TFT Examples & Illustrations

IEEE 802.3dj TF Plenary Session

July 13-17, 2026

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Comment Number	Resolution Material Page Number
79, 89, 90, 91	p. 21: Table 180-18
80, 196	p. 25: Title 180.9.8.2
118, 305, 312	p. 15: Test_margin
119	p. 8: max TDECQ value
121, 122	p. 12: OMA_{outer}
123	p. 12: ORx OMA_{outer}
125	p. 27: ORx OMA at Test_BER
132	p. 7, 24: FnRx
208	p. 22: LRS background
283	p. 26, 27: MPI & DGD penalties

TFT Outline

- ➢ Background
- ▪ Illustrations
- ▪ Examples
- ▪ Optional Penalties
- ▪ Calculations

Transmitter Functional Test (TFT) 802.3dj Background

- Not a standalone spec: normative w/ other transmitter characteristics
  - ex. TECQ & TDECQ, OMA (min) & (max), ER (min), over & undershoot (max)
- Uses 802.3 single power-penalty optics spec methodology capturing all impairments
- Uses Optical Receiver (ORx), instead of hardware Golden Rx, referenced to:
  - LRS & SRS conformance test signal transmitters characterized by TECQ
  - TECQ measured using scope-based software Golden Rx
- Addresses TECQ & TDECQ corner case problems, ex. Tx Dispersion Penalty spec proposal
- Does not use separate impairment spec methodology, ex. no separate jitter spec
- First proposal, 7/25: patch-cord only
- Update, 9/25: test-fiber added
- Update, 9/25: equations reorganized & full supporters list
- Update, 1/26: equations reorganized
- Update, 3/26, 5/26: variable names tweaked, functionally same as 7/25 & 9/25 proposals

Outline

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- **Illustrations**
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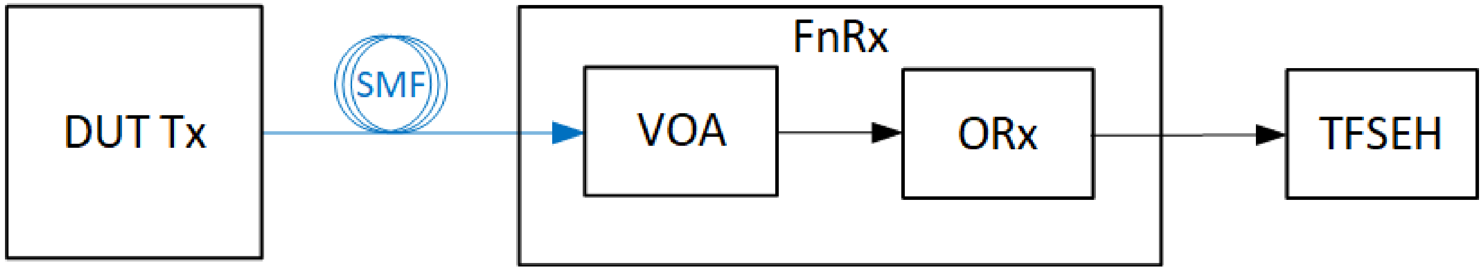
Set-up Illustration & VOA_level Equation



VOA_level = Test_fiber_correction + ORx_TECQ_correction - Test_margin (180-17)

Test_fiber_correction normalizes differences in test fibers so that symbol error counts are repeatable and is determined by the same algebraic expressions as determine normative transmitter characteristics.

ORx_TECQ_correction normalizes differences in optical receivers so that symbol error counts are repeatable and is determined by the same algebraic expressions as determine normative receiver characteristics.

Test_margin is additional ORx OMA, to improve SNR of the transmitter functional test. It equals 1.5 dB, which decreases the ORx operating BER target to 2.4×10^{-5}.

Test_fiber_correction Equation

Test_fiber_correction = Tx_DUT_power_budget - Test_fiber_power_budget (180-18)

- —Tx_DUT_power_budget is the transmitter under test power budget specified in Table 180-9 except instead of max TDECQ value, uses measured TDECQ value over the test fiber (180-19)
- —Test_fiber_power_budget is link power budget in Table 180-9, except instead of max values uses best estimates of the test fiber Channel insertion loss, MPI, DGD and TDECQ penalties (180-20)

Table 180–9—Illustrative link power budget

Parameter	Value	Unit
Power budget (for max TDECQ)	6.7	dB
Operating distance	500	m
Channel insertion loss[a, b]	3	dB
Maximum discrete reflectance	–35	dB
Allocation for penalties[c] (for max TDECQ)	3.7	dB
Additional insertion loss allowed	0	dB

Test_fiber_correction Examples

Test_fiber_correction = Tx_DUT_power_budget - Test_fiber_power_budget (180-18)

CIL ≡ Channel Insertion Loss

- Tx_DUT_power_budget = CIL_allocation + MPI_and_DGD_penalties_allocation
  + max(DUT_TECQ, Test_fiber_DUT_TDECQ)

Ex1. Patch cord at zero CIL & penalties allocation (TECQ test condition)

- Test_fiber_power_budget = DUT_TECQ
- Test_fiber_correction = Tx_DUT_power_budget – DUT_TECQ

Ex2. Test fiber at max CIL & penalties allocation

- Test_fiber_power_budget = Tx_DUT_power_budget
- Test_fiber_correction = 0

  (If Test_margin is positive, then VOA_level is negative, i.e. gain, Calculations Ex. 1)

Ex3. Test fiber at fraction α * CIL (α < 1) & full penalties allocation (TDECQ test condition)

- Test_fiber_power_budget = α CIL + Test_fiber_MPI_and_DGD_penalties + Test_fiber_DUT_TDECQ
- Test_fiber_correction = (1 - α) CIL

Test_fiber_correction Illustration

Test_fiber_correction = Tx_DUT_power_budget - Test_fiber_power_budget (180-18)

