

# Unveiling the secrets of 200G/400G optical transceivers

Validation of high-speed optical interfaces

app  
note

**EXFO**

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By Aldo Gutierrez, PhD.  
and Anabel Alarcon,  
Product Specialists,  
EXFO

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## Introduction

400G technologies are currently being rolled out thanks to advances in optical communications. However, this rapid data rate evolution is also stressing the development of network components, mainly pluggable optical transceivers—making it longer to achieve stable designs. Due to the wide-range presence of alpha and beta units in networks, the validation of transceivers is nowadays a highly-recommended task prior to installation and turn-up.

To meet the growing demands of traffic, transceiver vendors have adopted 4-level pulse amplitude modulation (PAM4) to implement 8 lanes of 50G or 4 lanes of 100G for different variants of OSFP and QSFP-DD, as an alternative to classical nonreturn-to-zero (NRZ)-based interfaces. The novel optical transceiver architectures support the transmission up to 400 Gbit/s Ethernet data over either multiwavelength or parallel fibers. However, the multilevel modulation involves a higher complexity for analysis, equalization and validation.

As a result, it is more complex to validate 400G interfaces because users must consider several aspects of the device under test (DUT) that can drastically impact performance (e.g., power consumption, temperature, skew and last stress test).

This application note presents the guidelines to perform the electrical and optical validation of 400G transceivers by using EXFO's most recent 400G solution, the FTBx-88460. Technical tips are also provided to help you in this challenging task.

## How to best validate 400G transceivers?

The validation of the quality of transceivers includes several electrical and optical tests. However, the setups are quite complex and expensive. Transceiver vendors are always on the lookout for simplified solutions capable to provide an accurate evaluation of bit error rate (BER), signal-to-noise ratio (SNR), temperature, electrical power consumption and optical power at the transmitter (Tx) and receiver (Rx) side, among others.

Most of the electrical signals of transceivers that are analyzed during the validation process are strongly related parameters of the eye diagram, such as the eye height, eye width and eye symmetry mask width. The modulation format in transmission, either NRZ or PAM4, rules the procedure to carry out the validation of the transceiver.

Over the past months, we have observed one request that keeps coming from network equipment manufacturers (NEMs), data centers and research labs. It is the development of tools for the analysis of the pluggable performance. Responding to these needs, EXFO has designed a solution that enables a comprehensive validation of transceivers, including electrical/optical tests, it also allows the enhancement of the transmitted signals by applying pre-emphasis procedures and Forward Error Correction (FEC) at Tx and compensating the losses with Equalization methods at Rx. The following sections cover key compliance tests using the FTBx-88640 module.



The advantages of PAM4 are counterweighted by the complexity to handle and analyze a four-level system.

## From NRZ to PAM4

Until recently, NRZ encoding has been historically the base of telecommunication networks. However, the need to optimize and to scale the network rates has led to implement multilevel pulsed amplitude encoding, being PAM4 the widest employed so far and its implementation is considered a milestone laying the foundations of the 100G and 400G transceivers.

NRZ is a two-level modulation technique, represented by logic 0 and logic 1. On the other hand, PAM4 encodes four levels, represented by four combinations of two bits logic: 00, 01, 10 and 11. In order to highlight the differences between both encoding techniques, the same bit stream (0,0,0,1,1,0,1,1,0,0,1,1,0,1) is represented in the figure below, using NRZ and PAM4 respectively:

