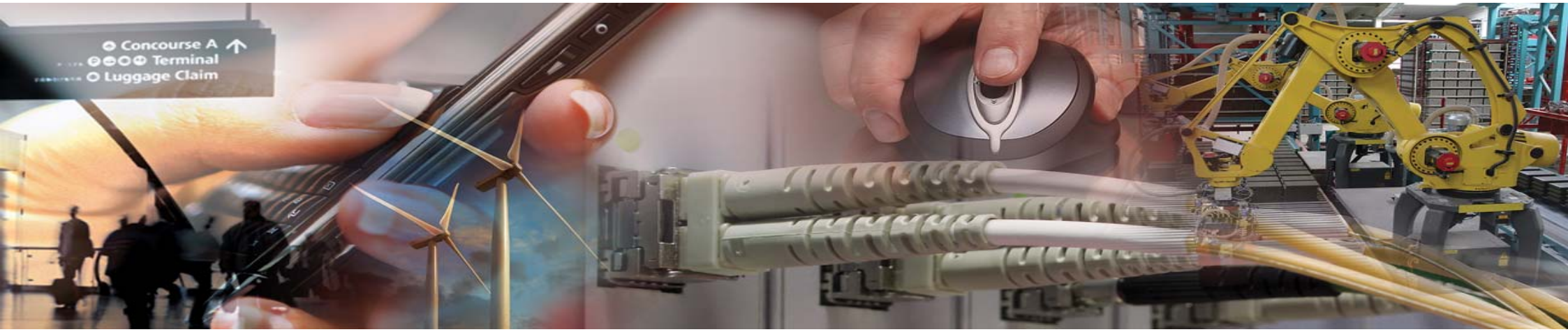
Trends In Data Rate And Link Length In Evolving Optical Standards



David Cunningham

22nd September 2013

AVAGO TECHNOLOGIES

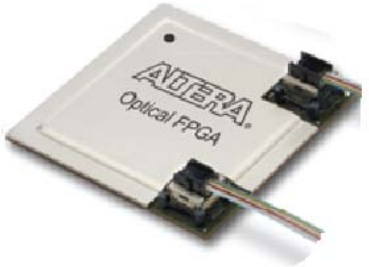
Outline

- Building and Data Centre link lengths
- Trends for standards-based electrical interfaces
- Data rate, transmission media and optical technology trends
- Multimode fibre link lengths
- Form factor evolution
- Summary

Transmission Technologies For Data Centre Networking

- Electrical Links:
  Used for on-board, in chassis, and rack to rack.

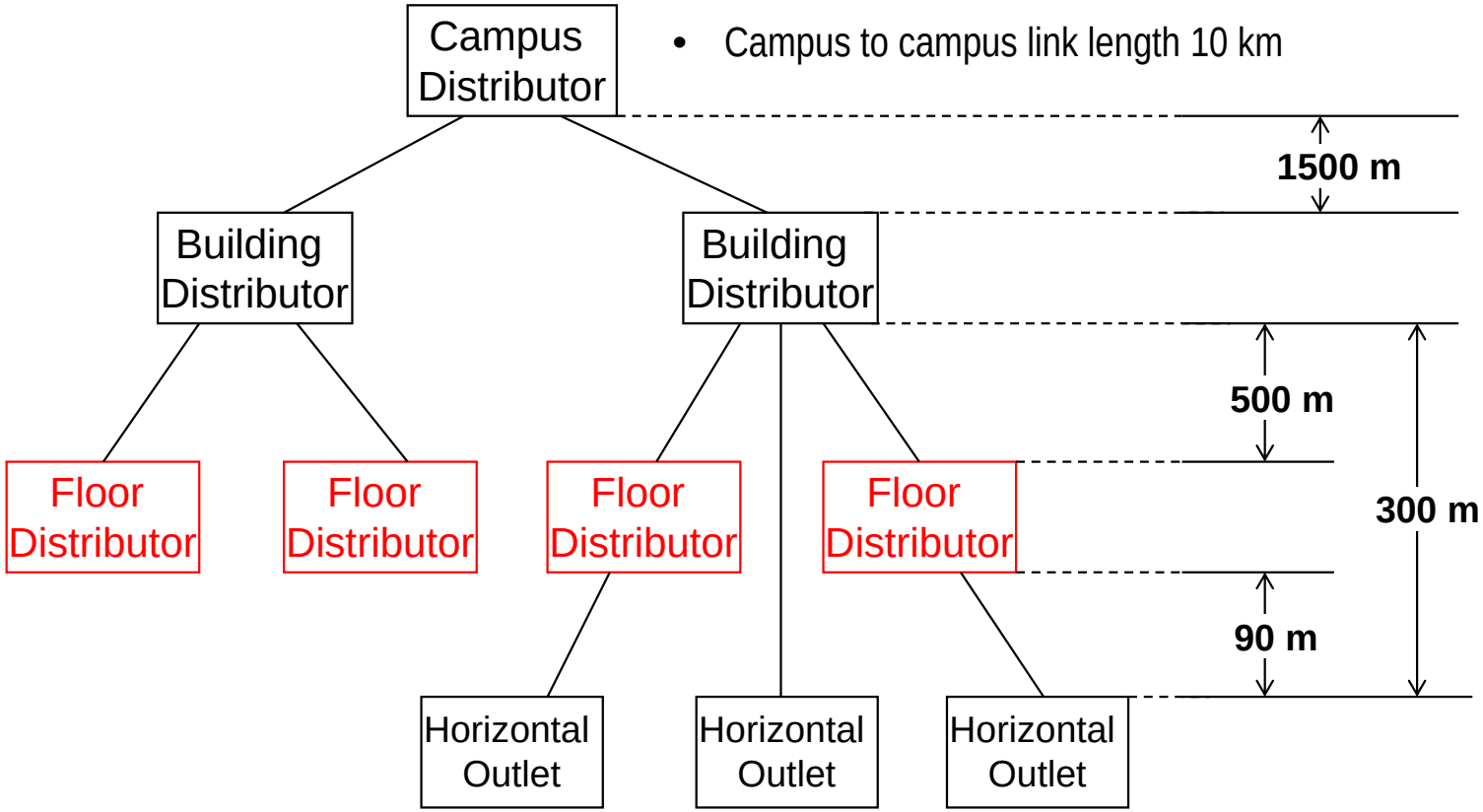
- Optical Links:
  Used where electrical can't work!



