TDECQ and SRS

Piers Dawe

Mellanox

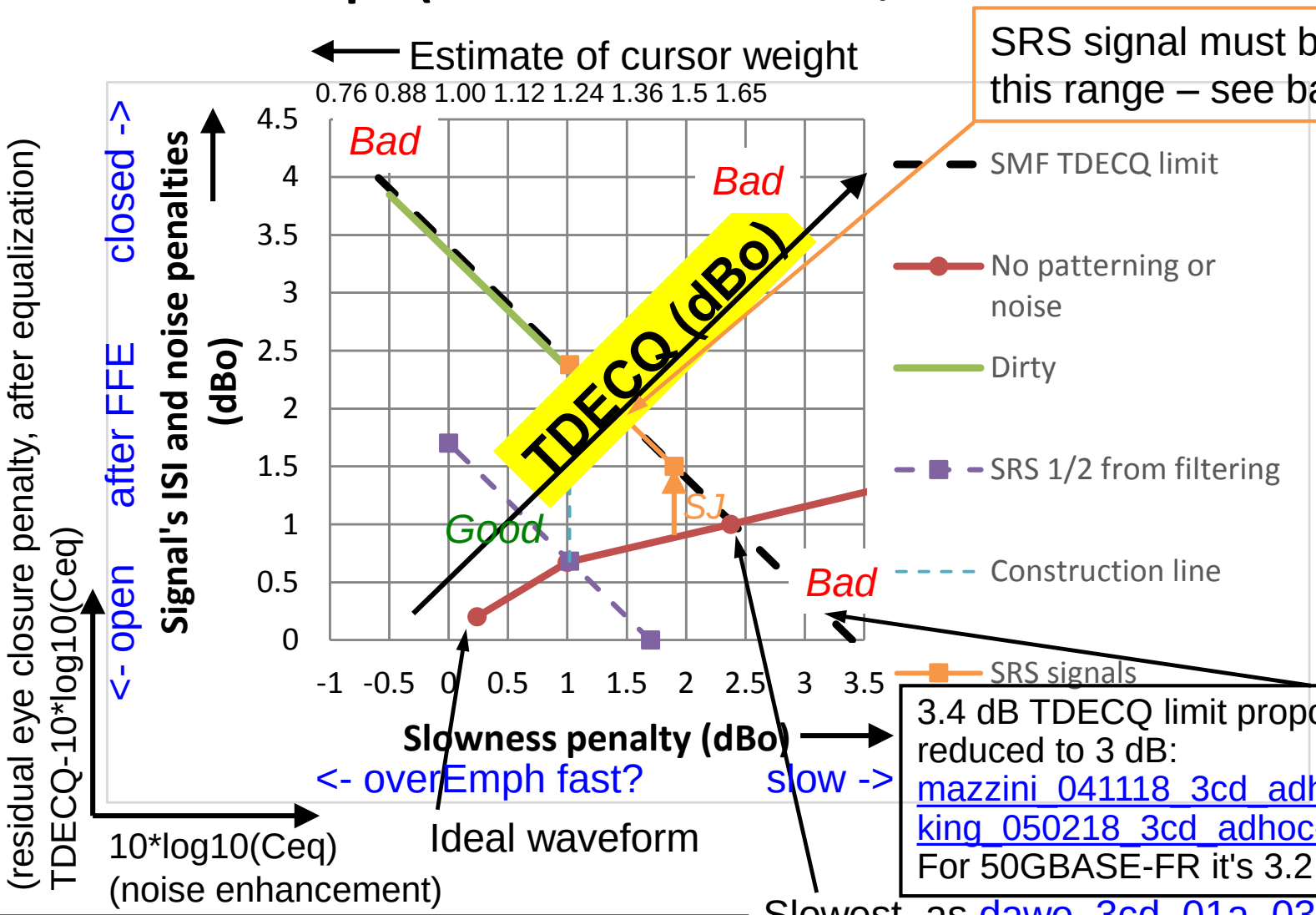
Supporters of the analysis

Phil Sun	Credo
Ken Jackson	Sumitomo
Mike Dudek	Cavium
Pavel Zivny	Tektronix
Johan Jacob Mohr	Mellanox
Marco Mazzini	Cisco
Pirooz Tooyserkani	Cisco
Rick Rabinovich	Keysight Technologies
Ed Ulrichs	Source Photonics
John Calvin	VTM

1-dimensional TDECQ is only part of what we need. SRS tweaks can follow

- Continuing to investigate the variety of bad signals (both in-service signals and stressed receive signals), considering where the limits of compliance should be and how to achieve them
- Follows dawe_3cd_01a_0318.pdf , dawe_032118_3cd_adhoc.pdf , dawe_040418_3cd_adhoc , dawe_1_0418 and dawe_041118_3cd_adhoc-v2 , dawe_050918_3cd_adhoc.pdf
- *New material since April – survey results, refinements to left and top limits, proposed changes for draft, number of adjustable thresholds, re-ordering, clarifications*
- *New since May 9th: More clarifications, more from survey. New slides 20 – 22*

TDECQ map (50GBASE-LR, 100GBASE-DR)



SRS signal must be in this range – see backup

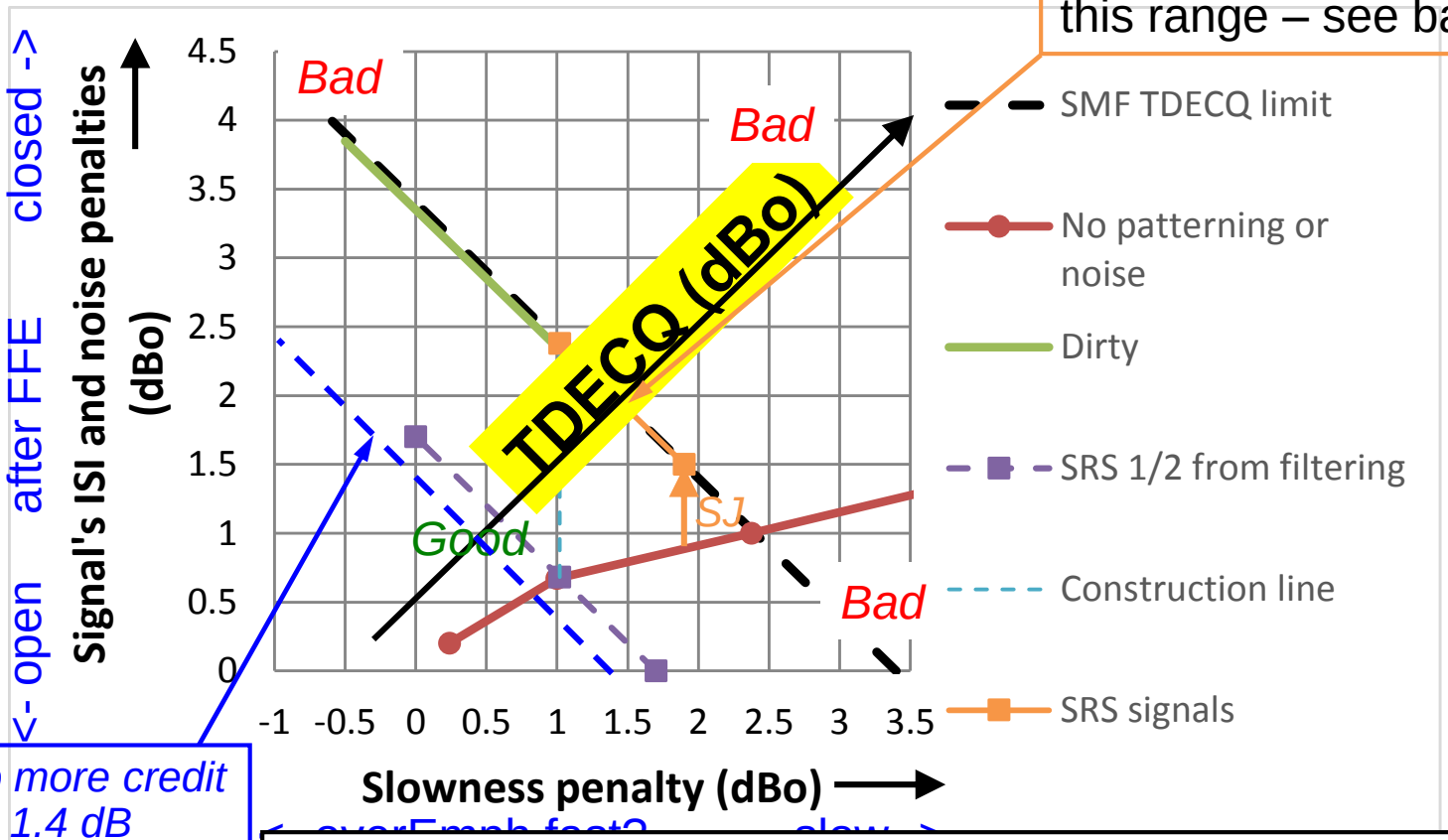
3.4 dB TDECQ limit proposed to be reduced to 3 dB: mazzini_041118_3cd_adhoc , king_050218_3cd_adhoc-v2
For 50GBASE-FR it's 3.2 > 2.8

Slowest, as dawe_3cd_01a_0318 slides 2 to 5

Signals at top left and bottom right with same TDECQ are very different – see backup