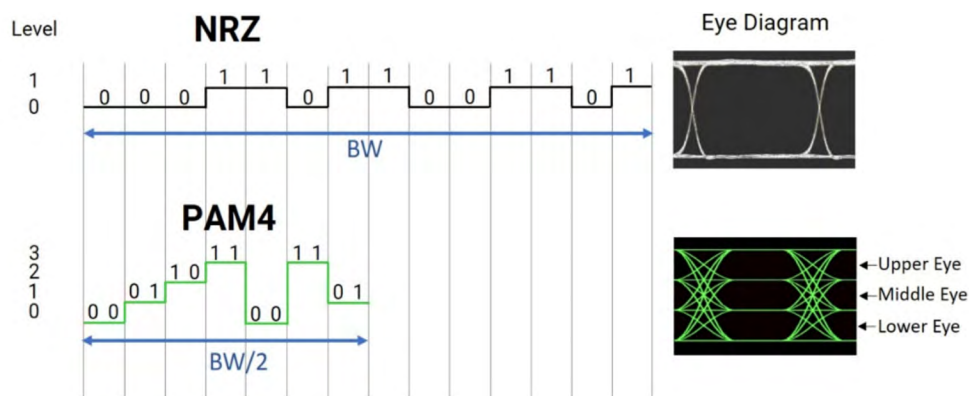


Figure 1. Waveforms and eye diagram representation for NRZ and PAM4 signals.

The PAM4 eye diagram presents three eye openings and four levels, as can be noticed in Figure 1. By increasing the number of levels of pulse-amplitude encoding, PAM4 doubles the number of bits per slot in serial data transmissions, which means that the density of data is doubled with respect to NRZ encoding, also the efficiency of Bandwidth (BW) is enhanced by two and the transmission cost is reduced.

PAM4 conveys 2 bits per symbol, thereby the bits-per-second rate is twice the symbol rate (also known as Baud). In current 50GE, 200GE and 400GE standards using PAM4 modulation at the electrical interface for instance, the symbol rate is 26.56 GBd corresponding to 53 Gbit/s. However, at the optical interface 400G-DR4 as an example uses 100 Gbit/s (with a corresponding 53 GBd PAM4).

The advantages of PAM4 are counterweighted by the complexity to handle and analyze a four-level system. In fact, one of the biggest concerns is that the SNR is reduced at least by factor 3 compared to NRZ, mainly because of the amplitude opening of the three PAM4-eyes. According to the IEEE 802.3bs standard, FEC has become mandatory in 200G and 400G interfaces due to the dramatic SNR drop. In this context, FEC provides the performance margin necessary to achieve a healthy BER value.

The FTBx-88460 module comes with an EtherBERT application, which allows the execution of BER test and the traffic generation of framed Ethernet from layer 2 to 4 and unframed 4, 8 and 16 for 200GAUI and 400GAUI interfaces. The unframed multilane testing in EtherBERT, provides a quick way to ensure that the link is condition appropriately, supporting the different patterns such as PRBS13Q, PRBS31Q and SSPRQ.

In addition, the FTBx-88460's GUI features a PAM4 histogram (shown in Figure 2), a reference tool for representing the 4 electrical levels of the modulation, enabling the real time PAM4 analysis per lane. As can be noticed in Figure 2, the PAM4 electrical levels and the eye openings represented in the histogram chart, have been 90° counterclockwise rotated with respect to the eye diagram.

