Tidying up the optical specifications

Piers Dawe
Mellanox

Contents

1. Too many measurement bandwidths
2. MMF signals can be more over-emphasised than SMF but should not be
3. MMF optical power levels got corrupted in the TDECQ churn
4. MMF TDECQ limit is too high
5. Second precursor not necessary for some PMDs

1. Too many measurement bandwidths

- TDECQ measurements in general come in pairs:
- SMF
  - Positive dispersion TDECQ, cursor tap, OMA*
  - No dispersion Transition time
  - Negative dispersion TDECQ, cursor tap, OMA*
  - Not specified OMA, extinction ratio
- MMF
  - Slow channel TDECQ, cursor tap, OMA*
  - Faster channel Transition time
  - Not specified OMA, extinction ratio
- More measurement setups than necessary
  - A single transmitter has to pass in 3 setups for SMF, 2 for MMF
    - Extinction ratio can be found with any of these setups
- Doesn't always constrain the what the receiver sees

* In practice it is necessary to derive OMA from the TDECQ waveform to avoid inconsistency

Adjust to protect the receiver and simplify the spec

- Find transition time from the TDECQ waveform, as we do for cursor tap:
- SMF
  - Positive dispersion TDECQ, cursor tap, transition time, OMA*
  - ~~No dispersion Transition time~~
  - Negative dispersion TDECQ, cursor tap, transition time, OMA*
  - Not specified OMA, extinction ratio
- MMF
  - Slow channel TDECQ, cursor tap, transition time, OMA*
  - ~~Faster channel Transition time~~
  - Not specified OMA, extinction ratio
- Only 2 (SMF) or 1 (MMF) measurement setups
  - Extinction ratio can be found from the TDECQ waveform too
- Better relevance to the receiver

* In practice it is necessary to derive OMA from the TDECQ waveform to avoid inconsistency

Discussion

- For SMF, the transition time spec is not challenging
  - Not likely that a transmitter that passes TDECQ would be so affected by dispersion as to fail this spec
  - Simplifying the spec and making it more consistent is still useful
- For MMF: the difference between a slowest signal measured in 13.28125 GHz and in 11.2 GHz is about 1.7 ps in 34 ps
- Because the same receiver ICs may be used in both SMF and MMF (and MMF is more challenging than short reach SMF already) the limit should be made consistent across PMDs
- When changing the MMF transition time bandwidth from 13.28125 GHz to 11.2 GHz, change the limit from 34 ps to 32 ps
- SECQ calibrations for SRS are always in 13.28125 GHz or 26.5625 GHz, so the transition time limit for MMF SRS signal should remain at 34 ps in 13.28125 GHz

Comment 17: simplify the observation bandwidths (SMF)

- *Cl* **139** *SC* **139.7.7** *P* **299** *L* **34** *#* r04-17 *Comment Type* **T**
- This is the only SMF Tx measurement that requires this specific observation filter without the test fiber.
- 1. The transmitter is responsible for dispersion effects and the "transmitter transition time" spec is there to protect the receiver (after dispersion).
- 2. For consistency and so that transition time is a free by-product of a TDECQ measurement as intended by D3.2 comment 54, we should measure transition time on the same pair of waveforms as for TDECQ.
- Production testing can learn the correlation with / without dispersion and read across if they want to: the slowest signals that might fail this spec are less likely to be strongly affected by dispersion than fast signals, so that should work.
- *Suggested Remedy*
- Change "The transmitter transition time of each lane" to "The transmitter transition time of each lane as observed in a TDECQ measurement (see 139.7.5)". In the second paragraph, delete "as measured through an optical..." **Consider adding statements that for transmitter transition time measurement, the polarization rotator, optical splitter and variable reflector may be omitted, and averaging may be used.**
- Similarly in 140.7.7.

Comment 15: simplify the observation bandwidths (MMF)

- *Cl* **138** *SC* **138.8.7** *P* **274** *L* **33** *#* r04-15 *Comment Type* **T**
- This is the only MMF Tx measurement that requires this specific observation filter.
- 1. Transition time measurement should be a free by-product of a TDECQ measurement, as intended by D3.2 comment 54. It should also be a free by-product of a SECQ calibration measurement for SRS.
- 2. As this spec is there to protect the receiver, what matters is the signal after the slowest channel. This should be the same (34 ps) for SMF and MMF to allow common equalizer silicon. At the limit, the transition time is dominated by the signal not the observation bandwidth: switching between 13.28125 and 11.2 GHz is worth 2 in 34 ps.
- *Suggested Remedy*
- **Change** "with a combined frequency response of a fourth-order Bessel-Thomson filter with a bandwidth of approximately 13.28125 GHz to at least 1.5 x 26.5625 GHz and at frequencies above 1.5 x 26.5625 GHz the response should not exceed -24 dB" to "with a combined frequency response as given for TDECQ in 138.8.5 for transmitters, or as given for SECQ in 138.8.10 for stressed receiver conformance test signal".
- Either, let the receiver see the same slowest signal as for MMF:
- **In Table 138-8, Transmit characteristics, change 34 to 32.**
- or, if allowing slower received signals in MMF than SMF can be justified:
- In 138.8.10 Stressed receiver sensitivity, change "the transition time is no greater than the value specified in Table 138-8" to "the transition time is no greater 36 ps" (this limit could be put in Table 138-9, Receive characteristics).

