Link budget analysis for technical feasibility assessment

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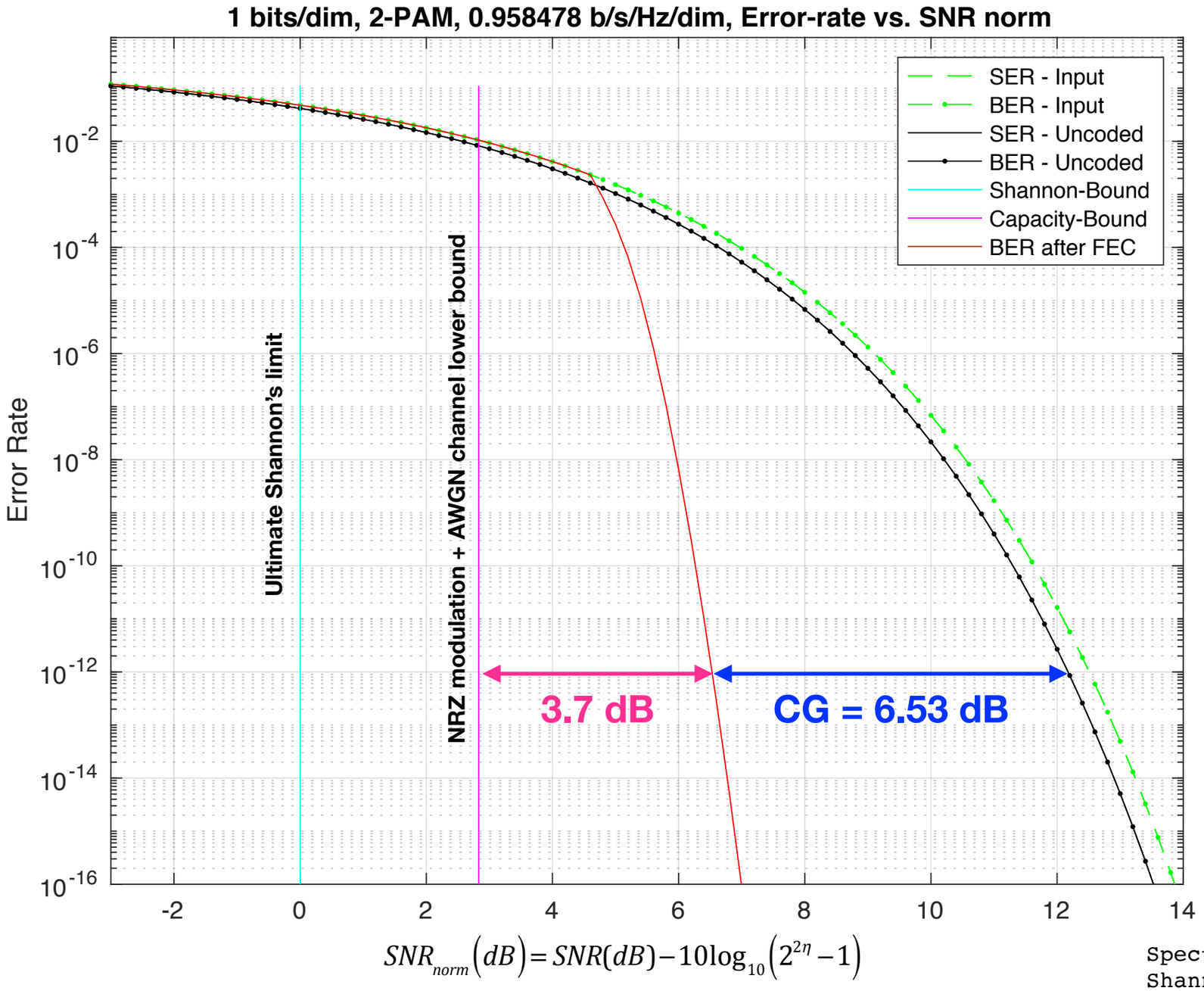
Introduction

- Based on Shannon's capacity analysis and simulation models of the different components that compose the communication channel, the receiver sensitivity and link budget is calculated for different conditions and data-rates
- Frequency-domain linear simulation models are assumed for Shannon's analysis
- Non-linear time-domain models of VCSEL have been matched with real measurements
- Implementation losses have been estimated based on time-domain stochastic simulations and applied afterwards to Shannon simulations
  - RIL = 0.4 dB
- Finite equalizer implementation, clock jitter, finite sampling precision (ENOB), and finite DSP arithmetic resolution are additionally included
- Frame estructure with real overheads (e.g. PCS encoding, FEC, OAM, etc) has been considered as well as training / tracking PHY states for timing-recovery and equalization
- Link budgets are only reported in the worst case: T_S = 125ºC (substrate)
- Method is according to "*perezaranda_OMEGA_01b_0919_techfeasibility.pdf*"

