100G SR4 TDP Update

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Presentation Summary

Presentation Objectives:

- Present update of TDP setup and requirements for 100G 100m MMF Tx
- Present results of analysis of additional worst case Tx cases
- Present proposed update to TP2 & SRS eye masks
- Present limitations of TDP metric for 100G 100m MMF
- Present alternative metric

Link Model References

http://www.ieee802.org/3/bm/public/may13/petrilla_04_0513_optx.pdf

http://www.ieee802.org/3/bm/public/may13/ExampleMMF%20LinkModel%20%20130503.xlsx

http://www.avagotech.com/docs/AV02-2485EN

100G SR4: Developing TDP Requirements 1

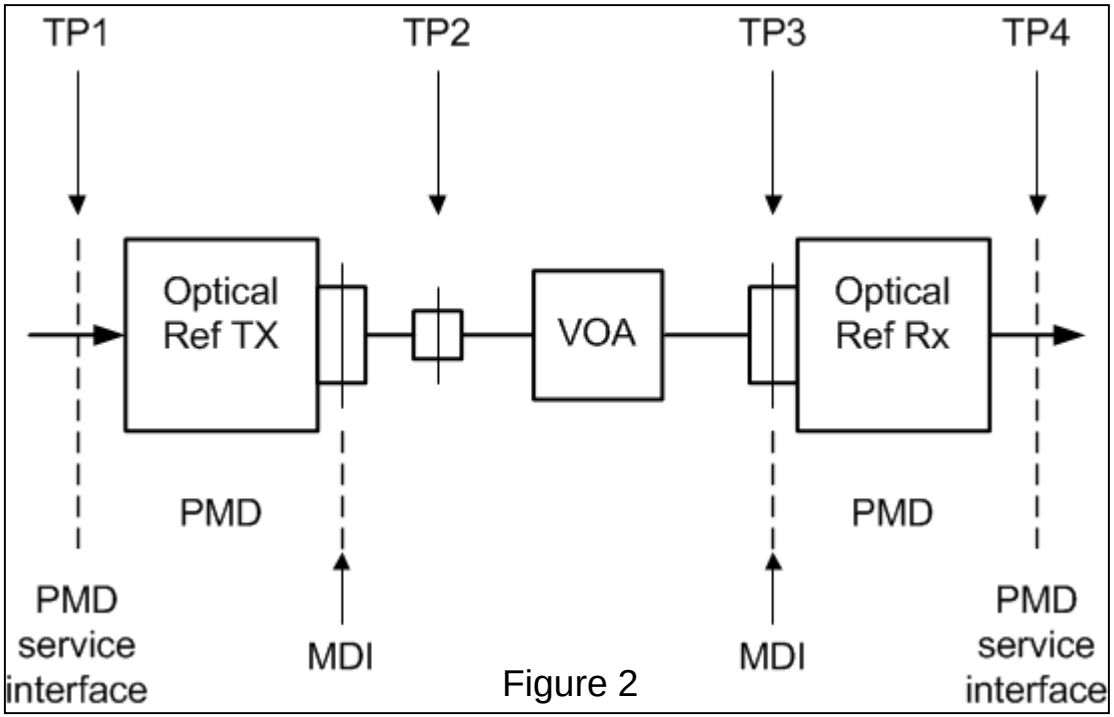


Figure 2

1) In setup of Figure 2, adjust VOA to yield TP4 TJ requirement. Measure OMA at TP3.
2) Determine residual link penalty if any.
3) Record OMA - residual link penalty as Test Reference Sensitivity, S.

•The above figure shows a starting point for development of TDP requirements for a MMF link.
•This is entirely a link model excerise based on idealized reference devices and the defined worst case Tx operating at defined worst case TP1 conditions over the defined worst case optical channel.
•A reference transmitter, Ref Tx, and a reference receiver, Ref Rx, are defined. These are idealized devices and are not expected to be implemented.
•The sensitivity, S, of the Ref Rx is defined by the signal level at TP3 at the point that the requirements at TP4 are met.
•Link model attributes for Ref Tx and Ref Rx, TP1 and TP3 are provided on following pages.
•In the spread sheet link model cell L7, normally the entry for connector loss, is used to enter the VOA attenuation.

100G SR4 with KR4 FEC: Example Ref (ideal) Tx Attributes

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
Center Wavelength	nm	860	
Spectral Width	nm	0.05	
OMA at max TDP	dBm	-3.0	
Extinction ratio	dB	4.77	
Tx output transition times, 20% -80%	ps	1.0	
$RIN_{12}OMA$	dB/Hz	-128	
RIN coefficient		0	
MPN coefficient		0	
Modal Noise Penalty	dB	0	
Tx reflectance, max	dB	-12	
Tx optical return loss tolerance, max	dB	12	

- Attributes and values in the above table represent an ideal device to use as a reference case. There's no expectation that such a transmitter can be implemented.
- Note that all noise sources are disabled.

100G SR4 with KR4 FEC: Example Ref Rx Attributes

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
Wavelength, min	nm	840	
Ref Rx sensitivity (OMA)	dBm	-14.60	-12.03 dBm at Q = 7.034
Rx Bandwidth	MHz	19,336	
RMS base line wander coefficient		0	
Rx reflectance, max	dB	-12	

•Attributes and values in the above table represent an ideal device to use as a reference case.

100G SR4 with KR4 FEC: Example Ref Ch Attributes

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
Reach	m	2	
Fiber Attenuation	dB/km	0	For 850 nm center wavelength
Dispersion min Uo	nm	1316	
Dispersion So	ps/nm^2km	0.10275	
Fiber modal bandwidth	MHz·km	2000	
Reflection Noise Factor		0	
Signal power budget at max TDP	dB	11.60	Model output
Fiber Insertion loss	dB	0.00	Model output

Attributes and values in the above table are provided in order to populate a link model representating the test setup for the TDP reference case.

100G SR4 with KR4 FEC: Example Ref Tx Ref Rx Link & Jitter Attributes

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
TP1 RJrms	UI	0	
TP1 DJ	UI	0	
TP3 DCD	UI	0	
TP3 DJ	UI	0	
Attenuation (aka Connector loss)	dB	11.50	Adjusted to yield zero margin
TP4 TJ at BER, max	UI	0.780	Model output
Residual Link Power Penalty	dB	0.10	ISI penalty for TP4 TJ = 0.78 UI

•Attributes and values in the above table represent an ideal input at TP1 to use as a reference case. There's no expectation that such an input can be realized.
•Note that the only noise in the link is the noise that determines the sensitivity of the Ref Rx
•Nomenclature: Terms TP1, TP2, TP3 and TP4 are used as defined in 802.3 clause 86 and shown in above Figure 1 and Figure 2.
• For the Ref Tx, Ref Rx, reference channel and TP1 conditions defined above, a VOA attenuation entry of 11.50 dB should yield a TP4 TJ (BER = $5x10^{-5}$) of 0.78 UI consistent with the TP4 requirement in the example link model for an S = -14.6 dBm.

100G SR4: Developing TDP Requirements 2

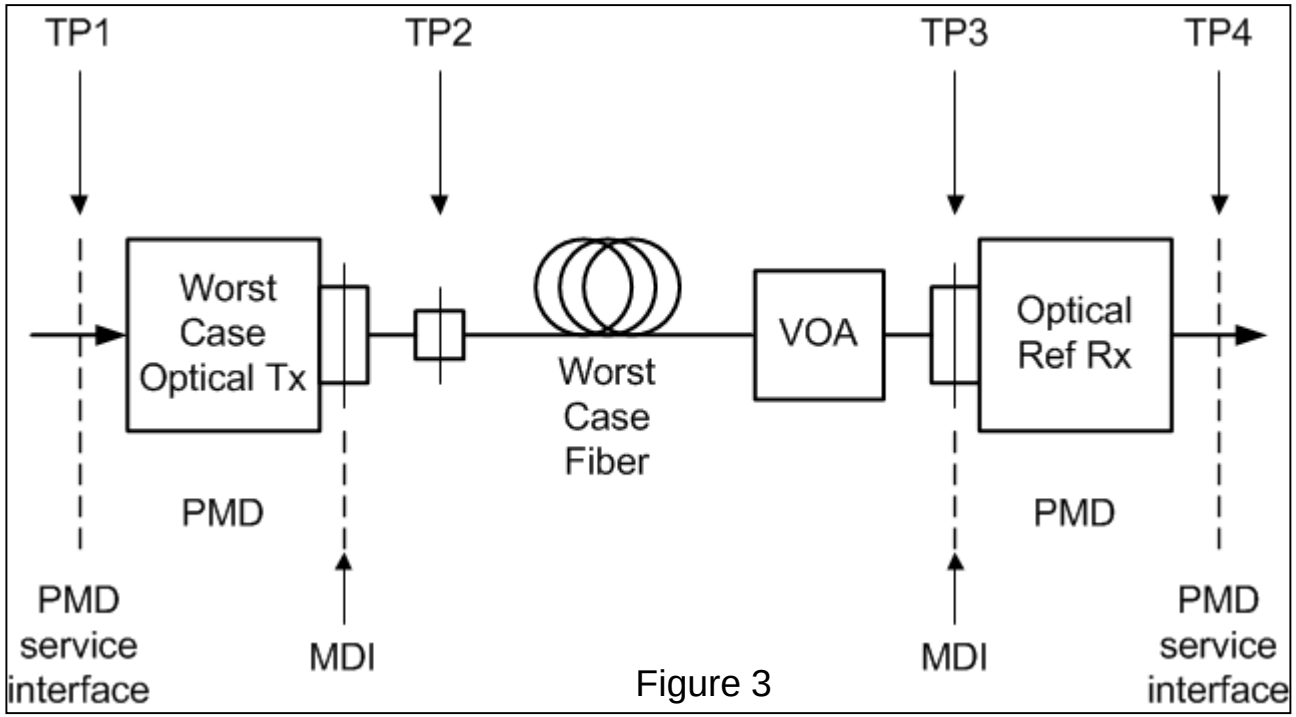


Figure 3

1) Replace Ref Tx in Figure 2 with Worst Case Tx (except for center wavelength and spectral width), worst case TP1 conditions and Worst Case Fiber as shown in Figure 3.
2) Adjust VOA to yield TP4 TJ requirement.
3) Record OMA at TP3
4) Max TDP = OMA – Ref Rx S.

•Now that the sensitivity, S, of the Ref Rx has been established, the Ref Tx and reference channel is replaced by the worst case Tx (except for center wavelength and spectral width which are set to match the Ref Tx) operating with the worst case TP1 conditions and the worst case optical channel. This channel includes a VOA that is adjusted such that the requirements at TP4 are met.

•The difference between the signal level at TP3 for this case and S yields the max limit for TDP, now 4.1 dB.