- As signaling speeds increase and the size of data centres expand, optics plays an increasing role.

AVAGO TECHNOLOGIES

Standards Based Building Wiring Link Lengths

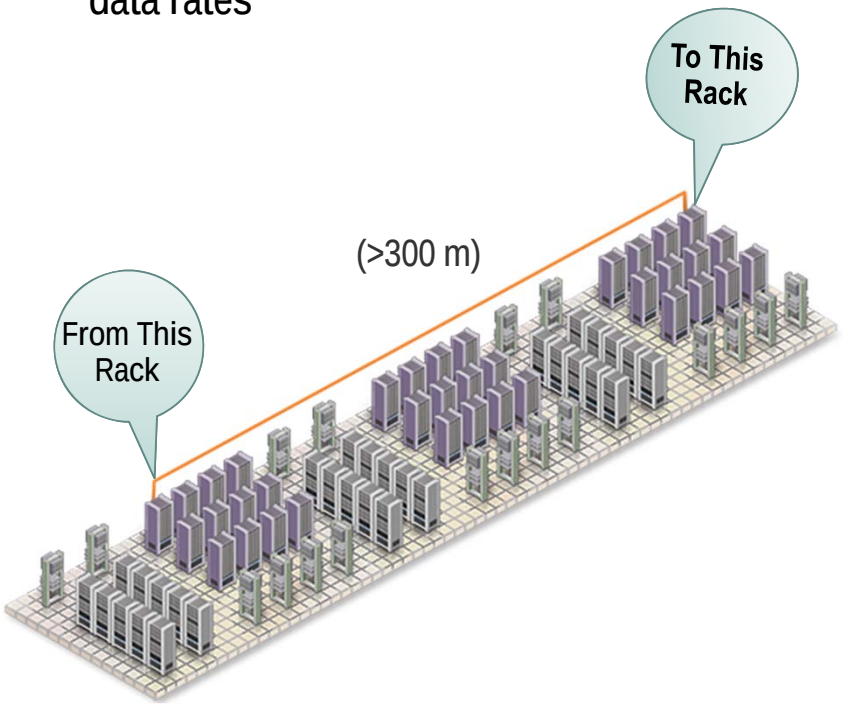


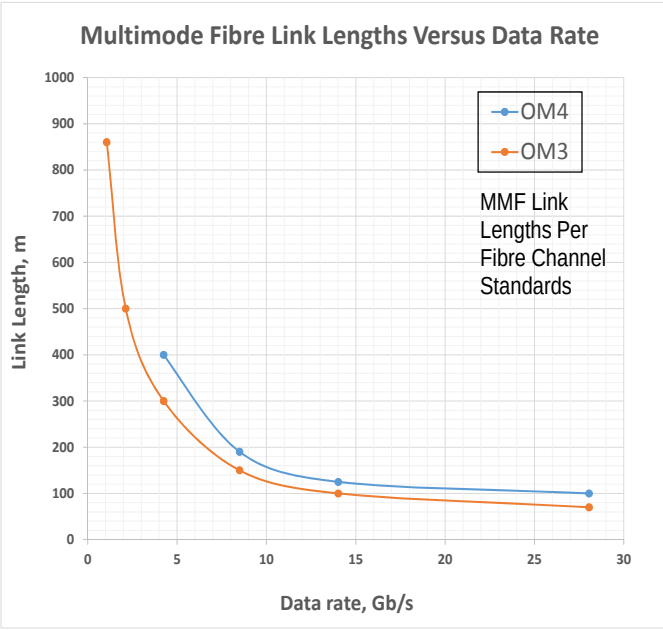
Fixed installed cable lengths per ISO/IEC 11801

AVAGO TECHNOLOGIES

Data Centres Now Use Structured Cabling Too

- ISO/IEC 24764 Generic Cabling Systems for Data Centres
- But data centres are getting huge and supported MMF link lengths are decreasing at higher data rates