2. Over-emphasised MMF transmitters

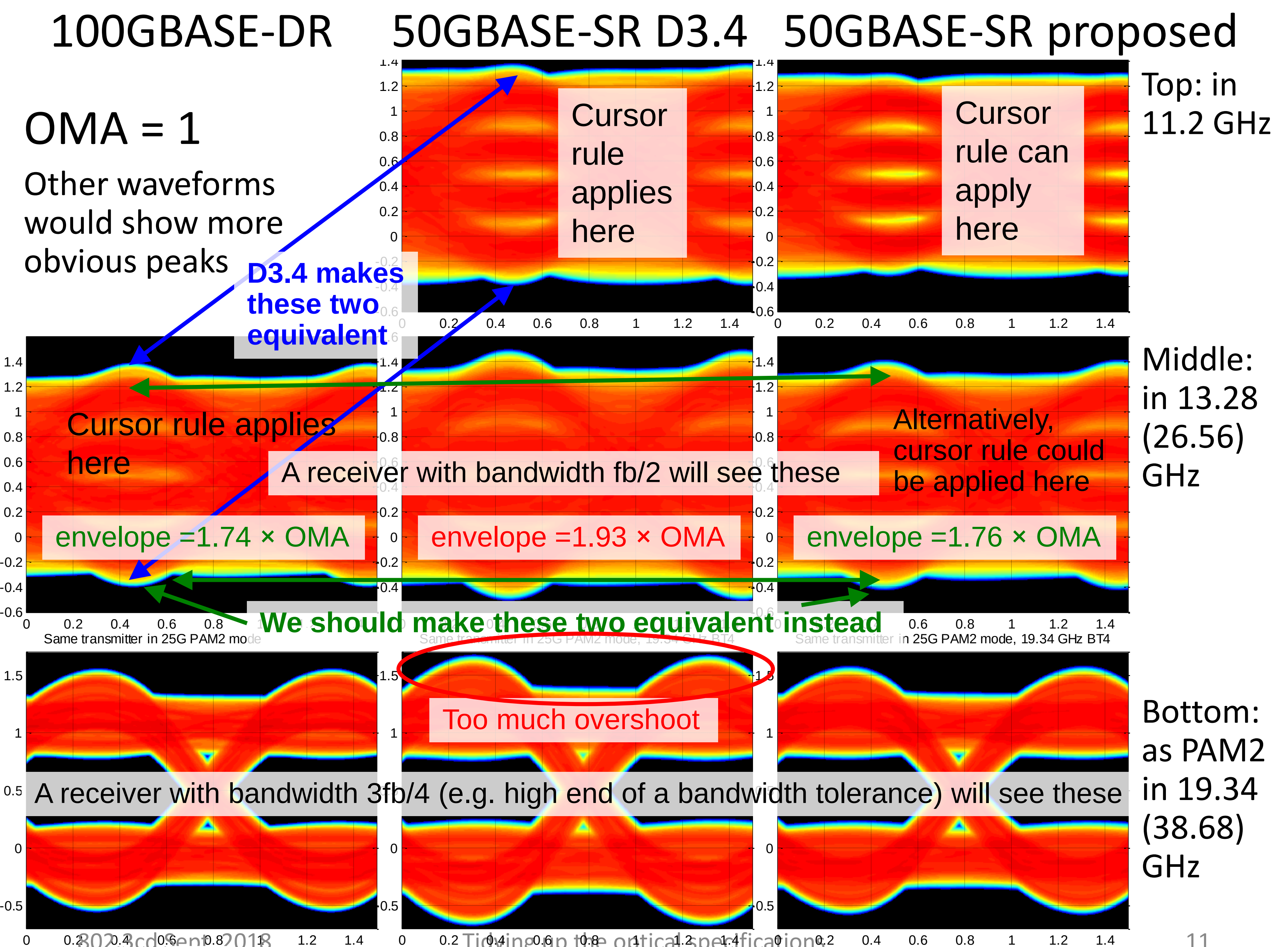
- Optical transmitters are allowed significant overshoot; this is OK if it is not excessive
  1. A high peak optical power could overload the optical receiver front end
  2. A high peak-to-peak swing could overload the optical receiver front end
  3. A high peak-to-peak swing/OMA could require a better A-to-D converter than would reasonably be needed
- Overshoot is bounded by the reference equalizer cursor tap coefficient minimum
- But this is not consistent across the PMDs

TDECQ measurements are paired

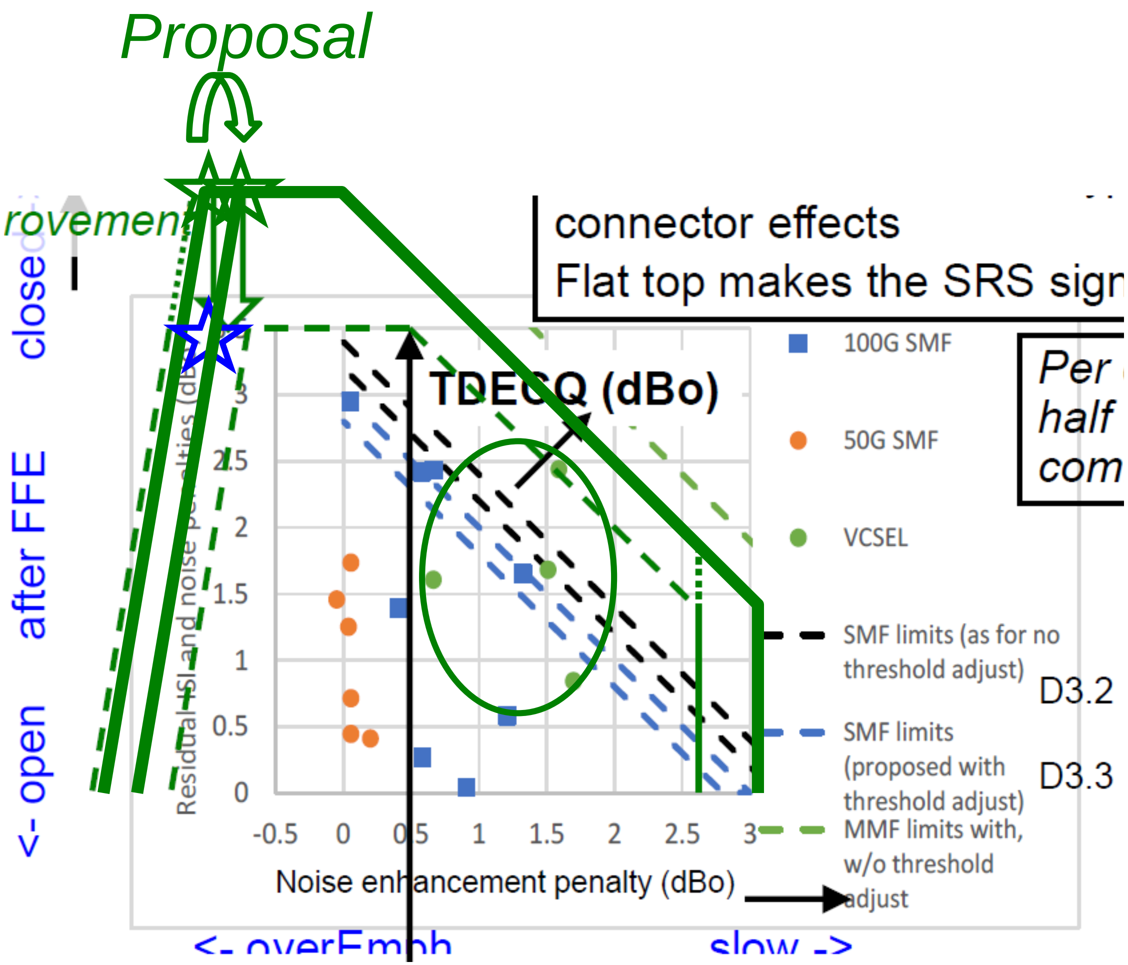
- The reference equalizer cursor tap coefficient minimum is applied as part of the TDECQ measurement
- In concept, TDECQ measurements are paired:
  - For SMF: most +ve chromatic dispersion and most –ve chromatic dispersion
  - For MMF: slowest (longest) fibre and fastest (shortest) fibre
  - We assume that the worst TDECQ is at one of the extremes of chromatic dispersion (SMF), or with the slowest longest fibre (MMF, which is emulated in the reference receiver bandwidth)
- The worst overshoot would be with the fastest (shortest) MMF
  - Which is the case we don't measure
  - We allow the MMF transmitter to appear as over-emphasised after the slow channel as an SMF transmitter after a negligible SMF channel
  - So it has more overshoot than that after a short MMF channel
  - This puts a special burden on MMF receivers that isn't needed

