

# P802.3cu DGD penalty

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# Introduction

A baseline was proposed for 100GBASE-LR in [welch\\_3cu\\_adhoc\\_050119](#) and a set of possible values for 400GBASE-LR4 was presented in [lewis\\_optx\\_01a\\_0319](#).

In both of these power budgets, an allowance of 0.5 dB or 0.6 dB has been made for MPI penalty (depending on ER value) in accordance with the budgets for 50GBASE-LR, 200GBASE-LR4, and 400GBASE-LR8.

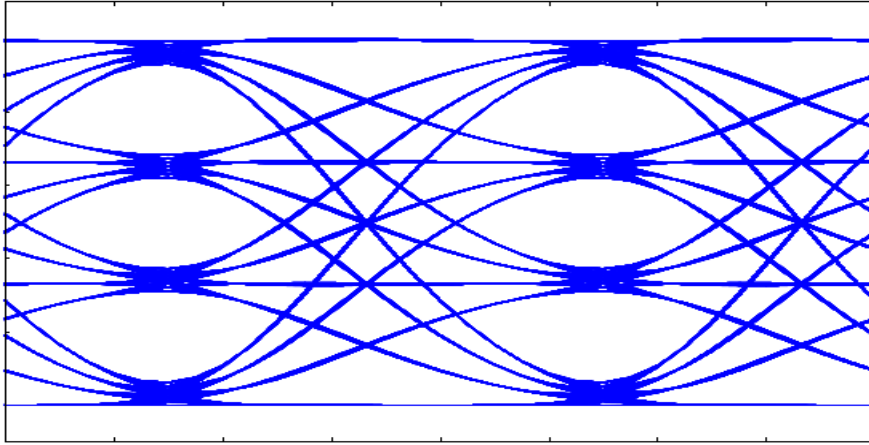
However, no additional allocation has been made for DGD penalty. This issue was raised in [shuai\\_3cu\\_adhoc\\_050119](#).

The DGD\_max value for 25GBASE-LR, 50GBASE-LR, 100GBASE-LR4, 200GBASE-LR4, and 400GBASE-LR8 is 8 ps.

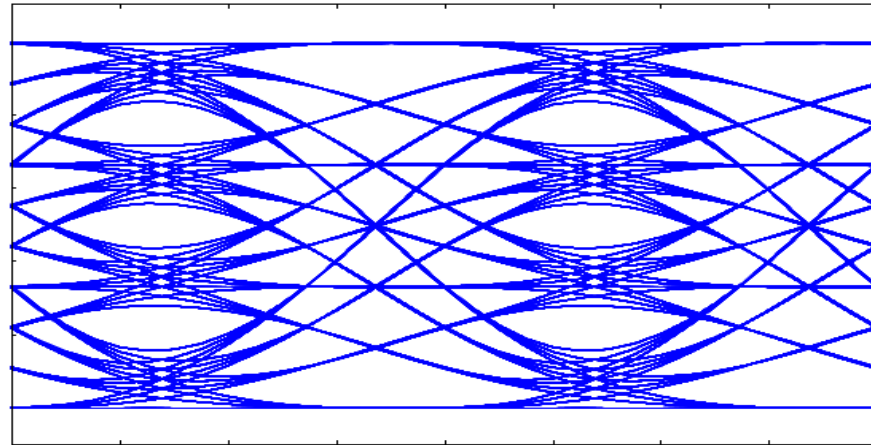
This presentation uses simulations to further investigate the DGD penalty that 100GBASE-LR and 400GBASE-LR4 could have.