TDECQ map (50GBASE-LR, 100GBASE-DR)

SRS signal must be in this range – see backup



Tx gets no more credit for OMA < 1.4 dB

Signals below the blue line have to provide more power than OMA-TDECQ limit

Need to be clear where signals can be

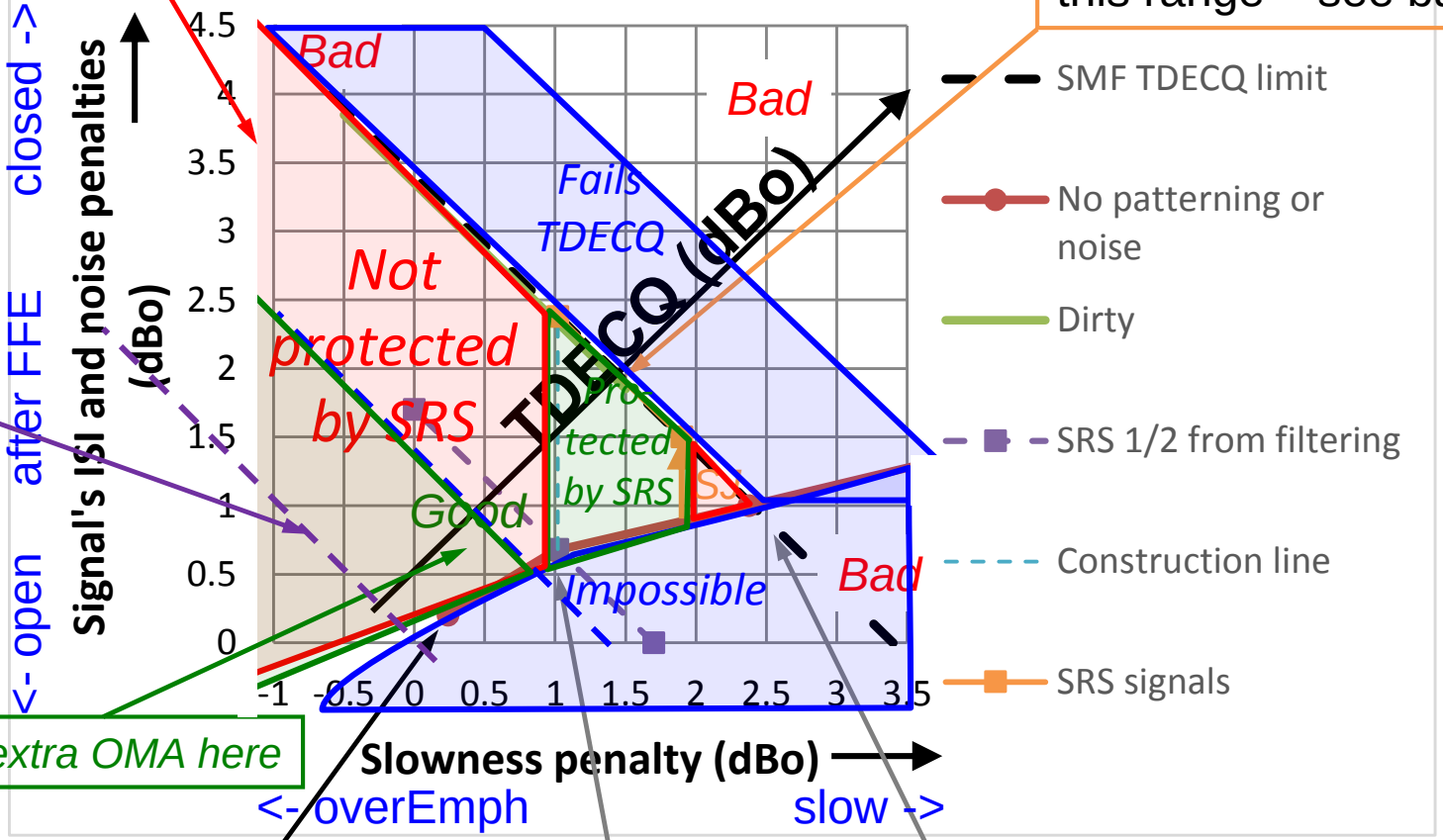
- √ Bottom: natural limit
- √ Upper right: TDECQ limit
- × Right: vertex where it appears real transmitters aren't
- × Top: no limit
- × Left: no limit

TDECQ map and Rx specs

There's no limit on the left in the draft

SRS signal must be in this range – see backup

The "other" receiver sensitivity is defined up to the max for TDECQ, with min. zero, which seems too low



Rx sees extra OMA here

Ideal waveform

Half the SECQ from filtering

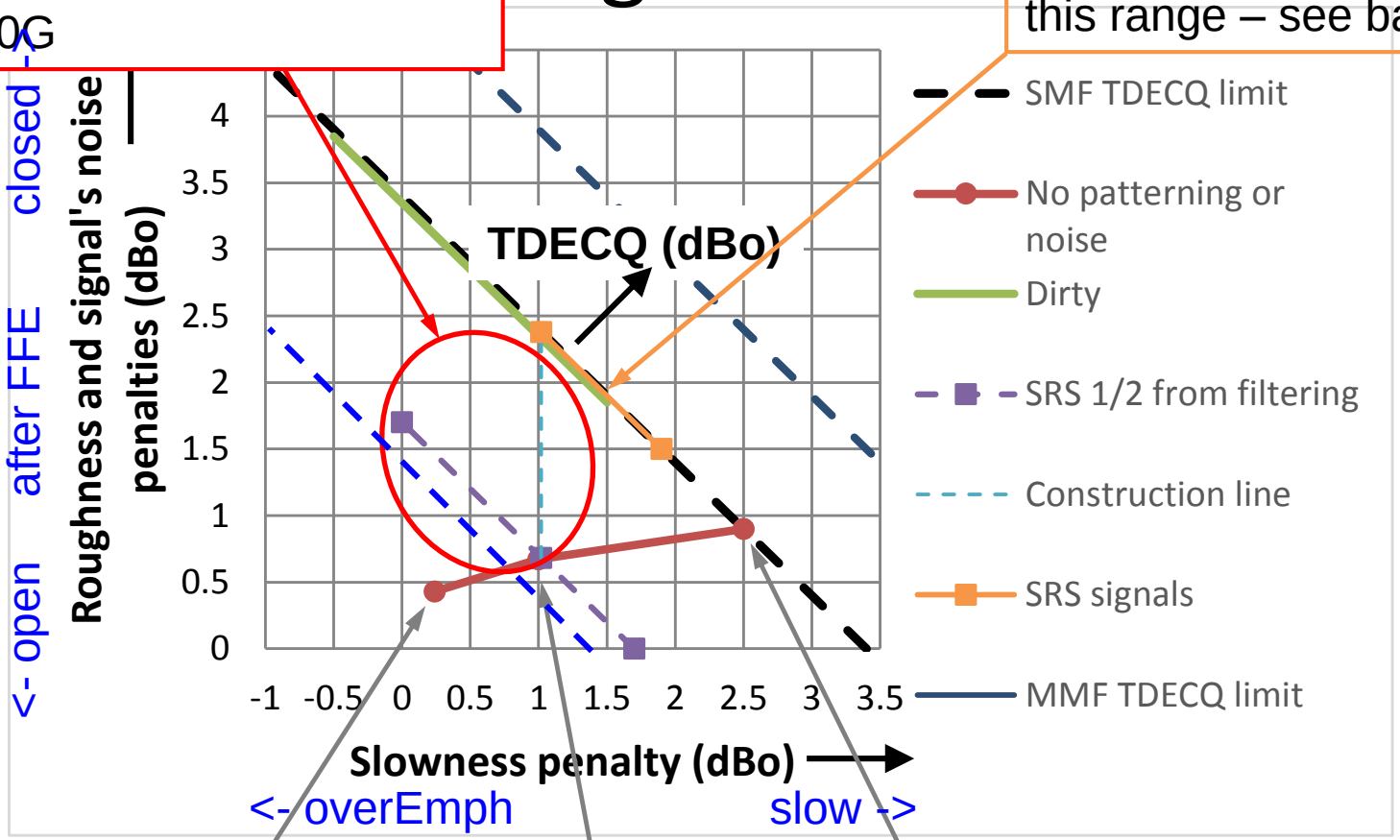
Slowest, as dawe_3cd_01a_0318 slides 2 to 5

Transmitted signals are allowed that receivers don't have to receive (red regions)

Mismatch between SRS and real signals?

