Modal noise penalty and link budget proposal for 25, 10, 5 and 2.5 Gb/s

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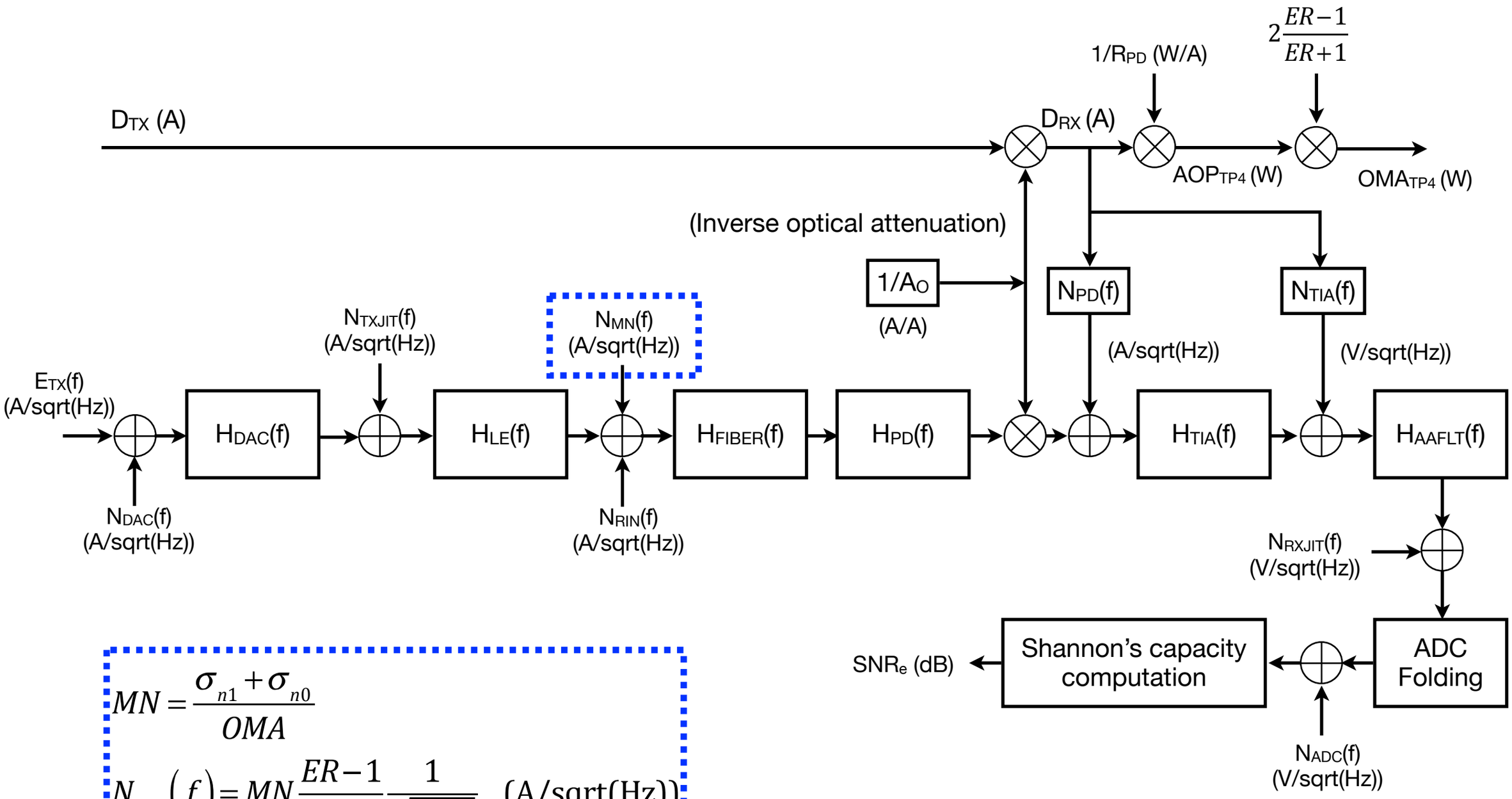
Overview

