

# MPI statistical model and results

7<sup>th</sup> January 2016

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# Aims

- 1) Show impact of 3 dB mid-span loss on MPI penalty  $P_{\text{MPI}}$
- 2) Look at MPI penalties for the 3 link scenarios shown in *kolesar\_01\_0715*
- 3) Make the spreadsheet based statistical MPI model suitable and available for sharing

# Section 3: Shared spreadsheet

- File name is king\_02\_0116\_smf.7z
  - Will be posted to SMF web page
  - It's a 7z zipped file which extracts to about 27M
    - and then needs to be extended by duplicating the bottom row of the spreadsheet

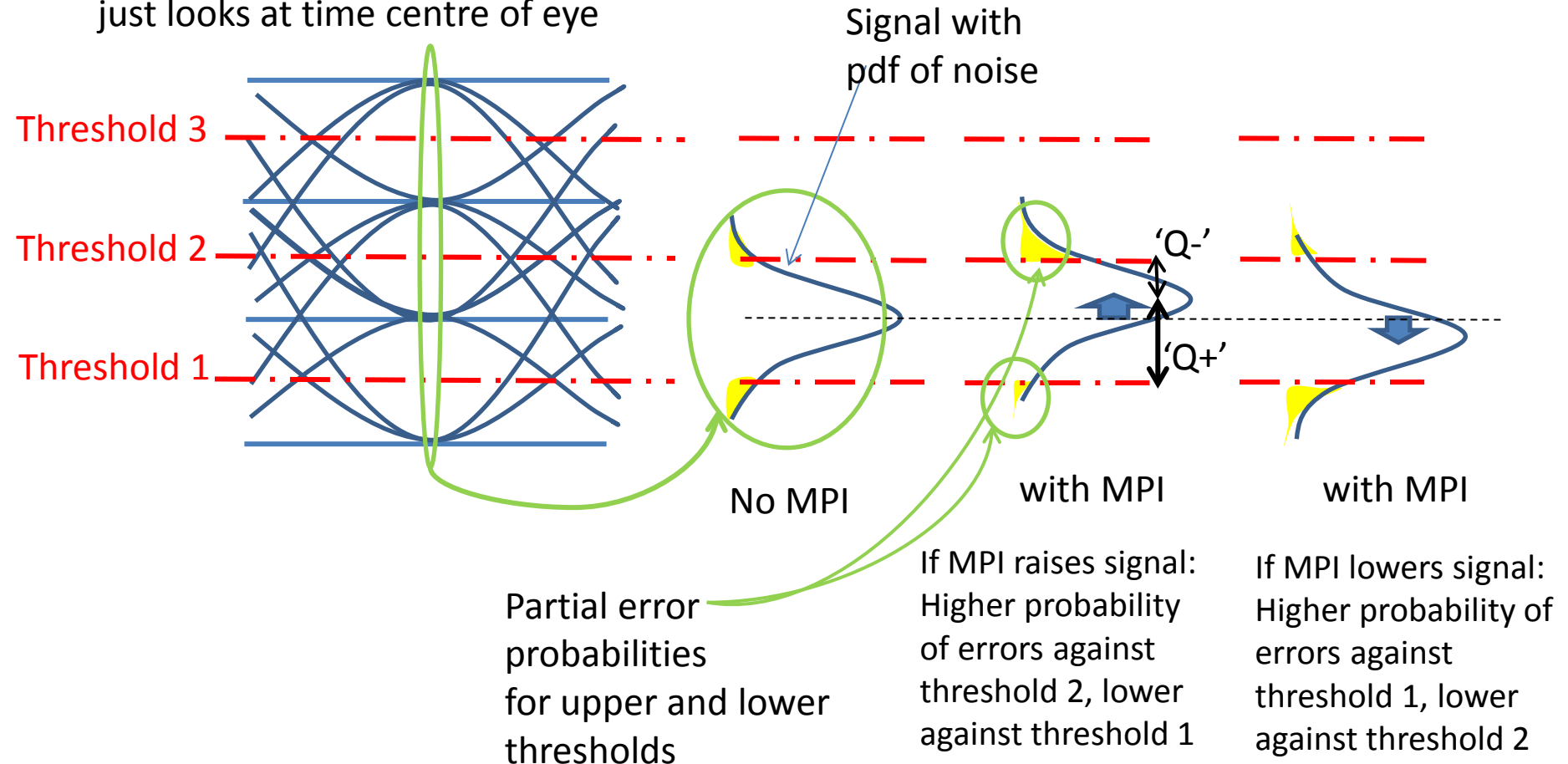
# Monte Carlo MPI spreadsheet model

- Up to 12 reflections
- Coherent mixing of signal and the sum of all doubly reflected signals
- Interfering signal field calculated explicitly for all possible reflection pairs
  - Random phases between reflectors
  - Random modulation level for reflector pairs, and partial error probabilities calculated for each signal modulation level for its adjacent threshold(s). Used to derive an average MPI penalty.
- MPI Penalties calculated at the time centre of eye, with no consideration of jitter or signal transition time, equalization, or eye closure due to ISI.

*Note: The posted version of the statistical MPI spreadsheet is truncated (just 500 rows) and zipped to make it small enough to post. The file should be extracted and the last row replicated to make the number of rows from between 4,000 (quicker to calculate and save) up to a maximum of 100,000 (captures better stats, but slow to run and save).*

# PAM4 cartoon – what the statistical MPI model does

ignores rise fall time and jitter effects,  
just looks at time centre of eye



Partial error probabilities are calculated for each signal modulation level and it's adjacent threshold(s), and used to derive a Q penalty due to MPI.

# Statistical MPI model snapshot

Input target BER

Input N

Input reflection levels, dB

Input ER, dB

All combinations of reflector pairs

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

|              |                |       |        |         |                 |                           |
|--------------|----------------|-------|--------|---------|-----------------|---------------------------|
| Baseline BER | average phase= | PAM-N | ER, dB | 1/1-dER | inner/outer OMA | 1 enables random data for |
| 2.4E-04      | 3.143          | 4     | 4.5    | 0.55    | 1.5499          | 0.33 1                    |

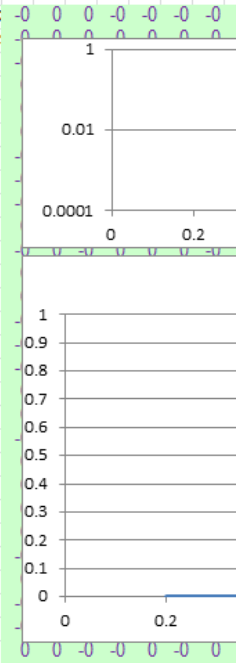
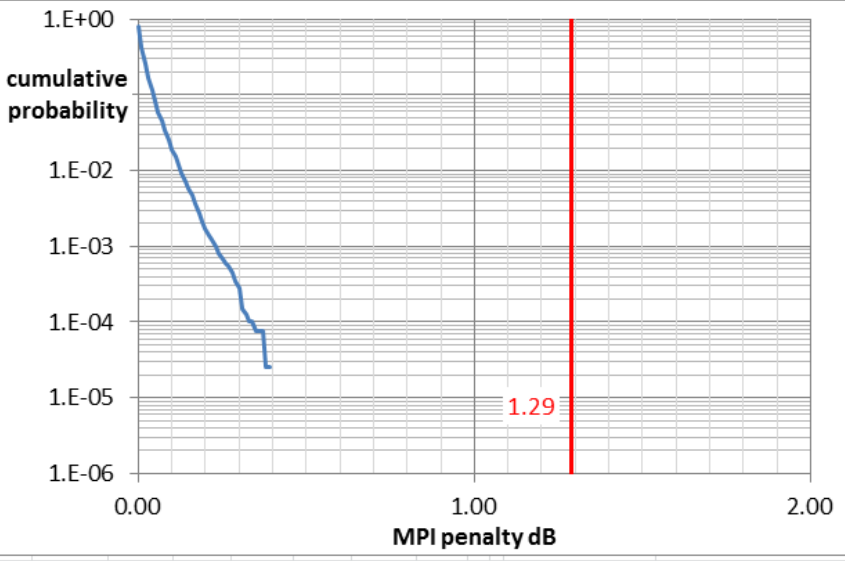
|                           |     |     |     |     |     |     |     |     |     |     |     |     |
|---------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Reflection level inputs-> | R1  | R2  | R3  | R4  | R5  | R6  | R7  | R8  | R9  | R10 | R11 | R12 |
|                           | -26 | -35 | -55 | -55 | -35 | -35 | -35 | -35 | -55 | -55 | -35 | -26 |

W/C phases row:

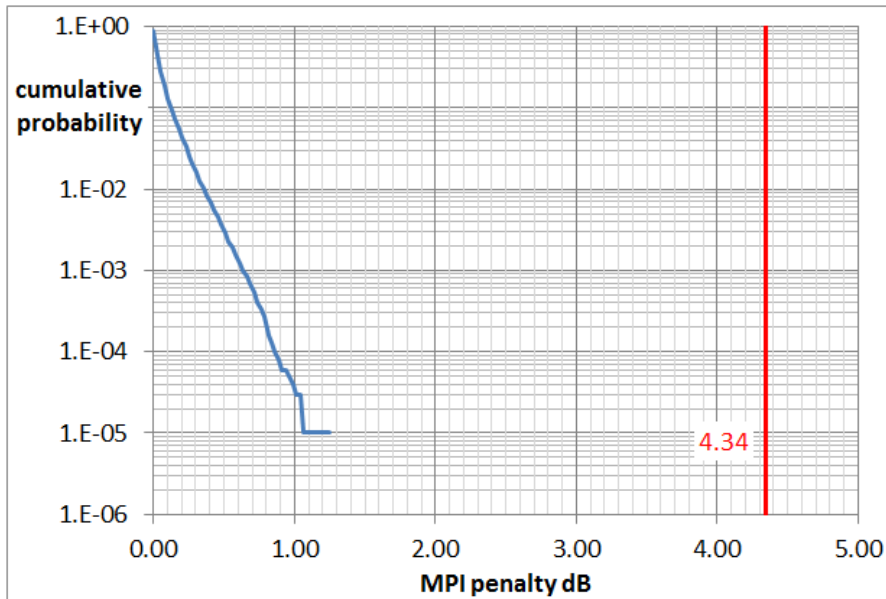
|                                       |   |   |   |   |   |   |   |   |   |   |   |   |        |
|---------------------------------------|---|---|---|---|---|---|---|---|---|---|---|---|--------|
| IL dB                                 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TotIL= |
| 1' adds 2dB distrib'd IL, 0 adds none | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3      |

switches on/off distributed 2dB IL

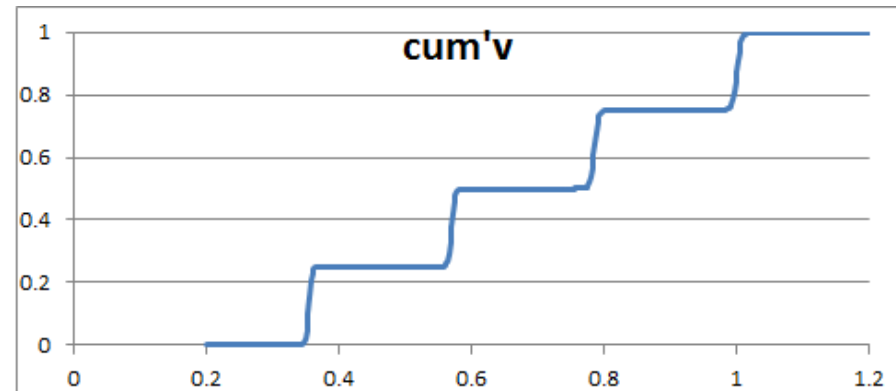
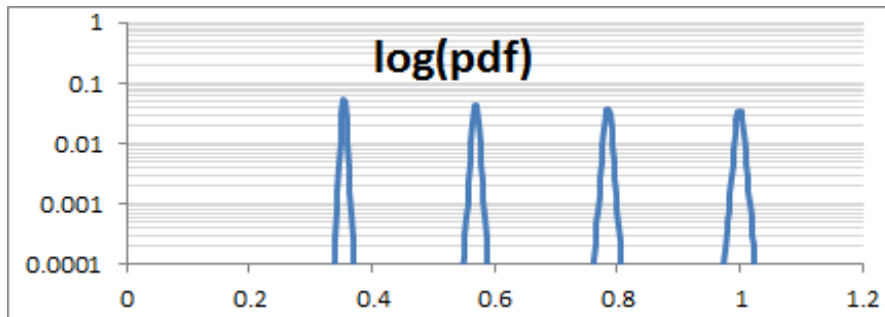
Input mid-span loss, dB



