Analysis of Phase-to-Intensity Noise by multiple reflections in 100G-PAM SMF links

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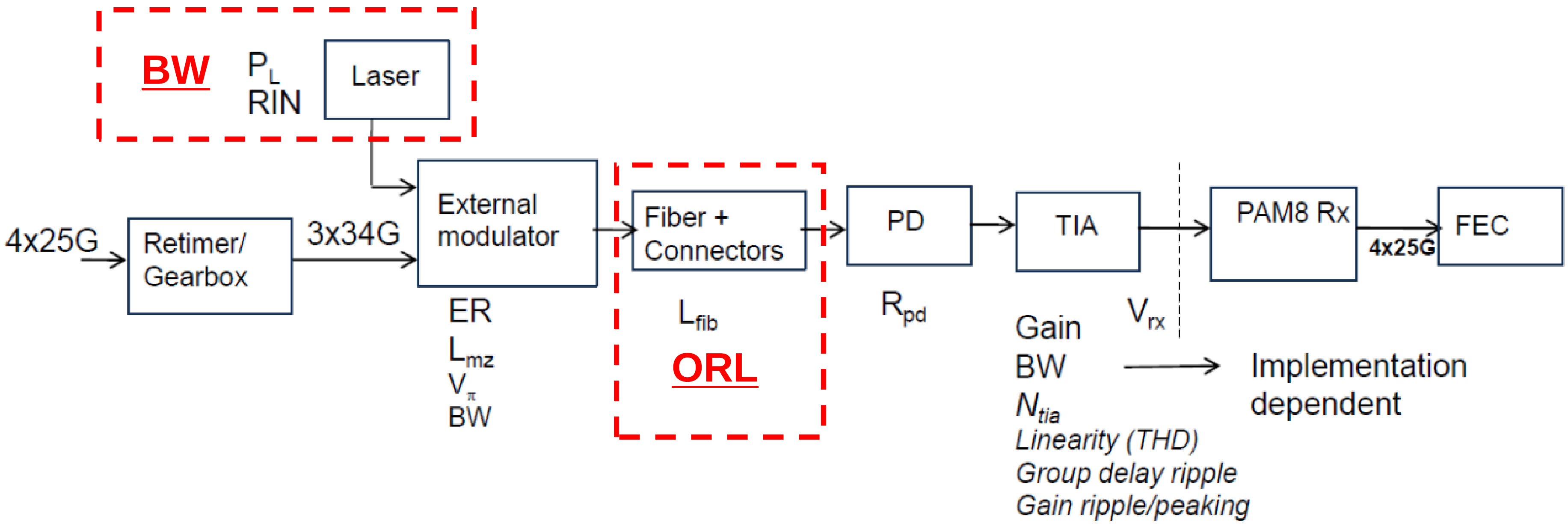
Introduction

- At the Newport Beach, 2011 SG meeting, PAM-N scheme with a single wavelength was proposed (bhoja_01_0112_NG100GOPTX). During the discussion, it was pointed out that multiple reflections may deteriorate PAM signal quality.
- This contribution provides extensive analysis of phase-to-intensity noise (Link RIN) induced by multiple reflection in 100G-PAM SMF links.

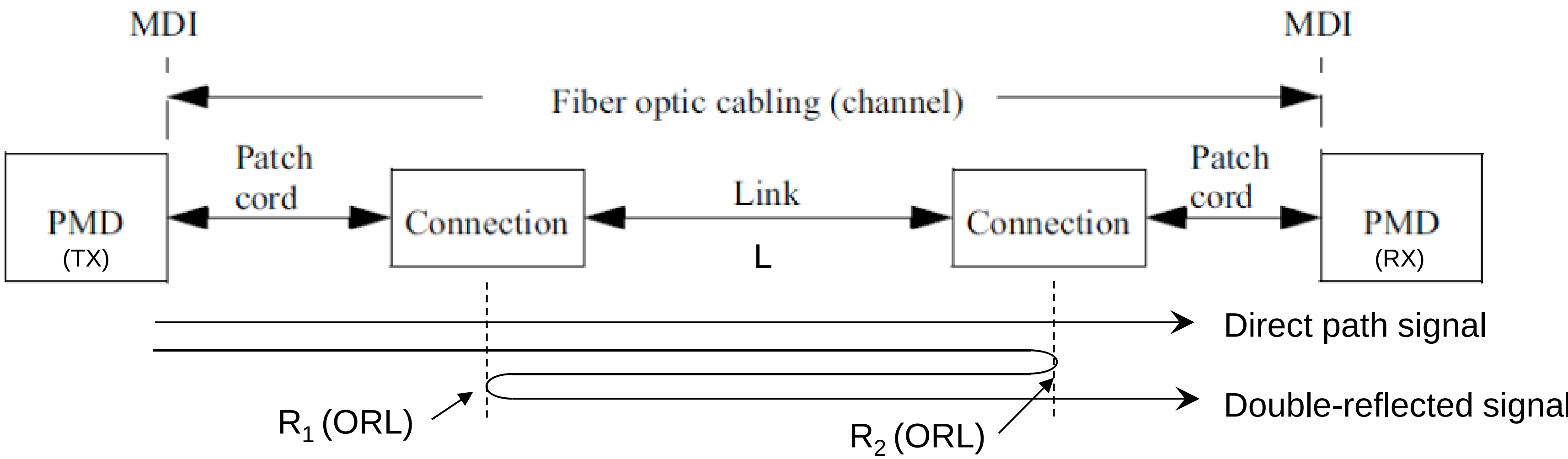
PAM-8 System Model



Two additional parameters, laser source spectral width (BW) and optical return loss in the link (ORL), are introduced to calculate Link-RIN for a performance verification of PAM-8 system model previously proposed (bhoja_01_0112).

Simulation Model with "Multiple reflections"

<Single-link case Cabling>



RIN spectrum induced by multiple reflections in the link for longer delayed paths (longer than coherent length) can be described as a following equations[1];

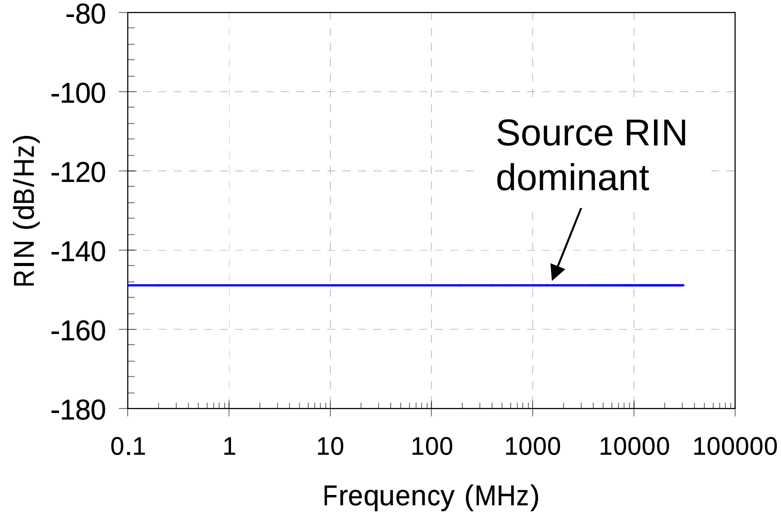
$$RIN(f) = \frac{4 \cdot R_1 \cdot R_2}{\pi} \left[\frac{\Delta \nu}{f^2 + (\Delta \nu)^2} \right] \quad (2\pi \cdot \Delta \nu \cdot \tau >> 1)$$

where R_n is an effective reflection coefficient of the link connections (assumed polarization axis of the two fields are the same as the worst case condition), $\Delta \nu$ is a spectral width of the laser and τ is a round-trip path (reflection) delay time.

