The future of optical fibre in data centers

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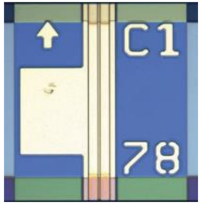
MMF will continue to provide 3 major benefits

1. Lower cost than single-mode data communications
   a) MM VCSEL transceivers are less expensive than SM DFB laser transceivers
   b) Relaxed manufacturing tolerances
   c) Lower transceiver power consumption
2. More robust connectivity
   a) Components more tolerant to dirt and dust
   b) Connectors do not require high return loss
   c) No multipath interference
   d) More forgiving to long-term connector degradation
3. Meets Data Centre & Enterprise reach & bandwidth requirements
   a) For foreseeable future (> 15 years)

VCSEL



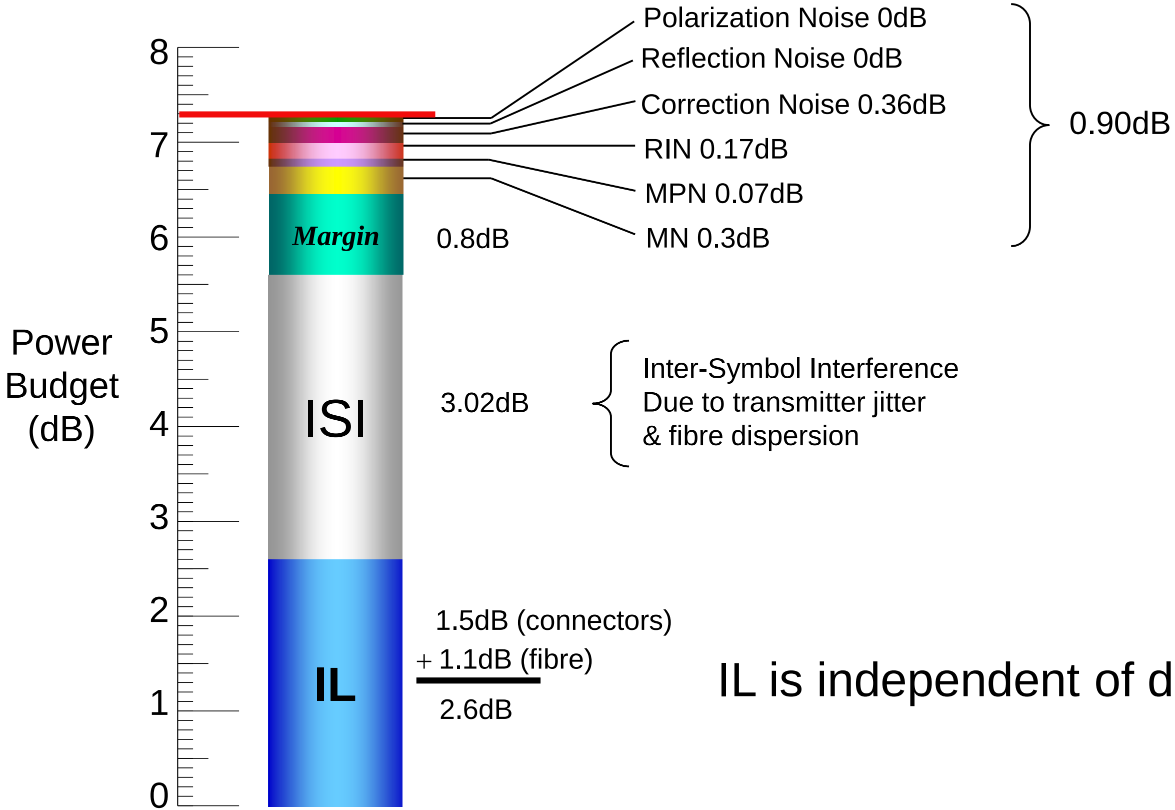
DFB

➡ Multimode fibre will be the main focus of this presentation

Technical Overview

- Differences between MMF types
  - Fundamental properties of MMF
  - Optical channel penalties
- Future applications for MMF in the DC
  - Parallel optics vs. SWDM
- Single-mode fibre & application
- Looking forward more than 15 years out
  - Future proofing your network

10 GbE Optical Power Budget for MMF

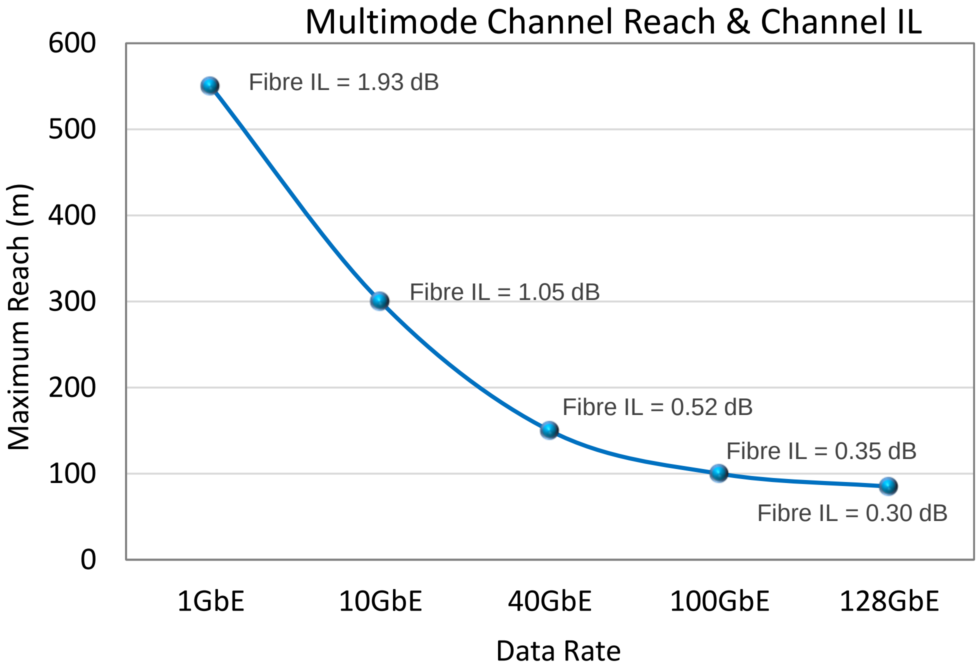


IL is independent of data rate

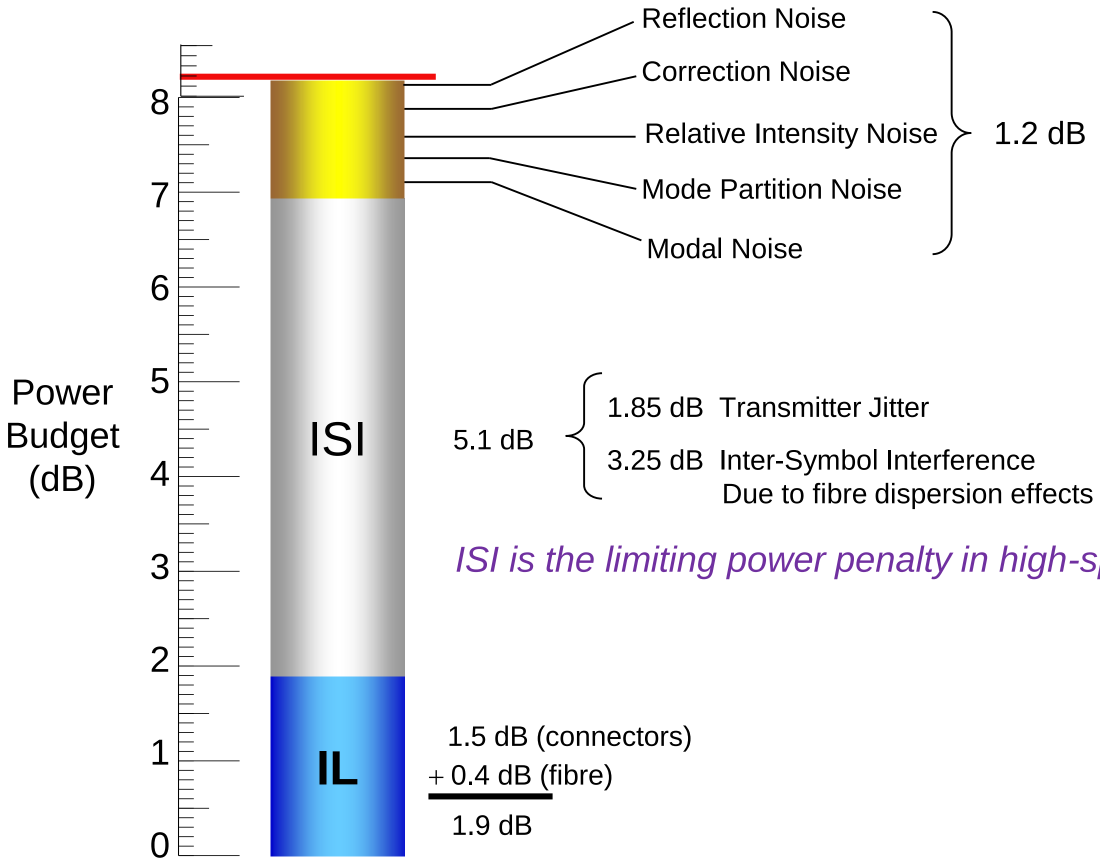
Channel insertion loss

For VCSEL Transmission Over MMF

Bit Rate	Reach (m)	Fibre Type
1 GbE	550	OM2
10 GbE	300	OM3
40 GbE	150	OM4
100 GbE	100	OM4/OM5
128 GbE	85	OM4/OM5



