Transmitter Functional Symbol Error Mask Test Proposal

(formerly Optical Tx Specification Proposal

Functional Receiver & FEC Code Word Mask)

IEEE P802.3dj Task Force

Plenary Meeting

July 31, 2025

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Comment 392

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Outline

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Introduction

- 100G/lane optics with compliant TDECQ have interoperability issues in deployment
- 200G/lane optics have poor if any TDECQ correlation to link performance
- Optimizing for link performance often increases TDECQ
- Some optimum link settings result in TDECQ exceeding compliance limits
- Relying only on TDECQ for interoperable Tx deployment is like a chef serving dishes without ever tasting them.

- End users require their own HW Rx / FEC code masks to qualify 200G/lane optical Tx
- Optical module vendors must test with varied HW Rx / FEC code word masks
- This proposal specifies HW Rx / FEC code masks to standardize functional Tx testing
- All cooking shows have the same mantra: taste, taste, taste.

Introduction: Jonathan King Observations

- Jonathan King invented TDECQ during 802.3bs: example contribution
  - https://www.ieee802.org/3/bs/public/15_09/king_3bs_01_0915.pdf
  - Relevant quote from above, cited by Ali Ghiasi on the reflector:

    “Tx quality metric should include Ref Rx and Ref EQ
    - most repeatable in software
    - hardware Rx and Eq capture long pattern effects and allows a 'real' BER test.”
- TDECQ was never intended to be the only Tx compliance test
  - It was supposed to be complemented by a functional test
- Unfortunately, during 802.3bs there was almost no hardware available to define and validate a functional receiver
- Recently, production grade hardware, including multiple DSPs, has become available

Transmitter Functional Symbol Error Mask Test

- The transmitter functional symbol error mask test is a transmitter test which supplements the existing transmitter tests. No existing tests are removed.
- The transmitter functional symbol error mask test is designed to identify transmitter problems that are not screened by existing tests.
- This is a transmitter test, not a link test.
    - The BER used to calculate the symbol error mask is specific to this test and does not constitute a link requirement.
- The test normalizes differences in sensitivity and equalizer performance of the optical receivers used in this test. This is to ensure consistency of the measurement between different test setups.
    - The intention is that pass/fail results are consistent regardless of the hardware used for the functional receiver.

Test Methodology Steps: Functional Receiver

1. Attenuate the optical receiver input by the difference between measured sensitivity and the IEEE spec @ Tx DUT TECQ. This normalizes out performance differences in the optical receiver for the test:
   - sensitivity
   - equalization
2. Attenuate the optical receiver input by the PMD's worst case channel penalties
   - dispersion estimate from Tx DUT TDECQ
   - channel loss
   - MPI, DGD
3. Reduce the attenuation by Tx_test_margin = 1.5dB per rodes_3dj_01b_2507
   - Reduces the variability and increases the consistency of the test by moving away from the noise limit
4. This becomes a "functional receiver" for transmitter functional symbol error mask test

Test Methodology Steps: Transmitter

4. Connect the transmitter under test to the functional receiver
5. Measure symbol error statistics and compare to transmitter functional error mask
   - Extrapolation can be utilized to limit test time

Transmitter Functional Error Mask

S_{01}	S_{02}	S_{03}	S_{04}	S_{05}	S_{06}	S_{07}	S_{08}
1.15E-01	7.47E-03	3.24E-04	1.05E-05	2.73E-07	5.88E-09	1.08E-10	1.75E-12

S_{09}	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
2.50E-14	3.21E-16	3.74E-18	3.98E-20	3.91E-22	3.56E-24	3.02E-26	2.40E-28

- Calculated based on Annex 174A.8.1.5 with BER = 2.40E-05
- Code bin (S_n) limits are the maximum probability of having exactly n symbol errors in a single codeword
- Extrapolation permitted (see test time presentation, "he_m_3dj_01c_2507")
- These values may be revised in future drafts after further testing and validation of the methodology

Functional Receiver: Definition

- The functional receiver (FRx) is defined to be a fully compliant receiver to 802.3dj
- The functional receiver is an optical receiver that meets the requirements of Table 180-9, 181-6, 182-8 or 183-7 with a variable optical attenuator (VOA) placed before the input which is set to achieve FRx OMA as defined in Equation on next slide.
    - This normalizes the differences in sensitivities between the optical receivers used in this test

