Proposal of revised Jitter budget table

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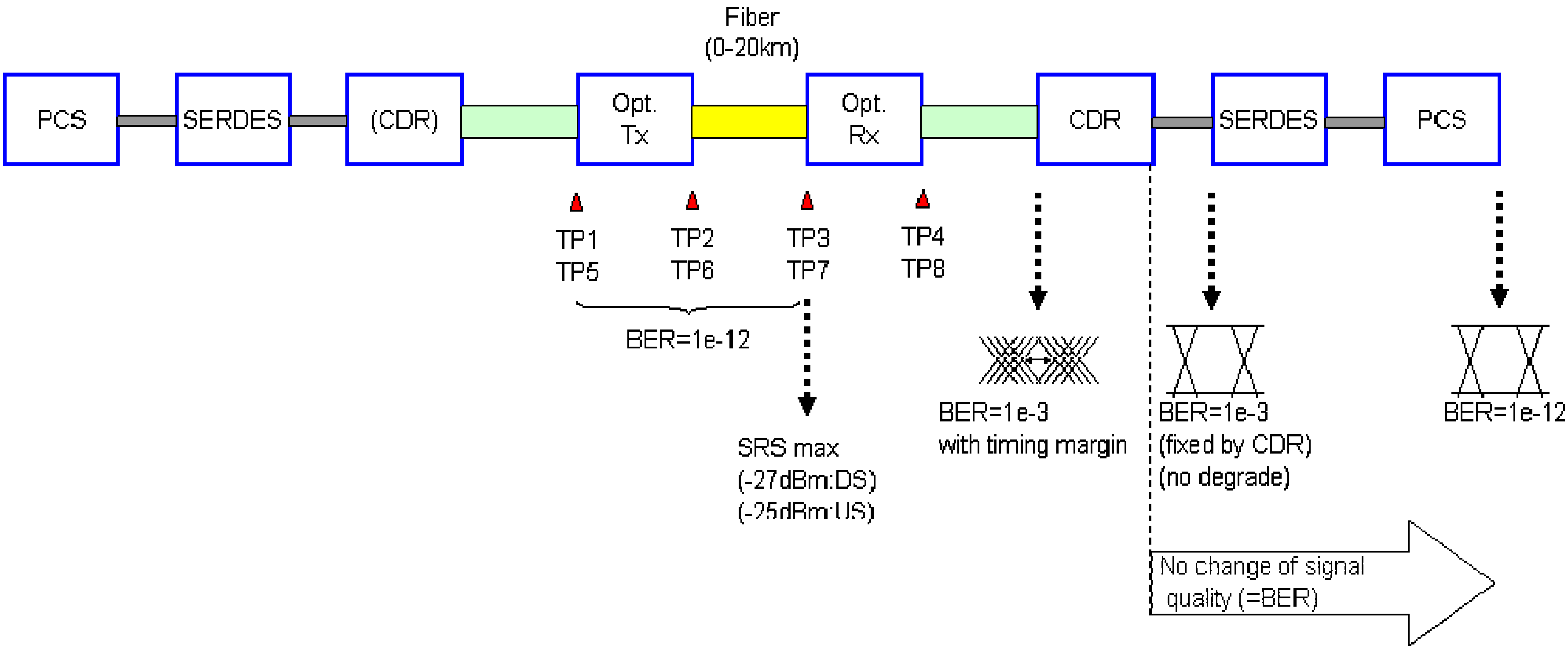
Reference points



Jitter components

Reference point	Source	Abbreviation	Element
->TP1	SERDES,OSC	Dj-serdes, Rj-serdes	Dj and Rj at SERDES transmitter
	Trace(PCB)	ISI-elc-D	Jitter at electric signal (Downstream)
TP1->TP2	Driver,Laser	Dj-tx-D, Rj-tx-D	Dj and Rj at optical Tx (Downstream)
TP2->TP3	Fiber	Dj-opt-D	Dj on optical fiber (Downstream)
TP3->TP4	PD,TIA,LIA	Dj-rx-D, Rj-rx-D	Dj at optical Rx, Rj at Rx under BER=1e-3 condition (Downstream)

