Revisiting MPI Penalty for Optical PMDs

(Addressing comments 143, 145, 147, 149)

Ali Ghiasi - Ghiasi Quantum/Marvell

IEEE 802.3dj Meeting

Atlanta

March 10, 2025

Supporters

- John Johnson – Broadcom
- Gary Nicoll – Cisco
- Vipul Bhatt – Coherent
- Chris Cole – Coherent
- Haifeng Liu – HG Genuine
- Mike Dudek – Marvell
- Mark Kimber – Semtech.

Overview

- Background on DGD penalty
- Background on MPI penalties
- Revisiting cable plants
- CL180/182 MPI penalties discrepancies
- Reconciling discrepancy in CL180/182 with method of CL140
- Underlaying MPI assumptions
- Few MPI analysis
- Summary.

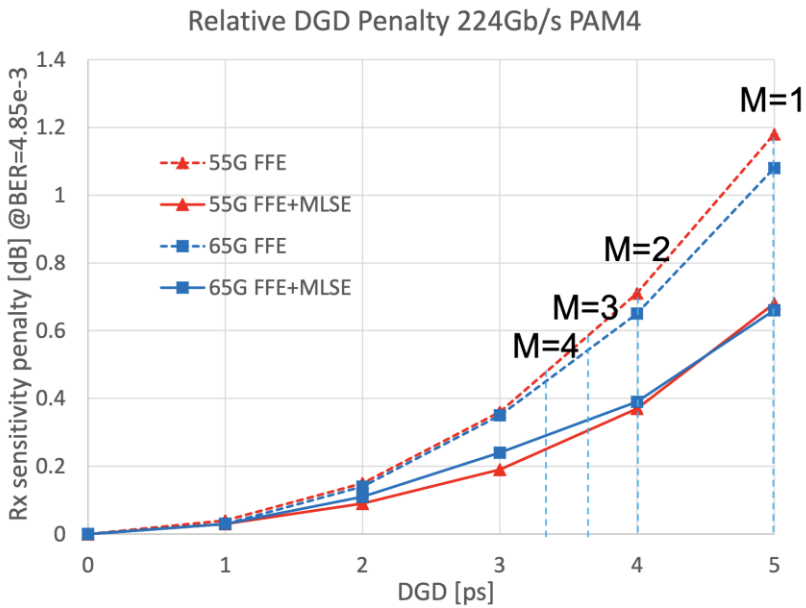
DGD Penalty for Clauses 180-183

- **kuschnerov_3dj_optx_01_230829 show worst case DGD penalty of 0.7 dB for clause 183 800GBASE-LR4 PMD for max DGD of 4 ps**
  - 800GBASE-FR4 with max DGD of 2.3 ps has ~0.18 dB penalty
  - 800GBASE-FR4/DRx-2 with max DGD of 2.3 ps has ~0.18 dB penalty
  - 800GBASE-FR4-500/DRx with max DGD of 2.24 ps has ~0.18 dB penalty
- **For PMDs listing combined DGD/MPI penalty the MPI value should be added to the above values of DGDs.**

DGD penalty for varying number of segments M

- The original single segment (M=1) PMD penalty was based on a FFE+MLSE receiver (0.7dB)
- Assuming multiple segments, a linear equalizer would be sufficient to achieve acceptable performance
- Given the available data and pending further discussion by the industry M=4 seems to be a reasonable assumption
- M=4 can achieve a penalty of ≤0.5dB with an linear FFE equalizer

