BS EN 61280-2-12:2014

BSI Standards Publication

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

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National foreword

This British Standard is the UK implementation of EN 61280-2-12:2014. It is identical to IEC 61280-2-12:2014.

The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/3, Fibre optic systems and active devices.

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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 (IEC 61280-2-12:2014)

Procédures d'essai des sous-systèmes de télécommunication à fibres optiques - Partie 2-12: Systèmes numériques - Mesure des diagrammes de l'oeil 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
(CEI 61280-2-12:2014)

Prüfverfahren für Lichtwellenleiter-Kommunikationssysteme - Teil 2-12: Digitale Systeme - Messungen von Augendiagrammen und des Q-Faktors mit einem Software-Triggerverfahren für die Qualitätsbewertung von Übertragungssignalen
(IEC 61280-2-12:2014)

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Foreword

The text of document 86C/1150/CDV, future edition 1 of IEC 61280-2-12, prepared by SC 86C "Fibre optic systems and active devices" of IEC/TC 86 "Fibre optics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61280-2-12:2014.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2015-03-10
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2017-06-10

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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

Publication	Year	Title	EN/HD	Year
IEC 61280-2-2	-	Fibre optic communication subsystem test procedures - Part 2-2: Digital systems - Optical eye pattern, waveform and extinction ratio measurement	EN 61280-2-2	-
ITU-T Recommendation G.959.1	2012	Optical transport network physical layer interfaces	-	-

CONTENTS

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*

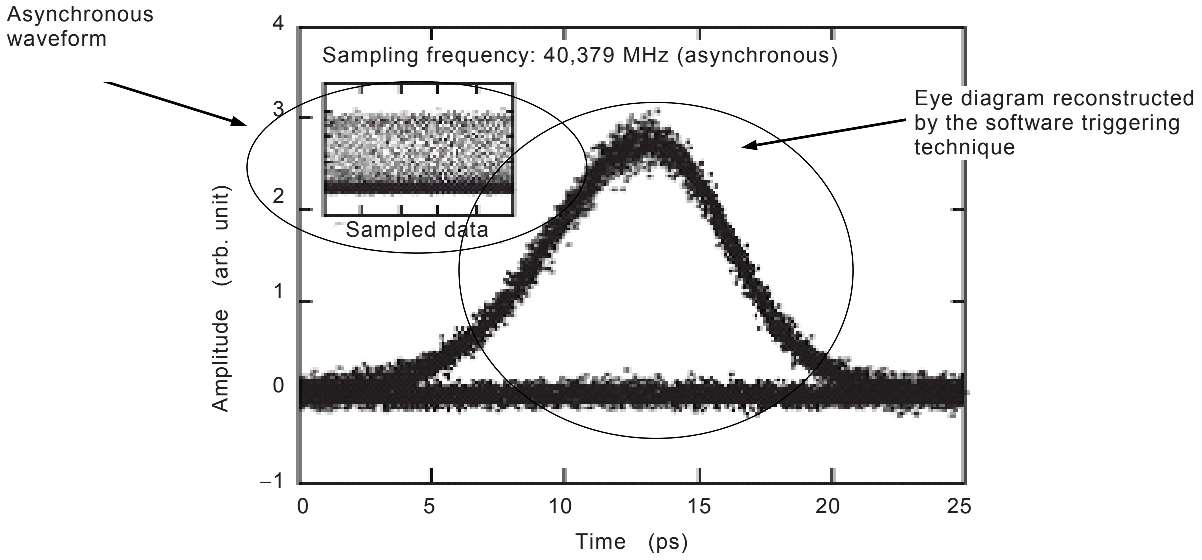
3 Abbreviated terms

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.



IEC 1198/14

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.

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 + \sigma_0} \tag{1}$$

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.

