TFT Illustrations & Examples

(SC: 180.9.8, 181.9.8, 182.9.8, 183.9.8)

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Outline

- ➢ Introduction
- Illustrations
- Examples
- Optional Tests
- Calculations

Transmitter Functional Test (TFT) Principle

- 802.3 single power-penalty optics spec methodology, capturing all impairments
  - Transmitter (Tx) optical power (Tx_OMA) is set proportional to Tx penalty
  - Receiver (Rx) sensitivity (RxS_OMA) is a function of Tx penalty, ideally proportional
  - Tx and Rx interoperate when Tx_OMA – RxS_OMA $\geq$ Tx power budget at Tx penalty
- HW golden receiver, HW GnRx, directly measuring BER is the best normative Tx test
  - Test set-up: Tx_DUT → Test_fiber → GnRx → GnRx_BER
  - Fully specified, including noise density, signal bandwidth, and jitter-tracking bandwidth
  - Progressively more difficult to implement as rates increase, until infeasible
  - Replaced by sampling-scope-based SW GnRx indirectly estimating BER from noise
- HW functional receiver, HW FnRx, in place of GnRx, using 802.3 optics spec methodology
  - Test set-up: Tx_DUT → Test_fiber → FnRx (VOA → Optical Rx (ORx)) → FnRx_BER
  - For any Tx_DUT, Test_fiber, GnRx and ORx, there is a unique VOA_level resulting in:

    FnRx_BER = GnRx_BER

(unique VOA_level maybe positive or negative)

Transmitter Functional Test (TFT) Summary

- BER spec is normative with other 802.3dj Tx characteristics (not standalone) including:
  - TECQ & TDECQ, OMA (min) & (max), ER (min), over & undershoot (max)
- Uses HW functional receiver, FnRx (VOA → ORx) instead of HW golden receiver, GnRx
  - Based on 802.3 single power-penalty optics spec methodology
  - Referenced to LRS & SRS conformance test signal transmitters characterized by TECQ
  - TECQ measured using sampling-scope-based SW GnRx
- Addresses TECQ & TDECQ corner case problems, ex. Tx Dispersion Penalty spec
- Does not use individual impairment spec methodology, ex. no separate jitter spec
- First proposal, 7/25, Patch cord only, followed by updates:
  - 9/25, Test fiber added
  - 9/25, equations reorganized w/ full supporters list
  - 1/26, equations reorganized
  - 3/26, 5/26, 7/26, variable names changed, functionally same as previous proposals

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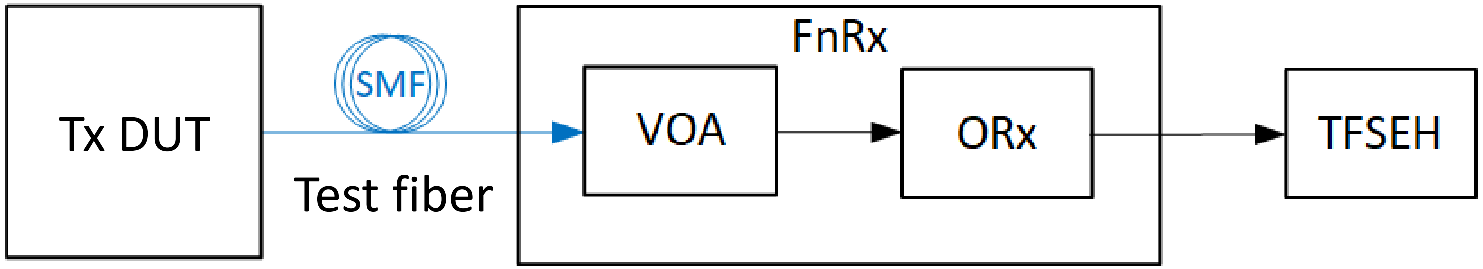
TFT Block Diagram & VOA_level Equation



Functional receiver (FnRx) is defined in SC 180.9.8.1 as a variable optical attenuator (VOA) followed by an optical receiver (ORx) that complies with the characteristics in Table 180–8.

VOA calibrates differences in test fibers and optical receivers, respectively, to reduce variability across different test conditions.

VOA_level = Test_fiber_correction + ORx_correction (180-15)

—Test_fiber_correction is the difference between the power budget used to determine the transmitter under test OMA_{outer} (min) and the best estimate of the Test fiber power budget.

—ORx_correction is the difference between receiver sensitivity (max) as given in Table 180-8, and best estimate of ORx receiver sensitivity at TFT operating BER, both at transmitter under test TECQ

Test_fiber_correction Equation

Test_fiber_correction = Tx_DUT_power_budget − Test_fiber_power_budget (180-16)

—Tx_DUT_power_budget is the transmitter under test power budget as specified in Table 180-9, except that the TDECQ value measured over the Test fiber is used instead of the max TDECQ value.

