Completing the family of TDECQ-related specifications

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Introduction

- We use transmitter specs to protect the link and the receiver
- The signal should not be too small or too bad
- OMA-TDECQ is a good measure of the useful signal strength – it stops the signal being too small
- TDECQ is the product of two things: the cost (in sensitivity) of equalizing the signal, and a measure of how bad the signal is after an ideal equalizer
- The first of these is already accounted for in OMA-TDECQ; the second is needed to stop the signal being too bad

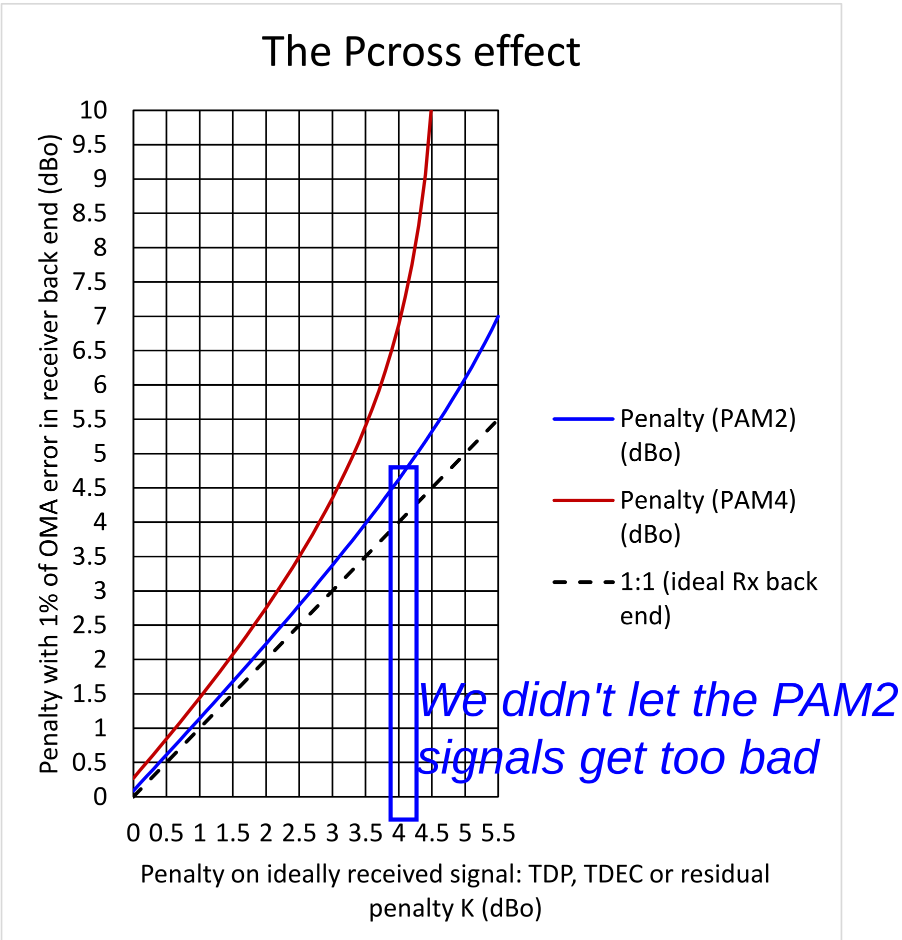
In algebra

- $TDECQ = 10\log_{10}(OMA_{outer}/(6Q_tR))$ (121–12)
  - Q_t is a constant for a given modulation (PAM4) and BER limit
- $R = \sigma_G$ (121–11)
  - (Setting σ_S , a measurement correction, to 0 for simplicity)
- $\sigma_G = \sigma_{eq}/C_{eq}$ where σ_{eq} is the noise that could be added after the ideal reference equalizer, and C_{eq} is the noise enhancement coefficient
- So $TDECQ = 10\log_{10}(OMA_{outer}/(6Q_t\sigma_{eq}/C_{eq}))$
- $= 10\log_{10}(OMA_{outer}/(6Q_t\sigma_{eq})) + 10\log_{10}(C_{eq})$
- $= 10\log_{10}(K) + 10\log_{10}(C_{eq})$ (introducing K)
- Product of two things: how bad and cost of equalizing

Comparison to real receiver

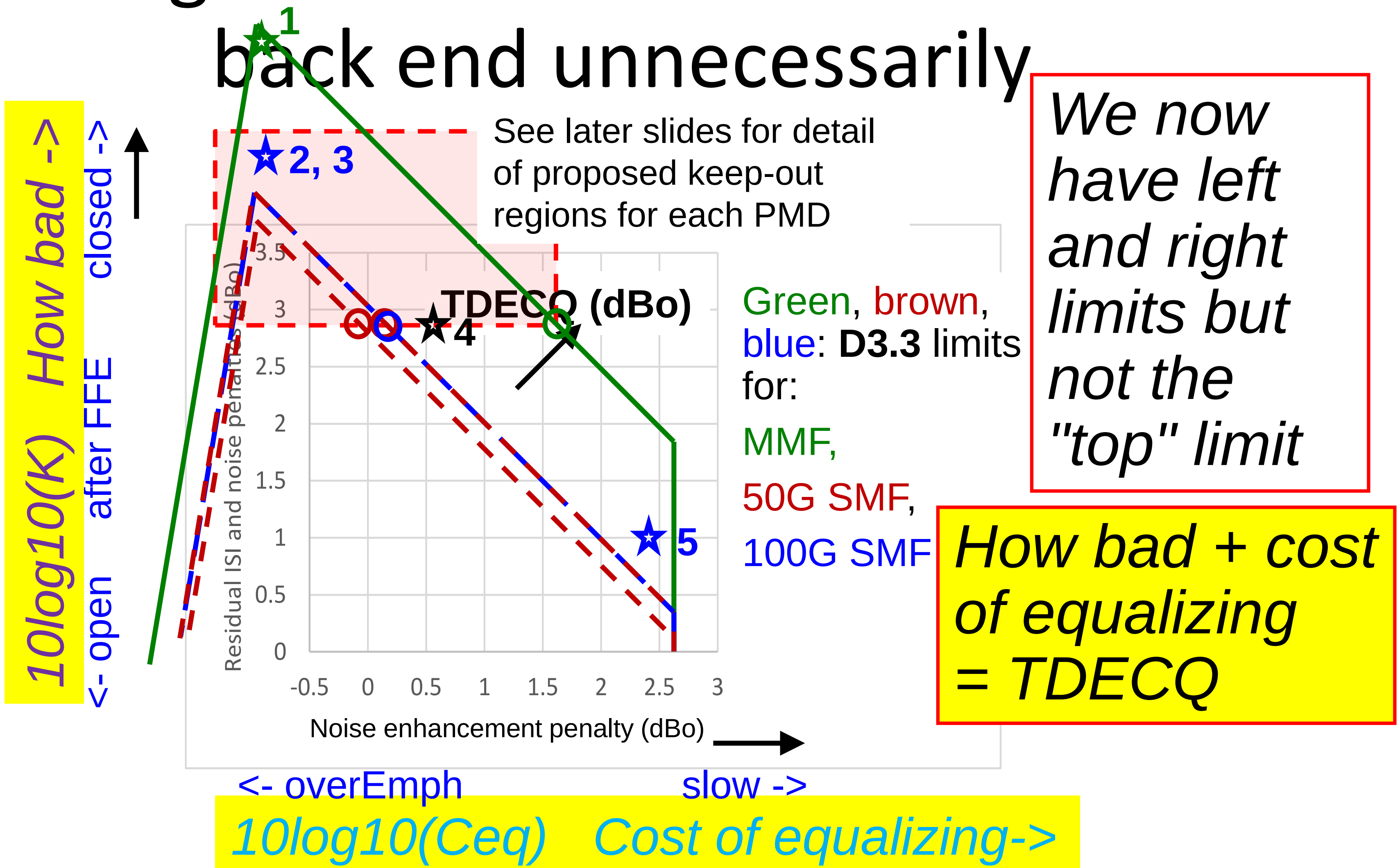
- A real receiver and equalizer might have better timing and more taps than the reference equalizer, but it also has sampling accuracy, quantization /resolution limitations, a filter that isn't an ideal BT4, and limited time and power to optimize its settings
  - These limitations mostly scale with the signal and cause the "Pcross" effect in the 10 Gigabit Ethernet link model
- For some signals, the better things won't help and the limitations still hurt
- The receive side can take more power than the transmit side, the equalizer is a significant portion of the receive side, its power consumption/dissipation depends on complexity and architecture. We are trying to *REDUCE* per-lane power as we transition to 8-lane modules by right-sizing what the receiver does
- If the signal is very bad, these little limitations close up the nearly-closed eye
  - The link isn't resilient, actual sensitivity disappoints, setting up SRS is inaccurate
- This is why we limit "how bad"
- For PAM2, we limited it to about 4 dB
- For PAM4, the effect is worse

