IEC 61280-2-12

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INTERNATIONAL STANDARD

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**Fibre optic communication subsystem test procedures –
Part 2-12: Digital systems – Measuring eye diagrams and Q-factor using a software triggering technique for transmission signal quality assessment**

**Procédures d'essai des sous-systèmes de télécommunication à fibres optiques –
Partie 2-12: Systèmes numériques – Mesure des diagrammes de l'œil et du facteur de qualité à l'aide d'une technique par déclenchement logiciel pour l'évaluation de la qualité de la transmission de signaux**

IEC 61280-2-12:2014-05(en-fr)

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The text of this standard is based on the following documents:

CDV	Report on voting
86C/1150/CDV	86C/1220/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61280 series, published under the general title *Fibre optic communication subsystem test procedures*, can be found on the IEC website.

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INTRODUCTION

Signal quality monitoring is important for operation and maintenance of optical transport networks (OTN). From the network operator's point of view, monitoring techniques are required to establish connections, protection, restoration, and/or service level agreements. In order to establish these functions, the monitoring techniques used should satisfy some general requirements:

- in-service (non-intrusive) measurement
- signal deterioration detection (both SNR degradation and waveform distortion)
- fault isolation (localize impaired sections or nodes)
- transparency and scalability (irrespective of the signal bit rate and signal formats)
- simplicity (small size and low cost).

There are several approaches, both analogue and digital techniques, which make it possible to detect various impairments:

- bit error rate (BER) estimation [1,2][1]
- error block detection
- optical power measurement
- optical SNR evaluation with spectrum measurement [3,4]
- pilot tone detection [5,6]
- Q-factor monitoring [7]
- pseudo BER estimation using two decision circuits [8,9]
- histogram evaluation with synchronous eye diagram measurement [10].

A fundamental performance monitoring parameter of any digital transmission system is its end-to-end BER. However, the BER can be correctly evaluated only with out of service BER measurements, using a known test bit pattern in place of the real signal. On the other hand, in-service measurement can only provide rough estimates through the measurement of digital parameters (e.g., BER estimation, error block detection, and error count in forward error correction) or analogue parameters (e.g., optical SNR and Q-factor).

An in-service optical Q-factor monitoring can be used for accurate quality assessment of transmitted signals on wavelength division multiplexed (WDM) networks. Chromatic dispersion (CD) compensation is required for Q monitoring at measurement point in CD uncompensated optical link. However, conventional Q monitoring method is not suitable for signal evaluation of transmission signals, because it requires timing extraction by complex equipment that is specific to each BER and each format.

The software triggering technique [11-14] reconstructs synchronous eye-diagram waveforms without an external clock signal synchronized to optical transmission signal from digital data obtained through asynchronous sampling. It does not rely on an optical signal's transmission rate and data formats (RZ or NRZ). Measuring method of eye diagrams and Q-factor using the software triggering technique is a cost-effective alternative to BER estimations. With eye diagrams and Q-factor using software triggering test method, signal quality degradations due to optical signal-to-noise ratio (OSNR) degradation, to jitter fluctuations and to waveform distortion can be monitored.

This is one of the promising performance-monitoring approaches for intensity modulated direct detection (IM-DD) optical transmission systems.

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[1] Numbers in square brackets refer to the Bibliography.

FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

Part 2-12: Digital systems – Measuring eye diagrams and Q-factor using a software triggering technique for transmission signal quality assessment

1 Scope

This part of IEC 61280 defines the procedure for measuring eye diagrams and Q-factor of optical transmission (RZ and NRZ) signals using software triggering technique as shown in 4.1 [14].