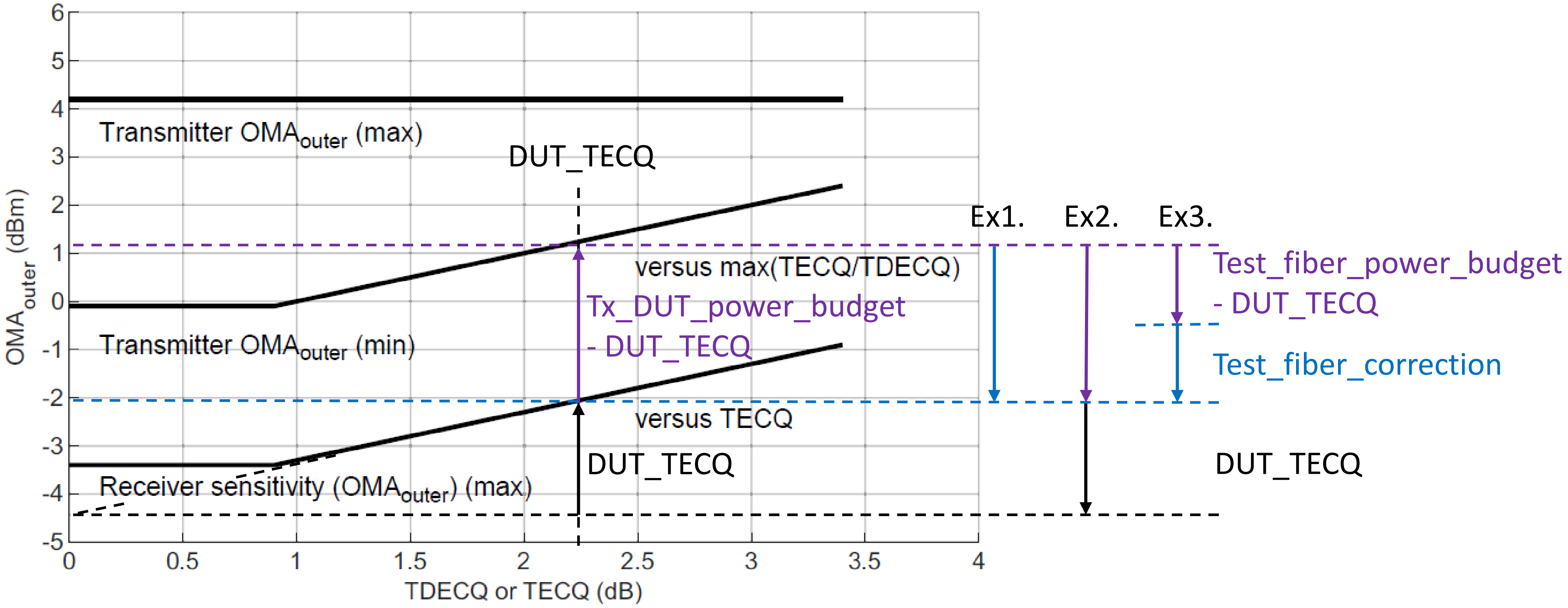


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

Test_fiber_correction Illustration

Test_fiber_correction = Tx_DUT_power_budget - Test_fiber_power_budget (180-18)

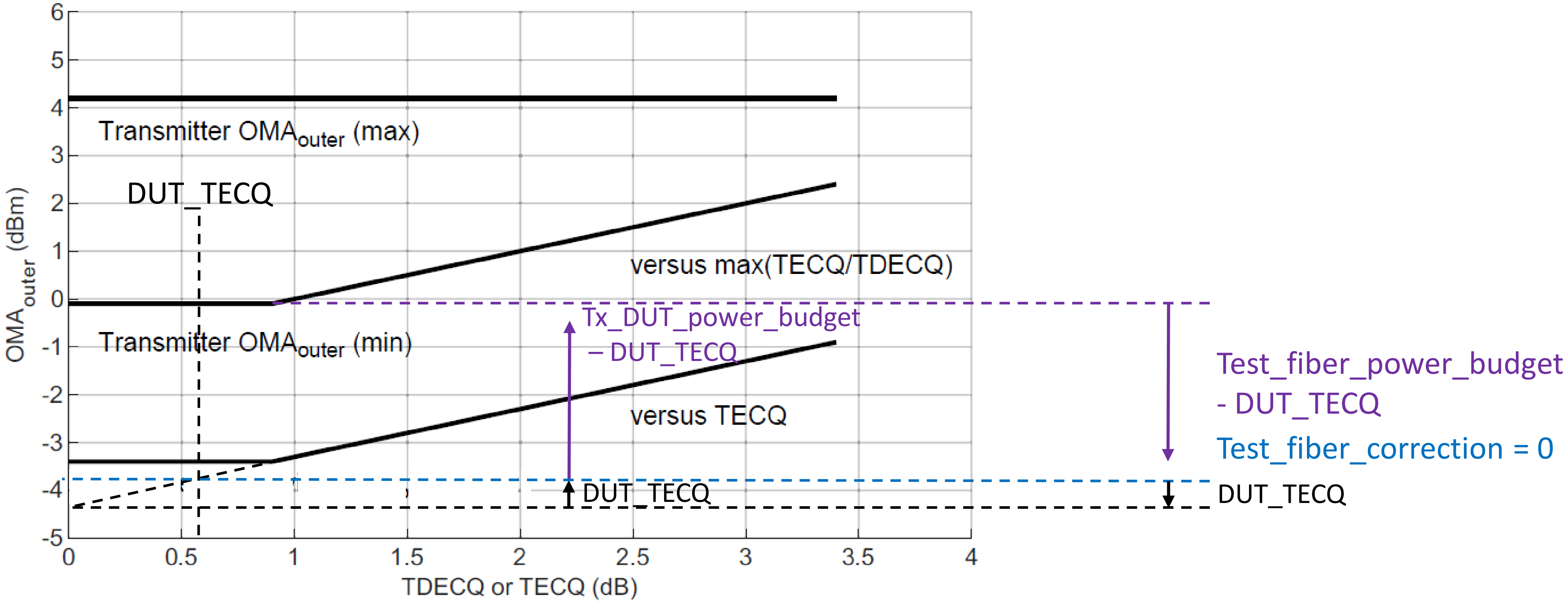


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

ORx_TECQ_correction Equation

ORx_TECQ_correction = RxS_OMA_max_at_DUT_TECQ - ORx_RxS_OMA_at_DUT_TECQ (180–21)

—RxS_OMA_max_at_DUT_TECQ is the receiver sensitivity OMA_{outer} (max), at the measured TECQ of the transmitter under test

—ORx_RxS_OMA_at_DUT_TECQ is the ORx receiver sensitivity OMA_{outer} at the measured TECQ of the transmitter under test

—ORx_TECQ_correction is minimized for most accurate ORx normalization results

ORx_TECQ_correction Illustration

ORx_TECQ_correction = RxS_OMA_max_at_DUT_TECQ - ORx_RxS_OMA_at_DUT_TECQ (180–21)

