Optical measurements: bandwidth of the roll-off (or cut-of) of the Bessel-Thomson filter.
Clauses 180.9.2, 181.9.2; 182.9.2; 183.9.2, and 180.9.6.3

Re. of the end-of-compliance of the Bessel-Thomson filter for the TECQ/TDECQ measurements as in comments R2-205, R2-188

Pavel Zivny, Lumilens

Supporters: update coming

2026/Sept., for the “P802.3dj Lisbon meeting”

Agenda

Problem definition:

- Optical measurement bandwidth,
  clauses 180.9.2, 181.9.2; 182.9.2; 183.9.2, and 180.9.6.3
  end-of-compliance roll-off is
  - unduly high
  - not in reach of current measurement equipment (amplified AM oscilloscope or MM capable oscilloscope)

Proposed solution

- Implementer can use lower cut-off bandwidth than the 138 GHz currently specified
- Proposed for 802.3dj, and/or future standards at same/similar symbol rates

Problem in D3.2
Optical Measurements reference receiver for 106 GBd: definition

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 unduly difficult with amplified SM in 2026* (and probably impossible at MM in 2026)

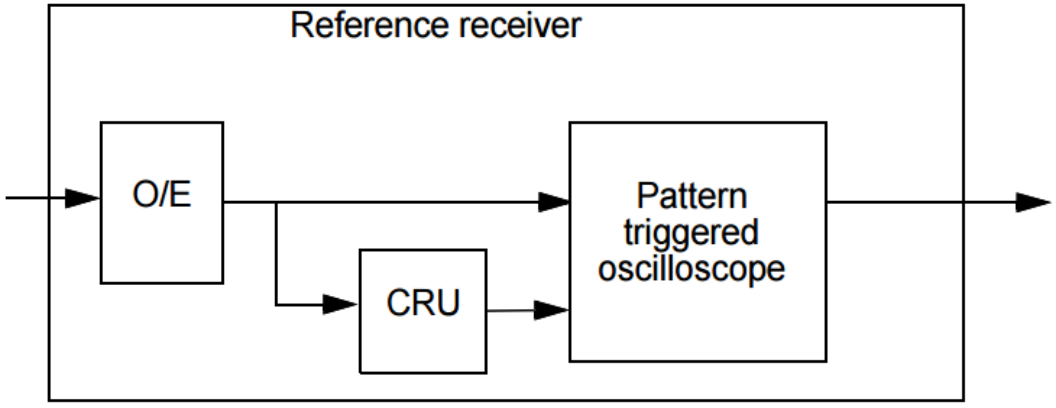


Figure 180–7—Reference receiver block diagram

*and fully impossible in MM in 2026

In D3.2 this issue is present in:

- 180.9.2 Reference receiver (-DRn)
- 181.9.2 Reference receiver (-FR4-500)
  - References 180.9.2
- A reference receiver is defined for transmitter
  182.9.2 Reference receiver (DRn-2)
- 183.9.2 Reference receiver (-FR4, -LR4)
- … and partially TDECQ Additive noise calculation, 180.9.6.3 Reference equalizer

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

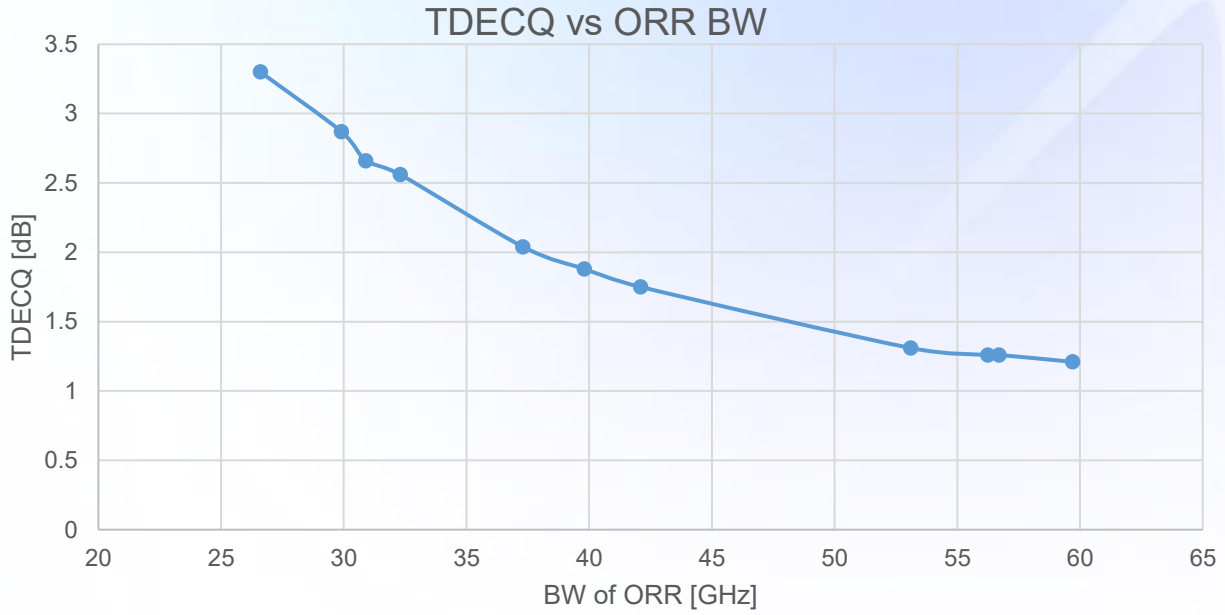
- Current filter is on the right (BW of 53.125 GHz or near that)
- Cut-off (i.e. filter response no longer has to be followed) around 138 GHz, i.e. right-end of the plot