kuschnerov_3df_01b_221012



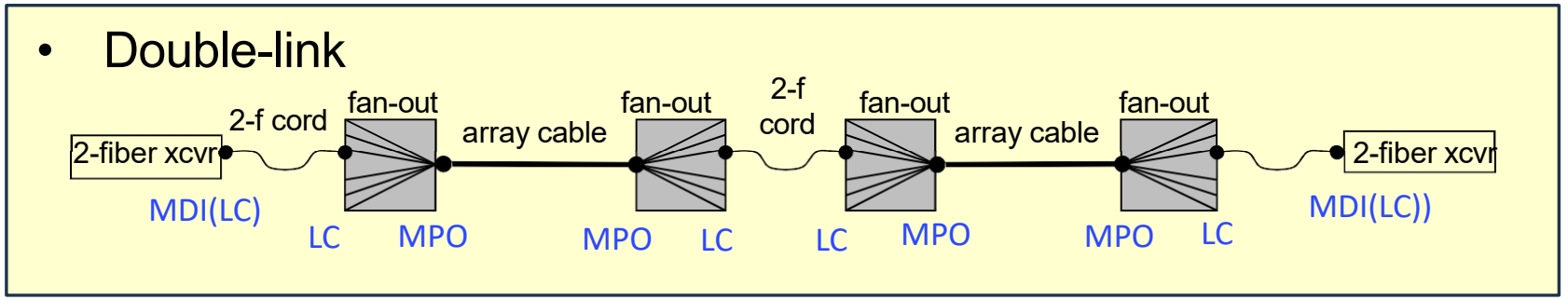
Revisiting the MPI/DGD Penalties

- **MPI penalty based on statistical model proposed by King_01a_01116_smf developed in 802.3bs has been adopted for MPI penalty estimation**
  - 802.3bs MPI analysis was based on assumption in liu_3bs_01a_0316
  - 802.3cd MPI analysis and how to reconcile PC and APC connectors penalties was based on traverso_3cd_01_0317
- **ghiasi_3dj_02_2501 raised concern regarding fixed allocation of MPI penalties**
  - 180.7.3 has allocation of 0.1 dB MPI/DGD penalty to support 200GBASE-DR1 @-35 dB discrete reflectance and 400GBASE-DR2/800GBASE-DR4/1.6TBASE-DR8 @-45 dB discrete reflectance
  - 182.7.3 has allocation of 0.4 dB MPI/DGD penalty to support 200GBASE-DR1-2 @-35 dB discrete reflectance and 400GBASE-DR2-2/800GBASE-DR4-2/1.6TBASE-DR8-2 @-45 dB discrete reflectance
  - Clause 181.7.3 and 183.7.3 generally is acceptable but may want to revisit some of the assumptions and make adjustment accordingly
- **johnson_3dj_adhoc_01_250220 additional background on the history of MPI penalty and there may be good reason to revisit some of the underlaying assumptions**
- **Reconciling PC and APC MPI penalties is top priority for 802.3dj**
  - Its also time to revisit underlaying MPI assumptions which applies to all clauses.

Cable Plants

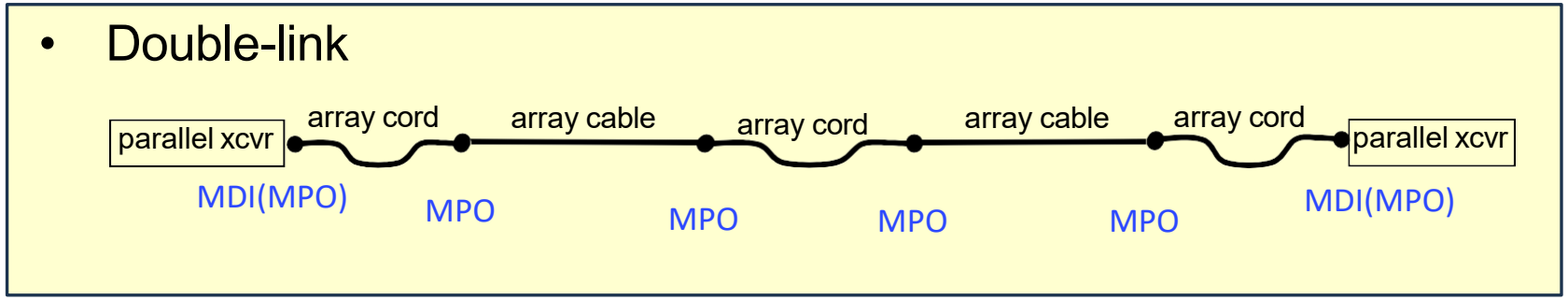
- **Cable plant model per kolesar_3bs_01_0514 double and triple link and nicholl_3bs_01a_0316 for MPI calculations**
  - Are these acceptable cable plant assumptions for 802.3dj optical PMDs?

