Extending the 10GbE Link Model

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Link Model Presentation Overview

- Link/Channel Models
- The 10G Ethernet Link Model
- Extended 10GbE Link Model
- Sensitivity Analysis
- Applications
- Base Case
- Recommendations for clause 86 items

Link and/or Channel Models

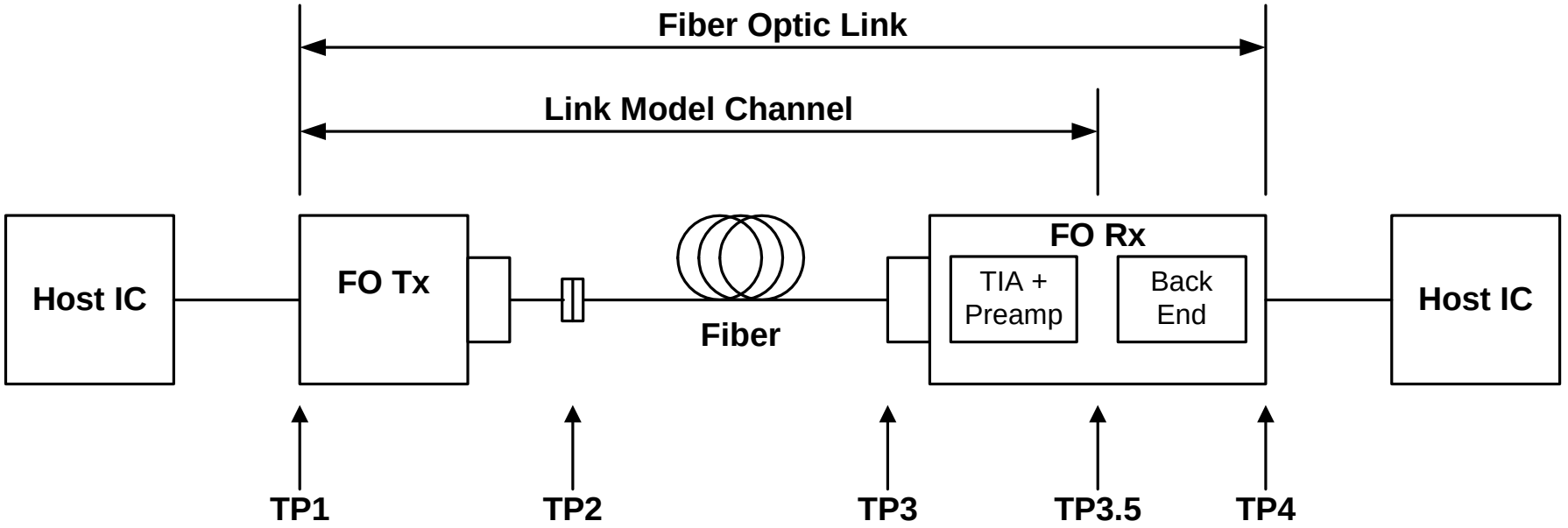
- Link and/or Channel models have value in
  - determining requirements for blocks comprising channel
  - setting specifications for interfaces in standards
  - comparing options
  - analyzing worst cases and/or yields
  - de-embedding DUT results from test set-ups
  - verifying designs.

The 10G Ethernet Link Model

The link model (hereafter 10GbE) used in development of 10G Ethernet (10GEPBud3_1_16a.xls) is available at the IEEE P802.3ae 10Gb/s Ethernet Task Force Serial PMD documents website http://www.ieee802.org/3/ae/public/adhoc/serial_pmd/documents/ .

One of several available discussions, The 10G Ethernet Link Model, is available at the IEEE HSSG website http://www.*ieee802.org/3/hssg/public/nov06/dawe_01_1106.pdf* . This presentation includes an extensive list of references.

Link Model Definition



- Fiber optic link and component specifications are often based on a link definition similar to that shown above. Shown in the above figure are functional link blocks and interfaces between blocks. In general, for standards, specifications apply at the interfaces. This can provide the basis for inter-operability among independently produced components.

- Ethernet has used the terms TP1, TP2, TP3 & TP4 for the interfaces. TP3.5 is added to represent better the decision point, that is, the end of the channel for the 10GbE model where penalty accounting is performed.

Extended 10GbE Link Model

Incentives for extension

- The 10GbE link model primarily addresses 10GbE compliance points, TP2 & TP3, and doesn't include effects of source RJ at TP1 and DJ added between TP3.5 and TP4 nor calculates the open eye width at TP4.
- Including the above effects provides a model that can be used to estimate jitter at any interface between TP1 and TP4, generate/evaluate eye masks and other aggregate attributes such as TDP.
- System and board designers are also interested in electrical signals and signal quality at TP1 and TP4.
- Without a means to link power penalties and jitter, jitter and power budgets are often not well harmonized.
- 802.3ba has decided to specify TP1 and TP4 as well as TP2 and TP3.

Extended 10GbE Link Model

Extension Overview

- An extended version, 10GbEx, of the industry standard 10GbE link model, 10GEPBud3_1_16a.xls has been developed. The extension adds a calculation for TP4 open eye width, hereafter eye-width, and provides means to include random jitter input at TP1, RJ_{TP1}, and DJ generated between TP3.5 and TP4.

  The extension is based on the concept that random amplitude noise, for which the 10GbE model calculates power penalties, is the source of RJ generated within the link. That is, the accumulated random noise of RIN, modal noise, mode partition noise and the noise of the receiver is transformed into RJ, RJ_{ch}, by the non-vertical edges of the signal waveforms during transitions between high and low states. For consistency the accumulated power penalties that close the eye in the vertical dimension are used to determine the eye closure due to RJ in the horizontal dimension.

