



Requirements for the Competence of Laboratories Testing Multi-Gigabit Optical Automotive Ethernet

Equipment and Procedure Specifications for
OMEGA Testing

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CHAIR AND VICE CHAIR

CHAIR	NAME	ORGANIZATION
OPEN Alliance TC7 Chair	Naoshi Serizawa	Yazaki Corporation
OPEN Alliance TC7 Vice Chair	Luis Manuel Torres	Knowledge Development S.L.

EDITOR

NAME	ORGANIZATION
Atsushi Kanno	Nagoya Institute of Technology

CONTRIBUTORS

NAME	ORGANIZATION
Gustavo Aguayo	Molex
Christoph Arndt	Continental
Daniel Bergemann	LEONI
Matthias Bude	Amphenol
Jae-Yong Chang	Keysight Technologies
Shruti Deore	Foxxconn

P. E. Ramesh	Tektronix
Gangolf Feiter	Concepts & Services Consulting
Alexander Felgenhauer	Yazaki Europe
German Feyh	Broadcom
Cliff Fung	Marvell
Ahmed Gharba	Volvo Cars
Darko Hlusicka	Yazaki Europe
Edward Jin	Molex
Manabu Kagami	Nagoya Institute of Technology
Keisuke Kawahara	Furukawa Electric Co., Ltd.
Hiroyuki Kodama	Sumitomo Electric Industries, Ltd
Sawan Kumar	Volvo Cars
Akshaya L K	Volvo Cars
Angela Lembart	Corning
Matthias Mahlich	Bosch
Luis Manuel Torres	KD
Darko Marinac	Yazaki Europe
Kjersti Martino	Inneos LLC
Yoshihiro Niihara	Fujikura Ltd.
Vimalli Raman	Yazaki System Technology GmbH
Michael Reinhard	SEI Automotive Europe GmbH
Masato Shiino	Furukawa Electric Co., Ltd.
Anbu Sowirajan	Marvell
Thomas Steuber	Teledyne LeCroy
Hideyuki Suzuki	Keysight Technologies
Shingo Uda	Murata Manufacturing Co., Ltd.
Ivan Vukosav	Yazaki Europe
Hayato Yuki	Sumitomo Electric Industries, Ltd
John Yurtin	Aptiv

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4 ABBREVIATION/SYMBOLS

AOP	Average optical power
BER	Bit error rate
E/O	Electrical-to-optical
ECU	Electronic control unit
ER	Extinction ratio
FFE	Feed forward equalizer
FOT	Fiber-optic transceiver
MDI	Medium-dependent interface
O/E	Optical-to-electrical
OMA	Optical modulation amplitude
PMA	Physical media attachment sublayer
PMD	Physical medium dependent sublayer
RIN	Relative intensity noise
RMS	Root-mean square
TDFOM	Transmitter distortion figure of merit
STDFOM	Stressed transmitter distortion figure of merit

5 TERMS AND DEFINITIONS

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

1. ISO Online browsing platform: available at <https://www.iso.org/obp>
2. IEC Electropedia: available at <http://www.electropedia.org/>

6 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- [1] ISO/IEC 17025:2017, “General requirements for the competence of testing and calibration laboratories, Third edition,” ISO/IEC, Geneva, November 2017.
- [2] IEEE Std 802.3cz:2023, “IEEE Standard for Ethernet Amendment 7: Physical Layer Specifications and Management Parameters for Multi-Gigabit Glass Optical Fiber Automotive Ethernet”, IEEE, USA, April 2023.
- [3] ISO 16750-3:2023, “Road vehicles — Environmental conditions and testing for electrical and electronic equipment Part 3: Mechanical loads,” ISO/IEC, Geneva, July 2023.
- [4] ISO 24581:2024, “Road vehicles — General requirements and test methods of in-vehicle optical harnesses for up to 100Gbit/s communication,” ISO/IEC, Geneva, September 2024.

7 INTRODUCTION

This document defines requirements for test houses and laboratories testing developed and fabricated devices to be complied with multi-gigabit automotive Ethernet standards. Test equipment and facilities are specified with example evaluation procedures. Minimum specification including functional specifications are also defined in the documents.

7.1 Relationship to ISO/IEC 17025:2017 [1]

The ISO/IEC 17025:2017 [1] provides the general description for test houses and laboratories, including the maintenance, calibration, reporting, and providing certificates for compliance. The standard provides no specific information and description to configure test houses and laboratories for evaluation of the devices developed and fabricated for multi-gigabit automotive Ethernet. This document follows the general description of the ISO/IEC 17025:2017 and additional and specific information for testing the devices for multi-gigabit automotive Ethernet.

7.2 Relationship to IEEE 802.3cz [2]

The IEEE 802.3cz specification [2] does not define the required equipment to evaluate the specifications for standardized transceiver systems. To evaluate the compliance of developed and fabricated devices to the IEEE standards, the minimum specification and specific evaluation procedures shall be specified. This document provides the information to configure test houses and laboratories for multi-gigabit optical automotive Ethernet.

7.3 Relationship to ISO 16750-3:2023 [3]

ISO 16750-3:2023 [3] defines mechanical load specification for road vehicle equipment. In this specification, no optical signal quality specification is defined. To organize the test house and laboratories, this document provides the minimum specification for optical signal quality test under mechanical loads to optical harnesses for multi-gigabit optical automotive Ethernet.

7.4 Relationship to ISO 24581:2024 [4]

ISO 24581:2024 [4] defines optical harness specification for road vehicles with a communication speed up to 100 Gbps. In the specification, no equipment specification is defined. To organize the test house and laboratories, this document provides the minimum specification for the equipment and specified procedures for multi-gigabit optical automotive Ethernet.

8 SCOPE

The following are the objectives of the requirements for the competence of laboratories testing multi-gigabit optical automotive Ethernet:

1. provide the test equipment information,
2. provide the evaluation procedure in specific test, and
3. report and certificate the results of evaluation.

9 GENERAL ENVIRONMENTAL CONFIGURATION

Facility and environmental conditions for test houses and laboratories shall follow the ISO/IEC 17025:2017. The other specifications that this document does not specify shall follow the ISO/IEC standard if needed.

10 TEST PROCEDURE EXAMPLE

10.1 Test point definitions

Test points evaluated for the multi-gigabit optical automotive Ethernet are shown in Figure 1, which is followed by Clause 166.6.2 and figure 166-36 in IEEE 802.3cz [2].

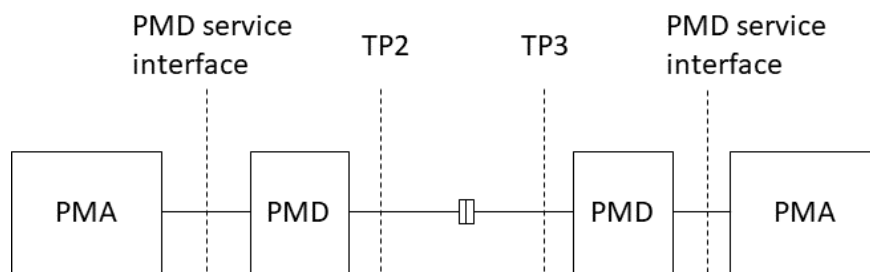


Fig 1. Test points specified in BASE-AU PHYs.

Test points evaluated for the multi-gigabit optical automotive Ethernet are shown in Figure 2, where TP2 and TP3 are defined in Clause 166.6.2 and Figure 166-36 in IEEE 802.3cz [2]. TP1 and TP4 are defined for fiber-optic transceiver (FOT) test described in Clause 11.2 or 11.3.

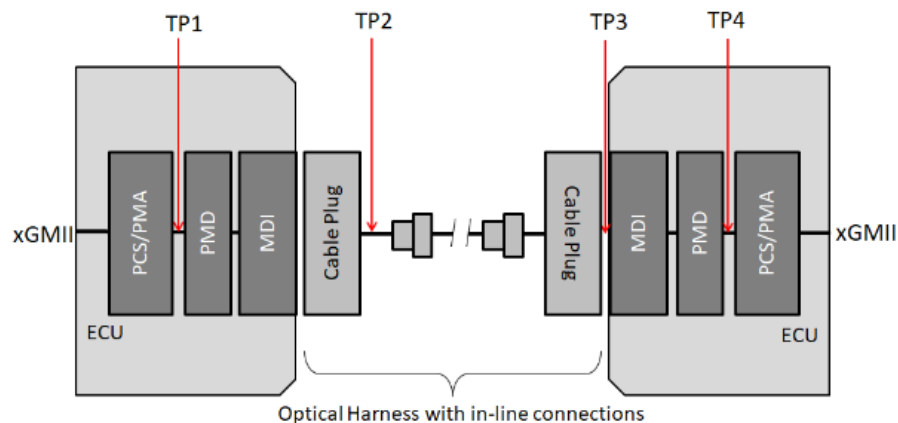


Fig 2. Test points for actual tests.

