100G TECHNICAL POSTER

EXFO

EXFO HEADQUARTERS

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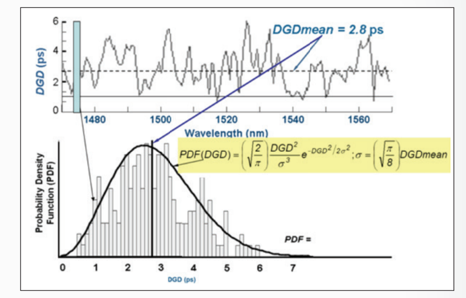
100 Gbit/s Line Side – Dispersion and OSNR

Polarization mode dispersion (PMD)

- Coherent systems promise to compensate for PMD, but do they actually deliver?
- PMD compensation is performed by the digital signal processor located in the receiver
- PMD changes as a function of time due to changes in temperature, mechanical stresses on the fiber (wind, vibrations, poor installation), etc.



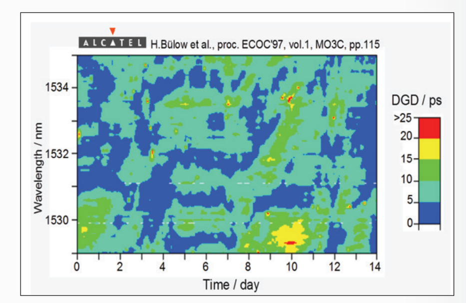
Probability distribution curve of differential group delay (DGD) values. PMD is the average of DGD for all wavelengths.

Properties of an Ideal PMD Compensator

PMD characteristic		Ideal PMD compensator feature
PMD range	>	PMDC must compensate for a wide range of PMD values
PMD/SOP is time variant	>	PMDC must be dynamic (compensate in real time)
PMD/SOP fast rate of change	>	PMDC must have a fast, reset-free tracking algorithm/circuitry
PMD equation expansion	>	PMDC must at least compensate for 1st order and 2nd order PMD

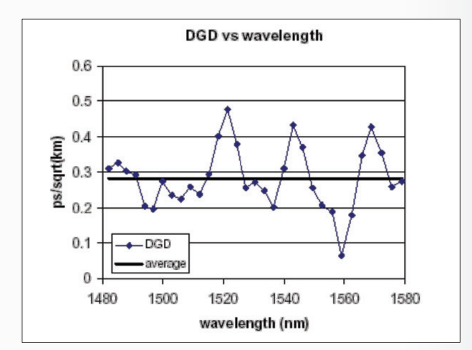
Differential group delay (DGD)

- Paper by Alcatel: measurement of DGD over 14 days.
- Yellow/red areas in graph to the right: high DGD.
- Blue/green areas: low DGD.
- While DGD is mostly low (blue/green), sometimes DGD reaches extreme values (yellow/red).
- Therefore, DGD varies greatly with time and wavelength.



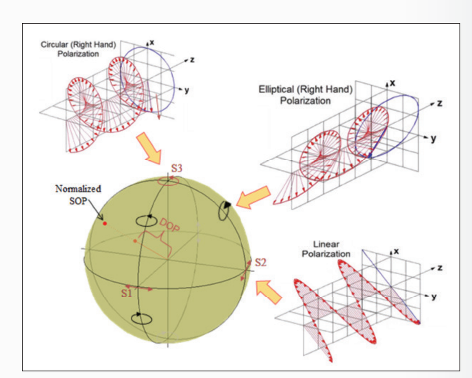
PMD and DGD

- DGD varies as a function of time and depends on wavelength.
- DGD: specific to one wavelength.
- PMD: average of DGD, for all wavelengths.



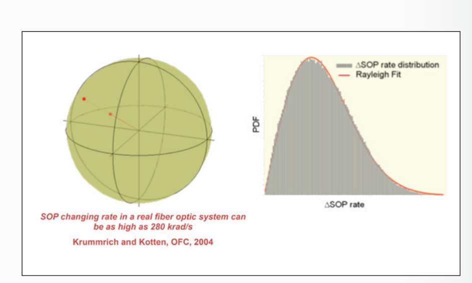
State of polarization (SOP)

- SOP describes how polarization changes as it propagates in fiber.
- SOP can be shown on a Poincaré sphere: each point on the sphere is a different SOP.
- SOP types include elliptical, circular, linear, etc.



SOP changes randomly in real fibers

- SOP rate of change follows a Rayleigh probability distribution.

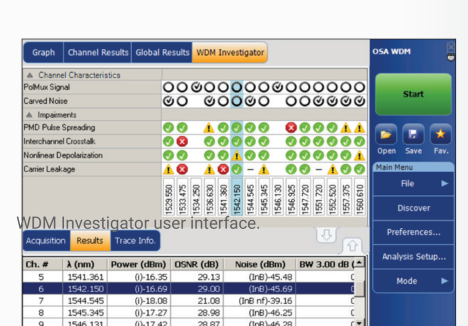


Consequences of PMD compensation failures

- Bursts of error increasing the bit error rate (BER)
- Loss of tracking and long recovery time, sometimes up to 20 seconds

7 reasons why PMD compensation in coherent systems can fail

1. Fast SOP changes
2. An abrupt SOP change
3. Loss of SOP orthogonality
4. Fast PMD changes
5. A sudden PMD change
6. Large PMD values
7. Presence of PDL



WDM Investigator user interface.

