STORAGE DEVELOPER CONFERENCE
SDC 23
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Fibre Channel, What's Old is New Again, 128GFC and Beyond

Today's Speakers

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About the FCIA

"The Fibre Channel Industry Association (FCIA) is a mutual benefit, non-profit, international organization of manufacturers, system integrators, developers, vendors, industry professionals, and end users."

SDC 23

25+ Years
Promoting Fibre Channel Technology

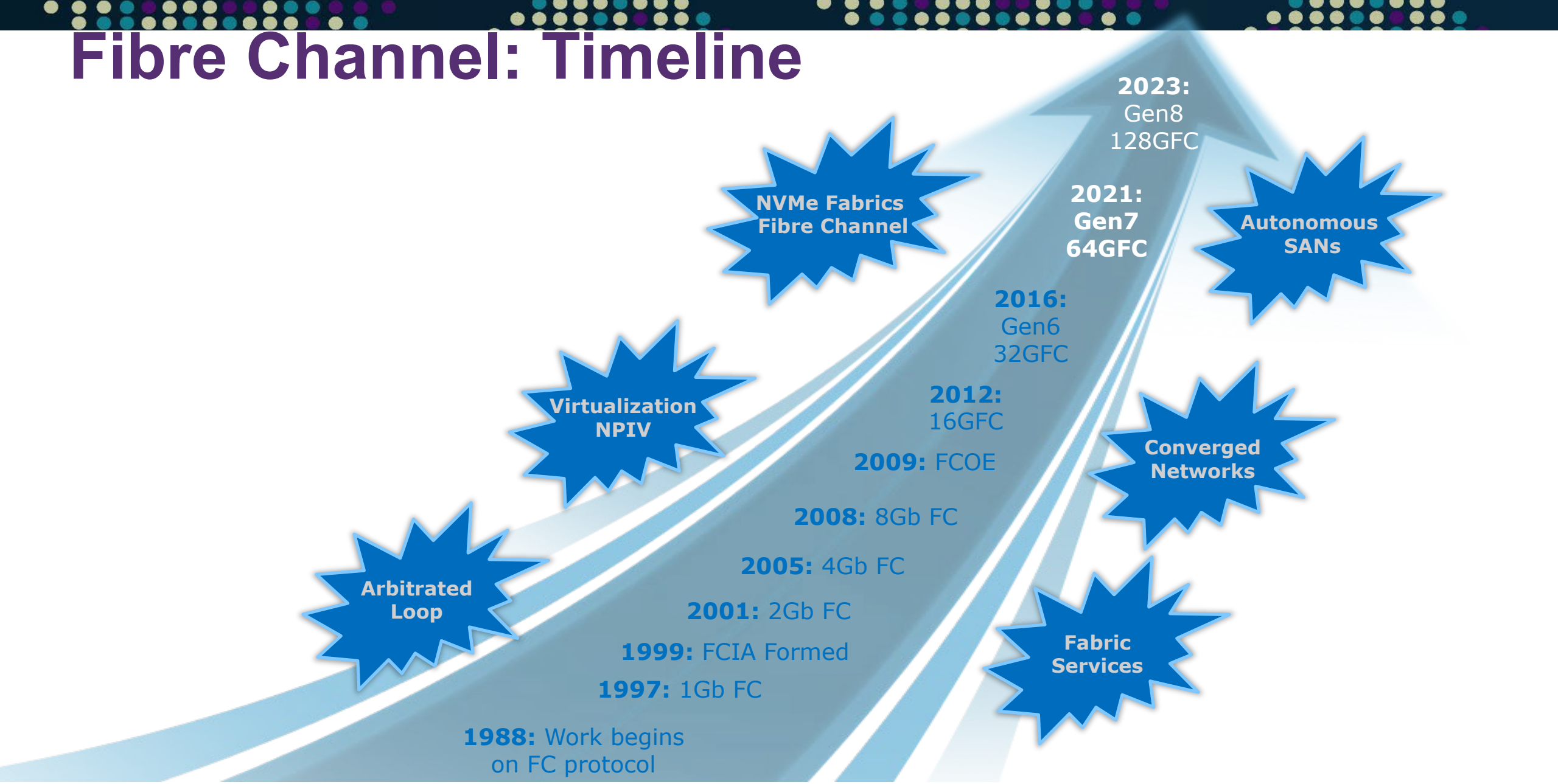
Industry Leading
Member Companies

160M FC Ports
Shipped Since 2001

Agenda

- Fibre Channel milestones
- Fibre channel terminology and nomenclature overview
- 128GFC standard FC-PI-8 (physical)
- 128GFC standard FC-FS-6 (framing and signaling)
- Optical transceivers used in 128GFC
- Protocol changes required for 128GFC implementation
- Future roadmap