200GBASE-DR
200GBASE-DR-2
800GBASE-FR4-500
800GBASE-FR4



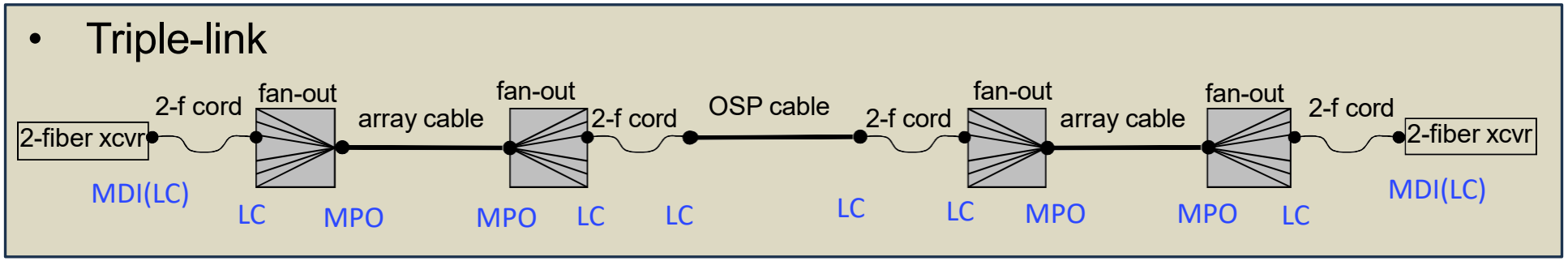
6 LC
+ 4 MPOs

400GBASE-DR2
400GBASE-DR2-2
800GBASE-DR4
800GBASE-DR2-4
1.6TGBASE-DR8
1.6TGBASE-DR8-2



6 MPO

800GBASE-LR4



8 LC
+ 4 MPO

Current Clause 180/182 Discrepancies

- **Clause 180 allocate 0.1 dB of MPI and DGD penalties for both LC and MPO cable plants**
  - See footnote in table 180-9
- **Clause 182 allocate 0.4 dB of MPI and DGD penalties for both LC and MPO cable plants**
  - See footnote in table 182-9

Table 180-12/182-12- Maximum value of each discrete reflectance

Number of discrete reflectances above –55 dB	Maximum value for each discrete reflectance for 200GBASE-DR1	Maximum value for each discrete reflectance for 400GBASE-DR2 800GBASE-DR4 1.6TBASE-DR8
1	–25 dB	–37 dB
2	–31 dB	–42 dB
4	–35 dB	–45 dB
6	–38 dB	–47 dB
8	–40 dB	–48 dB
10	–41 dB	–49 dB

Best Method to Reconcile MPI Penalty for Mixed MPO/LC PMDs

- **Clause 180 and 182 PMDs both use double link cable plant and using fixed MPI penalty doesn't work when LC reflectance is -35 dB and MPO -45 dB**
  - 2 fibers LC for 200GBASE-DR and 200GBASE-DR-2
  - Parallel fiber MPO for 400GBASE-DR2, 400GBASE-DR2-2, 800GBASE-DR4, 800GBASE-DR2-4, 1.6TGBASE-DR8, 1.6TGBASE-DR8-2
- **traverso_3cd_01_0317 proposed method can reconcile MPI penalty in mixed mode PMDs such as for 200GBASE-DR and 00GBASE-DR-2**
  - Row 0 with 0 >-45 dB and ≤-35 dB reflectance is the MPI for double link MPO cable plant
  - Row 0 with 0 >-45 dB and ≤-35 dB reflectance is used for MPI allocation of double link LC cable plant but cable plant loss are reduced with additional number of discrete reflectance's (LC) >-45 and ≤-35 dB.

