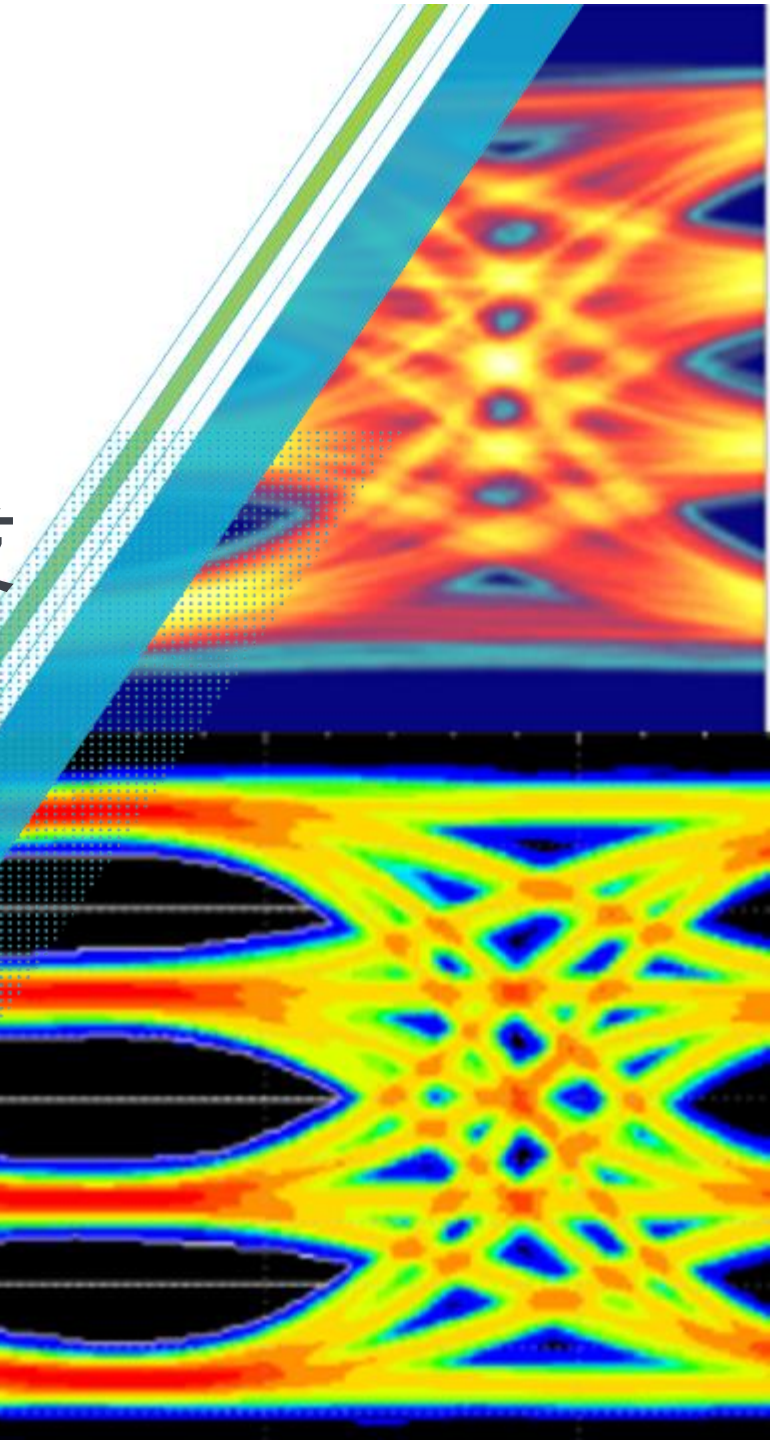
Tektronix

100G/200G/400G通讯发展浪潮及应对解决方案

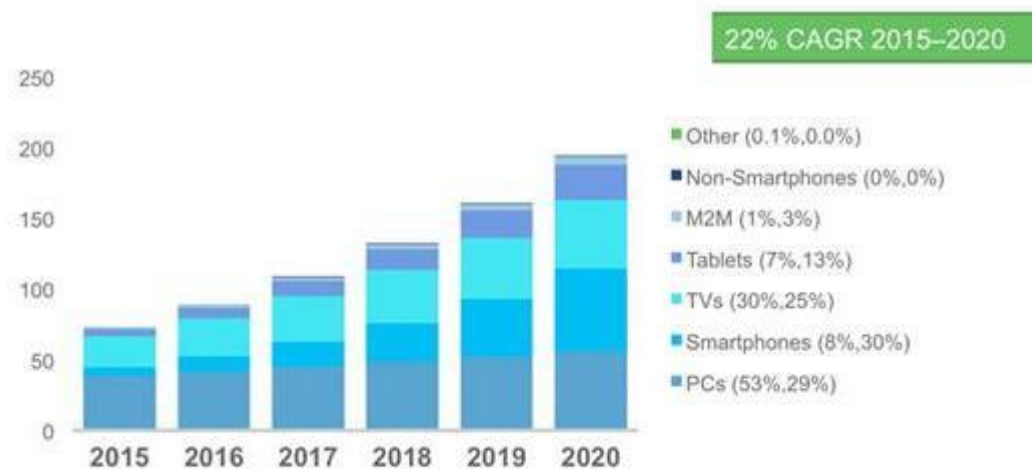


23 OCTOBER 2018

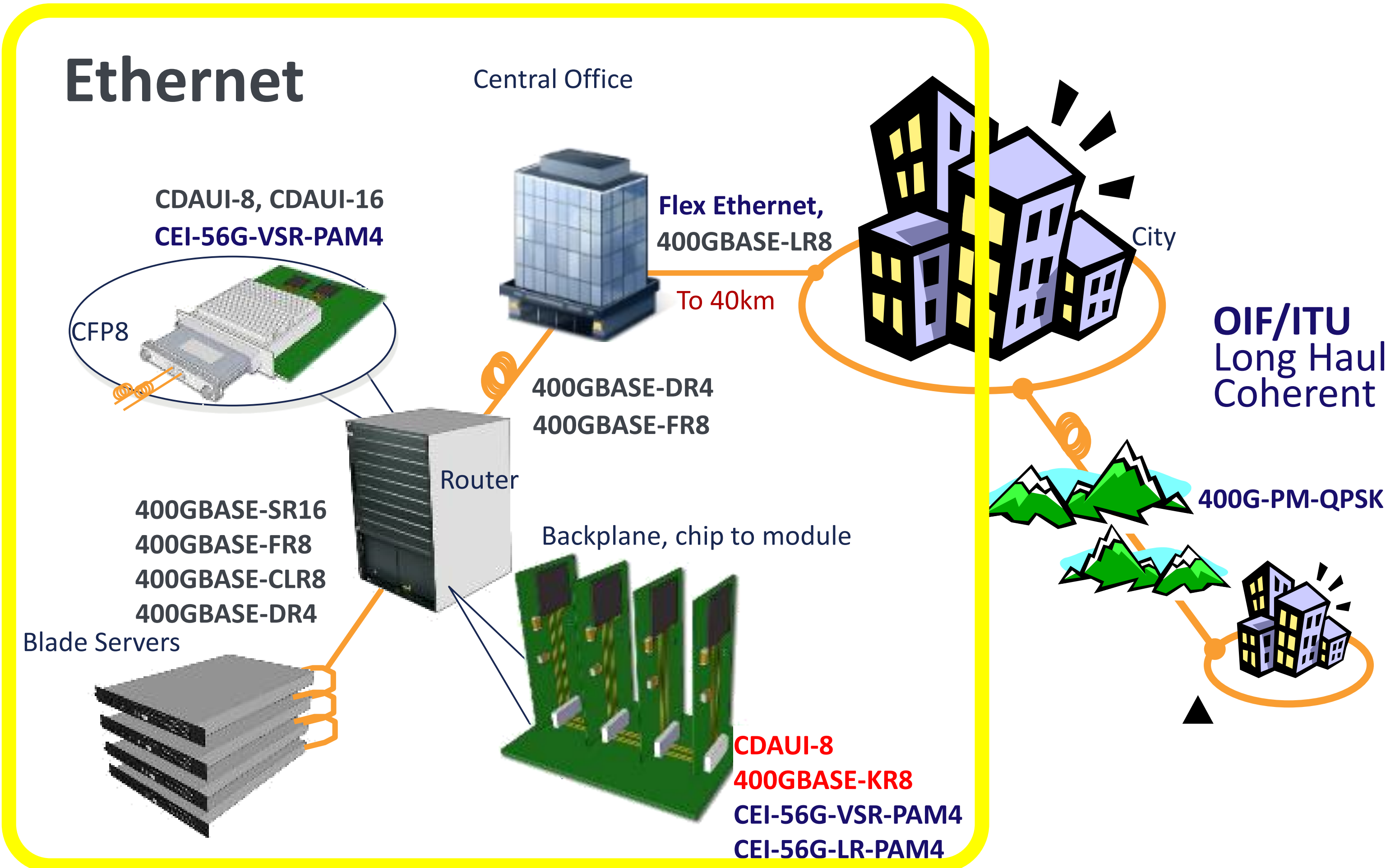

2018 This Is What Happens In An Internet Minute
facebook
973,000 Logins
18 Million Text Messages
YouTube
4.3 Million Videos Viewed
Google play
App Store
375,000 Apps Downloaded
174,000 Scrolling Instagram
481,000 Tweets Sent
1.1 Million Swipes
tinder
187 Million Emails Sent
936,073 Views
twitch
67 Voice-First Devices Shipped
amazon echo
38 Million Messages
25,000 GIFs Sent via Messenger
2.4 Million Snaps Created
$862,823 Spent Online
NETFLIX
266,000 Hours Watched
Google
3.7 Million Search Queries
60 SECONDS
Created By:
@LoriLewis
@OfficiallyChadd

Datacom and Networking Trends

- Global IP traffic to triple over next 5 years
- Smart phone traffic to exceed PC traffic by 2020
- Traffic from wireless devices will account for two thirds of the traffic
- Number of devices on IP networks will be more than 3x global population
- Broadband speeds to double by 2020
- PAM-4 signaling is being considered to double throughput to meet expected growth in IP traffic



PAM4 50G…400G Ecosystem



Optical PAM4 x n 50, 100, 200, *400G* standards

Optical Standard	Distance	Data Rate	Multiplex	Symbol Rate
200GBASE-SR4 (802.3cd) similar: 100GBASE-SR2, 50GBASE-SR	70m, 100m	N lane x 50Gbps	<n> parallel MMF	26.56 GBd
200GBASE-DR4 (802.3bs)	500m	4 lane x 50Gbps	4 parallel SMF	26.56 GBd
400GBASE-DR4 (802.3bs) similar: 100GBASE-DR	500m	<n> lane x 100Gbps	4 parallel SMF	53.125 GBd
100GLambda	~ 2 km	4 lane x 100 Gbps	1 SMF 8λ CWDM	53.125 GBd
Engineered links	> 2 km	n lane x 100 Gbps	1 SMF n x λ WDM	56 GBd
400GBASE-FR8 (802.3bs) similar: 200GBASE-FR4, 50GBASE-FR	2km	<n> lane x 50Gbps	1 SMF 8λ WDM	26.56 GBd
400GBASE-LR8 (802.3bs) similar: 200GBASE-LR4, 50GBASE-LR	10km	<n> lane x 50Gbps	1 SMF 8λ WDM	26.56 GBd

PAM4 across the stack

Electrical: 26 GB PAM4 x n 50, 100, 200, *400G*

Standard	reach	speed / lane	lanes	lane symb. Rate
