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INTERNATIONAL STANDARD

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Fibre optic communication subsystem test procedures – Part 2-2: Digital systems – Optical eye pattern, waveform and extinction ratio measurement

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Fibre optic communication subsystem test procedures – Part 2-2: Digital systems – Optical eye pattern, waveform and extinction ratio measurement

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FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

Part 2-2: Digital systems – Optical eye pattern, waveform and extinction ratio measurement

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International Standard IEC 61280-2-2 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This fourth edition cancels and replaces the third edition published in 2008 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) additional definitions;

b) clarification of test procedures.

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

CDV	Report on voting
86C/1043/CDV	86C/1074/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.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

Part 2-2: Digital systems – Optical eye pattern, waveform and extinction ratio measurement

1 Scope

The purpose of this part of IEC 61280 is to describe a test procedure to verify compliance with a predetermined waveform mask and to measure the eye pattern and waveform parameters such as rise time, fall time, modulation amplitude and extinction ratio.

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 61280-2-3, *Fibre optic communication subsystem test procedures – Part 2-3: Digital systems – Jitter and wander measurements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
amplitude histogram
graphical means to display the power or voltage population distribution of a waveform

3.2
contrast ratio
ratio of the nominal peak amplitude to the nominal minimum amplitude of two adjacent logical '1's when using return-to-zero transmission

3.3
duty cycle distortion
DCD
measure of the balance of the time width of a logical 1 bit to the width of a logical 0 bit, indicated by the time between the eye diagram nominal rising edge at the average or 50 % level and the eye diagram nominal falling edge at the average or 50 % level

3.4
extinction ratio
ratio of the nominal 1 level to the nominal 0 level of the eye diagram

3.5
eye diagram
type of waveform display that exhibits the overall performance of a digital signal by superimposing all the acquired samples on a common time axis one unit interval in width

3.6
eye height
difference between the 1 level, measured three standard deviation below the nominal 1 level of the eye diagram, and 0 level, measured three standard deviations above the nominal 0 level of the eye diagram

3.7
eye mask
constellation of polygon shapes that define regions where the eye diagram may not exist, thereby effectively defining the allowable shape of the transmitter waveform

3.8
eye width
time difference between the spread of the two crossing points of an eye diagram, each measured three standard deviations toward the centre of the eye from their nominal positions

3.9
jitter
deviation of the logical transitions of a digital signal from their ideal positions in time manifested in the eye diagram as the time width or spread of the crossing point

3.10
observed jitter transfer function
OJTF
ratio of the displayed or measured jitter relative to actual jitter, versus jitter frequency, when a test system is synchronized with a clock derived from the signal being measured

3.11
reference receiver
description of the frequency and phase response of a test system, typically a fourth-order Bessel-Thomson low-pass, used to analyze transmitter waveforms with the intent of achieving consistent results whenever the test system complies with this expected response

3.12
signal-to-noise ratio
SNR
similar to Q-factor, the ratio of the difference of the nominal 1 and 0 level of the eye diagram to the sum of the standard deviation of both the 1 level and the 0 level of the eye diagram

3.13
unit interval
for the NRZ signal, the unit interval is one bit period or the inverse of the signalling rate

4 Apparatus

4.1 General

The primary components of the measurement system are a photodetector, a low-pass filter, an oscilloscope, and an optical power meter, as shown in Figure 1. Many transmitter characteristics are derived from analysis of the transmitter time-domain waveform. Transmitter waveform characteristics can vary depending on the frequency response and bandwidth of the test system. To achieve consistent results, the concept of a reference receiver is used. The reference receiver definition defines the combined frequency and phase response of the optical-to-electrical converter, any filtering, and the oscilloscope. The reference receiver frequency response is typically a low pass filter design and is discussed in detail in 4.2. At high signalling rates, reference receiver frequency response can be difficult to achieve when configured using individual components. It is common to integrate the reference receiver within the oscilloscope system to achieve reference receiver specifications. Use of a low-pass filter which alone achieves reference receiver specifications often will not result in a test system that achieves the required frequency response.