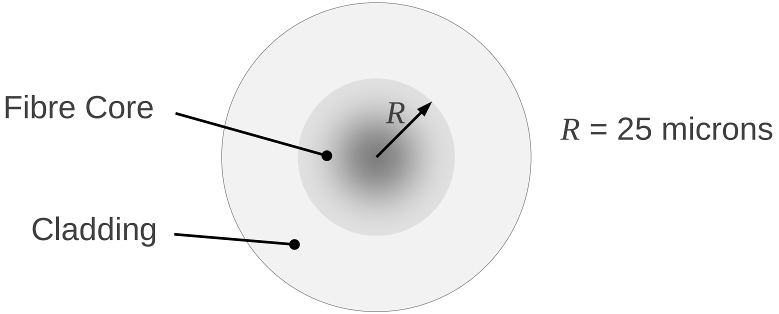
100G BASE-SR4 Optical Power Budget For MMF

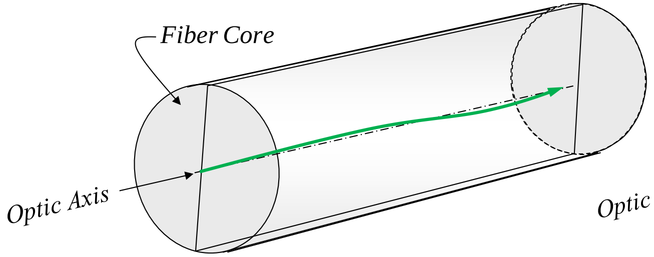


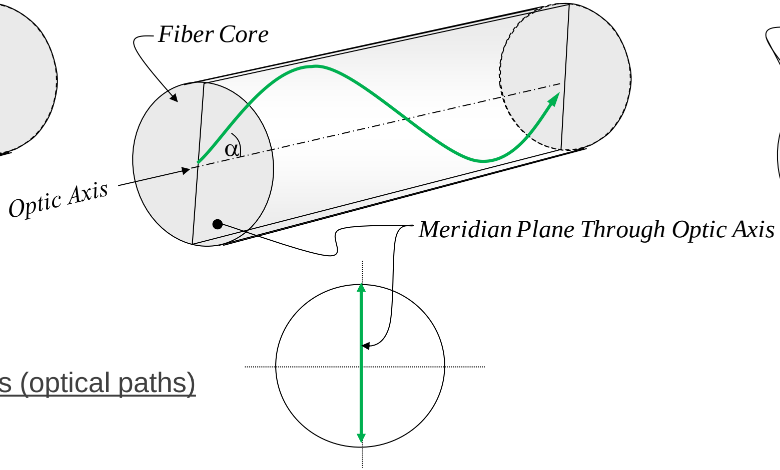
ISI is the limiting power penalty in high-speed links

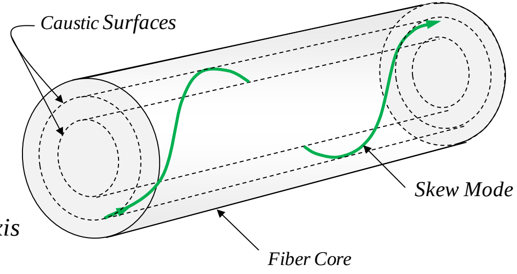
Multimode Fibre Modes

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



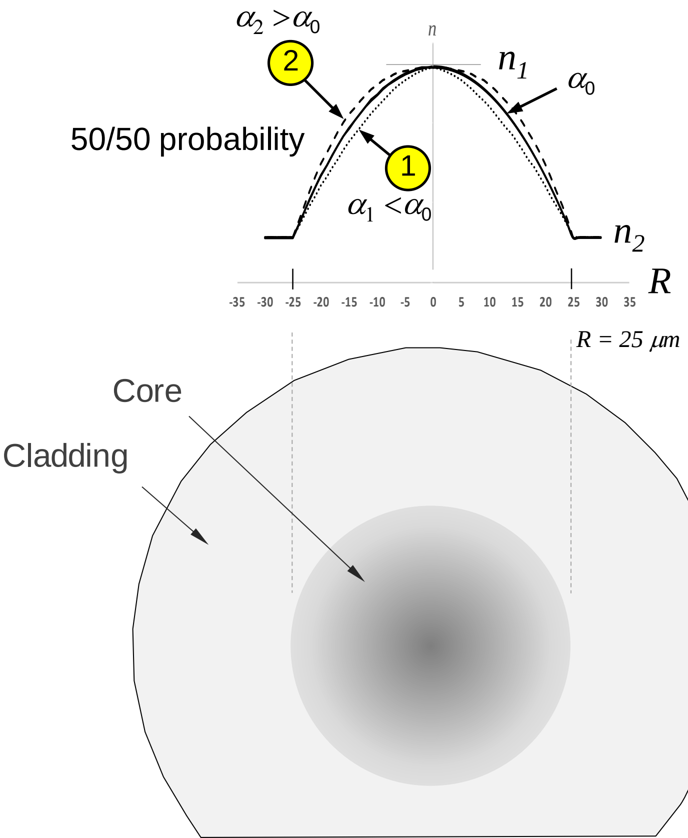






3 of 380 possible modes (optical paths)

Manufacturing Variation in Refractive Index Profile



$$n(r) = n_1\left[1 - 2\left(\frac{r}{R}\right)^{\alpha}\Delta\right]^{1/2}$$

where,

$\alpha \sim 2$ *for 850 nm*

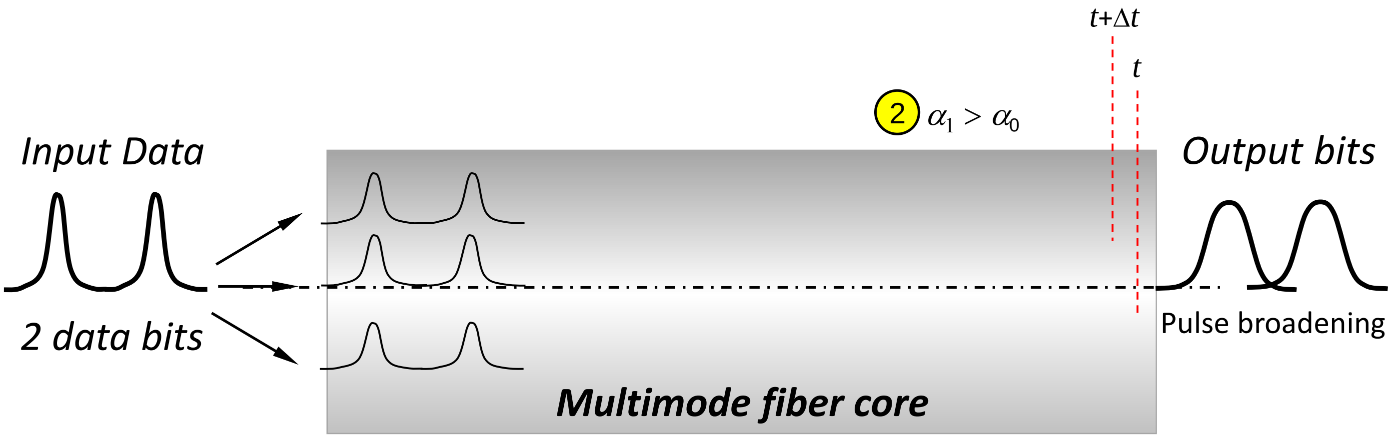
$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

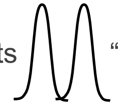
$\Delta = 1.02\ \%$

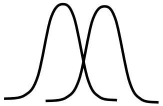
$$v = \frac{c}{n}$$

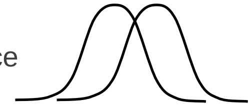
where, c = speed of light in vacuum
= 299,792,458 meters per second

ISI Contribution No. 1 – Modal Dispersion



Two sequential data bits  "Symbols"

