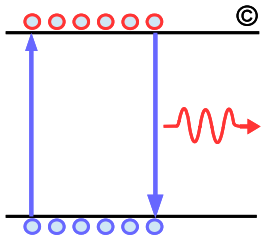


FEC Architecture with Evolution of AUI and PMDs

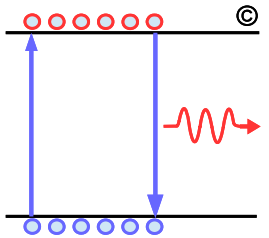
Ali Ghiasi, Ghiasi Quantum LLC

802.3df Task Force Meeting

May - Virtual Interim Meeting

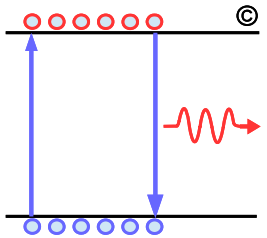
May 18, 2022

Supporters



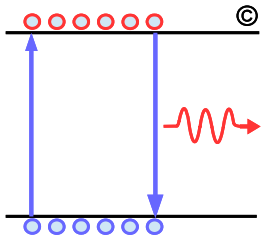
- **William Bliss – Broadcom**
- **Arash Farhoodfar – Marvell**
- **Lenin Patra - Marvell**

Overview



- 802.3df PMD landscape
- AUI/PPI interfaces
- Different classes of AUI
- Early result on 200G CR and AUI
- 800 GbE System evolution
- How to adopt 800 GbE overall architecture prior to full vetting of 200G optical/Cu FEC
- Can we follow 802.3bs FEC architecture and support electrical segments with end-end FEC
- Evolution of AUI and PMDs with common base FEC
- How to potentially partition 802.3df into 3 task forces
- Summary.

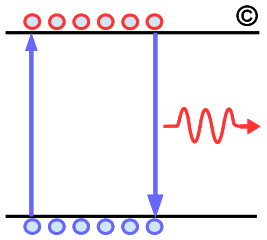
Adopted Objectives



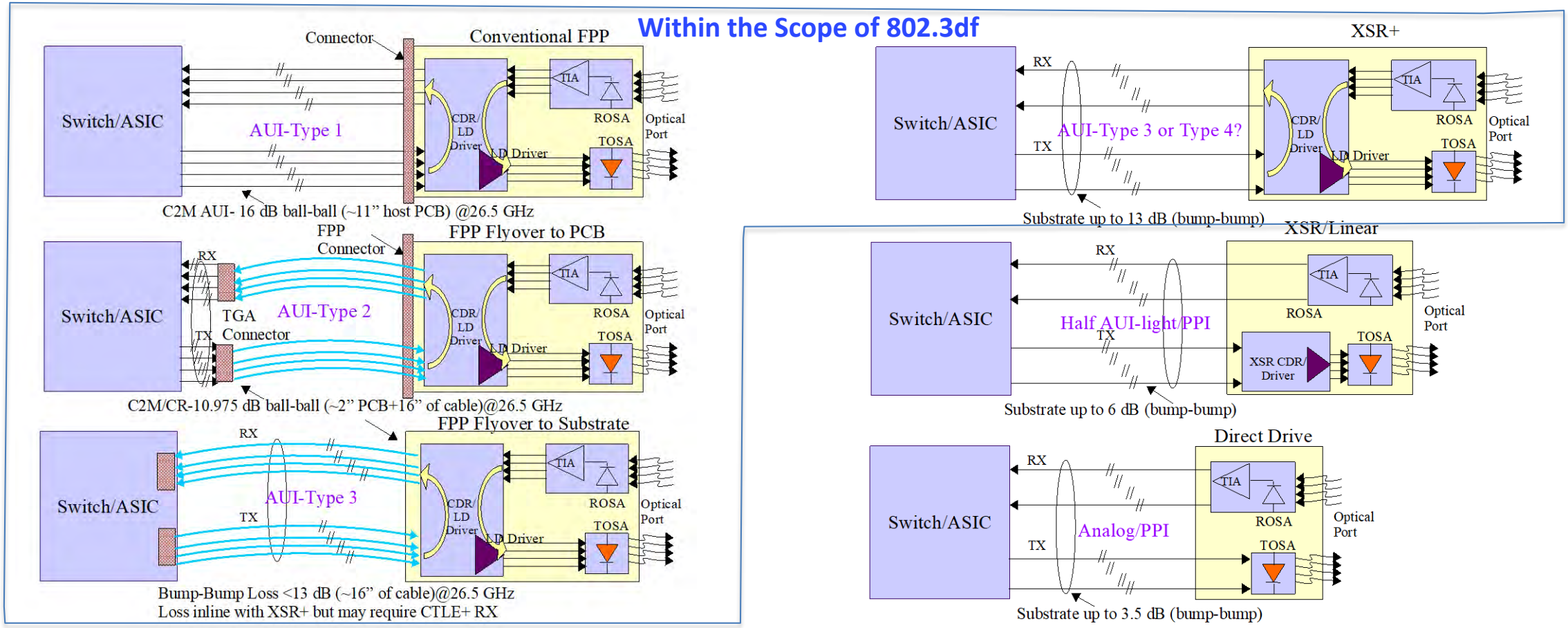
- **14 optical PMDs, 5 CR PMDs, 6 AUIs, and 1 BP PMDs**
  - Any deployment of 200G/lane or coherent optical PMDs will use 100G-AUI interfaces.

