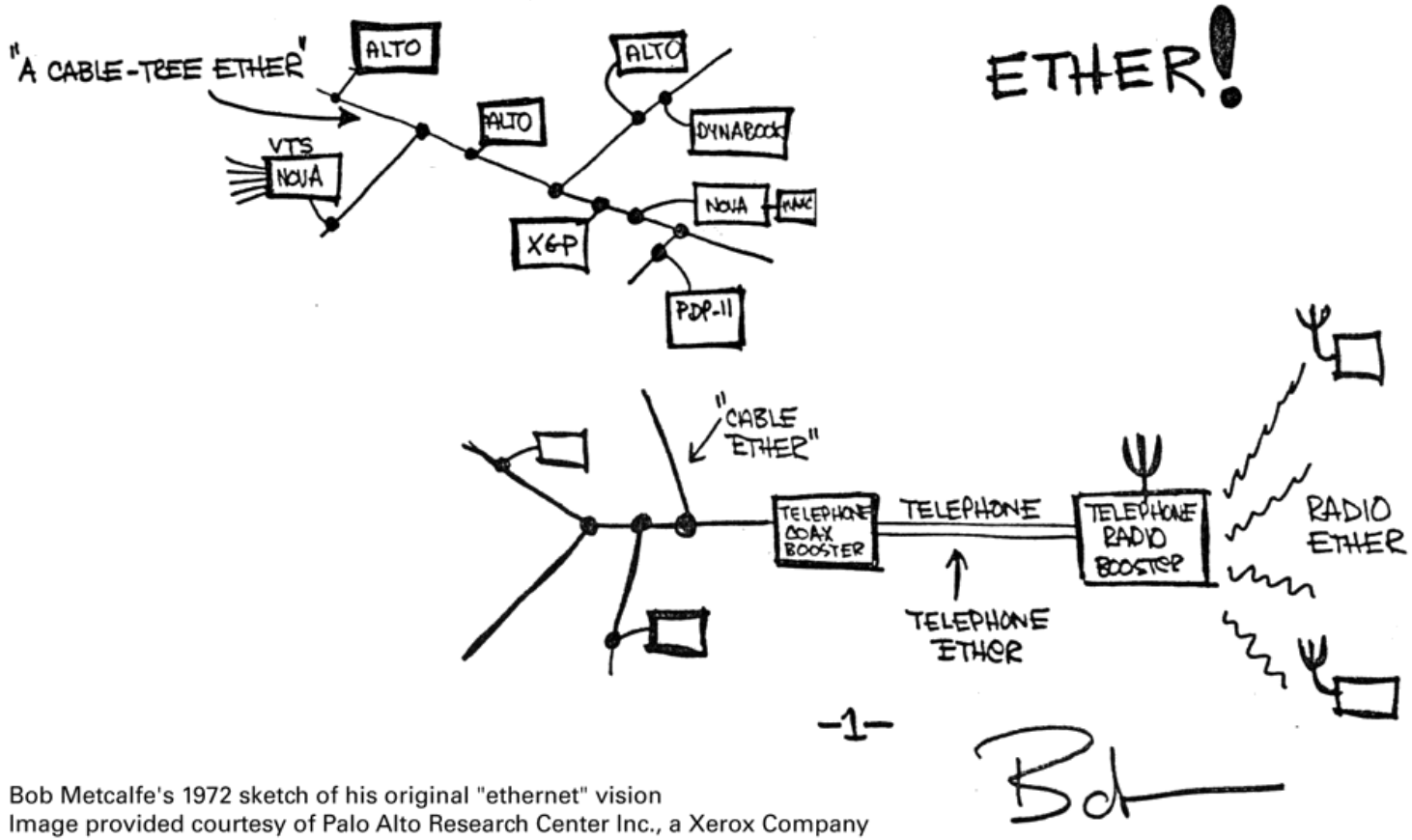
“Here is more rough stuff on the ALTO ALOHA network.”

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

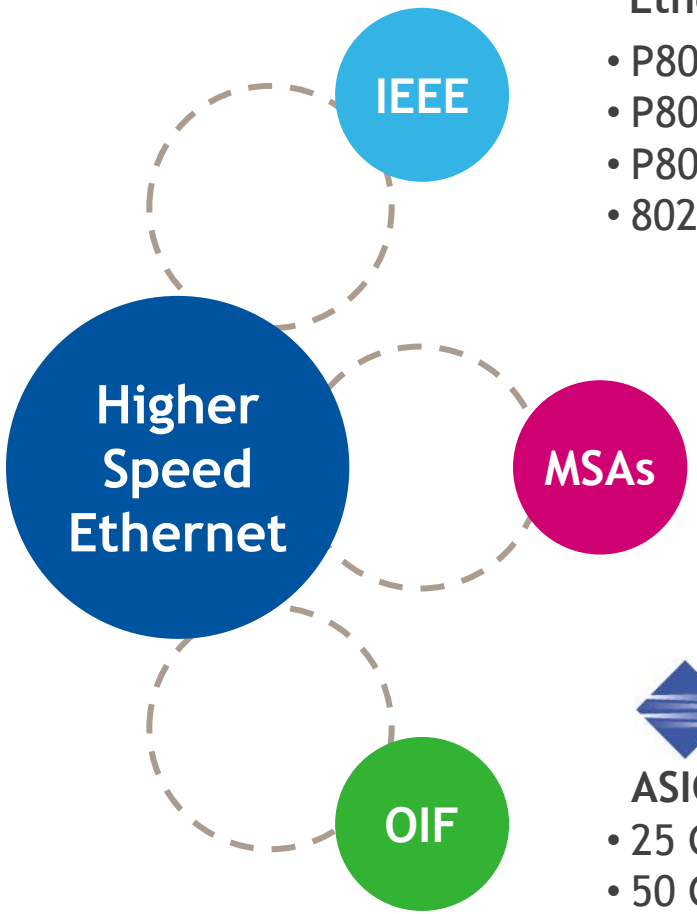
Greg Hankins <greg.hankins@alcatel-lucent.com>
APRICOT 2014

Alcatel·Lucent

AGENDA

1. Ethernet Speed Developments
2. 40 GE
3. 100 GE
4. 400 GE

KEY INDUSTRY DEVELOPMENTS FOR THE NEXT COUPLE OF YEAR



IEEE

Ethernet Standards

- P802.3bj 100 Gb/s Backplane and Copper Cable Task Force
- P802.3bm 40 Gb/s and 100 Gb/s Operation Over Fiber Optic Cables Task Force
- P802.3bq 40GBASE-T Task Force
- 802.3 400 Gb/s Ethernet Study Group