(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

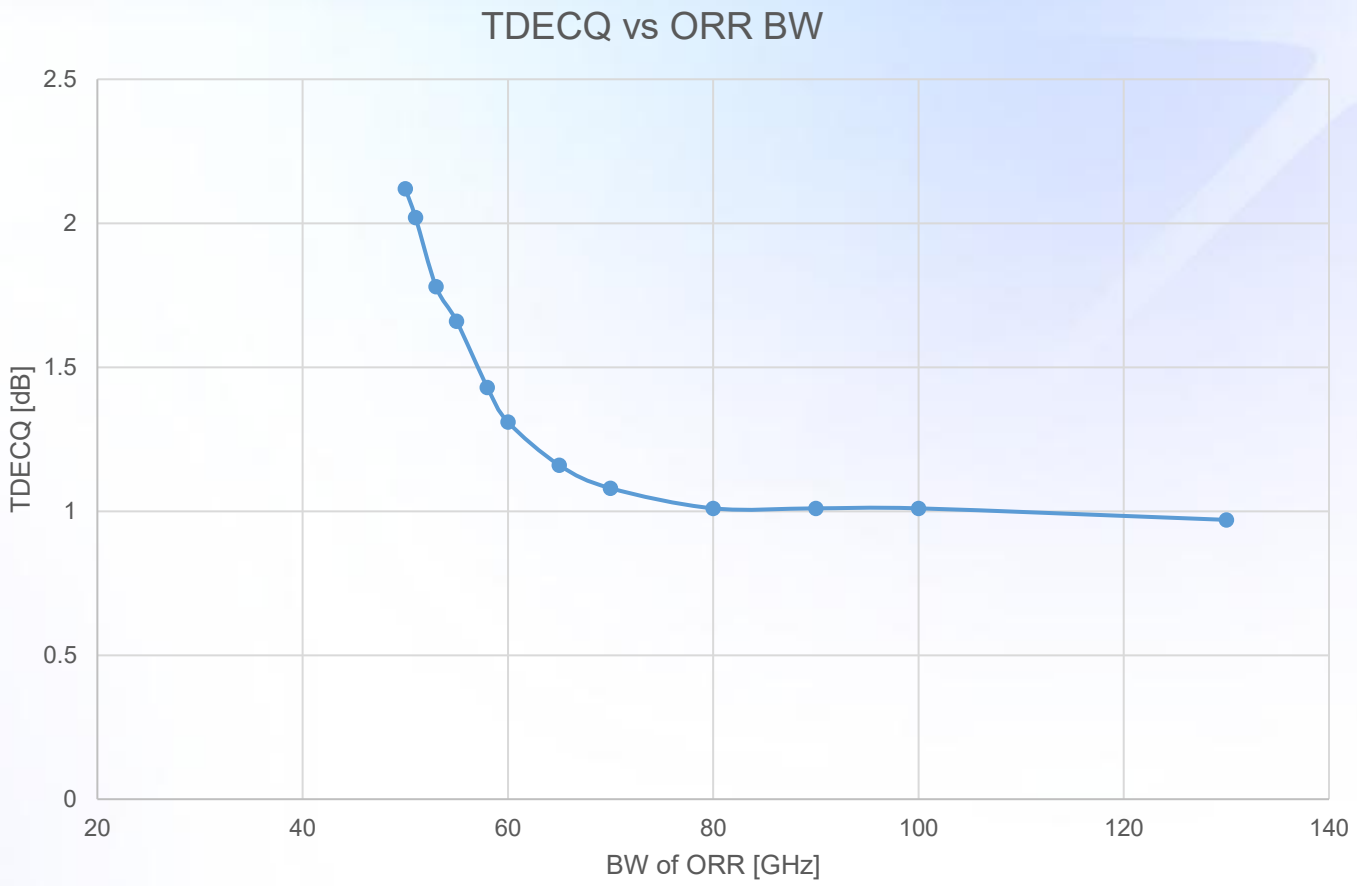


- Reasonable; leave this ORR BW as is.