10GbE Link Model - Assumptions

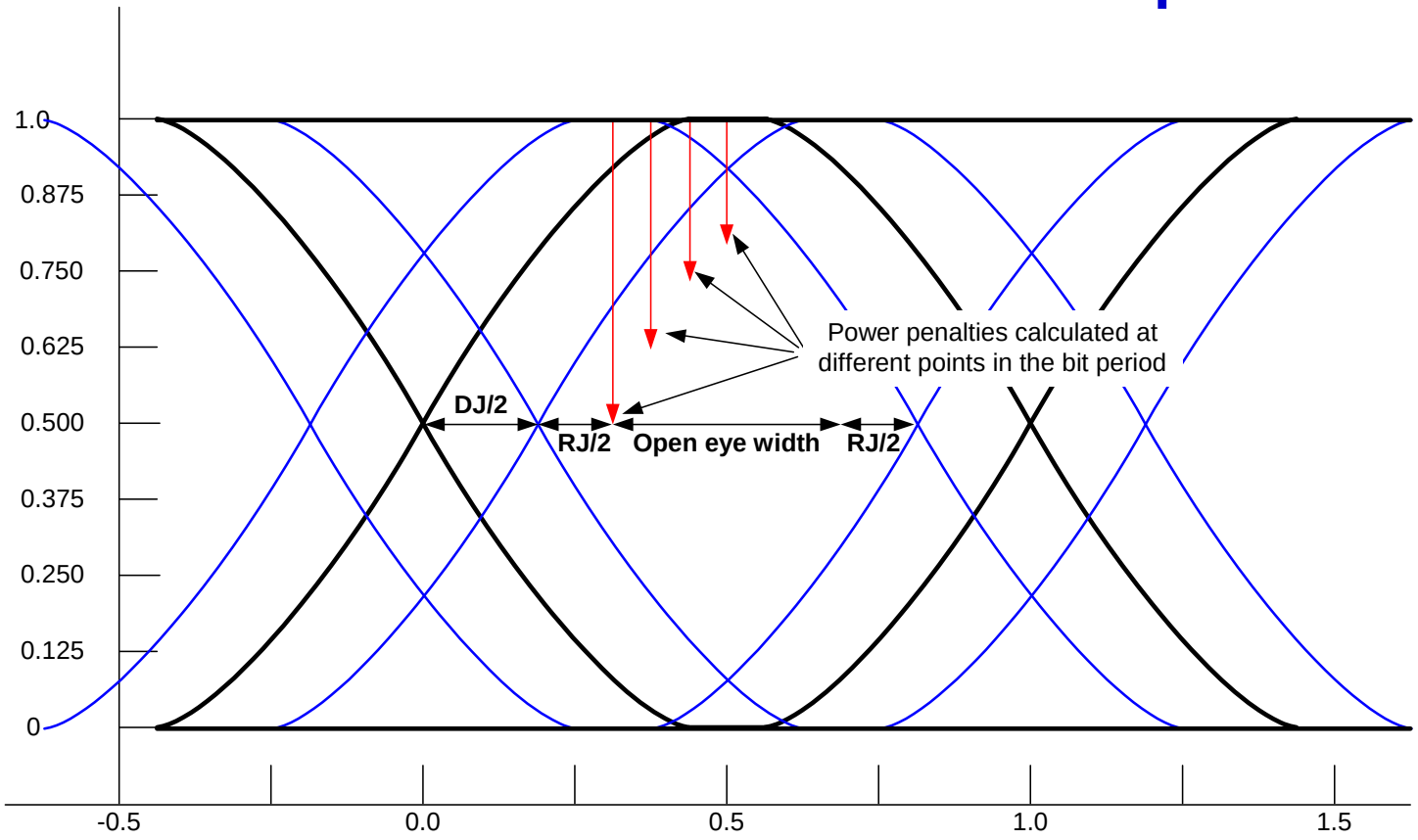
- Transmitters have a Gaussian impulse response with a similar step response for rising and falling edges.
- Fibers have a Gaussian impulse response.
- Receivers have a non-equalized, raised-cosine response.
- The reference (or test) receiver has a 4-th order Bessel-Thomson (BT) response at 7465 MHz.
- Modal noise introduced by partial optical mode coupling in the cable plant is limited to a noise penalty, Pmn, of 0.3 dB by limiting the maximum connector loss to 1.5 dB.
- RIN is white over the frequency range of interest.

Additional Assumptions for Extension

- Jitter at the interfaces can be partitioned into random, RJ, and deterministic, DJ, components using Dual Dirac jitter methods. For the rest of this presentation, DJ refers to Dual Dirac DJ.
- The signal (amplitude) noise in the optical link is transformed into random (Gaussian) jitter by the non-vertical edges of the signal transitions.
- Input referred receiver noise is Gaussian.
- At the corners of the eye opening, the vertical closure due to the power penalties and signal loss coincides with the horizontal closure due to jitter.
- Receiver sensitivity includes the minimum output swing requirements for the receiver.