CFP SFF Committee CDFP

Pluggable Module MSAs

- Next-generation form factors
- CFP4, QSFP28, CDFP

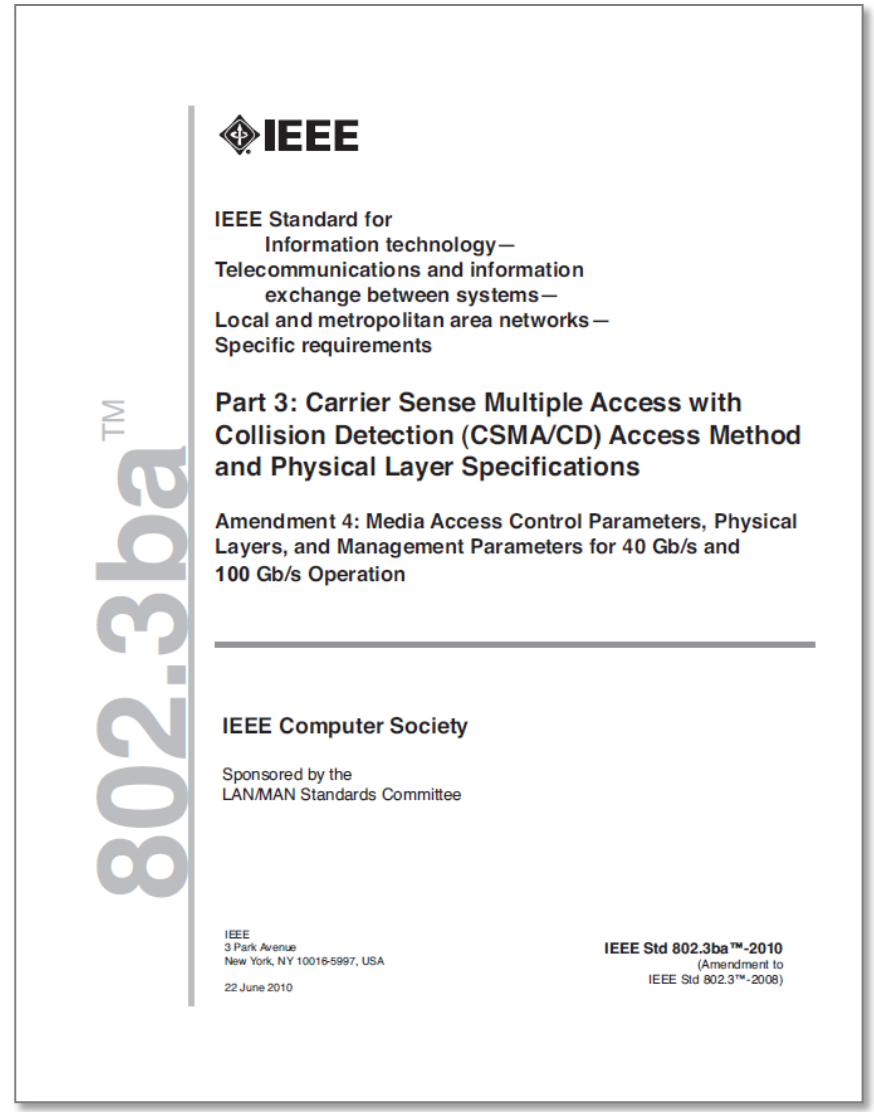
OIF OPTICAL INTERNETWORKING FORUM

ASIC to Pluggable Module Electrical Signaling

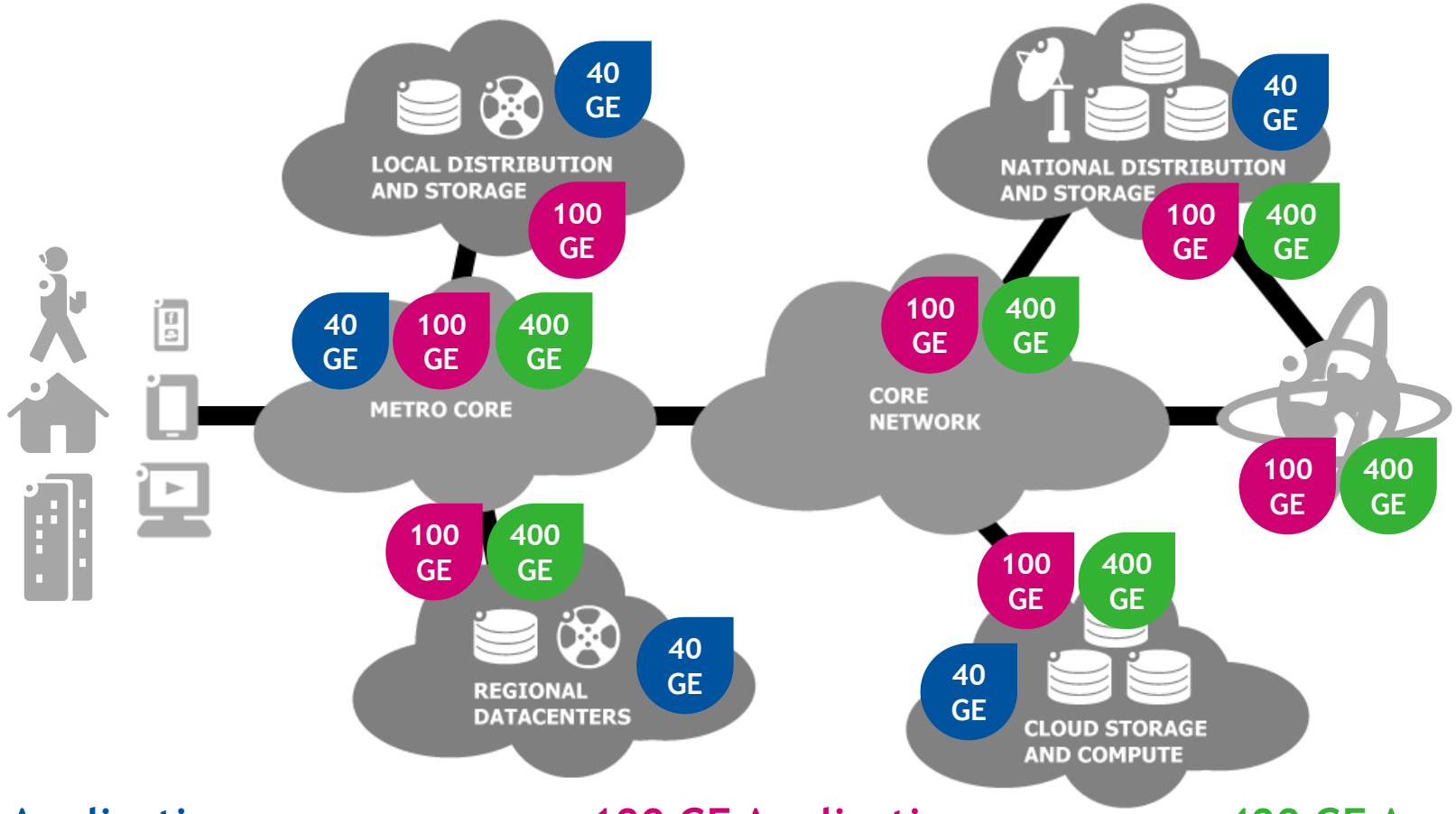
- 25 Gb/s (CEI-28G-VSR)
- 50 Gb/s (CEI-56G-VSR)

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 2016+



HIGHER SPEED ETHERNET TARGET APPLICATIONS



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

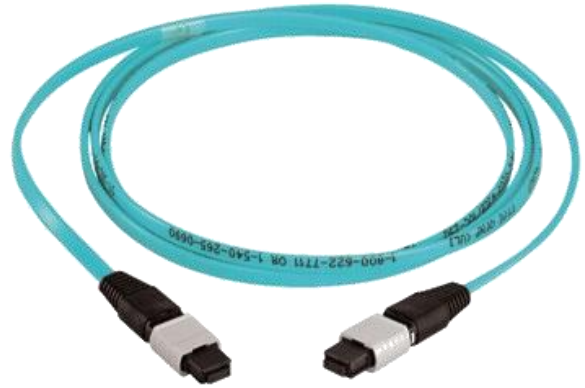
400 GE Applications (2016+)

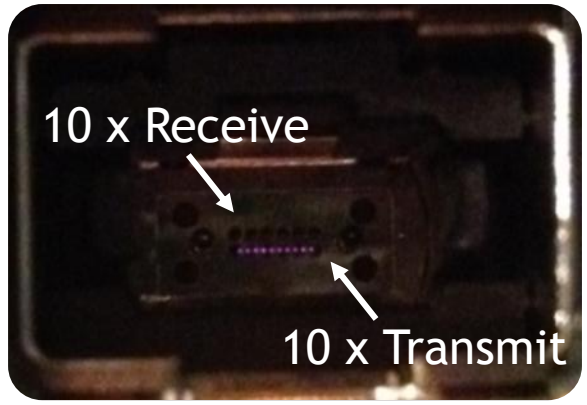
- Service Provider Core
- Large Data Center Core
- Large Metro Core

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





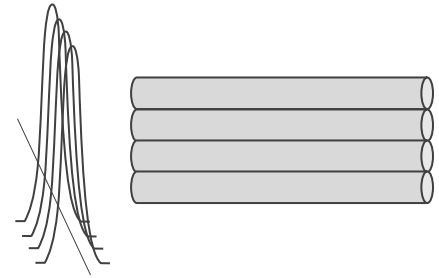
100GBASE-SR10 CXP

AGENDA

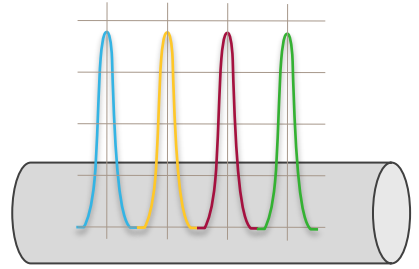
1. Ethernet Speed Developments
2. **40 GE**
3. 100 GE
4. 400 GE

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 lanes over one strand of fiber and four receive lanes over the other strand of fiber for 40GBASE-LR4 and 40GBASE-ER4
  - 40 Gb/s serial transmit over one strand of fiber and receive over the other strand of fiber 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

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 (8.5 mm high x 18.35 mm wide x 52.4 mm long)

40GBASE-SR4

40GBASE-LR4

Images courtesy of Finisar.

40 GBE QSFP+ PLUGGABLE MODULES

	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**
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.