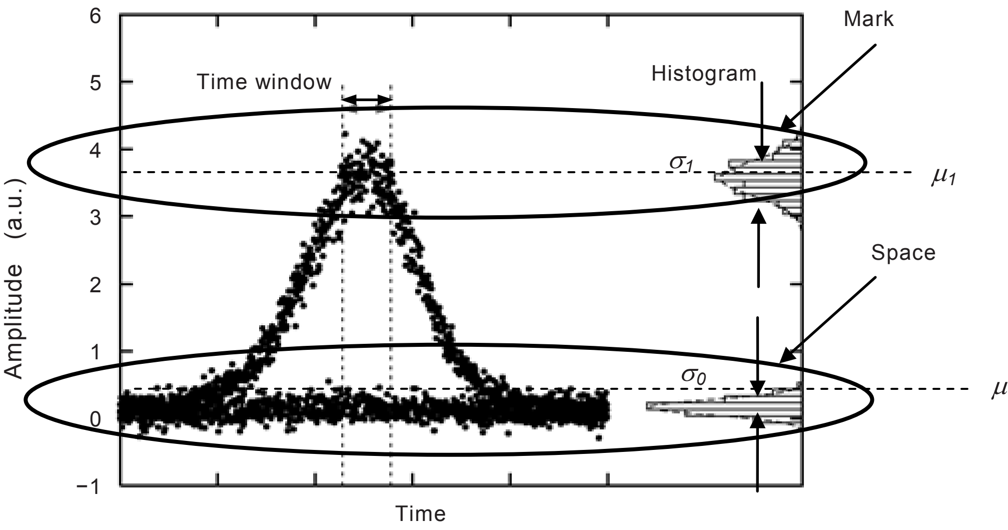


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Figure 2 – RZ synchronous eye diagram reconstructed by software triggering technique, time window, and histogram

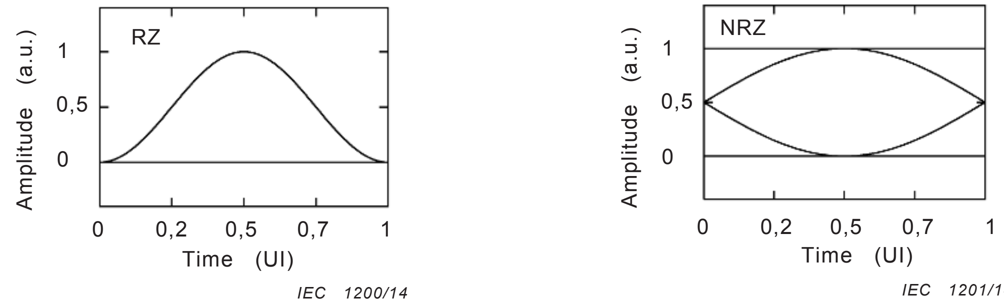

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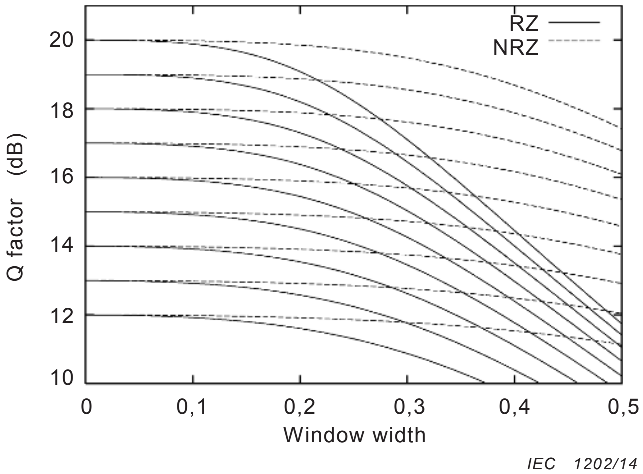
Figure 3a – Sinusoidal RZ with duty 50 %

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.