MPI Penalty Calculation Table from Traverso

MPI Penalty (dB)		Number of discrete reflectances > -55 dB and ≤ -45 dB								
		0	1	2	3	4	5	6	7	8
Number of discrete reflectances > -45 dB and ≤ -35 dB	0	0	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.10
	1	0.05	0.06	0.05	0.09	0.11	0.12	0.11	0.15	0.12
	2	0.1	0.12	0.13	0.16	0.19	0.2	0.22	0.23	0.22
	3	0.18	0.18	0.2	0.2	0.24	0.3	0.3	0.32	*
	4	0.26	0.27	0.32	0.34	0.36	0.4	0.41	*	*
	5	0.32	0.33	0.38	0.4	0.44	0.48	*	*	*
	6	0.45	0.48	0.51	0.54	0.57	*	*	*	*

x.yz = these values exceed the proposed MPI penalty limit – see slide 3

Table 140–12—Maximum channel insertion loss versus number of discrete reflectances

Maximum channel insertion loss (dB)		Number of discrete reflectances > –55 dB and ≤ –45 dB								
		0	1	2	3	4	5	6	7	8
Number of discrete reflectances > –45 dB and ≤ –35 dB	0	3	3	3	3	3	3	3	3	3
	1	3	3	3	3	3	3	3	3	3
	2	3	3	3	2.9	2.9	2.9	2.9	2.9	2.9
	3	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	—[a]
	4	2.8	2.8	2.8	2.8	2.7	2.7	2.7	—[a]	—[a]
	5	2.8	2.8	2.7	2.7	2.7	2.6	—[a]	—[a]	—[a]
	6	2.6	2.6	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]

[a]The indicated combination of reflectances does not provide a supported maximum channel insertion loss.

Underlaying MPI Penalty Assumptions

- **Underlaying assumptions in the 802.3bs/cd**
  - Cable plant follow double or tipple link model
  - Max loss at the end of cable plant
  - LC reflectance -35 dB
  - MPO reflectance -45 dB
  - ER=5 dB
  - BER 2E-4
  - MPI penalty extrapolated to 1E-6

- **Proposed assumptions for 802.3dj**
  - Cable plant follow double or tipple link model
  - Placing 3/4 of loss in middle of cable *
  - LC reflectance -35 dB
  - MPO reflectance -45 dB
  - ER=3.5 dB (min allowed) to better support 200G SiP
  - BER 2.28E-4 for CL180 and 182, BER 4.8E-3 for CL182 and 183
  - Given the work done to improve SMF channel model rodes_3dj_01a_2401 through Monte Carlo Analysis, extrapolation to 1E-5 is sufficient.

* MPI penalty is ~ the same as putting 100% of loss at RX input.

