GBASE-LR4** is at **10.3125Gb/s** and 4λ's (λ's different than 100GBASE-LR4/ER4)
   2. **100GBASE-LR4,ER4** are both at **25.78125Gb/s,** they share the same λ's

2. Use of **4 channel WDM** complicates testing
   1. Potentially need much **more** test **equipment**
   2. Need to add in or **split off** individual **wavelengths**
   3. Need to **adjust power** levels and **λs** of individual optical channels separately
   4. Need all four channels active – **crosstalk** is a real practical problem that needs to be included in the testing.
   5. If using **loopback** to count errors, need to split transmitter output also to error count on a particular wavelength.



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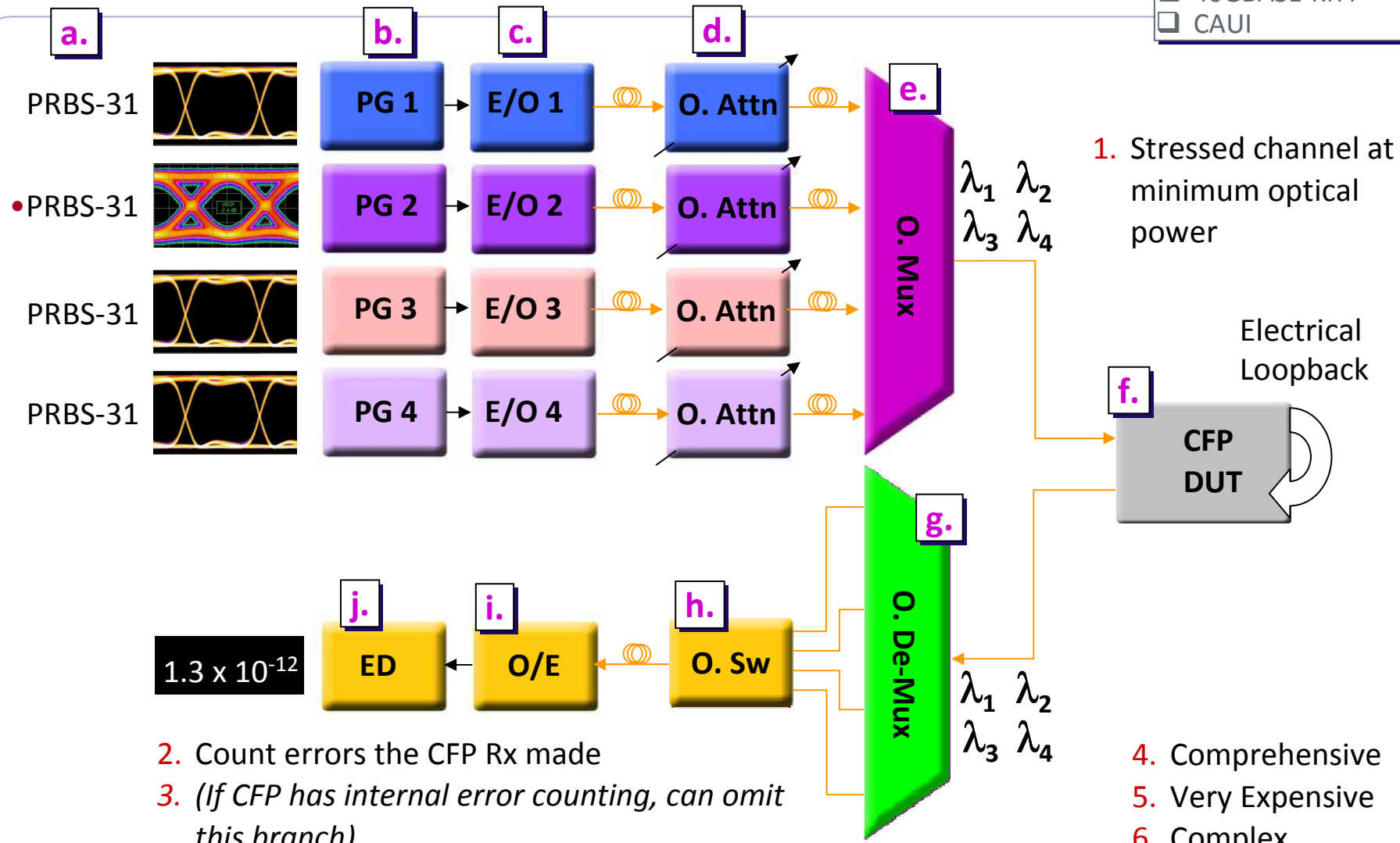
Literal SRS Implementation Set-Up

- ✓ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ✓ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ❑ CAUI



1. Stressed channel at minimum optical power
2. Count errors the CFP Rx made
3. *(If CFP has internal error counting, can omit this branch)*
4. Comprehensive
5. Very Expensive
6. Complex