Comparing over-emphasised waveforms

- The next slide shows simulated waveforms with the maximum emphasis allowed by the cursor minimum, and the worst TDECQ-10log10(Ceq) allowed. TDECQ is less than the limit in each case
- Left column: 100GBASE-DR per D3.4
  - Cursor = 0.8 for whichever dispersion is faster
- Middle column: 50GBASE-SR per D3.4
  - Cursor = 0.8 in 11.2 GHz
- Right column: proposed for 50GBASE-SR
  - Cursor = 0.85 in 11.2 GHz
- Real waveforms could have more overshoot than these simple ones


100GBASE-DR
50GBASE-SR D3.4
50GBASE-SR proposed
OMA = 1
Other waveforms would show more obvious peaks
Cursor rule applies here
Cursor rule can apply here
Top: in 11.2 GHz
D3.4 makes these two equivalent
Cursor rule applies here
A receiver with bandwidth fb/2 will see these
Alternatively, cursor rule could be applied here
Middle: in 13.28 (26.56) GHz
envelope =1.74 × OMA
envelope =1.93 × OMA
envelope =1.76 × OMA
We should make these two equivalent instead
Same transmitter in 25G PAM2 mode
Same transmitter in 25G PAM2 mode, 19.34 GHz BT4
Same transmitter in 25G PAM2 mode, 19.34 GHz BT4
Too much overshoot
A receiver with bandwidth 3fb/4 (e.g. high end of a bandwidth tolerance) will see these
Bottom: as PAM2 in 19.34 (38.68) GHz
UI at 51.5625 GBd
UI at 25.78125 GBd
UI at 25.78125 GBd

Actual MMF transmitters are not near this corner



- Simulations on previous page are at the three stars, top left
- Reported VCSEL transmitters are in the green ellipse, not near that corner
- From dawe_3cd_01b_0718 slide 19 with D3.4 limits added in thick green

Comment 13: make the over-emphasis rule for MMF consistent

- *Cl* **138** *SC* **138.8.5.1** *P* **276** *L* **29** *#* r04-13 *Comment Type* **TR**
- Make the MMF spec more consistent with the SMF specs so that a common equalizer IC can be used for both. While SMF TDECQ is measured for both extremes of channel, MMF TDECQ is measured for the slow channel only. That's OK, we can read across to the other case we don't measure, but recognise that a signal after a slow channel will look less emphasised than what the receiver has to tolerate. The reference equalizer's largest magnitude tap coefficient (0.8 for a fast channel) should be set consistently (as from the same transmitter) for the slow channel. dawe_3cd_01b_0518 proposed 0.87. The survey results for MMF (green points, slide 8, dawe_3cd_01b_0518) are all to the right of +0.5 dB (or tap strength about 1.1). So we could tighten up more than this proposal, but this is consistent with the SMF specs and still allows a strongly over-emphasised transmitter. See presentation.
- D3.3 comment 31.
- *Suggested Remedy*
- **In "the largest magnitude tap coefficient, which is constrained to be at least 0.8", change 0.8 to 0.85.** The SMF clauses can stay with 0.8.

But the limit for the stressed receiver signal, which is calibrated for SECQ in 13.28125 GHz, should stay at 0.8: add another exception to list in 138.8.10 Stressed receiver sensitivity.

3. MMF optical power levels got corrupted in the TDECQ churn

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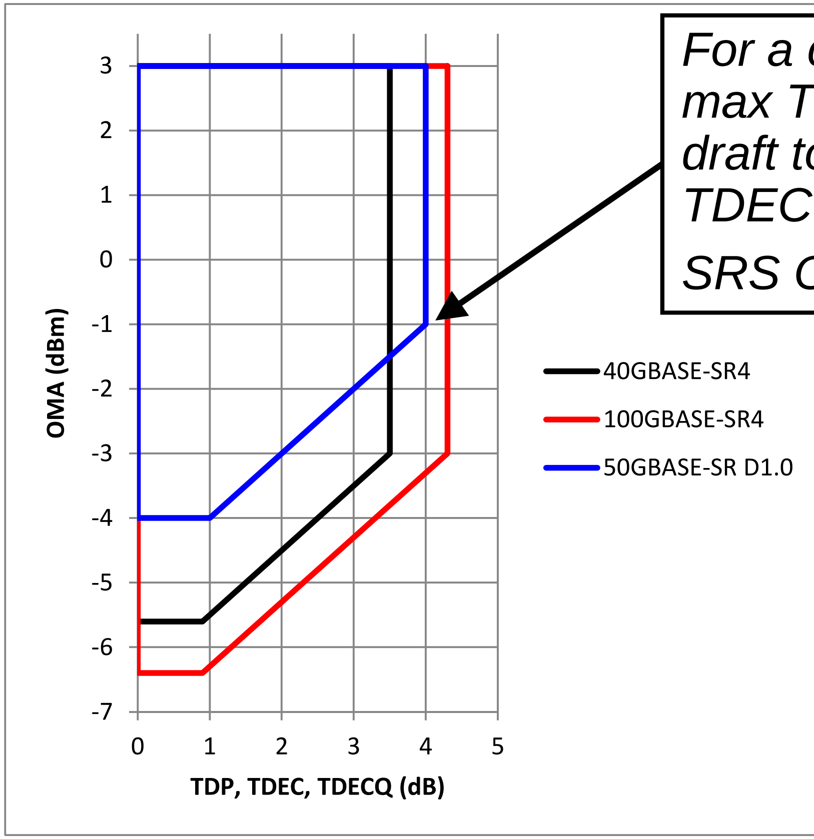
50 Gb/s per lane MMF baseline and earlier specs