Fibre Channel: Timeline



Fibre Channel Standards

- A short tour through the acronym soup that are Fibre Channel standards.
- The Fibre channel standards focused on in this presentation are:
  - Physical: Fibre-Channel-Physical-Interface, aka FC-PI
  - Protocol: Fibre-Channel-Framing-Signaling, aka FC-FS
- A number is appended to the acronym to represent the speed contained in the standard, FC-PI-9 represents 256GFC.

Document	Represents…
FC-PI	1GFC 2GFC
FC-PI-2	4GFC
FC-PI-4	8GFC
FC-PI-5	16GFC
FC-PI-6 FC-PI-6P	32GFC 128GFC (parallel)
FC-PI-7 FC-PI-7P	64GFC 256GFC (parallel)
FC-PI-8	128GFC
FC-PI-9	256GFC

FC-PI-8 Starting Requirements

- 128GFC had to be backward compatible to 64GFC and 32GFC.
  - Backward compatibility and “plug and play” to utilize existing infrastructure with new speeds is always a must have for FC development.
- Existing cable assemblies must plug into 128GFC capable products
  - LC (connector) and SFP+ (form factor)
- Reach goals
  - 100 meters for multi-mode short reach optical variant using OM4/OM5 cable plants
    - OM4 optical fibre has a higher optical bandwidth than OM3 fibre which leads to longer reach at a given speed.
  - 10KM for single mode optical variant
  - Electrical variant for backplane applications
- 128GFC doubles the throughput of 64GFC
- Corrected bit-error-rate (BER) target of 1e-15

INCITS T11 128GFC Standard Milestone

- 2023 INCITS T11 completes FC-PI-8
  - 128 GFC single lane specification
- 2023 INCITS T11 completes FC-FS-6
  - 128 GFC single lane framing and signaling specification
- 2023 INCITS T11 approves FC-PI-9 project
  - 256 GFC single lane specification
  - Committee work started December 2022

Fibre Channel Variants in FC-PI-8

SM OS2	128GFC-LW	1300nm	0.5 m-**10km**	sub-clause 5.4
SM OS2	128GFC-LI	1300nm	0.5 m-**2km**	sub-clause 5.4
MM 50m OM3	128GFC-SW	850nm	0.5 m-60m	sub-clause 5.5
MM 50m OM4,OM5	128GFC-SW	850nm	0.5 m-**100m**	sub-clause 5.5
Backplane	128GFC-EA			clause 7

Signaling Rate Abbreviations

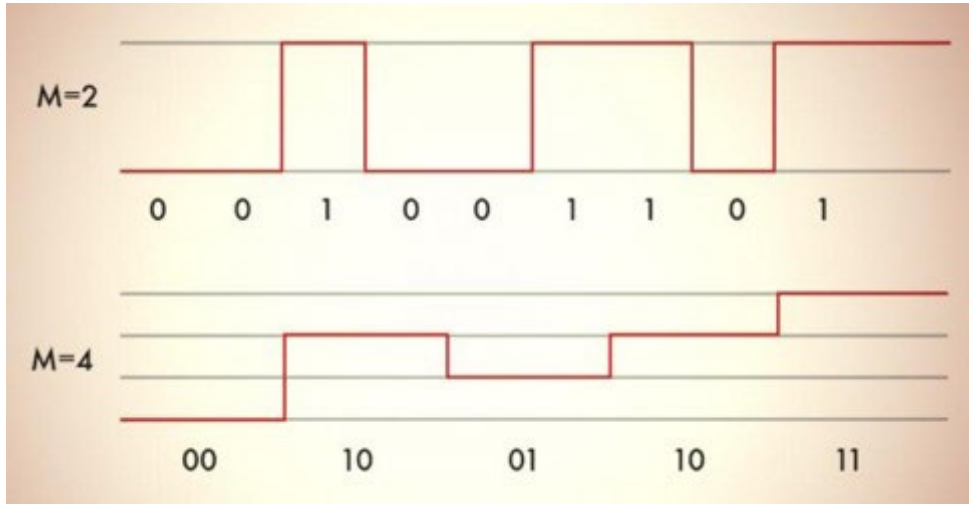
Abbreviation	Signaling rate	Number of Lanes	Data rate
1GFC	1.0625 MBd	1 (NRZ)	100 MB/s
2GFC	2.125 MBd	1 (NRZ)	200 MB/s
4GFC	4.250 MBd	1 (NRZ)	400 MB/s
8GFC	8.500 MBd	1 (NRZ)	800 MB/s
16GFC	14.025 MBd	1 (NRZ)	1600 MB/s
32GFC	28.050 MBd	1 (NRZ)	3200 MB/s
64GFC	28.900 MBd	1 (PAM4)	6400 MB/s
128GFC	56.1 MBd	1 (PAM4)	12425 MB/s
256GFC	112.200 MBd	1 (PAM4)	24850 MB/s