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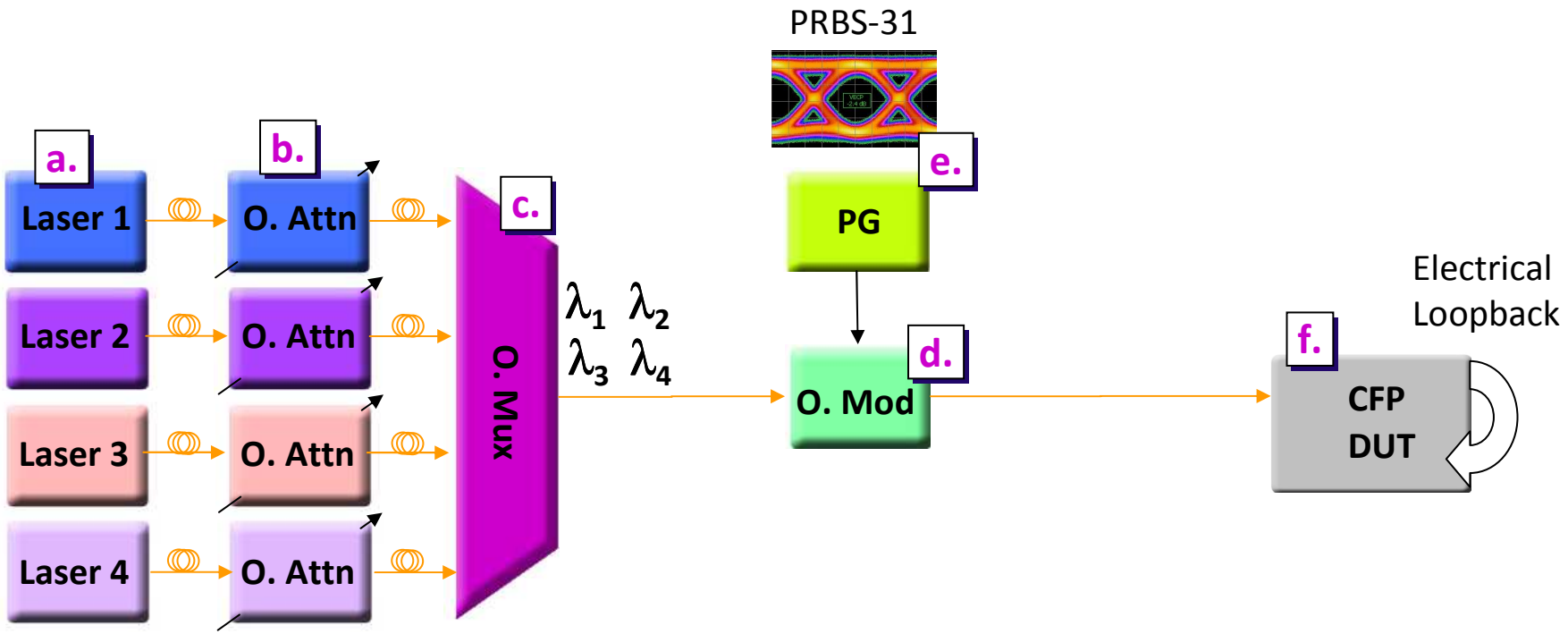
More Practical SRS Implementation Set-Up – PG Side

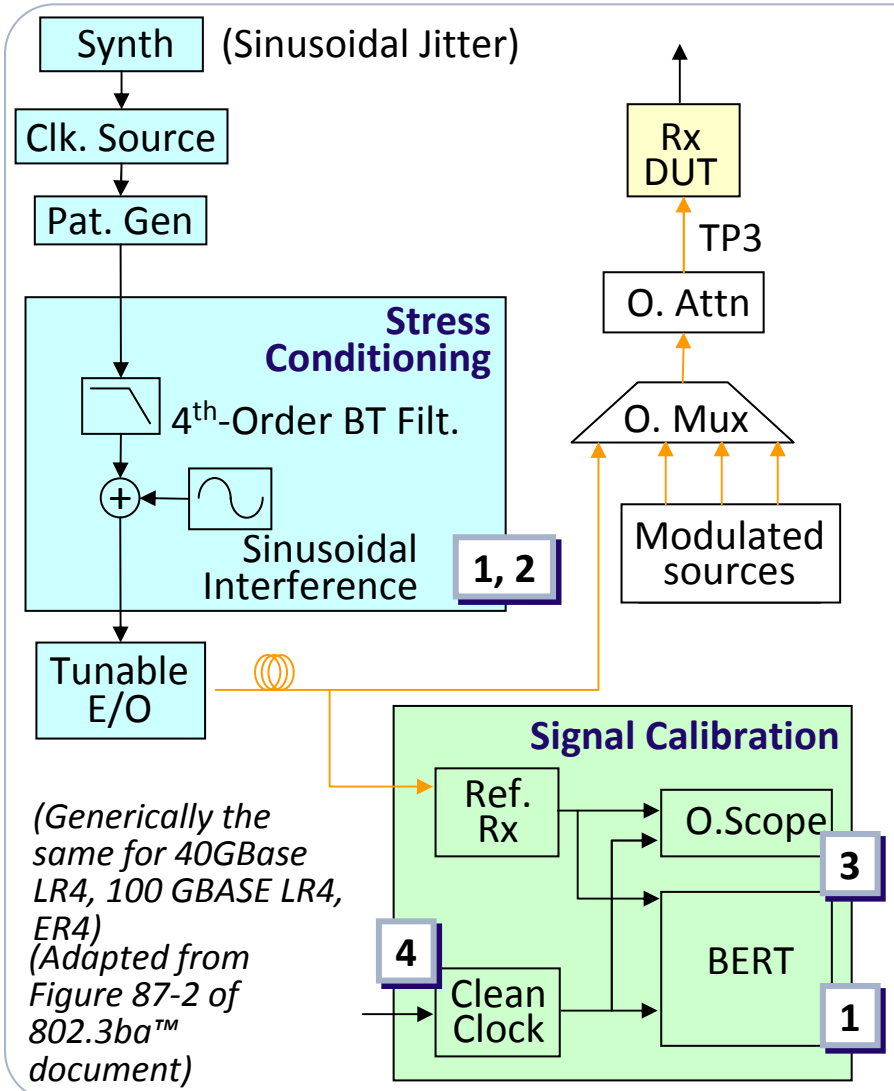
- ✓ 100GBASE-ER4/LR4
- ☐ 100GBASE-SR10
- ☐ 40GBASE-SR4
- ✓ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI



1. Simpler
2. Cheaper
3. All 4 channels are stressed, but only one is at minimum power
4. More likely to represent the situation in a real system.