Modal dispersion 

Inter-symbol Interference 

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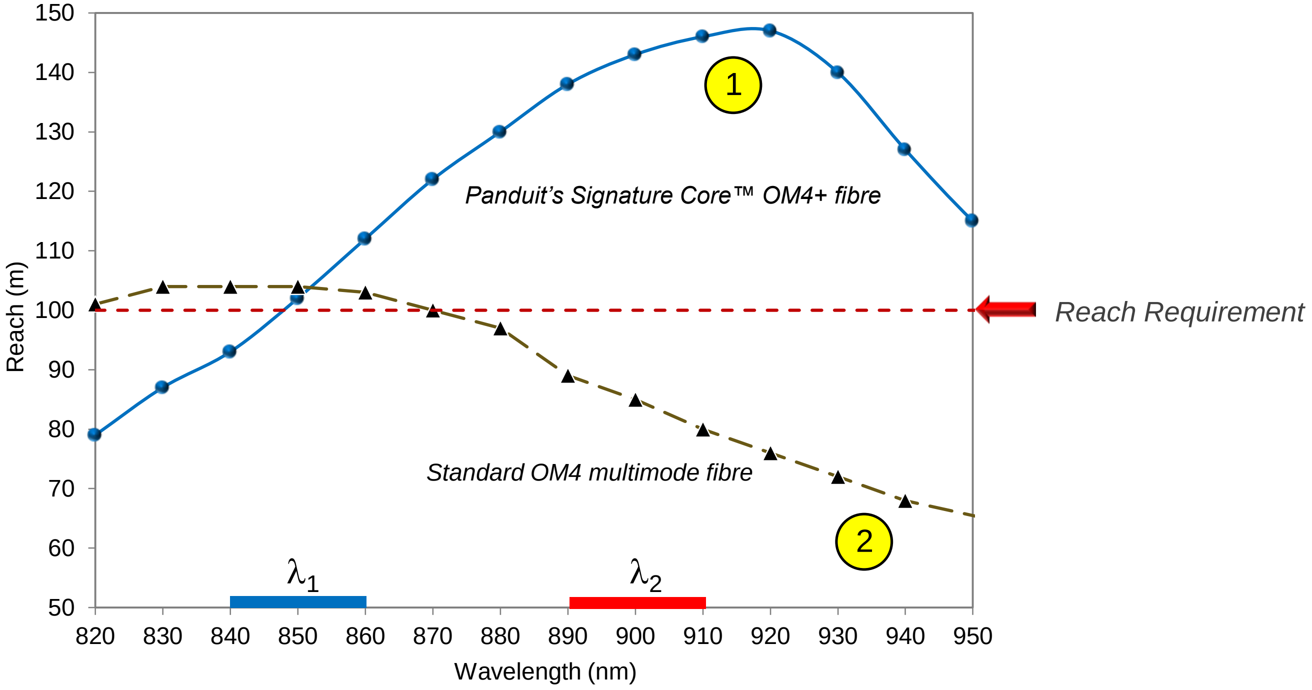
IEEE Link Model Calculated Channel Reach For Cisco’s 40G BiDi

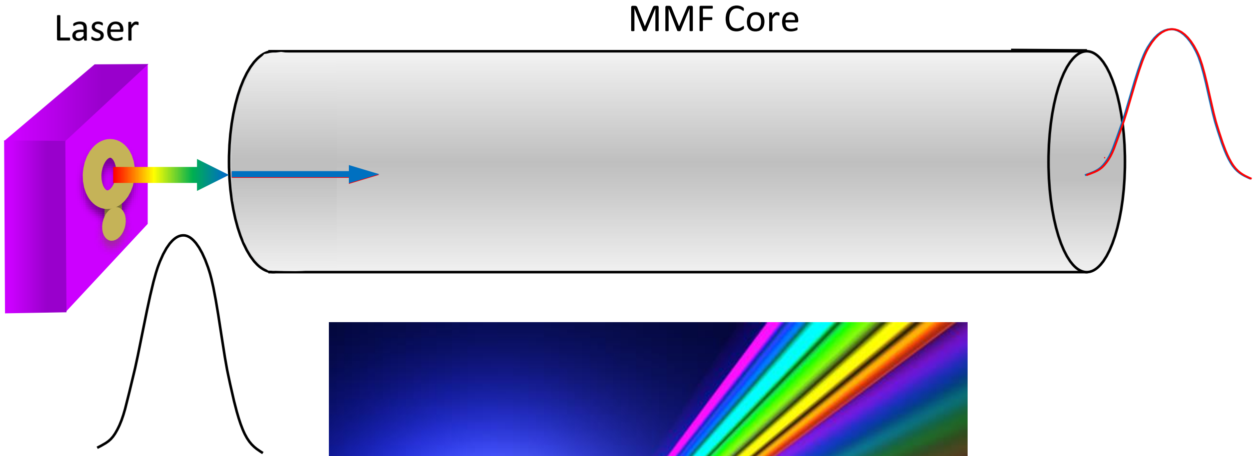
- ***Reaches using Measured EMB Wavelength Dependence***
- ***α_1 multimode fibres support longer wavelengths (SWDM)***

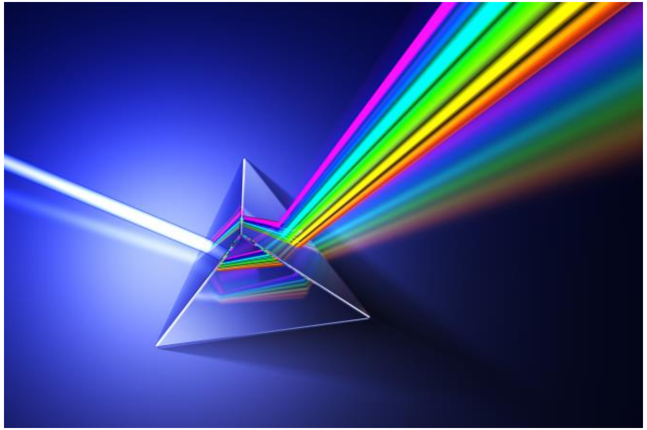


ISI contribution No. 3 – Chromatic dispersion

Different wavelengths travel at different velocities

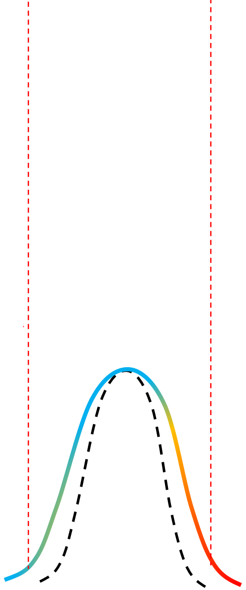
Shorter wavelengths travel slower





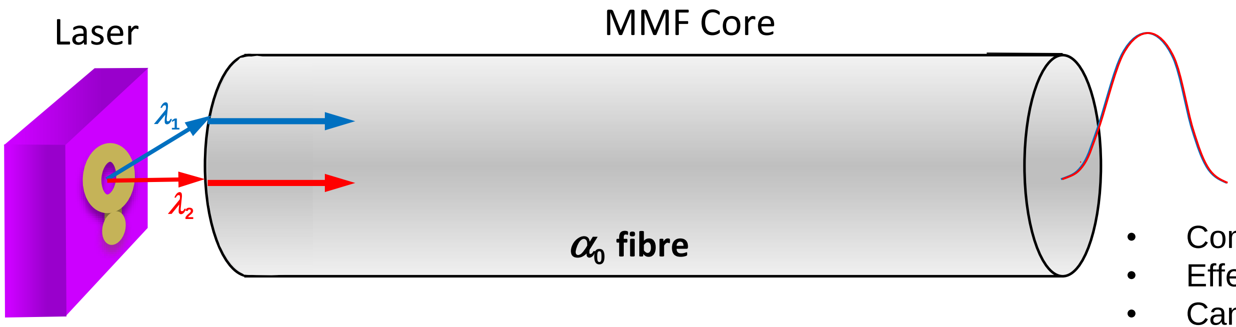
$$n^2(\lambda) = 1 + \sum_i \frac{B_i \lambda^2}{\lambda^2 - C_i}$$

