Fiber Optics Evolution & Trends

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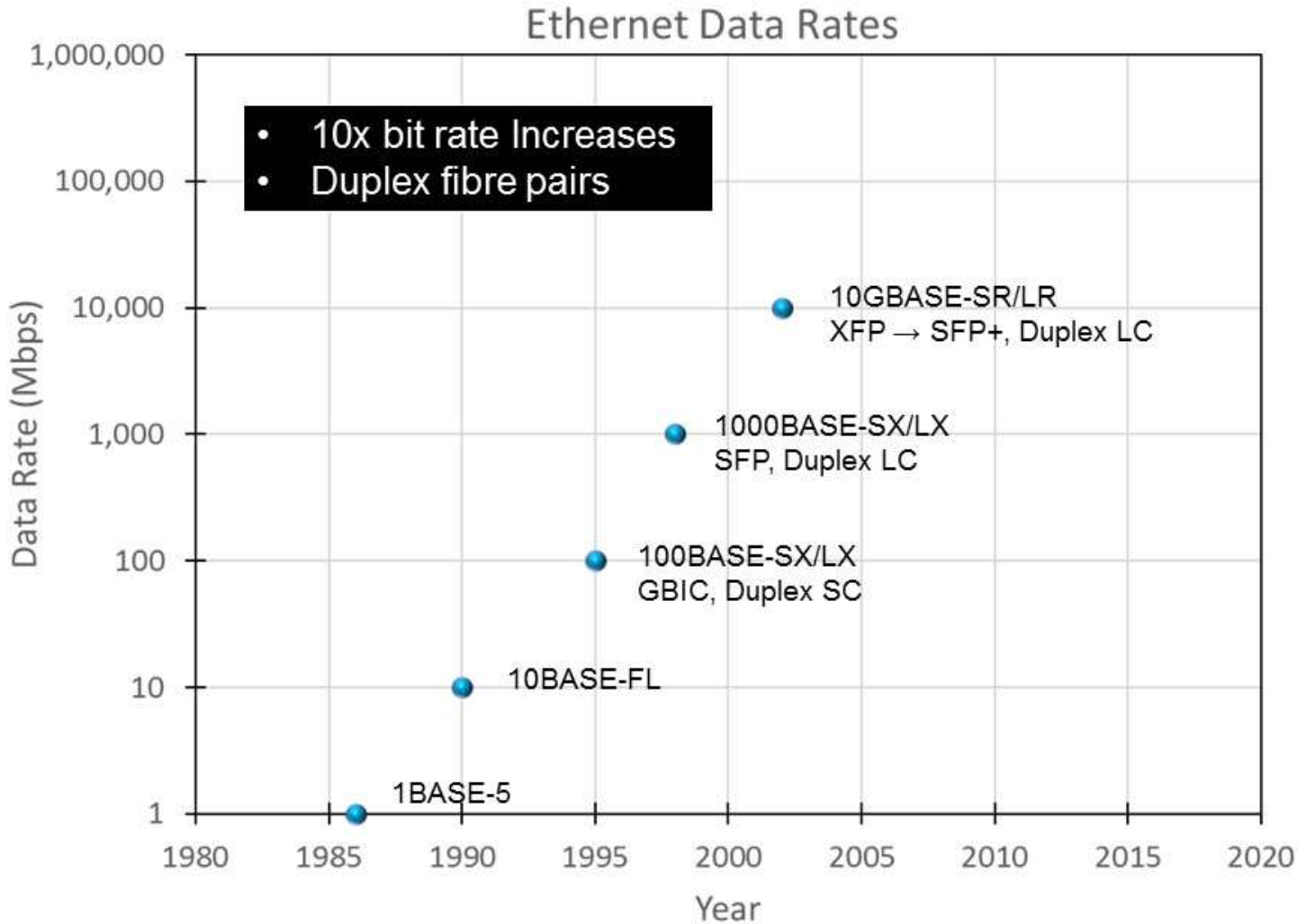
Evolution of Ethernet Baseband Data Rates