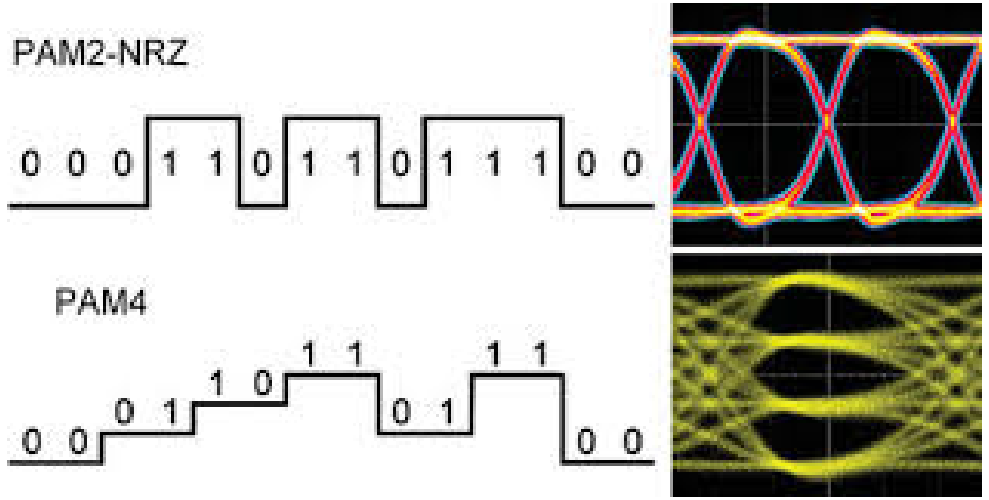
MB/s = Mega*bytes* per second
MBd = Mega*baud* per second

Modulation for 128GFC

- Modulation refers to the signal levels that are on the “wire” (physical interface) whether optical or electrical
  - The optical and electrical encoding and “wire” rate are the same
- 128GFC uses PAM4 modulation and is 112.2Gbps (56.1Gb)
- 64GFC also uses PAM4 modulation and is 57.8Gbps (28.9Gb)
  - For 64GFC studies by the Fibre Channel committee and other committees determined that moving to PAM4 modulation would be “easier” from a component and IP perspective than staying with the NRZ/PAM2 modulation and doubling the “wire” rate to 57.8Gb.
- 32GFC has a NRZ/PAM2 line rate of 28.05Gb.

Each PAM4 Signal Level Corresponds to a Two-bit Symbol





As serial data rates surpass 32Gb/s per channel, signal impairments caused by increasing bandwidth necessitate the high-speed serial data technology to shift from simple NRZ (non-return to zero PAM2) signal modulation to the bandwidth efficient PAM4 (4-level pulse amplitude modulation).