# Statistical MPI model outputs



- Worst case MPI
  - the no discount value
- Cumulative probability vs MPI for 12 reflectors, with or without loss
- ... and some pretty pictures showing pdf of modulation levels broadened by MPI



# Section 1: Effect of mid-span loss

- *Suggested by Mike Dudek - calculate MPI penalty for a link with and without a 3 dB mid span loss*

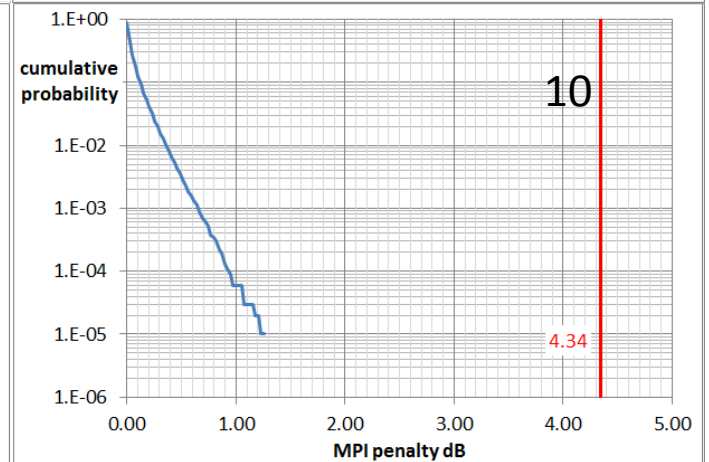
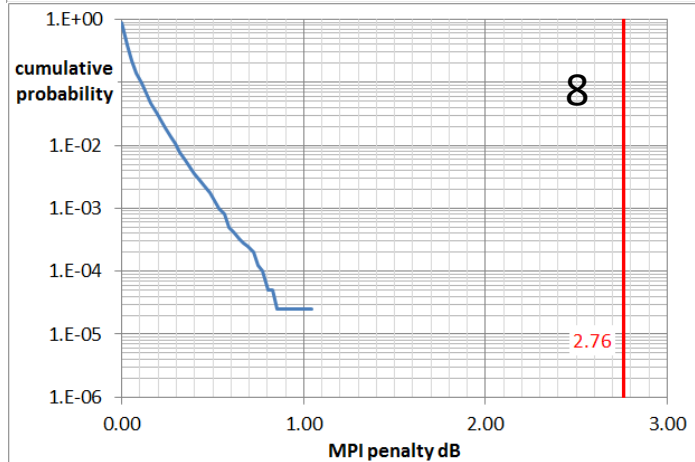
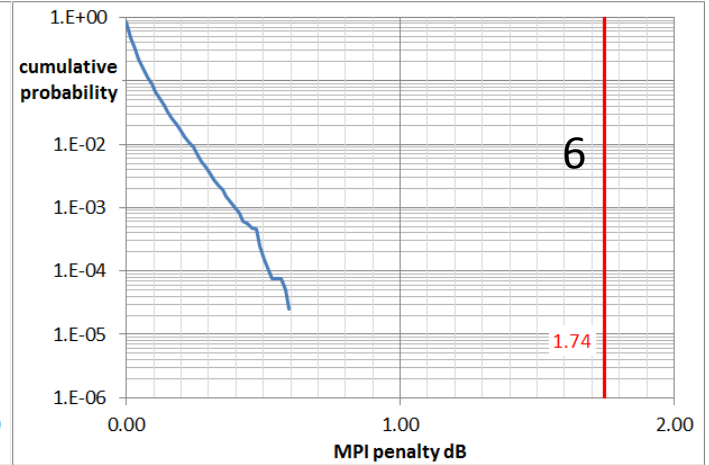
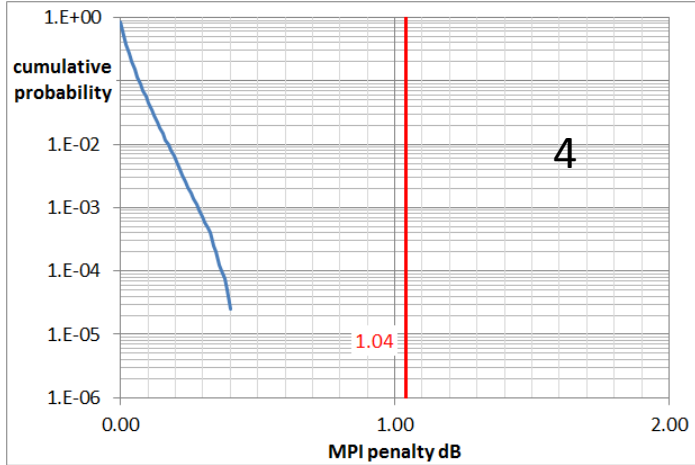
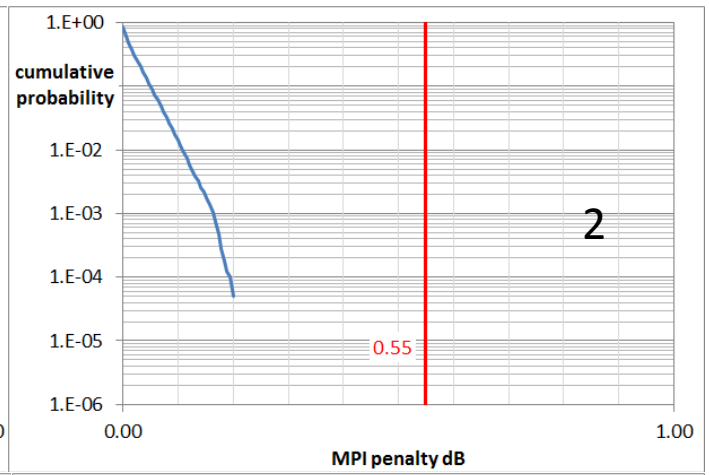
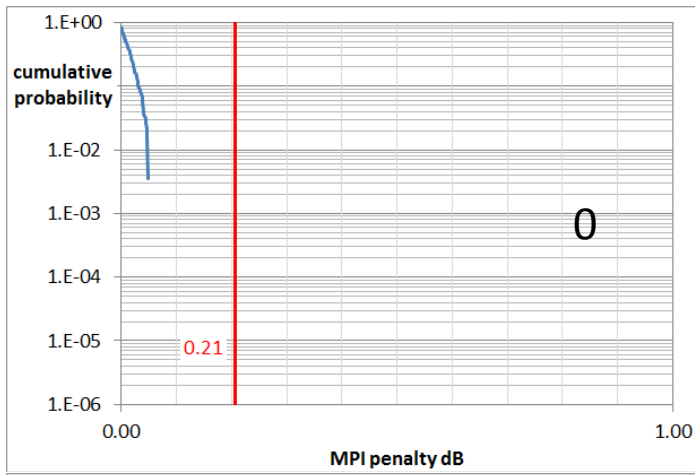


# Heuristic: Effect of mid-span loss on MPI penalty

- For a link with  $N$  reflectors, there are  $N(N-1)/2$  pairs of reflectors which contribute to MPI. Adding a 3 dB mid-span insertion loss:
  - reduces received signal power by 3 dB
  - reduces the doubly reflected power by 3 dB from  $\sim$ half the pairs of reflectors (0 dB loss relative to the signal)
    - e.g. for the pairs of reflectors which are both on one side of the mid span loss
  - reduces the doubly reflected power by 9 dB from  $\sim$ half of the pairs of reflectors (6 dB optical power loss relative to the signal)
    - for the pairs of reflectors spanning the mid-span loss
- MPI penalty is dependent on interfering *field*; so adding 3dB mid span insertion loss should reduce the MPI by about  $\frac{1}{2}$  to  $\frac{3}{4}$ 
  - about  $\frac{1}{2}$  if there's a dominant reflector pair that spans the mid-span loss
  - about  $\frac{3}{4}$  if all the reflectors are substantially equal