10.2 Test patterns

Patterns used for tests are defined in Table 1. The appropriate patterns used in each test are also shown in Table 2.

Table 1 Test patterns used in tests

PATTERN	PATTERN DESCRIPTION	DEFINED CLAUSE IN IEEE 802.3CZ
1	Slow sweep square waveform pattern (SSQWP)	166.5.2
2	Fast sweep square waveform pattern (FSQWP)	166.5.3
3	Short stress pattern for NRZ (SSPR-NRZ)	166.5.4
4	Short stress pattern for PAM4 (SSPR-PAM4)	166.5.5
5	Pattern for stressed receiver sensitivity (SRS) measurement	166.5.6

Table 2 Test pattern description and related subclauses for tests.

PARAMETER	PATTERN FOR 2.5GBASE-AU, 5GBASE-AU, 10GBASE-AU AND 25GBASE-AU	PATTERN FOR 50GBASE-AU	RELATED CLAUSE
Center wavelength and RMS spectral width	3, or valid BASE-AU signal	4, or valid BASE-AU signal	10.3.1
Average optical launch power	3, or valid BASE-AU signal	4, or valid BASE-AU signal	10.3.2

Outer optical modulation amplitude (OMA_{outer})	1 or 3	1 or 4	10.3.3
Transmitter distortion figure of merit (TDFOM)	3	4	10.3.3
Extinction ratio	1 or 3	1 or 4	10.3.3
Relative intensity noise ($RIN_{12}OMA$)	1	1	10.3.3
Uncorrelated random jitter	1 or 2	1 or 2	10.3.3
Signaling rate of transmitter	3, or valid BASE-AU signal	4, or valid BASE-AU signal	10.3.3
Signaling rate of receiver	5	5	10.3.8
Receiver sensitivity test	3	4	10.3.8
Stressed receiver conformance test signal calibration (Stressed TDFOM and ER)	3	4	10.3.9
Stressed receiver conformance test signal calibration (RIN and random jitter)	1	1	10.3.9
Stressed receiver sensitivity	5	5	10.3.9
BER test	5, or patterns defined in IEEE 802.3cz Clause 166.5.1	5, or patterns defined in IEEE 802.3cz Clause 166.5.1	10.3.6 and 10.3.10

10.3 Example configuration for tests

Example block diagrams of the test configuration are shown with the equipment. The detailed specification of the equipment is shown in Clause 11. In all of the following tests, the fiber optic cable specification shall be in accordance with IEC 60793-2-10 for Type A1a.2 (OM3) optical fiber.

10.3.1 Center wavelength and RMS spectral width measurement

This test shall be conformance to IEEE 802.3cz Clause 166.6.4.2. The example setup is shown in Figure 3.



- 1: Optical transmitter under test
- 2: Optical spectrum analyzer

Fig 3. Configuration block diagram of conformance test for center wavelength and RMS spectral width measurement.

10.3.1.1 Required specification

Measured values of center wavelength and RMS spectral width shall be within Table 3, which is specified in Table 166-9 of IEEE 802.3cz.

Table 3 Specified characteristics of center wavelength and RMS spectral width (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	VALUE	UNITS	NOTE
Center wavelength (range)	970 to 990	nm	
RMS spectral width (max)	0.7	nm	RMS spectral width is the standard deviation of the spectrum.

10.3.1.2 Test procedure

The test shall be performed as follows. The measurements shall also follow IEC 61280-1-3: Measurement of central wavelength, spectral width and additional spectral characteristics.

3. Connect an optical transmitter under test to optical spectrum analyzer with an optical fiber cable, whose length is 1 m from the MDI of the transmitter. Test point TP2 output shall be launched into the optical spectrum analyzer.
4. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
5. Turn on the output of the optical transmitter under test.
6. Measure the optical spectrum output from the transmitter.
7. Evaluate the center wavelength and RMS spectral width in maximum with Table 3.

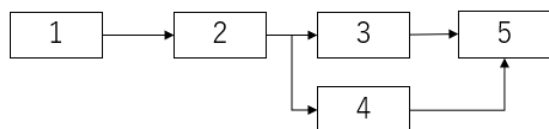
10.3.2 Average optical launch power measurement

This test shall be conformance to IEEE 802.3cz Clause 166.6.4.3. The example setup is shown in Figure 4. This test shall also be with a waveform analyzer as shown in Figure 5.



- 1: Optical transmitter under test
2: Optical power meter

Fig 4. Configuration block diagram of conformance test for average optical power measurement.



- 1: Optical transmitter under test
 2: Optical splitter
 3: O/E converter
 4: Clock recovery unit with optical input
 5: Waveform analyzer

Fig 5. Configuration block diagram of conformance using waveform analyzer with an optical signal input.

10.3.2.1 Required specification

Measured values of average optical launch power in each throughput at the ON state shall be within Table 4, which is specified in Table 166-9 of IEEE 802.3cz. Optical launch power in the OFF state shall be less than -30 dBm in each parameter.

Table 4 Specified characteristics of average optical launch power (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	AVERAGE OPTICAL LAUNCH POWER (MAX)	AVERAGE OPTICAL LAUNCH POWER (MIN)	UNITS	NOTE
2.5GBASE-AU	3.9	-4.3	dBm	Specified at TP2
5GBASE-AU		-3.3		
10GBASE-AU		-2.4		
25GBASE-AU		-1.4		
50GBASE-AU	5	-0.3		

10.3.2.2 Test procedure

The test based on the configuration of Figure 4 shall be performed as follows. The measurements shall also follow ANSI/TIA/EIA-455-95-2019: absolute optical power test for optical fibers and cables.

1. Connect an optical transmitter under test to an optical power meter with an optical fiber cable, whose length is 1 m from the MDI of the transmitter. Test point TP2 output shall be launched into the optical power meter.
2. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
3. Turn on the output of the optical transmitter under test.
4. Measure the optical launch power.
5. Evaluate the measured optical launch power with Table 4.
6. Turn off the optical transmitter and measure the average optical launch power.

7. Evaluate the measured optical launch power in the OFF state is less than -30 dBm.

The test based on the configuration of Figure 5 shall be performed as follows.

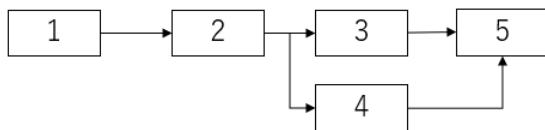
1. Connect an optical transmitter under test to a waveform analyzer system. The transmitter is connected to an input port of an optical coupler and then the output ports of the coupler are input into the analyzer and clock recovery unit, respectively. The recovered clock signal from the clock recovery unit is input into the clock/trigger port of the waveform analyzer.
2. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
3. Measure the eye diagram of the input signal.
4. Estimate the average optical power using the average of the mean values of highest state P_{max} and lowest state P_{min} of the eye diagram at a crossing point.
5. Calculate the average optical power by $\frac{P_{max}+P_{min}}{2}$.
6. Evaluate the measured optical launch power with Table 4.
7. Turn off the optical transmitter and measure the average optical launch power.
8. Evaluate the measured optical launch power in the OFF state is less than -30 dBm.

10.3.3 Outer optical modulation amplitude (OMA_{outer}), Uncorrelated random jitter, Relative intensity noise (RIN₁₂OMA), Extinction Ratio, and Transmitter distortion figure of merit (TDFOM), signaling rate measurements

Following tests shall be conformant to IEEE 802.3cz standards.

