# Getting to consensus on multipath interference penalties

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Reference D1.4 comments #143, 145, 147, 149

# Supporters

- Mike Dudek, Marvell
- Vipul Bhatt, Coherent
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# Multipath interference (MPI) penalty

- The MPI penalty allocations used in P802.3dj D1.4 were carried over unchanged from P802.3bs/cd clauses with similar fiber cabling.
  - Johnson_optx_01_250220 reviewed the assumptions used in the tables borrowed from P802.3bs/cd PMDs and discussed their validity for 200G per lane PMDs.
- Comments against P802.3dj D1.4 call into question the validity of assumptions behind the MPI penalty allocations and how to treat them in the power budgets.
  - See ghiasi_3dj_02_2501, ghiasi_3dj_01_2503, and D1.4 comments #143, 145, 147, 149.
  - The primary gap identified is the fiber cabling model used in Cl. 180 only applies to DR2/4/8 PMDs with MPO connectors, not DR1 PMDs which may also contain LC connectors.
  - Proposes using the MPI specification method of Table 140-13 to cover all cases.
  - Proposes different assumptions for the MPI calculations, including BER, ER and confidence level, which makes small changes in the MPI penalty allocations.
- This contribution discusses a path to consensus on changes to the magnitude and specification of MPI penalties in P802.3dj PMDs.
  - Part 1: Consensus on a consistent specification method for MPI penalty
  - Part 2: Consensus on the calculation assumptions and magnitude of MPI penalty
- Changes are proposed to be implemented by comments against P802.3dj D2.0 in May.

# Current MPI penalty specification method

- Each PMD is assumed to use a specific type of fiber cabling, with a specific connector type.
- The MPI penalty allocated in the power budget is calculated for the nominal number and reflectance of connectors in that cabling plan.
- The max discrete reflectance spec is then adjusted for cases with different number of connectors to give no worse MPI penalty than the nominal case.
- Pros:
  - The MPI penalty allocation, link power budget and max channel insertion loss are all constants.
- Cons:
  - Inflexible: Assumes all PMD instances follow the same fiber cabling plan.
  - The resulting connector reflectances aren't standard grades, so it's impractical to implement.

Table 121–15—Maximum value of each discrete reflectance

| Number of discrete reflectances above −55 dB | Maximum value for each discrete reflectance |
|---|---|
| 1 | −37 dB |
| 2 | −42 dB |
| 4 | −45 dB |
| 6 | −47 dB |
| 8 | −48 dB |
| 10 | −49 dB |

nominal

Table 122–19—Maximum value of each discrete reflectance

| Number of discrete reflectances above −55 dB | Maximum value for each discrete reflectance | | |
|---|---|---|---|
| | 200GBASE-FR4 or 400GBASE-FR8 | 200GBASE-LR4 or 400GBASE-LR8 | 200GBASE-ER4 or 400GBASE-ER8 |
| 1 | −25 dB | −22 dB | −19 dB |
| 2 | −31 dB | −29 dB | −27 dB |
| 4 | −35 dB | −33 dB | −32 dB |
| 6 | −38 dB | −35 dB | −35 dB |
| 8 | −40 dB | −37 dB | −37 dB |
| 10 | −41 dB | −39 dB | −39 dB |

# Proposed MPI penalty specification method

- A generalized fiber cabling model and specification method that isn't tied to any specific fiber cabling assumptions can be used for all PMDs.
  - Based on traverso_3cd_01_0317, adopted as Table 140-13 for 100GBASE-DR.
  - Fiber cabling contains arbitrary numbers of connectors in two classes:
    - -45 to -35 dB (e.g., LC-UPC)
    - -55 to -45 dB (e.g., angled MPO)
  - Max channel insertion loss is adjusted based on the calculated MPI penalty for each combination.
  - Link power budget remains a constant.
- This method specifically addresses the gap identified in Cl. 180.
- Recommend using this specification method for MPI penalty in all 3dj PMDs, with appropriate values.