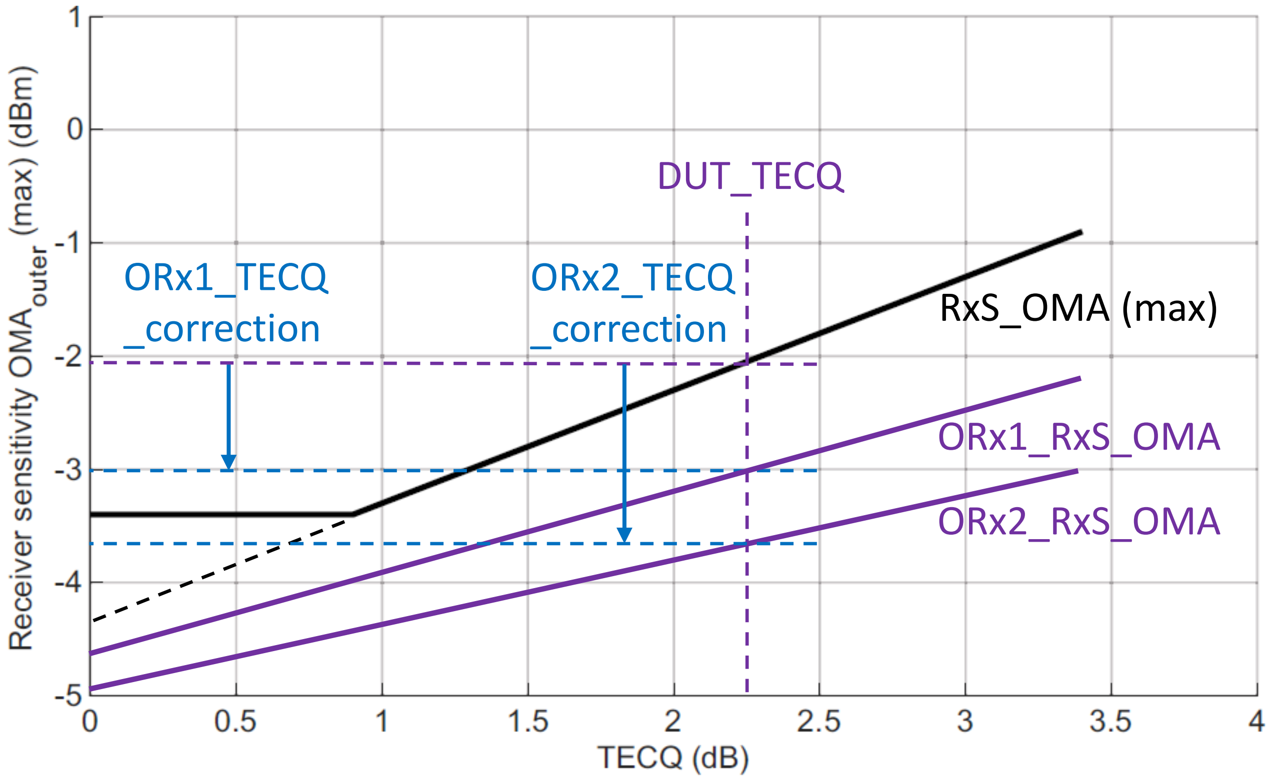


Figure 180–4—Receiver sensitivity (OMA_{outer}), each lane (max)

ORx_TECQ_correction Illustration

ORx_TECQ_correction = RxS_OMA_max_at_DUT_TECQ - ORx_RxS_OMA_at_DUT_TECQ (180–21)

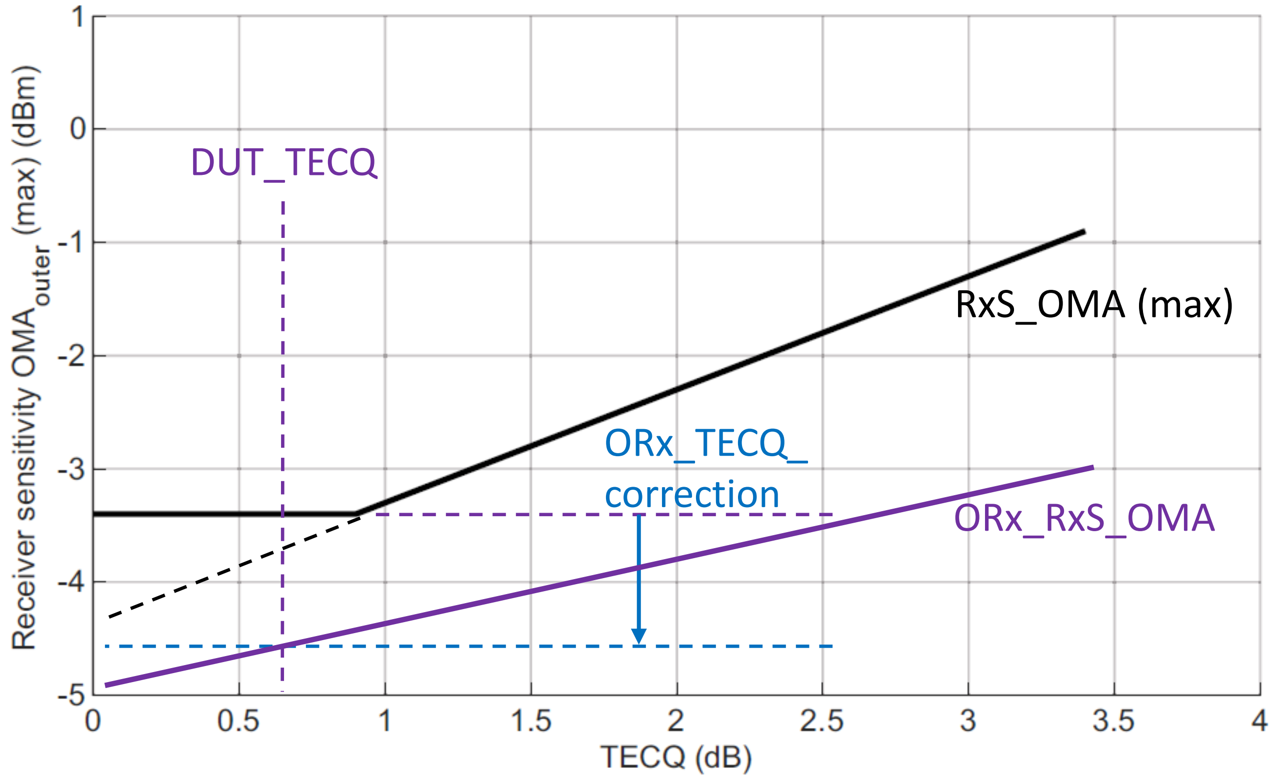


Figure 180–4—Receiver sensitivity (OMA_{outer}), each lane (max)

Test_margin Background

Test_margin is additional ORx OMA, to improve SNR of the transmitter functional test (see 180.9.8.2). It equals 1.5 dB, which decreases the ORx operating BER target to 2.4×10^{-5}.