1. Outer optical modulation amplitude (OMA_{outer}) measurement for IEEE 802.3cz Clause 166.6.4.4,
2. Uncorrelated random jitter for IEEE 802.3cz Clause 166.6.4.7,
3. Relative intensity noise (RIN₁₂OMA) measurement for IEEE 802.3cz Clause 166.6.4.6, and
4. Transmitter distortion figure of merit (TDFOM) measurement for IEEE 802.3cz Clause 166.6.4.8, and
5. Signaling rate measurement specified in IEEE 802.3cz Table 166-9

In these tests, a waveform analyzer and a clock recovery unit are connected with an optical splitter as shown in Figure 6.



- 1: Optical transmitter under test
- 2: Optical splitter
- 3: O/E converter
- 4: Clock recovery unit with optical input
- 5: Waveform analyzer

Fig 6. Configuration block diagram with use of the combination of a waveform analyzer and a clock recovery unit, which have an optical signal input port.

10.3.3.1 Required specifications

Measured values of outer optical modulation amplitude in each parameter shall be within Table 5, which is specified in Table 166-9 of IEEE 802.3cz. The minimum value of the OMA_{outer} is expressed by

$$\max(A, TDFOM + B)$$

with the specified values A and B . TDFOM is a target value for measure in transmitter test. The limitation of the TDFOM is also shown in this subclause.

Table 5 Specification of Outer optical modulation amplitude (OMA_{outer}) (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	OMA_{OUTER} (MAX)	VALUE A	VALUE B	UNITS	NOTE
2.5GBASE-AU	3.2	-5	-5	dBm	
5GBASE-AU		-4	-3.9		
10GBASE-AU		-3.1	-2.7		
25GBASE-AU		-2.1	-1.5		
50GBASE-AU	4.3	-1	-0.4		

Measured values of uncorrelated random jitter t_j , $RIN_{12}OMA$, extinction ratio, TDFOM and signaling rate in each throughput shall be within Table 6 to Table 10, which are specified in Table 166-9 of IEEE 802.3cz, respectively.

Table 6 Specification of uncorrelated random jitter (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	UNCORRELATED RANDOM JITTER t_j (MAX)	UNITS	NOTE
2.5GBASE-AU	0.02	UI	
5GBASE-AU			
10GBASE-AU			
25GBASE-AU			
50GBASE-AU	0.008		

Table 7 Specification of relative intensity noise ($RIN_{12}OMA$) (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	$RIN_{12}OMA$ (MAX)	UNITS	NOTE
2.5GBASE-AU	-120	dB/Hz	
5GBASE-AU			
10GBASE-AU			
25GBASE-AU	-124		

50GBASE-AU	-131		
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Table 8 Specification of extinction ratio (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	VALUE (MIN)	UNITS	NOTE
2.5GBASE-AU	4	dB	
5GBASE-AU			
10GBASE-AU			
25GBASE-AU			
50GBASE-AU	3.5		

Table 9 Specification of transmitter distortion figure of merit (TDFOM) (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	TDFOM (MAX)	TDFOM (MIN)	UNITS	NOTE
2.5GBASE-AU	1	-0.3	dB	
5GBASE-AU	1	-0.4		
10GBASE-AU	2	-1.0		
25GBASE-AU	2.5	-1.5		
50GBASE-AU	3	-1.7		

Table 10 Specification of signaling rate of transmitter (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	TRANSMITTER CLOCK FREQUENCY	UNITS	NOTE
2.5GBASE-AU	2.65625 ± 100 ppm	Gbd	
5GBASE-AU	5.3125 ± 100 ppm		
10GBASE-AU	10.625 ± 100 ppm		
25GBASE-AU	26.5625 ± 100 ppm		
50GBASE-AU			

10.3.3.2 Test procedures

For consistent measurement, TDFOM shall be measured first because the other parameters have included the measured TDFOM values. Second, OMA_{outer} shall be measured.

10.3.3.2.1 Transmitter distortion figure of merit (TDFOM)

This test shall be performed with the configuration of Figure 6.

1. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
2. Turn on the output of the optical transmitter under test.
3. Measure the mean value of TDFOM using the analyzer function.
4. Evaluate the measured uncorrelated random jitter with the values in Table 9.

10.3.3.2.2 Outer optical modulation amplitude (OMA_{outer})

This test shall be performed with the configuration of Figure 6.

1. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
2. Turn on the output of the optical transmitter under test.
3. Measure the mean value of signal over the center 3% of the time interval where the signal is in highest state as P_{max} .
4. Measure the mean value of signal over the center 3% of the time interval where the signal is in lowest state as P_{min} .
5. Calculate the OMA_{outer} using an equation of $P_{max} - P_{min}$ in Watts.
6. Evaluate the measured OMA_{outer} with the values in Table 5.

When the transmitter has large nonlinearity and large inter symbol interferences, the test pattern SSQWP defined in Table 1 may be used under noise and jitter measurement mode in the analyzer.

10.3.3.2.3 Uncorrelated random jitter

This test shall be performed with the configuration of Figure 6.

1. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
2. Turn on the output of the optical transmitter under test.
3. Measure the mean value of uncorrelated random jitter using the analyzer function feature. Typically, the function may be equipped in noise and jitter measurement mode.
4. Evaluate the measured uncorrelated random jitter with the values in Table 6.

When the analyzer has not equipped the measurement features in uncorrelated random jitter, the test shall be performed as following procedure.

1. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
2. Turn on the output of the optical transmitter under test.
3. Measure the standard deviation of the time measurements where the rising edge of the pattern crosses the average optical power in horizontal measurement window of the height 2% of OMA_{outer} as σ_{rise} .
4. Measure the standard deviation of the time measurements where the falling edge of the pattern crosses the average optical power in horizontal measurement window of the height 2% of OMA_{outer} as σ_{fall} .
5. Calculate the uncorrelated random jitter by $\sqrt{\frac{(\sigma_{rise})^2 + (\sigma_{fall})^2}{2}}$.
6. Evaluate the measured uncorrelated random jitter with the values in Table 6.

10.3.3.2.4 Relative intensity noise (RIN_{OMA})

This test shall be performed with the configuration of Figure 6..

1. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.

2. Measure the standard deviation of signal over the center 3% of the time interval where the signal is in the highest state as RN_1 .
3. Measure the standard deviation of signal over the center 3% of the time interval where the signal is in the lowest state as RN_0 .
4. Calculate $RIN_{12}OMA$ using the equation of $10 \log_{10} \frac{(RN_1 - RN_0)^2}{(OMA_{outer})^2 BW_N}$ in dB/Hz, where BW_N is the bandwidth factor of the receiver of 7.8 GHz for 2.5GBASE-AU, 5GBASE-AU and 10GBASE-AU, and 20.11 GHz for 25GBASE-AU and 50GBASE-AU, respectively, as shown in Table 166-14, IEEE 802.3cz.
5. Evaluate the measured $RIN_{12}OMA$ with the values in Table 7.

10.3.3.2.5 Extinction ratio

This test shall be configured with the setup shown in Figure 6.

1. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
2. Turn on the output of the optical transmitter under test.
3. Measure the mean value of signal over the center 3% of the time interval where the signal is in highest state as P_{max} .
4. Measure the mean value of signal over the center 3% of the time interval where the signal is in lowest state as P_{min} .
5. Calculate the extinction ratio using an equation of $10 \log_{10} \frac{P_{max}}{P_{min}}$.
6. Evaluate the measured extinction ratio with the values in Table 8.

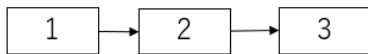
10.3.3.2.6 Signaling rate of transmitter

This test shall be configured with the setup shown in Figure 6.

6. Set the operation mode of the optical transmitter to generate test pattern defined in Table 2.
7. Turn on the output of the optical transmitter under test
8. Measure the mean value of signaling rate (transmitter clock frequency).
9. Evaluate the measured signaling rate with the values in Table 10.

10.3.4 Encircled flux test

This test shall be conformance to Table 166-9 BASE-AU PMD transmitter optical characteristics of IEEE 802.3cz. The example setup is shown in Figure 7.



- 1: Optical transmitter under test
 2: Standard OM3 optical fiber
 3: Optical modal pattern measurement equipment

Fig 7. Configuration of encircled flux test.

10.3.4.1 Required specifications

Measured values of encircled flux of the transmitter shall be within Table 11, which is specified in Table 166-9 of IEEE 802.3cz.