CEI-56G-VSR-PAM4	100mm	n lane x 56Gbps	1-n lanes	18-29 GBd
CEI-56G-MR-PAM4	500mm	n lane x 56Gbps	1-n lanes	18-29 GBd
CEI-56G-LR-PAM4	1m	n lane x 56Gbps	1-n lanes	18-29 GBd
50GAUI 100GAUI-2 200GAUI-4 400GAUI-8	250mm	n lane x 53 Gbps	1,2,4,8 lanes	26.56 GBd
50GBASE-KR 100GBASE-KR2 200GBASE-KR4	<1m	n lane x 53 Gbps	1,2,4 lanes	26.56 GBd
50GBASE-CR 100GBASE-CR2 200GBASE-CR4	<3m	n lane x 53 Gbps	1,2,4 lanes	26.56 GBd

PAM4 across the stack

Electrical: 53 GBd PAM4 x n (50, 100, 200, *400G*)

Standard	reach	speed / lane	lanes	lane symb. Rate
CEI-112G-VSR-PAM4	100mm	n lane x 112Gbps	1-n lanes	**36-58 GBd**
CEI-112G-MR-PAM4	500mm	n lane x 112Gbps	1-n lanes	**36-58 GBd**
CEI-112G-LR-PAM4	1m	n lane x 112Gbps	1-n lanes	**36-58 GBd**
100GAUI 200GAUI-2 400GAUI-4	250mm	n lane x 106 Gbps	1,2,4,8 lanes	**53.125 GBd**
100GBASE-KR 200GBASE-KR2 400GBASE-KR4	<1m	n lane x 106 Gbps	1,2,4 lanes	**53.125 GBd**
100GBASE-CR 200GBASE-CR2 400GBASE-CR4	<3m	n lane x 106 Gbps	1,2,4 lanes	**53.125 GBd**

PAM4 across the stack

… and Ethernet

- **Common interpretation* is as follows: Example: 400GBASE-DR4**

nTYPE-LLLm

Data rate:
- 10 — 10 Mb/s
- 100 — 100 Mb/s
- 1000 — 1000 Mb/s
- 10G — 10 Gb/s
- 40G — 40 Gb/s
- 100G — 100 Gb/s
- 400G — 400 Gb/s

Modulation type:
- BASE — Baseband

Last Number –
- " " — 1 Pair or Lane
- 2 — 2 pairs or Lanes
- 4 — 4 Pairs or Lanes
- 10 — 10 Pairs or Lanes or 10 kilometres

Third letter
- M — Multimode

First letter (media or wavelength)
- C — twin axial Copper cable
- D — Datacenter
- E — fiber, Extra long wavelnght. (1550nm) / or Extd. Reach
- F — Fiber
- K — bacKplane
- L — fiber, Long wavelength (1310nm) / or Long Reach
- S — fiber, Short wavelength (850nm) / or Short Reach
- T — Twisted pair

Second letter (reach or PCS encoding)
- R — ScRambled coding (64B66B)
- X — EXternal sourced coding (4B5B, 8B10B)
- W — WAN compatible
- P — (~~PAM modulation~~ *not any more…2017)*

- The IEEE does not specify the meanings of the letters, rather it simply identifies PHYs by combinations of letters.