100G SR4: Developing TDP Requirements 3

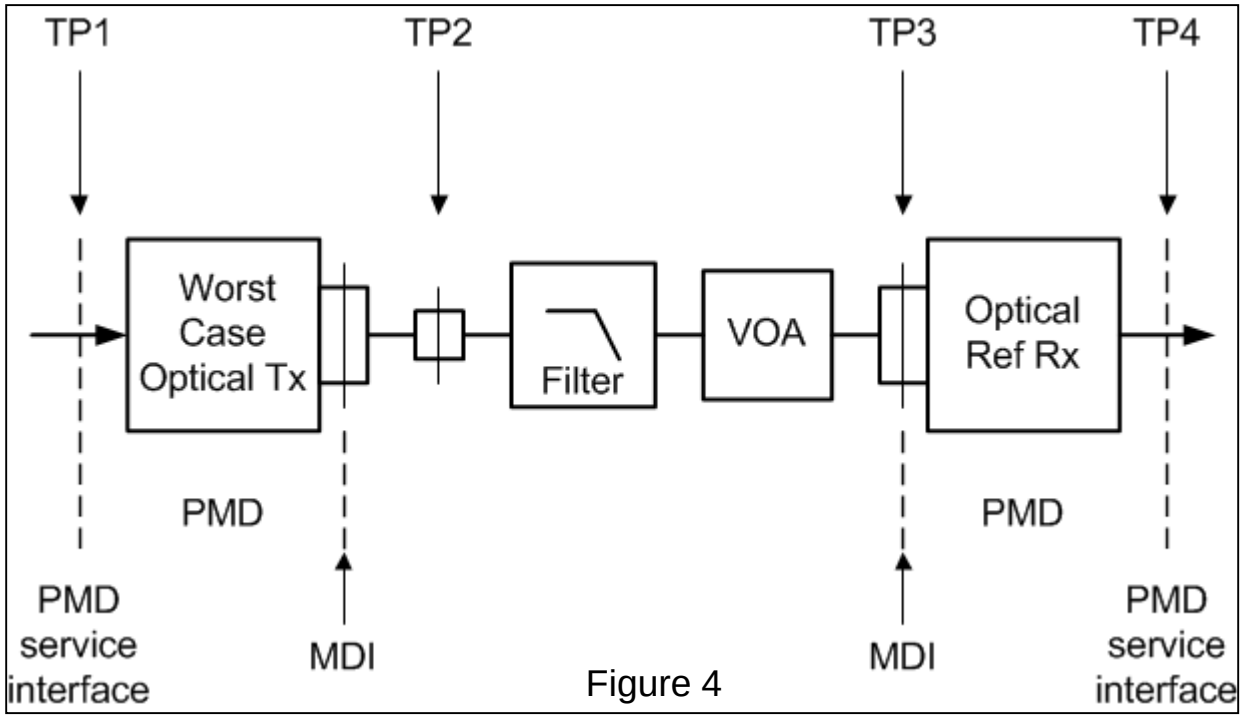


Figure 4

1) Replace Worst Case Fiber in Figure 3 with filter.
2) Adjust the VOA and Filter bandwidth to yield the same OMA at TP3, the same TP4 TJ and same total link penalties as seen in the setup of Figure 3.
3) Combine the bandwidth of the filter and Ref Rx and record as the Rx BW for the TDP measurement.

•Finally, the worst case channel is replaced by the reference channel and a filter is added to the Ref Rx input with a bandwidth that yields the same Ptotal central (link model cell T28) as did the worst case channel.
•Since the filter does not capture chromatic dispersion and mode partition noise, the spectral attributes of the Ref Tx are used for the worst case Tx and k(MPN) is set to 0 when determining the filter bandwidth (as is Pmn and the baseline wander coefficient).
•For the example link model, this filter in combination with the Ref Rx yields a BW of 16.21 GHz.
•TDP for 100G SR4 is now defined only to capture effects of jitter delivered to TP1, Tx transition times, noise, e.g. RIN, and jitter contributed by the laser and deviations from Gaussian waveforms.

100G SR4: Developing TDP Requirements 4

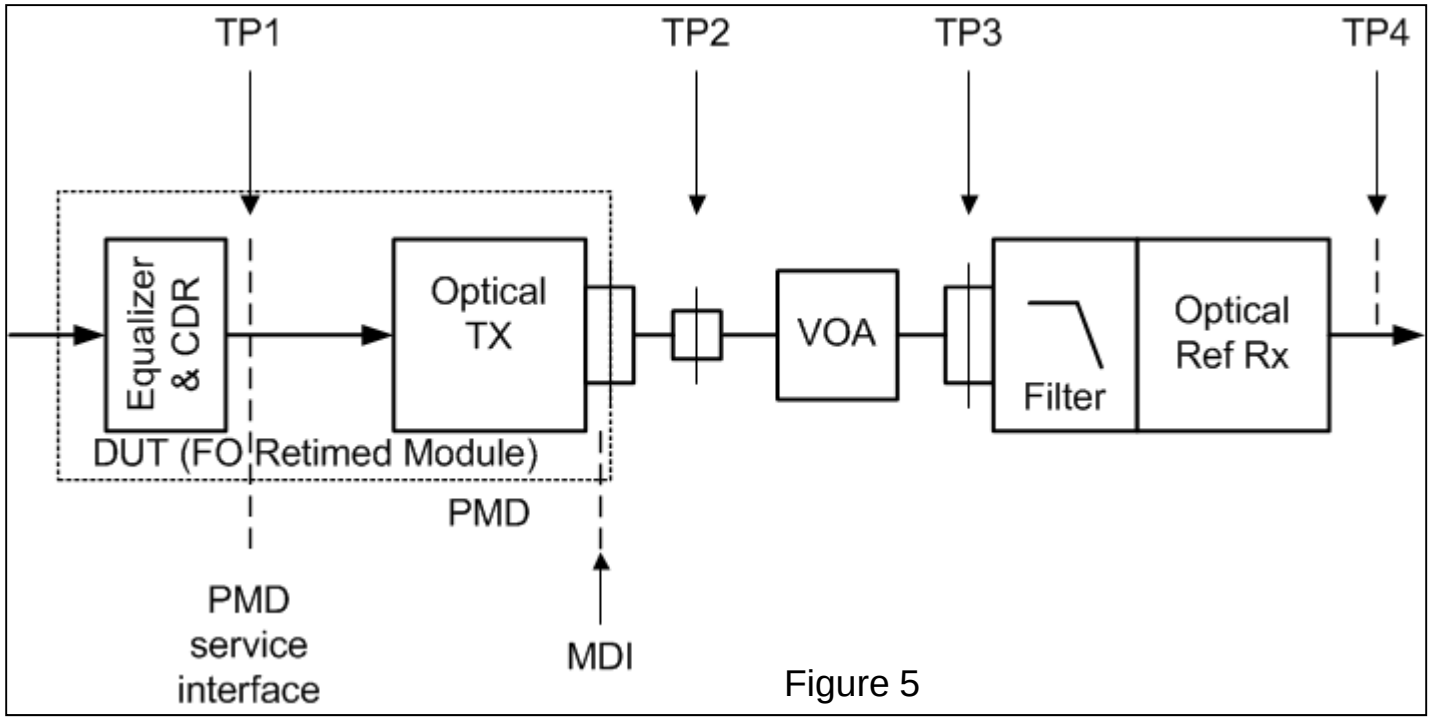


Figure 5

Testing a transceiver module for TDP:
1) Replace Worst Case Tx in Figure 4 with Tx DUT as shown in Figure 5.
2) Adjust the VOA to yield the same OMA at TP3, the same TP4 TJ and same total link penalties as seen in the setup of Figure 3.
3) Note the filter has been combined with the Ref Rx.

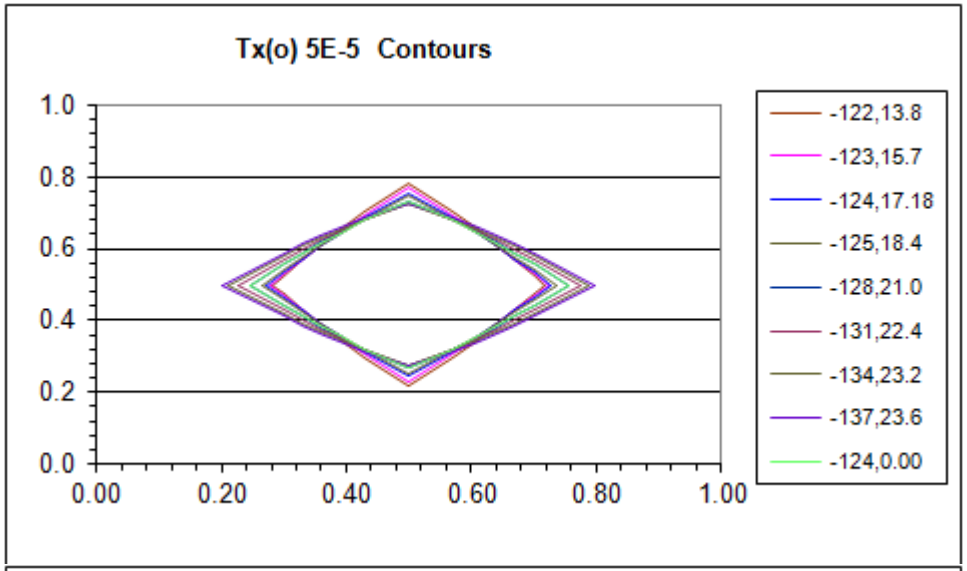
For the case where the ideal Tx in Figure 2 is used to calibrate the sensitivity of the combination of filter and Optical Ref Rx, i.e. a Ref Rx with a BW of 16.21 GHz instead of 19.336 GHz, a TDP penalty of 0.27 dB (all ISI) would be incurred.

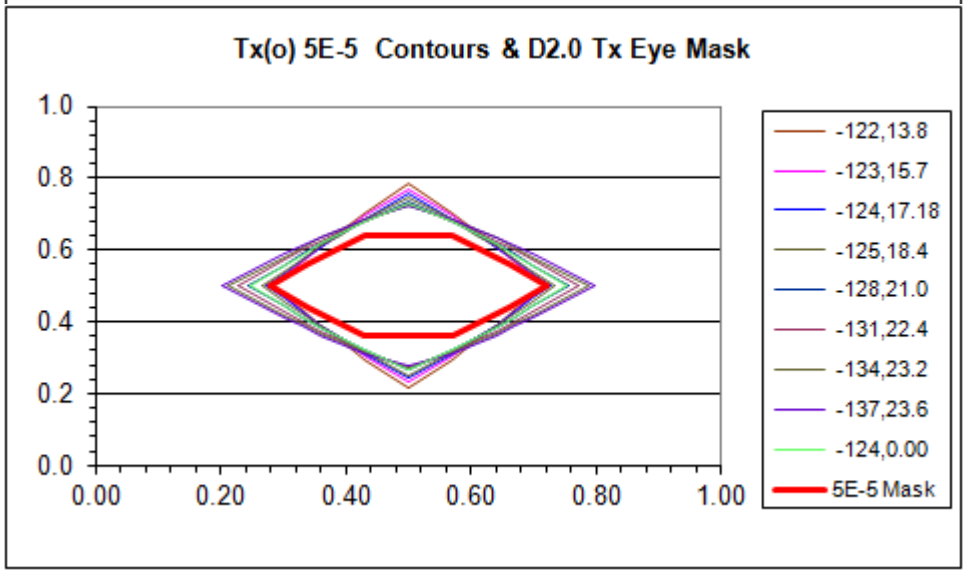
100G SR4 with KR4 FEC: Example TDP Test Channel (each lane)

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
Reach	m	2	
Fiber Attenuation	dB/km	0.0	For 850 nm center wavelength
Dispersion min Uo	nm	1316	
Dispersion So	ps/nm^2km	0.10275	
Fiber modal bandwidth	MHz·km	2000	
Reflection Noise Factor		0	
Signal power budget at max TDP	dB	11.60	Model output
Fiber Insertion loss	dB	0.00	Model output
Attenuation (aka Connector loss)	dB	7.52	Adjusted to yield zero margin
Rx Bandwidth for TDP	MHz	16210	Adjusted to match Ptot of Ref Ch with100 m of OM4
Max TDP	dB	4.1	

Attributes and values in the above table provide a summary of the test channel using the TDP filter.

100G 100m SR4: Transition time & RIN12OMA tradeoff set TP2 contours (1)





•For a system with three variables, transition time, RIN12 OMA & jitter, and one result, link margin, there is no unique worst case , rather a multiplicity of worst cases. Each of these cases yields a slightly different eye contour as can be seen in the figures on the right as well as a different TDP value that will be discussed later.

• The top chart shows 5E-5 contours of the Tx output (TP2) for transition time and RIN12OMA combinations providing zero link margin. Here a Gaussian response is assumed, consistant with the assumptions in the link model.

• The currently defined (draft 2.0) Tx eye mask is included in the bottom chart. It should be adjusted so that otherwise compliant transmitters are not rejected.

