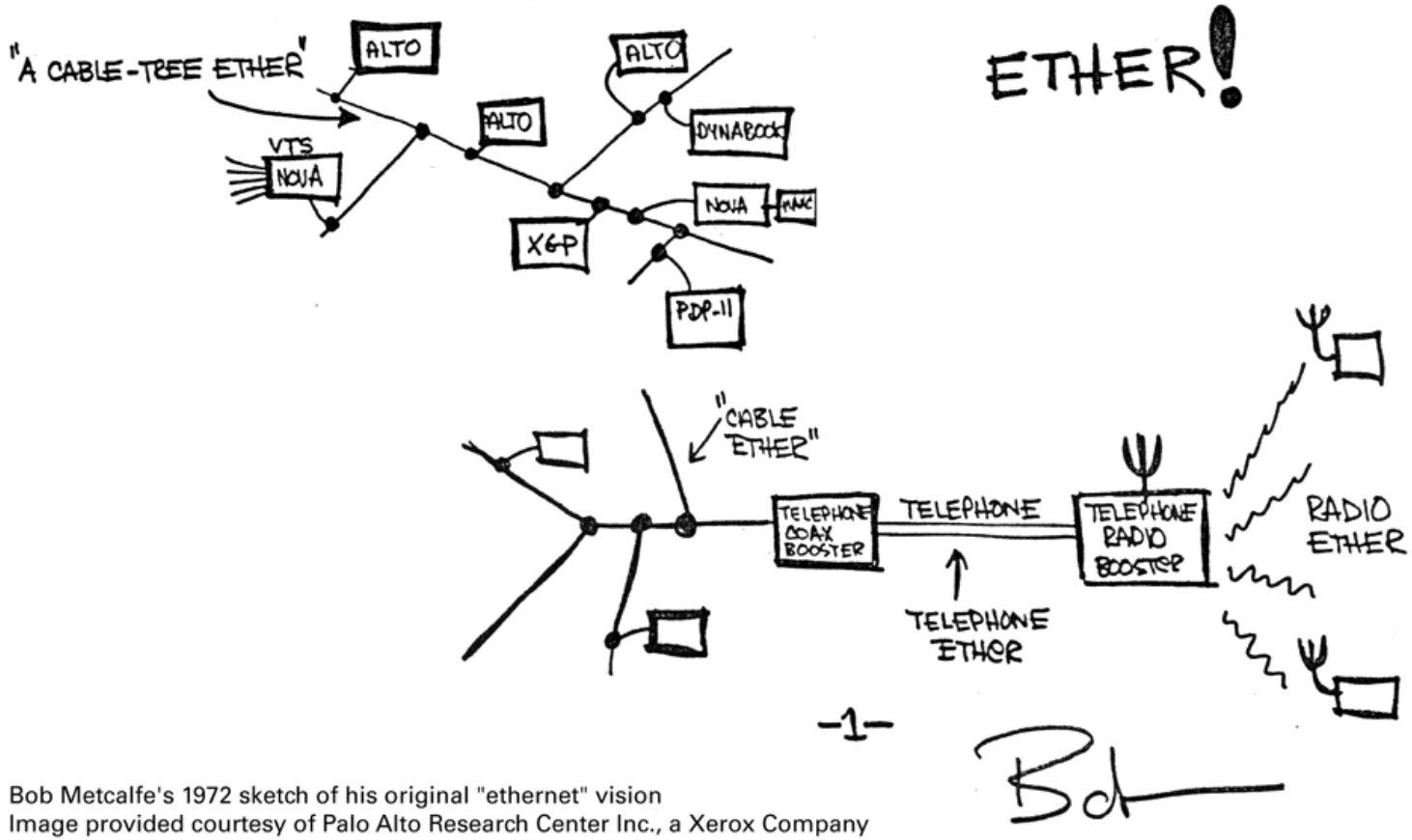
“Here is more rough stuff on the ALTO ALOHA network.”

Memo sent by Bob Metcalfe on May 22, 1973.



Bob Metcalfe's 1972 sketch of his original "ethernet" vision
Image provided courtesy of Palo Alto Research Center Inc., a Xerox Company

EVOLUTION OF ETHERNET SPEEDS
WHAT’S NEW AND WHAT’S NEXT

Greg Hankins <greg.hankins@alcatel-lucent.com>
RONOG 1

Alcatel·Lucent

AGENDA

1. **Ethernet Speed Evolution**
2. What's Next: 2.5 GE, 5 GE, 25 GE and 50 GE
3. What's New: 40 GE
4. What's New: 100 GE
5. What's Next: 400 GE

ETHERNET SPEED EVOLUTION OVER 40+ YEARS

EACH EVOLUTION DELIVERS HIGHER SPEEDS AND/OR LOWER COSTS PER BIT

Speed	Name	Year	
2.94 Mb/s	Ethernet Invented!	1973	
10 Mb/s	Ethernet II (DIX)	1982	
10 Mb/s	IEEE 802.3	1983	
100 Mb/s	IEEE 802.3u	1995	
1 Gb/s	IEEE 802.3z	1998	
2.5 Gb/s	**MGBASE-T**	**Soon**	New Speeds
5 Gb/s	**MGBASE-T**	**Soon**	
10 Gb/s	IEEE 802.3ae	2002	
25 Gb/s	**IEEE 802.3??**	**~2016**	
25 Gb/s	**25G-50G Specification**	**Soon**	
50 Gb/s	**25G-50G Specification**	**Soon**	
40 Gb/s	**IEEE 802.3ba**	**2010**	New Interfaces
100 Gb/s	**IEEE 802.3ba**	**2010**	
400 Gb/s	**IEEE 802.3bs**	**~2017**	

KEY INDUSTRY DEVELOPMENTS FOR THE NEXT COUPLE OF YEAR
MAKING ETHERNET FASTER AND CHEAPER

Ethernet Standards

IEEE
- 802.3 25 Gb/s Ethernet Study Group
- P802.3bm 40 Gb/s and 100 Gb/s Operation Over Fiber Optic Cables Task Force
- P802.3bq 40GBASE-T Task Force
- P802.3bs 400 Gb/s Ethernet Task Force

Ethernet MSAs and Consortiums

10X10 MSA
- 10x10: 2 km, 10 km, 40 km 100 GE

100G PSM4 MSA
- PSM4: 500 m 100 GE

CWDM4 MSA Group
- CWDM4: 2 km 100 GE

100G CLR4 Alliance
- CLR4: 2 km 100 GE

OpenOptics MSA
- OpenOptics: 2+ km 100 GE

- MGBASE-T Alliance: 2.5 GE and 5 GE

25G Ethernet 50G Consortium
- 25 Gigabit Ethernet Consortium: 25 GE and 50 GE

Pluggable Module MSAs

Next-generation form factors

CFP
- CFP MSA: CFP4 (100 GE)

SFF Committee
- SFF Committee: SFP28 (25 GE), QSFP28 (100 GE)

CDFP
- CDFP MSA: CDFP (400 GE)

Component Standards

OIF Optical Internetworking Forum

Electrical signaling from ASICs to pluggable modules
- 25 Gb/s (CEI-28G-VSR)
- 50 Gb/s (CEI-56G-VSR)

"MSA" means Multisource Agreement.

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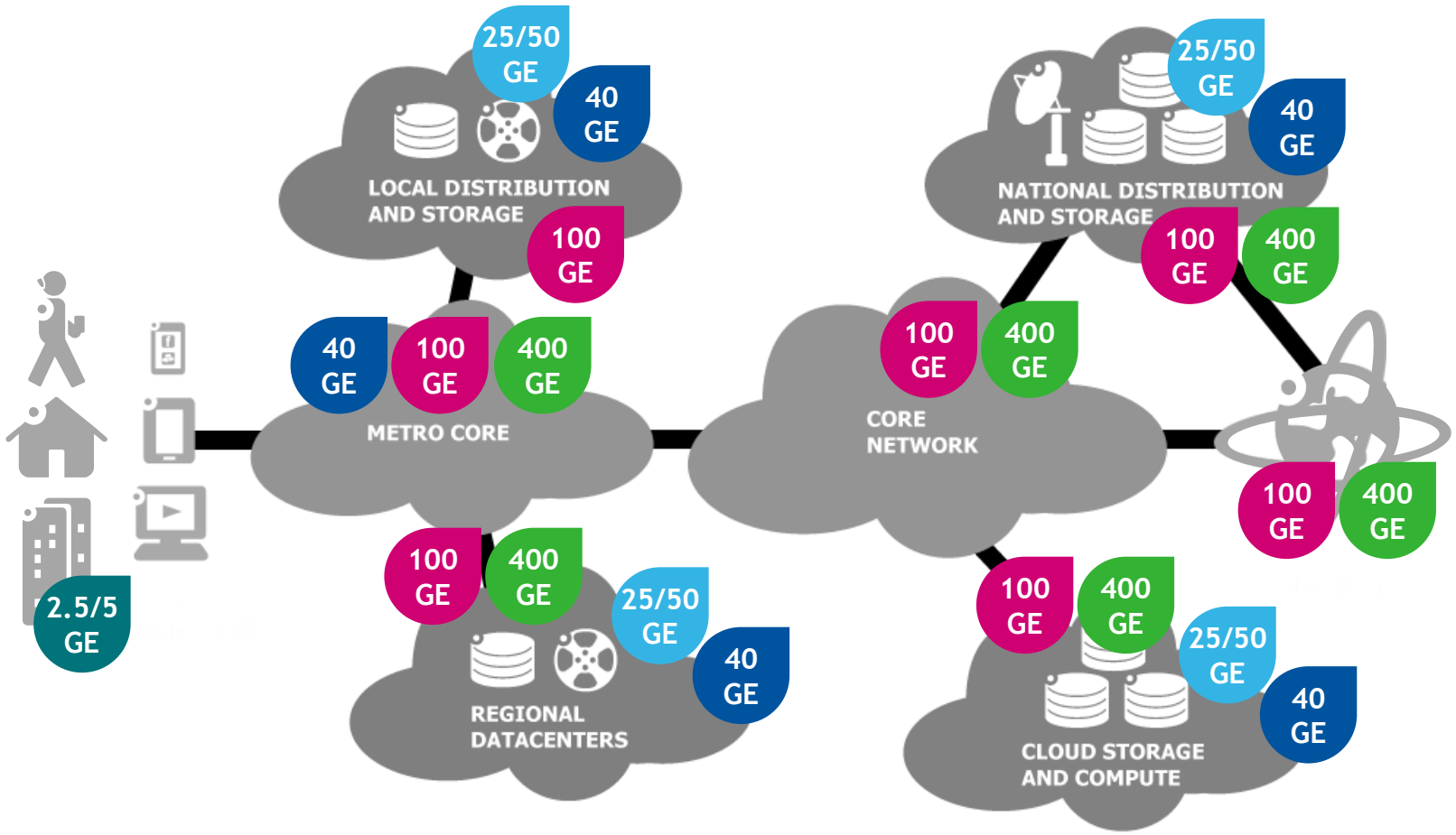
ETHERNET TARGET APPLICATIONS
KEY APPLICATION DRIVERS