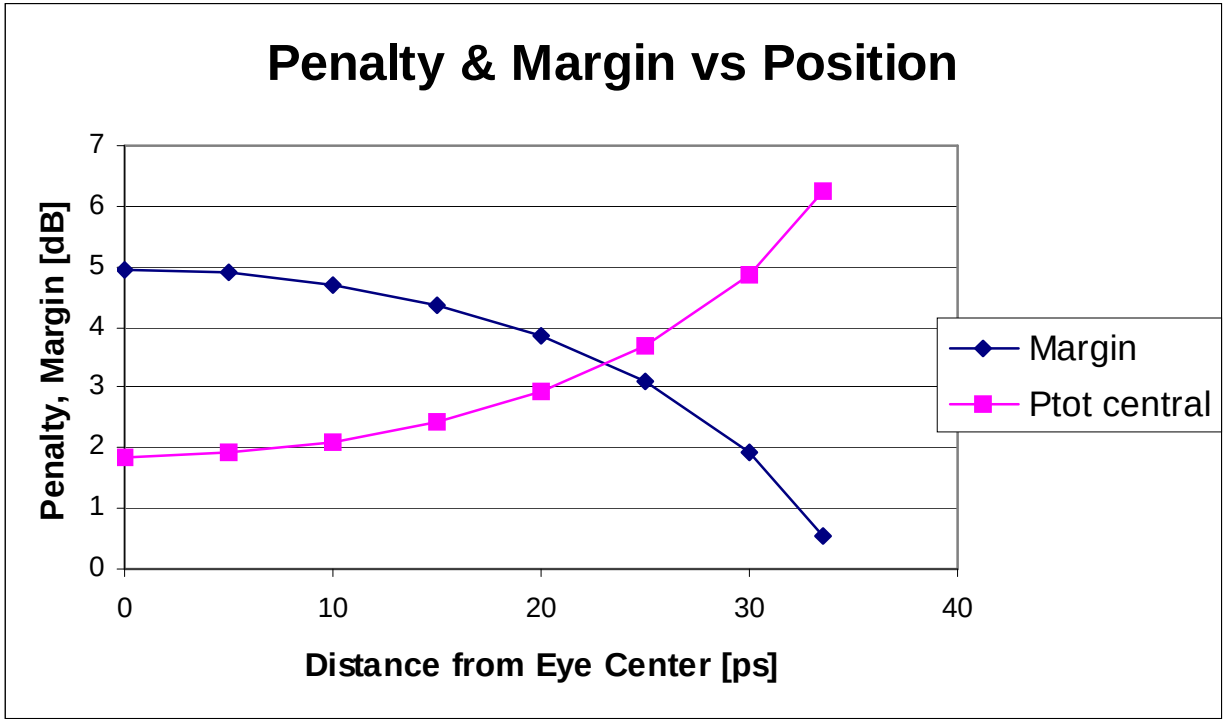
Extended 10GbE Link Model

RJ Generation Concept



- **Above, power penalties are calculated moving away from the center of the eye until the power penalties equal the signal magnitude. This defines the end point of the open eye for a 10^{-12} BER contour.**
- **For total penalties, Pt(ew/2), and displacement from the center of the eye, ew/2, find ew/2 where P(ew/2) = Power Budget – (Connector Loss +Pattenuation).**

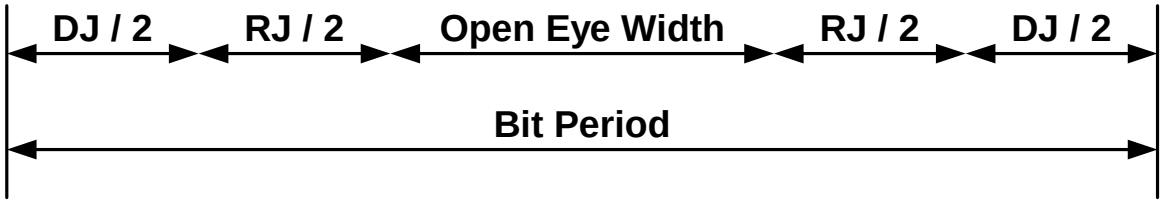
Extended 10GbE Link Model - Penalties



The above chart shows the effect on accumulated penalties and link margin as the accounting point is displaced from the center of the eye. For this example the link parameter values are found below. On following pages, charts showing the sensitivity of RJch to various model attributes are provided. One set shows the effect of an attribute with all other noise sources except the Rx input noise deactivated while the other has all noises sources active.

Extended 10GbE Link Model

Accounting at TP3.5



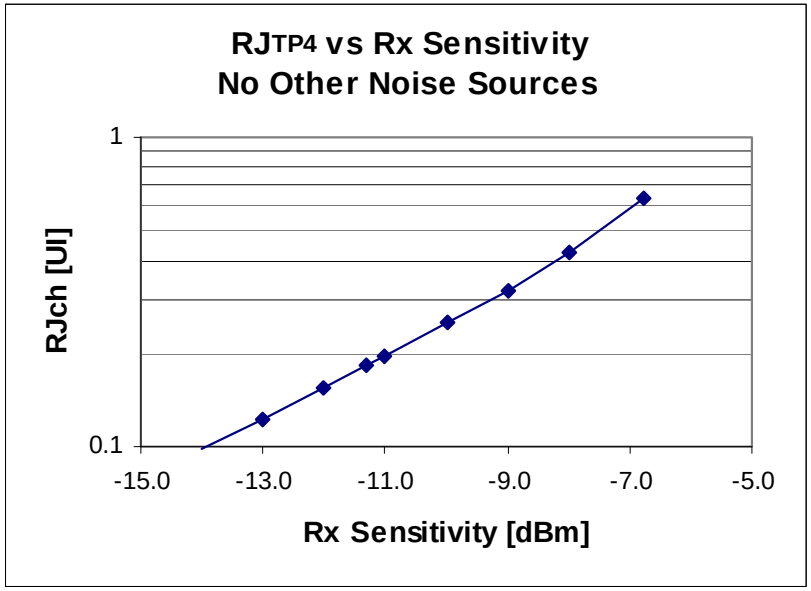
- Unit bit period = 1 = TJ + Eye-width = DJ + RJ + Eye-width.
- The bit period comprises only three terms. What isn't DJ or open eye-width is RJ. Since DJ, including DCD, is allocated, it is known. Then, all that is needed is to determine eye-width or RJ.
- The 10GbE model determines power penalties for the fiber optic channel from TP1 to TP3.5 but doesn't include the RJ present at TP1, RJ_{TP1}, and DJ, DJ_{Rx}, generated between TP3 and TP4. Consequently, first RJ generated between TP1 and TP3.5, RJ_{ch}, will be determined from the associated power penalties and then combined with RJ_{TP1} to yield RJ_{total}. Then TJ, TJ_{TP4}, and the eye width at TP4 will be determined as follows.
- $RJ_{total} = RJ_{TP4} = Sqrt(RJ_{ch}^2 + RJ_{TP1}^2)$
- $TJ_{TP4} = DJ_{TP3} + DJ_{Rx} + RJ_{total}$
- $Eye\text{-}width_{TP4} = 1 - TJ_{TP4}$