Ethernet Rate	Assumed Signaling Rate	AUI	BP	Cu Cable	MMF 50m	MMF 100m	SMF 500m	SMF 2km	SMF 10km	SMF 40km
200 Gb/s	200 Gb/s	Over 1 lane		Over 1 pair			Over 1 Pair	Over 1 Pair		
400 Gb/s	200 Gb/s	Over 2 lanes		Over 2 pairs			Over 2 Pair	Over 4 pair (New Objective)		
800 Gb/s	100 Gb/s	Over 8 lanes	Over 8 lanes	Over 8 pairs	Over 8 pairs	Over 8 pairs	Over 8 pairs	Over 8 pairs		
	200 Gb/s	Over 4 lanes		Over 4 pairs			Over 4 pairs	1) Over 4 pairs 2) Over 4 λ's		
	TBD								Over single SMF in each direction	Over single SMF in each direction
1.6 Tb/s	100 Gb/s	Over 16 lanes								
	200 Gb/s	Over 8 lanes		Over 8 pairs			Over 8 pairs	Over 8 pairs		

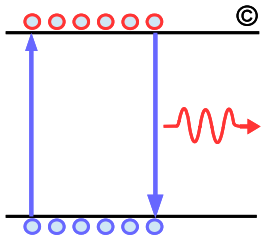
AUI and PPI Interfaces



- **XSR/Direct drive generally require optics engine to be bumped and the interface is an engineered analog drive – not an AUI interface**
  - With in the scope of 802.3df we have potentially up to 4 AUI classes and as few as 2 classes!

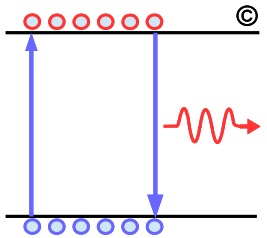


Different Classes of AUI



- **Conventional AUI with module cage mounted on the host PCB, early data indicates benefit of operating conventional AUI at 1E-4**
  - Conventional AUI may also be limited in use due to ~1.6 dB/in loss @53 GHz on large switches
  - Initial data with 8 taps DFE receiver indicate conventional AUI interface may need to operate at 1E-4 pre-FEC BER
- **Non-conventional AUIs expect to operate with simpler equalizer and with improved BER:**
  - Flyover AUI to host PCB - reduce host loss and eliminates cage to PCB transition
  - Co-Packaged Cu with Flyover to cage – reduce loss and eliminates 1st level package transition to host PCB
  - XSR+ in support of NPO (Near Package Optics) - losses are limited to HDI substrate and transition within the HDI substrate
    - HDI substrate has similar construction to conventional PCB but supports trace as narrow as 2 mils, with buried, blind, and laser vias
  - XSR in support of CPO (Co-packaged Optics) – interconnection is through the 1st level package substrate
    - 1st level package substrate commonly based on organic build-up with stack vias and traces as narrow as 0.4 mils
  - Non-conventional AUI expect to operate with simpler equalizer and at 1E-5 pre-FEC BER
- **At 100G both conventional AUI and Flyover AUI, and co-packaged AUIs all are supported with VSR/C2M SerDes**
  - The only exception is XSR+ which is a form of AUI in support of NPO and co-packaged Cu
- **Can at 200G both conventional and non-conventional AUI interfaces all be supported with just VSR/C2M and XSR+?**

Early Results for Conventional AUIs



- **For conventional AUI both Akinwale and Li used reference COM 3.7 with 8 taps DFE**
  - Early data indicate pre-FEC BER of 1E-4 will be beneficial
    - Results for Li was only for 1E-5 BER
  - Non-conventional AUIs expect to have simpler receiver and operating at pre-FEC BER 1E-5.