Table 11 Specified characteristics of encircled flux (referred to Table 166-9 of IEEE 802.3cz).

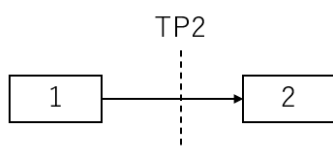
PARAMETER	VALUE	UNITS	NOTE
Encircled flux	≥ 86	%	at 19 μm
	≤ 30	%	at 4.5 μm

10.3.4.2 Test procedures

1. Set the test pattern generator to generate the pattern for average optical launch power defined in Table 2.
2. Measure the near field pattern.
3. Calculate a cumulative distributed function (CDF) of output optical power in radius.
4. Evaluate the measured CDF values with the values defined in Table 11.

10.3.5 Optical return loss tolerance measurement

This test shall be conformance to Table 166-9 BASE-AU PMD transmitter optical characteristics of IEEE 802.3cz. The example setup is shown in Figure 8.



- 1: Optical reflectometer
2: Transmitter under test

Fig 8. Configuration block diagram of optical return loss tolerance measurement for transmitter.

10.3.5.1 Required specifications

Measured value of optical return loss of the transmitter shall be within Table 12, which is specified in Table 166-9 of IEEE 802.3cz.

Table 12 Specified characteristic of optical return loss tolerance of transmitter (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	VALUE	UNITS	NOTE
Optical return loss tolerance (max)	12	dB	

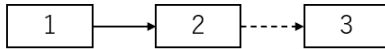
10.3.5.2 Test procedures

1. Turn on optical reflectometer.
2. Measure reflectance R_D from the optical transmitter under test, not TP2.
3. Calculate an optical return loss tolerance $T_0 = |R_D|$.

4. Evaluate the measured optical return loss tolerance values with the values defined in Table 12.

10.3.6 Transmitter BER test

This test evaluates the conformance of the patterns transmitted from the transmitter under test and the transmitter signal quality with the required system BER. The example setup is shown in Figure 9.



- 1: Optical transmitter under test
- 2: Golden receiver
- 3: BER tester

Fig 9. Configuration block diagram of transmitter BER test.

10.3.6.1 Required specifications

Measured system BER obtained golden receiver shall be less than 10^{-12} , which is specified in IEEE 802.3cz Clause 166.1.

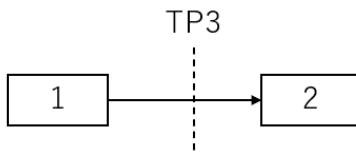
10.3.6.2 Test procedures

1. Set the operation mode of the optical transmitter under test to generate test pattern defined in Table 2.
2. Set BER test mode for both optical transmitter under test and golden receiver, which is defined in IEEE 802.3cz Clause 166.5.1.
3. Measure the system BER using the golden receiver. The BER tester is also available to measure the BER after processed in the golden receiver.
4. Evaluate the measured system BER of less than 10^{-12} .

The golden receiver shall be passed the tests from Clause 10.3.7 to Clause 10.3.10.

10.3.7 Receiver reflectance measurement

This test shall be conformance to Table 166-10 BASE-AU PMD receiver optical characteristics of IEEE 802.3cz. The example setup is shown in Figure 10.



- 1: Optical reflectometer
- 2: Receiver under test

Fig 10. Configuration block diagram of receiver reflectance.

10.3.7.1 Required specifications

Measured value of receiver reflectance shall be within Table 13, which is specified in Table 166-10 of IEEE 802.3cz.

Table 13 Specified characteristics of receiver reflectance (referred to Table 166-10 of IEEE 802.3cz).

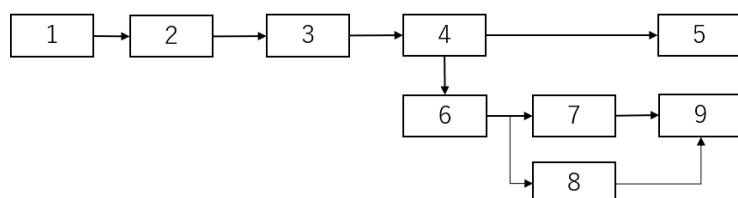
PARAMETER	VALUE	UNITS	NOTE
Receiver reflectance (max)	−12	dB	

10.3.7.1.1 Test procedures

5. Turn on optical reflectometer.
6. Measure receiver reflectance R_D from the optical receiver under test, not TP3.
7. Evaluate the measured receiver reflectance values with the values defined in Table 13.

10.3.8 Receiver sensitivity measurement

This test shall be conformance to IEEE 802.3cz Clause 166.6.4.12. This test shall be with a waveform analyzer and clock recovery unit as shown in Figure 11. The optical switch is used for calibration and receiver sensitivity measurement.



- 1: Waveform generator
- 2: Reference optical transmitter
- 3: Variable optical attenuator
- 4: Optical switch
- 5: Optical receiver under test
- 6: Optical power splitter
- 7: O/E converter
- 8: Clock recovery unit with optical input
- 9: Waveform analyzer

Fig 11. Configuration block diagram with use of an optical transmitter operated with optical-input-equipped clock recovery unit.

10.3.8.1 Required specification

Measured values of receiver sensitivity in each throughput shall be within Table 14, which is specified in Table 166-10 of IEEE 802.3cz. The receiver sensitivity with the values in the table is expressed by

$$\max(C, TDFOM + D).$$

Table 14 Specified characteristics of receiver sensitivity (referred to Table 166-9 of IEEE 802.3cz).

PARAMETER	VALUE C	VALUE D	UNITS	NOTE
2.5GBASE-AU	-16.1	-16.1	dBm	
5GBASE-AU	-15.1	-15.0		
10GBASE-AU	-14.2	-13.8		
25GBASE-AU	-11.2	-10.6		
50GBASE-AU	-6.4	-5.8		

10.3.8.2 Test procedure

1. Set the operation mode of reference optical transmitter to generate test pattern defined in Table 2.
2. Turn on the output of the optical transmitter under test.
3. Change the attenuation of the variable optical attenuator to zero.
4. Change the optical switch output to the analyzer.
5. Measure the OMA_{outer} and TDFOM of transmitter.
6. Calculate the maximum receiver sensitivity OMA_{max} by $\max(C, TDFOM + D)$
7. Switch the output of the optical switch to the receiver DUT.
8. Set optical transmitter to BER test mode per IEEE 802.3cz Clause 166.5.1.
9. Read number of error bits from the BER test mode counter, which is defined in Clause 45.2.3.94 of IEEE 802.3cz.
10. Calculate BER by dividing the number of error bits by the transmitted bits. If the BER is lower than 10^{-12} , increase the attenuation of the variable optical attenuator by 0.04 dB, and repeat the procedure 9-10 until calculated BER is greater or equal to 10^{-12} .
11. Record the received average optical power AOP.
12. Calculate the receiver sensitivity OMA by $AOP + 0.04$ [dBm].
13. Evaluate the measured receiver sensitivity OMA with the value OMA_{max} calculated in procedure 6.

10.3.8.3 Signaling rate test of the receiver

This test shall be conformance to IEEE 802.3cz Table 166-10. This test shall be with a reference optical transmitter as shown in Figure 11. The optical switch is used for calibration and signaling rate test.

10.3.8.3.1 Required specification

Signaling rate (clock frequency) of reference optical transmitter shall be set to the values in Table 15, which is specified in Table 166-10 of IEEE 802.3cz.

Table 15 Specification of signaling rate of receiver (referred to Table 166-10 of IEEE 802.3cz).

PARAMETER	SIGNALING RATE OF RECEIVER (RECEIVER FREQUENCY TOLERANCE)	UNITS	NOTE
2.5GBASE-AU	2.65625 ± 100 ppm	Gbd	

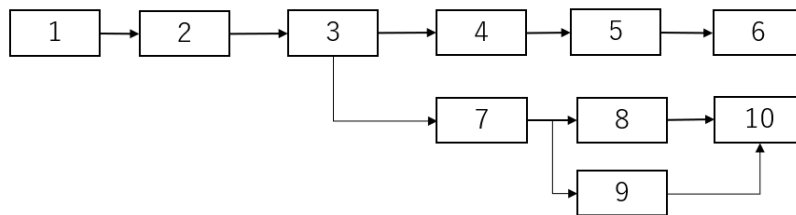
5GBASE-AU	5.3125 ± 100 ppm		
10GBASE-AU	10.625 ± 100 ppm		
25GBASE-AU	26.5625 ± 100 ppm		
50GBASE-AU			

10.3.8.3.2 Test procedure

8. Set the operation mode of reference optical transmitter to generate test pattern defined in Table 2.
9. Set the frequency of waveform generator in the reference optical transmitter to the values in Table 15.
10. Turn on the output of the reference optical transmitter.
11. Measure the bit error rate obtained in the receiver under test.
12. Evaluate and confirm obtained BER less than 10^{-12} .