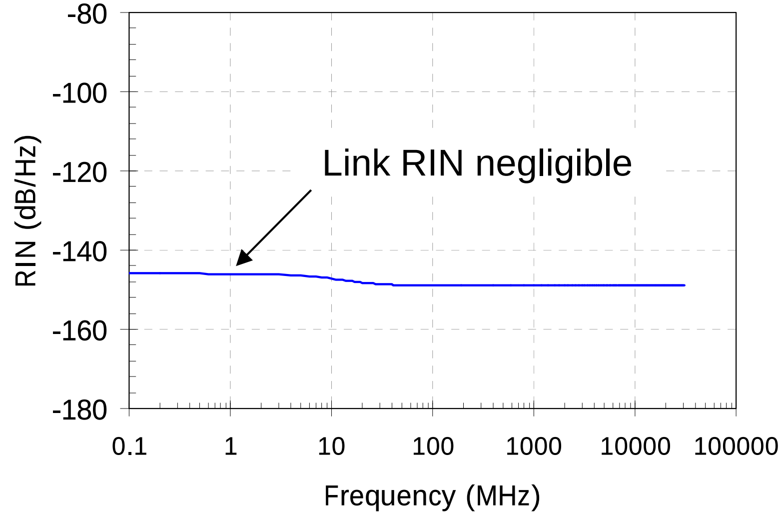
1) J.L.GIMLETT and N.K.CHEUNG, "Effects of Phase-to-Intensity Noise Conversion by Multiple Reflections on Gigabit-per-Second DFB Laser Transmission Systems," *J.Lightwave Technol*. Vol.7, No.6, pp. 888-895 (1989).

Calculated RIN spectra at Rx side

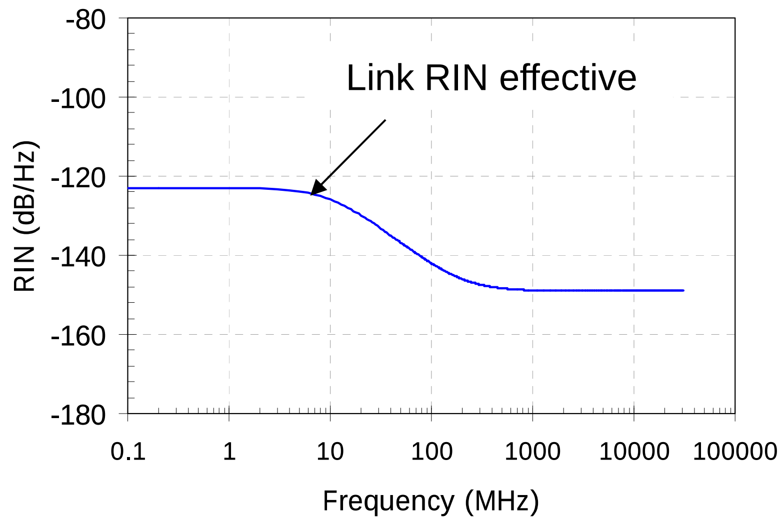
(Laser RIN = -149 dB/Hz, BW = 10 MHz)



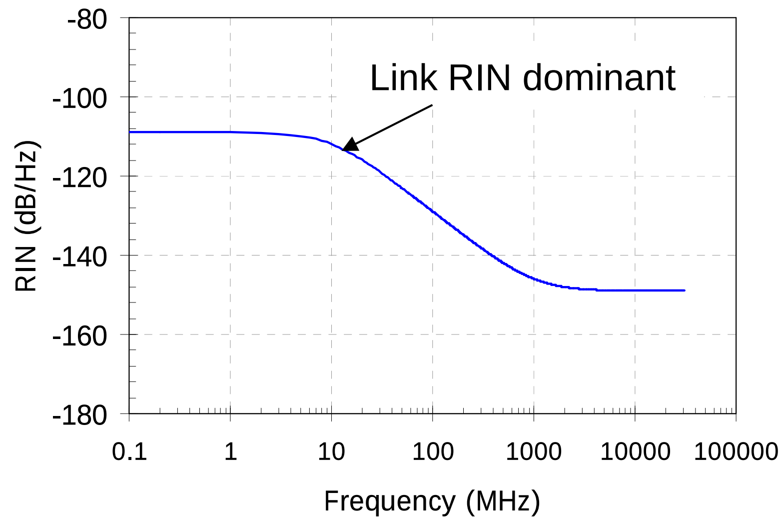
ORL = 60 dB (APC connection)



ORL = 40 dB (SPC connection)



ORL = 27 dB (ITU-T standard)



ORL = 21 dB (IEEE 100G-LR4)

Related Specification

Table 88–7—100GBASE-LR4 and 100GBASE-ER4 transmit characteristics

Description	100GBASE–LR4	100GBASE–ER4	Unit
Transmitter reflectance[c] (max)	–12		dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}		

[a]Average launch power, each lane (min) is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.
[b]Even if the TDP < 1 dB, the OMA (min) must exceed this value.
[c]Transmitter reflectance is defined looking into the transmitter.