Channel Results

[akinwale_3df_01_20220502]

								DER= 1e-4	DER= 1e-5
Channel	Tx Package Length[mm]	FOM_ILD	MDNEXT_ICNmV	MDFEXT_ICN_mV	ICN_mV	ERL(1e-4)	fitted_IL_dB_at_Fnq	COM[dB]	COM[dB]
C2M_PCB_10dB	15	0.54	1.08	3.72	3.88	12.23	10.32	3.53	1.38
C2M_PCB_10dB	31	0.54	1.08	3.72	3.88	12.23	10.32	3.08	1.93
C2M_PCB_11dB	15	0.60	1.08	3.41	3.58	12.73	11.05	2.84	1.68
C2M_PCB_11dB	31	0.60	1.08	3.41	3.58	12.73	11.05	3.38	2.21
C2M_PCB_12dB	15	0.55	1.04	3.16	3.33	13.20	11.94	3.06	1.90
C2M_PCB_12dB	31	0.55	1.04	3.16	3.33	13.20	11.94	3.37	2.20
C2M_PCB_13dB	15	0.54	1.02	2.90	3.08	13.64	12.81	3.13	1.98
C2M_PCB_13dB	31	0.54	1.02	2.90	3.08	13.64	12.81	3.41	2.25

								DER= 1e-4	DER= 1e-5
Channel	Tx Package Length[mm]	FOM_ILD	MDNEXT_ICN_mV	MDFEXT_ICN_mV	ICN_mV	ERL(1e-4)	fitted_IL_dB_at_Fnq	COM[dB]	COM[dB]
KEY_C2M_200G_120G_4p0HCB_022422_Thru	15	0.56	6.19	6.35	8.87	16.90	12.40	3.64	2.48
KEY_C2M_200G_120G_4p0HCB_022422_Thru	31	0.56	6.19	6.35	8.87	16.90	12.40	3.33	2.17
KEY_C2M_200G_120G_2pSHCB_022422_Thru	15	0.57	4.50	5.47	7.08	18.49	13.89	3.96	2.78
KEY_C2M_200G_120G_2pSHCB_022422_Thru	31	0.57	4.50	5.47	7.08	18.49	13.89	3.63	2.45

Channels from rabinovich_3df_01a_220224

Red indicates failing 3dB COM limit

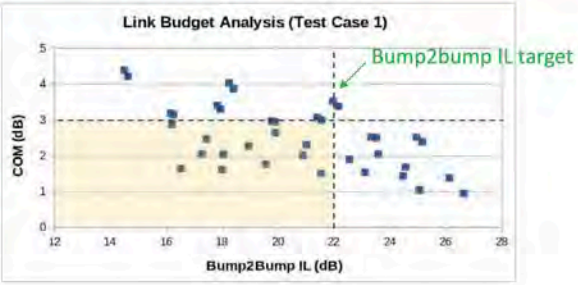
COM: version 3.7

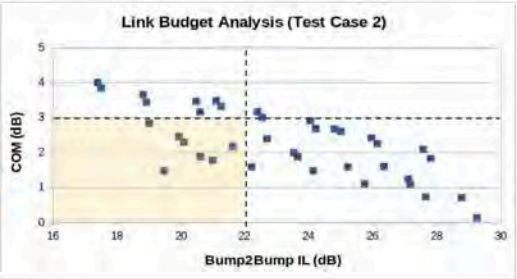
[tli_3df_01b_220316]

COM Simulation for 200G/L PAM4 C2M

- **Whole link budget analysis**
  - To allow the interoperability among channel components
  - Analyze performance from the system's point of view
  - Evaluate COM instead of VEC & VEO
- **Whether 200G/L PAM4 C2M works?**
  - If keep the same bump2bump IL target from 100G to 200G
    - IL target in 100G/L PAM4 C2M:
      16 dB ball2ball + PKG loss = ~22 dB bump2bump
  - If make SerDes capability aligned from 100G to 200G

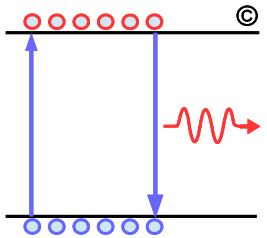
22dB bump2bump still reasonable for 200G/L C2M?