Table 140–13—100GBASE-DR maximum channel insertion loss versus number of discrete reflectances

MPO connectors

LC connectors

| 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.

Blue box shows max channel IL for parallel fiber double-link cabling with all MPO connectors, typical of DR2/4/8 PMDs.

Orange box shows max channel IL for double-link cabling with mix of LC and MPO connectors, typical of DR1 PMD.

# P802.3bs/cd MPI calculation assumptions

- "Baseline" BER = 2.4e-4 (host RS FEC)
  - The equivalent for 3dj FECo PMDs would be similar, 2.28e-4.
  - FECi PMDs would nominally use 4.8e-3, resulting in lower MPI penalty for the same cabling.
- Extinction ratio = 4.5 to 5 dB (> 1 dB margin to minimum)
  - A lower value may be more representative at 200G and will result in higher MPI penalty.
- Confidence level = 1e-6 (random reflection phases)
  - This is conservative since an MPI "failure" requires the joint probability of both worst-case fiber cabling and modules.
  - We could consider using a higher probability by taking this into account, as was considered in the statistical analysis of CD.
- Channel insertion loss:
  - Some 3bs contributions used half of the max channel IL at the middle of the link, but the adopted values were calculated with an assumption of the max IL at the far end of the link from the RX.
  - This is both a non-physical distribution of loss and is also not the worst case, which is IL = 0dB.
  - Using per-connector loss may be a more realistic way to model the channel, but does it matter for MPI?
- Connector reflectances:
  - Worst case TX and RX (MDI) reflectance= -26 dB.  This term dominates MPI calculations – is it overly pessimistic?
  - -35dB is assumed for the LC connectors in duplex fiber patch cords.  (IEC-61753-1 RL Grade 3)
  - -45dB is assumed for the angled MPO connectors in parallel fiber cables for DR4 (IEC-61753-1 RL Grade 2)
  - -55dB is assumed for the angled MPO connectors in FR4/LR4 duplex fiber cabling (IEC-61753-1 RL Grade 1)

