



# Link budget proposal for 50, 25, 10, 5 and 2.5 Gb/s

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# Overview

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- In [1], allocation for modal noise (MN) penalty was presented based on the dependence of MN with mode selective loss (MSL) and how MN impacts the RX sensitivity for 25 and 10 Gb/s operation
- In this contribution the same is going to be presented for 50 Gb/s
- Updated link budget results obtained by simulation for all the considered data-rates will be presented together with a baseline proposal for OM3 + VCSEL PMD that considers implementation margins

# Baseline for simulations of 25 Gb/s and below



- Data-rate:  $10 \cdot S$  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
- $F_s = 10.625 \cdot S$  GBd, where  $S = 2.5, 1.0, 0.5, 0.25$
- $SNR_d > 11.07$  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 GBd
- RX conditions: worst production corner,  $T_J = 125$  °C
- 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: Att=2.0 dB/km.  $BW_{eff} = 932$  MHz·km @ 980nm
  - EMB = 950 MHz·km @ 980nm
  - $BW_{CD} = 5498$  MHz·km @ 980nm
  - Attenuation and  $BW_{eff}$  are less at 980nm than at 850nm
- 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 °C

# Baseline for simulations of 50 Gb/s

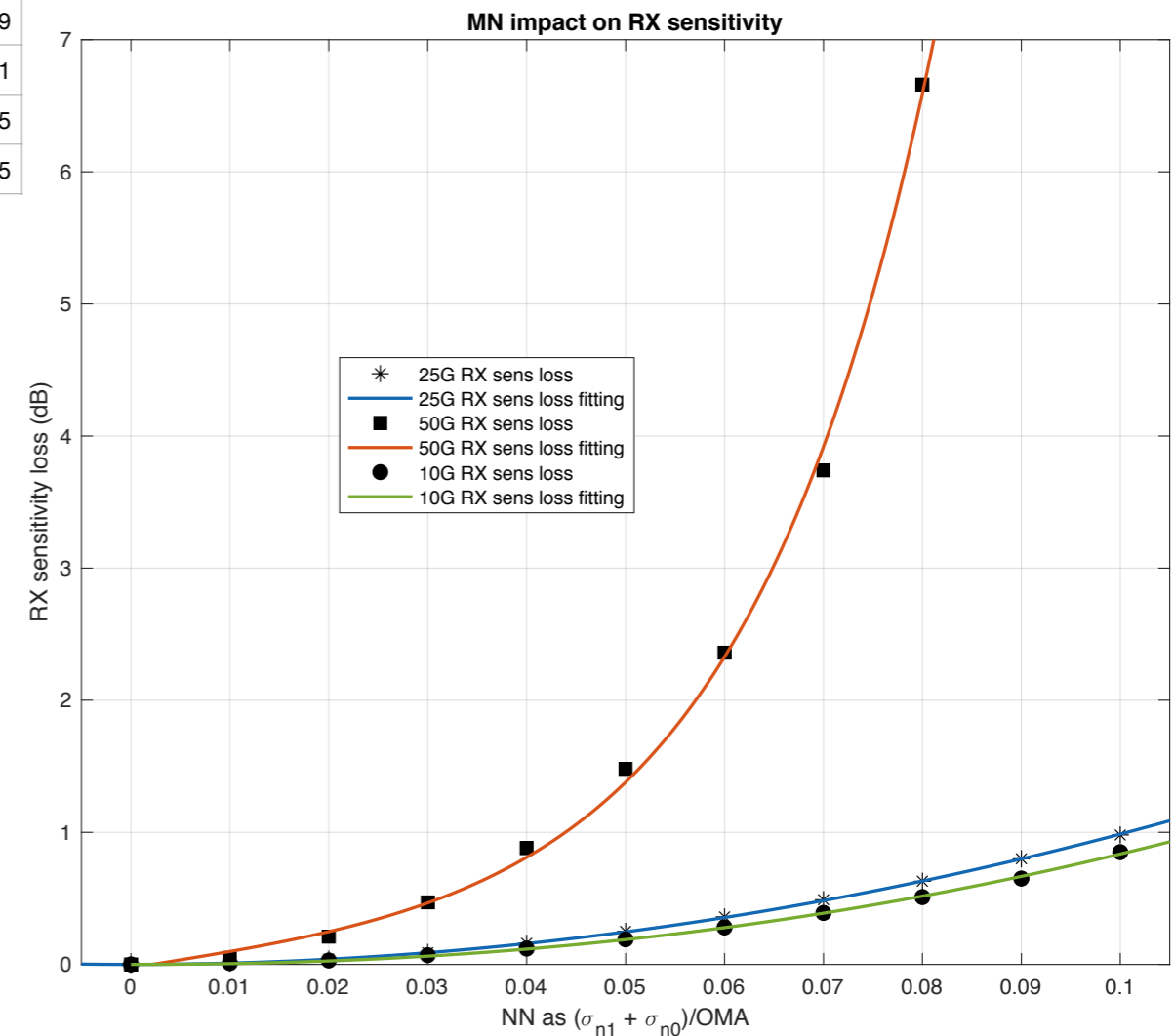


- Data-rate: 50 Gb/s
- Modulation: PAM4
- FEC: RS(544, 522) GF(2<sup>10</sup>)
  - Error correction capability:  $t = 11$
  - Code-rate: CR = 0.96
  - Coding-gain: CG (for BER = 10<sup>-12</sup> after FEC) = 5.49 dB
- BER before FEC (for BER = 10<sup>-12</sup> after FEC) = 0.00017
- Fs = 26.5625 GBd
- SNR<sub>d</sub> > 17.88 dB for BER < 10<sup>-12</sup> after FEC
- RX equalization: DFE
- TIA: Optimized parameters for 50 Gb/s
- PD: InGaAs PIN with 0.6 A/W @ 980nm, 25 GBd
- RX conditions: worst production corner, T<sub>J</sub> = 125 °C
- TX & RX clock random jitter (RMS): t<sub>J</sub> < 0.3 ps
- Fiber is OM3: Att=2.0 dB/km. BW<sub>eff</sub> = 932 MHz·km @ 980nm
  - EMB = 950 MHz·km @ 980nm
  - BW<sub>CD</sub> = 5498 MHz·km @ 980nm
  - Attenuation and BW<sub>eff</sub> are less at 980nm than at 850nm
- Fiber length = 40 meters
- Number of inline connections: N<sub>IC</sub> = 2
- VCSEL ER = 4 dB
- VCSEL driver:
  - Current driver
  - No FFE
- VCSEL RIN<sub>OMA</sub> < -128 dB/Hz, BW<sub>n</sub> = 20.7 GHz
- VCSEL I<sub>BIAS</sub> = 7 mA
- VCSEL temperatures (T<sub>BS</sub>) = 125 °C