How to reduce risk of PMD compensation failures in the fiber

PMDC compensation failures can be reduced by measuring the PMD of each fiber and by not using the fibers with high PMD, because all seven risk factors for PMD compensation failure **increase** when fiber PMD is high.

PMD measurement on live signals (with WDM Investigator)

- Identifies PMD issues on active noncoherent channels
- Ideal for PMD assessment prior to an upgrade to 100G

The challenge: reducing OPEX amid increasing network complexity

Challenge

Network complexity

- ROADMs
- Coherent
- Various modulation formats
- Various bandwidths
- Less dark fiber testing

Result: new impairments

- PMD pulse spreading
- Crosstalk
- Nonlinear effects (NLE)
- Carrier leakage (CL)

Many sources of noise to identify and mitigate

$$Noise = N_{ASE} + N_{NLE} + N_{x-talk} + N_{CL}$$

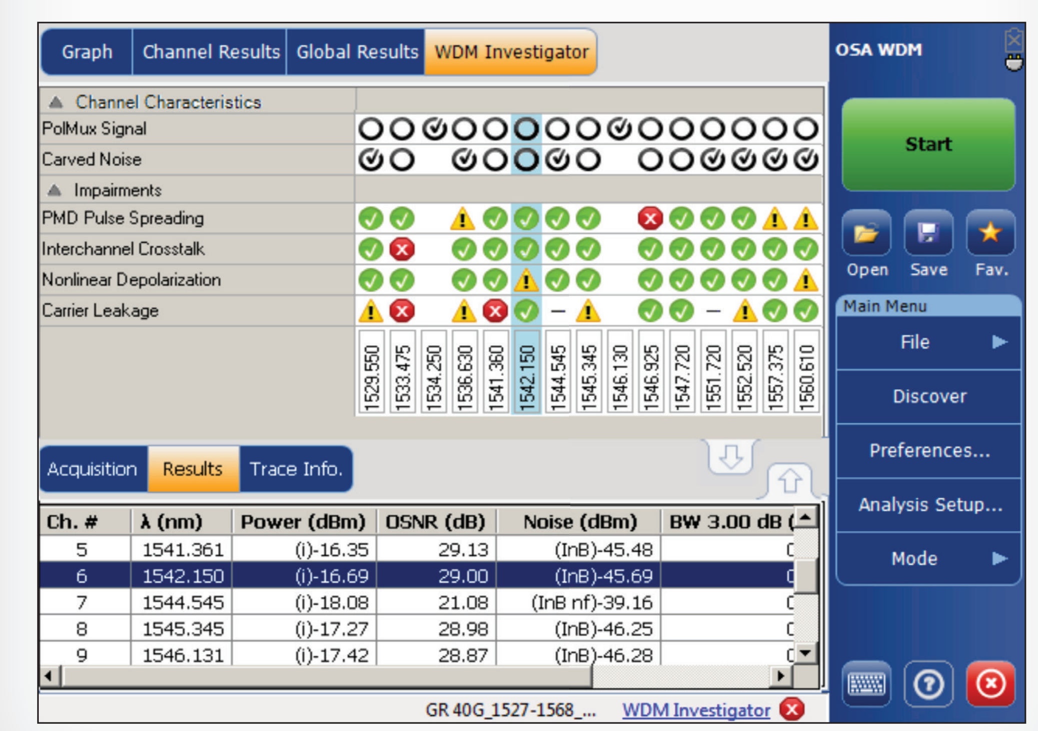
Fiber type	10G networks	40G and 100G networks
Noise types	ASE	ASE, instantaneous PMD, NLE, crosstalk and CL
Noise sources	Optical amplifiers	Amplifiers, fiber properties, neighboring channels, filters and transmitters
Troubleshooting noise issues	Easier	More complex, time consuming and expensive
Troubleshooting procedure for noise issues	Check amplifier-noise figure	Check amplifiers, channel power (NLE), channel spacing (crosstalk + NLE), transmitter CL, chromatic dispersion and PMD values (NLE), and filtering (OSNR)
Required test tools	Optical spectrum analyzer	WDM Investigator

Solution: WDM Investigator

- Identifies new sources of noise, such as interchannel crosstalk, nonlinear effects and carrier leakage
- Measures PMD on live signals (dark fiber is no longer a requirement for PMD measurement)

Benefits

- Enables you to diagnose your network
- Helps you identify more probable causes of noise
- Speeds up troubleshooting
- Reduces truck rolls
- Helps you regain control of your OPEX

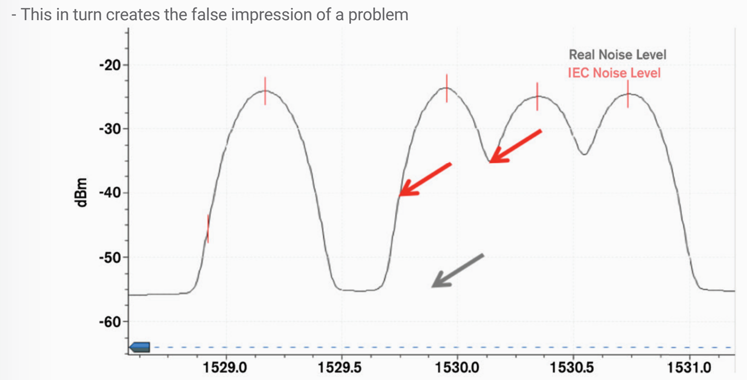


OSNR measurement of coherent 40G/100G signals

Why IEC method fails in coherent networks?