2.5/5 GE Applications (Soon)

- Cat 5/6e

25/50 GE Applications (~2016)

- Data Center Access
- Server NICs

40 GE Applications

- Data Center Aggregation and Core
- Data Center Access
- Server NICs
- Metro Core

100 GE Applications

- Service Provider Aggregation and Core
- Data Center Core
- Metro Core

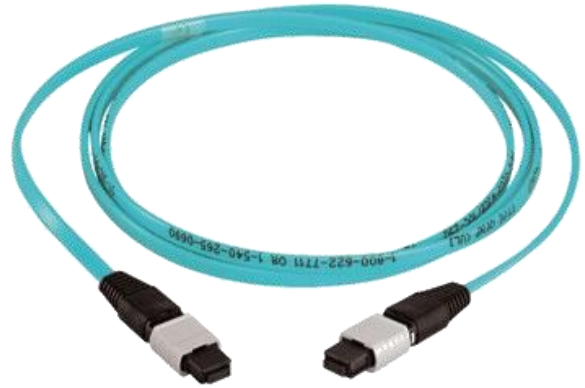
400 GE Applications (~2017)

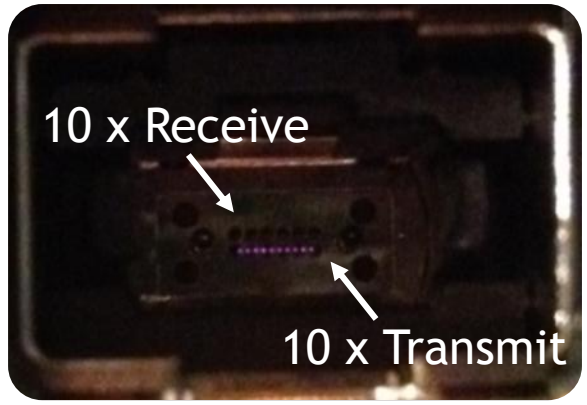
- Service Provider Core
- Large Data Center Core
- Large Metro Core

MPO CABLE ASSEMBLIES
HIGH DENSITY RIBBON FIBER CABLING

- 40 GE and 100 GE short reach pluggable modules use a multifiber push on (MPO) cable assembly to interconnect network devices
  - Also called MTP by US Conec
- Widely available in a variety of high density multimode fiber (MMF) and single-mode fiber (SMF) cabling options for data centers
  - MPO to MPO
  - MPO cassette for patch panels with into LC, SC, etc
  - Keyed connectors maintain correct transmit/receive orientation
- 40GBASE-SR4 uses a 12-fiber OM3 or OM4 MMF MPO cable
  - 8 fibers used, left 4 for transmit and right 4 for receive
  - 4 middle fibers are unused
- 100GBASE-SR10 uses a 24-fiber OM3 or OM4 MMF MPO cable
  - 20 fibers used, top middle 10 for receive and bottom middle 10 for transmit
  - 2 fibers on each end are unused

12-Fiber MPO Cable Connector





100GBASE-SR10 CXP

AGENDA

1. Ethernet Speed Evolution
2. **What's Next: 2.5 GE, 5 GE, 25 GE and 50 GE**
3. What's New: 40 GE
4. What's New: 100 GE
5. What's Next: 400 GE

WHY LOWER SPEEDS?

- 2.5 GE and 5 GE
  - Enabling the large installed base of Cat 5e/6 UTP cabling to support new applications
  - 802.11ac wireless capable of multiple Gb/s throughput needs faster Ethernet
  - 10GBASE-T has limited distance on existing cabling
- 25 GE and 50 GE
  - Single 25 Gb/s lane preferred over 40 GE's 4 x 10 Gb/s lanes in hardware design
  - Maximizes ports and bandwidth in ToR switch front panel: 48-port 25 GE + 4-port 100 GE (or 4 x 25 GE)
  - Lower cost of SFP28 compared to QSFP+

LOWER SPEED ETHERNET DEVELOPMENTS

	MGBASE-T Alliance	25 Gigabit Ethernet Consortium	IEEE 802.3 25 Gb/s Ethernet Study Group
Media	Cat 5e/6 UTP	Backplane Twinax Copper Active Optical Cable?	1 m Backplane 3 m and 5 m Twinax Copper 70 m OM3 and 100 m OM4 MMF
Signaling (Gb/s)	2.5 GE: 2 x 1.25 5 GE: 4 x 1.25	25 GE: 1 x 25 50 GE: 2 x 25	1 x 25
Founded	June 2014	July 2014	September 2014
Supporters	Broadcom	Arista, Broadcom, Brocade, Google, Mellanox, Microsoft	Industry
More Information	http://www.broadcom.com/support/MGBaseT/	25G Ethernet 50G Consortium http://www.25gethernet.org/	IEEE http://www.ieee802.org/3/25GSG/public/index.html

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40 GB/S QSFP+ MODULES OVERVIEW
QUAD SMALL FORM-FACTOR PLUGGABLE+

- Created for high density interfaces primarily short reach interfaces for data center applications
  - Small compact form factor enables low power consumption and high density
  - Also used for longer reach 40 GE
- Used for a variety of Ethernet, Fibre Channel and InfiniBand applications
  - 40 GE uses 4 x 10 Gb/s bidirectional channels
- Supports a variety of copper and fiber 40 GE interfaces
  - Breakout from 40 GE to 4 x 10 GE
- Same faceplate size as an XFP but slightly shorter

40GBASE-SR4

40GBASE-LR4

Images courtesy of Finisar.

40 GBE QSFP+ PLUGGABLE MODULE SUPPORT

	Data Center Server and Access *40 GE to 4 x 10 GE Breakout*			Aggregation and Core *Native 40 GE*	
Physical Layer Reach	**10 m Passive Copper Cable**	**100 m OM3/OM4**	**7 m Passive Copper Cable**	**100 m OM3/ 150 m OM4**	**10 km SMF**
Pluggable Module	 10GSFP+Cu	 10GBASE-SR	 40GBASE-CR4	 40GBASE-SR4	 40GBASE-LR4
Media	 Integrated Twinax (QSFP+ to 4 x SFP+)	 Parallel MMF (12-Fiber MPO to 4 x Duplex LC)	 Integrated Twinax (QSFP+ to QSFP+)	 Parallel MMF (12-Fiber MPO)	 Duplex SMF (LC)
Standard	July 2009 SFF-8431	June 2002 IEEE 802.3ae	June 2010 IEEE 802.3ba	June 2010 IEEE 802.3ba	June 2010 IEEE 802.3ba

40GBASE-SR4 and 40GBASE-LR4 QSFP+ images courtesy of Finisar.

40 GE TECHNOLOGY REFERENCE

Physical Layer Reach	1 m Backplane	7 m Copper Cable	30 m *TP	100 m OM3 / 150 m OM4	2 km SMF	10 km SMF	40 km SMF
Name	40GBASE-KR4	40GBASE-CR4	40GBASE-T	40GBASE-SR4	40GBASE-FR	40GBASE- LR4	40GBASE-ER4
Standard	June 2010 IEEE 802.3ba	June 2010 IEEE 802.3ba	September 2015 IEEE 802.3bq	June 2010 IEEE 802.3ba	March 2011 IEEE 802.3bg	June 2010 IEEE 802.3ba	March 2015 IEEE 802.3bm
Electrical Signaling (Gb/s)	4 x 10	4 x 10	4 x 10	4 x 10	4 x 10	4 x 10	4 x 10
Media Signaling (Gb/s)	4 x 10	4 x 10	4 x 10	4 x 10 850 nm	1 x 40 1310 nm (RX) 1550 nm (TX, RX)	4 x 10 1310 nm λs	4 x 10 1310 nm λs
Media Type	Backplane	Twinax	Cat 8.1 F/UTP? Cat 8.2 S/FTP?	Parallel MMF (12-Fiber MPO)	Duplex SMF	Duplex SMF	Duplex SMF
Module Type	Backplane	QSFP+	RJ45?, GG45?, TERA?	CFP, QSFP+	CFP	CFP, QSFP+	QSFP+
Market Availability	No Known Development	2010	2015+	2010	2012	CFP 2010 QSFP+ 2011	2015

AGENDA

1. Ethernet Speed Evolution
2. What's Next: 2.5 GE, 5 GE, 25 GE and 50 GE
3. What's New: 40 GE
4. **What's New: 100 GE**
5. What's Next: 400 GE

100 GE PLUGGABLE MODULES OVERVIEW

CXP
C (100)
X
Pluggable

- Designed for high-density short reach applications
  - Small compact form factor limits distance to MMF interfaces
- Used for 100GBASE-SR10 and InfiniBand 12X QDR
  - Provides 12 bidirectional channels over 24 parallel fibers
  - 100 GE uses 10 of the 12 channels
- Slightly wider and shorter than an XFP (27 mm wide x 45 mm long)

CFP
C (100)
Form-Factor
Pluggable

- New module optimized for 100 GE long reach applications, but also used for short reach applications
- Used for IEEE Ethernet and 10x10 MSA standards
- Complex electrical gearbox and optical components need a large module
  - Long reach modules contain an integrated WDM component for duplex SMF transmission
- Large size and power consumption limits front panel density
- Larger than an iPhone 4 (82 mm wide x 145 mm long)