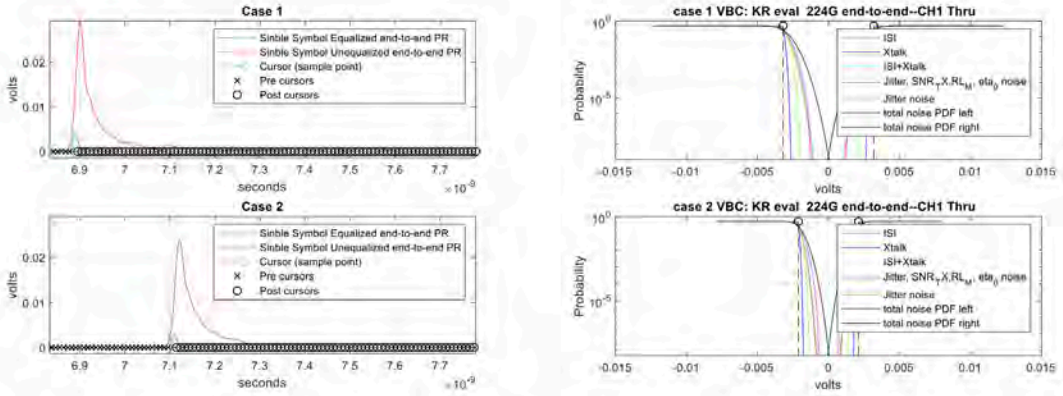
MEDIATEK

Early Results on 1 m CR Feasibility



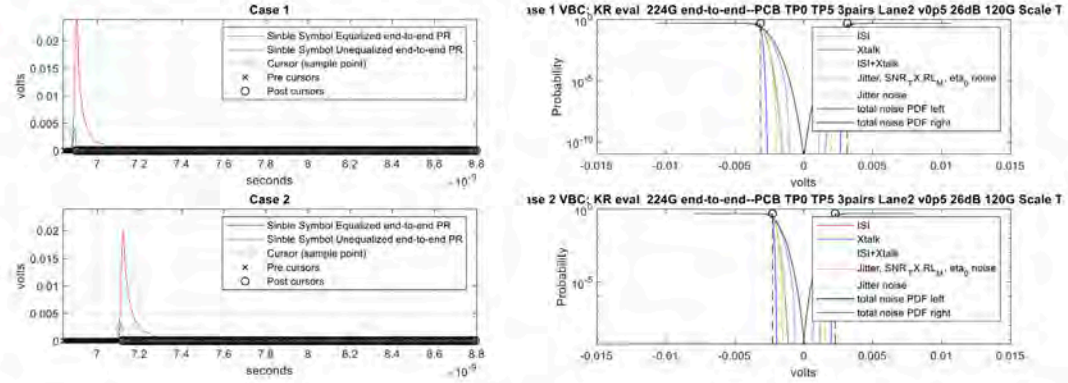
- **Early results indicates 1 m CR can be supported at pre-FEC BER of 1E-4**
  - For large switch implementation to overcome 8” inches of host PCB loss one would need to use Flyover to host TGA connector or use Flyover co-packaged Cu
  - Li’s results li_3df_02a_220322 has respectively COM of 3.5 dB and 4.3 dB!

Case A: 224 Gbps-PAM4 CR+ COM Analysis Results



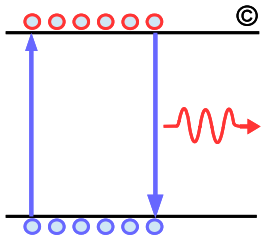
- COM = 3.517dB w/ [12, 12]mm pkg (Case 1), 3.049dB w/ [31, 29]mm pkg (Case 2)