Much worse



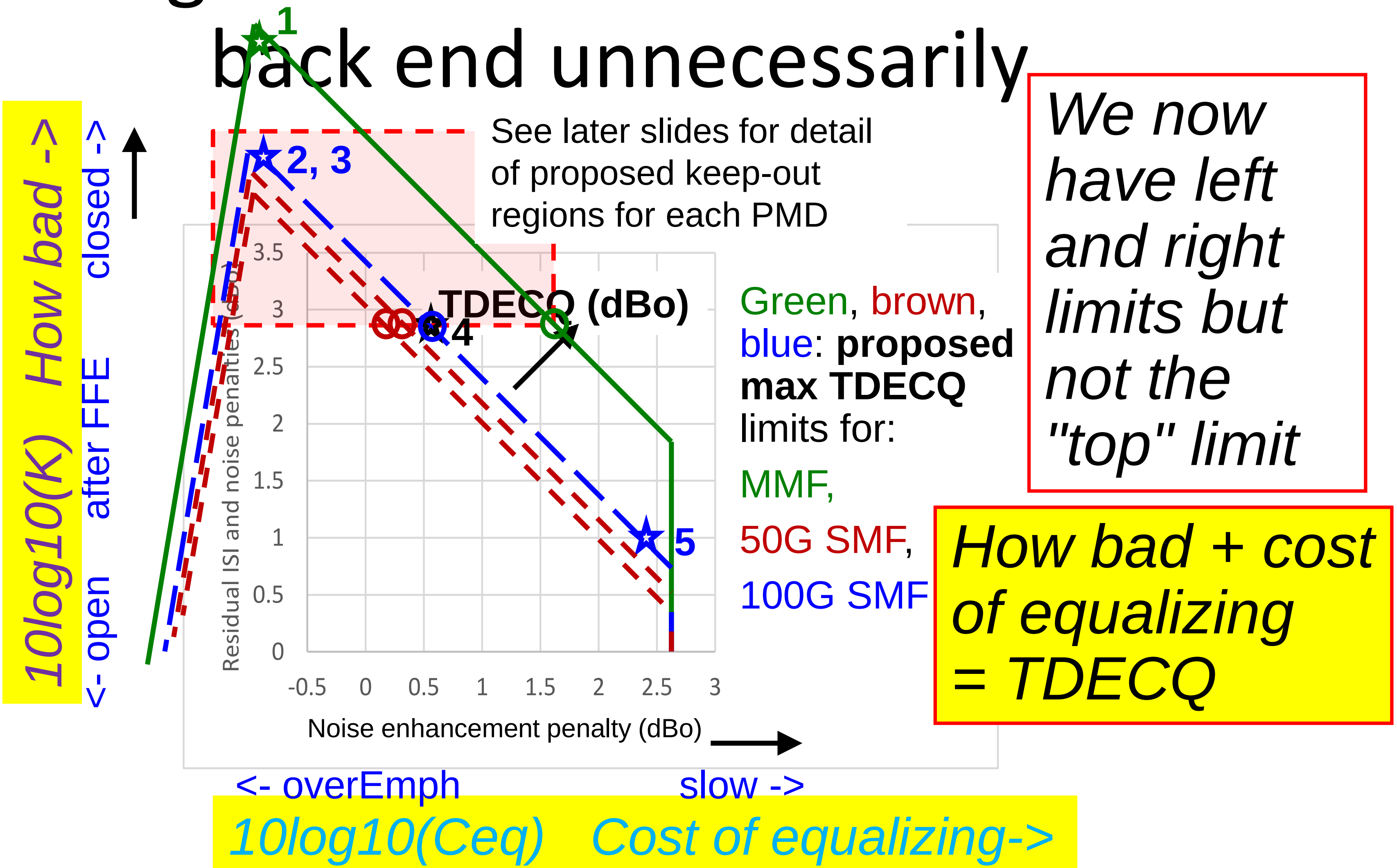
- This is from the standard dual-Dirac theory as in the 10 Gigabit Ethernet link model
  - Assumes samples within 1% of the threshold are wrong
  - If about half of them are right, the 1% would be somewhat more
- But the message is the same: Rx back end impairments that can be ignored for PAM2, can't be ignored for PAM4

