High-Speed Jitter Testing of XFP Transceivers

By Andreas Alpert

Abstract

Jitter is a key performance factor in high-speed digital transmission systems, such as synchronous optical networks/synchronous digital hierarchy (SONET/SDH), optical transport networks (OTN), and 10 Gigabit Ethernet (GigE). This paper outlines the differences between telecom and datacom jitter standards and describes the various jitter applications for compliance testing of 10G small form-factor pluggable (XFP) transceivers, which have become the dominant 10 Gb/s optical interface for telecom and datacom applications.

Introduction

Accurate jitter measurements are essential for ensuring error-free high-speed data transmission lines. Jitter which is any phase modulation above 10 Hz in a digital signal, is unwanted and always present within devices, systems, and networks. To ensure interoperability between devices and to minimize signal degradation due to jitter accumulation, limits must be set for the maximum level of jitter for an output interface as well as the maximum level tolerated at an input.

Standards bodies determined these limits which can be divided into two categories: telecommunications and data communications. The major telecom standards organizations are International Telecommunications Union (ITU-T) and Telcordia, while the Institute of Electrical and Electronic Engineers (IEEE) is the main datacom standardization organization.

Jitter Aspects and Characteristic Values for 10 Gb/s

Telecom and datacom technologies use different timing methods. The system components in synchronous systems, such as SDH/SONET, synchronized to a common clock. In asynchronous and serial systems, such as 10 GigE, distributed clocks or clock signals recovered from the data provide the component timing. While it is important to limit jitter generated by components jitter transferred from one component to another is less important than that for synchronous systems, where jitter can increase as it transfers from component to component. Well-defined band-limited jitter generation, tolerance, and transfer requirements exist for SDH/SONET/OTN.

Table 1 shows how the specifications and test methodologies for jitter in 10 GigE differ from those for SDH/SONET/OTN transceivers. Both the specifications and test methodologies attempt to verify that the relative time instability of transmitted signals is not excessive.

	Telecom	Datacom	Technology	10 Gb/s type	Bit Rate in Gb/s
Transmission System	Metro, long distance	Point-to-point	SDH	STM-64	9.95328
Technology	SDH/SONET/OTN	10 GigE LAN and WAN	SONET	OC-192	9.95328
Standards	ITU-T G.783, G.825, G.8251 ITU-T O.172, O.173 Telcordia GR-253	IEEE 802.3ae	OTN	OTU2	10.709225316
Jitter Applications	Jitter generation Jitter tolerance Jitter transfer	BERT scan Stressed eye Not defined	10 GigE LAN	10GBaseR	10.3125
Jitter Tolerance and Transfer	Sinusoidal	Impairments (RJ, DJ)	10 GigE WAN	10GBaseW	9.95328

Table 1: Views of jitter and characteristic values for 10 Gb/s

In SDH/SONET/OTN systems with regenerators, noise causes the greatest impairment and limiting factor for system performance. Jitter tolerance is measured using sinusoidal jitter. In Ethernet systems, jitter tolerance is measured using a stressed signal with combinations of impairments.

Table 1 shows characteristic values for XFP transceivers, which support the established telecom standards STM-64 /OC-192 at 9.95 Gb/s, and OTU2 at 10.7 Gb/s. The 10 GigE datacom standards are supported at 9.95 and 10.31 Gb/s, respectively. These transceivers are pluggable optics, replacing legacy optical circuits with a lot of advantages: cost savings, very compact and

flexible design, exchangeability and direct replacement with equipment from different vendors, and hot-plug capable.

SDH/SONET/OTN Jitter Measurements

Three relevant test configurations for jitter performance measurements are: jitter generation, jitter tolerance, and jitter transfer.