10.3.9 Stressed receiver sensitivity measurements

This test shall be conformance to IEEE 802.3cz Clause 166.6.4.10. The example setup is shown in Figure 12.



- 1: Waveform generator
- 2: Reference optical transmitter
- 3: Optical switch
- 4: 40-m-long optical fiber
- 5: Optical attenuator
- 6: Optical receiver under test
- 7: Optical power splitter
- 8: O/E converter
- 9: Clock recovery unit with optical input
- 10: Waveform analyzer

Fig 12. Configuration block diagram for stressed receiver sensitivity test.

10.3.9.1 Required specifications

Measured values of stressed receiver sensitivity in each throughput shall be within Table 16, which is specified in Table 166-10 of IEEE 802.3cz. In this table, condition 1 and 2 are specified in IEEE 802.3cz Clause 166.6.4.13.2. Table 17 shows the parameters for STDFOM set for a reference optical transmitter.

Table 16 Specified characteristics of stressed receiver sensitivity (referred to Table 166-10 of IEEE 802.3cz).

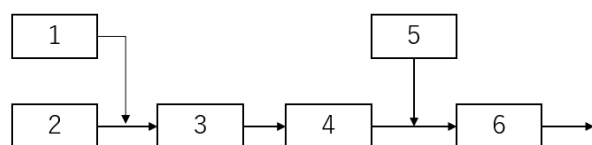
PARAMETER	VALUE IN CONDITION 1	VALUE IN CONDITION 2	UNITS	NOTE
2.5GBASE-AU	-15.1	-16.1	dB	
5GBASE-AU	-14.0	-15.1		
10GBASE-AU	-11.8	-14.2		
25GBASE-AU	-8.1	-11.2		
50GBASE-AU	-2.8	-6.4		

Table 17 Specified characteristics of stressed TDFOM (referred to Table 166-10 of IEEE 802.3cz).

PARAMETER	STDFOM, CONDITION 1	STDFOM, CONDITION 2	UNITS	NOTE
2.5GBASE-AU	1	0	dB	
5GBASE-AU	1	-0.1		
10GBASE-AU	2	-0.4		
25GBASE-AU	2.5	-0.6		
50GBASE-AU	3	-0.6		

10.3.9.2 Test procedures

The waveform generator for stressed signal generation is configured as shown in Figure 13. First, the stressed signal shall be calibrated, and then, the receiver test shall be performed.



- 1: Gaussian random jitter generator
- 2: Sinusoidal jitter generator
- 3: Clock source
- 4: Test pattern generator
- 5: Additive white Gaussian noise generator
- 6: Low-pass filter

Fig 13. Example configuration of waveform generator (refer to IEEE 802.3cz Fig. 166-45).

10.3.9.2.1 Generation method and calibration of stressed signal

1. Turn off jitter generator to generate clean clock from the clock source.
2. Turn on the output of the reference optical transmitter.
3. Set the test pattern generator to generate stressed receiver conformance test signal calibration (STDFOM and ER) defined in Table 2.
4. Switch the optical switch to the optical path connected to the waveform analyzer.
5. Measure the TDFOM.
6. Tune the 3-tap feed-forward equalizer (FFE) equipped in the test pattern generator to meet the maximum limitation of the stressed TDFOM (STDFOM) defined in Table 17 and to meet the minimum limitation of the extinction ratio as shown in Table 8.
7. Measure OMA_{outer} and average optical power AOP to calculate $\Gamma_{tx} = \frac{OMA_{outer}}{AOP}$.
8. Set the test pattern generator to generate stressed receiver conformance test signal calibration (RIN and random jitter) defined in Table 2.
9. Turn on jitter generator.
10. Tune the sinusoidal jitter generator to meet the requirements of the jitter as shown in Table 18.
11. Measure the uncorrelated random jitter.
12. Tune the Gaussian jitter generator to meet the maximum limitation of the uncorrelated random jitter defined in Table 6.
13. Turn on additive white Gaussian noise generator.
14. Tune the output power of Gaussian noise generator to meet the maximum limitation of $RIN_{12}OMA$ as shown in Table 7.
15. Set the test pattern generator to generate stressed receiver conformance test signal calibration (STDFOM and ER) defined in Table 2.
16. Measure the STDFOM.
17. Tune the tap coefficient of 3-tap FFE of the test pattern generator to meet the requirements of the STDFOM as shown in Table 17.

Table 18 Applied sinusoidal jitter (Peak-to-peak, UI).

FREQUENCY RANGE	2.5GBASE-AU	5GBASE-AU	10GBASE-AU	25GBASE-AU	50GBASE-AU
$f < 1 \text{ kHz}$	Not specified				
$1 \text{ kHz} \leq f < 300 \text{ kHz}$	$15 \text{ kHz}/f$			$150 \text{ kHz}/f$	$60 \text{ kHz}/f$
$1 \text{ kHz} \leq f < 3 \text{ MHz}$	0.05	0.05	0.05	0.05	0.02
$300 \text{ kHz} \leq f \leq 1 \text{ MHz}$	0.05	0.05	0.05	0.05	0.02
$3 \text{ MHz} \leq f \leq 10 \text{ MHz}$	0.05	0.05	0.05	0.05	0.02

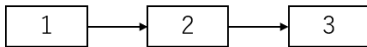
10.3.9.2.2 Stressed receiver sensitivity test

Stressed receiver sensitivity test shall be performed two conditions: condition 1 for maximum STDFOM and condition 2 for minimum STDFOM, defined in Table 17.

1. Set the test pattern generator to generate stressed receiver sensitivity defined in Table 2.
2. Switch the optical switch into the optical path connected to the optical fiber and optical receiver under test.
3. Set the optical receiver under test to receive the stressed receiver sensitivity (SRS) pattern.
4. Set the attenuation to zero in the variable optical attenuator.
5. Increase the attenuation when the following status is shown:
 - The RS-FEC codeword error ratio is over the limit of 4×10^{-10} .
 - Local link margin reported in register 3.2350 (see IEEE 802.3cz Clause 45.2.3.92) is lower than 0.
 - Local receiver status, link status, or local PHD reception status reported in register 3.2349 (see IEEE 802.3cz Clause 45.2.3.91) is equal to 0
6. Decrease the attenuation until none of the above status are met.
7. Measure the average optical power at TP3 AOP_{TP3} .
8. Calculate and evaluate the stressed receiver sensitivity OMA_{outer} at TP3 by $AOP_{TP3} \times I_{tx}$.

10.3.10 BER test at the output of the receiver

This test shall be conformance of the receiver function to IEEE 802.3cz Clause 166.1. The example setup using golden transmitter is shown in Figure 14. The test can be used with reference optical transmitter instead of the golden transmitter.



- 1: Golden transmitter, or reference optical transmitter
 2: Optical receiver under test
 3: BER tester

Fig 14. Configuration block diagram of BER test at the output of the receiver.

10.3.10.1 Required specifications

Measured system BER obtained at the output of the receiver shall be less than 10^{-12} , which is specified in IEEE 802.3cz Clause 166.1.

10.3.10.2 Test procedures

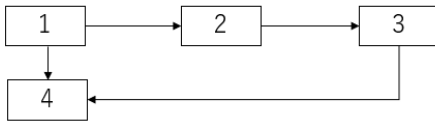
1. Set the operation mode of golden transmitter or reference optical transmitter to generate test pattern defined in Table 2.
2. Measure the BER at the output of the receiver using waveform analyzer.
3. Evaluate the measured system BER of the receiver of less than 10^{-12} .

10.3.11 Optical harness test

Following tests are not mandatorily required in IEEE 802.3cz. These are for design and evaluation of the characteristics of the optical harness. The optical harness is an optical communication medium that connects opposing electronic control units (ECUs), and is composed of the optical cable and several optical connectors.