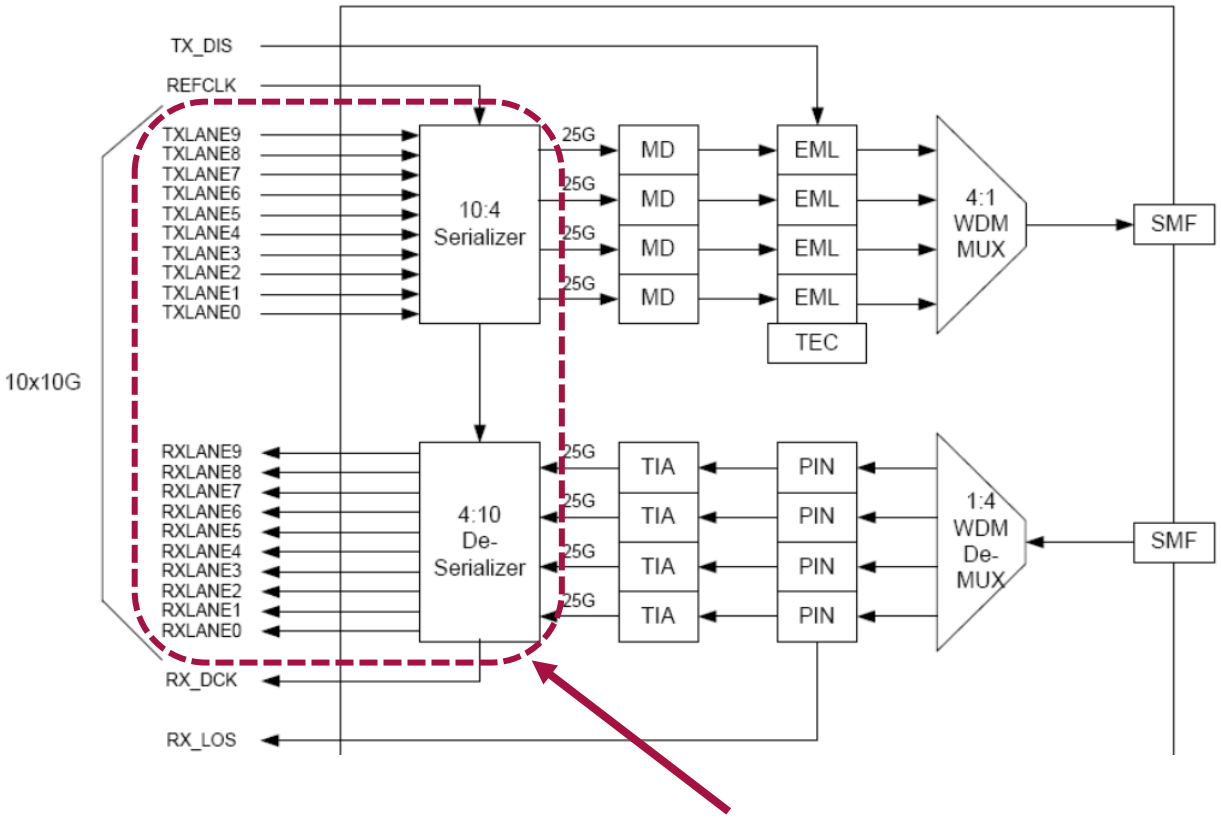
CFP2
C (100)
Form-Factor
Pluggable 2

- 2nd generation 100 GE module
- Optional external universal gearbox can convert electrical signaling so that all current IEEE and MSA 100 GE standards can be supported in the CFP2 module
- Smaller size and lower cost, complexity and power consumption than the CFP
- Approximately ½ the width of a CFP (41.5 mm wide x 107.5 mm long)

Images courtesy of Finisar.

1ST GENERATION VS 2ND GENERATION 100 GE SIGNALING

1st Generation 100 GE
10 x 10 Gb/s Electrical and 4 x 25 Gb/s Optical



10 Gb/s Electrical Signaling and
10:4 Gearbox Adds Complexity,
Cost, Space, and Consumes Power

2nd Generation 100 GE
4 x 25 Gb/s Electrical and Optical

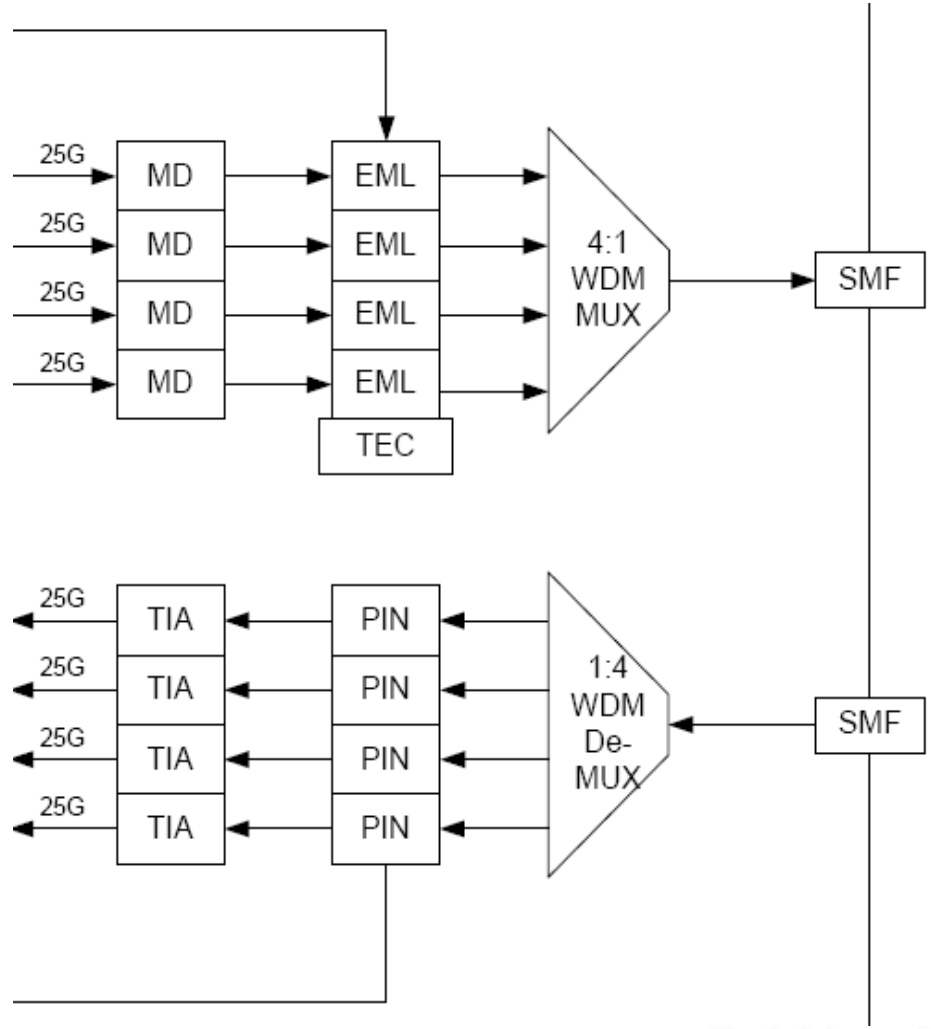


Diagram source: http://grouper.ieee.org/groups/802/3/ba/public/jul08/cole_03_0708.pdf

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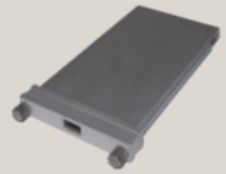
100 GE PLUGGABLE MODULE SUPPORT

	100 m OM3 / 150 m OM4			10 km SMF			40 km SMF	
Pluggable Module	 100GBASE-SR10 CXP	 100GBASE-SR10 CFP2	 100GBASE-SR10 CFP	 10x10-10km CFP	 100GBASE-LR4 CFP	 100GBASE-LR4 CFP2	 10x10-40km CFP	 100GBASE-ER4 CFP
Media	 Parallel MMF (24-Fiber MPO)	 Parallel MMF (24-Fiber MPO)	 Parallel MMF (24-Fiber MPO)	 Duplex SMF (LC)	 Duplex SMF (LC)	 Duplex SMF (LC)	 Duplex SMF (LC)	 Duplex SMF (LC)
Standard	June 2010 IEEE 802.3ba	June 2010 IEEE 802.3ba	June 2010 IEEE 802.3ba	August 2011 10x10 MSA	June 2010 IEEE 802.3ba	June 2010 IEEE 802.3ba	August 2011 10x10 MSA	June 2010 IEEE 802.3ba
Electrical Signaling (Gb/s)	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	4 x 25	10 x 10	10 x 10
Optical Signaling (Gb/s)	10 x 10 850 nm	10 x 10 850 nm	10 x 10 850 nm	10 x 10 1550 nm λs	4 x 25 1310 nm λs	4 x 25 1310 nm λs	10 x 10 1550 nm λs	4 x 25 1310 nm λs
Maximum Power Consumption (W)	3.5	TBD	12	19	20	TBD	TBD	26

Images courtesy of Finisar.

100 GE PLUGGABLE MODULE EVOLUTION

EACH MODULE INCREASES DENSITY, WHILE REDUCING COST AND POWER

	1st Generation		2nd Generation		
Market Availability	2010	2010	2014	2014	2015
Approximate Module Dimensions (Length x Width to Scale)					
Front Panel Density (1 RU)	4 Ports	12 Ports	8 Ports	22/44 Ports	16/32 Ports
Electrical Signaling (Gb/s)	10 x 10 CAUI-10	10 x 10 CPPI	10 x 10 CAUI-10[1] 4 x 25 CAUI-4	4 x 25 CAUI-4	4 x 25 CAUI-4
Media	MMF, SMF	Twinax, MMF	MMF, SMF	MMF, SMF	MMF, SMF
Power Consumption (W)	< 24 W (100GBASE-LR4) < 20 W (2nd Generation CFP)	< 6 W (100GBASE-SR10)	< 12 W (100GBASE-LR4)	< 3.5 W (100GBASE-SR10)	< 6 W (100GBASE-LR4)
Industry Standard Modules	 CFP (82 mm Wide)	 CXP (27 mm Wide)	 CFP2 (41.5 mm Wide)	 QSFP28 (18.35 mm Wide)	 CFP4 (21.7 mm Wide)
Cisco Proprietary Module			 CPAK (34.84 mm Wide)		

Pluggable module availability and capacity is based on industry developments, and are not a product roadmap commitment.

[1] Subject to market availability.