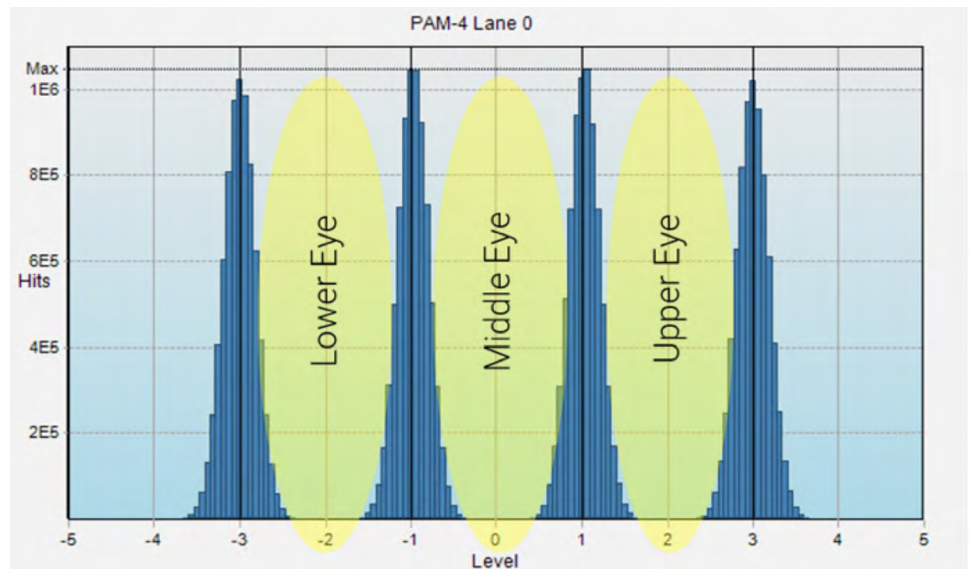


Figure 2. FTBx-88460's PAM4 histogram tool.

The FTBx-88460 also offers a suite for the pre-emphasis and equalization stages. This set of tools allows the user to adjust the Tx and the Rx parameters in order to transmit the maximum amount of information with the minimum amount of errors possible. By tuning the Tx and the Rx parameters of 200G and 400G PAM4-based transceivers, the eye-opening can be enhanced and finally verified with in the PAM4 histogram chart.

**Pre-emphasis** allows an analog enhancement of the signal being sent to the optical module. The TX signal manipulation is done per electrical lane improving the amplitude of each of the PAM4 eyes. The tuning to the Tx signal includes the relationship between the Pre, Main and Post cursor for a better definition of the three eyes on the PAM4 diagram per lane.

**Equalization** is the data filtering process applied on the Rx side, that attempts to reverse the distortion incurred by a signal transmitted through a channel. Equalization is useful in data communications to compensate the attenuation caused by the loss coming from line (either fiber, copper or even network elements back plane).

**Continuous time linear equalization (CTLE)** is one of the most popular equalizations implemented for PAM4 signals. It is a linear filter that boosts high-frequency signal components. CTLE is effective for reducing intersymbol interference (ISI). The gain of CTLE is commonly expressed in dB.

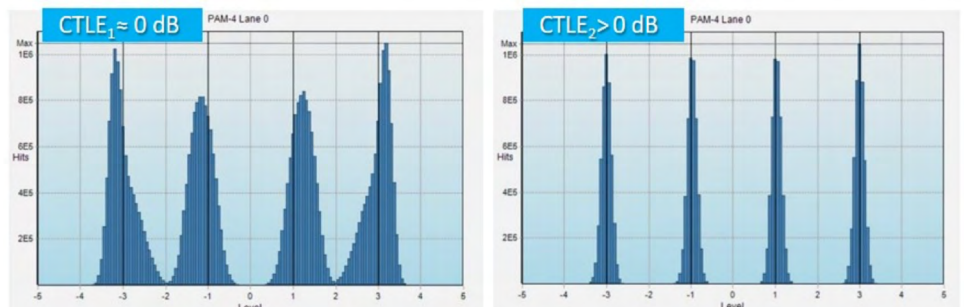


Figure 3. Example of Rx equalization using CTLE in a PAM4 interface.

In the FTBx-88460's GUI, the CTLE can be combined with different modes of **digital signal processing (DSP)** to optimize the loss compensation. The DSP modes implemented for this end are the following:

- **Feedforward equalizer (FFE)**: provides equalization between the main pulse and the pre- and post-cursor, using least mean squares (LMS) algorithm.
- **Decision-feedback equalizer (DFE)**: provides equalization for the main pulse without using LMS algorithm.
- **Reflection canceller (RC)**: reduces the group-delay effects.
- **Slicer (SLC)**: compares the FFE output with specific internal thresholds.
- **Level-dependent equalizer (LDEQ)**: specifically equalizes two inner levels of the PAM4 eye.