Table 88–8—100GBASE–LR4 and 100GBASE–ER4 receive characteristics

Description	100GBASE–LR4	100GBASE–ER4	Unit
Receiver reflectance (max)	–26		dB

Related Specification

Table 88–12—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
100GBASE–LR4	$0.2325 \cdot \lambda \cdot [1 - (1324 / \lambda)^4]$	$0.2325 \cdot \lambda \cdot [1 - (1300 / \lambda)^4]$	Minimum	20 dB	0.8 ps
100GBASE–ER4	$0.93 \cdot \lambda \cdot [1 - (1324 / \lambda)^4]$	$0.93 \cdot \lambda \cdot [1 - (1300 / \lambda)^4]$	Minimum	20 dB	0.8 ps

Table 88–14—Fiber optic cabling (channel) characteristics

Description	100GBASE–LR4	100GBASE–ER4		Unit
Optical return loss (min)	21	21	21	dB

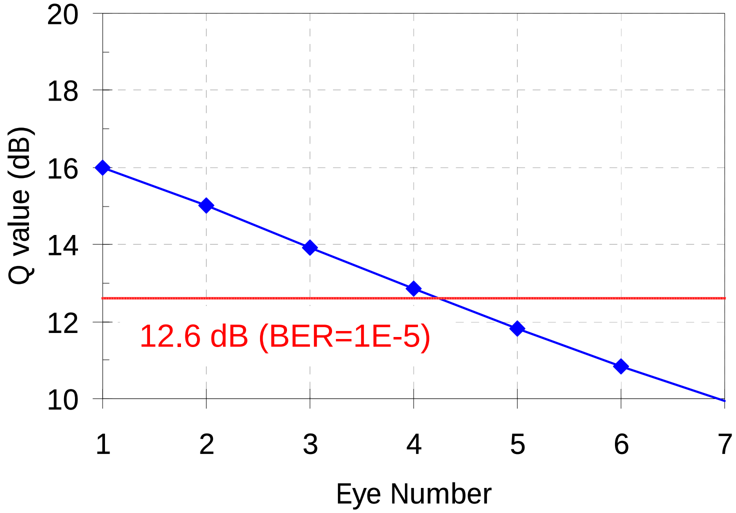
Case1: Calculation parameter List for PAM8 (Based on current standard)

#	Parameters	Category	Value	Units	Remarks
1	Wavelength	Tx	1310	nm	“bhoja_01_0112”
2	Spectral width	Tx	10	MHz	assumption, normal DFB-LD
3	Extinction ratio	Tx	8.0	dB	“bhoja_01_0112” (*2) Sub-eye #7(mark) / #1(space)
4	RIN	Tx	-149	dB/Hz	“bhoja_01_0112”
5	Transmitter reflectance	Tx	**-12**	dB	802.3ae Table 88-7
6	Responsivity	Rx	1.0	A/W	assumption
7	Receiver bandwidth	Rx	12.5	GHz	root raised cosine filter (*1)
8	Dark current	Rx	100	pA	assumption, negligible
9	Input referred noise	Rx	15	pA/sqrt(Hz)	“bhoja_01_0112”
10	Receiver reflectance	Rx	-26	dB	802.3ae Table 88-8
11	Rx OMA	Link	-7.75	dBm	“bhoja_01_0112”
12	Transmission distance	Link	1000	m	
13	Optical return loss	Link	Parameter	dB	

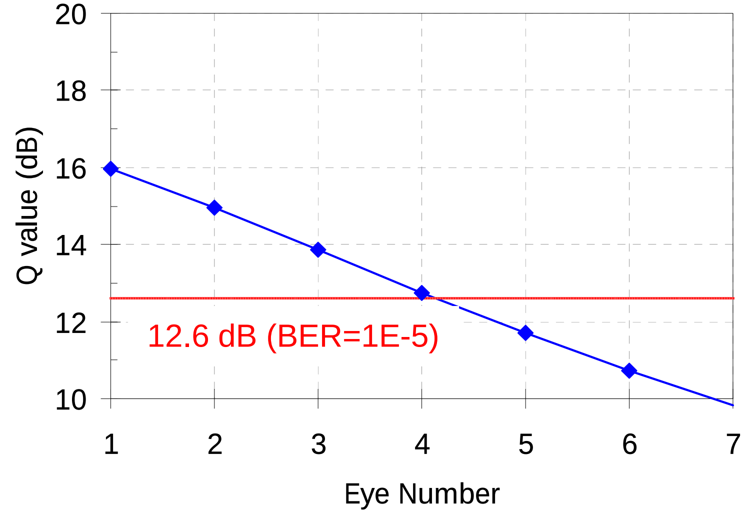
Note *1) Both filter profile and formula are shown in Appendix.A
*2) All sub-eyes have the same OMA.

<u>Case1: One end of reflection is Tx, and the other depends.</u>

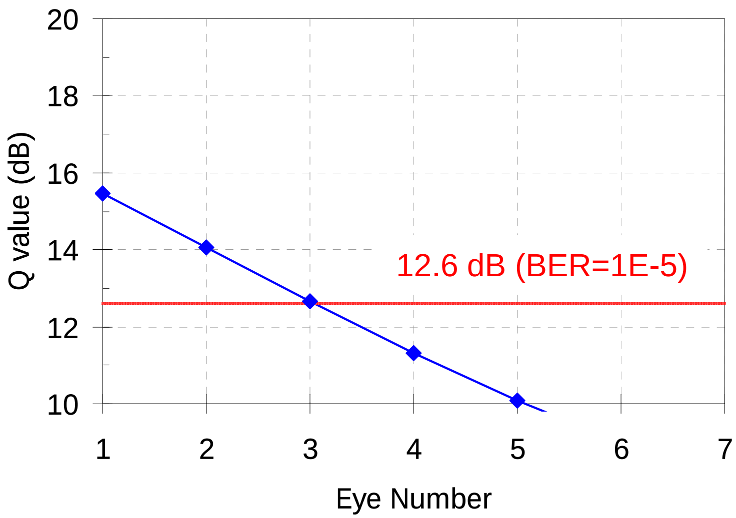
Case1: Calculated Q values of PAM8



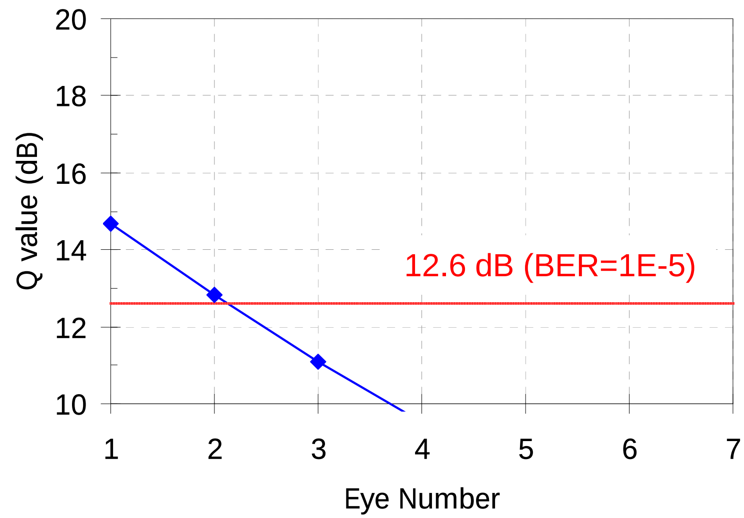
ORL = 60 dB (APC connection)



ORL = 40 dB (SPC connection)