Model: Tx_DUT → Channel → Rx

- SNR_M ≡ SNR of transmitter under test measurement
- ch_loss < 1 ≡ Channel insertion loss (linear)

▪ SNR_M = Tx_DUT_Signal * ch_loss / (Tx_DUT_Noise * ch_loss + Rx_Noise)

- SNR_M objective: SNR_M ≈ Tx_DUT_Signal / Tx_DUT_Noise → Tx_DUT_Noise * ch_loss > Rx_Noise
- At receiver sensitivity: Tx_DUT_Noise * ch_loss < Rx_Noise
- test_margin > 1 ≡ offset gain to reduce effect of ch_loss (linear)

▪ SNR_M = Tx_DUT_Signal * ch_loss * test_margin / (Tx_DUT_Noise * ch_loss * test_margin + Rx_Noise)

▪ Transmitter only test operating BER must be decreased from full link (PMD to PMD) BER of $2.28\text{x}10^{-4}$

▪ Experimental validation

▪ Example of common SNR_M improvement: after fiber eye measurement

- Tx_DUT → Fiber → Gain → DCA

VOA_level w/ no Tx_margin Illustration

VOA_level = Test_fiber_correction + ORx_TECQ_correction - Test_margin (180–17)

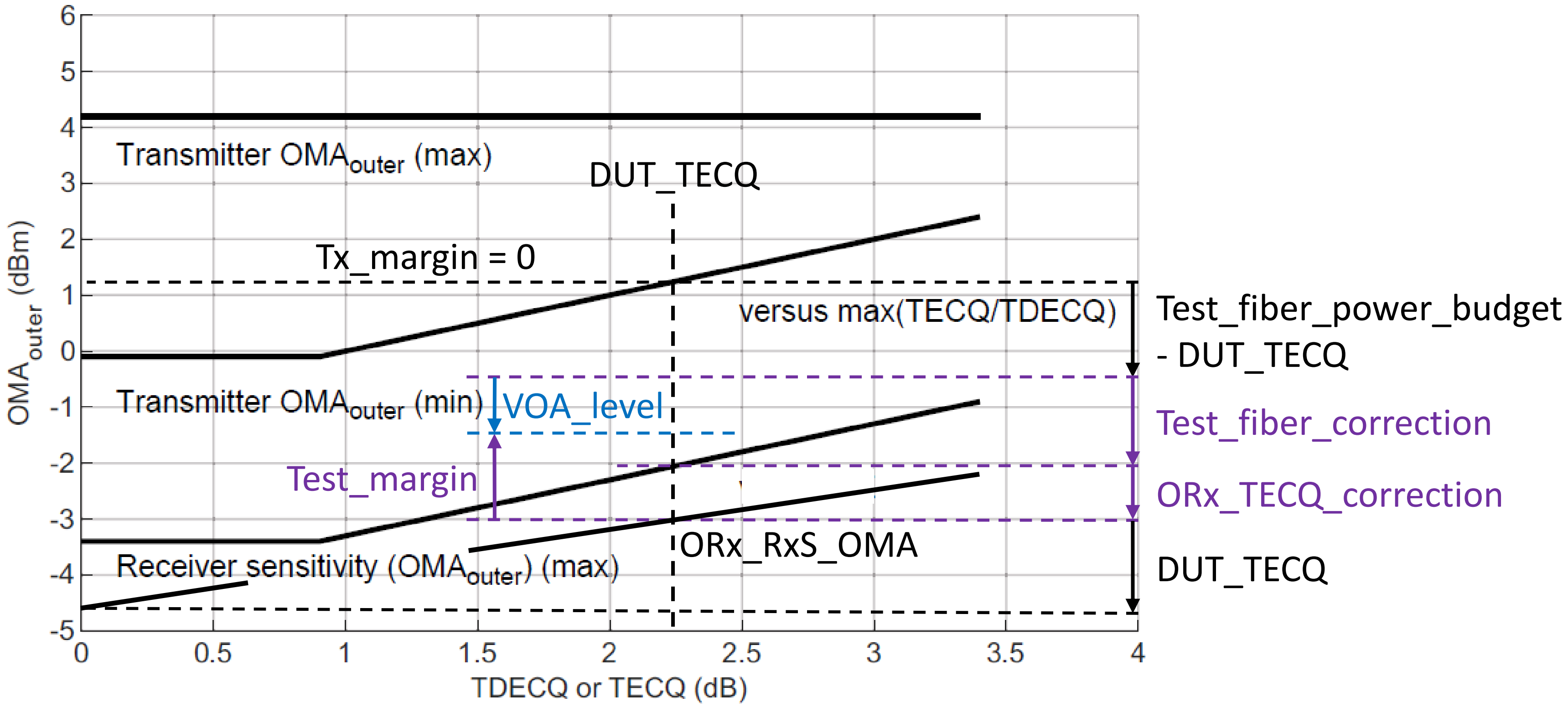


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

VOA_level w/ Tx_margin Illustration

VOA_level = Test_fiber_correction + ORx_TECQ_correction - Test_margin (180–17)