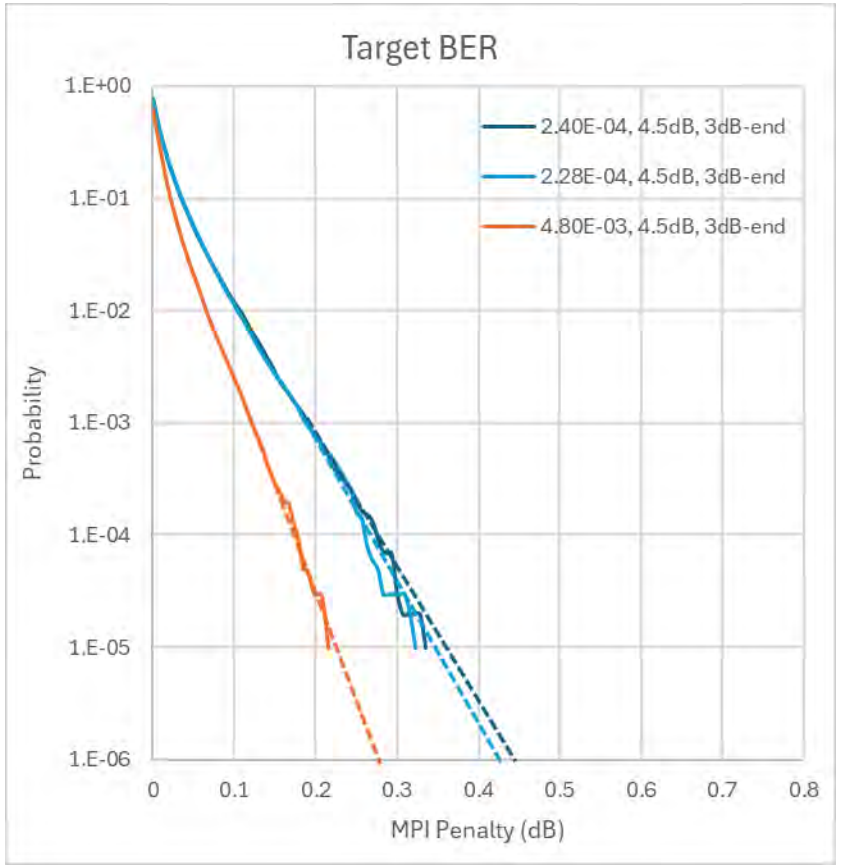
# New P802.3dj example

- See ghiasi_3dj_02_2501
- Target BER values specific to P802.3dj (2.28e-4 and 4.8e-3 vs. 2.4e-4)
  - This change should be implemented – should not be controversial.
- Connector reflectivities of -35 and -45 dB (same as 3bs/cd)
  - Keeping these “worst case” reflectivities is probably the best choice.
  - Allows for more variability in environment and installation.
- Reduced extinction ratio (3.5 dB vs. 4.5 dB)
  - Need to achieve consensus on using a more conservative value.
- Half of the maximum IL at the midpoint of the link, vs. maximum IL at the far-end used in liu_3bs_01a_0316.
  - Is there consensus to change this? Is it even significant?
- Reduced confidence level (1e-5 vs. 1e-6)
  - Need to achieve consensus on this, even if the impact is small.
  - Leverage consensus from the statistical analysis of channel CD (1e-4).

# Effect of changing target BER

Using J. King Monte Carlo tool.

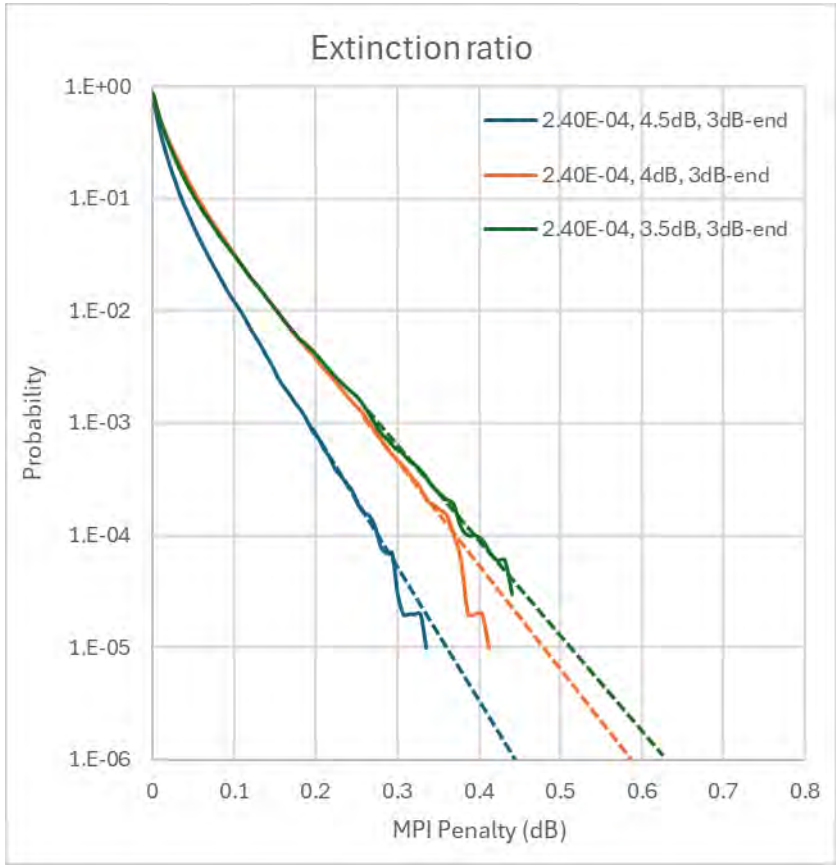
- Baseline MPI calculation settings based on P802.3bs/cd (dark blue):
  - 4x LC (-35dB) + 4x MPO (-45dB)
  - BER = 2.4e-4
  - ER = 4.5 dB
  - IL = 3 dB (at RX end)
  - Confidence level = 1e-6
  - 100k iterations
- 200G RS pre-FEC BER of 2.28e-4 is nearly the same as 2.4e-4, so the MPI penalty is unchanged.
- Reducing target BER to the inner FEC level of 4.8e-3 reduces the MPI penalty by ~0.15 dB for those PMDs.