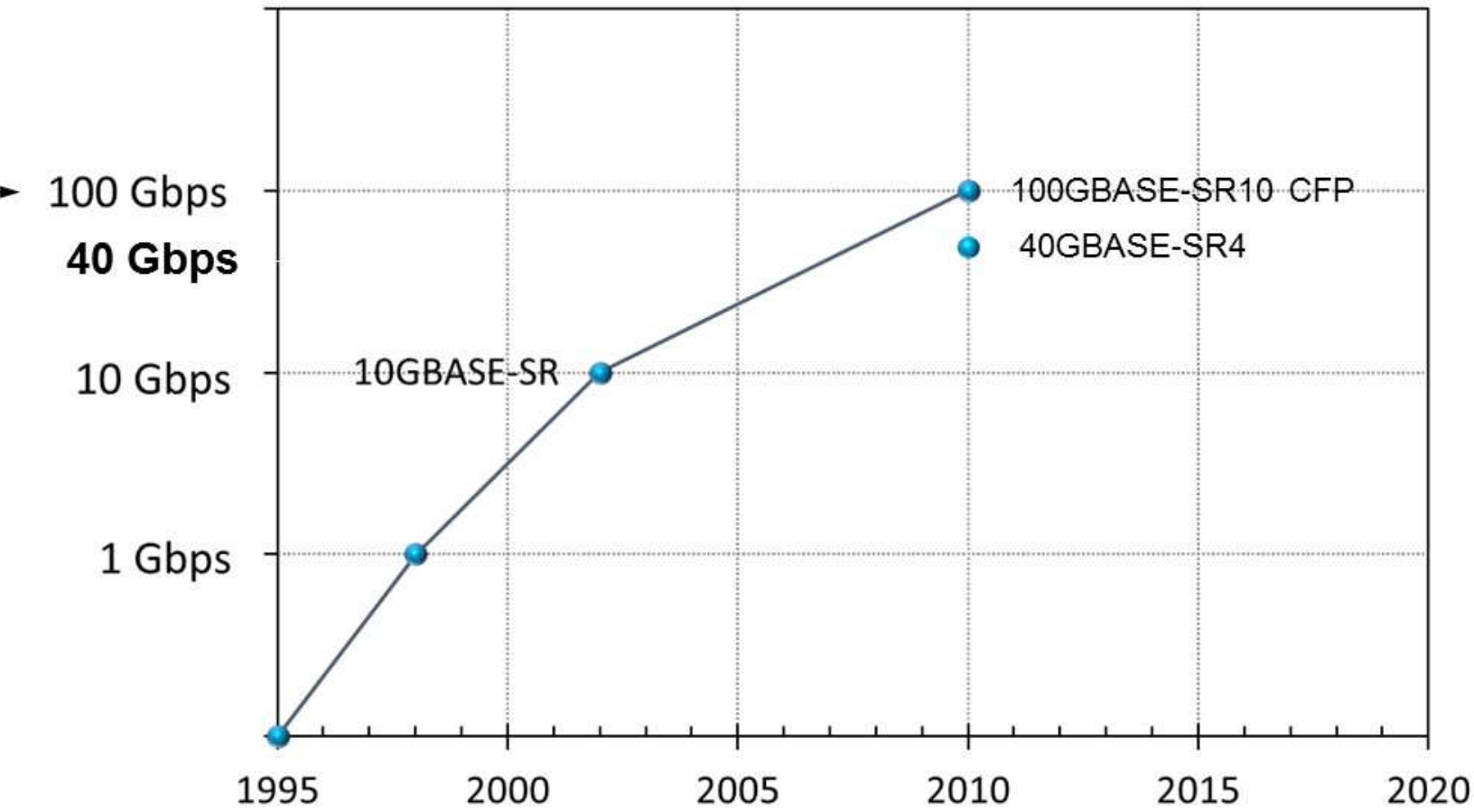
- 10x increases from 1986 to 2006



GBIC - Gigabit Interface Converter

Ethernet Data Rate Call-for-Interest (CFI) 2006

IEEE 802.3 Study Group
10 lanes x 10Gbps
Module Interface

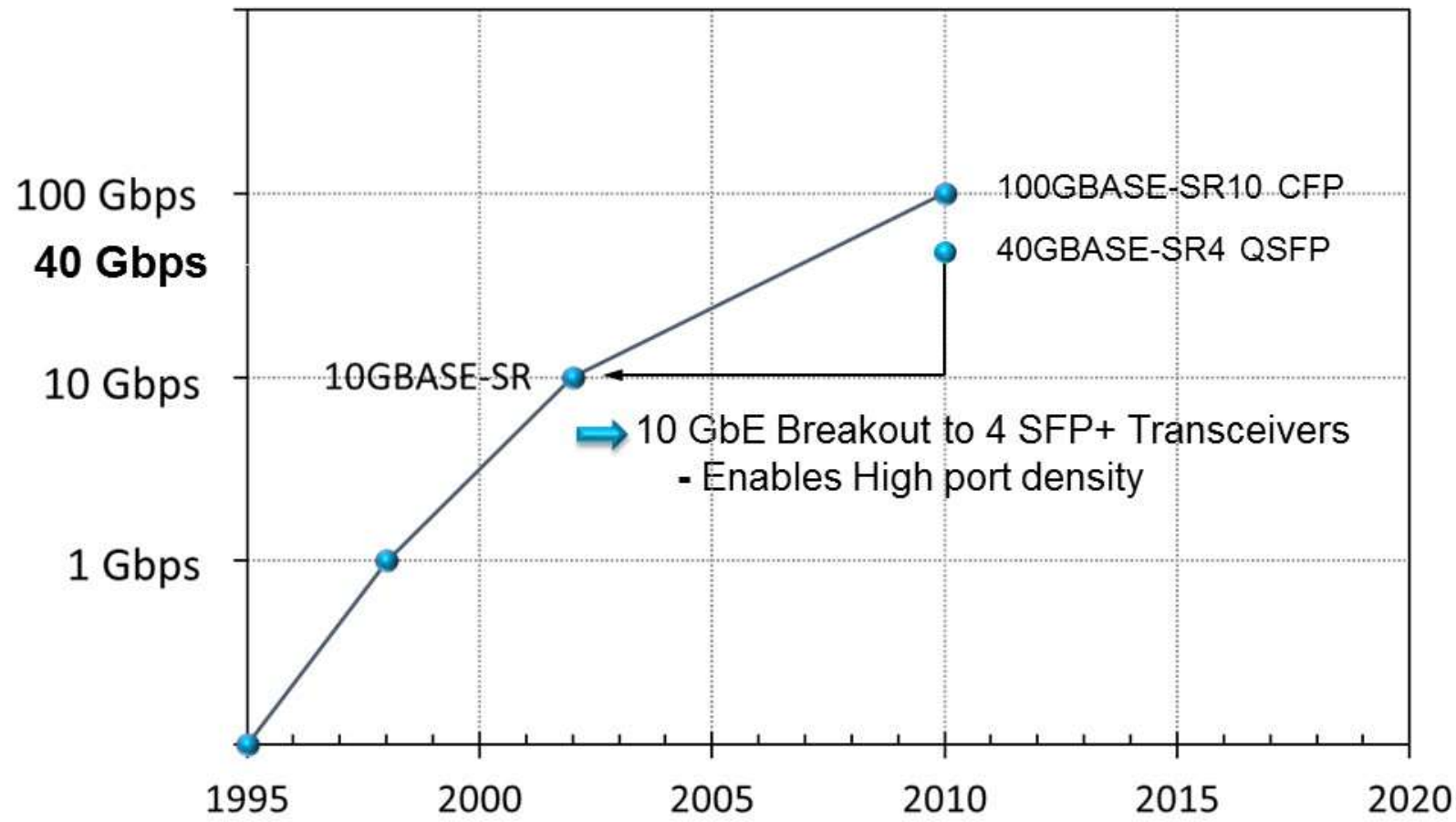


Ethernet Data Rate IEEE – four and ten 10Gb/s Lanes

Shift in Paradigm

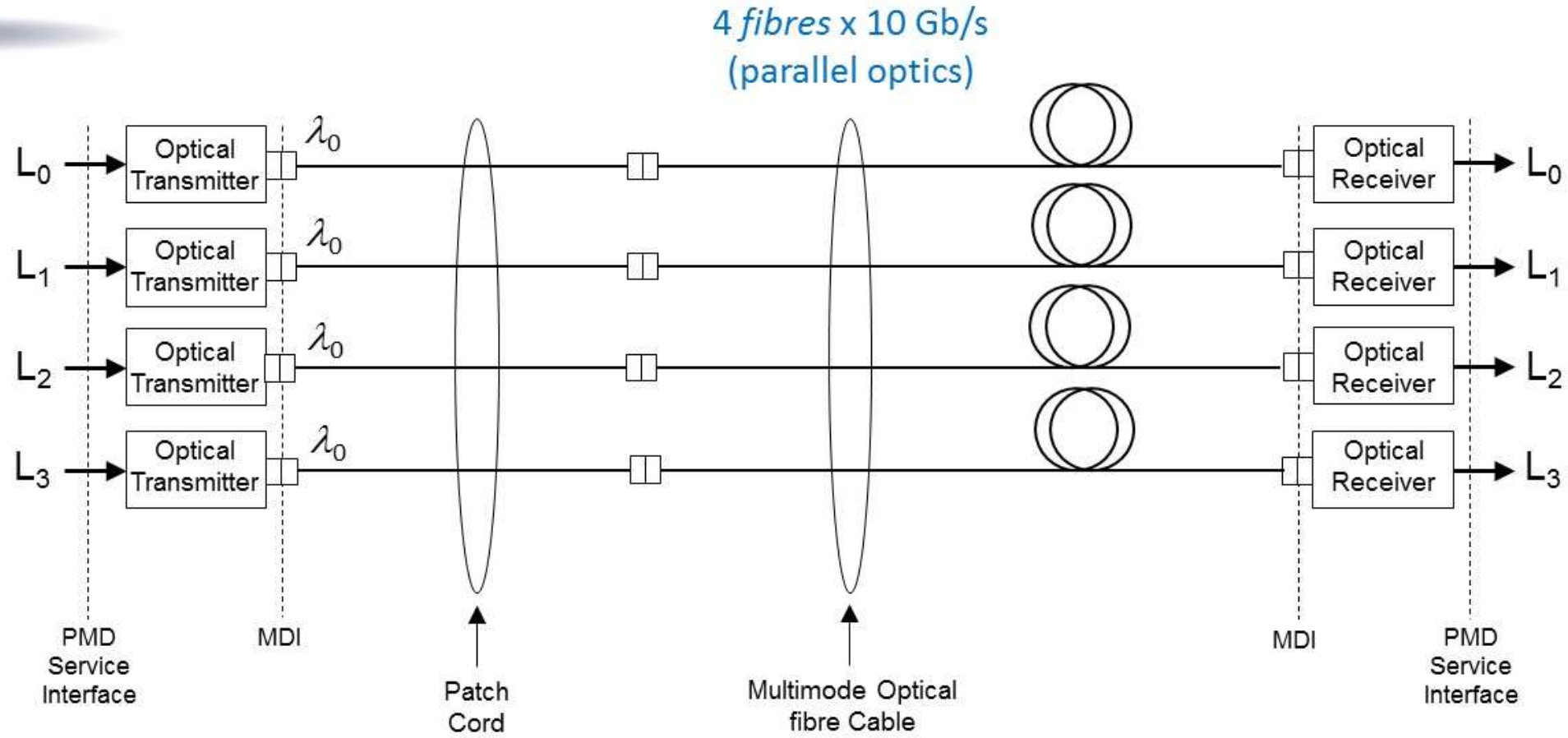
- Multiple increases in data rate
- Multiple lanes / Parallel Optics

Standard Ratified
June 2010



Block diagram for 40GbE Parallel Optics transmit/receive paths

For clarity, only one direction of transmission is shown

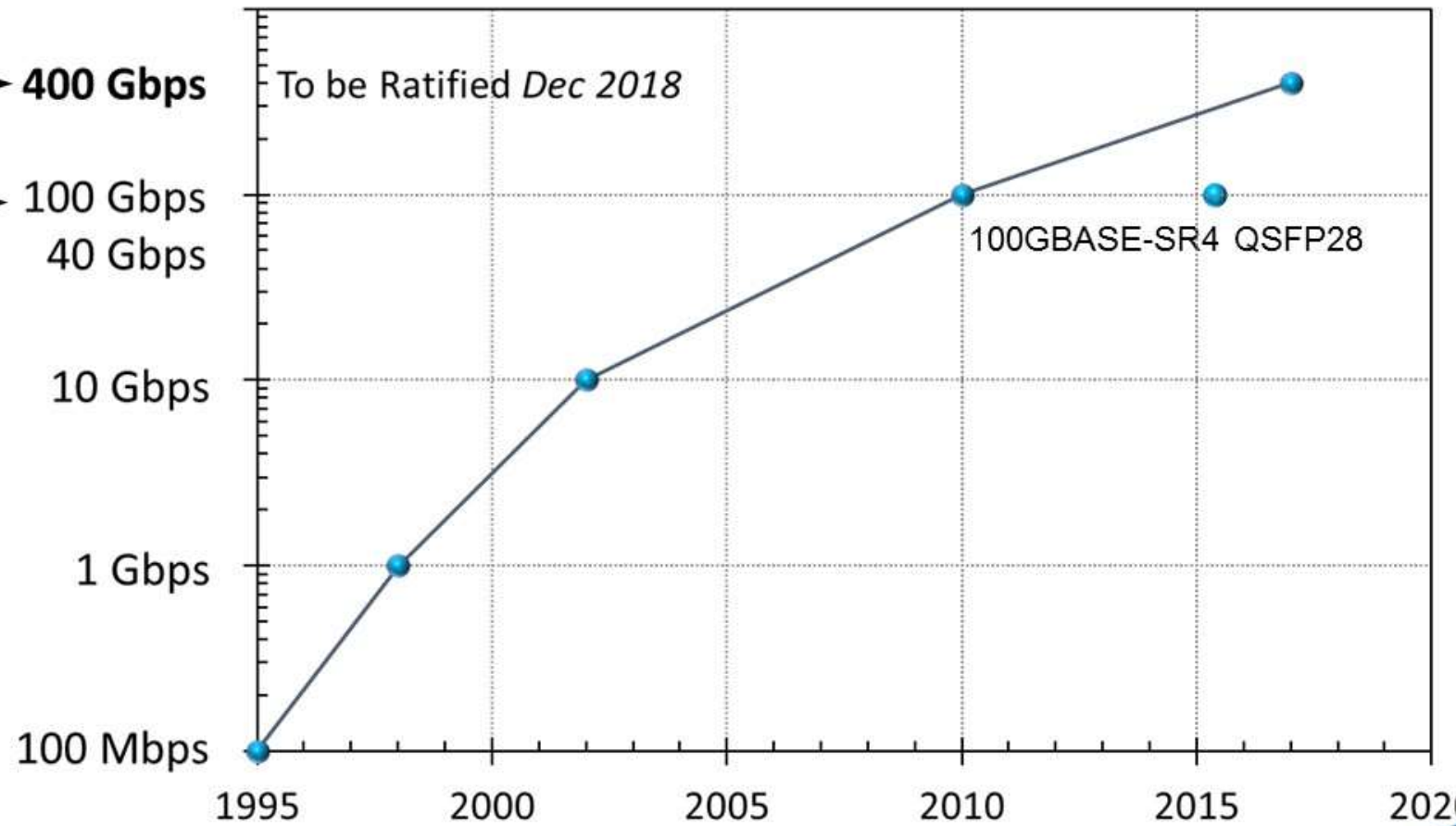


Supports Breakout Functionality

Ethernet Data Rate Increases – 25 Gb/s Lanes

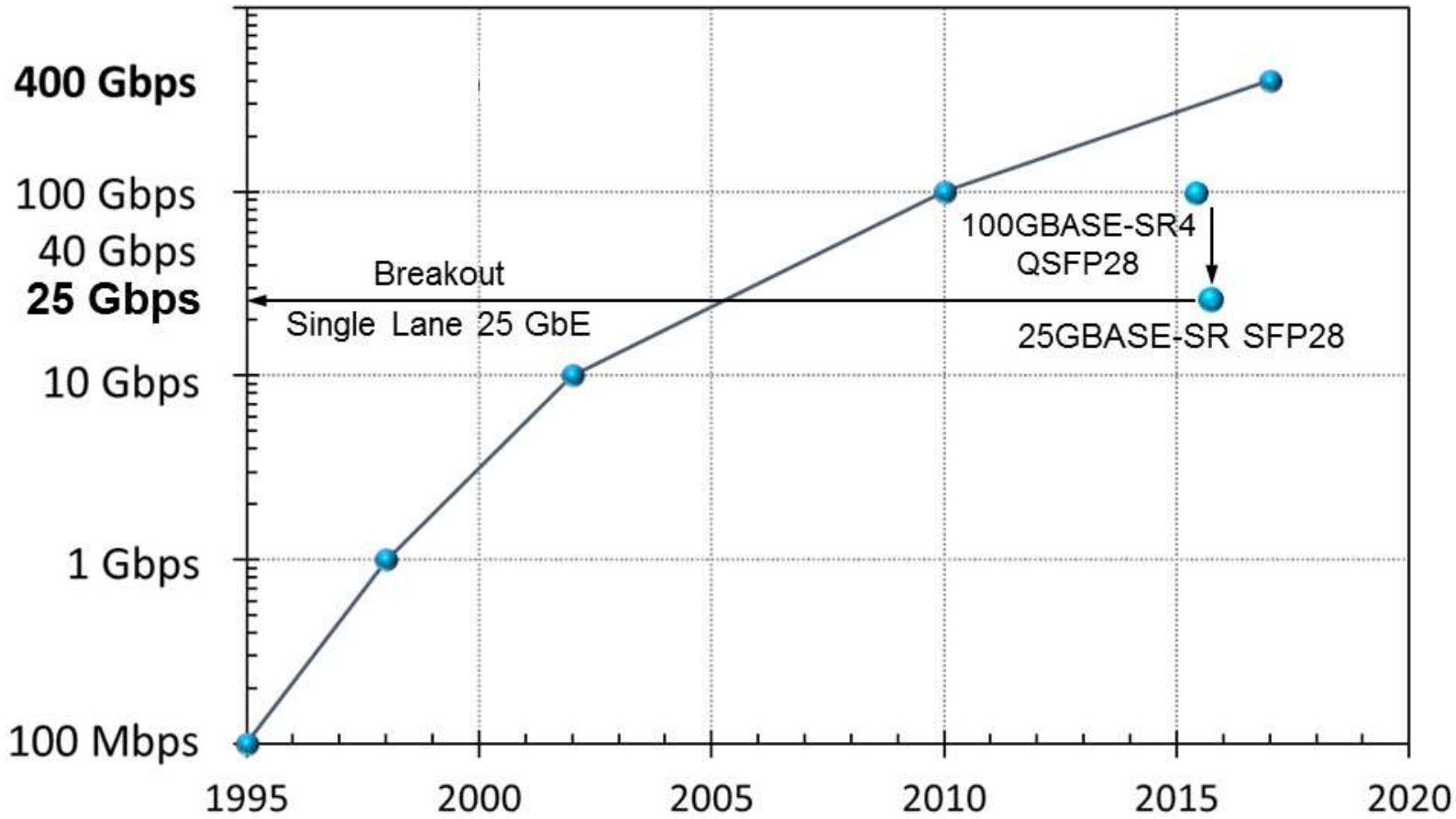
2 **Task Force P802.3bs**
- 400 GbE → **400 Gbps**
- 16 x 25G MMF (32f)

1 **IEEE 802.3bm** → 100 Gbps
- 100 GbE over MMF
- 25G Electrical lanes
- 4 x 25G parallel optics
  → Replaces 10 x 10G



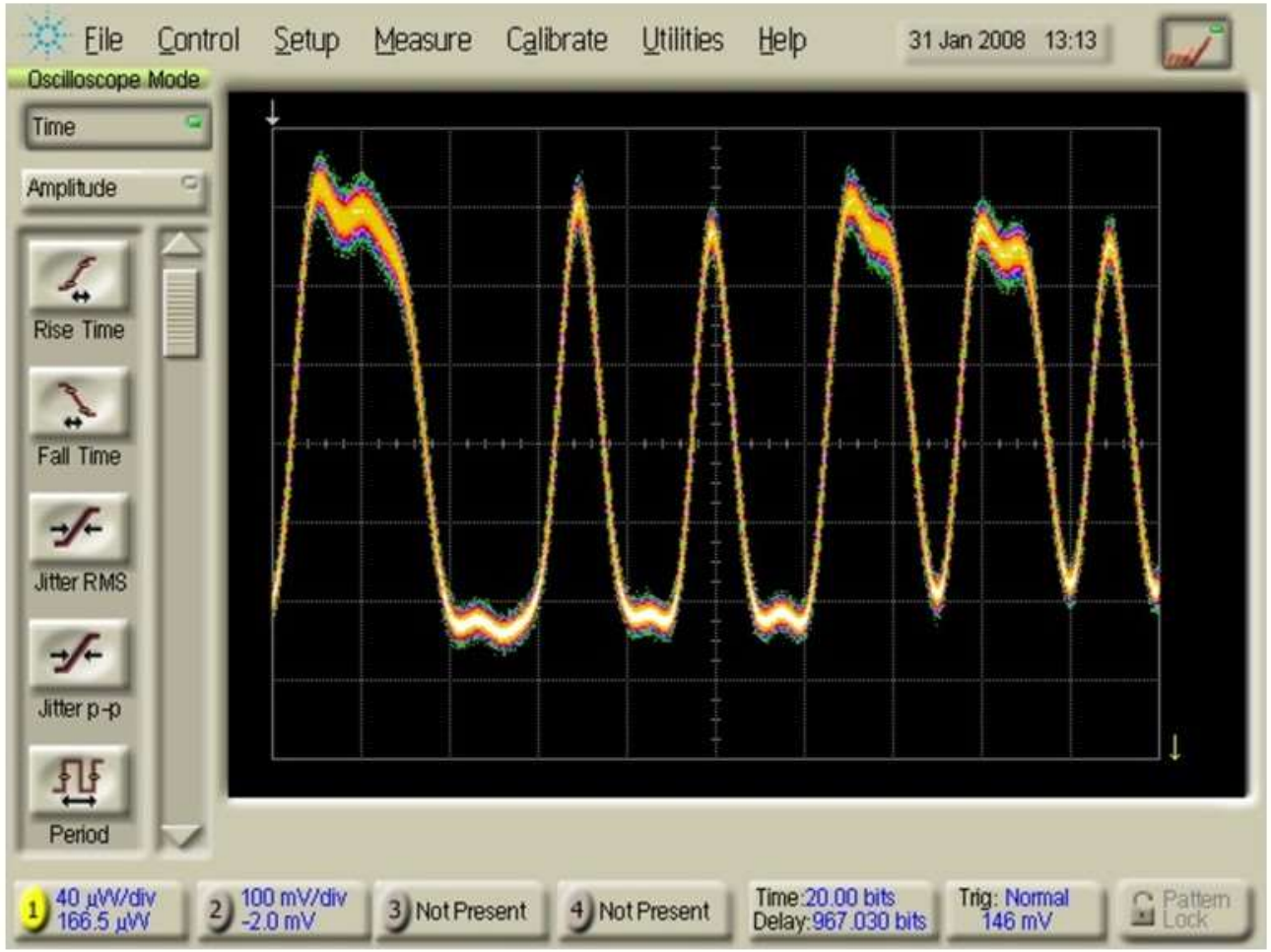
Ethernet Data Rate – 25Gb/s Servers

Task Forces 802.3by
Single lane 25GbE



Getting to Higher Speed Ethernet, 50 Gb/s +

- On-Off Keying (OOK)
  - Binary Data
  - Two Digital Levels – “0” or “1”
  - Non-Return to Zero (NRZ)
  - Bit Rate = Baud rate



