Systematic Jitter Allocation & Eye Mask Definition

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Presentation Overview

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- Extended 10GbE Link Model (Reference)
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Systematic Approach Proposition

Conclusions, Clause 86 Comments Summary

- It has been shown, petrilla_02_1108 and petrilla_03_1108, that a link model can be used to determine jitter at interfaces of interest as well as define Rx-requirement-based Tx eye masks. Further, jitter and eye masks can be defined in terms of TJ, J2, J9 or 5E-5 hit ratios in a consistent and balanced manner. Finally, stressed Rx sensitivity conditions, J and VECP can be determined.
- Comment 416: See page 13. SRS = -5.4 dBm, VECP = 2.0 dB, J (J2) = 0.35 UI.
- Comment 418: See pages 7 & 11. TP4 X1 = 0.26 UI.
- Comment 425: See pages 11 & 12. Here there's an update to the remedy proposed in 425: TP1 X1 = 0.10 UI & TP2 X2 = 0.27 UI.
- Comment 427: See page 9 & 10. Here there's an update to the remedy proposed in 427. For a 5E-5 hit ratio, X1 = 0.20 UI, X2 = X3 = 0.33 UI & Y1 = Y2 = 0.33 UA.

Systematic Approach Proposition

- Jitter Allocation: An extended 10GbE link model can be used to convert noise penalties into jitter at each interface of interest. See petrilla_02_1108. This reconciles jitter allocations with power penalties and permits balancing the burden at the various interfaces. It also permits a more appropriate determination of the jitter used for the stressed receiver test set-up.
- Eye Mask: An extended 10GbE link model can be used to define Tx eye masks that ensure better than required signal characteristics at Rx inputs while minimizing unneeded burdens. See petrilla_03_1108. By only requiring what is needed by the downstream receiver, neither the Tx nor the Rx face an unnecessary or disproportionate burden.

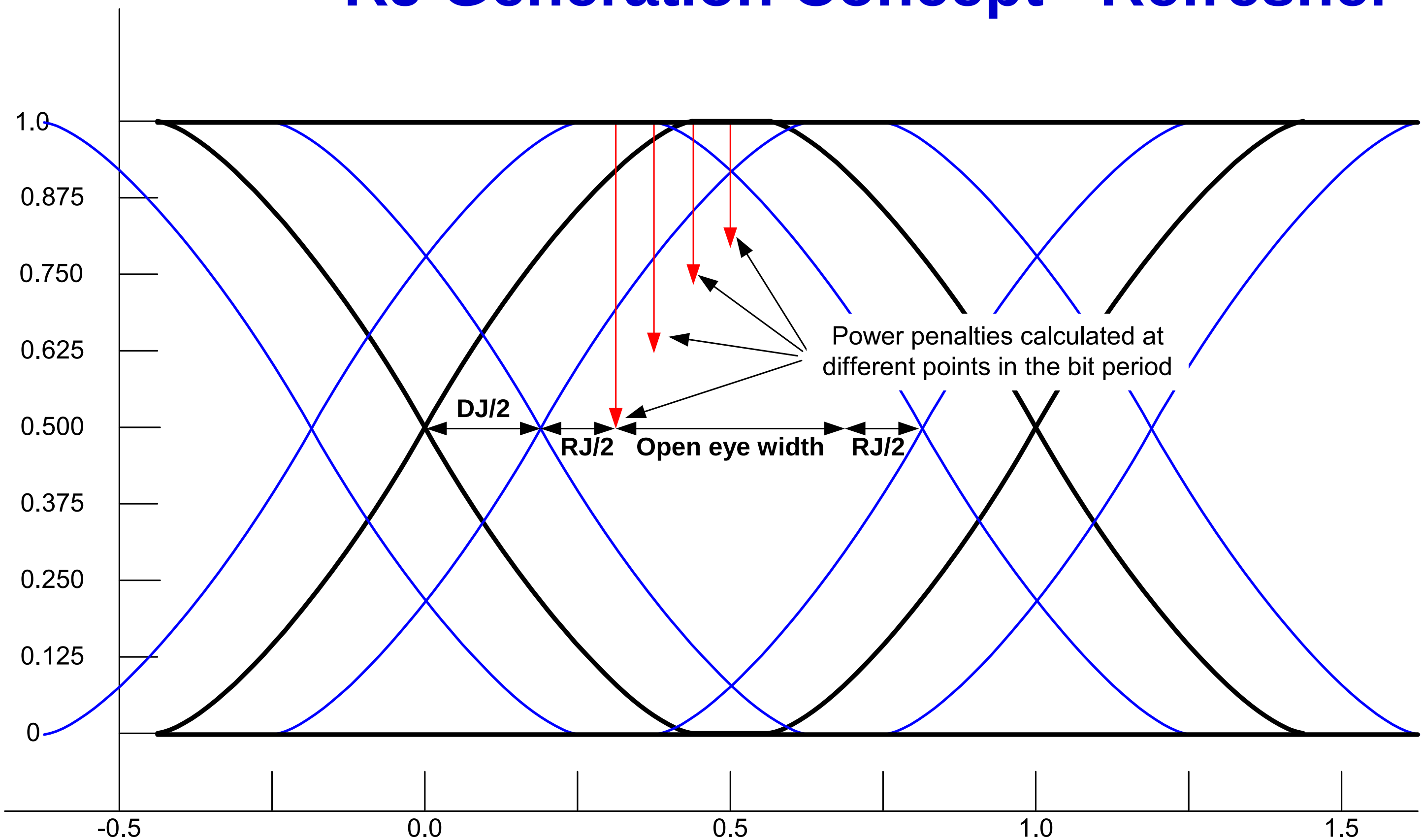
Systematic Approach Question

- Question: Should eye mask coordinate specifications include expected artifacts of the measurement equipment since it is difficult to de-embed these effects from test results?
- Proposal: Jitter, being one-dimensional, permits easier de-embedding of test equipment artifacts than the two-dimensional nature of eye displays. Consequently, while jitter specifications can be written without including consideration of test artifacts, it appears advantageous to define mask coordinates with a minimum performance level reference test system.