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

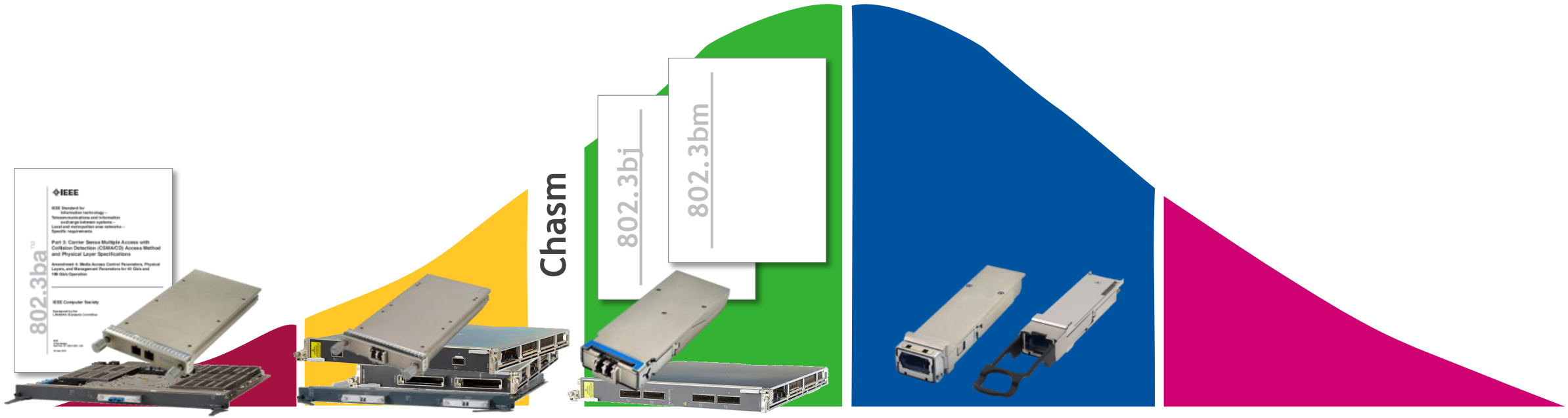
40 GE TECHNOLOGY REFERENCE

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 1550 nm	4 x 10 1310 nm	4 x 10 1310 nm
Media Type	Backplane	Twinax	Cat 8.1 F/UTP? Cat 8.2 S/FTP?	Parallel MMF	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	2016+	2010	2012	CFP 2010 QSFP+ 2011	2015

AGENDA

1. Ethernet Speed Developments
2. 40 GE
3. **100 GE**
4. 400 GE

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



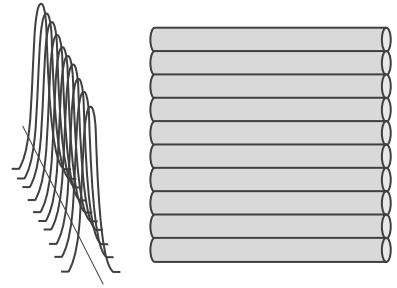
Innovators	Early Adopters	Early Majority	Late Majority	Laggards
2010/2011	**2012/2013**	**2014/2015**	**2015+**	**2022+**
1 - 2 Premium Ports/Slot 1st Generation CFP Modules	2 - 4 Premium Ports/Slot 2nd Generation CFP Modules	4 – 8 Lower-Cost Ports/Slot CFP2 Modules	8 – 16 Commodity Ports/Slot CFP4 and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

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

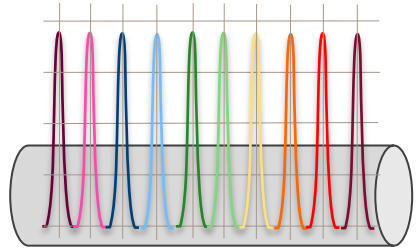
Pluggable module images courtesy of Finisar.
Adoption lifecycle curve based on “Crossing the Chasm” by Geoffrey Moore.

100 GE TRANSMISSION
MULTIMODE AND SINGLE-MODE FIBER

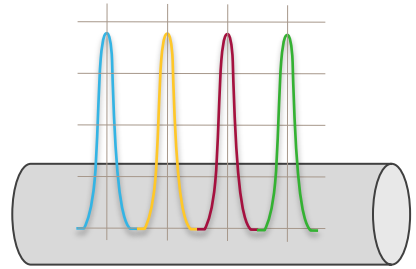
- Multimode ribbon fiber
  - Used for distances of 100 m on OM3 and 150 m on OM4 MMF
  - Data is sent using multiple 850 nm lasers transmitting over multiple parallel fibers
  - MPO cables provide multiple separate transmit and receive strands of multimode fiber in a ribbon cable assembly
- Single-mode duplex fiber
  - Used for distances of 2 km, 10 km and 40 km on standard duplex SMF
  - WDM component in the pluggable module multiplexes all transmit lanes over one strand of fiber and all receive lanes over the other strand of fiber
    - 10x10 MSA standards use 10 x 10 Gb/s λs in the 1550 nm range
    - IEEE standards use 4 x 25 Gb/s λs in the 1310 nm range



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

100 GE PLUGGABLE MODULES OVERVIEW

CXP
C (100)
X (10)
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

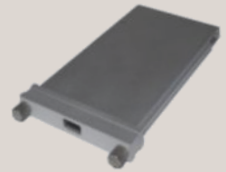
- New module optimized for 100 GE long reach applications, but also used for short reach applications
- Used for IEEE Ethernet and 10x10 MSA standards
- Complex electrical gearbox and optical components need a large module
  - Long reach modules contain an integrated WDM component for duplex SMF transmission
- 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.

100 GE PLUGGABLE MODULES

	100 m OM3 / 150 m OM4			10 km SMF			40 km SMF	
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	10 x 10	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	4 x 25 1310 nm	4 x 25 1310 nm	10 x 10 1550 nm	4 x 25 1310 nm
Market Availability	2012	2014	2012	2011	2010	2014	2014?	2012

Images courtesy of Finisar.