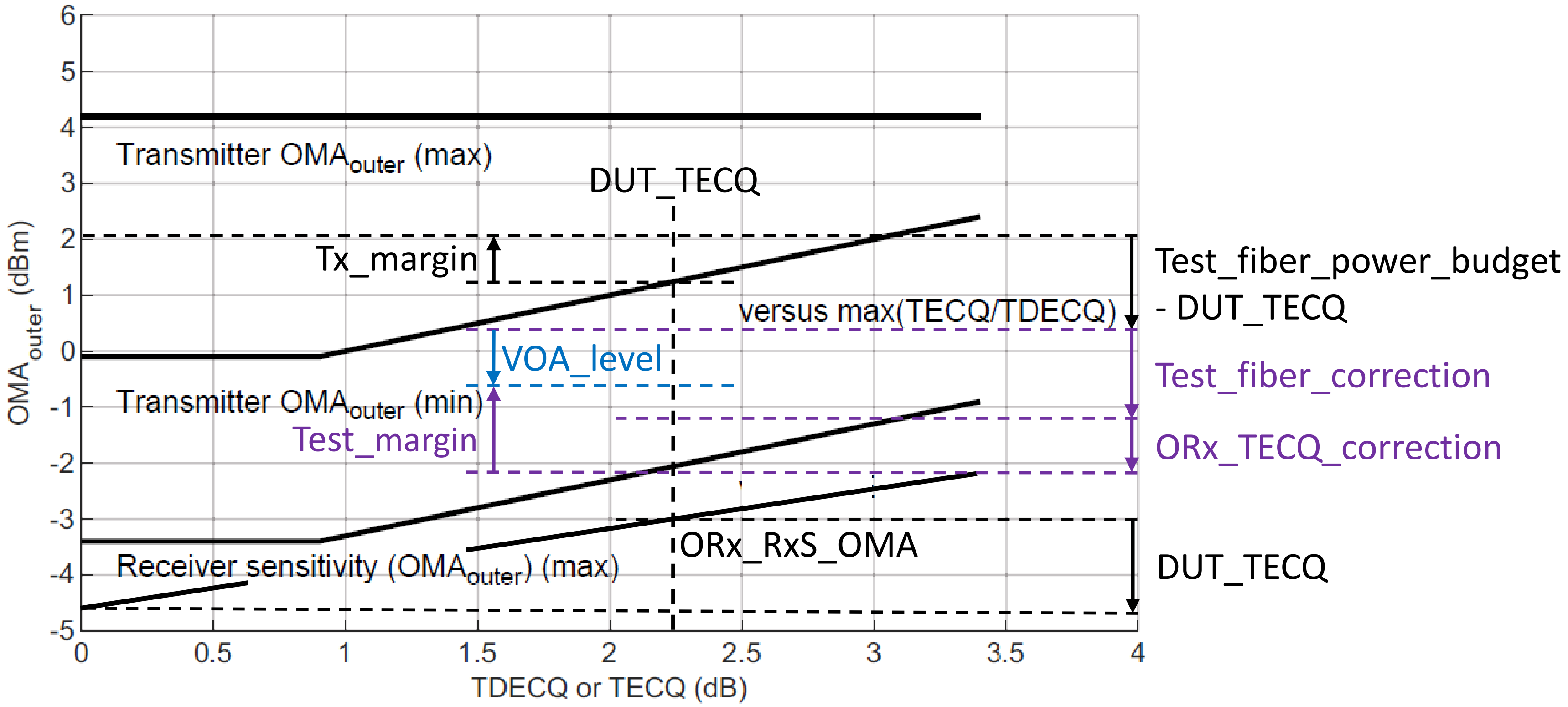


Figure 180–5—Transmitter OMA$_{outer}$ each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA$_{outer}$) each lane versus TECQ

VOA_level w/ no Tx_margin & low TECQ Illustration

VOA_level = Test_fiber_correction + ORx_TECQ_correction - Test_margin (180–17)

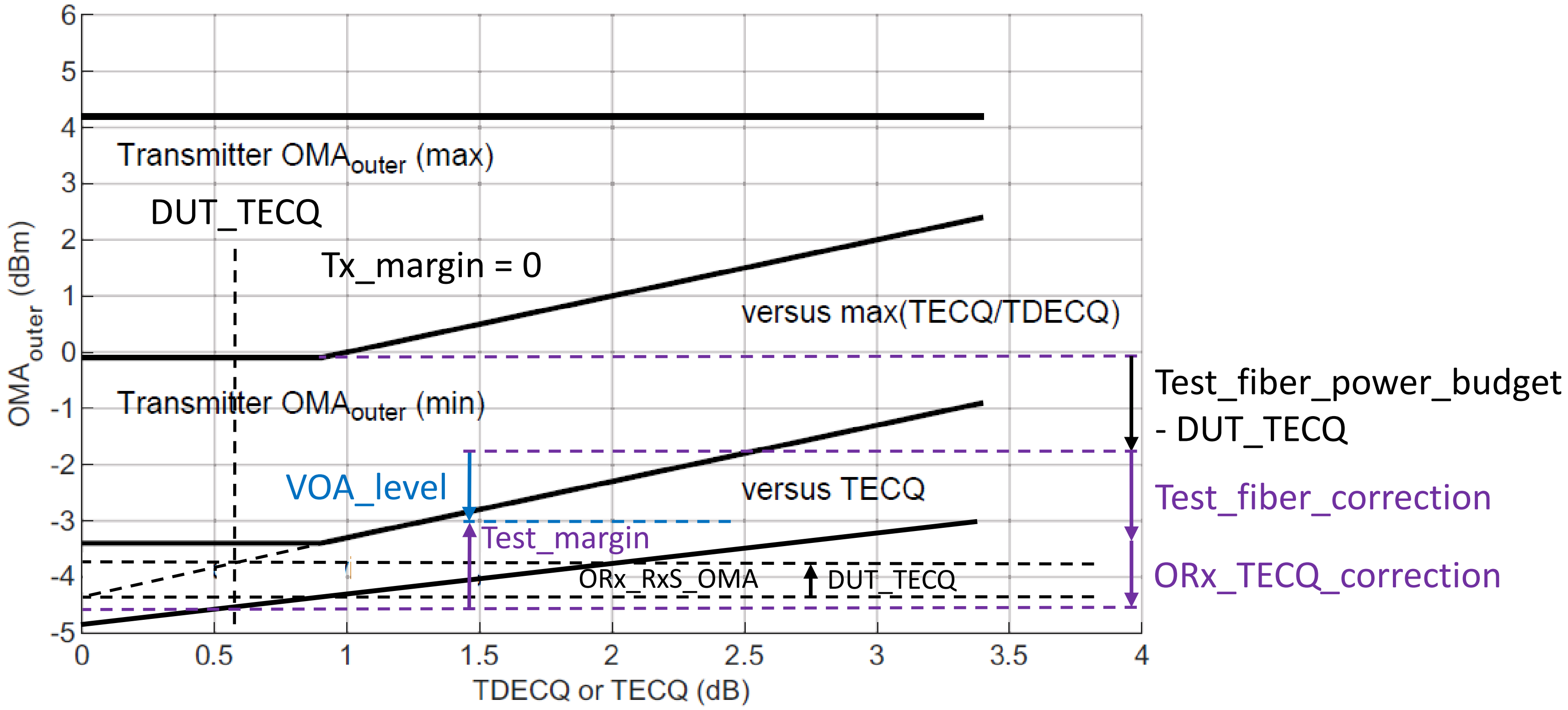


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

Outline

- Background
- Illustrations
- ➢ **Examples**
- Optional Penalties
- Calculations