- A modal noise model has been included in the link model of [1]. This model allows to calculate how the modal noise affects the receiver sensitivity, therefore calculate its penalty in the link budget
- From [2] we know that there is a direct dependence between IL due to misalignments (i.e. mode selective loss) and modal noise in BC and EBO connectors. Based on it, we can obtain an estimate of modal noise penalty as a function of MSL IL in the link
- Updated link budget results obtained by simulation will be presented together with a baseline proposal that considers implementation margins

Modal noise

Modal noise included in the link model

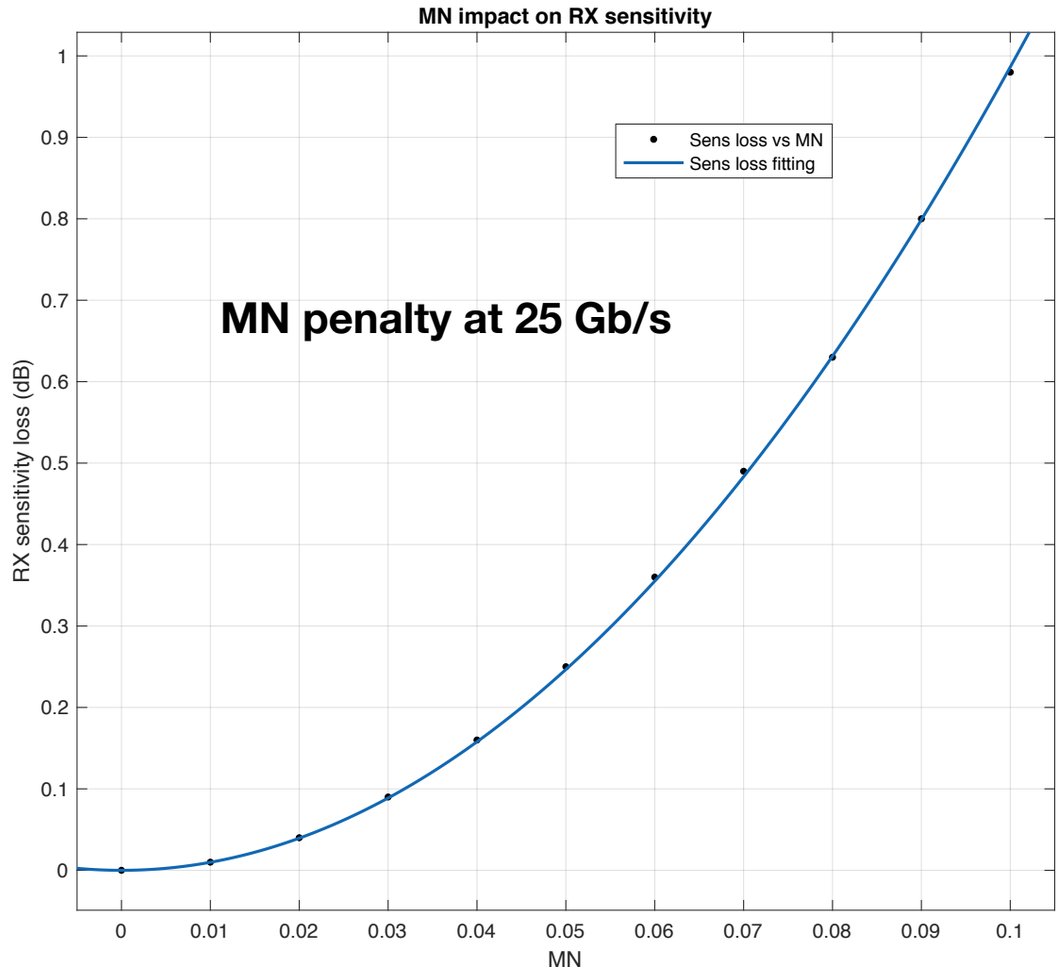


$$MN = \frac{\sigma_{n1} + \sigma_{n0}}{OMA}$$

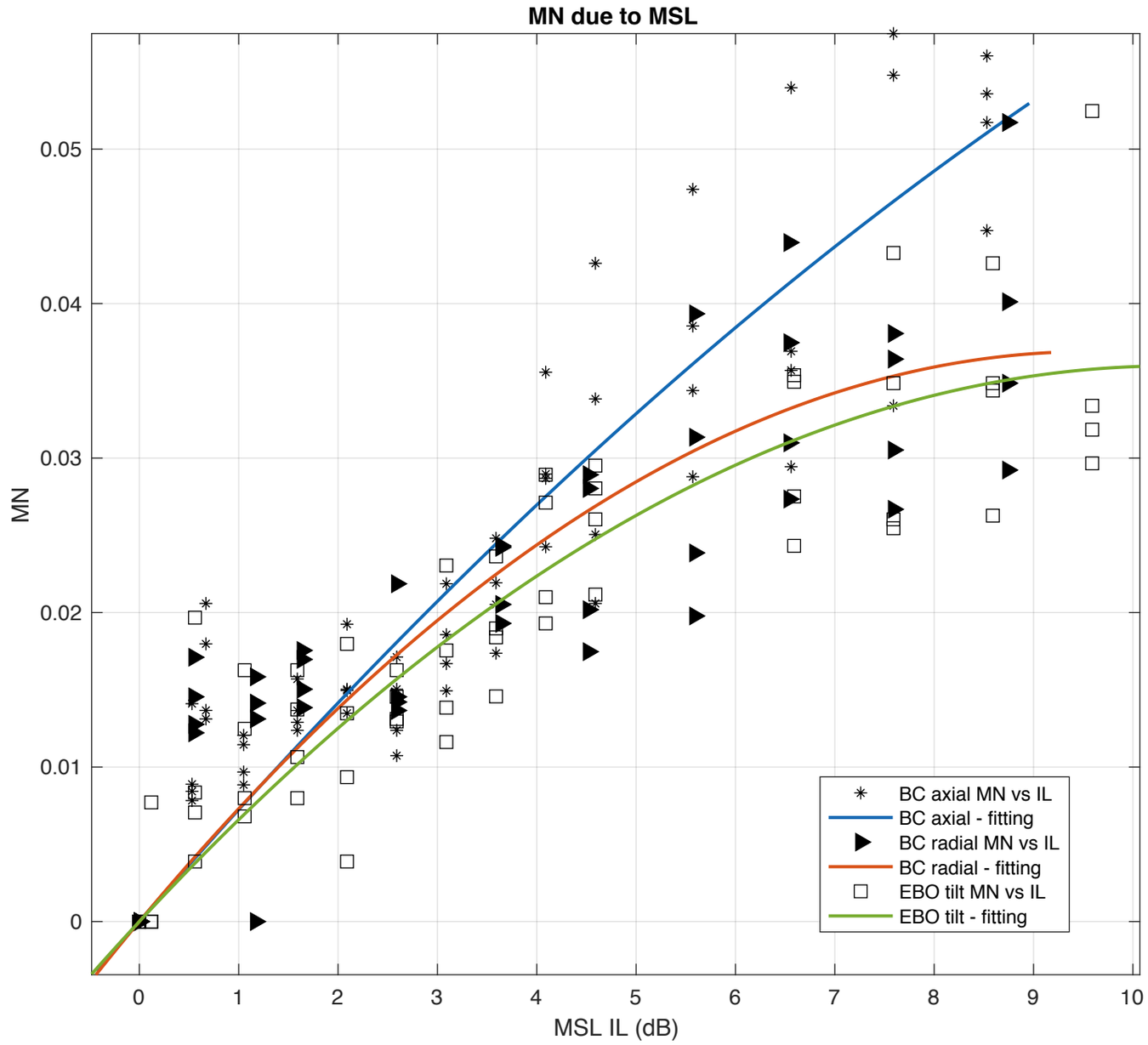
$$N_{MN}(f) = MN \frac{ER-1}{ER+1} \frac{1}{\sqrt{F_S/2}} \quad \text{(A/sqrt(Hz))}$$