Pulse broadening due to chromatic dispersion

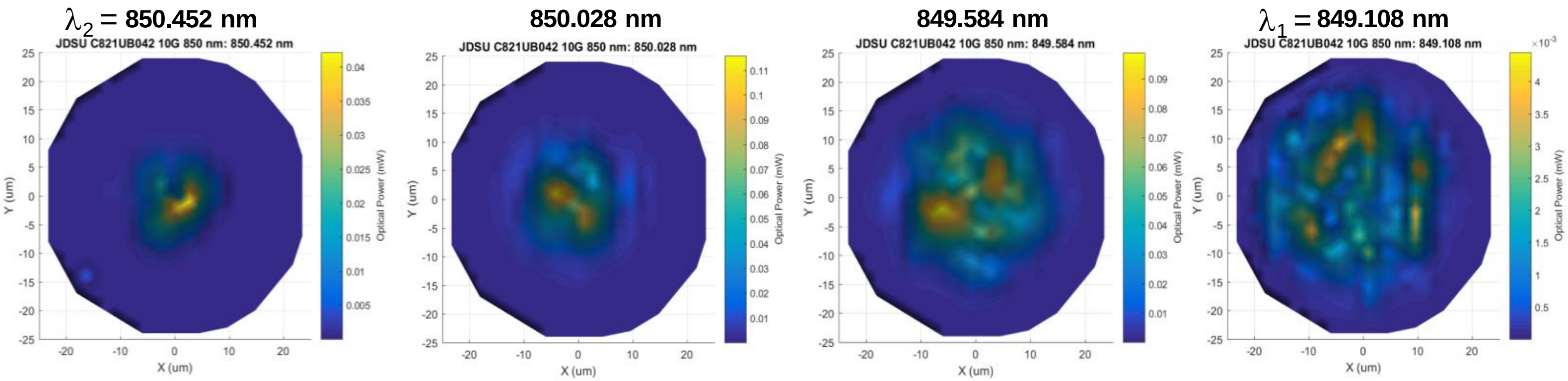


ISI contribution No. 4 – Modal-Chromatic dispersion

Modes undergo a relative chromatic dispersion – Panduit discovery

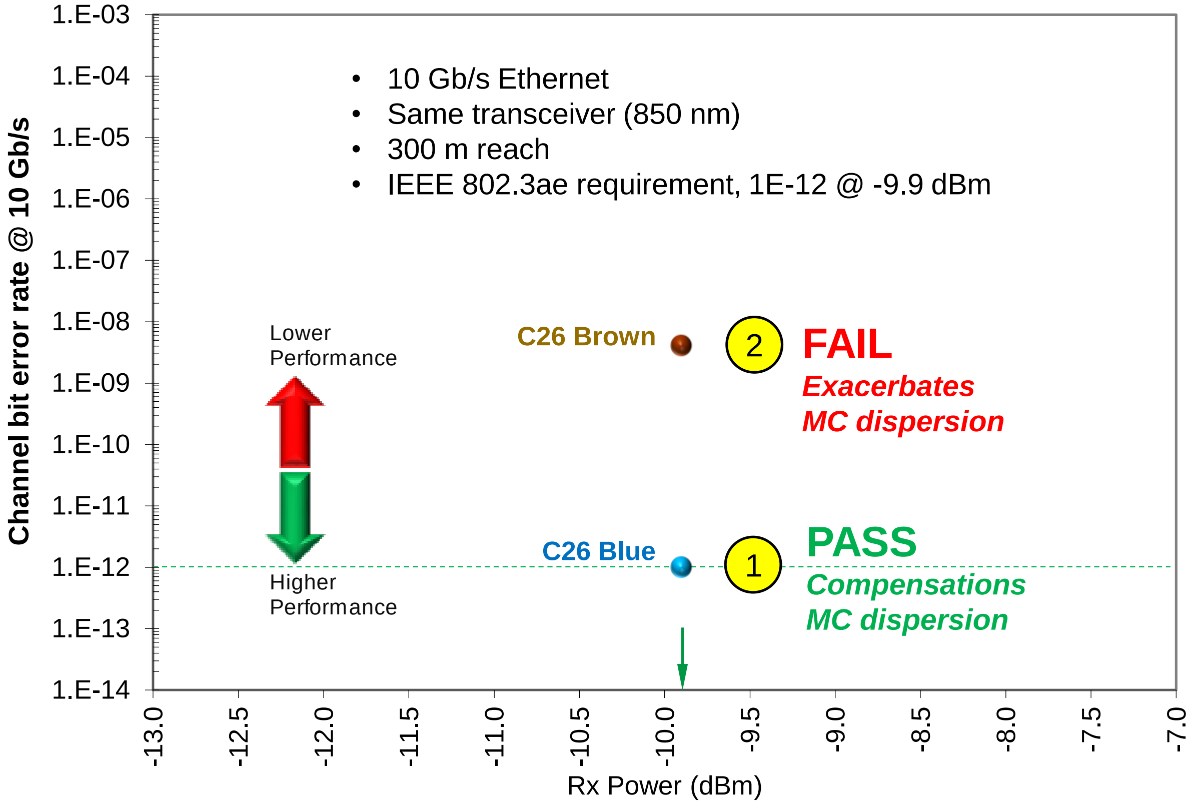


- Combination of Modal & Chromatic disp'n
- Effect previously unknown
- Can be compensated by α_1



Impact of modal-chromatic dispersion

- *Same fibre manufacturer, cable, and bandwidth (4700 MHz·km)*



Multimode fibre types

Laser Optimized Multimode Fibre Types

Fibre Sorted and Classified Based on Quality of Modal Dispersion

Fibre Type	EMB at 850 nm (MHz·km)	EMB at 953 nm (MHz·km)	Alpha profiles
OM3	2000	NA	50% α_1 & 50% α_2
OM4	4700	NA	50% α_1 & 50% α_2
OM5	4700	2470	~ α_1
Signature Core OM4+	5500	2000	Only α_1

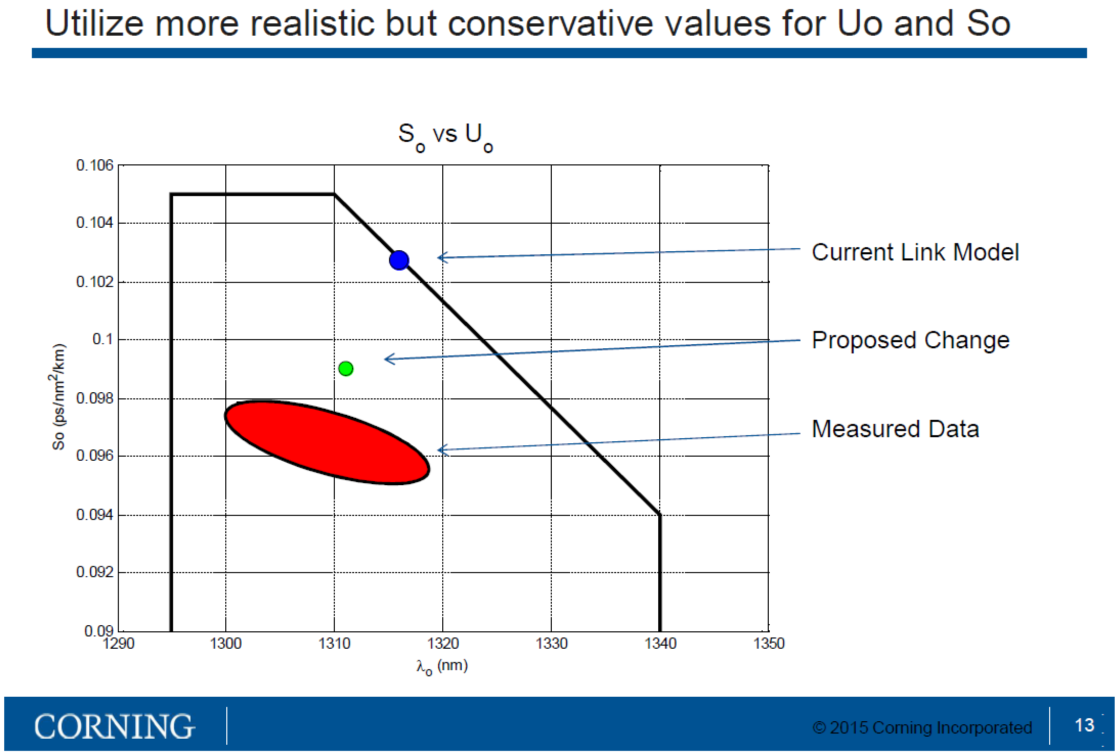
- MMF is sorted as OM3 & OM4 based on Effective Modal Bandwidth (EMB)
  - EMB is calculated from a Differential Mode Delay (DMD) measurement, i.e., modal dispersion
- OM3 and OM4 are designed for 850nm transmission and minimum channel reaches of 100 m and 150 m respectively
- OM5 includes a specified EMB at a longer wavelength (953nm)
  - Only provides a benefit for SWDM-4 applications where the required reach exceeds the standards specified maximum channel reach (non-standard)
- Signature Core OM4+ is a dispersion compensating (α_1) OM4 fibre

OM5 – Wide Band Multimode Fibre

- OM5 was developed under a TIA Joint Task Group
  - Organized under the TR42.12 and TR42.11 Subcommittees
    - TR42-12 Vice-Chaired by Panduit, Dr. Brett Lane
    - Task Group Chaired by Panduit
  - EMB shifted for longer wavelength operation
    - Higher bandwidth at 953 nm
    - Similar bandwidth at 850 nm