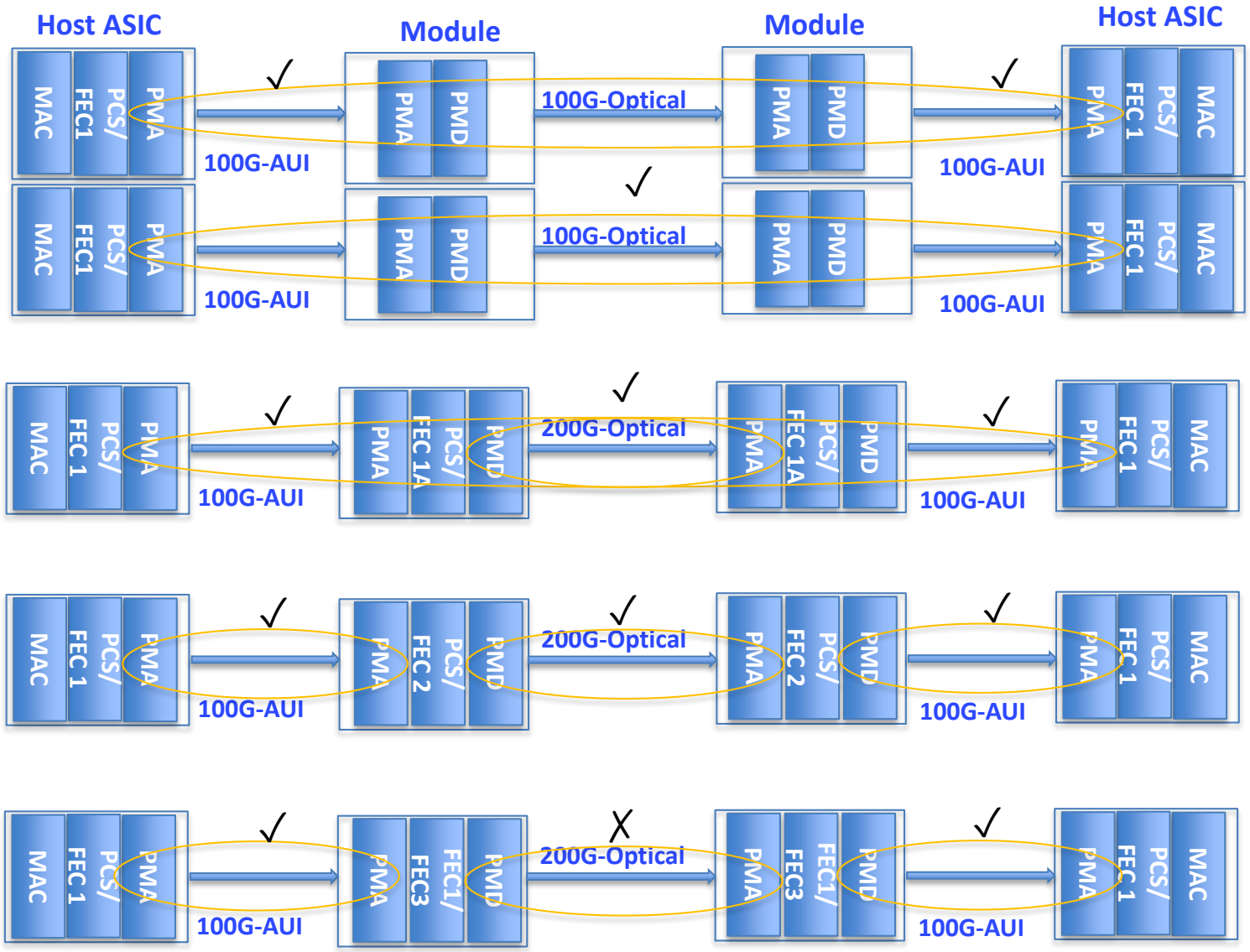
Case B: 224Gbps-PAM4 CR COM Analysis Results



- COM = 4.265dB w/ [12, 12]mm pkg (Case 1), 3.274dB w/ [31, 29]mm pkg (Case 2)

1st Generation 800 GbE Systems





I. **1st 800 GbE deployment will be based on 100G/lane and end-end RS (514,544) FEC "KP4"**

- 1st 800 GbE optical deployment
- 1st CR/KR deployment

II. **2nd Gen 800 GbE will be based on 200G/lane optical PMDs and end-end RS (514,544) FEC**

- These PMDs will plug into the Gen 1 host
- Concatenated RS(514,544)+ SFEC (soft decision) on top of FEC1 is the only compatible option
- SFEC can have 1.61-2.7 dB additional NCG

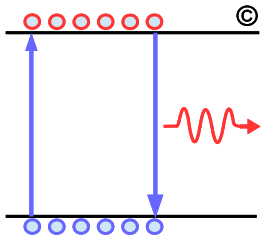
III. **1st Gen 800 GbE coherent based on segmented FEC**