Optical Receiver Characterization Definitions

- ORx ≡ Optical Receiver *(802.3dj receive characteristics compliant)*
- LRS ≡ Low-stressed Receiver Sensitivity
- LRS_Tx ≡ LRS conformance test signal transmitter
- LRS_TECQ ≡ LRS_Tx TECQ
- SRS ≡ Stressed Receiver Sensitivity
- SRS_Tx ≡ SRS conformance test signal transmitter
- SECQ ≡ SRS_Tx TECQ
- FnTx ≡ Functional transmitter with worst case impairments
- FnTx_TECQ ≡ Functional transmitter TECQ
- SRS_TECQ ≡ SECQ or FnTx_TECQ, depending on which Tx is used for worst case test signal
- ORx_RxS_OMA ≡ ORx_OMA RxS curve derived from zero TFSEH Mask Margin *(or pre-FEC Test_BER)* at LRS_TECQ and SRS_TECQ, using LRS_Tx and SRS_Tx/FnTx, respectively

LRS Background

- Receiver Sensitivity historically defined in 802.3 at two end points
  - Unstressed Receiver Sensitivity (URS) uses a near-perfect test transmitter with nearly zero signal degradation & URS_TECQ (informative)
  - Stressed Receiver Sensitivity (SRS) uses a worst-case test transmitter with noise, jitter, interferers and crosstalk for maximum signal degradation & SECQ (normative)
- Problem: use of URS as a normative spec despite test transmitter infeasibility
  - removed in 802.3cu
  - normative RxS limit curve specified as a function of TECQ
  - new second test point not defined *(implicitly assumed DUT_RxS vs. TECQ slope = 1)*
- Low-stressed Receiver Sensitivity (LRS) proposal
  - restores second Receiver Sensitivity test point (*no assumption on slope)*
  - defines best possible transmitter with minimal feasible signal degradation & LRS_TECQ

LRS Conformance Test Signal

The Low-stressed Receiver Sensitivity (LRS) conformance test signal at TP3 meets the transmit characteristics given in Table 180-7 except for characteristics in Table 180-18.

Table 180-18-LRS conformance test signal exceptions to transmit characteristics

Parameter	Value	Unit
TECQ (max)	1.8	dB
TECQ (min)	1.4	dB
Overshoot and undershoot (max)	10	%
Extinction ratio (max)	5.5	dB
Extinction ratio (min)	4.5	dB
Transition time (max)	6.5	ps
Transition time (min)	4.5	ps
Average launch power of each non test signal lane (max)	-15.0	dBm
ORL tolerance (max)	15.5	dB

Supporting data in Christian Reimer, et al., "Reference transmitter data in support of receiver sensitivity specification proposal"

Optical Receiver Characterization Illustration

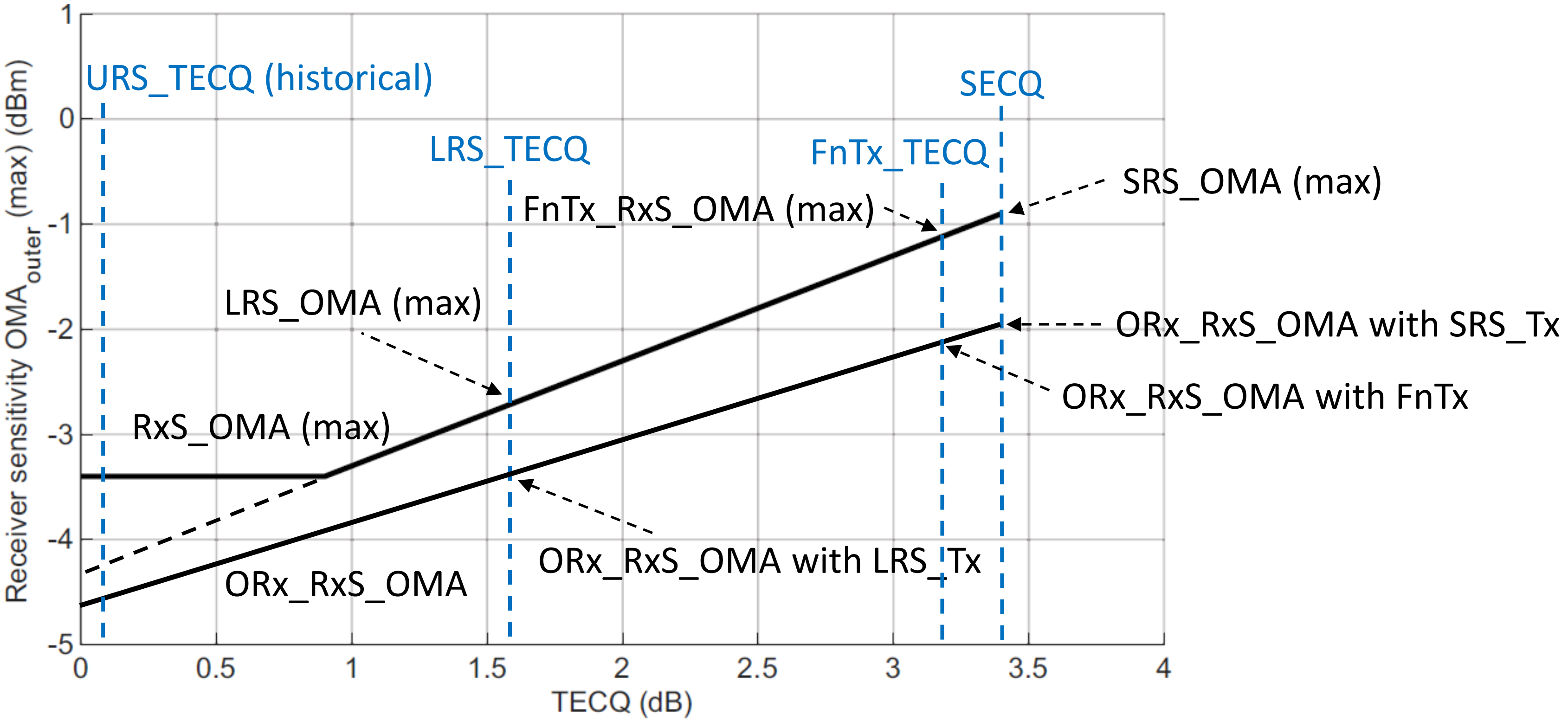
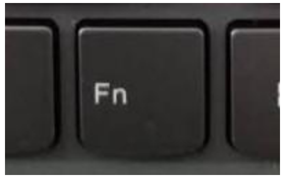