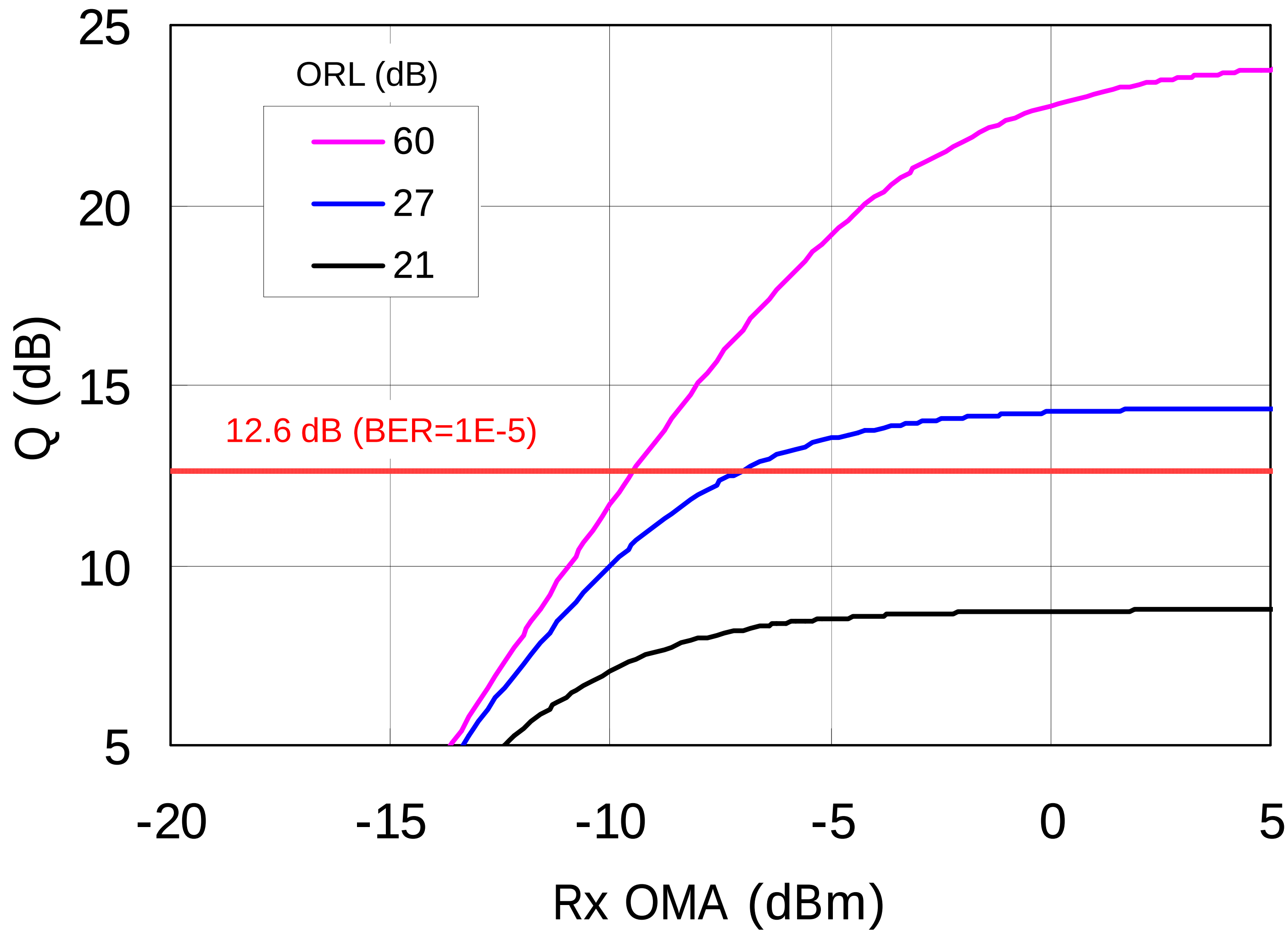


ORL = 27 dB (ITU-T standard)



ORL = 21 dB (IEEE 100G-LR4)

Case2: Simulation Result taking into account Link RIN



The result shows current Transmitter reflectance spec is not suitable for 100G-PAM8 to achieve required Q values.

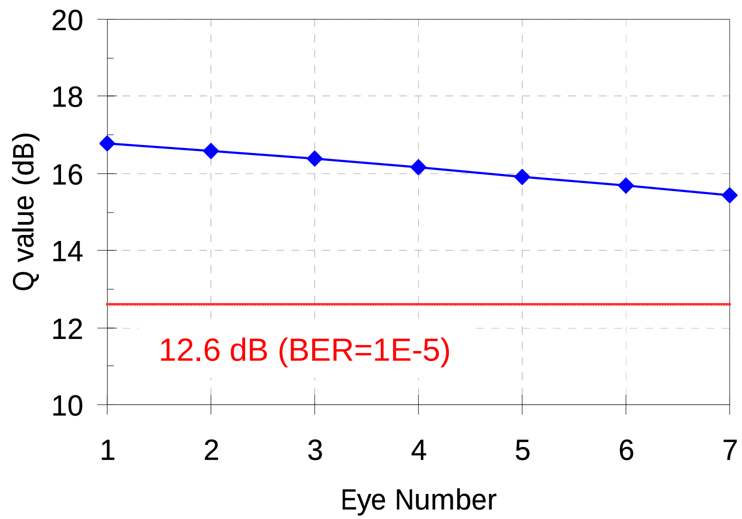
Case2: Calculation parameter List for PAM8 (PMD reflectance Improved)

#	Parameters	Category	Value	Units	Remarks
1	Wavelength	Tx	1310	nm	“bhoja_01_0112”
2	Spectral width	Tx	10	MHz	assumption, normal DFB-LD
3	Extinction ratio	Tx	8.0	dB	“bhoja_01_0112” (*2) Sub-eye #7(mark) / #1(space)
4	RIN	Tx	-149	dB/Hz	“bhoja_01_0112”
5	Transmitter reflectance	Tx	-30	dB	Practical value of 100G-LR4
6	Responsivity	Rx	1.0	A/W	assumption
7	Receiver bandwidth	Rx	12.5	GHz	root raised cosine filter (*1)
8	Dark current	Rx	100	pA	assumption, negligible
9	Input referred noise	Rx	15	pA/sqrt(Hz)	“bhoja_01_0112”
10	Receiver reflectance	Rx	-30	dB	Practical value of 100G-LR4
11	Rx OMA	Link	-7.75	dBm	“bhoja_01_0112”
12	Transmission distance	Link	1000	m	
13	Optical return loss	Link	Parameter	dB	