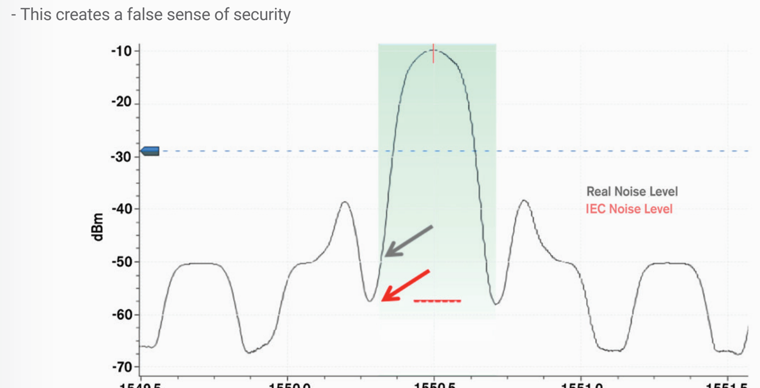
Case 1: Network operating at 40 Gbit/s or 100 Gbit/s

- Coherent 40G and 100G signals are closely spaced and therefore overlap
- The IEC interpolation method leads to an overestimation of the noise level
- This in turn creates the false impression of a problem



Case 2: ROADM present in the network

- A ROADM contains filters that reduce interchannel noise
- The traditional interpolation method leads to an underestimation of the noise
- This creates a false sense of security



Why in-band OSNR fails in coherent networks?

Polarization-based in-band OSNR does not work, because the signal appears unpolarized (two orthogonal polarizations).

- WDM-Aware does not work
- Polarization-nulling does not work

OSNR measurement standards

- New standards have been published for 100G+ OSNR measurements

IEC 61282-12 standard

- OSNR = 10log(R), $$R = \frac{1}{B_r}\int_{\lambda_1}^{\lambda_2} \frac{s(\lambda)}{\rho(\lambda)} d\lambda$$

- $s(\lambda)$: time-averaged signal spectral power density, not including ASE, expressed in W/nm;
- $\rho(\lambda)$: ASE spectral power density, independent of polarization, expressed in W/nm;
- Br: reference bandwidth expressed in nm (usually 0.1 nm)
- λ_1 to λ_2: signal spectral range.

China Communications Standards Association (CCSA) YD/T 2147-2010 standard

$$Pol\ Mux\ OSNR = 10\log_{10}\left(\frac{P-N}{n/2}\right)$$

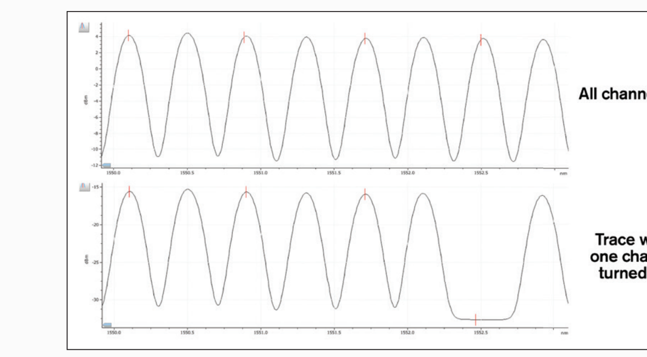
where for 50 GHz channel

- **P** = integrated power (signal + noise) over the 0.4 nm channel bandwidth
- **N** = integrated power (noise) over 0.4 nm bandwidth
- **n** = integrated power (noise) inside 0.2 m, then normalised to 0.1 nm

Solution at turn-up: Pol-Mux OSNR measurements with the Commissioning Assistant

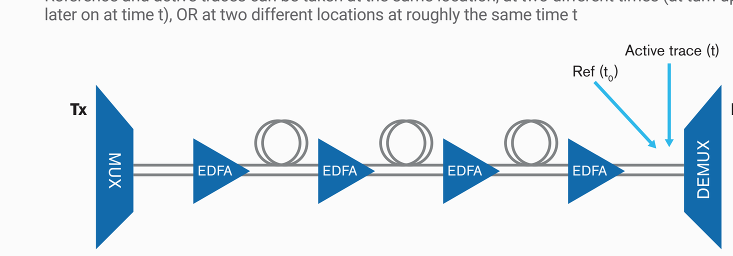
EXFO's Commissioning Assistant offers the option of measuring Pol-Mux OSNR based on the IEC 61282 standard or CCSA YD/T 2147-2010 method.

