International Photonics & Electronics Committee

Test Specification for 800 Gbit/s PAM4 Optical Module at 100 Gbit/s per Lane

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Test Specification for 800 Gbit/s PAM4 Optical Module at 100 Gbit/s per Lane

Summary

The specification is designed for 800 Gbit/s PAM4 optical modules operating at 100 Gbit/s per lane, detailing test procedures for optical and electrical interfaces, power consumption, and both interconnection and interoperability assessments.

Keywords

800 Gbit/s, PAM4, 100 Gbit/s per Lane, Test Specification

Working Group: Plugfest

TITLE: Test Specifications for 800 Gbit/s PAM4 Optical Modules at 100 Gbit/s per Lane

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1 General Description

1.1 Test Environment Requirements

The test environment requirements are as follows:

- Temperature：15℃~35℃
- Relative humidity：45%~75%
- Atmospheric pressure：86kPa~106kPa

1.2 Test Instrument Requirements

Test instruments must be calibrated within their valid periods. Unless otherwise specified, the precision of these instruments should exceed the required measurement accuracy by at least one order of magnitude.

1.3 Other Requirements

1. Unless otherwise stated, the following specifications apply:

  - The BERT output signal utilizes the PAM4 modulation format.
  - The term 'DUT' in the test block diagram denotes the Device Under Test, which is the optical module being evaluated.
  - The aggregate output service rate for the BERT is set at 850Gb/s.
  - For all tests, ensure the DUT is powered on and operating normally including verifying that the input voltage is within the operational range.

2. There are two primary methods for individual lane testing:

   a. Activating a single laser, which is typically controlled through software protocols.

   b. Utilize an external wavelength multiplexer/demultiplexer, as depicted in Figure 1-1. The adjacent channel isolation of this device must be at least 30.0dB. Furthermore, if the test includes optical power measurement, precise power calibration is essential.

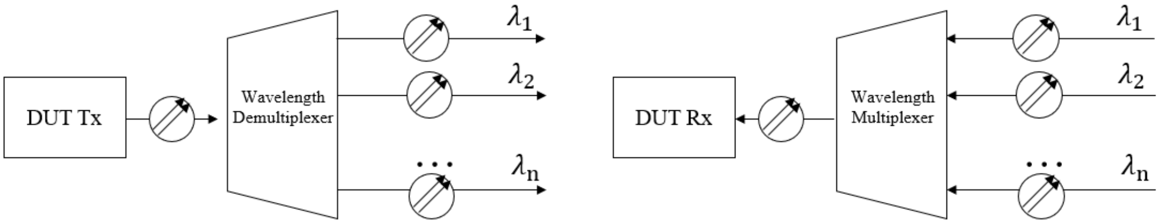


Figure 1- 1 The diagram for the external wavelength multi/demultiplexer

2 Optical Interfaces

The clause outlines various methods organized for industry reference during optical interface testing.

2.1 Test Patterns for Optical Parameters

Table 2- 1 Test patterns

Pattern	Pattern Description	Defined in[a]
Square wave	Square wave (8 threes, 8 zeroes)	120.5.11.2.4
3	PRBS31Q	120.5.11.2.2
4	PRBS13Q	120.5.11.2.1
5	Scrambled idle	119.2.4.9, or 172.2.4.11
6	SSPRQ	120.5.11.2.3

[a] These sub-clauses refer to relevant clauses of IEEE Std 802.3-2022.

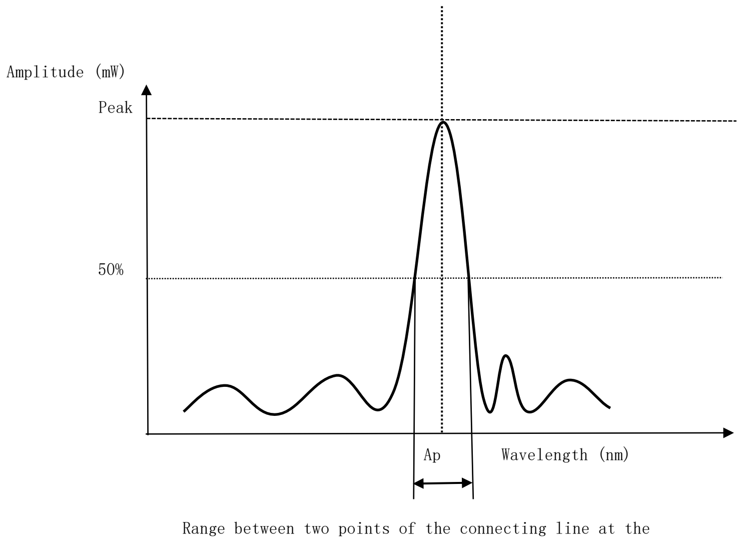
Table 2- 2 Test pattern definitions and related subclauses

Parameter	Pattern	Location
Center Wavelength	Square wave,3,4,5,6 or valid 800GBASE-R signal	2.2
Side Mode Suppression Ratio	3,5,6 or valid 800GBASE-R signal	2.3
RMS Spectral width	3,4,5,6 or valid 800GBASE-R signal	2.4
Average Optical Power	3,5,6 or valid 800GBASE-R signal	2.5
Average Launch Power of OFF Transmitter	3,5,6 or valid 800GBASE-R signal	2.6
Extinction Ratio	4 or 6	2.7
Outer Optical Modulation Ampltiude(OMAouter)	4 or 6	2.8
Transmitter and Dispersion Eye Closure for PAM4(TDECQ)	6	2.9
Transmitter transition time	Square wave or 6	2.10
RINxOMA	Square wave or 6	2.11
Transmitter Eye Closure for PAM4(TECQ)	6	2.12
Over/under-shoot	6	2.13
Transmitter Power Excursion	6	2.14
Receive Power (OMAouter)	3 or 5	2.15
Receiver Sensitivity (OMAouter)	3 or 5	2.16
Stressed Receiver Sensitivity	3 or 5	2.17
Optical Return Loss Tolerance	3,5,6 or valid 800GBASE-R signal	2.18
Receiver Reflectance	3 or 5	2.19

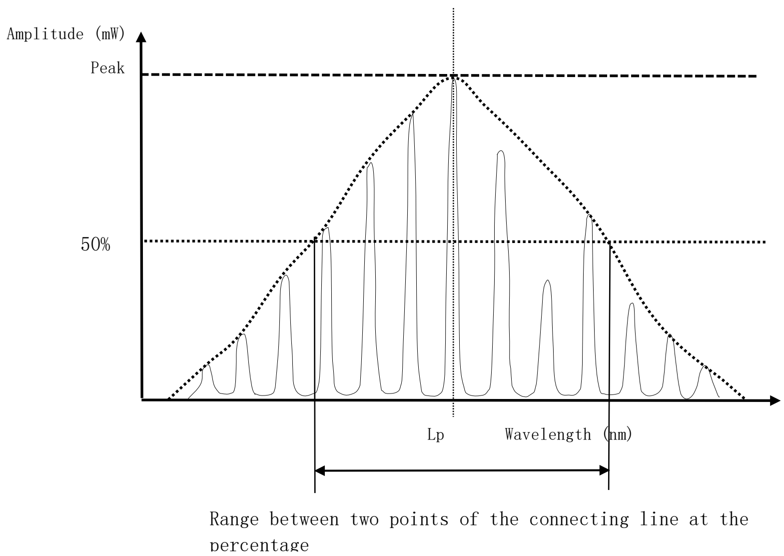
2.2 Center Wavelength

2.2.1 Definition

The term ‘**center wavelength**,’ synonymous with ‘half-power mid-point,’ denotes the mean of two optical wavelengths where the spectral radiant intensity drops to half of its peak. The unit is nm. Figures 2-1(a) and 2-1(b) illustrate the testing principles for determining the center wavelength in single-longitudinal mode and multi-longitudinal mode lasers, respectively.



a Single-longitudinal mode laser



b Multi-longitudinal mode laser

Figure 2- 1 Center wavelength test principles

2.2.2 Block Diagram

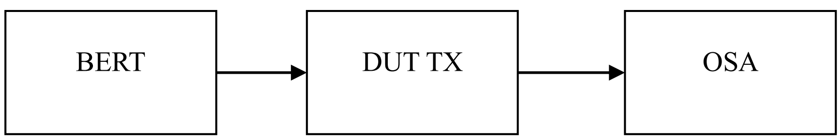


Figure 2- 2 Center wavelength test

2.2.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2- 2.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

Note: The amplitude for the **BERT** is advised to be set at 600mV.

c Determine the **'center wavelength'** using the **OSA**.

Note: Ensure the **OSA** is set to vacuum mode prior to taking the measurement.

2.3 Side Mode Suppression Ratio(SMSR)

2.3.1 Definition

In the context of a single-longitudinal mode laser, the term '**SMSR**' is calculated as the ratio of the optical power at the primary mode's peak to that at the highest secondary mode's peak. The unit is dB. Figure 2-3 depicts the principles for testing SMSR in such lasers.

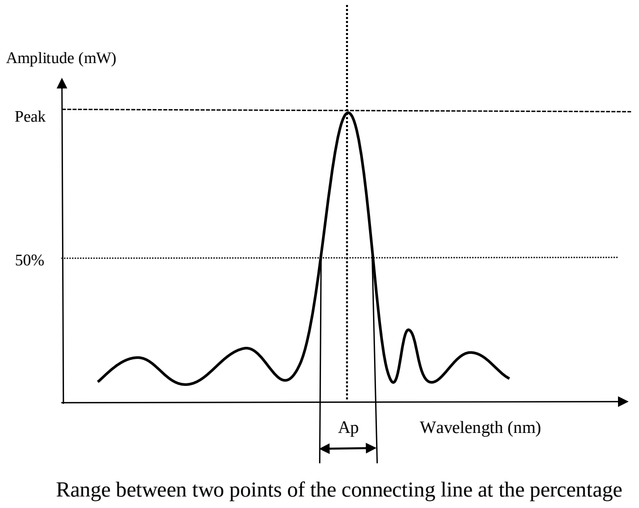


Figure 2- 3 SMSR test principles for the single-longitudinal mode laser

2.3.2 Block Diagram

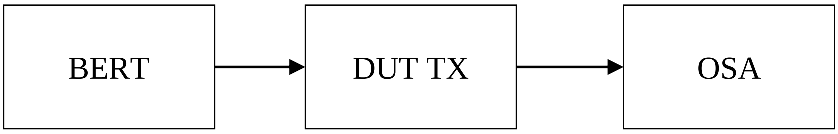


Figure 2- 4 SMSR test

2.3.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-4.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Determine the **'SMSR'** using the **OSA**.