TIA Round Robin Report

Used For Specifying OM5 Chromatic Dispersion

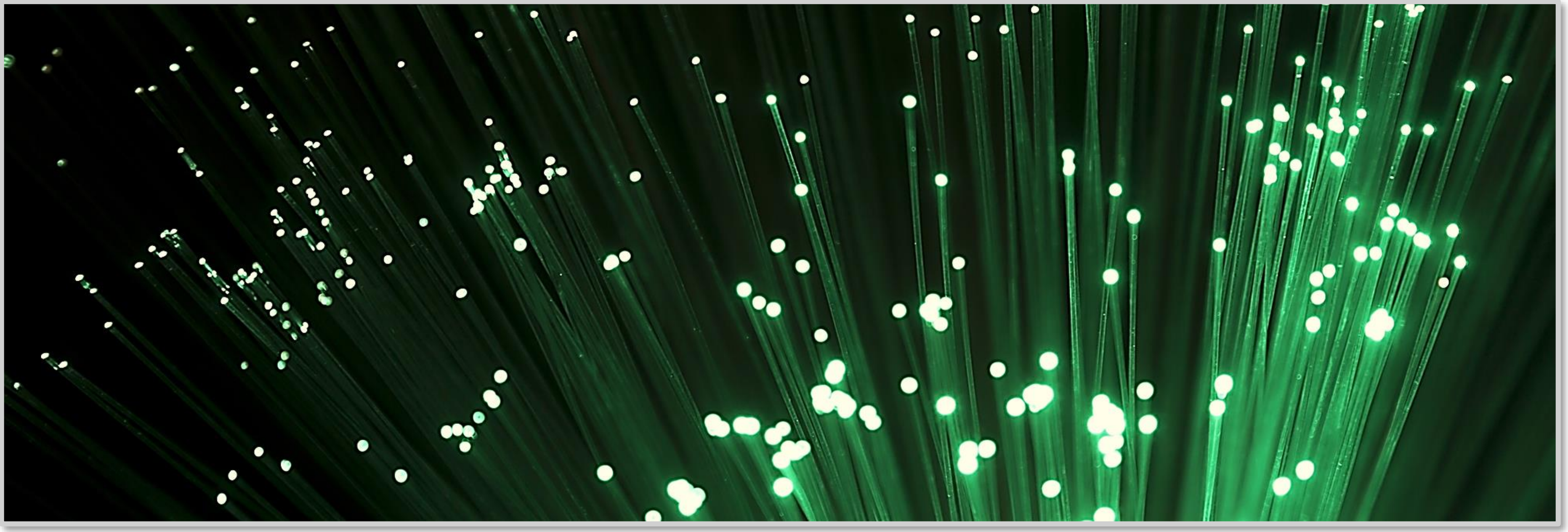


Standard MMF

Round Robin Participants

1. Corning
2. OFS
3. Panduit
4. Prysmian
5. J fibre
6. YOFC

Source: TR42.12-2015-06-022



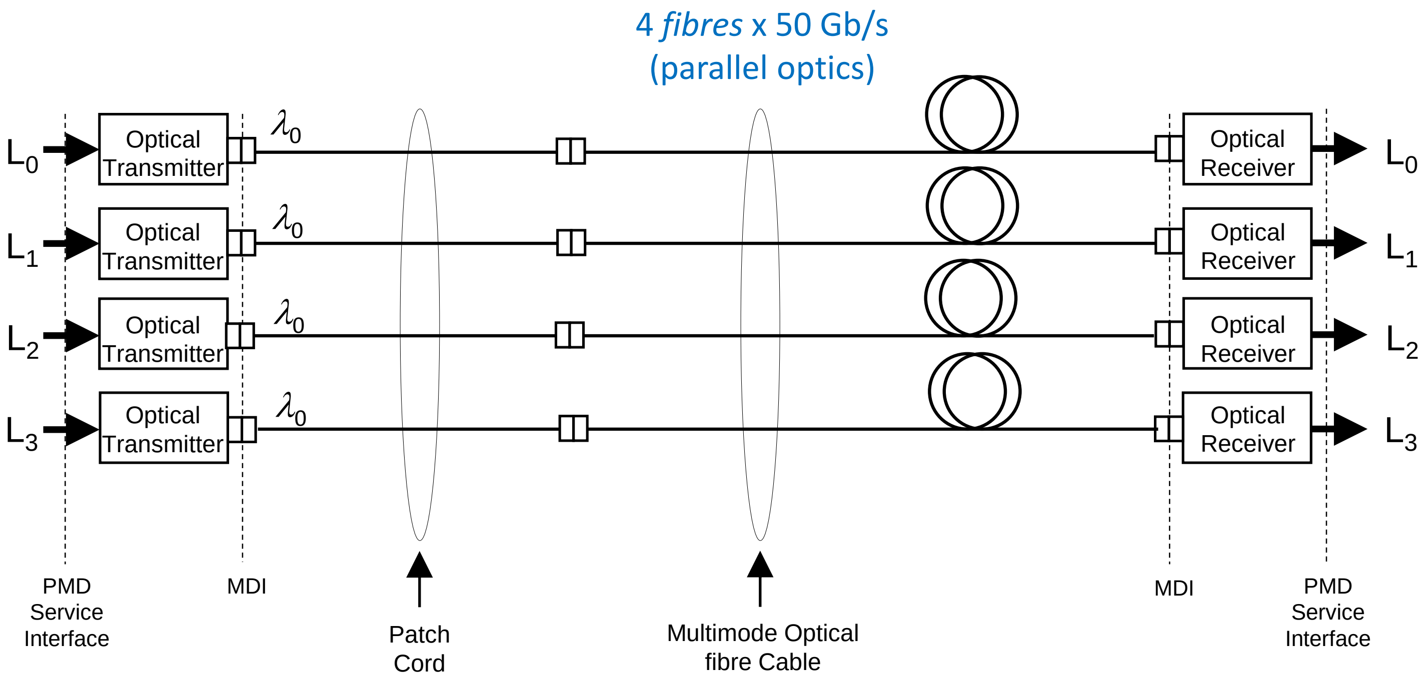
Future of Multimode Fibre

Lowest cost for short reach applications

Switch-to-server interconnections

Block Diagram For 200 GbE Parallel Optics Transmit/Receive Paths

For clarity, only one direction of transmission is shown

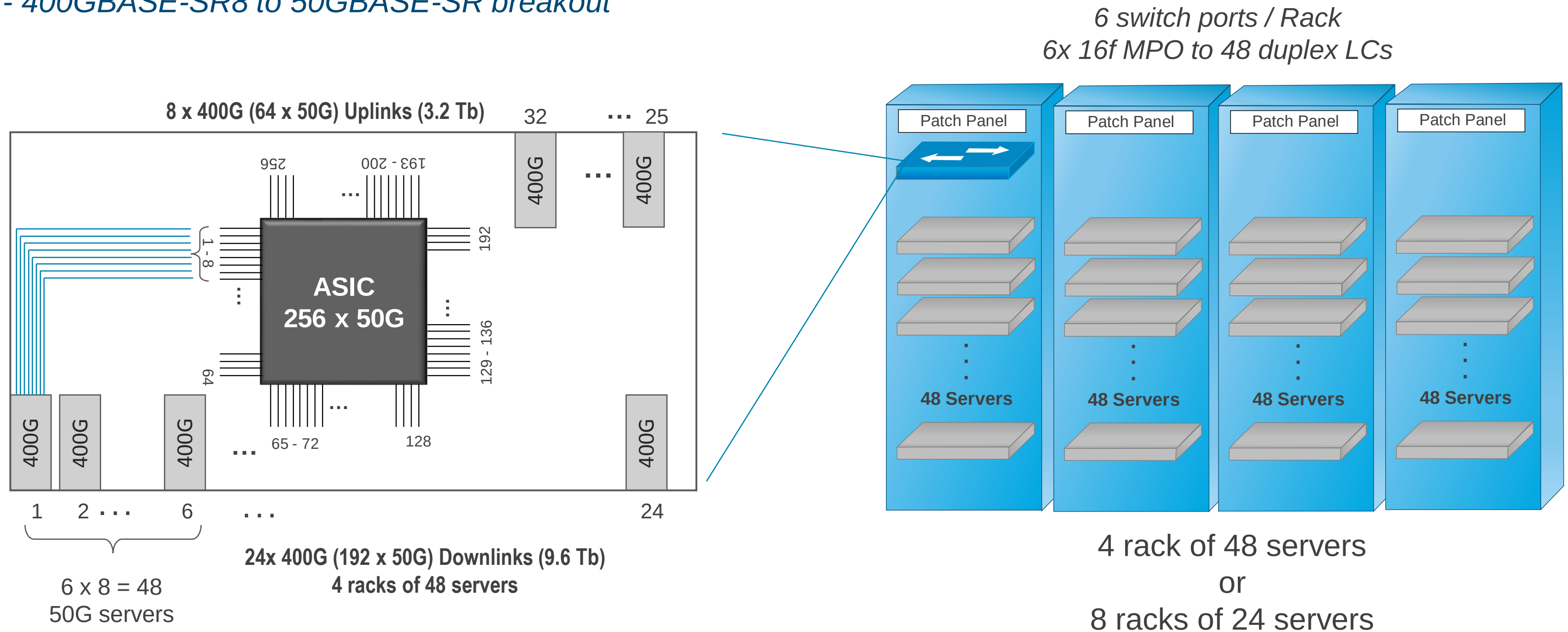


Supports Breakout Functionality

Multimode Fibre Application: Server Breakout

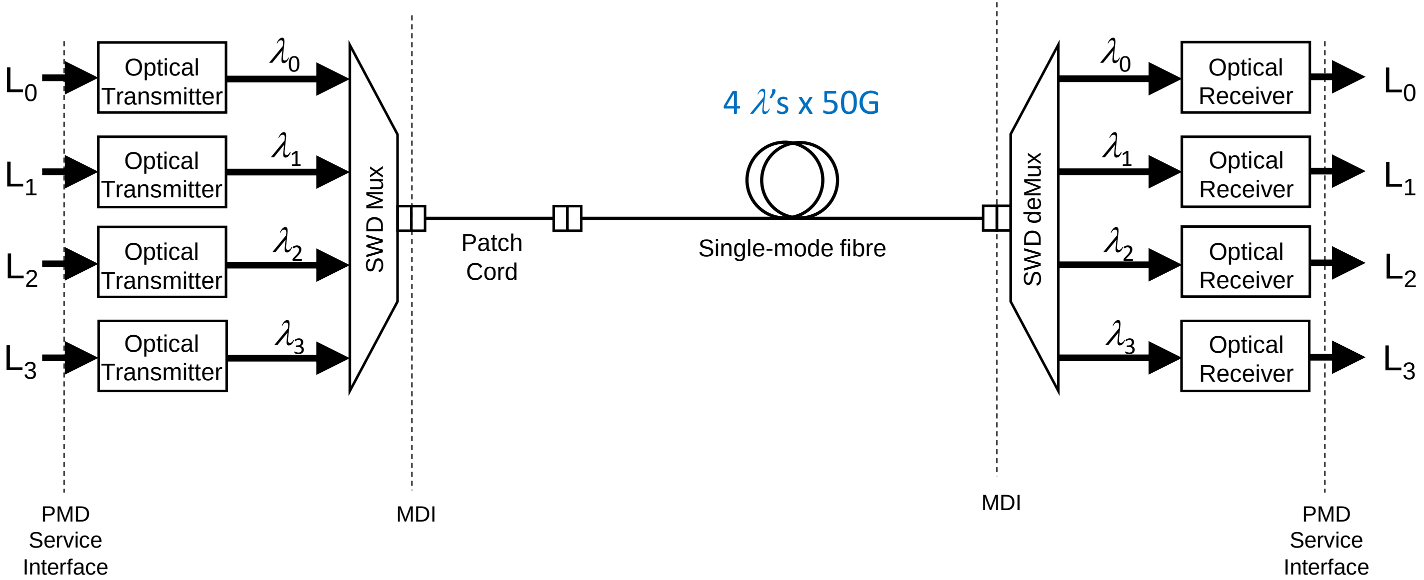
Ex: 256 x 50G Switch Radix – 3:1 Over Subscription