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61280-2-2, *Fibre optic communication subsystem basic test procedures – Part 2-2: Test procedure for digital systems – Optical eye pattern, waveform, and extinction ratio measurement*

ITU-T Recommendation G.959.1: 2012, *Optical transport network physical layer interfaces*

3 Abbreviated terms

ASE	amplified spontaneous emission
BER	bit error rate
CD	chromatic dispersion
EDFA	Er-doped fibre amplifier
IM-DD	intensity modulated direct detection
RZ	return-to-zero
NRZ	non-return-to-zero
OBPF	optical bandpass filter
OSNR	optical signal-to-noise ratio
OTN	optical transport networks
PMD	polarization mode dispersion
SNR	signal-to-noise ratio
WDM	wavelength division multiplexing

4 Software synchronization method and Q-factor

4.1 Example of asynchronous waveform and eye diagram reconstructed by software triggering technique

Figure 1 shows an example of a 40 Gb/s RZ-synchronous eye diagram constructed from asynchronous sampled data using the software triggering technique. The inset in Figure 1 shows an asynchronous waveform obtained from the same asynchronous sampled data.

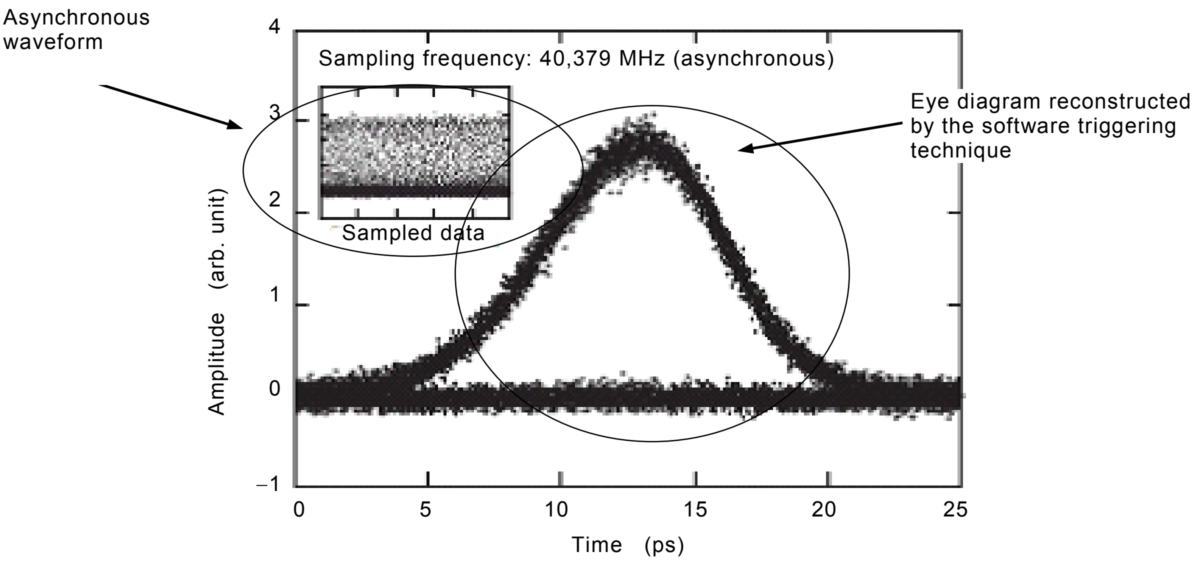


Figure 1 – Asynchronous waveform and synchronous eye diagram of 40 Gbps RZ-signal reconstructed by software triggering technique