# ~26.56 GHz bandwidth Tx eyes, 8 ps DGD

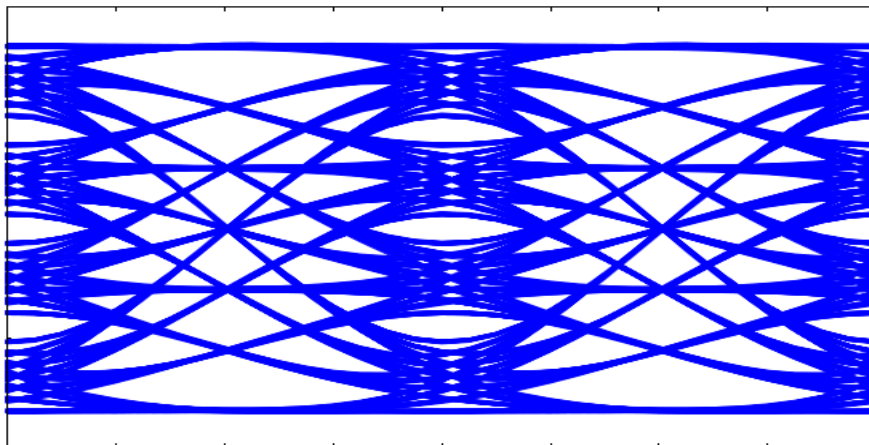
Tx eye 0 ps DGD



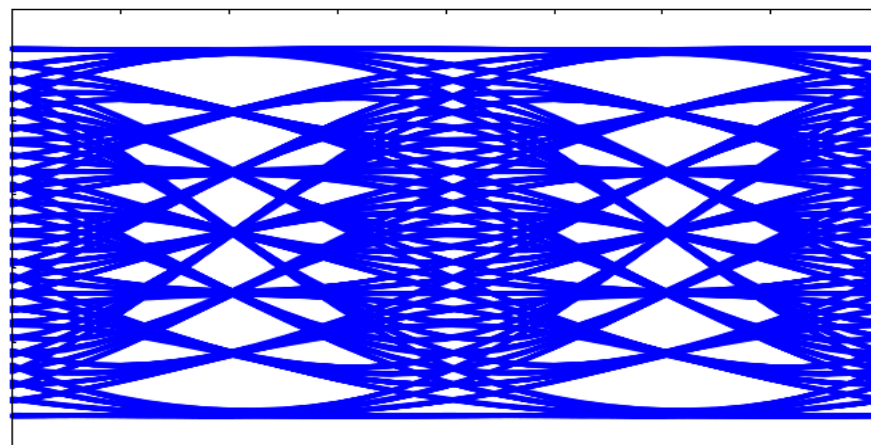
Tx eye 8 ps DGD



Eye as seen via a 26.56 GHz Rx 0 ps DGD

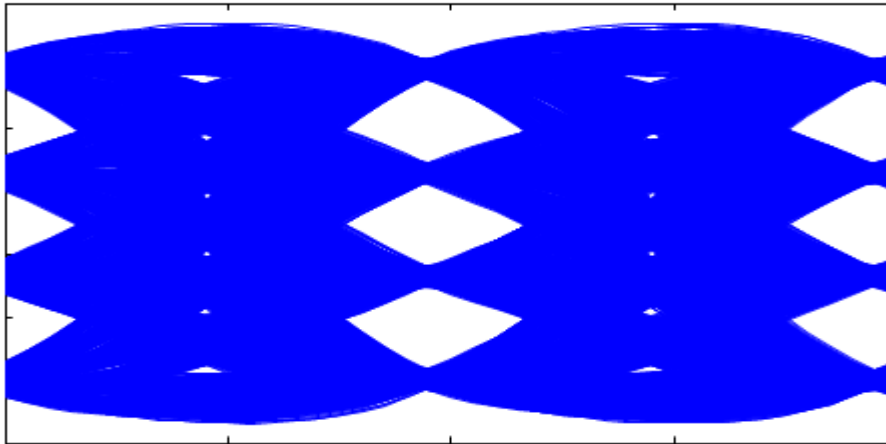


Eye as seen via a 26.56 GHz Rx 8 ps DGD



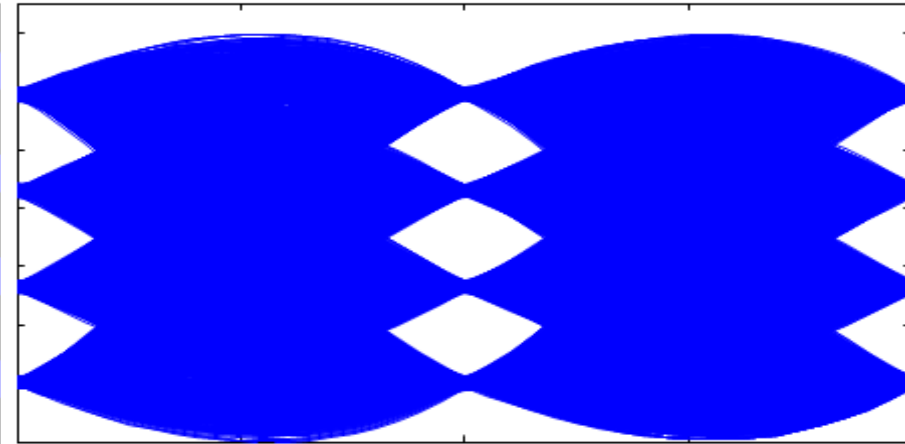
# SECQ for ~26.56 GHz bandwidth Tx , 8 ps DGD