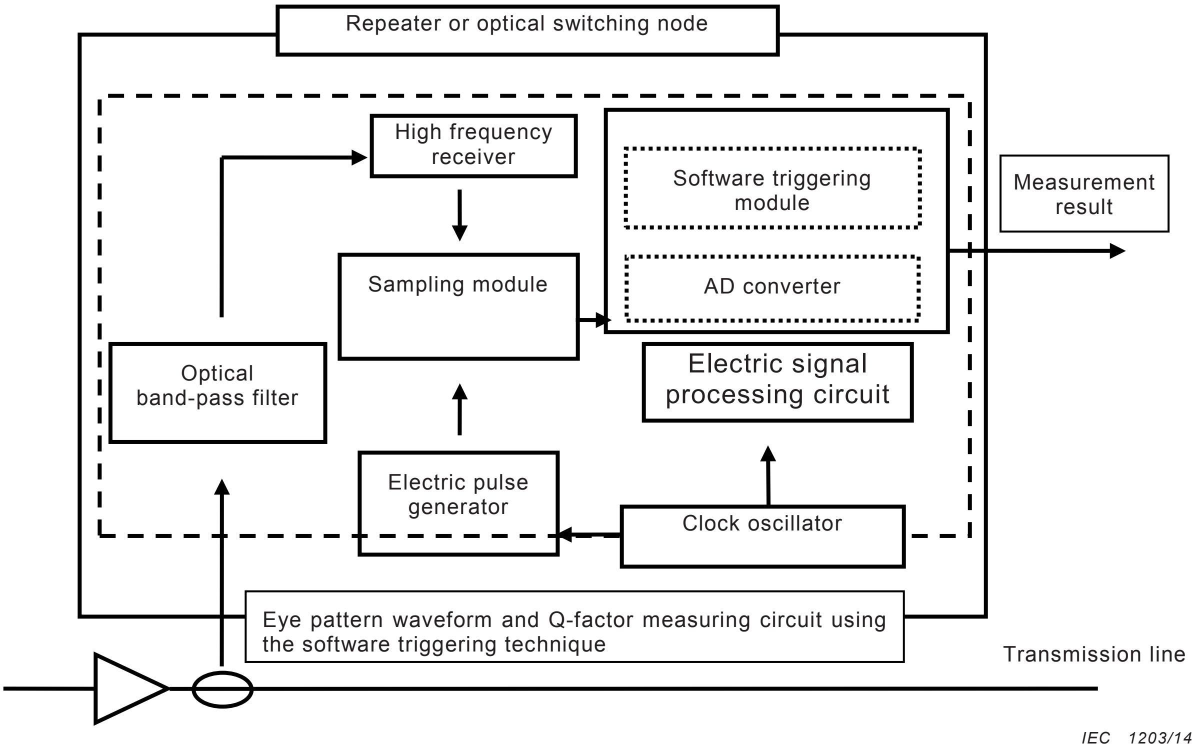


Figure 4 – Test system 1 for measuring eye diagrams and Q-factor using the software triggering technique