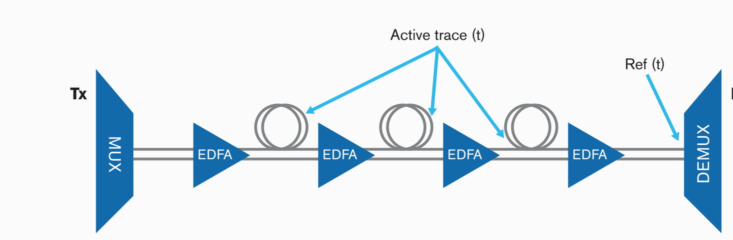
- Involves taking traces during commissioning (by turning off channels)
- Requires n + 1 traces (n = number of channels)
- The commissionning assistant then automatically calculates Pol-Mux OSNR
- Saves time and money and reduces the risk of human error with respect to manual calculations with channels turned off



Solution on live networks: in-service Pol-Mux OSNR

- Unique patented method offering robust, repeatable OSNR measurements of live, coherent signals
- Method consists of taking a reference and an active trace, in order to determine the OSNR of active trace
- Reference and active traces can be taken at the same location, at two different times (at turn-up, t_0 and later on at time t), OR at two different locations at roughly the same time t





Summary of OSNR methods

Data rate	ROADM present?	OSNR method	Works on live network?
≤10 Gbit/s	no	IEC 61280-2-9	Yes
≤10 Gbit/s	yes	In-band	Yes
Noncoherent 40 Gbits/s	yes or no	In-band	Yes
Coherent 40G/100G/200G/400G (at turn-up)	yes or no	Pol Mux (com. assistant)	No
Coherent 40G/100G/200G/400G (live network)	yes or no	In-service Pol-Mux	Yes

FTBx-5245/5255 Optical Spectrum Analyzer

› Robust In-service Pol-Mux OSNR for 40G/100G/200G/400G (FTBx-5255)

› Industry's smallest OSA/transport solution in a single platform (FTB-4 PRO)

› Industry's only all-in-one OSA covering all testing applications: high speed 100G+ (including In-service Pol-Mux OSNR), CWDM, O-band (1300 nm) and L-band (1600 nm range)

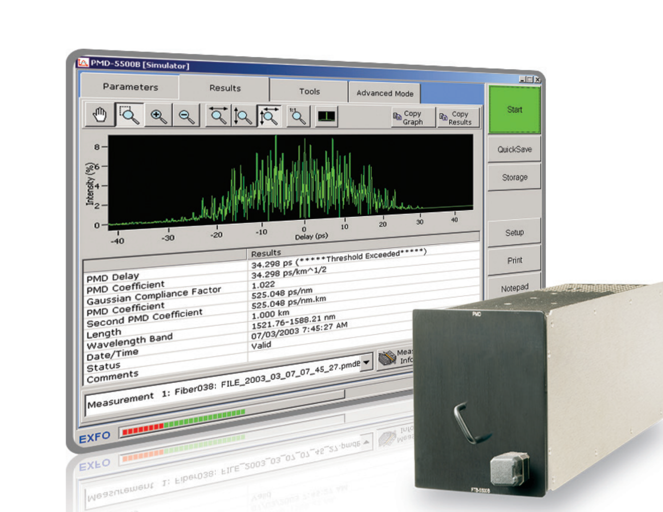
FTB-5500B PMD Analyzer

› Testing time under 5 seconds for any PMD range

› Compliant with TIA-FOTP-124A standard

› Patented design: test through EDFAs

› 100 Gbit/s-ready



FTB-5700 Dispersion Analyzer

› Single-ended testing of multiple links from one location—for fewer truck rolls and reduced OPEX

› Standards-compliant approach

› Get right results the first time thanks to a single-button operation

› Fully automated, smart interface

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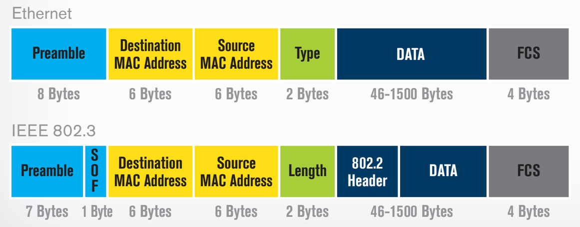
100G TECHNICAL POSTER

40G/100G Ethernet (IEEE 802.3ba)

Ethernet frame format and rates



Ethernet interface	Line rate
40G Ethernet	41.25 Gbit/s
100G Ethernet	103.125 Gbit/s

IEEE 802.3ba highlights

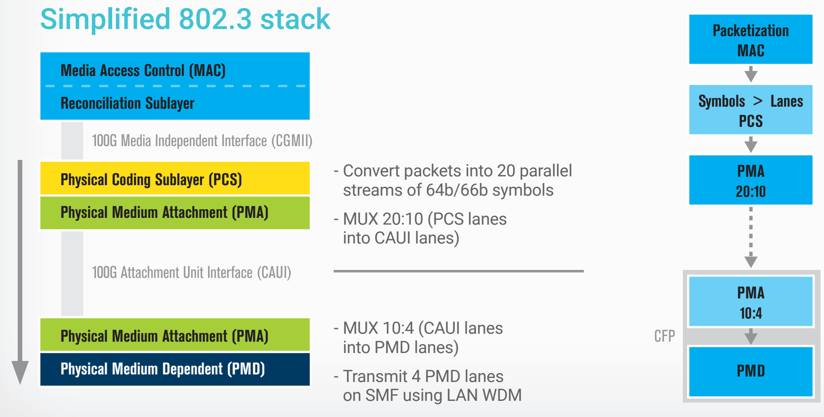
- Support a MAC data rate of 40 Gbit/s and 100 Gbit/s
- Provide a BER < 10-12 at the MAC layer
- Provide appropriate support for OTN

- Provide physical-layer specifications which support:

	40G Ethernet	100G Ethernet
40 km over SMF		100GBASE-ER4
10 km over SMF	40GBASE-LR4	100GBASE-LR4
100 m over OM3 MMF	40GBASE-SR4	100GBASE-SR10
10 m over copper cable	40GBASE-CR4	100GBASE-CR10
1 m over backplane	40GBASE-KR4	

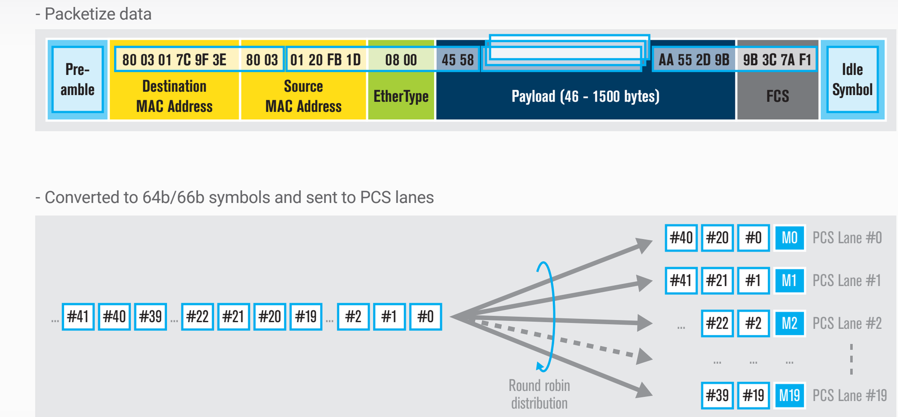
100GigE packet transmission

Simplified 802.3 stack



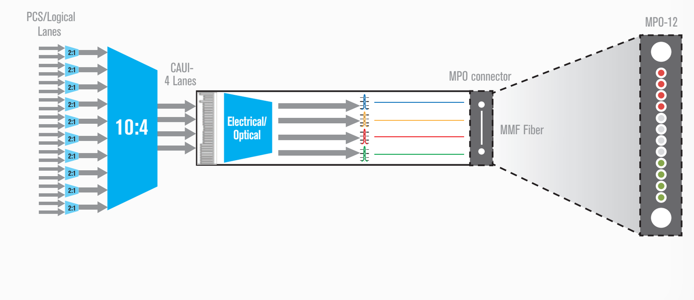
- Convert packets into 20 parallel streams of 64b/66b symbols
- MUX 20:10 (PCS lanes into CAUI lanes)
- MUX 10:4 (CAUI lanes into PMD lanes)
- Transmit 4 PMD lanes on SMF using LAN WDM

- Packetize data



- Converted to 64b/66b symbols and sent to PCS lanes
- Add PCS lane markers periodically to ensure reordering and realignment

1. The PMA next to the PCS multiplexes 20 PCS lanes into 10 CAUI lanes
2. The PMA next to the PMD multiplexes 10 CAUI lanes into 4 PMD lanes
3. The PMD converts each PMD lane into optical NRZ and multiplexes them
4. The 4 optical lanes are transmitted over singlemode fiber



PCS lane skew

- Skew is the difference in time it takes the signals traveling down one lane compared to the others
- Each element along the data path will contribute to the overall skew (i.e., CFP, fiber, etc.)

Skew Points	Maximum Skew (ns)	Maximum Skew for 40GBASE-R PCS Lane (UI)	Maximum Skew for 100GBASE-R PCS Lane (UI)
SP1	29	≈ 299	≈ 150
SP2	43	≈ 443	≈ 222
SP3	54	≈ 557	≈ 278
SP4	134	≈ 1382	≈ 691
SP5	145	≈ 1495	≈ 748
SP6	160	≈ 1649	≈ 824
At PCS receive	180	≈ 1856	≈ 928

Legend	
CAUI	100 Gbit/s Attachment Unit Interface
CGMII	100 Gbit/s Media Independent Interface
FEC	Forward Error Correction
MAC	Media Access Control
MDI	Medium Dependent Interface
PCS	Physical Coding Sublayer
PMA	Physical Medium Attachment
PMD	Physical Medium Dependent
XLAUI	40 Gbit/s Attachment Unit Interface
XLGMII	40 Gbit/s Media Independent Interface
n	4 or 10

Note 1: Optional or omitted depending on PHY type.

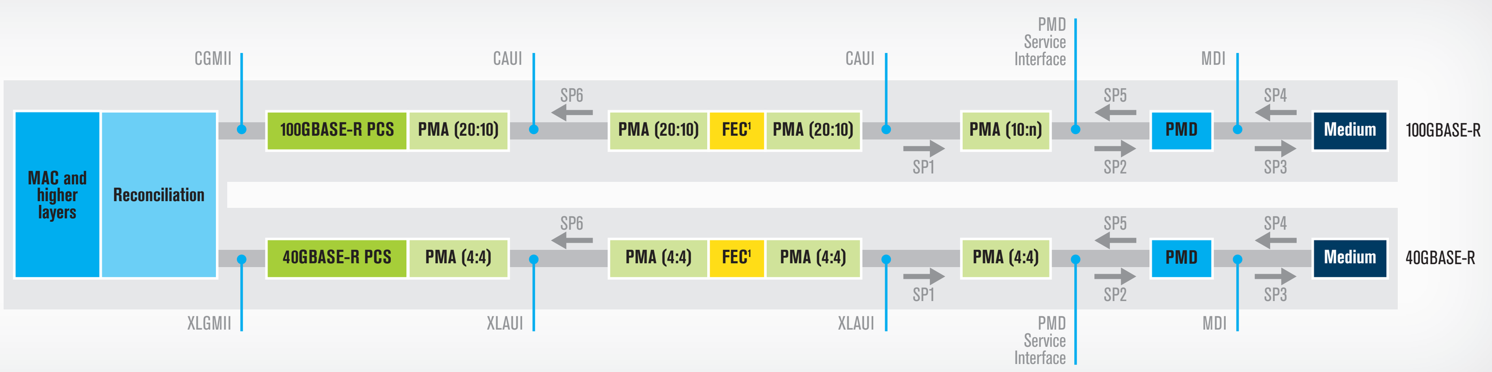
The maximum skew and skew variation at physically instantiated interfaces is specified at skew points SP1, SP2 and SP3 for the transmit direction and SP4, SP5 and SP6 for the receive direction.