  Herein, for eye diagrams, as an example of a minimum performance reference test system, a sampling scope was assumed with a timing uncertainty of 0.2 ps RMS, electrical sensitivity and BW that provide no significant impairment and an optical sensitivity of -14.5 dBm and BW of 7.5GHz. A BW requirement for an eye mask tests is already common practice.

Extended 10GbE Link Model

RJ Generation Concept - Refresher



- Above, power penalties are calculated, using relationships in the 10GbE model, 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 Pt(ew/2) = Power Budget – (Connector Loss +Pattenuation).

Jitter Allocation / Budget - Base Case*

Without Observation Impairments - Proposed

		TP1	TP2	TP3	TP4
DJ(δ δ)	UI	0.132	0.266	0.266	0.349
RJ	UI	0.131	0.193	0.234	0.325
TJ	UI	0.263	0.460	0.500	0.674
J9	UI	0.260 #	0.434	0.470	0.631
5E-5 HR	UI	0.204	0.373	0.396	0.529
J2	UI	0.180	0.337	0.352	0.468

* Base case has been updated for newly proposed TP1 allocations, see anslow_04_0109.
# Proposed value, 0.260 UI, does not fit the model which yields 0.246 UI.

For all the interface points as shown in the above table, the extended 10GbE link model can, from allocated dual-Dirac DJ and TP1 RJ, determine values for TJ, J9, J2 as well as the 5E-5 hit ratio proposed for eye masks. This systematic approach ensures consistency among the various interfaces and between the various jitter measures. The above values do not reflect any impairment due to test artifacts.

The TP1 J9 value in anslow_04_0109, appears as an anomaly (notice the lack of separation from TJ) and should be reviewed. Here a value of 0.246 UI is proposed.

Jitter Allocation / Budget - Base Case*

With Observation Impairments - Reference

		TP1	TP2	TP3	TP4
DJ(δ δ)	UI	0.132	0.266	0.266	0.349
RJ	UI	0.134	0.239	0.273	0.326
TJ	UI	0.266	0.505	0.539	0.675
J9	UI	0.263 #	0.473	0.503	0.632
5E-5 HR	UI	0.206	0.398	0.417	0.529
J2	UI	0.181	0.354	0.366	0.468

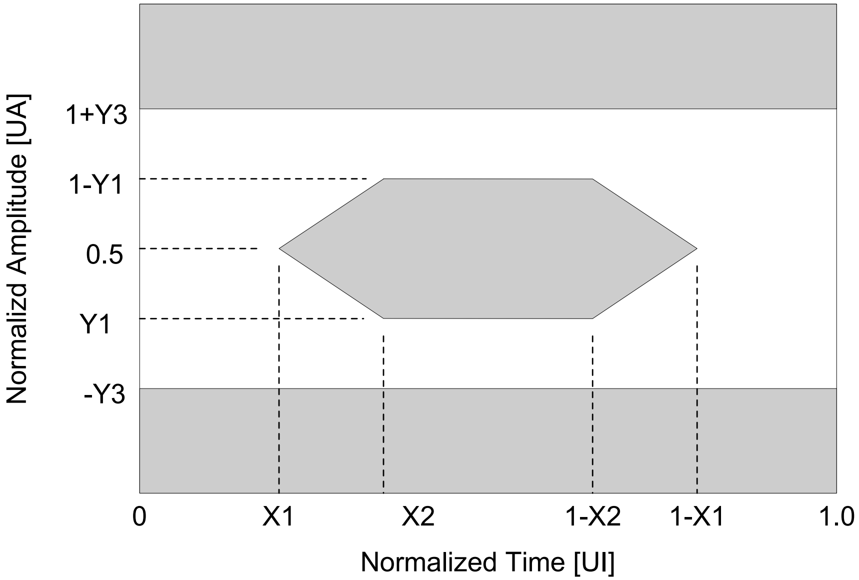
* Base case has been updated for new TP1 allocations.

Proposed value, 0.263 UI, does not fit the model which yields 0.248 UI when considering test artifacts.

The extended 10GbE link model can also determine the effect of impairments due to test equipment with known characteristics. Here, for example, a sampling scope was assumed with a timing uncertainty of 0.2 ps RMS, electrical sensitivity and BW that provide no significant impairment and an optical sensitivity of -14.5 dBm and BW of 7.5GHz. Such a system can be used as a reference test or minimum performance set-up. A comparison with the previous table shows that values at TP1 and TP2 for electrical signals are little affected but the difference for optical signals at TP2 and TP3 can be significant.