Modal noise impact on receiver sensitivity

	25G		10G	
MN=(sn1+sn0)/OMA	**OMA_{TP4} (dBm)**	**Sens. loss (dB)**	**OMA_{TP4} (dBm)**	**Sens. loss (dB)**
0.00	-17.07	0.00	-21.89	0.00
0.01	-17.06	0.01	-21.88	0.01
0.02	-17.03	0.04	-21.86	0.03
0.03	-16.98	0.09	-21.82	0.07
0.04	-16.91	0.16	-21.77	0.12
0.05	-16.82	0.25	-21.70	0.19
0.06	-16.71	0.36	-21.61	0.28
0.07	-16.58	0.49	-21.51	0.38
0.08	-16.43	0.63	-21.38	0.51
0.09	-16.27	0.80	-21.24	0.65
0.10	-16.09	0.98	-21.08	0.81

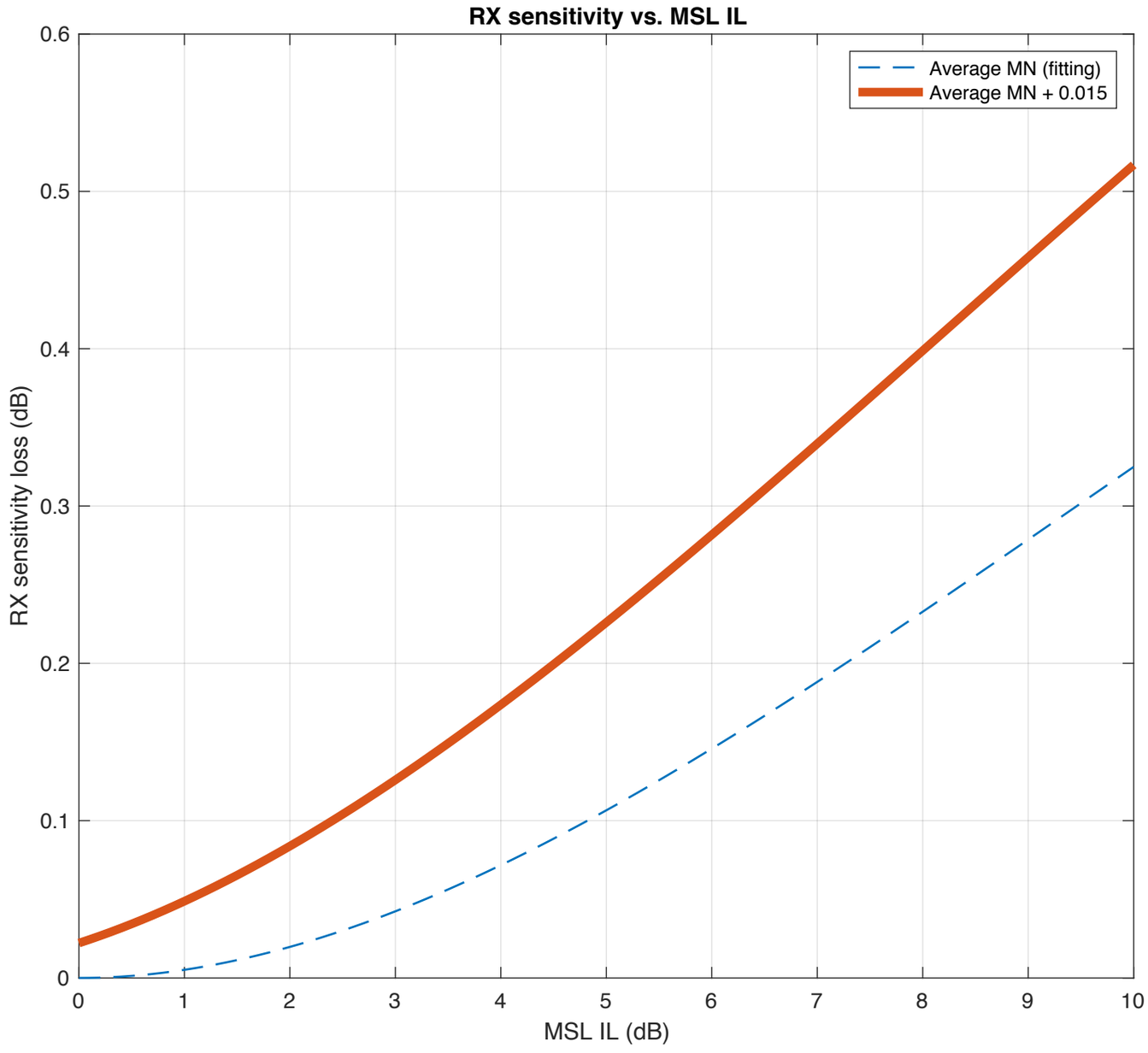


Modal noise vs. MSL IL (from [2])