10.3.11.1 Frequency response characteristics measurement

The test is for evaluation of the optical harness quality in frequency domain. Figure 15 shows the block diagram to measure the transmission characteristics in the range of the modulation frequency. S-parameter S21 is measured as a frequency response.



- 1: Optical reference transmitter
- 2: Optical harness under test
- 3: O/E converter
- 4: Vector network analyzer

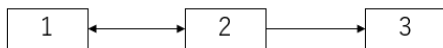
Fig 15. Configuration of frequency response characteristic measurement test.

10.3.11.1.1 Test procedures

1. Calibrate the optical frequency response of the optical reference transmitter and O/E converter using vector network analyzer without an optical harness under test.
2. Insert the optical harness under test between the reference optical transmitter and the O/E converter after calibration.
3. Measure the frequency response of the harness by sweeping the frequency of the vector network analyzer.
4. Evaluate the S21 parameter of the optical harness under test.

10.3.11.2 Reflection point measurement

The test is for the optical harness failure analysis of breaks of the harness and the connector-related reflection. This test can be used in quality assurance as well as detection of the fiber failure in deployed optical harness. The test is for the optical harness failure analysis of breaks of the harness and the connector-related reflection. This test can be used in quality assurance as well as detection of the fiber failure in deployed optical harness. Example configuration of the measurement is shown in Figure 16.



- 1: Optical reflectometer
- 2: Optical harness under test
- 3: Optical terminator

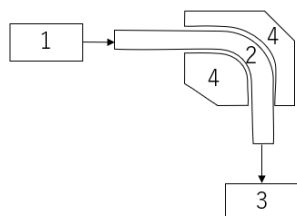
Fig 16. Configuration block diagram of the measurement of the reflection points of the optical harness.

10.3.11.2.1 Test procedure

1. Turn on the optical reflectometer to measure the reflection points
2. Evaluate S11 parameter at each reflection point of the optical harness under test.

10.3.11.3 Optical attenuation measurement of optical cable in bending stress

This test is for evaluation of the bending attenuation of optical signals transmitted over the optical cable. Figure 17 shows the example block diagram to measure the loss induced by cable bend. The configuration of bend jig is referred to ISO 24581:2024, subclause 6.3.8.



- 1: Lightwave source
- 2: Optical cable under test
- 3: Optical power meter
- 4: Bend jig

Fig 17. Configuration of test setup for optical attenuation measurement by bending stress.

10.3.11.3.1 Required specifications

Measured optical attenuation shall be within Table 19, which is specified in Subclause 6.3.8 of ISO 24581:2024.

Table 19 Specified characteristics of bending attenuation (referred to ISO 24581:2024 subclause 6.3.8).

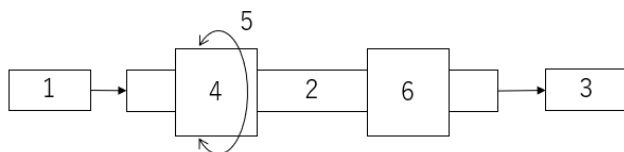
PARAMETER	VALUE	UNITS	NOTE
Bending attenuation (max.)	0.2	dB	

10.3.11.3.2 Test procedure

1. Measure the received average optical power AOP_{init} without bend jig.
2. Set the optical cable to bend jig.
3. Measure the received average optical power AOP_{bend} after enough time.
4. Calculate the bending attenuation by $-10 \log \frac{AOP_{bend}}{AOP_{init}}$.
5. Evaluate the measured values with the values defined in Table 19.

10.3.11.4 Optical attenuation measurement of optical harness in torsion stress

This test is for evaluation of the attenuation of optical signals induced by torsion stress to optical harnesses. Figure 18 shows the example block diagram to measure the loss induced by harness twisted. The torsion stress test shall refer to ISO 24581:2024, subclause 6.3.12.



- 1: Lightwave source
- 2: Optical harness under test
- 3: Optical power meter
- 4: Left torsion clamp
- 5: Torsion force
- 6: Right torsion clamp

Fig 18. Configuration of test setup for optical attenuation measurement by torsion stress.

10.3.11.4.1 Required specifications

Measured optical attenuation shall be within Table 20, which is specified in Subclause 6.3.12 of ISO 24581:2024.

Table 20 Specified characteristics of optical attenuation induced by torsion stress (referred to ISO 24581:2024 subclause 6.3.12).

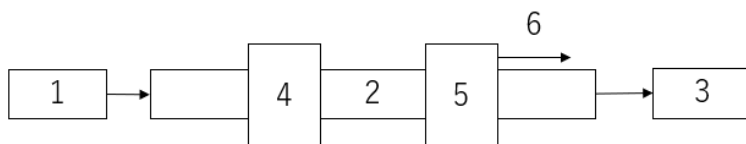
PARAMETER	VALUE	UNITS	NOTE
Attenuation induced by torsion stress (max.)	0.2	dB	

10.3.11.4.2 Test procedure

1. Set the distance between right and left clamps to $50 \text{ mm} \pm 2.5 \text{ mm}$.
2. Set the torsion stress to zero and measure the received average optical power AOP_{init} .
3. Rotate the left clamp 180 degrees clockwise.
4. Keep in 3 minutes.
5. Rotate the left clamp 360 degrees counter clockwise.
6. Keep in 3 minutes.
7. Measure the minimum received optical power $AOP_{minimum}$ during the torsion stress applied.
8. Rotate the left clamp 180 degrees clockwise to release the torsion stress.
9. To keep 1 minute.
10. Measure the received average optical power AOP_{after} .
11. Calculate the torsion stress attenuation by $-10 \log_{10} \frac{\max(AOP_{minimum}, AOP_{after})}{AOP_{init}}$.
12. Evaluate the measured values with the values defined in Table 20.

10.3.11.5 Optical attenuation measurement of optical harness in tensile stress

This test is for evaluation of the attenuation of optical signals induced by tensile stress to optical cables. Figure 19 shows the example block diagram to measure the loss induced by cable stretched. The tensile stress test shall refer to ISO 24581:2024, subclause 6.3.9.



- 1: Lightwave source
- 2: Optical cable under test
- 3: Optical power meter
- 4: Left tensile stress clamp
- 5: Right tensile stress clamp
- 6: Tensile stress force

Fig 19. Configuration of test setup for optical attenuation measurement by tensile stress.

10.3.11.5.1 Required specifications

Measured optical attenuation shall be within Table 21, which is specified in Subclause 6.3.9 of ISO 24581:2024.

Table 21 Specified characteristics of optical attenuation induced by tensile stress (referred to ISO 24581:2024 subclause 6.3.9).

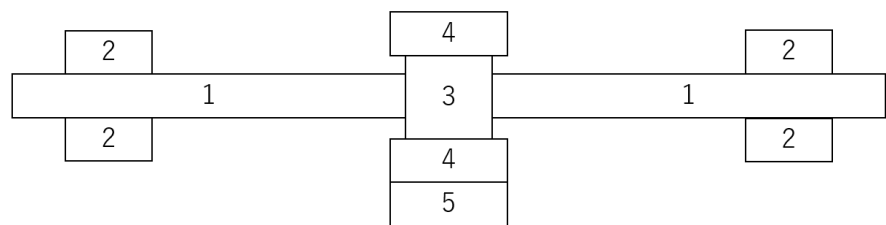
PARAMETER	VALUE	UNITS	NOTE
Attenuation induced by tensile stress (max)	0.2	dB	

10.3.11.5.2 Test procedure

- Set the tensile load to zero and measure the received average optical power AOP_{init} .
- Apply the tensile load up to 120 N with a speed of 50 mm/min.
- Keep in 1 minute with the load.
- Remove the tensile load with a speed of 50 mm/min.
- Measure the received average optical power AOP_{after} after 1 minute.
- Calculate the tensile stress attenuation by $10 \log_{10} \frac{AOP_{after}}{AOP_{init}}$.
- Evaluate the measured values with the values defined in Table 21.