Note:

- Ensure the OSA is set to vacuum mode prior to taking the measurement.
- The wavelength scanning range of the **OSA** is advised to be set at 20 nm, and the wavelength scanning accuracy is advised to be set at 0.02 nm.

2.4 RMS Spectral Width

2.4.1 Definition

The term **'RMS spectral width'**, a specific attribute of multi-longitudinal mode lasers, is determined by considering all longitudinal modes where the peak power is above a -20dB threshold. The unit is nm. Refer to Figure 2-5 for the conceptual framework of the test. For the calculation, apply Equations 2-1 and 2-2 accordingly.

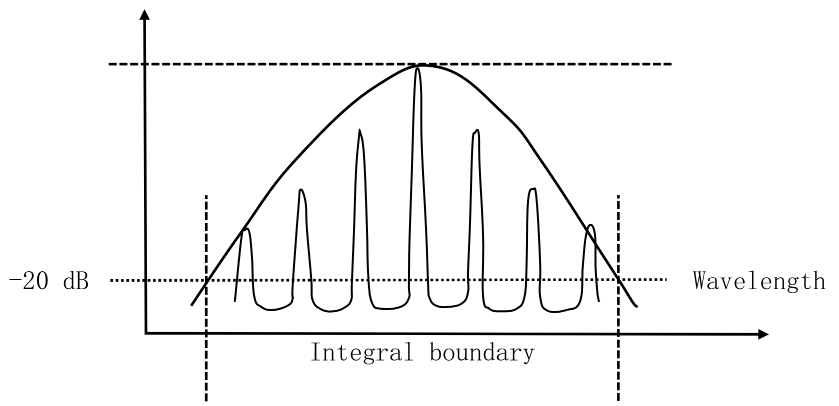


Figure 2- 5 RMS spectral width test principles

Equation 2-1: $$\Delta\lambda_{RMS} = \left[\frac{\Sigma P_i \times (\lambda_i - \lambda_c)^2}{\Sigma P_i}\right]^{\frac{1}{2}}$$

Equation 2-2: $$\lambda_c = \frac{\Sigma P_i \times \lambda_i}{\Sigma P_i}$$

Where:

$\Delta\lambda_{RMS}$: the **'RMS spectral width'**

λ_i: wavelength of the *i*th longitudinal mode

P_i: power of the *i*th longitudinal mode

2.4.2 Block Diagram

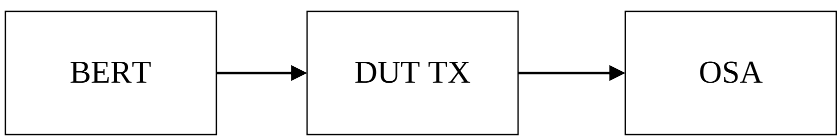


Figure 2- 6 RMS spectral width test

2.4.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-6.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Set the threshold and k value for the **OSA**.

Note: The threshold of the **OSA** is advised to be set at 20.00dB and k is advised to be set at 2.00.

d Determine the spectral width Δλ using **OSA**. The **'RMS spectral width'** is Δλ divided by 2.

2.5 Average Optcial Power

2.5.1 Definition

The term **'average optical power'** refers to the mean output optical power measured across all lanes under defined operating conditions. The unit is dBm.

2.5.2 Block Diagram

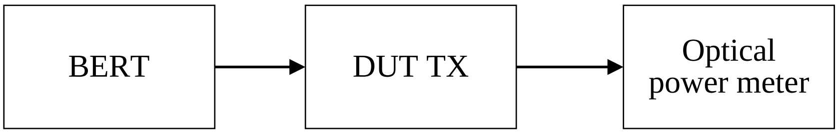


Figure 2- 7 Average optical power test

2.5.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-7.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Determine the **'average optical power'** using **Optical power meter**.

2.6 Average Launch Power of OFF Transmitter

2.6.1 Definition

The term **'average launch power of an OFF transmitter'** refers to the optical power emitted when the laser of a single lane is deactivated. The unit is dBm.

2.6.2 Block Diagram

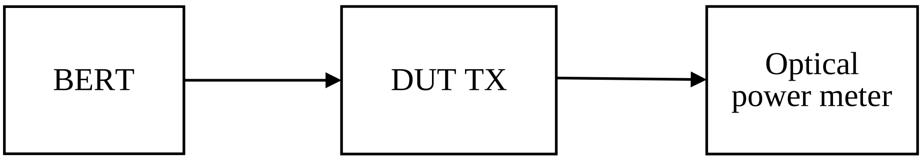


Figure 2- 8 Average launch power of off transmitter test

2.6.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-8.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Configure the protocol register of the **DUT** to disable the transmit optical power of the lane under test.

d Determine the '**average launch power of OFF transmitter'** using the **Optical power meter**.

2.7 Extinction Ratio

2.7.1 Definition

The term '**extinction ratio**' of PAM4 signal is defined as the ratio of the average optical launch power level P_3, measured over the central 2 UI of a run of 7 threes, and the average optical launch power level P_0, measured over the central 2 UI of a run of 6 zeros, as shown in Figure 2- 9. The unit is dB.

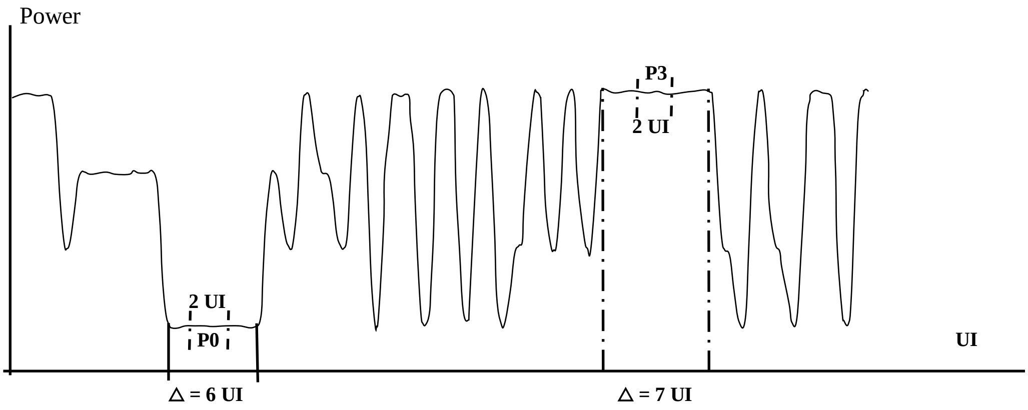


Figure 2- 9 Example power levels P_0 and P_3 from PRBS13Q test pattern

2.7.2 Block Diagram

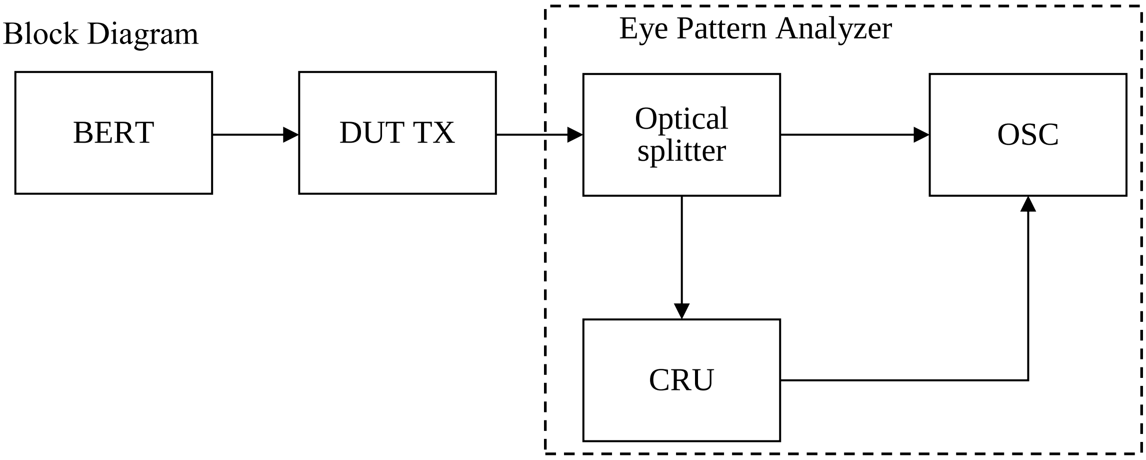


Figure 2- 10 Extinction ratio test

2.7.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-10.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Determine the '**ER**' using the **Eye Pattern Analyzer**.

Note:

- Perform **OSC** dark current calibration and enable pattern lock before reading the result.

2.8 Outer Optical Modulation Amplitude(OMA_{outer})

2.8.1 Definition

The term '**outer optical modulation amplitude**' of PAM4 signal is defined as the difference between the average optical launch power level P_3, measured over the central 2 UI of a run of 7 threes, and the average optical launch power level P_0, measured over the central 2 UI of a run of 6 zeros, as shown in Figure 2-11. The unit is dBm.

2.8.2 Block Diagram

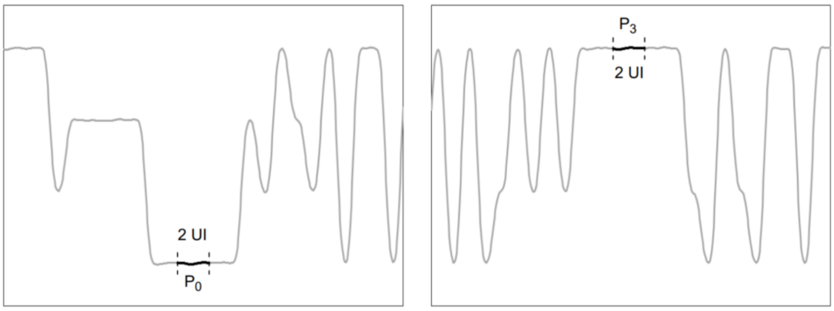


Figure 2- 11 Example power levels P_0 and P_3 from PRBS13Q test pattern

OMA_{outer} can be written mathematically as:

Equation 2-3: $OMAouter = P_3\text{-}P_0$

Equation 2-4: $P_{mean} = (P_3+P_0)/2$

Equation 2-5: $ER=P_3/P_0$

Through algebraic manipulation of Equations 2-3, 2-4 and 2-5, the following relationship can be obtained:

Equation 2-6: $OMA_{outer} = 2\times P_{mean}\times (ER_{outer}-1)/(ER_{outer}+1)$

Where:

P_3 is the average value of 2 UI in the middle of 7 consecutive 3-level bits, the unit is W.