The region in red burdens the receiver back end unnecessarily

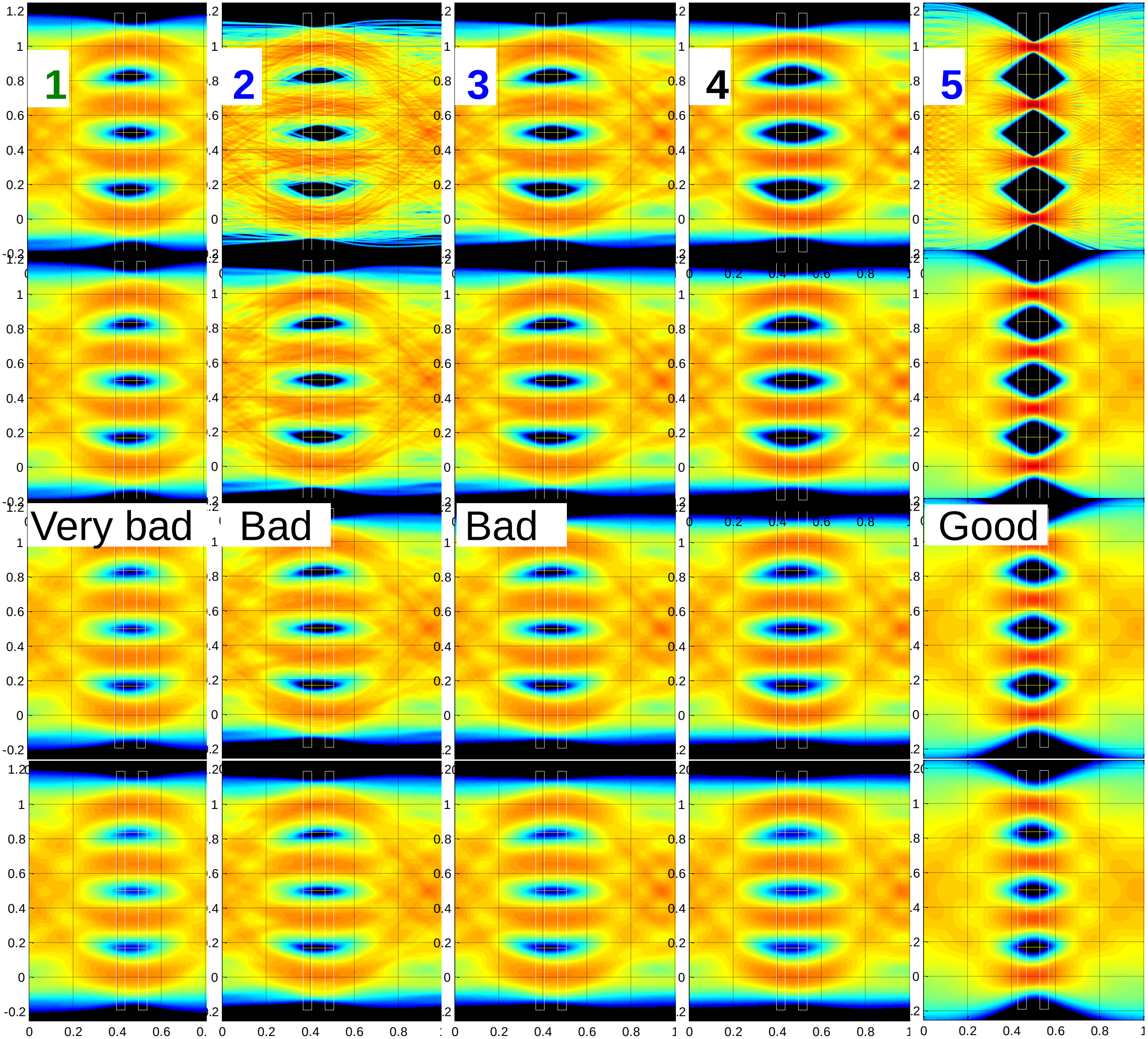


- Stars investigated in slides 4 and 5
  - More information on stars 2, 3 and 5 in previous presentations
- Circles: practical worst signal would be at intersection of diagonal and vertical limits (neither are as proposed – see later slides)
- tamura_3cd_01a_0718 and mazzini_3cd_01a_0718 propose different TDECQ limits: see next

The region in red burdens the receiver back end unnecessarily



- Stars investigated in slides 4 and 5
  - More information on stars 2, 3 and 5 in previous presentations
- Circles: practical worst signal would be at intersection of diagonal limits per tamura_3cd_01a_0718 and mazzini_3cd_01a_0718 and "top" limits as in this presentation (which are not as shown on this slide; see slide 22 for proposed MMF TDECQ and "top" limits)



Left: 4.5 dB TDECQ; 4 others: ~3.4 dB TDCEQ

From top:

Very little Rx noise

3 dB above sensitivity

1 dB above sensitivity

At sensitivity

Left: worst MMF (top green star), RIN -128 dB/Hz

2:dirty signal, bounded noise (top blue star)

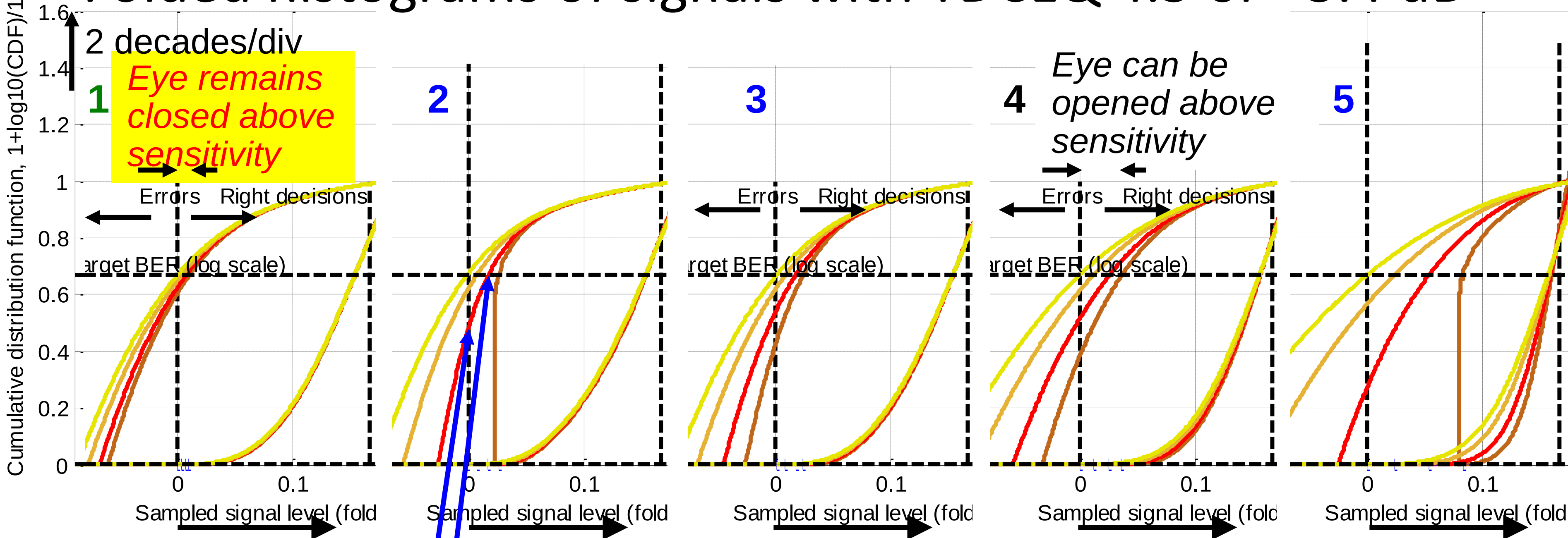
3: dirty, RIN -132 dB/Hz (50GBASE-FR and 50GBASE-LR) (also top blue star)

4: black star

Right: slow clean signal (bottom blue star)

To quantify these, the three sub-eyes of a histogram are overlaid and the histogram is folded about the threshold. The resulting vertical CDFs are plotted left-to-right on the next slide

Folded histograms of signals with TDCEQ 4.5 or ~3.4 dB



Vertically along the histograms

- Left: worst MMF (top green star) 2 and 3: dirty 4: black star Right: slow, clean
  - 1, 3 and 4 have RIN, 2 and 5 don't
  - 4 CDFs per signal: almost no Rx noise, 3, 1, 0 dB above sensitivity
  - The eyes are folded: threshold at 0, nominal signals at 1/6

BER =	BER =	BER =	BER =	BER =
4.9e-5 7.9e-5 1.4e-4 2.2e-4	0 2.6e-6 7.4e-5 2.6e-4	7e-7 1.0e-5 6.9e-5 2.0e-4	3e-7 6.7e-6 6.5e-5 2.3e-4	0 2.3e-8 2.1e-5 2.3e-4
2-sided eye opening / OMA	2-sided eye opening / OMA	2-sided eye opening / OMA	2-sided eye opening / OMA	2-sided eye opening / OMA
0.021 0.016 0.008 0.001	0.053 0.035 0.015 -0.002	0.050 0.036 0.018 0.003	0.074 0.052 0.025 0.001	0.167 0.108 0.048 0.001

3 dBo gives only 1.6% room for real EQ accuracy – "on the cliff edge"

up to 50% more room for EQ accuracy

anslow_062718_3cd_adhoc shows similar effect for cases similar to cases 2 and 4

Why do we care about the y axis? Isn't the TDECQ limit enough?