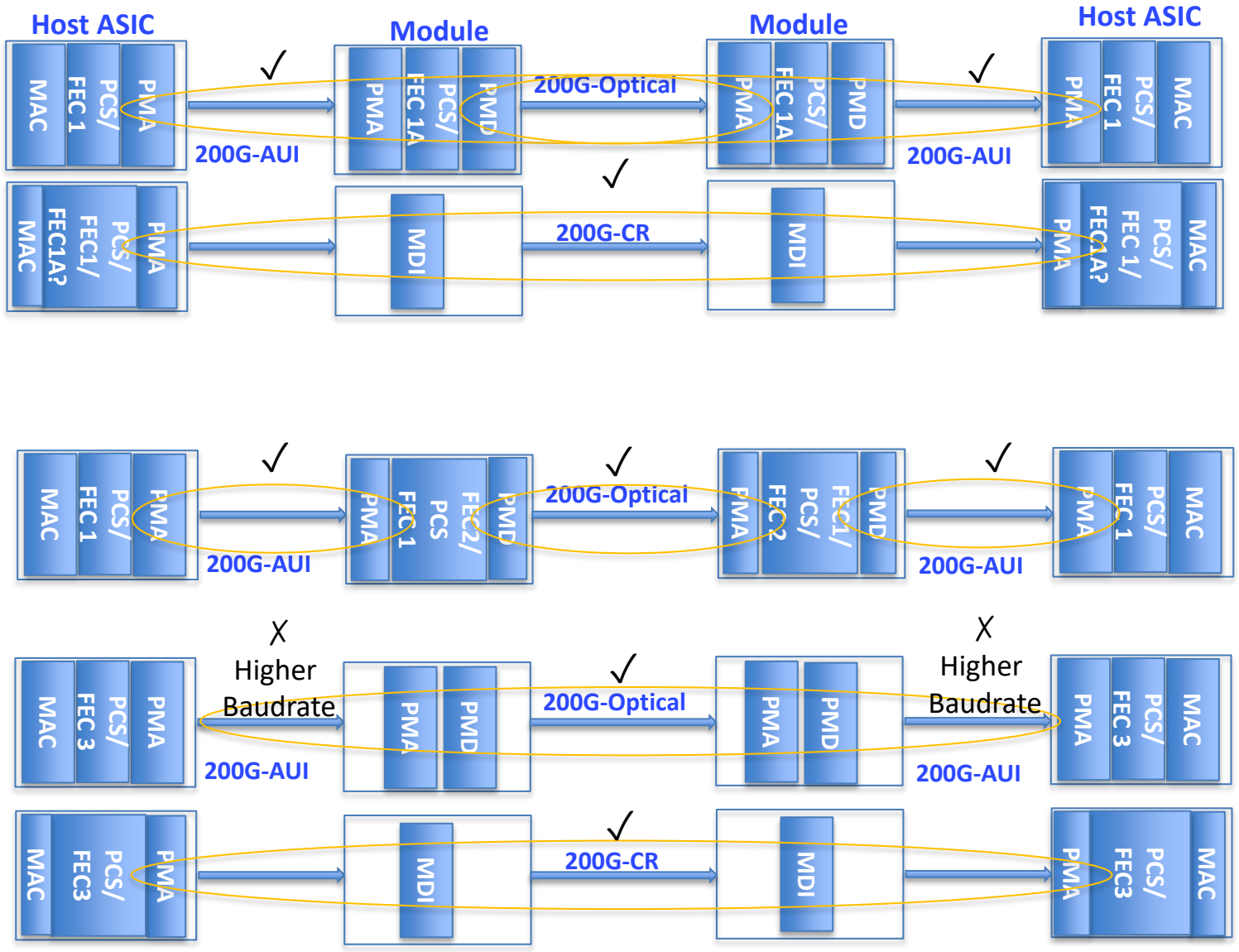
- Example of FEC2 are CFEC, SFEC+, etc.

IV. **2nd Gen 800 GbE PMDs (200G/lane) based on new strong FEC3 must plug into systems with RS (514, 544) FEC**

- Example of FEC3 is RS (514, 576) FEC
- Require termination of (514, 544) in modules!

2nd Generation 800 GbE Systems





I. **2nd Generation 800 GbE system based on 200G I/O with end-end RS (514,544) FEC offer seamless upgrade path**

- Optical PMDs based on 200G/lane replace 100G-AUI with 200G–AUI
- CR PMDs based on 200G/lane may operate with just FEC1 or optionally for greater reach may utilize FEC1A

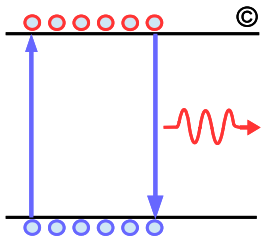
II. **2nd Gen 800 GbE coherent**

- Segmented RS(514,544)+CFEC, SFEC+, etc.
- Replace 100G-AUI with 200G-AUI

III. **2nd Gen 800 GbE will be based on 200G/lane optical PMDs and end-end RS (514,576) FEC3**

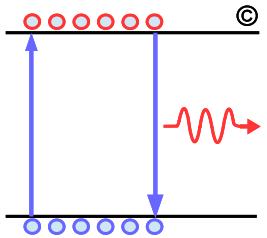
- Only when both AUI and optical PMDs are upgraded FEC3 offer some benefit
- Forces 200G-AUI and 200G-CR to higher Baudrate!