- ASIC – Application Specific Integrated Circuit
- High density 32 x 400G switch ports
- 50G servers supported by
  - *- 400GBASE-SR8 to 50GBASE-SR breakout*



Block Diagram For SWDM4 Transmit/Receive Path

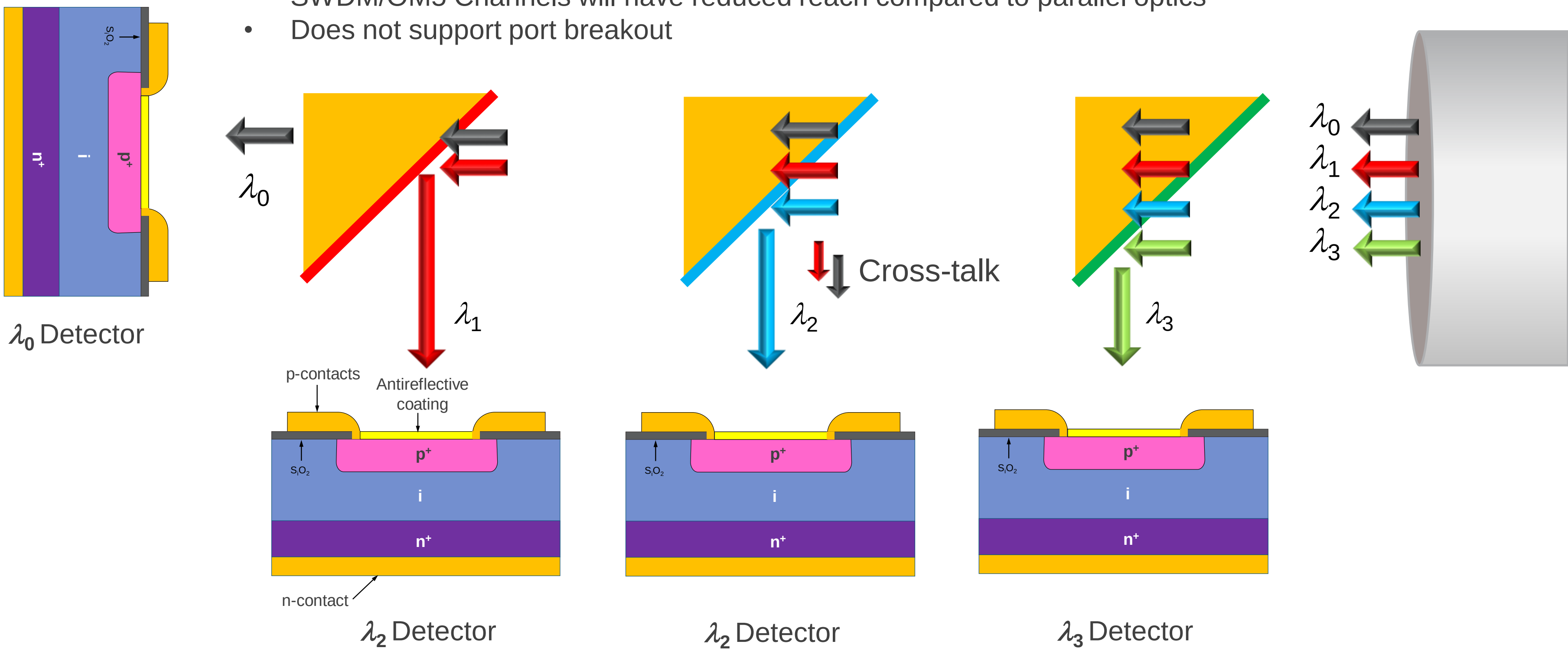
For clarity, only one direction of transmission is shown



SWDM = Short Wavelength Division Multiplexing
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
- Does not support port breakout



Double Link Channel Cost Comparison

IEEE Panduit contribution (pimpinella_NGMMF_03_0118.pdf)

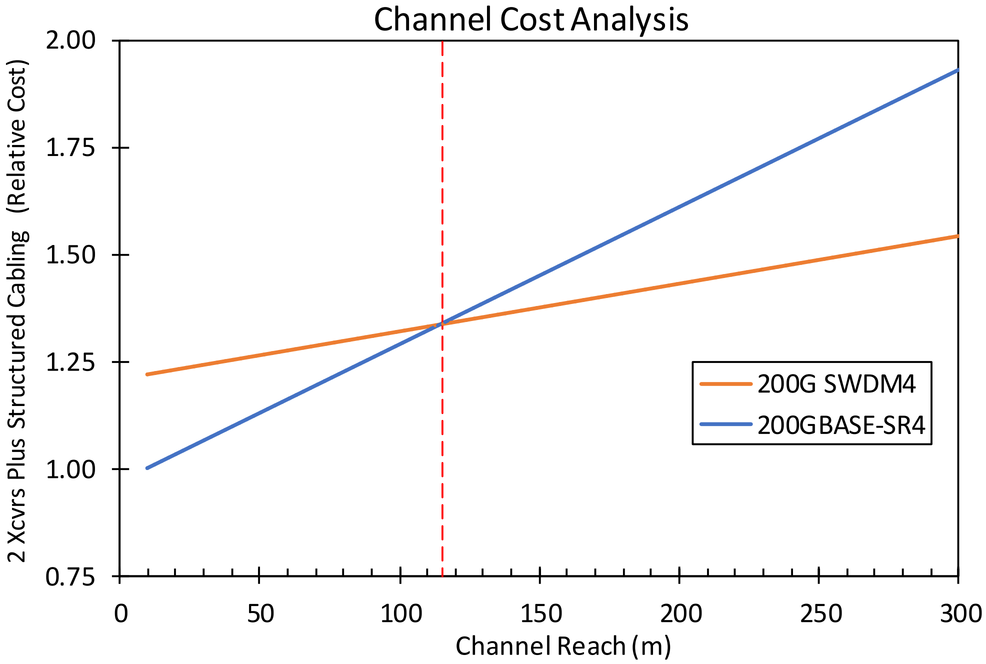
XCVR TYPES:	200GBASE-SR4	200G SWDM4
	n	δ
Cost multipliers =	**4.0**	**1.75**

n = cost multiplier compared to 10GBASE-SR

STRUCTURED CABLING:	Parallel Cabling	Duplex Cabling
Fiber Type =	OM4	OM5
Cable fiber count =	12	12
No. of used fibers =	8	2
No. of channel links =	2	2
No. of patch cords =	3	3

	Normalized Standard Costs *Material + Labor*	
Cable Termination =	0.65 ***Y***	1.0 ***Y***
Per meter adder =	0.81 ***Z***	1.0 ***Z***
Adapter panel or Cassette =	0.68 ***W***	1.0 ***W***
Patch Cord =	1.0 ***X***	0.25 ***X***

Cost crossover = 115 m



Panduit contribution to IEEE – Eye safety calculator

Class 1, 1M Emission Limits for range

700 nm to 1399 nm

Bi-directional = 0	1
Co-directional = 1	

Condition	1	= Telescope
	2	= Microscope
	3	= Naked eye

Class 1 Hazard	2.760	EXCEEDED
Class 1M Hazard	0.976	PASS

1.0 = Hazard

Based on measured VCSELs

Parameter	Wavelength 1			Wavelength 2			Wavelength 3			Wavelength 4			Units	Notes
λ =	844			874			904			934			nm	Wavelength each lane
Power =	2.75			2.75			2.75			2.75			dBm	Poewr each lane
NA =	0.172			0.157			0.161			0.170			-	Numberical Aperture + tolerance
N_fiber_vert	1.0												-	Number of fiber rows
N_fibers_horiz	1.0												-	Number of lit fibers in row
Distance_y	0.25												*mm*	Fiber row separtion distance
Distance_x	0.25												*mm*	Fiber pitch within row
Source size (one)	0.05												*mm*	MMF core diameter
condition	1	2	3	1	2	3	1	2	3	1	2	3		Telescope, microscope, naked eye
d_0 =	7.0	3.5	7.0	7.0	3.5	7.0	7.0	3.5	7.0	7.0	3.5	7.0	*mm*	Stop aperture
L =	2000	14	100	2000	14.0	100	2000	14	100	2000	14	100	*mm*	Source-aperture separation
worst_comb_y	1.00	1.00	1.00	1.0	1.0	1.0	1.00	1.00	1.00	1.00	1.00	1.00		
worst_comb_x	1.00	1.00	1.00	1.0	1.0	1.0	1.00	1.00	1.00	1.00	1.00	1.00		
total_fibers	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		Number of fibers in field of view
alpha (worst)	1.50	3.57	1.50	1.50	3.57	1.50	1.50	3.57	1.50	1.50	3.57	1.50	*mrad*	Subtense source angle
T2	10.00	10.50	10.00	10.00	10.50	10.00	10.00	10.50	10.00	10.00	10.50	10.00	*sec*	Emission duration
d_{63} =	410.83	2.88	20.54	374.05	2.62	18.70	383.83	2.69	19.19	405.91	2.84	20.30	*mm*	Beam diam. 63%
C_4 =	1.941	1.941	1.941	2.228	2.228	2.228	2.559	2.559	2.559	2.938	2.938	2.938		Correction factor 4
C_6 =	1.00	2.38	1.00	1.00	2.38	1.00	1.00	2.38	1.00	1.00	2.38	1.00		Correction factor 6
C_7 =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	Correction factor 7
η =	0.000	0.773	0.110	0.000	0.833	0.131	0.000	0.817	0.125	0.000	0.781	0.112	-	Fraction of power accessible