TP2 Eye Masks

Hit Ratio & Tester Effect Cases

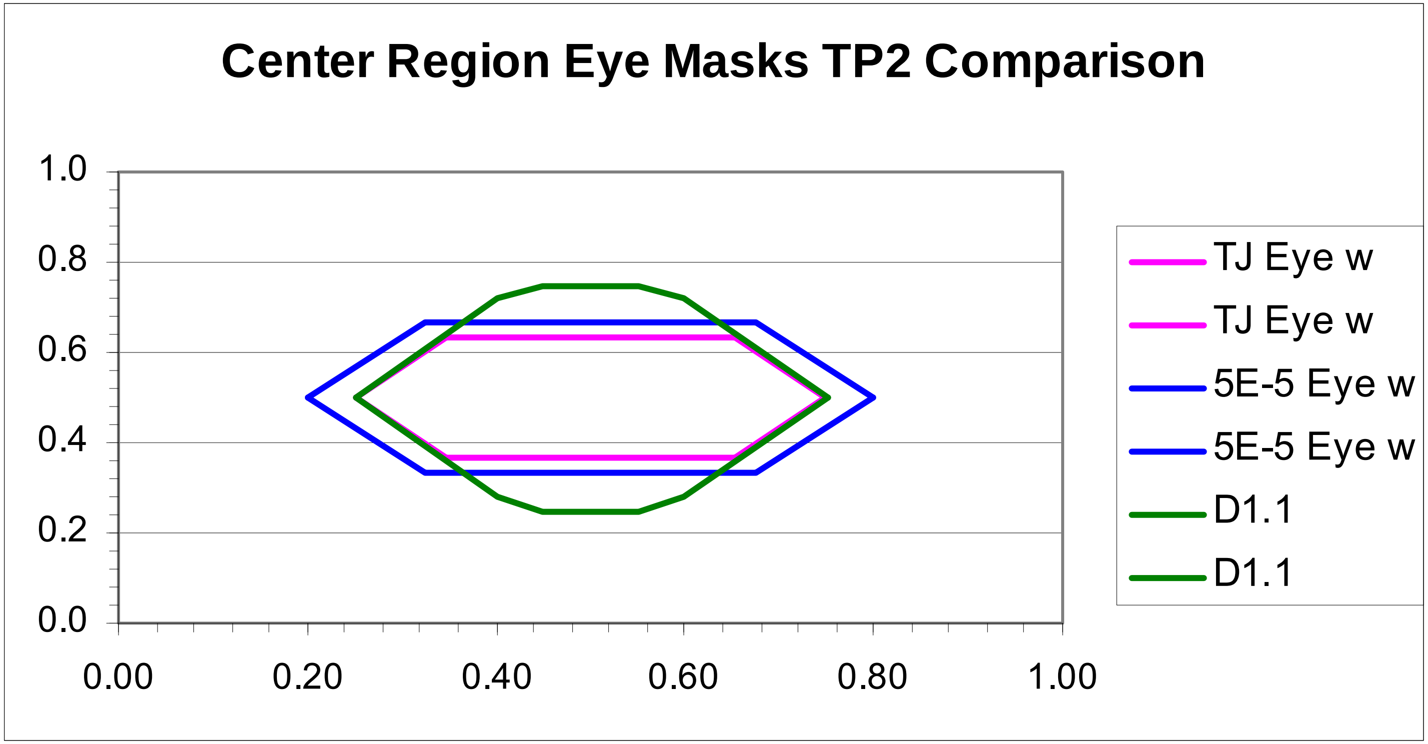


	TP2 TJ w/o Test Rx effect	TP2 TJ with Test Rx effect	TP2 5E-5 HR w/o Test Rx effect Reference	TP2 5E-5 HR with Test Rx effect Proposed
X1, UI	0.230	0.253	0.189	0.202
X2, UI	0.329	0.348	0.312	0.326
Y1, UA	0.365	0.369	0.332	0.333

It was shown, petrilla_03_1108 (excerpts in pages 19 -23 below), that a six-sided center-region Tx eye mask is sufficient to ensure better than required signal characteristics at Rx inputs. Additional corners can lead to additional test times or unnecessarily stress the Tx generating unnecessary costs. The coordinates for the mask can be TJ based or adjusted for a 5E-5 hit ratio to yield practical test times. Effects of a reference test set-up can also be included. All of the above may be considered statistically equivalent.

If observation impairments are not included in the eye mask coordinates, there should be a clear statement that measurement results are to be de-embedded from such impairments.

TP2 Eye Masks
Expansion for lower hit ratio and D1.1 comparison

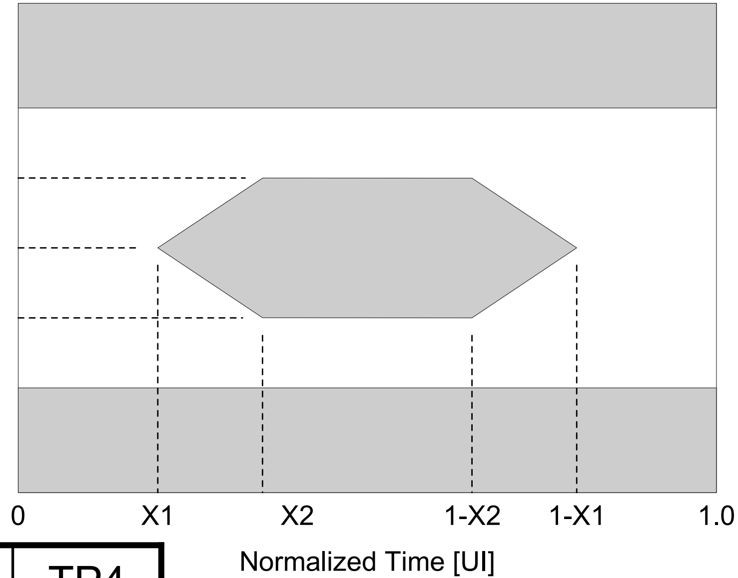


The above figure shows a mask based on TJ (TJ Eye w) and it's expansion to an equivalent mask based on a 5E-5 hit ratio. Both are adjusted for the effects of the example minimum performance test system. The D1.1 defined TP2 eye mask is included for comparison.