Reference point	Source	Abbreviation	Element
->TP5	SERDES	Dj-trans, Rj-trans	Transferred Dj and Rj (Loop-Timed)
	SERDES,OSC	Dj-serdes, Rj-serdes	Dj and Rj at SERDES transmitter
	Trace(PCB)	ISI-elc-U	Jitter at electric signal (Upstream)
TP5->TP6	Driver,Laser	Dj-tx-U, Rj-tx-U	Dj and Rj at burst Tx
TP6->TP7	Fiber	Dj-opt-D	Dj on optical fiber (downstream)
TP7->TP8	PD,TIA,LIA	Dj-rx-U, Rj-rx-U	Dj at burst Rx, Rj at Rx under BER=1e-3 condition (Upstream)

Dj on optical fiber

- **We can calculate Dj on the fiber using "Chirp" parameter or spectral width.**
- **We propose using Agrawal's formula**

$$\frac{T^2}{T_0^2} = \left(1 + \frac{C\beta_2 L}{T_0^2}\right)^2 + \left(\frac{\beta_2 L}{T_0^2}\right)^2$$

C: Chirp Parameter
L: Transmission distance

Source: Govind P. Agrawal, Fiber-Optic Communication System, second edition

Dj on optical fiber

- We estimated Chirp parameter according to [1].

	DS	US
Line rate	10.3125 Gb/s	10.3125 Gb/s
Dispersion	-4 ps/(km-nm)	17 ps/(km-nm)
Wavelength	1270 nm	1577nm
Distance	20 km	20 km
Chirp parameter	-0.35	-2.8

- Deterministic jitter on fiber

Dj-opt-D	0.05
Dj-opt-U	0.05

- Note that the Dj on the optical fiber doesn't include the effect by jitter on burst Tx.

Reference : [1] 3av_0705_saeki_1.pdf, IEEE802.3av Geneva meeting, May 28-30, 2007

Rj at Rx under BER=1e-3 condition

- Assumptions
  - Received Power: -27dBm (Downstream), -25dBm (Upstream)
  - APD

    Responsivity: 0.8A/W

    M: 8

    X: 0.7

    Bandwidth: 8.0GHz
  - TIA+LIM

    Input equivalent noise current: 1.5uA$_{rms}$
  - Voltage slope: Sinusoidal approximation
- Estimated APD+TIA+LIM Total input referred noise current:

  1.97uA$_{rms}$(Downstream), 2.19uA$_{rms}$(Upstream)
- Estimated Rj on Rx

  Rj-rx-D: 4.75ps$_{rms,}$ Rj-rx-U: 3.34ps$_{rms}$

Jitter at EML Laser Driver

- Assumptions
  - Refer ADN2849
  - Random jitter 0.75 ps RMS
  - Total jitter 10 ps p-p

  - Jitter Contributions of EML Laser Driver (BER 10E-12)
  - Estimated Rj 0.048UI p-p
  - Estimated Dj 0.005UI p-p

Jitter at EML Laser

- Assumptions
  - Formula for Rj

$$RJ_{laser} = \frac{t_{rise}}{0.6} \cdot \frac{P_{noise}}{P_{laser}} \qquad \left(where \quad P_{noise} = BW_{laser} \cdot 10^{\frac{P_{l\_dBm}+Rin}{10}} \right)$$

  - BW_{laser} 8.5 GHz
  - P_{l_dBm} +2 dBm
  - R_{in} -120 dB (CyOptics 1550XFP40/80)
  - t_{rise} 10 ps (20-80% rise time)
  - Jitter Contributions of EML Laser (BER 10E-12)
  - Estimated Rj 0.008UI p-p
  - Estimated Dj 0.080UI p-p
- Result
  - Dj-tx-D = 0.085 UI p-p (given by 0.005+0.080)
  - Rj-tx-D = 0.049 UI p-p (given by sqrt($0.048^2+0.008^2$))

Jitter at electric signal

- Tested Tx jitter performance using SFP+ compliant current 10GbE device (Vender X) and SFP+ Host Compliance Board.
- Measured an electrical trace jitter value for 2 trace length cases as shown in Table -1.
- Calculate an electrical trace jitter as a result of Case2 – Case1.
  =>0.01 UI @229mm FR4 trace jitter