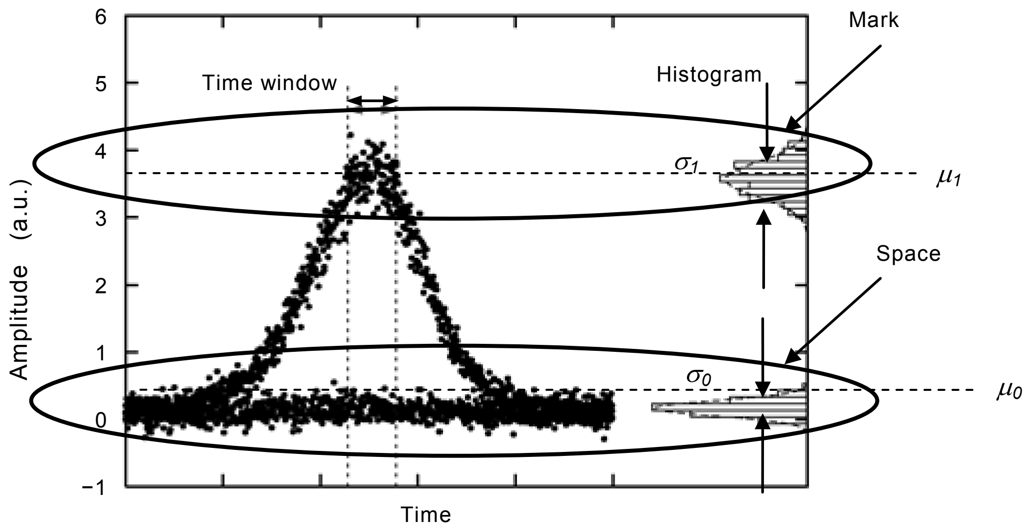
4.2 Q-factor formula

As shown in Figure 2, the Q-factor can be calculated from a histogram of "mark" ("1") and "space" ("0") levels in the time window, in which an appropriate time window is established in a large part of the eye opening. The time window is separated into "mark" ("1") and "space" ("0") levels, the average μ_0 and standard deviation σ_0 of the "space" ("0") level data and the average μ_1 and standard deviation σ_1 of the "mark" ("1") level data are calculated, and the Q-factor is calculated by substituting the obtained μ_0, σ_0, μ_1, and σ_1 into Formula (1).

The Q-factor depends on the position of the centre of the time window. For optical transmission signal quality evaluation, the maximum value obtained by calculating Formula (1) while changing the position of centre of the time window is defined as the Q-factor.

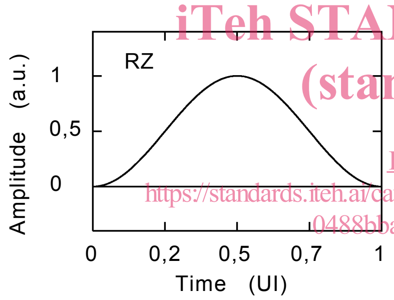
$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 + \sigma_0} \quad (1)$$

The Q-factor also depends on width of the time window. Assuming that the signal waveform is sinusoidal RZ with duty ratio of 50 % (Figure 3(a)) or sinusoidal NRZ (Figure 3(b)) and $\sigma_0 = \sigma_1$, calculated relationships between Q-factor and window width are shown in Figure 3(c). A suitable window width is 0,1 UI or less for an RZ signal and 0,2 UI or less for an NRZ signal.



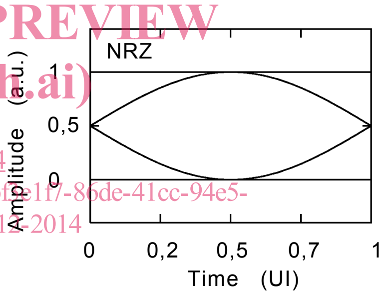
IEC 1199/14

Figure 2 – RZ synchronous eye diagram reconstructed by software triggering technique, time window, and histogram