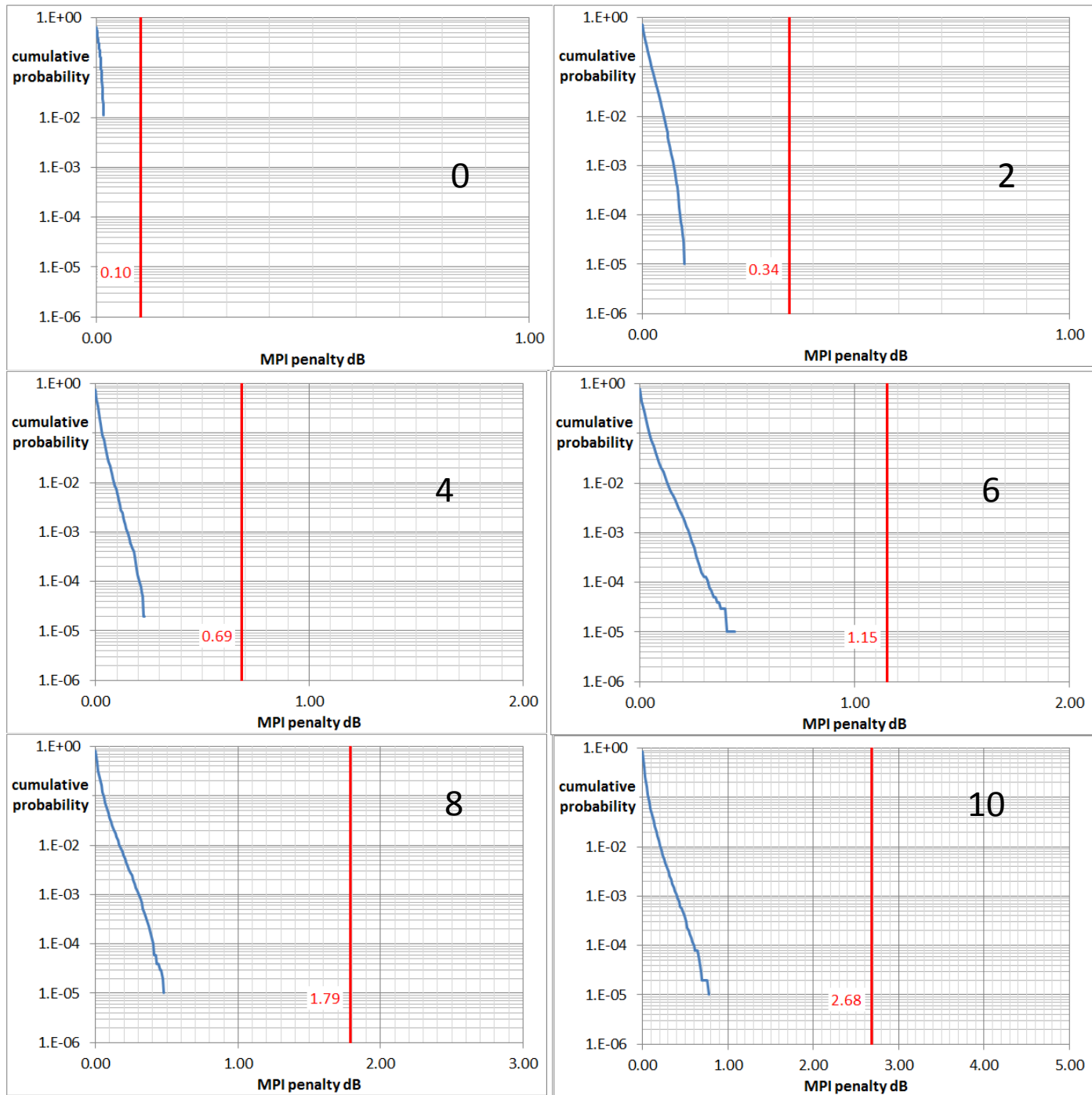
Effect of  
mid-span loss  
- 0 dB

26 dB PMD +  
n x 35 dB RL  
(4.5 dB ER, 0 dB  
link loss)



Effect of  
mid-span loss  
- 3 dB

26 dB PMD +  
n x 35 dB RL  
(4.5 dB ER, 3 dB  
mid link loss)



# Effect of mid-span loss conclusions

- A 3 dB mid span loss reduces  $P_{\text{MPI}}$  by about  $\frac{1}{2}$  to  $\frac{3}{4}$
- If  $P_{\text{MPI}}$  is calculated with an assumed link insertion loss, even if the link loss is lower (e.g. short links or low loss connectors) for reasonable  $P_{\text{MPI}}$ , the link margin increases even though the  $P_{\text{MPI}}$  is higher.
- *Seems reasonable to allow a some discount for insertion loss when calculating the  $P_{\text{MPI}}$  allocation in a link budget.*

# Section 2: MPI penalties for the 3 link scenarios shown in *kolesar\_01\_0715*

- All  $P_{\text{MPI}}$  calculated for ER = 4.5 dB and 0 dB link loss

# Section 2: Potential link models for MPI

|     | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 |
|-----|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| S1  | 26 | 35 | 55 | 55 | 35 | 26 |    |    |    |     |     |     |
| S2  | 55 | 55 | 55 | 55 |    |    |    |    |    |     |     |     |
| S2a | 35 | 35 | 35 | 35 |    |    |    |    |    |     |     |     |
| D1  | 26 | 35 | 55 | 55 | 35 | 35 | 55 | 55 | 35 | 26  |     |     |
| D2  | 55 | 55 | 55 | 55 | 55 | 55 |    |    |    |     |     |     |
| D2a | 35 | 35 | 35 | 35 | 35 | 35 |    |    |    |     |     |     |
| T1  | 26 | 35 | 55 | 55 | 35 | 35 | 35 | 35 | 55 | 55  | 35  | 26  |
| T2  | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 |    |     |     |     |
| T2a | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |    |     |     |     |

ER 4.5 dB, 0dB link loss

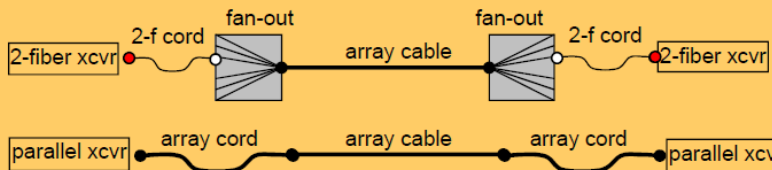
Common channel implementations with SM return loss

S1

S2: 4 x 55dB

S2a: 4 x 35dB

Single-link

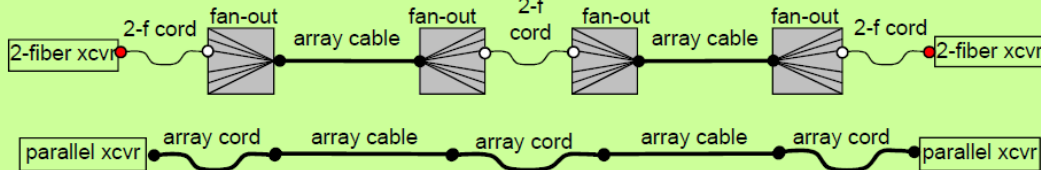


D1

D2: 6 x 55dB

D2a: 6 x 35dB

Double-link

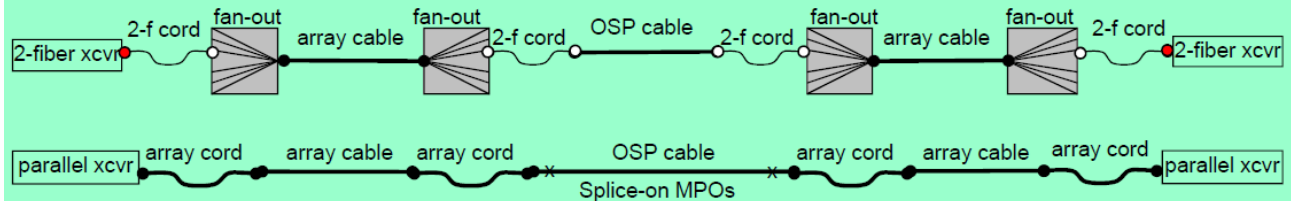


T1

T2: 8 x 55dB

T2a: 8 x 35dB

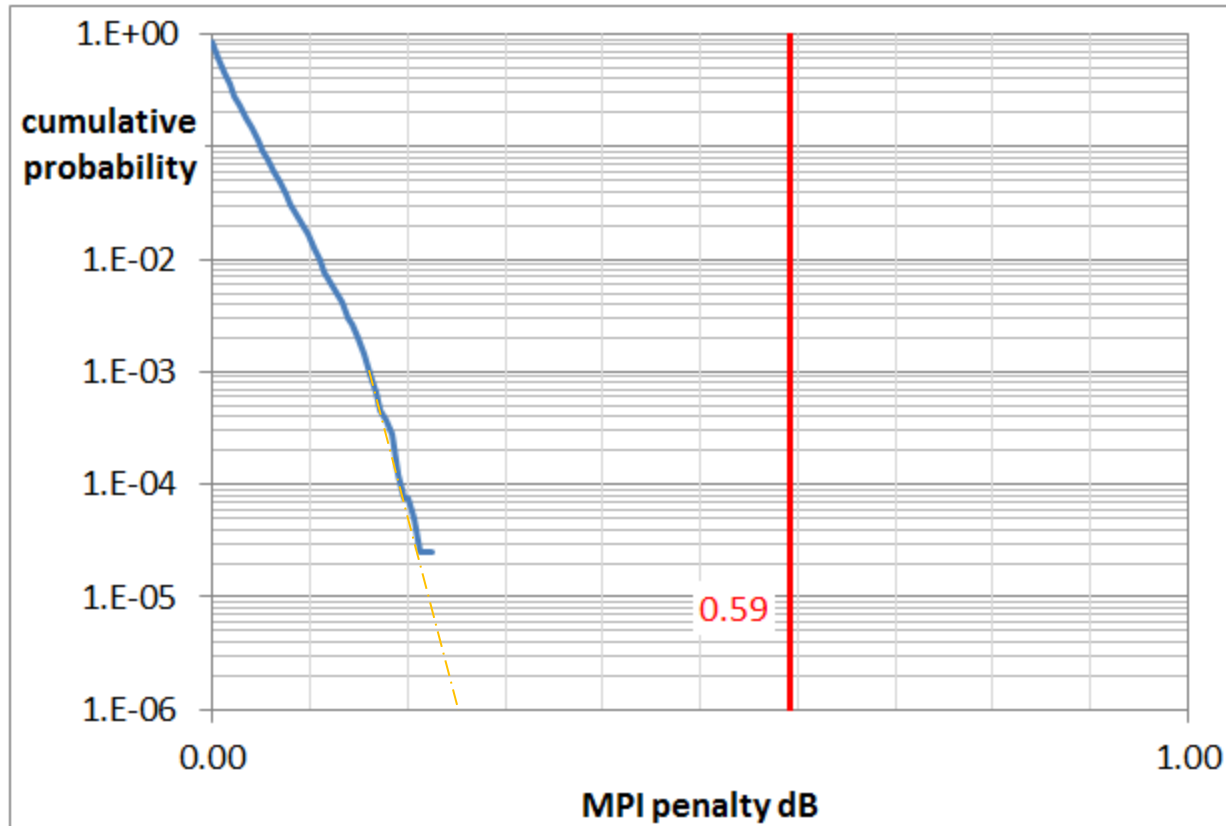
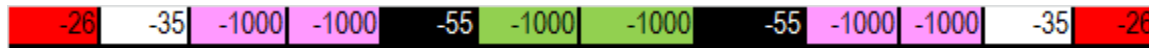
Triple-link