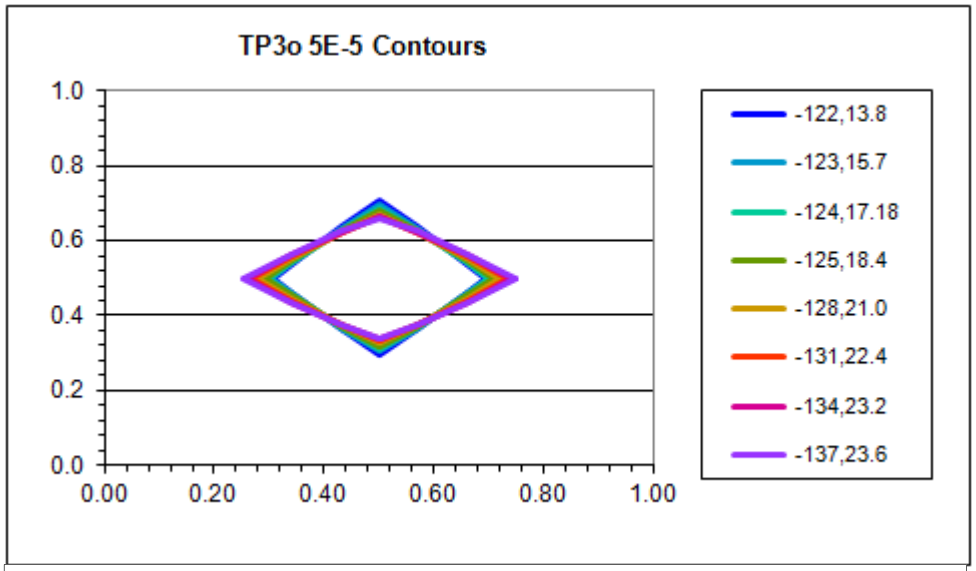
• Items to notice in this set of contours:

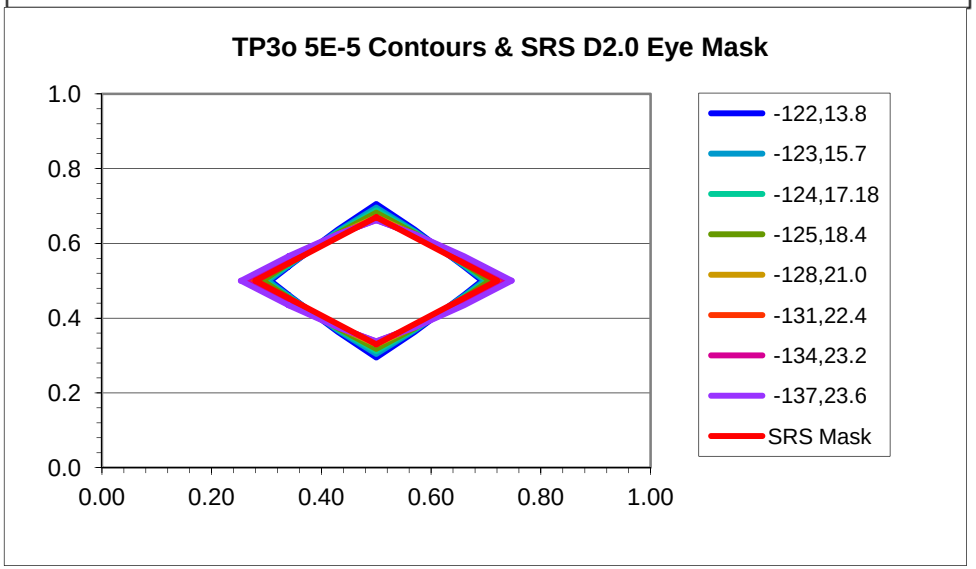
1, All of the Tx and TP1 attributes that are intended to be captured in the TDP metric are captured in the these contours.

2, The vertical position of a point on a contour represents the signal amplitude at that point relative to OMA and permits a measure of vertical eye closure.

3, There' s a crossover point where the variations in time and amplitude are minimized that, perhaps, offers a tighter relationship with link margin than TDP offers (more on this later).

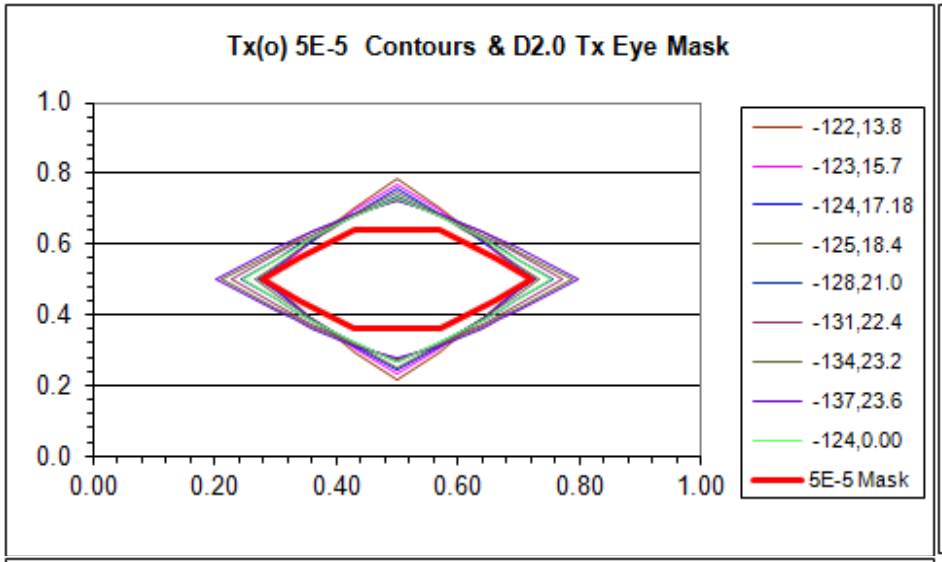
100G 100m SR4: Transition time & RIN12OMA tradeoff set TP3 contours (1)

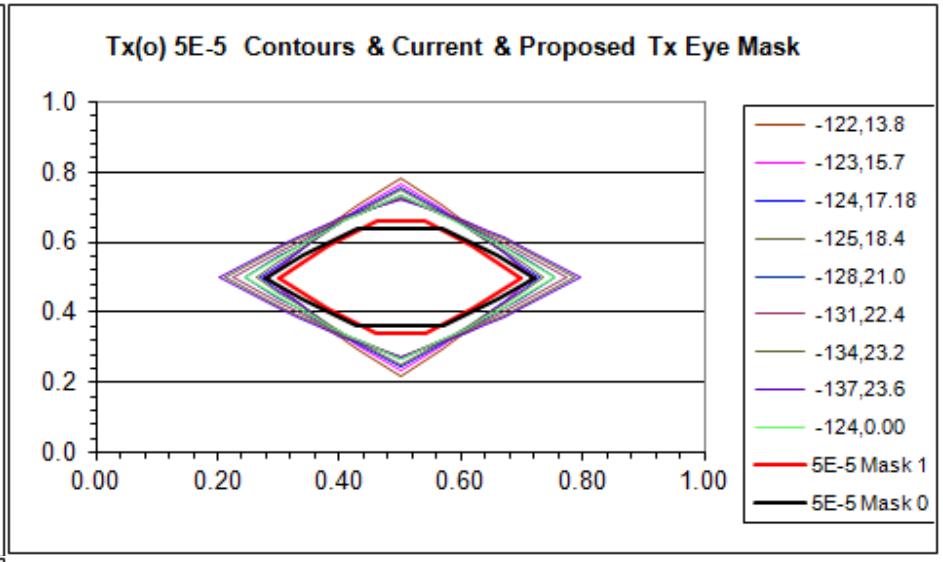


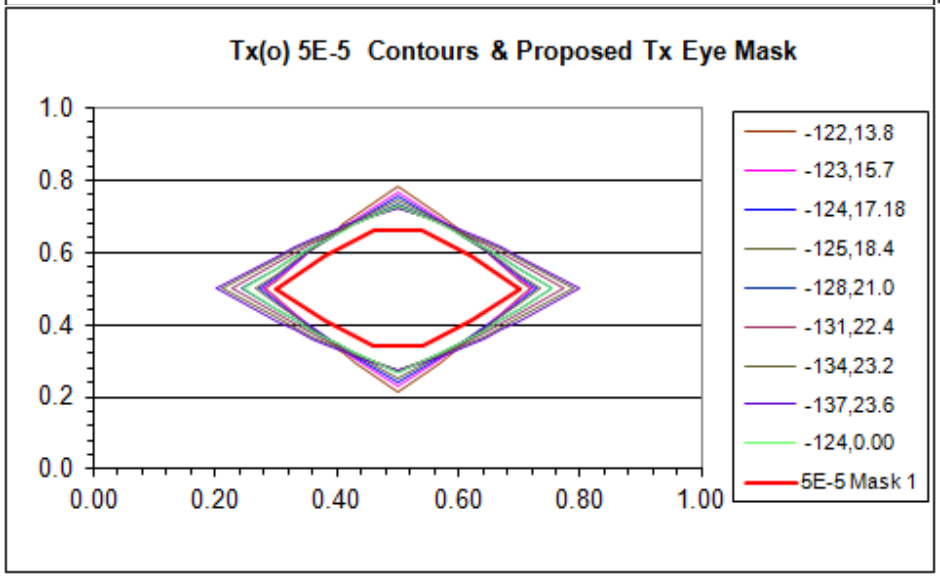


- The top chart shows 5E-5 contours of the fiber output (TP3) for the transition time and RIN12OMA combinations providing zero link margin used in an earlier page.
- The currently defined (draft 2.0) SRS eye mask is included for reference in the bottom chart. While it captures one of several worst case TP3 eyes, adjustment is appropriate to accommodate more of the worst case contour set.

100G 100m SR4: Transition time & RIN12OMA tradeoff set TP2 contours (2)





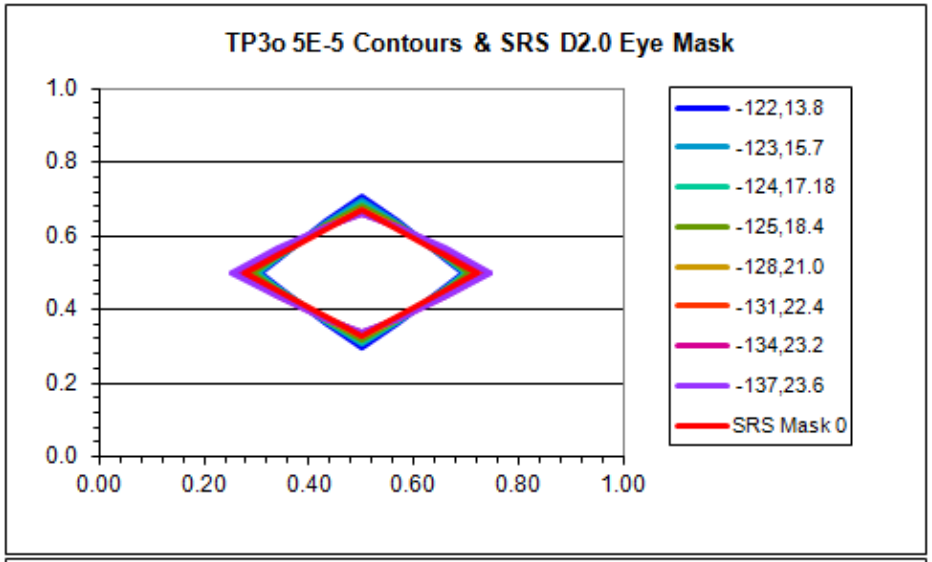


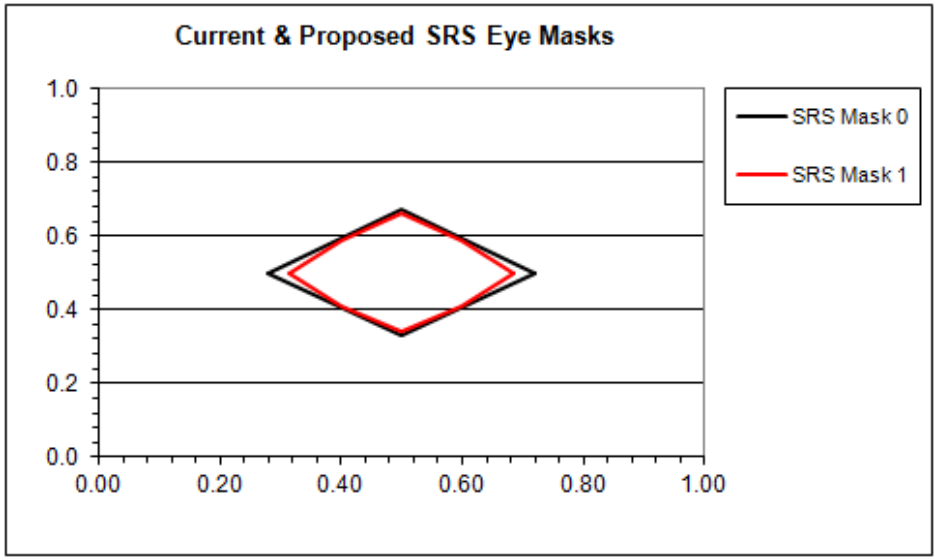
- All charts show a set of worst case Tx output 5E-5 contours.
- The currently defined (draft 2.0) Tx eye mask is shown in the top right chart with the set of 5E-5 contours.
- The proposed Tx eye mask (5E-5 Mask 1) is shown in the bottom left chart with the set of 5E-5 contours.
- Tx eye mask coordinates are determined by an expected set of worst case eye contours and independent of TDP use.
- The proposed Tx eye mask is compared with the existing Tx eye mask in the top right chart.
- Tx Eye Mask Coordinates: X1, X2, X3, Y1, Y2, Y3