Legend: BER, ER, IL

# Effect of changing extinction ratio

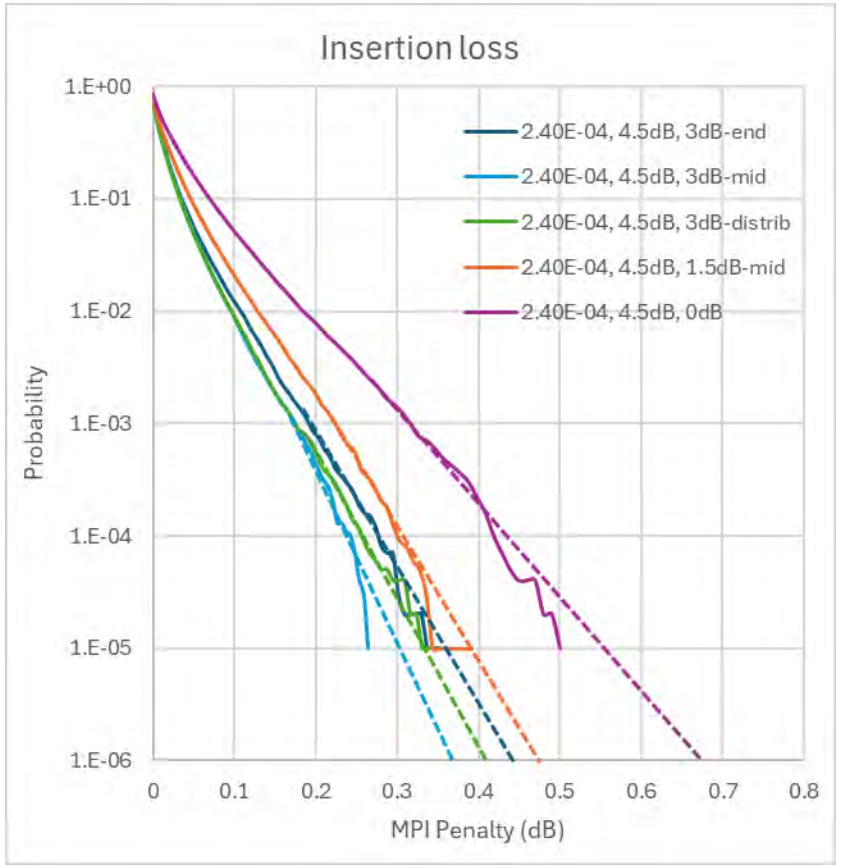
- Most P802.3bs/cd calculations assumed ER = 4.5 dB, which is typical for 50G and 100G TX.
- 4.5 dB may be higher than is typical for 200G TX.
  - 3.5dB would be the worst case
  - 4 dB may be “typical” with manufacturing margin
- Reduction of ER from 4.5dB increases MPI penalty by
  - ~0.15 dB for ER = 4 dB
  - ~0.18 dB for ER = 3.5 dB