P_0 is the average value of 2 UI in the middle of 6 consecutive 0-level bits, the unit is W.

P_{mean} is close to the mean of the light levels for "3-level" and "0-level", the unit is W.

ER_{outer} is the extinction ratio, the unit is dB.

2.8.3 Test Steps

a Record and document the **'average optical power'** for each lane as detailed in Chapter 2.5 .

b Record and document the '**extinction ratio**' for each lane as detailed in Chapter 2.7

c Calculate the **'OMA_{outer}'** value using the formula provided in Equation 2-6.

2.9 Transmitter and Dispersion Eye Closure for PAM4 (TDECQ)

2.9.1 Definition

The term '**TDECQ**' quantifies the vertical eye closure for optical transmitters under worst-case channel conditions as defined by IEEE 802.3-2018, Section 121.8.5.2. The measurement is obtained using an O/E converter and oscilloscope that meet the frequency response criteria outlined in Section 121.8.5.1 and is further refined through equalization with a reference equalizer, as detailed in Section 121.8.5.4. The reference receiver and equalizer can be software-based or integrated into an OSC which can be called Eye patter analyzer. The unit is dB.

2.9.2 Block Diagram

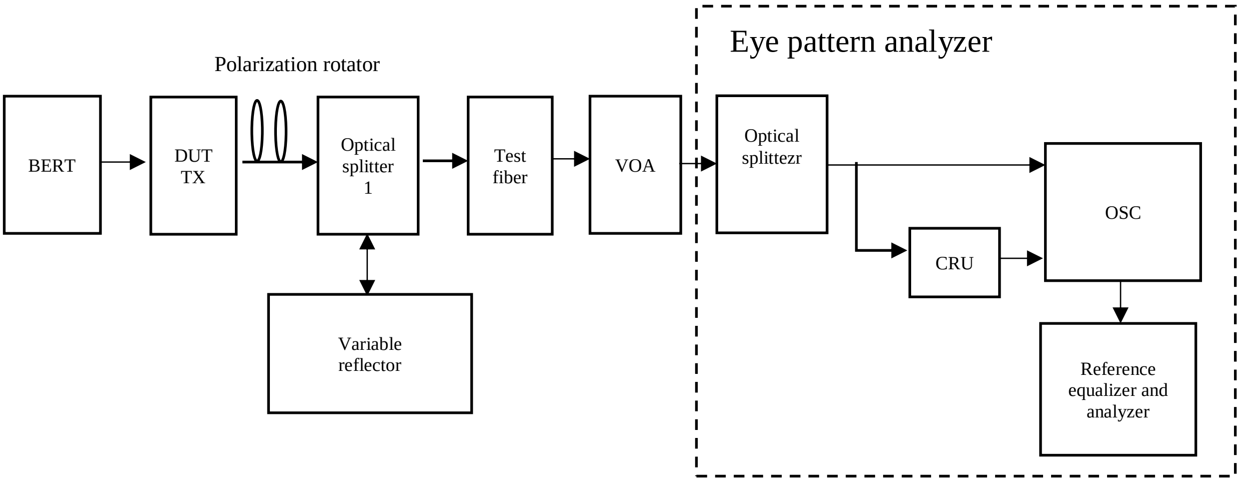


Figure 2- 12 TDECQ test

2.9.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2- 12. Other equivalent measurement implementations may be used with suitable calibration.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Fine-tune the settings of **Optical Splitter 1** and the **Variable Reflector** to achieve the required optical return loss for testing each lane's transmitter. Additionally, manipulate the **Polarization Rotator** state of the reflected light to maximize the RIN.

d Verify that both the **Test fiber** and **Optical attenuators** comply with the established specifications.

Note:

- The length of the **Test fiber** is advised to be set at 3m.

e Determine the '**TDECQ**' using **Eye pattern analyzer.**

Note:

- Configure the pattern-triggered Oscillograph **(OSC)** to capture the complete pattern for TDECQ analysis. The eye diagram is formed based on **CRU**. TDECQ is given after the equalization with the **Reference equalizer and analyzer**.

- The **Reference equalizer and analyze**r for TDECQ is a 5 tap, T spaced, feed-forward equalizer (FFE), where T is the symbol period. The sum of the equalizer tap coefficients is 1.
- The combination of the O/E and the **OSC** has a fourth-order Bessel-Thomson filter response with a bandwidth of approximately 13.28125GHz. Compensation may be made for any deviation from an ideal fourth-order Bessel-Thomson response.
- The test pattern (specified in Table 2-2) is transmitted repetitively by the optical lane under test and the **OSC** is set up to capture the complete pattern for TDECQ analysis as described in *IEEE 802.3-2018 121.8.5.3*. The **CRU** has a corner frequency of 4MHz and a slope of 20dB/decade. The **CRU** can be implemented in hardware or software depending on **OSC** technology.

2.10 Transmitter Transition Time

2.10.1 Definition

The term **'Transmitter transition time'** is defined as the slower of the time intervals of the signal to transition between 20% and 80% of OMA_{outer} levels for both rise and fall edges, as detected by an O/E converter and oscilloscope. The O/E and oscilloscope must have a combined 3 dB bandwidth near 26.5625 GHz and maintain a fourth-order Bessel-Thomson response up to at least 1.3 times 53.125 GHz. Beyond this frequency, the response must remain above –20dB. Adjustments should be applied to correct for any variance from the ideal fourth-order Bessel-Thomson response curve. The unit is ms.

The OMA_{outer} measurement procedure (IEEE 802.3cu-2021, Section 151.8.4) establishes P_0 as the 0% level and P_3 as the 100% level, allowing for the use of a square wave pattern in the test. When applying the SSPRQ pattern for measurement, identify the rising edge within a '000003333333' sequence and the falling edge within a '333330000000' sequence.

2.10.2 Block Diagram

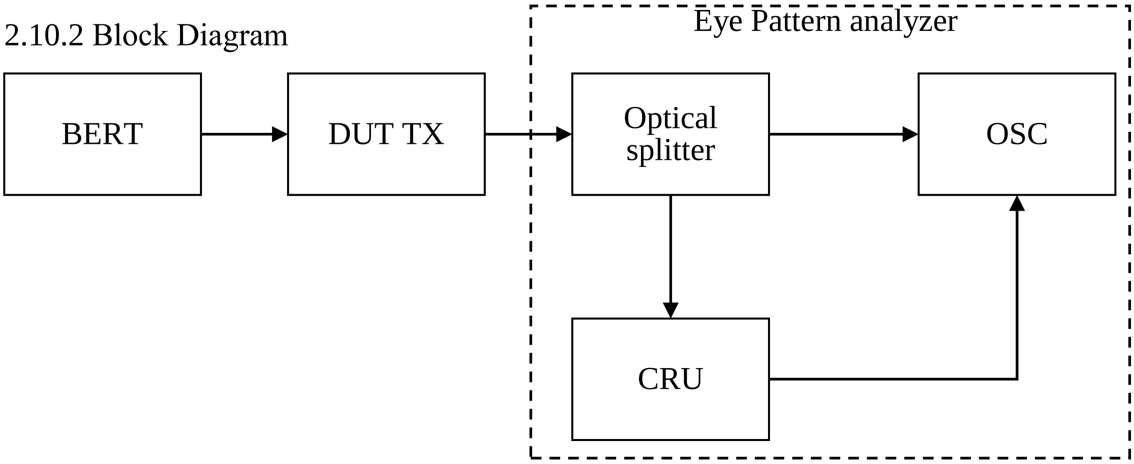


Figure 2- 13 Transmitter transition time test

2.10.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-13.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Determine the rising time and falling time using the **OSC**.

Note:

- Enable pattern lock before reading.
- Set the **CRU** with a corner frequency of 4 MHz and a slope of 20 dB/decade. Additionally, the integrated O/E converter and oscilloscope feature a fourth-order Bessel-Thomson filter response with a bandwidth of roughly 26.5625GHz.

2.11 RINxOMA

2.11.1 Definition

The term '**relative intensity noise optical modulation amplitude (RIN_xOMA)**' comparing the noise at 3-level and 0-level noise of the laser output optical signal within a specified bandwidth and under defined reflected optical power conditions, as detailed in Equation 2-7. The unit is dB/Hz.

Equation 2-7: $RIN_xOMA = 10\lg (RN_{three} + RN_{zero})/(OMA \times BW)$

RIN_xOMA: relative intensity noise optical modulation amplitude in dB/Hz.

RN_{three} : 3-level random noise power in W.

RN_{zero} : 0-level random noise power in W.

OMA : optical modulation amplitude in W.

BW : bandwidth of low-pass filter in Hz.

2.11.2 Block Diagram

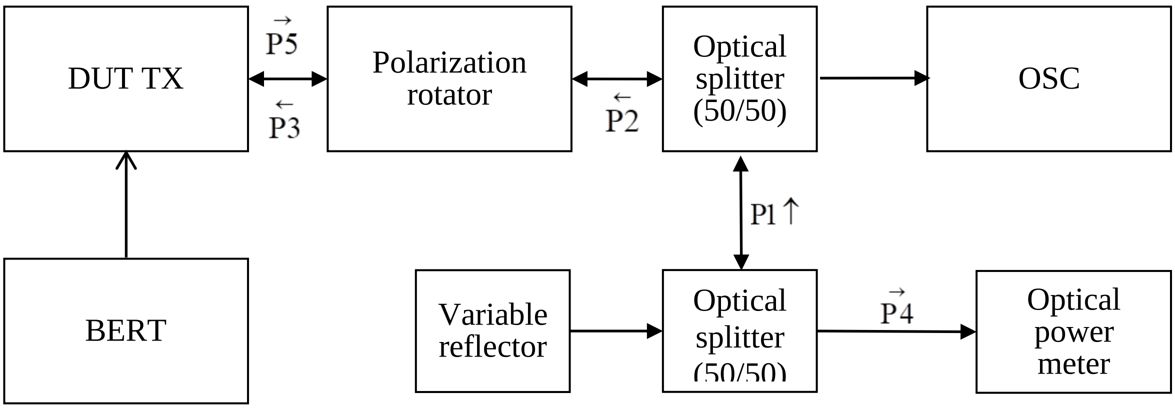


Figure 2- 14 RIN_xOMA test

2.11.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-14.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Determine P1, P2, P3, P4, P5 defined in Figure 2-14 using the **Optical power meter**.

d Calculate as follows: $\Delta P1 = P1 - P4$, $\Delta P2 = P2 - P1$, $\Delta P3 = P3 - P2$. Then, calculate the reflected optical power as follows: $Pr = P4 + \Delta P1 + \Delta P2 + \Delta P3$, $x = |Pr - P5|$, x should meet specified return loss.

e Prevent the optical power of the **DUT** reaching the **OSC.** Activate the **OSC** optical port and utilize a histogram to measure the background noise. Calculate the RMS of the random noise power to determine the standard deviation and establish the compensation value for noise test results.