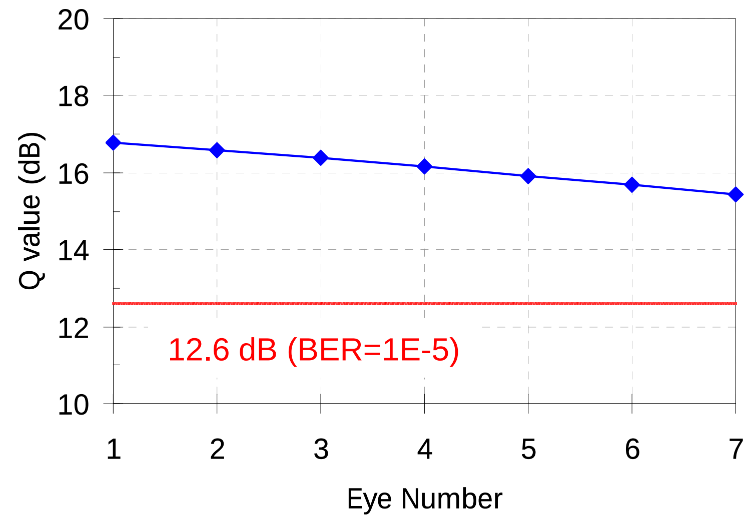
Note *1) Both filter profile and formula are shown in Appendix.A
*2) All sub-eyes have the same OMA.

Case2: Both ends of reflection are cabling fiber connectors.

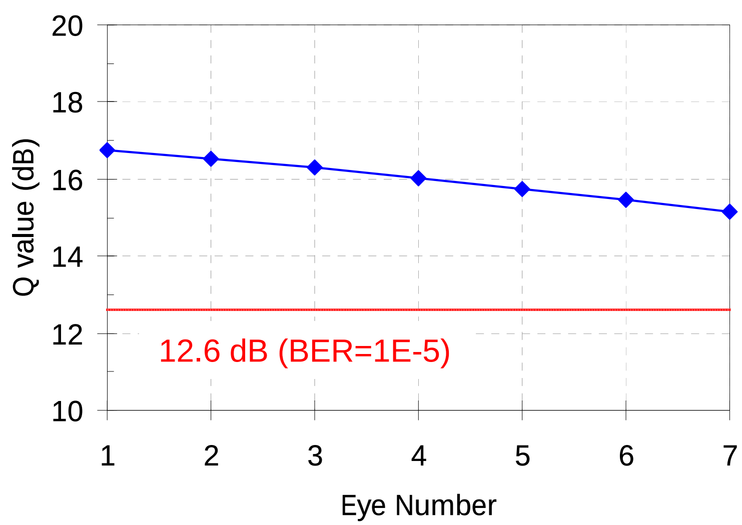
Case2: Calculated Q values of PAM8



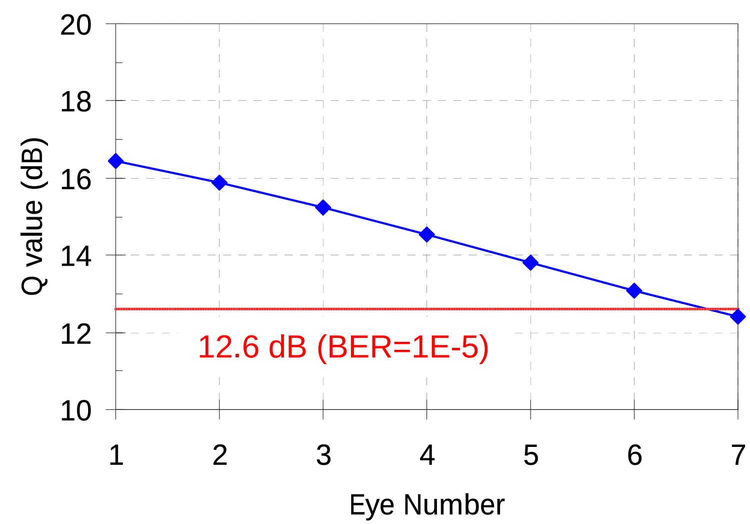
ORL = 60 dB (APC connection)



ORL = 40 dB (SPC connection)