Figure 180–4—Receiver sensitivity (OMA_{outer}), each lane (max)

Transmitter Functional Test Definitions

- DUT_Tx ≡ Device under test transmitter
- DUT_Tx_OMA ≡ OMA of device under test transmitter
- VOA ≡ Variable Optical Attenuator
- VOA_level ≡ VOA attenuation
- ORx ≡ Optical Receiver
- ORx_OMA ≡ Optical Receiver input OMA
- FnRx ≡ Functional Receiver = VOA → ORx
- FnRx_OMA ≡ Functional Receiver input OMA
- ORx_OMA = FnRx_OMA - VOA_level



Transmitter Functional Symbol Error Histogram (TFSEH) Definition

The transmitter functional symbol error histogram mask for each lane is given in Table180–17 and is measured using the test pattern as given in Table180–14. Minimum measurement time is 60 seconds.

A probable failure is indicated by exceeding the transmitter functional symbol error histogram mask defined in Table180–17, or by one or more counts in test symbol errors k per test block with k > 8.

Table 180–17—Transmitter functional symbol error mask

Test symbol errors per test block, k	Probability $H_{max}(k)$
1	1.15×10^{-1}
2	7.47×10^{-3}
3	3.24×10^{-4}
4	1.05×10^{-5}
5	2.73×10^{-7}
6	5.88×10^{-9}
7	1.08×10^{-10}
8	1.75×10^{-12}

TFSEH Compliance Test

- DUT_Tx Set-up
  - Measure DUT_TECQ and DUT_TDECQ, w/ Patch Cord and Test Fiber, respectively
  - DUT_Tx_OMA = Tx_OMA_min_at_TECQ=0 + max(DUT_TECQ, DUT_TDECQ) + Tx_margin

    (TX_OMA_min_at_TECQ=0 is the extrapolation to zero TDECQ or TECQ of the Transmitter OMA_{outer} (min) versus TDECQ or TECQ curve specified above the knee)
- At DUT_TECQ *(zero CIL & zero penalties, Calculations Ex. 4 & 5)*
  - DUT_Tx → Patch Cord → (FnRx = VOA → ORx)
  - VOA_level = Test_fiber_correction + ORx_TECQ_correction - Test_margin

    = Tx_DUT_OMA (min spec) - ORx_RxS_OMA_at_DUT_TECQ - Test_margin
  - TFSEH $\leq$ Table 180-17 symbol error mask
- At DUT_TDECQ *(fraction α * CIL & full penalties, Calculations Ex. 2 & 3)*
  - DUT_Tx → Test Fiber → (FnRx = VOA → ORx)
  - VOA_level = (1 - α) CIL + ORx_TECQ_correction - Test_margin
  - TFSEH $\leq$ Table 180-17 TFSEH symbol error mask

Pre-FEC BER Waterfall Optional Compliance TFT

- Test conditions requiring Pre-FEC Test_BER < 2.28e-4 examples:
  - TFT Pre-FEC Test_BER = 2.4e-5 *(Test_margin = 1.5dB)*, or = 1e-6 *(Error floor screen)*
- ORx Characterization at Test_BER
  - RxS_OMA_max at_DUT_TECQ = RxS_OMA (max) spec at DUT_TECQ, at Test_BER
  - ORx_RxS_OMA_at_DUT_TECQ = ORx_OMA using DUT_Tx, at Test_BER
  - ORx_TECQ_correction = RxS_OMA_max at_DUT_TECQ - ORx_RxS_OMA_at_DUT_TECQ
- At DUT_TECQ *(zero CIL & zero penalties, no Test_margin)*
  - DUT_Tx → Patch Cord → (FnRx = VOA → ORx)
  - VOA_level = Tx_DUT_OMA (min spec) - ORx_RxS_OMA_at_DUT_TECQ
  - ORx Pre-FEC BER ≤ Test_BER
- At DUT_TDECQ *(fraction α * CIL & full penalties, no Test_margin)*
  - DUT_Tx → Test Fiber → (FnRx = VOA → ORx)
  - VOA_level = (1 - α) CIL + ORx_TECQ_correction
  - ORx Pre-FEC BER ≤ Test_BER

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TP & TDP Optional Functional Test Definitions

- ORx_LRS_OMA ≡ ORx_OMA at zero TFSEH Mask Margin (MM) *(or at pre-FEC Test_BER)* measured with LRS_Tx
- ORx_SRS_OMA ≡ ORx_OMA at zero TFSEH Mask Margin (MM) *(or at pre-FEC Test_BER)* measured with SRS_Tx or FnTx
- DUT_TP ≡ DUT Transmitter Penalty *(measured with Patch Cord)*
- DUT_TDP ≡ DUT Transmitter & Dispersion Penalty *(measured with Test Fiber)*

TP & TDP Optional Functional Test

- DUT_TP *(Calculations Ex. 4 & 5)*
  - DUT_Tx → Patch Cord → (FnRx = VOA → ORx)
  - ORx_RxS_OMA_with_DUT_Tx = ORx_OMA at zero TFSEH MM (*or at pre-FEC Test_BER*)
  - DUT_TP = LRS_TECQ + (SRS_TECQ - LRS_TECQ)
    * (ORx_RxS_OMA_with_DUT_Tx - ORx_LRS_OMA) / (ORx_SRS_OMA - ORx_LRS_OMA)
- DUT_TDP *(Calculations Ex. 2 & 3)*
  - DUT_Tx → Test Fiber → (FnRx = VOA → ORx)
  - ORx_RxS_OMA_with_DUT_Tx = ORx_OMA at zero TFSEH MM (*or at pre-FEC Test_BER*)
  - DUT_TDP = LRS_TECQ + (SRS_TECQ - LRS_TECQ)
    * (ORx_RxS_OMA_with_DUT_Tx - ORx_LRS_OMA) / (ORx_SRS_OMA - ORx_LRS_OMA)
- DUT_Tx_OMA = Tx_OMA_min_at_TECQ=0 + max(DUT_TP, DUT_TDP) + Tx_margin

(TX_OMA_min_at_TECQ=0 is the extrapolation to zero TDECQ or TECQ of the Transmitter OMA_{outer} (min) versus TDECQ or TECQ curve specified above the knee)