Note: The upper –3 dB bandwidth limit of the measurement apparatus is to be equal to the signaling rate (i.e., 53.125 GHz).

f Direct the DUT's optical power to **OSC** optical port using a short optical fiber patch cord (<2m). Then utilize the **OSC** to measure the random noise power at both the 3-level random noise power (RN_{three}) and the 0-level random noise power (RN_{zero}) of the DUT optical eye diagram.

g Determine the optical modulation amplitude depicted in Chapter 2.8 .

h Calculate the RIN_xOMA value using the formula provided in Equation 2-7.

2.12 Transmitter Eye Closure for PAM4 (TECQ)

2.12.1 Definition

The term '**transmitter eye closure for PAM4 (TECQ)**' test evaluates the performance of an optical module transmitter by quantifying the optical power penalty relative to that of an ideal transmitter. The unit is dB.

Calculate the '**TECQ**' value using the following formula:

Equation 2-8**:** $TECQ = 10 \times \lg[OMA_{outer} / (6 \times Q_t \times R)]$

Where:

OMA_{outer}: outer optical modulation amplitude.

Q_t : 3.414, consistent with the target symbol error ratio for Gray coded PAM4.

R : derived from the equation: $R = \sqrt{\sigma_{G2} + \sigma_{S2}}$

σ_S : standard deviation of the noise of the O/E and oscilloscope combination.

σ_G : Gaussian probability density functions centered around the sub-eye thresholds.

2.12.2 Block Diagram

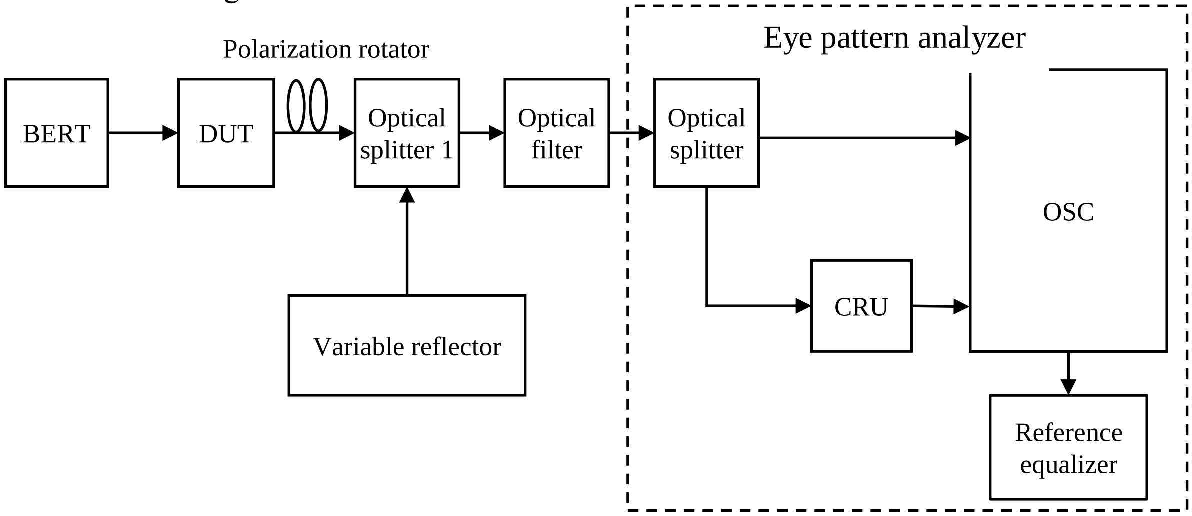


Figure 2- 15 TECQ test

2.12.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-15.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Fine-tune the **Optical splitters 1** and **Variable reflector** to achieve the desired optical return loss for the transmitter.

d Use **Polarization rotator** to set the state of polarization of the back reflection.

e Determine the '**TECQ**' value using the **Eye pattern analyzer**.

Note:

- Set the CRU with a corner frequency of 4 MHz and a slope of 20 dB/decade.
- Select the bandwidth with a fourth-order Bessel-Thomson filter response specified for the module test.
- Configure the **OSC** to capture the complete pattern before reading the result.

2.13 Over/under-shoot

2.13.1 Definition

The term '**overshoot'** is defined as the maximum power above the 3-level power relative to '**OMA$_{outer}$**', calculated as Equation 2-9.The unit is %.

Equation 2-9: Overshoot = $(P_{max} - P_3)/OMA_{outer} \times 100$

The '**undershoot**' is defined as the minimum power from the transmitter (P_{min}) below the 0-level power relative to the 'OMA$_{outer}$', calculated as Equation 2-10.The unit is %.

Equation 2-10: Undershoot = $(P_0 - P_{min})/OMA_{outer} \times 100$

Where:

P_{max} : is based on a 10^{-2} or $3x10^{-3}$ hit ratio, where P_{max} is the smallest power level that results in the number of samples above that level not exceeding the product of the hit ratio and total number of observed samples, with all samples acquired in a single unit interval eye diagram. The unit is W.

P_{min} : is based on a 10^{-2} or $3x10^{-3}$ hit ratio, where P_{min} is the largest power level that results in the number of samples below that level not exceeding the product of the hit ratio and total number of observed samples, with all samples acquired in a single unit interval eye diagram. The unit is W.

P_3 : is the power of the PAM4 3-level defined in *IEEE 802.3cu-2021 122.8.4*.

P_0 : is the power of the PAM4 0-level defined in *IEEE 802.3cu-2021 122.8.4*.

OMA_{outer}: is the outer optical modulation amplitude defined in Chapter 2.9

2.13.2 Block Diagram

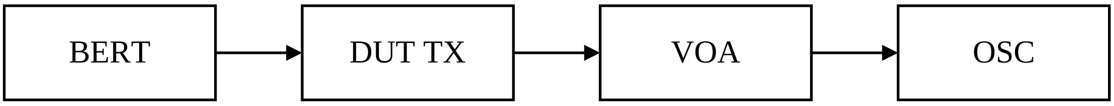


Figure 2- 16 Overshoot/undershoot test

2.13.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-16.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Use the waveform captured from the TDECQ test (reference Chapter 2.9) and the waveform captured from TECQ test (reference Chapter 2.12), ensuring the reference equalizer being is not engaged for either test scenario. Determine the P_{max}, P_{min}, P_3 and P_0(defined in chapter 2.13.1) using the **OSC**.

d Record and document the '**OMA_{outer}**' values of each lane as specified in Chapter 2.9

e Calculate the **'overshoot'** and '**undershoot**' values using the formula provided in Equation 2-9 and Equation 2-10, respectively.

2.14 Transmitter Power Excursion

2.14.1 Definition

The term **'transmitter power excursion'** is calculated using the formula provided in Equation 2-11.The unit is dBm.

Equation 2-11**:** Transmitter power excursion = max ($P_{max} – P_{average}$, $P_{average}$ - P_{min})

Where:

P_{max} and P_{min} : defined in Chapter 2.13.

$P_{average}$: defined in Chapter 2.5 .

2.14.2 Block Diagram

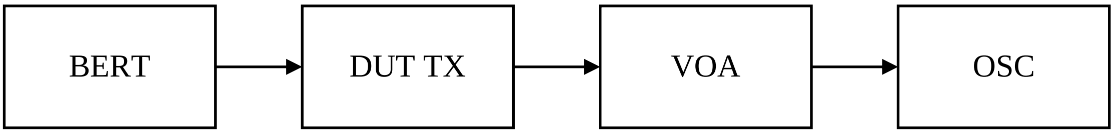


Figure 2- 17 Transmitter power excursion test

2.14.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-17.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Use the waveform captured from the TDECQ test (reference Chapter 2.9) and the waveform captured from TECQ test (reference Chapter 2.12), ensuring the reference equalizer being is not engaged for either test scenario. Determine the P_{max}, P_{min} using the **OSC**.

d Record and document the OMA_{outer} values of all lanes as specified in Chapter 2.9

e Calculate the **'transmitter power excursion'** values using the formula given in Equation 2-11.

2.15 Receive Power (OMAouter)

2.15.1 Definition

The term '**receive power (OMA_{outer})**' is defined as outer optical modulation amplitude of the receive power per lane. The unit is dBm. Calculate receive power (OMA_{outer}) using the formula provided in Equation 2-12:

$$P_{r(OMA)} = 10 \times \log_{10}\left(2 \times 10^{\frac{P_r}{10}} \times \frac{10^{\frac{ER}{10}} - 1}{10^{\frac{ER}{10}} + 1}\right)$$

Equation 2-12:

Where:

$P_{r(OMA)}$: 'receive power(OMA_{outer})'.

P_r: receive power.

ER: 'ER' defined in Chapter 2.7 .

2.15.2 Block Diagram

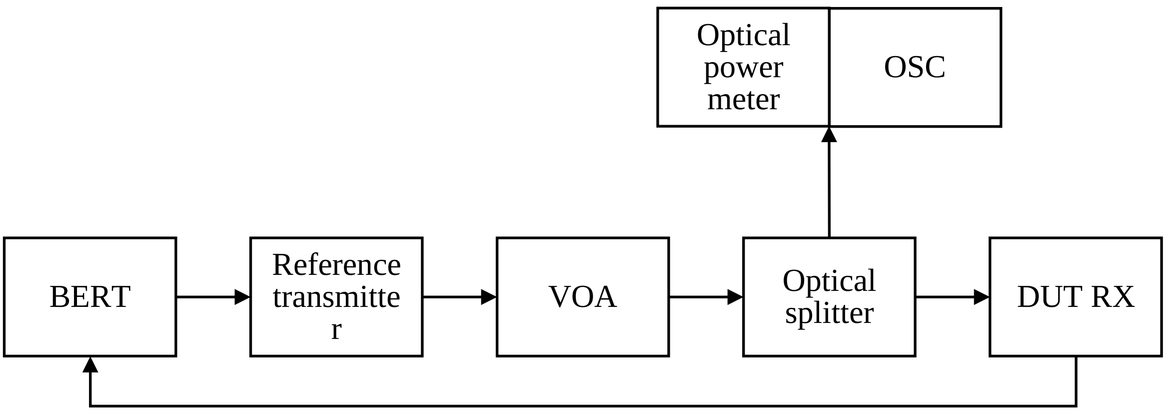


Figure 2- 18 Receive power (OMAouter) test

2.15.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-18.

b Adjust the launch optical power of the **Reference transmitter** and record the receive power (P_r) of each lane.

c Record and document the '**ER**' value of each lane by as specified in Chapter 2.7

d Calculate the '**receive power (OMAouter)**' using the formula provided in Equation 2-12.

