TDECQ changes (and consequent spec changes) for SMF and MMF clauses

Revision 1a

802.3cd, Berlin, Germany, July 2017

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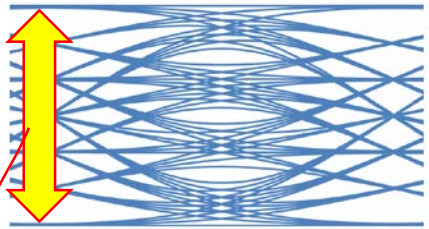
Background: changes to TDECQ in 802.3bs draft 3.2

- Reference EQ replaced with 5 tap T spaced FFE
- Reference receiver bandwidth lowered to 50% of symbol rate
  - Representative of expected 50Gb/s and 100Gb/s PAM4 receivers with digital EQ implementations
    - The lower bandwidth reference receiver can be thought of as an anti-aliasing filter - it filters high frequency noise and signal components which are not addressable with a T spaced EQ
- The changes to TDECQ introduced in draft 3.2 will increase TDECQ values (~0.9 dB) for the same transmitter waveforms. This is expected to be fully accommodated by:
  - an appropriate increase of TDECQ and SECQ specs for each PMD
  - a similar decrease in the OMA_{outer} minus TDECQ spec
    - so that min Tx OMA_{outer} at max TDECQ is unchanged
  - no changes to OMA_{outer} spec for SRS test
  - no change to the informative receiver sensitivity spec value, but receiver sensitivity expected to be noted as being defined for a test transmitter with SECQ = 0.9 dB*

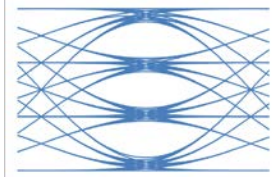
**depending on resolution of comments against 802.3bs D3.2*

TDECQ old TDECQ new

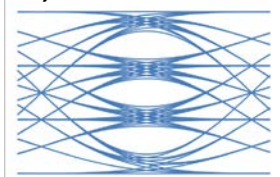
Just compliant
Tx waveform



Equalized eye
5xT/2, 0.75xBaud rate



Equalized eye
5xT, 0.5xBaud rate

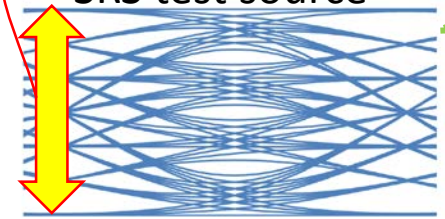


Tx OMA_{outer}

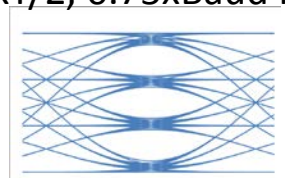
Changing the TDECQ methodology doesn't change the transmitter characteristics, it's the same transmitter, but it's TDECQ is measured as larger for D3.2 TDECQ

SRS OMA_{outer}

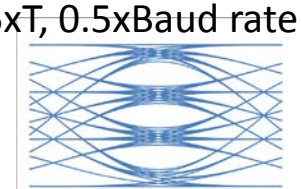
SRS test source



Calibrated SRS test eye
5xT/2, 0.75xBaud rate

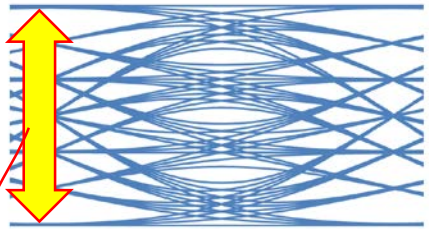


Calibrated SRS test eye
5xT, 0.5xBaud rate

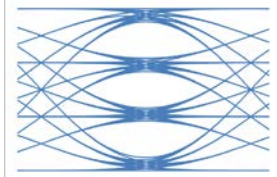


TDECQ old TDECQ new

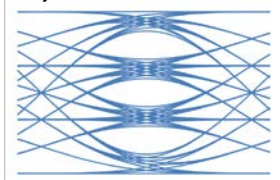
Just compliant
Tx waveform



Equalized eye
5xT/2, 0.75xBaud rate



Equalized eye
5xT, 0.5xBaud rate



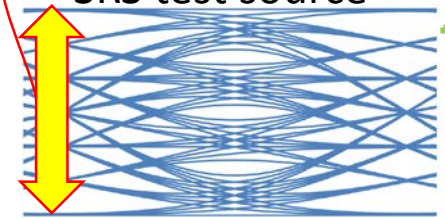
Tx OMA_{outer}

Changing the TDECQ methodology doesn't change the transmitter characteristics, it's the same transmitter, but it's TDECQ is measured as larger for D3.2 TDECQ