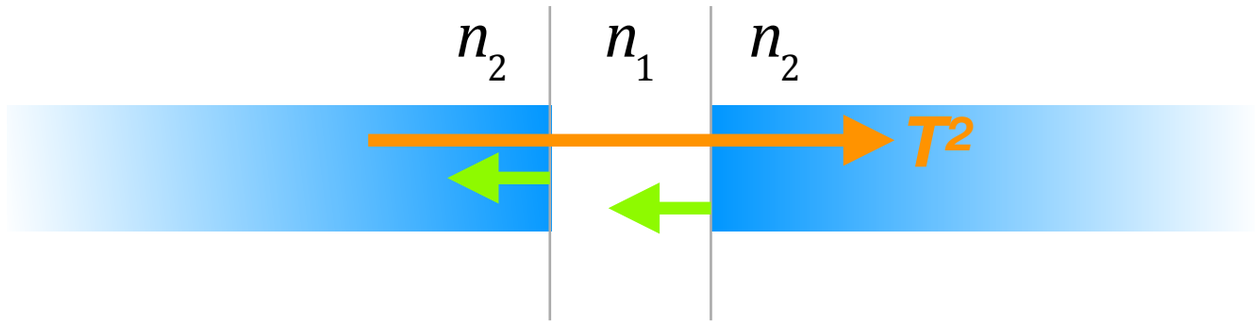
Let's consider BC axial misalignment because it is the worst case

RX sensitivity vs MSL IL



Minimum non-MSL IL for inline connections

$$T = \frac{4 n_1 n_2}{\left(n_1 + n_2\right)^2}$$



- Butt coupling connection
  - n_1 = 1 (air), n_2 = 1.48 (OM3), $(T_{Fresnel})^2$ = 92.7%, IL = 0.33 dB per inline connection
  - Min IL for 4 connections: 1.32 dB without MSL or misalignments
  - Considering maximum 2 dB per inline connector, that gives max 8 - 1.3 = 6.7 dB attenuation due to MSL for 4 inline connections
  - This gives max 0.32 dB modal noise penalty (see slide 7)
- EBO connection at 980nm
  - ULTEM material is considered for EBO lenses: n_2 = 1.6324
  - Lens length: 3.5 mm each
  - $(T_{Fresnel\text{-}ULTEM\ to\ air})^2$ = 88.8%, $(T_{Absorption\text{-}ULTEM})^2$ = 96.5%, $(T_{Fresnel\text{-}ULTEM\ to\ OM3})^2$ = 99.25%
  - IL = 0.70 dB per inline connection
  - Considering max 2 dB per inline connector, that gives max 8 - 2.8 = 5.2 dB due to MSL for 4 inline connections
  - This gives max 0.23 dB modal noise penalty
- Considering 2.5 dB/IC & butt coupling: 10 - 1.3 = 8.7 dB max attenuation due to MSL: 0.45 dB modal noise penalty