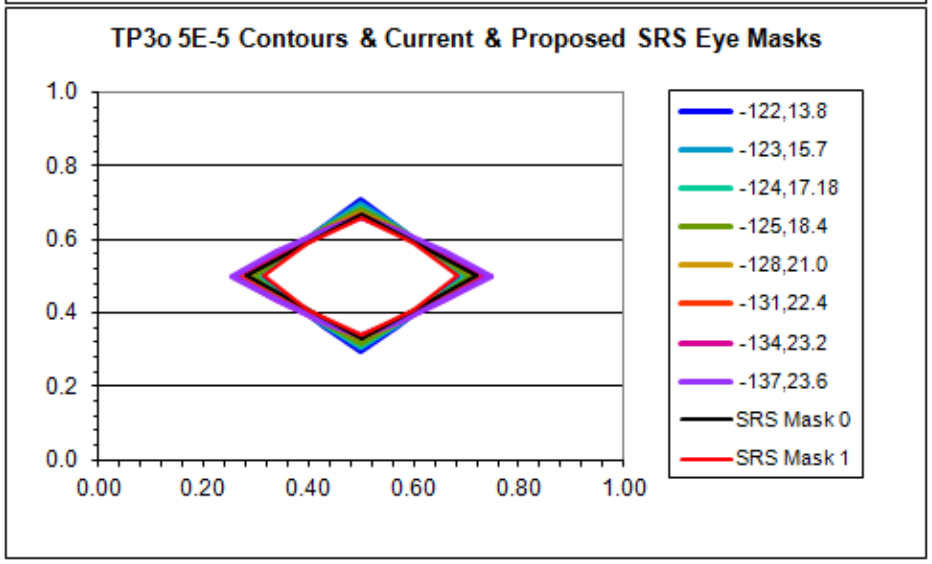
  Current: 0.28, 0.34, 0.43, 0.36, 0.44, 0.4

  Proposed: 0.3, 0.38, 0.46, 0.34, 0.41, 0.4

100G 100m SR4: Transition time & RIN12OMA tradeoff set TP3 contours (2)





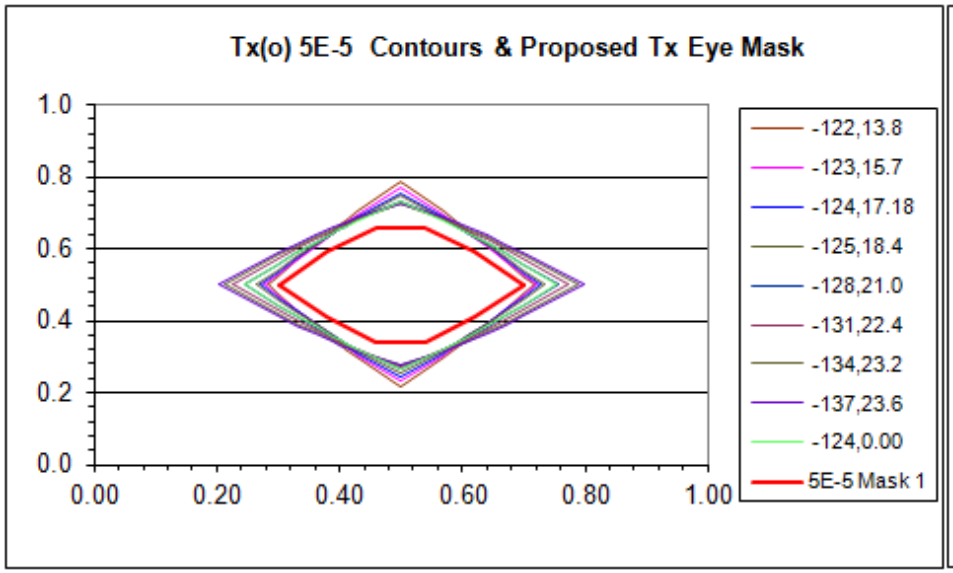


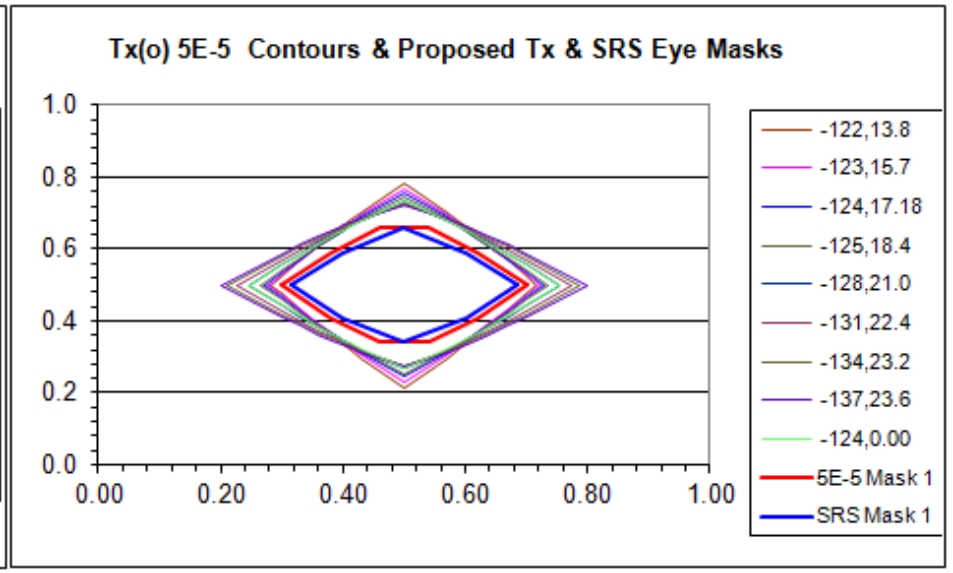
- The top left chart shows 5E-5 contours of the fiber output (TP3) for the transition time and RIN12OMA combinations providing zero link margin used in an earlier page and the current SRS mask (SRS Mask 0)
- The bottom left chart repeats the above and also shows the proposed SRS mask (SRS Mask 1).
- The top right chart provides a comparison of the current and proposed SRS masks.
- SRS Eye Mask Coordinates: X1, X2, X3, Y1, Y2, Y3

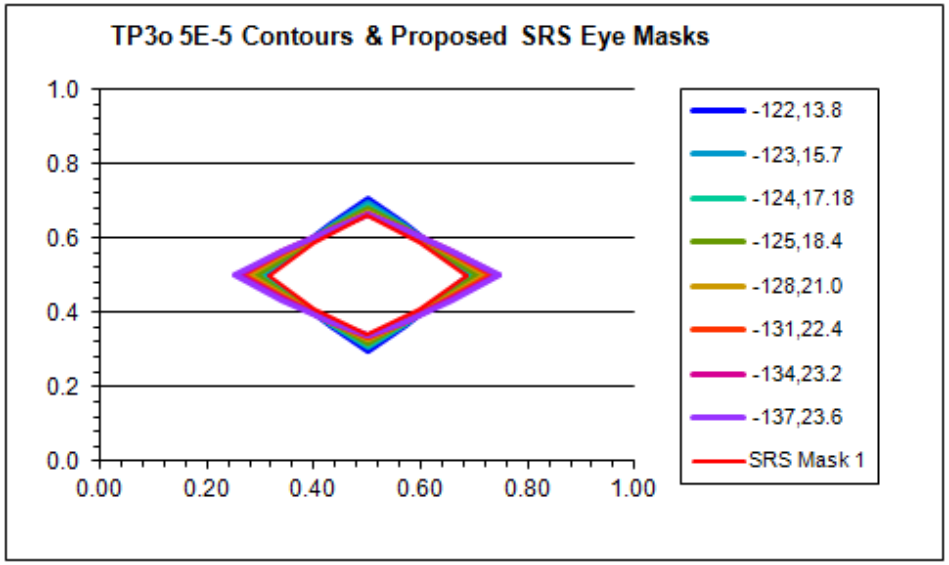
  Current: 0.28, 0.5, 0.5, 0.33, 0.33, 0.4