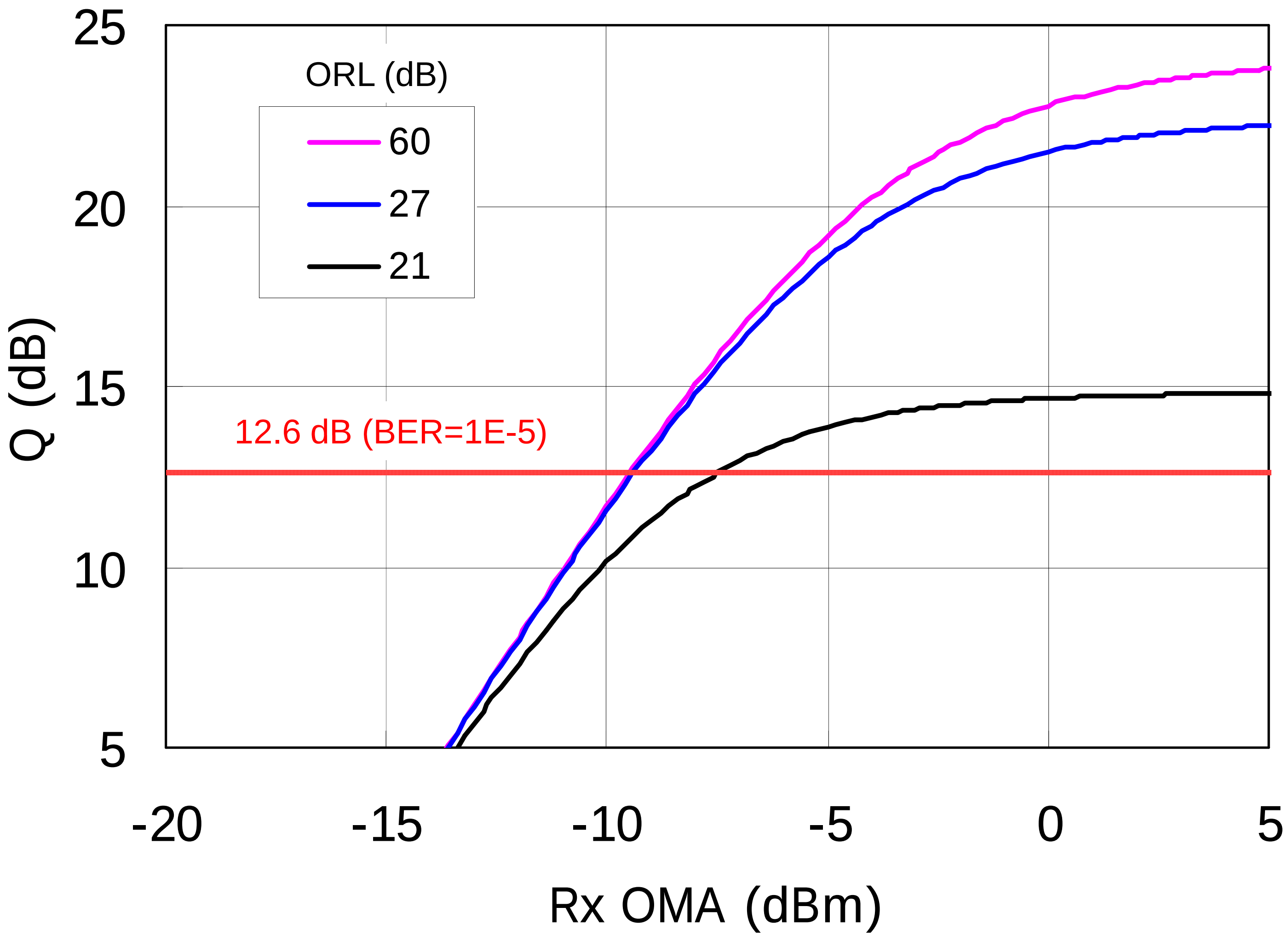


ORL = 27 dB (ITU-T standard)



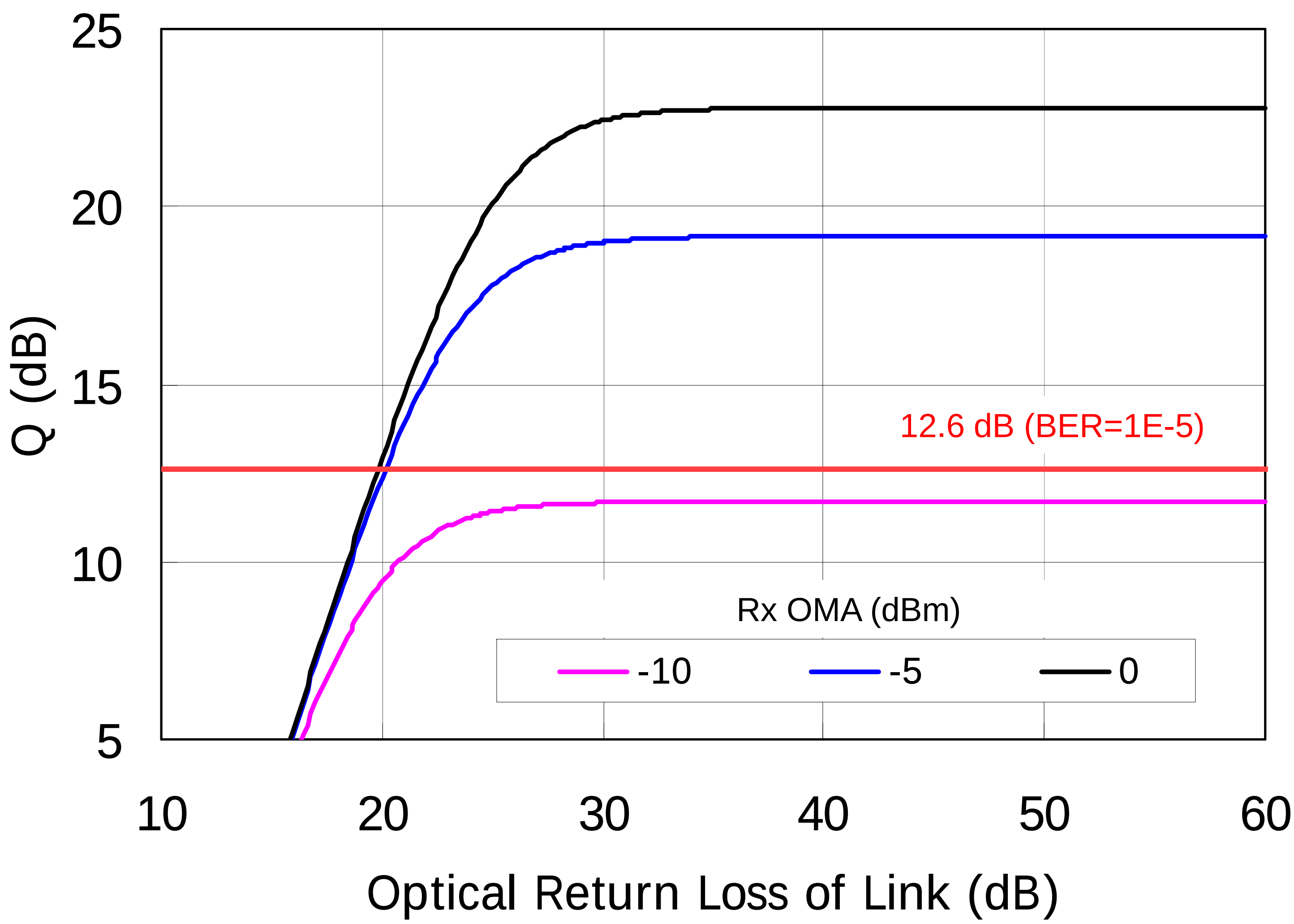
ORL = 21 dB (IEEE 100G-LR4)

Case2: Simulation Result taking into account Link RIN



Even PMD reflectance is improved, the result shows current ORL spec of cabling fiber is marginal for 100G-PAM8 to achieve required Q values.

Case2: Simulation Result taking into account Link RIN



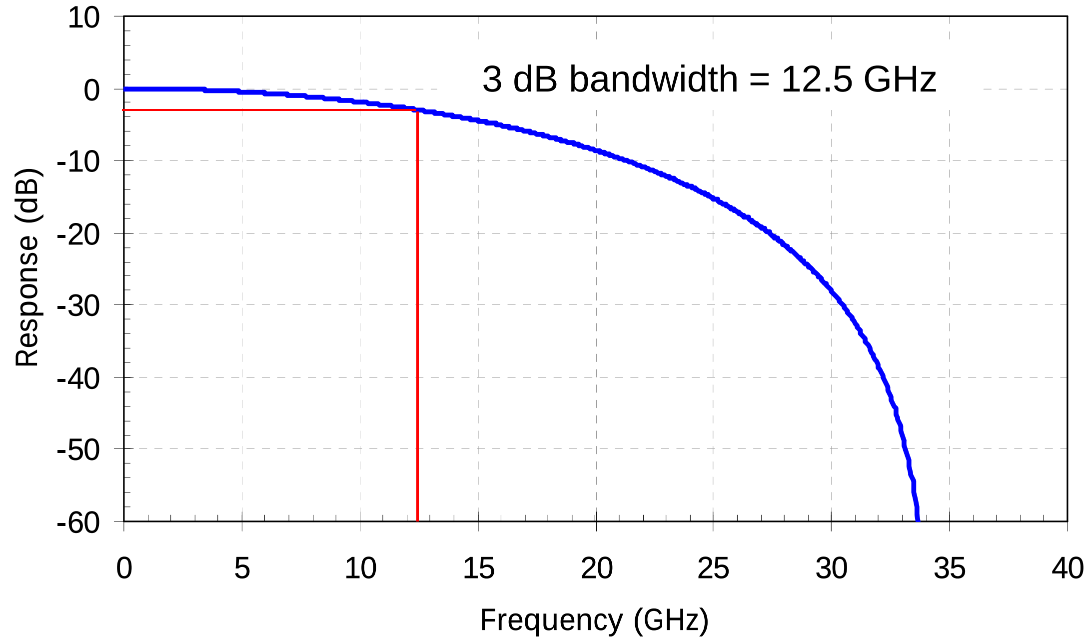
Less than 27 dB of ORL spec seems too steep for FEC to be used due to FEC nature (Steep I/O performance of error correction).