The D1.1 TP2 mask reuses the coordinates from clause 52 without consideration of differences between the applications. There is no consensus regarding the appropriate hit ratio and it appears designed around the expected capability of transmitters instead of the requirements of the downstream receiver. For example, 40GBASE-SR4 receivers are expected to provide 0.32 UI eye openings at TP4, while the D1.1 TP2 mask only offers a flat full-amplitude region of 0.10 UI.

Eye Masks

Consistency & balance among test points



5E-5 Hit Ratio	TP1	TP2	TP3	TP4
X1 (w/o Test Rx effect) D1.1	0.12	0.25*		0.35*
X1 (w/o Test Rx effect) Reference	0.10	0.19	0.20	0.26
X1 (w Test Rx effect) Proposed	0.10	0.20	0.21	0.27
X2 (w/o Test Rx effect) D1.1	0.33	0.40*		0.5*
X2 (w/o Test Rx effect) Reference	0.27	0.31	0.5	0.5
X2 (w Test Rx effect) Proposed	0.27	0.33	0.5	0.5

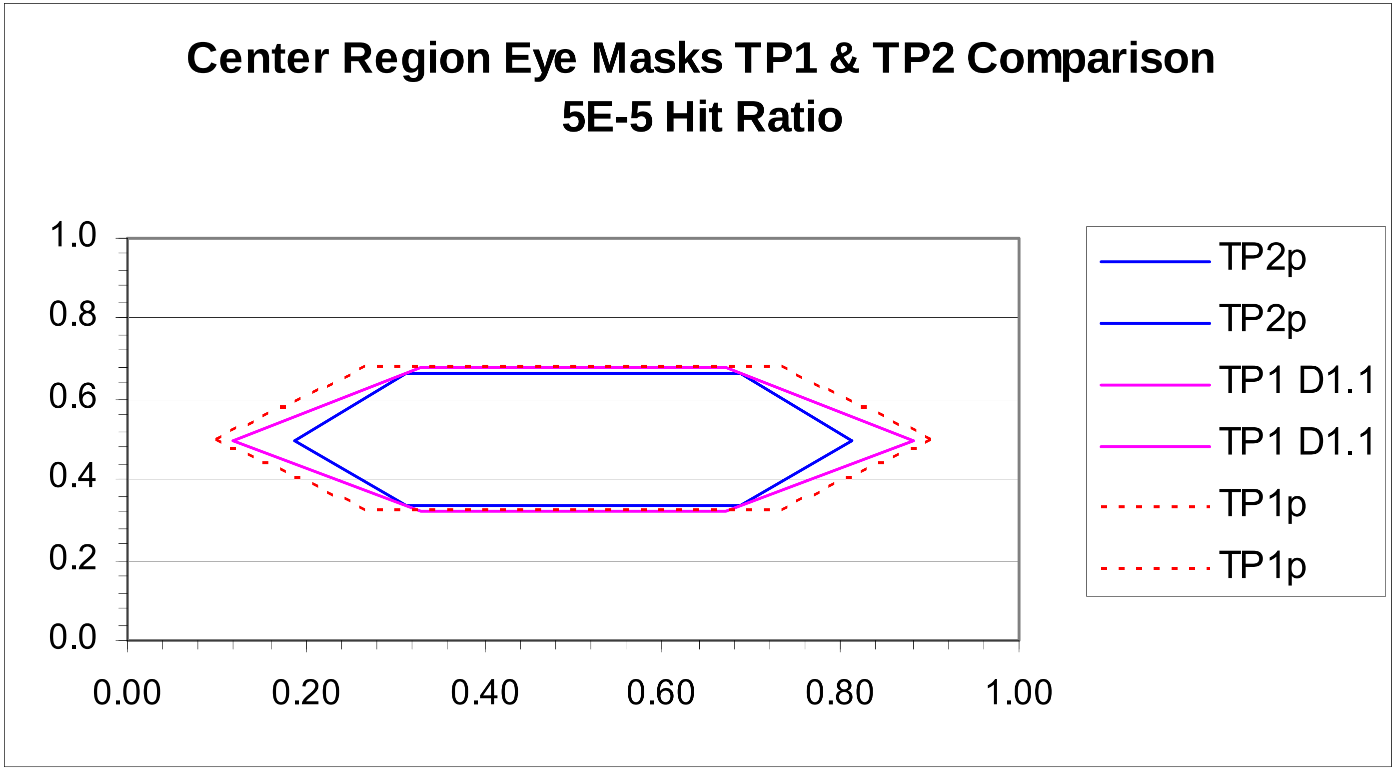
*Unspecified hit ratio.

TP1 X1 and X2 values in D1.1 were taken from SFF-8431 without sufficient consideration that the PPI channel is more benign than SFI permitting a reduction in TP1 TJ (0.300 UI to 0.263 UI) and do not fully reflect this recent reduction in TP1 jitter allocation.

Also note that TP1 X2 in D1.1 is larger than the proposed TP2 X2 value which is based on the requirements of the optical Rx. This places a disproportionate burden on the optical Tx.

Eye Masks

Consistency & balance among test points



The above figure shows the proposed mask for TP1 (TP1p) and TP2 (TP2p) and includes the D1.1 defined TP1 mask for comparison. Here the TP1 masks were scaled in the vertical axis for a similar amplitude as the TP2 mask.

X1 and X2 values in D1.1 were taken from SFF-8431 without sufficient consideration that the PPI channel is more benign than SFI permitting a reduction in TP1 TJ (0.300 UI to 0.263 UI). To avoid a disproportionate burden on the optical Tx there should be reasonable margin between the X2 coordinates for TP1 and TP2 that define the minimum-height eye corners.