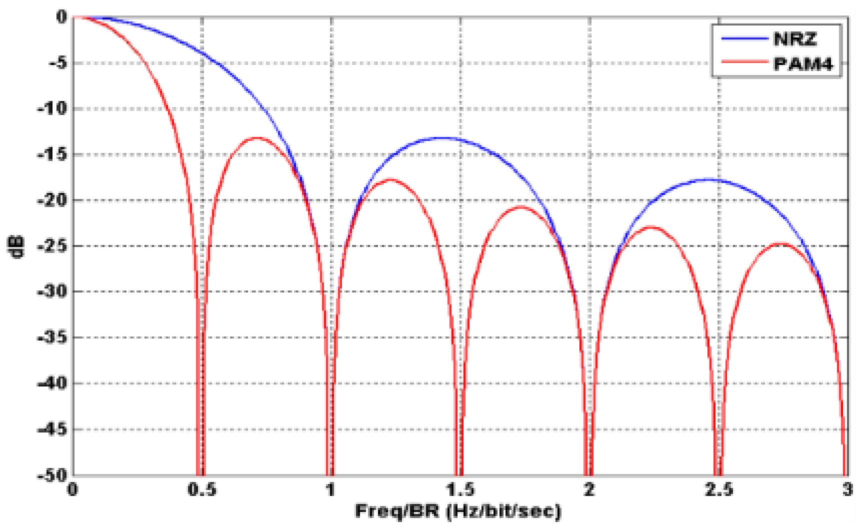
There is no guarantee that in the future these interpretations will retain whatever meaning they presently have.
Slide based on an Ethernet Alliance slide by Scott Kipp, with Tektronix extensions.

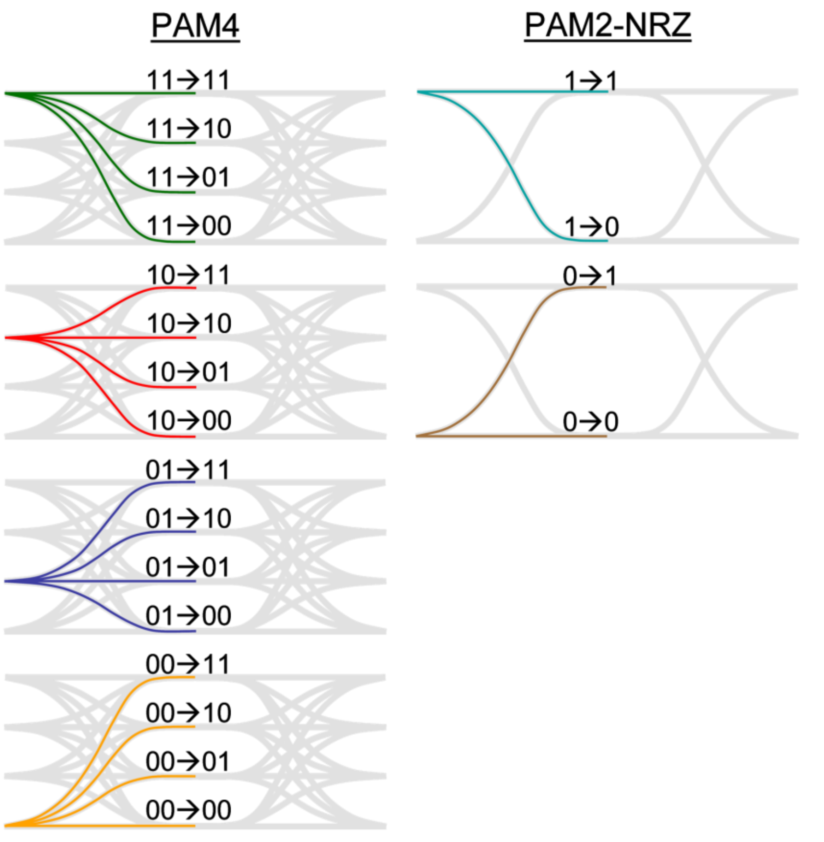
So what is …AUI ? (CAUI, 400GAUI-8): It's a sub-standard inside Ethernet. AUI: "Attachment Unit Interface" … where "Attachement" is the optical module

What is PAM4 ?

- Pulse Amplitude Modulation
- 4-level signaling
- Transmit 2 bits per UI
- PAM4 requires half of the BW of NRZ for the same data throughput

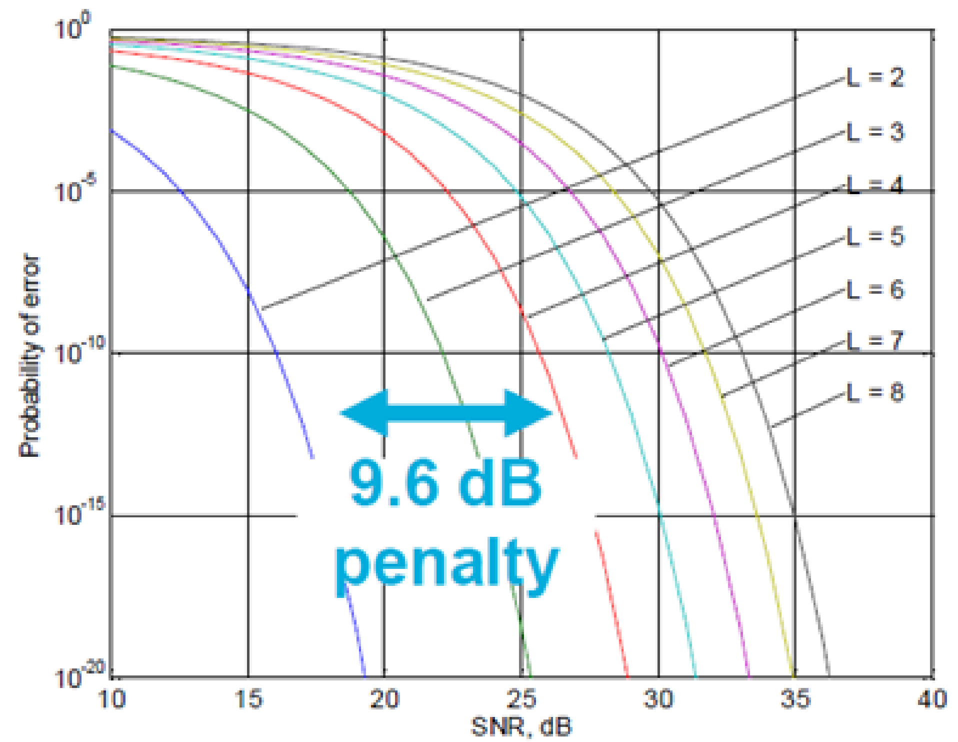
	PAM-4	NRZ
Bits per UI	2	1
Levels	4	2
Rising/Falling Edges	6	2
Transitions	12	2
Eye Diagrams per UI	3	1