  Proposed: 0.315, 0.4, 0.5, 0.34, 0.41, 0.4

100G 100m SR4: Tx and SRS Eye Masks

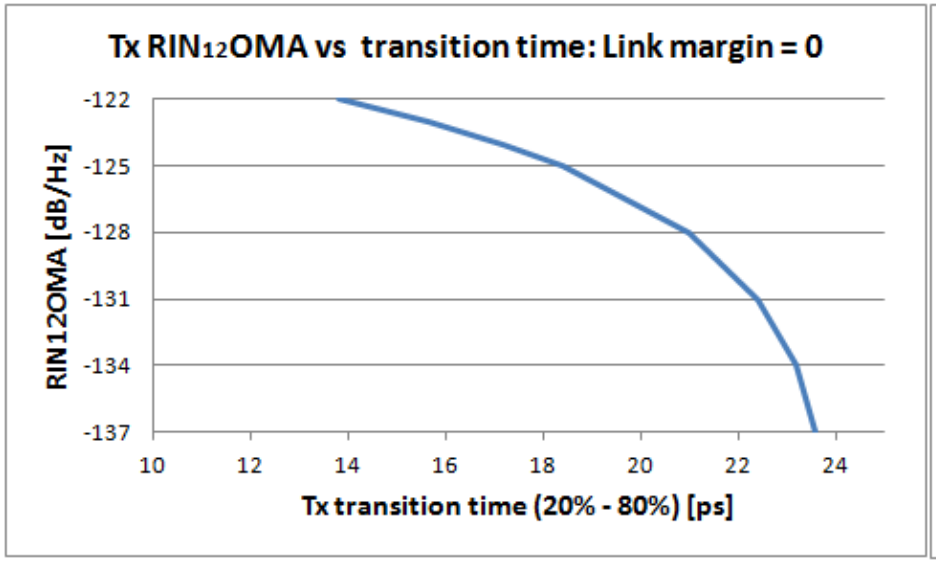


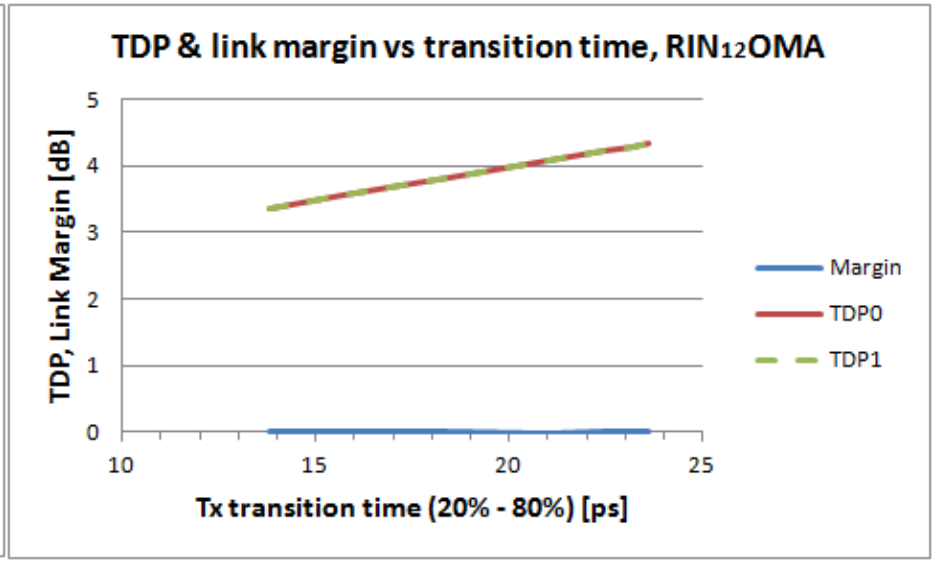




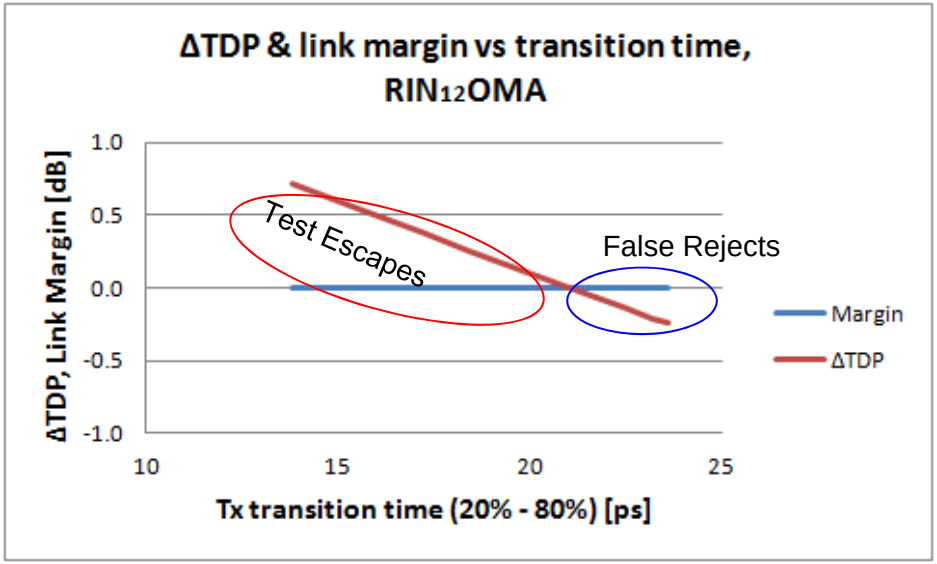
- The top left chart shows 5E-5 contours of the Tx output, TP2, and the proposed Tx eye mask
- The bottom left chart shows 5E-5 contours at the fiber output, TP3, and the proposed SRS eye mask
- The top right chart repeats the top left chart with the addition of the proposed SRS mask included for comparison.

100G 100m SR4: Attribute tradeoffs using TDP & Link Margin (1)

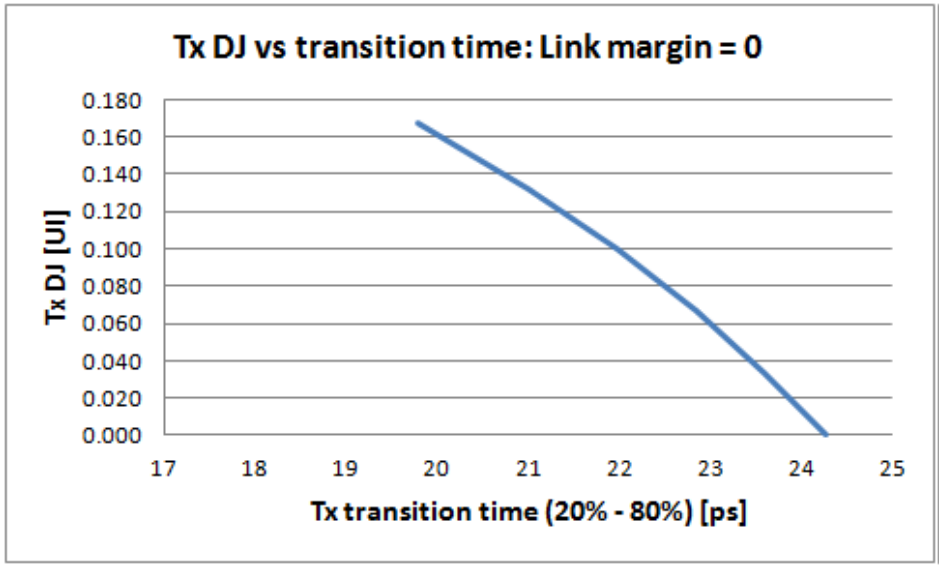


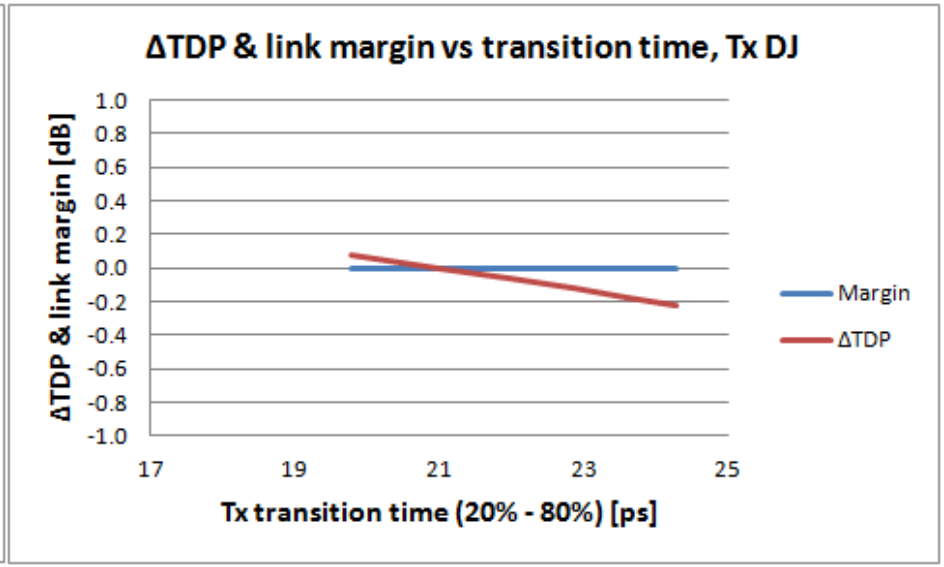


- The top left chart shows the tradeoff between Tx transition time and RIN12OMA using the Example Link Model when holding link margin constant at 0 dB. The values in the Example Link Model are transition time = 21 ps and RIN12OMA = -128 dB/Hz.
- The top right chart shows TDP values calculated for the combinations of transition times and RIN12OMA . Here TDP0 is for a 100 m reach case and TDP1 is for the test filter case. While the link margin is constant the TDP results are not, i.e. TDP does not tradeoff transition time and RIN as the link model does.
- The bottom right chart shows the deviation in link margin and TDP from the initial combination of transition time = 21 ps and RIN12OMA = -128 dB/Hz. Positive ΔTDP values may lead to test escapes and negative values may lead to rejecting acceptable units.



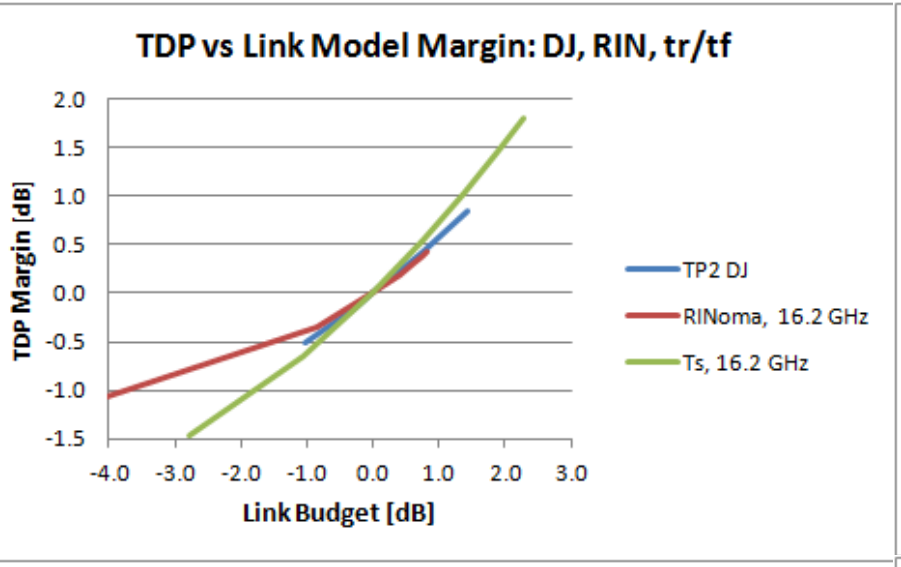
100G 100m SR4: Attribute tradeoffs using TDP & Link Margin (2)

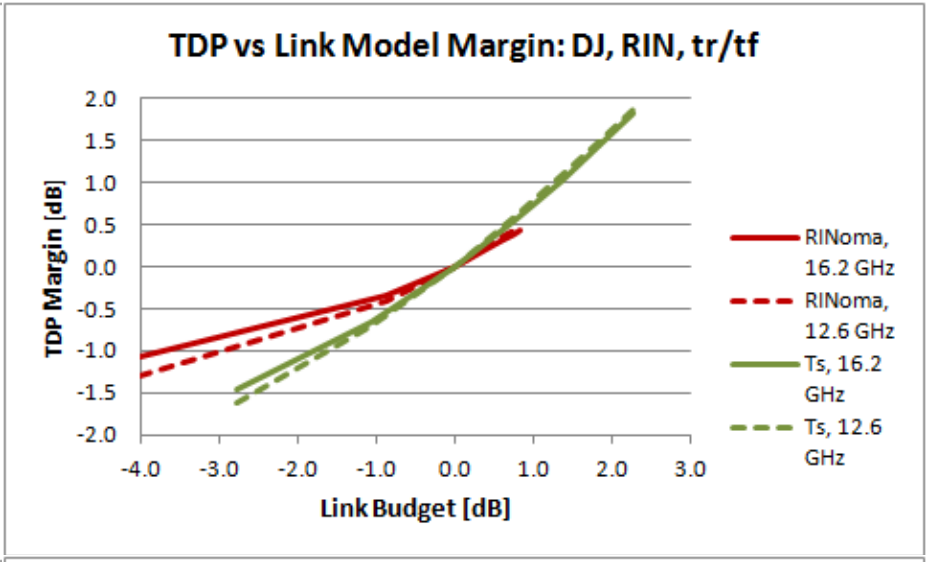




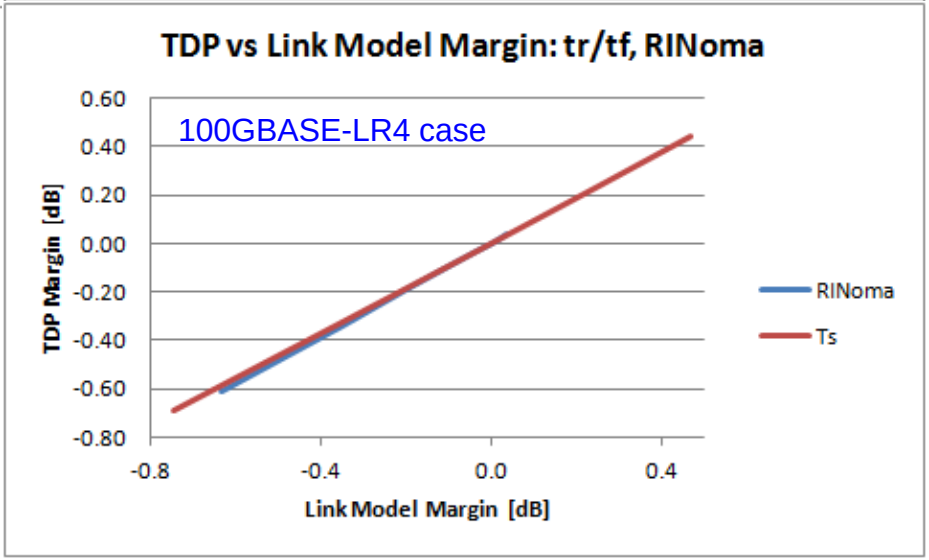
- Here the tradeoff between Tx transition time and Tx DJ is examined.
- Again, TDP does not provide the same tradeoff as the link model.