- TDECQ is useful because it feeds into OMA-TDECQ which is a measure of the useful signal strength, so OMA-TDECQ protects the receiver front end from excessive sensitivity demands
- But we also need some limit to how bad the signal can be
- For that, the equivalent of TDP in 10G (3.9 dB) and some 25G/lane optical PMDs, or TDEC in other 25G/lane (4.3 dB) isn't TDECQ, which is the product of a noise enhancement penalty and the penalty of the signal after the reference equalizer, it ***is*** the penalty of the signal after the reference equalizer: 10log10(K) = $TDECQ$–10log10(C_{eq})
- Which **protects the decision circuit or A to D and ensures that the equalizer doesn't need very challenging accuracy and resolution**
- Remember this is PAM4, so if we say TDECQ is 3.5 dB, 10log10(K) = $TDECQ$–10log10(C_{eq}) can be 4.5 dB without a "top limit", that's a comparable challenge for accuracy/OMA to 3.5+1+4.8 = 9.3 dB TDEC for PAM2
  - Receiver impairments in addition to sensitivity and jitter now have to be allowed room in a very squeezed vertical eye "budget"
  - In the past, we could overlook the receiver's need for a few % of the OMA because this cost very little sensitivity in PAM2. In PAM4, it can cost a lot
- Limiting 10log10(K) = $TDECQ$–10log10(C_{eq}) is part of going to PAM4

Alternative candidate remedies could be used, but...

- *Any of these could limit the top of the chart*

1. **10 log10(*K*) = *TDECQ* – 10log10(C_{eq})**
   - **Free by-product of TDECQ measurement**
2. Minimum C_{eq} inside the TDECQ algorithm
   - Combines top and diagonal limits into one
   - Variant on option 1
   - As well as excluding the worst signals, it gives reduced credit to clean over-emphasised signals, which may not be what we want
3. TDECQrms
   - Free by-product of TDECQ measurement
4. SNDR
   - Used in several 802.3 equalized electrical standards. Could modify the definition to use same equalizer as TDECQ
5. EVM (reduced to one dimension)
   - Error vector magnitude, used by ITU-T (Draft G.698.2,7.2.12: see references), to be used by OIF 400ZR
6. Broad thresholds

- **No strong request for any of the others, so continue to focus on option 1**

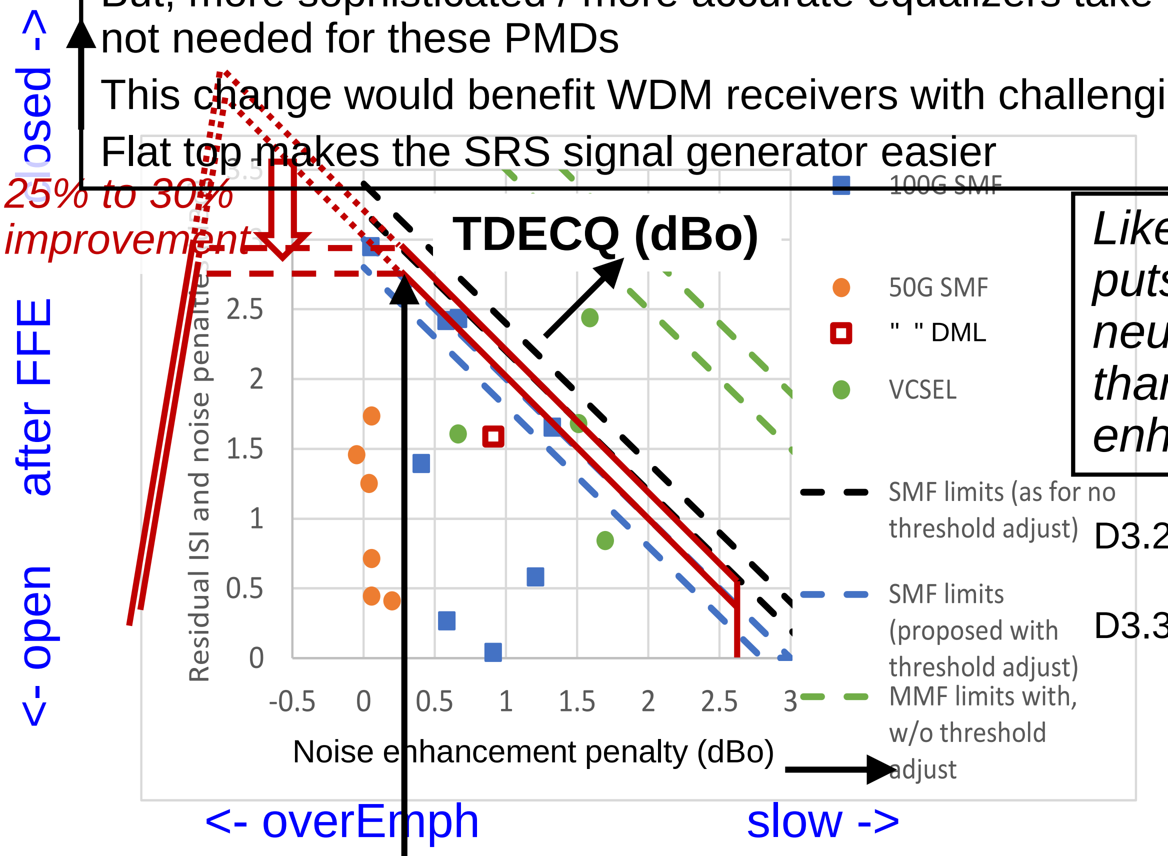
Proposed limits for 50GBASE-FR and 50GBASE-LR

Equalizers that can cope with more closed eyes than this must be made for 100G and for MMF

But, more sophisticated / more accurate equalizers take more power, and are not needed for these PMDs

This change would benefit WDM receivers with challenging sensitivity specs too

Flat top makes the SRS signal generator easier



Like comment 36 but puts the corner at neutral emphasis rather than 0 dB noise enhancement

- Corners at +0.3 dB NE representing most open eye for traditional non-EQ Rx, 0.75*fb BT4
- Also, use this corner as left end of SRS setup range to avoid need for strong FIR in pattern generator
- Real EMLs (brown) pass this with ease. More emphasis is allowed, although not needed
- DMLs would be further to the right, similar to VCSELs (brown square: tamura_3cd_01a_0718 slide 13)

Changes to Clause 139

Table 139–6, 50GBASE-FR and 50GBASE-LR transmit characteristics

Description	50GBASE-FR	50GBASE-LR	Unit
...			
Transmitter and dispersion eye closure for PAM4 (TDECQ) (max)	~~2.8~~3.0	~~3.0~~3.2	dB
$10\log_{10}(K)$ (max)	2.7	2.9	dB
Average launch power of OFF transmitter (max)	–16		dBm
...			