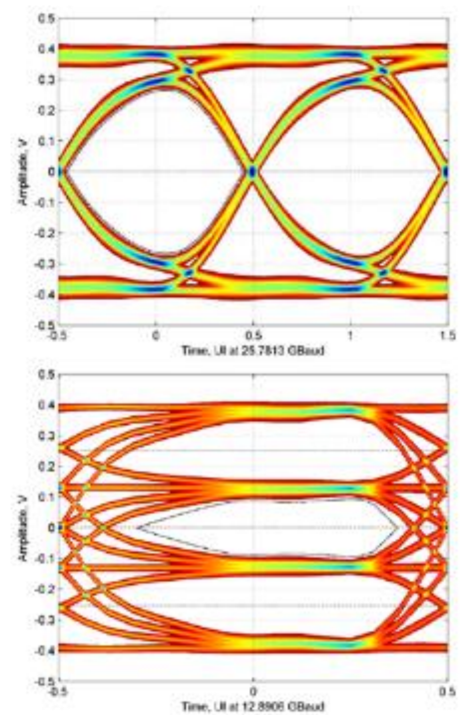




Design and Test Challenges in the 100G-400G transition

- Channels are Modulation methods are ”out of Bandwidth” at 56Gbps.
  - Higher order modulation (PAMn) is one means of combating incredibly high channel losses.
  - Multiple bits/symbols results in a reduced overall symbol rate and fundamental transmission frequency. 14GHz rather than 28GHz.



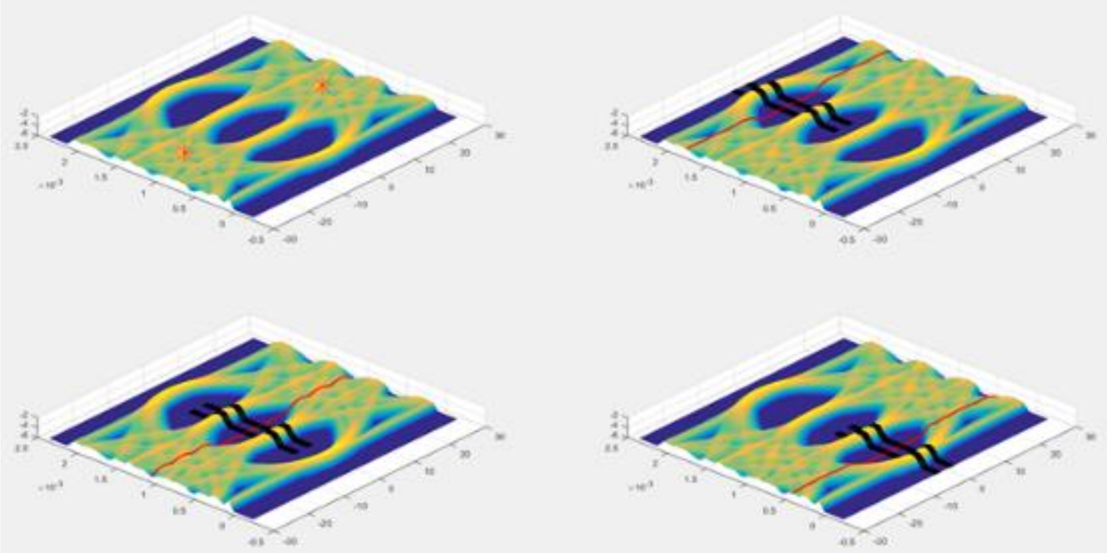


Terms in times of PAM4

- Data rate: aka Bit rate: information throughput on a line. [b/s]
- Symbol rate: frequency at which new symbols are sent.
  The unit to use is Baud [Bd]. (Not Baud/sec!)
  Example: PAM4: 4 levels of PAM4 do code 2 bits per symbol. So the symbol rate of 10 GBd transfers 20 Gb/s (if no coding overhead)
- Unit Interval (UI): = 1/(Symbol rate)
- Pulse Amplitude Modulation: (PAM): information is passed by modulating the pulse amplitude with no regard to phase.
- An academic point: Pulse shaping: RZ, NRZ, etc. (Return to Zero, No Return to Zero)
  Commonly misunderstood as signifying PAM2… note that e.g. PAM4 can be RZ or NRZ

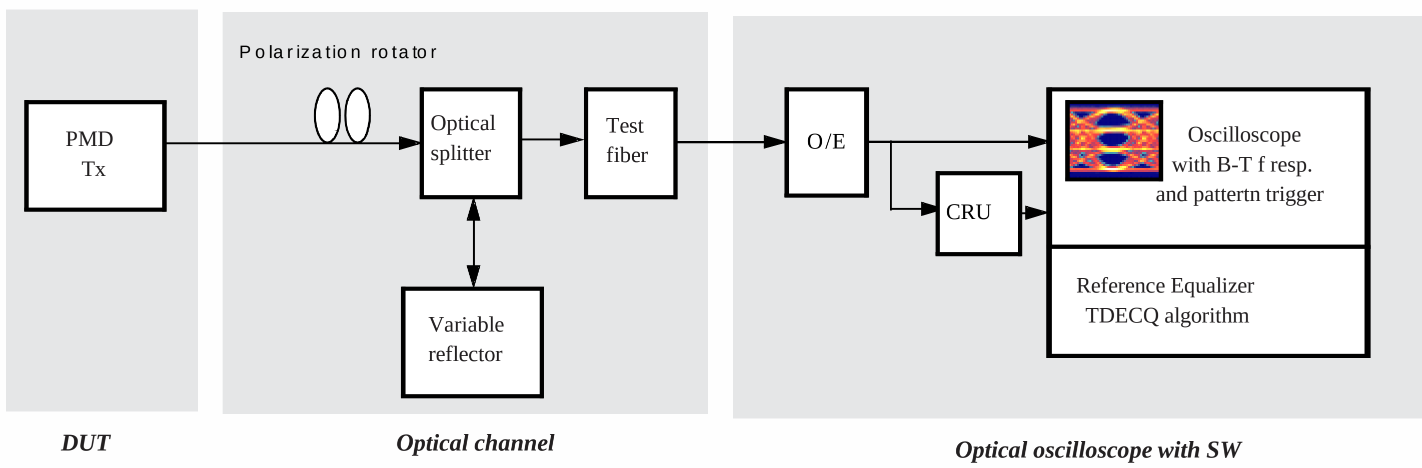
PAM4 signaling:
Mask → TDEC → TDECQ (quaternary)

- Optical measurement on *equalized* optical links with PAM4
- Transmitter waveform-shape penalty
- Dispersion penalty: insert fiber (see next page) with max and with min dispersion



TDECQ measurement setup

(TDEC: Transmitter and Dispersion Eye Closure penalty Quaternary)



After 802.3bs D2.1 Figure 121–4—TDECQ conformance test block diagram

- Difficult part of TDECQ: Equalization!
- SECQ: Stressed Eye Closure for RX testing: no fiber, otherwise the same

TDECQ: the remaining piece

TDECQ is a measure of the optical transmitter's vertical eye closure (via closure with noise) when transmitted through a worst case optical channel, as measured through an optical to electrical converter (O/E) with a bandwidth equivalent to a reference receiver, and equalized with the reference equalizer.