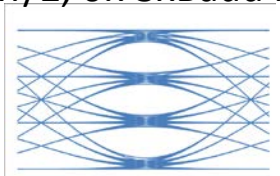
*The change to SECQ doesn't change the stress applied to the SRS test source, but it's SECQ is **measured** as larger for the D3.2 SECQ.*

SRS OMA_{outer}

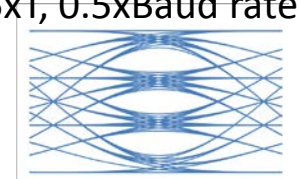
SRS test source



Calibrated SRS test eye
5xT/2, 0.75xBaud rate

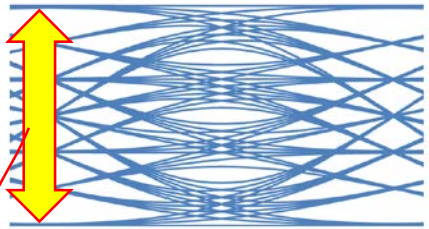


Calibrated SRS test eye
5xT, 0.5xBaud rate

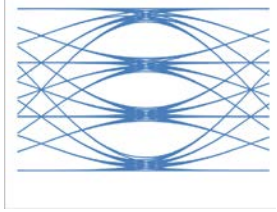


TDECQ old TDECQ new

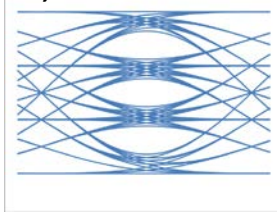
Just compliant
Tx waveform



Equalized eye
5xT/2, 0.75xBaud rate



Equalized eye
5xT, 0.5xBaud rate



Tx OMA_{outer}

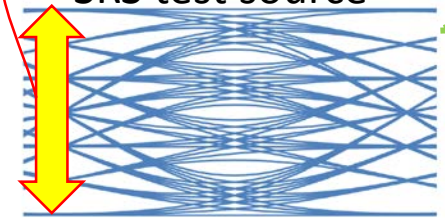
*Changing the TDECQ methodology doesn't change the transmitter characteristics, it's the same transmitter, but it's TDECQ is **measured** as larger for D3.2 TDECQ.*

The change to SECQ doesn't change the stress applied to the SRS test source, but it's SECQ is measured as larger for the D3.2 SECQ.

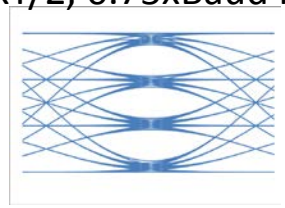
A specific receiver implementation isn't changed by the D3.2 SECQ - it's still the same receiver. If it could equalize and close the link with the SRS test source calibrated with D3.1 SECQ, it will still close link with D3.2 SECQ, without needing to change the input OMA to the receiver.