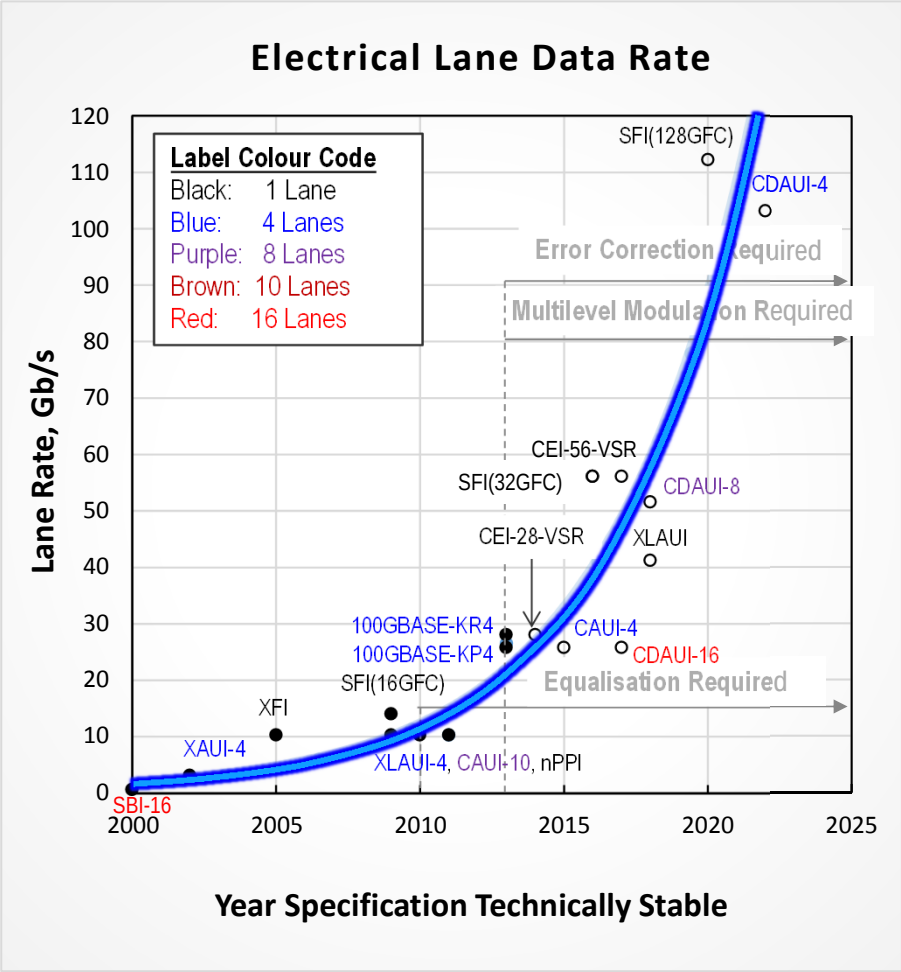




- SMF solutions for 500 m under active consideration for higher speeds

AVAGO TECHNOLOGIES

Trends For Standards-Based Electrical Interfaces



As the electrical data rate seems to be expected to increase with an exponential trend it will quickly get harder and harder to maintain electrical signal integrity.

Already, in order to maintain signal integrity, an evolution of various mitigation methods is obvious:

- Number of lanes:
  16, 4, 1……10, 4, 1…..16, 8, 4 ,1…..
- Clock Recovery
- Equalization
- Error Correction
- Advanced Modulation Formats

Unfortunately these mitigations increase the required electrical power dissipation.

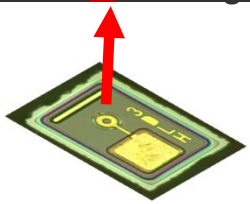
They also increase transmission latency.

- Development of Electrical Interfaces For 50-56 Gb/s per lane via NRZ/PAM4 and FEC has already started.

AVAGO TECHNOLOGIES

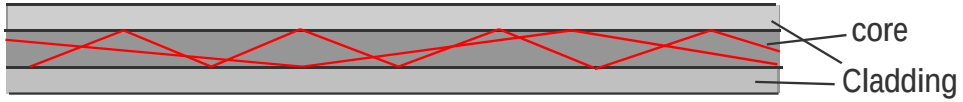
Basic Optical Technologies For Data Centres

850nm VCSELs (Vertical- Cavity Surface-Emitting Lasers)



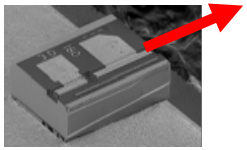
Low-cost laser source
Low Current & Low Power
Compatible with MMF
Enable low-cost, low power transceivers

Multimode Fibre (MMF)



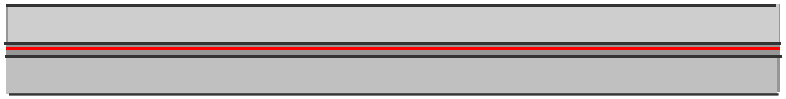
OM3 and OM4 50-micron core fibre is most common today.
Optimized for transmission using 850-nm VCSELs.
Easy to maintain, low-cost connectors, low cost transceivers

1310nm edge-emitting lasers



Higher cost laser source
High Current & Power
Used predominantly with SMF
Various wavelengths for WDM applications
Typically more expensive to package
Used to power Si and InP Photonics

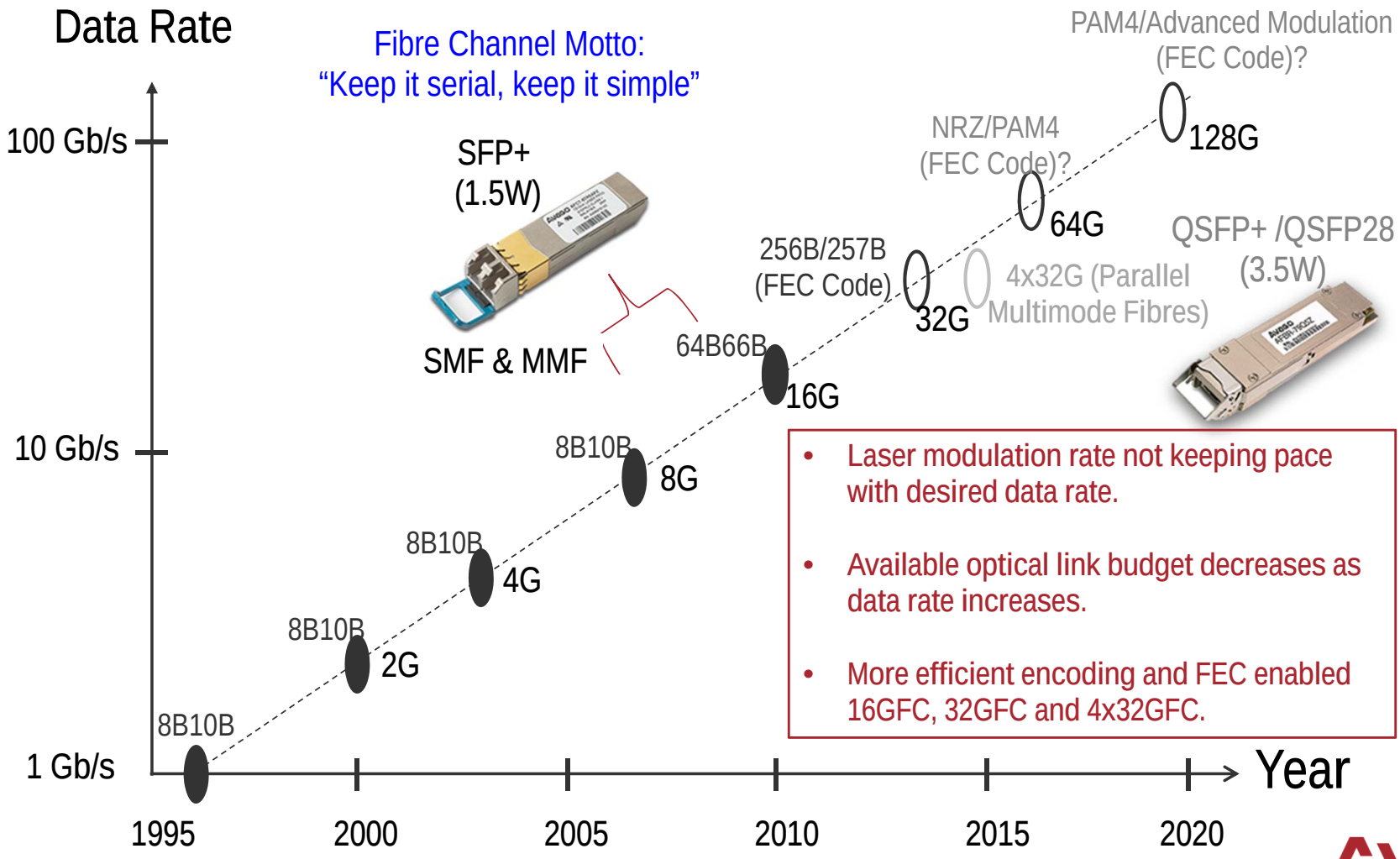
Single mode Fibre (SMF)



