Link budget proposal
25, 10, 5 and 2.5 Gb/s for GIPOF @850nm

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Summary

- In [1] a complete link budget proposal for a PMD based on VCSEL 980nm and OM3 was presented for links of 50, 25, 10, 5, and 2.5 Gb/s operating over 40 meters of fiber cable
- This contribution uses the same link models, conditions and implementation penalties of [1] to calculate link budget for a PMD based on VCSEL 850nm and GIPOF for links of 25, 10, 5, and 2.5 Gb/s operating over 15 meters of fiber cable
- Considerations:
  - 850nm VCSEL is biased at 5 mA vs. 980nm VCSEL, which is biased at 7 mA: min OAM_{TP1} at T_{BS} = 125ºC is 0.5 dBm for 850nm instead of 2 dBm of 980nm
  - In order to compensate the bandwidth loss of 850nm VCSEL at 125ºC, a FFE is used in the current driver
  - Same responsitivity, 0.6 A/W is considered for GaAs PD @850nm and InGaAs PD @980nm
  - GIPOF EMB = 350 MHz·km is assumed reported with launching condition compliant with EF specification and EMBc test method
  - $BW_{EFF\text{-}GIPOF}$ = 344 MHz·km @850nm vs. $BW_{EFF\text{-}OM3}$ = 932 MHz @980nm
  - 344·1000/15 ≈ 932·1000/40, therefore same optical channel bandwidth
  - Under these conditions, similar receiver sensitivity is obtained for OM3 @980nm 40 m and GIPOF @850 15 m

Disclaimer

- In this contribution GIPOF EMB = 350 MHz·km is assumed reported with launching condition compliant with EF specification and DMD test method
- **If** modal bandwidth is reported with **OFL**, the EMB with EF specification is unknown and the **link budget reported here is not longer valid**
- Modal bandwidth-length product is expected not to be constant in GIPOF due to high mode coupling (see [2], slide 21). Therefore, it is expected smaller modal bandwidth-length product for shorter lengths than for longer lengths when DMD method is applied
- Mode coupling is also responsible of non constant attenuation per unit length
- **Specifically, the minimum expected modal bandwidth of GIPOF compliant with EF specification and DMD method should be specified for 15 meters (vs. length product). EF should be also used for specification of the fiber attenuation at 15 meters**

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: GaAs PIN with 0.6 A/W @ 850nm, 25 GBd
- 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 GIPOF: Att=100 dB/km. BW_{eff} = 344 MHz·km @ 850nm
  - EMB = 350 MHz·km @ 850nm
  - BW_{CD} = 1852 MHz·km @ 850nm
- Fiber length = 15 meters
- Number of inline connections: data-rate dependent
- VCSEL ER = 4 dB
- VCSEL driver:
  - Current driver
  - FFE = [-0.125 1.25 -0.125]
- 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} = 5 mA
- VCSEL temperatures (T_{BS}) = 125 ºC

Proposal for 25 Gb/s — consistent with OM3 + 980nm

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		
$IL_{TP1\text{-}to\text{-}TP2}$, 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		
$IL_{TP3\text{-}to\text{-}TP4}$, max (dB)	3.30	$E = E_0 + E_1$		
Insertion loss per inline connection, IL_{IC} max (dB)	2.00	F	**2.00**	
Number of inline connections (N_{IC})	2	G	**2**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	5.70	L = (F × G) + J + (15/1000 × K)	**5.70**	
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	13.00	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-3.50	O = N - D	**-4.00**	**0.50**
OMA_{TP4} max (dBm)	-16.60	P		
OMA_{TP3} max (dBm)	-13.30	Q = P + E	**-11.20**	**2.10**
Power budget (dB)	9.80	R = O - Q	**7.20**	
Allocation for modal noise (dB)	0.30	S	**0.30**	
Unallocated margin (dB)	3.80	T = R - L - S	**1.20**	

Proposal for 25 Gb/s — lower IL per connection

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		
$IL_{TP1\text{-}to\text{-}TP2}$, 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		
$IL_{TP3\text{-}to\text{-}TP4}$, max (dB)	3.30	$E = E_0 + E_1$		
Insertion loss per inline connection, IL_{IC} max (dB)	1.70	F	**1.70**	
Number of inline connections (N_{IC})	3	G	**3**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	6.80	L = (F × G) + J + (15/1000 × K)	**6.80**	
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	14.10	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-3.50	O = N - D	**-4.00**	**0.50**
OMA_{TP4} max (dBm)	-16.60	P		
OMA_{TP3} max (dBm)	-13.30	Q = P + E	**-11.20**	**2.10**
Power budget (dB)	9.80	R = O - Q	**7.20**	
Allocation for modal noise (dB)	0.30	S	**0.30**	
Unallocated margin (dB)	2.70	T = R - L - S	**0.10**	

Proposal for 25 Gb/s — lower IL per connection

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		
$IL_{TP1\text{-to-}TP2}$, 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		
$IL_{TP3\text{-to-}TP4}$, max (dB)	3.30	E = E_0 + E_1		
Insertion loss per inline connection, IL_{IC} max (dB)	1.25	F	**1.25**	
Number of inline connections (N_{IC})	4	G	**4**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-to-}TP3}$, max (dB)	6.70	L = (F × G) + J + (15/1000 × K)	**6.70**	
$IL_{TP1\text{-to-}TP4}$, max (dB)	14.00	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-3.50	O = N - D	**-4.00**	**0.50**
OMA_{TP4} max (dBm)	-16.60	P		
OMA_{TP3} max (dBm)	-13.30	Q = P + E	**-11.20**	**2.10**
Power budget (dB)	9.80	R = O - Q	**7.20**	
Allocation for modal noise (dB)	0.30	S	**0.30**	
Unallocated margin (dB)	2.80	T = R - L - S	**0.20**	

