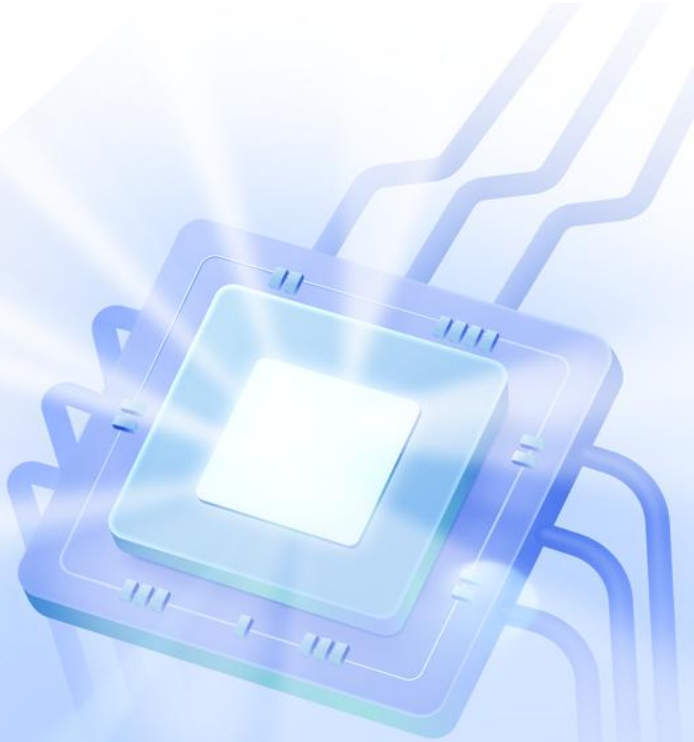
Optical measurements: frequency of the roll-off cut-off of the Bessel-Thomson filter

Presentation in support of a comment previewing a comment against D2.0 (pending TF and WG approval to move forward to WG ballot)

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Supporters

- Adee Ran, Cisco
- Klaus Engenhart, Teradyne Quantifi Photonics
- Michael He, Terahop
- Mike Dudek, Marvell
- Piers Dawe, NVidia
- Ramana Murty, Broadcom

Problem/Solution Summary

Problem definition

- Optical measurement bandwidth has a property, the end-of-compliance roll-off, that is in D1.3: $f_{compliance\text{-}end}$ = 1.3 * 106.25 = 138.125 [GHz,GHz] (or similar when fiber BW is included)
- This high a bandwidth is not in reach of practical measurement equipment, i.e. an MM oscilloscope with a high sensitivity, fit for manufacturing;
- And it is not necessary since the DUTs do not have significant energy going that high
- And the receivers would not be impacted anyway since their BW is intentionally more limited
- Currently in clauses 193.9.3, Reference Receiver (page 67, lines 25–30); 193.9.7, TDECQ (page 68, lines 15–22); 193.9.8, page 69 . Comment will be brought re. these on D2.0 .

Proposed solution:

1. Set a lower cut-off bandwidth (than the 138 GHz currently specified) for 802.3ds
2. Work on similar for other standards including the 802.3dj and 802.3dv… outside of this presentation

802.3 related clauses 180.9.2, 181.9.2, 182.9.2, 183.9.2 and 180.9.6.3 not discussed this 802.3ds presentation

Problem in D1.3
Optical Measurements reference receiver for 106 GBd: definition

This all follows the older Clause **180.9.2 Reference receiver:**

- A reference receiver is defined for transmitter measurements. The reference receiver is composed of an O/E converter, a clock recovery unit (CRU), and a pattern-triggered oscilloscope as shown in Figure 180–7. The combined frequency response of the O/E converter and oscilloscope has a 3 dB bandwidth of approximately 53.125 GHz with a fourth-order Bessel-Thomson response for frequencies up to at least **1.3 x 106.25 GHz** and a response no higher than –20 dB for frequencies greater than 1.3 x 106.25 GHz [bold mine, prz]

- So as is, the 4th order B-T has to be followed to **at least 138.125 GHz**
- This is measuring much beyond what the DUT RX does capture, and DUT TX generates
- This is unduly difficult with MM in 2026*
- The factor of **1.3** in fact was negotiated for 53 GBd only – it was 1.5 at 26 GBd PAM4; similar step down is needed for the 106 GBd
-