1. Jitter generation: A certain amount of jitter will appear at the output port of any network element (NE), even with an entirely jitter-free digital or clock signal applied to the input, effect known as jitter generation. The NE itself produces this intrinsic jitter, for example due to thermal noise and drift in clock oscillators and clock data recovery circuits. Output jitter is the total jitter measured at the output of a system, specified in unit intervals (UI). One UI corresponds to an amplitude of one clock period, independent of bit rate and signal coding, displays results as a peak-to-peak value or root mean square (RMS) value over a defined frequency range. Peak-to-peak results provide a better measure of the effect on performance, as the extremes can cause errors, whereas RMS values provide information about the average total amount of jitter.

2. Jitter tolerance (maximum tolerable jitter, MTJ): A measurement that checks the resilience of equipment after the input of jitter, which is required to confirm that the NEs in the transmission system can operate error-free in the presence of worst-case jitter from preceding sections. Jitter tolerance is one of the most important characteristics of the clock recovery and input circuitry of network equipment.

3. Jitter transfer (jitter transfer function, JTF): A measure of the amount of jitter transferred from the input to the output of the network equipment. JTF is important for cascaded clock recovery circuits in long-distance transmission systems with regenerators and line terminals. In addition, the jitter transfer measurement is required to confirm that cascaded NEs in the transmission system have not amplified the jitter.

Figure 1 describes the typical values/ranges for the three jitter characteristics.
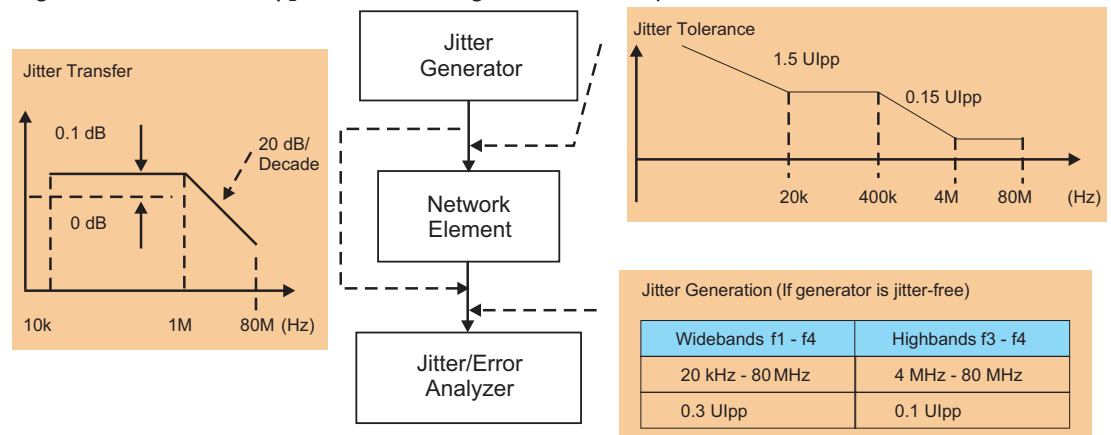

Figure 1: Definition of jitter generation, tolerance, and transfer, according to STM-64/OC-192/OTU2