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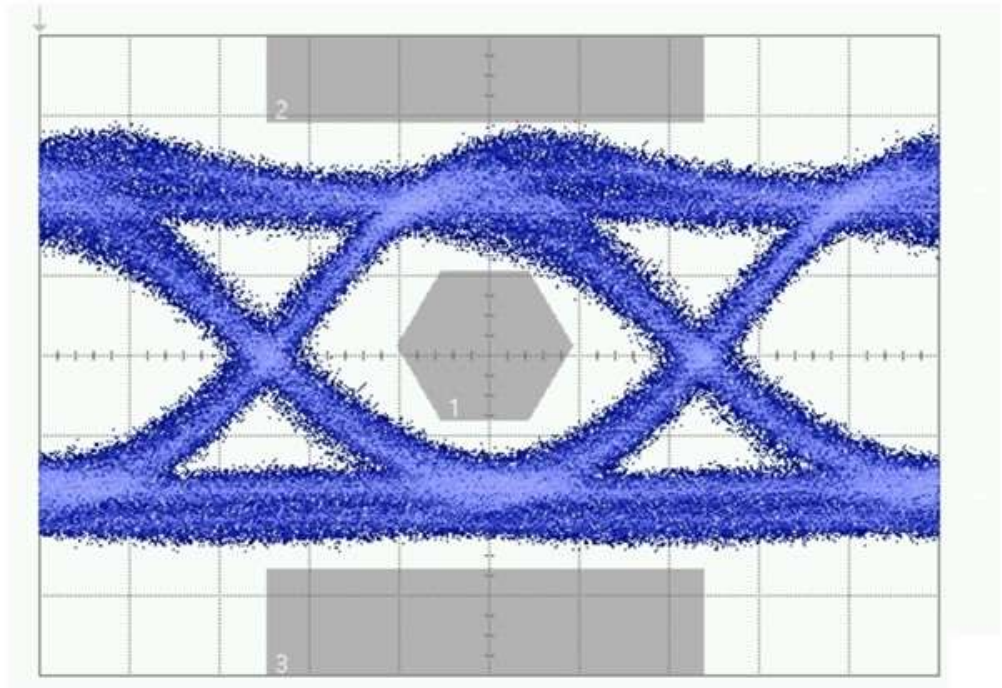
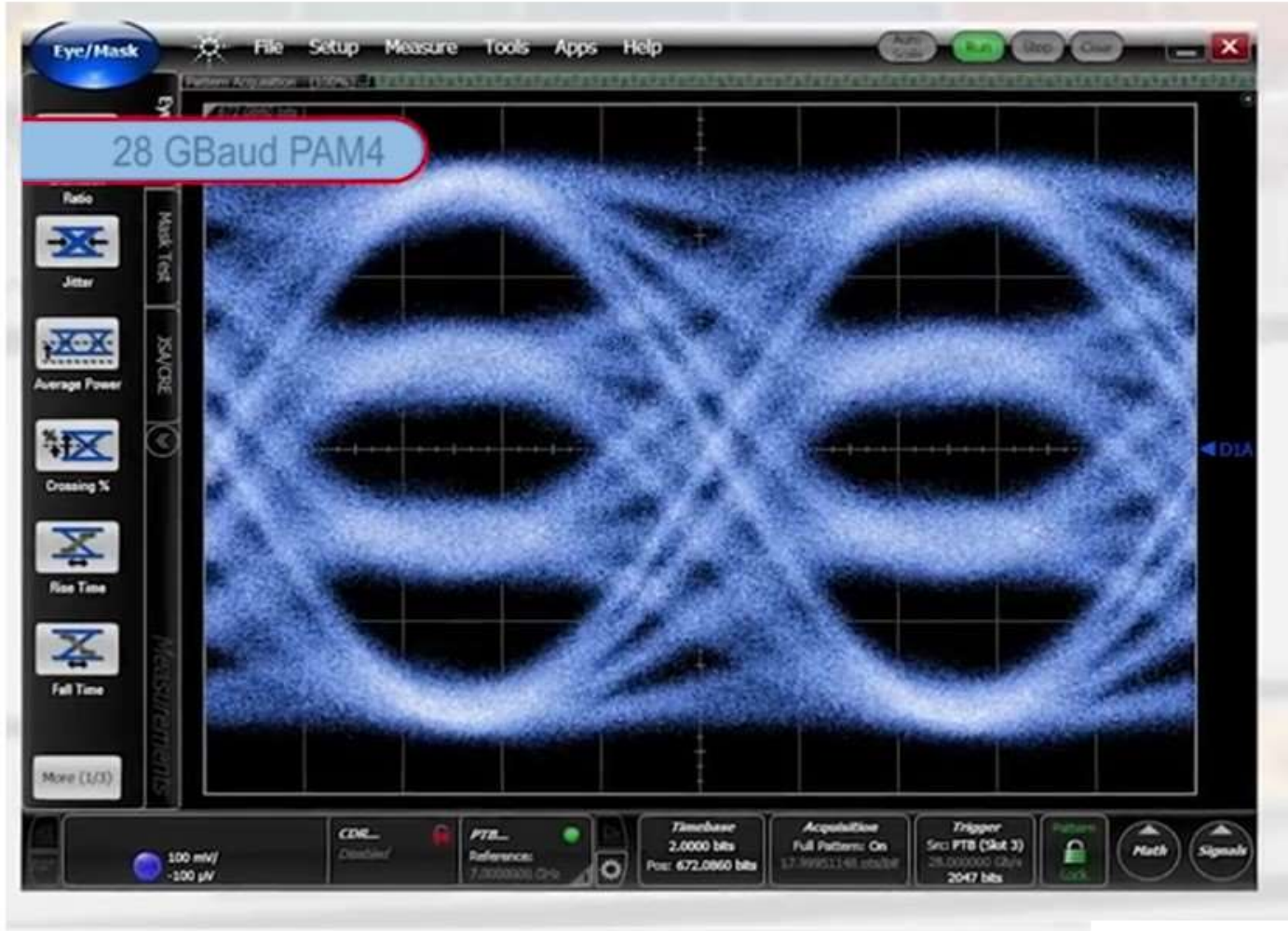
Getting to 50G Duplex Ethernet *(cont'd)*

- Signal quality is described by an eye diagram
  - Uses a Pseudo-Random Binary Sequence (PRBS 2^{31}-1)
  - Used to qualify transceiver performance (can calculate BER)



Getting to 50G Duplex Ethernet *(cont'd)*

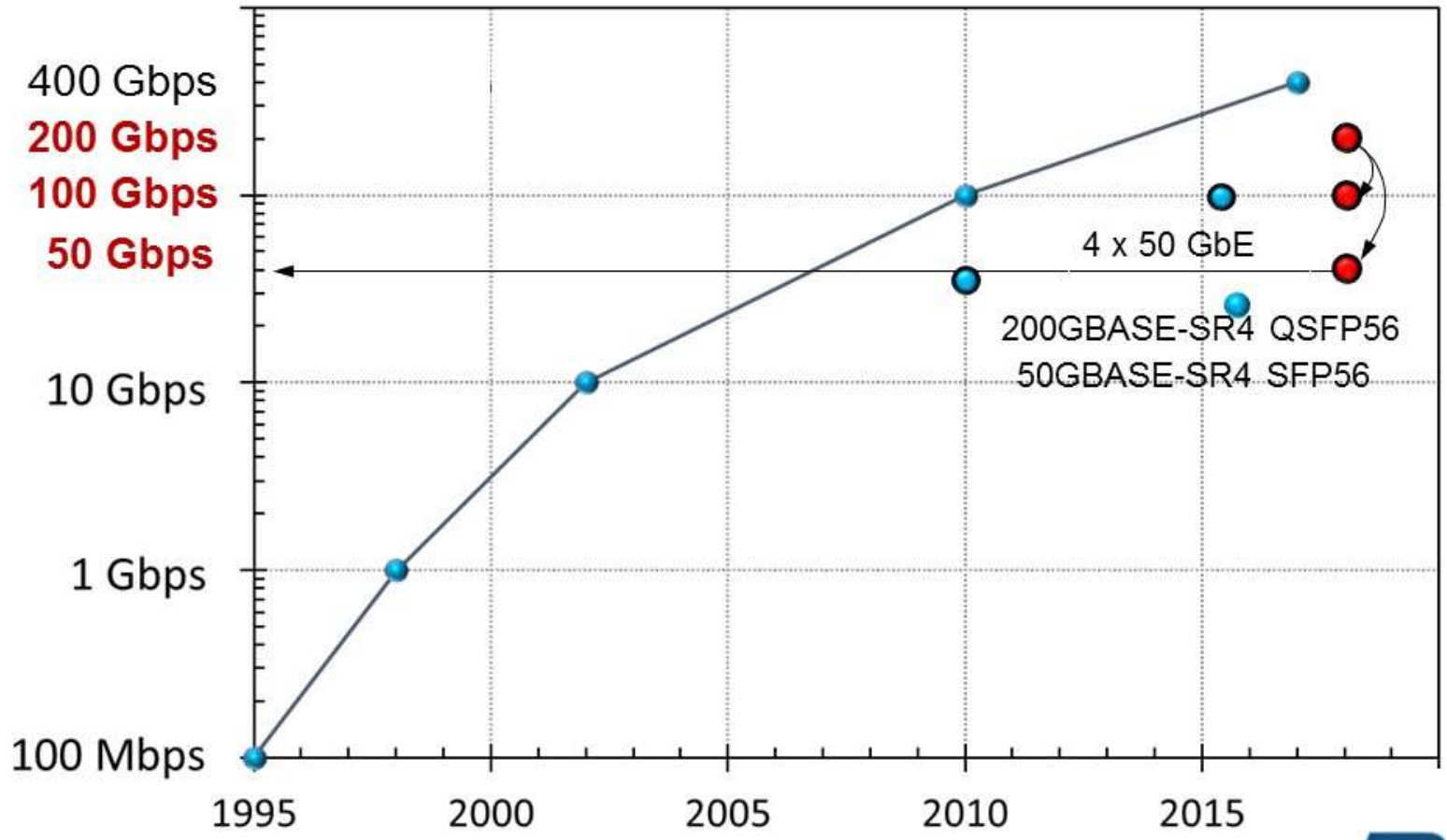
- New Signaling Technology
  - Pulse Amplitude Modulation
  - 4 Levels (PAM-4)
  - 25 Gbaud, 50 Gb/s