Eye after equalizer 0 ps DGD



SECQ = 1.52 dB

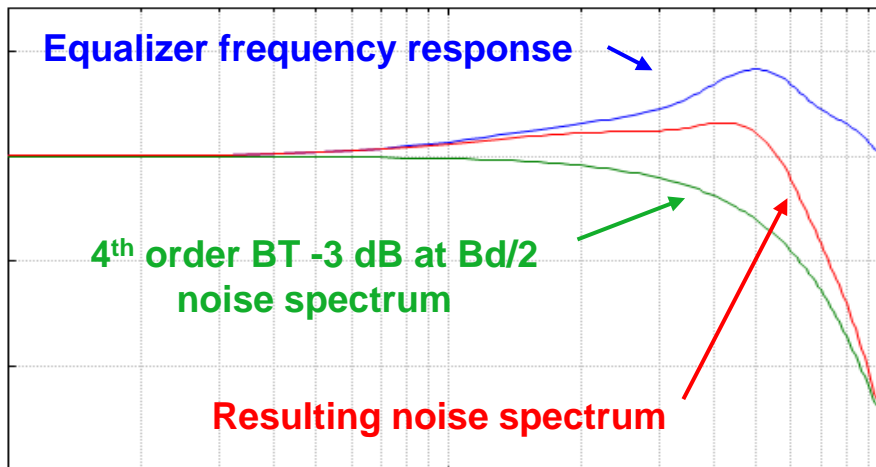
Eye after equalizer 8 ps DGD



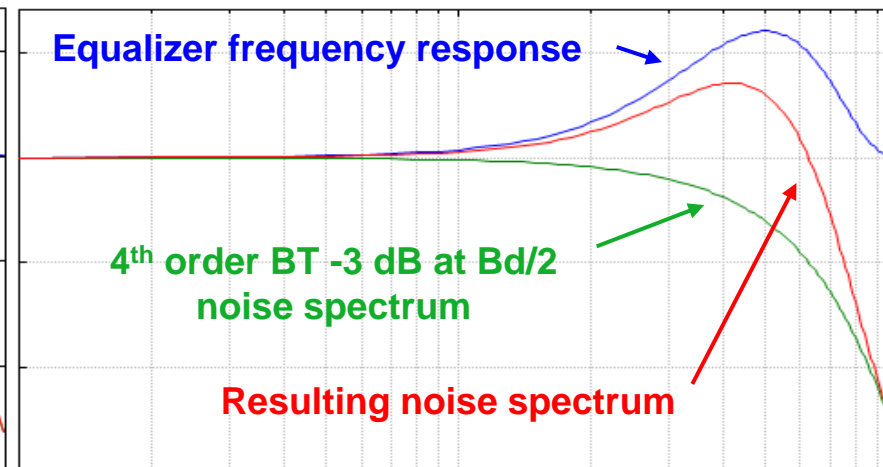
SECQ = 2.07 dB

0.55 dB DGD penalty

Equalizer frequency response 0 ps DGD



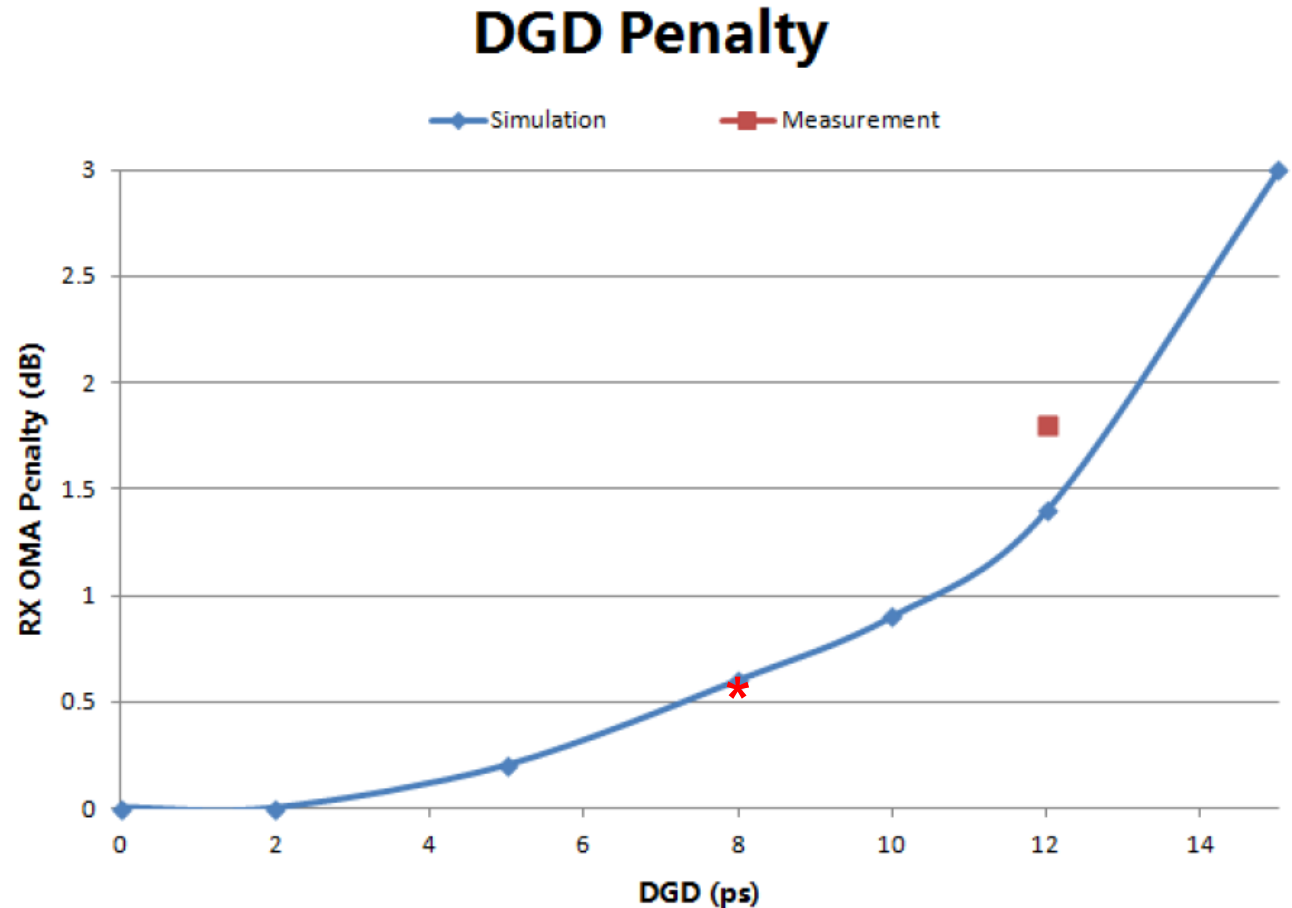
Equalizer frequency response 8 ps DGD



# DGD penalty for 8 ps

The value of 0.55 dB obtained on the previous page (“\*” right) agrees very closely with the predicted penalty for 8 ps of DGD in [shuai\\_3cu\\_adhoc\\_050119](#).

However, it would be difficult to find an extra ~0.6 dB in the optical power budget for this (particularly for 400GBASE-LR4).



# G.652 fiber specifications

The 2009 version of [G.652](#) contained specifications for:

- G.652.A and G.652.C with a maximum  $\text{PMD}_Q$  of 0.5 ps/ $\sqrt{\text{km}}$