Link budget

Baseline for simulations of 25 Gb/s and below

- Data-rate: 10·S Gb/s, where S = 2.5, 1.0, 0.5, 0.25
- Modulation: NRZ, PAM M = 2
- FEC: RS(544, 522) GF(2^{10})
  - Error correction capability: t = 11
  - Code-rate: CR = 0.96
  - Coding-gain: CG (for BER = 10^{-12} after FEC) = 5.55 dB
- BER before FEC (for BER = 10^{-12} after FEC) = 0.00017
- Fs = 10.625·S GBd, where S = 2.5, 1.0, 0.5, 0.25
- SNRd > 11.07 dB for BER < 10^{-12} after FEC
- RX equalization: DFE
- TIA: Optimized parameters for 25 Gb/s
- PD: InGaAs PIN with 0.6 A/W @ 980nm, 25 GBaud
- RX conditions: worst production corner, T_J = 125 ºC
- TX & RX clock random jitter (RMS):
  - 25 Gb/s: t_J < 0.7 ps, 10 Gb/s: t_J < 1.8 ps
  - 5 Gb/s: t_J < 3.6 ps, 2.5 Gb/s: t_J < 7.0 ps
- Fiber is OM3: 2.0 dB/km. BW_{eff} = 932 MHz·km @ 980nm
  - EMB = 950 MHz·km @ 980nm
  - BW_{CD} = 5498 MHz·km @ 980nm
- Fiber length = 40 meters
- Number of inline connections: N_{IC} = 4
- VCSEL ER = 4 dB
- VCSEL driver:
  - Current driver
  - No FFE
- VCSEL RIN_{OMA}:
  - 25 Gb/s: -124 dB/Hz, BW_n = 20.7 GHz
  - 10 Gb/s and below: -120 dB/Hz, BW_n = 8.3 GHz
  - 5 Gb/s and below: -120 dB/Hz, BW_n = 4.1 GHz
  - 2.5 Gb/s and below: -120 dB/Hz, BW_n = 2.1 GHz
- VCSEL I_{BIAS} = 7 mA
- VCSEL temperatures (T_{BS}) = 125 ºC

Link budget proposal for 25 Gb/s

25 Gb/s link budget

Parameter	Simulation	Proposal	
VCSEL SE variation (dB)	1.50		**A**
VCSEL aging (dB)	0.50		**B**
VCSEL to TP2 max coupling loss (dB)	2.50		**C**
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	4.50		**D = A + B + C**
PD responsivity variation (dB)	0.80		**E_0**
TP3 to PD max coupling loss (dB)	2.50		**E_1**
$IL_{TP3\text{-}to\text{-}TP4}$, max (dB)	3.30		**E = E_0 + E_1**
Insertion loss per inline connection, IL_{IC} max (dB)	2.00	**2.00**	**F**
Number of inline connections (N_{IC})	4	**4**	**G**
Macrobend insertion loss, max (dB)	0.20		**H**
Microbend insertion loss, max (dB)	0.00		**I**
Bending insertion loss, IL_{BEND} max (dB)	0.20		**J = H + I**
Fiber attenuation (dB/km)	2.00		**K**
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	8.28	**8.28**	**L = (F × G) + J + (40/1000 × K)**
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	16.08		**M = D + E + L**
OMA_{TP1} min (dBm)	2.50		**N**
OMA_{TP2} min (dBm)	-2.00	**-2.50**	**O = N - D**
OMA_{TP4} max (dBm)	-17.00		**P**
OMA_{TP3} max (dBm)	-13.70	**-11.20**	**Q = P + E**
Power budget (dB)	11.70	**8.70**	**R = O - Q**
Allocation for modal noise (dB)	0.30	**0.30**	**S**
Unallocated margin (dB)	3.12	**0.12**	**T = R - L - S**

Link budget proposal for 10 Gb/s

10 Gb/s link budget

Parameter	Simulation	Proposal	
VCSEL SE variation (dB)	1.50		**A**
VCSEL aging (dB)	0.50		**B**
VCSEL to TP2 max coupling loss (dB)	3.50		**C**
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	5.50		**D = A + B + C**
PD responsivity variation (dB)	0.80		**E_0**
TP3 to PD max coupling loss (dB)	3.50		**E_1**
$IL_{TP3\text{-}to\text{-}TP4}$, max (dB)	4.30		**E = E_0 + E_1**
Insertion loss per inline connection, IL_{IC} max (dB)	2.50	**2.50**	**F**
Number of inline connections (N_{IC})	4	**4**	**G**
Macrobend insertion loss, max (dB)	0.20		**H**
Microbend insertion loss, max (dB)	0.00		**I**
Bending insertion loss, IL_{BEND} max (dB)	0.20		**J = H + I**
Fiber attenuation (dB/km)	2.00		**K**
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	10.28	**10.28**	**L = (F × G) + J + (40/1000 × K)**
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	20.08		**M = D + E + L**
OMA_{TP1} min (dBm)	2.50		**N**
OMA_{TP2} min (dBm)	-3.00	**-3.50**	**O = N - D**
OMA_{TP4} max (dBm)	-21.90		**P**
OMA_{TP3} max (dBm)	-17.60	**-14.40**	**Q = P + E**
Power budget (dB)	14.60	**10.90**	**R = O - Q**
Allocation for modal noise (dB)	0.50	**0.50**	**S**
Unallocated margin (dB)	3.82	**0.12**	**T = R - L - S**