10.3.12 Vibration test for transmitter, receiver, and optical harness

This test evaluates the transmitter, receiver, and optical harness under vibrational conditions. Figure 19 shows an example of how vibration is applied to the optical connector in the harness. The vibration conditions for the test shall follow ISO 16750-3:2023—particularly Clause 4.1.8 for components installed in passenger cars—and related standards. All tests defined in the document shall be performed and passed under these vibration conditions.



- 1: Optical cable under test
- 2: Cable clamp
- 3: Optical connector under test
- 4: Clamp for vibration tester
- 5: Vibration tester

Fig 20. Example configuration of vibration test for optical connector.

10.3.12.1 Example requirements for optical harness test under vibration conditions

Vibration conditions for testing the optical harness shall follow those specified in Table 22. Under these conditions, all tests related to the optical harness defined in the document shall be passed.

Table 22 Example specification of the vibrational condition for optical harness tests.

PARAMETER	VALUE	UNITS	NOTE
Excitation frequency	33 or 67	Hz	
Acceleration of excitation (max.)	45	m/s ²	

11 TEST EQUIPMENT

11.1 Equipment commonly used for the tests based on IEEE 802.3cz and ISO 24581:2024

11.1.1 Optical spectrum analyzer

11.1.1.1 Purpose

To evaluate the center wavelength and RMS spectral width for compliance tests.

11.1.1.2 Related test points

- Transmitted signal test at TP2

11.1.1.3 Required minimum specification

Table 23 Specification of optical spectrum analyzer.

ITEMS	VALUES	UNIT	
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	MINIMUM	TYPICAL	MAXIMUM		NOTE
Wavelength range	840		990	nm	
Wavelength accuracy		±0.1		nm	
Wavelength repeatability		±0.01		nm	at 1 min. accumulation
Wavelength resolution		0.05	0.1	nm	
Wavelength resolution accuracy		±5		%	
Level sensitivity		-90		dBm	
Level accuracy		±0.5		dB	
Level flatness		±0.1		dB	
Maximum input power			+20	dBm	
Dynamic range	55			dB	

11.1.2 Optical power meter

11.1.2.1 Purpose

To measure and evaluate average optical powers and receive optical powers in conformance tests.

11.1.2.2 Related test points

- Transmitted signal test at TP2
- Calibration and measurements of the signal input into receiver at TP3

11.1.2.3 Required minimum specifications

Table 24 Specification of optical power meter.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Power range	-70		10	dBm	
Power accuracy		±0.1		dB	
Repeatability		±0.05		dB	
Uncertainty		±4.0% ±0.5		pW	at 25°C, 40%RH
Noise (peak to peak)		0.5		pW	
Numerical aperture		≤0.3			MMF max 50 µm core size

Maximum safe input power	16			dBm	
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11.1.3 Variable optical attenuator

11.1.3.1 Purpose

To evaluate a receiver sensitivity test and stressed receiver sensitivity test to check conformance.

11.1.3.2 Related test points

- Transmitted signal test at TP2
- Launch power level management of the signal input into the fiber and receiver at TP3

11.1.3.3 Required minimum specification

Table 25 Specification of variable optical attenuator.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Variable attenuation range	0		35	dB	
Attenuation resolution		0.03		dB	
Attenuation accuracy	±0.25	±0.15		dB	Input optical signal shall have the spectral bandwidth of input signal > 30 nm for unpolarized light. Output signal of encircled flux shall be < 30% in 4.5 µm radius and > 86% inside 19 µm for 50/125 µm fiber.
Attenuation repeatability		±0.025		dB	
Return Loss		25		dB	
Maximum safe input power	23			dBm	

11.1.4 Light source

11.1.4.1 Purpose

- To configure a reference optical transmitter, and
- To test and calibrate the equipment.

11.1.4.2 Related test points

- Transmitted signal test at TP2
- Signal test transmitted over optical fibers and signal input into a receiver at TP3

11.1.4.3 Required minimum specification*Table 26 Specification of light source.*

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Wavelength accuracy		±1		nm	
Output optical power	-10			dBm	
Linewidth			100	MHz	in single-mode operation
Relative intensity noise		-120		dBm	

11.1.5 Optical-to-electrical converter**11.1.5.1 Purpose**

To evaluate an optical frequency-domain characteristics in the optical harness.

11.1.5.2 Related test points

- Transmitted signal test at TP2
- Signal test transmitted over optical fibers and signal input into a receiver at TP3

11.1.5.3 Required minimum specification*Table 27 Specification of optical-to-electrical converter.*

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Bandwidth (≤10 Gbps)	10			GHz	
(≤50 Gbps)	25			V/W	
Conversion efficiency		10		V/W	
Optical input power			4	mW	

11.1.6 Waveform analyzer

11.1.6.1 Purpose

- To measure and evaluate the parameters such as OMA_{outer} , RIN_{12} , OMA , TDFOM, uncorrelated random jitter, extinction ratio, and signaling rate,
- To calibrate the signal quality in receiver sensitivity test and stressed receiver sensitivity test, and
- To measure and evaluate the signal quality used in the tests.

11.1.6.2 Related test points

- Quality confirmation of the signal output from PMA/PCS at TP1
- Transmitted signal test at TP2
- Signal test transmitted over optical fibers and signal input into a receiver at TP3
- Received signal test at TP4 in the receiver

11.1.6.3 Required minimum specification

Table 28 Specification of waveform analyzer.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Electrical Channel Bandwidth, -3 dB (for ≤ 10 Gbps)	2.5	12.5	20	GHz	
(for ≤ 50 Gbps)		28	50	GHz	
Electrical channel RMS noise		275		μV	20 GHz BW
		420 450 500		μV	30 GHz BW 40 GHz BW 50 GHz BW
Electrical channel DC accuracy		± 1.15		mV	
Jitter RMS		160	200	fs	
Record Length	1		268,435,456		with pattern lock and "Acquire Entire Pattern"
Electrical channel nominal Input Impedance		50		Ω	
Input	Supports differential signal measurement				

Signal modulation format	NRZ (for <=25 Gbps), PAM4 for 50 Gbps
Signal Processing	TDFOM, Equaliser (LFE, CTLE , DFE) are available.

Table 29 Specification of optical input channel of waveform analyzer (mandatory).

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Optical channel bandwidth , -3 dBo (for <=10 Gbps)		7.5		GHz	4th order Bessel-Thomson low-pass response* for OMA, ER, RIN and uncorrelated jitter measurement
Optical channel bandwidth, -3 dBo (for 25/50 Gbps)		19.34		GHz	4th order Bessel-Thomson low-pass response* for OMA, ER, RIN and uncorrelated jitter measurement
Optical channel bandwidth, -3 dBo (for all data rates)		16.4		GHz	4th order Bessel-Thomson low-pass response* for TDFOM
Optical channel RMS Noise		8	10	μW	At 26.5625 Gbaud
Maximum measurable input optical power	4			mW	at 500 μW/division scale factor
Average optical power monitor accuracy		200 ± 10%		nW	Without connector uncertainty
Jitter RMS		160	200	fs	
Record length	1		268,435,456		with pattern lock and "Acquire Entire Pattern"
Fiber Input		50/125 um			
Fiber input/output connector		FC/PC			
Signal modulation format	NRZ for <=25 Gbps, PAM4 for 50 Gbps				
Signal Processing	TDFOM, Equalizer (LFE , CTLE , DFE) are available.				
Other	Need the pattern lock and Impulse Response Correction to get an ideal channel response.				

Note*	4 th order Bessel-Thomson response should extend out to 3 x BW-3dB and at frequencies above 3 x BW-3dB, the response should not exceed -24 dB.
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11.1.7 Clock Recovery Unit

11.1.7.1 Purpose

To recover the clock signal driving the waveform analyzer using input signals output from the transmitter.

11.1.7.2 Related test points

- Transmitter signal test at TP2
- Signal test transmitted over optical fibers and signal input into a receiver at TP3

11.1.7.3 Required minimum specification

Table 30 Specification of clock recovery unit.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Input frequency range			26.5625	GHz	
Clock output frequency			26.5625	GHz	Divided clock output of f/2, f/4, f/8, f/16 is implemented.
Output voltage		500		mVp-p	
Corner frequency (for <= 10 Gbps)		0.1		MHz	Slope of 20 dB/decade
(for <= 50 Gbps)		1		MHz	Slope of 20 dB/decade
Signal format support (for <= 10 Gbps)					NRZ
(for <= 50 Gbps)					NRZ and PAM4
Fiber Input		50/125 μ m			
Fiber input/output connector		FC/PC			
Other CRU capabilities		External signal splitter			

11.1.8 Bit error rate tester**11.1.8.1 Purpose**

To measure BERs.