—Test_fiber_power_budget is the power budget of the Test fiber using the best estimates of the Test fiber Channel insertion loss (CIL), MPI and DGD penalties, and TDECQ of the DUT over the Test fiber.

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] (CIL_allocation)	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

- CIL ≡ Channel insertion loss (dB) of Test fiber $\geq$ 0
- Tx_DUT_power_budget = CIL_allocation + MPI_and_DGD_penalties_allocation + max(DUT_TECQ, Test_fiber_DUT_TDECQ)

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

- Test_fiber_power_budget = DUT_TECQ
- Test_fiber_correction = Tx_DUT_power_budget – DUT_TECQ

Ex2. Test fiber at fraction (α < 1) CIL & max penalties (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

Ex3. Test fiber at max CIL & max penalties

- Test_fiber_power_budget = Tx_DUT_power_budget
- Test_fiber_correction = 0

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

Test_fiber_correction Illustration

Test_fiber_correction = Tx_DUT_power_budget − Test_fiber_power_budget

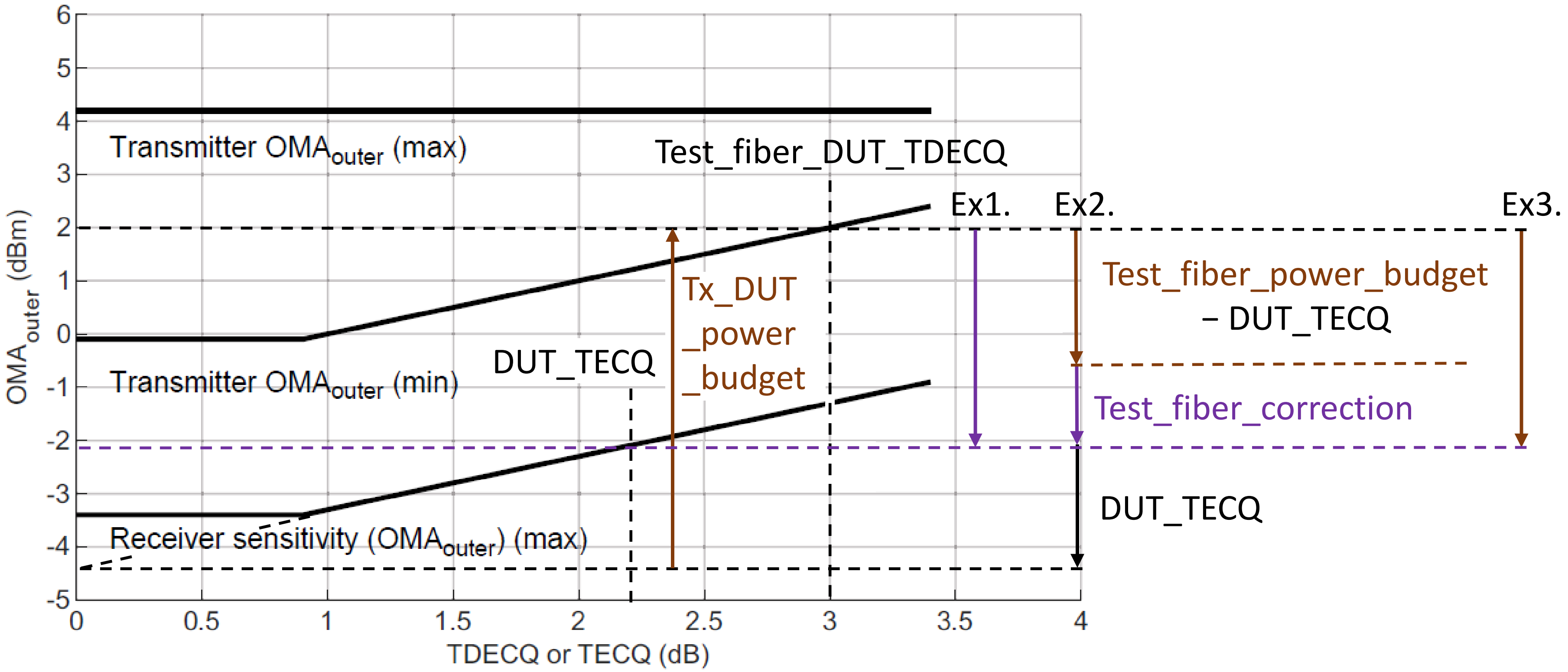


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

ORx_correction Equation

ORx_correction = RxS_OMA_max at_DUT_TECQ − ORx_RxS_OMA_at_DUT_TECQ − Test_margin (180-19)

—RxS_OMA_max_at_DUT_TECQ is the receiver sensitivity OMA_{outer} (max) spec 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

—Test_margin is the additional ORx_OMA to improve SNR of the transmitter functional test. It is equal to 1.5 dB. The ORx operating BER target assuming random errors is changed to 2.4×10^{-5}. The transmitter functional symbol error mask (see Table 180–17) is calculated using this BER target.