Items	Point B	TP1 (Case 1)	TP1 (Case 2)	Case 2 - Case 1
	(Spec.)	Include 10.5 inch (267mm) FR4 Strip line	Include 1.5 inch (38mm) FR4 Strip line	10.5 - 1.5 = 9 inch (229 mm) FR4 Strip line
TJ	27 ps (0.28 UI)	11 ps (0.113 UI)	9.9 ps (0.102 UI)	1.1 ps (0.011 UI)
DDJ	10 ps (0.1 UI)	8.6 ps (0.088 UI)	7.4 ps (0.076 UI)	1.2 ps (0.012 UI)

Note1) Measurement condition: 10.3125 Gbps, 2^{10-1} PRBS

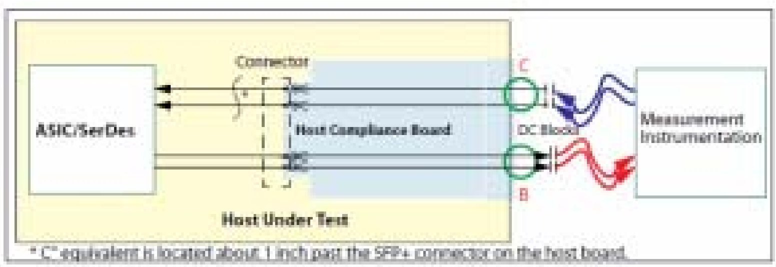
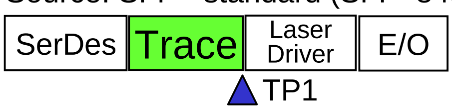


Figure 13 Host Compliance Board

Source: SFP+ standard (SFF- 8431v2.0)



Jitter at electric signal

Conclusion

- **Propose an electrical trace jitter value 0.02 UI (Ref. point TP1, TP5)**
  - **Based on a current 10GbE device performance test result.**
  - **Consider 10GbE device vender differences of performance and jitter margin.**

◆ **A Proposal of an electrical trace jitter table**

Reference point	Dj	Value	Unit	Note
TP1	ISI-elc-D	0.02	UI (pp)	
TP5	ISI-elc-U	0.02	UI (pp)	

Note) Assuming trace length condition: 200mm (max)

Loop-Timed (jitter transfer)

TP5 Transfer Rj/Dj

Transfer_Jitter at TP5 is the jitter derived from DS jitter at TP4 by PLL. High-frequency elements of transferred jitter are assumed to be suppressed by the loop filter.

TP5 Transfer_Dj = 0.03 UI

Since Dj at TP4 consists mostly of high-frequency elements, most of Dj is suppressed.

TP5 Transfer_Rj = 0.07 UIp-p

Transferred Rj is assumed to be derived only from the phase noise coming from OLT PLL which has a lower frequency element.

Dj at optical Rx

- Dj-rx-D depends on the frequency response of a receiver, e.g. bandwidth, gain peaking, etc.
- Estimated Dj-rx-D is < 0.15 UIpp under the condition that the bandwidth of the receiver is > 70% of the data rate and the gain peaking is < 2 dB

Dj at optical Rx

- Assumptions
  - Dj-rx-U is Dj-rx-D plus Dj-rx_{BM} arisen from BM operations
  - AC coupled BM receiver with the time constant of 20 ns
  - DJ caused by CIDs is a dominant factor of Dj-rx_{BM}
    - An effect of baseline wander at a BER of 10^{-3} and residual DC offset from the previous burst are small and those influences on Dj-rx_{BM} is negligible
- Estimated Dj-rx_{BM} is = 0.03 UIpp with the CID of 17 bits
  - A probability of occurrence of 17-bit CID is about 1/100 of the BER concerned
- Dj-rx-U = Dj-rx-D + Dj-rx_{BM} = 0.18 UIpp