SRS OMA_{outer}

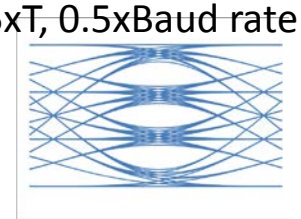
SRS test source



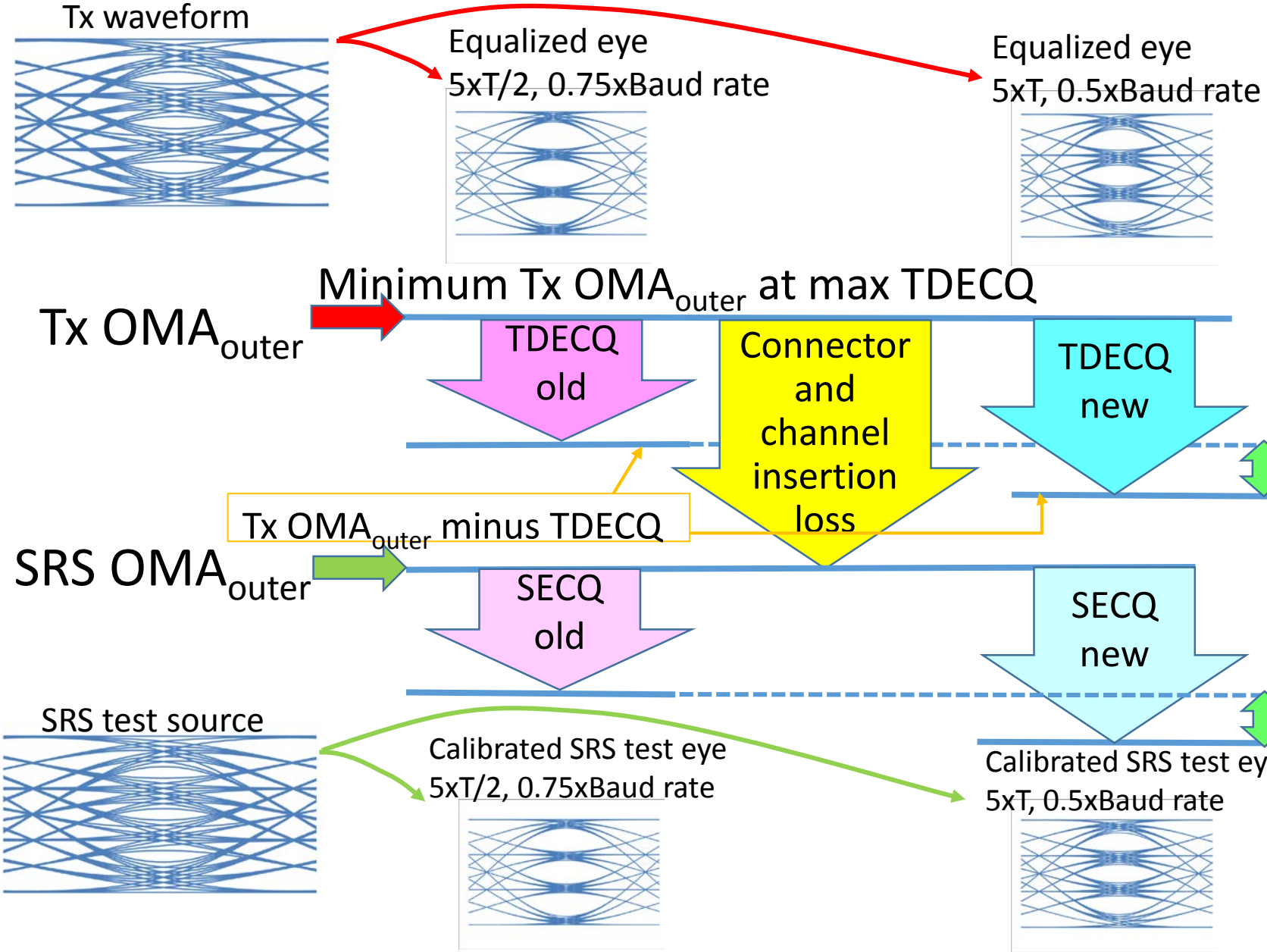
Calibrated SRS test eye
5xT/2, 0.75xBaud rate



Calibrated SRS test eye
5xT, 0.5xBaud rate



TDECQ old TDECQ new



Outline of proposed changes for 802.3cd D2.1

- Following 802.3bs:
  - Change reference EQ to a 5 tap, T spaced, FFE.
  - Change TDECQ reference receiver bandwidth to 50% of symbol rate.
    - Except for the MMF clause, where the O/E bandwidth is intended to be the combined bandwidth of a reference receiver and a worst case channel.
    - Add an exception to N(f), the normalized noise power density spectrum in equation 121-9, to be equivalent to white noise filtered by a fourth-order Bessel-Thomson response filter with a bandwidth of 50% of the symbol rate.
  - Increase TDECQ and SECQ values by 0.9 dB.
  - Decrease the transmitter "OMA_{outer} minus TDECQ" spec by 0.9 dB.
    - i.e. the required minimum Tx OMA at max TDECQ value will be maintained.
  - Keep "Receiver sensitivity" spec value the same, but add note which says that receiver sensitivity is defined for a test transmitter with SECQ = 0.9 dB.
  - Increase the power budget for max TDECQ by 0.9 dB.
  - Increase the allocation for penalties by 0.9 dB.
- Specific changes for 138, 139 and 140 follow