Test_margin Principle

- Model: Tx_DUT → Channel → ORx
  - SNR_M ≡ SNR of transmitter under test measurement
  - cil ≡ channel insertion loss (linear) of Channel ≥ 1
- SNR_M = (Tx_DUT_Signal / cil) / ((Tx_DUT_Noise / cil) + ORx_Noise)
  - SNR_M objective: SNR_M ≈ Tx_DUT_Signal / Tx_DUT_Noise → (Tx_DUT_Noise / cil) >> ORx_Noise
  - However, at receiver sensitivity: (Tx_DUT_Noise / cil) ~ ORx_Noise
  - test_margin ≡ offset gain (linear) ≥ 1, to counter cil term
- SNR_M = (Tx_DUT_Signal * test_margin / cil) / (Tx_DUT_Noise * test_margin / cil) + ORx_Noise)
- Transmitter only test operating BER must be decreased from full link (PMD to PMD) BER = 2.28×10^{-4}
- Experimental validation
- Example of common SNR_M improvement: after fiber eye measurement
  - Tx_DUT → Channel → Gain → DCA_Rx

ORx_correction Illustration

ORx_correction = ΔRxS − Test_margin

ΔRxS = RxS_OMA_max at_DUT_TECQ − ORx_RxS_OMA_at_DUT_TECQ

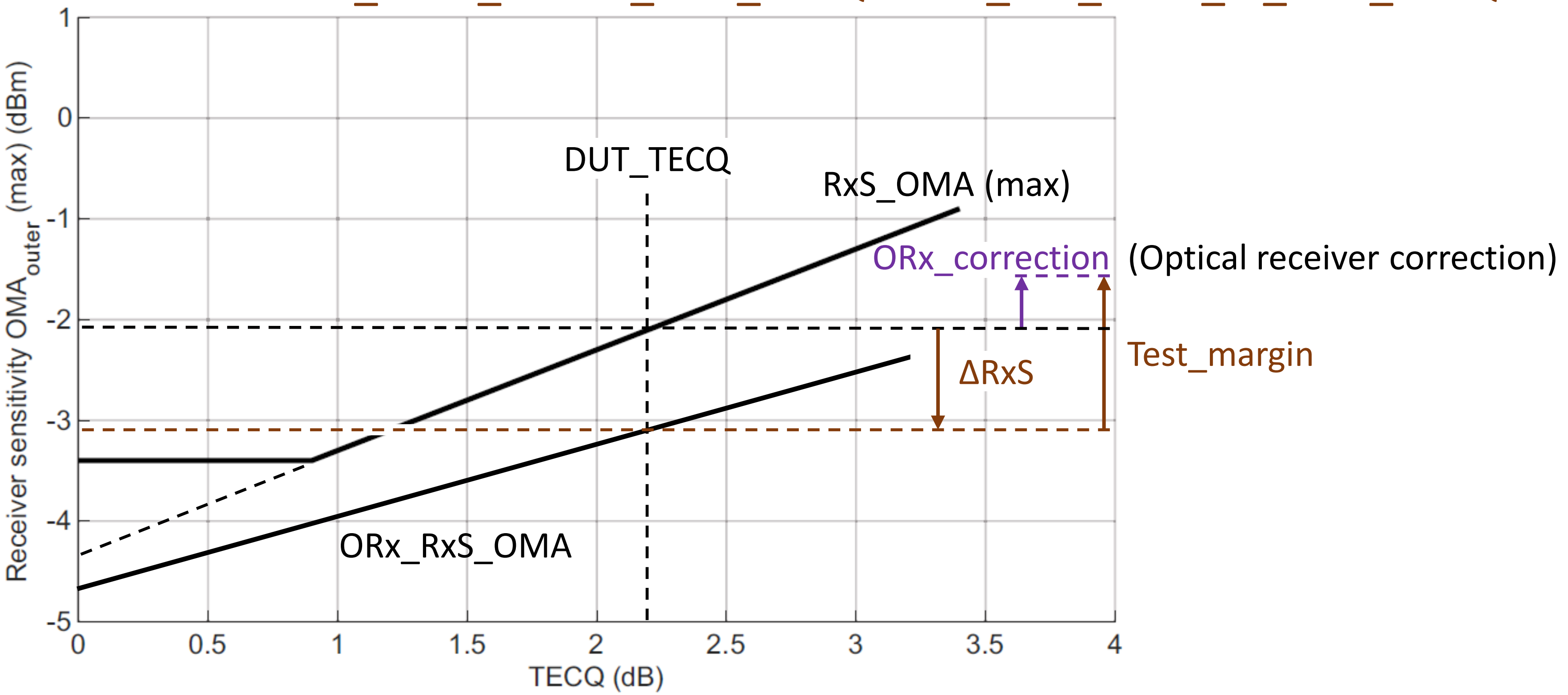


Figure 180–4—Receiver sensitivity (OMA_{outer}), each lane (max)