Where will real poor signals be? Here? 50G can be better than 100G

SRS signal must be in this range – see backup

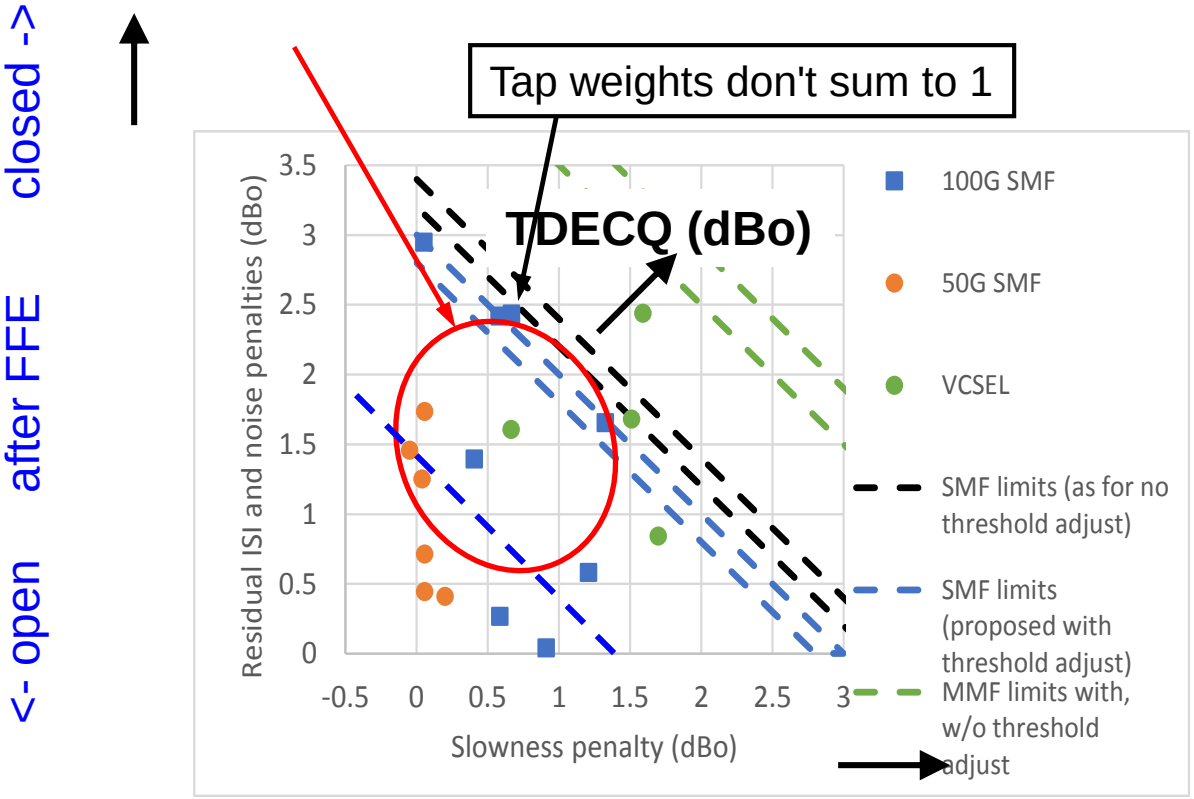


Ideal waveform

Half the SECQ from filtering

Slowest, as dawe_3cd_01a_0318 slides 2 to 5

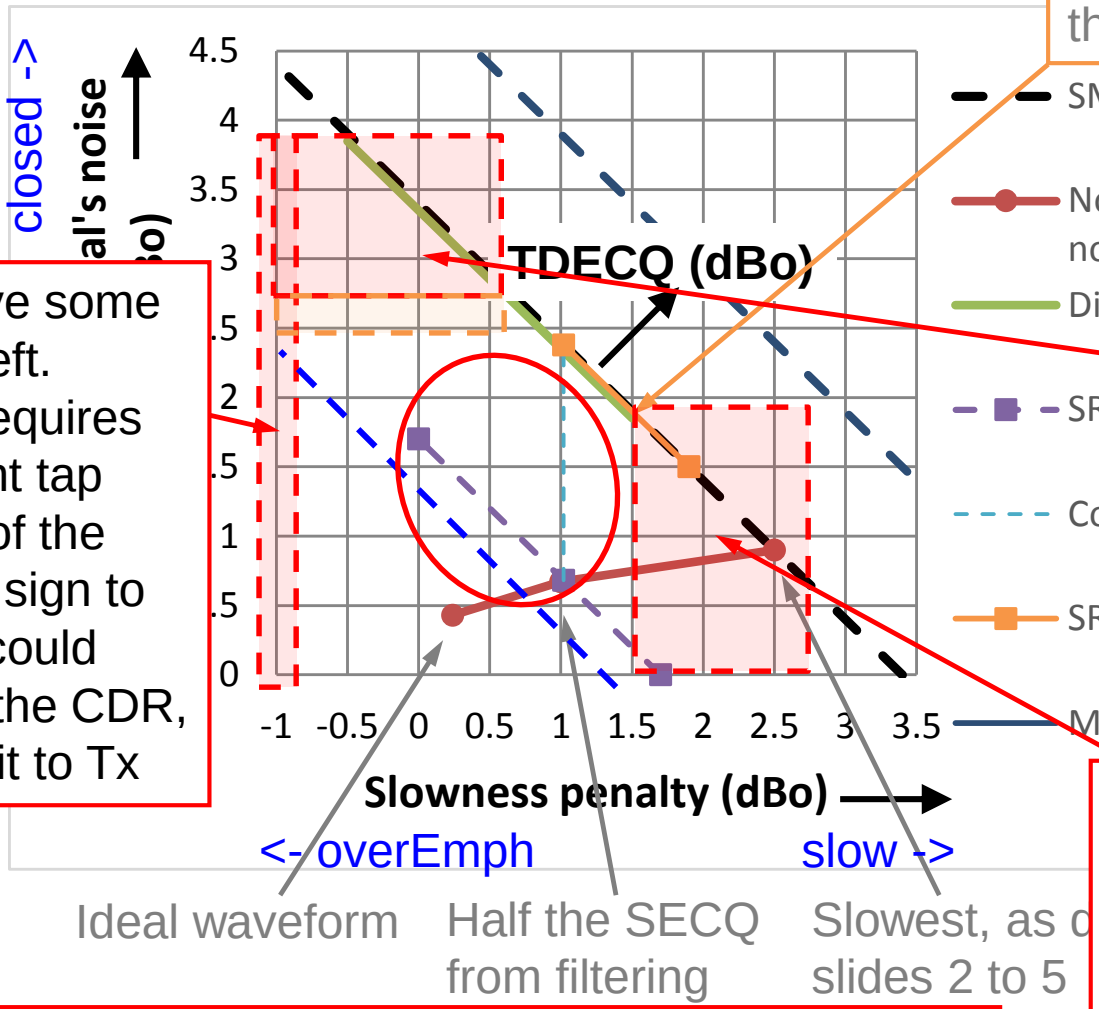
Real signals, from an anonymous survey



- Transmitters include EML, SiP, one MZM, VCSELs
  - One high-TDECQ point has a data error?
- The red ellipse is a compromise between 50G and 100G, SMF
- The 50G signals have TDECQ well below the TDECQ limits
- All 50G SMF signals are far to the left of the slowest allowed
- Many SMF transmitters seem to be using emphasis – some want to be on the left of zero

See later for more, inc. Rx tap coefficients

Don't support unrealistic bad scenarios



SRS signal must be in this range – see backup

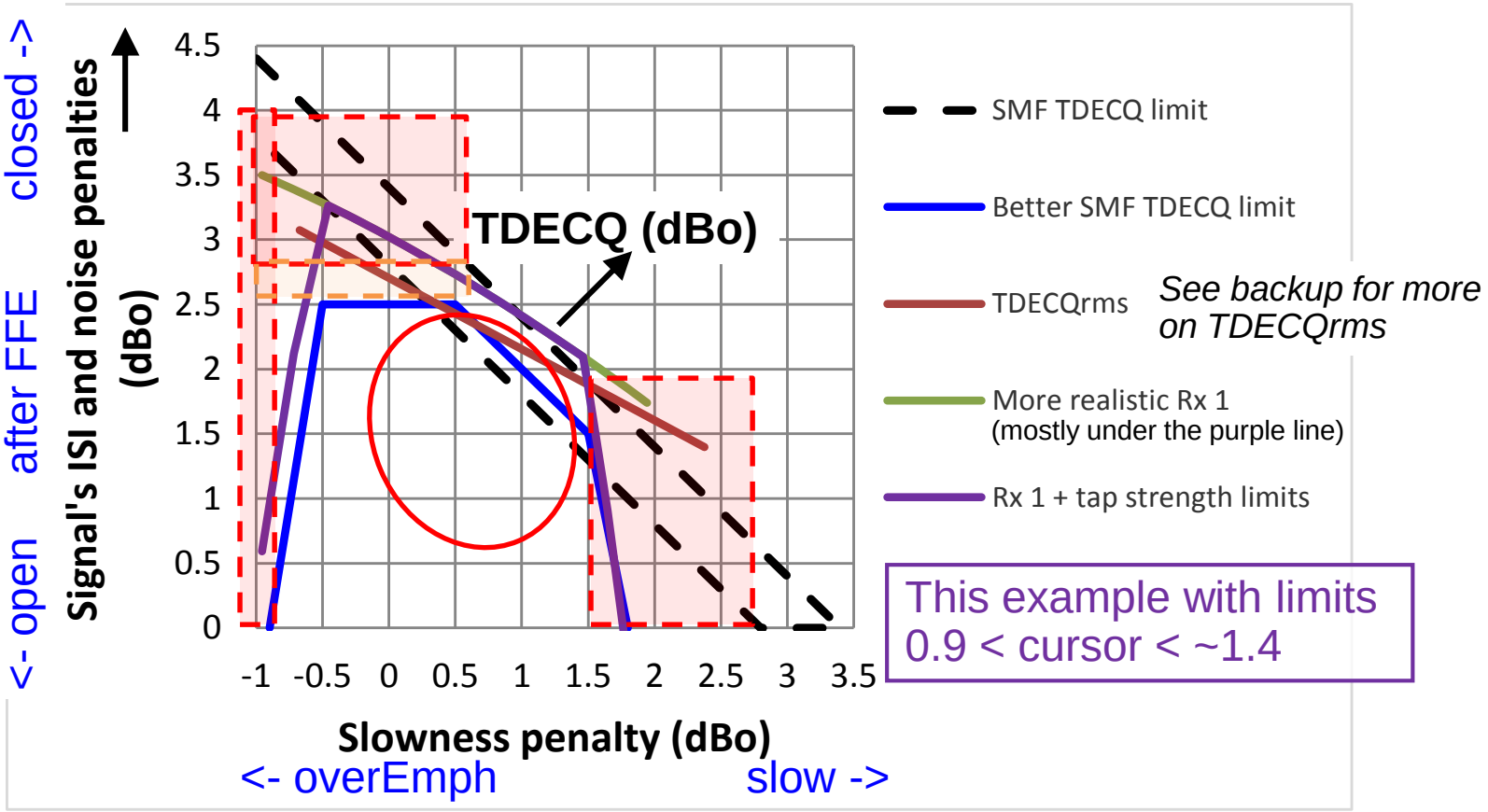
Should be excluded because the eye after FFE is very closed, and small inaccuracies in Rx would cause big additional penalties (cliff edge)
Like VEC issue in C2M