Note: The SECQ of **Reference transmitter**'s optical eye is 0.9 dB (an ideal input signal without overshoot). The test signal should have negligible impairments such as inter-symbol interference (ISI), rise/fall times, jitter and RIN.

2.16 Receiver Sensitivity (OMA_{outer})

2.16.1 Definition

The receiver sensitivity is defined as the minimum average optical power per lane when the specified BER of the optical module is met at the specified modulation rate. The unit is dBm.

The term '**receiver sensitivity (OMA_{outer})**' is defined as optical modulation amplitude of the receiver sensitivity. The unit is dBm.

2.16.2 Block Diagram

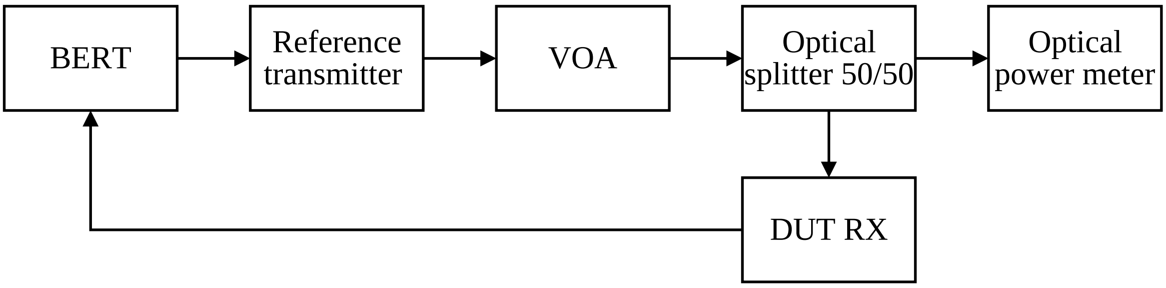


Figure 2- 19 Receiver sensitivity test

2.16.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-19.

d Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

b Fine dune the attenuation value of the **VOA** to gradually reduce the optical power received by the **DUT**, until the BER detected by **BERT** increases to the specified value.

Note: The step of adjusting the **VOA** is advised to be set at 0.5dB until the measured BER is around 1E-6. The step of adjusting the **VOA** is advised to be set at 0.1dB until the measured BER rests stably at 2.4E-4.

c Measure the optical power with the '**Optical Power Meter**' to obtain the receiver sensitivity.

d Record and document the '**ER**' of each lane as specified in Chapter 2.7

e Calculate the '**Receiver sensitivity (OMA_{outer})**' using the formula provided in Equation 2-12.

Note:

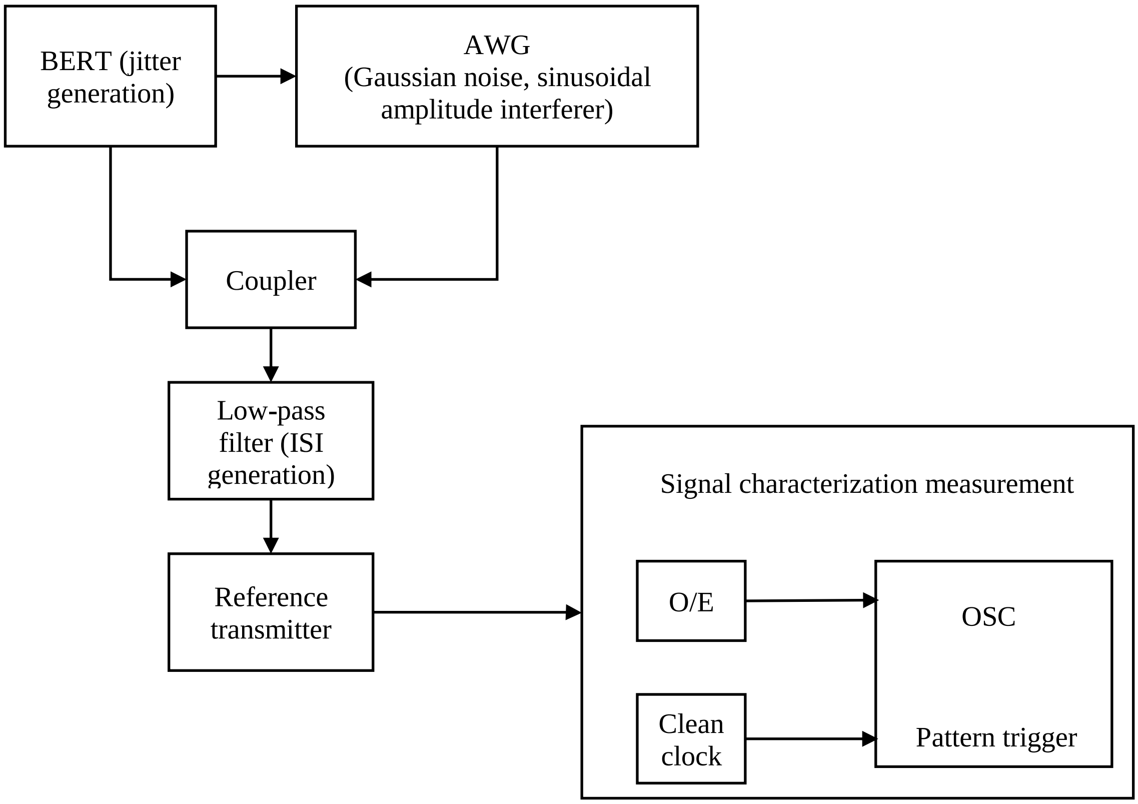
1. The SECQ of **Reference transmitter's** optical eye is 0.9 dB (an ideal input signal without overshoot). The test signal should have negligible impairments such as inter-symbol interference (ISI), rise/fall times, jitter and RIN.

2.17 Stressed Receiver Sensitivity

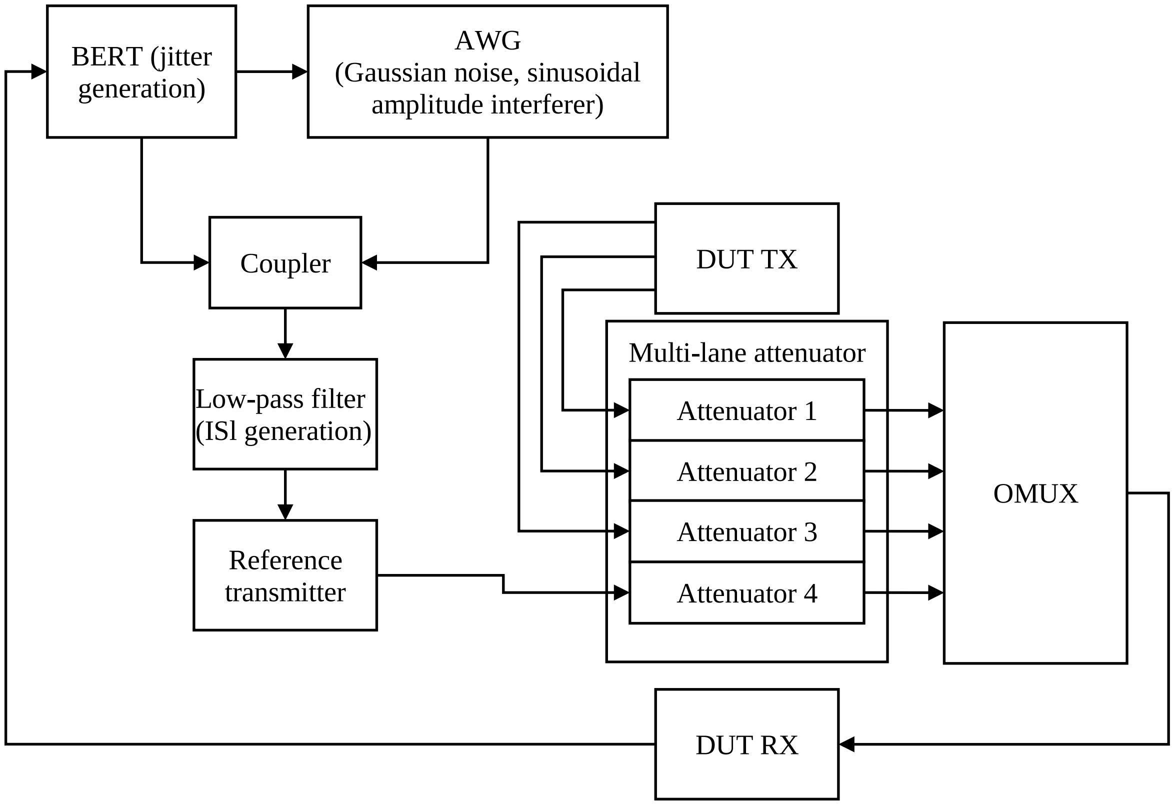
2.17.1 Definition

The term **'stressed receiver sensitivity'** is defined as the minimum average optical power per lane when the specified BER of the optical module is met at the specified modulation rate under specified pressurization conditions. The unit is dBm.

2.17.2 Block Diagram



(a) Stressed eye calibration test



(b) Stressed receiver sensitivity test

Figure 2- 20 Stressed receiver sensitivity test

2.17.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2- 20.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Turn off the **BERT**'s jitter generation, the **AWG**'s noise and sinusoidal interference outputs. Configure the external modulator and light source, including setting the optical power and determining the modulator's operating point.

d Evaluate the optical eye pattern for the signals emitted by the modulator, confirming that the ER exceeds the minimum threshold stipulated by the protocol. It is mandatory to utilize polarization-maintaining fibers in conjunction with the external modulator and light source.

e Perform the SECQ calibration, which follows the TDECQ method except for the absence of the test fiber. For calibration, if no interference or jitter is added, employ a low-pass filter with a variable cut-off frequency to produce half of the SECQ value. Utilize the the **BERT** and **AWG** to adjust for sinusoidal interference, sinusoidal jitter, and Gaussian noise contributing to the remaining half. Ensure that the sinusoidal peak-to-peak (UI) and the frequency spectrum conform to the protocol' criteria outlined in Table 2-3.