VOA_level Illustration

VOA_level = Test_fiber_correction + ORx_correction

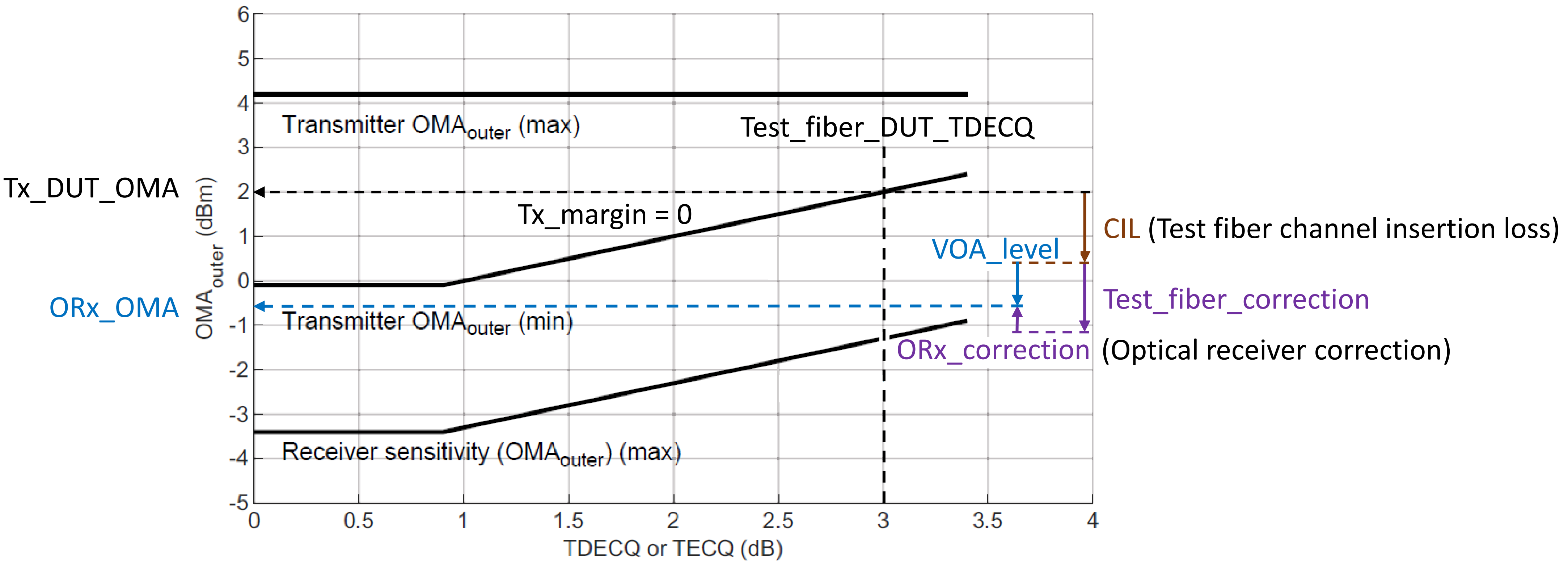


Figure 180–5—Transmitter OMA$_{outer}$ each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA$_{outer}$) each lane versus TECQ