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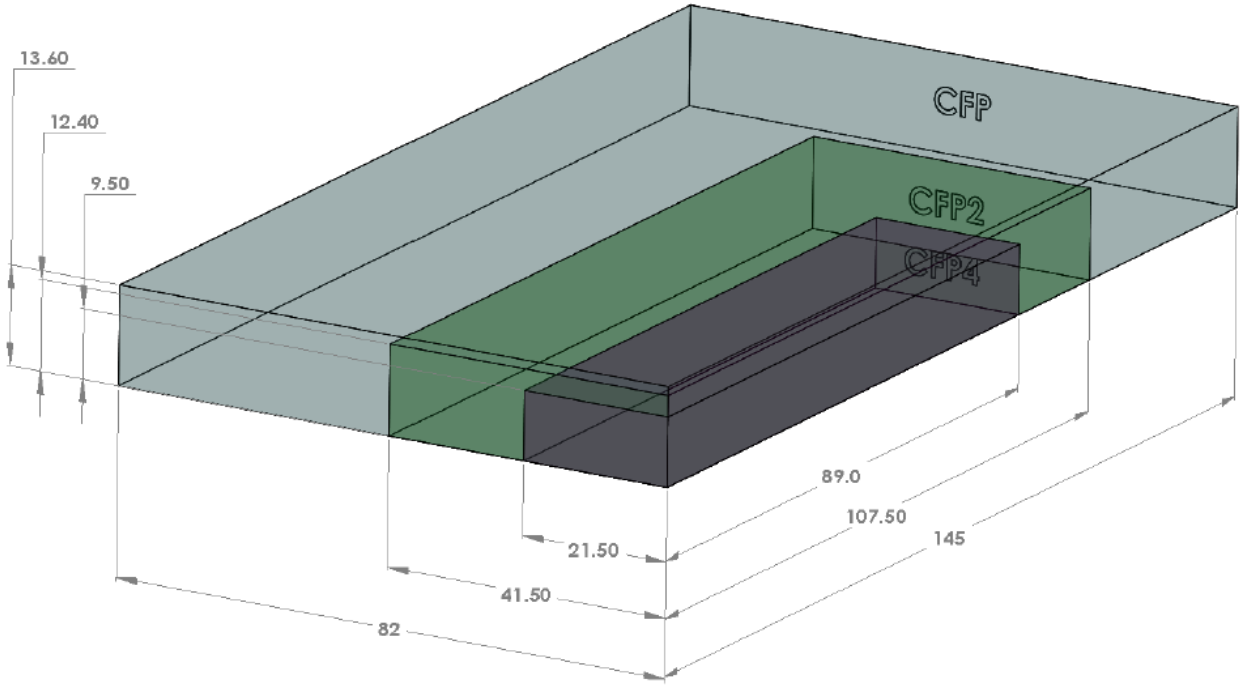
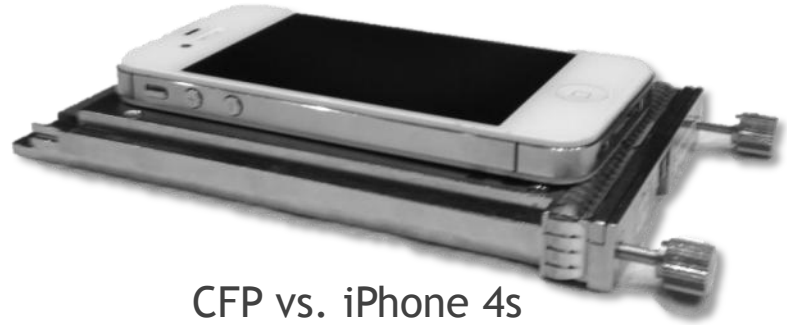
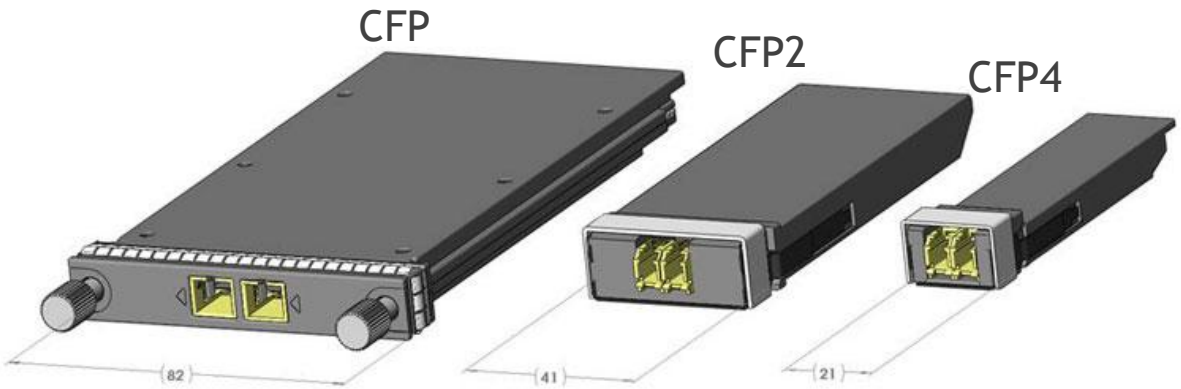
100 GE MODULE EVOLUTION
GRAPHICAL VIEW OF MODULE FORM FACTORS



CXP vs. iPhone 4s



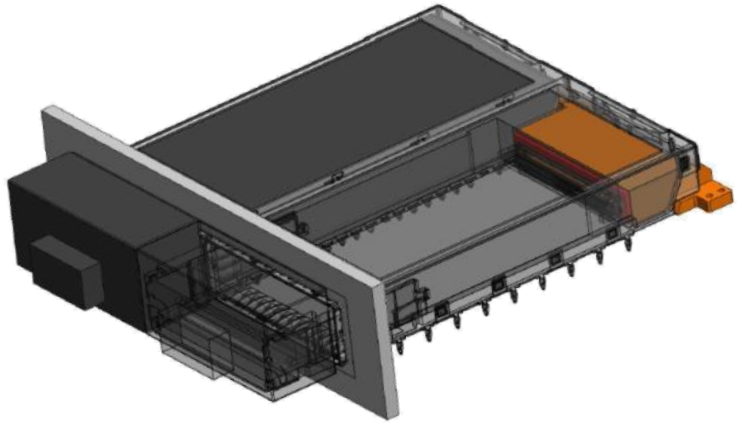
CFP vs. iPhone 4s



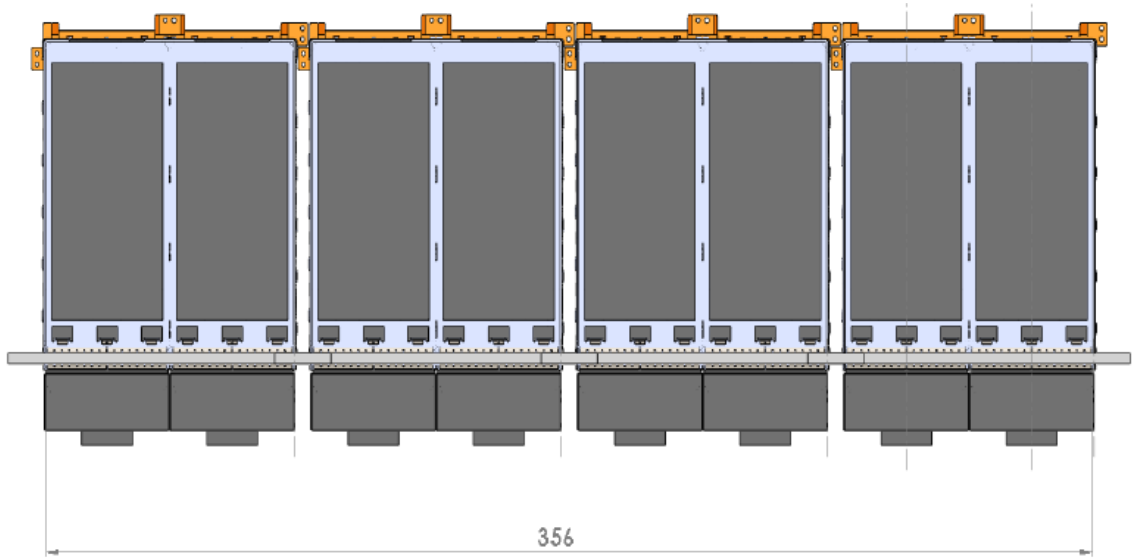
CFP2 vs. iPhone 4s

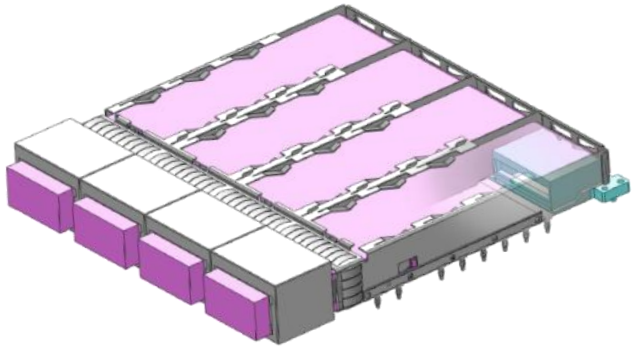
Diagrams courtesy of the CFP MSA.

CFP MODULE EVOLUTION FOR 100 GE AND 400 GE
HIGHER DENSITY CAGES AND FRONT PANEL DENSITY

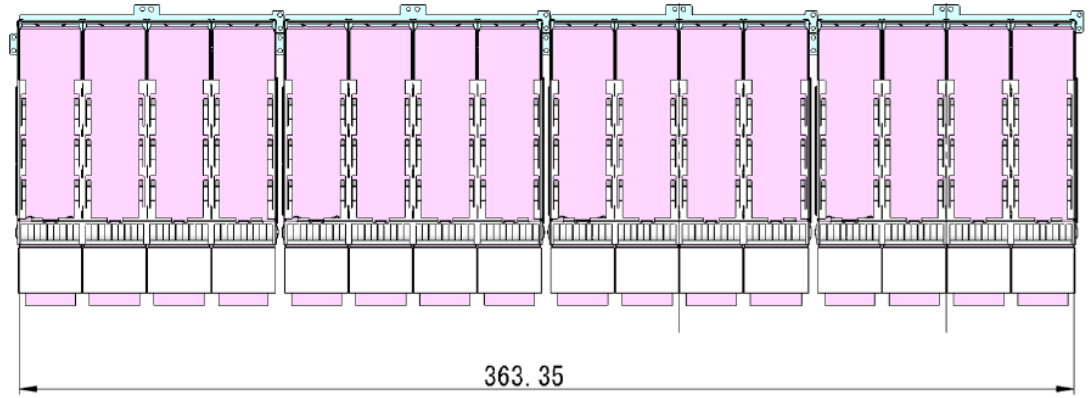


CFP2
8 Ports Per Card
Front Panel Density





CFP4
16 Ports Per Card
Front Panel Density



Diagrams courtesy of the CFP MSA.

100 GE MSAS
THIS SPACE IS A LITTLE CROWDED…

	10x10 MSA	100G PSM4 MSA	CWDM4 MSA Group	100G CLR4 Alliance	OpenOptics MSA
Pluggable Module	CFP	CFP4, QSFP28	CFP2, CFP4, QSFP28	QSFP28	QSFP28
Media	 Duplex SMF	 Parallel SMF (12-Fiber MPO)	 Duplex SMF	 Duplex SMF	 Duplex SMF
Physical Layer Reach	2 km, 10 km, 40 km	500 m	2 km	2 km	> 2 km
Optical Signaling (Gb/s)	10 x 10 1550 nm λs	4 x 25 1310 nm λs	4 x 25 1310 nm λs	4 x 25 1310 nm λs	4 x 25 1550 nm λs
Founded	December 2010	January 2014	March 2014	April 2014	March 2014
Supporters	Component Vendors, System Vendors, Network Operators	Component Vendors, System Vendors, Microsoft	Avago, Finisar, JDSU, Oclaro, Sumitomo	Intel, Arista, Component Vendors, System Vendors, Network Operators	RANOVUS, Mellanox
More Information	10X10 MSA www.10x10msa.org	100G PSM4 MSA www.psm4.org	CWDM4 MSA Group www.cwdm4-msa.org	100G CLR4 Alliance www.clr4-alliance.org	OpenOptics MSA www.openopticsmsa.org

"MSA" means Multisource Agreement.