- Or, could use the same limit for *K* (2.9 dB) for both PMDs
- No change to receiver or budget table for the *K* limit
  - But changes follow the changed TDECQ limit
- In 139.7.5, TDECQ, define *K* by

$$\mathbf{10\ \log10(\mathit{K}) = \mathit{TDECQ} - 10\log10(\mathit{C_{eq}})}$$

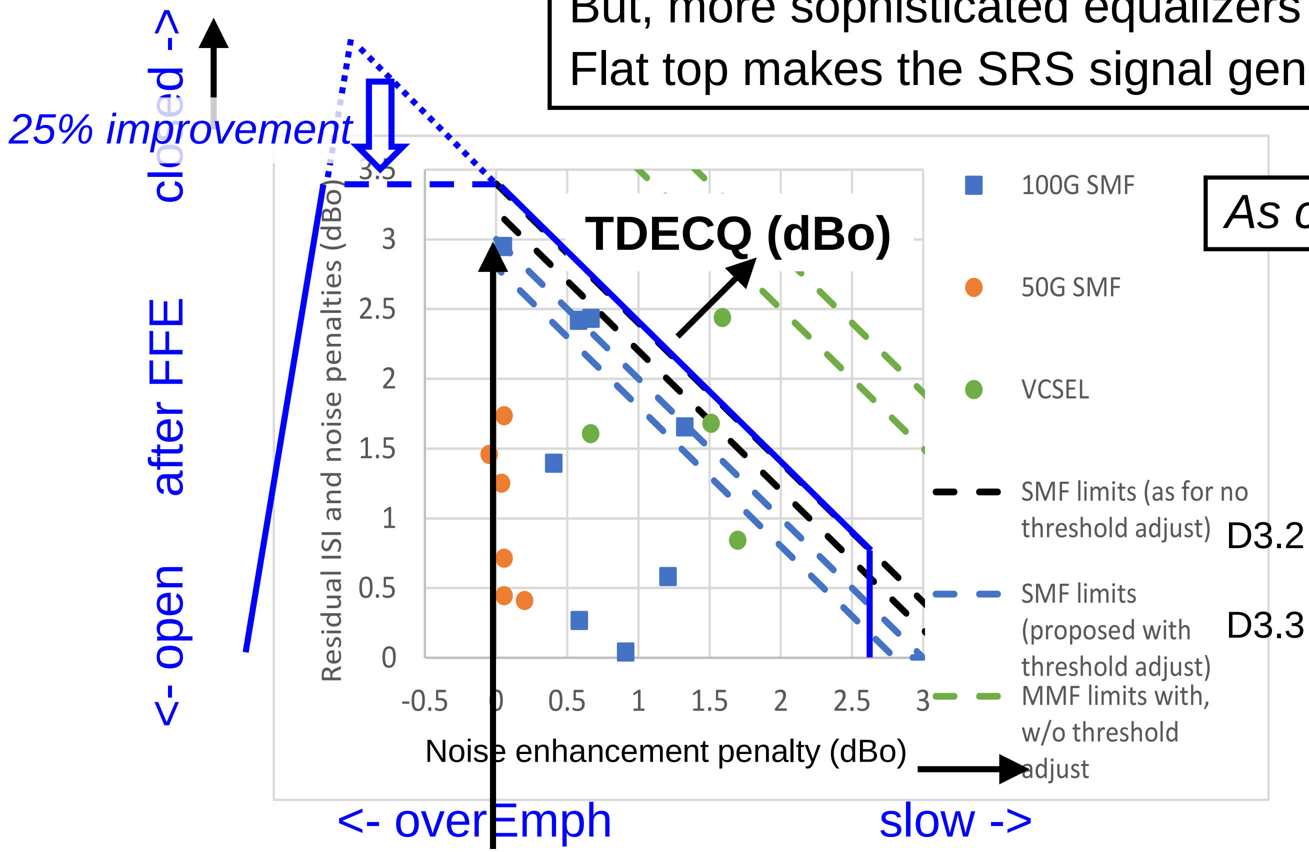
- In 139.7.10.2 SRS calibration, apply *K* limit – see slide 24

Proposed limit for 100GBASE-DR

Equalizers that can cope with more closed eyes than this must be made for MMF, at half the rate

But, more sophisticated equalizers take more power

Flat top makes the SRS signal generator easier



As comment 40

- Corner at 0 dB noise enhancement penalty, representing a slightly over-emphasised signal
- More emphasis is allowed, but reasonable signal quality is now enforced
- Also, use this corner as left end of SRS setup range to avoid need for stronger FIR in pattern generator
- If the max TDECQ is increased, as expected, keep the corner at 0 dB

Changes to Clause 140 – option 1

Table 140–6—100GBASE-DR transmit characteristics

Description	100GBASE-DR	Unit
...		
Transmitter and dispersion eye closure for PAM4 (TDECQ) (max)	3.~~0~~4	dB
$10\log_{10}(K)$ (max)	3.4	dB
Average launch power of OFF transmitter (max)	–15	dBm
...		

Same

- Keep the limit for K the same as the limit for TDECQ
- No change to receiver or budget table for the *K* limit
  - But changes follow the changed TDECQ limit
- In 140.7.5, TDECQ, define *K* by

$$\mathbf{10\ log10(\mathit{K}) = \mathit{TDECQ} – 10log10(\mathit{C_{eq}})}$$

- In 140.7.10, Stressed receiver sensitivity, apply *K* limit

Changes to Clause 140 – option 2

Table 140–6—100GBASE-DR transmit characteristics

Description	**100GBASE-DR**	**Unit**
...		
Transmitter and dispersion eye closure for PAM4 (TDECQ) (max)	3.~~0~~4	dB
Average launch power of OFF transmitter (max)	–15	dBm
...		

- No change to receiver or budget table for the *K* limit
  - But changes follow the changed TDECQ limit
- Change 140.7.5, TDECQ, as follows:

The TDECQ shall be within the limits given in Table 140–6 if measured ..., with the following exceptions:

indented list

In addition, *TDECQ* – 10log10(C_{eq}) shall be shall be within the limits given in Table 140–6

- In 140.7.10, Stressed receiver sensitivity, apply *TDECQ* – 10log10(C_{eq}) limit – see slide 25