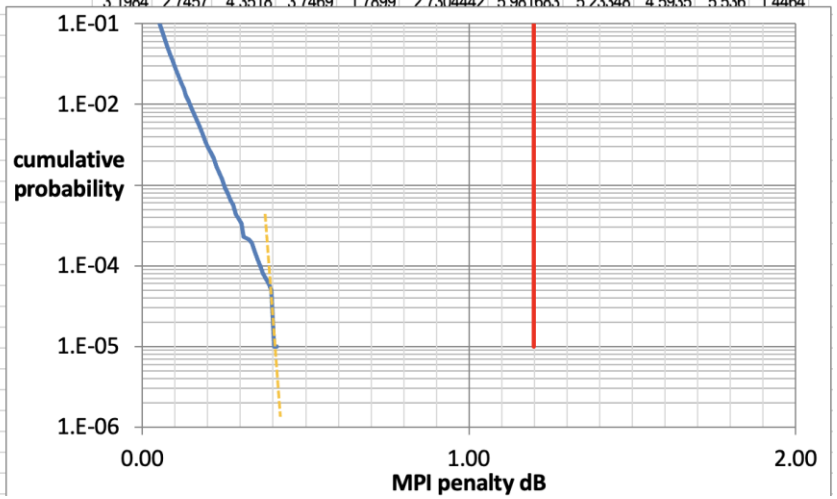
Adding Loss in the Middle vs the End

- **Adding Loss at middle result in higher MPI (Double link with 4 LC and 4 MPO)**
  - At confidence 1E-5 adding loss in the middle result in MPI penalty of 0.4 dB vs 0.45 dB with loss at the end
  - Putting the loss in the middle seems more reasonable but we may not want to use max loss in the middle!

Random phase between reflectors, random selection of modulation levels
Polarization assumed aligned

Baseline BER 2.28E-04	average phase= 3.1397	PAM-N N= 4	ER 3.5	dE 0.

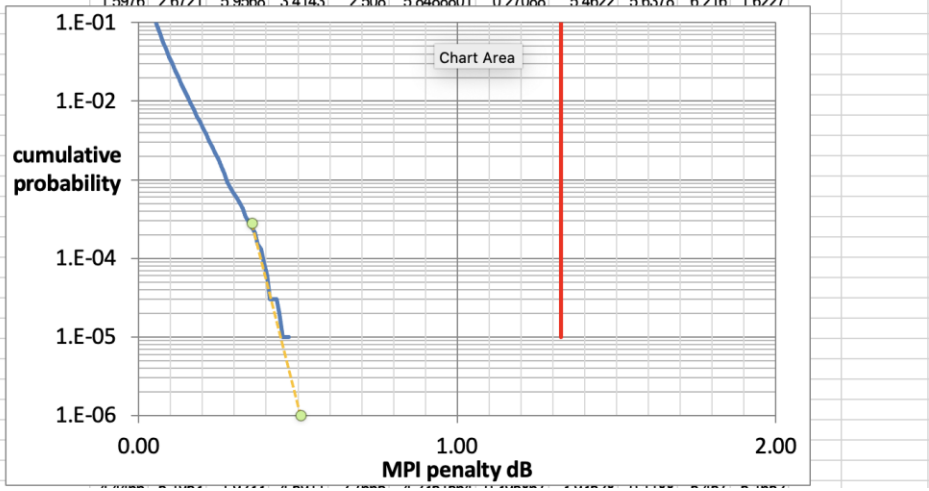
	PMD											PM
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R
	Rpmd	RconF	RconG	RconG	RconH	RconK	RconK	RconH	RconG	RconG	RconF	Rp
Reflection level inputs->	-26	-35	-45	-45	-35	-1000	-1000	-35	-45	-45	-35	-2
	phase b	phase b	phase be	-90	phase be	phase betwe	phase betv	phase bet	phase between			
	int1-int2	int2-int3	int3-int4	int4-int5	int5-int6	int6-int7	int7-int8	int8-int9	int9-int1	int10-in	int11-int12	
W/C phases row:	0	0	0	0	0	0	0	0	0	0	0	
						mid-span IL						
IL dB	0	0	0	0	0	2.75	0	0	0	0	0	
1' adds distrib'd IL, 0 adds none	0											
2xcum IL dB	0	0	0	0	0	0	-5.5	-5.5	-5.5	-5.5	-5.5	
Random phases =>	3.1984	2.7457	4.3518	3.7469	1.7899	2.7304442	5.981683	5.23348	4.5935	5.536	1.4464	



Random phase between reflectors, random selection of modulation levels
Polarization assumed aligned