100 GE TECHNOLOGY REFERENCE

1st Generation IEEE
1st Generation 10x10 MSA
2nd Generation IEEE

Physical Layer Reach	1 m Backplane	5 m Copper Cable	7 m Copper Cable	70 m OM3 / 100 m OM4	100 m OM3 / 150 m OM4	2 km SMF	10 km SMF		40 km SMF	
Name	100GBASE-KP4 100GBASE-KR4	100GBASE-CR4	100GBASE-CR10	100GBASE-SR4	100GBASE-SR10	10x10-2km	10x10-10km	100GBASE-LR4	10x10-40km	100GBASE-ER4
Standard	June 2014 IEEE 802.3bj	June 2014 IEEE 802.3bj	June 2010 IEEE 802.3ba	March 2015 IEEE 802.3bm	June 2010 IEEE 802.3ba	March 2011 10x10 MSA	August 2011 10x10 MSA	June 2010 IEEE 802.3ba	August 2011 10x10 MSA	June 2010 IEEE 802.3ba
Electrical Signaling (Gb/s)	4 x 25	4 x 25	10 x 10	4 x 25	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10
Media Signaling (Gb/s)	4 x 25 NRZ and PAM-4	4 x 25	10 x 10	4 x 25 850 nm	10 x 10 850 nm	10 x 10 1310 nm λs	10 x 10 1310 nm λs	4 x 25 1550 nm λs	10 x 10 1310 nm λs	4 x 25 1550 nm λs
Media Type	Backplane	Twinax Copper	Twinax Copper	Parallel MMF (12-Fiber MPO)	Parallel MMF (24-Fiber MPO)	Duplex SMF	Duplex SMF	Duplex SMF	Duplex SMF	Duplex SMF
Module Type	Backplane	CFP2, CFP4, QSFP28	CXP, CFP2, CFP4, QSFP28	CFP2, CFP4, CPAK, QSFP28	CFP, CFP2, CFP4, CPAK, CXP	CFP, CFP2?	CFP, CFP2?	CFP, CFP2, CFP4, CPAK, QSFP28	CFP, CFP2?	CFP, CFP2, CPAK?
Market Availability	2014+	2014+	2010	2015+	2012	2011	2011	2010	2014?	2012

AGENDA

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2. What's Next: 2.5 GE, 5 GE, 25 GE and 50 GE
3. What's New: 40 GE
4. What's New: 100 GE
5. **What's Next: 400 GE**

IEEE BANDWIDTH REQUIREMENT PROJECTIONS

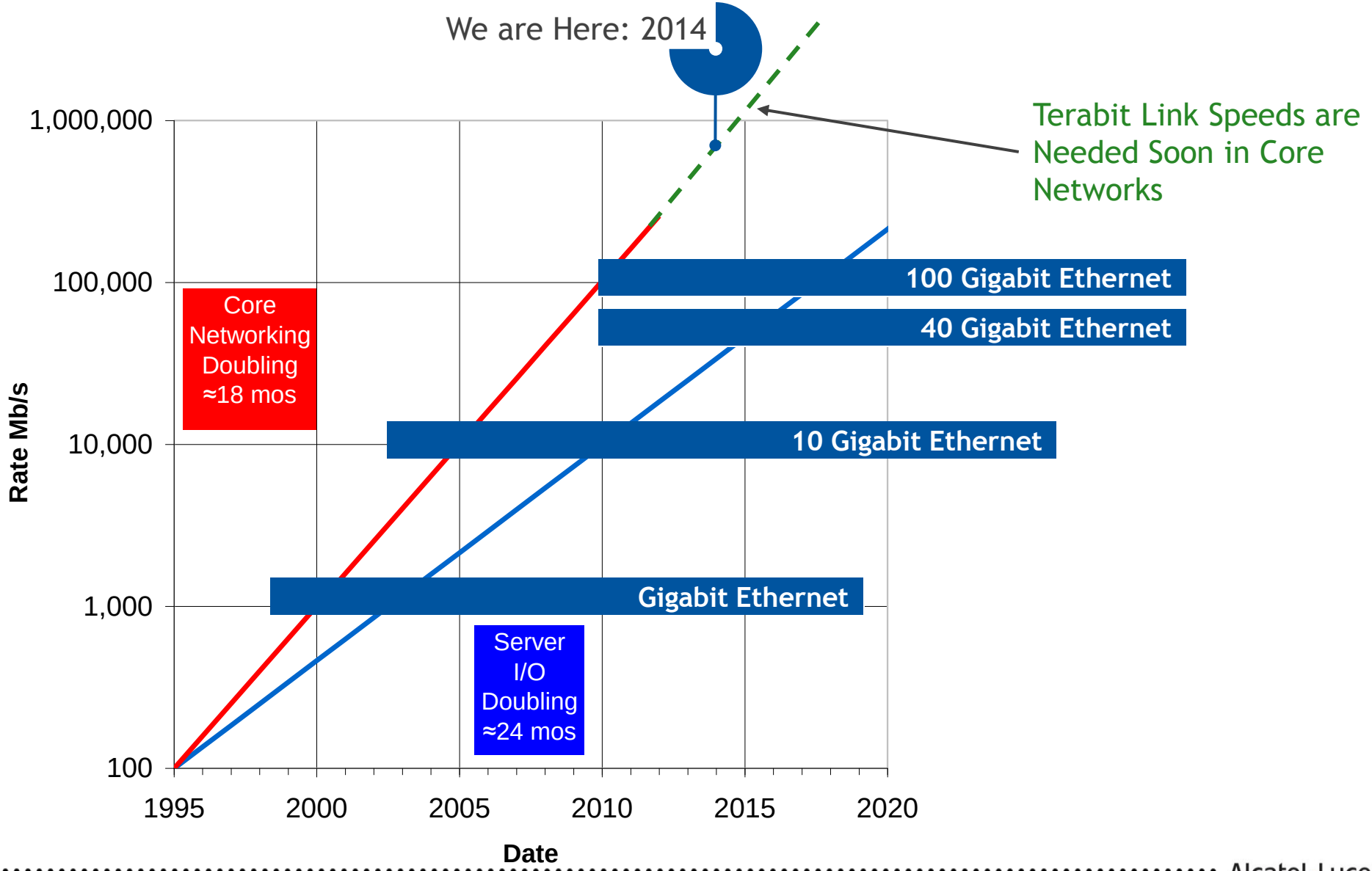


Diagram source: http://www.ieee802.org/3/hssg/public/nov07/HSSG_Tutorial_1107.zip

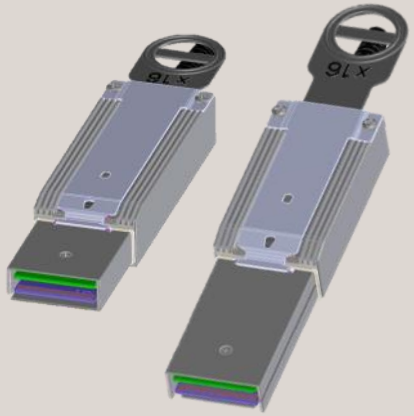
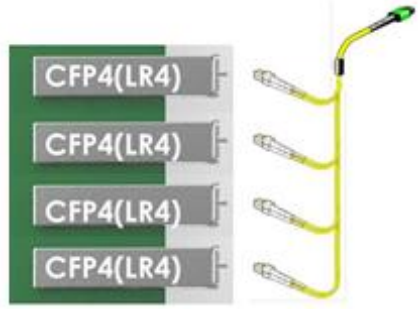
IEEE P802.3BS 400 GB/S ETHERNET TASK FORCE
WHY 400 GE? WHY NOT TERABIT SPEEDS?

- Given that Ethernet at terabit speeds is technically and economically impractical to develop until 2020+ we had to make a choice
  - Wait… for >10 years between Ethernet speed increases (100 GE June 2010)
  - Start a feasible higher speed Ethernet standard now that can be ready by 2017 when the market needs something faster
- High degree of consensus in the IEEE that 400 GE should be the next Ethernet speed
- P802.3bs 400 Gb/s Ethernet Task Force approved March 27, 2014

- Reach objectives adopted by Study Group at the November 2013 IEEE Plenary
  - 100 m MMF
  - 500 m SMF
  - 2 km SMF
  - 10 km SMF
  - Strong desire to support 400 GE to 4 x 100 GE breakout functionality based on 40 GE to 4 x 10 GE success
- 400 GE standard expected February 2017
- First interfaces expected to be available in 2017+
- Task Force web page http://www.ieee802.org/3/bs/

400 GE PLUGGABLE MODULE EVOLUTION ESTIMATES

EACH MODULE INCREASES DENSITY, WHILE REDUCING COST AND POWER

	1st Generation		2nd Generation	3rd Generation
Year	2017+	2017+	2019+	2022+
Electrical Signaling	CDAUI-16 16 x 25 Gb/s	CDAUI-16 16 x 25 Gb/s	CDAUI-8 8 x 50 Gb/s	CDAUI-4 4 x 100 Gb/s
Module				
	CDFP	4 x CFP4	CFP2	CFP4

Ethernet at Terabit Speeds Becomes Feasible

CDFP images courtesy of the CDFP MSA.
CFP images courtesy of Finisar and TE Connectivity.

ETHERNET SPEED EVOLUTION SUMMARY

- 2.5 GE and 5 GE is coming soon for higher speed Cat 5e/6 applications
- 10 GE is being widely deployed in every part of the network
  - 10 GE servers are driving the need for 40 GE and 100 GE in data centers
- 25 GE and 50 GE is coming soon for server NIC and ToR
- 40 GE is increasingly deployed in data center networks
  - Popular in data centers for 40 GE and 4 x 10 GE breakout
  - 40GBASE-ER4: 40 km expected March 2015
  - 40GBASE-T: 30 m expected September 2015
- 100 GE is in transition to 2nd generation technology with CFP2
  - Still a couple of generations away from 100 Gb/s serial signaling
  - 100GBASE-SR4: expected March 2015
- 400 GE development has started and will leverage 100 GE
- Electrical signaling is increasingly challenging at higher speeds
  - Maturing 25 Gb/s technology, working on 50 Gb/s technology
- Ethernet at Terabit speeds is still unfeasible in the near future, but we'll get there eventually (2022+)

MORE INFORMATION

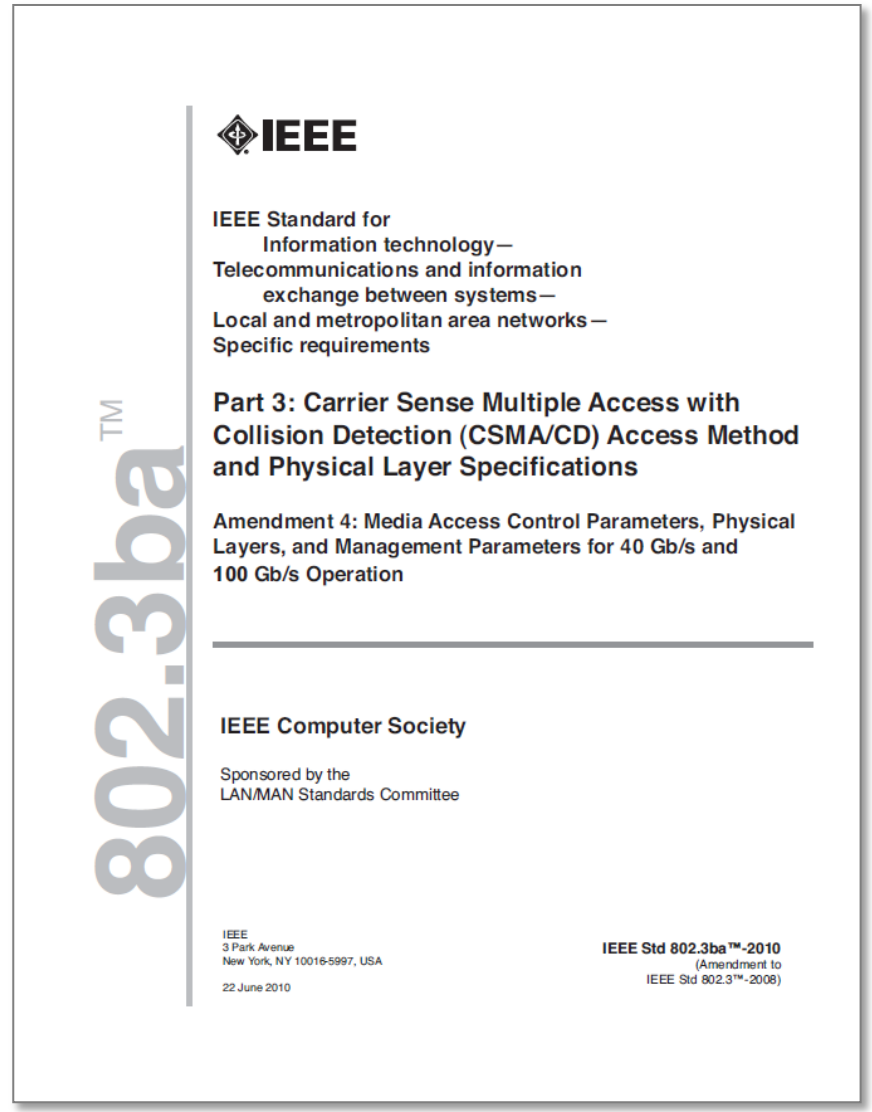
- IEEE 802.3 25 Gb/s Ethernet Study Group
  - http://www.ieee802.org/3/25GSG/public/index.html
- IEEE P802.3bm 40 Gb/s and 100 Gb/s Operation Over Fiber Optic Cables Task Force
  - http://www.ieee802.org/3/bm/
- IEEE P802.3bq 40GBASE-T Task Force
  - http://www.ieee802.org/3/bq/
- IEEE P802.3bs 400 Gb/s Ethernet Task Force
  - http://www.ieee802.org/3/bs/
- CFP MSA
  - http://www.cfp-msa.org/
- SFF Committee
  - http://www.sffcommittee.com/
- CDFP MSA
  - http://www.cdfp-msa.com/