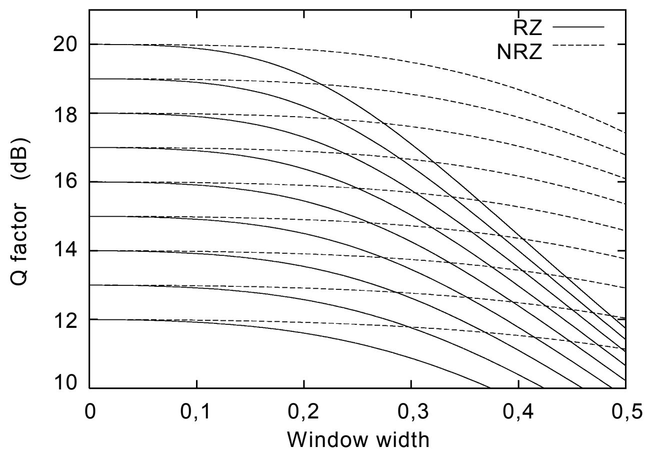
IEC 1200/14

Figure 3a – Sinusoidal RZ with duty 50 %



IEC 1201/14

Figure 3b – Sinusoidal NRZ



IEC 1202/14

Figure 3c – Calculated relationships between Q-factor and window width

Figure 3 – Example of relationship between Q-factor and window width

5 Apparatus

5.1 General

Test systems are mainly composed of an optical bandpass filter, a high frequency receiver, a clock oscillator, an electric pulse generator, a sampling module, an electric signal processing circuit with an AD converter and a software triggering module (Figure 4); or, an optical bandpass filter, an optical clock pulse generator, an optical sampling module, an optical signal processing circuit with an AD converter, a low frequency receiver and software triggering module (Figure 5).

In the typical case, eye diagram and Q-factor measurements are performed after the optical amplifier of the repeaters, optical-cross connects, and other nodes, because sufficient signal power level and CD compensation are required for the Q-factor monitoring.