In the transmit direction, the skew points are defined in the following locations:

- SP1 on the XLAUI/CAUI interface, at the input of the PMA closest to the PMD;
- SP2 on the PMD service interface, at the input of the PMD;
- SP3 at the output of the PMD, at the MDI.

In the receive direction, the skew points are defined in the following locations:

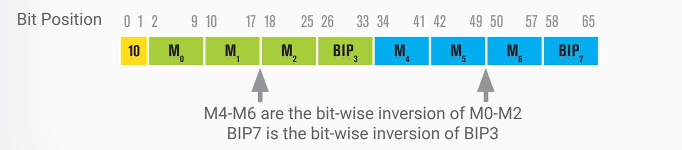
- SP4 at the MDI, at the input of the PMD;
- SP5 on the PMD service interface, at the output of the PMD;
- SP6 on the XLAUI/CAUI interface, at the output of the PMA closest to the PCS.



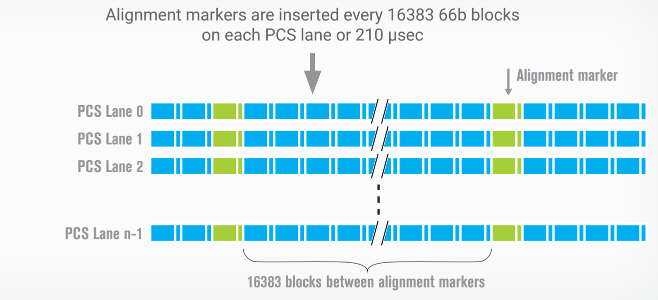
PCS lane markers

PCS lane marker is the mechanism used to reorder and realign the PCS lanes

- The marker has the form of a specially defined 66b block (to maintain 1's density) and its format is as follows:

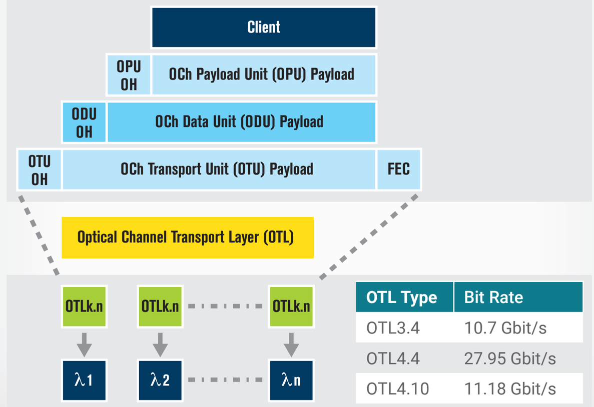


- The lane number is coded in the M1 byte field
- A BIP field is used for the calculation of the BER per PCS lane
- Markers are not scrambled in order to allow the receiver to search and find the markers
- Bandwidth for the alignment markers is created by periodically deleting IPG Skew tolerance is 180 nsec maximum for both the 40G and 100G



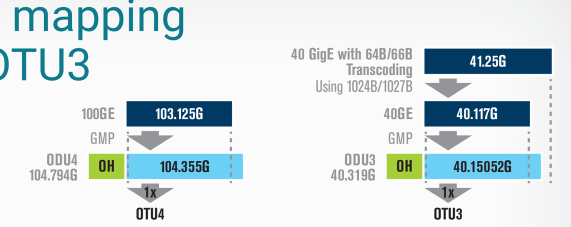
OTU4/OTU3 (ITU-T G.709)