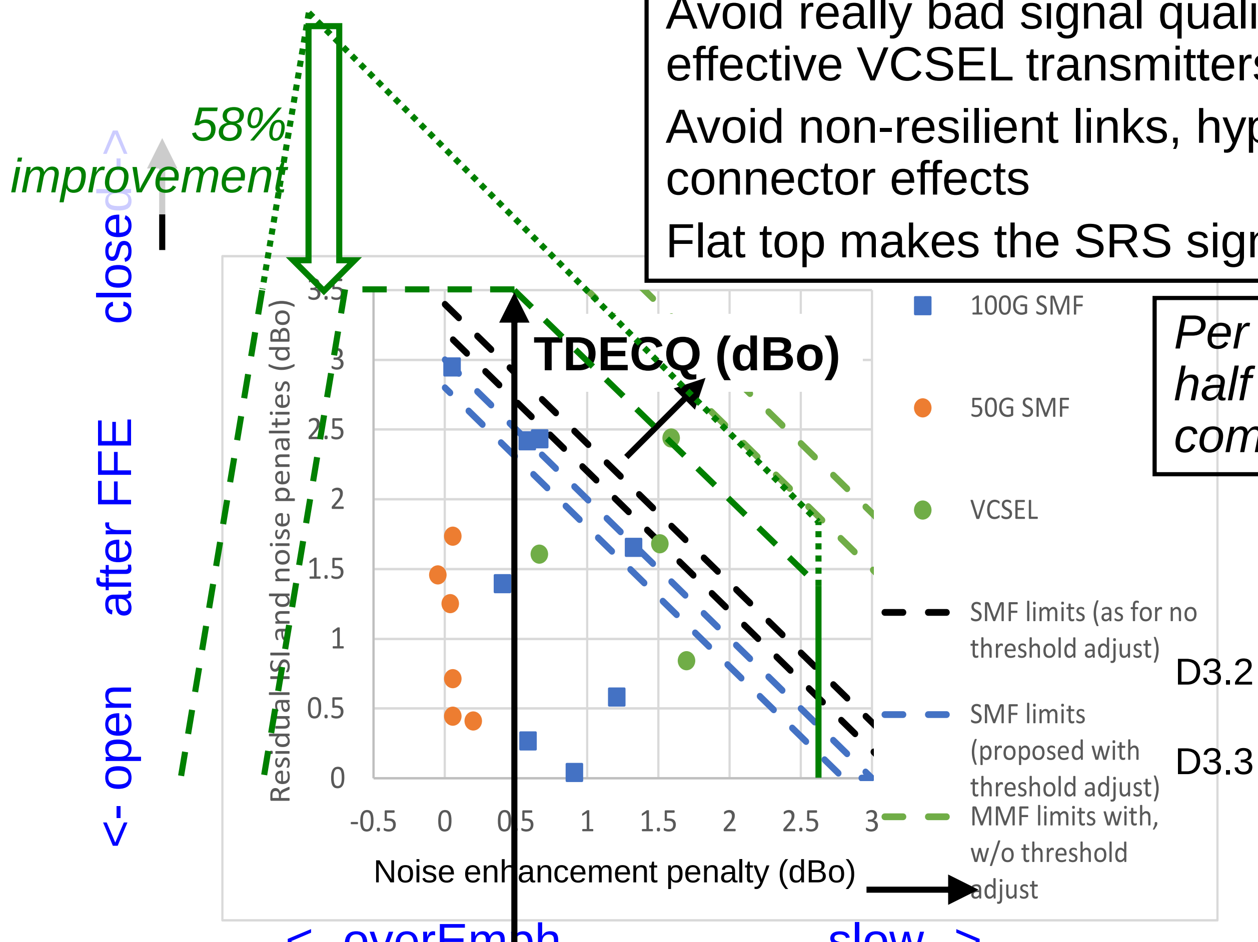
Proposed limit for 50-, 100-, 200GBASE-SR4

Avoid really bad signal quality yet allow cost-effective VCSEL transmitters

Avoid non-resilient links, hyper-sensitive to e.g. connector effects

Flat top makes the SRS signal generator easier

Per comments 30, 27; half the change of comment 31



- Limiting TDECQ-10log10(Ceq) – ***ESSENTIAL,*** *although still the hardest of all the bs, cd PAM4 optical PMDs*
- Reducing max TDECQ – worthwhile improvement
- Corner at +0.5 dB NE representing a neutral signal, but still to left of survey results
- More emphasis is allowed, but reasonable signal quality is now enforced
- Also, use this corner as left end of SRS setup range to avoid need for strong FIR in pattern gen.

Changes to Clause 138 (50-, 100-, 200GBASE-SR4) 1/2

Table 138–8—Transmit characteristics

Description	Value	Unit
...		
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	4~~.5~~	dB
$10\log_{10}(K)$ (max)	3.5	dB
Average launch power of OFF transmitter (max)	–30	dBm
...		

Table 138–8—Illustrative link power budget

Parameter	OM3	OM4	OM5	Unit
...				
Power budget (for max TDECQ)	6~~.5~~			dB
...				
Allocation for penalties[c] (for max TDECQ)	4.~~6~~1			dB
...				

Changes to Clause 138 (50-, 100-, 200GBASE-SR4) 2/2

- In 138.8.5, TDECQ, define *K* by

  $$10 \log10(K) = TDECQ - 10\log10(C_{eq})$$

- Change 138.8.5.1 TDECQ reference equalizer, as follows:

Tap 1, tap 2, or tap 3, has the largest magnitude tap coefficient, which is constrained to be at least 0.~~8~~9.

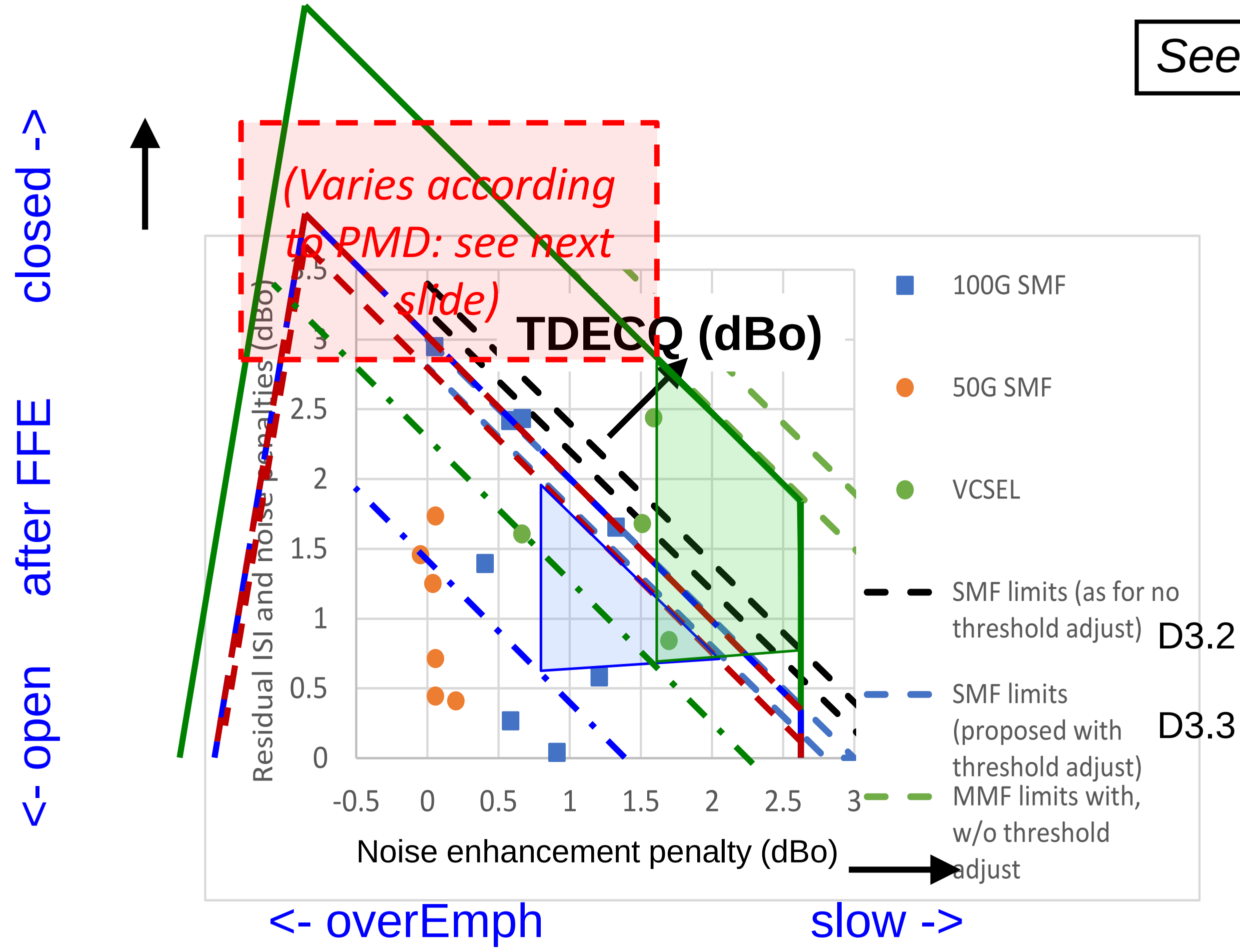
- Change 138.8.9, Receiver sensitivity, as follows:

Receiver sensitivity is informative and is defined for a transmitter with a value of SECQ up to 4~~.5~~ dB.