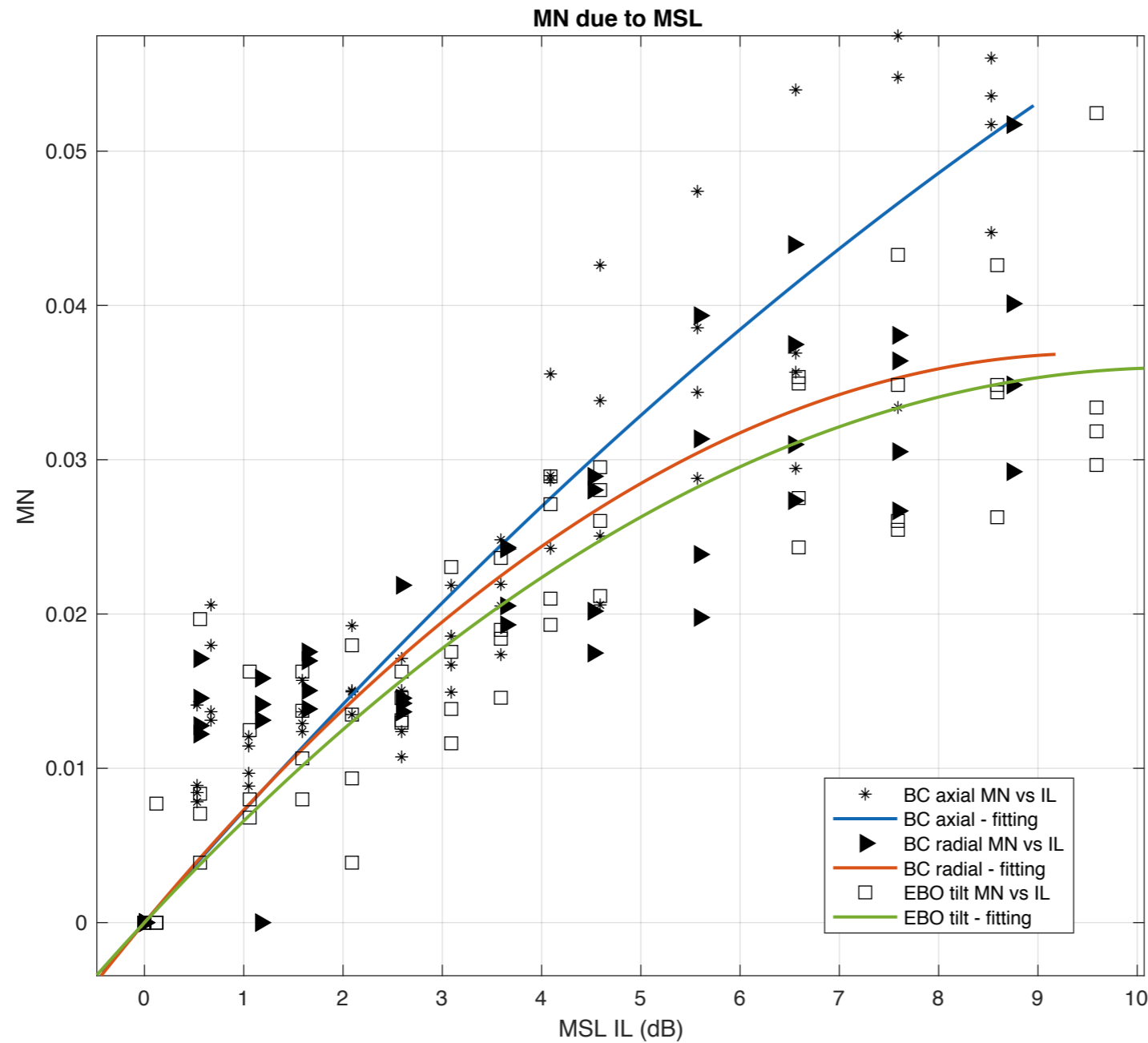
# Modal noise impact on receiver sensitivity at 50 Gb/s



MN=(sn1+sn0)/OMA	50G		25G		10G	
	OMA <sub>TP4</sub> (dBm)	Sens. loss (dB)	OMA <sub>TP4</sub> (dBm)	Sens. loss (dB)	OMA <sub>TP4</sub> (dBm)	Sens. loss (dB)
0.00	-12.81	0.00	-16.60	0.00	-21.35	0.00
0.01	-12.76	0.05	-16.59	0.01	-21.34	0.01
0.02	-12.60	0.21	-16.56	0.04	-21.32	0.03
0.03	-12.34	0.47	-16.51	0.09	-21.28	0.07
0.04	-11.93	0.88	-16.43	0.17	-21.23	0.12
0.05	-11.33	1.48	-16.34	0.26	-21.16	0.19
0.06	-10.45	2.36	-16.22	0.38	-21.07	0.28
0.07	-9.07	3.74	-16.09	0.51	-20.96	0.39
0.08	-6.15	6.66	-15.94	0.66	-20.84	0.51
0.09	no link	Inf	-15.77	0.83	-20.70	0.65
0.10	no link	Inf	-15.58	1.02	-20.50	0.85