138

Specific changes for Clause 138 TDECQ sections

- In 138.8.5
  - Change “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 12.6 GHz” to “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 11.2 GHz”.
- In 138.8.5.1
  - Change “The reference equalizer for 50GBASE-SR, 100GBASE-SR2, and 200GBASE-SR4, is a 5 tap, T/2 spaced, feed-forward equalizer” to “The reference equalizer for 50GBASE-SR, 100GBASE-SR2, and 200GBASE-SR4, is a 5 tap, T spaced, feed-forward equalizer”.
- In 138.8.8
  - Change “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 19.34 GHz” to “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of approximately 13.28125 GHz”.

Specific changes for Clause 138, Table 138-6

Description	Value	Unit
Signaling rate (range)	26.5625 100 ppm	GBd
Modulation format	PAM4	-
Center wavelength (range)	840 to 860	nm
RMS spectral width[a]	0.6	nm
Average launch power, each lane (max)	4	dBm
Average launch power, each lane (min)	-6	dBm
OMA_{outer} (max)	3	dBm
OMA_{outer} (min)[b]	-4	dBm
Launch power in OMA_{outer} minus TDECQ (min)	~~-5~~ -5.9	dBm
TDECQ	~~4~~ 4.9	dB
Average launch power of OFF transmitter (max)	-30	dBm
Extinction ratio	3	dB
Optical return loss tolerance (max)	12	dB
Encircled flux[c]	≥ 86% at 19 µm ≤ 30% at 4.5 µm	

a) RMS spectral width is the standard deviation of the spectrum.

b) Even if the TDECQ < 1.9 dB, the OMA (min) must exceed this value.

c) If measured into type A1a.2 or type A1a.3, or A1a.4, 50 µm fiber, in accordance with IEC 61280-1-4.

Specific changes for Clause 138, Table 138-7

Description	Value	Unit
Signaling rate (range)	26.5625 100 ppm	GBd
Modulation format	PAM4	-
Center wavelength (range)	840 to 860	nm
Damage threshold[a] (min)	5	dBm
Average receive power, each lane (max)	4	dBm
Average receive power, each lane[b] (min)	-7.9	dBm
Receive power, each lane (OMA_{outer}) (max)	3	dBm
Receiver reflectance (max)	-12	
Stressed receiver sensitivity (OMA_{outer}), each lane[c] (max)	-3	dBm
Receiver sensitivity (OMA_{outer}), each lane[d] (max)	-7	dB
Conditions of stressed receiver sensitivity test[e]		
Stressed eye closure (SECQ), lane under test	~~4~~ 4.9	dB
OMA_{outer} of each aggressor lane[f]	3	dB

a) The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level. The receiver does not have to operate correctly at this input power.

b) Average receiver power, each lane (min) is informative and not the principal indicator of signal strength. A received power below this values cannot be compliant; however, a value above this value does not ensure compliance.

c) Measured with a conformance test signal t TP3 (see 138.8.8) for the BER specified in 138.1.1.

d) Receiver sensitivity is informative and is defined for a transmitter with SECQ = 0.9 dB.

e) These test conditions are for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

f) Only applies to 100GBASE-SR2 and 200GBASE-SR4

Specific changes for Clause 138, Table 138-8

Parameter	OM3	OM4	OM5	Unit
Effective modal bandwidth at 850 nm[a]	2000	4700		
Power budget (for maximum TDECQ)	~~6~~ 6.9			dB
Operating distance	0.5 to 70	0.5 to 100		km
Channel insertion loss[b]	1.8	1.9		dB
Allocation for penalties[c] (for maximum TDECQ)	~~4.1~~ 5			dB
Additional insertion loss allowed	0.1	0		dB

a) Per IEC 60793-2-10.