VOA_level w/ Tx_margin Illustration

VOA_level = Test_fiber_correction + ORx_correction

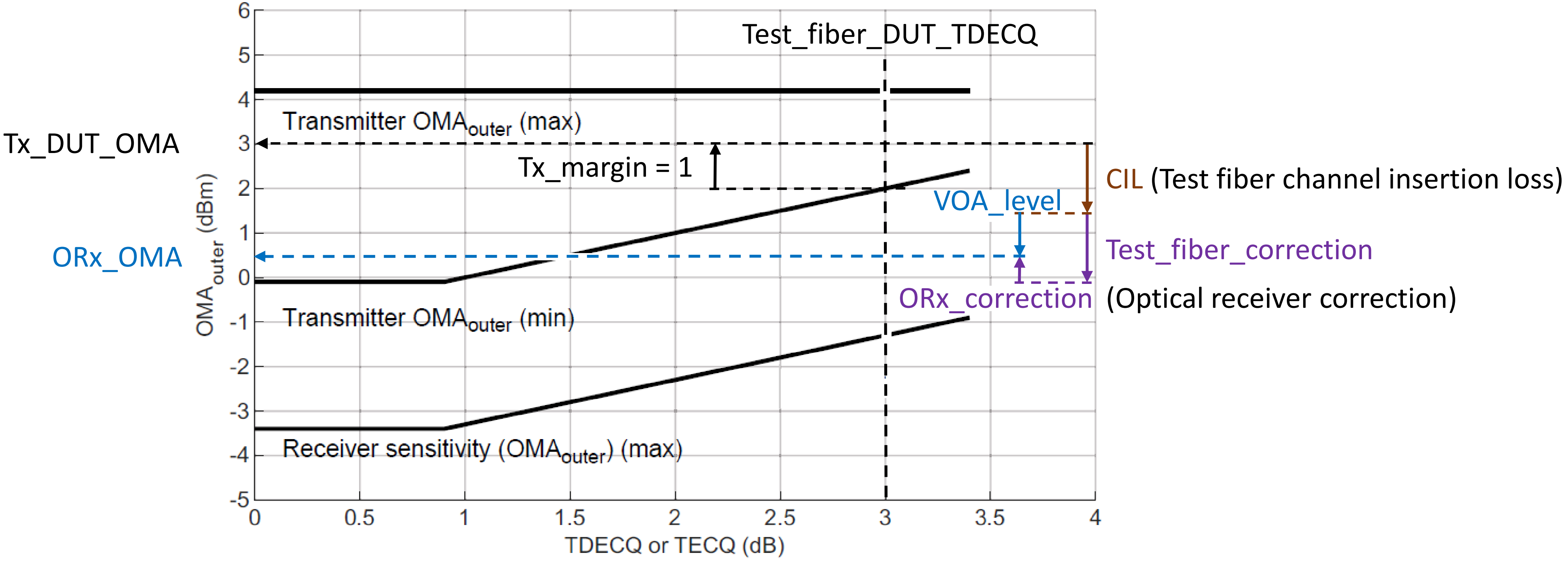


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

VOA_level Illustration w/ low TECQ

VOA_level = Test_fiber_correction + ORx_correction

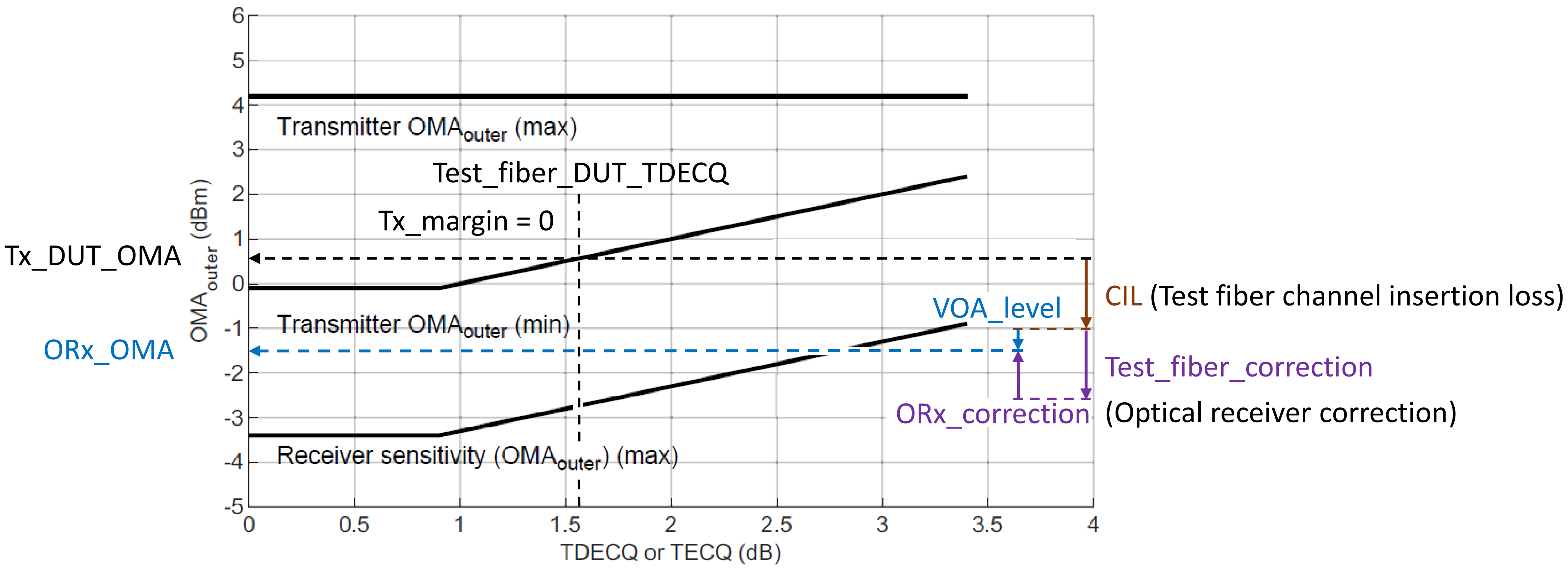


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

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Optical Receiver Characterization Background