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

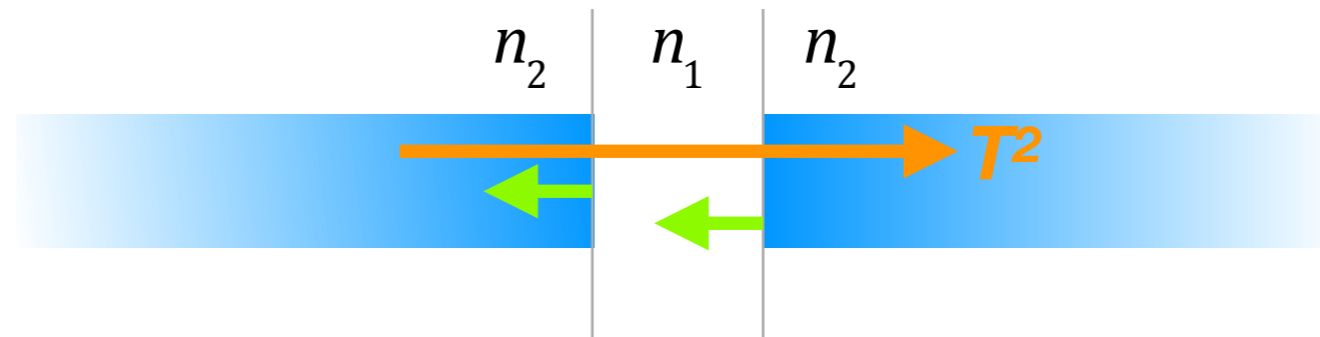


Let's consider BC axial misalignment because it is the worst case

# Minimum non-MSL IL for inline connections (based on [1])



$$T = \frac{4n_1n_2}{(n_1 + n_2)^2}$$



- Butt coupling connection

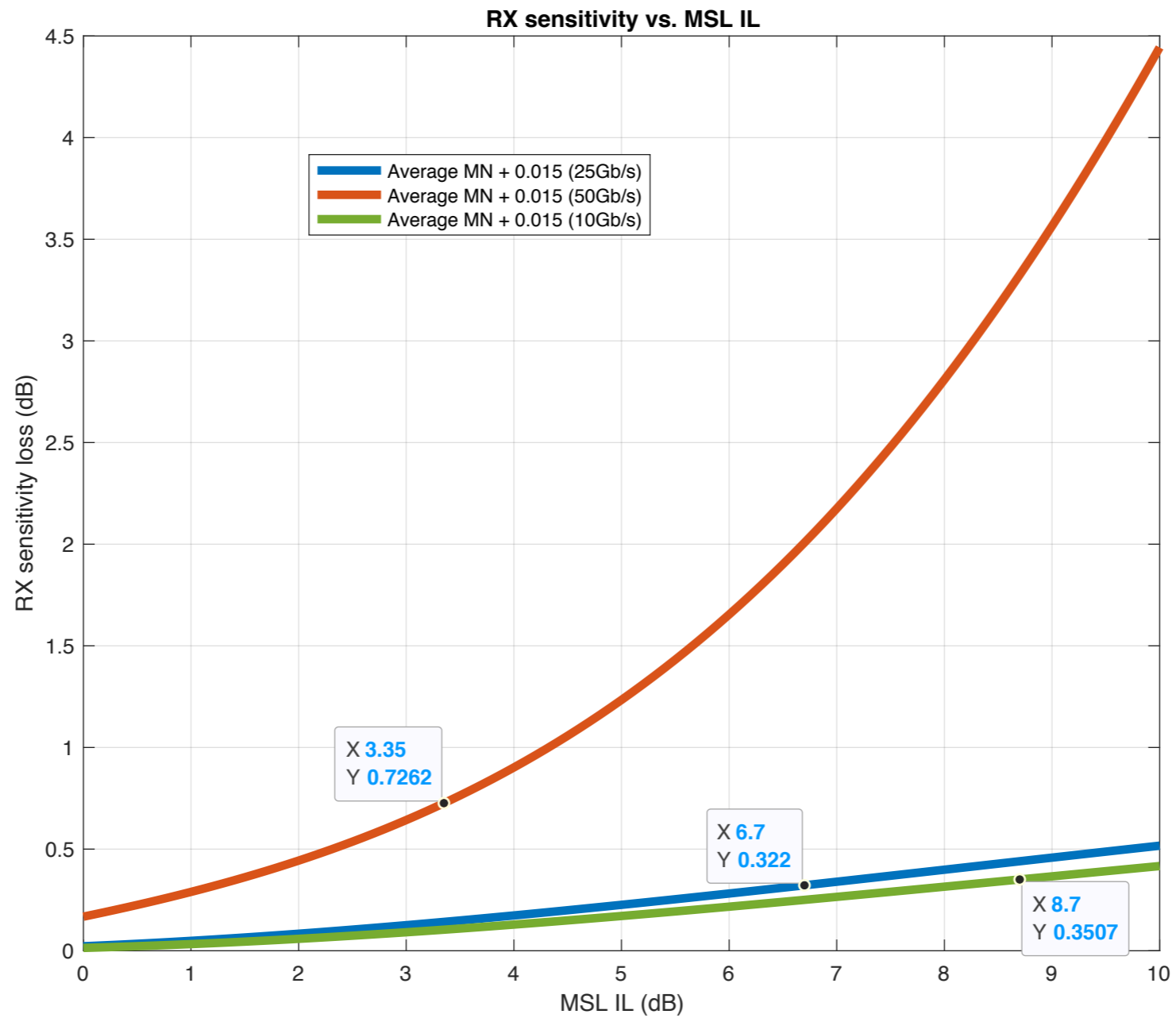
- $n_1 = 1$  (air),  $n_2 = 1.48$  (OM3),  $(T_{\text{Fresnel}})^2 = 92.7\%$ , IL = 0.33 dB per inline connection
- Min IL for 4 connections: 1.32 dB without MSL or misalignments
- Considering maximum 2 dB per inline connector, that gives max  $8 - 1.3 = 6.7$  dB attenuation due to MSL for 4 inline connections
- **In case of 2 inline connections with max 2 dB per inline connection, 3.35 dB is the max MSL attenuation considered**