Return Loss Legend

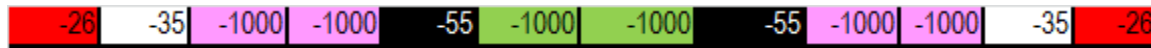
- 26 dB
- 26 to 35 dB
- 55 dB

# Single link: S1



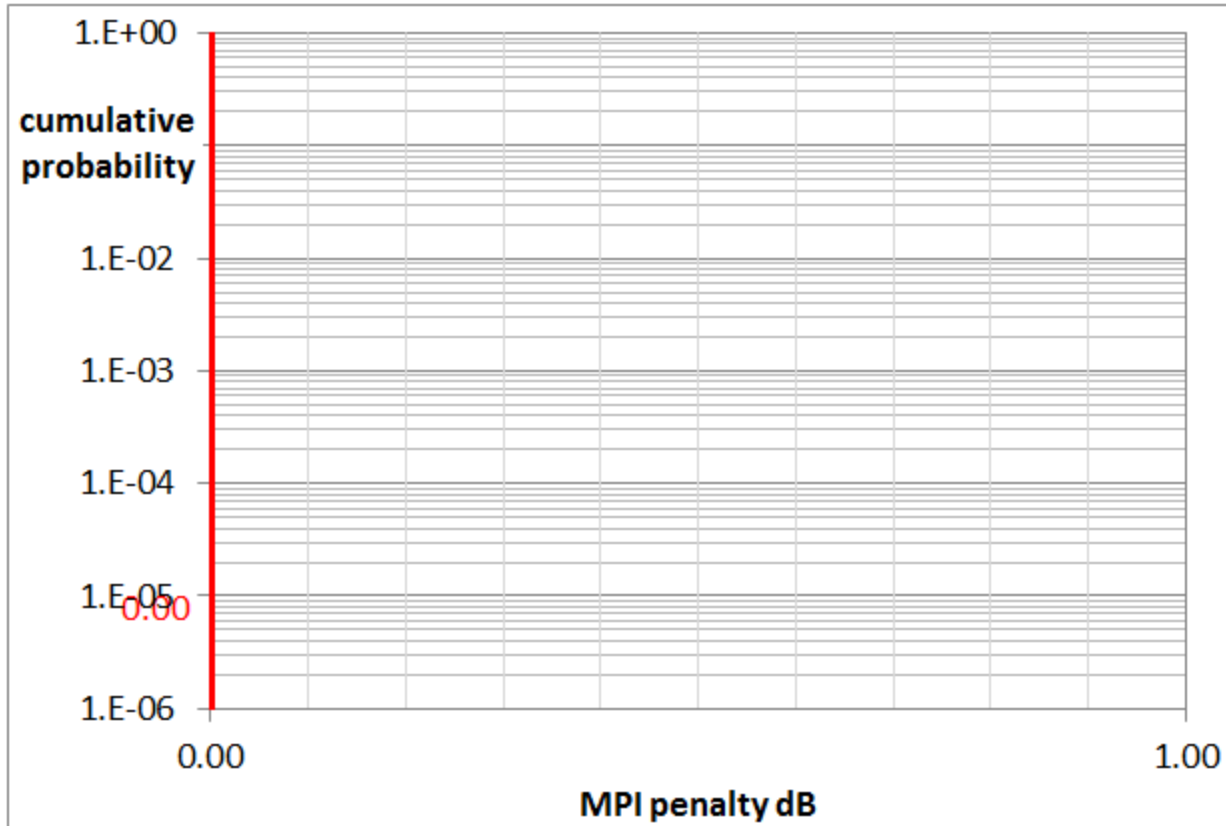
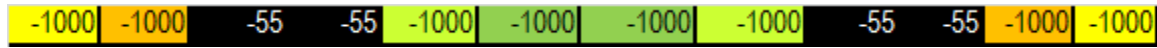
- Worst case penalty 0.59 dB
- Penalty  $\leq 0.19$  dB with 99.99% confidence
- Penalty  $\leq 0.25$  dB with 99.9999%

# Single link: S1 with 3 dB mid span loss

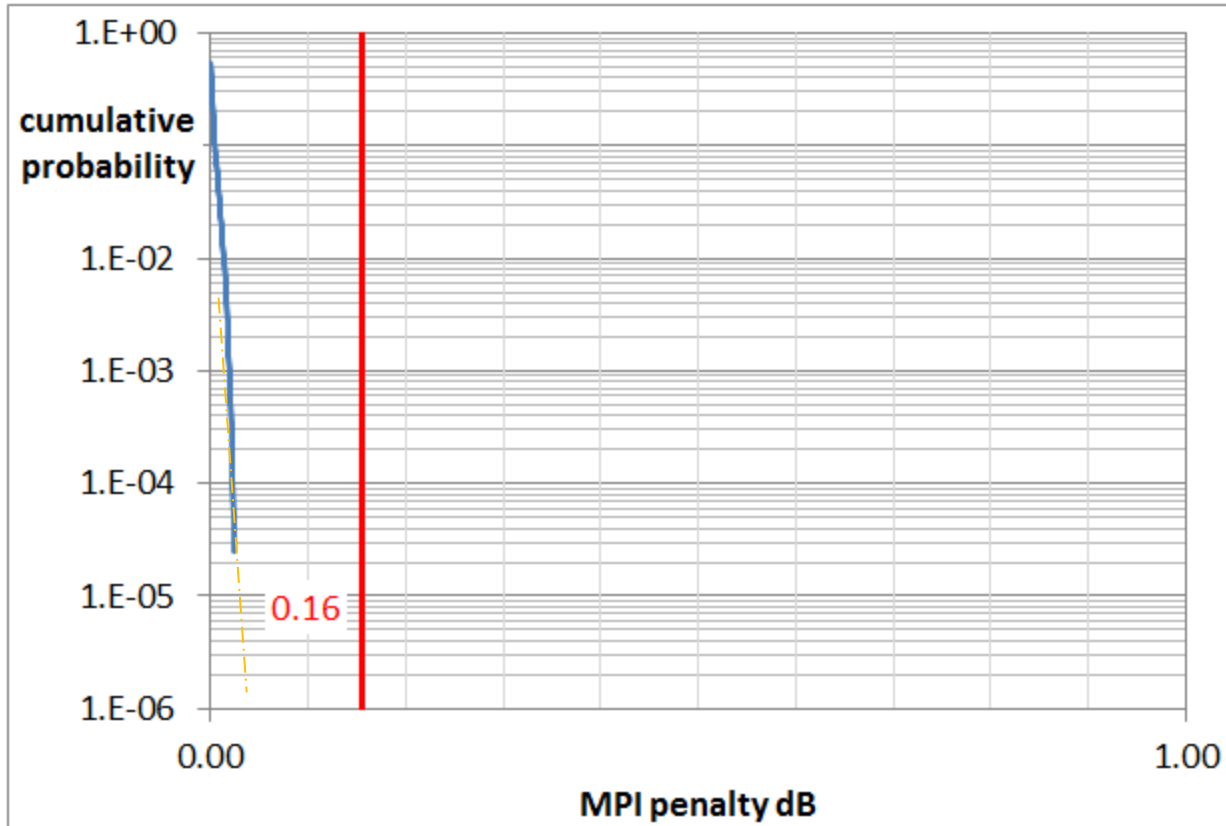




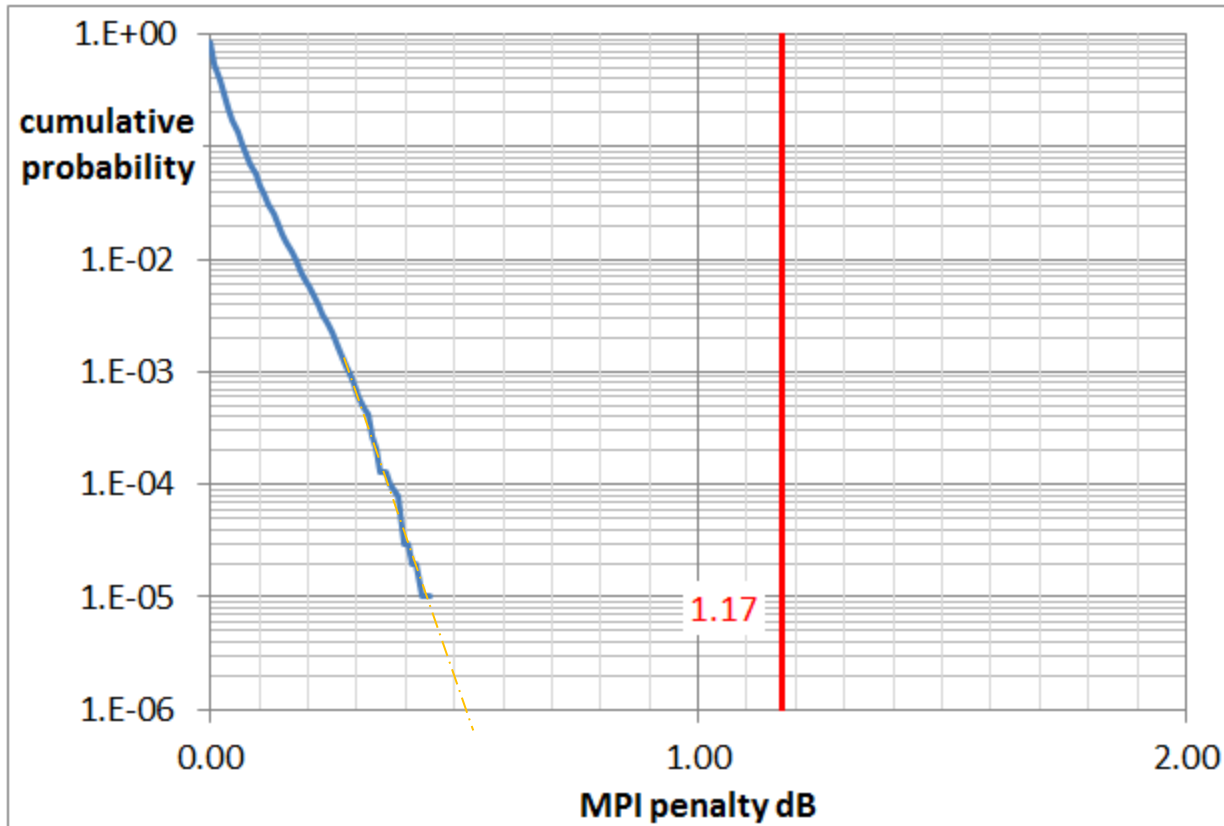
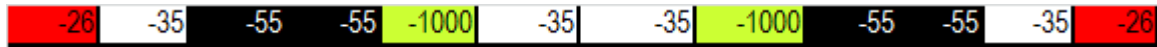
# Single link: S2