OTU4/OTU3 over parallel optics

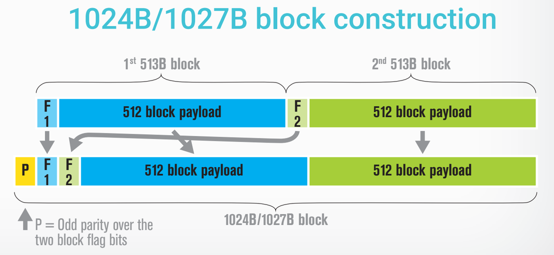


OTL Type	Bit Rate
OTL3.4	10.7 Gbit/s
OTL4.4	27.95 Gbit/s
OTL4.10	11.18 Gbit/s

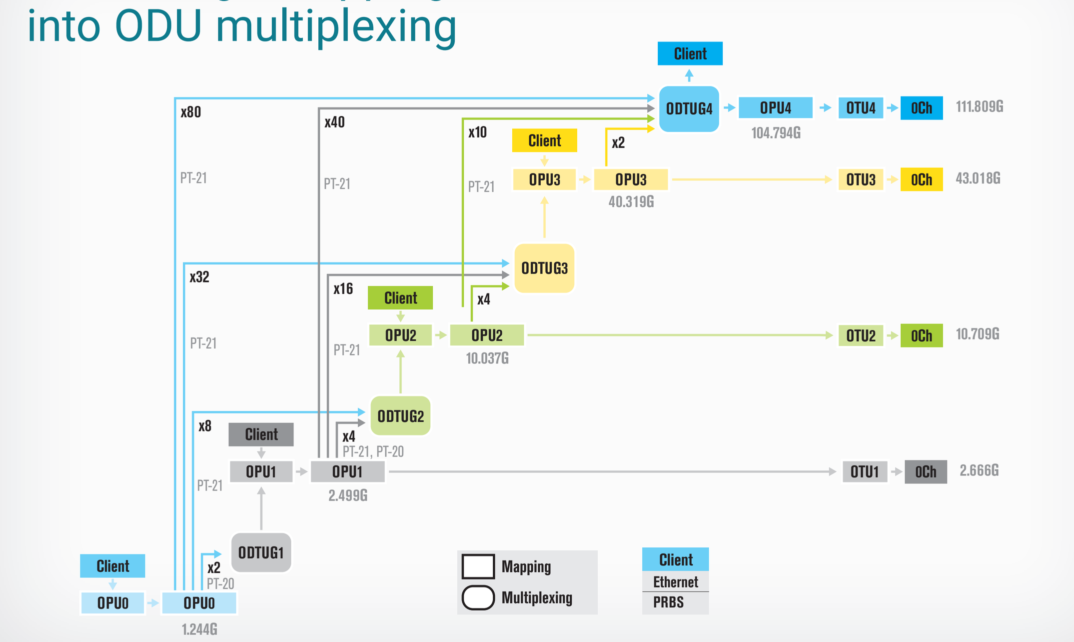
40/100GigE mapping into OTU4/OTU3



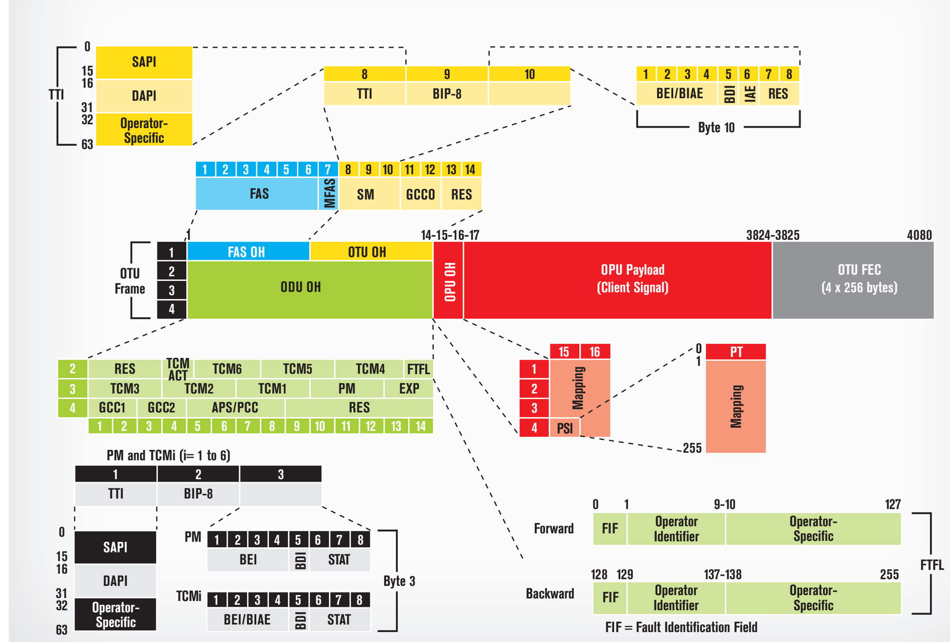
1024B/1027B block construction



40/100GigE mapping into ODU multiplexing



OTN frame structure



Frame rates

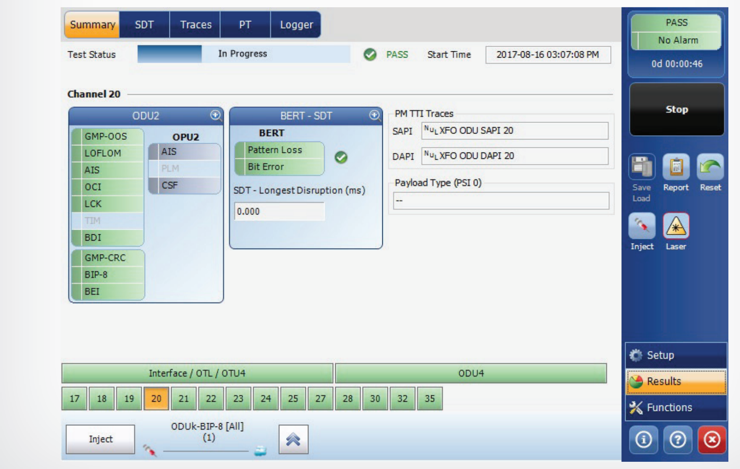
OTN interface	Line rate	Corresponding service
OTU3	43.018 Gbit/s	OC-768/STM-256 40GigE
OTU3e1	44.57 Gbit/s	4 x ODU2e (uses 2.5Gig TS; total of 16)
OTU3e2	44.58 Gbit/s	4 x ODU2e (uses 1.25Gig (ODU0) TS; total of 32)
OTU4	111.81 Gbit/s	100GigE