Jitter at burst Tx

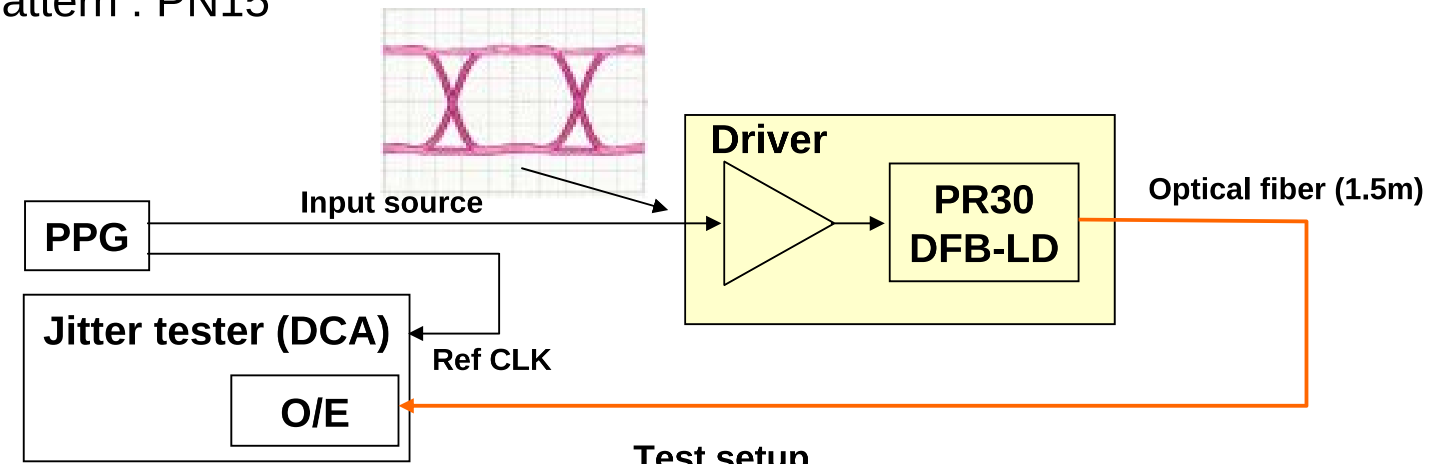
We had experimental evaluations on optical burst transmitters provided by several venders for PR30 using DM-DFB laser.

Setup:

Transmitter : PR30 compliant Directly-modulated DFB-LD + Driver circuit (w/o CDR)

Input source : Low jitter PPG

Test pattern : PN15



Test setup

Measured result of input source jitter

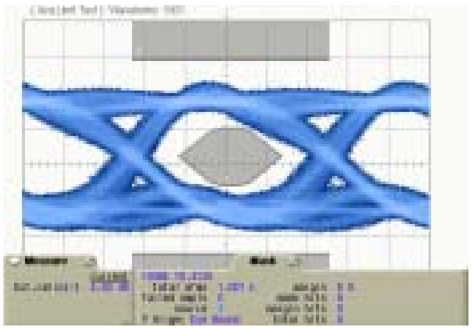
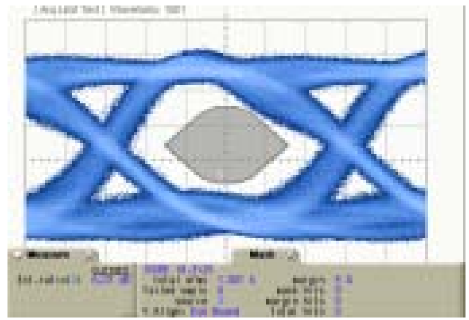
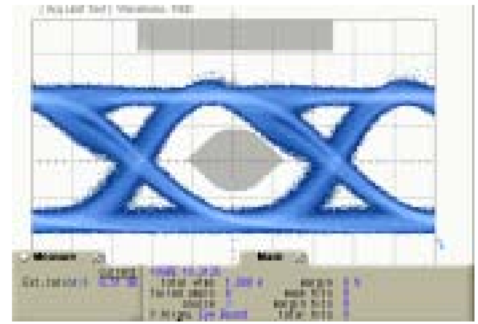
Rj(UI-rms)	Rj (UI-pp)	Dj (UI-pp)	Tj@1e-12(UI-pp)
0.0081	0.113	0.099	0.212

Jitter at burst Tx (vender A)

Transmitter setup (worst condition):

Worst waveform: No eye-mask margin 0 %

Power : +6 dBm (LD drive current is reduced by -40 %)

Ext = 4.5 dB	Ext = 6.0 dB	Ext = 8.5 dB
		

Measured result of Transmitter eye waveforms (worst)

Measured result of Transmitter jitter (worst)