www.alcatel-lucent.com

QUESTIONS?

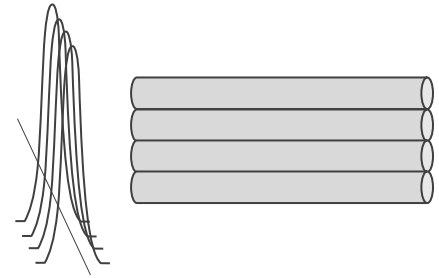
ETHERNET STANDARDS DEVELOPMENT SUMMARY
CONTINUING TECHNOLOGY EVOLUTION

- IEEE 802.3ba standard for 40 GE and 100 GE approved June 17, 2010
  - 340 pages added to IEEE Std 802.3-2012
- Shipping 1st generation 40 GE and 100 GE media, test equipment, router interfaces, and optical transport gear in 2011/2012
  - Mature, interoperable technology with broad vendor support
- 2nd generation technology projects for both 40 GE and 100 GE are nearly finished
  - Available on the market this year
- 400 GE under development as the next Ethernet speed
  - Expected on the market in 2017+

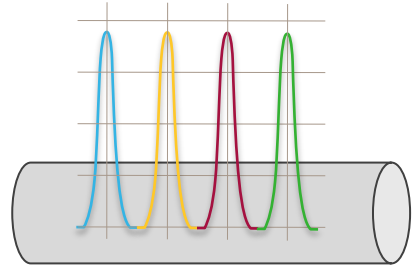


40 GE TRANSMISSION
MULTIMODE AND SINGLE-MODE FIBER

- Multimode ribbon fiber
  - Used for distances of 100 m on OM3 and 150 m on OM4 MMF
  - Data is sent using multiple 850 nm lasers transmitting over multiple parallel fibers
  - MPO cables provide multiple separate transmit and receive strands of multimode fiber in a ribbon cable assembly
- Single-mode duplex fiber
  - Used for distances of 2 km, 10 km and 40 km on standard duplex SMF
  - WDM component in the pluggable module multiplexes four transmit λs over one strand of fiber and four receive λs over the other strand of fiber in the 1310 nm CWDM band for 40GBASE-LR4 and 40GBASE-ER4
  - 40 Gb/s serial transmit over one strand of fiber and receive over the other strand of fiber on one 1550 nm λ is used for 40GBASE-FR



4 x 10 Gb/s Over Parallel MMF
40GBASE-SR4



4 x 10 Gb/s Over Duplex SMF
40GBASE-LR4 and 40GBASE-ER4

RECENT 40 GE DEVELOPMENTS

- IEEE P802.3bj 100 Gb/s Backplane and Copper Cable Task Force started in September 2011
  - Optional Energy Efficient Ethernet (EEE) operation for 40 GE backplane links and copper cable interfaces
  - Task Force web page: http://www.ieee802.org/3/bj/
  - Standard expected in June 2014
- IEEE P802.3bm 40 Gb/s and 100 Gb/s Operation Over Fiber Optic Cables Task Force started in September 2012
  - 40GBASE-ER4: 4 x 10 Gb/s over 40 km SMF
  - Optional EEE operation for 40 GE and 100 GE fiber interfaces
  - Task Force web page http://www.ieee802.org/3/bm/
  - Standard expected in March 2015
- IEEE P802.3bq 40GBASE-T Task Force started in May 2013
  - 40GBASE-T: 4 x 10 Gb/s over 30 m 4-pair balanced twisted-pair copper cabling (ISO/IEC JTC1 SC25 WG3 and TIA TR-42.7)
  - Task Force web page http://www.ieee802.org/3/bq/
  - Standard expected in September 2015

100 GE TECHNOLOGY ADOPTION LIFECYCLE
CROSSING THE CHASM INTO 2ND GENERATION 100 GE

Innovators	Early Adopters	Early Majority	Late Majority	Laggards
2010/2011	**2012/2013**	**2014/2015**	**2015+**	**2022+**
1 - 2 Premium Ports/Slot 1st Generation CFP Modules	2 - 4 Premium Ports/Slot 2nd Generation CFP Modules	4 – 8 Lower Cost Ports/Slot CFP2 Modules	8 – 16 Lower Cost Ports/Slot CFP4 and QSFP28 Modules	24 – 48 Commodity Ports/Slot Serial 100 Gb/s Modules

1st Generation 100 GE	2nd Generation 100 GE	3rd Generation 100 GE

Pluggable module images courtesy of Finisar.

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100 GE TRANSMISSION
MULTIMODE AND SINGLE-MODE FIBER

- Multimode ribbon fiber
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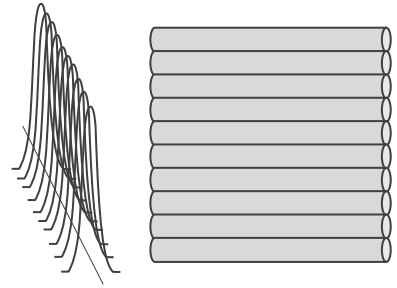
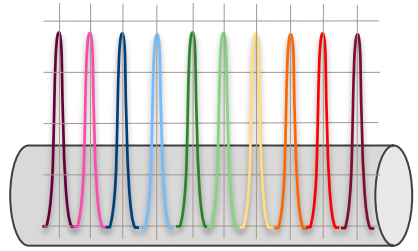
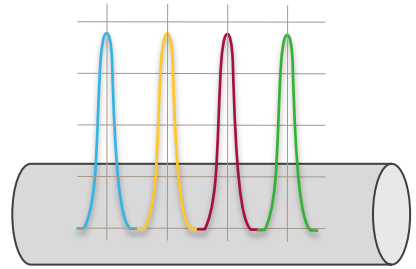
  - Data is sent using multiple 850 nm lasers transmitting over multiple parallel fibers
  - MPO cables provide multiple separate transmit and receive strands of multimode fiber in a ribbon cable assembly
- Single-mode duplex fiber
  - Used for distances of 2 km, 10 km and 40 km on standard duplex SMF
  - WDM component in the pluggable module multiplexes all transmit λs over one strand of fiber and all receive λs over the other strand of fiber
    - 10x10 MSA standards use 10 x 10 Gb/s λs in the 1550 nm DWDM band
    - IEEE standards use 4 x 25 Gb/s λs in the 1310 nm CWDM band



10 x 10 Gb/s Over Parallel MMF
100GBASE-SR10



10 x 10 Gb/s Over Duplex SMF
10x10-2km, 10x10-10km and 10x10-40km



4 x 25 Gb/s Over Duplex SMF
100GBASE-LR4 and 100GBASE-ER4

1ST GENERATION 100 GE

- Fundamental 1st generation technology constraints limit higher 100 GE density and lower cost
- Electrical signaling to the CFP
  - 100 Gb/s Attachment Unit Interface (CAUI) uses 10 x 10 Gb/s lanes (CAUI-10)
- Optical signaling on the media
  - 100GBASE-SR10: 10 x 10 Gb/s parallel
  - 10x10 MSA: 10 x 10 Gb/s λs
  - 100GBASE-LR4 and 100GBASE-ER4: 4 x 25 Gb/s λs
- CFP module size, complexity and power consumption
- 2nd generation modules based on 4 x 25 Gb/s electrical signaling are available now