TP & TDP Optional Functional Test Illustration

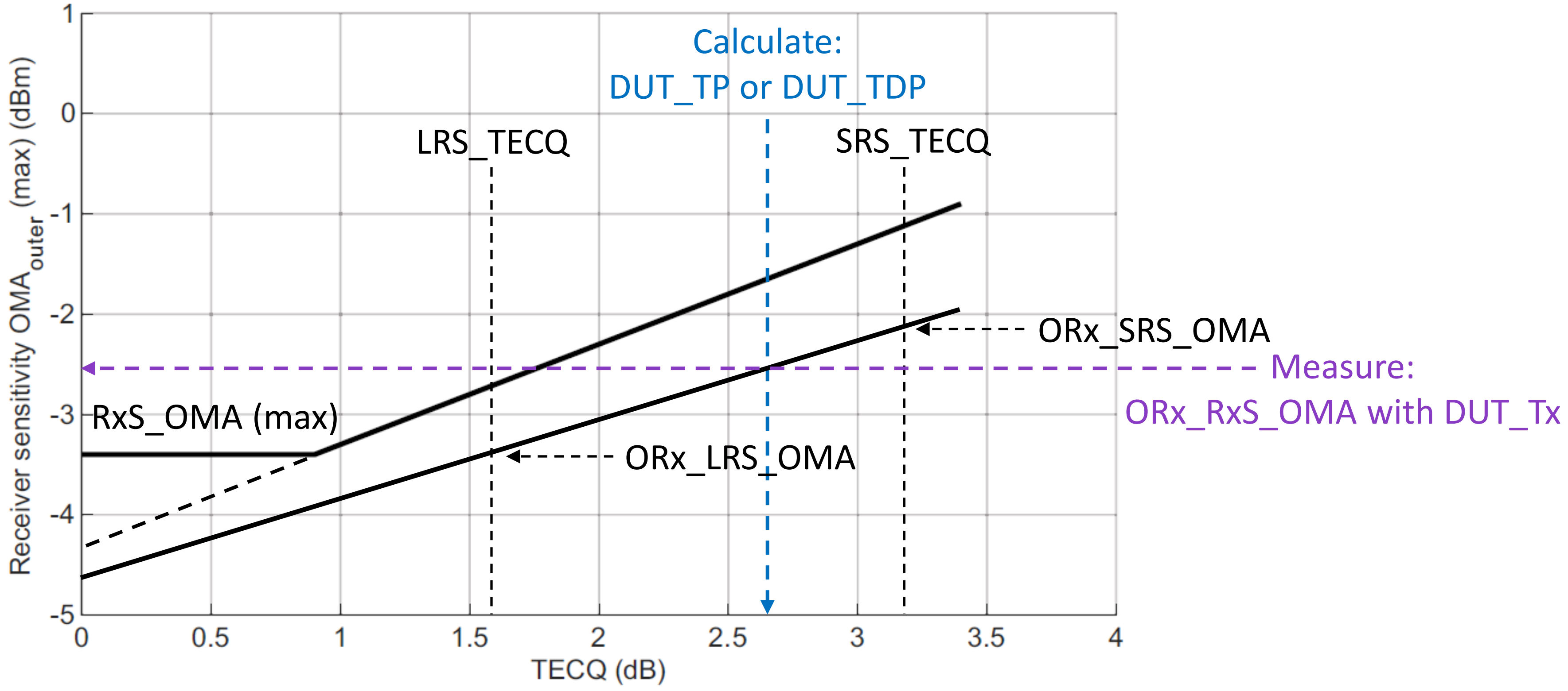

Figure 180–4—Receiver sensitivity (OMA_{outer}), each lane (max)

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LR4 Test Fiber & Patch Cord TFT Calculations

LR4	RxS_OMA(max) at TECQ=0:			-6.9		Channel_insertion_loss:			6.3	MPI+DGD_penalty_allocation:			1.1	ORx_RxS_OMA at TECQ=0:			-7.9
Ex.	**Tx DUT**	Tx (min)	0.5	Tx_margin	1.0	**Test Fiber**								**FnRx**		Test_margin	1.5
no.	actual TECQ	estimated TECQ /TP	estimated TDECQ /TDP	max (TECQ, TDECQ)	Tx _OMA dBm	actual loss	actual MPI+DGD	actual CD penalty	actual TDECQ	estimated loss	estimated MPI+DGD	estimated TDECQ	Test _fiber_ correction	ORx _TECQ_ correction	VOA _level	ORx_OMA / zero MM ORx_OMA dBm	TFSEH Mask _margin
1	2.0	2.0	3.5	3.5	5.0	6.3	1.1	1.5	3.5	6.3	1.1	3.5	0.0	1.0	-0.5	-0.8	0.0
	2.0	2.0	3.5	3.5	5.0	5.3	0.5	1.5	3.5	5.3	0.5	3.5	1.6	1.0	1.1	-1.4	0.0
2	2.0	2.0	2.5	2.5	4.0	5.3	0.5	1.5	3.5	5.3	0.5	2.5	1.6	1.0	1.1	-2.4	-1.0
	2.0	2.0	3.5	3.5	5.0	5.3	0.5	1.5	3.5	5.3	0.5	3.5	1.6	1.0	1.1	-1.4	0.0
3	2.0	2.0	5.5	5.5	7.0	5.3	0.5	1.5	3.5	5.3	0.5	5.5	1.6	1.0	1.1	0.6	2.0
	2.0	2.0	3.5	3.5	5.0	5.3	0.5	1.5	3.5	5.3	0.5	3.5	1.6	1.0	1.1	-1.4	0.0
4	2.0	1.5	3.5	3.5	5.0	0.0	0.0	0.0	2.0	0.0	0.0	1.5	9.4	1.0	8.9	-3.9	-0.5
	2.0	2.0	3.5	3.5	5.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0	8.9	1.0	8.4	-3.4	0.0
5	2.0	3.0	2.5	3.0	4.5	0.0	0.0	0.0	2.0	0.0	0.0	3.0	7.4	1.0	6.9	-2.4	1.0
	2.0	2.0	2.5	2.5	4.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0	7.9	1.0	7.4	-3.4	0.0

Mask_margin = (ORx_OMA = Tx_OMA - Test_SMF_actual_loss - VOA_level) - (ORx_RxS_OMA at TECQ=0 + Test_SMF_actual_MPI+DGD+TDECQ_penalties + Tx_margin + Test_margin)

TFT Examples & Illustrations

Thank you