Stressed Receiver Sensitivity Conditions

		TP3
DJ(δ δ)	UI	0.266
RJ	UI	0.234
TJ	UI	0.500
J9	UI	0.470
5E-5 HR	UI	0.396
J2	UI	0.352

This table repeats the TP3 column from the above jitter allocation table. Here J2, representing all but 1% jitter expected at TP3 under worst case conditions, can be used as the jitter condition, J, for the stressed receiver sensitivity test. J9 can be used as an additional constraint on the SRS jitter stress composition.

The Stressed Receiver Sensitivity, SRS, test is based on an input signal stressed in the horizontal axis by jitter, J, and in the vertical axis by Vertical Eye Closure Penalty, VECP. J is defined as all but 1% of the jitter histogram and VECP is defined as all but 0.1% of the vertical eye closure histogram. See 52.9.10.2. J2 above is consistent with 52.9.10.2 requirements.

To determine VECP from the 10GbE link model, all but 0.1% of vertical eye closure is calculated from the combine effects of ISI and noise. See 52.9.10.2. For the base case, the ISI penalty is 1.67 dB and the combined noise penalty is 0.61 dB yielding 1.96 dB.

With these conditions, the SRS requirement for a TP4 open eye width of 0.326 UI is -5.40 dBm. To calculate SRS for a target eye width instead of just the center of the eye, the margin used to open the eye to the target width is zeroed out of the SRS calculation.

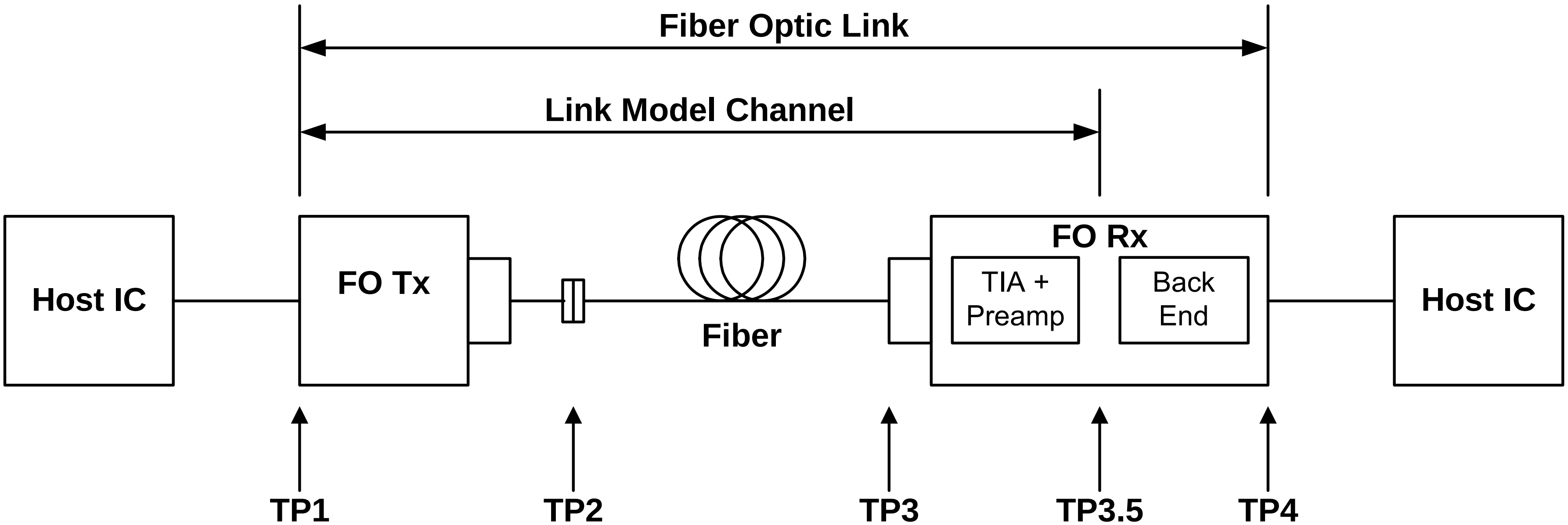
10G Ethernet Link Models

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.

Extensions for the 10GbE model that include effects of source RJ at TP1 and DJ added between TP3.5 and TP4, calculates the open eye width at TP4, providing a means to harmonized power penalties and jitter are described in petrilla_02_1108. Using the extended model to generate Tx eye masks is described in petrilla_03_1108.

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.

10GbE Link Model - Assumptions

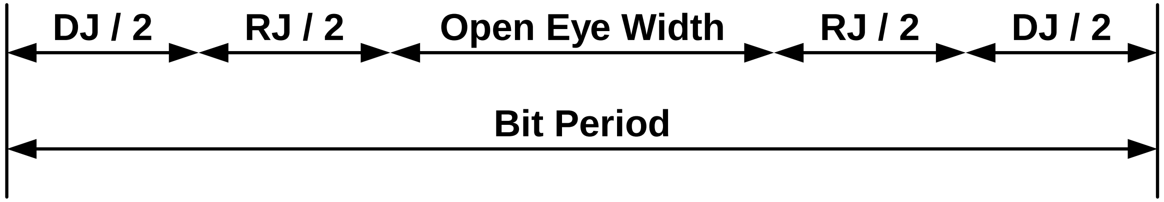
- Transmitters have a Gaussian impulse response with a similar step response for rising and falling edges.
- Fibers have a Gaussian impulse response.
- Receivers have a non-equalized, raised-cosine response.
- The reference (or test) receiver has a 4-th order Bessel-Thomson (BT) response at 75% of the signal rate.
- 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

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.
- $RJ_{total} = RJ_{TP4} = Sqrt(RJ_{ch}^2 + RJ_{TP1}^2)$
- $TJ_{TP4} = DJ_{TP3} + DJ_{Rx} + RJ_{total}$
- $Eye\text{-}width_{TP4} = 1 – TJ_{TP4}$