Creating the Stressed Eye

- ✓ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ✓ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ❑ CAUI



(Generically the same for 40GBase LR4, 100 GBASE LR4, ER4)
(Adapted from Figure 87-2 of 802.3ba™ document)

1


- **BERTScope Si**
- Pattern generation
- Stressed eye
- Error detection and analysis
- 12.5, 17.5, 26Gb/s models

2


- **Photline Mod Boxes**
- 1-4 channels, 25.78Gb/s etc.
- 1310nm WDM
- Allow SI injection

3

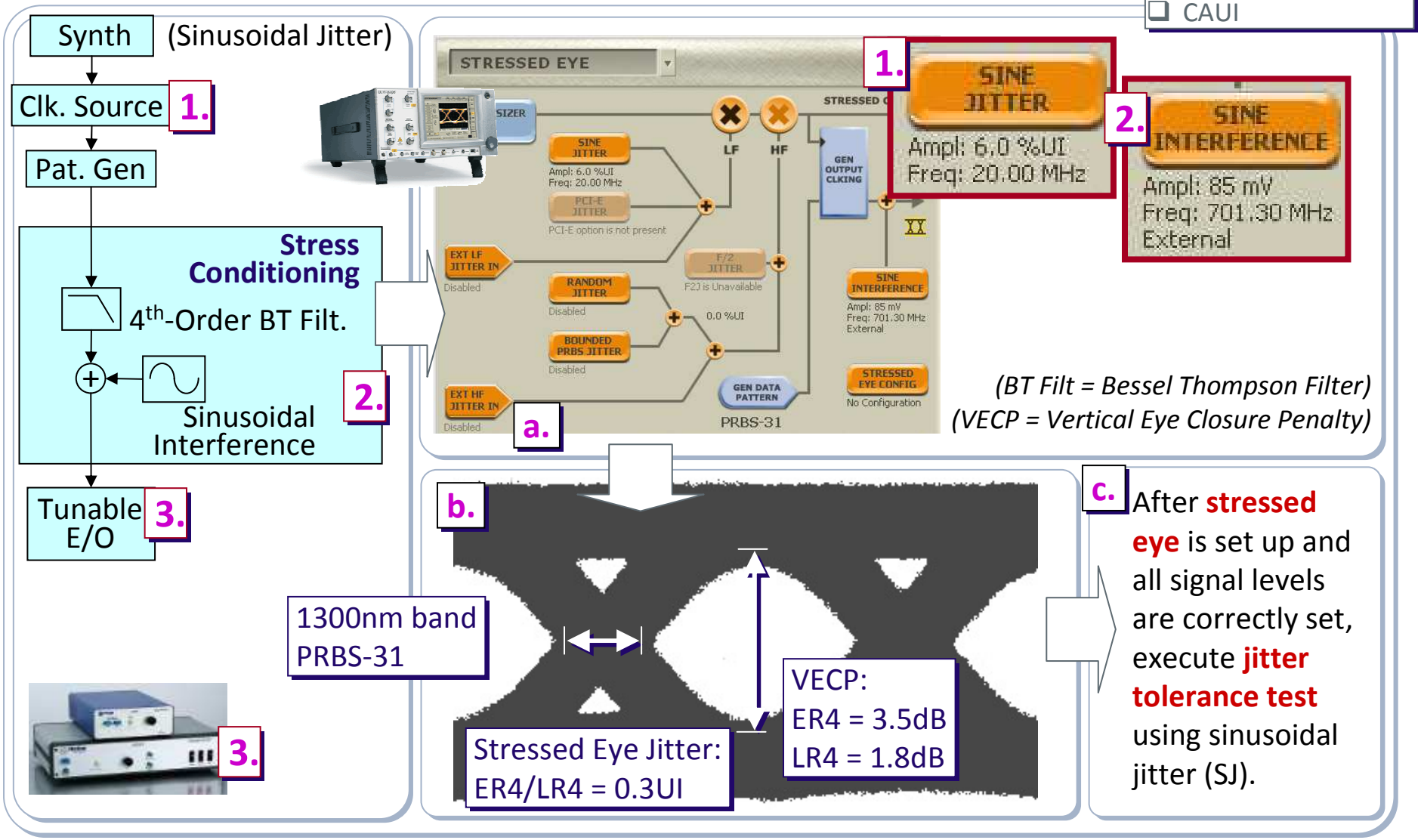

- **Tektronix DSA8200**
- Compliant ref. receiver
- Jitter analysis

4


BERTScope Clock Recovery
- Models to 28.6 Gb/s
- Flexible loop bandwidth & peaking

Creating the Stressed Eye

- ☑ 100GBASE-ER4/LR4
- ☐ 100GBASE-SR10
- ☐ 40GBASE-SR4
- ☑ 40GBASE-LR4
- ☐ 40GBASE-KR4
- ☐ CAUI



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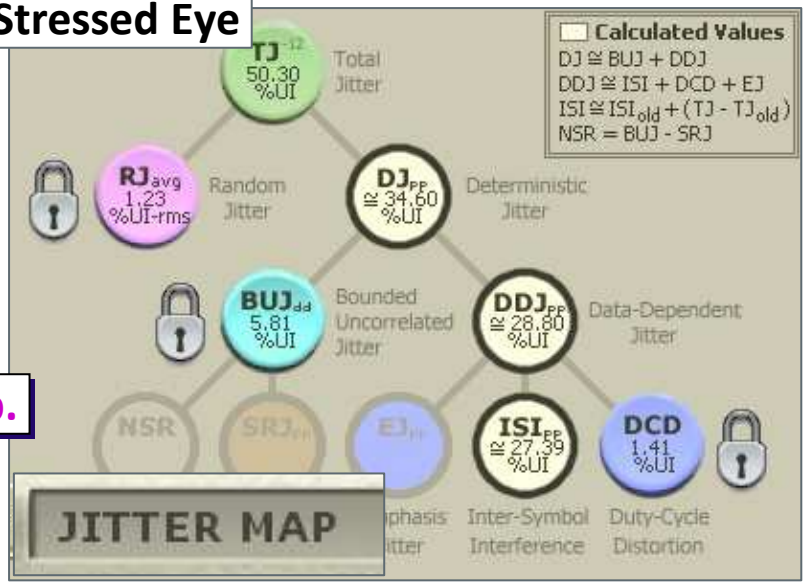
100 GBASE-LR4/ER4
Example Optical Stressed Eye