It is a penalty vs. ideal (simulated) TX. So TDECQ = 0 dB ➔perfect TX; around 2.5 dB the TX fails the standard.

$$TDECQ = 10\log_{10}\left(\frac{OMA_{outer}}{6} \times \frac{1}{Q_t R}\right)$$

- OMA_{outer} = amplitude of PAM4 signal
- R = standard deviation of acceptable receiver noise @ SER of 4.8 E-4
- - compensated for scope and E to O noise
- Q,t = 3.414
- Smaller TDECQ is better (penalty). More acceptable receiver noise is better.

PAM4 test: things are different

- Outer OMA and ER test do not base on eye-diagram anymore
  - P3: average of center 2UI from seven “3” of PRBS13Q pattern
  - P0: average of center 2UI of six “0” of PRBS13Q pattern

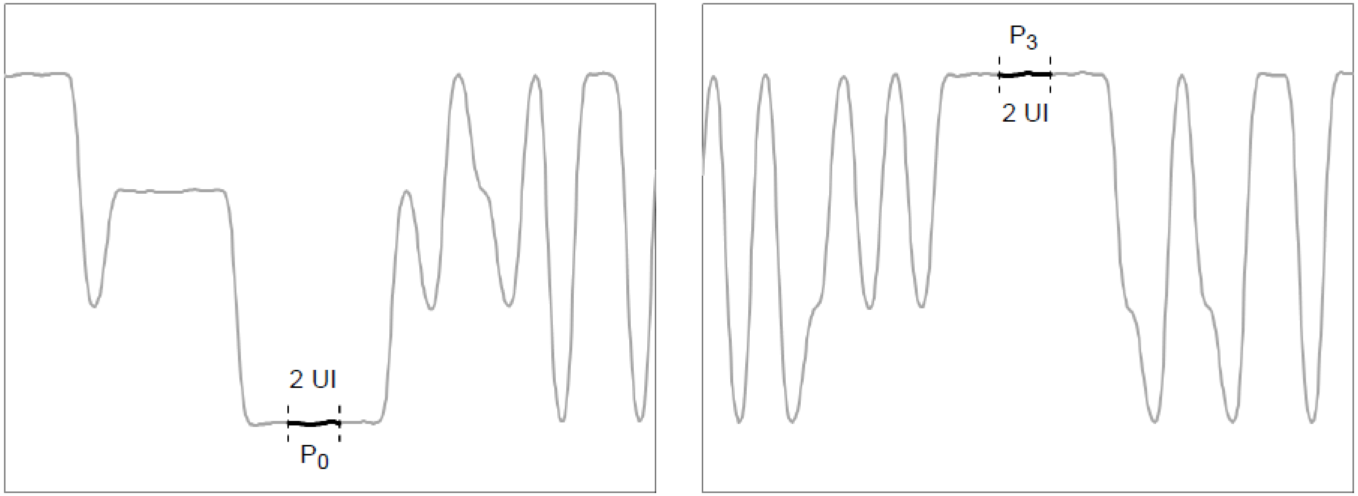
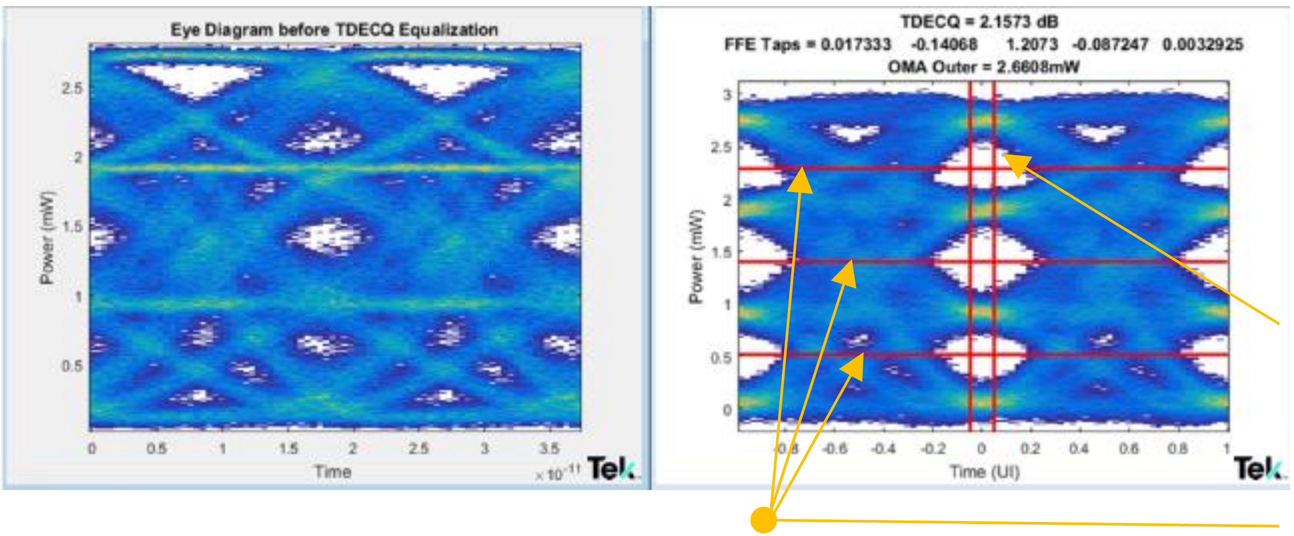


Figure 121–3—Example power levels P_0 and P_3 from PRBS13Q test pattern

Methodology for measurements evolved for TDECQ

- Before equalization



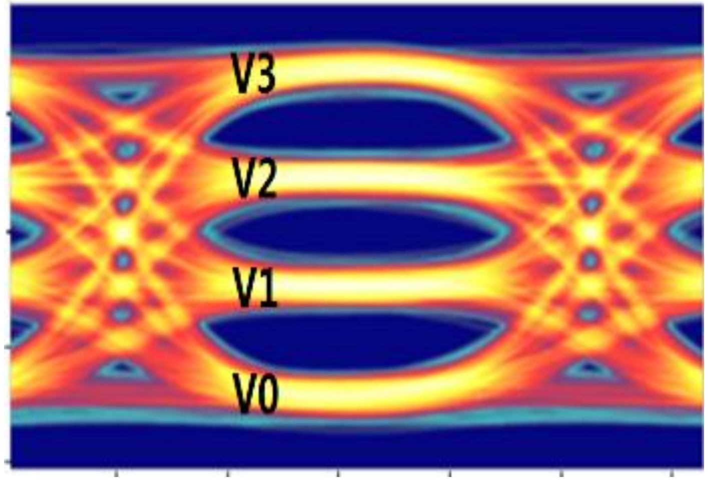
- Before equalization
- After equalization