Ext. ratio (dB)	Eye mask margin (%)	Rj(UI-rms)	Rj (UI-pp)	Dj (UI-pp)	Tj@1e-12(UI-pp)
4.5	6.0	0.003	0.042	0.123	0.165
6.0	5.0	0.002	0.028	0.102	0.130
8.5	0.0	0.003	0.042	0.165	0.207

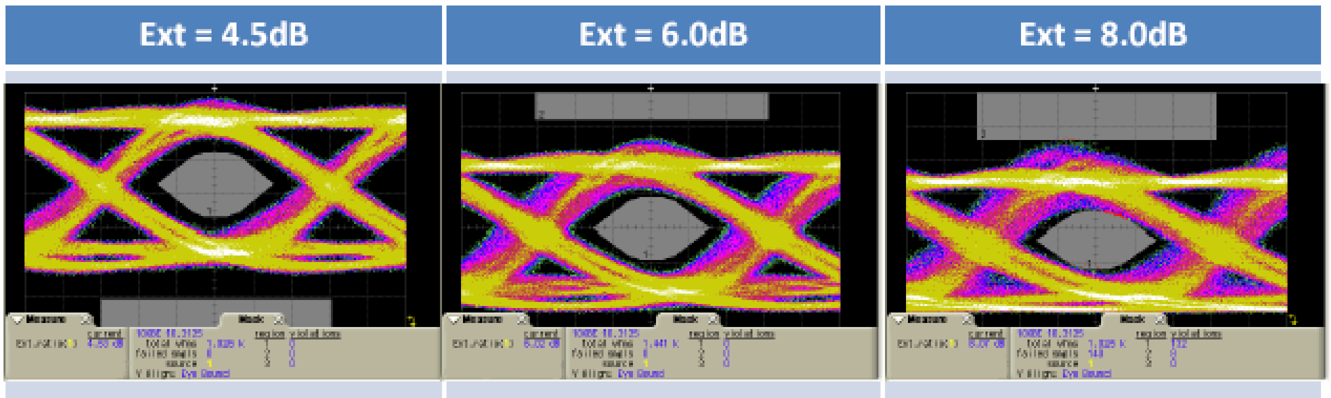
Note : Input source jitter is calibrated

Jitter at burst Tx (vender B)

Transmitter setup (worst condition):

Worst waveform: No eye-mask margin 0 %

Power : +6 dBm (LD drive current is reduced by -40 %)



Measured result of Transmitter eye waveforms (worst)

Measured result of Transmitter jitter (worst)

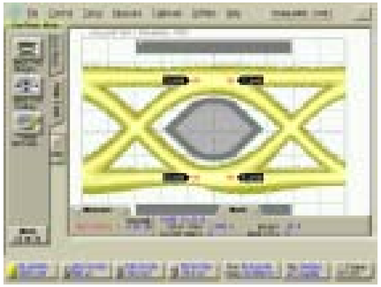
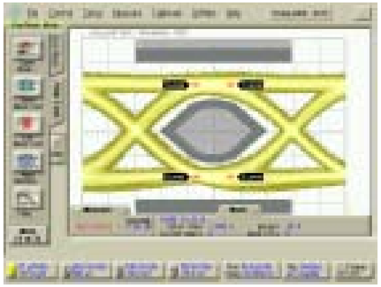
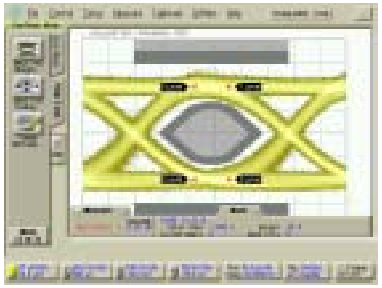
Ext. ratio (dB)	Eye mask margin	Rj(UI-rms)	Rj (UI-pp)	Dj (UI-pp)	Tj@1e-12(UI-pp)
4.5	+	0.0079	0.111	0.137	0.248
6.0	+	0.0073	0.103	0.184	0.286
8.0	-	0.0064	0.090	0.323	0.413

Note : Input source jitter is calibrated

Jitter at burst Tx (Vender C)

Transmitter setup:

OMA ~ 5 mW (Power: +4.3 ~ +6.7 dB)

Ext = 4.5 dB	Ext = 6.0 dB	Ext = 8.0 dB
		

Measured result of transmitter eye waveform

Measured result of transmitter jitter

Ext. Ratio (dB)	Launched OMA (mW)	Eye mask margin (%)	Rj (UI-rms)	Rj (UI-pp)	Dj (UI-pp)	Tj@1e-12 (UI-pp)
4.5	5.3	30	0.000	0.000	0.184	0.184
6.0	4.9	38	0.000	0.000	0.179	0.179
8.0	4.8	36	0.001	0.019	0.221	0.240

Note: Input source jitter is calibrated.