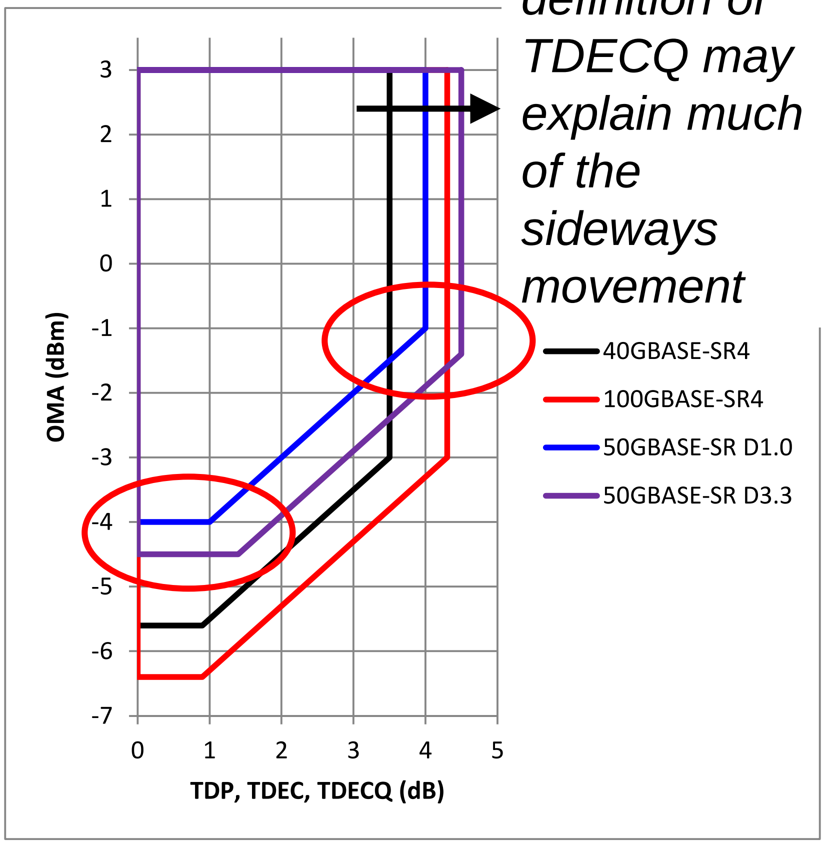


For a consistent worst signal, the OMA at max TDECQ should stay constant from draft to draft even as the definition of TDECQ changes

SRS OMA follows this (1.9 dB lower)

- Black: 10G/lane, PAM2
- Red: 25G/lane, PAM2, with FEC
- Blue: 50G/lane, PAM4, with FEC
- From adopted baseline king_3cd_01a_0516 and D1.0 Cl. 138 50GBASE-SR, 100GBASE-SR2, 200GBASE-SR4 (contained some TBCs)

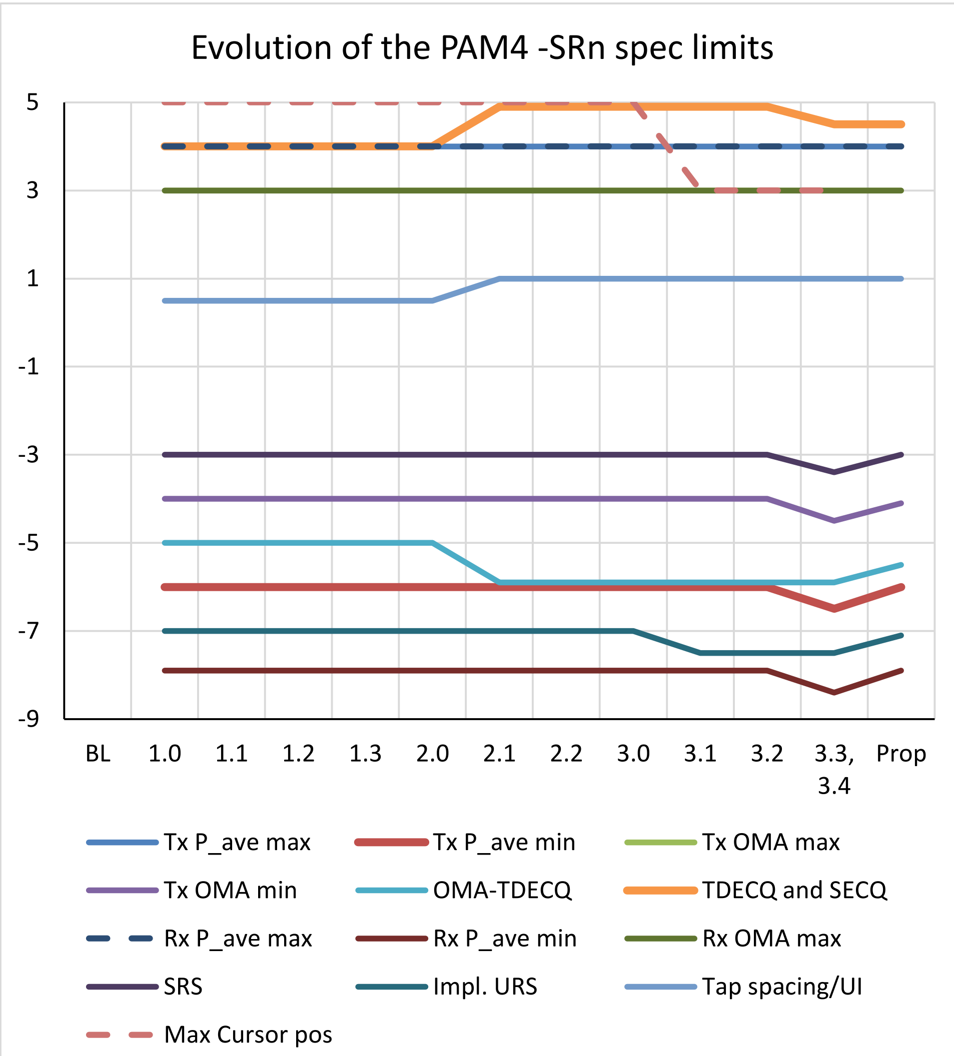
The spec has drifted



Changing definition of TDECQ may explain much of the sideways movement

- In D3.3, the min. OMA at max TDECQ, and the SRS OMA, were moved down by 0.4 dB
- This should not have happened
  - Our idea of a worst signal hasn't changed, but the TDECQ score it gets, has changed
  - king_3cd_01_0518 had proposed different changes to the ones adopted for D3.3
  - In D3.3 we aimed to correct a discrepancy introduced by the floating thresholds, but created a new error in the process