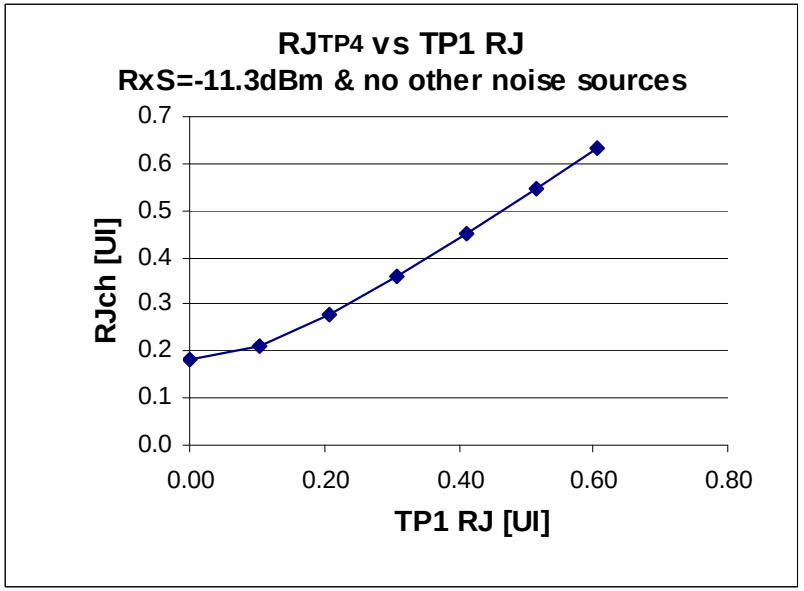
Extended 10GbE Link Model

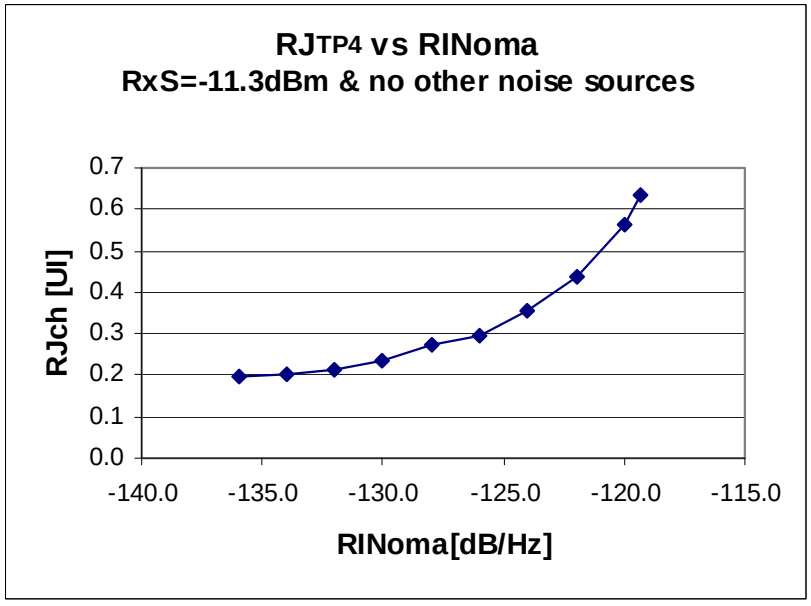
Why not use the corner penalties determined by 10GbE?

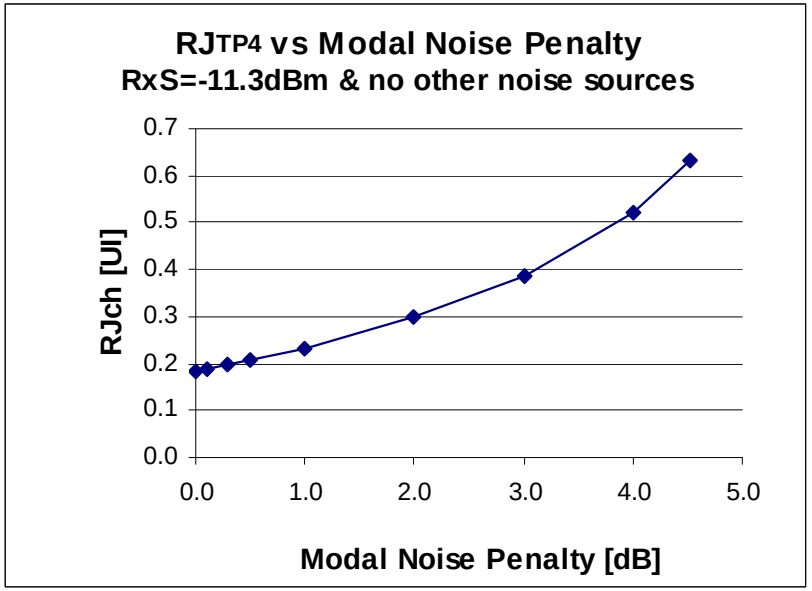
- 10GbE provides <Ptotal corners (cells U18:38), why not use that?
- The difference between Ptotal central (cells T18:38) and Ptotal corners is a step in the right direction. Unfortunately, the Ptotal corner is based on Tx mask X2, cell C13 which is not necessarily set to represent the desired eye opening at TP4. Further, the calculation of Ptotal corner, while including a Pcross penalty (Pcross central cells S18:38), only calculates the penalty at the center of the eye and not at the corner. If these shortcomings are addressed, then, Ptotal corners should be useful.