Ethernet Jitter Measurements

Jitter is not directly measured in the 10 GigE Ethernet specification. Instead, it specifies separate requirements for transmitters and receivers. Ethernet uses the approach that essentially two mechanisms cause jitter, namely deterministic jitter (DJ) and random jitter (RJ). RJ results from random processes, such as thermal noise, and follows a Gaussian distribution. DJ includes sinusoidal (SJ) or periodic jitter (PJ), crosstalk (or bounded uncorrelated jitter [BUJ]), and data dependent jitter (DDJ), such as duty-cycle distortion (DCD) and intersymbol interference (ISI).
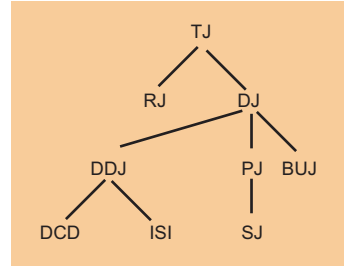
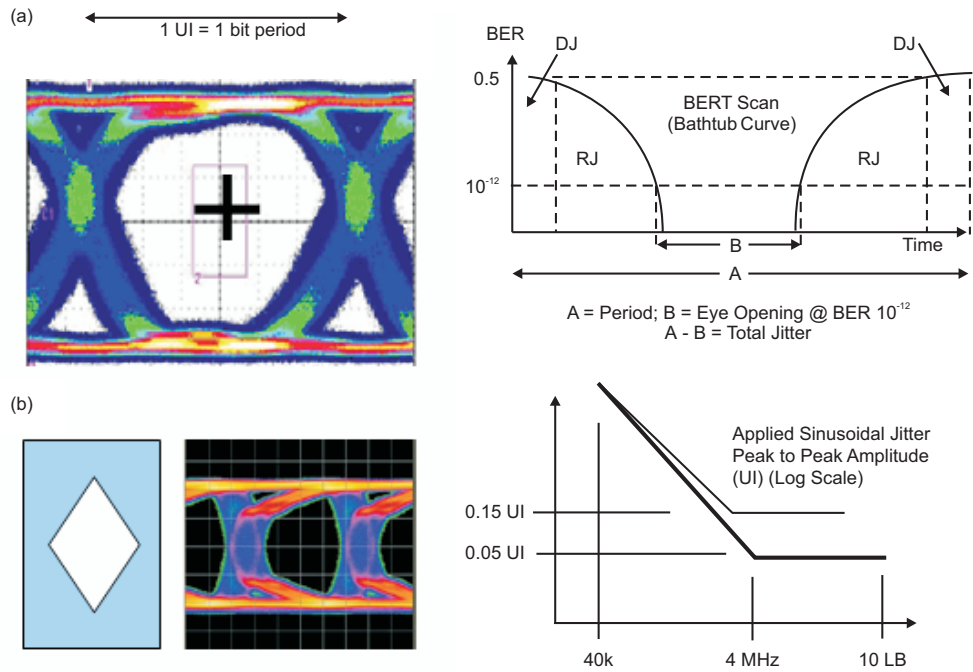Two measurements shown in Figure 2 are relevant for defining the jitter performance.

Figure 2: (a) Optical eye BERT scan and (b) stressed receiver sensitivity (SRS) test

1. **BERT Scan (Bathtub Curve):** A bit error ratio tester (BERT) creates BERT scans. A BERT passes data through a NE, and compares the transmitted data for errors to determine the bit error ratio (BER). Jitter can be measured by moving the sampling point across the eye pattern into the crossing region step-by-step. The sampling point, or amplitude decision threshold and time at which the bits are measured, is scanned across the eye pattern for a given time period while monitoring the BER. As the sampling point moves from the center

incrementally toward the crossing region, the BER increases continuously until it reaches a maximum of 0.5.

The level of output jitter is defined as the intersection of the bathtub curve and a BER of 10^{-12}, shown in Figure 2(a).

The further the left edge of the bathtub curve is from the right edge at the specified BER 10^{-12}, the greater the tolerance margin to jitter of the design; the closer these edges are to each other, the lower the available margin.

The bathtub curve can also be used to separate random (RJ) from deterministic jitter (DJ). The slope of the bathtub curve can be used to measure the random jitter, whereas the slope offset positions on the time axis are set by the deterministic jitter. Total jitter (TJ) is quantified by noting the points where the BER reduces to 10^{-12} at both eye edges, and subtracting this interval from the bit period. The measurement unfortunately takes a long time. In practice, the data points are measured from a BER of 10^{-3} to 10^{-8} and then extrapolated to a BER of 10^{-12}.

2. **Stressed Eye, or stressed receiver sensitivity (SRS):** The SRS test verifies that a receiver can operate at a BER of better than 10^{-12} when receiving the worst-case permitted signal, which is analogous to jitter tolerance. A SRS test consists of two parts: an eye mask and a sinusoidal jitter template , both of which are used for step-through measurements. The eye mask is designed to simulate a variety of stresses, including RJ, DCD, ISI, and PJ. The different stressing components are added to close the eye (blue area in Figure 2b), leaving an assured area of error-free operation in the center (white area in Figure 2b). The receiver is expected to operate successfully within this small area despite the impairments.