- Receiver sensitivity historically defined in 802.3 at two end points
  - Unstressed receiver sensitivity (URS) using a near-perfect test transmitter with nearly zero signal degradation and URS_TECQ (informative)
  - Stressed receiver sensitivity (SRS) using a worst-case test transmitter with noise, jitter, interferers and crosstalk for maximum signal degradation and SECQ (normative)
- Problem: URS used as a normative spec despite infeasibility of near-perfect test transmitter
  - removed in 802.3cu
  - normative RxS_OMA (max) curve specified as a function of TECQ
  - new 2nd test point not defined *(implicitly assumed DUT_RxS_OMA vs. TECQ slope = 1)*
- Low-stressed receiver sensitivity (LRS) defined in SC 180.9.14
  - restores second receiver sensitivity test point *(no assumption on slope)*
  - defines best possible transmitter with minimal feasible signal degradation and LRS_TECQ

Optical Receiver Characterization Definitions

- LRS ≡ Low-stressed receiver sensitivity
- LRS_Tx ≡ LRS conformance test signal transmitter
- LRS_TECQ ≡ TECQ of LRS_Tx
- SRS ≡ Stressed receiver sensitivity
- SRS_Tx ≡ SRS conformance test signal transmitter
- SECQ ≡ TECQ of SRS_Tx
- FnTx ≡ Functional transmitter with worst case impairments
- FnTx_TECQ ≡ TECQ of functional transmitter
- SRS_TECQ ≡ SECQ or FnTx_TECQ, depending on which Tx is used for worst case test signal
- ORx_RxS_OMA ≡ ORx receiver sensitivity OMA curve at TFSEH zero Mask margin based on LRS_TECQ and SRS_TECQ measurements, using LRS_Tx and SRS_Tx or FnTx, respectively

LRS Conformance Test Signal Characteristics

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-Conformance test signal LRS transmit characteristics exceptions to Table 180-7

Parameter	Reference	Value	Unit
Average launch power of each non-test-signal lane (max)	-	−15	dBm
TECQ (max)	180.9.8	1.8	dB
TECQ (min)	180.9.8	1.4	dB
Overshoot and undershoot (max)	180.9.10	10	%
Extinction ratio (max)	180.9.12	5.5	dB
Extinction ratio (min)	180.9.12	4.5	dB
Transition time (max)	180.9.13	6.5	ps
Transition time (min)	180.9.13	4.5	ps
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