Legend: BER, ER, IL

# Effect of changing insertion loss

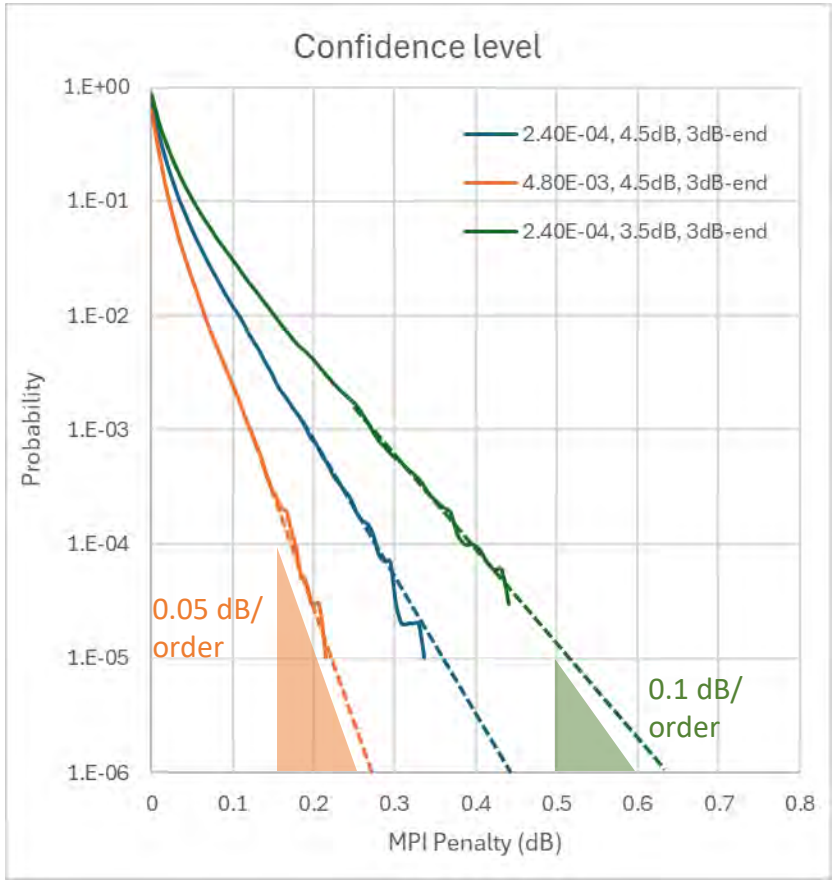
- P802.3bs/cd used the convention of maximum IL at the RX end – should P802.3dj continue to use this convention?
- Using the full IL at the end, mid-span or distributed gives the same MPI penalty within ± 0.05 dB.
- Using half the IL at mid-span increases MPI penalty by < 0.05 dB.
- MPI penalty for 0dB loss is ~0.2 dB higher than the nominal case
  - This is too conservative for a channel with 8 connectors, where the practical minimum IL is around 1 dB.
- Recommend to stick with using the full IL at the RX end since the differences are small.




Legend: BER, ER, IL

# Effect of changing confidence level

- The confidence level in the MPI Monte Carlo is the probability of the channel having higher MPI (reflectance) than allocated in the budget
- MPI penalty changes from 0.05 to 0.1 dB per order of magnitude of confidence level
- A link outage due to MPI should only occur when the entire link is at the specification limits in the absence of MPI. This includes:
  - Worst case TX: min OMA, max TECQ, max RIN
  - Worst case RX: max RS, max block error ratio
  - Worst case channel: max IL, max CD, max DGD
- If each of these probabilities is < 1e-3, an MPI channel confidence level of 1e-6 results in a link outage probability < 1e-15.
- A similar analysis drove the adoption of 1e-4 as an acceptable confidence level for maximum channel chromatic dispersion in P802.3dj.




Legend: BER, ER, IL

# Summary of MPI penalty adjustments

| Parameter | 802.3bs/cd assumptions | Possible MPI assumption changes | Approx ΔMPI penalty, dB | Comments |
|---|---|---|---|---|
| Target BER | 2.4e-4 | 2.28e-4 (FECo)<br>4.8e-3 (FECi) | 0<br>-0.15 | Significant impact for FECi PMDs |
| Extinction ratio (dB) | 4.5 | 3.5 | +0.18 | Most significant change<br>Consensus required |
| Insertion loss (dB) | Max IL at RX end | Half max IL at mid-span | +0.05 | Minor impact<br>Suggest no change |
| Channel confidence level | 1e-6 | 1e-5 | -0.1 | Small impact<br>Consensus required |
| Connector reflectivities (dB) | -35 (LC)<br>-45 (MPO) | -35 (LC)<br>-45 (MPO) | N/A | Suggest no change |

These are all small changes – nothing that will make or break any power budget – but consensus building is required to implement them.