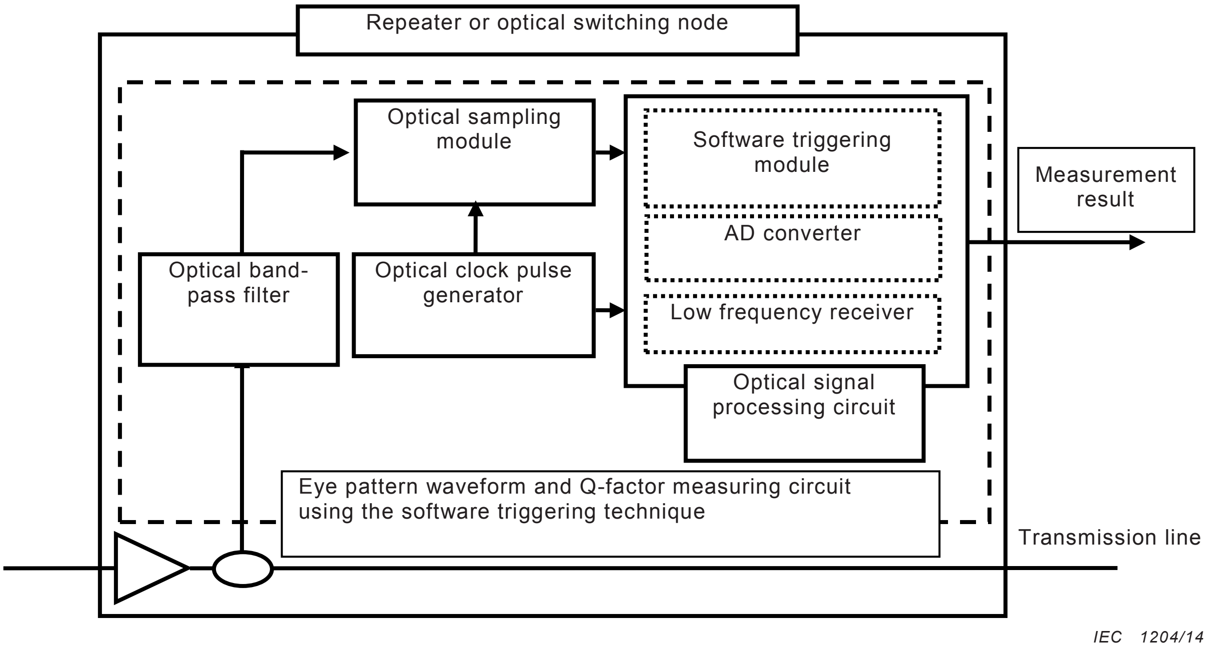


Figure 5 – Test system 2 for measuring eye diagrams and Q-factor using the software triggering technique

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 $1/T_{\mathrm{samp}}$. 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}.

5.7 Electric signal processing circuit

The electric signal processing circuit should reconstruct the eye-diagram waveform and calculate the Q-factor (and the amplitude histogram) utilizing the asynchronous sampled signals from the sampling module and the clock signal from the clock oscillator. Q-factor formula is shown in 4.2.

Within the electric signal processing circuit, the electric signal sampled by the sampling module is digitized by the AD converter, and then the temporal axis is calculated from that digitized value in the software triggering module. An example of a principle of signal processing in the software triggering module is shown Annex A [14].

5.8 Optical clock pulse generator

The optical clock pulse generator generates an optical pulse train and a clock signal at the sampling rate. The generated optical pulse train and a clock signal are sent to the optical sampling module and the optical signal processing circuit respectively. The repetition frequency of the optical pulse train is synchronous with the clock signal. The generated optical pulse train jitter at frequencies above the software clock recovery loop bandwidth shall be sufficiently smaller than the bit period for clear eye diagrams. The higher optical clock frequency is desirable for wide clock recovery bandwidth.

5.9 Optical sampling module

The optical sampling module should sample the optical signal at a specified repetition rate with an adequate sampling time width (sampling window or gate width) that depends on the bit rate of the optical signal. Varying a sampling time width leads to change the upper cut-off (-3 dB) frequency B_{mes} of the measurement system. The sampled optical signal is sent to the optical signal processing circuit.

The calculated relationship between the adequate sampling time width (gate width) and the bit rate of the optical signal is shown in Annex B.

5.10 Optical signal processing circuit

The optical signal processing circuit should reconstruct the eye-diagram waveform and calculate the Q-factor (and the amplitude histogram) utilizing the asynchronous sampled signals from the sampling module and the clock signal from the optical clock pulse generator. The Q-factor formula is in 4.2.

Within the optical signal processing circuit, the optical signal sampled by the optical sampling module is digitized by the low frequency receiver and the AD converter. Then, the temporal axis is calculated from that digitized value in the software triggering module. The bandwidth of the low frequency receiver shall be over 2 times the sampling rate. An example of a principle of signal processing in the software triggering module is shown Annex A [14].

5.11 Synchronization bandwidth

In the guidelines of IEC 61280-2-2, an oscilloscope triggering system using a recovered clock from the signal under test is discussed. The clock recovery bandwidth for eye pattern measurements will be similar to that of the communications system receiver to suppress unimportant jitter which does not degrade system level communications. High sampling frequency more than 1 GSample/s is required to achieve such a wide clock recovery bandwidth of the communications system receiver by using software synchronization method.

However, low sampling frequency less than 1 GSample/s is desirable for low-cost Q-factor monitor using software synchronization method, and the clock recovery bandwidth of the Q-factor monitor may be lower than that of the communications system receiver. If the jitter frequency is higher than the clock recovery bandwidth, the jitter will appear in the eye diagram, and the horizontal eye opening will be decreased by the jitter. Therefore, the low-cost Q-factor monitor is more sensitive to high frequency jitter than the measuring instruments with high clock recovery bandwidth.