AEL per Class/condition

Class 1 AEL	0.757	1.797	0.757	0.869	2.063	0.869	0.998	2.369	0.998	1.146	2.720	1.146	*mW*
Class 1M AEL	0.757	500.000	0.757	0.869	500.000	0.869	0.998	500.000	0.998	1.146	500.000	1.146	*mW*
Max permissible power for hazerd 1:	2607.67	2.33	6.90	2482.02	2.48	6.65	3000.69	2.90	8.01	3852.91	3.48	10.22	*mW*
Max permisible power for hazerd 1M:	500.00	500.00	6.90	500.00	500.00	6.65	500.00	500.00	8.01	500.00	500.00	10.22	*mW*
Total Power per wavelength per condition:	1.884	1.884	1.884	1.884	1.884	1.884	1.884	1.884	1.884	1.884	1.884	1.884	*mW*
Hazard per wavelength per conditions Class 1 =	0.0007	0.8098	0.2728	0.0008	0.7600	0.2833	0.0006	0.6494	0.2351	0.0005	0.5406	0.1844	-
Hazard per wavelength per conditions Class 1M =	0.0038	0.0038	0.2728	0.0038	0.0038	0.2833	0.0038	0.0038	0.2351	0.0038	0.0038	0.1844	-

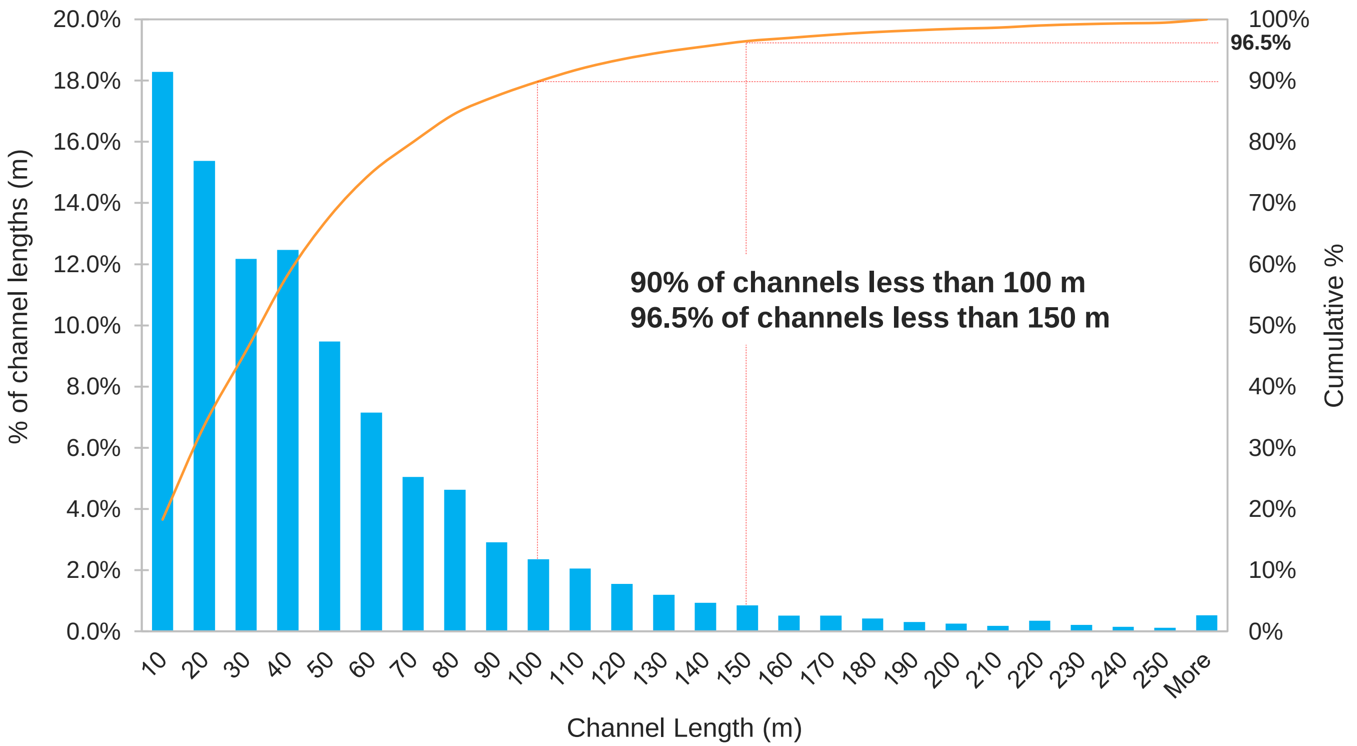
Maximum Level per wavelength					
	Class 1	0.810	0.760	0.649	0.541
	Class 1M	0.273	0.283	0.235	0.184

Worst case for each wavelength

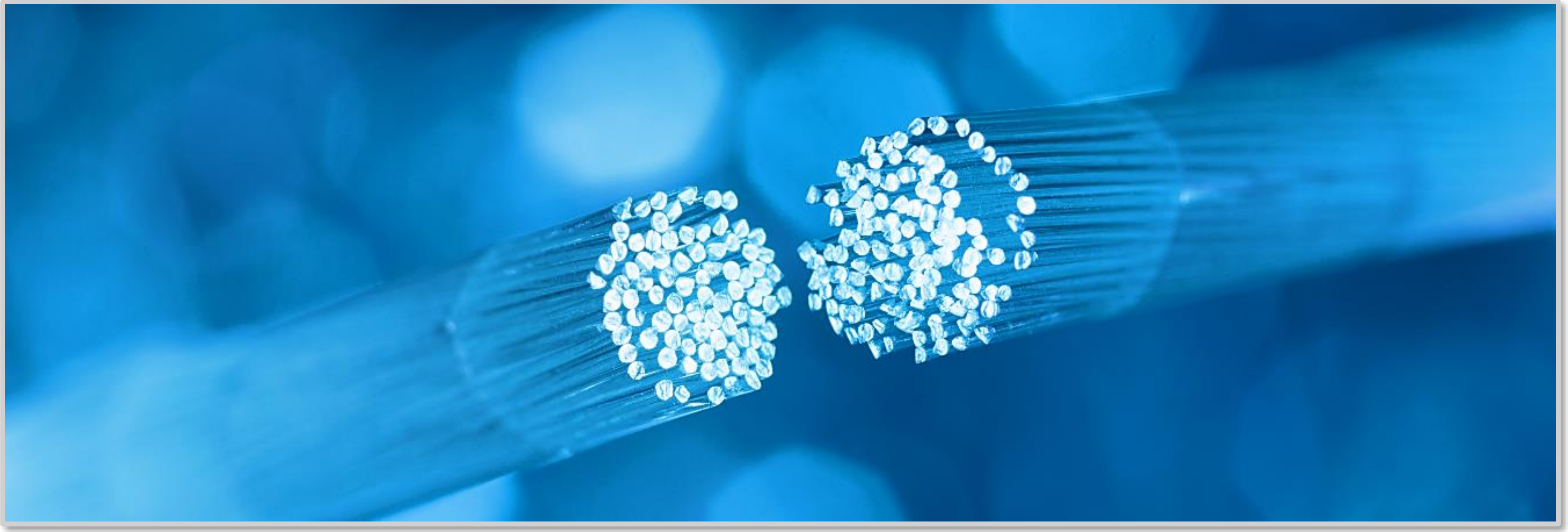
Progression of Multimode Fibre Ethernet PMDs

	Data Rate Gb/s	Nomenclature	Lane Rate Gb/s	Number of fibre pairs	Number of wavelengths	Year Standardized
10G PMD Series	10 40	10GBASE-SR 40GBASE-SR4	10	1 4	1	2002 2015
25G PMD Series	25 100	25GBASE-SR 100GBASE-SR4	25	1 4	1	2016 2015
50G PMD Series	50 100 200	50GBASE-SR 100GBASE-SR2 200GBASE-SR4	50	1 2 4 8	1	2018
NEW →	400	400GBASE-SR8				~2021
		400GBASE-SR4.2		4	2 BiDi	