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

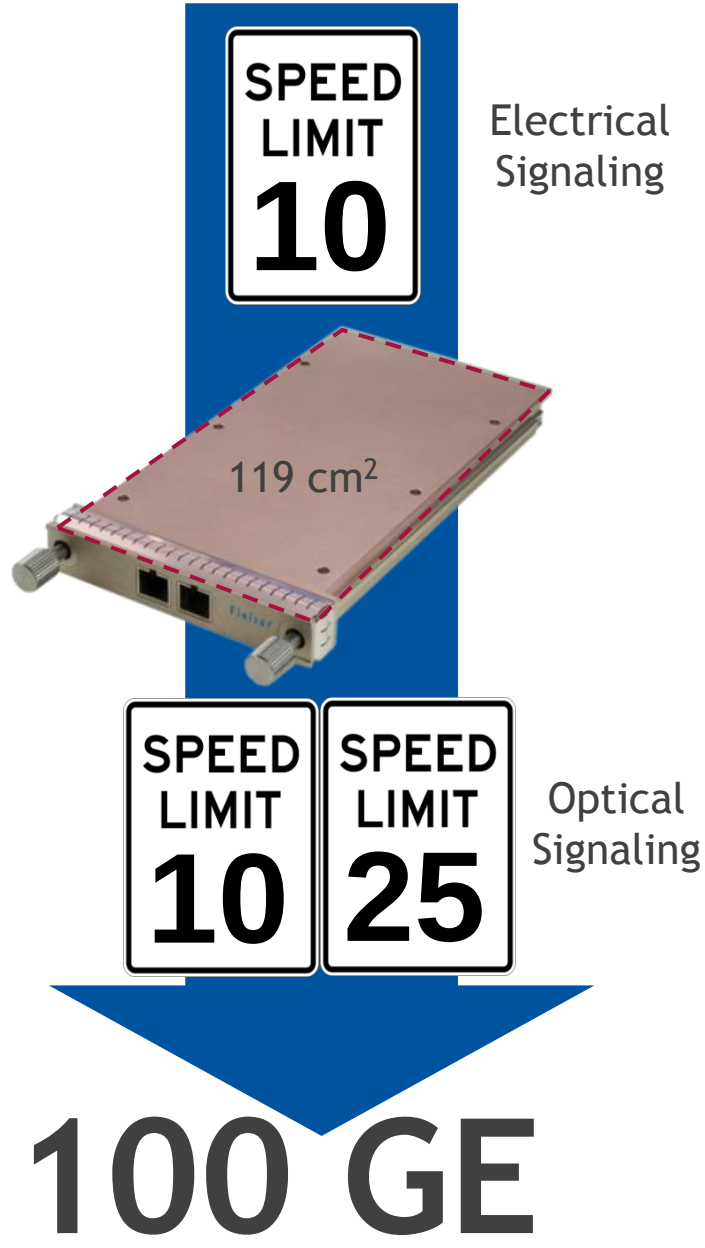
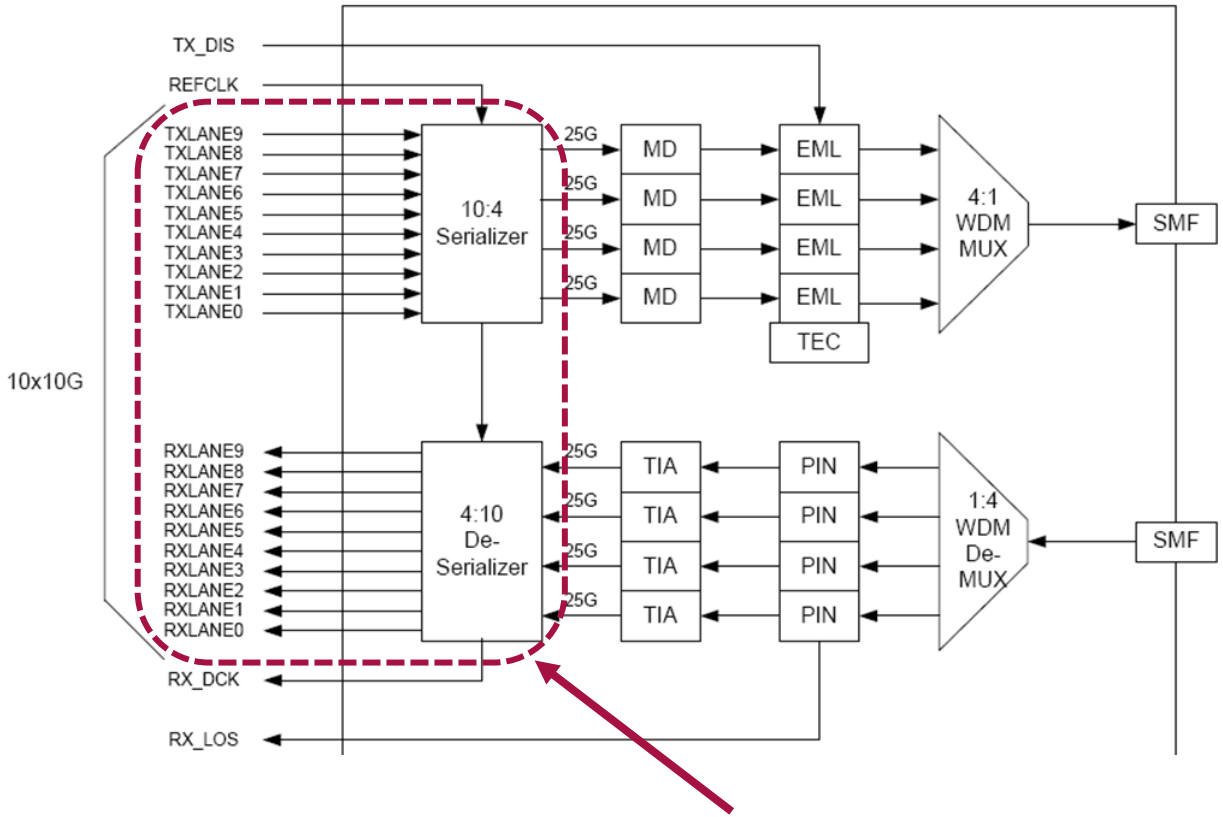


Image courtesy of Finisar.

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

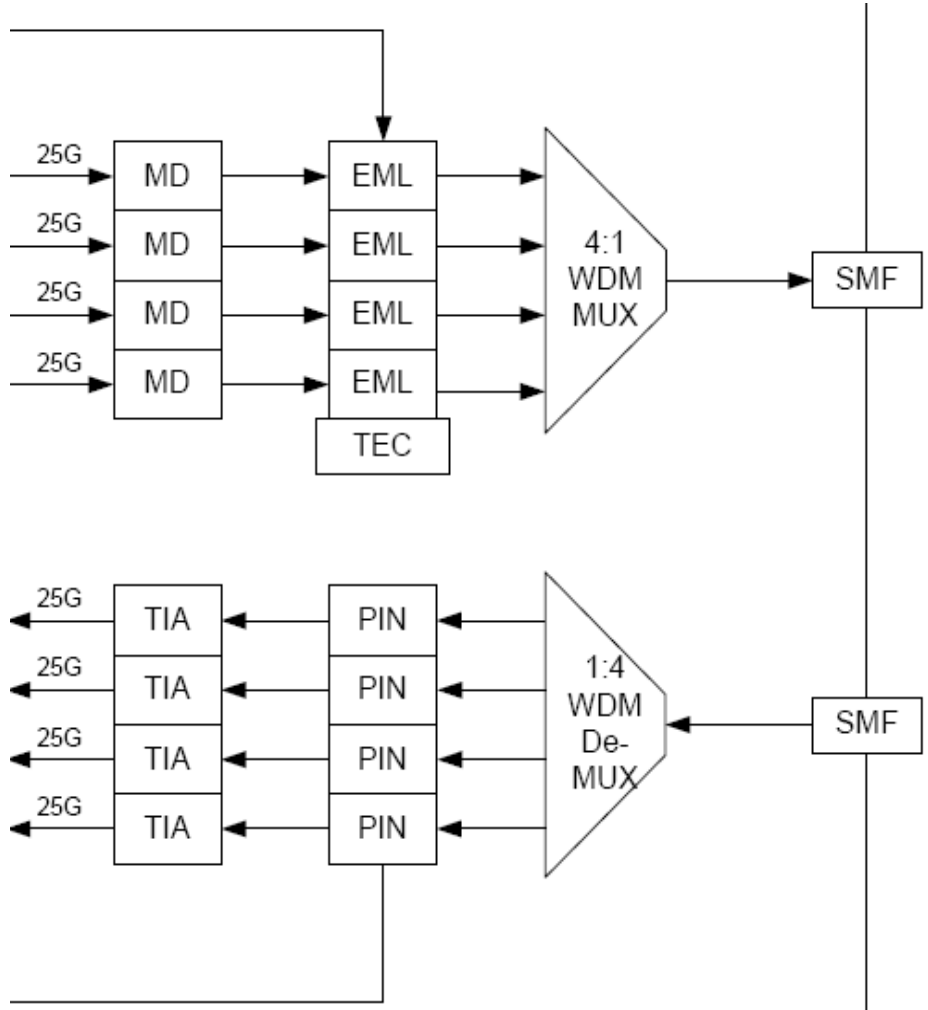


Diagram source: http://grouper.ieee.org/groups/802/3/ba/public/jul08/cole_03_0708.pdf

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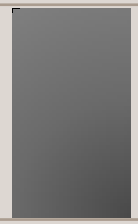
100 GE PLUGGABLE MODULE EVOLUTION

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 Capacity (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 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) < 14 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)		

Industry standard images courtesy of Finisar.

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 MSA 100 GE standards can be supported in the CFP2 module
- Smaller size and lower cost, complexity and power consumption than the CFP