Optical Transceivers for 128GFC

- Optical transceivers used for both short reach (multi-mode) and long reach (single mode) utilize PAM4 signaling on the optical cable
- Electrical signal presented to the optical transceiver is PAM4 encoded also
  - Optical transceiver transmits on the optical cable using PAM4; no modulation conversion needed in the optical transceiver
- The optical transceiver has a clock and data recovery circuit (CDR) in the module on both the transmit and receive path
  - CDR resets the jitter budget at each optical transceiver; needed to close the link budget for the end to end link

128GFC SR, FR, LR SFP112 Form Factor

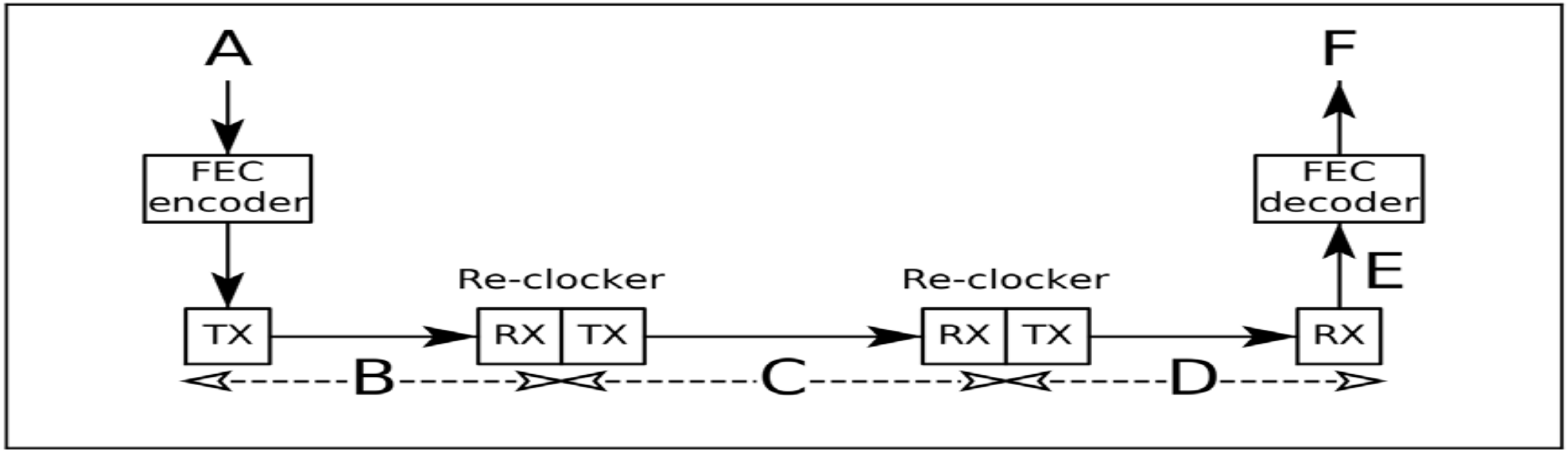
- 128GFC PAM4 electrical I/O, PAM4 optical I/O (host FEC)
- Tri-rate 128GFC/64GFC/32GFC SFP112 capability
- Retimer Technology
- Standard Diagnostics per SFF-8472
- CMIS support

128GFC variants
- 128GFC-SW (100 meter reach MM)
- 128GFC-LI (2KM reach SM)
- 128GFC-LW(10KM reach SM)

SFP112 Form Factor

Fibre Channel Link

- The diagram below represents a simple Fibre Channel link.
- The link budget analysis looks at all the electrical and optical impairments end to end to determine if a transmitted signal can be received with a bit error rate below the minimum required.



BER per Link Location/Segment

Location	Description	BER segement	BER cumlative
A	Input signal	0	0
B	Host Tx to Module electrical link	$1.09x10^{-5}$	
C	Optical Link	$1.09x10^{-4}$	
D	Module to Host Rx electrical link	$1.09x10^{-5}$	
E	Cumulative uncorrected BER for A-E		$1.31x10^{-4}$
F	Final FEC BER for A-F		$1.0x10^{-15}$

Forward Error Correction for 128GFC

- Forward Error Correction (FEC) is mandatory for all types of 128GFC links
- How it works
  - The transmitter encodes the data stream in a redundant way using an error correcting code
- 128GFC uses a block code called Reed Solomon.
  - The particular code used for 128GFC is RS(544,514)
  - This particular code allows correction of single bit errors or burst errors for 15 ten bit symbols out of 5140 bits sent
- 128GFC uses terms such as uncorrected BER which is the minimum BER to be expected pre-FEC encoding/decoding
  - Uncorrected BER is in the 1e-04 range or lower for 128GFC
  - FEC corrected BER is in the 1e-15 range or lower for 128GFC
  - These numbers help identify the usefulness of FEC in making 128GFC links robust