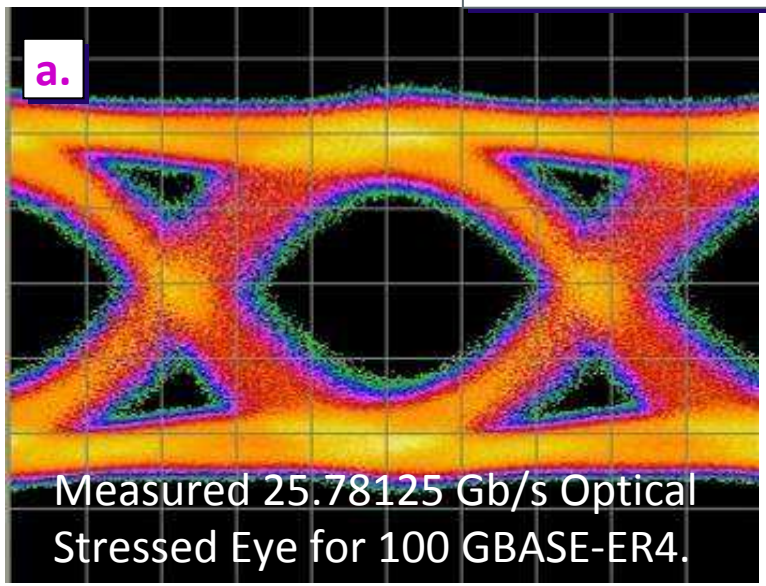
- ✓ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ❑ CAUI

Calibrated Stressed Eye

b.



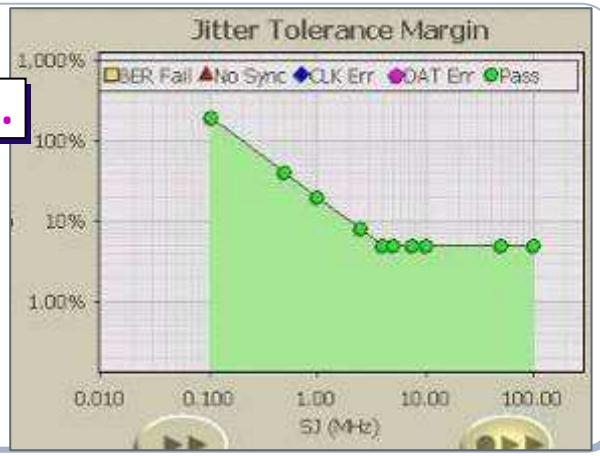
a.



Measured 25.78125 Gb/s Optical Stressed Eye for 100 GBASE-ER4.

1. **Jitter Tolerance** test performed by introducing the **stressed eye to the DUT,** then changing the **SJ** amplitudes and frequencies to the **prescribed template**, ensuring there are no errors at each point.
2. Go beyond the required values to assess design margin.

c.



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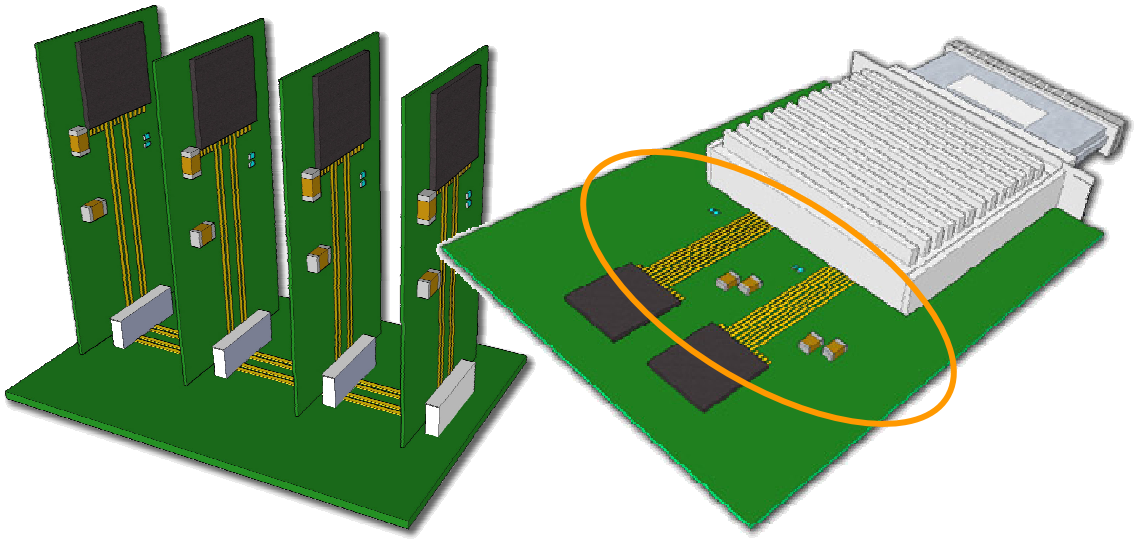
Interconnect Testing



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10G Receiver Testing (CAUI/XLAUI Interface on Transmitter)

- ❑ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ❑ 40GBASE-KR4
- ☑ CAUI

1. 10.3125 Gb/s, **10 lanes** or **4 Lanes** in/out
2. Receiver Jitter tolerance test is similar to **10GBASE-KR**. It includes:
   1. DJ from **Low Pass Filter (a)** is followed by Limiting Amplifier for 0.25UI of the required 0.42UI of DJ.
   2. DJ from **PC trace** generated ISI **(b)** contributes the remaining 0.17UI of required DJ.
   3. **Gaussian noise (c)** is added using an adjustable external noise source to set required 0.62UI TJ.
3. Jitter levels are set to match the specified **input jitter mask (d)**
4. Sinusoidal jitter **template test** (same as is used for 10 GbE) is made to confirm BER ratio better than **10^{-12}**
5. See **Ref [3]**
6. [**nPPI receiver testing** is similar to SFP+ - see references [4] & [5] for SFP+ testing]