# Single link: S2a

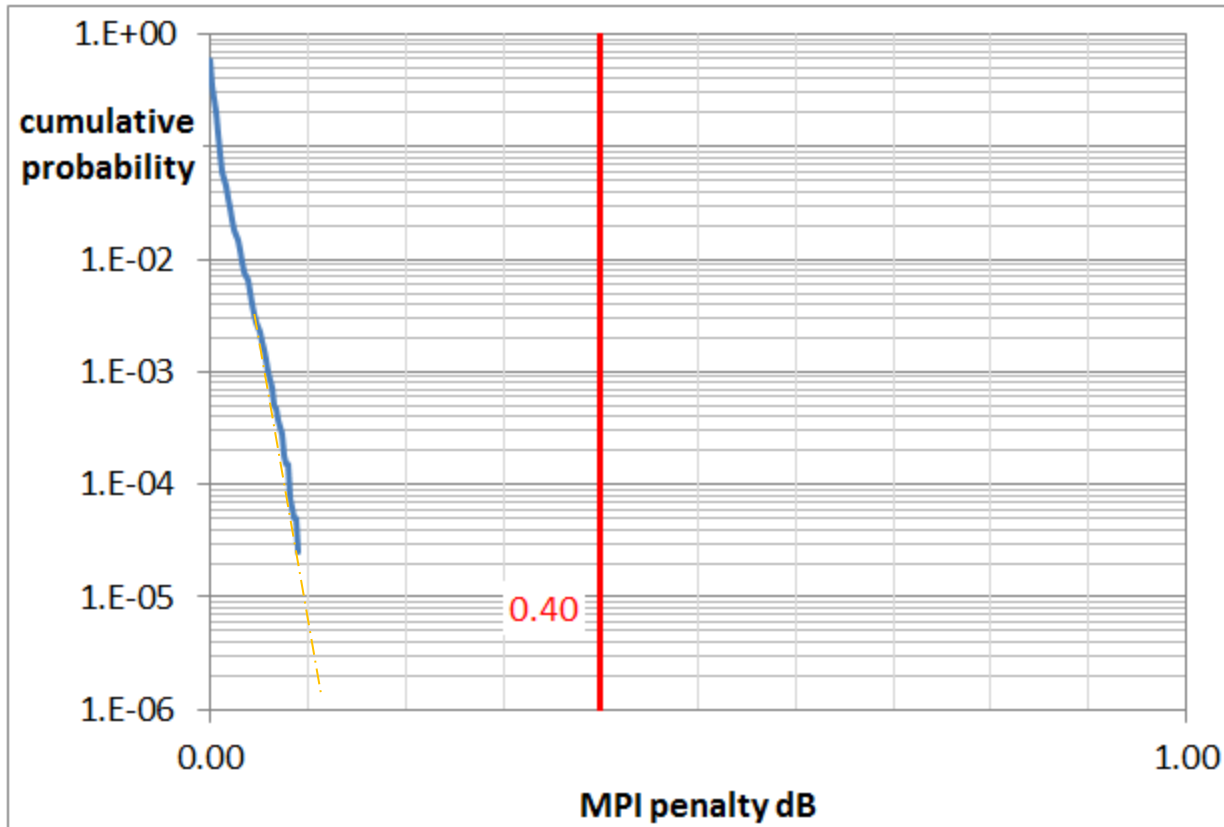
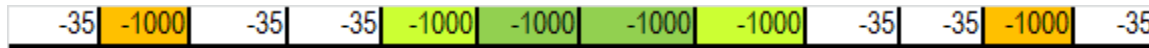


# Double link: D1

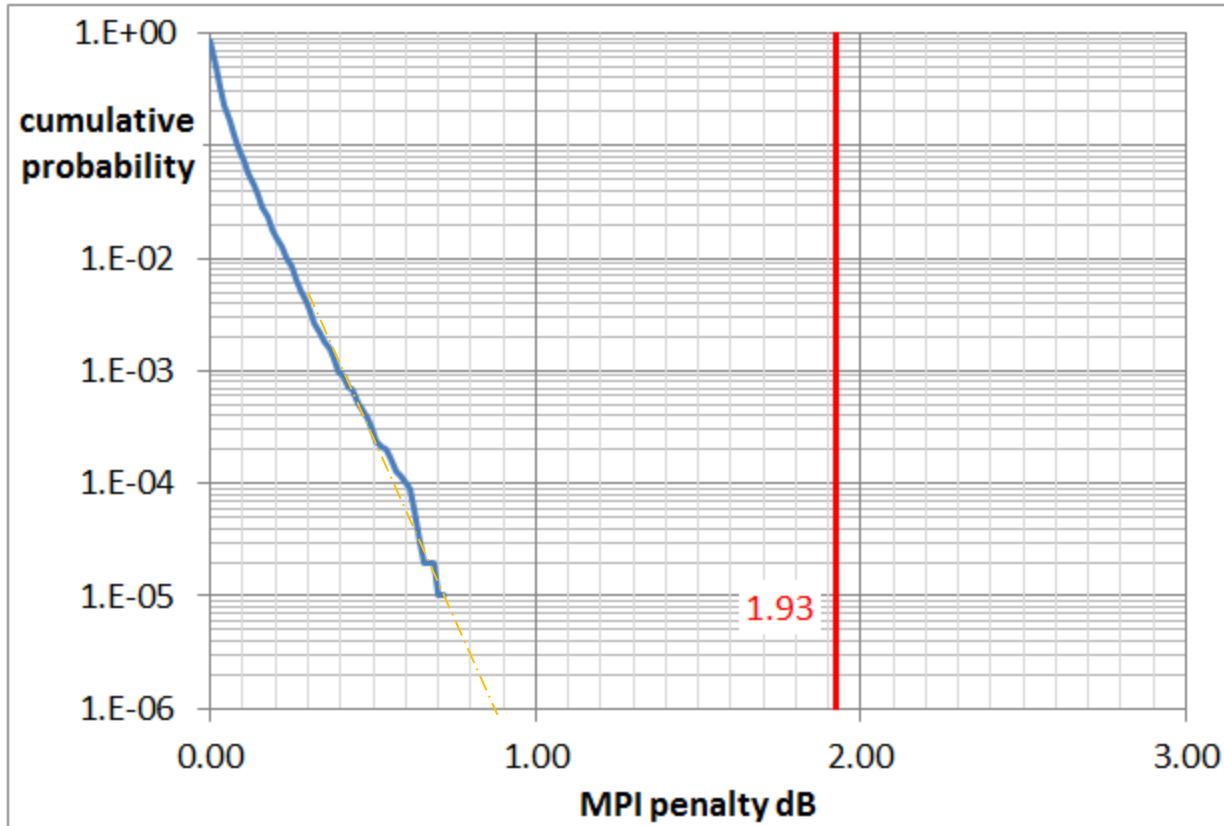
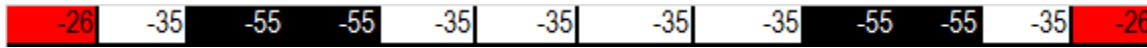