Evolution of the PAM4 -SRn spec limits

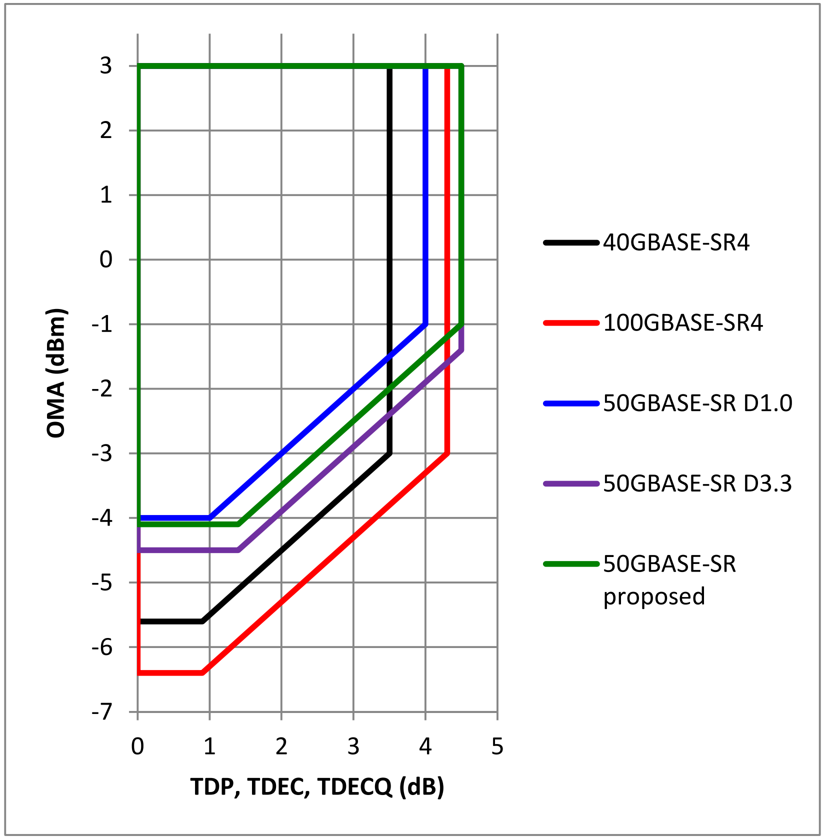


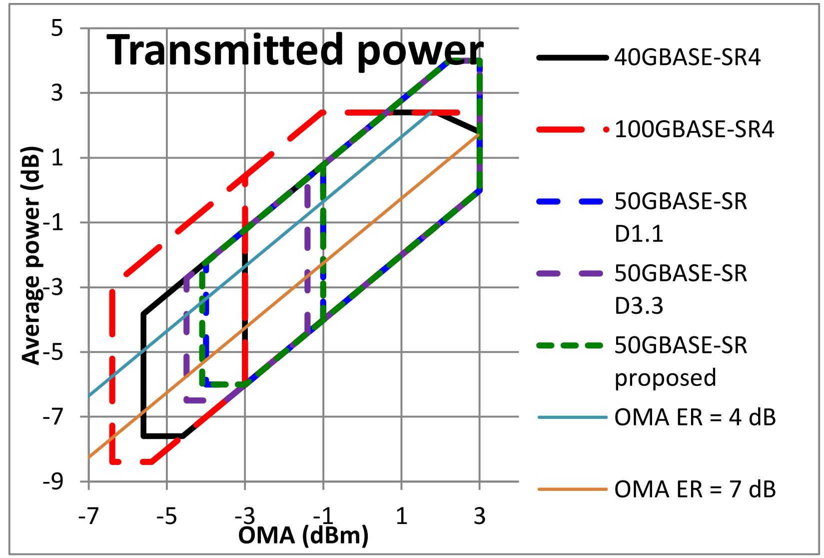
- D3.3 adjusted TDECQ limits to catch up with an earlier change introducing threshold adjust
- Not a real change in Tx or Rx performance
- Should not have changed the optical power limits, or the OMA at max TDECQ

Does this matter?

- In D3.3, the implied unstressed sensitivity for 50GBASE-SR (100 m) is about -7.3 dBm
- After converting optical power to photocurrent (subtract 1.9 dB for 1310 nm equivalent), this is equivalent to 50GBASE-LR (10 km) and 1.5 dB harder for the receiver than 50GBASE-FR (2 km)
- As well as much higher stress levels (higher TDECQ and residual penalty
- This is the wrong way round! The very short reach MMF PMD should be easier and lower power than the short reach SMF PMD
- For MMF, the receiver takes more power than the transmitter, and receiver performance (complexity) is a non-negligible contributor to receiver power: if there is a choice, MMF optical power levels should be set high
  - SMF is the opposite

Restoring the optical power levels





The changes on the left (green) restore the status quo within 0.1 dB, assuming today's TDECQ reads about 0.5 dB higher than the baseline's (4.5 vs. 4 dB)

- *See next slide for the same in bigger type*
- OMA-TDECQ from -5.9 to -5.5 dBm
- SRS OMA from -3.4 back to -3 dBm (as in the baseline and D3.2)
- Other receiver sensitivity, equation 138-1, from max(-6.5, SECQ - 7.9) to max(-6.1, SECQ - 7.5).
- Tx min OMA from -4.5 in D3.3 to -4.1 (nearly the -4 from the baseline);
- Min average power at Tx from -6.5 in D3.3 to -6 (back to the baseline);
- Min average power at Rx from -8.4 in D3.3 to -7.9 (back to the baseline)

Restoring the optical power levels

- OMA-TDECQ from -5.9 to -5.5 dBm
- SRS OMA from -3.4 back to -3 dBm (as in the baseline and D3.2)
- Other receiver sensitivity, equation 138-1, from max(-6.5, SECQ - 7.9) to max(-6.1, SECQ - 7.5).
- Tx min OMA from -4.5 in D3.3 to -4.1 (nearly the -4 from the baseline);
- Min average power at Tx from -6.5 in D3.3 to -6 (back to the baseline);
- Min average power at Rx from -8.4 in D3.3 to -7.9 (back to the baseline)