- G.652.B and G.652.D with a maximum  $\text{PMD}_Q$  of 0.2 ps/ $\sqrt{\text{km}}$

The 2016 version of [G.652](#) contains only the newer G.652.B and G.652.D fibre types with a maximum  $\text{PMD}_Q$  of 0.2 ps/ $\sqrt{\text{km}}$ . It is believed that these fiber types represent the bulk of recently deployed fiber.

Note that  $\text{PMD}_Q$  is the PMD coefficient that will be exceeded by less than 0.01% of links made up of 20 cable sections in series.

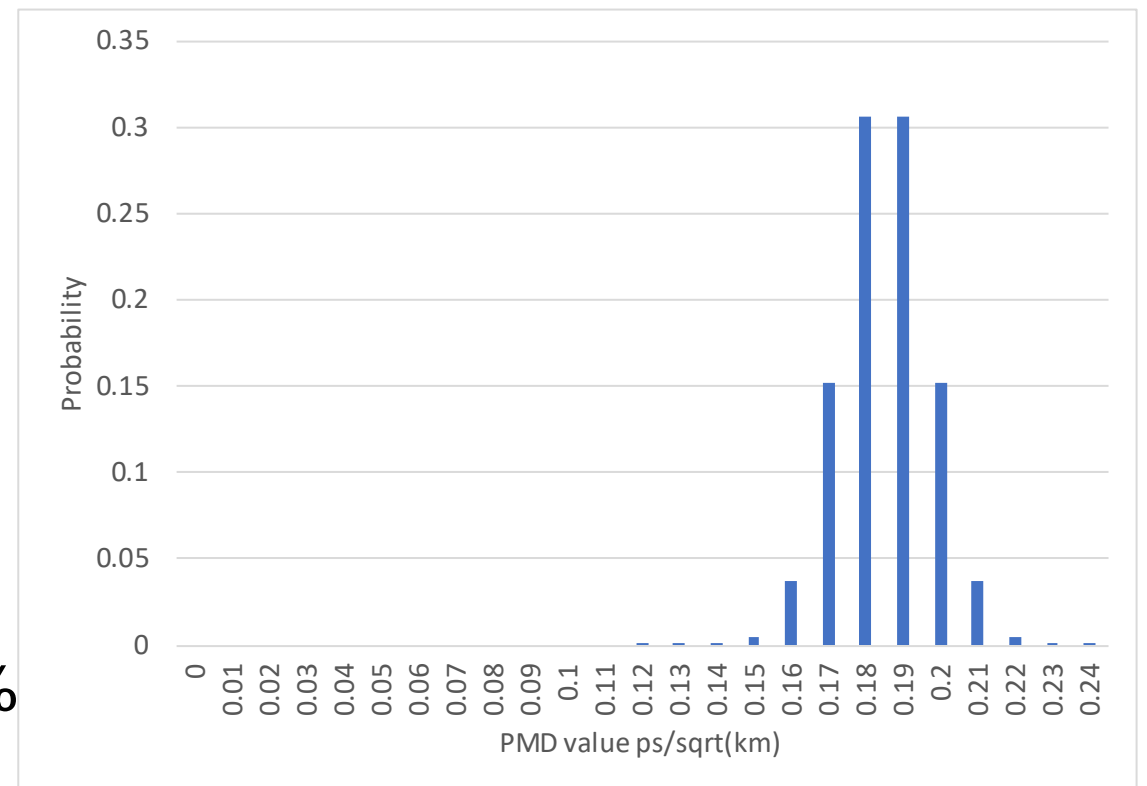
# DGD\_max 1

If the maximum  $\text{PMD}_Q$  is  $0.2 \text{ ps}/\sqrt{\text{km}}$ , what is the  $\text{DGD}_{\text{max}}$  for a 10 km link?

This depends on the statistical distribution of the cable sections that make up the link. At one extreme, the cable sections could all have a PMD coefficient that is close to  $0.2 \text{ ps}/\sqrt{\text{km}}$  with little scatter.