P802.3cd Task Force for Next Gen Ethernet Data Rates

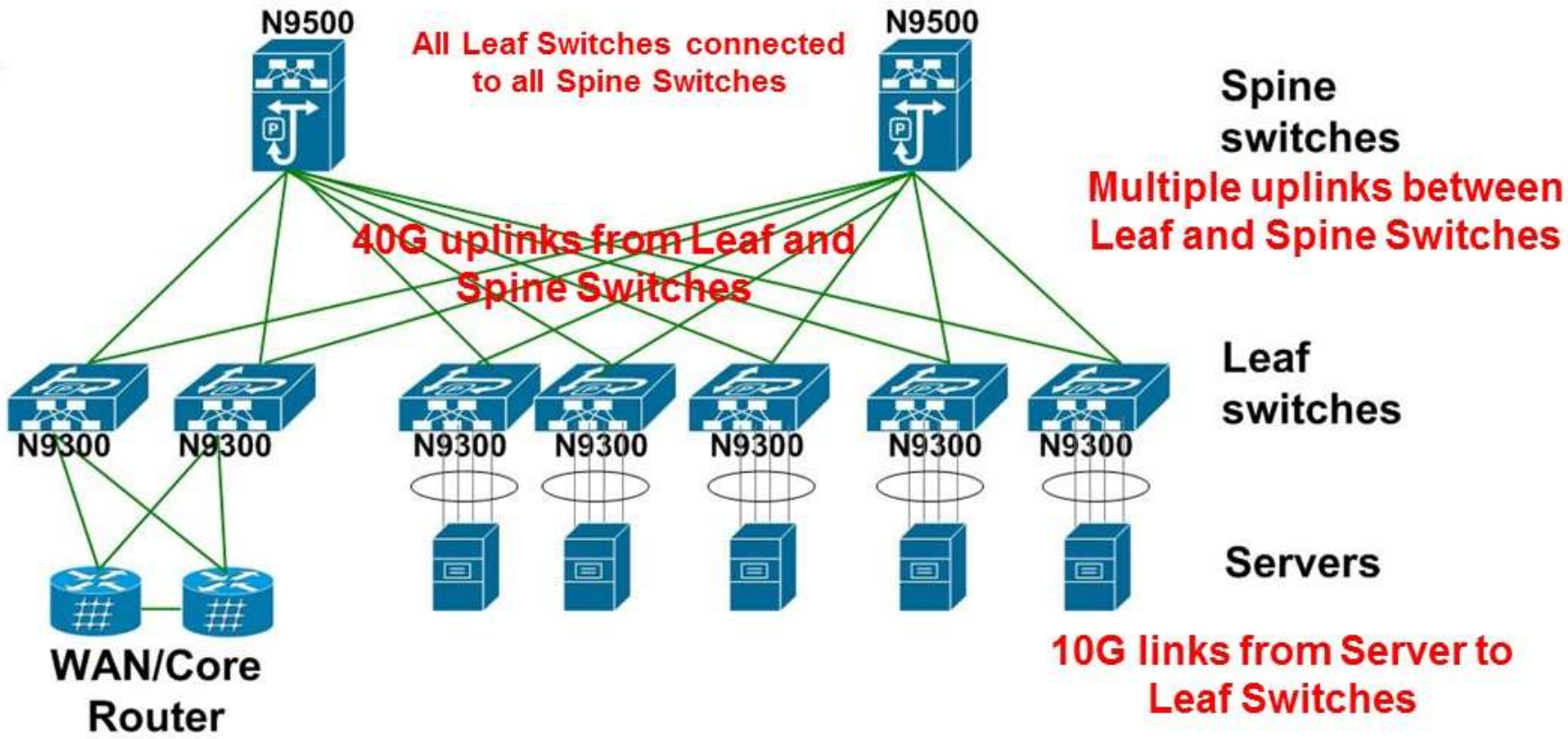
PAM-4 Modulation

New Data Rates



NEW NETWORK ARCHITECTURE - SPINE/LEAF

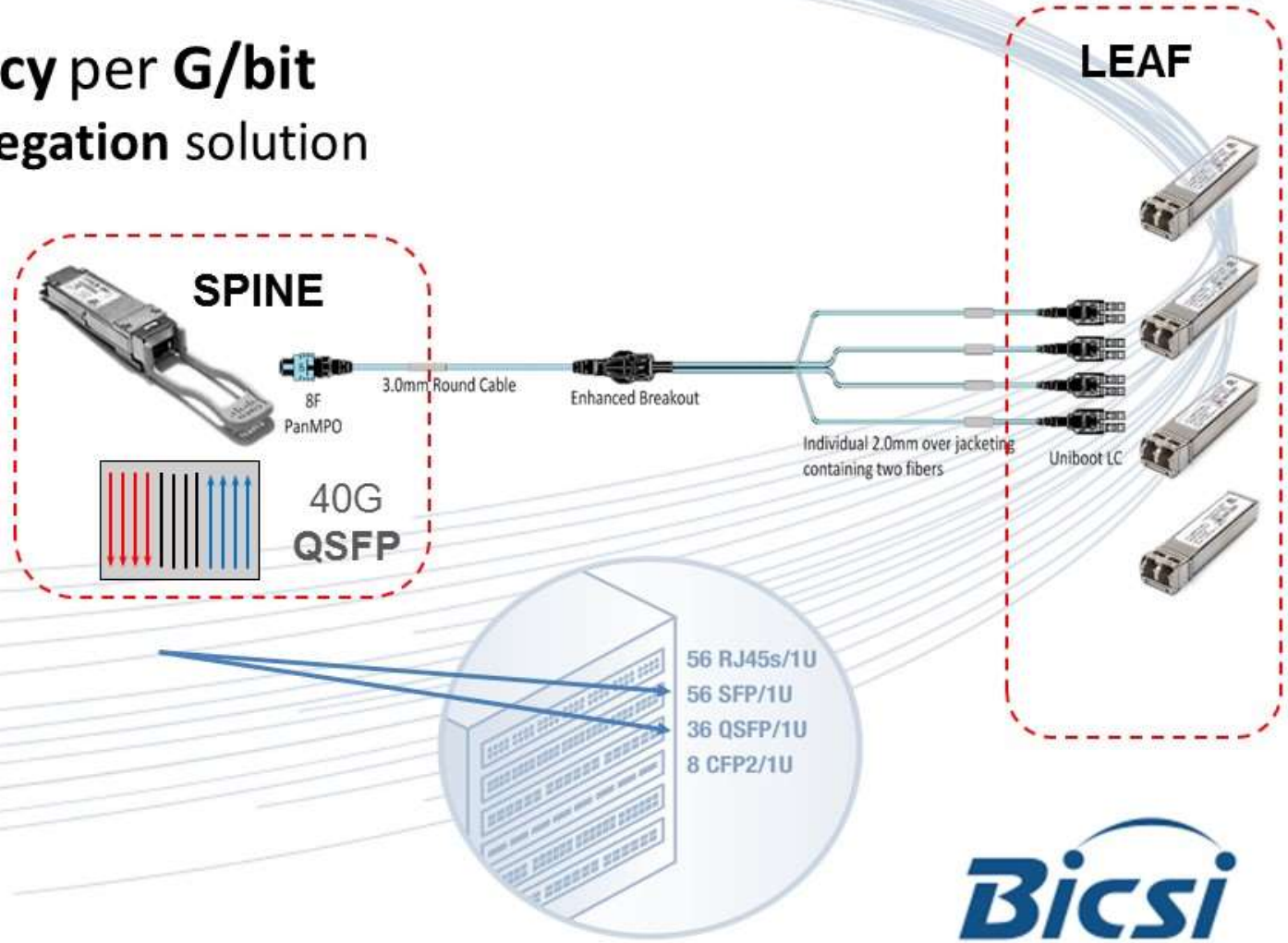
Spine/Leaf Data Center Network Architecture



Proliferation of Breakout

- **Cost, Power** and **Space** = **efficiency** per **G/bit**
  - Wide adoption of **breakouts/aggregation** solution
    - 40G to 4x10G
    - 100G to 4x25G
    - 200G to 4x50G (future)
    - 400G to 4x100G (future)

- Circa 30% cost saving
- >60% less power
- **>Space saving 2:1 – 3:1 typical**
  - More space for revenue generating equipment
  - Where space is a premium/limited
  - Multiple generations of switch refreshes



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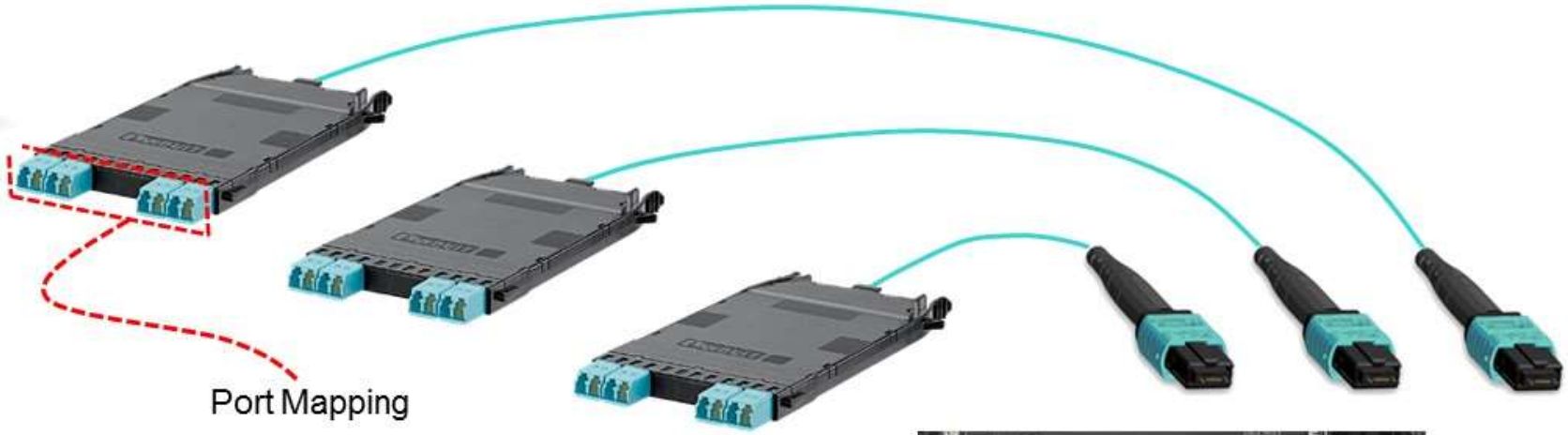
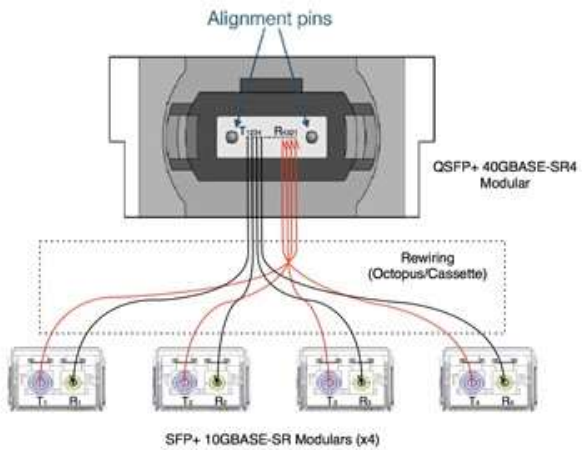
Break-out Options At Panduit





Ethernet Data Rates

Data Rate Gb/s	Lane Rate Gb/s	Number of fibres	Number of Wavelengths	Year Standardized
10 40	10	2 8	1	2002 2015
25 100	25	2 8	1	2016 2015
50 100 200	50	2 4 8	1	2018
100 (TBD) 200 400	50	2 4 or 2 (TBD) 8 or 4 (TBD)	2 2 or 4 (TBD) 2 or 4 (TBD)	~2021

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50G, 100G, & 200G PAM-4 Ethernet Standardization

50GbE Interfaces Standardized in IEEE P802.3cd

Interface	Channel Distance	Media Type	Technology
50GBASE-SR	100 m	Duplex MMF	50G PAM4 850nm
50GBASE-FR	2 km	Duplex SMF	50G PAM4 1300nm window
50GBASE-LR	10 km	Duplex SMF	50G PAM4 1300nm window

100GbE Interfaces Standardized in IEEE P802.3cd

Interface	Channel Distance	Media Type	Technology
100GBASE-SR4	100 m	4f Parallel MMF	4x50G PAM4 850nm
100GBASE-DR4	500 m	Duplex SMF	100G PAM4 1300nm window

400G PAM-4 Ethernet Standardization

200GbE Interfaces Standardized in IEEE P802.3cd/bs

Interface	Channel Distance	Media Type	Technology
200GBASE-SR4	100 m	8f Parallel MMF	4x50G PAM4 850nm
200GBASE-DR4	500 m	8f Parallel SMF	4x50G PAM4 1300nm window
200GBASE-FR4	2 km	Duplex SMF	4x50G PAM4 CWDM
200GBASE-LR4	10 km	Duplex SMF	4x50G PAM4 LAN-WDM

400GbE Interfaces Standardized in IEEE P802.3bs

Interface	Channel Distance	Media Type	Technology
400GBASE-SR16	100 m	32f Parallel MMF	16x25G NRZ 850nm Parallel
400GBASE-DR4	500 m	8f Parallel SMF	4x 100G PAM4 1300nm window
400GBASE-FR8	2 km	Duplex SMF	8x 50G PAM4 LAN-WDM
400GBASE-LR8	10 km	Duplex SMF	8x 50G PAM4 LAN-WDM

➡ **IEEE 802.3 CFI for 400GBASE-SR4.2 (or 400GBASE-SR2.4)**

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Ethernet Module Form Factors

- Two MMF Transceiver Form Factors – Duplex and Quad fibre pairs:
- 50G duplex is replacing 40G parallel (electronics no longer made)

Per lane rate Gb/s	Single lane rate Form factor	IEEE Standard	Quad lane rate Gb/s	Quad lane rate Form Factor	IEEE Standard
1	SFP	1000BASE-SR	1	N/A	N/A
10	SFP+	10GBASE-SR	40	QSFP+	40GBASE-SR4
25	SFP28	25GBASE-SR	100	QSFP28	100GBASE-SR4
50	SFP56	50GBASE-SR	200	QSFP56	200GBASE-SR4