SMF generally used for >300 links using 1310nm sources
Long reach capable, low cost/meter
More expensive to connectorize than MMF

AVAGO TECHNOLOGIES

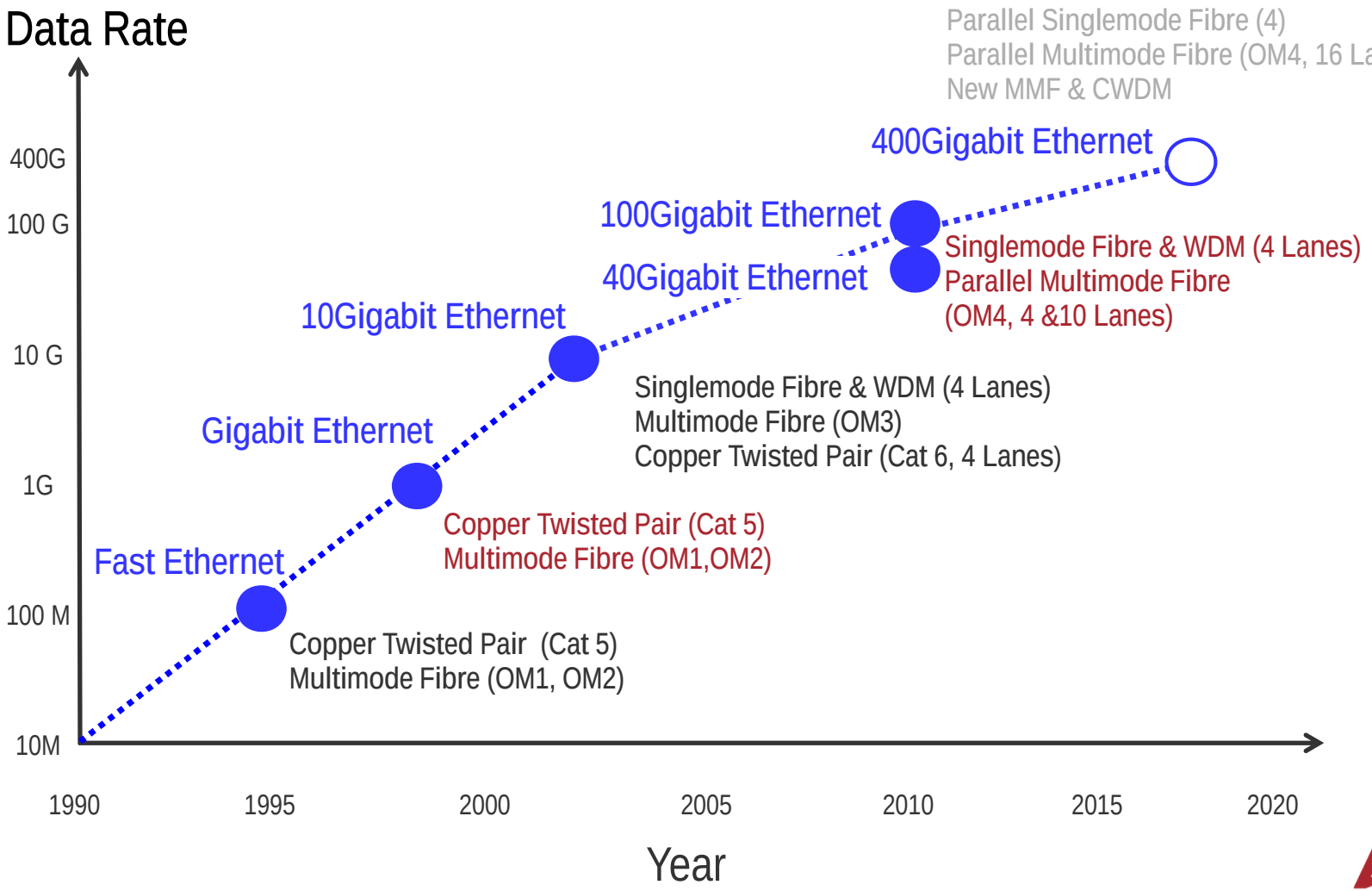
Fibre Channel Data Rate & Encoding Roadmap