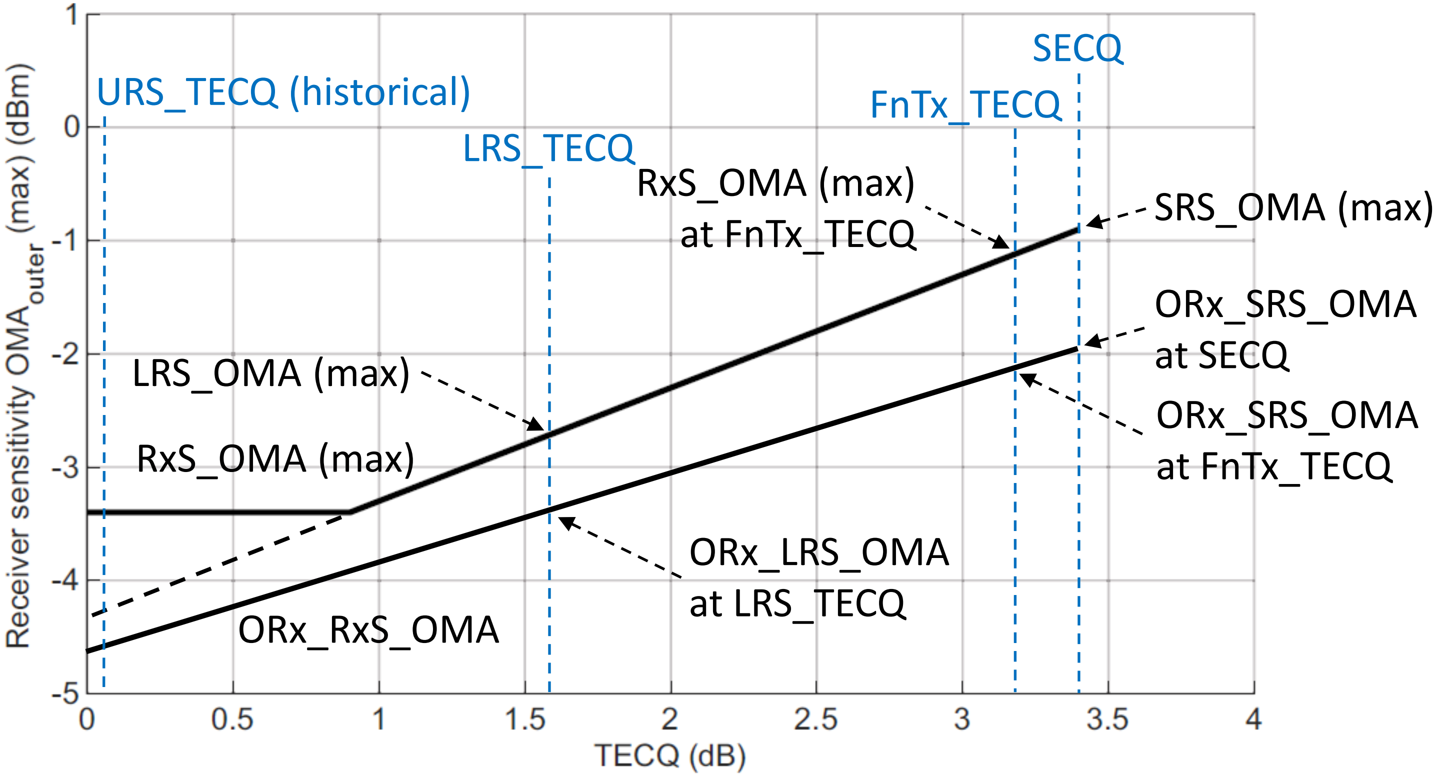

Figure 180–4—Receiver sensitivity (OMA$_{outer}$), each lane (max)

Transmitter Functional Test Definitions

- Tx_DUT ≡ Device under test transmitter
- Tx_DUT_OMA ≡ OMA of device under test transmitter
- FnRx_OMA ≡ OMA at functional receiver (FnRx) input
- VOA_level ≡ Attenuation of variable optical attenuator (VOA)
- ORx_OMA ≡ OMA of optical receiver (ORx)

  = FnRx_OMA − VOA_level
- Tx_DUT_ORx_OMA_at_ZMM ≡ ORx_OMA at TFSEH zero Mask margin (ZMM)

  measured using Tx_DUT

Transmitter Functional Symbol Error Histogram (TFSEH) Mask

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 Mask Compliance Test

- Tx_DUT_OMA setting
  - Measure DUT_TECQ and DUT_TDECQ, w/ Patch cord and Test fiber, respectively
  - Tx_DUT_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)

- DUT_TECQ *(zero CIL & zero penalties, see Calculations Ex. 4 & 5)*
  - Tx_DUT → Patch cord → FnRx (VOA → ORx)
  - VOA_level = Test_fiber_correction + ORx_correction

    = Tx_DUT_OMA (Tx_margin = 0) − Tx_DUT_ORx_OMA_at_ZMM − Test_margin
- DUT_TDECQ *(fraction α CIL & max penalties, see Calculations Ex. 2 & 3)*
  - Tx_DUT → Test fiber → FnRx (VOA → ORx)
  - VOA_level = (1 − α) CIL + ORx_correction
- ORx TFSEH < Table 180-17 TFSEH Mask

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Pre-FEC BER Waterfall Compliance TFT

- Pre-FEC Test_BER < 2.28e-4 test condition examples:
  - 2.4e-5 *(TFSEH Mask Compliance Test)*
  - 1e-6 *(Error floor screen)*
- ORx Characterization at Pre-FEC Test_BER *(no Test_margin)*
  - RxS_OMA_max at_DUT_TECQ ≡ RxS_OMA (max) spec at DUT_TECQ *(same as for TFSEH Test)*
  - Tx_DUT_ORx_OMA_at_Test_BER ≡ ORx_OMA at Test_BER measured using Tx_DUT
  - ORx_correction = RxS_OMA_max at_DUT_TECQ − Tx_DUT_ORx_OMA_at_Test_BER *(different)*
- DUT_TECQ *(zero CIL & zero penalties)*
  - Tx_DUT → Patch cord → FnRx (VOA → ORx)
  - VOA_level = Tx_DUT_OMA (Tx_margin = 0) − Tx_DUT_ORx_OMA_at_Test_BER
- DUT_TDECQ *(fraction α CIL & max penalties)*
  - Tx_DUT → Test fiber → FnRx (VOA → ORx)
  - VOA_level = (1 − α) CIL + ORx_correction
- ORx Pre-FEC BER < Test_BER

TP & TDP Functional Test Definitions

- ORx_LRS_OMA ≡ ORx_OMA at zero TFSEH Mask Margin *(or at pre-FEC Test_BER)*
  measured using LRS_Tx
- ORx_SRS_OMA ≡ ORx_OMA at zero TFSEH Mask Margin *(or at pre-FEC Test_BER)*
  measured using SRS_Tx or FnTx
- DUT_TP ≡ DUT Transmitter Penalty
  measured using Patch cord
- DUT_TDP ≡ DUT Transmitter & Dispersion Penalty
  measured using Test fiber
- Tx_DUT_ORx_OMA ≡ ORx_OMA at TFSEH zero Mask margin *(or at pre-FEC Test_BER)*
  measured using Tx_DUT