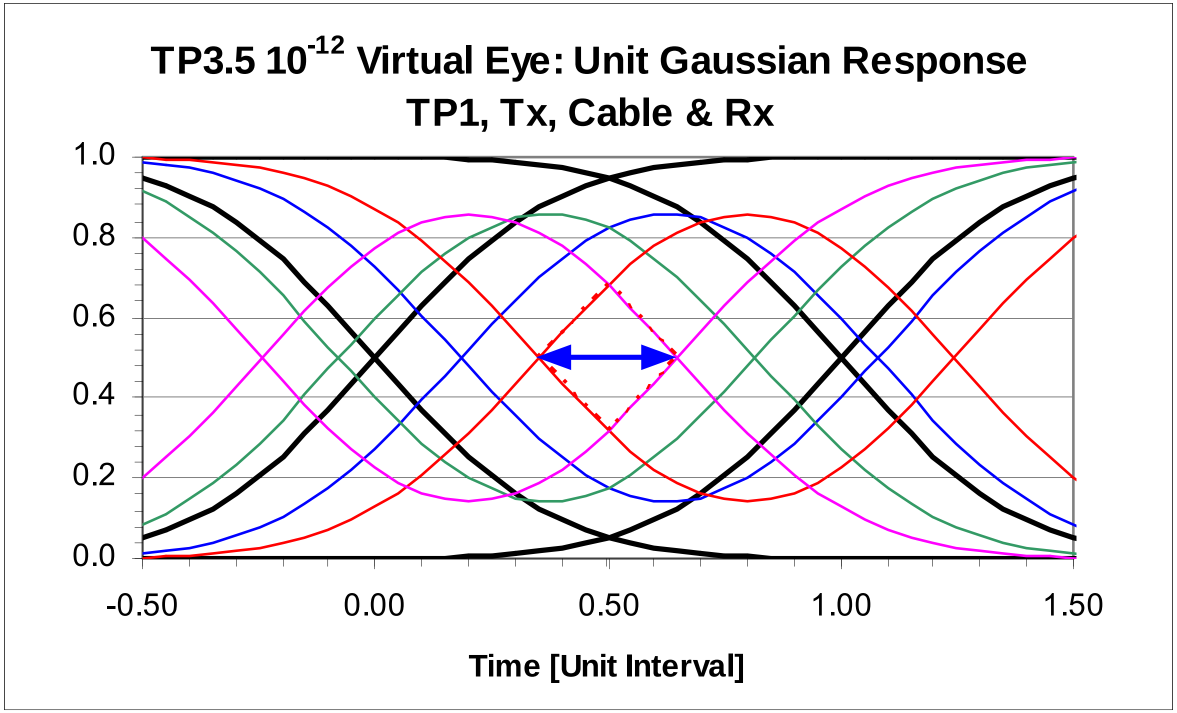
Tx Eye Mask

Generation - Overview

- The following pages present a method of generating eye masks based on BER contours, i.e.
  - show 10^-12 BER contours
  - show progression of required contour/eye from TP3.5 to TP2
  - show translation of contour into mask
  - show translation of contours and masks from 10^-12 to ~10^-5.

  <u>Contour/Mask Generation Approach and/or Assumptions:</u>
  - For contours each bit is at worst case DJ.
  - Receiver requirements are based on unstressed receiver sensitivity.
  - The Reference/Test Rx only contributes RJ and ISI generated DJ.
  - In test set-ups, observed optical-noise and random jitter beyond that due to TP1 jitter, RIN of the device under test, test receiver sensitivity or test equipment timing uncertainty, is due to modal noise associated with incomplete modal coupling at the optical connectors.
  - Although the Reference/Test Rx assumes a 4^{th}-Order BT response, no adjustment is made to the receiver time constant parameter in the spreadsheet.

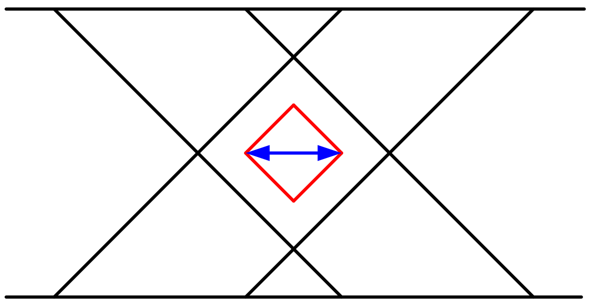
Tx Eye Mask - Generation at TP3.5



- The above figure shows eye contours generated at TP3.5, i.e. decision point for defined worst case link conditions. All Rx DJ allocation is also included. Impairments from the observing test equipment are not included. Note approximate diamond shape.
- The contours are generated as if every bit is at the maximum DJ. For PRBS patterns only 25% of the bits are isolated center bits in …010… or …101… patterns. Consequently, the contours are conservative.
- In the eye contour for TP3.5 recall that since the decision point in the receiver is followed by a high gain comparator and/or the Rx minimum output swing is included in the sensitivity test, BER requirements are satisfied even if the diamond is collapsed to the blue line. The required length of the blue is given by the eye opening required at TP3.5 plus any Rx contributed DJ generated after the decision point.

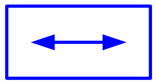
Tx Eye Mask – Simplified Rx Based Requirement

Generation – Progression (1)

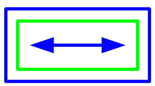


- Here the above figure shows a simplified eye contour for TP3.5. Again, the BER requirement is satisfied by the blue line. On the right a progression is shown beginning with the eye contour required at TP3.5 and working upstream to the output of the transmitter. For brevity only eye height adjustments are discussed. Adjustments are, however, also required for eye width. The combined effect may produce rounded or semi-ellipsoidal ends.