An example distribution with a mean of  $0.19 \text{ ps}/\sqrt{\text{km}}$  and a standard deviation of  $0.0116 \text{ ps}/\sqrt{\text{km}}$  is shown on the right. This meets the  $\text{PMD}_Q$  requirement as 20 cable sections taken at random from this distribution have a probability of the combined PMD coefficient exceeding  $0.2 \text{ ps}/\sqrt{\text{km}}$  of 0.008%.

If the 10 km link is only 1 cable section, the probability of the PMD coefficient exceeding  $0.24 \text{ ps}/\sqrt{\text{km}}$  is less than 0.01%.



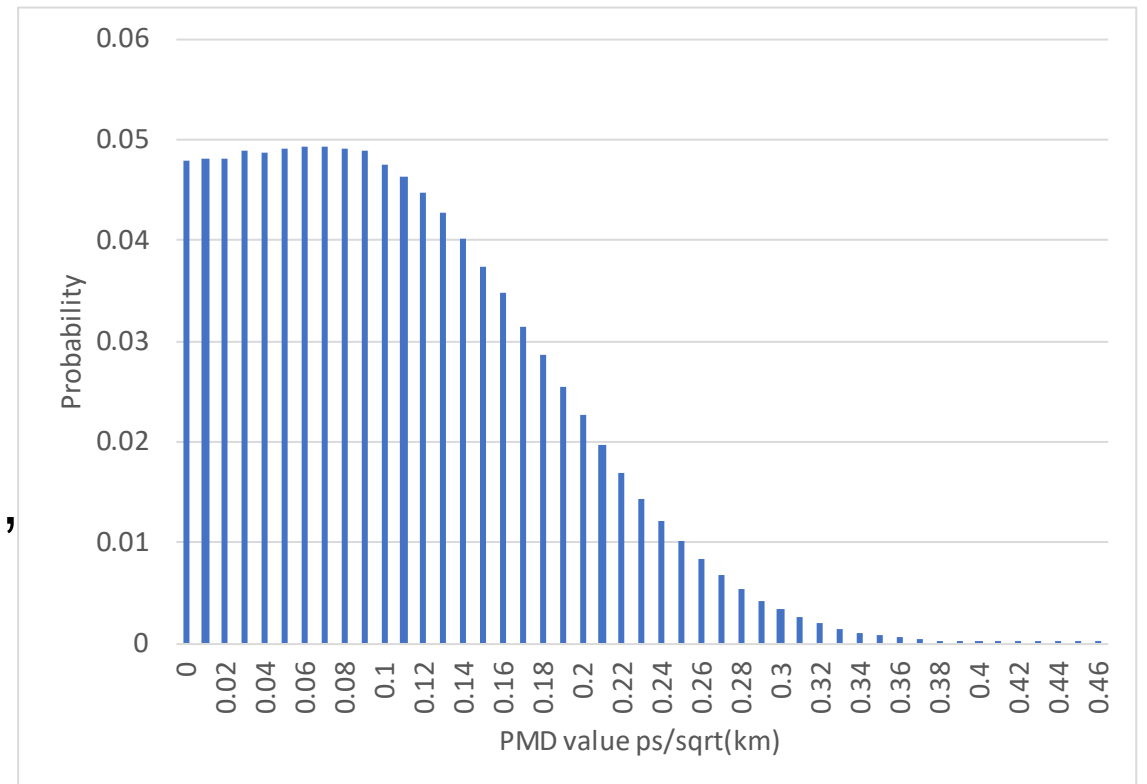
## DGD\_max 2

A more realistic statistical distribution of the cable sections that make up the link would be a mean of 0.1 ps/ $\sqrt{\text{km}}$  and a standard deviation of 0.09 ps/ $\sqrt{\text{km}}$  as shown below. This also meets the  $\text{PMD}_Q$  requirement as 20 cable sections taken at random from this distribution have a probability of the combined PMD coefficient exceeding 0.2 ps/ $\sqrt{\text{km}}$  of 0.009%.

If the 10 km link is only 1 cable section, the probability of the PMD coefficient exceeding 0.43 ps/ $\sqrt{\text{km}}$  is 0.012%.

0.43 ps/ $\sqrt{\text{km}}$  for a 10 km link corresponds to a mean DGD of 1.36 ps.

If the ratio of “Max” DGD to mean DGD is set to 3.75 (see page 8 [anslow\\_01\\_0308](#)), this corresponds to a DGD\_max of 5 ps.





## DGD\_max 3

Vince Ferretti from Corning has helpfully pointed out a relevant publication:

JACOBS, S.A. et al., Statistical Estimation of PMD Coefficients for System Design. Electronics Letters, 1997, 33, pp. 619-621

This includes an analysis of 288 randomly selected scaled cabled fibers.