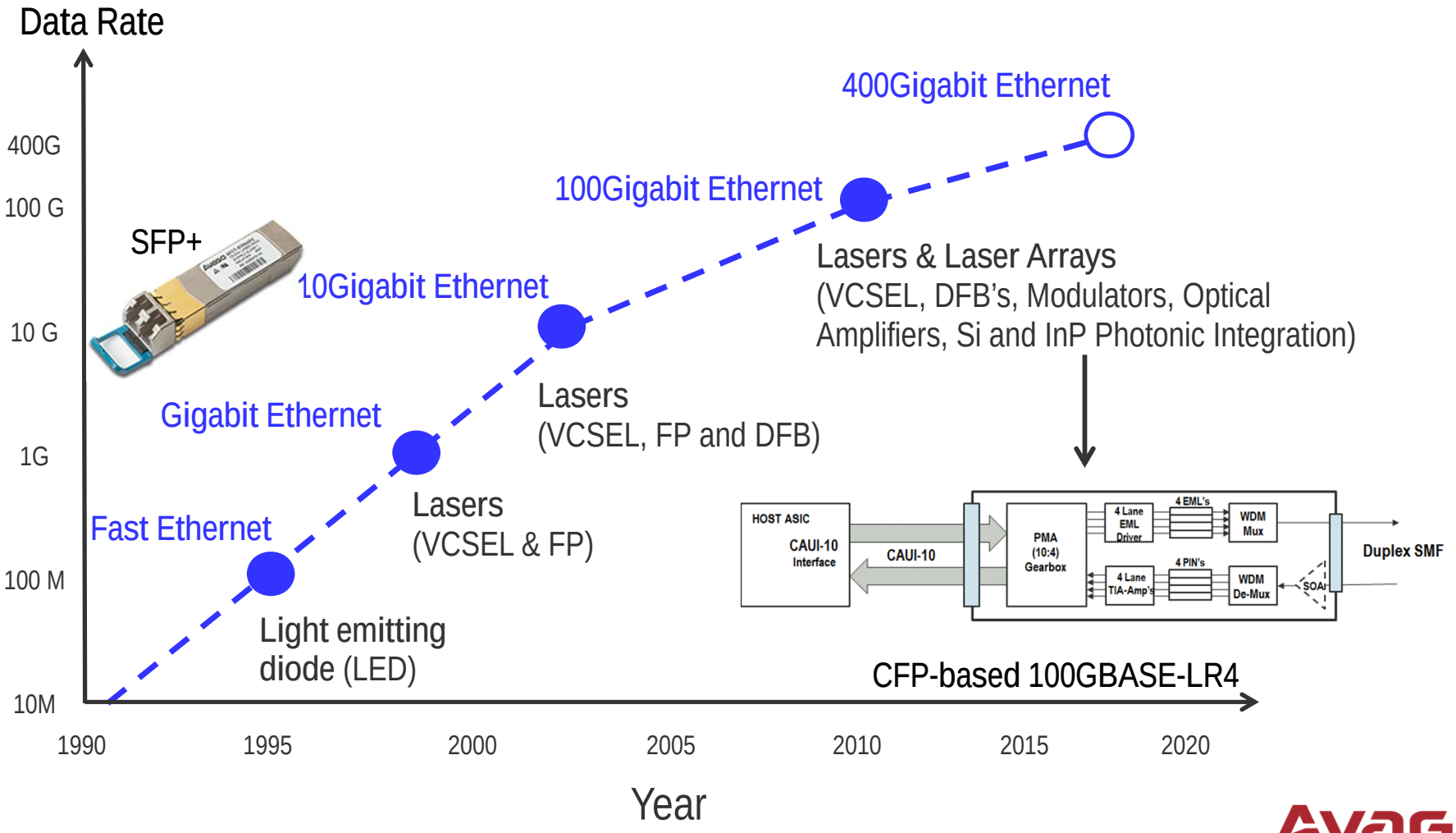
- Laser modulation rate not keeping pace with desired data rate.
- Available optical link budget decreases as data rate increases.
- More efficient encoding and FEC enabled 16GFC, 32GFC and 4x32GFC.

AVAGO TECHNOLOGIES

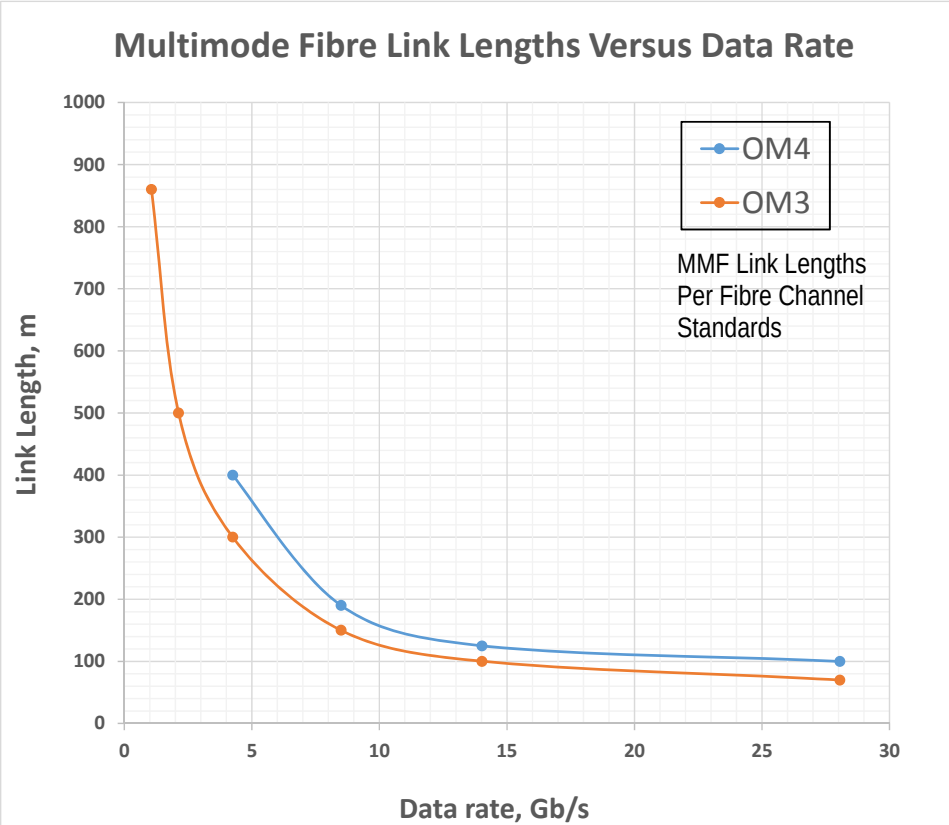
Ethernet Data Rate & Transmission Media Evolution