b) The channel insertion loss is calculated using the maximum distance specified in Table 138–7 and cabled fiber attenuation of 3.5 dB/km at 850 nm plus an allocation for connection and splice loss given in 138.10.2.2.1.

c) Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

139

Specific changes for Clause 139 TDECQ sections

- In 139.7.5.1:
  - Change “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 19.34 GHz” to “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of approximately 13.28125 GHz”.
- In 139.7.5.4
  - Change “The reference equalizer for 50GBASE-FR and 50GBASE-LR is a 5 tap, T/2 spaced, feed-forward equalizer” to “The reference equalizer for 50GBASE-FR and 50GBASE-LR is a 5 tap, T spaced, feed-forward equalizer”.

Specific changes for Clause 139, Table 139-6

Description	50GBASE-FR	50GBASE-LR	Unit
Signaling rate (range)	26.5625 100 ppm		GBd
Modulation format	PAM4		-
Wavelengths (range)	1304.5 to 1317.5		nm
Side mode suppression ratio (SMSR), (min)	30		dB
Total average launch power (max)	3	4.2	dBm
Average launch power[a] (min)	-3.6	-4	dBm
OMA_{outer} (max)	2.8	4	dBm
OMA_{outer} (min)[b]	-2	-1	dBm
Launch power in OMA_{outer} minus TDECQ (min)	~~-3~~ -3.9	~~-2~~ -2.9	dBm
TDECQ	~~2.3~~ 3.2	~~2.5~~ 3.4	dB
Average launch power of OFF transmitter (max)	-16		dBm
Extinction ratio	4.5		dB
$RIN_{16.5}OMA$ (max)	-132		dB/Hz
$RIN_{15.1}OMA$ (max)		-132	dB/Hz
Optical return loss tolerance (max)	16.5	15.1	dB
Transmitter reflectance[c] (max)	-26		dB

a) Average launch power (min) is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.

b) Even if the TDECQ < ~~1~~ 1.9 dB, the OMA_{outer} (min) must exceed this value.

c) Transmitter reflectance is defined looking into the transmitter.

Specific changes for Clause 139, Table 139-7

Description	50GBASE-FR	50GBASE-LR	Unit
Signaling rate (range)	26.5625 100 ppm		GBd
Modulation format	PAM4		-
Wavelengths (range)	1304.5 to 1317.5		nm
Damage threshold	5.2	5.2	dBm
Average receive power (max)	3	4.2	dBm
Average receive power[a] (min)	-7.6	-10.3	dBm
Receive power (OMA_{outer}) (max)	2.8	4	dBm
Receiver reflectance (max)	-26		dB
Receiver sensitivity (OMA_{outer})[c] (max)	-7.3	-8.8	dBm
Stressed receiver sensitivity (OMA_{outer})[d] (max)	-5	-6.3	dBm
Conditions of stressed receiver sensitivity test[e]			
SECQ	~~2.3~~ 3.2	~~2.5~~ 3.4	dB

a) The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level.

b) Average receiver power (min) is informative and not the principal indicator of signal strength. A received power below this values cannot be compliant; however, a value above this value does not ensure compliance.

c) Receiver sensitivity is informative and is defined for a transmitter with SECQ = 0.9 dB.

d) Measured with conformance test signal at TP3 (see 139.7.9) for the BER specified in 139.1.1.

e) These test conditions are for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

Specific changes for Clause 139, Table 139-8

Parameter	50GBASE-FR	50GBASE-FR	Unit
Power budget (for maximum TDECQ)	~~6.6~~ 7.5	~~9.3~~ 10.2	dB
Operating distance	2	10	km
Channel insertion loss	4[a]	6.3[b]	dB
Maximum discrete reflectance	See 139.10.2.2	See 139.10.2.2	dB
Allocation for penalties[c] (for maximum TDECQ)	~~2.6~~ 3.5	~~3~~ 3.9	dB
Additional insertion loss allowed	0	0	dB

a) The channel insertion loss is calculated using the maximum distance specified in Table 139–5 for 50GBASE-FR and fiber attenuation of 0.5 dB/km plus an allocation for connection and splice loss given in 139.10.2.1.

b) The channel insertion loss is calculated using the maximum distance specified in Table 139–5 for 50GBASE-LR and fiber attenuation of 0.43 dB/km at 1304.5 nm plus an allocation for connection and splice loss given in 139.10.2.1.

c) Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

140

Specific changes for Clause 140 TDECQ sections

- In 140.7.5:
  - Change “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 38.68 GHz” to “The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of approximately 26.5625 GHz”
  - Add an exception: “The normalized noise power density spectrum, N(f) in equation 121-9, is equivalent to white noise filtered by a fourth-order Bessel-Thomson response filter with a bandwidth of 26.5625 GHz.