Equation 10 of this is:

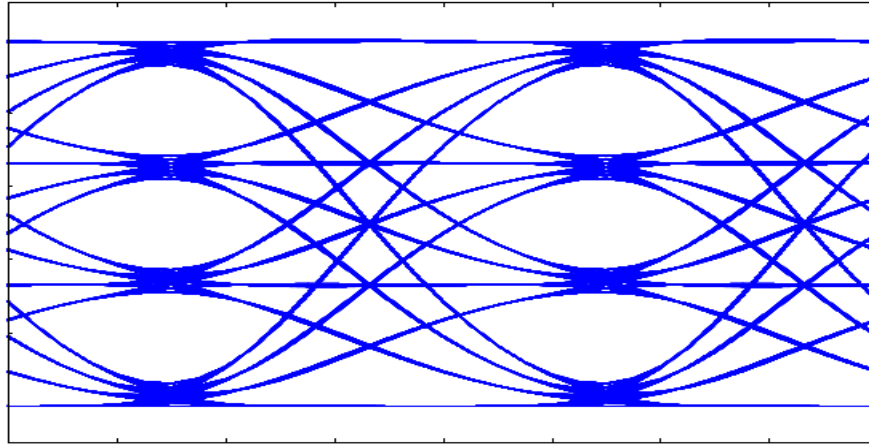
$$X_Q = \frac{(2.004 + 0.975\sqrt{n \times 0.979})}{\sqrt{n \times 48.6}}$$

For  $n = 1$  (one cable segment), this evaluates to  $X_Q = 0.426$  ps/ $\sqrt{\text{km}}$

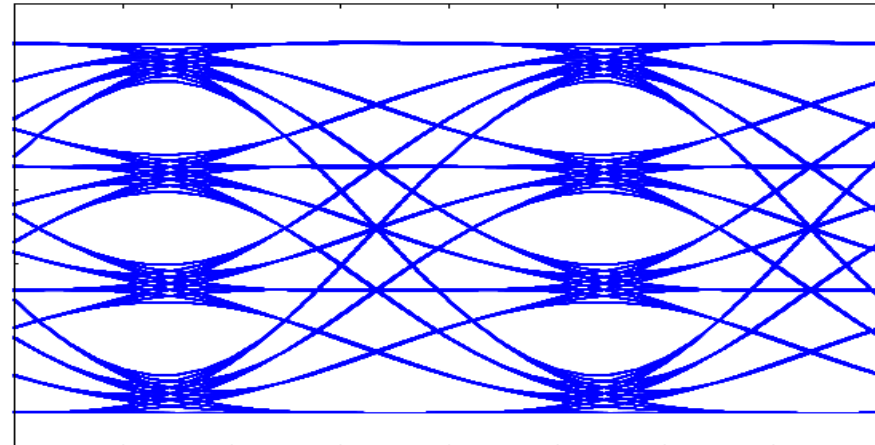
For a 10 km link and with a ratio of “Max” DGD to mean DGD of 3.75, this is also a DGD\_max of 5 ps.