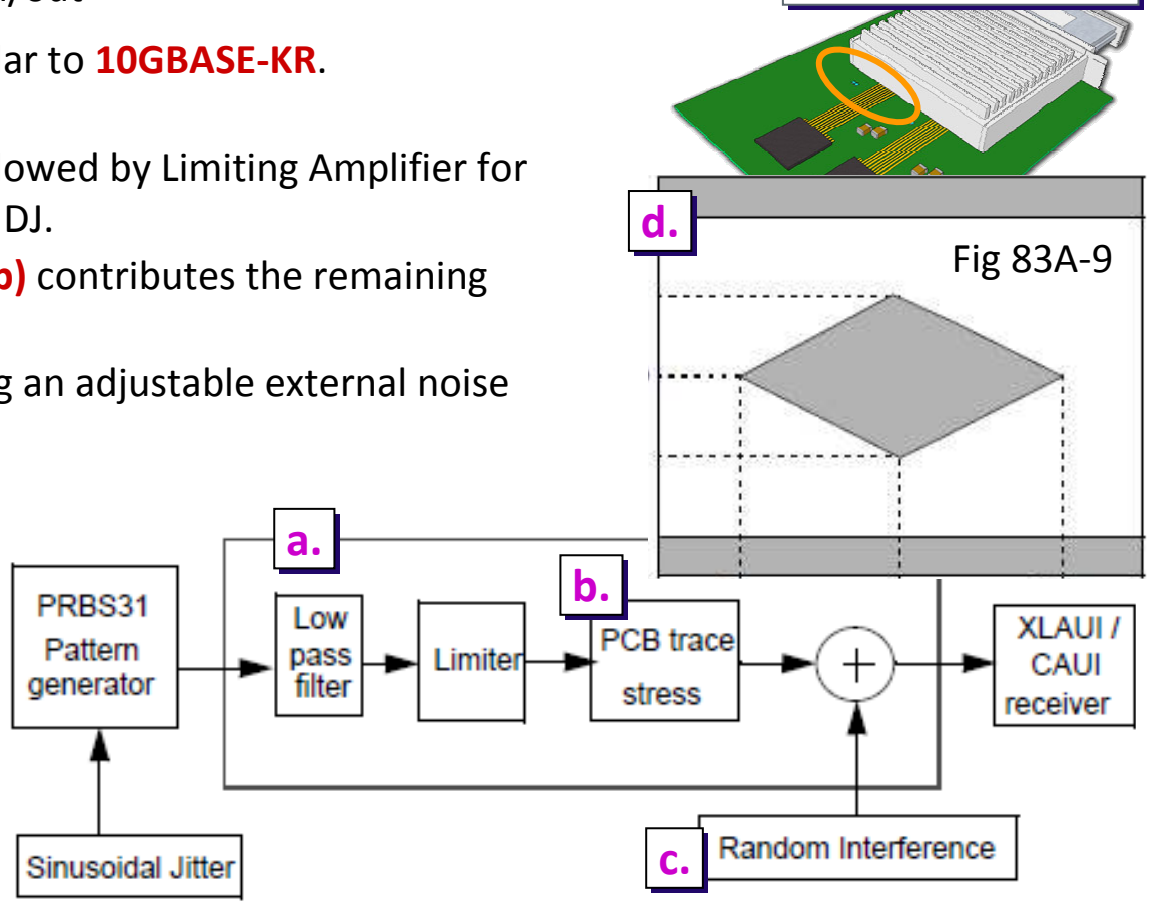

Figure 83A–15—Stressed-eye and jitter tolerance test setup

Figures from IEEE P802.3ba™ D3.0

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40GBASE-KR4

- ❑ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ✓ 40GBASE-KR4
- ❑ CAUI

1. 40 GBASE-KR4 Transmitter and Stressed Receiver Testing is **just like 10GBASE-KR**.
2. Please refer to 10GBASE-KR **Application Note.** [3]