TP & TDP Functional Test

- DUT_TP or DUT_TDP *(see Calculations Ex. 4 & 5 or 2 & 3, respectively)*
  - Tx_DUT → Patch cord or Test fiber → FnRx (VOA → ORx)
  - DUT_TP or DUT_TDP = LRS_TECQ + (SRS_TECQ − LRS_TECQ)

    * (Tx_DUT_ORx_OMA − ORx_LRS_OMA)

    / (ORx_SRS_OMA − ORx_LRS_OMA)
- Tx_DUT_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 Functional Test Illustration

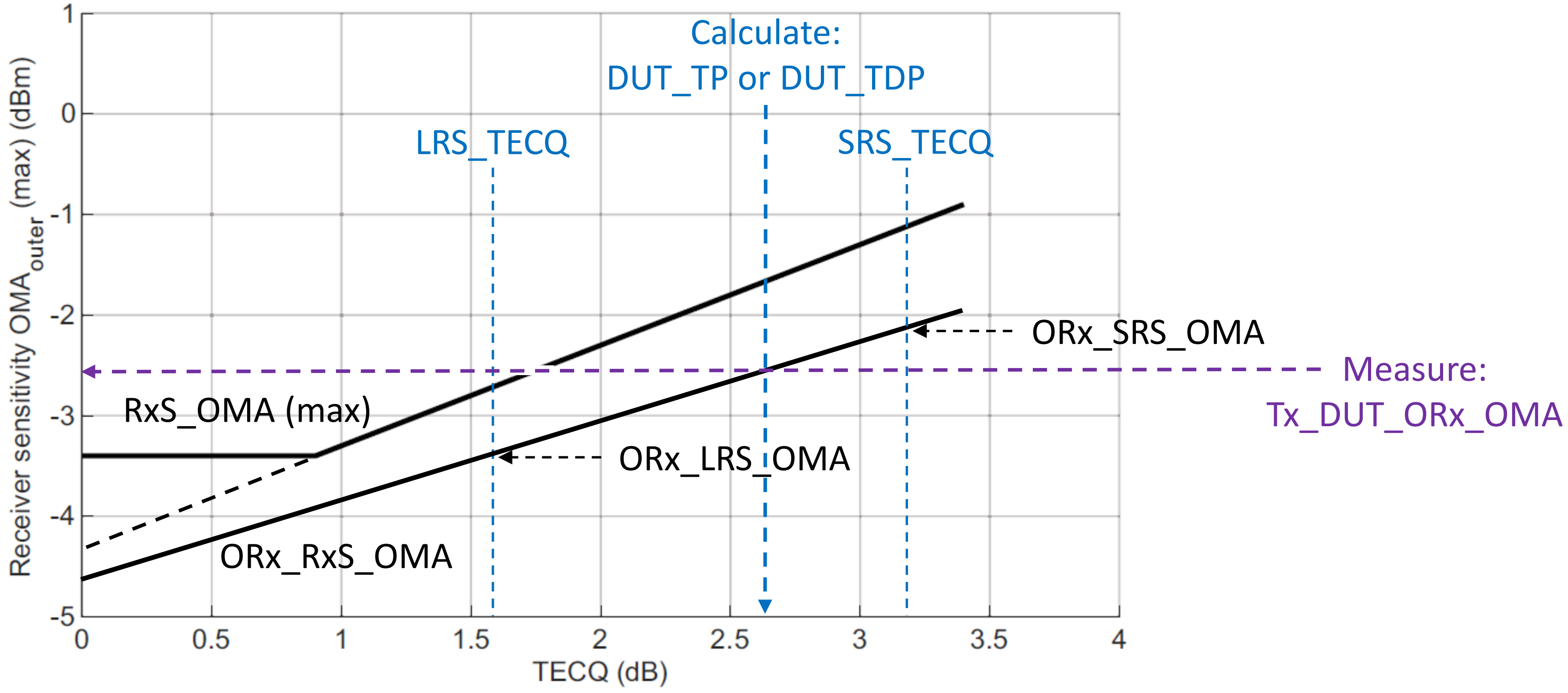

Figure 180–4—Receiver sensitivity (OMA$_{outer}$), each lane (max)

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LR4 Test Fiber & Patch Cord TFT Calculations

LR4	RxS_OMA(max) at TECQ=0:	−6.9				CIL_allocation:	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	estimated		max (TECQ, TDECQ)	Tx_OMA	actual				estimated			Test_ fiber_ correction	ORx_ correction	VOA _level	ORx_OMA	TFSEH Mask _margin
	TECQ	TECQ /TP	TDECQ /TDP		dBm	CIL	MPI+DGD	CD penalty	TDECQ	CIL	MPI+DGD	TDECQ				dBm	
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	−0.5	−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	−0.5	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	−0.5	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	−0.5	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	−0.5	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	−0.5	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	−0.5	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	−0.5	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	−0.5	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	−0.5	7.4	−3.4	0.0

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

TFT Illustrations & Examples

Thank you