- Evolution of equalization in measurement methodology:

1. **Allow optimization for best TDECQ**
   - since TDECQ should be tracking BER of the receiver
2. **Allow timing optimization** (of the common decision point)
3. limit the max. pre-cursor number to 2,
4. **A**daptive Threshold Adjust (**optimization of receiver threshold) 2018/02**
5. **Other changes**

PAM4 test: things are different

- More than one eye in one UI
  - Need to considerate the transmitter linearity
  - The level separation mismatch ration: R_{LM} Need to be test
  - The R_{LM} defined as(120D) : min[(3*ES1),(3*ES2),(2-3*ES1),(2-3*ES2)]
  - The idea R_{LM} is 1



V0~V3 is the mean value of the levels
Measure base on PRBS13Q pattern

$$V_{mid} = \frac{V_0 + V_3}{2}$$

$$ES1 = \frac{V_1 - V_{mid}}{V_0 - V_{mid}}$$

$$ES2 = \frac{V_2 - V_{mid}}{V_3 - V_{mid}}$$

Rlm: Algorithm comparison "Clause 94"/"120D"

$$S_{min} = \frac{min(V_D - V_C, V_C - V_B, V_B - V_A)}{2} \quad \text{(a)}$$

$$V_{avg} = \frac{V_A + V_B + V_C + V_D}{4} \quad \text{(b)}$$

$$ES_1 = \frac{V_B - V_{avg}}{V_A - V_{avg}} \quad \text{(c)}$$

$$ES_2 = \frac{V_C - V_{avg}}{V_D - V_{avg}} \quad \text{(d)}$$

$$R_{LM} = \frac{6 \cdot S_{min}}{V_D - V_A} \quad \text{(e)}$$

$$V_{mid} = \frac{V_0 + V_3}{2} \quad \text{(120D–3)}$$

$$ES1 = \frac{V_1 - V_{mid}}{V_0 - V_{mid}} \quad \text{(120D–4)}$$

$$ES2 = \frac{V_2 - V_{mid}}{V_3 - V_{mid}} \quad \text{(120D–5)}$$

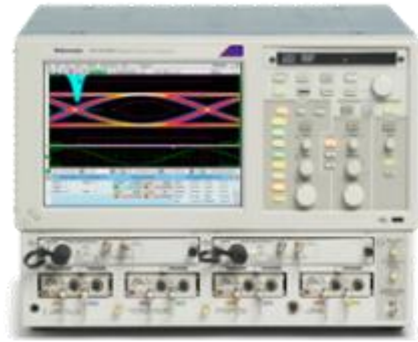
The level separation mismatch ratio R_{LM} is defined by Equation (120D–6).

$$R_{LM} = \min((3 \times ES1), (3 \times ES2), (2 - 3 \times ES1), (2 - 3 \times ES2)) \quad \text{(120D–6)}$$

- July 2018, San Diego, CA
- May 2018, Pittsburgh, PA
- March 2018, Rosemont, IL
- Jan 2018, Geneva, CH
- Nov 2017, Orlando, FL
- Sept 2017, Charlotte, NC
- July 2017, Berlin, Germany
- May 2017, New Orleans, La
- March 2017, Vancouver, BC, Canada
- Jan 2017, Huntington Beach, CA
- Nov 2016, San Antonio, Tx
- Sept 2016, Fort Worth, Tx
- July 2016, San Diego, CA
- May 2016, Whistler, BC Canada

Test Requirements

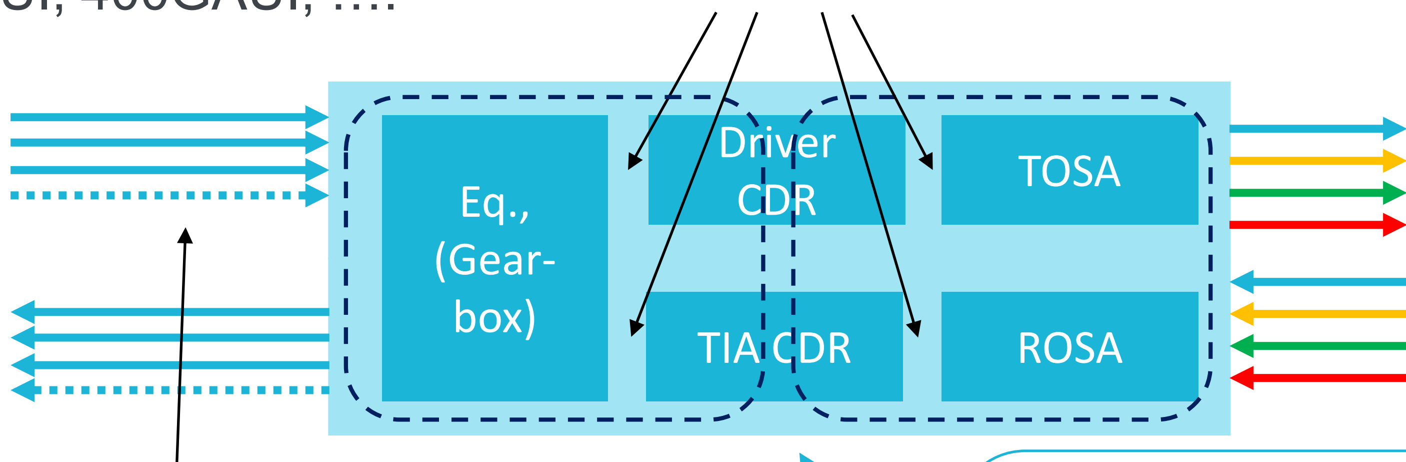
OPTICAL TRANSCEIVERS

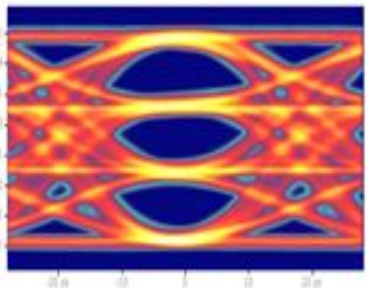


Electrical interface
CDAUI, 400GAUI, ….

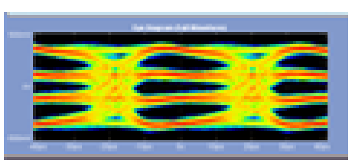
Intermediate test points
Characterization on evaluation boards

Optical
LR8/DR4/…
IEEE 802.3





and debug everywhere!!!