Table 2- 3 Applied sinusoidal jitter

Frequency Range	Sinusoidal Jitter, Peak-to-Peak (UI)
f < 40 kHz	Not specified
40 kHz < f ≤ 4 MHz	$2 \times 10^5/f$

4 MHz < f < 10 *LB*[a]	0.05
[a]*LB* = loop bandwidth: upper frequency bound for added sine jitter should be at least 10 times the loop bandwidth of the receiver being tested.	

Note:

- Although the protocol does not specify sinusoidal interference and Gaussian noise levels, adjust them according to site-specific requirements

f Verify that the optical stressed eye's parameters—ER, SECQ, and OMA—comply with the protocol's stipulations.

g Replace the eye pattern analyzer system with the stressed receiver sensitivity system, as depicted in Figure 2-20(b), maintaining the stressed eye calibration parameter adjustments and switching the test modulation format to PRBS31Q.

h Carry out the stressed receiver sensitivity test in accordance with the setup illustrated in Figure 2-20.

2.18 Optical Return Loss Tolerance

2.18.1 Definition

The term '**optical return loss tolerance (max)**' is the ratio of the **'average launch power'** to the maximum returned optical power that can be tolerated. The unit is dB.

2.18.2 Block Diagram

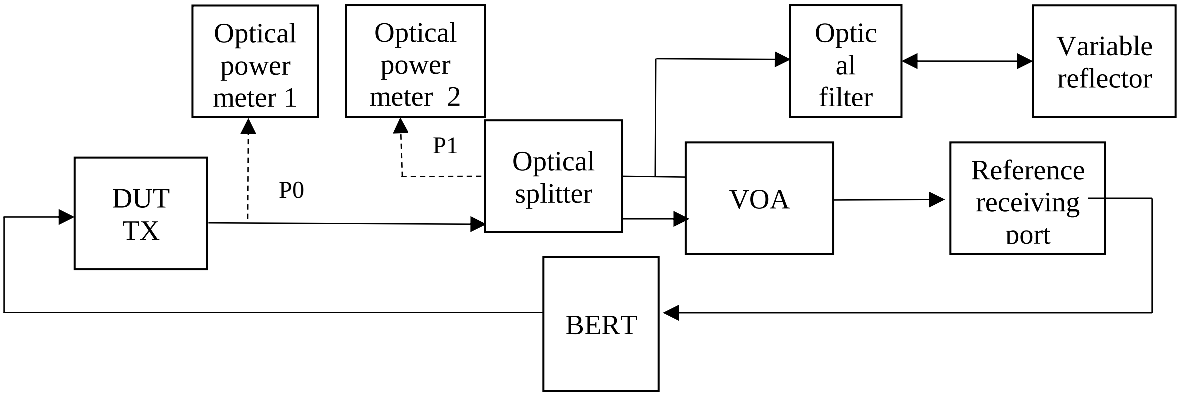


Figure 2- 21 Optical return loss tolerance test

2.18.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-21.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Disconnect the variable reflector and terminate the corresponding port. Measure the launch optical power P0(in dB) of the optical module using **Optical Power Meter_1** while maintaining an error-free transmission condition.

d Fine-tune the **VOA** so that the optical power at the **Reference receiving**'s input aligns with the receiver sensitivity threshold.

e Attach the **Variable reflector** and adjust its settings to incrementally raise the optical reflectance level. When bit errors are detected, measure the reflected power P1 of the optical module using **Optical Power Meter_2**. Ensure that all relevant parameters, including **'TDECQ'** and **'SMSR'**, comply with the specified requirements.

f Calculate the **'optical return loss tolerance (max)'** as P0-P1.

2.19 Receiver Reflectance

2.19.1 Definition

The term **'receiver reflectance'** is the ratio of the incident optical power to the total returned optical power from the optical module receiver. The unit is dB.

2.19.2 Block Diagram

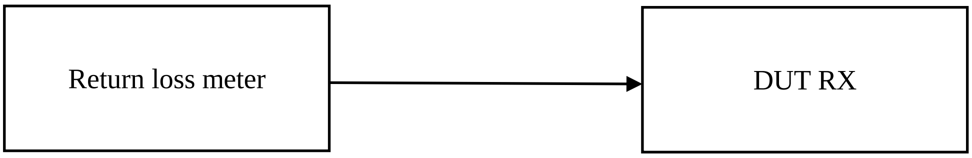


Figure 2- 22 Receiver reflectance test

2.19.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 2-22.

b Power down the **DUT** and configure the **Return Loss Meter**'s transmission wavelength within the operational wavelength range of the optical module.

Note: The light source of the **Return loss meter** should support tunable multi-wavelength.

c Read the '**reflection coefficient**' value on the **Return loss meter**.

Note: If the transmit wavelength of the **Return loss meter** cannot be set to a value within the working wavelength range of the optical module, use the circulator method.

3 Electrical Interfaces

The clause outlines various methods organized for industry reference during electrical interface testing.

3.1 Module Output Characteristics

3.1.1 Test Item

The test items of this clause are differential peak-to-peak output voltage, peak-to-peak AC common-mode Voltage, transition time and eye height.

3.1.2 Crosstalk Signal Calibration

a Assemble the test system in accordance with the schematic depicted in Figure 3-1.

b Calibrate the crosstalk signal at TP1a utilizing a QPRBS13-CEI pattern.

c The requirements for crosstalk parameters defined in *IEEE 802.3ck-2022 120G.3.2.2*.

3.1.3 Block Diagram

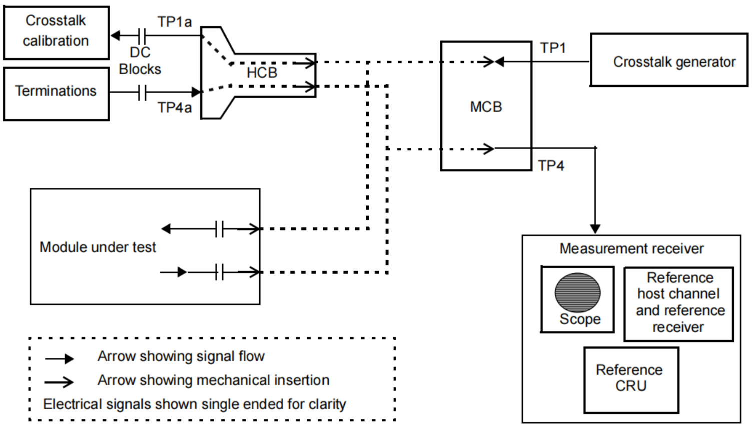


Figure 3- 1 Module output test configuration [3]

3.1.4 Test Steps

Assemble the test system in accordance with the schematic depicted in Figure 3-1. Add the pattern generator at TP1 and use the data pattern QPRBS13-CEI. Add crosstalk generators at all other lanes. Connect TP2 and TP3 of the optical module with a short optical fiber. The tested signal at TP4 is transmitted to the oscilloscope and the reference CRU with a microwave pike-off. The CRU uses a first-order transfer function with a 3 dB tracking bandwidth of fb/6640. Configure the oscilloscope to collect 10 samples/UI and 2048 samples/waveform. Stop the test when 10 patterns and 100 waveforms are collected.

3.1.4.1 Differential Peak-to-peak Output Voltage

a Observe the waveform through a fourth-order Bessel-Thomson filter response with a bandwidth of 40 GHz.

b Configure the oscilloscope to operate in eye/mask mode. Set up a vertical histogram with full display width.

c Determine the **'differential peak-to-peak output voltage'** by measuring the pk-pk value of the histogram.

3.1.4.2 Peak-to-peak AC Common-mode Voltage

a The oscilloscope bandwidth shall be 40 GHz.

b Waveforms are not triggered (free-run mode). Ensure that the oscilloscope, including its probes, has a bandwidth of at least 1.8 times the signaling rate to accurately capture the waveform.

c For common mode analysis, calculate the aggregate signal of the two inputs. Configure the oscilloscope's horizontal scale to fully encompass one unit interval (UI). Additionally, establish a vertical histogram that utilizes the full width of the display.

d Determine the RMS value from the histogram, which will serve as a measure of the signal's variability. The **'peak-to-peak AC common-mode voltage'** is the calculated as half the RMS value.

3.1.4.3 Transition Time

a Observe the waveform using a fourth-order Bessel-Thomson filter response with a 40GHz bandwidth.

b Measure the **'transition time'** within the sequences that follow a pattern of three consecutive -1s by three consecutive +1s, and three consecutive +1s by three consecutive -1s.

3.1.4.4 Eye Height

a Observe the waveform using a fourth-order Bessel-Thomson filter response with a 40GHz bandwidth.

b Use an oscilloscope to capture the differential signal at TP4, triggered by the clock signal from the reference CRU with a first-order transfer function and a 3 dB tracking bandwidth of fb/6640.

c Configure the oscilloscope for jitter/noise mode and set the measurement probability threshold to 10^{-6}.

d Employ a reference equipped with a CTLE to determine the eye diagram's width and height and incorporate a linearity test to the measurement process.

e Set the CTLE peaking in the reference receiver to 1dB, 1.5dB, or 2dB for the near-end test.

f Convolute the TP4 signal with a 7dB loss at fb/2 to simulate worst-case lane loss for the far-end compliance test. Set the reference receiver's CTLE peaking between 1dB and 9dB.

g Measure the **'eye height'** on the oscilloscope.

3.2 Module Stress Input Test

The ability of the module input to tolerate the specification defined in *IEEE 802.3ck-2022 Table 120G-9* under a stressed input test.

3.2.1 Module Input Signal Calibration

a Assemble the test system in accordance with the schematic depicted in Figure 3-2.

b Create a 12.2 dB signal loss at the Nyquist frequency for TP1a, derived from the pattern generator's output, which has an approximate rise/fall time of 10.5 picoseconds.

c Apply a QPRBS13-CEI pattern for calibrating the stressed input at TP1a and crosstalk at TP4.

d The requirements for crosstalk parameters defined in *IEEE 802.3ck-2022 120G.3.4.3.2*.

e Sinusoidal jitter (10x the reference CRU's bandwidth) and UUGJ are added to a clean test pattern until the jitter (except for EOJ) at the output of the pattern generator approximates the informative transmit recommendations defined in *IEEE 802.3ck-2022 120G.4.3.2*.

f Define the optimal CTLE peaking value as the one yielding the highest product of eye width and eye height. Modify the pattern generator's output settings to ensure this optimal peaking is at least 7dB.

g Fine-tune the Unequal Unit Interval Gaussian Jitter (UUGJ) and the amplitude of the pattern generator to achieve the smallest possible eye height, eye width, and linearity. Ensure that the upper and lower PAM4 eyes are reduced in size compared to the central eye, while still adhering to the minimum requirements for eye dimensions.