100G 100m SR4: TDP & Link Margin sensitivities

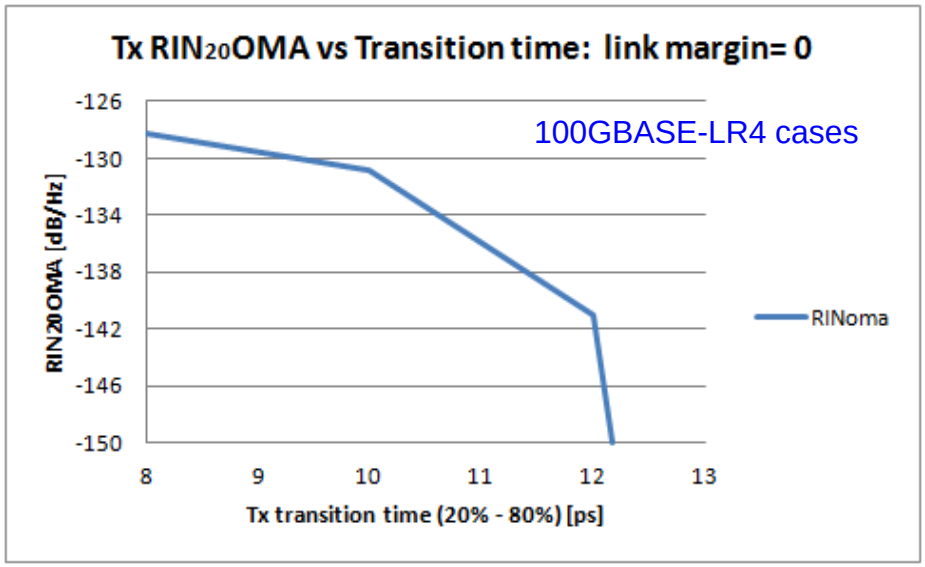


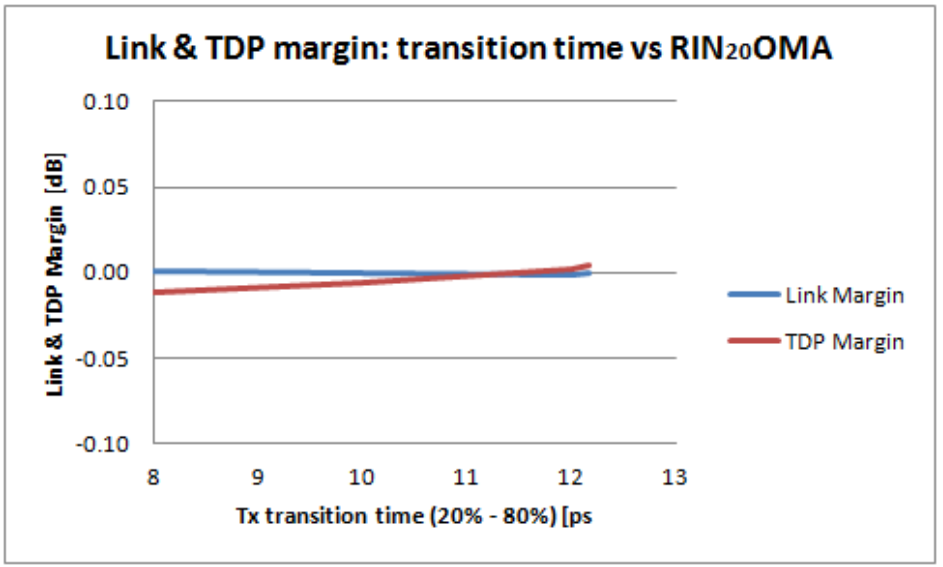


- Here attributes are examined individually for effect on link model and TDP margin. Then the effect on TDP margin is compared to the link model margin. For reference TDP was computed using 16.2 GHz and 12.6 GHz filters. In addition, SM cases were explored.
- The alignment of TDP with link margin is different for MMF cases with respect to SMF cases.
- The TDP MM filter bandwidth has an affect but it's not sufficient to resolve the problem.

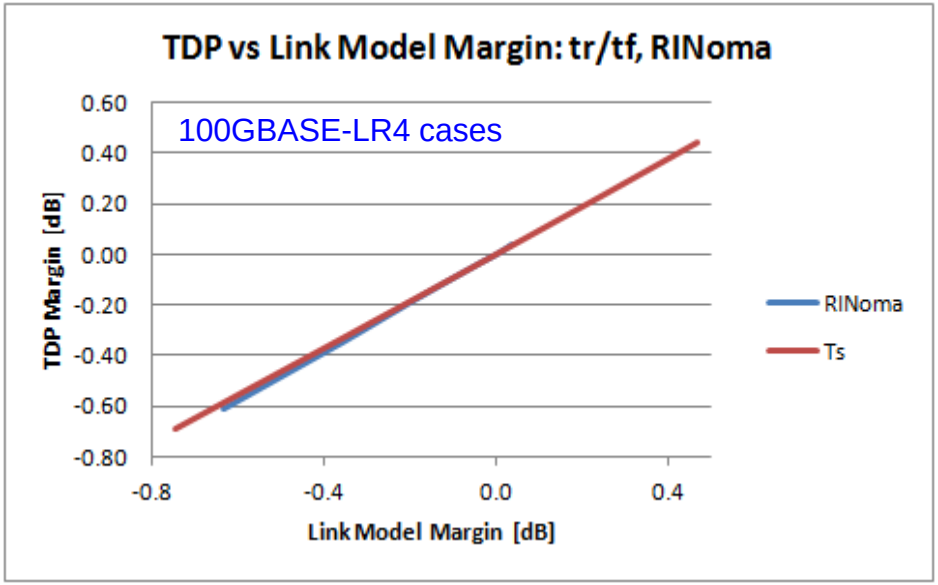


100G 100m SR4: SMF attribute tradeoffs using TDP & Link Margin

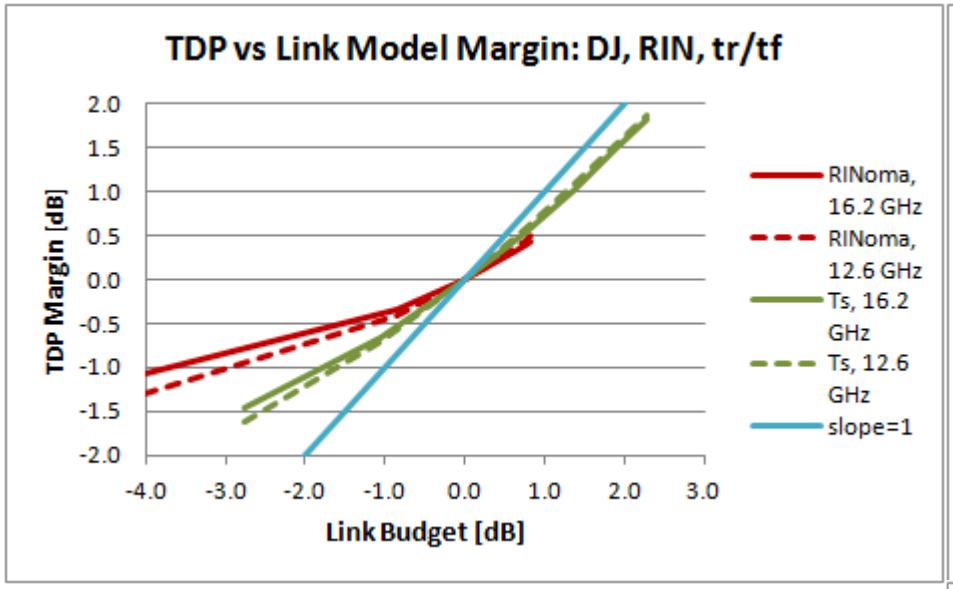


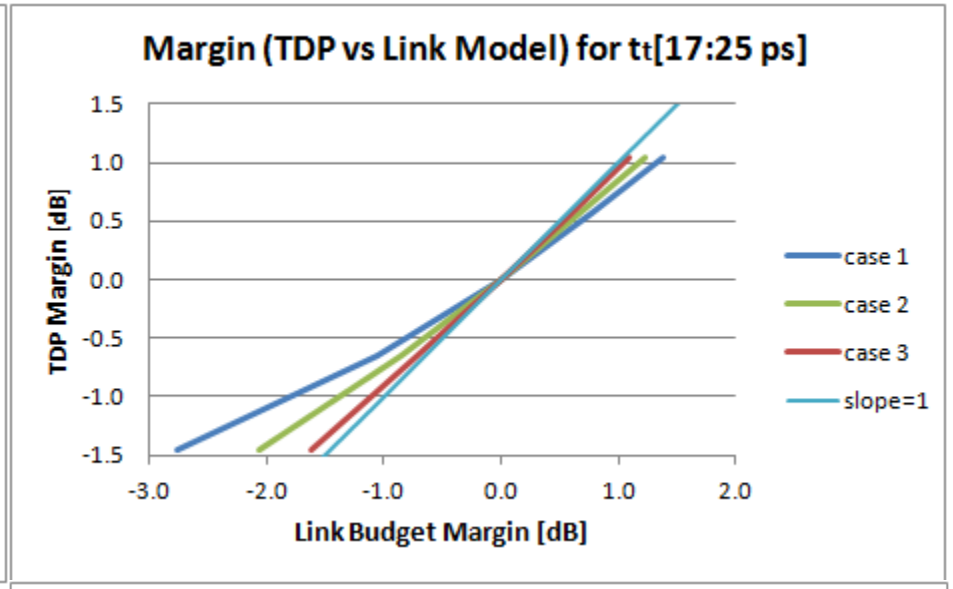


- Here relationships among link margin, TDP, transition time and RIN20OMA for SMF cases are explored.
- The top left chart shows the tradeoff between Tx transition time and RIN20OMA when holding link margin constant at 0 dB.
- The top right chart shows TDP margin calculated for the combinations of transition times and RIN20OMA . There appears little variation in TDP for SMF cases.
- The bottom right chart shows the deviation in link margin and TDP from the initial combination of transition time and RIN20OMA. Changes from varying transition time are labeled Tx and changes from varying RIN20OMA are labeled RINoma. Again, the change in TDP is very consistent with the change in link margin for SMF cases.