How to Define 200G/lane Optical PMDs Prior to 200G/lane AUI

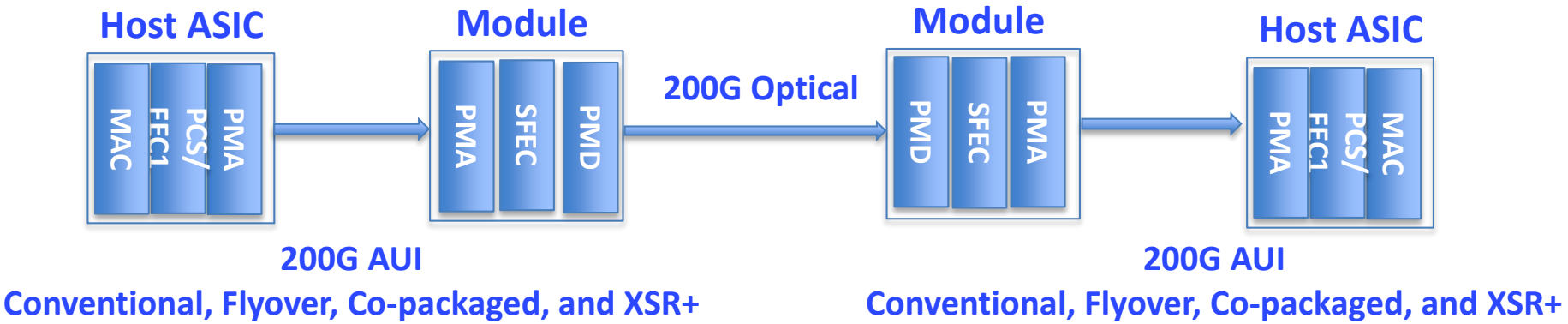


- **Early data indicate potential feasibility even conventional 200G-AUI may operate at pre FEC BER of 1E-5**
  - Nonconventional AUI with Flyover Cu and co-packaged expect to operate at 1E-5 BER with simpler equalizer
  - Nonconventional AUIs expect to operate on the electrical segments at 1E-5 pre-FEC BER with end-end RS (514,544) FEC for both 100G and 200G optical PMDs
    - 200G optical PMDs with SFEC in the module based on interleaver will have 1.6-2.7 dB of additional NCG
  - Conventional 200G-AUI due to high loss and ILD may benefit operating at 1E-4
    - To limit the impact on optical gain conventional 200G-AUI with RS (514,544) could be terminated in the module
- **Based on early data on 200G-AUI and 200G-CR with addition of SFEC with high confidence we can follow 802.3bs architecture that operated with an end-end FEC and by allocating 0.1-0.2 dBo to electrical sub-links**
  - There are potentially 3-4 types of AUIs some expect to operate with end-end FEC with 0.1-0.2 dBo allocation to the electrical sublinks
  - With emergence of optics/Cu co-packaging there are more implementation options than traditional AUIs
  - Some of the optics co-packaging may use low speed parallel buses, PPIs, or even PMD interfaces
  - It is plausible that future 200G system may not have any conventional PCB based AUIs
- **Conventional 200G AUI expect to be have substantially higher loss, ILD, and reflections**
  - 802.3df should not tax everyone for implementation that may not get used broadly
  - Segmented FEC based on termination of KP4 FEC in the module is an option that may be required to support conventional 200G AUI based on today's data
- **SFEC+KP4 provides seamless migration from 100G AUI hosts to 200G AUI with backward compatibility!**

802.3bs FEC Architecture Can be Followed at 200G

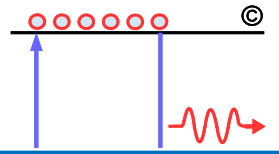


- **802.3df task force need to define a new 200G/lane optics FEC with 0.1-0.2 dBo reserved for PMA/PMD/PPI sub-links as shown below**
  - SFEC+RS(514,544) allow seamless upgrade of 100G-AUIs to 200G/lane optics without rate increase on the 802.3ck interfaces
  - It is also expected the end-end SFEC+RS(514,544) to support a range of AUIs plus optical PMDs
  - Conventional AUI based 9” host PCB loss will be 14.4* dB (~1.6 dB/in) may require FEC termination
    - Expect to push 100G-AUI bump-bump loss from ~22 dB to ~26 dB!



* Assumes 6.5 mils wide striplines with DK=3.0, DF=0.0015, 1 μm finish.