Comment 10: correct the MMF optical power levels

- *Cl* **138** *SC* **138.7.1** *P* **270** *L* **16** *#* r04-10 *Comment Type* **TR**
- The optical power levels were consistent from D1.0 to D3.2 while TDECQ evolved. In D3.3, they went wrong.
- Minimum OMA at max TDECQ was -1 dBm TBC in D1.0, -1 in D3.2, is now -1.4. In D1.0, OMA-TDECQ was -5 dBm TBC, and the unstressed sensitivity was -7 dBm. Now, OMA-TDECQ is -5.9 and the implied unstressed sensitivity is about -7.3, equivalent to 50GBASE-LR and 1.5 dB harder for the receiver than 50GBASE-FR. The definition of TDECQ has changed a few times, which I think explains why the budget has gone up from 6 dB TBC to 6.5 dB. It looks like OMA-TDECQ should have been increased to -5.5 when the apparent TDECQ was reduced following the introduction of adjustable decsision thresholds. king_3cd_01_0518 had proposed -5.7 dBm. See dawe_3cd_02_0718 or successor. D3.3 comment 25.
- *Suggested Remedy*
- To restore the intent of D1.0, which was based on a TDECQ from about 0 to 4 dB, to go with the present TDECQ which goes from about 0.5 to 4.5 dB:
- Increase OMA-TDECQ from -5.9 to -5.5 dBm. Increase SRS OMA from -3.4 back to -3 dBm (as in D1.0 and D3.2). Increase the other receiver sensitivity, equation 138-1, from max(-6.5, SECQ - 7.9) to max(-6.1, SECQ - 7.5). Tx min OMA from -4.5 in D3.3 to -4.1 (nearly the -4 from the baseline). Min average power at Tx from -6.5 in D3.3 to -6 (back to the baseline). Min average power at Rx from -8.4 in D3.3 to -7.9 (back to the baseline).

And see the following slides that concern the same numbers

4. MMF TDECQ limit is too high

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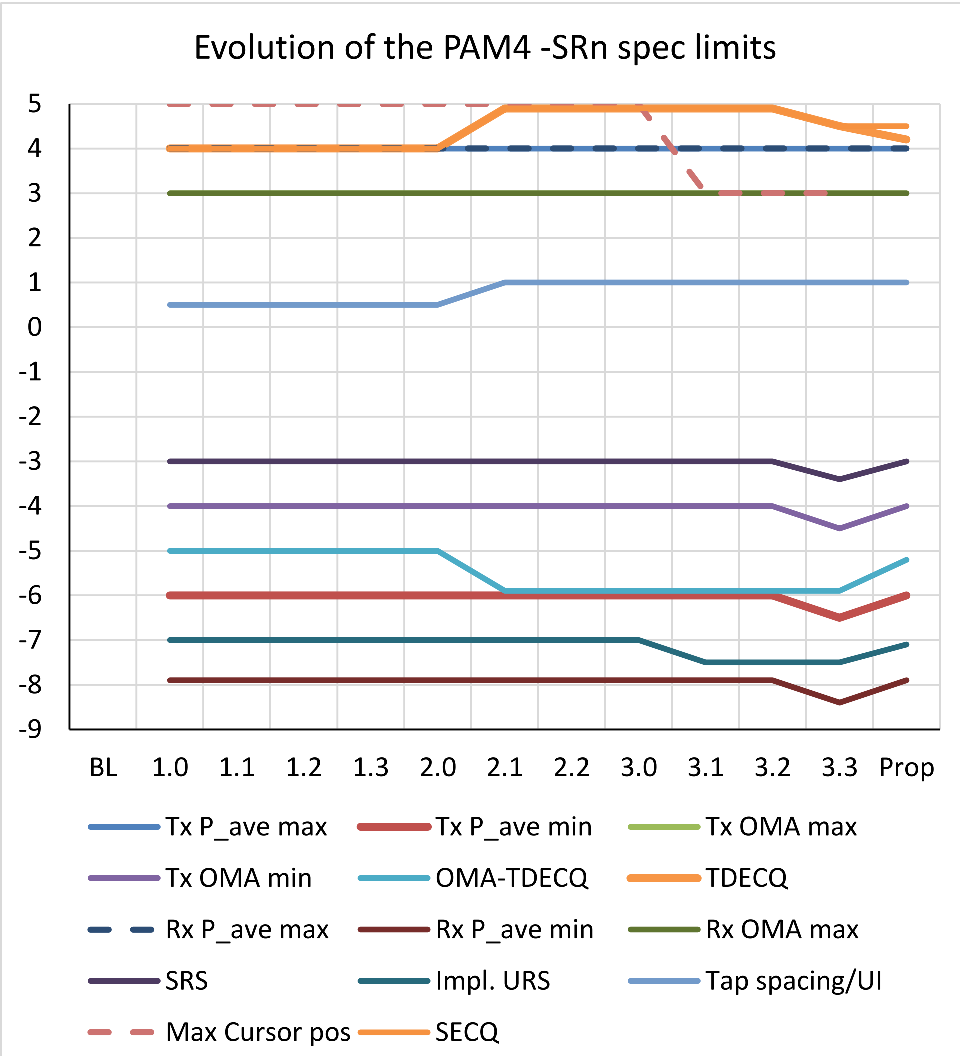
When we are back on solid ground...