Ethernet Data Rate & Optical Device Technology Evolution



Trend Of Multimode Fibre Link Lengths



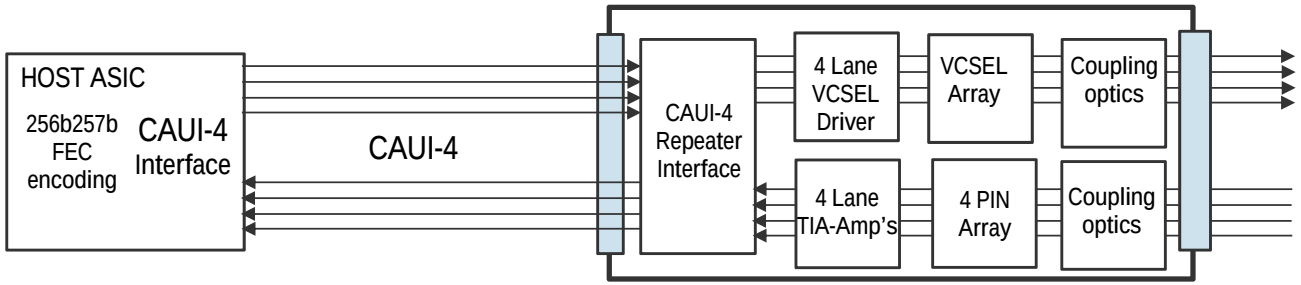
- The historical trend for multimode fibre link lengths is shown in the graph.
- Methods are under discussion to ensure at least 100 m operation for higher data rates.

Methods under discussion include:

- VCSEL's operating at longer wavelengths than 850 nm: increases VCSEL bandwidth and decreases mode partition noise
- Multilevel modulation, which is enabled by the emergence of PAM based electrical specifications and FEC: even at 850 nm PAM4 would enable 100 m links for 64GFC
- VCSEL-based CWDM, wavelengths TBD

The need to reduce the lane count for SMF optics and the lack of bandwidth of the SMF optical components means that multilevel modulation with FEC is also being considered for next generation SMF links.

100GBASE-SR4 Parallel MMF (4x 25.78125 Gb/s)



- Parallel MMF
- 100 m OM4
- 70 m OM3

- At 25.8 Gb/s MMF-based optics is bandwidth and noise challenged
- Therefore, 64b66b will be transcoded into 256b257b to provide FEC
- The Reed Solomon Code (RS (528,514)) provides about 3 dBo of coding gain
- The FEC reduces the optical power budget and ensures signal integrity
- Can expect that 100GBASE-SR4 will use QSFP+
- Board mounted 4x25.8 Gb/s optics will also be available for high density applications

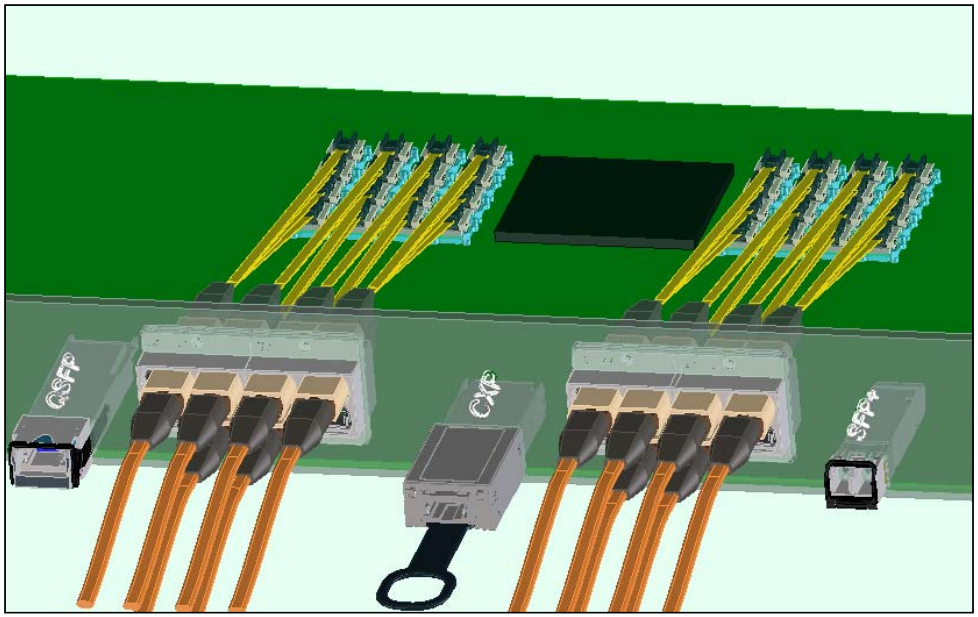
Pluggable Form Factor Choices For 10G to 100G Applications

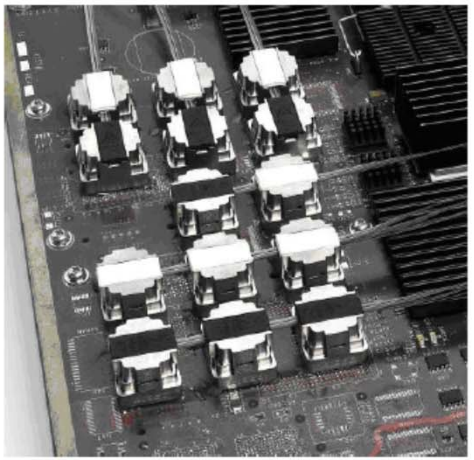
Which to choose? It depends upon the application.		Industry Pluggable Form factor (with Max power)			
		SFP+ (1.5W) 	QSFP+ /QSFP28 (3.5W) 	CXP (3.5W) 	CFP / CFP2 / CFP4 (32W / 12W / 6W) 
Lane Signaling Rate	~10G	8GFC,10GbE Duplex MMF & SMF	4x10GbE / 1x40GbE QDR-IB Parallel MMF & SMF	12x10GbE /100G SR10 QDR-IB Parallel MMF only	CFP:100G MMF/SMF CFP2: 100G SR10
	~14G	16GFC Duplex MMF & SMF	16GFC FDR-IB MMF & SMF	FDR-IB Proprietary inter. Parallel MMF only	NA
	~25G	32GFC Duplex MMF & SMF	100GbE / EDR-IB 128GFC MMF & SMF	EDR-IB Proprietary inter. MMF only	CFP2: 100G SR4/LR4 CFP4 :100G SR4/LR4 MMF & SMF

It is expected that a new form factor “CDCFP” will emerge for 400Gigabit Ethernet.