# Discussion

- Using the specification method of Cl. 140 to trade off channel IL for higher MPI penalty is an elegant generic approach.
  - Avoids the need for any fiber cabling assumptions for PMDs
  - Leaves full implementation freedom for the fiber cabling plan to the user
  - Addresses the gap identified in Cl. 180 for 200GBASE-DR1 MPI penalty
- Changing the underlying assumptions in the MPI Monte Carlo calculations results in relatively minor changes in the MPI penalty.
  - None of the proposed changes result in major changes to MPI penalty.
  - This should be considered a spec refinement rather than fixing a gap.
- The time before the availability of P802.3dj D2.0 in May should be used to:
  - Develop consensus on new parameter assumptions (BER, ER, IL, Conf. Level)
  - Generate new tables based on Table 140-13 for all 802.3dj PMDs
  - Submit the results as consensus comments against D2.0.

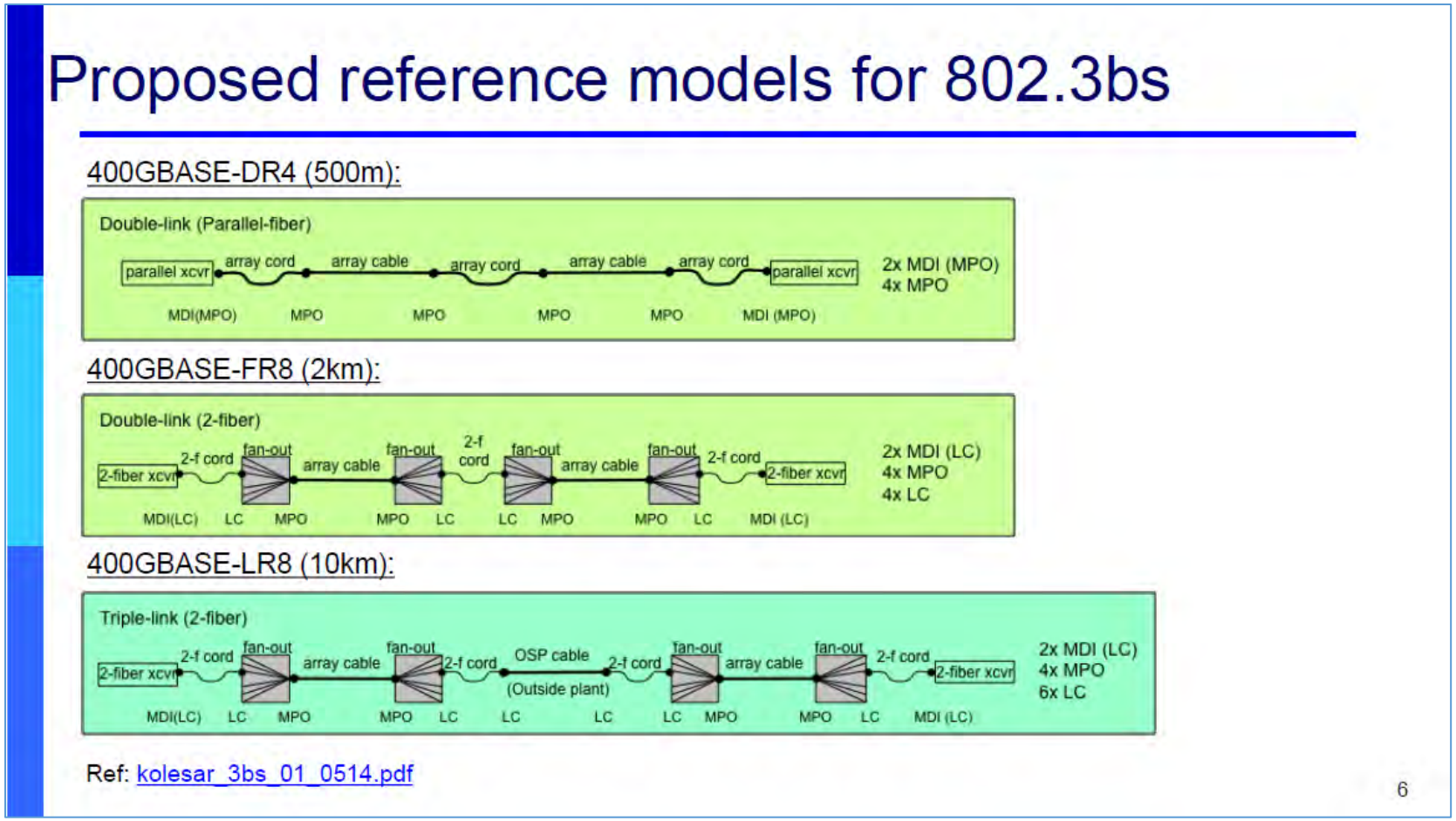
# Thank You

# Appendix

# P802.3bs/cd MPI references

- Kolesar_3bs_01_0514 proposed models for fiber cabling and channel insertion loss. Nicholl_3bs_01a_0316 presented fiber cabling models that were adopted during 3bs comment resolution.