PHY FEC

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Spect. Eff. (η): 0.958478 b/s/Hz/dim
Shannon gap (BER = 1e-12):          6.53 dB
Capacity bound gap (BER = 1e-12): 3.7 dB
SNR (BER = 1e-12):                  10.96 dB
Coding gain (BER = 1e-12):          5.64 dB
Input SER (BER = 1e-12):            0.00020491
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VCSEL parameters

Configuration	A	B	C	D
Description	14G Low Ith	14G High Ith	25G Low Ith	25G High Ith
VCSEL Material / Structure	GaAs QWs	GaAs QWs	InGaAs MQW	InGaAs MQW
VCSEL T substrate (ºC)	125	125	125	125
VCSEL Wavelength (nm)	850	850	850	850
VCSEL Oxide apperture, max (µm)	**6.5**	**8.7**	**6.5**	**7.5**
VCSEL Slope efficiency (mW/mA), min	**0.20**	**0.18**	**0.285**	**0.265**
VCSEL Threshold current (mA), max	1.16	1.43	0.95	1.36
VCSEL Bias current (mA), max	**3.0**	**4.0**	**3.0**	**4.0**
VCSEL Current density (kA/cm2), max	**9.05**	**6.73**	**9.05**	**9.06**
VCSEL ER (dB), min	**3**	**3**	**3**	**3**
VCSEL ER (lin), min	2.00	2.00	2.00	2.00
VCSEL Current modulation amplitude (mApp), min	1.22	1.71	1.36	1.75
VCSEL AOP (mW), min	0.37	0.46	0.59	0.70
VCSEL AOP (dBm), min	-4.34	-3.35	-2.33	-1.55
VCSEL OMA (mW), min	0.24	0.31	0.39	0.46
VCSEL OMA (dBm), min	-6.12	-5.12	-4.10	-3.33
VCSEL SE dispersion (dB), max	1.0	1.0	1.0	1.0
VCSEL Aging factor (dB), max	1.0	1.0	1.0	1.0
VCSEL OMA (dBm) with aging, min	**-8.12**	**-7.12**	**-6.10**	**-5.33**
VCSEL Relaxation Resonance Frequency (GHz)	5.0	5.2	9.3	7.9
VCSEL Damping factor (GHz)	19.4	20.3	30.5	24.8
VCSEL Extrinsic Fp (GHz), min	8.7	11.4	7.0	8.6
VCSEL BW (GHz), min	**6.6**	**7.1**	**11.0**	**10.2**
VCSEL RIN_xOMA (dB/Hz), max spec, assumption	**-120.0**	**-120.0**	**-124.0**	**-124.0**
VCSEL RIN delta (dB) due to ER	9.6	9.6	9.6	9.6
VCSEL RIN (dB/Hz), max	-129.6	-129.6	-133.6	-133.6
VCSEL AC Coupling, max (MHz)	0.1	0.1	0.1	0.1

PD, TIA and optical connectivity parameters

PD Parameters

PD Material	GaAs
PD Tj (ºC)	125
PD Wavelength (nm)	850
PD responsitivity (A/W), min	0.6
PD diameter (um), max	55
PD capacitance (fF), max	180
PD pad cap (fF), max	10
PD series resistance (Ohm), max	20
PD bandwidth (GHz), min	12

TIA parameters

TIA Tj (ºC)	125
TIA corner process	SLOW
TIA Tech node	CMOS 28 nm
TIA Gamma, max	1.5
TIA Gm + Gmb (mS), min	120
TIA Cgate (fF), max	165
TIA Cpad (fF), max	70

Two grades of connectivity are defined with expected different tolerances and relative cost.

Grade and acceptable relative cost is expected to scale with data-rate.