Functional Receiver: OMA Input Definition

- FRx_OMA is the Tx test functional receiver (FRx) input operating point OMA in dB:
  - *FRx_OMA = Tx_DUT_OMA - max(TDECQ - TECQ, 0) - RxS_TECQ_correction*
    - Channel_Insertion_Loss - MPI_DGD_penalty_alloc + Tx_test_margin
  - *Tx_DUT_OMA complies with Table 180-7, 181-5, 182-7 or 183-6*
  - *RxS_TECQ_correction is for* FRx RxS deviation from RxS OMA (max) at TECQ of TX DUT specified in Figure 180-4, 181-4, 182-4 or 183-4:
    - *RxS_TECQ_correction = RxS_OMA(max)_spec - FRx_RxS (@ Tx DUT TECQ)*
  - *Tx_test_margin* increases *FRx_OMA* away from noise limit
    - *Tx_test_margin = 1.5dB*
- Transmitter performance relative to the symbol error mask is measured at a margin (Tx_test_margin) above the functional receiver's RxS

Transmitter Functional Symbol Error Mask Proposed Wording

- Following slides are the proposed wording to be adopted into Clauses 180, 181, 182, 183.
- Only Clause 180 version is shown
- With Editorial license

Table 180–7—200GBASE-DR1, 400GBASE-DR2, 800GBASE-DR4, and 1.6TBASE-DR8 transmit characteristics

Description	200GBASE-DR1	400GBASE-DR2 800GBASE-DR4 1.6TBASE-DR8	Unit
Signaling rate, each lane (range)	106.25 ± 50 ppm		GBd
Modulation format	PAM4		—
Lane wavelength (range)	1304.5 to 1317.5		nm
Side-mode suppression ratio (SMSR), each lane (min)	30		dB
Average launch power, each lane (max)	4		dBm
Average launch power, each lane[a] (min)	–3.3[b]		dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	4.2		dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min) for max(TECQ, TDECQ) < 0.9 dB for 0.9 dB ≤ max(TECQ, TDECQ) ≤ 3.4 dB	 –0.3 –1.2 + max(TECQ, TDECQ)		 dBm dBm
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	3.4		dB
Transmitter eye closure for PAM4 (TECQ), each lane (max)	3.4		dB
|TDECQ – TECQ|, each lane (max)	2.5		dB
Transmitter functional symbol error mask	See Table 180–8		
Transmitter overshoot and undershoot, each lane (max)	22		%
Transmitter power excursion, each lane (max)	2.3		dBm
Extinction ratio, each lane (min)	3.5		dB

Table 180–8—Transmitter functional error mask

Functional receiver symbol errors per test block (see 174A.8.1.2)	Probability (max)
S_{01}	1.15×10^{-1}
S_{02}	7.47×10^{-3}
S_{03}	3.24×10^{-4}
S_{04}	1.05×10^{-5}
S_{05}	2.73×10^{-7}
S_{06}	5.88×10^{-9}
S_{07}	1.08×10^{-10}
S_{08}	1.75×10^{-12}
S_{09}	2.5×10^{-14}
S_{10}	3.21×10^{-16}
S_{11}	3.74×10^{-18}
S_{12}	3.98×10^{-20}
S_{13}	3.91×10^{-22}

Functional receiver symbol errors per FEC code word	Probability (max)
S_{14}	3.56×10^{-24}
S_{15}	3.02×10^{-26}
S_{16}	2.4×10^{-28}

All new

Table 180–15—Mapping of parameters to test patterns and related subclauses

Parameter	Pattern	Related subclause
Wavelength	Square wave, 3, 4, 5, 6 or 7	180.9.2
Side mode suppression ratio	3, 5, 6 or 7	180.9.2
Average optical power	3, 5, 6 or 7	180.9.3
Outer Optical Modulation Amplitude (OMA_{outer})	4 or 6	180.9.4
Transmitter and dispersion eye closure for PAM4 (TDECQ)	6	180.9.5
Transmitter functional symbol error mask	3	180.9.6
Transmitter eye closure for PAM4 (TECQ)	6	180.9.7
Transmitter overshoot and undershoot	6	180.9.8
Transmitter power excursion	6	180.9.9
Extinction ratio	4 or 6	180.9.10
Transmitter transition time	Square wave or 6	180.9.11
$RIN_{xx}OMA$	4 or 6	180.9.12
Receiver sensitivity	3 or 5	180.9.13
Stressed receiver conformance test signal calibration	6	180.9.14
Stressed receiver sensitivity	3 or 5	180.9.14

All new

180.9.6 Transmitter functional symbol error mask

The transmitter functional symbol error histogram shall be below the limits given in Table 180–9 if measured using the method defined in 180.9.6.1. The transmitter functional symbol error histogram is measured using the test pattern defined in Table 180–15.