Baseline BER 2.28E-04	average phase= 3.1443	PAM-N N= 4	ER 3.5	dER 0.447	1/1-dER 1.8072842

	PMD											PMD
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R 12
	Rpmd	RconF	RconG	RconG	RconH	RconK	RconK	RconH	RconG	RconG	RconF	Rpmd
Reflection level inputs->	-26	-35	-45	-45	-35	-1000	-1000	-35	-45	-45	-35	-26
	phase b	phase b	phase be	-90	phase be	phase betwe	phase betv	phase bet	phase between			
	int1-int2	int2-int3	int3-int4	int4-int5	int5-int6	int6-int7	int7-int8	int8-int9	int9-int1	int10-in	int11-int12	
W/C phases row:	0	0	0	0	0	0	0	0	0	0	0	w/c
						mid-span IL						
IL dB	0	0	0	0	0	0	0	0	0	0	2.75	Tot IL=
1' adds distrib'd IL, 0 adds none	0											
2xcum IL dB	0	0	0	0	0	0	0	0	0	0	0	-5.5
Random phases =>	1.5976	2.6721	5.9568	3.4143	2.508	5.8488801	0.27088	5.4622	5.6378	6.216	1.6227	2.75

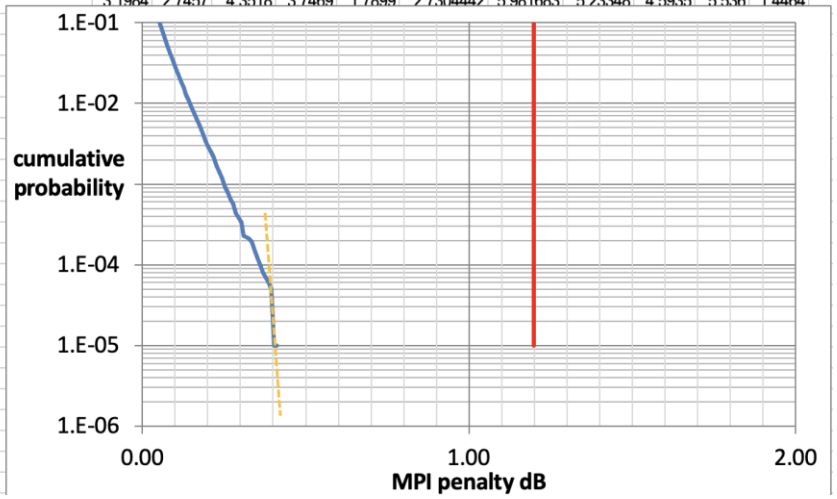


MPI for 3.5 and 5 dB ER

- **For Double link with 4 LC and 4 MPO with max loss in the middle**
  - ER of 3.5 dB results in MPI penalty of 0.4 dB
  - ER of 5.0 dB result in MPI penalty of 0.27 dB!

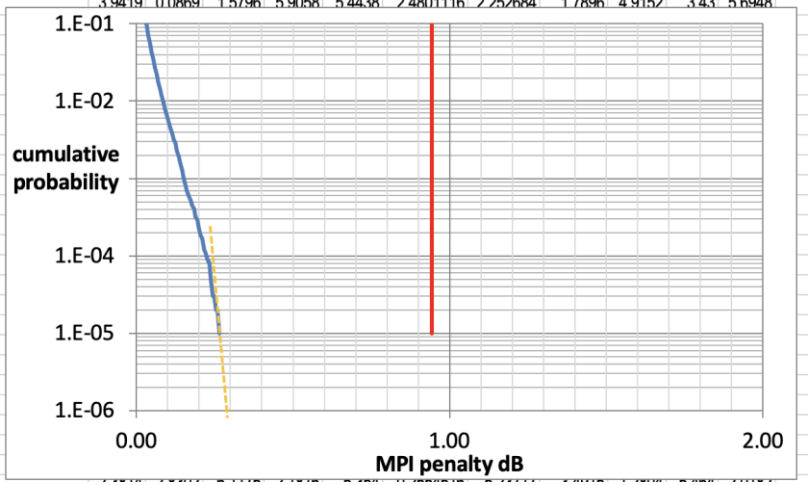
Random phase between reflectors, random selection of modulation levels
Polarization assumed aligned