# ~26.56 GHz bandwidth Tx eyes, 5 ps DGD

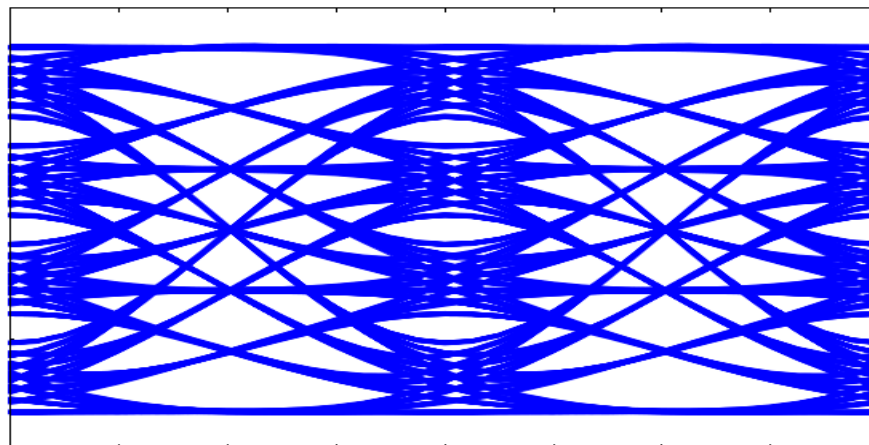
Tx eye 0 ps DGD



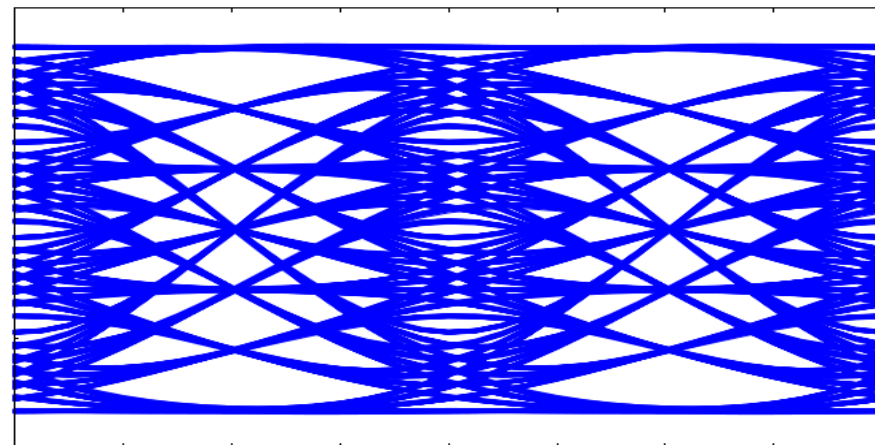
Tx eye 5 ps DGD



Eye as seen via a 26.56 GHz Rx 0 ps DGD

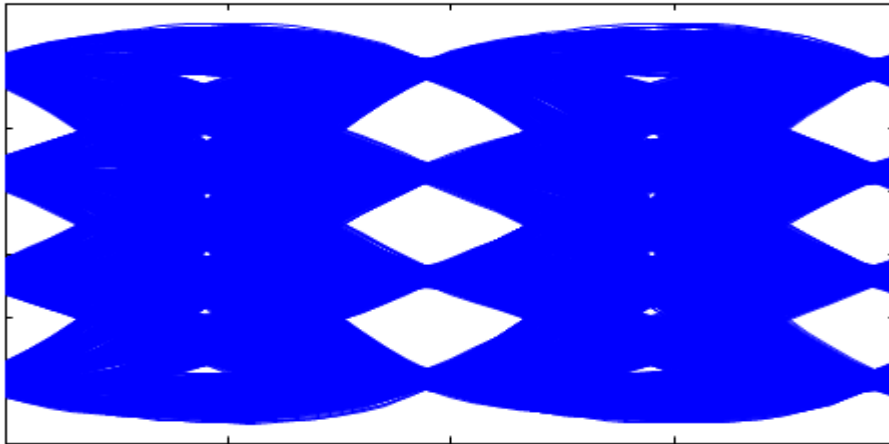


Eye as seen via a 26.56 GHz Rx 5 ps DGD



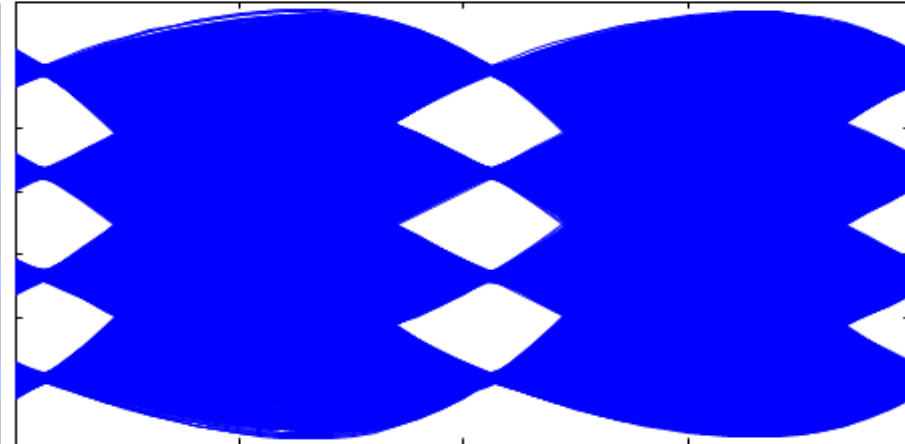
# SECQ for ~26.56 GHz bandwidth Tx, 5 ps DGD