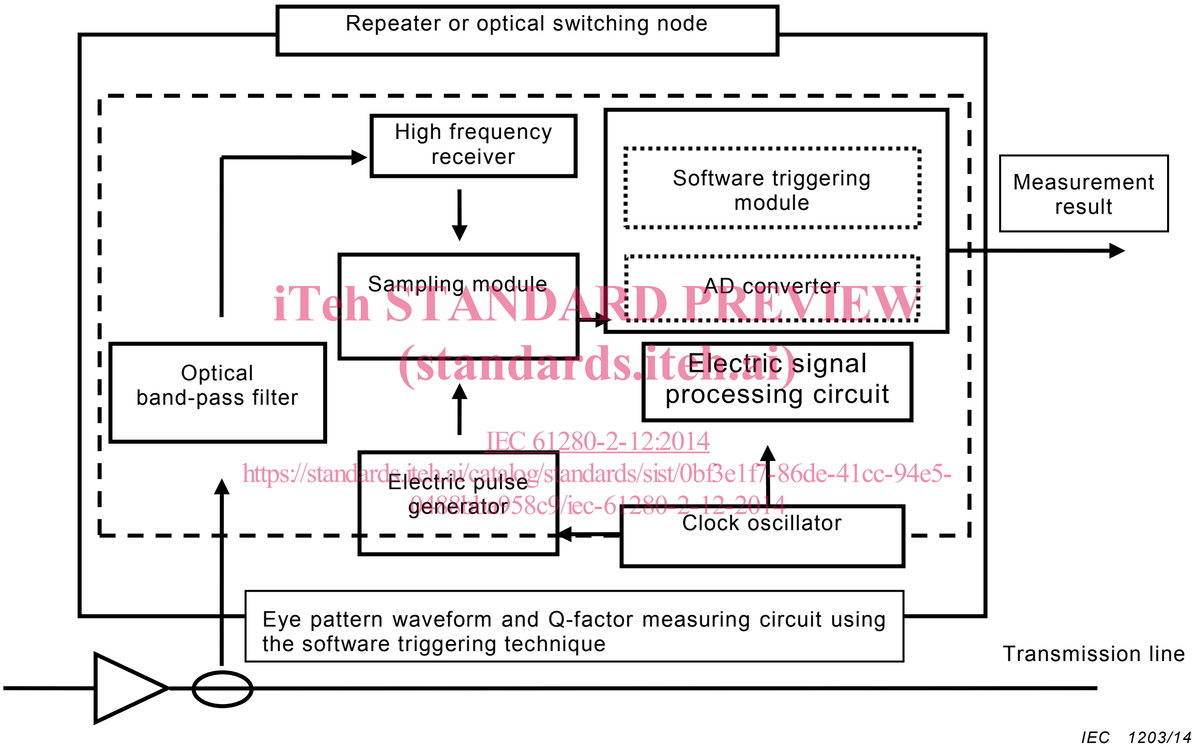
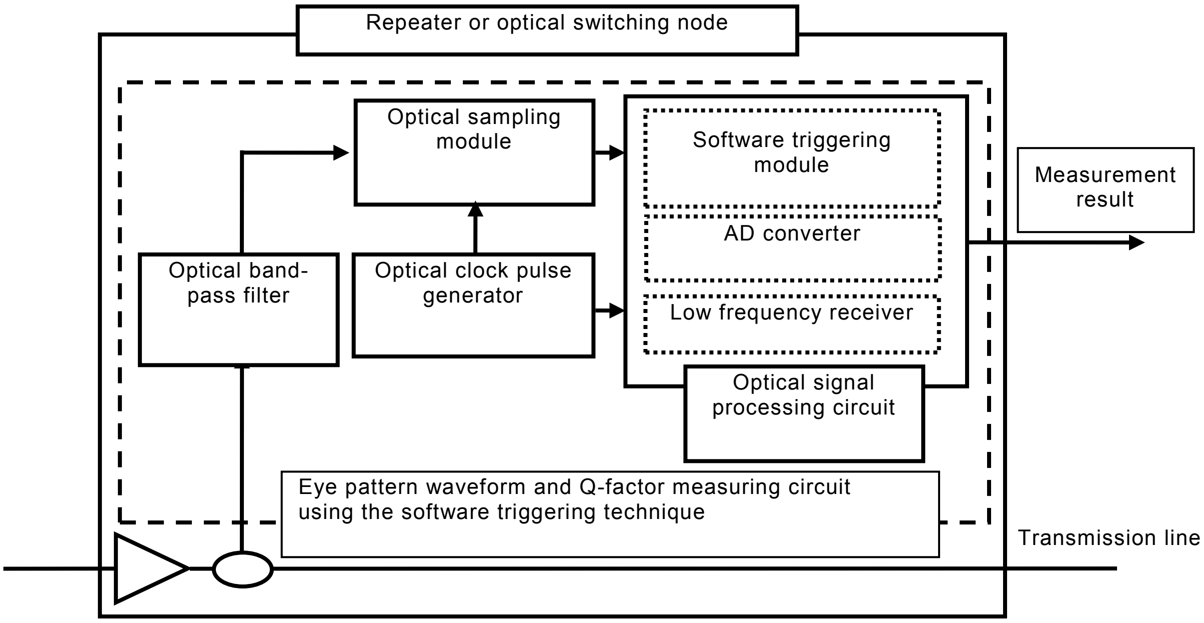


Figure 4 – Test system 1 for measuring eye diagrams and Q-factor using the software triggering technique



IEC 1204/14

Figure 5 – Test system 2 for measuring eye diagrams and Q-factor using the software triggering technique

5.2 Optical bandpass filter

The optical bandpass filter (OBPF) should be used to remove unnecessary ASE noise from the optical amplifier or/and to extract the necessary channel from the WDM signals. The bandwidth of the optical filter B_{opt} should be broader than the bit rate of the optical signal. The shape of the OBPF is shown in ITU-T Recommendation G.959.1: 2012, Figure B.2, where two parameters, the power suppression ratio of adjacent channel and the central frequency deviation, are defined.

5.3 High frequency receiver

The high frequency receiver is typically a high-speed photodiode, followed by electrical amplification. The high frequency receiver is equipped with an appropriate optical connector to allow connection to the optical interface point, either directly or via an optical jumper cable.