			PAM-N									ER	dE
Baseline BER	average phase=		N=									3.5	0.
2.28E-04	3.1397		4										
	PMD												PM
	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R
	Rpmd	RconF	RconG	RconG	RconH	RconK	RconK	RconH	RconG	RconG	RconF	Rp
Reflection level inputs->	-26	-35	-45	-45	-35	-1000	-1000	-35	-45	-45	-35	-2
	phase b	phase b	phase be	-90	phase be	phase betwe	phase betv	phase bet	phase between			
	int1-int2	int2-int3	int3-int4	int4-int5	int5-int6	int6-int7	int7-int8	int8-int9	int9-int1	int10-in	int11-int12	
W/C phases row:	0	0	0	0	0	0	0	0	0	0	0	
						mid-span IL						
IL dB	0	0	0	0	0	2.75	0	0	0	0	0	
1' adds distrib'd IL, 0 adds none	0											
2xcum IL dB	0	0	0	0	0	0	-5.5	-5.5	-5.5	-5.5	-5.5	
Random phases =>	3.1984	2.7457	4.3518	3.7469	1.7899	2.7304442	5.981683	5.23348	4.5935	5.536	1.4464	



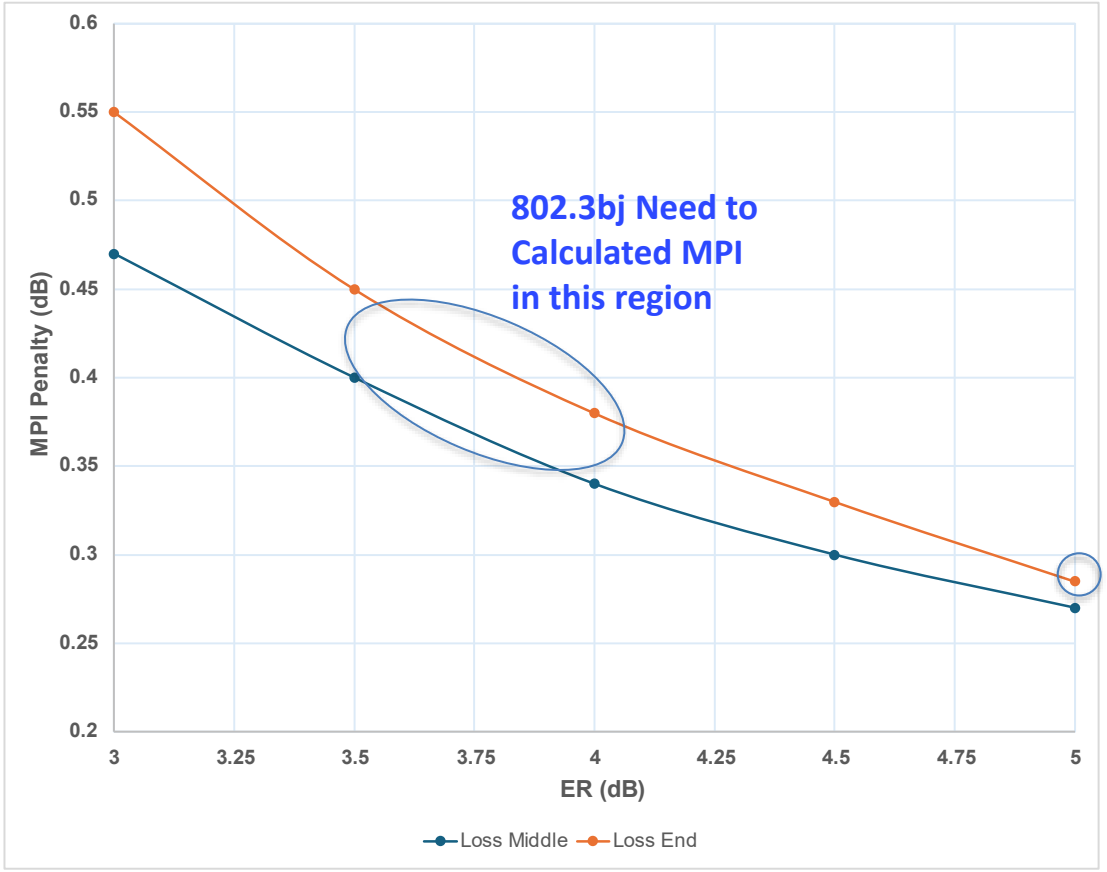
Random phase between reflectors, random selection of modulation levels
Polarization assumed aligned