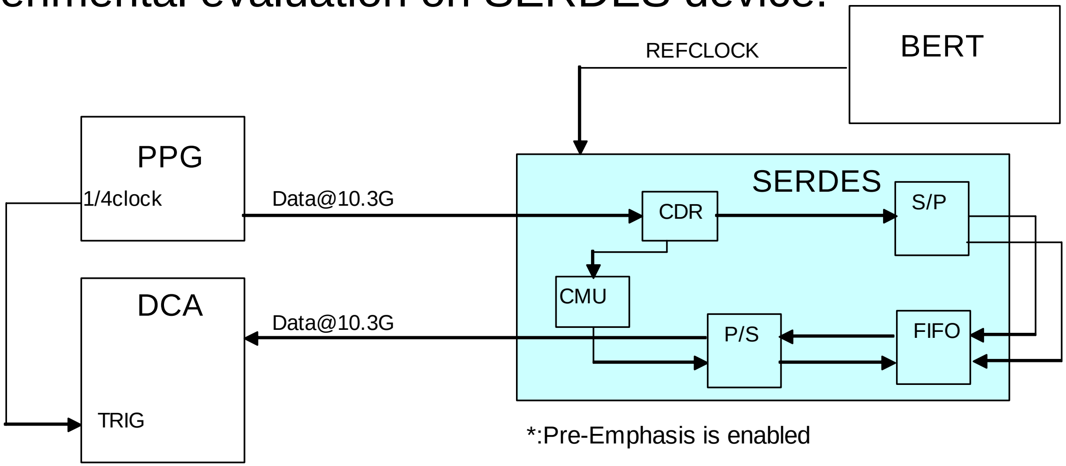
A Proposal for Upstream optical transmitter jitter (Dj-tx-U, Rj-tx-U):

Worst case value (no eye-mask margin) + measurement error (margin)

Rj(UI-rms)	Rj (UI-pp)	Dj (UI-pp)	Tj@1e-12(UI-pp)
0.010	**0.140**	**0.180**	**0.320**

Dj and Rj at SERDES transmitter

We had an experimental evaluation on SERDES device.



Test setup

Measured result

Ref CLK	Rj(UI-rms)	Rj (UI-pp)	Dj (UI-pp)	Tj@1e-12(UI-pp)
161MHz	0.006	0.08	0.04	0.12
645MHz	0.005	0.07	0.03	0.10

A Proposal for Dj and Rj on SERDES transmitter (Dj-serdes, Rj-serdes):

Rj(UI-rms)	Rj (UI-pp)	Dj (UI-pp)	Tj@1e-12(UI-pp)
0.010	**0.14**	**0.07**	**0.21**

Note : This value includes margin for applying CMOS process and using an oscillator as reference clock.

Summary

Reference point	Component			Tj @1e-12 (1e-3 at TP4)	Source
	Dj	Rj			
		rms	p-p		
TP1	ISI-elc-D				Trace(PCB)
	0.02				
	Dj-serdes	Rj-serdes		0.211	SERDES,OSC
	0.07	0.0100	0.1407		
	0.09	0.0100	0.1407	0.231	
TP2	Dj-tx-D	Rj-tx-D		0.134	Driver,Laser
	0.085	0.0035	0.0492		
	0.175	0.0106	0.1491	0.324	
TP3	Dj-opt-D			0.050	Fiber
	0.05				
	0.225	0.0106	0.1491	0.374	
TP4	Dj-rx-D	Rj-rx-D		0.453	PD,TIA,LIA
	0.15	0.0490	0.3027		
	0.375	0.0501	0.3097	0.685	