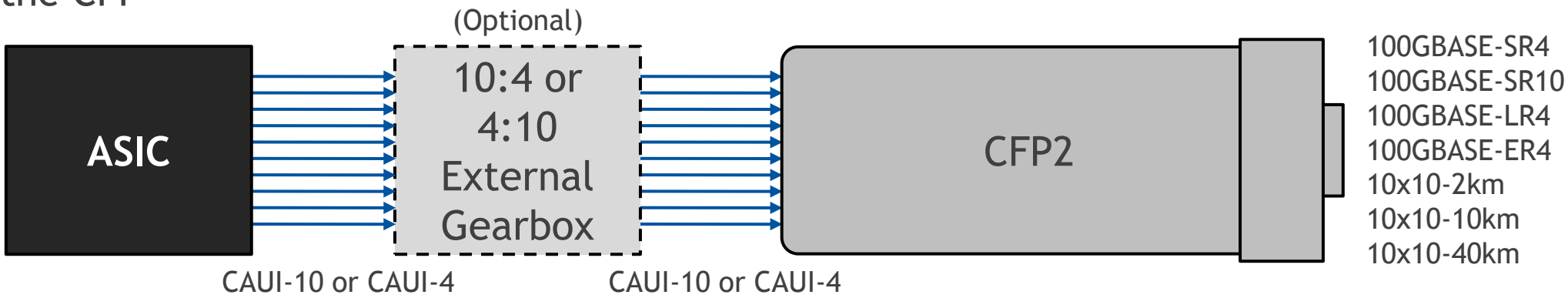
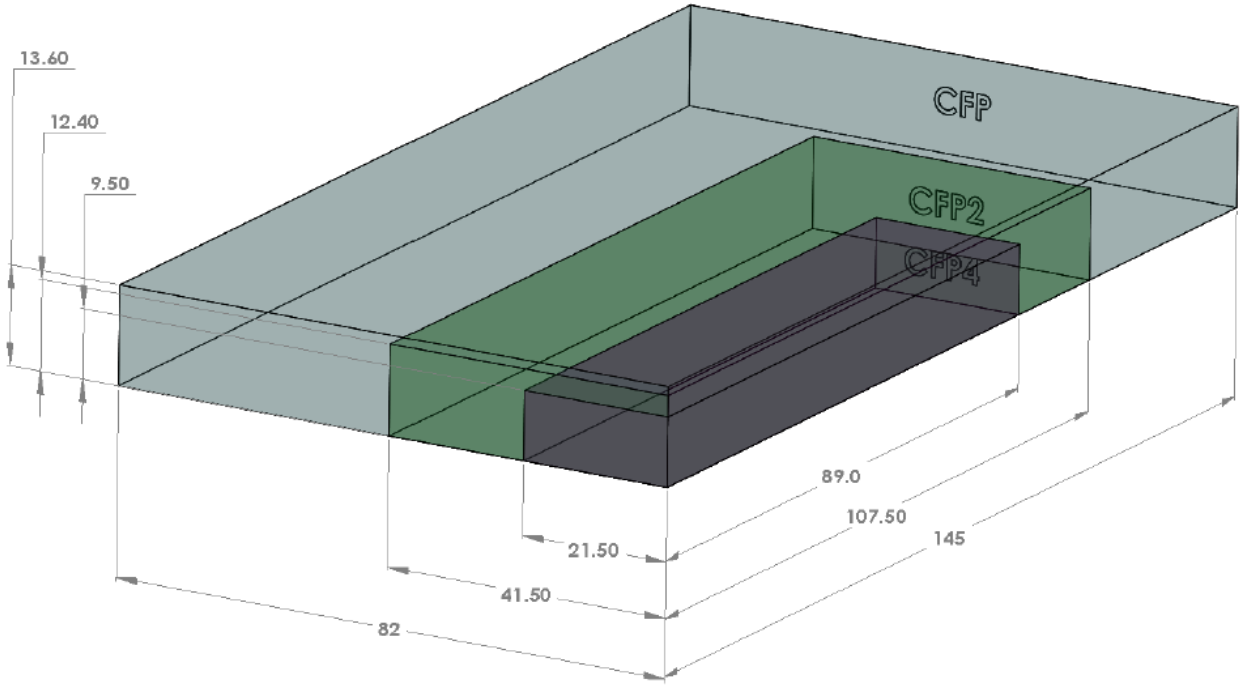
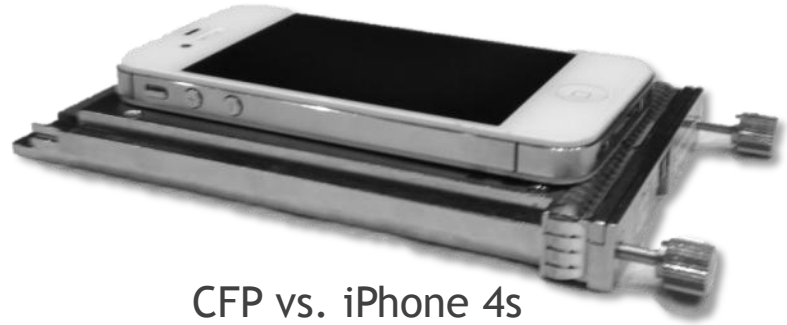


Image courtesy of Finisar.

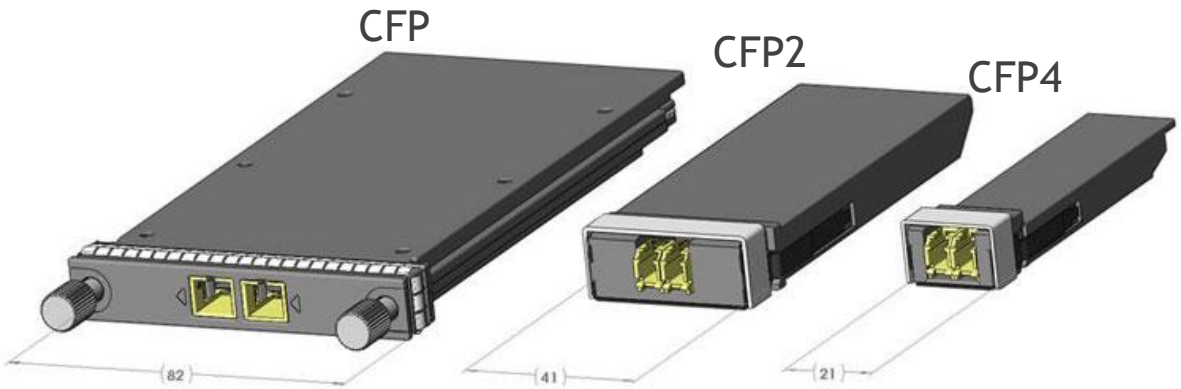
100 GE MODULE EVOLUTION
GRAPHICAL VIEW OF MODULE FORM FACTORS



CXP vs. iPhone 4s



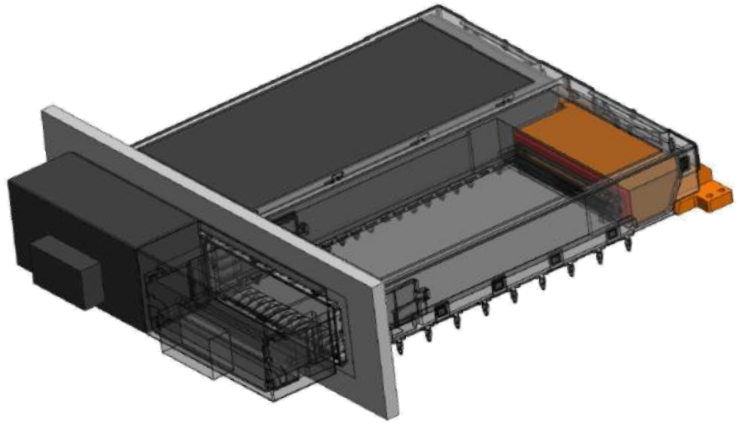
CFP vs. iPhone 4s



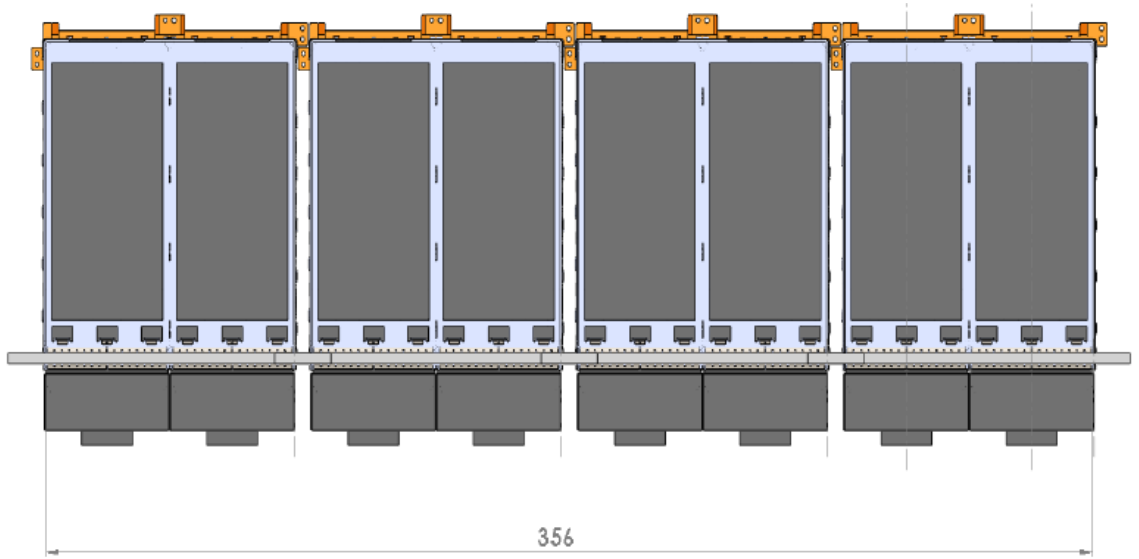
CFP2 vs. iPhone 4s

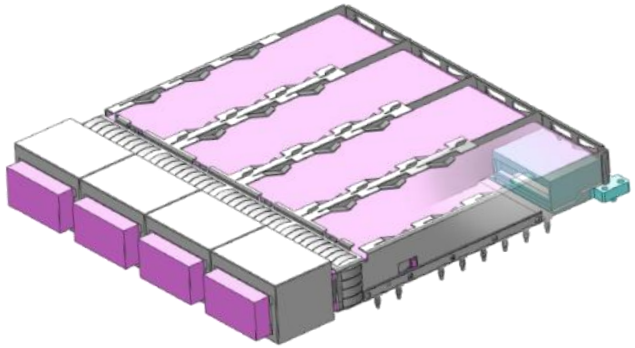
Diagrams courtesy of the CFP MSA.