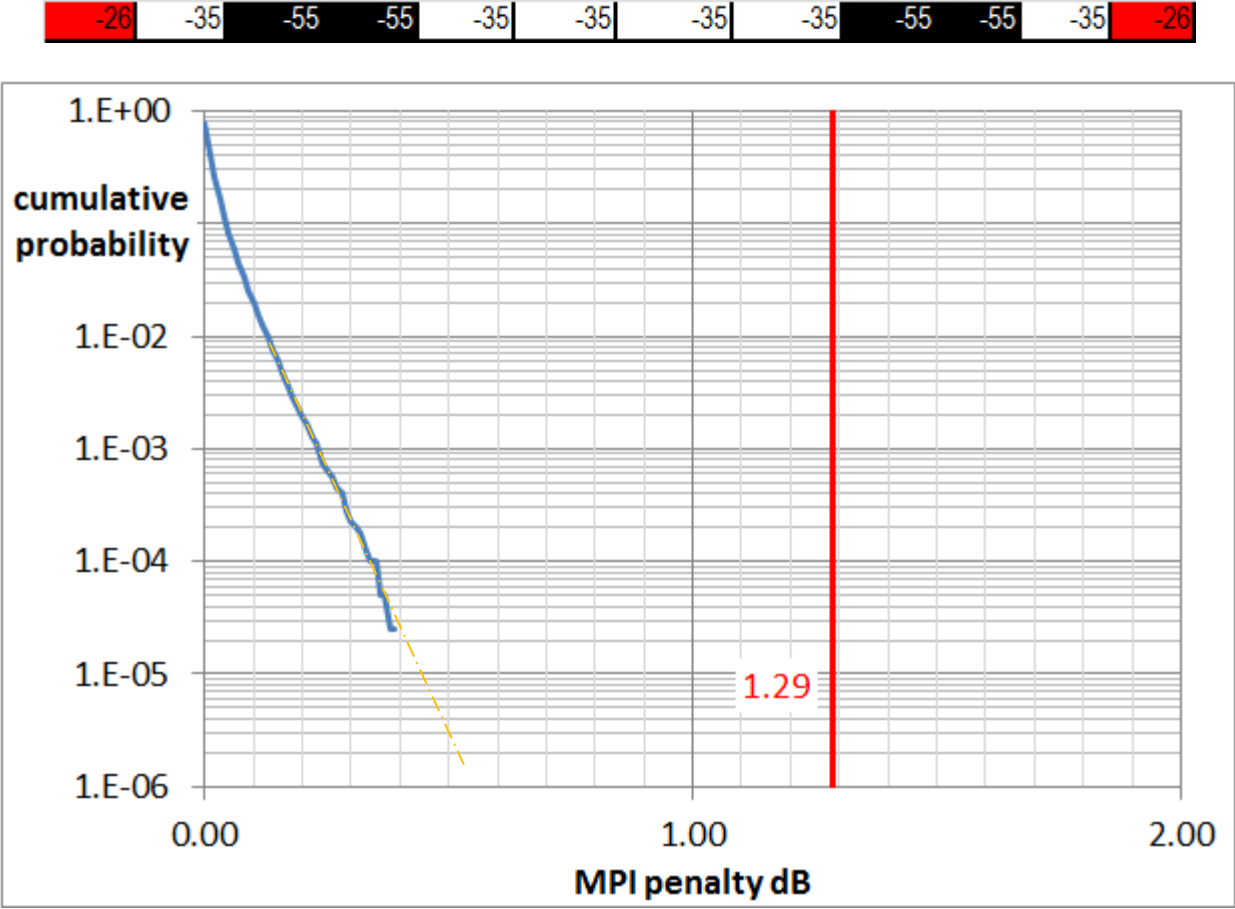
# Double link: D2a



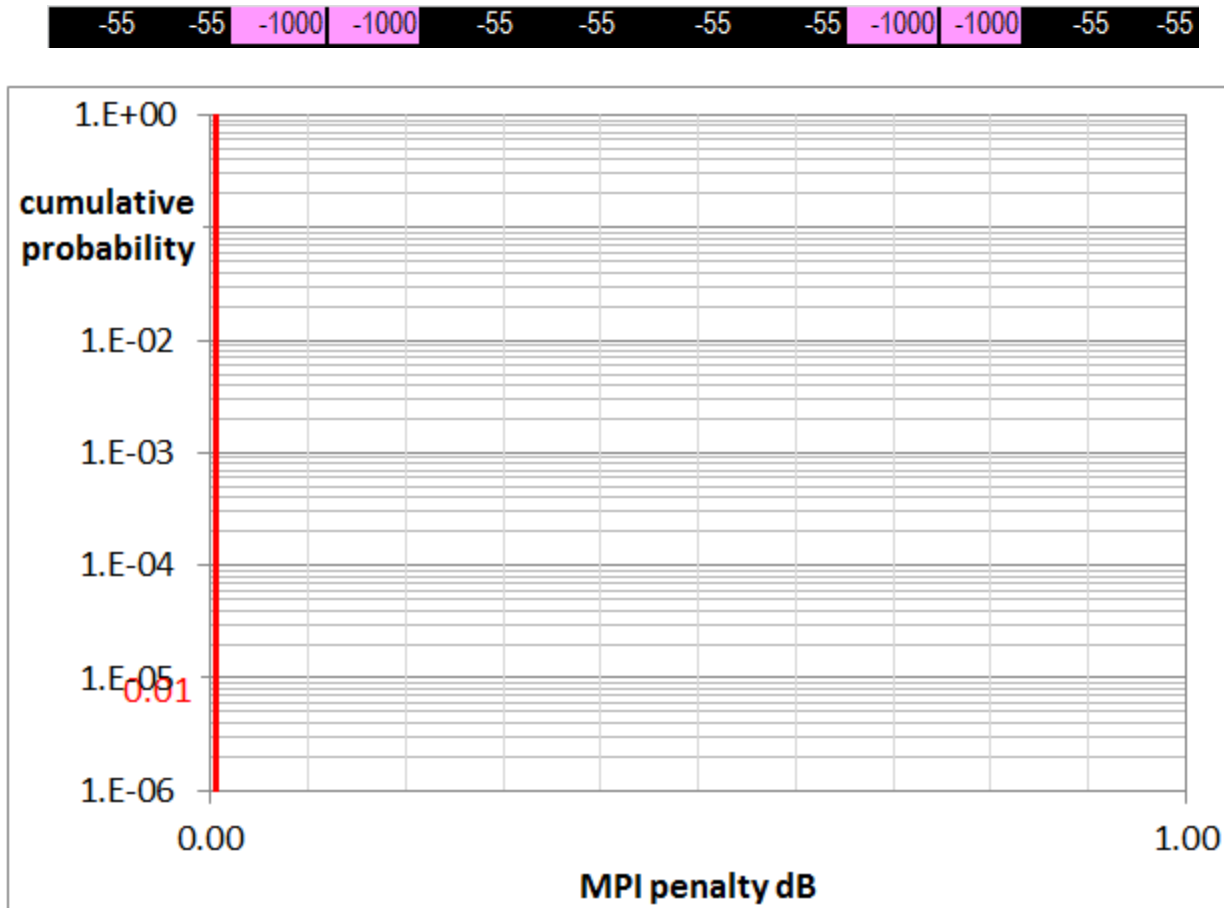
# Triple Link: T1



# Triple Link: T1 with 3 dB mid span loss



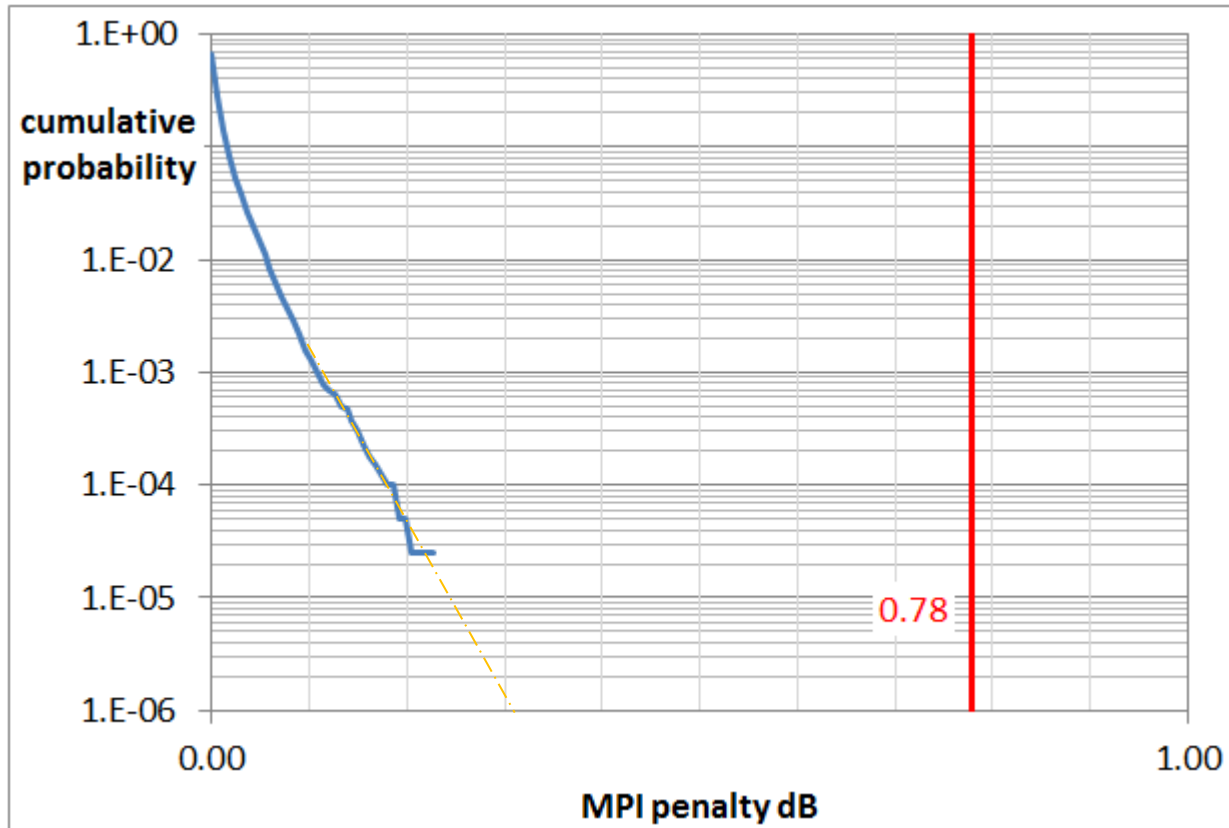
# Triple Link: T2





# Triple Link: T2a

-35 | -35 | -1000 | -1000 | -35 | -35 | -35 | -35 | -1000 | -1000 | -35 | -35



# Link scenarios: Summary

- With 55 dB RL connectors, all the single, double, and triple link parallel array fibre models have very low  $P_{\text{MPI}}$
- Even with 35 dB RL connectors, all the single, double, and triple link parallel array link models have 99.9999% probability  $P_{\text{MPI}} \leq 0.3$  dB.
- The triple link scenario with lower RL connections (26 dB PMD and mix of 35 dB and 55 dB RL connectors) has 99.9999% probability  $P_{\text{MPI}} \leq 0.9$  dB.

# Worst case and statistical MPI penalty for the cases in bhatt\_01\_0116\_smf (6 dB ER, 0 dB link loss)

| Case | Tx RL | Rx RL | Con RL | $P_{\text{mpi}}(2)$<br>w/c | $P_{\text{mpi}}(4)$<br>w/c | $P_{\text{mpi}}(6)$<br>w/c | $P_{\text{mpi}}(2)$<br>Stat. $10^{-4}$ | $P_{\text{mpi}}(4)$<br>Stat. $10^{-4}$ | $P_{\text{mpi}}(6)$<br>Stat. $10^{-4}$ |
|------|-------|-------|--------|----------------------------|----------------------------|----------------------------|--|--|--|
| DR4  | 20    | 26    | 35     | 0.81                       | 1.42                       | 2.27                       | 0.33                                   | 0.52                                   | 0.73                                   |
| A    | 26    | 26    | 26     | 1.19                       | 3.9                        |                            | 0.52                                   | 1.5                                    |  |
| B    | 20    | 20    | 26     | 3.13                       |                            |                            | 1.5                                    |  |  |
| C    | 26    | 26    | 35     | 0.47                       | 0.88                       | 1.46                       | 0.14                                   | 0.29                                   | 0.4                                    |
| D    | 35    | 35    | 35     | 0.13                       | 0.34                       | 0.66                       | 0.02                                   | 0.06                                   | 0.12                                   |
| E    | 26    | 26    | 55     | 0.2                        | 0.23                       | 0.26                       | 0.045                                  | 0.05                                   | 0.053                                  |
| F    | 26    | 26    | 45     | 0.26                       | 0.36                       | 0.47                       | 0.063                                  | 0.085                                  | 0.092                                  |
| G    | 20    | 26    | 55     | 0.4                        | 0.45                       | 0.49                       | 0.13                                   | 0.146                                  | 0.15                                   |
| H    | 20    | 26    | 45     | 0.49                       | 0.64                       | 0.8                        | 0.18                                   | 0.225                                  | 0.24                                   |

- Statistical MPI penalties recorded at 0.01% cumulative probability
  - i.e. 99.99% probability that the MPI penalty is equal to or less than this value.
- **Worst case MPI penalties agree with bhatt\_01\_0116\_smf for all cases.**

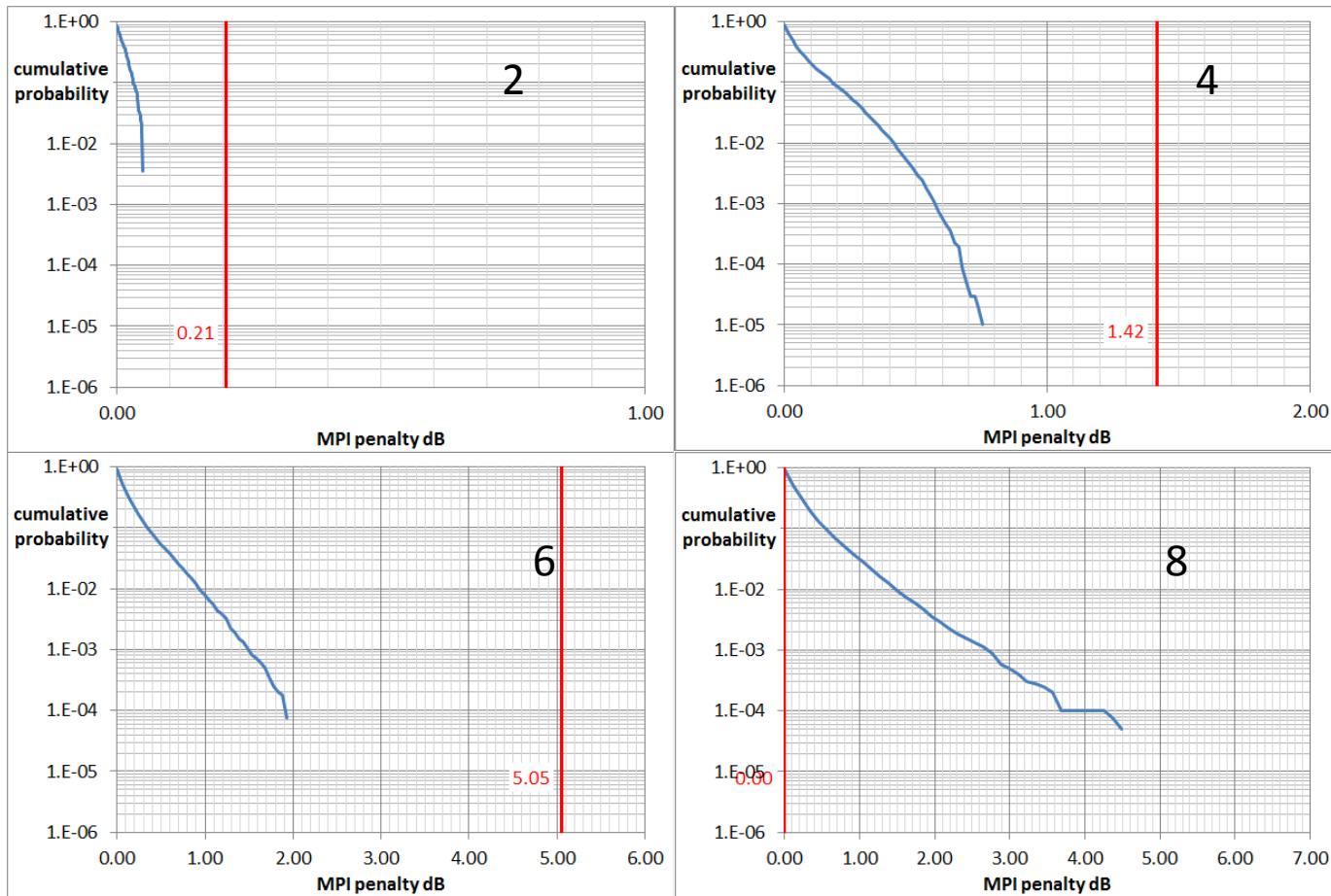
Worst case and statistical MPI penalty for the cases in  
bhatt\_01\_0116\_smf  
(6 dB ER, 0 dB link loss)