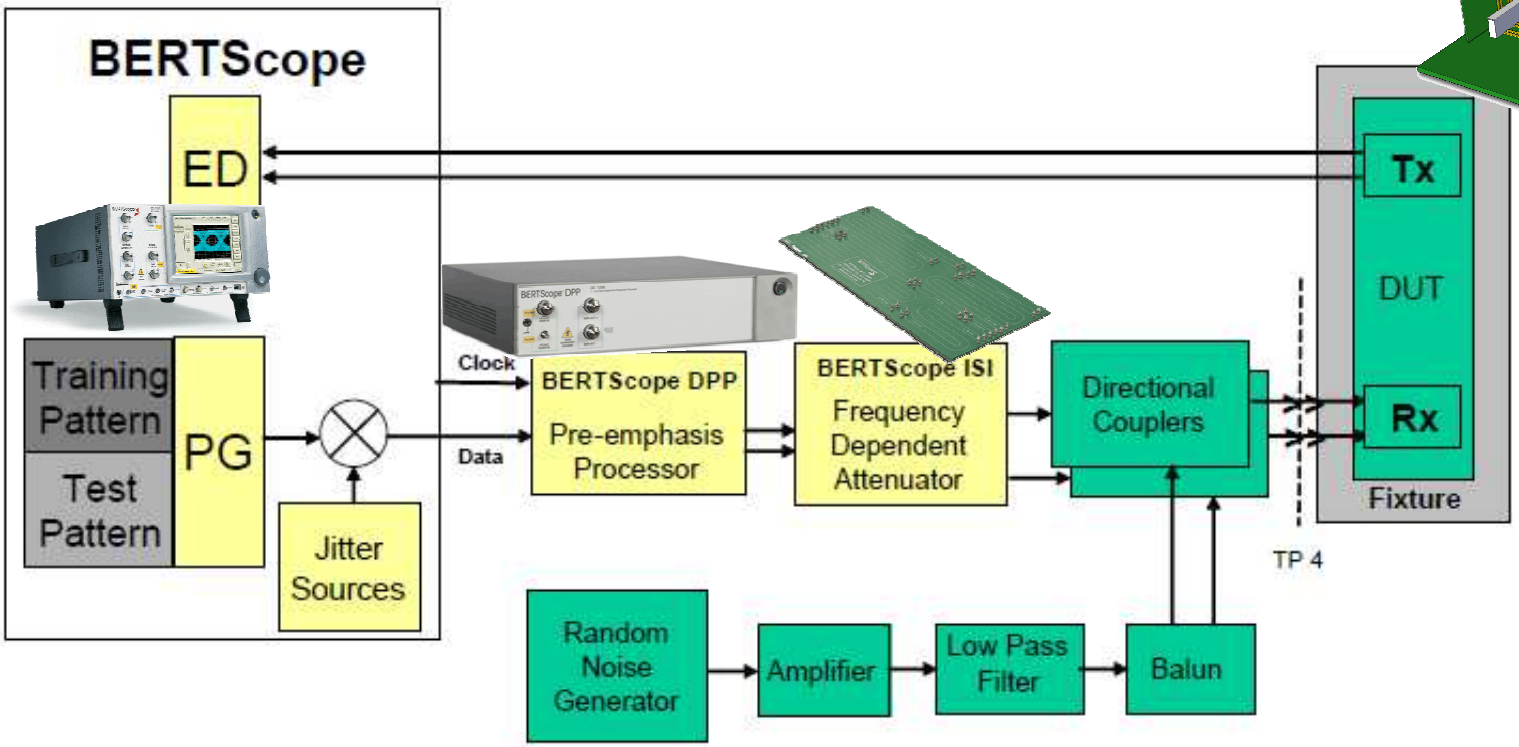


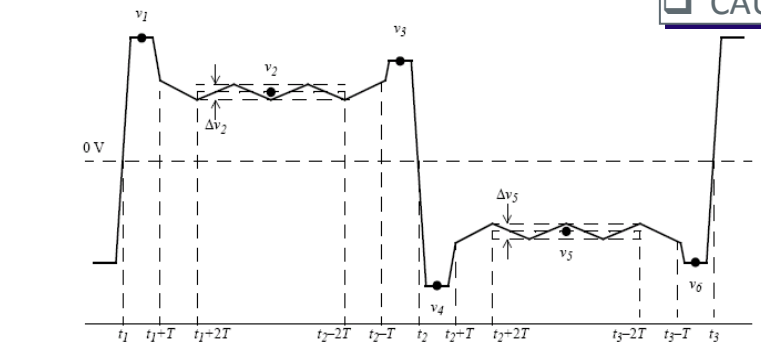
Figure 29. Basic test setup for 10GBASE-KR receiver compliance test for a DUT that supports loopback

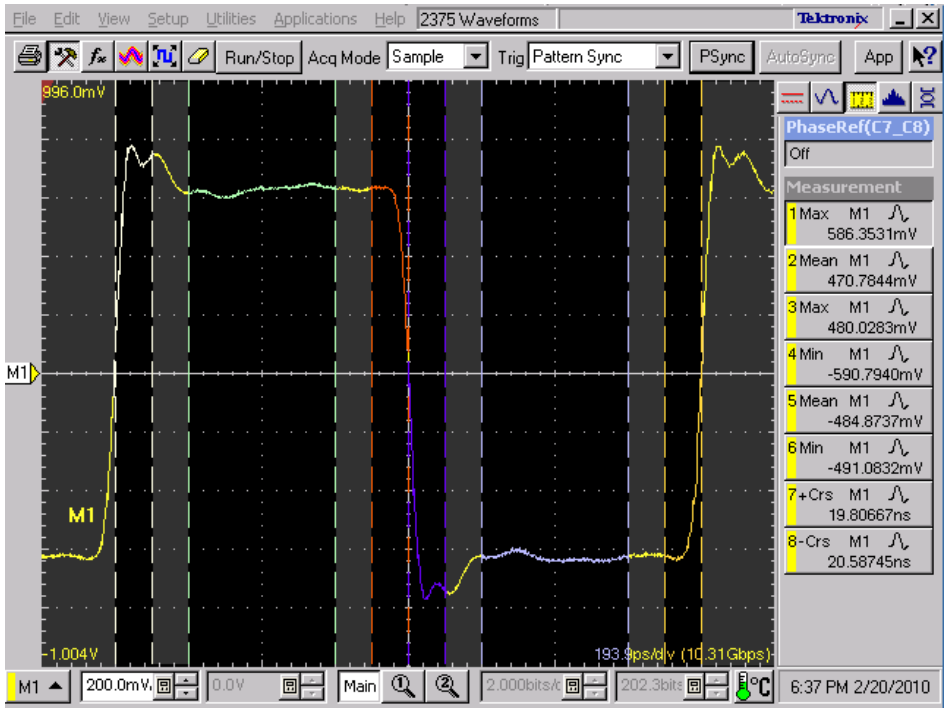
From Ref [3]

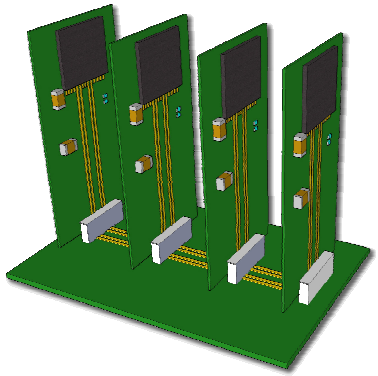
40GBASE-KR
Similar to 10GBASE-KR IEEE 802.3ap™