### Forward Error Correction (FEC): error detection and correction

The FEC is a digital signal processing method of correcting errors that can occur on a serial link. For its implementation, a codeword is formed when the transmitter's encoder adds parity bits (redundant extra bits) to the original block message, then the receiver can detect incurred errors during transmission and automatically correct them without retransmission of data. The FEC has been defined as mandatory in the specifications for 400G Ethernet, according to the IEEE 802.3bs task group.

The FTBx-88460 features a FEC tool based on the Reed Salomon coding, also known as RS (544, 514), for which the codeword is structured with 544 symbols, where 514 symbols are dedicated for payload and 30 symbols for parity. This type of FEC can correct up to 15 symbols in error per codeword.

The FEC statistics graph is a reference metric displaying the distribution of the number of errored symbols per correctable codeword, considering that a correctable codeword can have from 1 to 15 errored symbols. The metric is made of 15 bins each giving the count of events where a correctable codeword was detected with the associated number of symbols in error, as can be seen in the figure below. The ratio between codeword count and the total of correctable codewords is presented in percentage.

Symbol Error per Correctable Codeword		
Number of Symbols	Codeword Count	%
1	252903128	95.607761914470
2	9937470	3.756771508940
3	1318677	0.498514026517
4	268294	0.101426143195
5	66569	0.025165814093
6	18730	0.007080708708
7	5754	0.002175248153
8	1917	0.000724704677
9	659	0.000249129046
10	224	0.000084681193
11	75	0.000028353078
12	30	0.000011341231
13	11	0.000004158451
14	5	0.000001890205
15	1	0.000000378041

Figure 4. Distribution of the number of errored symbols per correctable codeword in the FTBx-88460.



iOptics is now available in the FTBx-88460 for testing of 200GAUI and 400GAUI interfaces.

In the FTBx-88460, PAM4 signals are by default coded in gray (binary-reflected) for facilitating the error correction, as referred in the IEEE and OIF recommendations.

Decimal	Binary	Gray (Binary-reflected)
0	00	00
1	01	01
2	10	11
3	11	10

Figure 5. Equivalence between decimal, binary and Gray encoding.

## Automated validation with iOptics

Moving forward towards the field of intelligent testing solutions, EXFO has designed iOptics, an automated application that provides a quick and easy validation of additional parameters of the transceiver that are essential for transporting information. iOptics is now available in the FTBx-88460 for testing of 200GAUI and 400GAUI interfaces.

**iOptics**, includes the following 7 subtests:

### 1. Power consumption monitoring

The power consumption monitoring measures the current and the power drawn by the selected optical device. This monitoring is performed for the entire duration of the test, following which a pass verdict is obtained if the maximum power was equal to or less than the power threshold over the entire duration of the test.

### 2. Optical device I/O interface quick check

The optical device I/O interface quick check validates the MDIO/ I2C and hardware-pin operation using a sample of common commands and controls applied to the selected optical device. The verdict provided by this test is therefore a combination of the MDIO/I2C interface test and the control/status pin check results.

### 3. Temperature monitoring

Temperature monitoring determines the internal temperature of an optical device in degrees Celsius until the end of the test. A pass verdict is obtained if the maximum temperature is equal to or less than the temperature threshold over the entire duration of the test.

### 4. Optical TX power level range test

This test samples the TX power level, compares it with the device's applicable TX power range and provides a verdict. For devices that operate with multiple lanes, each lane is sampled and compared to the applicable TX power range. Additionally, this test reports both the minimum and maximum TX power levels (in dBm) collected during the subtest. A pass verdict is obtained if the measured TX power level is within the TX power range defined by the device manufacturer. A fail verdict indicates that the pluggable is not operating at the range specified by the manufacturer.