Conclusion

1. Multiple reflections in the SMF-Link may induce phase-noise converted RIN (Link RIN) which is different from intrinsic laser RIN.
2. Current specification of both optical return loss for SMF-Link connectors (21 dB) and reflectance for PMD (Tx -12 dB, Rx -26 dB) is not suitable for 100G PAM 8 or beyond.
3. Need further experimental verification of Link RIN effect under the practical conditions, i.e. state of polarization, laser linewidth and reach variation (coherent length).

Appendix
(Backup)

A. Root raised cosine filter to be used for Q value Calculation



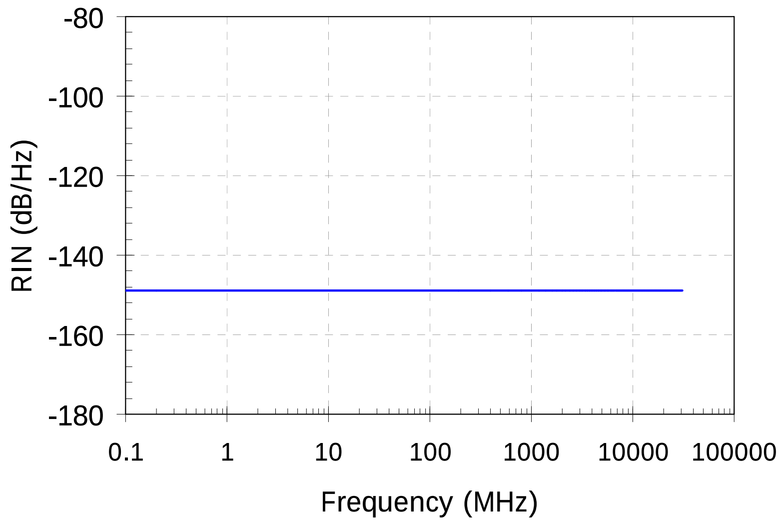
Filter frequency-domain description is given by:

$$H(f) = \begin{cases} T, & |f| \le \frac{1-\beta}{2T} \\ \left\{ \frac{T}{2} \cdot \left[1 + \cos\left(\frac{\pi T}{\beta} \cdot \left[|f| - \frac{1-\beta}{2T} \right] \right) \right] \right\}^{\frac{1}{2}}, & \frac{1-\beta}{2T} < |f| \le \frac{1+\beta}{2T} \\ 0, & |f| > \frac{1+\beta}{2T} \end{cases}$$

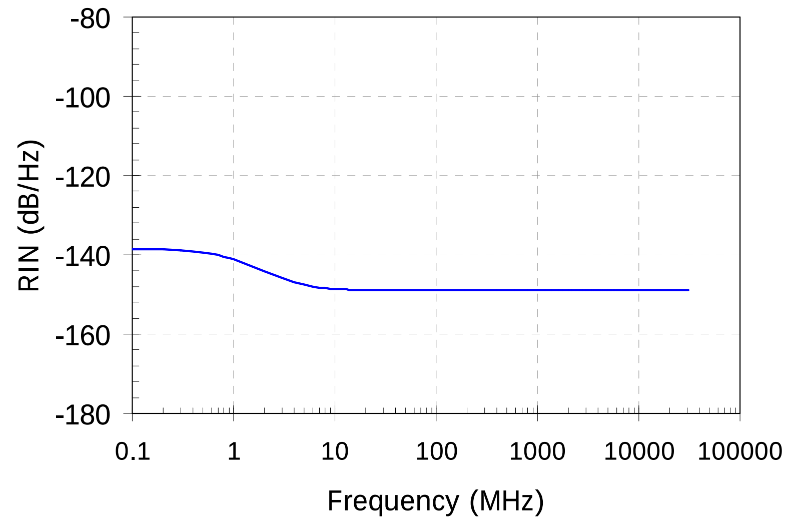
where T is the symbol period and β is roll-off factor. In calculation, T = 29 ps (=34.375 Gbaud) and β = 1 are used.

Calculated RIN spectra at Rx side

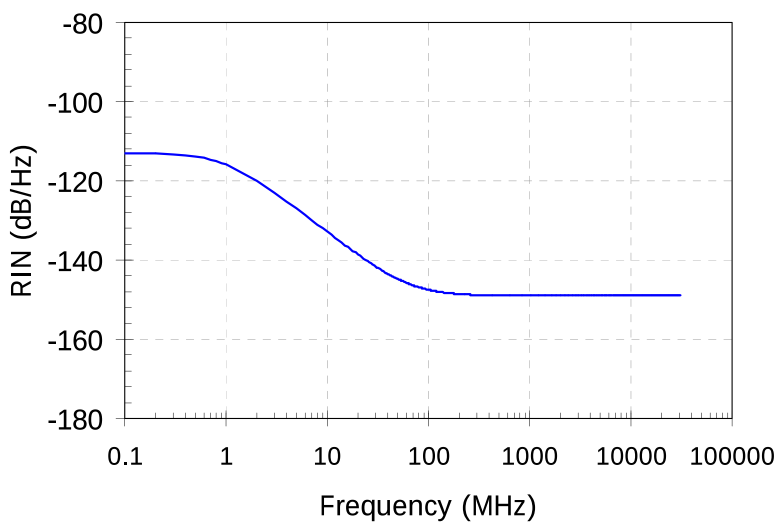
(Laser RIN = -149 dB/Hz, BW = 1 MHz)