Proposal for 10 Gb/s — consistent with OM3 + 980nm

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		
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	5.00	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	F	**2.50**	
Number of inline connections (N_{IC})	2	G	**2**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	6.70	L = (F × G) + J + (15/1000 × K)	**6.70**	
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	16.00	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-4.50	O = N - D	**-5.00**	**0.50**
OMA_{TP4} max (dBm)	-21.35	P		
OMA_{TP3} max (dBm)	-17.05	Q = P + E	**-14.30**	**2.75**
Power budget (dB)	12.55	R = O - Q	**9.30**	
Allocation for modal noise (dB)	0.35	S	**0.35**	
Unallocated margin (dB)	5.50	T = R - L - S	**2.25**	

Proposal for 10 Gb/s — lower IL per connection

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		
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	5.00	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)	2.35	F	**2.35**	
Number of inline connections (N_{IC})	3	G	**3**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	8.75	L = (F × G) + J + (15/1000 × K)	**8.75**	
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	18.05	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-4.50	O = N - D	**-5.00**	**0.50**
OMA_{TP4} max (dBm)	-21.35	P		
OMA_{TP3} max (dBm)	-17.05	Q = P + E	**-14.30**	**2.75**
Power budget (dB)	12.55	R = O - Q	**9.30**	
Allocation for modal noise (dB)	0.35	S	**0.35**	
Unallocated margin (dB)	3.45	T = R - L - S	**0.20**	

Proposal for 10 Gb/s — lower IL per connection

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		
$IL_{TP1\text{-to-}TP2}$, max (dB)	5.00	D = A + B + C		
PD responsivity variation (dB)	0.80	E_0		
TP3 to PD max coupling loss (dB)	3.50	E_1		
$IL_{TP3\text{-to-}TP4}$, max (dB)	4.30	$E = E_0 + E_1$		
Insertion loss per inline connection, IL_{IC} max (dB)	1.75	F	**1.75**	
Number of inline connections (N_{IC})	4	G	**4**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-to-}TP3}$, max (dB)	8.70	L = (F × G) + J + (15/1000 × K)	**8.70**	
$IL_{TP1\text{-to-}TP4}$, max (dB)	18.00	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-4.50	O = N - D	**-5.00**	**0.50**
OMA_{TP4} max (dBm)	-21.35	P		
OMA_{TP3} max (dBm)	-17.05	Q = P + E	**-14.30**	**2.75**
Power budget (dB)	12.55	R = O - Q	**9.30**	
Allocation for modal noise (dB)	0.35	S	**0.35**	
Unallocated margin (dB)	3.50	T = R - L - S	**0.25**	

Proposal for 5 Gb/s — consistent with OM3 + 980nm

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		
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	5.00	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	F	**2.50**	
Number of inline connections (N_{IC})	4	G	**4**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	11.70	L = (F × G) + J + (15/1000 × K)	**11.70**	
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	21.00	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-4.50	O = N - D	**-5.00**	**0.50**
OMA_{TP4} max (dBm)	-25.10	P		
OMA_{TP3} max (dBm)	-20.80	Q = P + E	**-17.80**	**3.00**
Power budget (dB)	16.30	R = O - Q	**12.80**	
Allocation for modal noise (dB)	0.35	S	**0.35**	
Unallocated margin (dB)	4.25	T = R - L - S	**0.75**	

Proposal for 2.5 Gb/s — consistent with OM3 + 980nm

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		
$IL_{TP1\text{-}to\text{-}TP2}$, max (dB)	5.00	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	F	**2.50**	
Number of inline connections (N_{IC})	4	G	**4**	
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)	100.00	K		
Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$, max (dB)	11.70	L = (F × G) + J + (15/1000 × K)	**11.70**	
$IL_{TP1\text{-}to\text{-}TP4}$, max (dB)	21.00	M = D + E + L		
OMA_{TP1} min (dBm)	0.50	N		
OMA_{TP2} min (dBm)	-4.50	O = N - D	**-5.00**	**0.50**
OMA_{TP4} max (dBm)	-28.10	P		
OMA_{TP3} max (dBm)	-23.80	Q = P + E	**-20.80**	**3.00**
Power budget (dB)	19.30	R = O - Q	**15.80**	
Allocation for modal noise (dB)	0.35	S	**0.35**	
Unallocated margin (dB)	7.25	T = R - L - S	**3.75**	

References

- [1] R. Pérez-Aranda, “Link budget proposal for 50, 25, 10, 5 and 2.5 Gb/s,” August 2021, [Online], Available: https://www.ieee802.org/3/cz/public/3_aug_2021/perezaranda_3cz_01a_030821_link_budget_proposal.pdf
- [2] J. Abbott, “Laser Optimized Fiber for 10+ Gb/s Applications,” May 2021, [Online], Available: https://www.ieee802.org/3/cz/public/may_2021/abbott_3cz_02_0521_Laser_Optimized_Fiber.pdf

Thank you