180.9.6.1 Functional receiver (FRx) definition

The functional receiver is an optical receiver that meets the requirements of Table 180–9 with a variable optical attenuator (VOA) placed before the input which is set to achieve functional receiver (FRx) OMA as defined in Equation (180–1).

$$\text{FRx OMA} = \text{Tx DUT OMA} - \max(\text{TDECQ} - \text{TECQ}, 0) - \text{RxS TECQ correction} - \text{channel insertion loss} - \text{MPI DGD penalty allocation} + \text{Tx test margin} \quad (180\text{–}1)$$

where:

— Tx DUT OMA is the outer optical modulation amplitude (OMAouter) of the transmitter under test,

— RxS TECQ correction is the deviation between the optical receiver sensitivity and the minimally compliant receiver sensitivity specified in Figure 180–4, at TECQ of the transmitter under test,

— Channel insertion loss is as given in Table 180–10,

— MPI DGD penalty allocation is as given in Table 180–10,

— Tx test margin = 1.5dB,

All new

$$\text{RxS TECQ}_{\text{correction}} = \text{RxS OMA(max) spec} - \text{FRx RxS} \qquad (180\text{–}2)$$

where:

— RxS OMA(max) is the receiver sensitivity (OMAouter), each lane (max) is as given in Table 180–9,

— FRx RxS is the receiver sensitivity (OMAouter), each lane for the optical receiver used in the functional receiver,

180.9.6.2 Test symbol error measurement

The test symbols errors are measured using the method described in 174A.8.1.3.

Appendix: Transmitter Functional Test Scenarios

DRn Case		0	1				2				3				4				5				6			
Tx DUT characte-ristics	Tx OMA (min) margin	0.0	0				1				-1				0				0				0			
	TECQ	1.5	1.5				1.5				1.5				1.5				3.5				1.5			
	Dispersion (D)	1.0	1				1				1				-1				1.5				3.5			
FRx characte-ristics	Equalizer	Std	Std	Std	Plus	Plus	Std	Std	Plus	Plus	Std	Std	Plus	Plus	Std	Std	Plus	Plus	Std	Std	Plus	Plus	Std	Std	Plus	Plus
	RxS	Min	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus	Min	Plus
Tx	Tx Spec OMA (min)	1.3	1.3				1.3				1.3				0.3				3.8				3.8			
	Tx Spec equation @ TECQ =0	-1.2	-1.2				-1.2				-1.2				-1.2				-1.2				-1.2			
	Tx DUT TECQ	1.5	1.5				1.5				1.5				1.5				3.5				1.5			
	Tx DUT TDECQ	2.5	2.5				2.5				2.5				0.5				5.0				5.0			
	Tx DUT OMA	1.3	1.3				2.3				0.3				0.3				3.8				3.8			
Channel	Channel Insertion Loss	3.0	3.0				3.0				3.0				3.0				3.0				3.0			
	MPI DGD Penalty Allocation	0.1	0.1				0.1				0.1				0.1				0.1				0.1			
Rx	RxS Spec (max)	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-0.8	-0.8	-0.8	-0.8	-2.8	-2.8	-2.8	-2.8
	RxS Spec equation @ TECQ =0	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3
	FRx RxS @ TECQ = 0	-4.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3	-4.3	-5.3
	FRx RxS vs. TECQ slope	1.0	1.0	1.0	0.5	0.5	1.0	1.0	0.5	0.5	1.0	1.0	0.5	0.5	1.0	1.0	0.5	0.5	1.0	1.0	0.5	0.5	1.0	1.0	0.5	0.5
	FRx RxS @ Tx DUT TECQ	-2.8	-2.8	-3.8	-3.6	-4.6	-2.8	-3.8	-3.6	-4.6	-2.8	-3.8	-3.6	-4.6	-2.8	-3.8	-3.6	-4.6	-0.8	-1.8	-2.6	-3.6	-2.8	-3.8	-3.6	-4.6
FRx FEC	Test margin	0.0	1.5				1.5				1.5				1.5				1.5				1.5			
FRx OMA	FRx Test OMA (min)	-2.8	-1.3	-2.3	-2.1	-3.1	-1.3	-2.3	-2.1	-3.1	-1.3	-2.3	-2.1	-3.1	-1.3	-2.3	-2.1	-3.1	0.7	-0.3	-1.1	-2.1	-1.3	-2.3	-2.1	-3.1
	FRX Test OMA	-2.8	-1.3	-2.3	-2.1	-3.1	-0.3	-1.3	-1.1	-2.1	-2.3	-3.3	-3.1	-4.1	-1.3	-2.3	-2.1	-3.1	0.7	-0.3	-1.1	-2.1	-1.3	-2.3	-2.1	-3.1
Test pass/fail criteria correct		Yes	Yes				Yes				Yes				Yes				No				No			

Transmitter Functional Symbol Error Mask Test Proposal

Thank you