- EBO connection at 980nm

- ULTEM material is considered for EBO lenses:  $n_2 = 1.6324$
- Lens length: 3.5 mm each
- $(T_{\text{Fresnel-ULTEM to air}})^2 = 88.8\%$ ,  $(T_{\text{Absorption-ULTEM}})^2 = 96.5\%$ ,  $(T_{\text{Fresnel-ULTEM to OM3}})^2 = 99.25\%$
- 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
- **In case of 2 inline connections with max 2 dB per inline connection, 2.6 dB would be the max MSL attenuation considered**

- Considering 2.5 dB/IC & butt coupling:  $10 - 1.3 = 8.7$  dB max attenuation due to MSL

# RX sensitivity vs MSL IL





# Link budget proposal for 50 Gb/s



50 Gb/s link budget

Parameter	Simulation	Equations	Proposal	Other penalties
VCSEL SE variation (dB)	1.00	A		
VCSEL aging (dB)	0.50	B		
VCSEL to TP2 max coupling loss (dB)	2.50	C		
IL <sub>TP1-to-TP2</sub> , max (dB)	4.00	D = A + B + C		
PD responsivity variation (dB)	0.80	E <sub>0</sub>		
TP3 to PD max coupling loss (dB)	2.50	E <sub>1</sub>		
IL <sub>TP3-to-TP4</sub> , max (dB)	3.30	E = E <sub>0</sub> + E <sub>1</sub>		
Insertion loss per inline connection, IL <sub>IC</sub> max (dB)	2.00	F	<b>2.00</b>	
Number of inline connections (N <sub>IC</sub> )	2	G	<b>2</b>	
Macrobend insertion loss, max (dB)	0.20	H		
Microbend insertion loss, max (dB)	0.00	I		
Bending insertion loss, IL <sub>BEND</sub> max (dB)	0.20	J = H + I		
Fiber attenuation (dB/km)	2.00	K		
Channel attenuation, IL <sub>TP2-to-TP3</sub> , max (dB)	4.28	L = (F × G) + J + (40/1000 × K)	<b>4.28</b>	
IL <sub>TP1-to-TP4</sub> , max (dB)	11.58	M = D + E + L		
OMA <sub>TP1</sub> min (dBm)	2.00	N		
OMA <sub>TP2</sub> min (dBm)	-2.00	O = N - D	<b>-2.50</b>	<b>0.50</b>
OMA <sub>TP4</sub> max (dBm)	-12.80	P		
OMA <sub>TP3</sub> max (dBm)	-9.50	Q = P + E	<b>-7.60</b>	<b>1.90</b>
Power budget (dB)	7.50	R = O - Q	<b>5.10</b>	
Allocation for modal noise (dB)	0.70	S	<b>0.70</b>	
Unallocated margin (dB)	<b>2.52</b>	<b>T = R - L - S</b>	<b>0.12</b>	