Eye after equalizer 0 ps DGD



SECQ = 1.52 dB

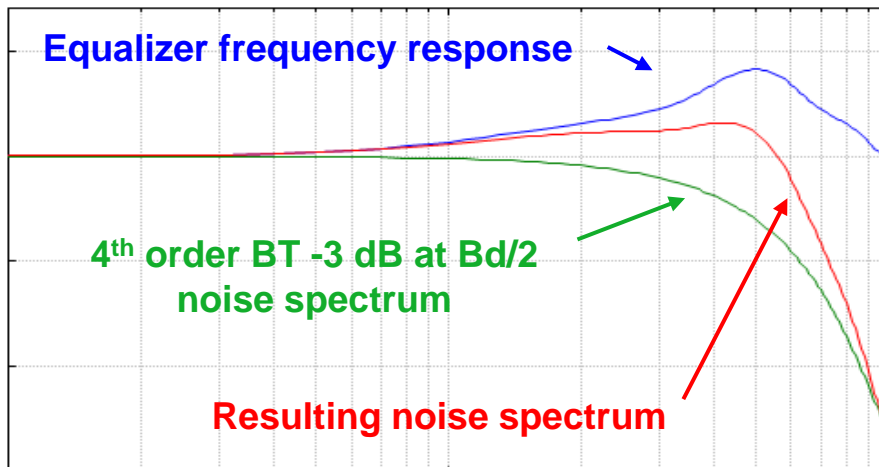
Eye after equalizer 5 ps DGD



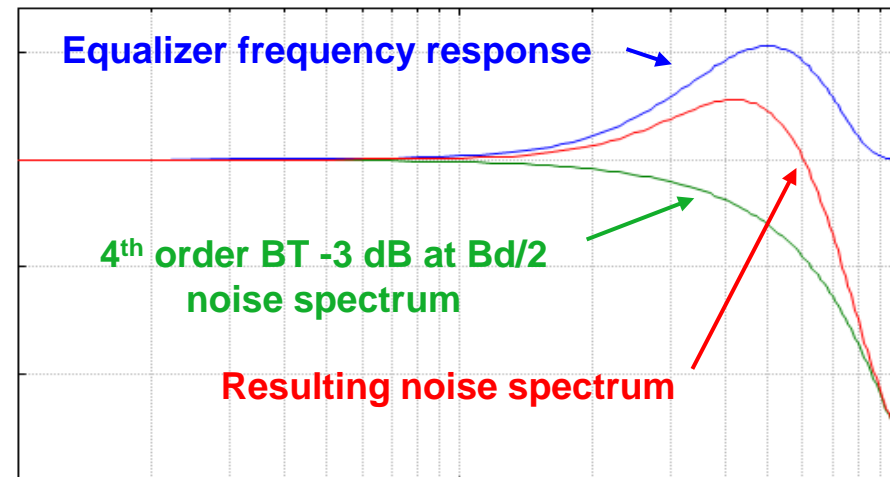
SECQ = 1.78 dB

0.26 dB DGD penalty

Equalizer frequency response 0ps DGD



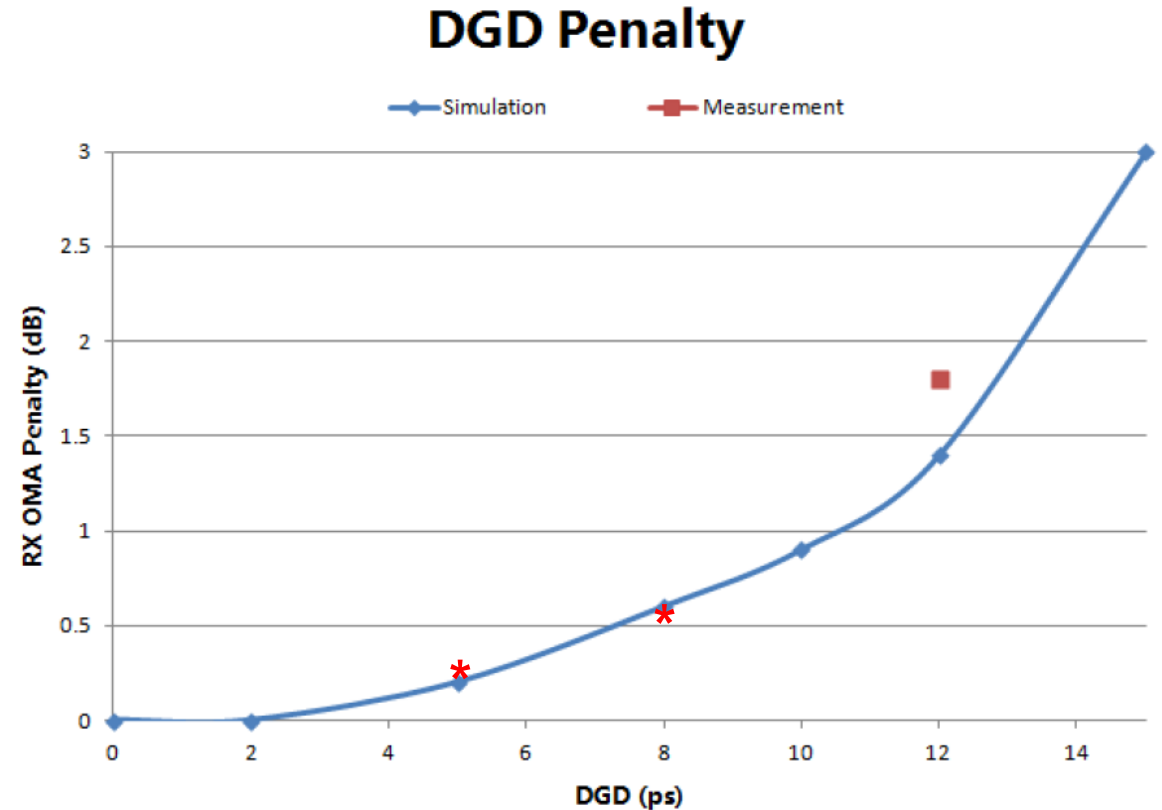
Equalizer frequency response 10.3ps DGD



# DGD penalty for 5 ps

The value of 0.26 dB obtained on the previous page (second “\*” right) agrees very closely with the predicted penalty for 5 ps of DGD in [shuai\\_3cu\\_adhoc\\_050119](http://shuai_3cu_adhoc_050119).

It would be more feasible to find an extra ~0.25 dB in the optical power budget for this.



# Conclusion

A specification of 8 ps for DGD\_max for 100GBASE-LR and 400GBASE-LR4 would require an additional allowance of about 0.6 dB in the optical budget.

Based on the assumption that the newer G.652.B and G.652.D fibre types with a maximum  $PMD_Q$  of 0.2 ps/ $\sqrt{\text{km}}$  represent the bulk of recently deployed fiber, a value of around 5 ps for DGD\_max seems possible.

A specification of 5 ps for DGD\_max for 100GBASE-LR and 400GBASE-LR4 would require an additional allowance of about 0.25 dB in the optical budget.

Thanks!