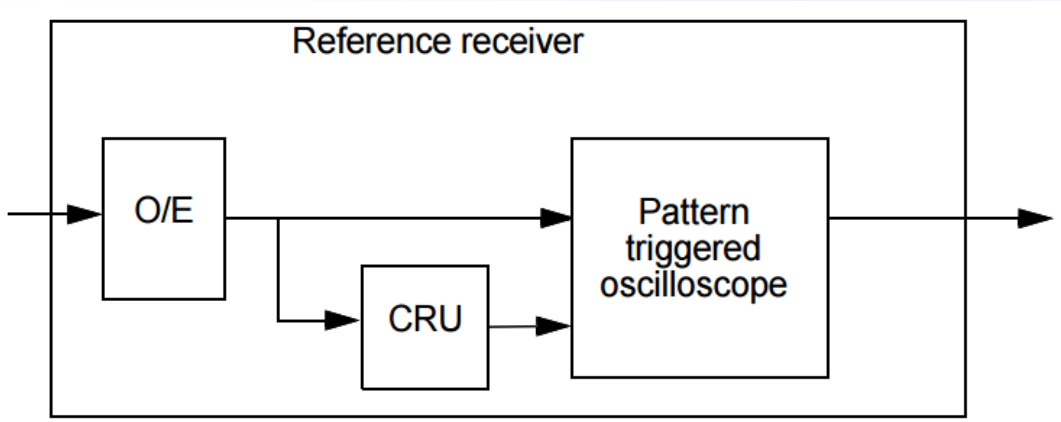


Figure 180–7—Reference receiver block diagram

*similarly so in SM, not discussed here

In D1.3 this issue is present in:

- subClause 193.9.3, Reference Receiver (page 67, lines 25–30);
- subClause 193.9.7, TDECQ (page 68, lines 15–22);
- subClause 193.9.8, page 69

In addition, this figures in the calculation of the additive noise

- 180.9.6.3 **Reference equalizer**
- The reference equalizer is a T-spaced, discrete-time equalizer with 15 feed-forward taps and a single decision feedback tap, where T is the symbol period. Equalizer coefficient constraints are given in Table 180–16. The reference equalizer may be implemented in the oscilloscope. The equalizer is modeled as shown in Figure 180–10, where — r(t) is the output of the reference receiver defined in 180.9.2 — η(t) is colored Gaussian noise, generated from additive white Gaussian noise (AWGN) *filtered by a Bessel-Thomson (BT) filter as defined in* **180.9.2 (bold,** *italics* mine, prz**)**

Current Nominal Optical Reference Receiver filter

- Current filter is on the right (BW of 53.125 GHz or near that)
- Cut-off (i.e. filter response no longer has to be followed) around 138 GHz, i.e. right-end of the plot

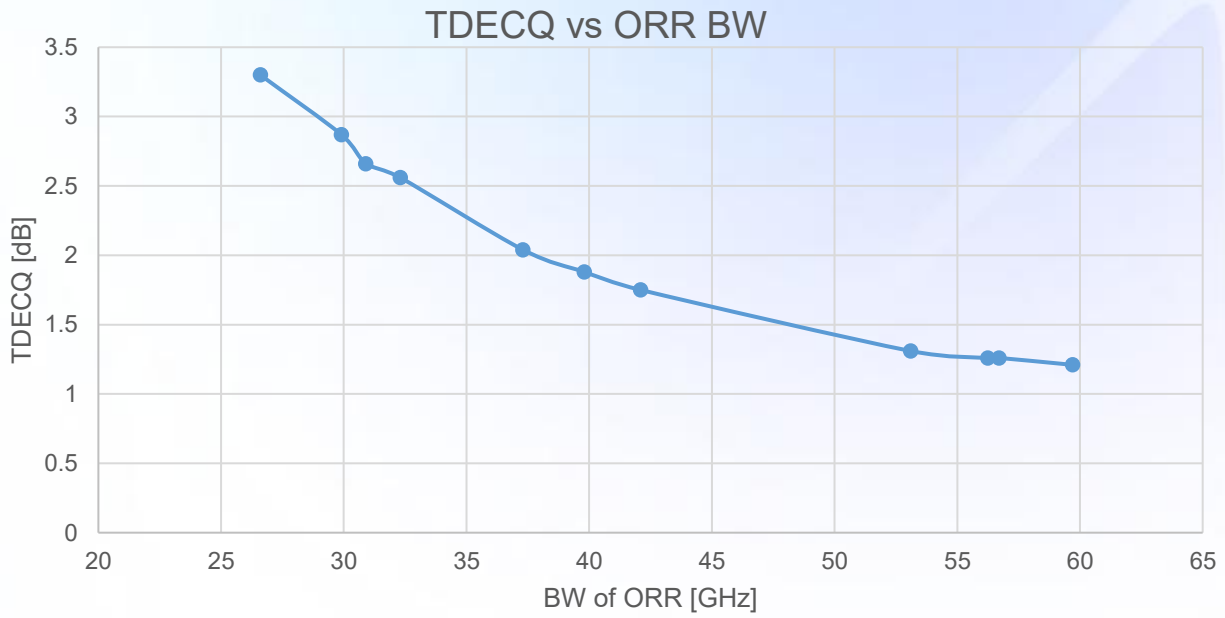
(the filter is also know as ORR, Optical Reference Receiver)