- Modify Figure 138–4, Illustration of receiver sensitivity by removing line to right of 4 dB of SECQ
  - Editorial: could reduce the y axis maximum
- In 138.8.10, Stressed receiver sensitivity, apply *K* limit – see slide 23

In D3.3, SRS areas don't align with Tx specs

See comment 39



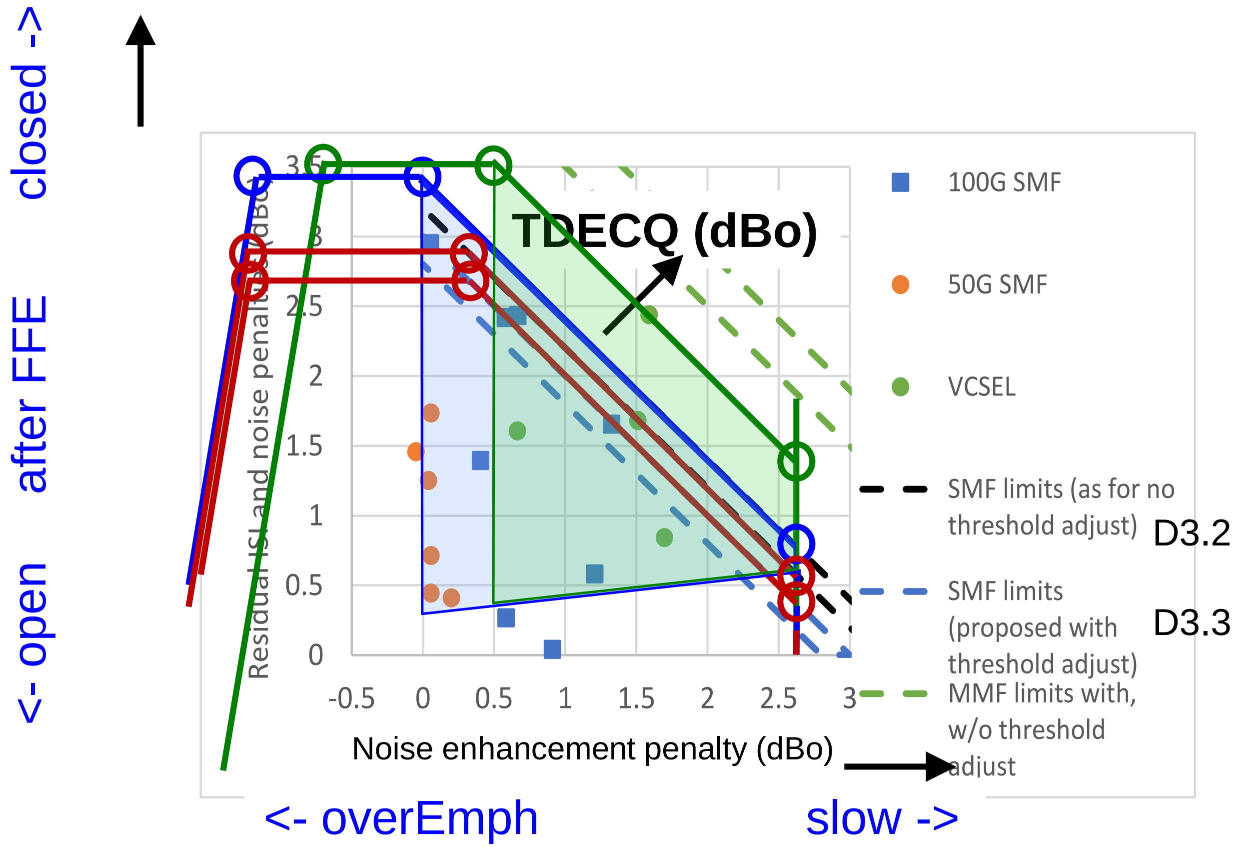
Green, brown, blue: **D3.3** limits for:
MMF,
50G SMF,
100G SMF

-.- Green "half the penalty" rule and SRS area for MMF

-.- Blue "half the penalty" rule and SRS area for SMF

- Remove "half the penalty" rule
- Set SRS signal's SECQ at max TDECQ *and* *SECQ*-10log10(C_{eq}) less than 10log10(K)=*TDECQ*-10log10(C_{eq}) limit in Tx spec

How many SRS test cases do we need?



Green, brown, blue: **proposed** limits for:

MMF,

50G SMF,

100G SMF

- Blue, brown and green circles indicate possible SRS test cases
- Propose SRS tests for middle and right circles
- Testing the left hand circles is not a good use of resource
  - See addendum

Possible changes to SRS section - 138

Change **138.8.10 Stressed receiver sensitivity** as follows:

Stressed receiver sensitivity shall be ... with the following exceptions:

— ... The optical splitter and variable reflector shown in Figure 121–4 are not used~~, and~~.

— There are two test conditions. In the first, "slow" condition, the transition time is close to but no greater than the value specified in Table 138–8, the sinusoidal interference is very small and the applied sinusoidal jitter may be less than specified in 138.8.10.1. In the second condition, the low-pass filter of Figure 121-8 is | may be omitted, emphasis may be used to create a signal with 10log10(C_{eq}) close to 0.5 | 0 dB*, and the applied sinusoidal jitter is as specified in 138.8.10.1.

— With the Gaussian noise generator on ... in Table 138–12.

— The signaling rate and the required stressed eye closure (SECQ) of the stressed receiver conformance test signal is specified in Table 138–9. The required SECQ parameter *K* of the stressed receiver conformance test signal is as given in Table 138–8^.

— The restriction that at least half of the dB value of the SECQ is due to the frequency response of the combination of the low-pass filter and the E/O converter in 121.8.9.1 and 121.8.9.2 does not apply.

~~— The applied sinusoidal jitter is specified in 138.8.10.1.~~

...

- And similarly for 140.7.10, Stressed receiver sensitivity, with adjustments to suit the different base text

* The C_{eq} corner in slides 18, 13, 15, for each clause

^ The transmitter table. Could repeat it in the receiver table if preferred

Possible changes to SRS section - 139

Change **139.7.10 Stressed receiver sensitivity** as follows:

139.7.10.1 Stressed receiver conformance test block diagram

...

A suitable test set is needed to characterize the signal used to test the receiver. Stressed receiver conformance test signal verification is described in 139.7.10.3.

The low-pass filter ismay be used to create ISI. The combination of the low-pass filter and the E/O converter should have a frequency response that results in at least half of the dB value of the stressed eye closure (SECQ) specified in Table 139–7 for 50GBASE-FR and 50GBASE-LR before the sinusoidal and Gaussian noise terms are added, according to the methods specified in 139.7.10.2. The sinusoidal amplitude interferer causes additional eye closure, but in conjunction with the finite edge rates, also causes some jitter.

...

139.7.10.2 Stressed receiver conformance test signal characteristics and calibration

The stressed receiver conformance test signal characteristics and calibration methods are as described in

121.8.9.2 with the following exceptions:

— There are two test conditions. In first, "slow" condition, the transition time of the stressed receiver conformance test signal is close to but no greater than the limit specified in Table 139–6, the the sinusoidal interference is very small and the applied sinusoidal jitter may be less than specified in 121.8.9.4. In the second condition, the low-pass filter of Figure 139-7 is | may be omitted, emphasis may be used to create a signal with 10log10(C_{eq}) close to 0.3 dB*, and the applied sinusoidal jitter is as specified in 121.8.9.4.