- ❑ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ✓ 40GBASE-KR4
- ❑ CAUI

- **Pulse 'mask'** – voltage measurements in a range of bands
- TX **Equalization** evaluation
- **Normative impedance** measurements on TX, RX
- **Informative impedance** measurements on Channel
- VNA or **TDR+IConnect** for **s-parameters** measurements







Measured KR Pulse Mask (above) and Waveform (below)

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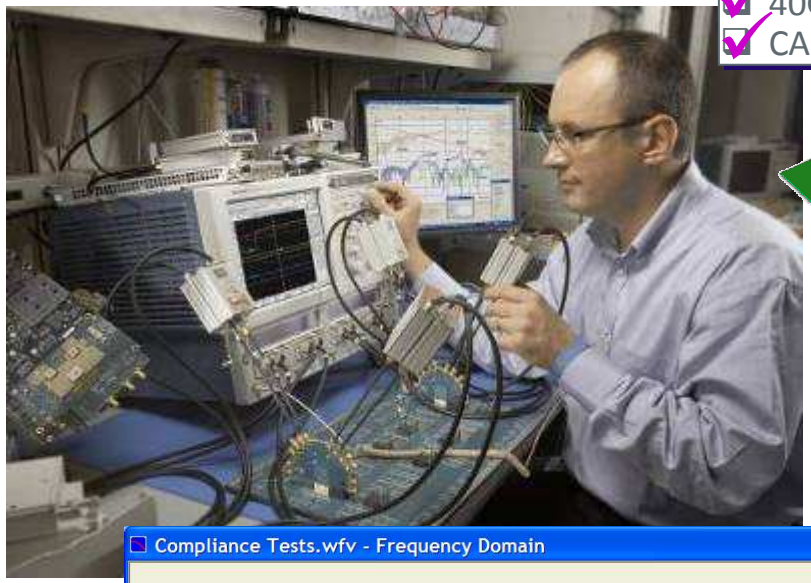
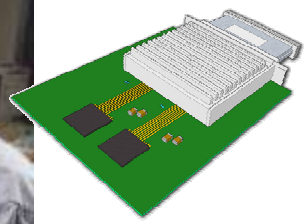
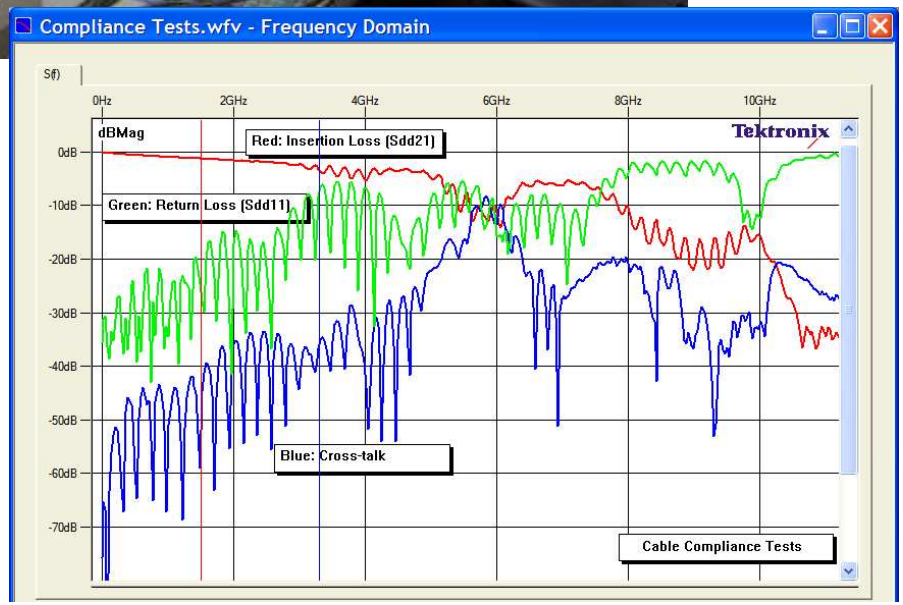
Interconnect Measurements

- ❑ 100GBASE-ER4/LR4
- ❑ 100GBASE-SR10
- ❑ 40GBASE-SR4
- ❑ 40GBASE-LR4
- ✓ 40GBASE-KR4
- ✓ CAUI

- Simple **time domain** tests
  - Impedance
  - Delay
  - Intra-pair, Inter-pair skew
- **Frequency domain** tests
  - Differential return loss
  - Differential insertion loss
  - Frequency domain crosstalk
- How much **performance** do you need?
  - 40GBASE-KR4 (4 x 10.3125Gb/s)
  - 25.78GHz bandwidth desirable (5th harmonic)
  - 80E08 30GHz, or **80E10 50GHz TDR module** for -54dB dynamic range at required bandwidth







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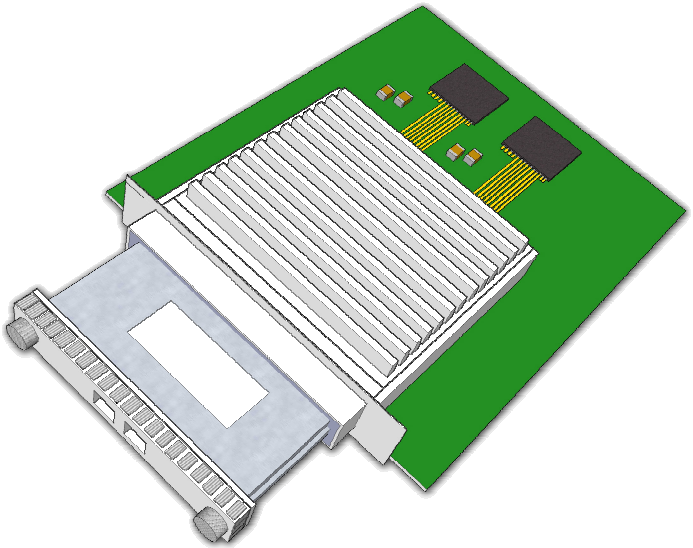
Summary