SFP – Small Form factor Pluggable
QSFP – Quad SFP

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Future Higher Speed Ethernet

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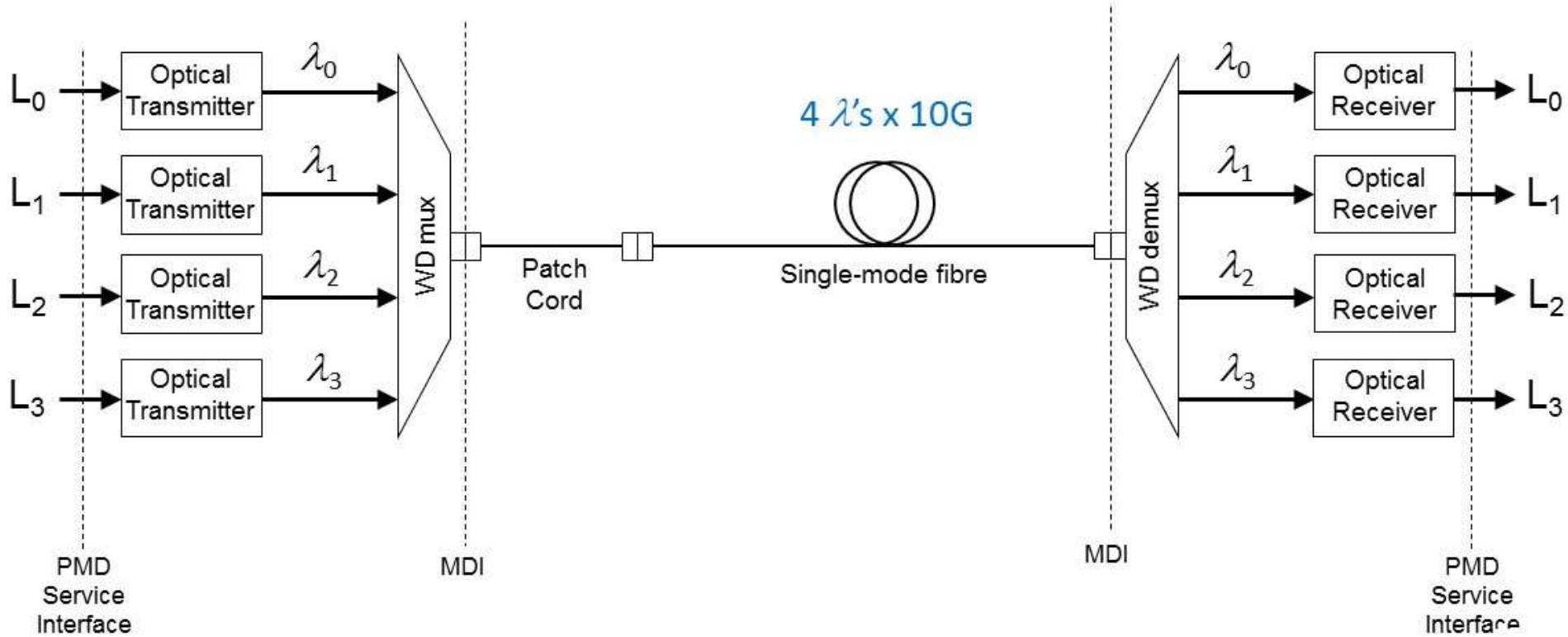
Block diagram for SWDM (shortwave wavelength division multiplexing) transmit/receive paths

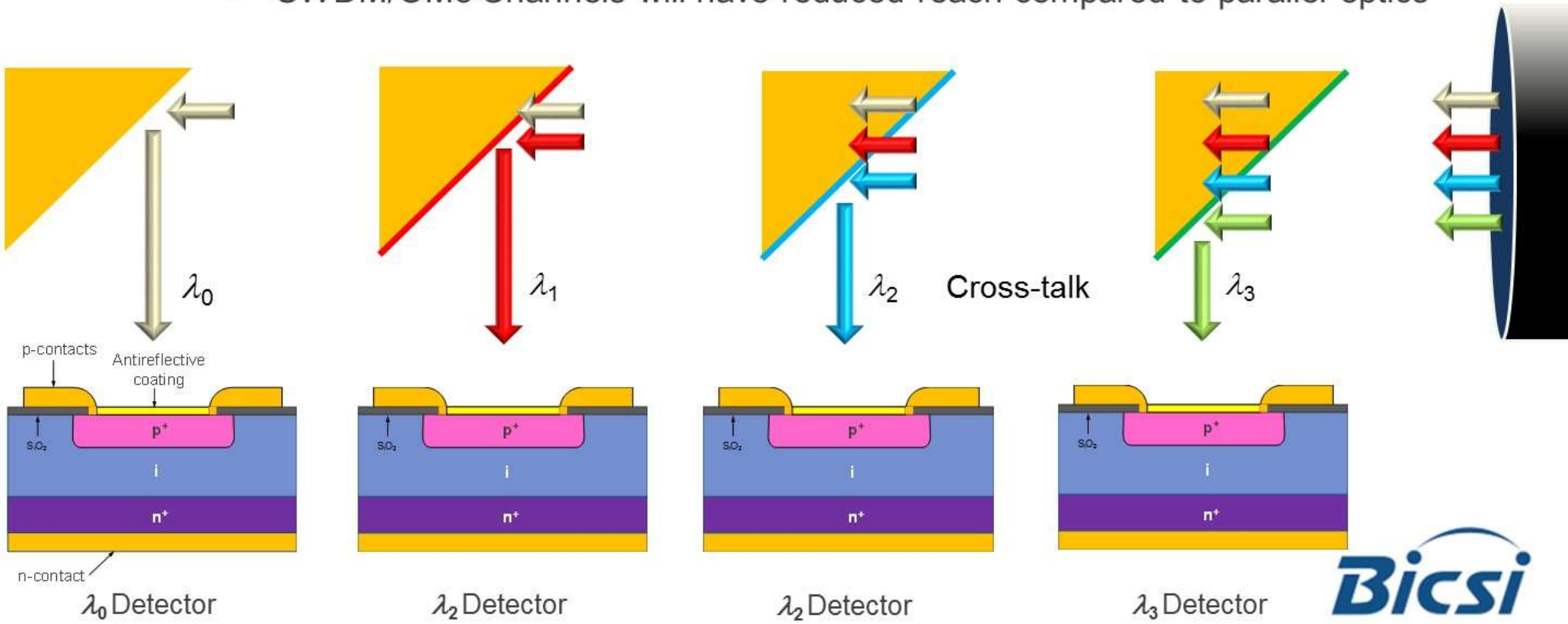
For clarity, only one direction of transmission is shown



WD = Wavelength Division
MDI – Media Dependent Interface
PMD = Physical Media Dependent

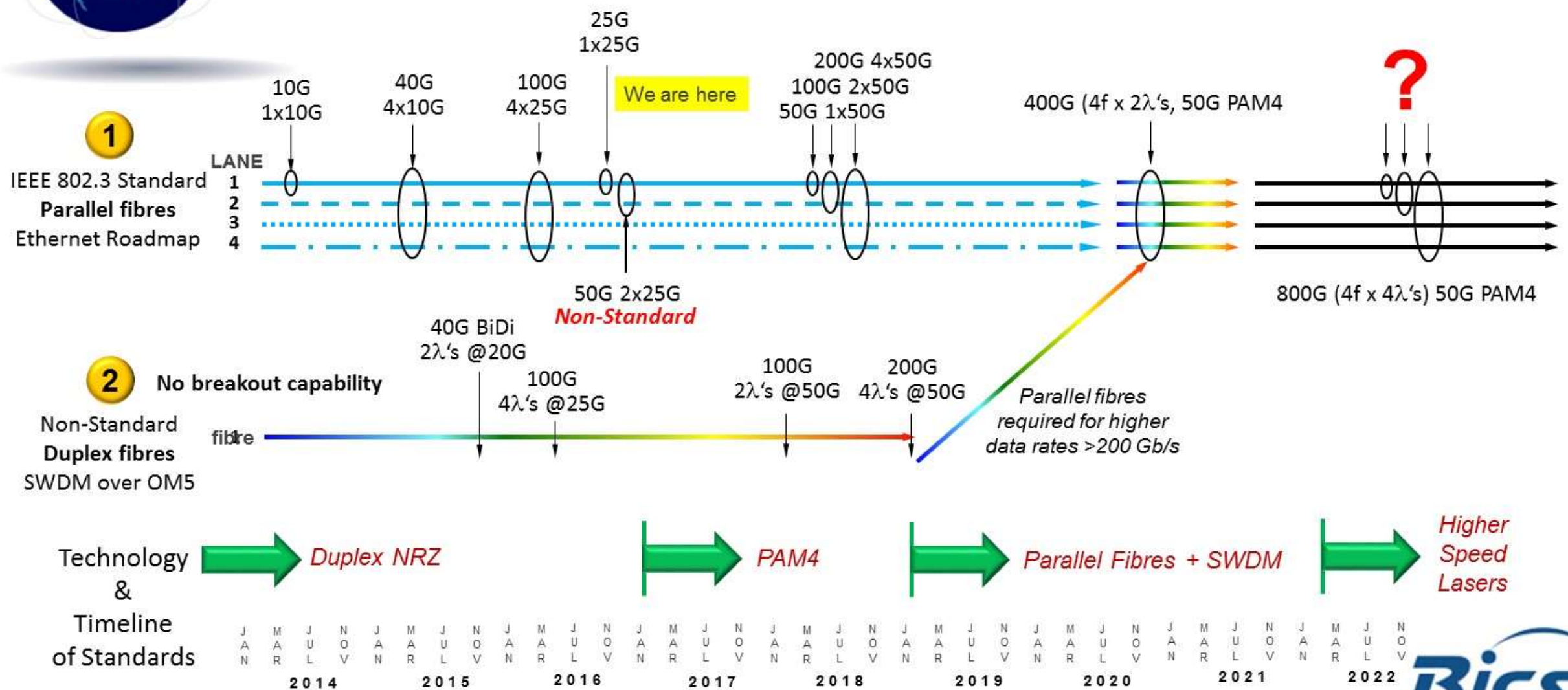
SWDM Transmission

- SWDM requires a filter for each λ, each filter adds an insertion loss 1.5 dB dB
- End-to-end (TX & RX) has a reduction in signal power 3dB
- Has a 3 dB reduction in SNR compared to parallel optics
- SWDM/OM5 Channels will have reduced reach compared to parallel optics



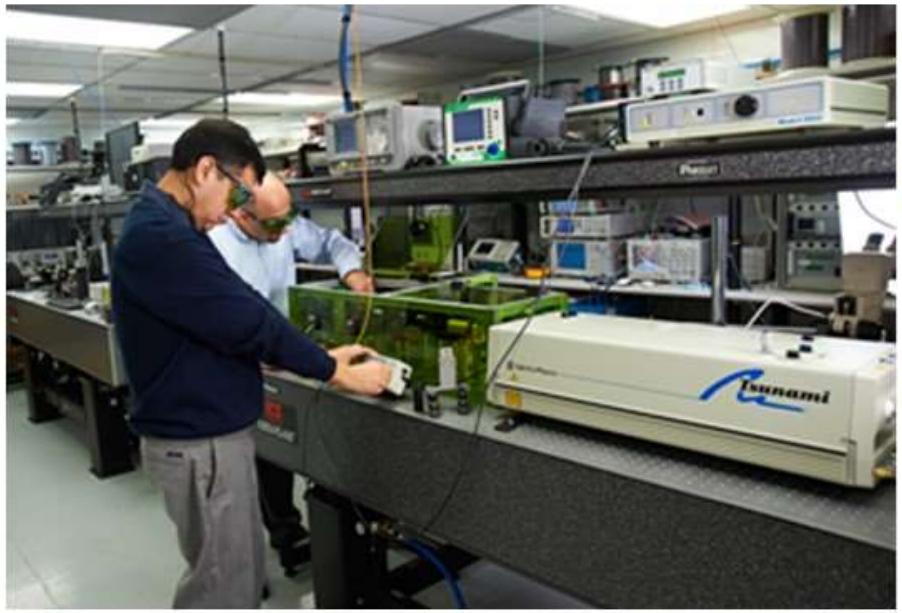
Two migration paths to higher data rates

1) Standards compliant & 2) Non-standard



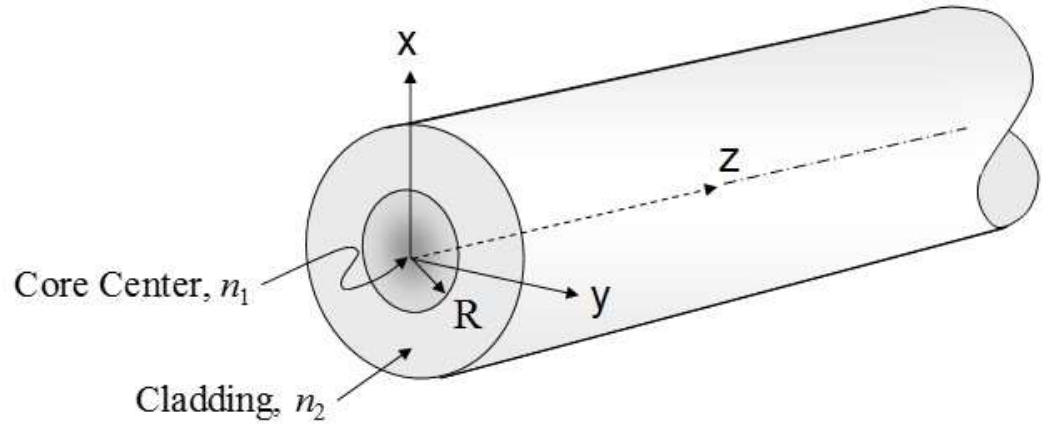
Multimode fibre Performance
Panduit Signature Core V OM5