AVAGO TECHNOLOGIES

Pluggable Embedded Parallel Optics & CXP Modules For High Density 100GbE & Infiniband





For MMF applications board mounted pluggable optics and front panel pluggable CXP modules with electrical nPPI interfaces offer higher density than front panel pluggable CFP# modules.

AVAGO TECHNOLOGIES

Summary

- Standards-based electrical and optical lanes operating at 20 – 28 Gb/s are almost specified and are getting ready for products.
- The next generation of standards-based electrical and optical lane rates will be around 50-56 Gb/s.
- To support 50-56 Gb/s and higher lane rates various methods will be reused or developed:
  - More lanes (via parallel conductors, fibres or wavelengths), Multilevel modulation, FEC and integrated photonics.
  - For multimode fibre applications new, higher bandwidth, longer wavelength, VCSEL's are likely to emerge along with a new MMF optimised for CWDM operation at longer wavelengths. At a minimum these developments will maintain the MMF worst case link distance of 100 m.
- Whilst 100GbE implementations continue to reduce their lane count, power, size and cost, early implementations of 400GbE may start with 16 lanes of 25.8 Gb/s per lane in large packages and the cycle will continue again.

Backup Slides

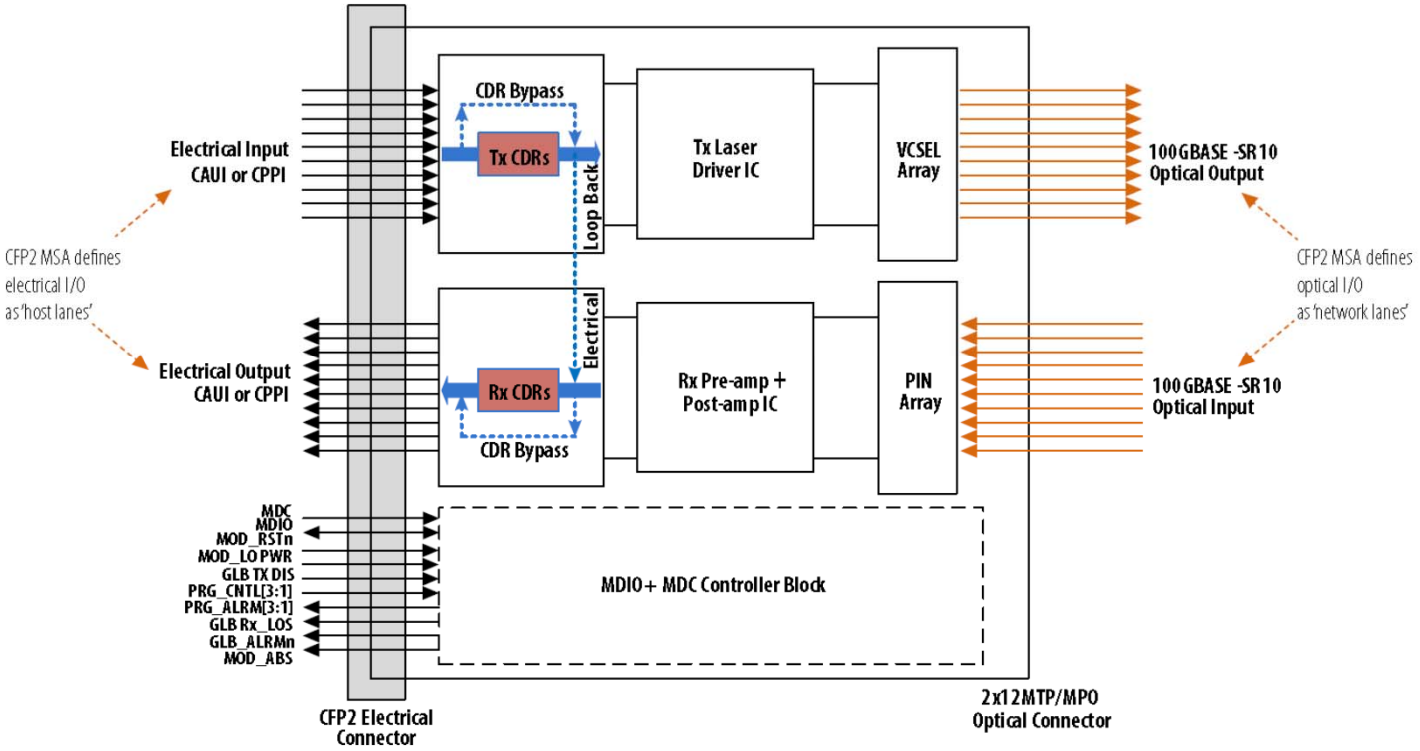
Trends For Standards-Based Electrical Interfaces

Interface Name	Year	Per Lane Rate (Gb/s)	Number of Lanes	Modulation (Encoding)	FEC	Equalization Required
SBI	2000	0.645	16	NRZ (64B66B)	None	No
XAUI	2002	3.125	4	NRZ (8B10B)	None	No
XFI	2005	10.3125	1	NRZ (64B66B)	None	No
SFI	2009	10.3125	1	NRZ (64B66B)	None	No
SFI 16GFC	2009	14.025	1	NRZ (64B66B)	None	No
10GBASE-KR	2010	10.313	1	NRZ (64B66B)	Optional	Yes
XLAUI-4	2011	10.3125	4	NRZ (64B66B)	None	No
CAUI-10	2011	10.3125	10	NRZ (64B66B)	None	No
CEI-28-VSR	2014	28.050	As required by application	NRZ (per application)	None	Yes
SFI 32GFC	2013	28.050	1	NRZ (256B/257B)	RS(528,514)	Yes
100GBASE-KR4	2013	25.7813	4	NRZ (256B/257B)	RS(528,514)	Yes
100GBASE-KP4	2013	26.5625	4	PAM4	RS(544,514)	Yes
128GFC (4x32GFC)	2014	28.0500	4	NRZ (256B/257B)	RS(528,514)	Yes
CAUI-4	2015	25.7813	4	NRZ (256B/257B)	RS(528,514)	Yes
CDAUI-16	2017	25.7813	16	NRZ (256B/257B)	RS(528,514)	Yes
CEI-56-VSR	2016	56.1	As required by application	PAM4	?	Yes
SFI 64GFC	2016	56.1	1	PAM4 ?	Yes (TBD)	Yes
256GFC (4x64)	2017	56.1	4	PAM4 ?	Yes (TBD)	Yes
CDAUI-8	2018	51.5625	8	PAM4 ?	Yes (TBD)	Yes
XLAU	2018	41.25	1	PAM4 ?	Yes (TBD)	Yes
SFI 128GFC	2020	112.2	1	Complex Modulation ?	Yes (TBD)	Yes
CDAUI-4	2022	103.125	4	Complex Modulation ?	Yes (TBD)	Yes