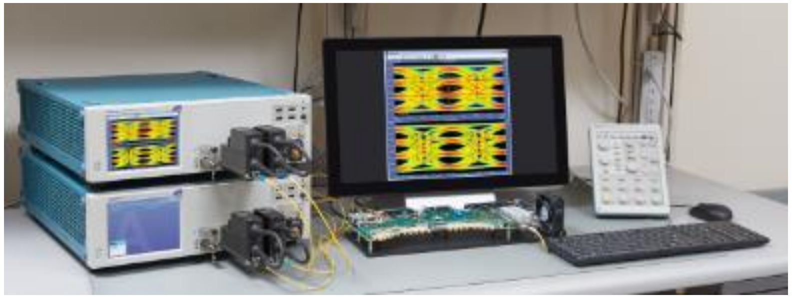


Clock recovery
Channel modelling
Equalization
Error Detection post-equalization
Error rate and location
DSP simulation

Tektronix 400G Acquisition Solutions

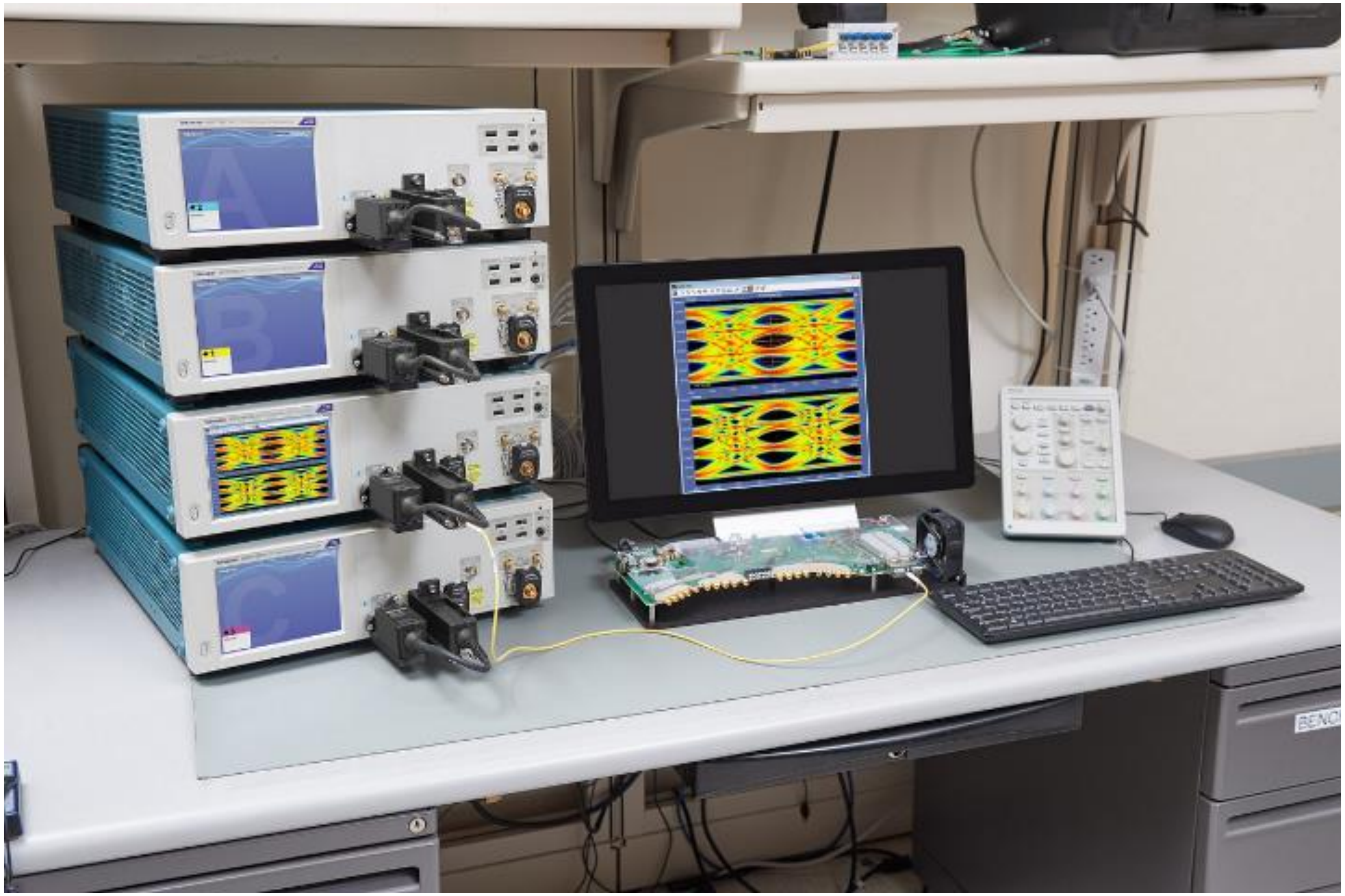
Equivalent Time Scope	Real Time Scope
85GHz Optical Bandwidth 70GHz Electrical Bandwidth <100fs jitter noise floor 20nW to .6uW Optical Resolution Automated test of 80+ Industrial Standards Best overall Optical solution	70GHz Analog Bandwidth 4.3ps rise time (20%-80%) 200GS/s Sample Rate <125fs jitter noise floor ≥25GHz Edge trigger bandwidth Compact 5 ¼” Oscilloscope package SW clock recovery required (key to 400G) Comprehensive CTLE, DFE, FFE signal processing Lowest noise real time acquisition system

ET



RT

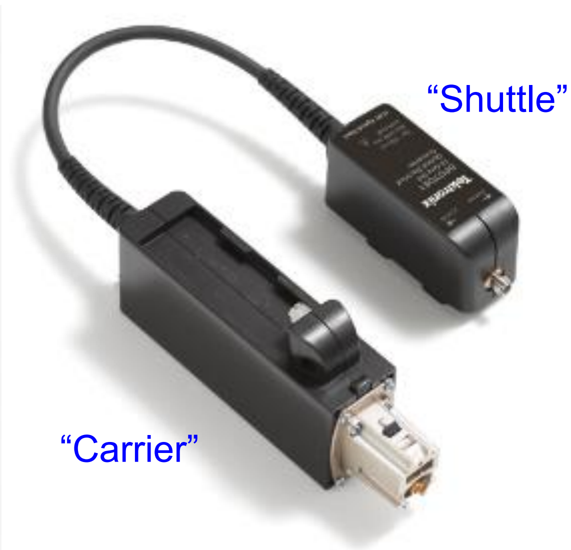
Industries Most Comprehensive PAM4 & NRZ Optical Analysis Solution



Introducing DPO7OE1/OE2 Optical Probe

- Broad wavelength O/E optimized for 28G/56GB Data Center Network App’s
- 33/59GHz GHz Optical bandwidth, DC coupled
- Single mode, multi-mode, 750nm – 1650nm
- Compatible with TekConnect and ATI inputs
- Use with DPO/MSO70kC/D/DX and DPO70kSX