Multiplexing capacity

Multiplexing	Number of channels
OTU4/ODU4/ODU0	80
OTU4/ODU4/ODU1	40
OTU4/ODU4/ODU2	10
OTU4/ODU4/ODU3	2

Multichannel OTN BERT

Multiplexing capabilities from OTN allow it to carry data containers inside an OTU4, if the user wants to do more exhaustive testing of the multiplexing capabilities of their network elements. Multichannel OTN enhanced with the mix mapping functionality help users start testing on a basic scenario by saturating the capacity from the pipe with the same type of data units (80 ODU0s) or will enable them to select different types of data units (ODU0/ODU1/ODU2/ODU3) in the ODU4 container, providing statistics for each channel separately for more granularity while testing 100G OTN links.



40G/100G interfaces and pluggable transceivers

Compatibility between 40G/100G transceivers

The table below depicts the compliance of different interfaces to the multiple port types used in the industry. The interfaces that are grouped within the same port-type column are interoperable, provided that the appropriate connectors are used.

	100G Base								
Interfaces	SR10	LR10	SR4	CLR4	CWDM4	PSM4	LR4	ER4	ER4f
CFP	•	•						•	
CFP2	•						•	•	
CFP4			•				•	•	•
QSFP28			•	•	•	•	•	•	•

	40G Base		
Interfaces	SR4	LR4	FR
CFP	•	•	•
QSFP+	•	•	

MSA optical wavelengths

100 GigE/OTU4

Lane	Center wavelength	Wavelength range
L_0	1295.56 nm	1294.53 to 1296.59 nm
L_1	1300.05 nm	1299.02 to 1301.09 nm
L_2	1304.58 nm	1303.54 to 1305.63 nm
L_3	1309.14 nm	1308.09 to 1310.19 nm

100GBASE CLR4/CWDM4

Lane	Center wavelength	Wavelength range
L_0	1271 nm	1264.5 to 1277.5 nm
L_1	1291 nm	1284.5 to 1297.5 nm
L_2	1311 nm	1304.5 to 1317.5 nm
L_3	1331 nm	1324.5 to 1337.5 nm

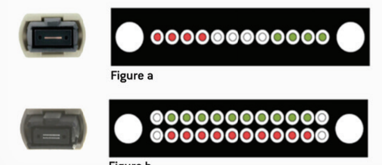
100GBase CFPs with MPO connector

- MPO: Multifiber-push-on or Multi-fiber-pulloff
- MPO-12 (see figure a) and MPO-24 (see figure b) most common

MTP® vs. MPO

MTP: Mechanical-transfer-pulloff *:

- Used interchangeably and compatible with MPO male and female connectors
- Superior style of MPO connector with many design improvements
- Same appearance on the outside; differences mostly on the inside



12-fiber MPO/MTP® (a) vs. 24-fiber MPO/MTP® (b)

* Specific brand of MPO designed by US Conec.

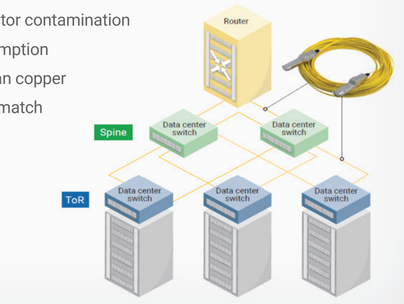
High speed active optical cables (AOC)

These cables are an alternative to optical transceivers.

AOC have a fixed fiber connection inside the transceiver – permanently attaching the fibers to the optics. Their main application is intended for connections between 5-100 meters.

Key benefits

- No optical connector contamination
- Low power consumption
- More flexibility than copper
- No transceiver mismatch
- Low cost



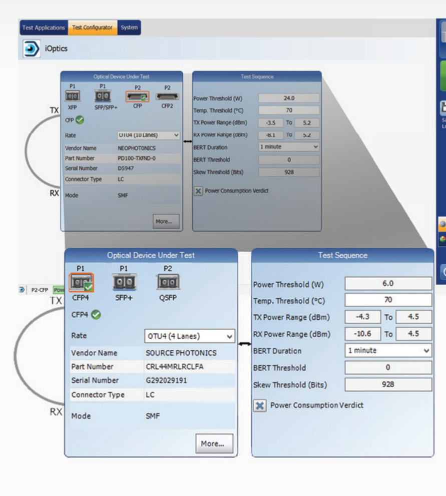
iOptics

Smart test application that quickly validates transceiver and cables through a sequence of basic subtests.

Supports a wide range of of optical modules and cables:

QSFP28, QSFP+, CFPx, SFP+, SFP and AOC cables

1. Power monitoring
2. Quick check (common status/control pins)
3. Temperature monitoring
4. Optical TX power level range test (each lane is individually tested for multilane devices)
5. Optical RX signal presence and level range test (each lane is individually tested for multilane devices)
6. Stress BERT
7. Frame excessive skew test (40G/100G devices only)



Our test solutions

EXFO