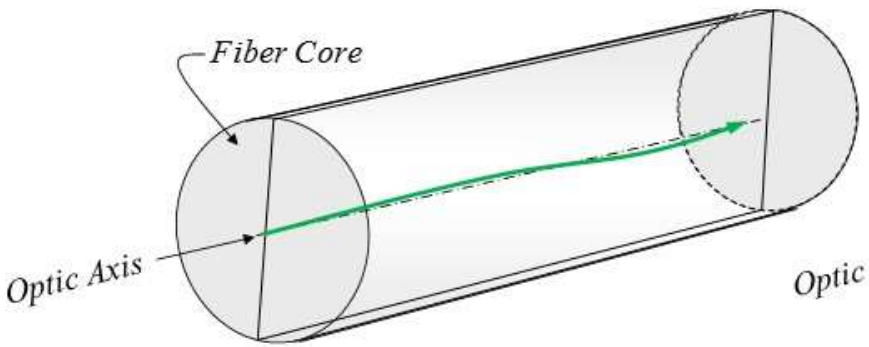
Panduit's Optical Research Laboratory

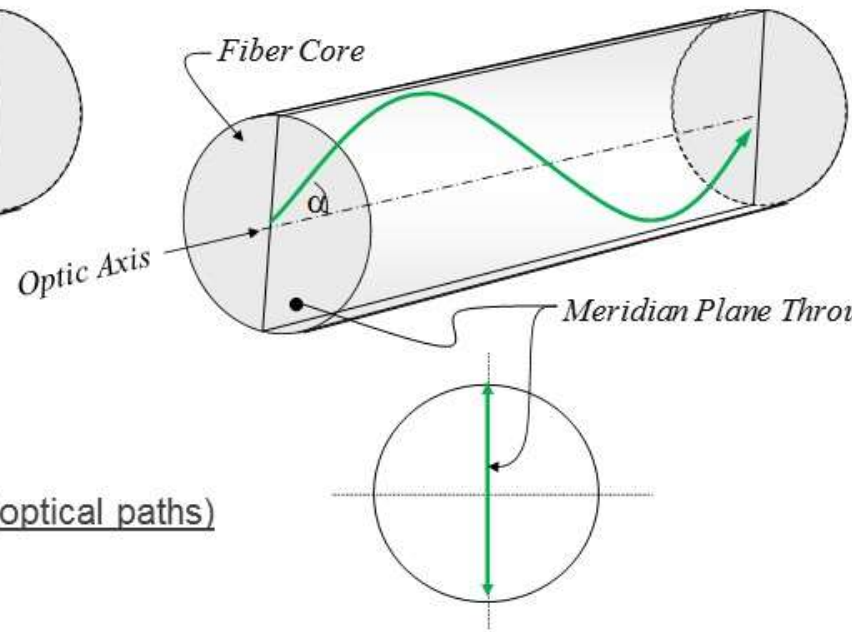


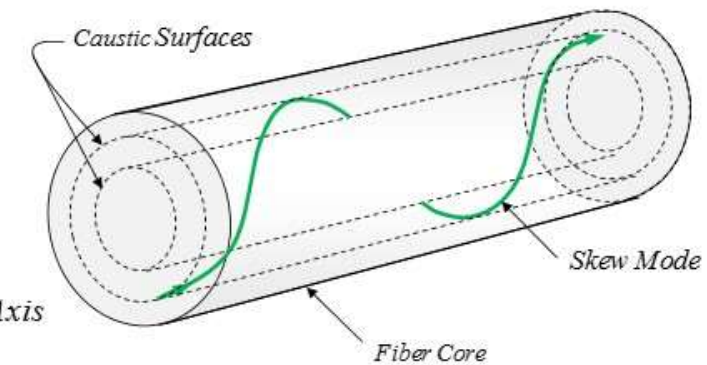
Fibre Modes in Multimode Fibre

A pulse of light splits and travels along different optical paths called "modes"



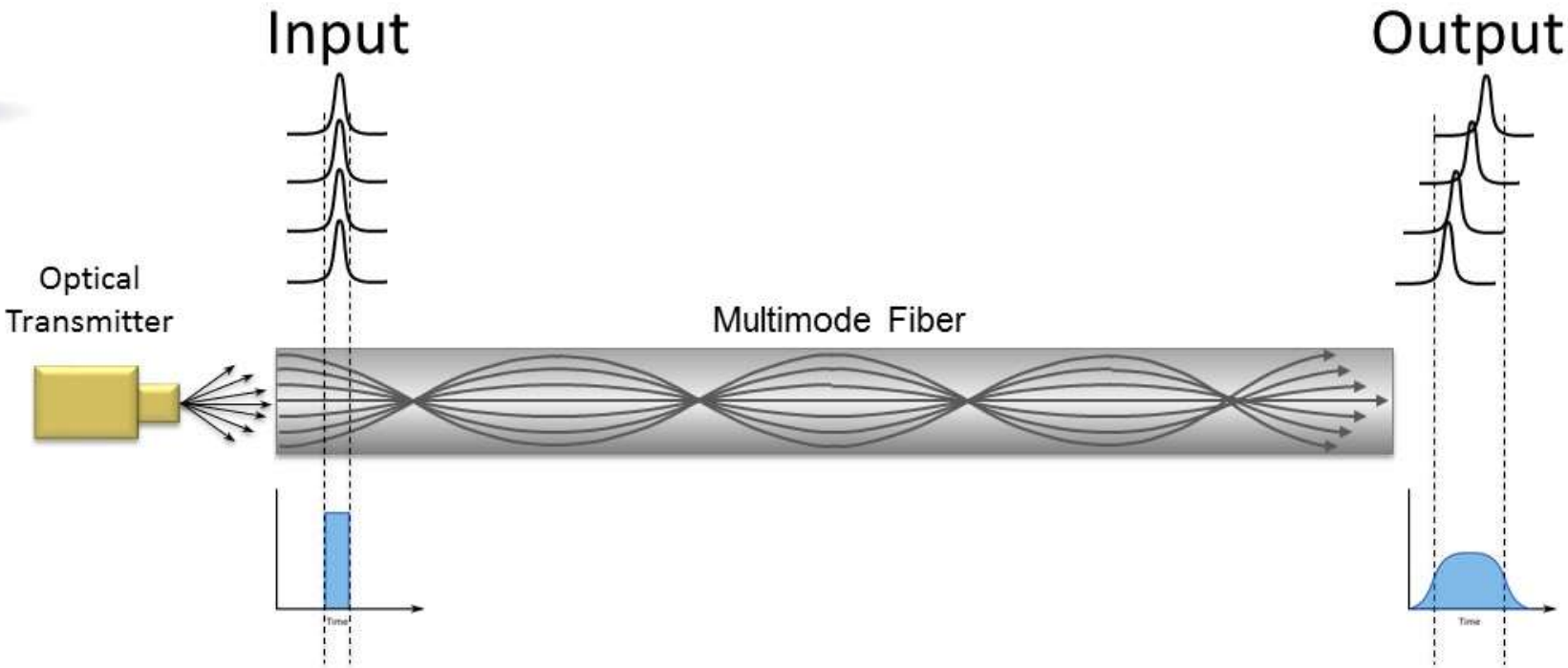






Three possible modes (optical paths)

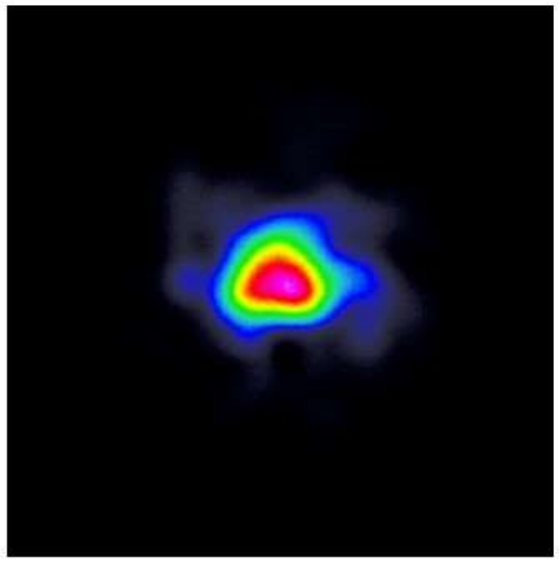
Mode Distortion at Work



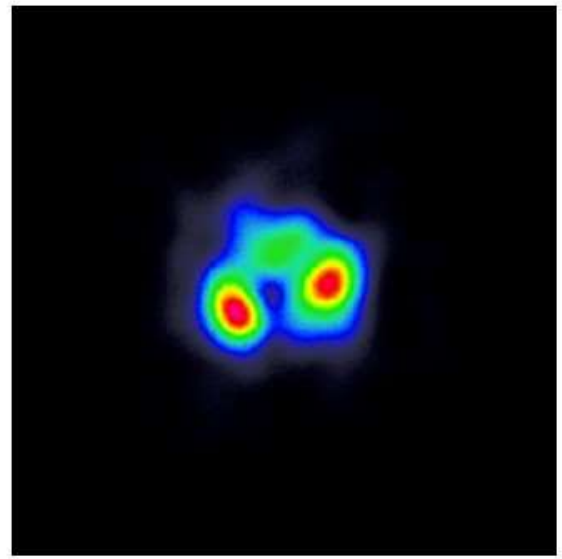
- Laser optimized multimode fiber corrects for this distortion
  - Speeds up the modes traveling the longer paths
  - Keeps the individual modes (pulses) aligned
- Predominate multimode fiber sold today

Images of visible modes in MMF

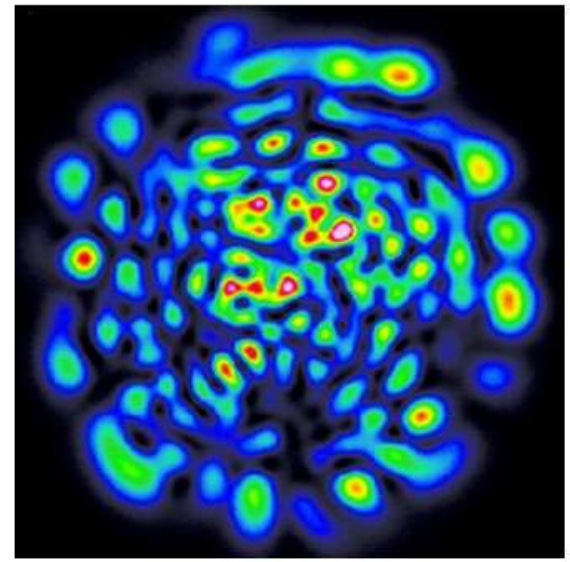
Near-field Images - Ti: Al_2O_3 Laser SM launch into 3m fibre (850μm)



2 μm Offset

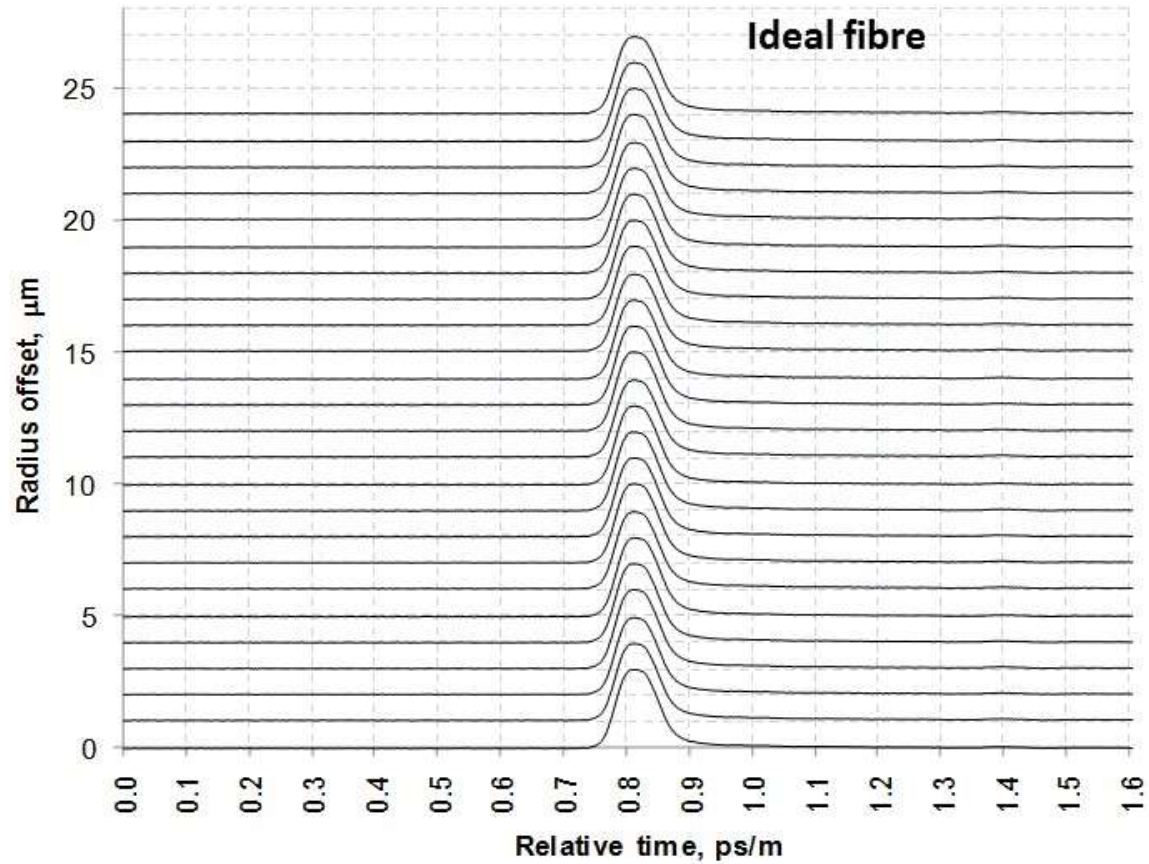


4 μm Offset



24 μm Offset

Laser Optimized Multimode fibres (OM3, OM4, and OM5 (Wideband), are designed so that all radial mode groups have the same delays –