Optical connectivity parameters

Grade 1	**VCSEL to TP2 IL_{MAX} (dB)**	**1.6**	< 1.0
	TP3 to PD IL_{MAX} (dB)	**1.6**	< 1.0
	IC Att. Max (dB) (w/c, dust, aging)	**1.7**	< 0.75
	Macrobend IL_{MAX} (dB)	**0.2**	< 0.1
	Microbend IL_{MAX} (dB)	**0.0**	
	Bend IL_{MAX} (dB)	**0.2**	
Grade 2	**VCSEL to TP2 IL_{MAX} (dB)**	**1.7**	< 1.0
	TP3 to PD IL_{MAX} (dB)	**1.7**	< 1.0
	IC Att. Max (dB) (w/c, dust, aging)	**2.3**	< 0.75
	Macrobend IL_{MAX} (dB)	**0.2**	< 0.1
	Microbend IL_{MAX} (dB)	**0.0**	
	Bend IL_{MAX} (dB)	**0.2**	

Worst/case in datacenter applications

Sensitivity and link budget

xMII DR (Gb/s)	PAM	Phase Jitter $PLL_{tx,rx}$ (ps RMS)	VCSEL CFG	VCSEL Pre-emphasis	BLP (MHz·km)	Fiber att. (dB/km)	Length (m)	Conn. grade	OMA_{VCSEL} (dBm)	OMA_{TP2} (dBm)	OMA_{PD} (dBm) BER < 10^{-12}	OMA_{TP3} (dBm)	VCSEL to PD link budget (dB)	TP2 to TP3 link budget (dB)	Allocation for connectors & bending
25	2	0.8	D	0	200	3.5	15	1	-5.33	-6.93	-14.96	-13.36	**9.63**	6.43	**6.38**
25	2	0.8	D	0	500	3.0	15	1	-5.33	-6.93	-15.66	-14.06	**10.33**	7.13	**7.09**
25	2	0.8	D	0	2000	3.0	15	1	-5.33	-6.93	-15.79	-14.19	**10.46**	7.26	**7.22**
25	2	0.8	D	0	500	3.0	40	1	-5.33	-6.93	-14.85	-13.25	**9.52**	6.32	**6.20**
25	2	0.8	D	0	2000	3.0	40	1	-5.33	-6.93	-15.74	-14.14	**10.41**	7.21	**7.09**
25	2	0.8	C	1	200	3.5	15	1	-6.10	-7.70	-15.70	-14.10	**9.60**	6.40	**6.35**
25	2	0.8	C	1	500	3.0	15	1	-6.10	-7.70	-16.44	-14.84	**10.34**	7.14	**7.09**
25	2	0.8	C	1	2000	3.0	15	1	-6.10	-7.70	-16.58	-14.98	**10.48**	7.28	**7.23**
25	2	0.8	C	1	500	3.0	40	1	-6.10	-7.70	-15.58	-13.98	**9.48**	6.28	**6.16**
25	2	0.8	C	1	2000	3.0	40	1	-6.10	-7.70	-16.52	-14.92	**10.42**	7.22	**7.10**
10	2	1.9	C	0	200	3.5	15	2	-6.10	-7.80	-21.69	-19.99	**15.59**	12.19	**12.14**
10	2	1.9	C	0	500	3.0	15	2	-6.10	-7.80	-21.85	-20.15	**15.75**	12.35	**12.30**
10	2	1.9	C	0	200	3.5	40	2	-6.10	-7.80	-20.56	-18.86	**14.46**	11.06	**10.92**
10	2	1.9	C	0	500	3.0	40	2	-6.10	-7.80	-21.66	-19.96	**15.56**	12.16	**12.04**
10	2	1.9	B	0	200	3.5	15	2	-7.12	-8.82	-22.51	-20.81	**15.39**	11.99	**11.93**
10	2	1.9	B	0	200	3.5	15	2	-7.12	-8.82	-22.66	-20.96	**15.54**	12.14	**12.08**
10	2	1.9	B	0	200	3.5	40	2	-7.12	-8.82	-21.45	-19.75	**14.33**	10.93	**10.79**
10	2	1.9	B	0	500	3.5	40	2	-7.12	-8.82	-22.49	-20.79	**15.37**	11.97	**11.83**
10	2	1.9	A	0	200	3.5	15	2	-8.12	-9.82	-22.44	-20.74	**14.32**	10.92	**10.87**
10	2	1.9	A	0	500	3.0	15	2	-8.12	-9.82	-22.58	-20.88	**14.46**	11.06	**11.02**
10	2	1.9	A	0	200	3.5	40	2	-8.12	-9.82	-21.39	-19.69	**13.27**	9.87	**9.73**
10	2	1.9	A	0	500	3.0	40	2	-8.12	-9.82	-22.41	-20.71	**14.29**	10.89	**10.77**
5.0	2	3.8	A	0	200	3.5	15	2	-8.12	-9.82	-25.33	-23.63	**17.21**	13.81	**13.76**
5.0	2	3.8	A	0	200	3.5	40	2	-8.12	-9.82	-24.99	-23.29	**16.87**	13.47	**13.33**
2.5	2	7.5	A	0	200	3.5	15	2	-8.12	-9.82	-27.96	-26.26	**19.84**	16.44	**16.39**
2.5	2	7.5	A	0	200	3.5	40	2	-8.12	-9.82	-27.89	-26.19	**19.77**	16.37	**16.23**