3.2.2 Block Diagram

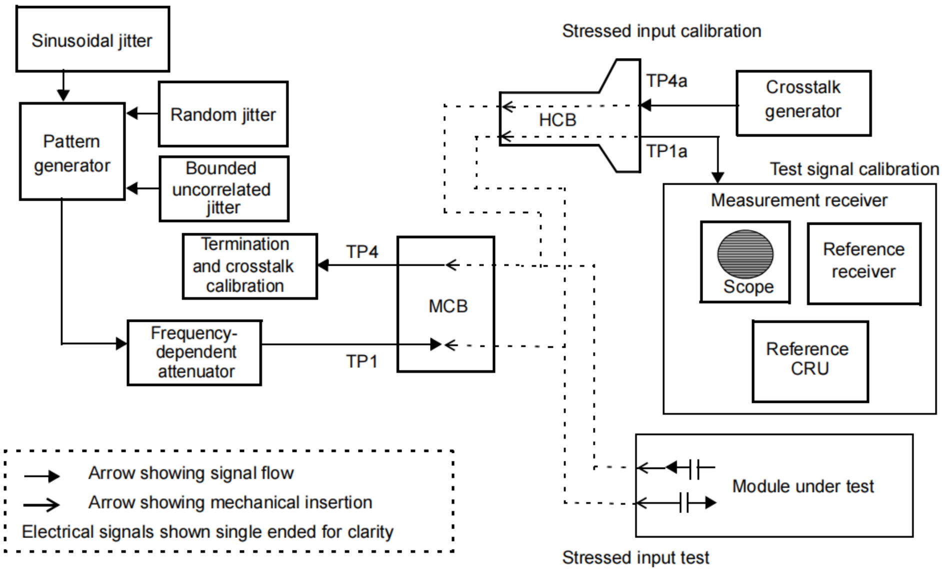


Figure 3- 2 Module stressed input test [3]

3.2.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 3-2.

b Connect RX and TX of the optical module's optical interface with a short optical fiber.

c Install the pattern generator at TP1, utilizing the QPRBS31-CEI data pattern.

d Deploy crosstalk generators across all other active lanes.

e Configure the sinusoidal jitter frequencies to fCRU/100, fCRU/3, fCRU, 3fCRU, and 10fCRU, where fCRU is the corner frequency derived from fb/6640.

f Ensure the module attains a raw BER of 10^{-6} or better during the stressed input test at TP4.

3.3 Mated HCB and MCB S-parameters

The reference mated MCB-HCB loss is given in Equation 3-1.

Equation 3-1: $SDD21, SDD12 = (-0.475)\sqrt{f} - 0.1204 f - 0.002 f^2$

(0.05 GHz < f < 29.0 GHz, f is frequency in GHz, loss in dB)

The FOMILD for the mated HCB and MCB pair is ≤ 0.1 dB.

4 Power Consumption

The clause outlines various methods organized for industry reference during power consumption test.

4.1 Definition

Power consumption is defined as the product of normal working voltage and current of a transceiver, and the unit is W.

Note:

Module power consumption generally refers to the maximum consumption value of the module operating in the full temperature range (for example, the operating temperature range of an industrial module is from –40°C to +85°C, and that of a commercial module is from 0°C to 70°C) and voltage range (for example, from 3.13 V to 3.47 V).

4.2 Block Diagram

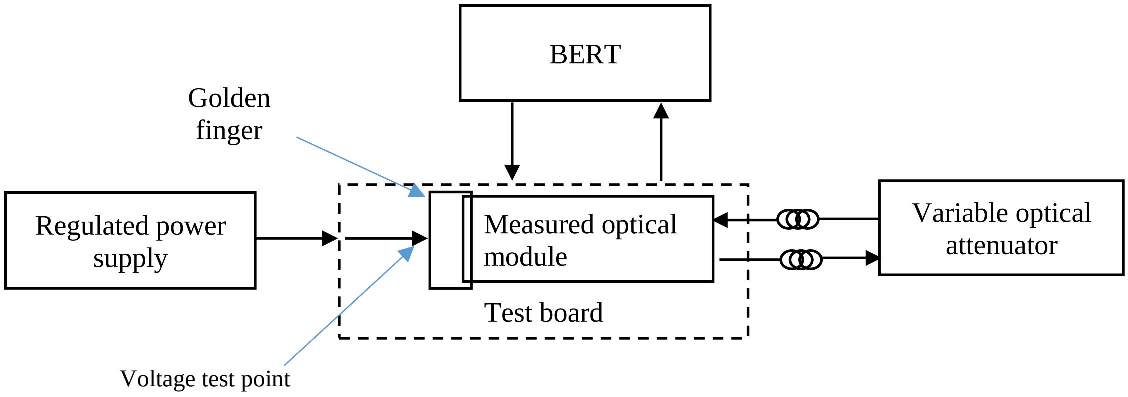


Figure 4- 1 Power consumption test

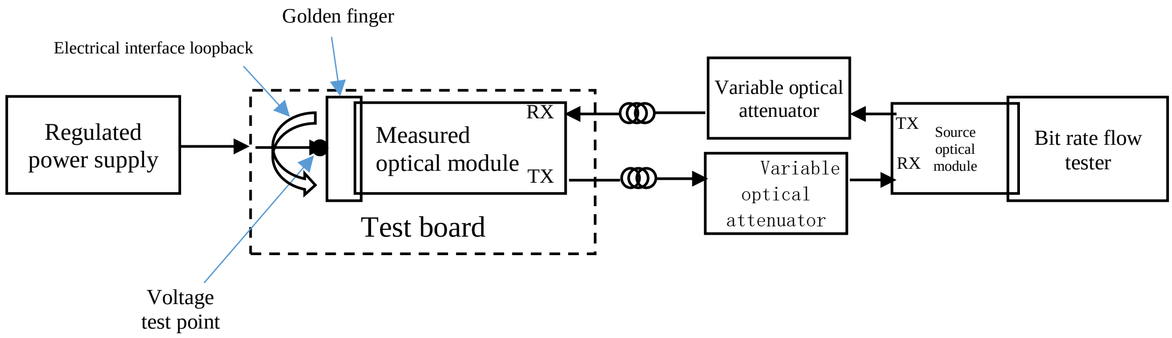


Figure 4- 2 Power consumption test

4.3 Test Steps

a Connect the test system according to Figure 4-1 or Figure 4-2.

b Set the rate, pattern, and amplitude for the output modulation signals of the BERT or bit rate flow tester with FEC function.

c Set the regulated power supply and output the specified voltage and current within the ranges.

d Adjust the variable optical attenuator so that the optical power entering the measured optical module receiver is within the normal operating range, to ensure that the measured optical module works properly.

e Use a multimeter to test the voltage at the voltage test point as close as possible to the golden finger and read the current values of the regulated power supply and multiply them to obtain the power consumption.

5 Interconnection and Interworking

The clause outlines various methods organized for industry reference during interconnection and interworking test.

5.1 Interworking Receiver Sensitivity(OMAouter)

5.1.1 Definition

The term interworking receiver sensitivity is defined as the minimum average optical power per lane within an interoperable network environment when the specified BER of the optical module is met at the specified modulation rate. The unit is dBm.

The term '**interworking receiver sensitivity (OMA$_{outer}$)**' is defined as optical modulation amplitude of the receiver sensitivity within an interoperable network environment. The unit is dBm.

5.1.2 Block Diagram

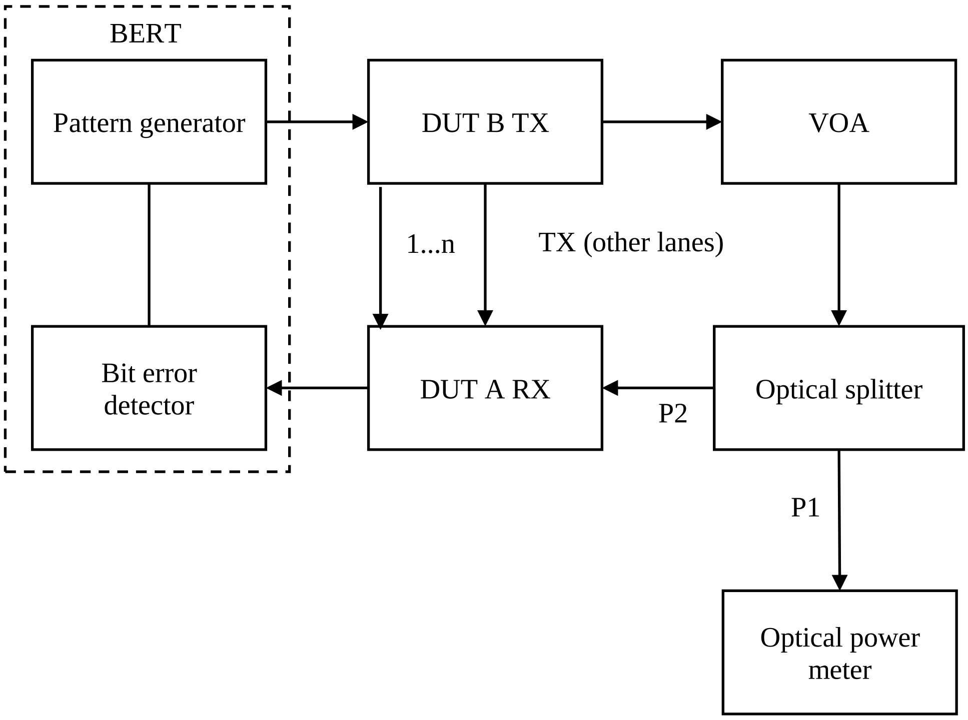


Figure 5- 1 Interworking Receiver sensitivity test

5.1.3 Test Steps

a. Assemble the test system in accordance with the schematic depicted in Figure 5-1.

b. Configure the BERT with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c. Measure the optical power values of the two output ports of the **Optical splitter** to P1 and P2 defined in Figure 10-1. Determine the optical power compensation value using the following equation: ΔP = P2 – P1. Then the receive optical power(P2) of the DUT can be calculated as P2=P1+ΔP.

d. Set the optical attenuator to 0 dB, allow a brief stabilization period, and once the **BERT** phase lock is confirmed and the BER reaches stability, record the BER value after a 3-second interval.

Note:

Determine the duration required for error bit accumulation during BER testing, given a 95% confidence level and a BER threshold of 2.4E-4, using the following equation:

Equation 5-1: $CL = 1\text{-}e^{-N_{\text{bits}} \cdot BER}$
Where:

CL: confidence level.