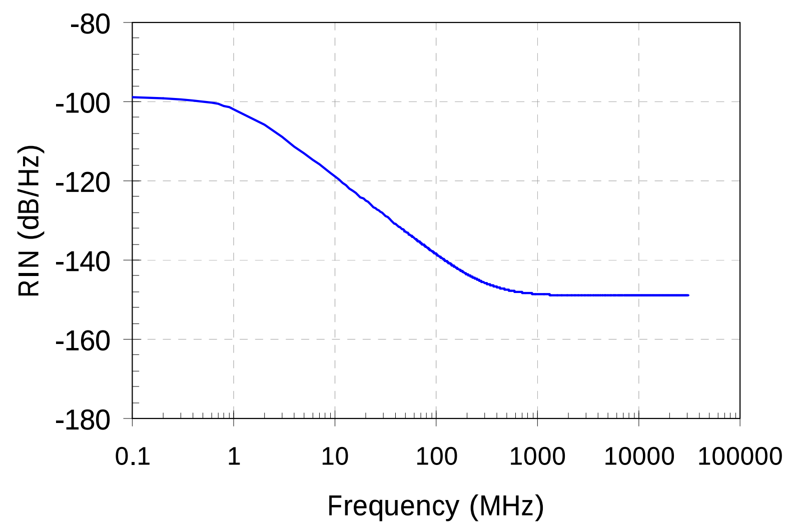
ORL = 60 dB (APC connection)



ORL = 40 dB (SPC connection)



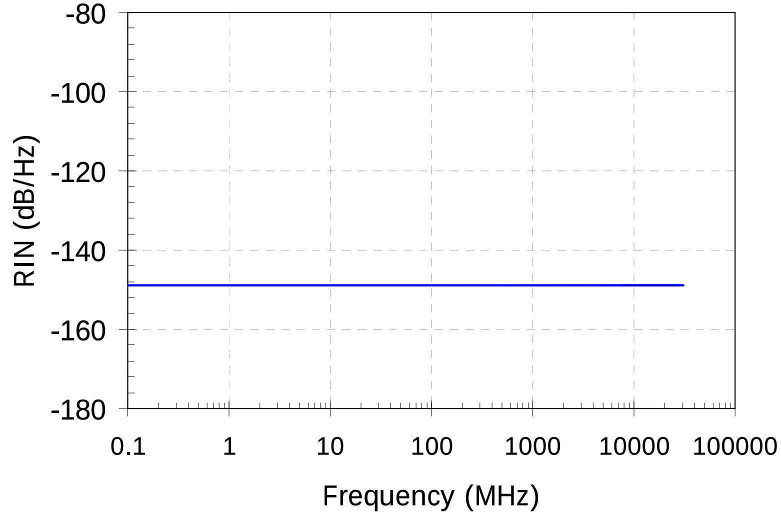
ORL = 27 dB (ITU-T standard)



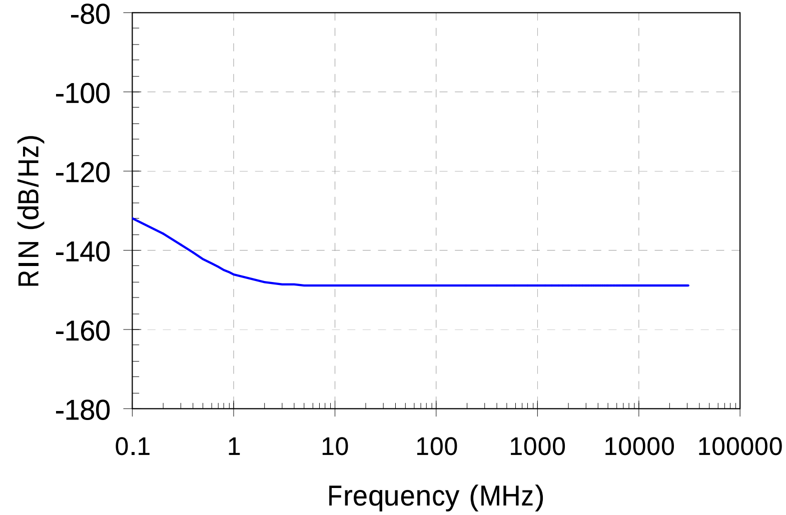
ORL = 21 dB (IEEE802.3)

Calculated RIN spectra at Rx side

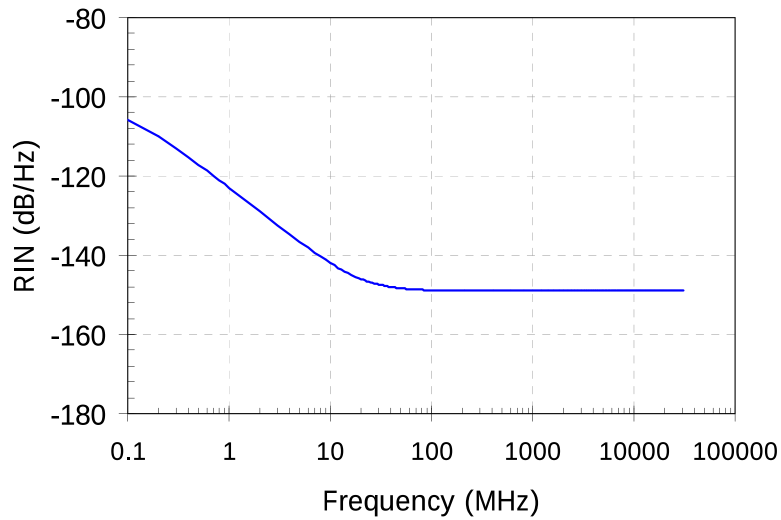
(Laser RIN = -149 dB/Hz, BW = 100 kHz)



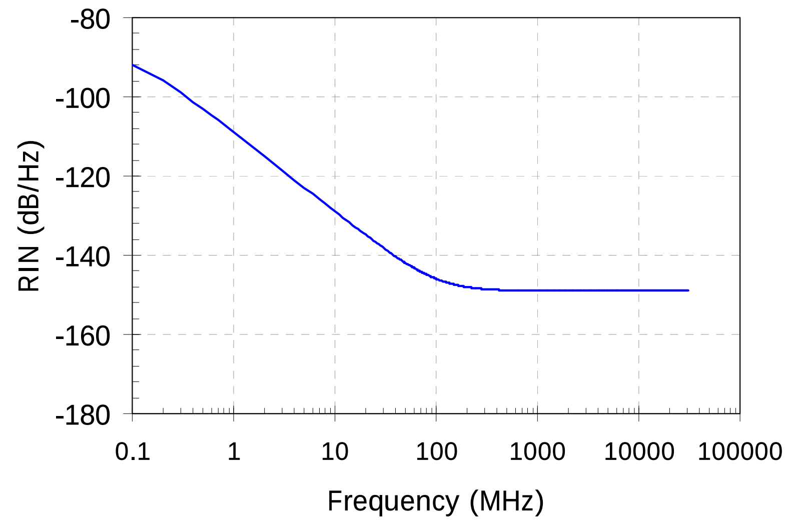
ORL = 60 dB (APC connection)



ORL = 40 dB (SPC connection)



ORL = 27 dB (ITU-T standard)



ORL = 21 dB (IEEE 802.3)