10GbEx RJ sensitivity charts 1/4

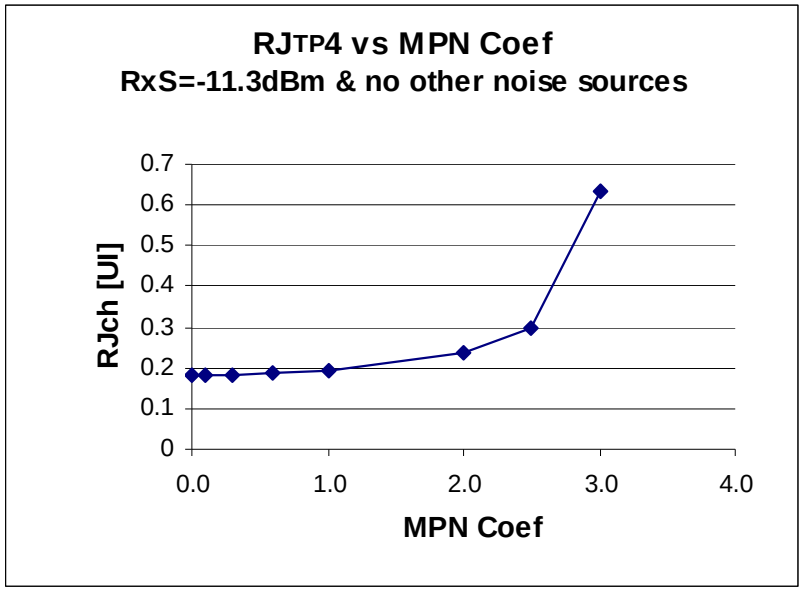


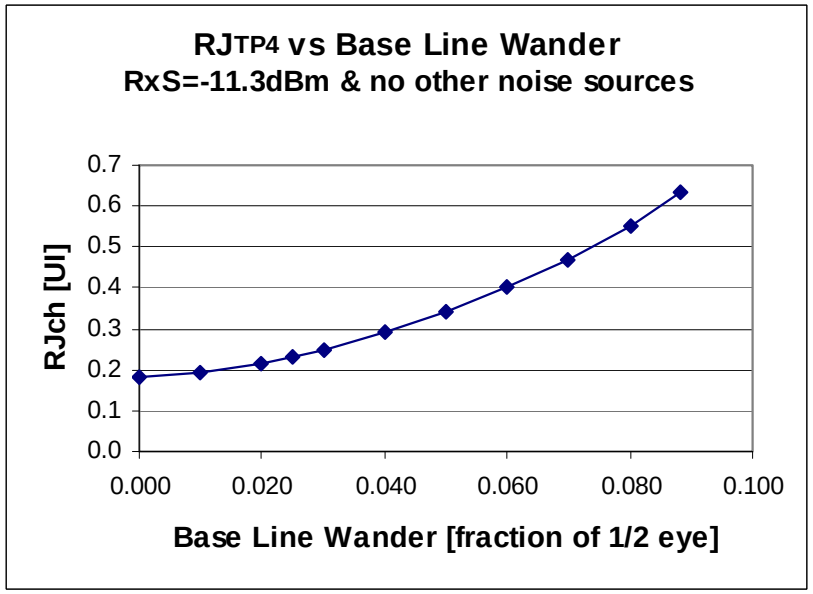


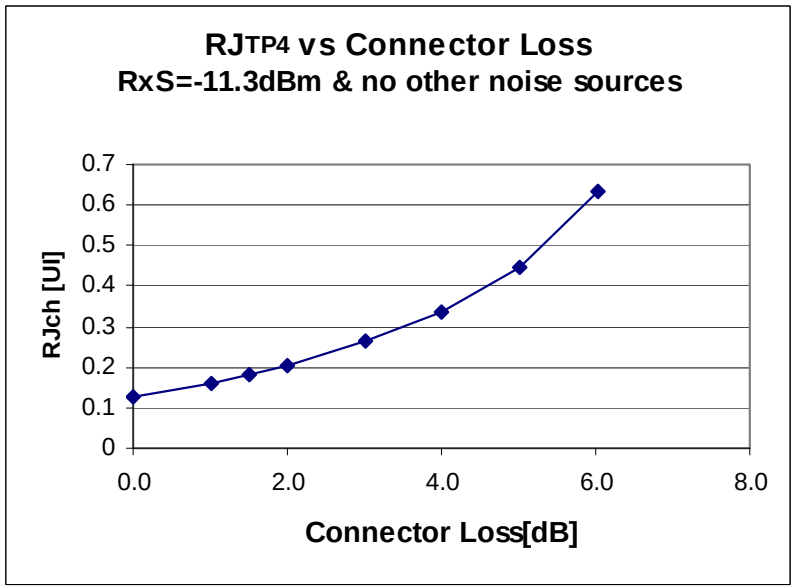


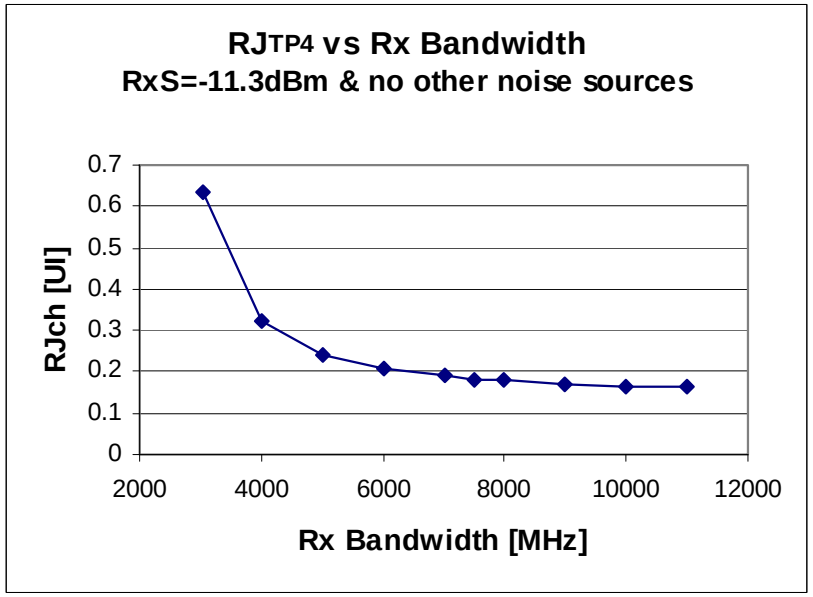


10GbEx RJ sensitivity charts 2/4

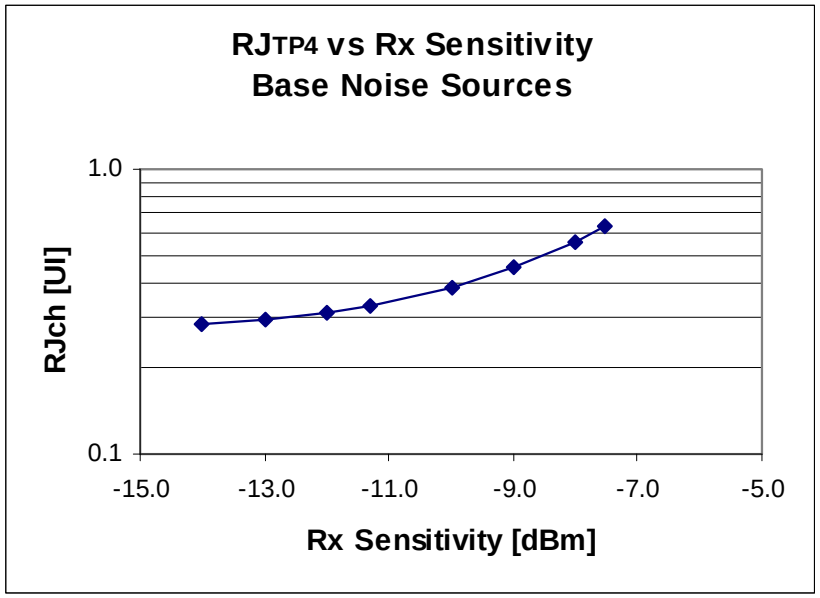


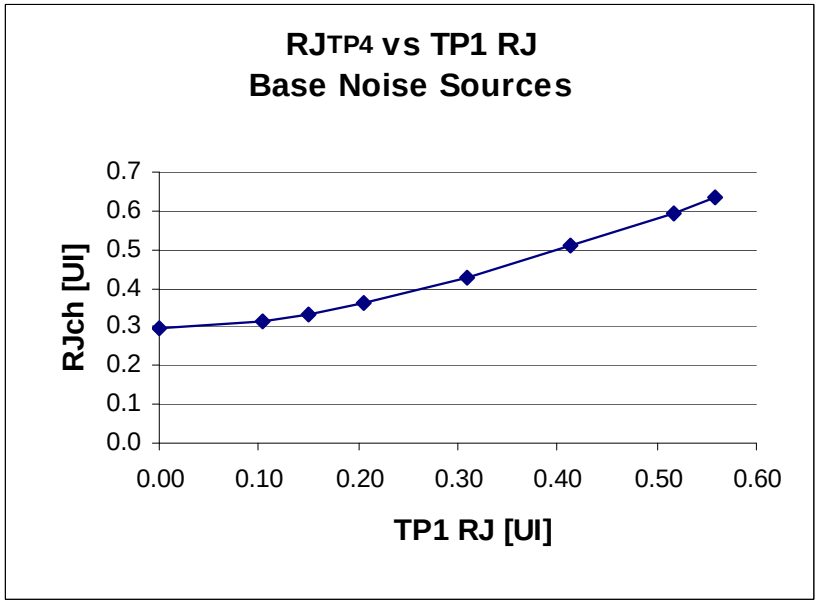


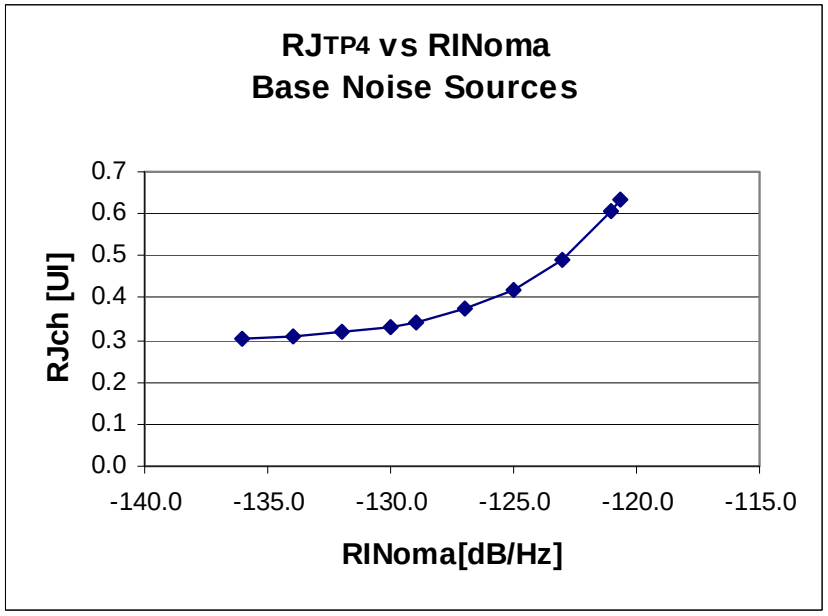


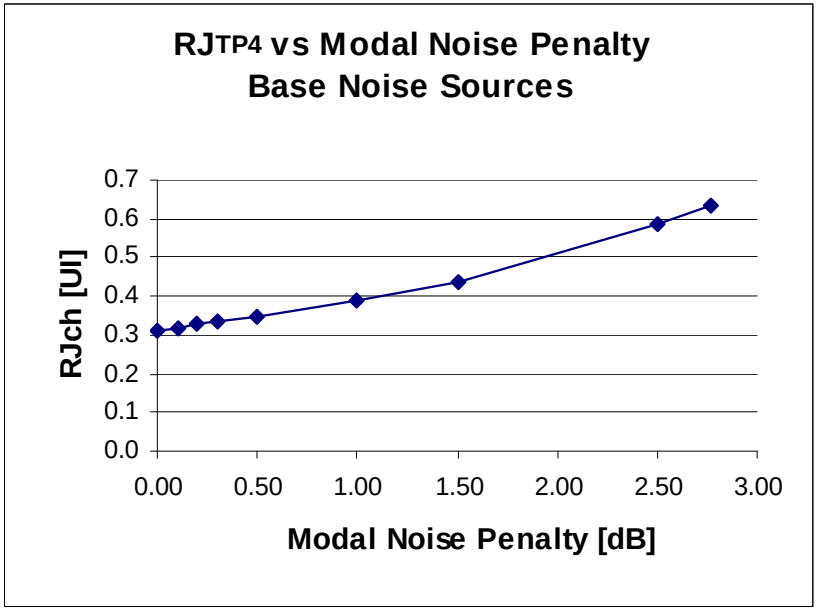


10GbEx RJ sensitivity charts 3/4

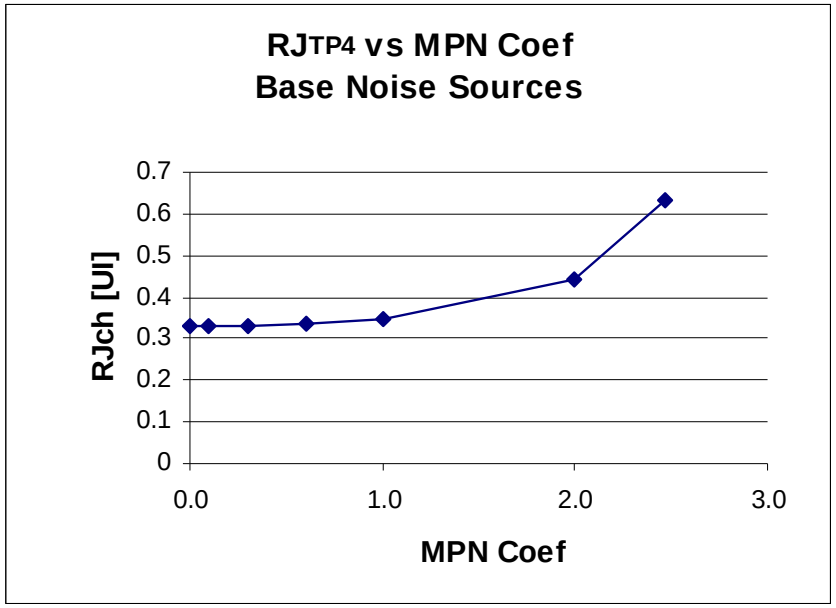


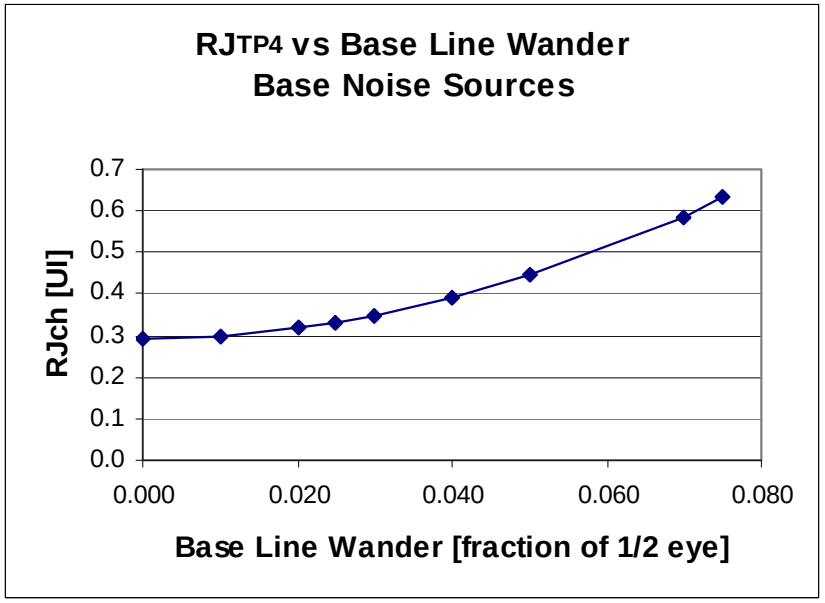


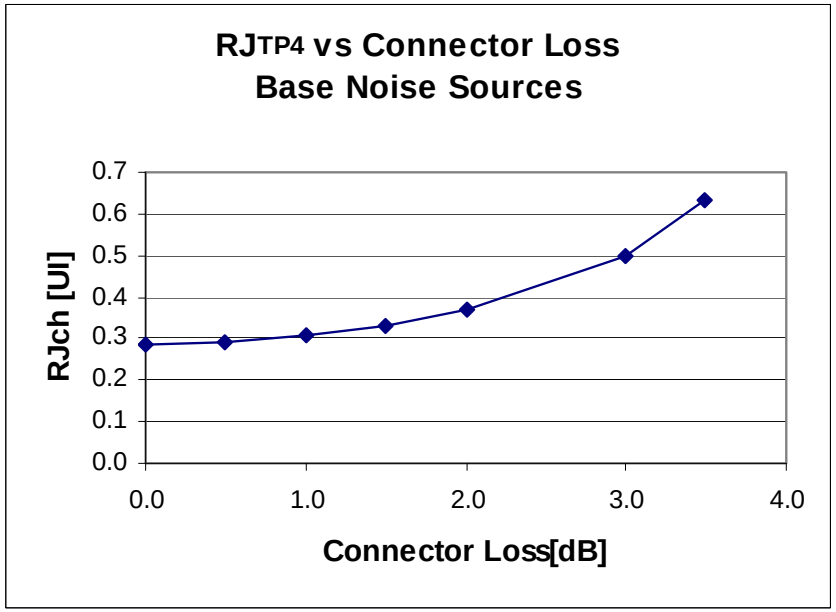


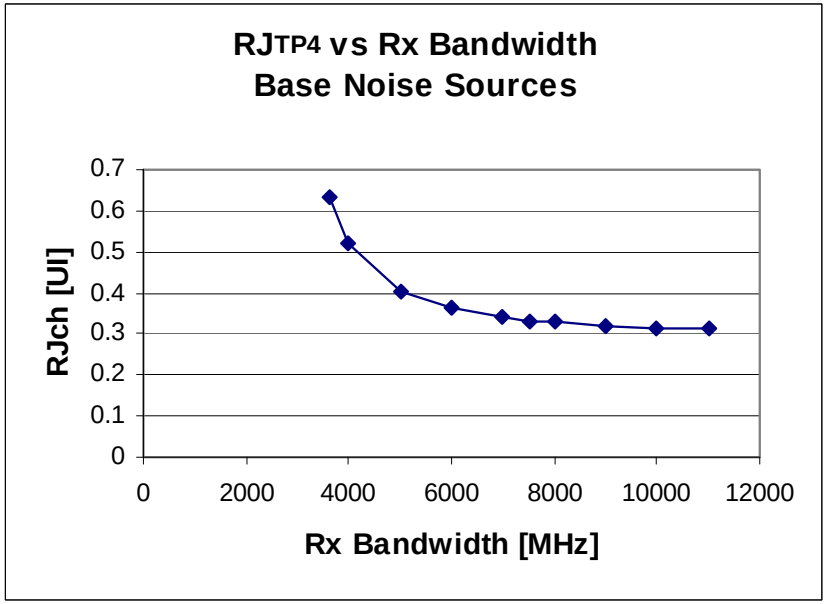


10GbEx RJ sensitivity charts 4/4









Extended 10GbE Link Model
Application: Determine RJ at TP2 & TP3

1. For a given set of link attributes (initially Tx, Cable Plant (CP), Rx and DJ allocations), determine $RJ_{TP3.5}$ at TP3.5 using the above extension.