# Link budget proposal for 25 Gb/s



25 Gb/s link budget

Parameter	Simulation	Equations	Proposal	Other penalties
VCSEL SE variation (dB)	1.00	A		
VCSEL aging (dB)	0.50	B		
VCSEL to TP2 max coupling loss (dB)	2.50	C		
IL <sub>TP1-to-TP2</sub> , max (dB)	4.00	$D = A + B + C$		
PD responsivity variation (dB)	0.80	$E_0$		
TP3 to PD max coupling loss (dB)	2.50	$E_1$		
IL <sub>TP3-to-TP4</sub> , max (dB)	3.30	$E = E_0 + E_1$		
Insertion loss per inline connection, IL <sub>IC</sub> max (dB)	2.00	F	<b>2.00</b>	
Number of inline connections (N <sub>IC</sub> )	4	G	<b>4</b>	
Macrobend insertion loss, max (dB)	0.20	H		
Microbend insertion loss, max (dB)	0.00	I		
Bending insertion loss, IL <sub>BEND</sub> max (dB)	0.20	$J = H + I$		
Fiber attenuation (dB/km)	2.00	K		
Channel attenuation, IL <sub>TP2-to-TP3</sub> , max (dB)	8.28	$L = (F \times G) + J + (40/1000 \times K)$	<b>8.28</b>	
IL <sub>TP1-to-TP4</sub> , max (dB)	15.58	$M = D + E + L$		
OMA <sub>TP1</sub> min (dBm)	2.00	N		
OMA <sub>TP2</sub> min (dBm)	-2.00	$O = N - D$	<b>-2.50</b>	<b>0.50</b>
OMA <sub>TP4</sub> max (dBm)	-16.60	P		
OMA <sub>TP3</sub> max (dBm)	-13.30	$Q = P + E$	<b>-11.20</b>	<b>2.10</b>
Power budget (dB)	11.30	$R = O - Q$	<b>8.70</b>	
Allocation for modal noise (dB)	0.30	S	<b>0.30</b>	
Unallocated margin (dB)	<b>2.72</b>	$T = R - L - S$	<b>0.12</b>	

# Link budget proposal for 10 Gb/s



10 Gb/s link budget

Parameter	Simulation	Equations	Proposal	Other penalties
VCSEL SE variation (dB)	1.00	A		
VCSEL aging (dB)	0.50	B		
VCSEL to TP2 max coupling loss (dB)	3.50	C		
IL <sub>TP1-to-TP2</sub> , max (dB)	5.00	D = A + B + C		
PD responsivity variation (dB)	0.80	E <sub>0</sub>		
TP3 to PD max coupling loss (dB)	3.50	E <sub>1</sub>		
IL <sub>TP3-to-TP4</sub> , max (dB)	4.30	E = E <sub>0</sub> + E <sub>1</sub>		
Insertion loss per inline connection, IL <sub>IC</sub> max (dB)	2.50	F	2.50	
Number of inline connections (N <sub>IC</sub> )	4	G	4	
Macrobend insertion loss, max (dB)	0.20	H		
Microbend insertion loss, max (dB)	0.00	I		
Bending insertion loss, IL <sub>BEND</sub> max (dB)	0.20	J = H + I		
Fiber attenuation (dB/km)	2.00	K		
Channel attenuation, IL <sub>TP2-to-TP3</sub> , max (dB)	10.28	L = (F × G) + J + (40/1000 × K)	10.28	
IL <sub>TP1-to-TP4</sub> , max (dB)	19.58	M = D + E + L		
OMA <sub>TP1</sub> min (dBm)	2.00	N		
OMA <sub>TP2</sub> min (dBm)	-3.00	O = N - D	-3.50	0.50
OMA <sub>TP4</sub> max (dBm)	-21.35	P		
OMA <sub>TP3</sub> max (dBm)	-17.05	Q = P + E	-14.30	2.75
Power budget (dB)	14.05	R = O - Q	10.80	
Allocation for modal noise (dB)	0.35	S	0.35	
Unallocated margin (dB)	3.42	T = R - L - S	0.17	