Must have some limit on left.
Too far requires significant tap weights of the opposite sign to normal, could confuse the CDR, no benefit to Tx

Should be excluded because it requires strong tap weights not useful in practice, for SMF would have failed T/2-spaced TDECQ

"Exclusion" could be by giving signals in the red boxes worse TDECQ scores, or by "hard" pass-fail rules

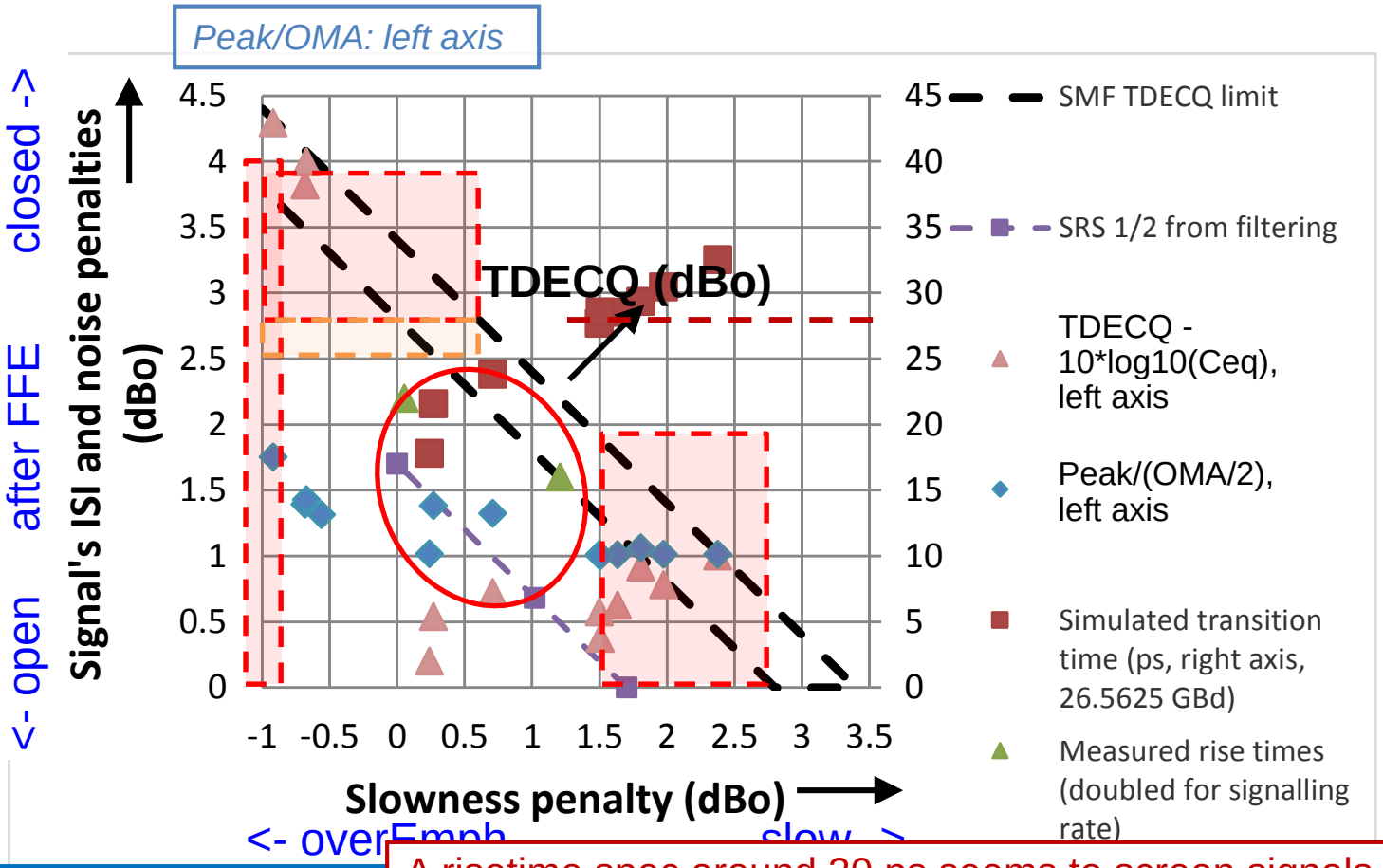
More realistic receiver; tap limits



The green and blue-green lines represent receivers with some internal impairments such as finite tap and threshold setting accuracy

The purple line *(improved but still preliminary)* shows how a finite range of tap weights affects things, with either a real receiver or the reference FFE in TDECQ

Possible peak/OMA and risetime specs



A peak/OMA spec would exclude signals that have too much "dynamic range", but does not seem to control over-emphasis unless very bad

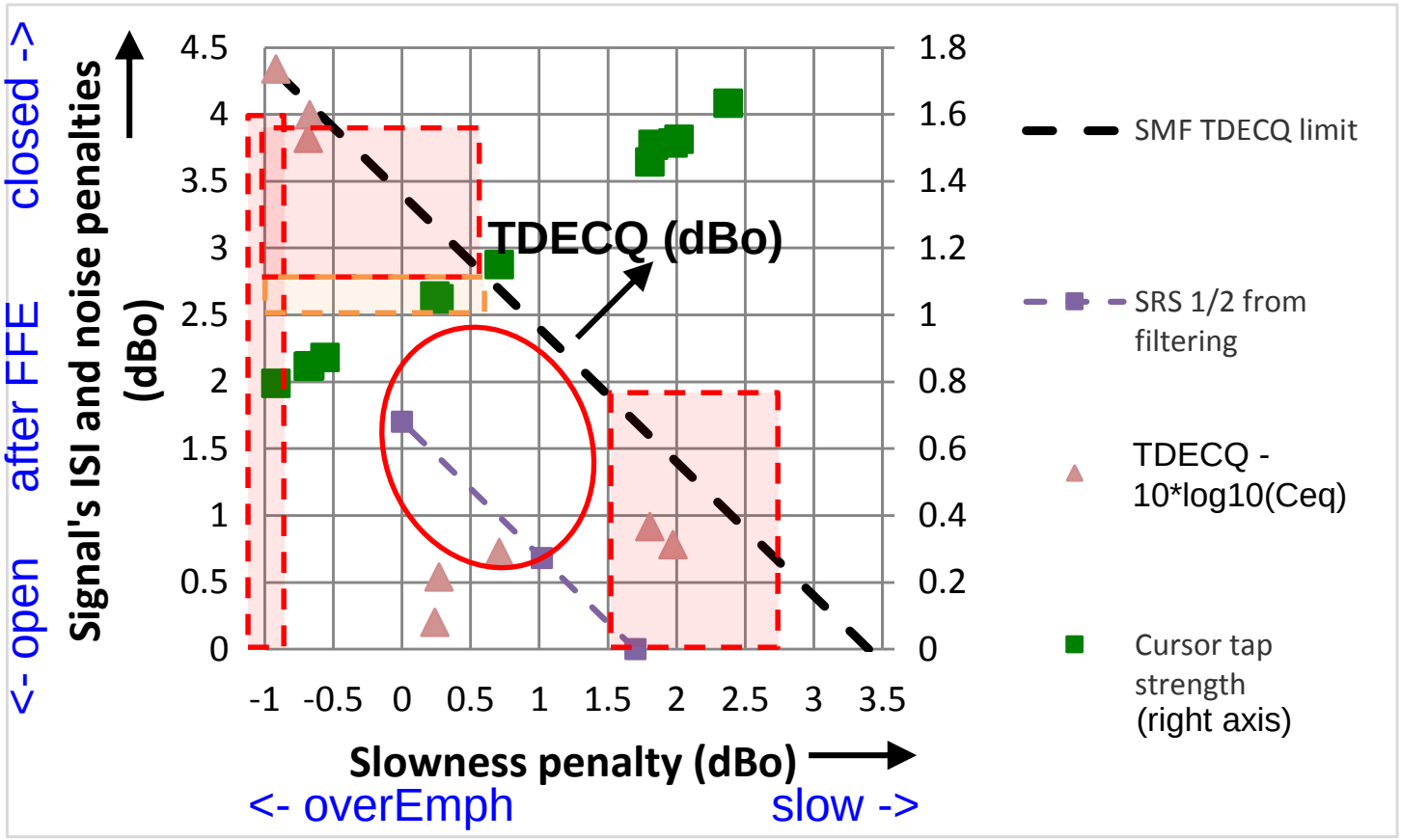
A risetime spec around 30 ps seems to screen signals that are slower than allowed for PAM2