Precise specifications are precluded by the wide variety of possible implementations. However, the high frequency receiver shall follow the general guideline based on IEC 61280-2-2 as follows:

a) acceptable input wavelength range, adequate to cover the intended application;

b) responsivity, adequate to produce an eye-pattern;

   For example, assume that a non-return-to-zero (NRZ) optical data stream with an average power of –15 dBm is to be measured. If the sensitivity of the signal processing circuit with sampling module is 10 mV/div, a responsivity of 790 V/W is required in order to produce an eye-pattern of 50 mV peak-to-peak.

c) optical noise-equivalent power, low enough to result in accurate measurements;

   For example, assume that a non-return-to-zero (NRZ) optical data stream with an average power of –15 dBm is to be measured. If the effective noise band width of the measurement system is 470 MHz, and if the displayed root-mean-square noise is to be less than 5 % of the asynchronous eye-pattern height, the optical noise-equivalent power should be 145 pw-Hz$^{-1/2}$ or less.

d) Upper cut-off (–3 dB) frequency, B_{mes} Hz;

In order to ensure repeatability and accuracy, the upper cut-off frequency (bandwidth), B_{mes}, of the measurement system should be explicitly stated in the detail specifications.

For NRZ format signals, the high frequency receiver and sampling module that have a combined impulse response with a −3 dB bandwidth of 0,75/T (where T is the bit interval, in seconds, of the data signal) are often used. For RZ format signals, the spectral content may be significantly higher than the NRZ signal at the same signal bit rate. This can lead to measurement system bandwidth that is in excess of the clock frequency.

e) lower cut-off (−3 dB) frequency, B_{low} Hz;

In order to avoid significant distortion of the detected eye-pattern due to lack of low frequency spectral components, the lower cut-off frequency, B_{low}, of the measurement system should be sufficiently low compared with $1/T_{samp}$. T_{samp}, is the total sampling time described in 5.12. DC coupling is not always necessary for Q-factor measurements, because the DC component of the eye-pattern will be cancelled by $\mu_1 - \mu_0$ in Formula (1).

f) transient response, overshoot, undershoot, and other waveform aberrations should be minor so as not to interfere with the measurement;

The upper cut-off frequency (bandwidth), B_{mes}, of the measurement system should primarily determine the system transient response.

g) the corresponding software clock recovery loop bandwidth should be high enough for tracking of the signal under tests phase noise. The resulting loop bandwidth is related to the sampling rate and synchronization algorithm. In practice, the loop bandwidth is at least 100 times less than the sampling rate. For example, in IEC 61280-2-2 loop bandwidths of 4 MHz are recommended for 10 G NRZ data, which would yield a recommended sampling rate of 400 MSample/s. With better control of the signal VCOs, the recommended loop bandwidth could be reduced.

h) output electrical return loss, high enough that reflections from the sampling module following the receiver are adequately suppressed, from 0 Hz to a frequency significantly greater than the bandwidth of receiver;

A time-domain measurement may be very inaccurate if significant multiple reflections are present. A minimum value of 15 dB for the return loss is recommended when many components are employed following the receiver. The effective output return loss of the receiver may be improved with in-line electrical attenuators, at the expense of reduced signal levels. Finally, the return loss specification extends to DC, since otherwise, a DC shift in the waveform will occur, causing Q-factor measurements to be in error.

5.4 Clock oscillator

The clock oscillator generates a clock signal that corresponds to the sampling rate. The generated clock signal jitter at frequencies above the software clock recovery loop bandwidth shall be sufficiently smaller than the bit period for clear eye diagrams, and is sent to an electric pulse generator and a signal electric processing circuit. A high clock frequency is desirable for wide clock recovery bandwidth.

5.5 Electric pulse generator

The electric pulse generator should be capable of providing an electric short pulse train or electrical clock signal with proper slew rate to the sampling module. The electric pulse repetition frequency is identical to the sampling rate.

5.6 Sampling module

The sampling module should sample the electrical signals at a specified repetition rate with a specified sampling time width (sampling window) by using the electric pulse train generated by the electrical pulse generator and detect the level of the sampled signals. The sampled values are sent to the electric signal processing circuit.

The accuracy of Q is dependent on the measurement system bandwidth B_{mes}.