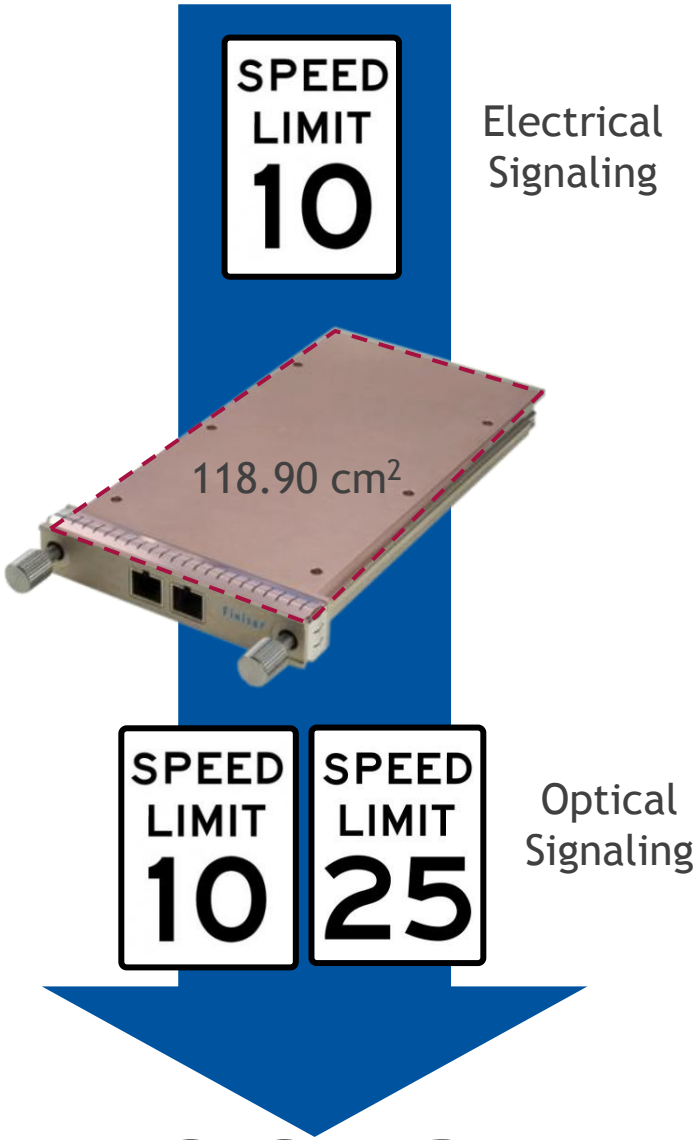
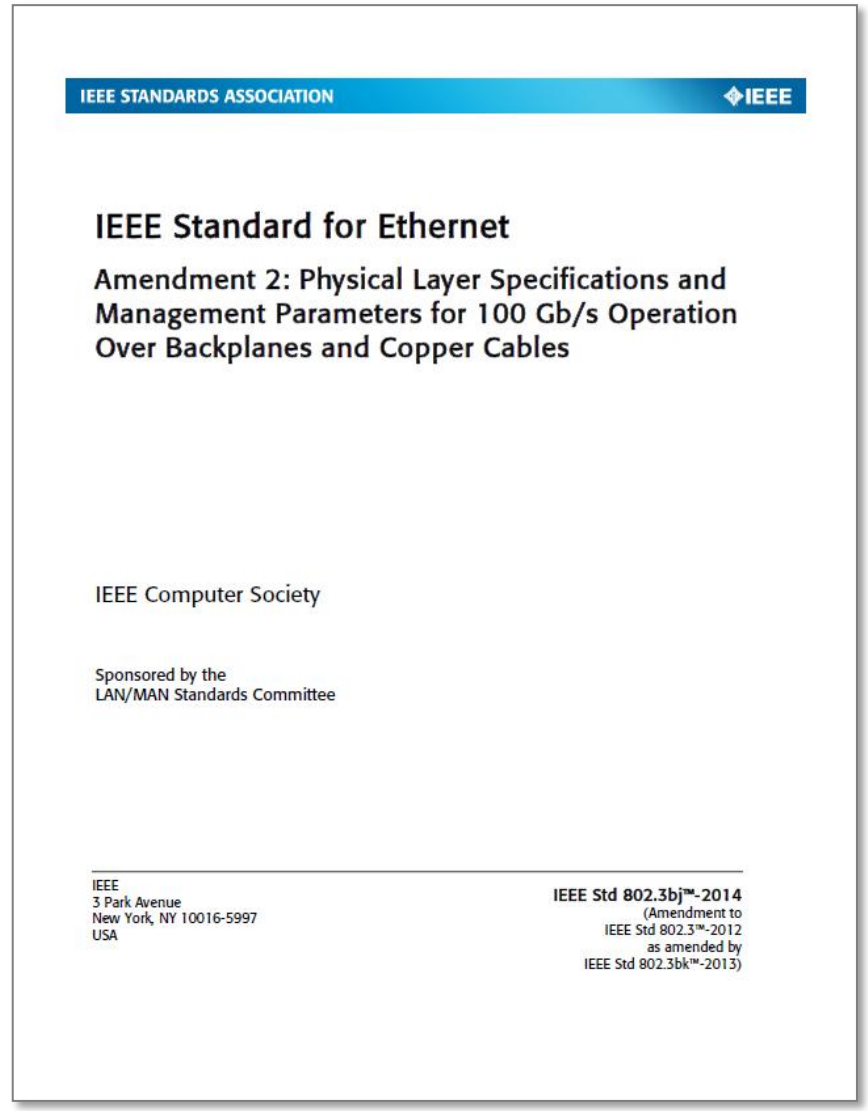


Image courtesy of Finisar.

100 GE DEVELOPMENTS
BACKPLANE AND COPPER CABLE

- IEEE P802.3bj 100 Gb/s Backplane and Copper Cable Task Force started in September 2011
  - 100GBASE-KR4: 4 x 25 Gb/s NRZ 25 GBd on Megtron 6 backplane
  - 100GBASE-KP4: 4 x 25 Gb/s PAM-4 12.5 GBd on enhanced FR4 backplane
  - 100GBASE-CR4: 4 x 25 Gb/s over 5 m copper twinax cable
- Optional Energy Efficient Ethernet (EEE) operation for 40 GE and 100 GE backplane links and copper cable interfaces
- Task Force web page: http://www.ieee802.org/3/bj/
- IEEE Std 802.3bj-2014 approved on June 12, 2014


IEEE STANDARDS ASSOCIATION

IEEE

IEEE Standard for Ethernet

Amendment 2: Physical Layer Specifications and Management Parameters for 100 Gb/s Operation Over Backplanes and Copper Cables

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.3bj™-2014
(Amendment to
IEEE Std 802.3™-2012
as amended by
IEEE Std 802.3bk™-2013)

100 GE DEVELOPMENTS
FIBER OPTIC CABLES

- IEEE P802.3bm 40 Gb/s and 100 Gb/s Operation Over Fiber Optic Cables Task Force started in September 2012
  - 40GBASE-ER4: 4 x 10 Gb/s over 40 km SMF
  - ~~4 x 25 Gb/s over 20 m MMF~~
    - Removed because there is not enough economic or technical advantage vs. existing MMF alternatives
  - 100GBASE-SR4: 4 x 25 Gb/s over 70 m OM3 and 100 m OM4 parallel MMF
  - ~~4 x 25 Gb/s over 500 m SMF~~
    - Removed due to lack of consensus that any of the proposals (CWDM, DMT, PAM-n, PSM4) provided sufficient size, cost and power reduction vs. existing SMF alternatives
  - CAUI-4 electrical signaling to the CFP2, CFP4 and QSFP28
- Optional Energy Efficient Ethernet (EEE) operation for 40 GE and 100 GE fiber interfaces
- Task Force web page http://www.ieee802.org/3/bm/
- Working on Draft 3.2 for 2nd Sponsor recirculation ballot
- Standard expected in March 2015

CFP2 MODULE OVERVIEW

- CFP2 supports electrical lanes that can run at multiple speeds
  - 10 x 10 Gb/s lanes (CAUI-10) for 100 GE
  - 8 x 25 Gb/s lanes (CAUI-4) for 100 GE
  - 8 x 50 Gb/s lanes (CDAUI-8) for 400 GE
- Optional external universal gearbox can convert electrical signaling so that all current IEEE and 10x10 MSA 100 GE standards can be supported in the CFP2 module
- Smaller size and lower cost, complexity and power consumption than the CFP

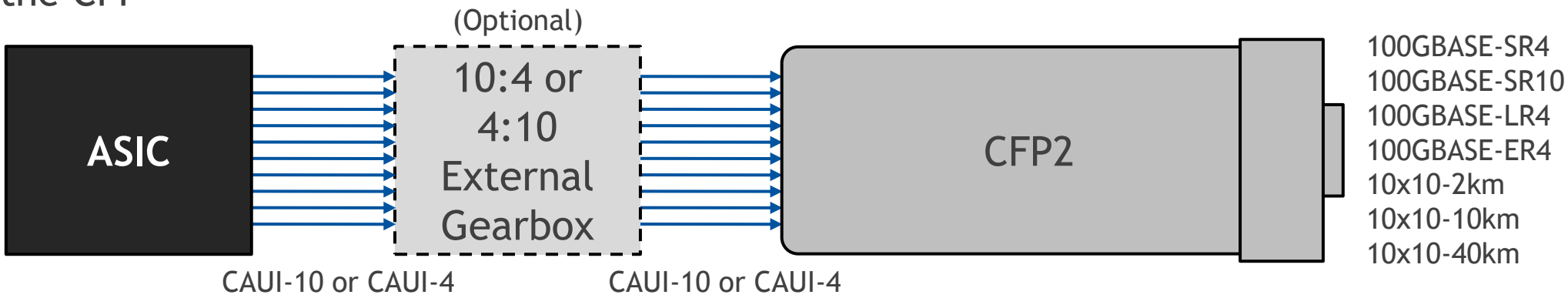
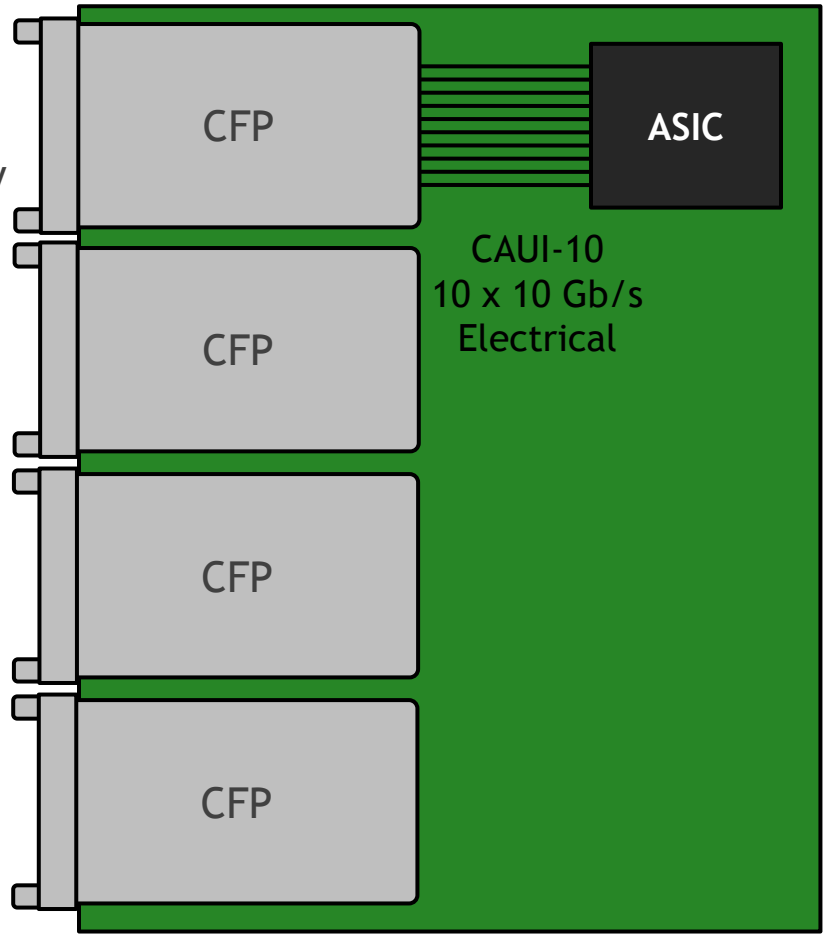


Image courtesy of Finisar.