Forward Error Correction (FEC)

A set of algorithms that perform corrections that allow for recovery of one or more bit errors

- SNIA Dictionary

Forward Error Correction for 128GFC

- FEC has been used in previous FC variants
  - 64GFC had mandatory RS(544,514) FEC
  - 32GFC had mandatory RS(528,514) FEC
  - 16GFC had optional (2112,2080) FEC which was primarily used for copper variants
- The small baud rate increase for 64GFC (28.9Gb PAM4) versus 32GFC (28.05Gb PAM2) can be explained by the more powerful FEC used for 64GFC
- The extra parity bits needed for the 32GFC RS(528,514) came from transcoding the 64/66 bit stream using a 256/257 transcoder. This allowed gaining 140 parity bits without increasing the baud rate
- For 64GFC RS(544,514) is used and an additional 160 parity bits are needed and the only way to get the parity bits is to run at a slightly higher baud rate of 3.03%, i.e. 28.9Gb versus 28.05Gb
- The FEC from 128GFC to 64GFC was unchanged so no additional changes to baud rate were required

128GFC Speed Negotiation

- Fibre Channel link bring up phases, Link Speed Negotiation -> Optical Module bringup -> Transmitter Training -> Mission Mode
- Typical devices support three speeds 32/64/128
- LSN baud rate 32G (28.05Gb)NRZ
- advertise supported speeds in Extended Marker (32G,64G,128G)
- IEEE Clause 72 Training Signal
- The control and status frames are exchanged between link partners using Differential Manchester Encoding (DME)
- The DME run at 1/8 of the nominal signaling rate
- The DME coding runs at a lower signaling rate so that there is a high probability that the training control and status frames can be exchanged error free

128GFC Speed Negotiation

- Training Signal negotiates capabilities between transmitter and receiver
- advertise supported speeds via Extended Marker field
- FEC type for 128G
- FEC transmission mode (interleaved vs single, symbol forward vs bit interleave)
- Speed Negotiation (SN) field
- 0 = LSN finished
- 1 = LSN in progress

128GFC Transmit Training

- After Optical Module has indicated CDR lock, transition to Transmitter Training
- Negotiates capabilities between transmitter and receiver
- Transmitter equalizer coefficients
- Receiver adaptive equalization
- FEC support
- FEC is optional for 16G
- FEC is mandatory for 32G/64G/128G
- Training algorithms derived from IEEE
  - 802.3-2018 Clause 72 (16G and 32G)
  - 802.3cd Clause 136 (64G)
  - 802.3ck Clause 162 (128G)

256GFC FC-PI-9 Planned Requirements

- FC-PI-9 is an approved project at INCITS
- Backward compatible to 128GFC and 64GFC
- Same external connectors as 128/64GFC
- Existing cable assemblies will work with 256GFC
- Multi-mode cable plant reach is 100 meters on OM4/OM5
- Single mode cable plant reach of 10KM
- 256GFC links should double the throughput in MB/sec of 128GFC links
- Corrected BER target of 1e-15

Fibre Channel Speeds

Product Naming	Throughput (Mbytes/s)*	Line Rate (Gbaud)	T11 Specification Technically Complete (Year) †	Market Availability (Year) †
8GFC	1,600	8.5 NRZ	2006	2008
16GFC	3,200	14.025 NRZ	2009	2011
32GFC	6,400	28.05 NRZ	2013	2016
64GFC	12,800	28.9 PAM-4	2017	2020
128GFC	24,850	56.1 PAM-4	2022	2024
256GFC	49,700	112.2 PAM-4	2025	Market Demand
512GFC	TBD	TBD	2029	Market Demand
1TFC	TBD	TBD	2033	Market Demand

"FC" used throughout all applications for Fibre Channel infrastructure and devices, including edge and ISL interconnects. Each speed maintains backward compatibility at least two previous generations (I.e., 32GFC backward compatible to 16GFC and 8GFC)

*These numbers are representative throughput values for the line rate and are payload dependent

† Dates: Future dates estimated

Thank You