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

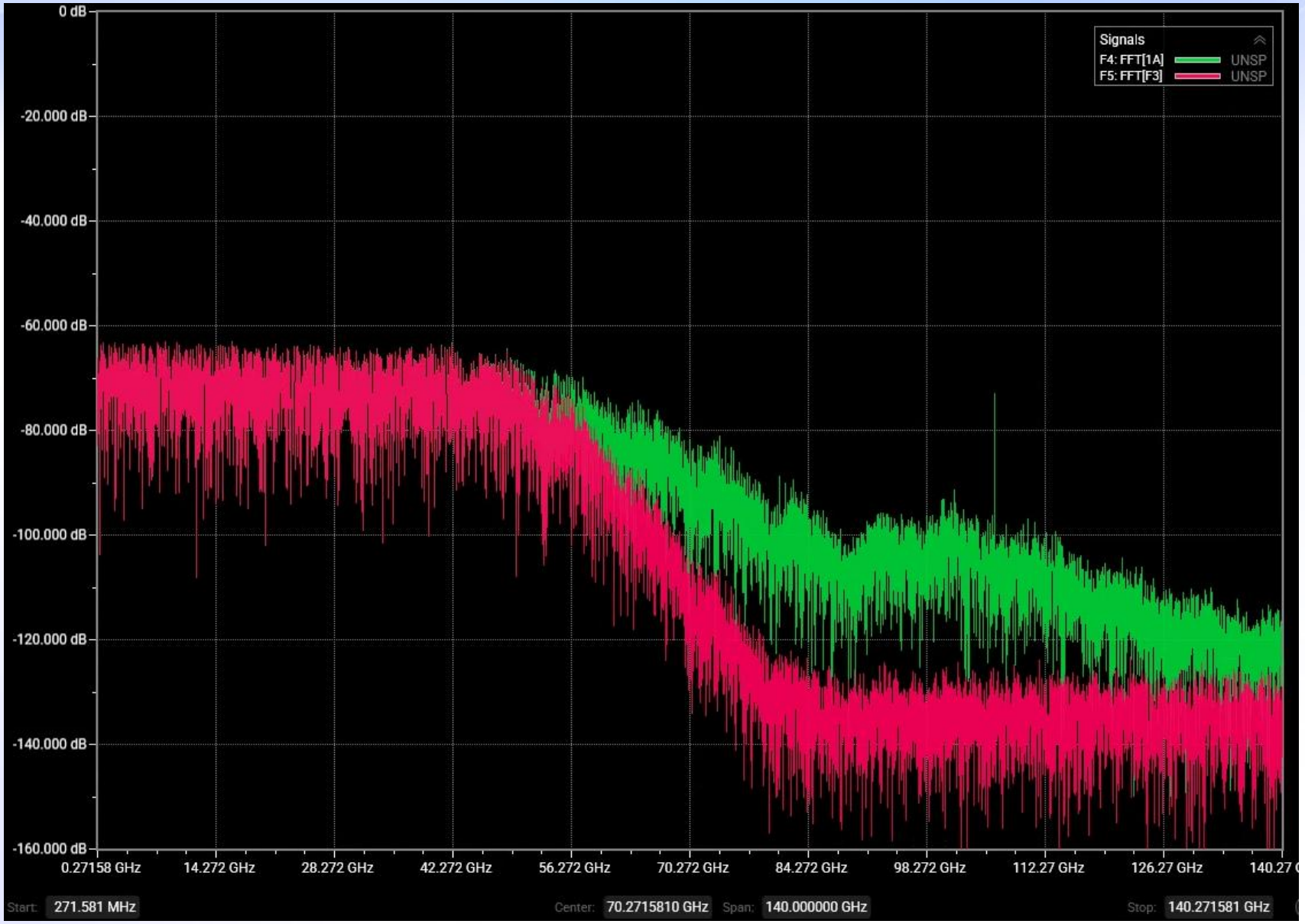
- Cutting the Bessel-Thomson BW tail
- (cut-off implemented as a 10th Order Butterworth filter; others show same result)

- 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 has little energy past 90 GHz



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

The Bessel-Thomson filter:

- Has about the appropriate Bandwidth
- Has a roll off specified to 138 GHz - much too far
- Today's designs are unlikely to show noticeable energy after 90 GHz
- So the B-T going to only about 100 GHz is fine, allows for lower noise and lower T&M expense

What to do today, at Draft 3.2 / Sponsor Ballot:

- We don't need to change the standard since the 138 GHz BW cut-off is given w/o tolerance anyway
- Implementer might want to verify that their optical signals are mute in the 100 GHz to 138+ GHz range (e.g. check with a non-amplified, ultra-high optical BW oscilloscope)
- … and then typically measure (only) with an oscilloscope that is following the B-T filter to at least 100 GHz – cut-off around there is ok, and the oscilloscope will be more economical
- This info is fine as an FYI, no need to put into the standard at this late a draft

Lumilens

Thanks!