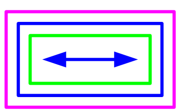
- 10^-12 eye contour needed at TP3.5



- Eye contour for a virtual TP3 adjusted for worst case Rx sensitivity. Eye Height = Rx sensitivity.



- Eye contour for an observed TP3 adjusted for worst case Rx sensitivity and difference between the worst case receiver and the test equipment receiver.

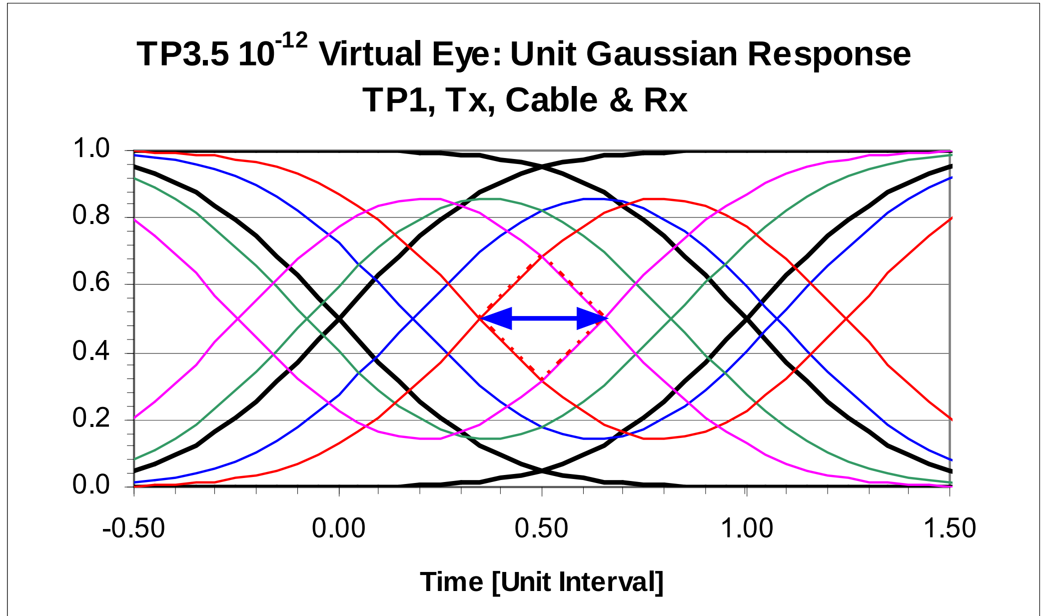


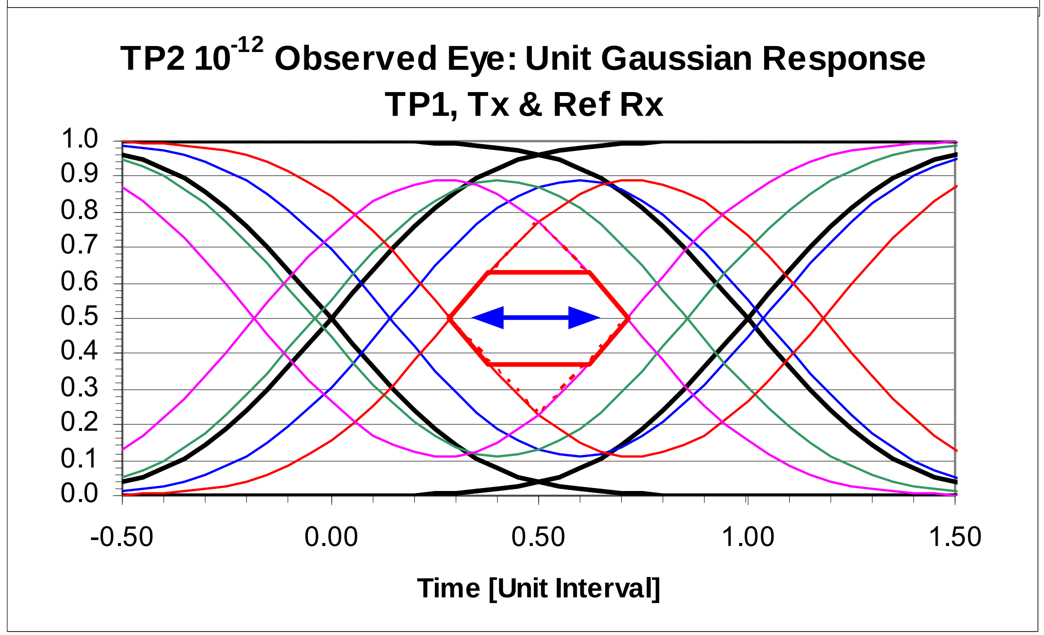
- Eye contour for an observed TP2 adjusted for worst case Rx sensitivity and difference between the worst case receiver and the test equipment receiver and further adjusted for channel losses and penalties.

Tx Eye Mask

Generation – Progression (2)

- Repeating the previous page, an eye mask can be based on the input signal requirements of the Rx. Here the height is based on the unstressed sensitivity and link penalties and the ends are based on the simplified diamond-shaped eye contour yielding a six-sided polygon.