| Case | Tx<br>RL | Rx<br>RL | Con<br>RL | $P_{\text{mpi}}(2)$<br>w/c | $P_{\text{mpi}}(4)$<br>w/c | $P_{\text{mpi}}(6)$<br>w/c |  | $P_{\text{mpi}}(2)$<br>Stat. $10^{-6}$ | $P_{\text{mpi}}(4)$<br>Stat. $10^{-6}$ | $P_{\text{mpi}}(6)$<br>Stat. $10^{-6}$ |
|------|----------|----------|-----------|----------------------------|----------------------------|----------------------------|--|--|--|--|
| DR4  | 20       | 26       | 35        | 0.81                       | 1.42                       | 2.27                       |  | 0.38                                   | 0.67                                   | 1.0                                    |
| A    | 26       | 26       | 26        | 1.19                       | 3.9                        |                            |  | 0.6                                    | 1.8                                    |  |
| B    | 20       | 20       | 26        | 3.13                       |                            |                            |  | 1.7                                    |  |  |
| C    | 26       | 26       | 35        | 0.47                       | 0.88                       | 1.46                       |  | 0.15                                   | 0.38                                   | 0.6                                    |
| D    | 35       | 35       | 35        | 0.13                       | 0.34                       | 0.66                       |  | 0.03                                   | 0.09                                   | 0.2                                    |
| E    | 26       | 26       | 55        | 0.2                        | 0.23                       | 0.26                       |  |  |  |  |
| F    | 26       | 26       | 45        | 0.26                       | 0.36                       | 0.47                       |  |  |  |  |
| G    | 20       | 26       | 55        | 0.4                        | 0.45                       | 0.49                       |  |  |  |  |
| H    | 20       | 26       | 45        | 0.49                       | 0.64                       | 0.8                        |  | 0.2                                    | 0.27                                   | 0.3                                    |

- Statistical MPI penalties recorded at 0.0001% cumulative probability
  - i.e. 99.9999% probability that the MPI penalty is equal to or less than this value.
- **The  $10^{-6}$  statistical MPI penalties are equal to, or slightly lower than, the D=0.5 discounted worst case MPI penalties in bhatt\_01\_0116\_smf for the cases examined.**

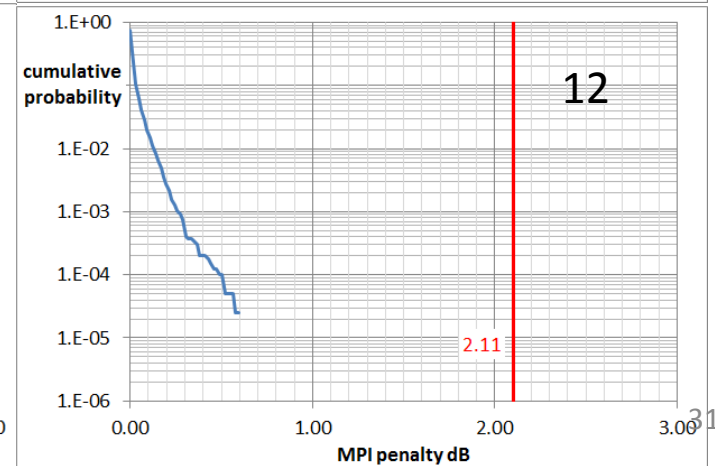
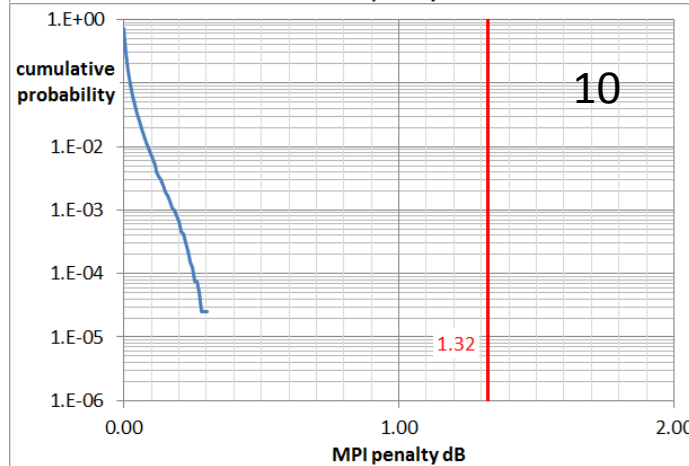
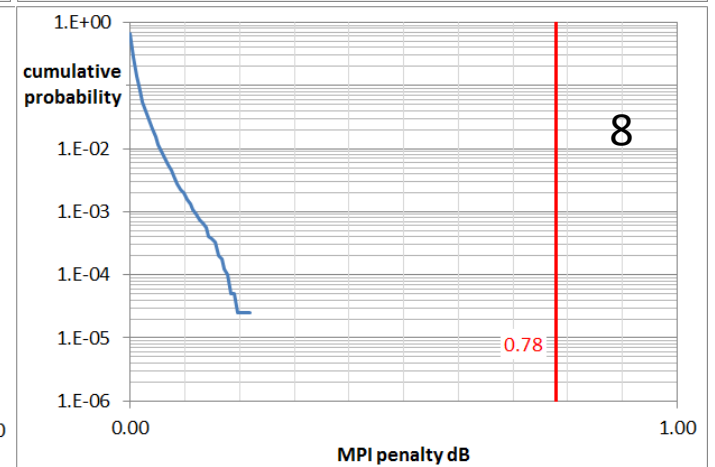
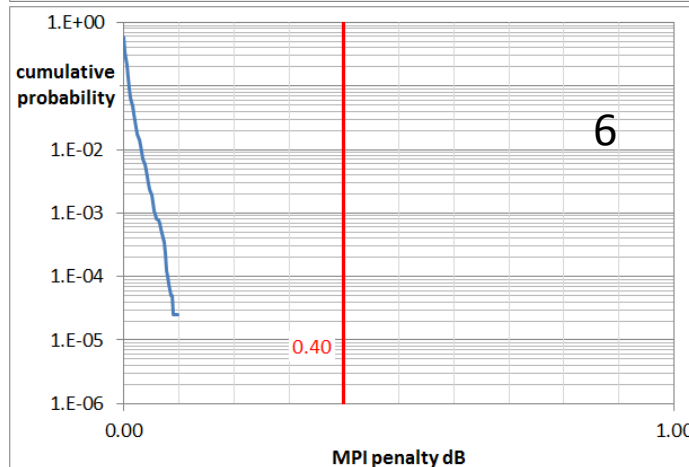
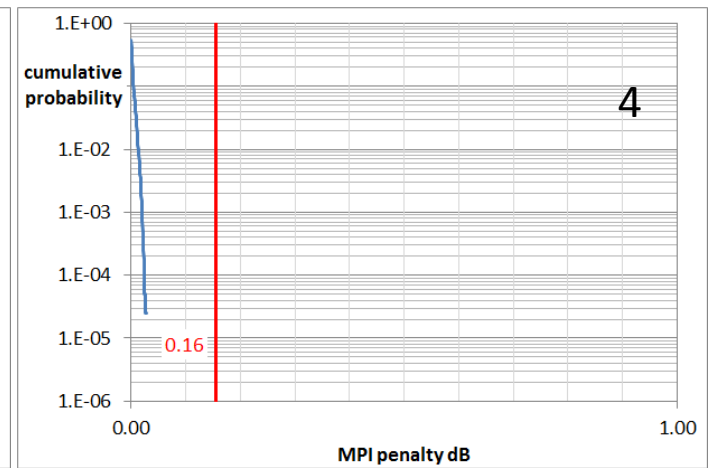
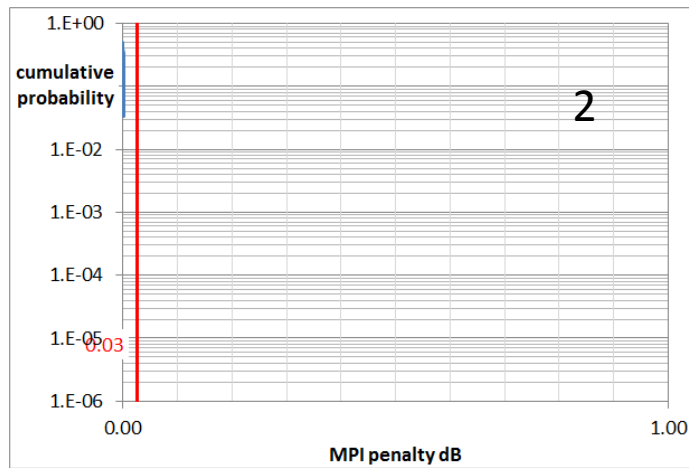
# Odd socks