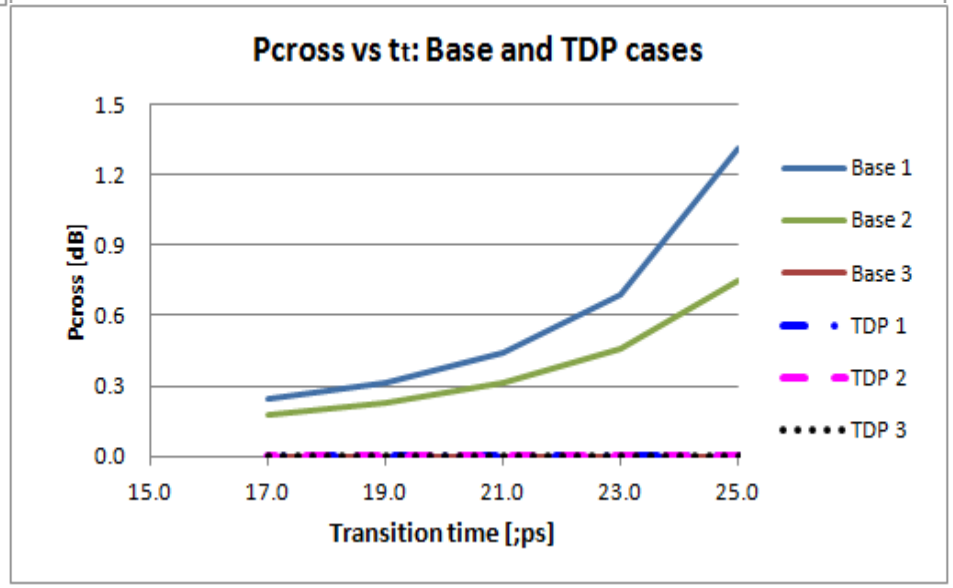


100G 100m SR4: Why MMF & SMF yield TDP differences

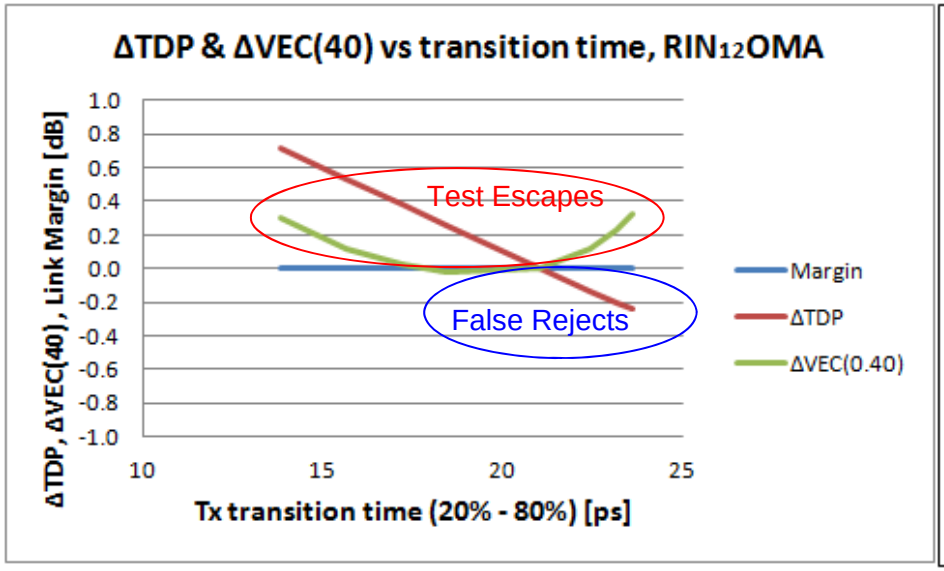


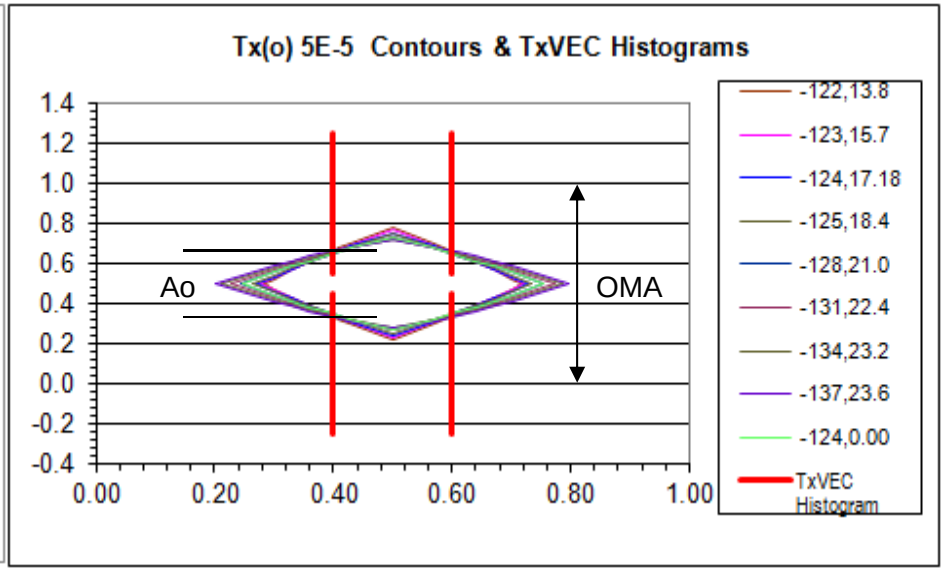


- Above it was shown that while SMF yields a one-to-one alignment between link model margin and TDP, MMF does not.
- The top left chart is a repeat of MM cases with a slope of one line added.
- The top right chart shows three link model cases: case 1 = original WC link model, case 2 replaces Rx from original link model with one with same jitter and BW as the Ref Rx in TDP test, case 3 = case 2 and zeroes out BLW, Pmn and Pmpn.
- As shown in the bottom right chart, the difference in link budget margin and TDP is due to absence of BLW, Pmn and Pmpn that are not captured in the TDP test and differences between the Ref Rx and WC Rx.



100G 100m SR4: A metric to replace TDP (1 of 4)





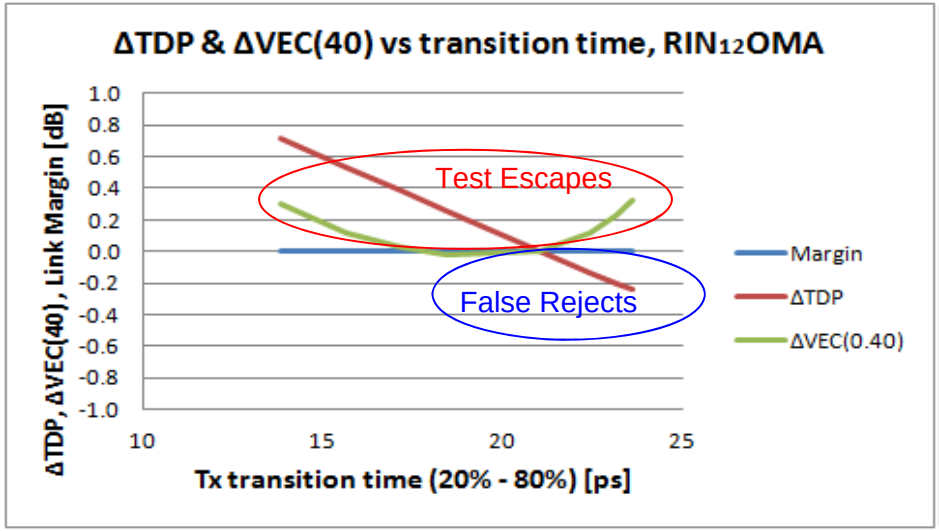
•The chart on the left indicates that a TxVEC metric, where TxVEC = 10Log10(OMA/Ao), can offer a better balance of test-escapes versus false-rejects than a TDP metric . Here histograms are taken at ± 0.10 UI offsets from the center of the eye. Ao is the vertical eye height between 5E-5 points on the histogram tails. OMA is the signal amplitude measured with the OMA measurement method.

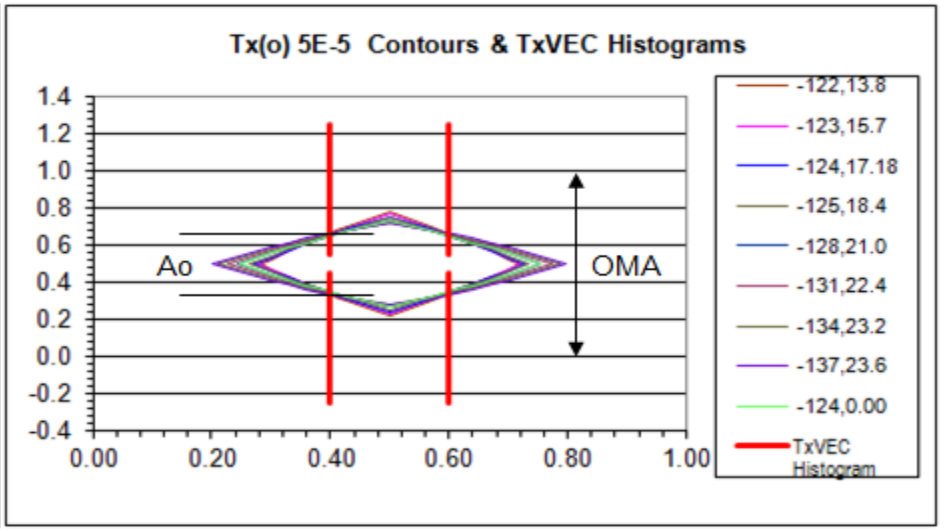
•The ΔVEC(0.40) line is based on deviation from TxVEC calculated for the Tx baseline condition of a 21 ps Tx transition time and a $RIN_{12}OMA$ of -128 dB/Hz. For this baseline condition TxVEC = 5.12 dB and based on this condition a TxVEC max = 5.1 dB is recommended.

•Note that there is no need for a reference transmitter for the TxVEC measurement. With the inability of TDP to predict link margin shown above, the use of a non-ideal Ref Tx to calibrate the Sensitvity of the Ref Rx is suspect.

•Also note that Fibre Channel uses a transmitter vertical eye closure metric for MMF transmitters and not TDP.

100G 100m SR4: A metric to replace TDP (2 of 4)





•Based on the new metric TxVEC, in Draft 2.0 replace

in Table 95-6, Transmitter and dispersion penalty (TDP), each lane (max) = 5 dB

with Transmitter vertical eye closure, each lane (max) = 5.1 dB

in Table 95-6, Launch power in OMA minus TDP (min) = -8 dBm

with Launch power in OMA minus TxVEC (min) = -8.1 dBm

in Table 95-6, Optical Modulation Amplitude (OMA), each lane (min)[b] = -7.1 dBm

with Optical Modulation Amplitude (OMA), each lane (min)[b] = -7.2 dBm

in Table 95-6, footnote b, Even if the TDP < 0.9 dB, the OMA (min) must exceed this value.

with Even if the TxVEC < 0.9 dB, the OMA (min) must exceed this value.

in Table 95-8, Power budget (for max TDP) = 8.2 dB

with Power budget (for max TxVEC) = 8.2 dB

in Table 95-8, Allocation for penalties (for max TDP) = 6.3 dB

with Allocation for penalties (for max TxVEC) = 6.3 dB

100G 100m SR4: A metric to replace TDP (3 of 4)

Proposed replacement text for 95.8.5

95.8.5 Transmitter Vertical Eye Closure

Transmitter Vertical Eye Closure (TxVEC) shall be as follows:

a) Each optical lane is tested individually with all other lanes in operation.

b) The transmitter is tested using an optical channel with an optical return loss of 12 dB.

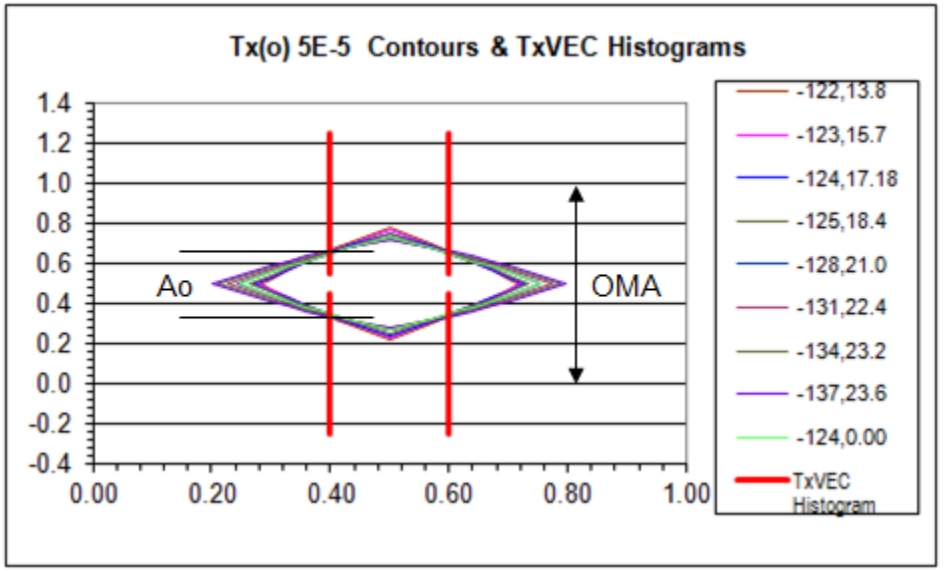
c) OMA shall be measured as defined in 95.8.4.

d) The transmit eye is observed as defined in 95.8.7 with the following exception: eye mask coordinates are not applied.

e) The transmitter optical waveform is measured for vertical eye closure (TxVEC), as defined in Equation (52-4) for vertical eye closure penalty, but evaluated at ± 0.1 UI from the eye center and Ao is the amplitude of the eye opening from the 99.995th percentile of the lower histogram to the 0.005th percentile of the upper histogram. Ao is the smaller of the two measurements.

f) The test setup illustrated in Figure 52-9 shows the reference method. Other measurement implementations may be used with suitable calibration.

g) TxVEC is defined for each lane, at the BER specified in 95.1.1 and is for the lane under test on its own. See 95.8.1.1 for multi-lane pattern considerations. NOTE—Sampling instant offsets have to be calibrated because practical receivers and decision circuits have noise and timing impairments. One method of doing this is via a jitter bathtub method using a known low-jitter signal.