The future trend, in blue, is based on the author's interpretation of publicly available roadmaps or predictions per IEEE 802.3, Fibre Channel and the OIF websites.

A graph might show the trend better than a table…… queue next slide.

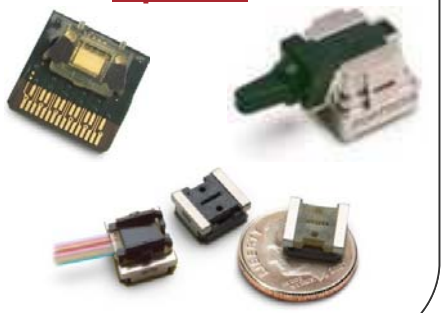
CFP2 100GBASE-SR10



- 100 m on OM3
- 150 m on OM4

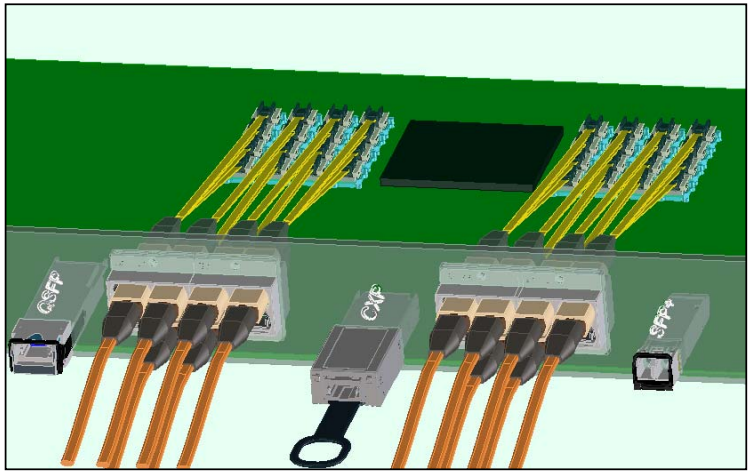
Optical Form Factor Options

Board mounted optics



Pluggable transceivers

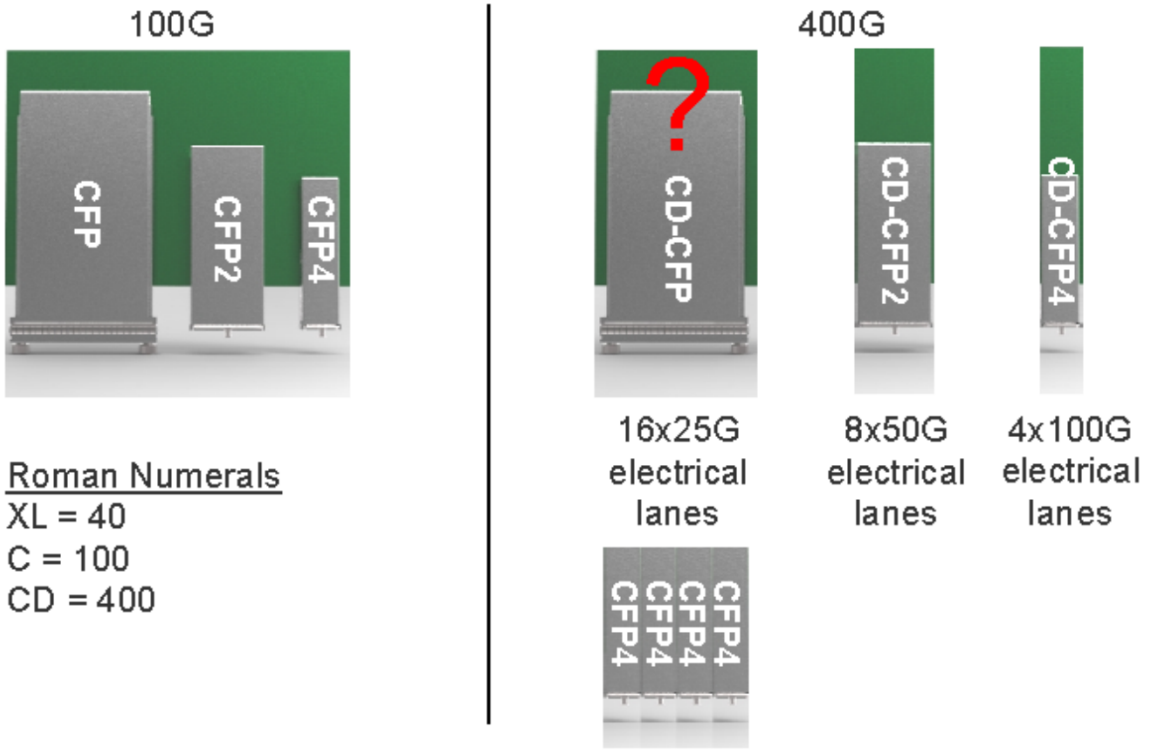
Pluggable AOCs



Board mounted optics offer density advantages.

Pluggable optics offer flexibility.

Form Factor Evolution to 400G



3 400 Gb/s Ethernet Study Group Geneva, Switzerland, July 2013

JUNIPER NETWORKS

Slide taken from:
http://www.ieee802.org/3/400GSG/public/13_07/maki_400_01_0713.pdf

AVAGO TECHNOLOGIES