  - For DR4: double link, parallel fiber
  - For FR8: double link, duplex fiber (also used for DR in traverso_3cd_01_0317)
  - For LR8: triple link, duplex fiber
- king_01a_0116_smf presented the details of MPI calculations and provided an Excel spreadsheet-based Monte Carlo model to explore various scenarios.
  - Phases between reflections are random, but reflections and losses are fixed
  - Analyses the histograms of the vertical sub-eye openings to estimate Q and BER
- liu_3bs_01a_0316 presented the MPI analyses and penalties for 400GBASE-DR4/FR8/LR8 that were adopted during 3bs comment resolution.
  - The power budget allocation for MPI penalty is constant and the connector reflectance varies with the number of connectors (see Table 121-15 and Table 122-19)
- traverso_3cd_01_0317 presented the MPI analysis and penalties that were adopted for 100GBASE-DR during 3cd comment resolution.
  - The result is a power budget that trades insertion loss for MPI penalty (see Table 140-13).

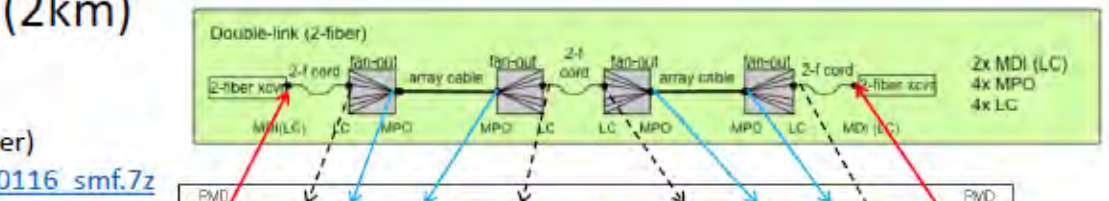
# Fiber cabling models adopted by P802.3bs (Nicholl_3bs_01a_0316)



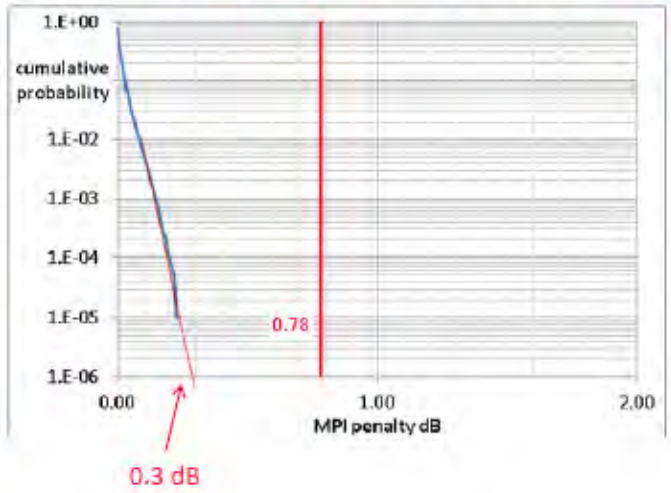
# Example MPI penalty calculation (liu_3bs_01a_0316)