# n x 26dB RL series (4.5 dB ER, 0 dB link loss)

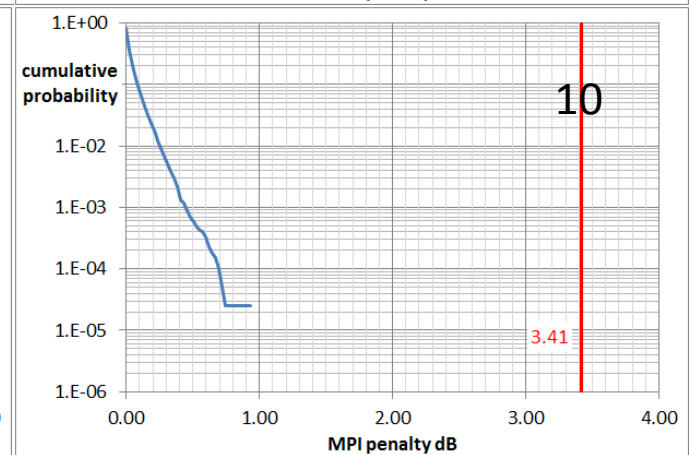
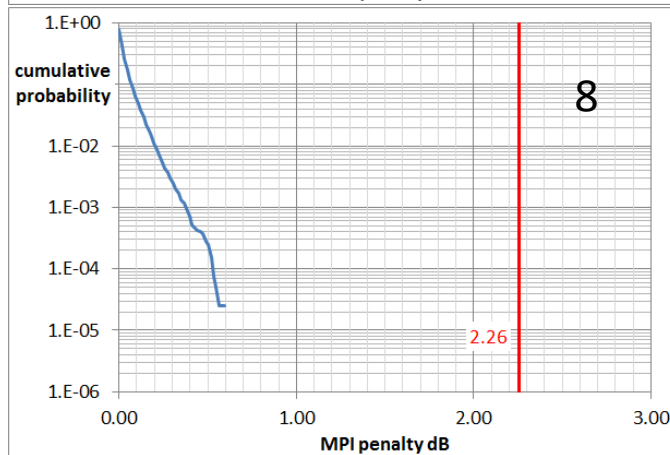
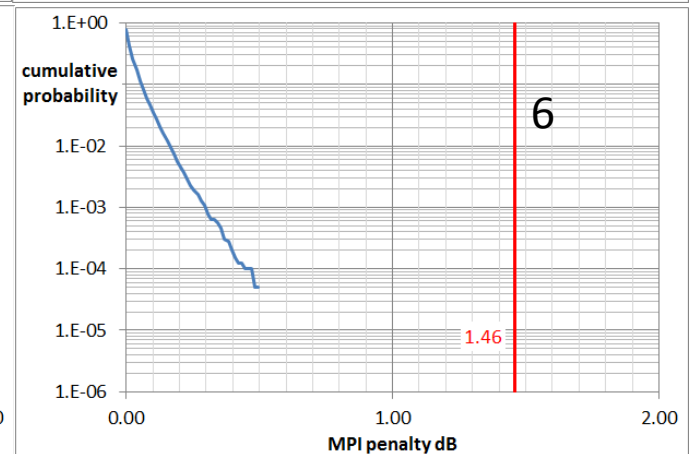
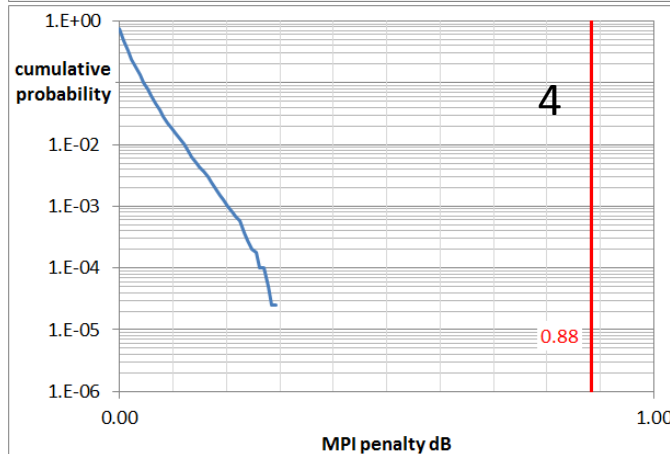
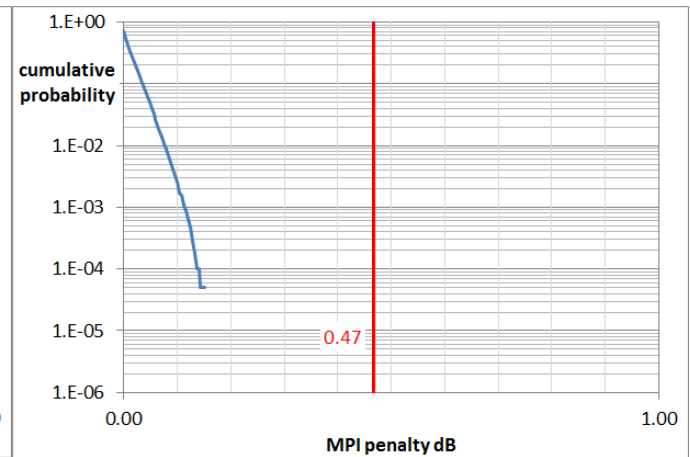
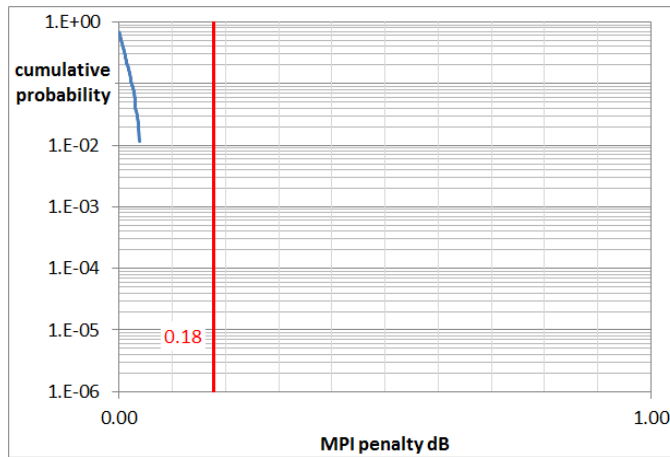


*worst case penalty is infinite for 8x*

n x 35dB  
RL series  
(4.5 dB ER, 0 dB  
link loss)

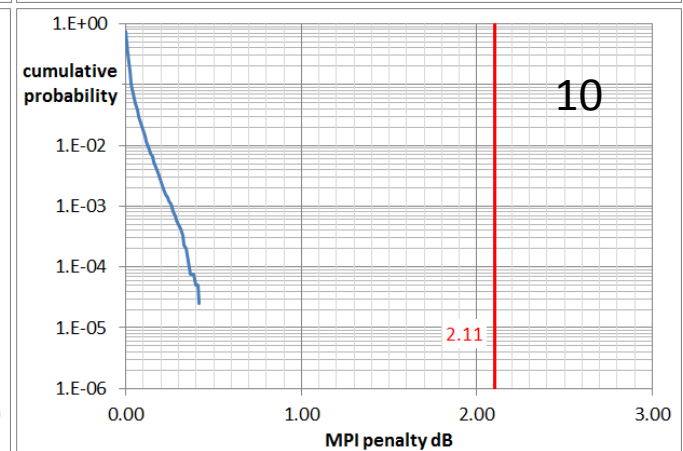
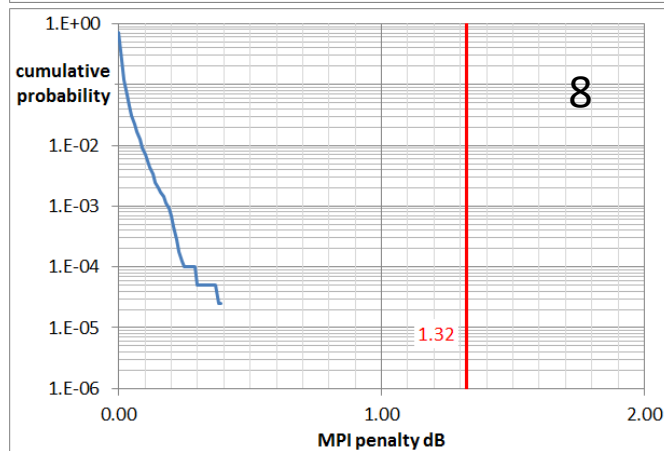
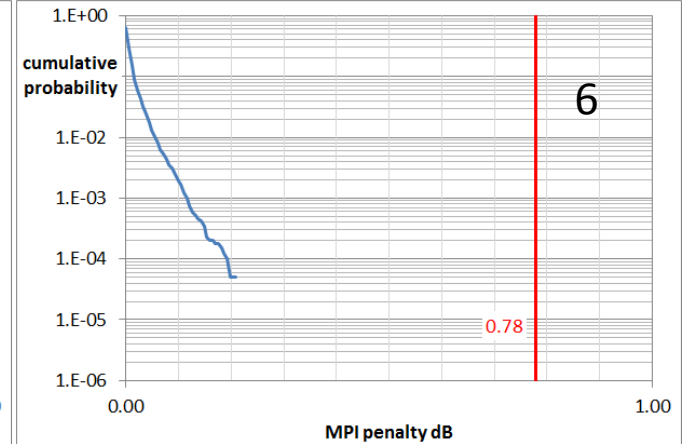
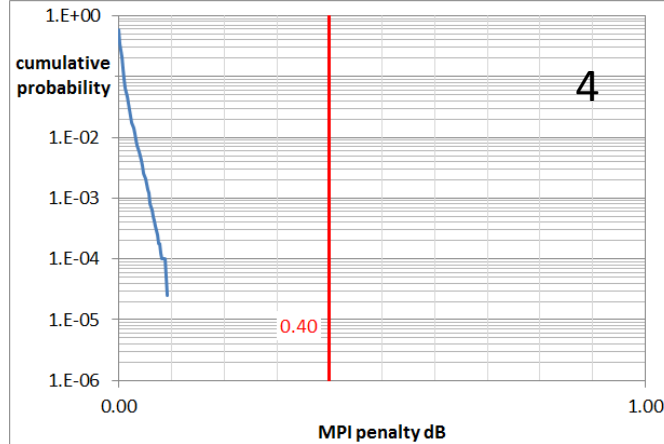
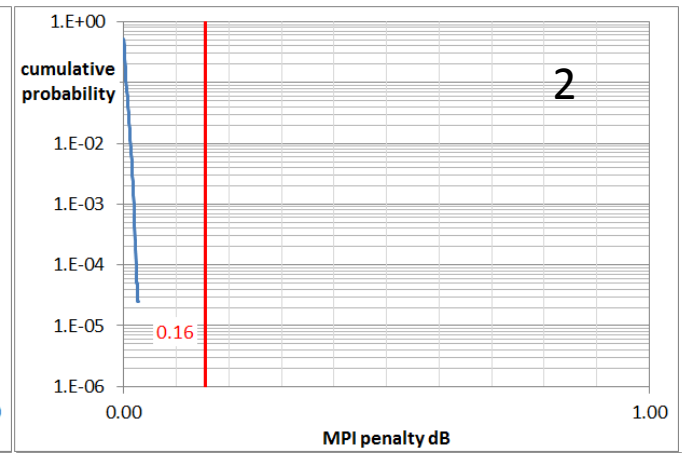
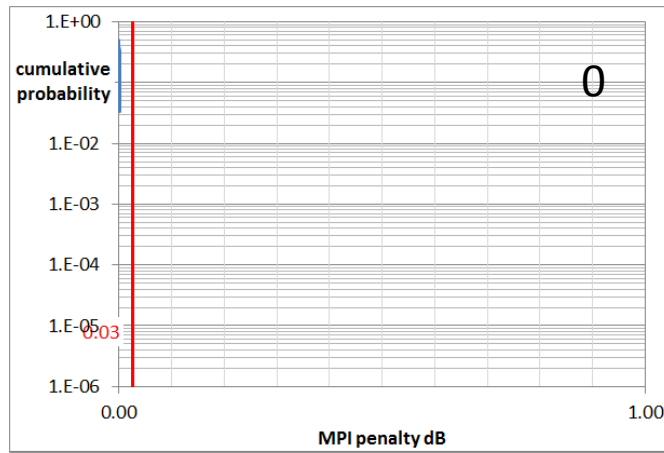


26 dB PMD +  
n x 35 dB RL,  
6 dB ER, 0dB  
link loss





35 dB PMD +  
n x 35 dB RL,  
6 dB ER, 0dB  
link loss



Q & A

thanks !