- Note that the reference equalizer for 100GBASE-DR refers to clause 121.8.5.4 which defines a 5 tap, T spaced, feed-forward reference equalizer.

Specific changes for Clause 140, Table 140-6

Description	Value	Unit
Signaling rate (range)	53.125 100 ppm	GBd
Modulation format	PAM4	-
Wavelengths (range)	1304.5 to 1317.5	nm
Side mode suppression ratio (SMSR), (min)	30	dB
Total average launch power (max)	4	dBm
Average launch power[a] (min)	-2.4	dBm
OMA_{outer} (max)	4.2	dBm
OMA_{outer} (min)[b]	-0.3	dBm
Launch power in OMA_{outer} minus TDECQ (min)	~~-1.3~~ -2.2	dBm
TDECQ	~~2.5~~ 3.4	dB
Average launch power of OFF transmitter (max)	-15	dBm
Extinction ratio	5	dB
$RIN_{15.1}OMA$ (max)	-136	dB/Hz
Optical return loss tolerance (max)	15.5	dB
Transmitter reflectance[c] (max)	-26	dB

a) Average launch power (min) is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.

b) Even if the TDECQ < ~~1~~ 1.9 dB, the OMA_{outer} (min) must exceed this value.

c) Transmitter reflectance is defined looking into the transmitter.

Specific changes for Clause 140, Table 140-7

Description	Value	Unit
Signaling rate (range)	53.125 100 ppm	GBd
Modulation format	PAM4	-
Wavelengths (range)	1304.5 to 1317.5	nm
Damage threshold	6.5	dBm
Average receive power (max)	4	dBm
Average receive power[a] (min)	-5.4	dBm
Receive power (OMA_{outer}) (max)	4.2	dBm
Receiver reflectance (max)	-26	dB
Receiver sensitivity (OMA_{outer})[c] (max)	-4.4	dBm
Stressed receiver sensitivity (OMA_{outer})[d] (max)	-1.9	dBm
Conditions of stressed receiver sensitivity test[e]		
SECQ	~~2.5~~ 3.4	dB

a) The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level.

b) Average receiver power (min) is informative and not the principal indicator of signal strength. A received power below this values cannot be compliant; however, a value above this value does not ensure compliance.

c) Receiver sensitivity is informative and is defined for a transmitter with SECQ = 0.9 dB.

d) Measured with conformance test signal at TP3 (see 139.7.9) for the BER specified in 139.1.1.

e) These test conditions are for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

Specific changes for Clause 140, Table 140-8

Parameter	Value	Unit
Power budget (for maximum TDECQ)	~~5.6~~ 6.5	dB
Operating distance	500	m
Channel insertion loss[a]	See 140.9	dB
Maximum discrete reflectance	-35	dB
Allocation for penalties[b] (for maximum TDECQ)	~~5.6~~ 6.5 minus max channel insertion loss per Table 140-12	dB
Additional insertion loss allowed	0	dB

a) The channel insertion loss is calculated using the maximum distance specified in Table 140–5 and cabled fiber attenuation of 0.5 dB/km at 1304.5 nm plus an allocation for connection and splice loss given in 140.10.2.1.