Multimode fibre structured cabling channel Lengths



Source: Ethernet Alliance 23 March 2016



Single-mode Fibre

Required for Long or Extended reach Applications

Single-mode fiber types specified by ITU-T

1984 CCITT Blue Book	#	ITU-T Spec	IEC	Description	OFS	Corning	Prysmian
1988	1	G.652.A	B1.1	"Standard" SMF w/ ZDW ~1310nm.	AllWave	SMF-28	
OS1 → 2000	2	G.652.B	B1.1	"Standard" SMF w/ ZDW ~1310nm, 1625nm Atten, low PMD.	AllWave		SSMF
Obsolete	3	G.652 C	B1.3	"Standard" SMF w/ ZDW ~1310nm, LWP	AllWave		
OS2 → 2003	4	G.652 D	B1.3	"Standard" SMF w/ ZDW ~1310nm, LWP, low PMD.	AllWave, AllWave FLEX	SMF-28e SMF-28e+	ESMF
	5	G.653.A	B2	Dispersion –Shifted SMF.	Not branded.Offered upon request.		
	6	G.653.B	B2	Dispersion –Shifted SMF, Low PMD.	Not branded. Offered upon request.		
	7	G.654.A	-	Cutoff-Shifted SMF.	*Obsolete*		
	8	G.654.B	B1.2_b	Cutoff-Shifted SMF, med MFD, low PMD.	TeraWave		
	9	G.654.C	B1.2_c	Cutoff-Shifted SMF, low PMD.	TeraWave		
	10	G.654.D	-	Cutoff-Shifted SMF, high MFD, low PMD.	TeraWave Ocean SLA+ / ULA	Vascade	LongLine
	11	G.655.C	B4_c	Non-Zero Dispersion Shifted SMF	TrueWave RS, TrueWave REACH, TrueWave LA (Large Area)	Leaf	
	12	G.655.D	B4_d	Non-Zero Dispersion Shifted SMF, low 1625nm bend.	TrueWave RS, TrueWave LA *(Large Area)*	Leaf	
	13	G.655.E	B4_e	Non-Zero Dispersion Shifted SMF, positive dispersion, low 1625nm bend.	TrueWave REACH		TeraLight, TeraLight Ultra
	14	G.656	B5	Non-Zero Dispersion Shifted SMF for Wideband.	TrueWave REACH		TeraLight, TeraLight Ultra
Transitioning away from G.652.D (OS2) — 2006/ 2009	15	G.657.A1	B6_a	Bending-Loss Insensitive SMF, *r* =10mm, G.652.D compliant.	AllWave+	ClearCurve XB	Bendbright
	16	G.657.A2	B6_a	Bending-Loss Insensitive SMF, *r* =7.5mm, G.652.D compliant.	AllWave FLEX+	ClearCurve LBL	BendBright-XS
	17	G.657.B2	B6_b	Bending-Loss Insensitive SMF, *r* =7.5mm	AllWave FLEX Max	ClearCurve LBL	BendBright-XS
2012	18	G.657.B3	B6_b	Bending-Loss Insensitive SMF, *r* =5mm	AllWave FLEX Max, EZ-Bend *(r=2.5mm)*	ClearCurve ZBL	BrendBright Elite

CCITT – International Telegraph and Telephone Consultative Committee
ITU – International Telegraph Union (1864), Now known as International Telecommunications Union

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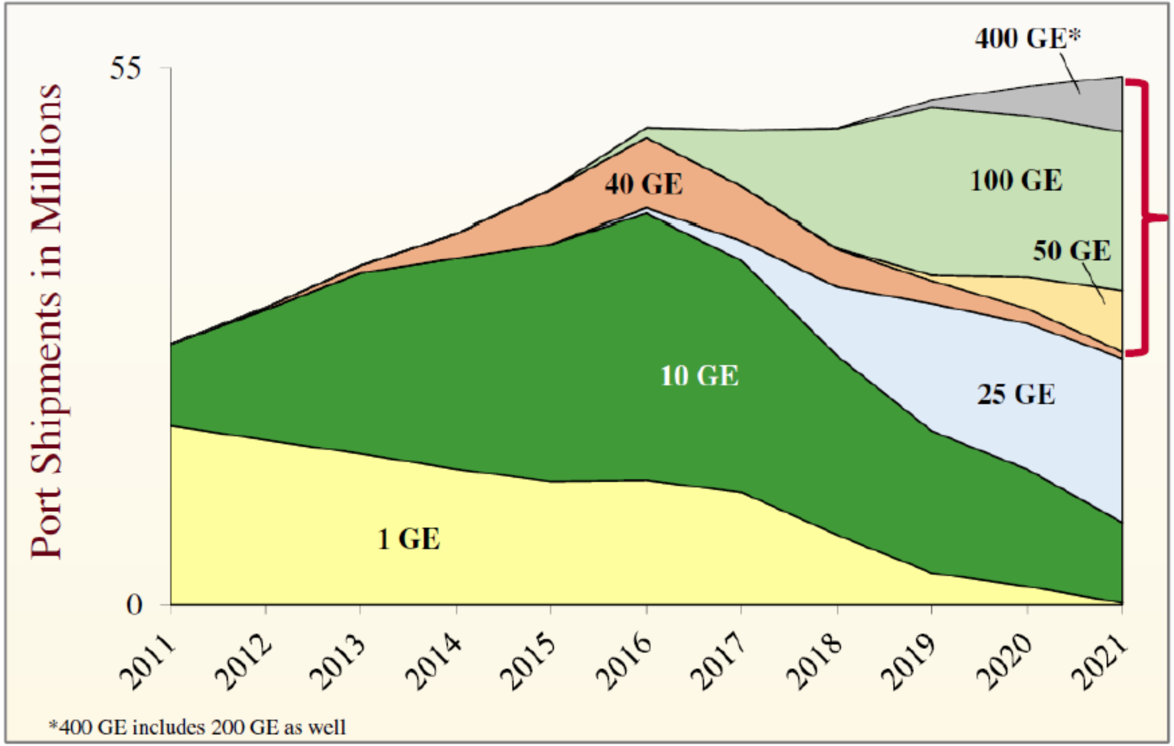
Hyperscale data center Ethernet Market



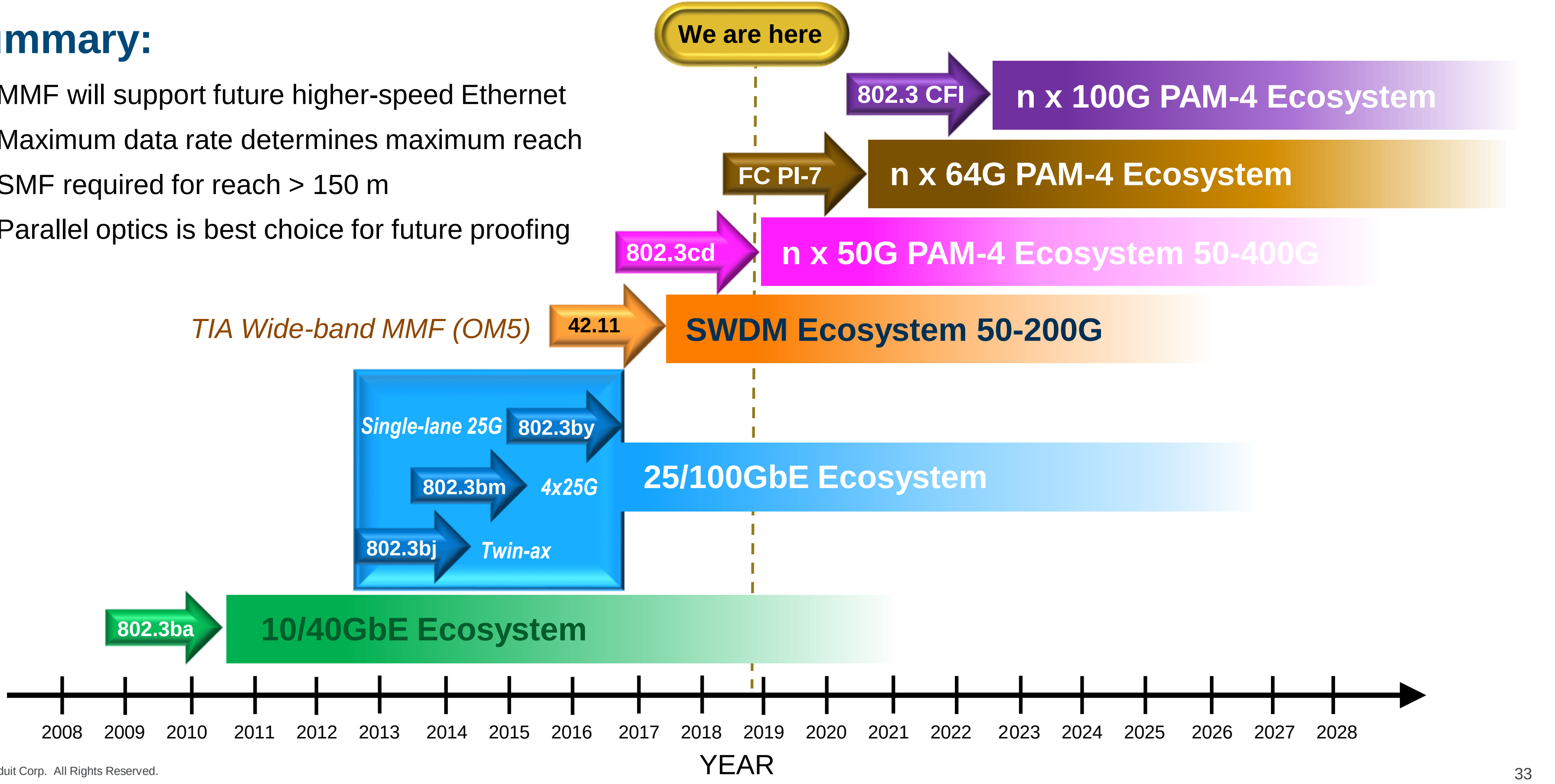
50/100/200/400GE Approaches 50% of All Data Center Ports by 2021

Source: Dell'Oro July 2017 Long Range Data Center Forecast

IEEE 802.3 MMF Ethernet Data Rate Timeline

Summary:

- MMF will support future higher-speed Ethernet
- Maximum data rate determines maximum reach
- SMF required for reach > 150 m
- Parallel optics is best choice for future proofing



The future of optical fibre in the data center

Dr. Rick Pimpinella, Panduit Fellow