— The restriction that at least half of the dB value of the SECQ is due to the frequency response of the combination of the low-pass filter and the E/O converter does not apply.

— For each test condition, tThe SECQ and *K* and transition time of the stressed receiver conformance test signal isare measured according to 139.7.5, except that the test fiber is not used. The transition time of the stressed receiver conformance test signal is no greater than the value specified in Table 139–6. The filter response of the combination...

...

— An example stressed receiver conformance test setup is shown in Figure 139–7; however, alternative test setups that generate equivalent stress conditions may be used.

— The signaling rate of the test pattern generator and the extinction ratio of the E/O converter are as given in Table 139–6 for 50GBASE-FR and 50GBASE-LR.

— The required values of the “Stressed receiver sensitivity (OMAouter) (max)” and “Stressed eye closure for PAM4 (SECQ)” are as given in Table 139–7 for 50GBASE-FR and 50GBASE-LR. The required SECQ parameters *K* of the stressed receiver conformance test signals are as given in Table 139–6^.

* The C_{eq} corner in slide 13

^ The transmitter table. Could repeat it in the receiver table if preferred

Possible changes to SRS section – Clause 140 option 2 (no explicit *K*)

Change **140.7.10 Stressed receiver sensitivity** as follows:

Stressed receiver sensitivity shall be ... with the following exceptions:

— ... except that the test fiber is not used.

— There are two test conditions. In the first, "slow" condition, the transition time is close to but no greater than the value specified in Table 140–6, the sinusoidal interference is very small and the applied sinusoidal jitter may be less than specified in 121.8.9.4. In the second condition, the low-pass filter of Figure 121-8 is | may be omitted, emphasis may be used to create a signal with 10log10(C_{eq}) close to 0 dB, and the applied sinusoidal jitter is as specified in 121.8.9.4.

— The restriction that at least half of the dB value of the SECQ is due to the frequency response of the combination of the low-pass filter and the E/O converter in 121.8.9.1 and 121.8.9.2 does not apply.

— With the Gaussian noise generator on ... in Table 140–6.

— The signaling rate of the test pattern generator and the extinction ratio of the E/O converter are as given in Table 140–6 using test patterns specified in Table 140–9. The required stressed eye closure (SECQ) of the stressed receiver conformance test signal is specified in Table 140–7. The required SECQ parameter *K* of the stressed receiver conformance test signal is as specified in Table 140–6^.

— The required values of the “Stressed receiver sensitivity (OMA_{outer}) (max)” and “Stressed eye closure for PAM4 (SECQ)” are as given in Table 140–7.

^ The transmitter table. Could repeat it in the receiver table if preferred

SRS discussion

- Really, SRS protects along lines between test points; the other sensitivity is there to protect a region going down the page
- The alternatives to two (or three) SRS test cases are:
  - An explicit allowed range of SRS test cases
  - In effect, to use SRS for the "slow" case and the other sensitivity for the second case
- What extra would we add to the other sensitivity?
  - Make it normative? Normative but just recommended?
  - Include SJ?
  - Add statement that the signal could be slow, fast or over-emphasised
    - Guidance for C_{eq}?

The "at least half" rule in 121.8.9.1

121.8.9.1 Stressed receiver conformance test block diagram

...

The low-pass filter is used to create ISI. The **combination of the low-pass filter and the E/O converter should have a frequency response that results in at least half of the dB value of the stressed eye closure (SECQ) specified in Table 121–7 before the sinusoidal and Gaussian noise terms are added**, according to the methods specified in 121.8.9.2. The sinusoidal amplitude interferer causes additional eye closure, but in conjunction with the finite edge rates, also causes some jitter.

121.8.9.2 Stressed receiver conformance test signal characteristics and calibration

...

3) The required value of SECQ is given in Table 121–7. **With the sinusoidal jitter, sinusoidal interferer, and Gaussian noise generator turned off, at least half of the dB value of SECQ should be created by the selection of the appropriate bandwidth for the combination of the low-pass filter and the E/O converter.** Any remaining SECQ must be created with a combination of sinusoidal jitter, sinusoidal interference, and Gaussian noise. Sinusoidal jitter is added as specified in Table 121–12.

Clarifications to the other sensitivity

- Change 138.8.9, 139.7.9, 140.7.9 as follows:

For 50GBASE-F|LR, Receiver sensitivity is informative and is defined for a transmitter with a value of SECQ up to 4~~.5~~ | ~~2.8~~3 | 3.2 | 3.~~0~~4 dB, and a transmitter transition time (see 138.8.7 | 139.7.7 | 140.7.7) and *K* (see 138.8.5 | 139.7.5 | 140.7.5) no greater than the limits specified in Table 138–8 | 139–6 | 140–6.

- But what about average power, RIN and extinction ratio specs?
- Alternatively, change 138.8.9, 139.7.9, 140.7.9 as follows

Receiver sensitivity is informative and is defined for an otherwise compliant transmitter with a value of SECQ up to 4~~.5~~ | ~~2.8~~3 | 3.2 | 3.~~0~~4 dB.

Conclusion

- Add "how bad" transmitter limits:
- 50GBASE-FR and 50GBASE-LR
  - A small worthwhile improvement, which would help WDM receivers too, and does not preclude DML transmitters
- 100GBASE-DR
  - Balance the interests of receiver and EML transmitter
- 50-, 100-, 200GBASE-SR4
  - Protect the receiver without compromising VCSEL's needs
- Change SRS setup rules to align with transmitter specs

Addendum

- Possible means of using a TDECQ-like definition to avoid an SRS test point for very over-emphasised signals that are not expected to occur in practice

Changes to Clause 140, preparing for 2-point SRS

Purple material for discussion

Table 140–6—100GBASE-DR transmit characteristics

Description	100GBASE-DR	Unit
…		
Launch power in OMA_{outer} minus TDECQ2 (min)	–5.9	dBm
Transmitter and dispersion eye closure for PAM4 (TDECQ) (max)	3.04 Same	dB
$10\log_{10}(K)$ (max)	3.4	dB
Average launch power of OFF transmitter (max)	–15	dBm
…		

- If the max TDECQ is increased, keep the limit for K the same as the limit for TDECQ
- No change to receiver or budget table for the *K* limit
  - But changes follow the changed TDECQ limit
- In 140.7.5, define *K* by

  $$\mathbf{10\log10(\mathit{K}) = \mathit{TDECQ} - 10\log10(\mathit{C}_{eq})}$$

- and define

  $$\mathbf{\mathit{TDECQ2} = 10\log10(\mathit{OMA}_{outer}/(6\mathit{Q}_t\mathit{R}) + \max(10\log10(\mathit{C}_{eq}),0)}$$

- which has the effect of not giving a C_{eq} credit for points to the left of the corner. Similarly in other clauses, with the appropriate corner x coordinate (0.3 or 0.5).
  - For reference, $TDECQ' = 10\log10(OMA_{outer}/(6Q_tR)$ (Eq. 121–12)
- In 140.7.10 Stressed receiver sensitivity, apply *K* limit

This would be more applicable to clauses 138 and 139 where there's no need to deliberately go to the left of the corner

References

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- Concerning Comments r03-21, -22, -42, -43 On TDECQ
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- Achieving closure on TDECQ/SRS
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