5.12 Monitoring system parameters

For the measurement of the eye diagram and Q-factor of the optical transmission signals using the software triggering technique, appropriate parameters for the test system shall be selected. The optical filter bandwidth, B_{opt}, determines the bandwidth and optical SNR of the optical signal to be processed. The measurement system bandwidth, B_{mes}, is determined by the high frequency receiver and the sampling module in test system 1 (Figure 4) or the optical sampling module in test system 2 (Figure 5); it influences the eye diagram and Q-factor. The sampling number, N_{samp}, is the number of sampled points for drawing the amplitude histogram. The sampling number, N_{total}, is the total number of sampled points. The sampling rate, R_{samp}, is repetition rate of the sampling clock. The total sampling time, T_{samp}, is a parameter that is related to the clock recovery bandwidth. The terms T_{samp}, N_{samp}, N_{total} and R_{samp} are related as

$$N_{\mathrm{total}} = T_{\mathrm{bit}} / T_{\mathrm{window}} \times N_{\mathrm{samp}} \tag{2}$$

$$T_{\mathrm{samp}} = N_{\mathrm{total}} / R_{\mathrm{samp}} \tag{3}$$

The monitoring system parameters are listed in Table 1.

Table 1 – Monitoring system parameters

B_{opt}	Optical filter bandwidth
B_{mes}	Measurement system bandwidth
T_{bits}	Time of 1bit
T_{window}	Time of window width
N_{samp}	Number of samples
R_{samp}	Sampling frequency
T_{samp}	Total sampling time

6 Procedure

6.1 General

By using the software triggering technique, eye diagrams can be reconstructed from asynchronous sampled data, and Q-factor can be calculated from those waveforms.

6.2 Measuring eye diagrams and Q calculations

The procedure for measuring eye diagrams using the software triggering technique and Q-factor measurement is shown below.

a) Turn on the measuring instruments and wait a sufficient amount of time until its temperature and performance are stable.

b) Connect the optical signal on the transmission line to the test system, as shown in Figure 4 or Figure 5An EDFA is required only if the power from the transmission line is insufficient to provide a sufficiently high signal level to high frequency receiver or low frequency receiver. When an EDFA is used, an ASE from the EDFA modifies the OSNR. Therefore, it is necessary to confirm that the required Q-factor measurement can be realized.

c) Reconstruct the eye diagram through the asynchronous sampled data and calculate the Q-factor from the amplitude histogram using software triggering.

NOTE Q-factor can be calculated by Formula (1).

Annex A
(informative)

Example of the signal processing required to reconstruct the synchronous eye diagram

The software triggering technique for measuring the eye diagrams and Q-factor of RZ optical transmission signals reconstructs synchronous eye diagrams from asynchronous sampling data through a signal processing technique. Figure A.1 shows a block diagram of the software triggering module, which is necessary to reconstruct eye diagrams from digital data obtained through asynchronous sampling.

As shown in Figure A.1, the asynchronous sampling data that was digitized by the AD converter is divided into two branches, one of which is sent directly to the eye diagram display as an amplitude signal (a vertical axis signal). The other signal is branched again into two signals. For one of these branches, discrete Fourier transform is performed to obtain the discrete spectrum. The obtained discrete spectrum data is interpolated, and a precise peak frequency is obtained from the spectrum. (This peak frequency is used as the beat frequency between the clock frequency of the optical transmission signal and a frequency that is a multiple of the sampling frequency. Figure A.2 shows an example of obtaining a beat frequency by interpolating the discrete spectrum). For the other branched signal, the phase of the signal component at the beat signal when the amplitude signal is obtained is detected, the temporal axis (horizontal axis) is normalized at one unit interval (UI), and the temporal axis signal is sent to the eye diagram display so that the centre of the temporal axis becomes 0 degree phase.