N_{bits}: the accumulation of bits sent by the pattern generator during the specified time interval.

BER: bit error ratio.

According to the calculation, the time interval for the accumulation of error bits is 2.35E-7s and the test duration is 3 seconds.

e. Fine-tune the VOA to achieve a measured BER approximately equal to 1E-6.

   Note: The step of adjusting the attenuation value is advised to be set at 0.5dB.

f. Fine-tune the VOA to achieve a measured BER approximately equal to 2.4E-4.

   Note: The step of adjusting the attenuation value is advised to be set at 0.1dB.

g. The received optical power and its corresponding BER are plotted on a BER curve. From this curve, the optical power required to achieve the target BER is determined, which is defined as the receiver sensitivity.

h. Record and document the ‘ER’ of each lane as detailed in Chapter 2.7

i. Calculate the ‘Receiver sensitivity (OMAouter)’ using the formula specified in Equation 2-12.

5.2 Interworking FEC Capability

5.2.1 Definition

For optical modules that have a built-in FEC function, the term ‘**interworking FEC Capability**’ is to verify the limit of the BER that can be corrected by FEC under interworking. For optical modules without built-in FEC function, the term ‘**interworking FEC Capability**’ is to verify correctable BER limit using the host under interworking.

5.2.2 Block Diagram

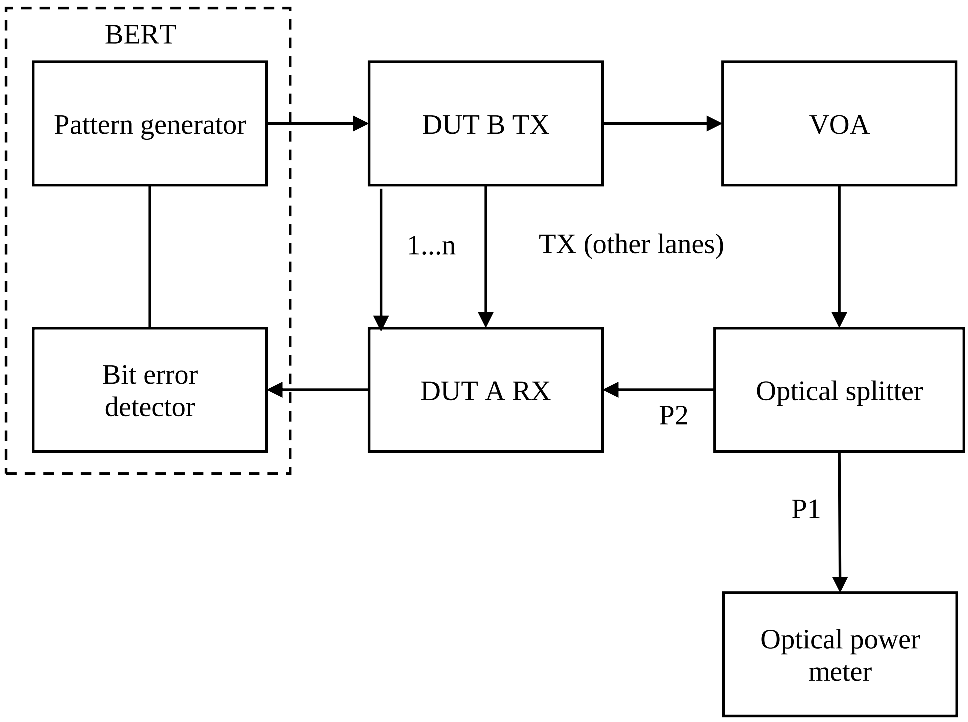


Figure 5- 2 Interworking FEC capability test

5.2.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 5-2.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Utilize **BERT** to document the distribution of bit errors.

d Incrementally decrease the receive optical power by fine-tuning the **VOA** settings and continue this adjustment until the bit errors indicated by the **BERT** are eliminated.

Note: It is recommended that the adjustment step of the attenuator be set to 0.5 dB and when receiver optical power approaches the receiver sensitivity limit, the adjustment step of the attenuator be set to 0.1dB.

e Evaluate the optical module's performance by documenting the bit error ratio in its uncorrected state and mapping the distribution of bit errors.

5.3 Interworking Receive Overload Power

5.3.1 Definition

The term '**interworking receive overload**' is defined as the maximum average optical power per lane under interworking when the specified BER of optical module is met at the specified modulation rate. The unit is dBm.

5.3.2 Block Diagram

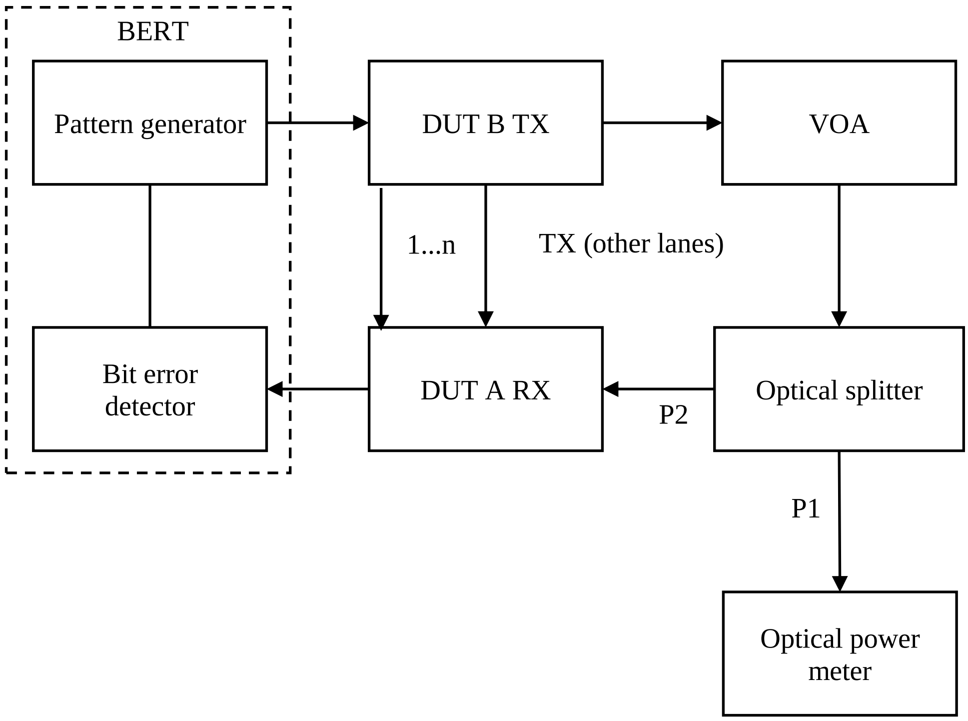


Figure 5- 3 Interworking overload optical power test

5.3.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 5-3.

b Configure the **BERT** with the desired output service rate, modulation format, amplitude, and other necessary parameters. Utilize the test pattern specified in Table 2-2.

c Incrementally decrease the receive optical power by fine-tuning the VOA settings and continue this adjustment until the bit rate detected by the **BERT** increases to the specified value.

Note: The power should not exceed the optical power damage threshold of the optical module.

d Read the optical power of the measured lane.

5.4 Interworking Transfer Delay

5.4.1 Definition

The term '**interworking transfer delay**' is the longest data transmission latency experienced when moving between disparate layers within an interoperable network environment.

5.4.2 Block Diagram

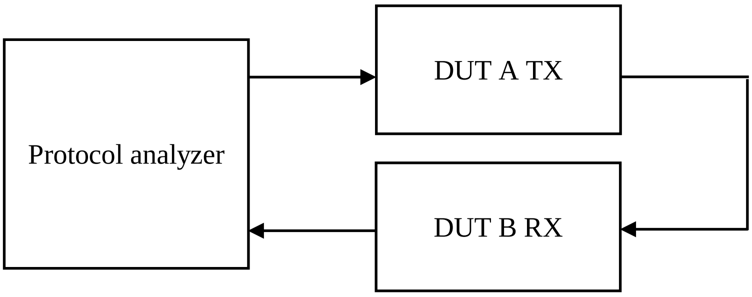


Figure 5- 4 Interworking transfer delay test

5.4.3 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 5-4.

b Configure the matched service on **Protocol analyzer.**

c Record the initial delay value T0 using the **Protocol analyzer**, ensuring that the optical module is not engaged in a self-loop configuration.

d Record the delay value T1 of the interworking system using **Protocol analyzer**, ensuring that the optical modules are connected in series.

e Calculate the 'interworking transfer delay' as T1 – T0.

5.5 Interworking Maximum Skew

5.5.1 Definition

The term '**Interworking Maximum Skew**' refers to the greatest disparity in timing between the first and last PCS lanes as they transition from a one to a zero state in the alignment marker sync bits within an interoperable network environment.

5.5.2 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 5-4.

b Configure the matched service on **Protocol analyzer** and it is necessary to calibrate the instrument for skew before commencing the test.

c Record the difference between the maximum lane and the minimum lane of the interworking system using **Protocol analyzer,** ensuring that the optical modules are connected in series. The difference is the 'interworking maximum skew'.

5.6 Interworking Maximum Skew Variation

5.6.1 Definition

Skew variation can occur as a result of fluctuations in electrical, thermal, or environmental conditions. The term **'interworking maximum skew variation'** describes the largest recorded difference in skew between any pair of PCS lanes during the entire active period of a link in an interoperable network setup.

5.6.2 Test Steps

a Assemble the test system in accordance with the schematic depicted in Figure 5-4.

b Configure the matched service on **Protocol analyzer** and it is necessary to calibrate the instrument for skew before commencing the test.

c Record the change value of skew in the same lane of the interworking system using **Protocol analyzer,** ensuring that the optical modules are connected in series.

d Record the skew change values of all lanes in the same way. Select the maximum skew change value and the minimum skew change value for the difference. The difference is the ‘interworking maximum skew variation’.

6 References

[1] IEEE Std 802.3 -2018: Standard for Ethernet.

[2] IEEE 802.3cu-2021: IEEE Standard for Ethernet - Amendment 11: Physical Layers and Management Parameters for 100 Gb/s and 400 Gb/s Operation over Single-Mode Fiber at 100 Gb/s per Wavelength.

[3] IEEE 802.3ck-2022：IEEE Standard for Ethernet Amendment 4: Physical Layer Specifications and Management Parameters for 100 Gb/s, 200 Gb/s, and 400 Gb/s Electrical Interfaces Based on 100 Gb/s Signaling.

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