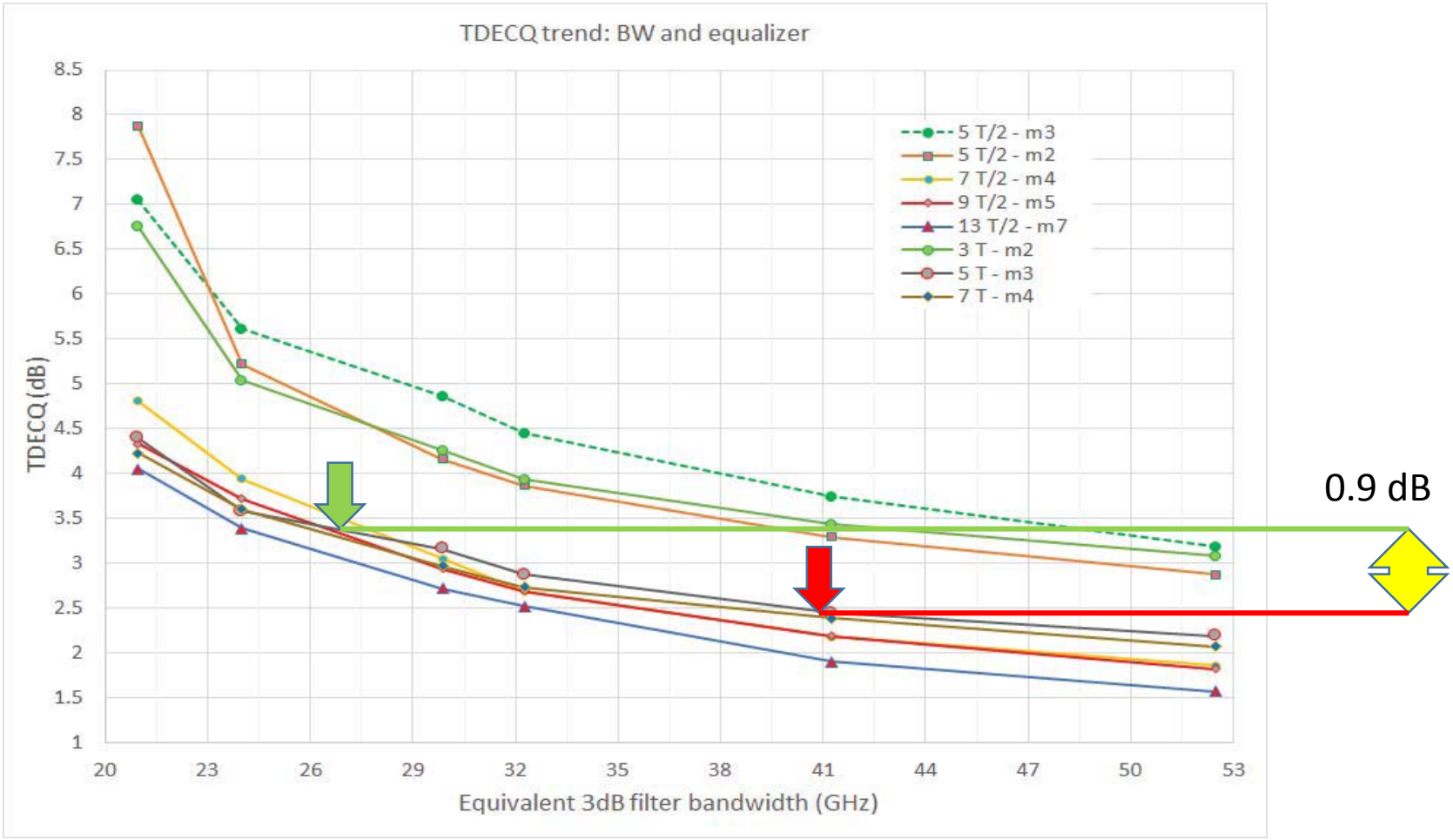
b) Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