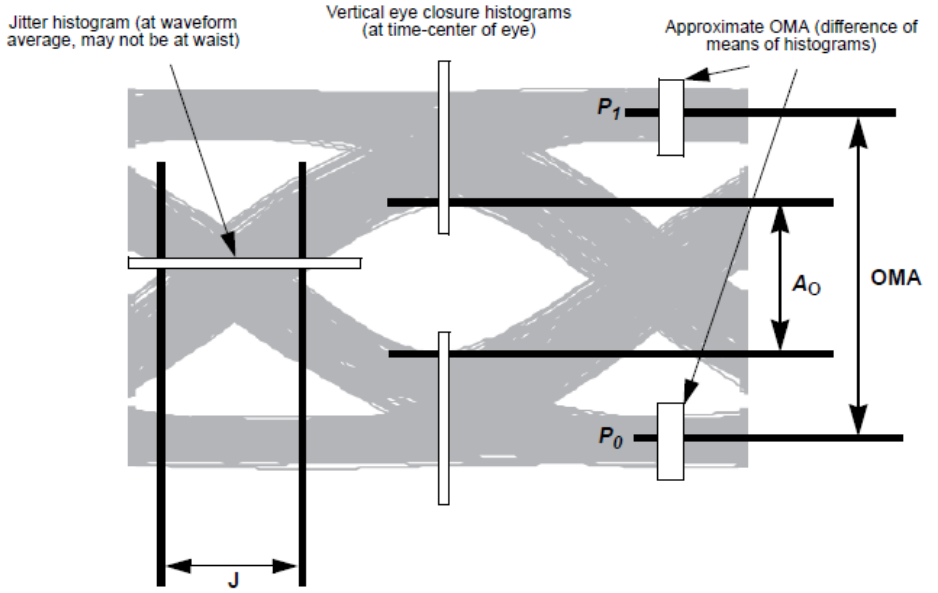


Figure 52–11—Required characteristics of the conformance test signal at TP3

100G 100m SR4: A metric to replace TDP (4 of 4)

Transmitter and dispersion penalty (TDP) Summary

•TDP results for MMF cases are not well aligned with margin calculations from the link model.

• TDP measurements require either an ideal reference transmitter or the ability to calibrate a reference for TDP with respect to the ideal. Since TDP results are not well aligned with link model margin, such a calibration now seems problematic. Underestimating the TDP of the Ref Tx is easy, perhaps common, permitting test escapes.

•TDP requires a reference receiver with a non-standard BW that will need setup and calibration.

•The complexities with TDP has limited its acceptance and use in the industry.

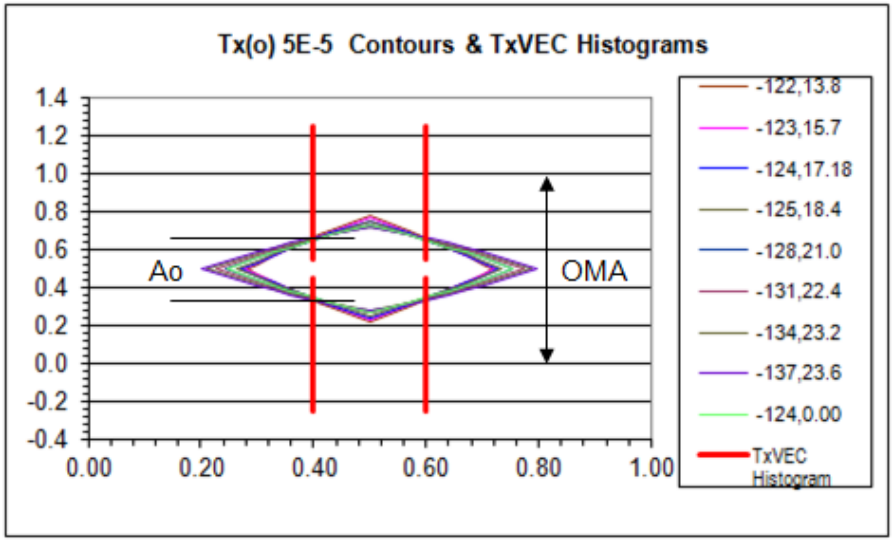
Transmitter Vertical Eye Closure (TxVEC) Summary

•TxVEC results for MMF cases are better aligned with link model margin than TDP results, promising a better balance of test escapes with rejecting acceptable devices.

•TxVEC does not require a reference transmitter.

•The Ref Rx for TxVEC can be an oscilloscope with a standard optical plug-in for the 25G signal rate.

•TxVEC uses the same test setup as the Tx eye mask test and same techniques as SRS VECP; no new equipment or techniques are needed.



•TxVEC provides better results for MMF cases than TDP while using a simpler and friendlier test setup that is more likely to be adopted in the industry.

•The simpler and friendlier test requirements for TxVEC make it a preferable test even if TDP provided comparable results.

•802.3bm should replace TDP with TxVEC.

Reference/Backup Material

Fiber Optic Links Interfaces

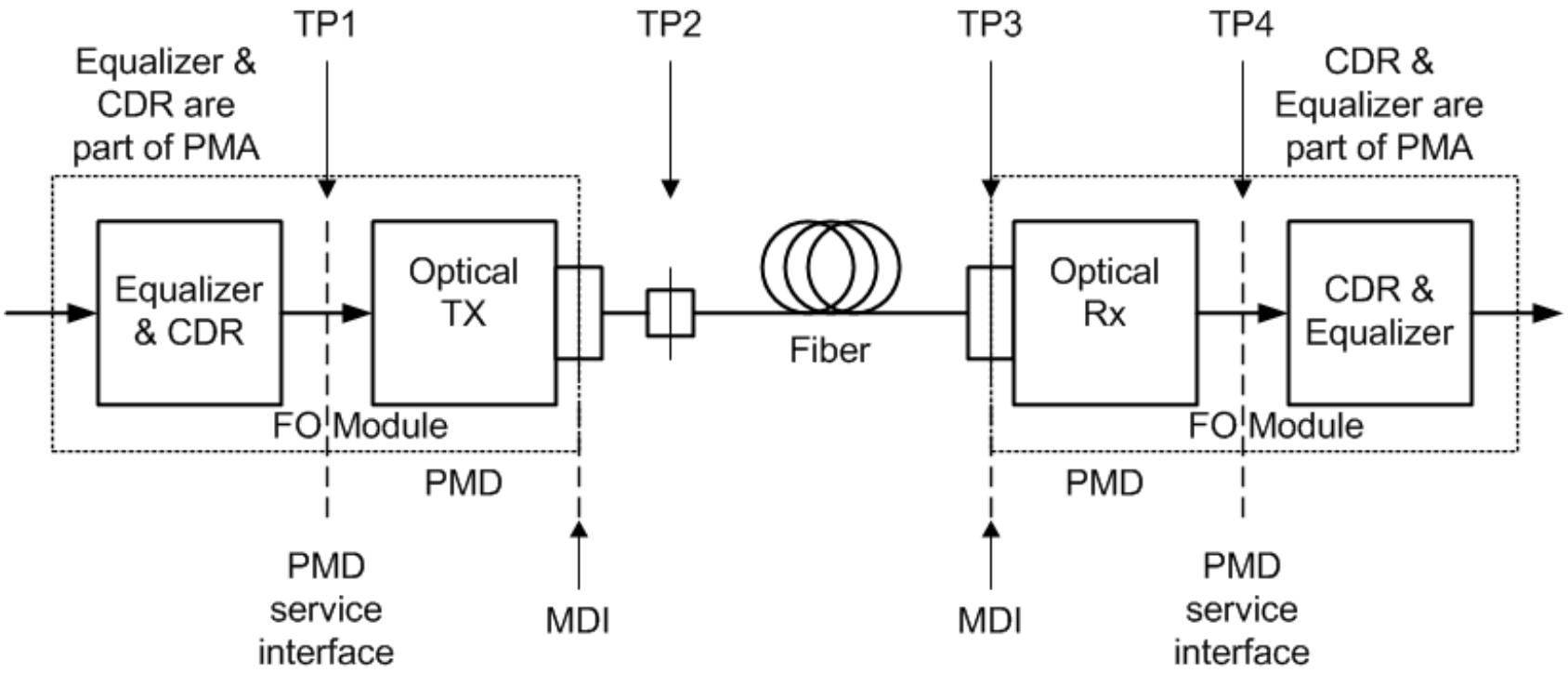


Figure 1

• For cases, as shown above in Figure 1, where retimers are embedded in the optical module, the PMD service interface is not exposed. TP1 and TP4 remain as points on the PMD service interface and, consequently, not exposed.

• The high speed signal inputs and outputs of the optical module are expected to be defined by CAUI-4.

100G SR4 with KR4 FEC: Example Link Model Tx Attributes (each lane)

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
Center Wavelength, min	nm	840	
Spectral Width, max	nm	0.60	
OMA at max TDP, min	dBm	-3.0	
Extinction ratio, min	dB	3.0	
Tx output transition times, 20% -80%, max	ps	21	
$RIN_{12}OMA$, max	dB/Hz	-128	
RIN coefficient		0.7	
MPN coefficient		0.3	
Modal Noise Penalty	dB	0.129	Scaled with Q^2
Tx reflectance, max	dB	-12	
Tx optical return loss tolerance, max	dB	12	

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations.

100G SR4 with KR4 FEC: Example Link Model Rx Attributes (each lane)

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
Center Wavelength, min	nm	840	
Rx sensitivity (OMA), max	dBm	-11.2	-8.63 dBm at Q = 7.034
Rx Bandwidth, min	MHz	18,047	
RMS base line wander coefficient		0.025	
Rx reflectance, max	dB	-12	

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations.

100G SR4 with KR4 FEC: Example Link Model Ch Attributes (each lane)

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.0E-5)	FEC corrects BER to < 1.0E-12
Reach	m	100	
Fiber Attenuation	dB/km	3.5	For 850 nm center wavelength
Dispersion min Uo	nm	1316	
Dispersion So	ps/nm^{2}km	0.10275	
Fiber modal bandwidth	MHz·km	4400	For 840 nm center wavelength, 4700 MHz·km at 850 nm
Reflection Noise Factor		0	
Signal power budget at max TDP	dB	8.20	Model output
Connector & splice loss allocation	dB	1.50	
Fiber Insertion loss	dB	0.36	Model output
Allocation for penalties at max TDP	dB	6.34	Model output Includes Peye
Allocation for target TP4 eye at max TDP	dB	0	1.88 dB included in Allocation for penalties at max TDP
Additional insertion loss allowed	dB	0	Model output

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations. Various model outputs are provided.

100G SR4 with KR4 FEC: Example Link Model Jitter Attributes (each lane)

Parameter	Unit	100G SR4	
Signal rate	GBd	25.78125	
Q (BER)		3.8905 (5.00E-5)	FEC corrects BER to < 1.0E-12
TP1 RJrms tolerance, min	UI	0.0079	
TP1 DJ tolerance, min	UI	0.11	
TP3 DCD tolerance, min	UI	0.05	
TP3 DJ tolerance, min	UI	0.243	
TP4 J2, max	UI	0.592	Model output
TP4 TJ at BER, max	UI	0.780	Model output

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations. Various model outputs are provided.

Nomenclature: Terms TP1, TP2, TP3 and TP4 are used as defined in 802.3 clause 86 and shown in above Figure 1. Note that TP1 is downstream of the input CDR and equalizer for an optical transmitter.

Eye Mask Coordinates Reference/Definition