The principles are explained here using the RZ optical transmission signal, but even if measuring NRZ optical transmission signals that do not have a clock frequency component, synchronous eye diagrams can be reconstructed using the software triggering technique by non-linear calculation of the asynchronous sampling data before the discrete Fourier transform processing.

On typical software synchronization method, since the beat frequency is assumed to be constant during the total sampling time, T_{samp}, averaged clock frequency during T_{samp} is detected for synchronization. The jitter transfer function is corresponding to transfer function of rectangular impulse response with width of T_{samp}, and therefore the clock recovery bandwidth (equivalent noise bandwidth) becomes $1/(2T_{\text{samp}})$. For example, the sampling frequency, R_{samp}, is 40 MSample/s, the total number of sampling points, N_{total}, is 10 000, the equivalent clock recovery bandwidth becomes 2 kHz which is lower than that of the typical communications system receiver.

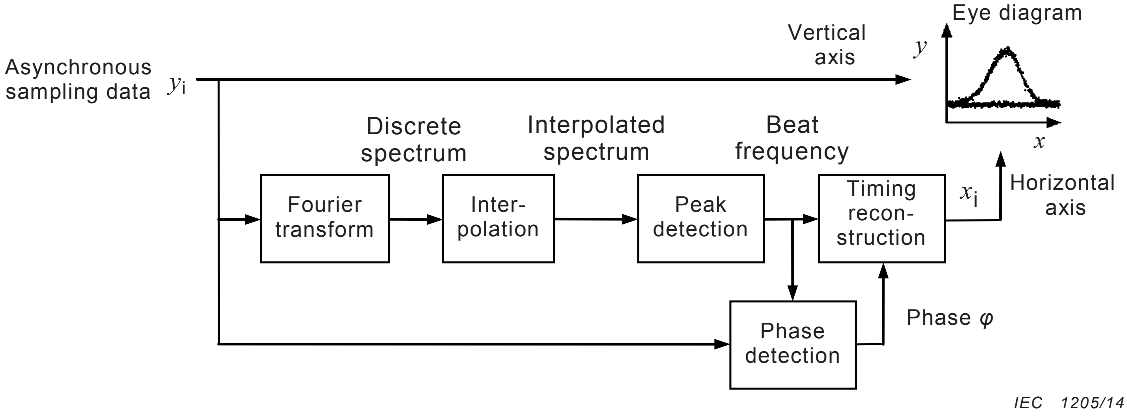
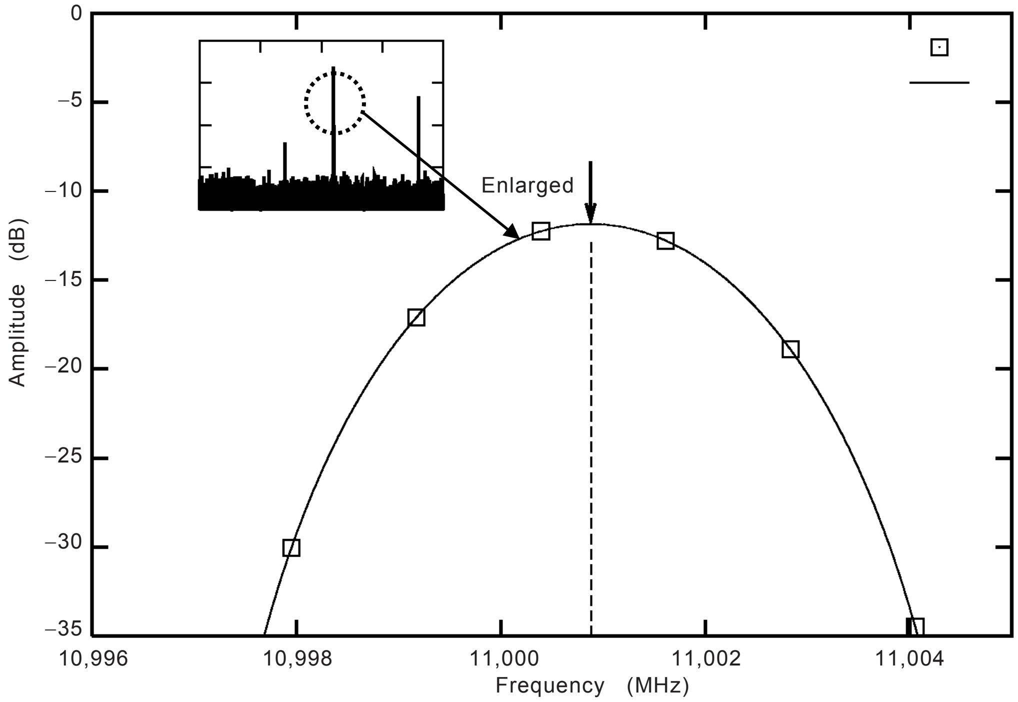