Reference point	Component			Tj @1e-12 (1e-3 at TP8)	Source
	Dj	Rj			
		rms	p-p		
TP5	Transfer	Transfer		0.102	SERDES,OSC
	0.03	0.00515	0.0725		
	ISI-elc-U			0.020	Trace(PCB)
	0.02				
	Dj-serdes	Rj-serdes		0.211	SERDES,OSC
	0.07	0.0100	0.1407		
	0.12	0.0112	0.1583	0.278	
TP6	Dj-tx-U	Rj-tx-U		0.321	Driver,Laser
	0.18	0.0100	0.1407		
	0.3	0.0151	0.2117	0.512	
TP7	Dj-opt-U			0.050	Fiber
	0.05				
	0.350	0.0151	0.2117	0.562	
TP8	Dj-rx-U	Rj-rx-U		0.393	PD,TIA,LIA
	0.18	0.0344	0.2129		
	0.530	0.0376	0.2323	0.762	

- based on measured data
- based on measured data and data sheet spec
- based on calculated or simulated value

◆**This jitter budget for downstream places all the slack at the receiver.**
◆**At BER of 10-3 the expected receive tolerance is between 0.75UIpp and 0.80UIpp.**
◆**Jitter should be normalized to this value to distribute the excess evenly in budget.**

We should add an adequate margin to downstream.

Method-1: Relaxing Tx
Considering common use for all PMD classes.
(Using optical amplifier for PR20, etc..)
-> Not so much margin is needed.

Method-2: Relaxing Rx
Cost effective for ONU receiver.
-> To be main target.

Mainly the margin should be added to Rx side.

Adjusting for downstream

Reference point	Component			Tj @1e-12 (1e-3 at TP4)	Source
	Dj	Rj			
		rms	p-p		
TP1	ISI-elc-D				Trace(PCB)
	0.02				
	Dj-serdes	Rj-serdes		0.211	SERDES,OSC
	0.07	0.0100	0.1407		
	0.09	0.0100	0.1407	0.231	
TP2	Dj-tx-D	Rj-tx-D		0.241	Driver,Laser
	0.1	0.0100	0.1407		
	0.19	0.0141	0.1990	0.389	
TP3	Dj-opt-D			0.050	Fiber
	0.05				
	0.24	0.0141	0.1990	0.439	
TP4	Dj-rx-D	Rj-rx-D		0.508	PD,TIA,LIA
	0.18	0.0531	0.3282		
	0.42	0.0550	0.3397	0.760	

Reference point	Component			Tj @1e-12 (1e-3 at TP8)	Source
	Dj	Rj			
		rms	p-p		
TP5	Transfer	Transfer		0.102	SERDES,OSC
	0.03	0.00515	0.0725		
	ISI-elc-U			0.020	Trace(PCB)
	0.02				
	Dj-serdes	Rj-serdes		0.211	SERDES,OSC
	0.07	0.0100	0.1407		
	0.12	0.0112	0.1583	0.278	
TP6	Dj-tx-U	Rj-tx-U		0.321	Driver,Laser
	0.18	0.0100	0.1407		
	0.3	0.0151	0.2117	0.512	
TP7	Dj-opt-U			0.050	Fiber
	0.05				
	0.350	0.0151	0.2117	0.562	
TP8	Dj-rx-U	Rj-rx-U		0.393	PD,TIA,LIA
	0.18	0.0344	0.2129		
	0.530	0.0376	0.2323	0.762	

Conclusion

A Proposal of new Jitter budget table

(1) Each value is based on the summarized spread sheet.
(2) The table consists of Rj and Dj.
(because of difference of integration rule between Rj and Dj)
(3) Define the BER condition for each reference point.

Reference point	Dj (UI p-p)	Rj (UI p-p)	Tj (UI p-p)
TP1	0.09	0.14	0.23
TP2	0.19	0.20	0.39
TP3	0.24	0.20	0.44
TP4	0.42	0.34	0.76

Reference point	Dj (UI p-p)	Rj (UI p-p)	Tj (UI p-p)
TP5	0.12	0.16	0.28
TP6	0.30	0.21	0.51
TP7	0.35	0.21	0.56
TP8	0.53	0.23	0.76

Note : BER conditions for TP1,2,3,5,6 and 7 are 1.0E-12, for TP4 and 8 are 1.0E-3
All jitter values relate to high frequency (>4 MHz) jitter.
0.1 UI of sinusoidal jitter stress is assumed at the receiver.
The Gaussian jitter is assumed to be weak function of BER.
In downstream external modulator is assumed.