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

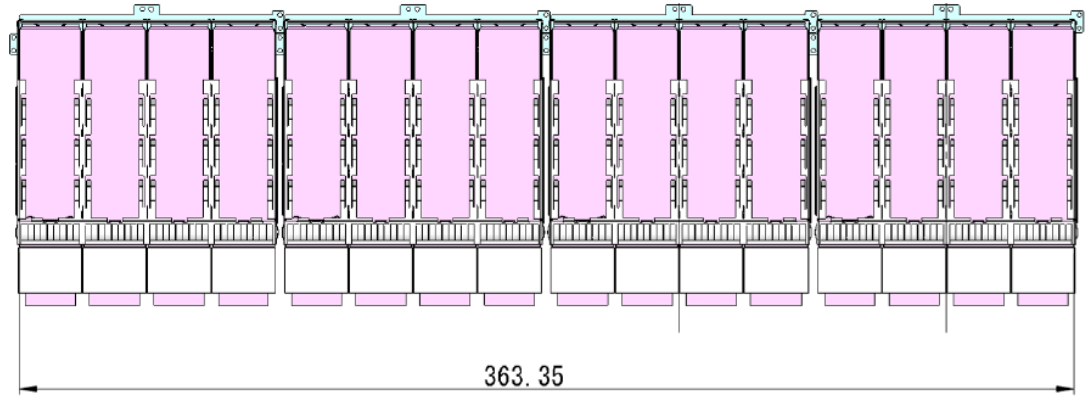


CFP2
8 Ports Per Card
Front Panel Density





CFP4
16 Ports Per Card
Front Panel Density



Diagrams courtesy of the CFP MSA.

100 GE 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/
- Working on Draft 3.1 for 1st Sponsor recirculation ballot
- Standard expected in June 2014

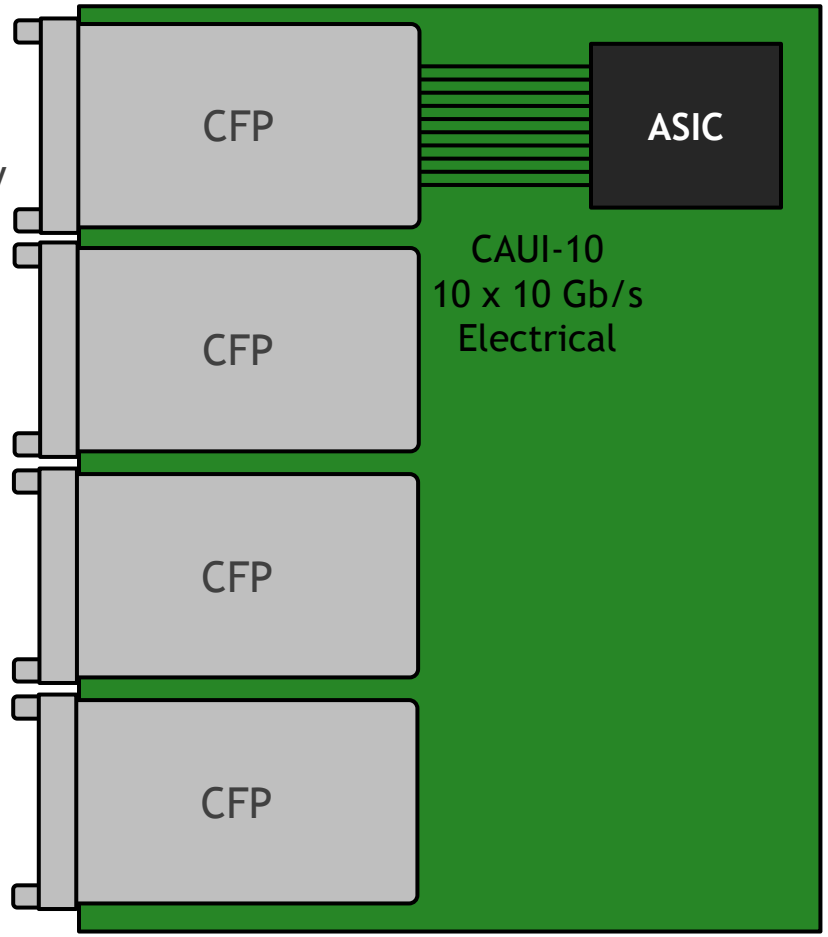
100 GE DEVELOPMENTS
FIBER OPTIC CABLES

- 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 2.1 for 1st Working Group recirculation ballet
- Standard expected in March 2015

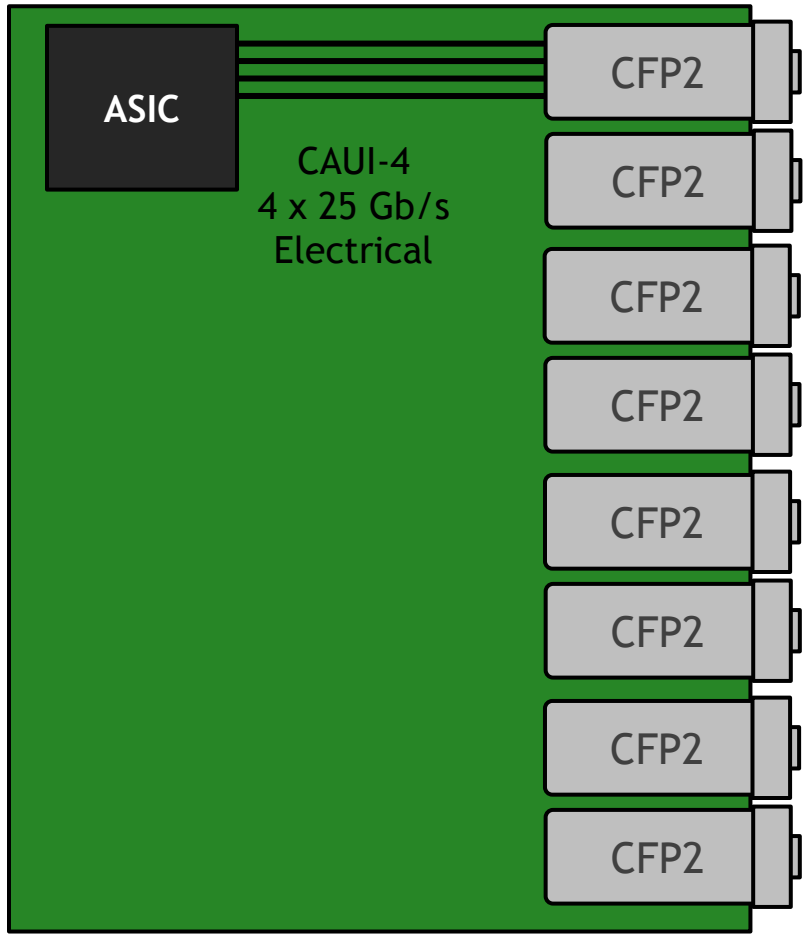
100 GE TECHNOLOGY GENERATIONS
PUTTING IT ALL TOGETHER

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

- Available in 2010
- More expensive, higher complexity and power consumption
- 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
- 800 Gb/s slot capacity
- Supports existing interfaces plus 100GBASE-SR4

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	10 x 10 1310 nm	4 x 25 1550 nm	10 x 10 1310 nm	4 x 25 1550 nm
Media Type	Backplane	Twinax Copper	Twinax Copper	Parallel MMF	Parallel MMF	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