Link margin with inline connectors

xMII DR (Gb/s)	PAM	Phase Jitter $PLL_{tx,rx}$ (ps RMS)	VCSEL CFG	VCSEL Pre-emphasis	BLP (MHz·km)	Fiber att. (dB/km)	Length (m)	Conn. grade	Link Margin (dB) 4 Inliners	Link Margin (dB) 3 Inliners	Link Margin (dB) 2 inliners	Link Margin (dB) 1 inliner	Link Margin (dB) 0 inliners
25	2	0.8	D	0	200	3.5	15	1	-0.62	1.08	2.78	4.48	6.18
25	2	0.8	D	0	500	3.0	15	1	0.09	1.79	3.49	5.19	6.89
25	2	0.8	D	0	2000	3.0	15	1	0.22	1.92	3.62	5.32	7.02
25	2	0.8	D	0	500	3.0	40	1	-0.80	0.90	2.60	4.30	6.00
25	2	0.8	D	0	2000	3.0	40	1	0.09	1.79	3.49	5.19	6.89
25	2	0.8	C	1	200	3.5	15	1	-0.65	1.05	2.75	4.45	6.15
25	2	0.8	C	1	500	3.0	15	1	0.09	1.79	3.49	5.19	6.89
25	2	0.8	C	1	2000	3.0	15	1	0.23	1.93	3.63	5.33	7.03
25	2	0.8	C	1	500	3.0	40	1	-0.84	0.86	2.56	4.26	5.96
25	2	0.8	C	1	2000	3.0	40	1	0.10	1.80	3.50	5.20	6.90
10	2	1.9	C	0	200	3.5	15	2	2.74	5.04	7.34	9.64	11.94
10	2	1.9	C	0	500	3.0	15	2	2.90	5.20	7.50	9.80	12.10
10	2	1.9	C	0	200	3.5	40	2	1.52	3.82	6.12	8.42	10.72
10	2	1.9	C	0	500	3.0	40	2	2.64	4.94	7.24	9.54	11.84
10	2	1.9	B	0	200	3.5	15	2	2.53	4.83	7.13	9.43	11.73
10	2	1.9	B	0	200	3.5	15	2	2.68	4.98	7.28	9.58	11.88
10	2	1.9	B	0	200	3.5	40	2	1.39	3.69	5.99	8.29	10.59
10	2	1.9	B	0	500	3.5	40	2	2.43	4.73	7.03	9.33	11.63
10	2	1.9	A	0	200	3.5	15	2	1.47	3.77	6.07	8.37	10.67
10	2	1.9	A	0	500	3.0	15	2	1.62	3.92	6.22	8.52	10.82
10	2	1.9	A	0	200	3.5	40	2	0.33	2.63	4.93	7.23	9.53
10	2	1.9	A	0	500	3.0	40	2	1.37	3.67	5.97	8.27	10.57
5.0	2	3.8	A	0	200	3.5	15	2	4.36	6.66	8.96	11.26	13.56
5.0	2	3.8	A	0	200	3.5	40	2	3.93	6.23	8.53	10.83	13.13
2.5	2	7.5	A	0	200	3.5	15	2	6.99	9.29	11.59	13.89	16.19
2.5	2	7.5	A	0	200	3.5	40	2	6.83	9.13	11.43	13.73	16.03

Conclusions

- Data-rates of 2.5, 5 and 10 Gb/s over at least OM1 based link segments with up to 4 inline connectors and 40 meters have been demonstrated feasible at $T_{S(VCSEL)} = T_{J(PD/TIA)} = 125°C$ using low current density VCSEL driving and optical connectivity grade 2

- Data-rates of 25 Gb/s over at least OM2 based link segments with up to 4 inline connectors and 15 meters have been demonstrated feasible at $T_{S(VCSEL)} = T_{J(PD/TIA)} = 125°C$ using low current density VCSEL driving and optical connectivity grade 1

- Data-rates of 25 Gb/s over at least OM3 based link segments with up to 4 inline connectors and 40 meters have been demonstrated feasible at $T_{S(VCSEL)} = T_{J(PD/TIA)} = 125°C$ using low current density VCSEL driving and optical connectivity grade 1

- Both optical connectivity grades 1 and 2 are much worse than any real implementation used today in datacenter applications

Thank you