			PAM-N									ER	dER
Baseline BER	average phase=		N=									5	0.3
2.28E-04	3.1423		4										
	PMD												PMI
	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 1	
	Rpmd	RconF	RconG	RconG	RconH	RconK	RconK	RconH	RconG	RconG	RconF	Rpm	
Reflection level inputs->	-26	-35	-45	-45	-35	-1000	-1000	-35	-45	-45	-35	-26	
	phase b	phase b	phase be	-90	phase be	phase betwe	phase betv	phase bet	phase between				
	int1-int2	int2-int3	int3-int4	int4-int5	int5-int6	int6-int7	int7-int8	int8-int9	int9-int1	int10-in	int11-int12		
W/C phases row:	0	0	0	0	0	0	0	0	0	0	0		
						mid-span IL							
IL dB	0	0	0	0	0	2.75	0	0	0	0	0		
1' adds distrib'd IL, 0 adds none	0												
2xcum IL dB	0	0	0	0	0	0	-5.5	-5.5	-5.5	-5.5	-5.5	-5	
Random phases =>	3.9419	0.0869	1.5796	5.9058	5.4438	2.4801116	2.252684	1.7896	4.9152	3.43	5.6948		



MPI Penalty as Function of ER

- **MPI penalty as function of ER for link configuration on previous page**
  - 802.3bs/cd calculated MPI penalty with max loss at receive end with assumed ER=5 dB
  - More typical cable plant have max loss is in the middle
    - Loss in the middle has slightly lower MPI penalty
    - Putting ~75% of loss in the middle produces about the same MPI and more aligned with cable plant
  - 200G SiP MZM typically operate closer to 3.5 dB



802.3bs/CD Calculated MPI at this point

Summary

- **The biggest issue in D1.4 is associated with 200GBASE-DR and 200GBASE-DR-2 PMDs as they use LC connector with reflectance of -35 dB with fixed MPI penalty allocation**
  - Use of Method in CL140 (Table 140-12) reducing maximum cable plant loss to offset increased MPI as result of LC -35 dB connectors
- **Assuming use of CL140 MPI-loss trade off Clauses 180 and 182 total allocated penalty must be adjusted to support MPI+DGD penalties without any LC -35 dB connectors**
  - Current CL180 with combined MPI+DGD penalties of 0.1 dB insufficient to support these penalties
- **Key items for the task force is to decide on the MPI calculation conditions**
  - Cable plant follows double or tipple link model
  - Where and how much loss to place for MPI analysis
  - LC reflectance -35 dB and MPO reflectance -45 dB
  - ER=3.5 dB (min) better aligned with 200G SiP MZM
  - BER 2.28E-4 for CL180 and 182, BER 4.8E-3 for CL182 and 183
  - Confidence level at 1E-5
- **After agreeing on the underlaying assumption next step is updating MPI penalty for all the clauses**
  - All incorporate CL140 MPI-loss trade-off for CL180 and 182 PMDs.

Thank You!