1. Ethernet Speed Developments
2. 40 GE
3. 100 GE
4. **400 GE**

IEEE BANDWIDTH REQUIREMENT PROJECTIONS

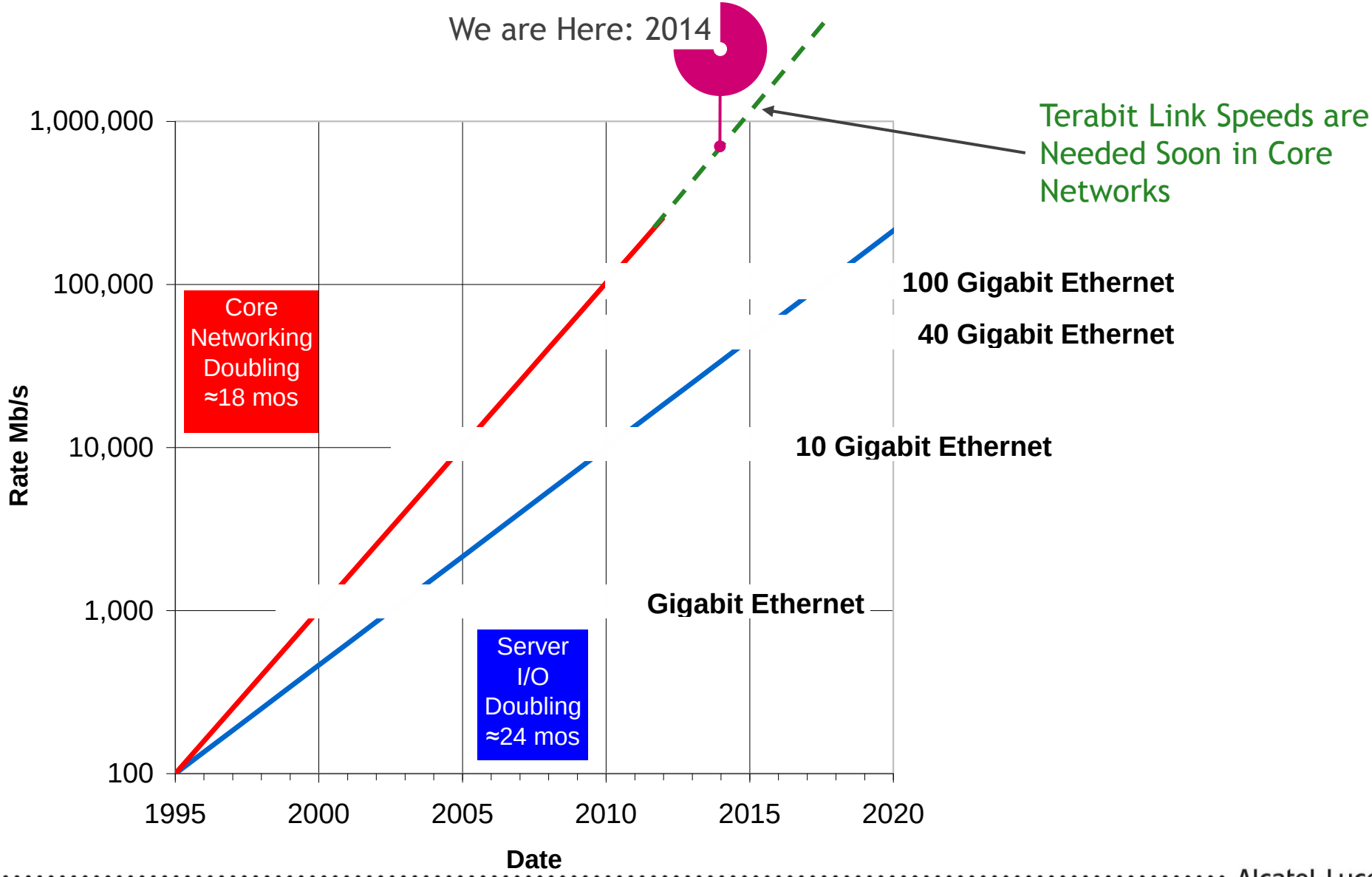
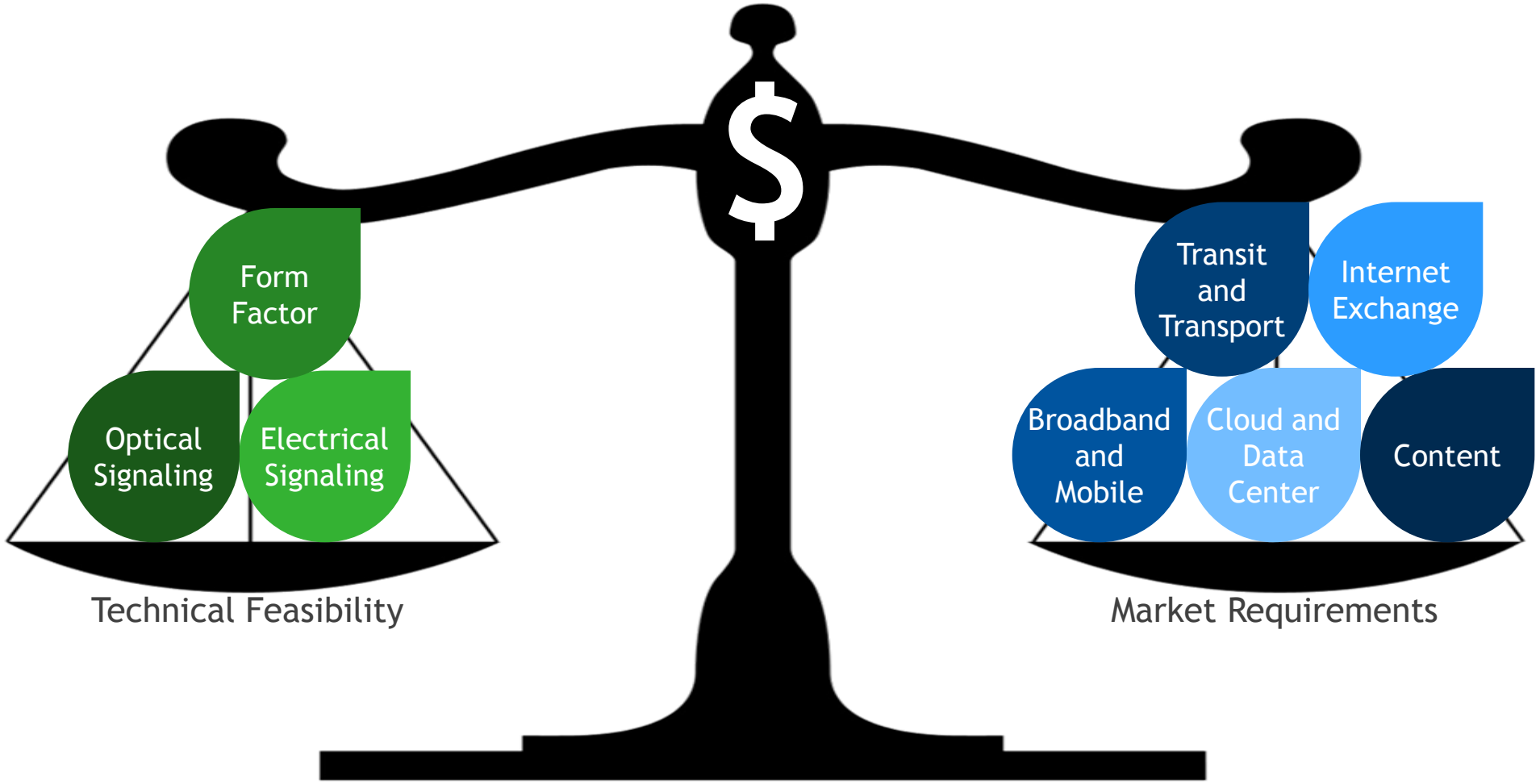


Diagram source: http://www.ieee802.org/3/hssg/public/nov07/HSSG_Tutorial_1107.zip

INDUSTRY CHALLENGES FOR 400 GE AND BEYOND

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



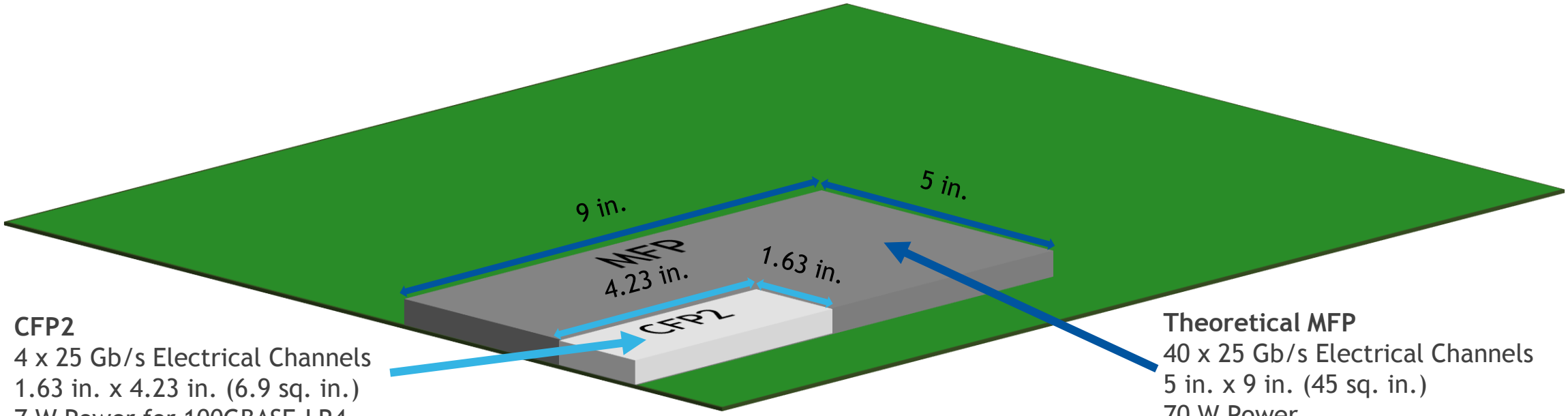
Economics Dictate the Solution

IEEE Provides an Open Industry Forum to Make Decisions

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 2016 when the market needs something faster
- IEEE 802.3 Ethernet Bandwidth Assessment (BWA) Ad Hoc and the IEEE 802.3 Higher Speed Ethernet (HSE) Consensus Ad Hoc spent a lot of time analyzing market demand and technical options
- High degree of consensus in the IEEE that 400 GE should be the next Ethernet speed
  - CFI straw poll: yes 132, no 0, abstain 1
  - Motion for Study Group: yes 87, no 0, abstain 4
- IEEE 802.3 Higher Speed Study Group first had to analyze market demand and technical options
  - Eventually decided on 40 GE and 100 GE