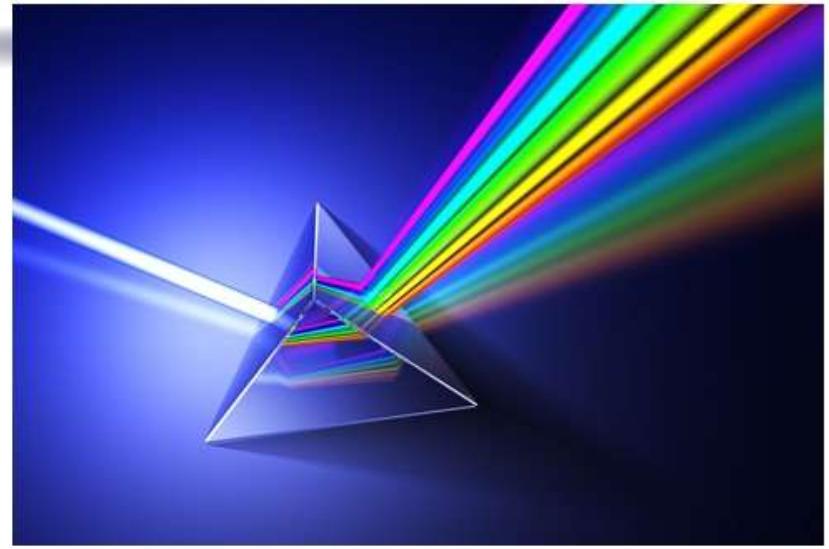
Effective **M**odal **B**andwidth (*EMB*)

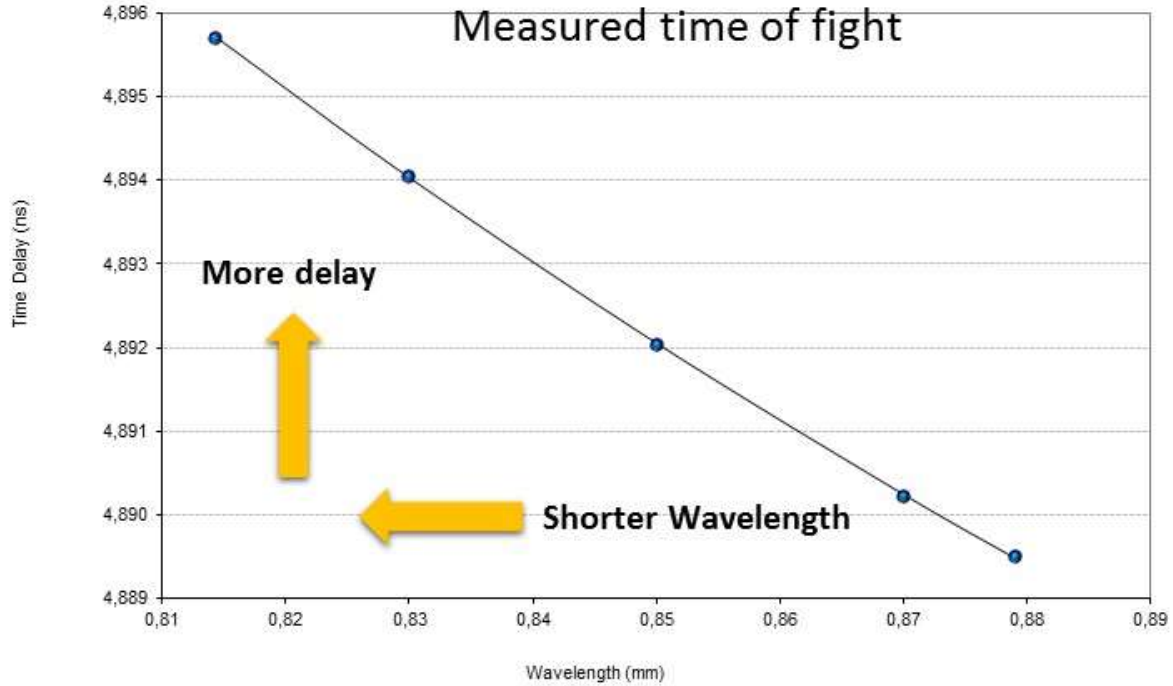
Is calculated from

the DMD waveforms

Chromatic Dispersion

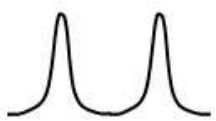
Different wavelengths propagate at different velocities



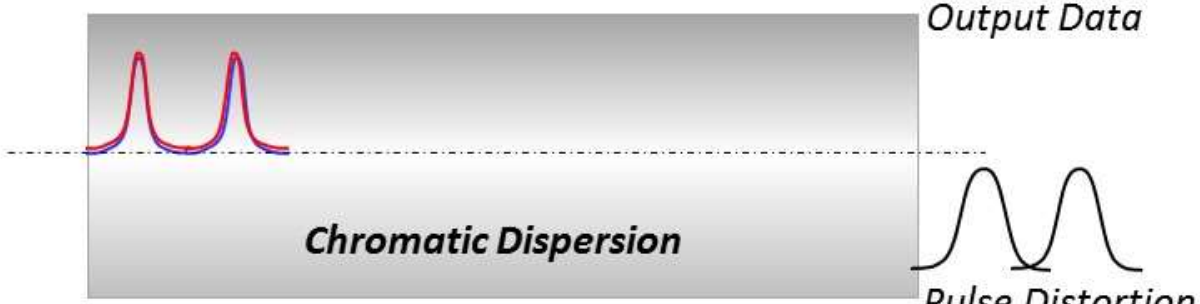


$$n^2(\lambda) = 1 + \sum_i \frac{B_i \lambda^2}{\lambda^2 - C_i}$$

$$v = \frac{c}{n}$$



Input Data



C = speed of light in vacuum

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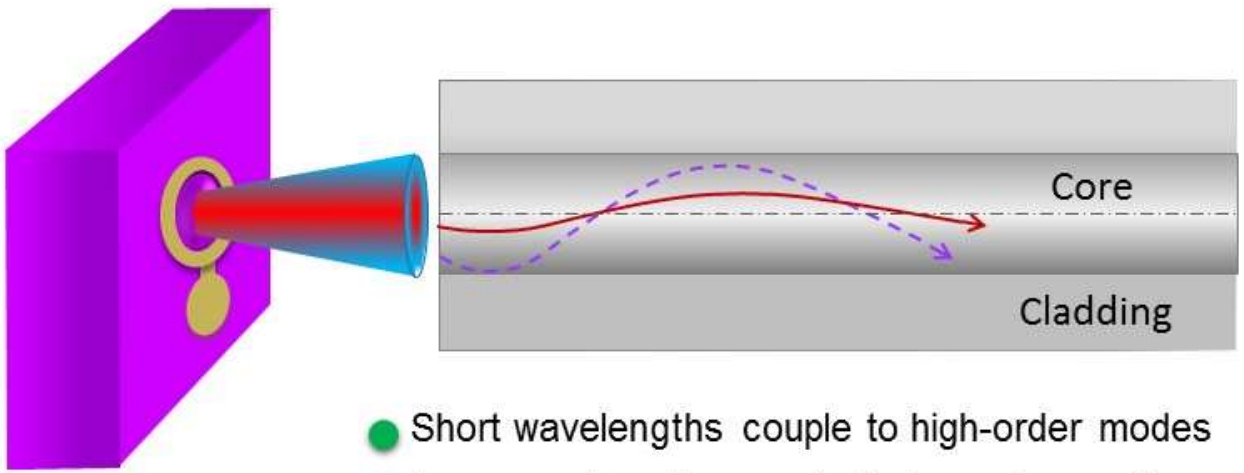
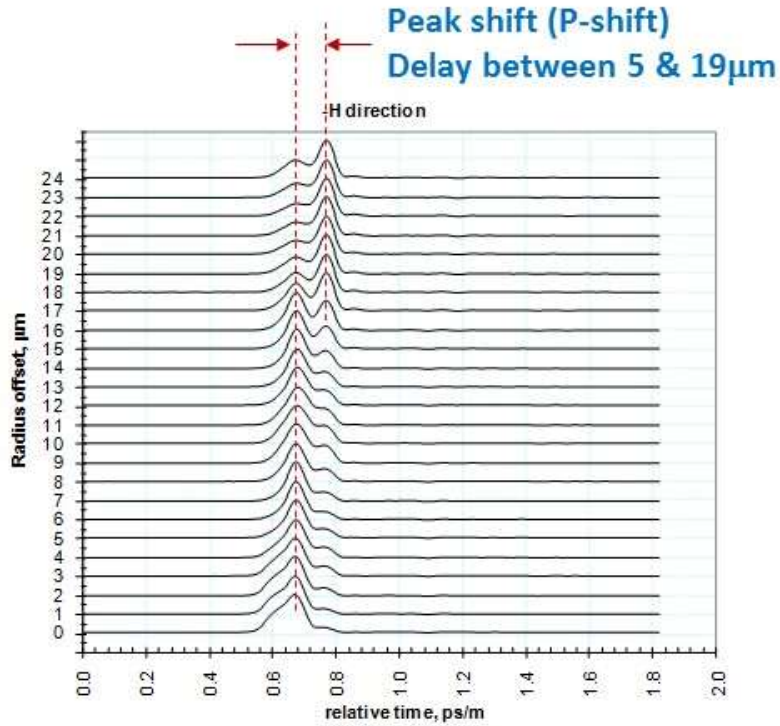
Panduit's fibre Research Discovery
VCSEL spatial-spectral coupling into MMF

Radial Spectral Dependency



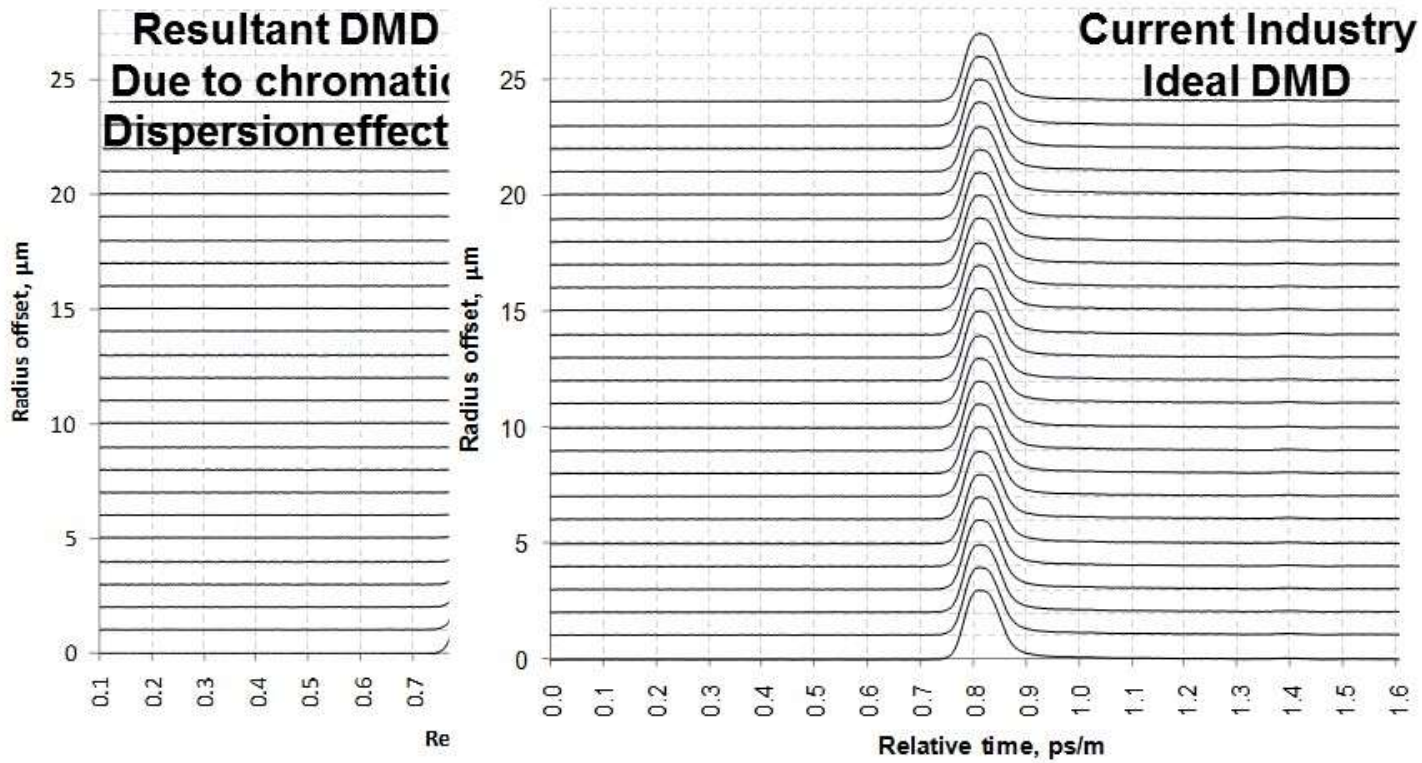
- Short wavelengths couple to high-order modes
- Long wavelengths couple to low-order modes