Measured data:
1st order dependency: TECQ = f(ORR_BW)

- lowering the Bessel-Thomson BW_{-3dB} shows the expected dependency of TECQ result to the BW of the B-T
- The cut-off is still at a very high frequency similar to 138 GHz of the D3.2

throughout the slides:
Source signal: BERT Keysight M8042A, MZM E/O; oscilloscope Keysight N1093A

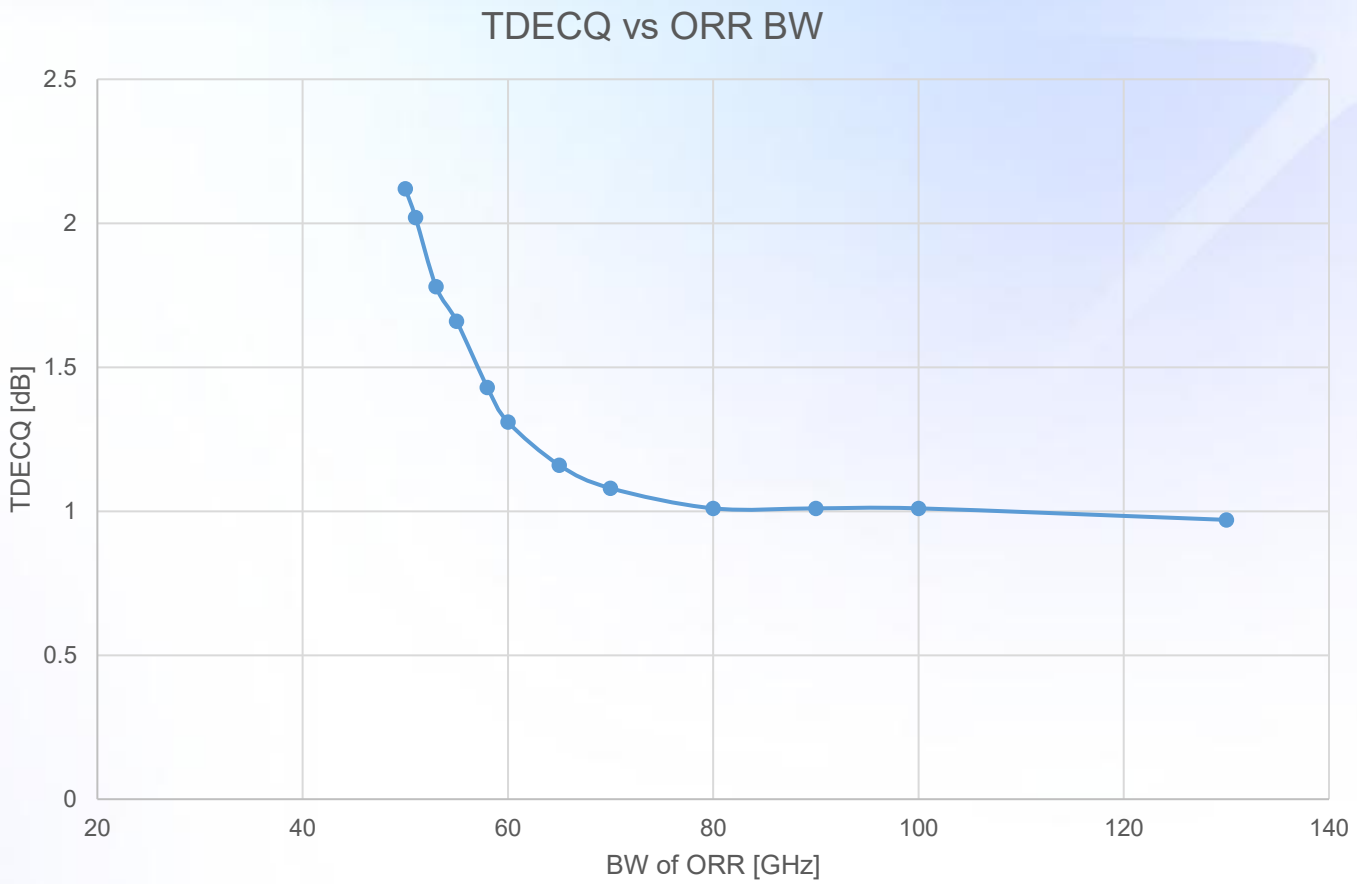


- Reasonable; leave this ORR BW as is.