Figure A.1 – Block diagram of the software triggering module



IEC 1206/14

Figure A.2 – Example of interpolating a discrete spectrum and determining beat frequency

Annex B
(informative)

Adequate sampling time width (gate width)

The adequate sampling time width (gate width) is calculated by an equivalent bit rate. The equivalent bit rate is determined by a fitting theoretical impulse response of 5th-order Bessel filter with cut-off frequency of 75 % of bit rate to impulse response of the sampling gate.

Figure B.1 shows a calculated relationship between adequate sampling time width (gate width) and the bit rate of NRZ optical signal.

In the typical case, electro-absorption modulator is used as the optical sampling module because the gate width of this device can be adjusted by the optical pulse input power level and/or DC bias level [15].

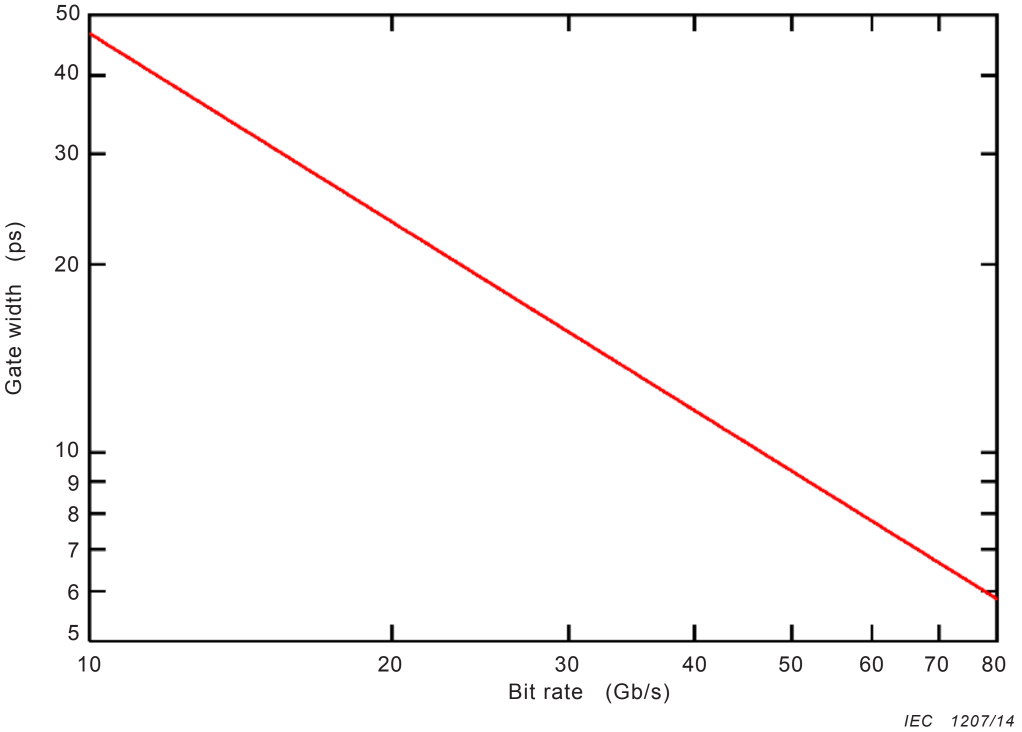


Figure B.1 – The typical calculated relationship between the adequate sampling time width (gate width) and the bit rate of the optical signal

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