## 5. Optical RX signal presence and power level range test

A physical loopback is required for this test, which validates the presence of an RX signal and samples the optical RX power level. The test compares the obtained RX level with the device's applicable RX power range and provides a verdict. For devices that operate with multiple lanes, each lane is sampled and compared to the applicable RX power range. This test reports both the minimum and maximum RX power levels (in dBm). A pass verdict is obtained if the measured RX power level is within the RX power range defined by the device manufacturer.

## 6. Stress test

A physical loopback is required for this test, which validates the bit-error performance of the optical module. The validation is performed at the highest rate/protocol supported by the optical device. Additionally, the validation is performed with and without generation of a frequency offset at the respective protocol boundaries. The user can configure the duration of the test, and a passing verdict will be assigned to the test if the following conditions are met:

- No loss of signal
- No pattern loss
- Bit error count  $\leq$  BER threshold

For devices operating at multiple lanes, if any lanes present a problem, this will result in a fail verdict.

## 7. Excessive skew test

This test is only executed for the validation of CFP, CFP2, CFP4, QSFP+ and QSFP28 optical devices. A physical loopback is required for this test, which measures the skew associated to each physical coding sublayer (PCS) lane. iOptics automatically sets up an OTN BERT or an EtherBERT test based on the highest rate supported by the device.

The skew threshold is also automatically configured by iOptics based on the rate/protocol used. A pass verdict is assigned to the test when the highest measured skew is equal to or less than the skew threshold. In the event of a fail verdict during the execution of any subtest, the test is aborted, and the fault is reported to signal that the faulty transceiver device should not be used.

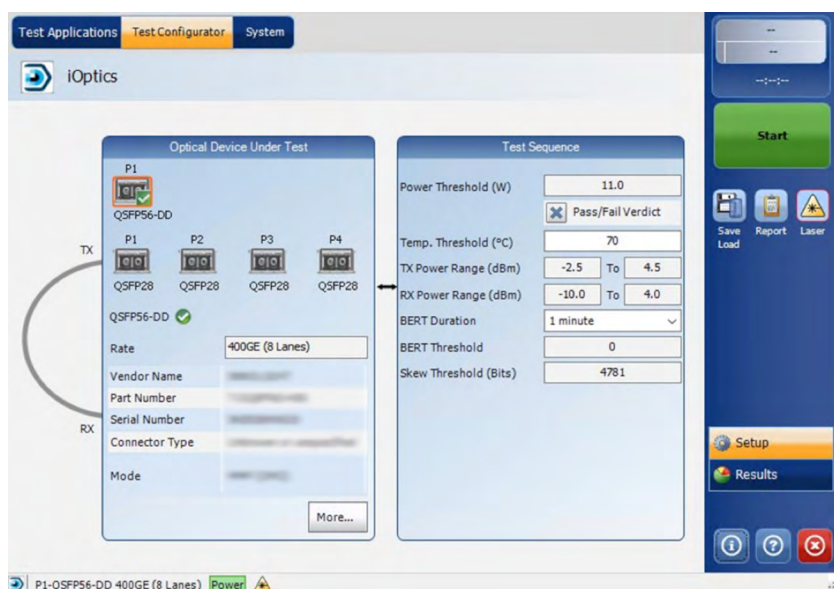


Figure 6. Automated validation of transceivers using iOptics.

**Learn more**

[FTBx-88400NGE Power Blazer - 400G multiservice test solution](#)

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## Summary

The dire need to properly qualify transceivers arises from the lack of maturity in the design and manufacturing process. EXFO's FTBx-88460 module is a unique solution that quickly and easily validates 200G and 400G transceivers, including QSFP56-DD for 200G-based and OSFP or QSFP-DD for 400G-based pluggables. Compatible with portable and rackmount platforms, the module can be used for both field and lab applications allowing for optimal flexibility.

EXFO serves over 2000 customers in more than 100 countries.  
To find your local office contact details, please go to [www.EXFO.com/contact](http://www.EXFO.com/contact).