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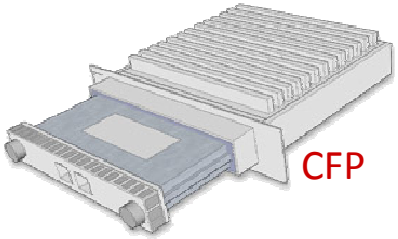
Summary: 40/100GbE

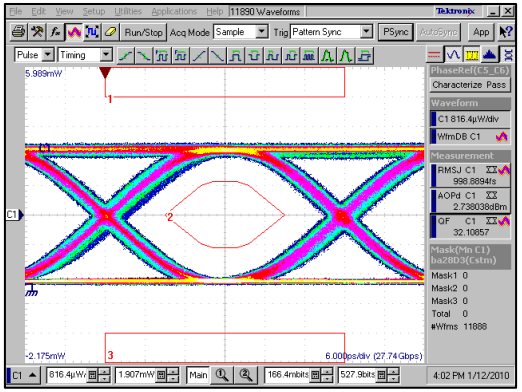


CFP

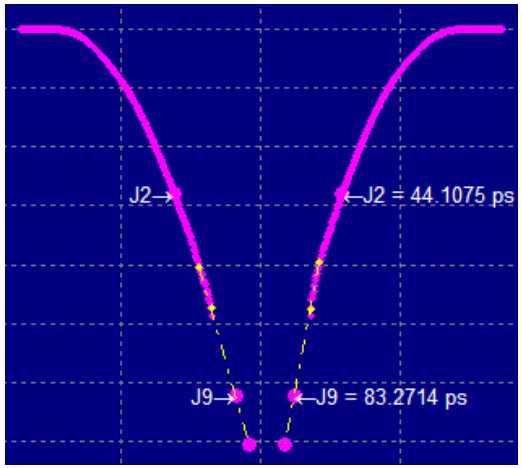
- **New test challenges** including:
  - New module types including **CFP**
  - **25 Gb/s** optical signaling
  - **WDM** channels complicate testing
  - Many **more channels**
  - **Crosstalk** is increasingly important

- Key **measurements**
  - New scaled **25/28G masks**
  - **J2/J9 jitter** measurements
  - **Stressed eye** testing
  - Frequency domain **channel measurements**

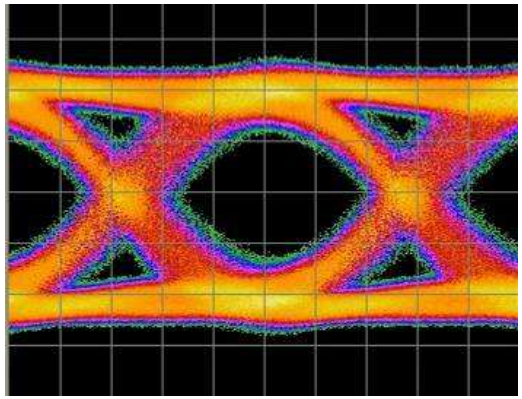
25G Mask



J2/J9 Jitter



Stressed Eye



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It's Time for Questions

You can submit a question using the question tool on your screen.

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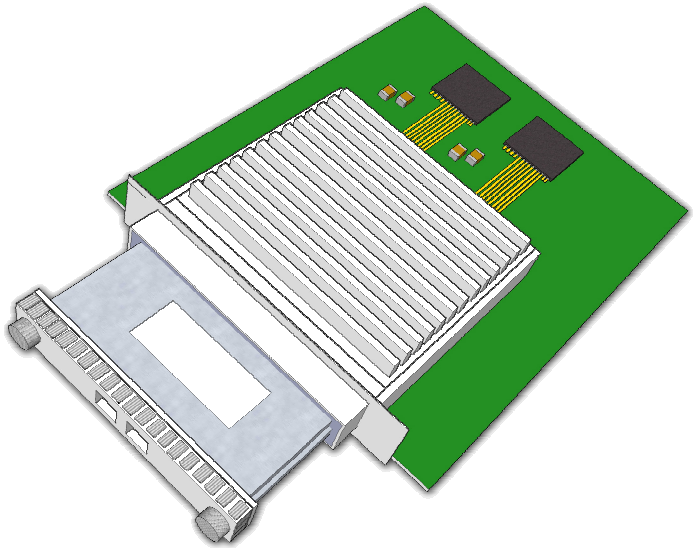
Further Reading



- [1] **802.3ba**, www.ieee802.org/3/ba/public/
- [2] "Constructing a 10 Gb/s Ethernet Optical **Stressed Eye**", January 2006, SR-TN049, www.bertscope.com
- [3] "10GBASE-**KR Compliance** Testing", December 2008, SR-TN079 Rev. 1.1, www.bertscope.com
- [4] "Product Note: Testing an **SFP+** Transceiver to the **10GbE** Electrical Specifications", Feb 2009, www.bertscope.com
- [5] "Testing an **SFP+** Transceiver to the **8x Fibre Channel** Specifications" Parts 1 & 2, August 2008, www.bertscope.com
- [6] "Modeling of Gigabit **Backplanes** from Measurements, 2005, www.tek.com
- [7] "TDR and **S-parameters** Measurements – How Much Performance Do You Need?", 2006, www.tek.com
- [8] "High-speed **Interconnects**, Characterization and Measurement–Based Modeling" Primer, 2008. www.tek.com
- [9] "The Case of the **Closing Eye**", 2008, www.tek.com
- [10] "Acting on Impulse: **Equalization** and **Emphasis**", 2008, www.tek.com

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More questions? You can contact our speakers directly:

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