TekConnect – 33/59 GHz O/E



ATI – 28G/53G ORR

ATI – Mechanical support deck

Comprehensive Measurement Suite

PAM4 Optical Measurements	
Error Analysis	• Symbol Errors, • SER • BER
Linearity	
Jitter	• Rj • Dj • Tj@BER
Statistical Eye Analysis	• Vertical Eye Closure • EW6 / EW5 • EH6 / EH5 • V_{upp} / V_{mid} / V_{low} • H_{upp} / H_{mid} / H_{low}
Optical	• ER • OMA • AOP
IEEE Specific	• TDECQ
Correlated Waveform	• Level Deviation • Level Thickness • Time Deviation • Rise and Fall

PAM4 Electrical Measurements	
Error Analysis	• Symbol Errors, • SER • BER
Linearity	
Jitter	• Rj • Dj • Tj@BER
Statistical Eye Analysis	• Vertical Eye Closure • EW6 / EW5 • EH6 / EH5 • V_{upp} / V_{mid} / V_{low} • H_{upp} / H_{mid} / H_{low}
SNDR	• SNDR • P_{max} • σ_e • σ_n
OIF-CEI	• UUGJ • UBHPJ • EOJ
IEEE Specific	• Jrms • J4 • EOJ • Rise Time • Fall Time • SNR_ISI
Correlated Waveform	• Level Deviation • Level Thickness • Time Deviation • Rise and Fall

Tektronix

80C17/18 28GBd

80C20/21 56GBd

New Optical Modules for DSA8300

80C17/18 vs 80C15

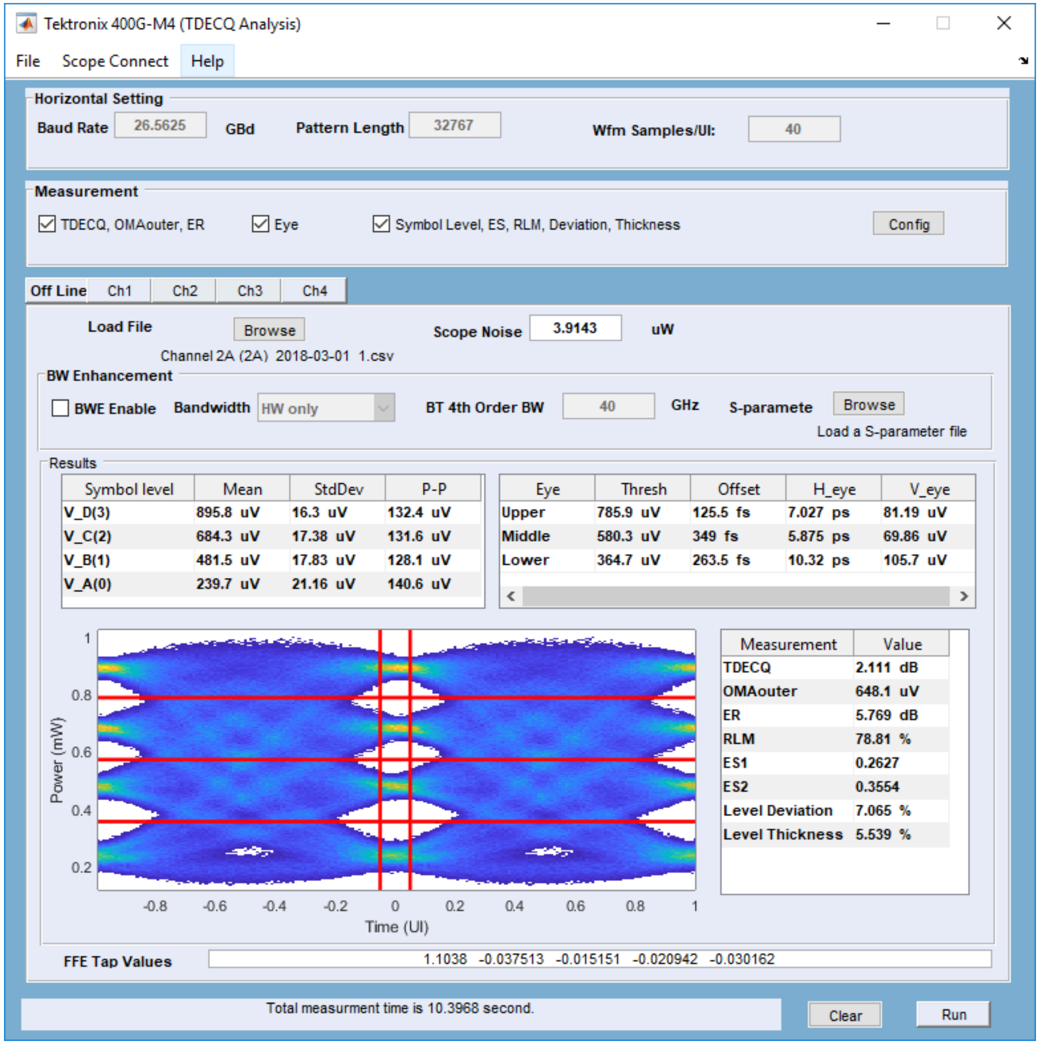
Feature / Function	80C17/18 *Target Specs*	80C15 *Current Specs*
# Channels	1 or 2	1
Input Fiber Type	MM + SM 9, 50 µm (no 62.5 µm)	MM + SM 9, 50, 62.5 µm
Wavelength Range	800nm - 1650nm	800nm - 1650nm
Unfiltered Optical Bandwidth	>30 GHz	>32 GHz
Unfiltered Risetime (typical)	14 ps	14 ps
Optical Reference Receivers	25.78 – 28.05 Gb/s	25.78 – 28.05 Gb/s
RMS Optical Noise Typical @ 1310 nm @ 25.78 Gb/s	3.9 µW	11 µW
Mask Test Sensitivity Typical @ 1310nm	-14 dBm	-8 dBm
Power Meter Zero Level Performance - Sample rate reduced by increasing channels	None	2 ch – half 4 ch - quarter

80C20/21 vs 80C10C

Feature / Spec	80C20/21 *Target Specs*	80C10C *Current Specs*
# Channels per Module / System	1 or 2 / 1, 2, 3, 4	1 / 1, 2
Unfiltered Optical Bandwidth (-3dBo)	53 GHz	80 GHz
Wavelength Range	1200 to 1650 nm	1290 to 1620 nm
Calibrated Wavelengths	1310 nm / 1550 nm	1310 nm / 1550 nm
Optical Noise (RMS) @ 1310 nm @ 37 GHz, Typical / Maximum	9 µW / 12 µW	29.9 µW / 52 µW
Optical Sensitivity @ 1310 nm	-10 dBm	-6 dBm
Max input power, non-destruct, average/peak	4 mW / 8 mW	30 mW
Dynamic range (full scale)	3 mW	15 mW
Optical return loss	>25 dB	>30 dB
Acquisition delay adjustment range on each channel	+/- 65 ps	---
Power meter range	+6 dBm to -27 dBm	+13 dBm to -21 dBm
Input Fiber Type	9 µm	9 µm
Clock Recovery Trigger Pick-off Option	No	Yes

DSA8300 400G-M4 Overview

DSA8300 400G-M4 SOFTWARE APPLICATION



Tektronix®

Measurement Solutions to
Accelerate Innovation