- Max TDECQ and max residual penalty, TDECQ-10log10(Ceq), are much higher for MMF than for SMF
- Although the receiver circuitry could be similar, and lower power for lower distance would be desirable
- We believe MMF transmitters aren't 4.5 dB bad
- In addition, we need more in the budget for impairments from the channel
  - It's worse because it's PAM4

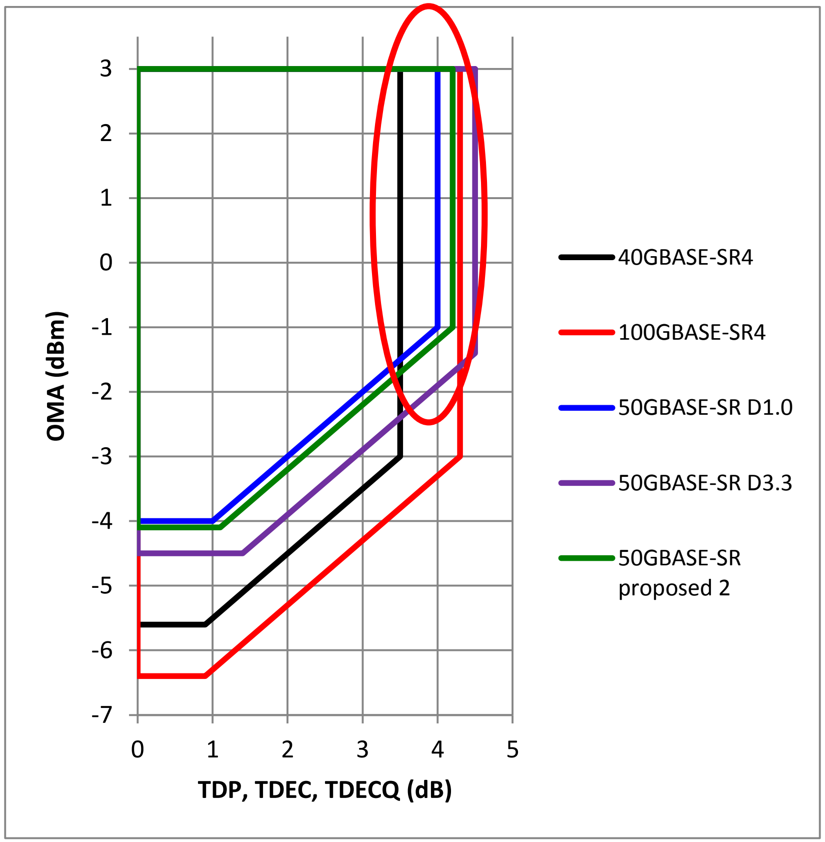
Evolution of the PAM4 -SRn spec limits – complete proposal

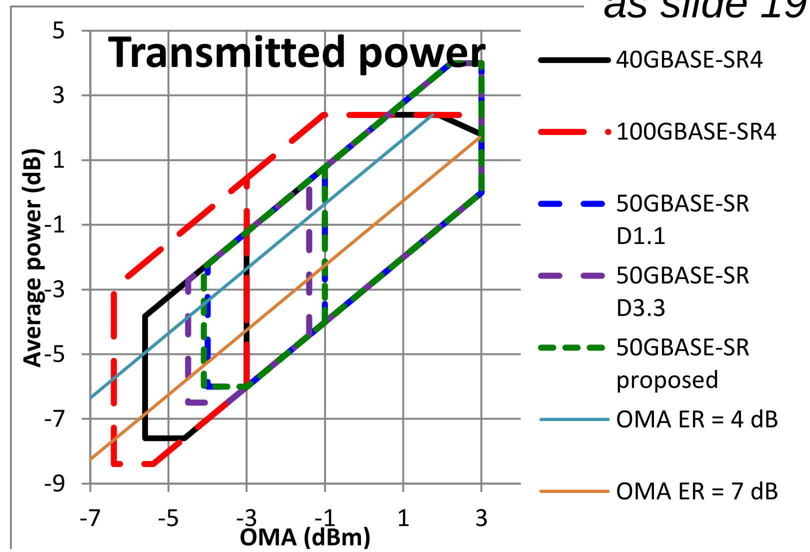


- Restores average powers and unstressed sensitivity to the baseline
- Restores OMA to within 0.1 dB of the baseline
- Provides a robust link
- Allows a variety of VCSEL transmitters, leveraging the measurement improvement of threshold adjust
  - Note SECQ becomes slightly higher than TDECQ (already it's measured in a different bandwidth)
  - The "Even if" limit changes as a consequence

Restoring the optical power levels – complete proposal

RH chart same as slide 19





The changes on the left (green) restore the status quo within 0.1 dB then provide a more robust link

- *See next slide for the same in bigger type*
- OMA-TDECQ from -5.9 to -5.2 dBm
- Max TDECQ from 4.5 to 4.2 dB
- SRS SECQ stays at 4.5 dB
- SRS OMA from -3.4 back to -3 dBm (as in the baseline and D3.2)
- Other receiver sensitivity, equation 138-1, from max(-6.5, SECQ - 7.9) to max(-6.4, SECQ - 7.5).
- Tx min OMA from -4.5 in D3.3 to -4.1 (nearly the -4 from the baseline);
- Min average power at Tx from -6.5 in D3.3 to -6 (back to the baseline);
- Min average power at Rx from -8.4 in D3.3 to -7.9 (back to the baseline)

Restoring the optical power levels – complete proposal

- OMA-TDECQ from -5.9 to -5.2 dBm
- Max TDECQ from 4.5 to 4.2 dB
- SRS SECQ stays at 4.5 dB
- SRS OMA from -3.4 back to -3 dBm (as in the baseline and D3.2)
- Other receiver sensitivity, equation 138-1, from max(-6.5, SECQ - 7.9) to max(-6.1, SECQ - 7.5).
- Tx min OMA from -4.5 in D3.3 to -4.1 (nearly the -4 from the baseline);
- Min average power at Tx from -6.5 in D3.3 to -6 (back to the baseline);
- Min average power at Rx from -8.4 in D3.3 to -7.9 (back to the baseline)
- Table 138-10, power budget (for max TDECQ) doesn't change

Comment 12: MMF TDECQ should be reduced

- *Cl* **138** *SC* **138.7.1** *P* **270** *L* **22** *#* r04-12 *Comment Type* **TR**
- TDECQ limit of 4.5 dB (on top of the 4.8 dB PAM4 penalty), is extremely high. Technology that can do 100GBASE-SR4 (PAM2, almost the same signalling rate but no equalizer) should do better. king_3cd_02_0118 showed 1 to 2.5 dB with representative drive, and king_3cd_03_0518 shows better than 3.7 dB. chang_011018_3cd_01_adhoc-v2 showed 2.1 to 3.1 dB, the lower end with threshold adjust, although much of this was with PRBS15.
- king_3cd_02a_0718 slide 12 showed a multi-peaked distribution including some "failing" transmitters. dawe_3cd_01b_0518 slide 8 showed one at 4 dB and a few significantly better.
- The high limit in the draft requires a better equalizer (e.g. more precise tap and threshold settings) than needed for the SMF PMDs, and we need some more room in the budget for modal noise. D.30 comment 119, D3.1 comment 70, D3.2 comment 40, D3.3 comment 27.
- *Suggested Remedy*
- **Change max TDECQ and max TDECQ-10log10(Ceq) from 4.5 to 4.2 dB. Increase OMAouter-TDECQ in step.**