Once the stressed eye is constructed, BER performance is verified while stepping the sinusoidal jitter through the levels specified in the jitter template (jitter frequencies and amplitudes, see Figure 2b). The receiver must accommodate an impaired incoming signal with applied jitter and crosstalk, and must achieve a BER of $<10^{-12}$.

Test Setup

In the typical test setup for XFP shown in Figure 3, the JDSU ONT-506 is used to verify the jitter integrity of the transceiver. The XFP module contains an optical transmitter and receiver in the same unit. One end of the module is 10 Gb/s chip-to-chip electrical interface, or XFI serial interconnect, handles differential 10 Gb/s signals, which the other end is an optical connection, that complies with 10 Gb/s standards.

XFP modules are tested using a compliance test board that has four high-speed electrical connections, two inputs and two outputs. The ONT-506 injects a signal to the transmit side of the module at test point B' and measures the receive side of the module at test point C'. Accurate characterization of transmit and receive sides of the XFP module requires both electrical-to-optical (B' testing) and optical-to-electrical (C' testing) measurements.

The optical output (TX) looped back to the optical input (RX) allows for an electrical-to-electrical jitter test. The electrical output (C') looped back to the electrical input (B') allows for an optical-to-optical jitter test. The loopback method can be used for module verification but cannot be used to verify the performance of the transmit and receive sides independently.
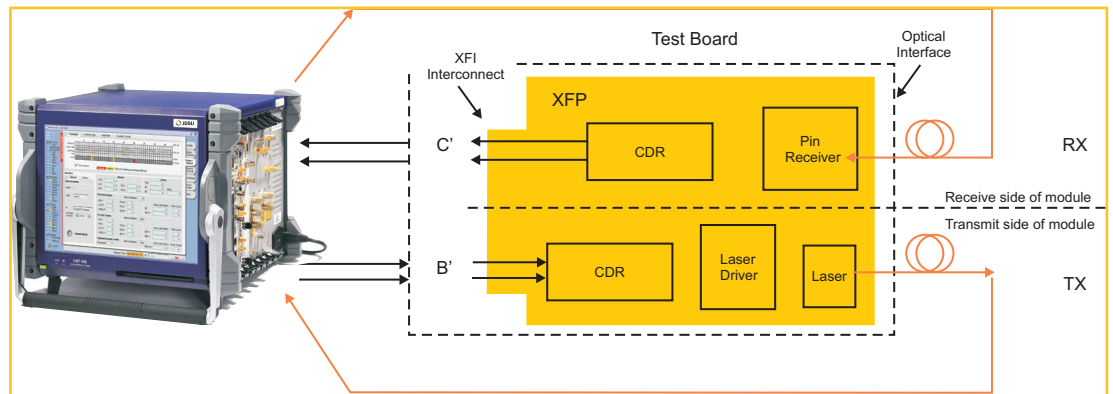

Figure 3: XFP transceiver connected to a JDSU ONT-506 tester

Conclusion

Both telecom and datacom market segments use the term jitter. Standardization bodies have developed well-documented jitter specifications and measurements, for which the requirements differ for each sector. XFP transceivers provide a very good example for different jitter standards supporting multiple data rates.

Three basic test configurations are used to test XFP jitter. For test equipment to meet compliance requirements, it must support all basic jitter applications for both electrical and optical interfaces. The JDSU ONT-506, shown in Figure 3, quickly and easily measures all of the high-speed jitter parameters required by the telecom segment. In addition, the ONT-506 provides a modular platform that delivers full range of applications from 1.5 Mb/s up to 43 Gb/s that offers industry-leading, high-accuracy jitter solutions.

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