# Link budget proposal for 5 Gb/s



5 Gb/s link budget

Parameter	Simulation	Equations	Proposal	Other penalties
VCSEL SE variation (dB)	1.00	A		
VCSEL aging (dB)	0.50	B		
VCSEL to TP2 max coupling loss (dB)	3.50	C		
IL <sub>TP1-to-TP2</sub> , max (dB)	5.00	D = A + B + C		
PD responsivity variation (dB)	0.80	E <sub>0</sub>		
TP3 to PD max coupling loss (dB)	3.50	E <sub>1</sub>		
IL <sub>TP3-to-TP4</sub> , max (dB)	4.30	E = E <sub>0</sub> + E <sub>1</sub>		
Insertion loss per inline connection, IL <sub>IC</sub> max (dB)	2.50	F	2.50	
Number of inline connections (N <sub>IC</sub> )	4	G	4	
Macrobend insertion loss, max (dB)	0.20	H		
Microbend insertion loss, max (dB)	0.00	I		
Bending insertion loss, IL <sub>BEND</sub> max (dB)	0.20	J = H + I		
Fiber attenuation (dB/km)	2.00	K		
Channel attenuation, IL <sub>TP2-to-TP3</sub> , max (dB)	10.28	L = (F × G) + J + (40/1000 × K)	10.28	
IL <sub>TP1-to-TP4</sub> , max (dB)	19.58	M = D + E + L		
OMA <sub>TP1</sub> min (dBm)	2.00	N		
OMA <sub>TP2</sub> min (dBm)	-3.00	O = N - D	-3.50	0.50
OMA <sub>TP4</sub> max (dBm)	-25.10	P		
OMA <sub>TP3</sub> max (dBm)	-20.80	Q = P + E	-17.80	3.00
Power budget (dB)	17.80	R = O - Q	14.30	
Allocation for modal noise (dB)	0.35	S	0.35	
Unallocated margin (dB)	7.17	T = R - L - S	3.67	

# Link budget proposal for 2.5 Gb/s



2.5 Gb/s link budget

Parameter	Simulation	Equations	Proposal	Other penalties
VCSEL SE variation (dB)	1.00	A		
VCSEL aging (dB)	0.50	B		
VCSEL to TP2 max coupling loss (dB)	3.50	C		
IL <sub>TP1-to-TP2</sub> , max (dB)	5.00	D = A + B + C		
PD responsivity variation (dB)	0.80	E <sub>0</sub>		
TP3 to PD max coupling loss (dB)	3.50	E <sub>1</sub>		
IL <sub>TP3-to-TP4</sub> , max (dB)	4.30	E = E <sub>0</sub> + E <sub>1</sub>		
Insertion loss per inline connection, IL <sub>IC</sub> max (dB)	2.50	F	<b>2.50</b>	
Number of inline connections (N <sub>IC</sub> )	4	G	<b>4</b>	
Macrobend insertion loss, max (dB)	0.20	H		
Microbend insertion loss, max (dB)	0.00	I		
Bending insertion loss, IL <sub>BEND</sub> max (dB)	0.20	J = H + I		
Fiber attenuation (dB/km)	2.00	K		
Channel attenuation, IL <sub>TP2-to-TP3</sub> , max (dB)	10.28	L = (F × G) + J + (40/1000 × K)	<b>10.28</b>	
IL <sub>TP1-to-TP4</sub> , max (dB)	19.58	M = D + E + L		
OMA <sub>TP1</sub> min (dBm)	2.00	N		
OMA <sub>TP2</sub> min (dBm)	-3.00	O = N - D	<b>-3.50</b>	<b>0.50</b>
OMA <sub>TP4</sub> max (dBm)	-28.10	P		
OMA <sub>TP3</sub> max (dBm)	-23.80	Q = P + E	<b>-20.80</b>	<b>3.00</b>
Power budget (dB)	20.80	R = O - Q	<b>17.30</b>	
Allocation for modal noise (dB)	0.35	S	<b>0.35</b>	
Unallocated margin (dB)	<b>10.17</b>	<b>T = R - L - S</b>	<b>6.67</b>	

# References

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- [1] R. Pérez-Aranda, “Modal noise penalty and link budget proposal for 25, 10, 5 and 2.5 Gb/s,” July 2021, [Online], Available: [https://www.ieee802.org/3/cz/public/jul\\_2021/perezaranda\\_3cz\\_05\\_0721\\_mn\\_link\\_budget.pdf](https://www.ieee802.org/3/cz/public/jul_2021/perezaranda_3cz_05_0721_mn_link_budget.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](https://www.ieee802.org/3/cz/public/15_jun_2021/pinzon_3cz_01_150621.pdf)



Thank you