Limit for 50G lanes should be a bit tighter than that: propose 27 to 28 ps if no tap limit

This is 20-80% observed in the usual fb/2 BW

Scatter needs more investigation, but promising for right side, not so for left side

Possible largest tap spec



- So far, the correlation between slowness penalty in dB and largest tap coefficient looks promising
- This might be just luck
- This is a simplification of a previous proposal that used the sum of the other four taps

Most serious gaps

- The most serious gaps are on the left and top
  - *See waveforms in backup that illustrate this*
- To address over-emphasis (left), either

1. Constrain cursor, or
2. Constrain C_{eq} or main tap weight, in TDECQ, or
3. Reject signals with C_{eq} < limit, or main tap weight > limit
4. Reject signals with (peak-mean)/OMA > limit

- Options 1 and 2 are more lenient to otherwise good signals
- All are "free": by-product of TDECQ measurement, or part of it
- Option 4 can be done without the full TDECQ analysis
  - but may not work so well
- See next two slides for example remedies

Bound the left side (too much emphasis)

From the comments report

Cl **138** *SC* **138.8.5.1** *P* **273** *L* **41** # r02-47 *Comment Type* **TR**

In this draft, it is possible to make a bad transmitter (e.g. with a noisy or distorted signal), use emphasis to get it to pass the TDECQ test, yet leave a realistic, compliant receiver with an unreasonable challenge, such as high peak power, high crest factor, or a need to remove a lot of emphasis from the signal, contrary to what equalizers are primarily intended to do ("gaming the spec": D3.1 comment 70). Note the receiver is tested for medium to slow signals only, not for any of these abusive signals. This is an issue for all the PAM4 optical PMDs, although it may be worse for MMF because of the high TDECQ limit and because the signal is measured in a particularly low bandwidth. On the TDECQ map (see e.g. dawe_041818_3cd_adhoc-v2) we need to stop signals that are too far to the left, which would be outside the range of what a typical equalizer would be designed to cope with (e.g. would need strong tap weights of the opposite sign to normal) and provide no practical benefit in a system. At present there is no boundary on the left.

D3.0 comment 116, D3.1 comments 70, 71.

SuggestedRemedy

To protect the receiver from having to "invert" heavily over-emphasised signals, change "largest magnitude tap coefficient" to "largest magnitude tap coefficient, which is constrained to be **at least 0.95**."

Similarly in clauses 139, 140.

It may make sense to have a higher limit (1 to 1.1) for MMF because the transmitter is not tested without the filter emulating a low-pass fibre.

Revised proposal

- *Survey would support 0.99 but lower is requested*
- *Important to have some limit: not so important to optimise it*
- ***Propose 0.8 for SMF***
- *Error in suggested remedy: MMF signal is measured as if after slowest channel; with a faster channel the same transmitter would be further to the right. So need **higher limit for MMF** so EQ IC can work in same range. Propose at least 0.3 dB of Ceq higher, **tap min. 0.87***
- *The remedy doesn't directly outlaw excessively over-emphasised signals, but gives them worse TDECQ scores*
- *Alternatives considered: peak-peak/OMA limit, minimum C_{eq} limit, minimum risetime limit*

Bound the top (irreparably bad)

From the comments report

- Cl **139** SC **139.7.5.3** P **297** L **52** # r02-52 Comment Type **TR**
- In this draft, it is possible to make a bad SMF transmitter with emphasis (e.g. with a noisy or distorted signal) that even an equalizer better than the reference equalizer won't be able to improve. Note the receiver is tested for a slow signal only, not for such signals.
- On the TDECQ map (see e.g. dawe_041818_3cd_adhoc-v2) **we need to stop signals that are too high up the page**.
- D3.0 comment 116, D3.1 comment 71.
- SuggestedRemedy
- For a SMF TDECQ limit of 3.2 or 3.4 dB: **Either:**
- **1. Limit TDECQ -10*log10(Ceq) to <=2.8 dB for SMF PMDs.**
- **or:**
- **2.** Define **TDECQrms** = 10*log10(A_RMS/(s*3*Qt*R)) where A_RMS is the standard deviation of the measured signal after the 13.28125 GHz filter response (before the FFE), Qt and R are as already in Eq 121-12. s is the standard deviation of a fast clean signal with OMA=2 and without emphasis, observed through the reference Bessel-Thomson filter response but before the reference equalizer (0.6254 for 13.28125 GHz).

Revised proposal

- **Limit 3 dB for SMF PMDs.** This could be added to the transmitter tables.
- *Either is a free by-product of a TDECQ measurement*
- *Is there an alternative?*
- *Option 1: for 50G SMF, if TDECQ limits are reduced to 2.8, 3.2 dB as expected, this should be **2.5 dB** as shown. For 100G SMF, survey indicates a higher limit would help some transmitters: suggest 2.8 dB as proposed in the comment. For MMF: depends on MMF TDECQ limit*

Bound the right (slower than expected)

From the comments report

- *Cl* **139** *SC* **139.7.5.4** *P* **298** *L* **6** *#* r02-54 *Comment Type* **TR**
- The draft transmitter spec allows signals that are slower than the receiver is tested for in SRS, slower than the equivalent SMF PAM2 spec, and I believe slower than were allowed when the draft had a T/2-spaced equalizer. I have seen no evidence that implementers want to make super-slow transmitters. Yet receiving such a signal would place an extra burden on the receive equalizer e.g. better linearity and/or finer AtoD or tap resolution. This is one kind of "abusive signal" mentioned in D3.1 comment 71. See e.g. dawe_041818_3cd_adhoc-v2. The first option more directly protects the receiver and allows more trade-offs in transmitter design; both are free by-products of a TDECQ measurement and are at about 1.7 dB slowness penalty.
- *SuggestedRemedy*
- Limit the signals on the right of e.g. dawe_041818_3cd_adhoc-v2. **Either:**
- **Set a maximum cursor strength limit,1.4**
- **or:**
- **Set a maximum 20-80% transition time limit as observed after the reference Bessel-Thomson filter response but before the reference equalizer, 28 ps.**
- For Clause 140, the limits would be 1.5 and 15 ps (allowing relatively slower signals).
- For Clause 138, the transmitters would have similar speed to Clause 139, but the signals are observed in a lower bandwidth, so a limit in between 1.4 and 1.5 should be used.

Revised proposal

- *Either is a free by-product of a TDECQ measurement.*
- *Transition time would be based on isolated edges (see 120E.3.1.5 Transition time) and P0, P3 (see 121.8.4 Outer Optical Modulation Amplitude (OMAouter)*
- *Comments 57 and 58 also propose a maximum rise time specification*
- *The cursor strength limit allows a trade-off, more representative of receiver's needs: an otherwise better Tx can be a little slower*
- *Based on survey result: for **50G SMF, propose maximum cursor strength limit of 1.35** or transition time 27 to 28 ps, for "slowness penalty", ~1.5 dB as illustrated*

Additions to 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)	3.2 2.8	3.4 3.0	dB
Tap coefficient for TDECQ (max)	1.35	1.35	–
Main tap coefficient for TDECQ (min)	0.8	0.8	–
TDECQ minus $10\log_{10}(C_{eq})$ (max)	2.5	2.5	dB
Average launch power of OFF transmitter (max)	–16		dBm
...			

The change to TDECQ limits is proposed in king_050218_3cd_adhoc-v2

Three adjustable thresholds or six?