2. Replace the CP and Rx with a Ref-CP and Ref-Rx and repeat step 1 to determine RJ_{Refch} at the end of the reference channel. Here Ref-Rx is assumed to be the optical front end of a DCA-J or comparable test equipment and Ref-CP is assumed to be a short 2 m to 5 m patch cord with no cable or connector losses. Then the only noise sources in the reference channel are RIN from the Tx and Ref-Rx input noise and the resultant RJ, RJ_{Refch}, is due to this combination .
3. Set RIN_Coef (cell G6) to zero and repeat step 2. Now the only noise source in the reference channel is the Ref-Rx input noise and the resultant RJ, $RJ_{Ref\text{-}Rx}$, is due to the Ref-Rx. Using the result, RJ_{Refch}, from step 2, the RJ contribution from the Tx, RJ_{Tx}, can be determined.
4. Replace the Ref-CP with CP, reset RIN_Coef (cell G6) to 0.70 and repeat step 1. Now the calculated RJ includes the effect of the cable plant. $RJ_{Ref\text{-}Rx}$ and RJ_{Tx} from step 2 can be backed-out, yielding RJ_{CP}.
5. Replace the Ref-Rx with Rx, and repeat step 4. As above, RJ from the Tx and CP can be backed-out, yielding RJ_{Rx}.

40GBASE-SR4 & 100GBASE-SR10 Proposal

Link Model Transmitter Attributes (Each Lane) – Base Case

- **Min OMA: -3.0 dBm**
- **Min ER: 3.0 dB**
- **Min Center Wavelength: 840 nm**
- **Max RMS Spectral Width: 0.65 nm**
- **Max Transition Time (20%, 80%): 35.6 ps**
- **Max RIN12OMA: -130 dB/Hz**
- **RIN Coefficient: 0.70**
- **Mode Partition Noise Coefficient: 0.30**
- **Min Optical Reflection Tolerance: -12 dB**
- **TP1 Jitter Allocation: TJ = 0.300 UI, DJ = 0.150 UI**
- **TP2 Jitter Allocation: TJ = 0.488 UI, DJ = 0.284 UI**

40GBASE-SR4 & 100GBASE-SR10 Proposal

Link Model Receiver Attributes (Each Lane) – Base Case

- **Max Sensitivity: -11.3 dBm**
- **Min Bandwidth: 7500 MHz**
- **RMS Base Line Wander: 0.025**
- **Max Rx Reflection: -12 dB**
- **TP3 Jitter Allocation: DJ = 0.284 UI, DCD = 0.103 UI**
- **TP3 Jitter Allocation: TJ = 0.511 UI**
- **TP4 Jitter Allocation: TJ = 0.700 UI**