Evolution of AUI and PMDs with Common KP4 FEC



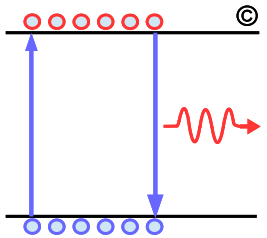
Ethernet MAC Speed	Signaling Rate per AUI Lane	AUI Lanes	Singling Rate per PMD Lane	Copper Cable		MMF Parallel		SMF Parallel		SMF Duplex		
				1 m	2 m	50 m	100 m	500 m	2 km	2 km	10 km	40 km
200 Gb/s	200 Gb/s	1 Lane 200GAUI-1 KP4 end-end FEC*	200 Gb/s	200G-CR KP4 or KP4+SFEC				200G-DR KP4+SFEC		200G-FR KP4+SFEC		
400 Gb/s	200 Gb/s	2 Lanes 400G-AUI2 KP4 end-end FEC*	200 Gb/s	400G-CR2 KP4 or KP4+SFEC				200G-DR2 KP4+SFEC	200G-DR2-2 KP4+SFEC			
800 Gb/s	100 Gb/s	8 Lanes 800GAUI-8 KP4 end-end FEC	100 Gb/s		800G-CR8 KP4	800G-VR8 KP4	800G-SR8 KP4	800G-DR8 KP4	800G-DR8-2 KP4			
			200 Gb/s					800G-DR4 PAM4 KP4+SFEC	800G-DR4-2 PAM4 KP4+SFEC	800G-FR4 PAM4? KP4+SFEC		
			TBD								800G-LR4/ KP4+SFEC DP-QAM/ CFEC, SFEC+*	DP-QAM/ CFEC, SFEC+*
800 Gb/s	200 Gb/s	4 Lanes 800GAUI-4 KP4 end-end FEC**	200 Gb/s	800G-CR4 KP4 or KP4+SFEC				800G-DR4 KP4+SFEC	800G-DR4-2 KP4+SFEC	800G-FR4 PAM4? KP4+SFEC		
			TBD								800G-LR4/ KP4+SFEC DP-QAM/ CFEC, SFEC+*	DP-QAM/ CFEC, SFEC+*

* Coherent PMDs with CFEC require termination but with concatenated SFEC+ does not.

** Conventional 200G-AUI with higher loss/ILD may require segmented KP4 FEC.

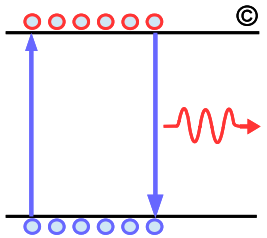
Baselines Adopted PAM4 with KP4 FEC | **Agreed on PAM4 need to adopt FEC** | **Expect PAM4 but need to adopt FEC** | **Need to adopt modulation & FEC**

Breaking B400G PMDs Sets Potentially into 3 Taskforces



- **802.3df taskforce – with potential decision on 800G FEC and migration path with RS (514,544) FEC this task force can proceed to D1.0**
  - Update CL119 PCS/FEC to support 800 GbE
  - Define 800G-DR8, 800G-SR8, 800G-FR8
  - 800G-AUI8, 800G-CR8/KR8
- **2nd taskforce "200G Optical" – adopt SFEC+KP FEC or introduce a new higher NCG RS FEC that require termination of KP FEC in the module**
  - 200G/lane SMF optics PMDs
  - 800G-ZR
  - 1600 GbE MAC/PCS
- **3rd taskforce "200G Cu" – SFEC+KP FEC offer more flexible architecture without pushing the 200G AUI rate up**
  - 200G-AUI/C2C, and CR.

Summary



- **Adopting CL119 style PCS with RS (514, 544) FEC "KP4" shrikhande_3df_01_220517 for 800 GbE based on 32 VLs allow 800 GbE eco-system proceed to deployment based on 100G PMDs and 100G-AUI**
  - Need to get to D2.0 given that products are already in development
- **Concatenated SFEC bliss_3df_01_220517 and lenin_3df_01_220518 provides 2+ dB of NCG on top of RS(514,544) FEC assuming at least 4-way interleaving**
  - The combination of RS(514, 544) FEC with concatenated SFEC provide seamless migration from 100G-AUI systems to 200G-AUI systems
  - Stronger RS FEC such as (514,576) doesn't provide seamless migration
- **Early result of 200G-CR and 200G-AUI indicate these interfaces may operate even at 1E-4 pre-FEC**
  - Some of variants of 200G-AUI based on Flyover cables and co-packaged Cu expect to even operate at 1E-5 pre-FEC
  - Operating 200G-AUI at lower KP4 Baudrate is advantages due strong roll off at higher frequency
  - 200G-CR may operate with end-end KP4 FEC with advantage of lower Baudrate
  - Optionally SFEC can be turned on longer reach CR links or if there is sufficient benefit
- **RS(514, 544) in conjunction with concatenated SFEC not only provide seemless migration but also offer more flexible overall solution for 200G-CR and 200G-AUI!**