Resultant DMD due to Modal Chromatic Dispersion

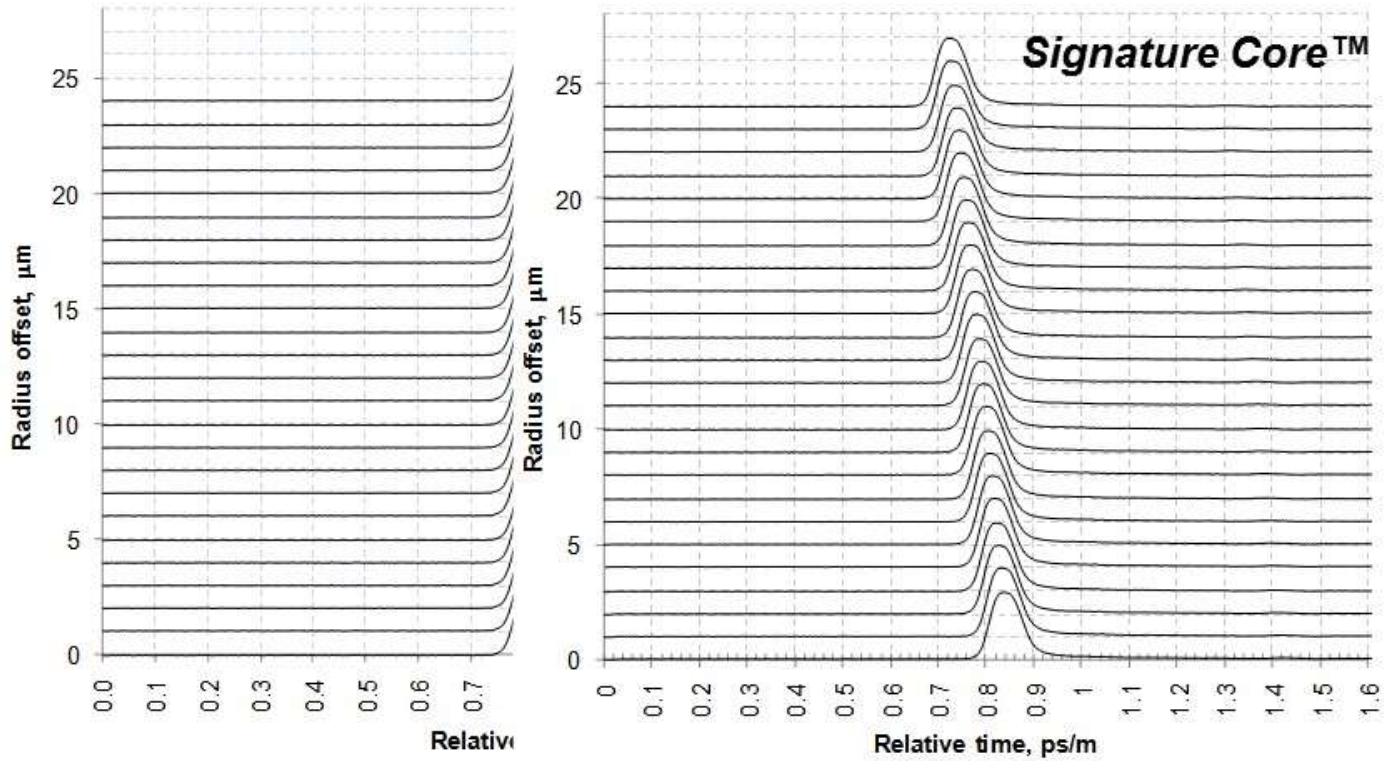
Traditional DMD Core Index Profile Design

Requires All Radial Peaks Aligned



Signature Core™ DMD Core Index Profile

Compensates for Modal Chromatic Dispersion



Laser Optimized Multimode fiber Types

Fiber is Sorted and classified based on quality of Modal Dispersion

Fibre Type	EMB at 850 nm (MHz·km)	EMB at 953 nm (MHz·km)
OM3	2000	NA
OM4	4700	NA
Signature Core	5500	TBD
WBMMF (OM5)	4700	2470

- OM3 and OM4 are designed for high bandwidth at 850 nm
- MMF is sorted as OM3 & OM4 based on Effective Modal Bandwidth (EMB)
  - EMB is calculated from DMD measurement
- WBMMF is designed for high bandwidth at longer wavelengths (953 nm)
- Signature Core is the highest performance MMF available for single wavelength and BiDi systems
- WBMMF required for future generation SWDM 800 Gb/s with breakout to 400 Gb/s and 200 Gb/s
  - 4 wavelength transmission per fibre

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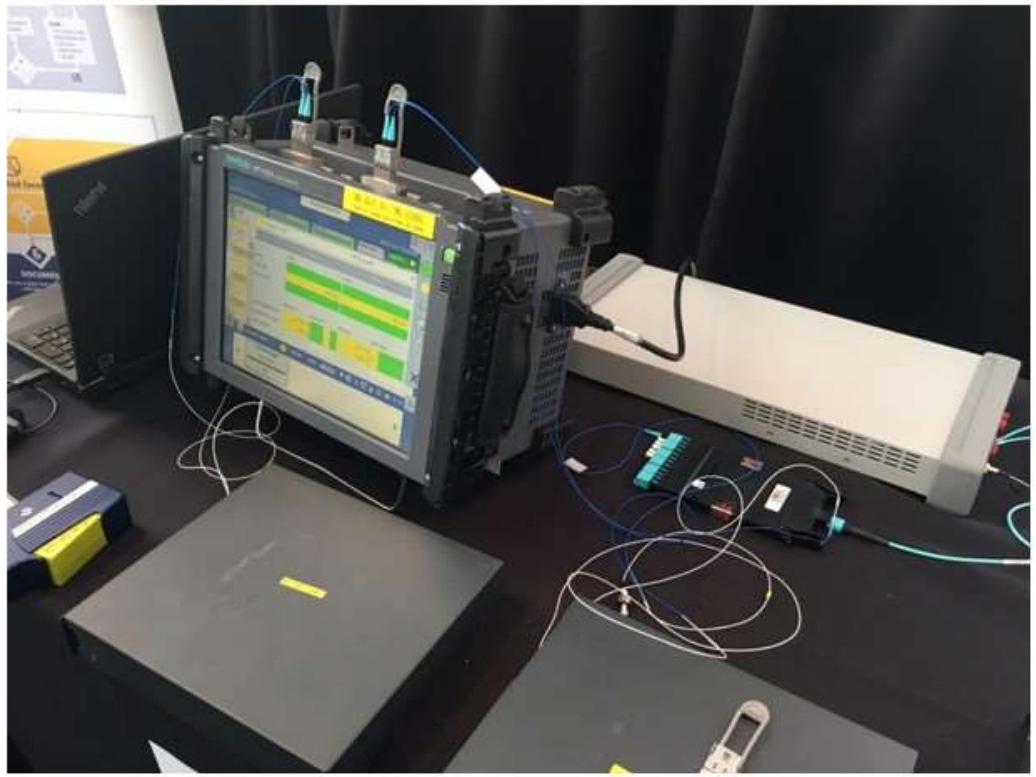
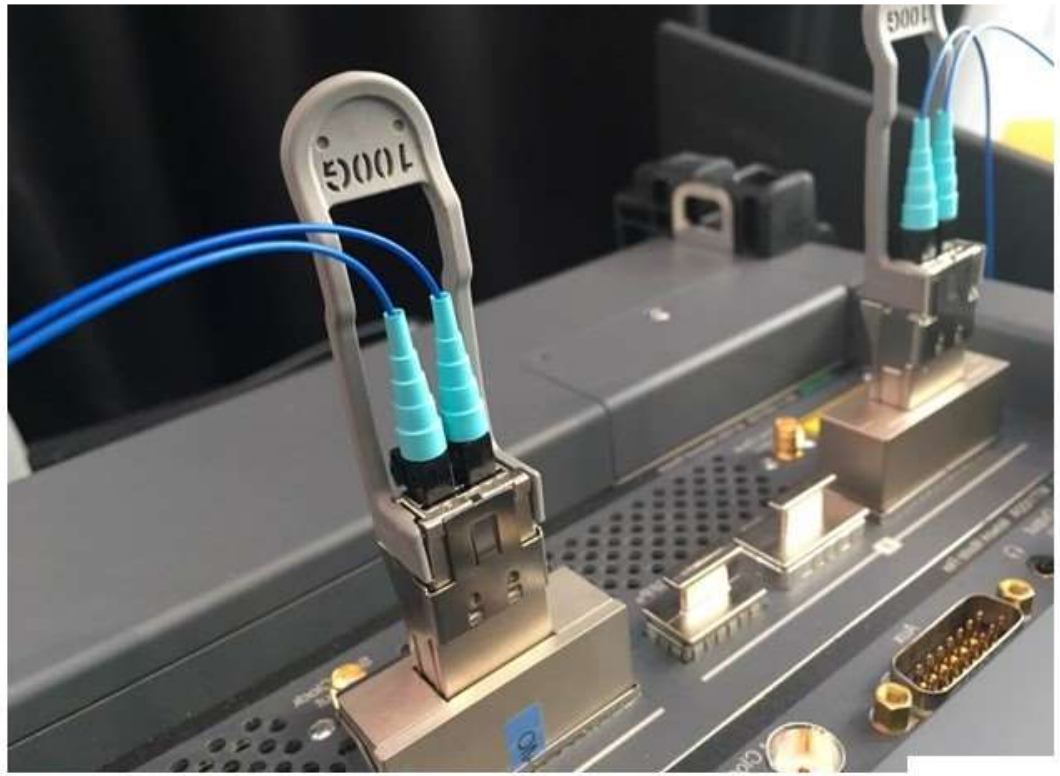
400G Light Speed Event Demo – 7th March

100G SWDM1.4 - λ4, Duplex – Beta Modules

- Signature Core™ 300 meters - ZERO bit errors!





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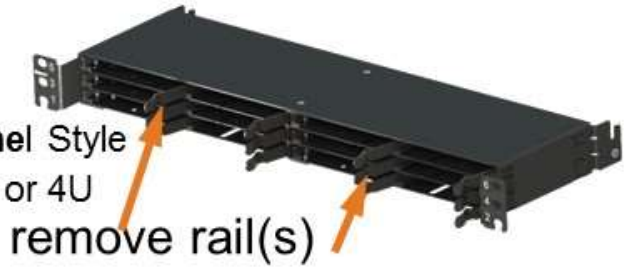
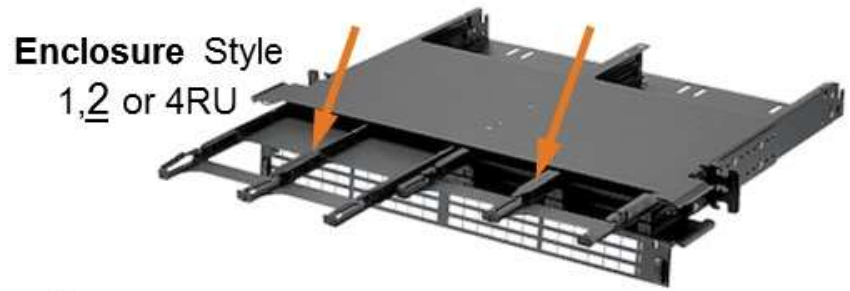
Consider ease of migration and scale

- PanMPO™ – always have the right cord
  - 8F PanMPO and 24F MPO added FY17



- Chassis to accepts multiple width cassettes
  - 4 Port Cassettes – 32 port switch map
  - 6 Port Cassettes – large install base
  - 12 Port Cassettes – **cost effective** & faster to deploy



- Field convertible – no tools required
- Mix & match cassette widths

Questions?

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