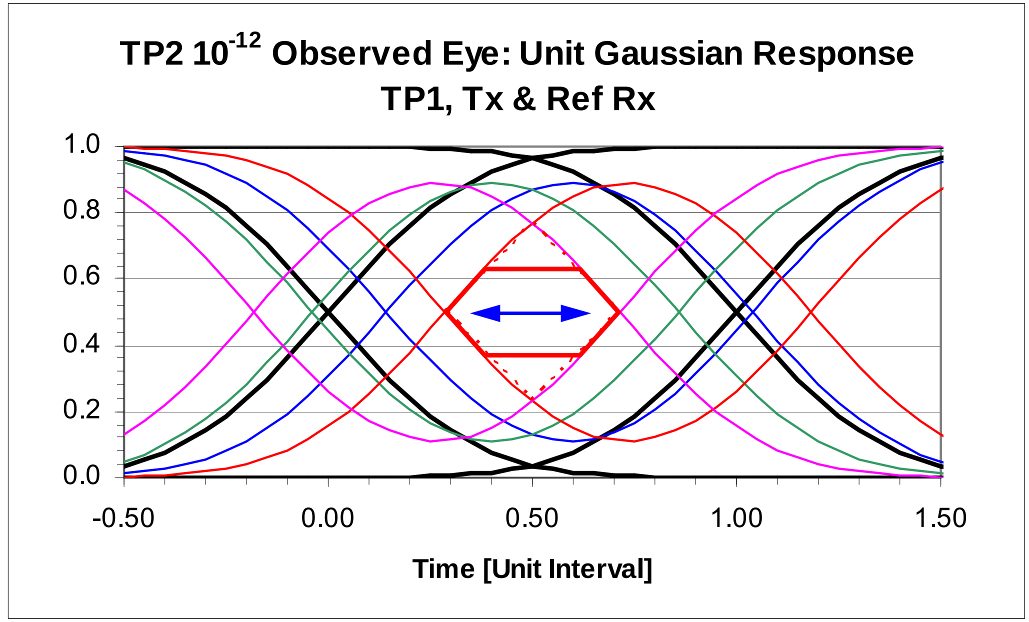


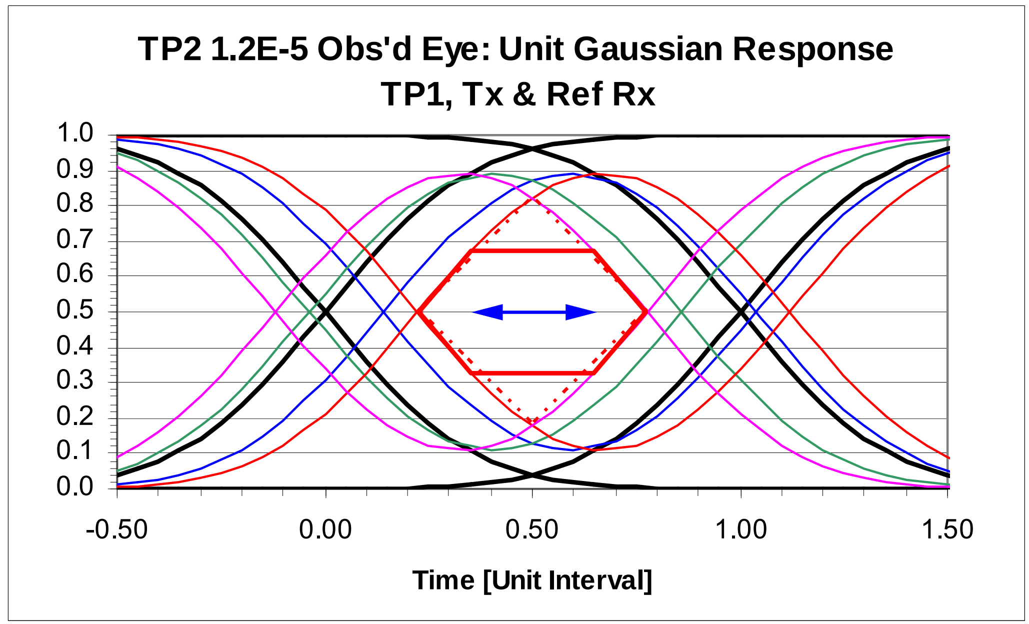
Tx Eye Mask

Generation Lower Q Contours

- Contours for hit ratios higher than 1E-12 can be used to define equivalent but less time consuming measurements. Here, for comparison with BER = 1E-12 contours, contours are also plotted for a test based on a hit ratio = 1.23E-5 e.g. rejecting on 11 hits in 1000 waveforms where each waveform comprises 1350 samples, 60% of which are in the UI of interest.

  Rejecting on a larger number of hits should reduce the variability of the margin result. Note that the contour represents a mean position for which there's a confidence interval and associated measurement variability. It's expected that the width of the confidence interval and associated measurement variability is inversely related to the square root of the reject value.





40GBASE-SR4 & 100GBASE-SR10 Base Case

Link Model Transmitter Attributes (Each Lane)

- **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 = 0.263 UI, DJ = 0.132 UI**
- **TP2 Jitter Allocation:* TJ = 0.460 UI, DJ = 0.266 UI**

*** Updated for new TP1 allocation**

40GBASE-SR4 & 100GBASE-SR10 Base Case

Link Model Receiver Attributes (Each Lane)

- **Max Sensitivity: -11.3 dBm**
- **Min Bandwidth: 7500 MHz**
- **RMS Base Line Wander: 0.025**
- **Max Rx Reflection: -12 dB**
- **TP3 Jitter Allocation:* DJ = 0.266 UI, DCD = 0.103 UI**
- **TP3 Jitter Allocation:* TJ = 0.500 UI**
- **TP4 Jitter Allocation:* TJ = 0.674 UI**
- **TP4 Jitter Allocation:* DJ = 0.349 UI**

*** Updated for new TP1 allocation.**

40GBASE-SR4 & 100GBASE-SR10 Base Case

Link Model Channel Attributes (Each Lane)

- **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**