## 400GBASE-FR8 (2km)

**Simulation Parameters:**
Link model: Double link (2-fiber)
Simulation model: king_02a_0116_smf.7z
Runs: 100k
BER: 2e-4
ER: 4.5 dB
Confidence: 1e-6
Tx/Rx MDI: 26 dB
LC: 35 dB
Angle polished MPO: 55 dB
Loss: 4 dB at end of link




| | PMD | | | | | | | | | | | PMD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ER | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 | R10 | R11 | R12 |
| 4.5 | RpmdF | RconF | RconG | RconG | RconH | RconK | RconK | RconH | RconG | RconG | RconF | RpmdF |
| Reflection level inputs-> | -26 | -35 | -55 | -55 | -35 | -1000 | -1000 | -35 | -55 | -55 | -35 | -26 |
| IL dB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | |




Recommend to include 0.3 dB MPI penalty into the link budget.

Using the nominal fiber cabling models and reflectance values, Hai-Feng proposed the following MPI penalty allocations for the 802.3bs power budgets:

400GBASE-DR4: 0.1 dB
400GBASE-FR8: 0.3 dB
400GBASE-LR8: 0.5 dB

# Specification Method 1: Fixed MPI penalty

- Max MPI penalty is calculated for the nominal number of connectors and nominal max reflectance.
- The max discrete reflectance spec is then adjusted for cases with different number of connectors to give no worse MPI penalty than the nominal case.
- Pros:
  - The MPI penalty allocation, link power budget and max channel insertion loss are all constants.
- Cons:
  - The connector reflectances given aren't standard grades, so it's impractical to implement in this way.

Table 121–15—Maximum value of each discrete reflectance

| Number of discrete reflectances above –55 dB | Maximum value for each discrete reflectance |
|---|---|
| 1 | –37 dB |
| 2 | –42 dB |
| 4 | –45 dB |
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| 8 | –48 dB |
| 10 | –49 dB |

nominal

Table 122–19—Maximum value of each discrete reflectance

| Number of discrete reflectances above –55 dB | Maximum value for each discrete reflectance | | |
|---|---|---|---|
| | 200GBASE-FR4 or 400GBASE-FR8 | 200GBASE-LR4 or 400GBASE-LR8 | 200GBASE-ER4 or 400GBASE-ER8 |
| 1 | –25 dB | –22 dB | –19 dB |
| 2 | –31 dB | –29 dB | –27 dB |
| 4 | –35 dB | –33 dB | –32 dB |
| 6 | –38 dB | –35 dB | –35 dB |
| 8 | –40 dB | –37 dB | –37 dB |
| 10 | –41 dB | –39 dB | –39 dB |

# Specification Method 2: Variable MPI penalty

- MPI penalty is calculated over a broad range of cable models.
- As MPI penalty increases, link power budget is shifted from channel insertion loss to penalties.
- Pros:
  - Link power budget is a constant.
  - Channel IL is easily measured.
  - More connectors can be accommodated by procuring lower loss connectors and cables.
- Cons:
  - Channel IL is not a constant, complicating network design.

Table 140–13—100GBASE-DR maximum channel insertion loss versus number of discrete reflectances

MPO connectors

| Maximum channel insertion loss (dB) | | Number of discrete reflectances > –55 dB and ≤ –45 dB | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| LC connectors<br>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.

No adjustment for MPI penalty < 0.15 dB

Double link, duplex fiber case

-35dB and -45dB are used in the simulations, even though these are the worst cases for each class of connector.