Comment 11: allocations in MMF budget

- *Cl* **138** *SC* **138.7.2** *P* **271** *L* **17** # r04-11 *Comment Type* **TR**
- Even after the recent improvement to the transmitter spec, the penalty after equalization but before modal noise, at 4.5 dB on top of the 4.8 dB PAM4 penalty = 9.3 dB, is far higher than for any other optical Ethernet PMD type. Tiny amounts of modal noise will cause an additional penalty, magnified up by the "Pcross effect". There is only 0.1 dB in the budget for both mode partition noise and modal noise, which is about the same as in 100GBASES-R4 (max TDEC 4.3 dB << 9.3). This is too small unless these noises are much smaller this time. The effect of modal noise and mode partition noise with a very high TDECQ transmitter (D.30 comment 119, D3.1 comment 70, D3.2 comment 40, D3.0 comment 116, D3.1 comment 71, D3.2 comment 46, D3.3 comment 26) is higher than with a more moderate penalty after equalization or without equalization as in 100GBASE-SR4.
- 100GBASE-SR4 takes this "Pcross" effect into account inside TDEC. Limiting TDECQ-10log10(Ceq) helps, but more improvement is needed.
- *Suggested Remedy*
- **Reduce max TDECQ and max TDECQ-10log10(Ceq) from 4.5 dB to 4.2 dB,**
- **Increase TDECQ-OMAouter min from -5.9 to -5.6 dBm,**
- and increase the allocation for mode partition noise and modal noise in the budget from 0.1 dB to 0.4 dB; and/or
- Adjust the definition of TDECQ for MMF to take these noises into account.
- The SECQ in SRS should be the combination of Tx TDECQ and these other penalties (still 4.5, so no change), and the SRS OMA should be the lowest OMA that can be received, not below (receiver should not be tested outside its operating range): change SRS OMA from -3.4 to -3.3 (but see another comment pointing out that the power levels have slipped and should be corrected).

See complete proposal on slides 25 and 26

- The budget table stays the same.

5. Second precursor not necessary for some PMDs

- But not compatible with a low-power future
- For MMF, the transmitter's TDECQ is defined with a neutral filter (doesn't particularly need precursor). The MMF transmitter could be set up to require a precursor, but that won't happen naturally (it's made of real "causal" filter elements such as driver and laser)
- For 50GBASE-FR, the distance and wavelength mean that the effects of chromatic dispersion won't be very large. Everything else should be neutral to post-cursor, as for MMF

Chromatic dispersion in 50GBASE-FR

- 50GBASE-FR might use MZ, EML, or direct mod transmitter (or other)
- Maximum chromatic dispersion is 3.2 ps/nm
- Compare 10GBASE-LR (direct mod, higher chirp than a modulator): 48 ps/nm
- Scale 10GBASE-LR by square of signalling rate gives 7.2 ps/nm, twice as much as 50GBASE-FR
- 10GBASE-LR doesn't have a receive equalizer and is not seen as dispersion-challenged
- Chromatic dispersion e.g. makes rising edges later and falling edges earlier or vice versa, depending on the sign. This changes TDECQ but it isn't the same as making the signal slower
- It seems safe to assume that a modulator-based 50GBASE-FR transmitter won't need a second precursor
- Also, it is likely that with a direct mod 50GBASE-FR transmitter doesn't need / won't significantly benefit from, a second precursor
- **Can we find a chromatically dispersed waveform (even PAM2 or 10G?) to check?**

Comment 14: remove 2nd precursor from PAM4 MMF PMDs

- *Cl* **138** *SC* **138.8.5.1** *P* **274** *L* **2** *#* r04-14 *Comment Type* **TR**
- For some equalizer architectures, precursors are much more expensive than post-cursors (sun_3cd_042518_adhoc).
- D3.1 comment 73, D3.2 comments 7, 8, 48, 53, D3.3 comment 32. A direct-mod transmitter is not naturally biased to postcursor, nor is the reference filter the transmitter is assessed with. The argument in the response to comment 32 was incorrect for MMF. We should not allow deliberately strange transmitted signals that cause an extra burden for low-power
- receivers.
- *Suggested Remedy*
- Continue the improvement made in king_3cd_03_0118: change "Tap 1~~,~~ tap 2~~, or tap 3,~~ has"
- to "Tap 1 or tap 2 has".
- There is a separate comment for SMF because the different TDECQ limit, dispersion and
- TDECQ test method there could lead to a different conclusion.

Comment 16: remove 2nd precursor from 50GBASE-FR

- *Cl* **139** *SC* **139.7.5.4** *P* **299** *L* **5** *#* r04-16 *Comment Type* **TR**
- For some equalizer architectures, precursors are much more expensive than post-cursors (sun_3cd_042518_adhoc). Investigation of possible minimally compliant SMF signals and their associated TDECQ FFE settings indicates that 2 pre, 2 post (making the cursor the third tap) is never significantly better than 1 pre, 3 post (making it the second tap), for compliant signals (but not yet including chromatic dispersion). See dawe_3cd_01a_0318.
- The maximum chromatic dispersion is 3.2 ps/nm for 50GBASE-FR and 16 ps/nm for 50GBASE-LR. Compare 10GBASE-LR which is allowed 48 ps/nm. Scaling for signalling rate gives 7.2 ps/nm, twice as much as 50GBASE-FR. 10GBASE-LR doesn't have a receive equalizer and is not seen as dispersion-challenged. This indicates that **it is likely that 50GBASE-FR doesn't need a second precursor, even with a direct mod transmitter**.
- Improving the TDECQ search rules will avoid inefficiency both in product receiver design, testing and operation, and in TDECQ testing. D3.1 comment 76, D3.2 comment 53, D3.3 comment 37.
- *Suggested Remedy*
- Continue the improvement made in king_3cd_03_0118, as done for 100GBASE-DR: change
- "Tap 1, tap 2, or tap 3, has the largest magnitude tap coefficient~~, which~~ is constrained to be at least 0.8" to "For 50GBASE-FR, tap 1 or tap 2, has the largest magnitude tap coefficient, and for 50GBASE-LR, tap 1, tap 2, or tap 3, has the largest magnitude tap coefficient. This coefficient is constrained to be at least 0.8".
- There is a separate comment for MMF because the different TDECQ limit, dispersion and TDECQ test method there could lead to a different conclusion.