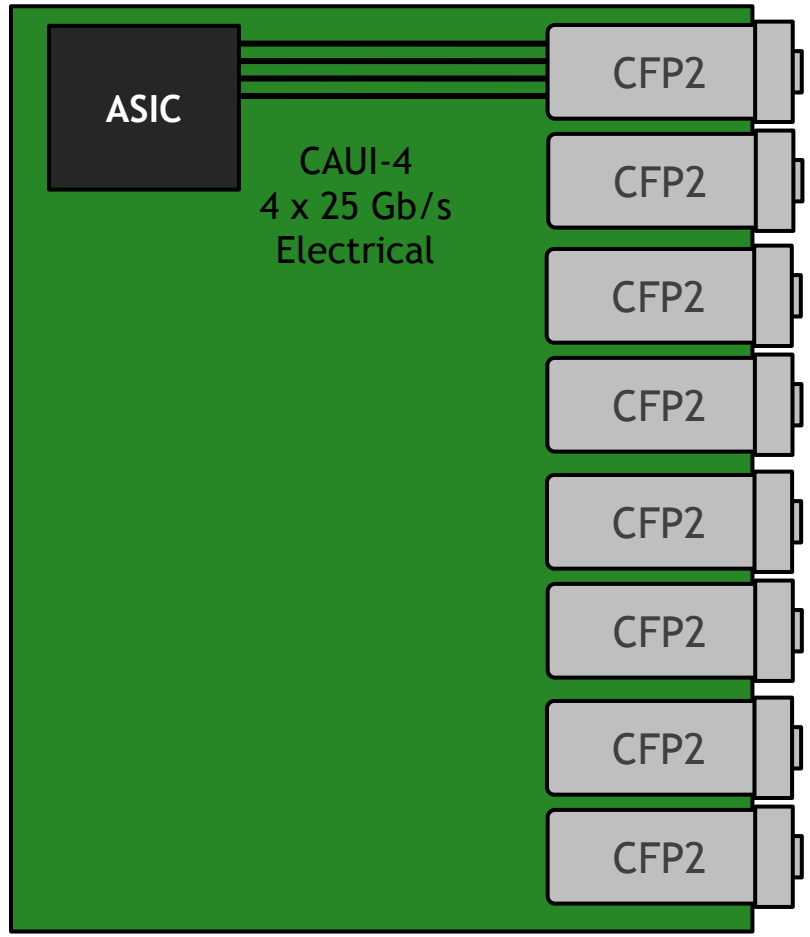
100 GE TECHNOLOGY GENERATIONS
PUTTING IT ALL TOGETHER

1st Generation 100 GE
10 Gb/s and 25 Gb/s Signaling

- Available in 2010
- More expensive, higher complexity and power consumption
- Supports up to 400 Gb/s slot capacity
- Interfaces
  - 100GBASE-SR10
  - 10x10-2km
  - 100GBASE-LR4
  - 10x10-10km
  - 100GBASE-ER4
  - 10x10-40km



2nd Generation 100 GE
25 Gb/s Signaling



- Available in 2014
- Less expensive, lower complexity and power consumption
- Supports up to 800 Gb/s slot capacity
- Supports existing interfaces plus 100GBASE-SR4

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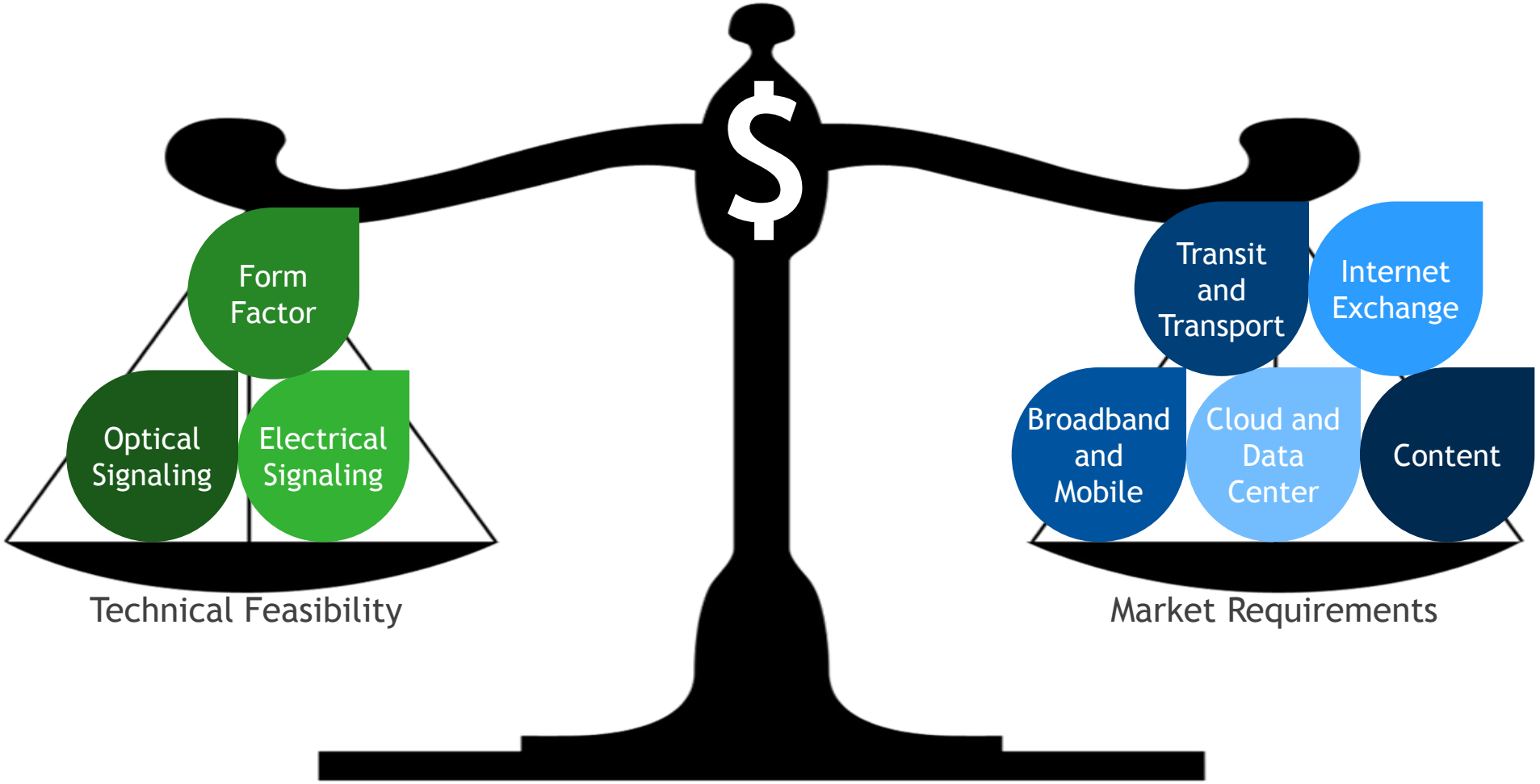
INDUSTRY CHALLENGES FOR 400 GE AND BEYOND

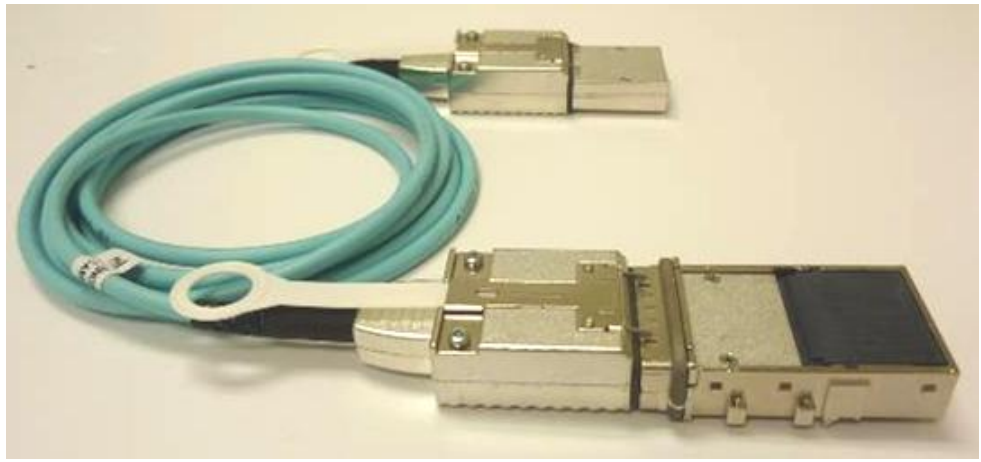
SOLUTIONS ARE GOOD, FAST, OR CHEAP – PICK ANY TWO

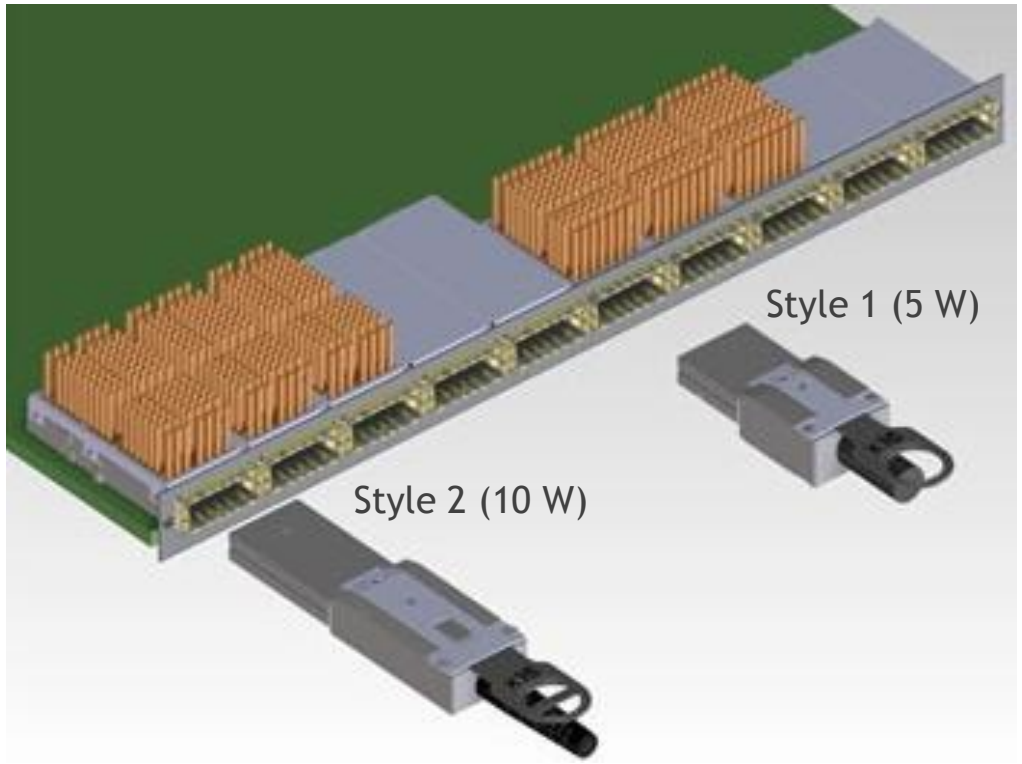


Economics Dictate the Solution

IEEE Provides an Open Industry Forum to Make Decisions

400 GB/S CDFP MODULE OVERVIEW
DESIGNED TO SUPPORT 4 TB/S PER SLOT





- CD = 400 in Roman numerals, C = 100 and D = 500
- Optimized for short reaches and targeted for distances up to 500 m
- Supports copper cables, active optical cables and transceivers
- Initial focus is active optical cables

Images courtesy of TE Connectivity and the CDFP MSA.