Link budget proposal for 5 Gb/s

5 Gb/s link budget

Parameter	Simulation	Proposal	
VCSEL SE variation (dB)	1.50		**A**
VCSEL aging (dB)	0.50		**B**
VCSEL to TP2 max coupling loss (dB)	3.50		**C**
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	5.50		**D = A + B + C**
PD responsivity variation (dB)	0.80		**E_0**
TP3 to PD max coupling loss (dB)	3.50		**E_1**
$IL_{TP3\text{-}to\text{-}TP4}$, max (dB)	4.30		**$E = E_0 + E_1$**
Insertion loss per inline connection, IL_{IC} max (dB)	2.50	**2.50**	**F**
Number of inline connections (N_{IC})	4	**4**	**G**
Macrobend insertion loss, max (dB)	0.20		**H**
Microbend insertion loss, max (dB)	0.00		**I**
Bending insertion loss, IL_{BEND} max (dB)	0.20		**J = H + I**
Fiber attenuation (dB/km)	2.00		**K**
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	10.28	**10.28**	**L = (F × G) + J + (40/1000 × K)**
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	20.08		**M = D + E + L**
OMA_{TP1} min (dBm)	2.50		**N**
OMA_{TP2} min (dBm)	-3.00	**-3.50**	**O = N - D**
OMA_{TP4} max (dBm)	-25.60		**P**
OMA_{TP3} max (dBm)	-21.30	**-18.10**	**Q = P + E**
Power budget (dB)	18.30	**14.60**	**R = O - Q**
Allocation for modal noise (dB)	0.50	**0.50**	**S**
Unallocated margin (dB)	7.52	**3.82**	**T = R - L - S**

Link budget proposal for 2.5 Gb/s

2.5 Gb/s link budget

Parameter	Simulation	Proposal	
VCSEL SE variation (dB)	1.50		**A**
VCSEL aging (dB)	0.50		**B**
VCSEL to TP2 max coupling loss (dB)	3.50		**C**
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	5.50		**D = A + B + C**
PD responsivity variation (dB)	0.80		**E_0**
TP3 to PD max coupling loss (dB)	3.50		**E_1**
$IL_{TP3\text{-}to\text{-}TP4}$, max (dB)	4.30		**E = E_0 + E_1**
Insertion loss per inline connection, IL_{IC} max (dB)	2.50	**2.50**	**F**
Number of inline connections (N_{IC})	4	**4**	**G**
Macrobend insertion loss, max (dB)	0.20		**H**
Microbend insertion loss, max (dB)	0.00		**I**
Bending insertion loss, IL_{BEND} max (dB)	0.20		**J = H + I**
Fiber attenuation (dB/km)	2.00		**K**
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	10.28	**10.28**	**L = (F × G) + J + (40/1000 × K)**
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	20.08		**M = D + E + L**
OMA_{TP1} min (dBm)	2.50		**N**
OMA_{TP2} min (dBm)	-3.00	**-3.50**	**O = N - D**
OMA_{TP4} max (dBm)	-28.40		**P**
OMA_{TP3} max (dBm)	-24.10	**-20.90**	**Q = P + E**
Power budget (dB)	21.10	**17.40**	**R = O - Q**
Allocation for modal noise (dB)	0.50	**0.50**	**S**
Unallocated margin (dB)	10.32	**6.62**	**T = R - L - S**

References

- [1] R. Pérez-Aranda, “OMEGA link model,” October 2020, [Online], Available: https://www.ieee802.org/3/cz/public/13_oct_2020/perezaranda_3cz_01_131020_link_model.pdf

- [2] P. Pinzón et al., “Modal Noise vs Misalignment Losses in MMFs Connectors,” June 2020, [Online], Available: https://www.ieee802.org/3/cz/public/15_jun_2021/pinzon_3cz_01_150621.pdf

Thank you