Back up

Unstressed receiver sensitivity - notes

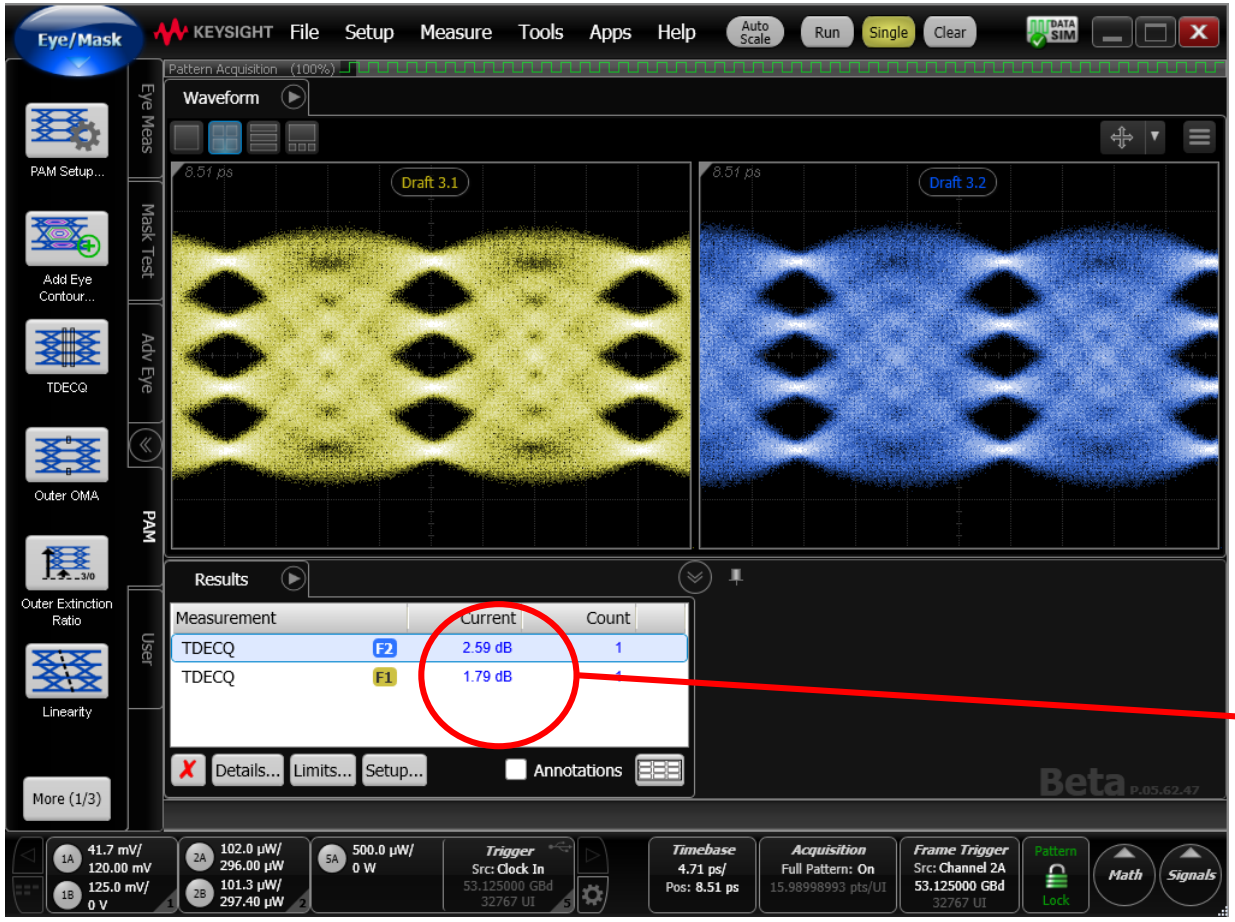
- The OMA_{outer} spec value for receiver sensitivity cannot be seen with compliant transmitters and links.
- Expectations for sensitivity for an ideal receiver with a bandwidth of 50% and 75% of symbol rate:
  - For constant input referred noise density, reducing receiver noise bandwidth from 75% to 50% of symbol rate would reduce total RMS noise by 0.9 dB.
- Test transmitter for measuring receiver sensitivity
  - One way to arrive at an equivalent “unstressed receiver sensitivity” is to subtract the measured SECQ of the test transmitter from the receiver sensitivity measured with it.
  - With the changes to the reference EQ and reference receiver bandwidth, SECQ values are expected to increase by 0.9 dB.
  - So equivalent unstressed receiver sensitivity for a particular receiver should decrease (compared to 802.3bs D3.1).

TDECQ plots from Mazzini_01a_0517_smf



Example simulated waveforms from Keysight

Result of simulated waveforms with a modest amount of ISI and RIN included. The increase of TDECQ from draft 3.1 to draft 3.2 is about 0.8 dB for this configuration.



0.8 dB difference

BER plots from Mazzini_01a_0517_smf