- The draft says:
- — P_{th1}, P_{th2}, and P_{th3} are varied from their nominal values by up to ±1% of OMAouter in order to optimize TDECQ.
- Three thresholds, used for both left and right histograms, but one could use six
- If we think the worst-case receiver is either like the left histogram or the right one but never both together (lower setup-and-hold time and jitter), low, choose six
  - This allows twisted eyes: 2% of OMA or 6% of a sub-eye in 0.1 UI or 60%/UI
- If we think the worst-case receiver is like both together (higher setup-and-hold time and jitter), choose three

Text changes to TDECQ definition

138.8.5 Transmitter and dispersion eye closure - quaternary (TDECQ), 139.7.5.3 TDECQ measurement method, 140.7.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)

TDECQ of each lane shall be within the limits given in Table 138–8 if measured using the methods specified in 121.8.5, with the following exceptions:

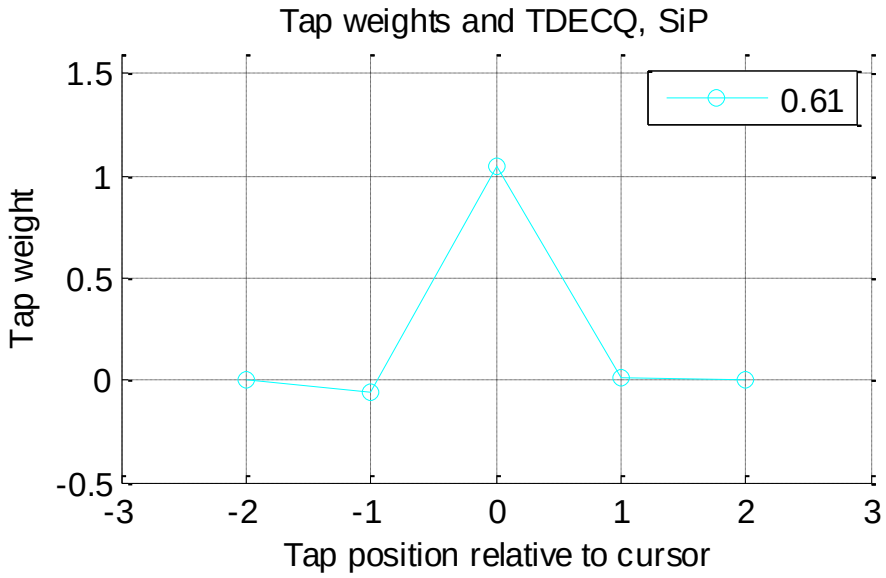
...

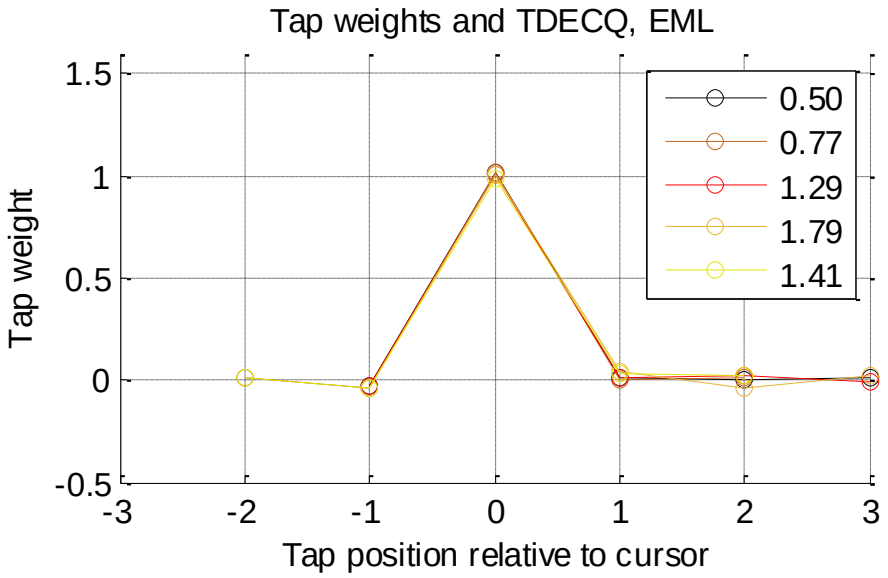
— P_{th1}, P_{th2}, and P_{th3} are varied from their nominal values by up to ±1% of OMAouter in order to optimize TDECQ. The same three thresholds are used for both the left and the right histogram.

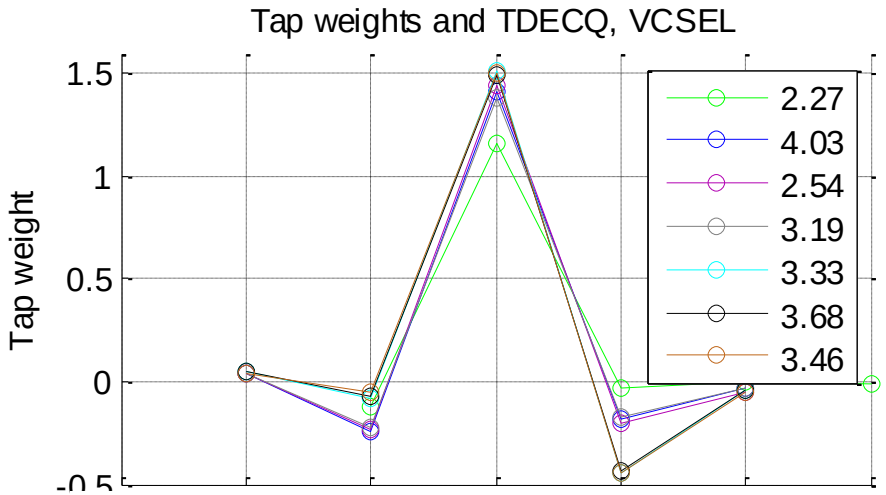
— The equalizer tap coefficients are adjusted within the constraints given in Table 138–8 / 139–6 / 140–6.

— C_{eq} is as defined in Eq (121–9) with the same tap coefficients used for TDECQ.

50G/lane reference receiver tap weights



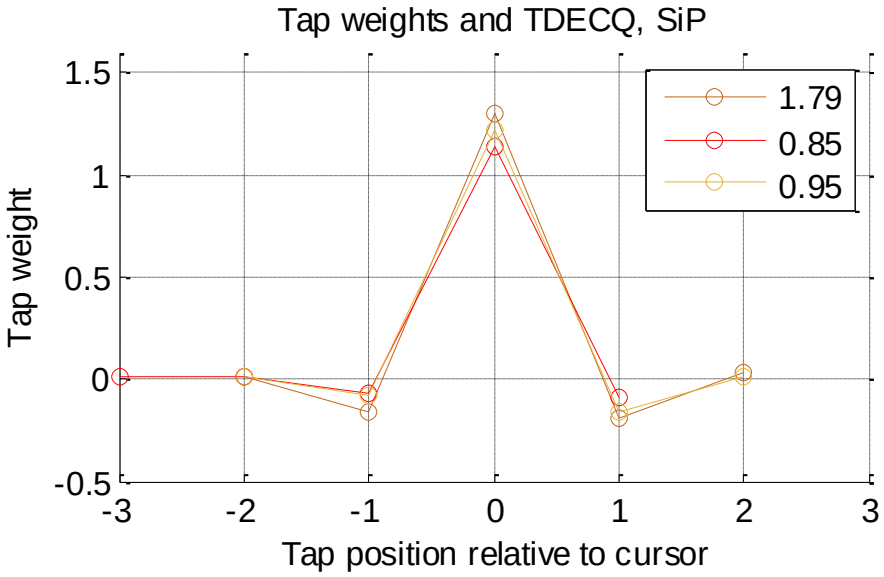


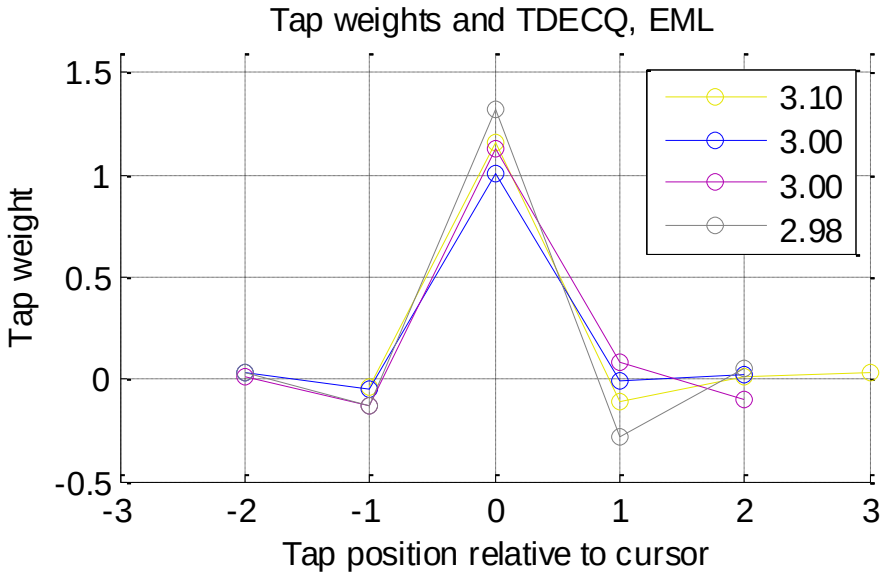


- Main tap is in position 2 or 3
- Not position 1

- Here, taps are numbered relative to the main tap
- Outer taps are small
  - Indicates that other solutions are possible, some almost as good

100G/lane reference receiver tap weights





- Main tap is in position 2 or 3 (or 4 – not allowed)
- Not position 1
- Here, taps are numbered relative to the main tap
- Outer taps are small
  - Indicates that other solutions are possible, some almost as good
- TDECQ for SiP is way below the threshold. Maximum weight of precursor 2 is 0.015, 1.2% of the main cursor
- For EML, maximum precursor 2 weight is less than 3% of main cursor. Postcursor 2 weight for the same transmitter is about 4.1%. One other test has 2.6% postcursor 3 and no precursor 2

Summary

- TDECQ is not the whole story
- Add spec limits for left, top and right in addition to TDECQ limit, to protect cost-effective receivers:

Left Largest magnitude tap coefficient min. 0.8 for SMF, 0.87 for MMF

Top TDECQ minus 10log10(Ceq) max. 2.5 for TDECQ max 2.8, or 2.8 for 3.2 (SMF)

Right Max. tap coefficient 1.35 *or* max. transition time 27 to 28 ps, for 50G SMF

To do

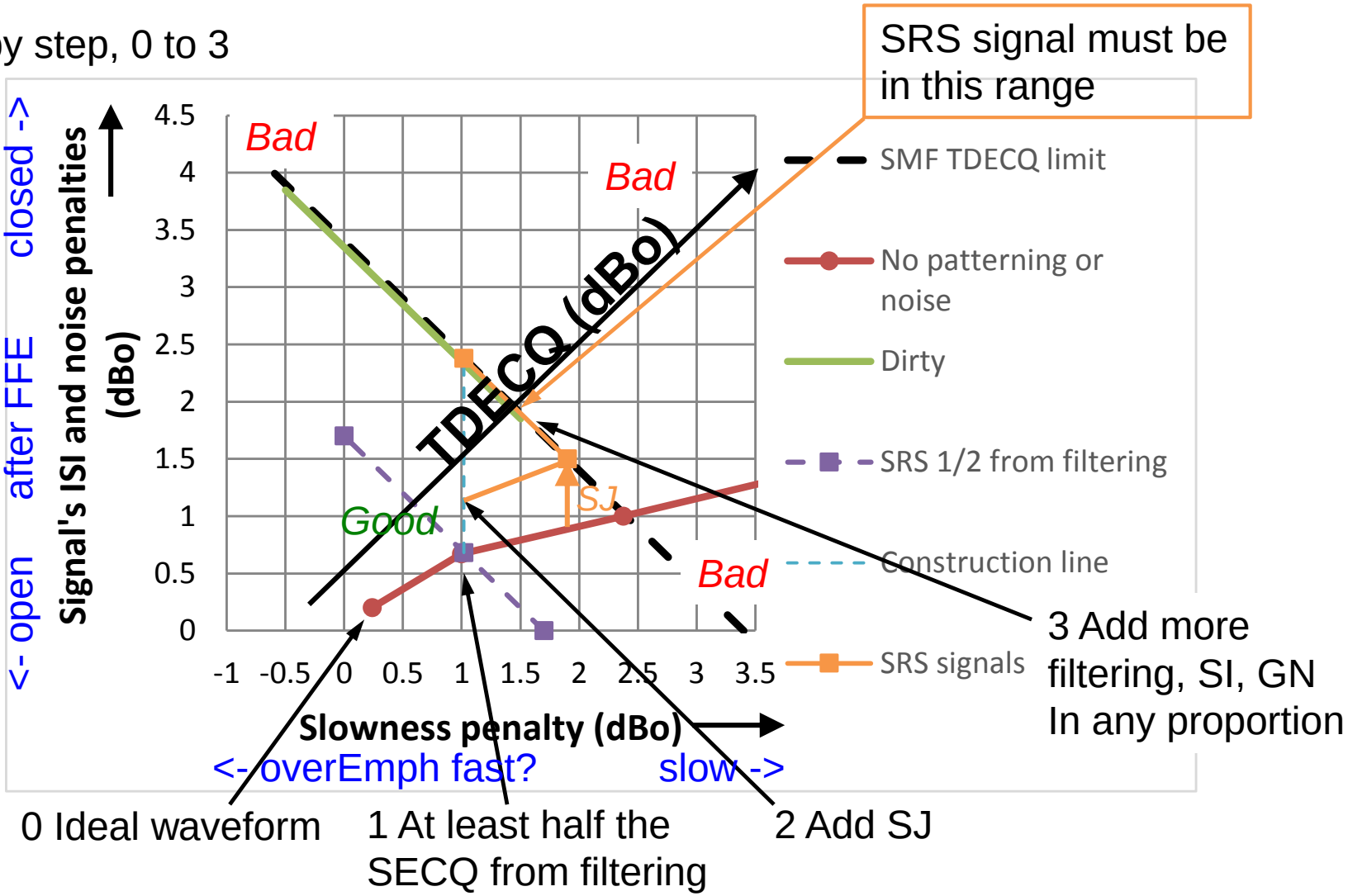
- Tweak the SRS calibration recipe to better align with the chosen range of Ceq
  - Avoid too much residual penalty (including transmitter noise, as requested by others: see comment r02-27)
- Choose reasonable TDECQ and top limits for MMF

Backup slides

-

Calibration of signal for stressed receiver sensitivity

Step by step, 0 to 3

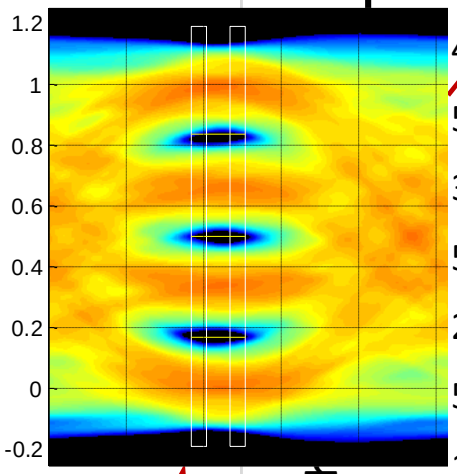


- *Present draft allows unrealistic amounts of Gaussian noise*
- *When we know where acceptable transmitters are (left to right) we can adjust the "at least half the SECQ from filtering" rule to adjust the coverage (comment 55)*

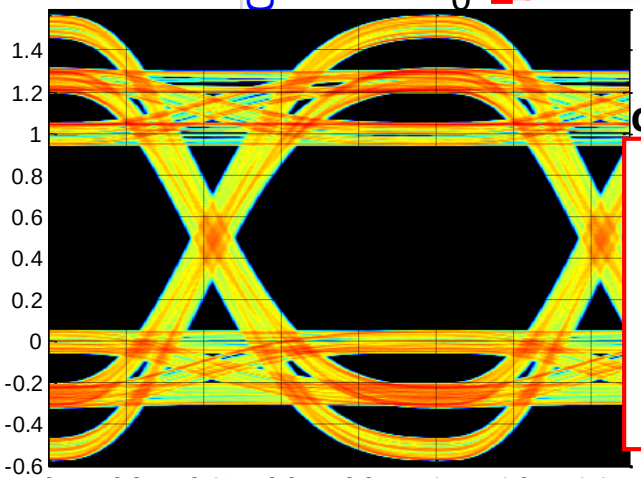
Extremes of worst-case signals

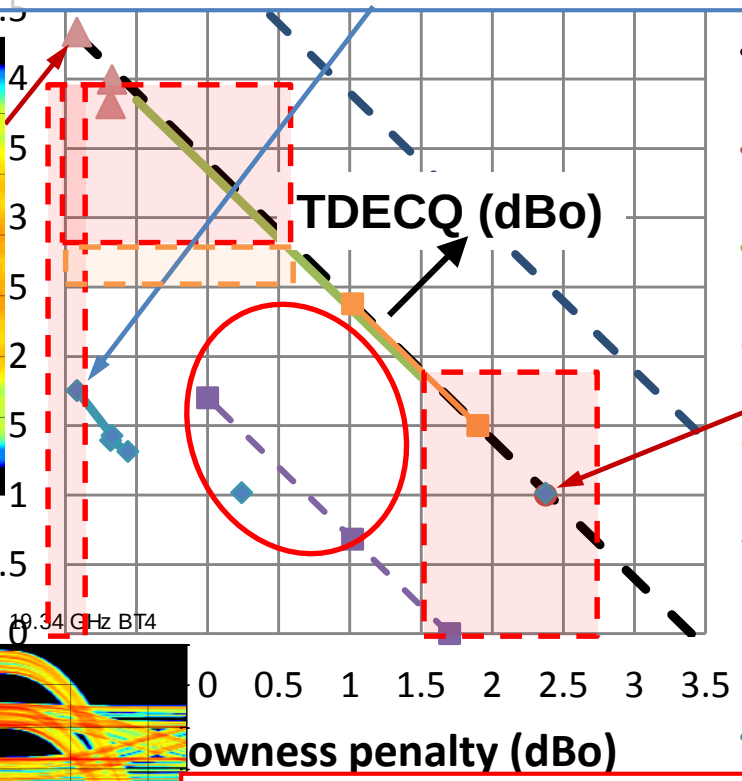
The two upper signals (after reference Rx FFE) are shown with all but 1 dBo of Rx noise

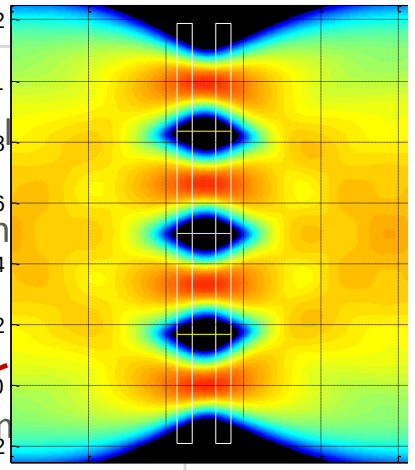
Peak/OMA increases when signal is over-emphasised or slow-but-emphasised
These points are observed in the same fb/2 BW as TDECQ. See later.