THEORETICAL M (1000) FORM-FACTOR PLUGGABLE USING TODAY'S TECHNOLOGY IS IMPRACTICAL



CFP2
4 x 25 Gb/s Electrical Channels
1.63 in. x 4.23 in. (6.9 sq. in.)
7 W Power for 100GBASE-LR4

Theoretical MFP
40 x 25 Gb/s Electrical Channels
5 in. x 9 in. (45 sq. in.)
70 W Power

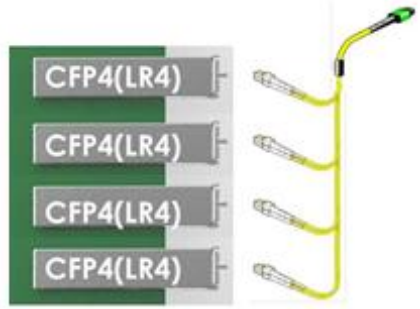
- Using current technology with 25 Gb/s electrical signaling, a TbE module (MFP) would use 40 channels
- The size of the module can be estimated at ½ sq. in. per W of power consumed
- If a CFP2 module consumes 7 W, then the MFP could consume 70 W
- This would require 45 sq. in. to cool and could make the module 5 in. by 9 in., which is too big to power and cool

IEEE 802.3 400 GB/S ETHERNET STUDY GROUP

- 400 GE Call for Interest (CFI) was presented at the March 2013 IEEE Plenary and approved to be an official IEEE Study Group
- Project Authorization Request (PAR) and Criteria for Standards Development (CSD) for P802.3bs adopted at the January 2014 IEEE Interim
  - Project approval request planned for March 27, 2014
  - 1st Task Force meeting expected in May, 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 in 2016+
- First interfaces expected to be available in 2016+
- Study Group web page http://www.ieee802.org/3/400GSG/

400 GE PLUGGABLE MODULE EVOLUTION ESTIMATES

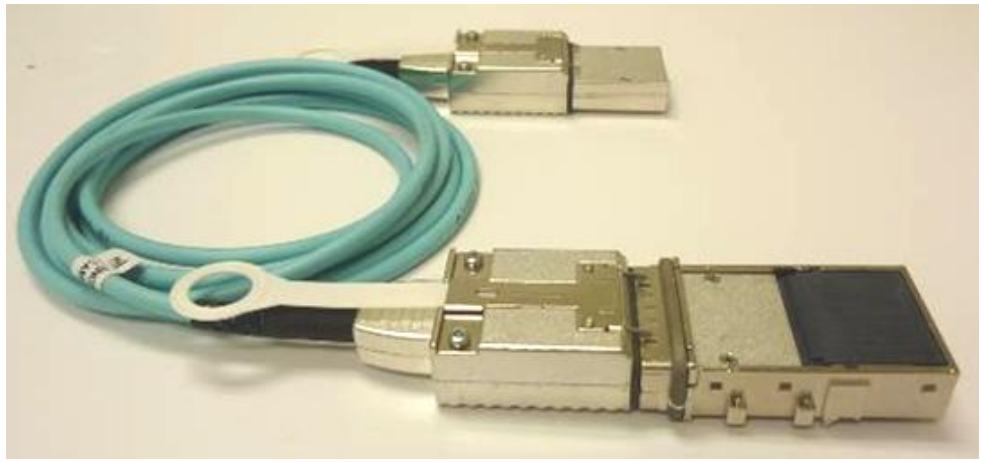
EACH MODULE INCREASES DENSITY, WHILE REDUCING COST AND POWER

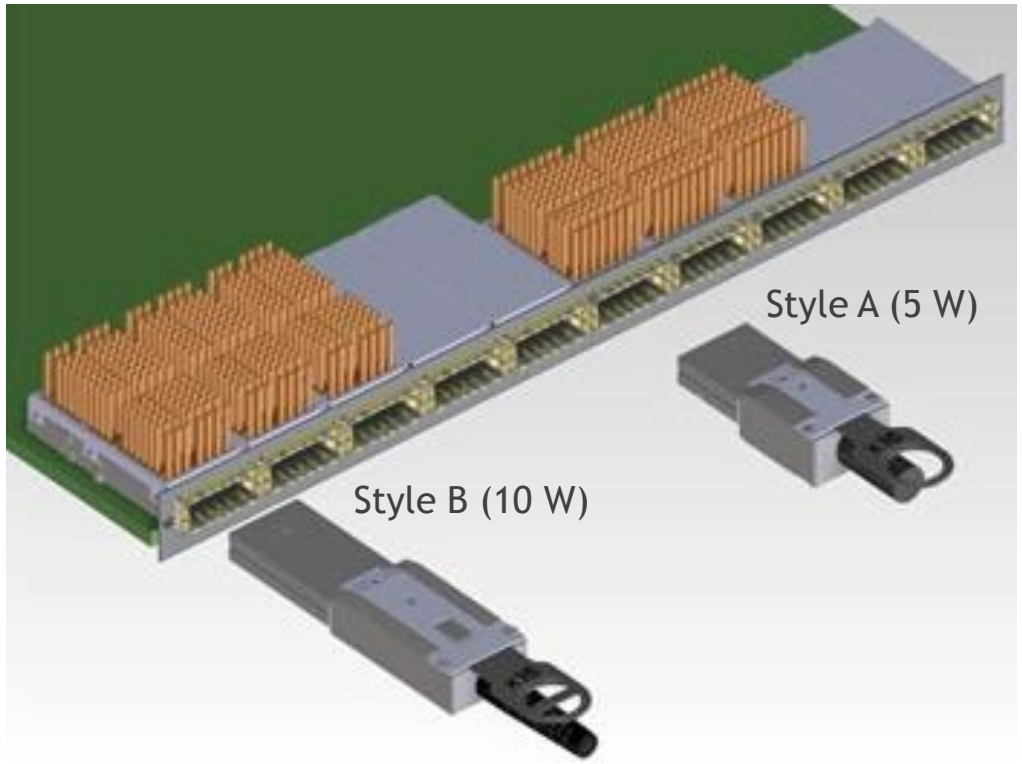
	1st Generation		2nd Generation	3rd Generation
Year	2016+	2016+	2019+	2022+
Electrical Signaling	CDAUI-16 16 x 25 Gb/s	CDAUI-16 16 x 25 Gb/s	CDAUI-8 8 x 50 Gb/s	CDAUI-4 4 x 100 Gb/s
Module				
	CDFP	4 x CFP4	CFP2	CFP4

Ethernet at Terabit Speeds Becomes Feasible

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

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.

ETHERNET SPEED EVOLUTION SUMMARY

- 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
- 40 GE is increasingly deployed in data center networks
  - Popular in data centers for 40 GE and 4 x 10 GE breakout
- 100 GE is in transition to 2nd generation technology
  - Still a couple of generations away from 100 Gb/s serial signaling
- 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 P802.3bj 100 Gb/s Backplane and Copper Cable Task Force
  - http://www.ieee802.org/3/bj/
- 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 802.3 Higher Speed Study Group
  - http://www.ieee802.org/3/hssg/index.html
- IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc
  - http://www.ieee802.org/3/ad_hoc/bwa/index.html
- IEEE 802.3 Industry Connections Higher Speed Ethernet Consensus Ad Hoc
  - http://www.ieee802.org/3/ad_hoc/hse/public/index.html
- IEEE 400 GE Call-For-Interest presentation
  - http://www.ieee802.org/3/cfi/0313_1/CFI_01_0313.pdf
- IEEE 802.3 400 Gb/s Ethernet Study Group
  - http://www.ieee802.org/3/400GSG/
- 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?