Measured data:
2nd order dependency: TDECQ = f(ORR_BW Cut-off)

- Cutting the Bessel-Thomson BW tail
- (cut-off implemented as a 10th Order Butterworth filter; others show same result)

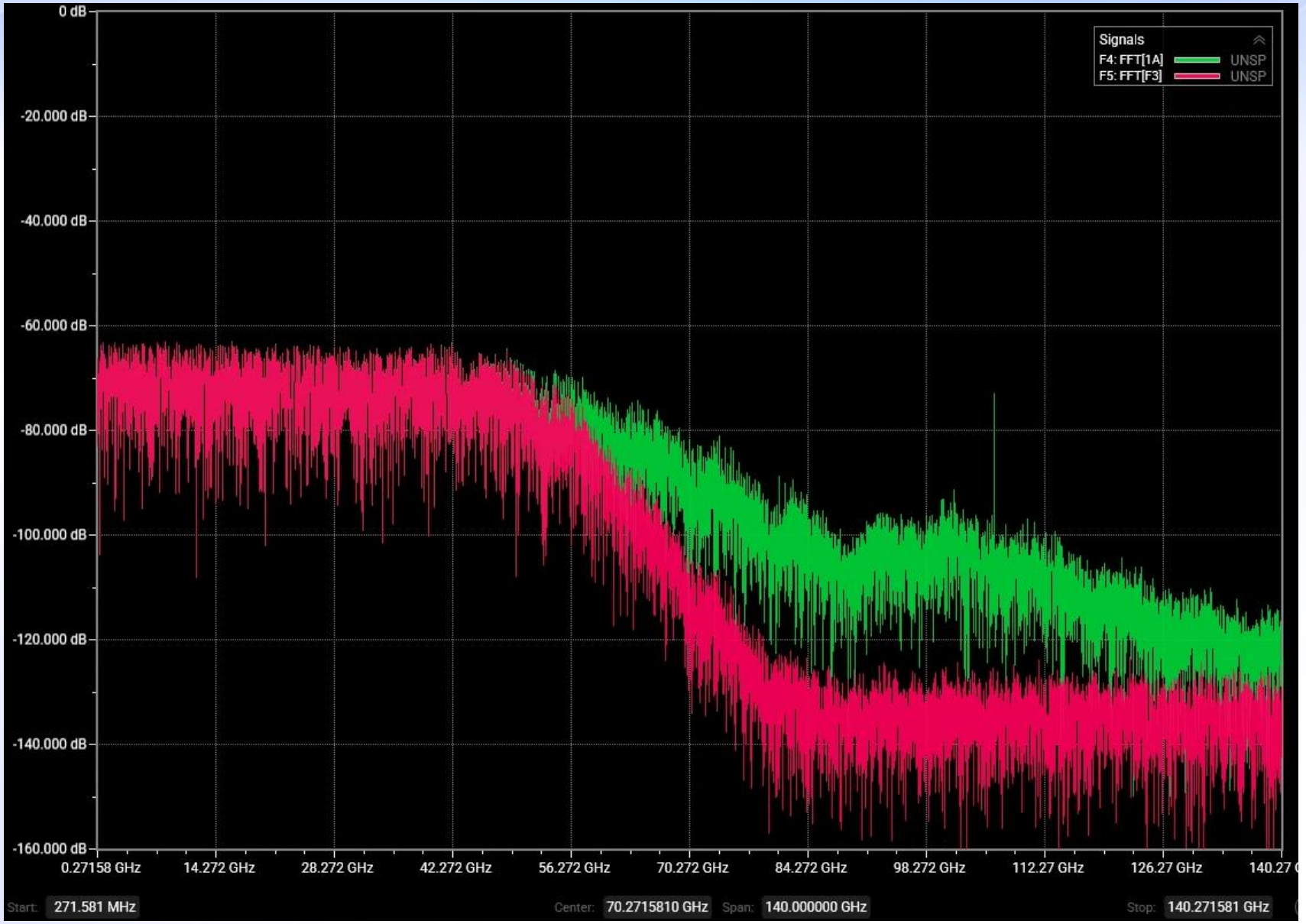
- Observe a (left) hockey-stick dependency of TDECQ on the BW cut-off of the frequency response
- The TDECQ value is stable above ca. 80 GHz



Frequency-domain view (measured signal)

- Green trace: spectrum with just Bessel-Thomson 4th order
- Red trace: same signal, but here the B-T spectrum is cut-off with a Butterworth (in this example to 55 GHz)
- Note that the signal's energy is more than 30 dB down at 90 GHz

(a SM lab source used here)



Conclusion: we don’t need to measure with bandwidth controlled to 138 GHz … and we shouldn’t

The Bessel-Thomson filter inherited from 802.3dj should be changed as it:

- Has a roll-off cut-off mandated to ≥138 GHz - much too far
- The B-T roll-off cut-off ≥ 100 GHz is fine and future-proof
- And worth specifying here as it:
  - Enables lower noise in oscilloscope captures – hence more accurate measurements
  - Enables lower T&M expense

Future work: consider the same for SM (future, maintenance for .3dj)

Lumilens

Thanks!