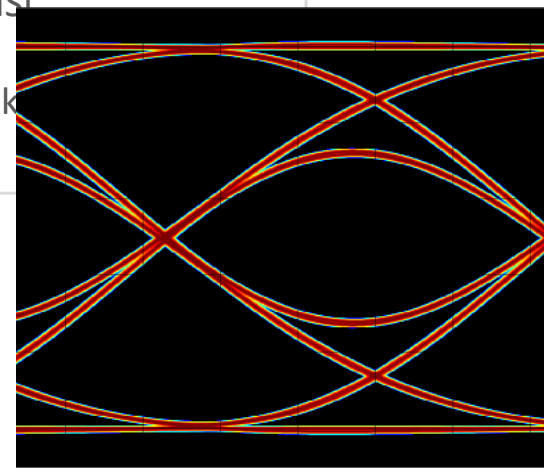
Same transmitter in 25G PAM2 mode, 19.34 GHz BT4







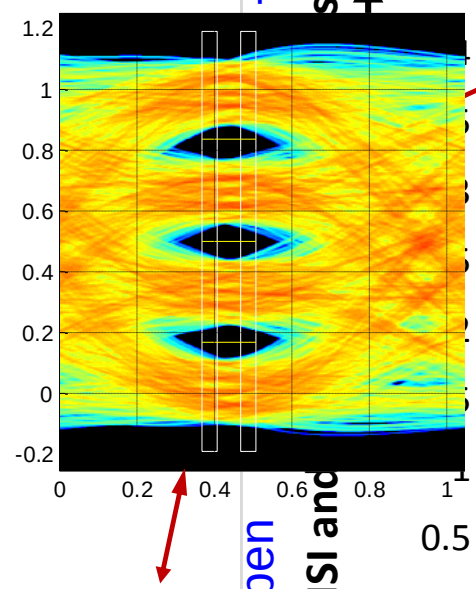
Same transmitter in 25G PAM2 mode, 19.34 GHz BT4

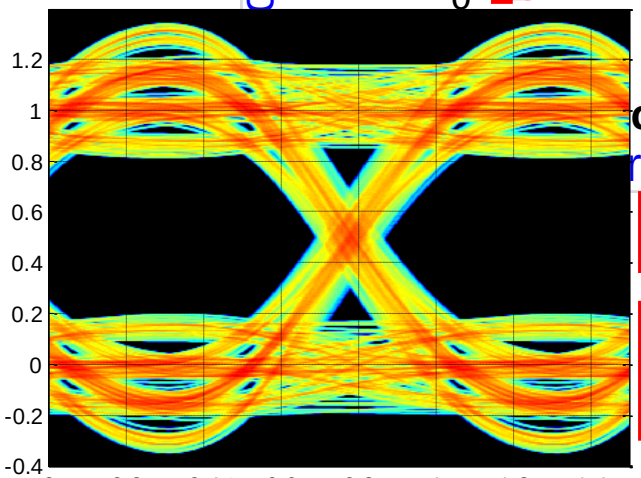


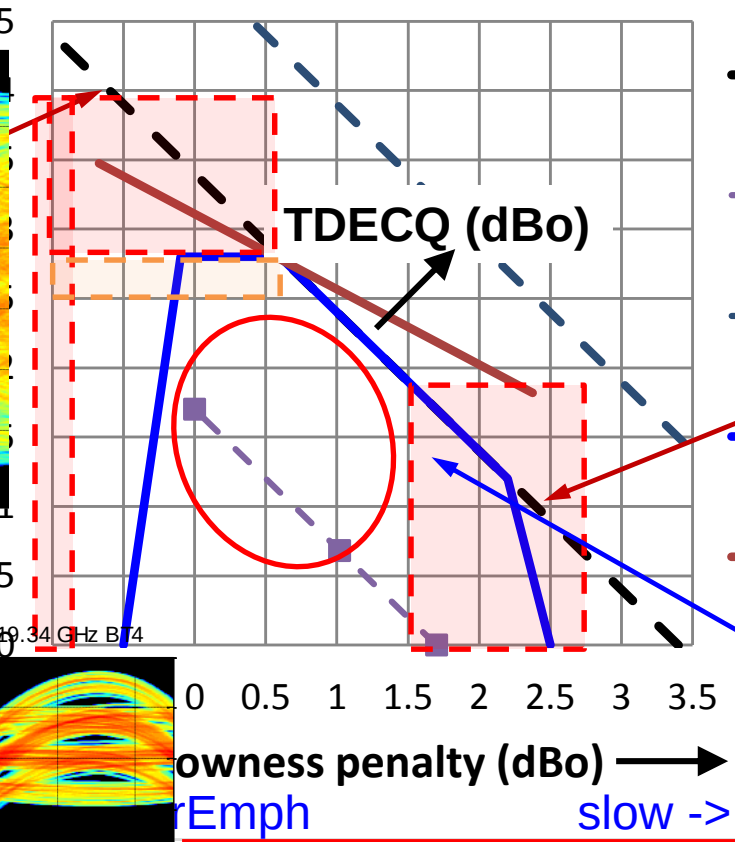
The signal on the left is bad because nothing can be done to improve it – neither sensitivity nor EQ.
Worse is allowed by the draft

Example improved specs

These signals are shown with very little noise



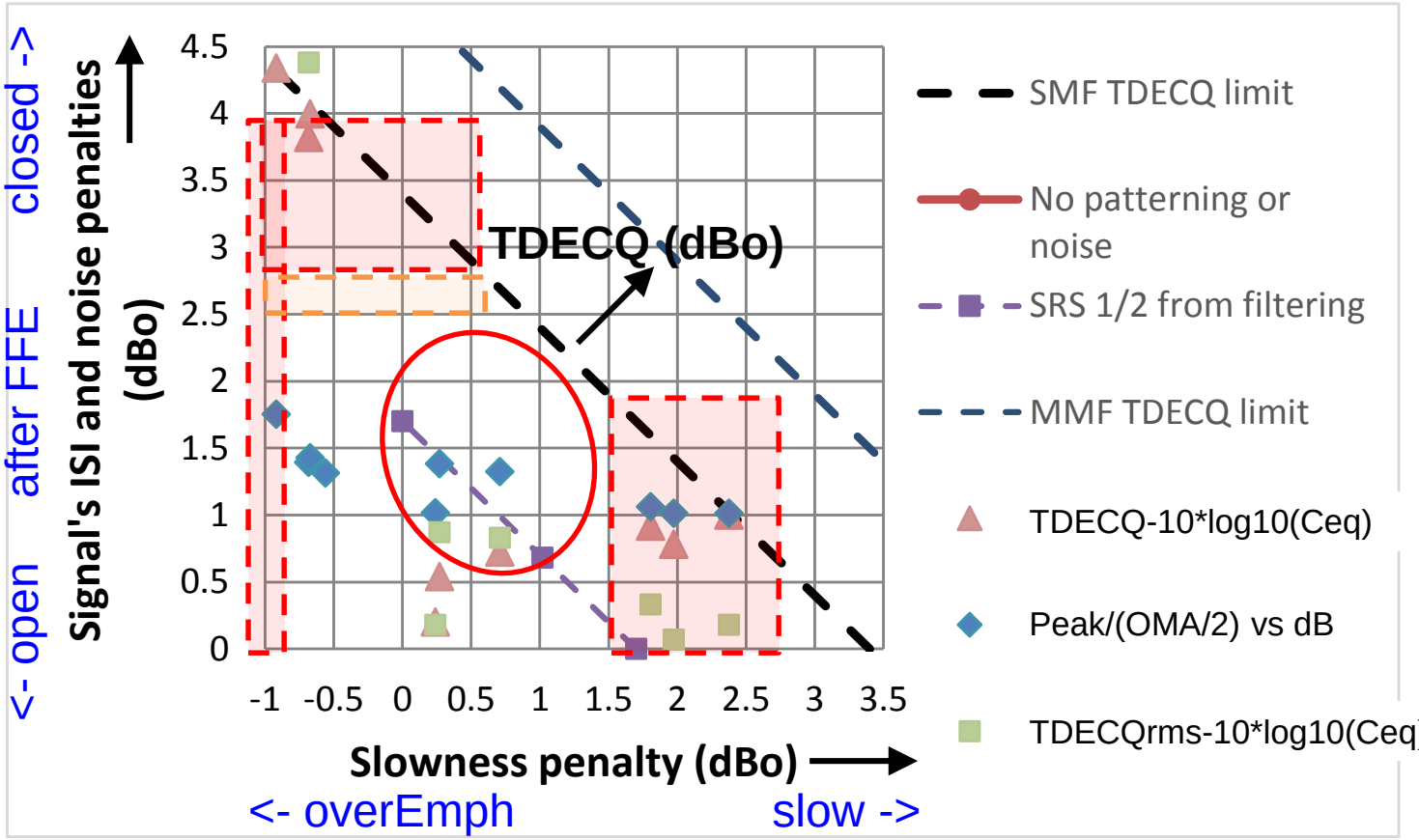




Need to come to a consensus on what's reasonable

Upper left: Example of a signal that no reasonable 400GBASE-F/D/LRn should have to receive

TDECQrms



TDECQrms is below TDECQ on the right, above on the left – goes with a TDECQ limit having a shallower slope on this plot, as on slide 9