11.1.8.2 Related test points

- Transmitter signal converted by O/E converter at TP2
- Output signal from the receiver

11.1.8.3 Required minimum specifications

Table 31 Specifications of BER tester.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Frequency clock	2.5		26.5625	Gbd	
Input sensitivity		10		mVpp	Single-end
Clock input frequency			26.5625	GHz	Divided clock of f/2, f/4, f/8, f/16 is implemented.
Received format	NRZ and PAM4				
Test Patterns	PRBS7, PRBS15, PRBS 31, user pattern (length >32768)				

11.2 Transmitter Test**11.2.1 Waveform generator****11.2.1.1 Purpose**

To generate test patterns.

11.2.1.2 Related test points

- FOT test between TP1 and TP2 in the transmitter
- Transmitter signal test at TP2

11.2.1.3 Pulse pattern generator**11.2.1.3.1 Required minimum specifications**

- 3-tap feed-forward equalization feature shall be equipped in each bit rate.
- Clock input to operate the pulse pattern generator shall be equipped.

Table 32 Specification of pulse pattern generator.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Bit rate (for <=10 Gbps)	2.5		10.625	Gbps	
(for <=25 Gbps)	2.5		26.5625	Gbps	
(for 50 Gbps)		53.125		Gbps	PAM4 waveform output
Output voltage	100		1000	mVp-p	
Test patterns					PRBS7, PRBS15, PRBS31
Clock output frequency (for <=10 Gbps)			10	GHz	Divided clock output of f/2, f/4, f/8, f/16 is implemented.
(for <=50 Gbps)			25	GHz	Divided clock output of f/2, f/4, f/8, f/16 is implemented.

11.2.1.4 Arbitrary waveform generator

11.2.1.4.1 Required minimum specifications

Table 33 Specification of arbitrary waveform generator.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Analog bandwidth (for <=10 Gbps)			10.625	GHz	3 dB, excl. sin(x)/x roll-off)
(for <=50 Gbps)			26.5625	GHz	3 dB, excl. sin(x)/x roll-off)
Sample Rate (for <=10 Gbps)	25			GSa/s	
(for <=50 Gbps)	65			GSa/s	
Rise/fall time(20%-80%) (for <=10 Gbps)		23		ps	Output amplitude 500 mVp-p(se)

(for <=50 Gbps)		18			ps	Output amplitude 500 mVp-p(se)
Bit resolution		8			bit	
Output voltage single-ended into 50 Ω differential	75 150		1000 2000		mVp-p	Without pre- distortion
Clock output frequency (for <=10 Gbps)			10		GHz	Divided clock output of f/2, f/4, f/8, f/16 is implemented.
(for <=50 Gbps)			25		GHz	Divided clock output of f/2, f/4, f/8, f/16 is implemented.
Memory length	256k				Samples/channel	
Random jitter, RMS		200			fs	
Impedance		50			Ω	
Output type	Single ended (Unused output must be terminated with 50 Ω to GND) or differential					
Other	It is recommended that calibration can be performed at the end of the RF cable connector with sampling oscilloscope.					

11.3 Receiver test

11.3.1 Reference optical transmitter

11.3.1.1 Purpose

- To generate the stressed signal for the receiver test, and
- To measure the optical frequency characteristics in the harness test as an E/O converter.

11.3.1.2 Related test points

- FOT test between TP3 and TP4 in receiver
- Receiver test at TP3 and TP3

11.3.1.3 Required minimum specification

Table 34 Specification of reference optical transmitter.

ITEMS	VALUES	UNIT	
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	MINIMUM	TYPICAL	MAXIMUM		NOTE
Wavelength range	840		990	nm	
Optical output power		0		dBm	In CW operation
Relative intensity noise		-120		dBm	
Analog bandwidth			26.5625	GHz	

11.4 Optical harness test

11.4.1 Optical reflectometer

11.4.1.1 Purpose

To check the defects and unwanted reflection in the optical harness.

11.4.1.2 Related test points

- Transmitted signal test between TP2 and TP3

11.4.1.3 Required minimum specification

Table 35 Specification of optical reflectometer.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Dynamic range		27		dB	
Event dead zone		0.5	1	m	
Attenuation dead zone			2.5	m	
Distance uncertainty				m	$\pm(0.75 + 0.0025\% \times \text{distance} + \text{sampling resolution})$
Linearity		± 0.03		dB/dB	

11.4.2 Vector Network Analyzer

11.4.2.1 Purpose

To measure the optical frequency response of the optical harness.

11.4.2.2 Related test points

- Transmitted signal test between TP2 and TP3

11.4.2.3 Required minimum specification

Table 36 Specification of vector network analyzer.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Frequency range	<1		30	GHz	
Dynamic range		140		dB	
Output power			10	dBm	
Number of ports		2			
Temperature stability		0.005		dB/°C	

11.4.3 Tensile stress application system

11.4.3.1 Purpose

To evaluate the optical attenuation induce by tensile stress to the optical harness.

11.4.3.2 Related test points

- Transmitted signal test between TP2 and TP3

11.4.3.3 Required minimum specification

- Rotary-type tensile strength tester has rotating mandrels.

Table 37 Specification of tensile strength measurement.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Applied load		120	200	N	
Diameter of mandrel	60			mm	
Distance of clamps	100		200	mm	
Accuracy		± 2		%	
Tensile speed		50		mm/min.	

11.4.4 Bend jig for bending attenuation measurement

11.4.4.1 Purpose

To evaluate the optical attenuation induce by bending stress to the optical harness.

11.4.4.2 Related test points

- Transmitted signal test between TP2 and TP3

11.4.4.3 Required minimum specification*Table 38 Specification of bend jig.*

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Bending radius	15.0		15.1	mm	
Accuracy		+0.7		%	

11.4.5 Static torsion stress application system**11.4.5.1 Purpose**

To evaluate the optical attenuation induce by torsion stress to the optical harness.

11.4.5.2 Related test points

- Transmitted signal test between TP2 and TP3

11.4.5.3 Required minimum specification*Table 39 Specification of torsion stress application system.*

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Clockwise torsion angle			180 ± 9	degrees	
Counter clockwise torsion angle			360 ± 18	degrees	
Distance of clamps	47.5		52.5	mm	
Accuracy		± 2		%	

11.5 Encircled flux and optical spatial mode measurement**11.5.1 Optical near-field pattern measurement equipment****11.5.1.1 Purpose**

- To measure the near field pattern irradiated from the optical harness facet for evaluation of the encircled flux, and

- To evaluate the modal noises induced by the transmission over an optical harness.

11.5.1.2 Related test points

- Transmitted signal test at TP2 and TP3

11.5.1.3 Required minimum specification

Table 40 Specification of optical near-field pattern measurement equipment.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Horizontal pixel number	640			pixel	
Vertical pixel number	480			pixel	
Pixel resolution		0.5		μm/pixel	
Dynamic range	8			bit/pixel	

11.5.2 Optical excitation point controller

11.5.2.1 Purpose

To induce the optical modal noise into the optical harness for worst-channel case evaluation.

11.5.2.2 Related test points

- Transmitted signal test at TP2 and TP3

11.5.2.3 Required minimum specification

Table 41 Specification of optical excitation point controller.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Wavelength range	840		990	nm	
Diameter of spot size	10		50	μmΦ	
Displacement of spot center		50		μm	Displacement from the center of the fiber core

11.6 Vibration tester

11.6.1 Purpose

To induce vibrations to the transmitter, receiver, and optical cables with optical in-line connectors.

11.6.2 Required minimum specification

Table 42 shows an example of tester specification. The equipment shall induce vibration to the transmitter, receiver, and optical harness for the tests defined in ISO 16750-3:2023 and the related standards.

Table 42 Specification of vibration tester.

ITEMS	VALUES			UNIT	NOTE
	MINIMUM	TYPICAL	MAXIMUM		
Excitation force (sinusoidal wave)		300		N	
(random wave)		200		N rms	
(shock wave)		300		N	
Excitation frequency	0		1000	Hz	