- **TP4 Jitter Allocation: DJ = 0.367 UI**

40GBASE-SR4 & 100GBASE-SR10 Proposal

Link Model Channel Attributes (Each Lane) – Base Case

- **Signal Rate: 10.3125 GBd**
- **BER: < 10^{-12} (Q = 7.034)**
- **100 m of OM3**
- **1.5 dB connector loss allocation**
- **Signal Power Budget: 8.3 dB**
- **Attenuation = 0.36 dB**
- **Center Eye Penalties**
  - **Pisi = 1.45 dB**
  - **Pdj = 0.22 dB**
  - **Pmn = 0.30 dB**
  - **Pmpn = 0.02 dB**
  - **Prin = 0.15 dB**
  - **Pcross = 0.14 dB**

Extended 10GbE Link Model
TBDs and open items

The Extended 10GbE link model can address the following open items in clause 86.

1. **Table 86-6, TP1a DJ: Max from blank to 0.15**
2. **Table 86-10, Stressed Rx Sensitivity (OMA) from TBD to -5.4 dBm (This level supports a TP4 eye width of 0.30 UI.)**
3. **Table 86-10, Vertical eye closure penalty from TBD to 1.67 dB**
4. **Table 86-10, Stressed eye jitter from TBD to 0.37 UI**
5. **Table 86-13, Allocation for penalties from TBD to 6.8 dB**