4.2 Reference receiver definition

A reference receiver typically follows a fourth-order low-pass Bessel response. A well-defined low-pass frequency response will yield consistent results across all test systems that conform to the specification. A low-pass response reduces test system noise and approaches the bandwidth of the actual receiver that the transmitter will be paired with in an actual communications system. As signal transients such as overshoot and ringing, which can lead to eye mask failures, are usually suppressed by the reduced bandwidth of the system receiver, it is appropriate to use a similar bandwidth in a transmitter test system. The Bessel phase response yields near constant group delay in the passband, which in turn results in minimal phase distortion of the time domain optical waveform. The bandwidth of the frequency response typically is set to 0,75 (75 %) of the signalling rate. For example, the reference receiver for a 10,0 GBd signal would have a –3 dB bandwidth of 7,5 GHz. For non-return to zero (NRZ) signals, this response has the smallest bandwidth that does not result in vertical or horizontal eye closure (inter-symbol interference). When the entire test system achieves the fourth-order Bessel low-pass response with a bandwidth of 75 % of the baud rate, this is referred to as a Bessel-Thomson reference receiver. Return-to-zero (RZ) signals require a larger bandwidth reference receiver, but which has not been specified in any standards committees.

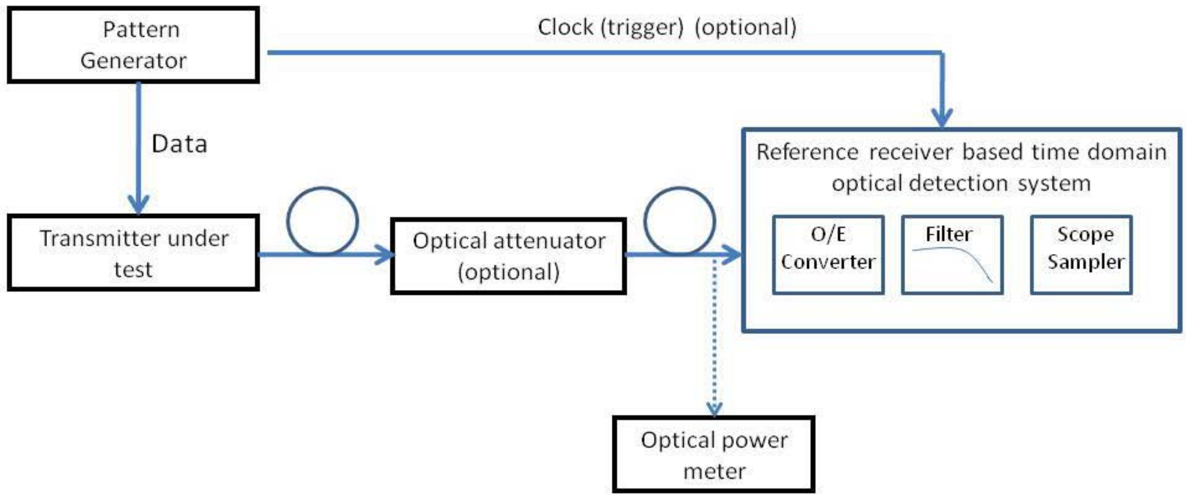


Figure 1 – Optical eye pattern, waveform and extinction ratio measurement configuration

4.3 Time-domain optical detection system

4.3.1 Overview

The time-domain optical detection system displays the power of the optical waveform as a function of time. The optical detection system is comprised primarily of a linear optical-to-electrical (O/E) converter, a linear-phase low-pass filter and an electrical oscilloscope. The output current of the linear photodetector must be directly proportional to the input optical power. When the three elements are combined within an instrument, it becomes an optical oscilloscope and can be calibrated to display optical power rather than voltage, as a function of time. More complete descriptions of the equipment are listed in 4.3.2 to 4.3.4.

4.3.2 Optical-to-electrical (O/E) converter

The O/E converter is typically a high-speed photodiode. The O/E converter is equipped with an appropriate optical connector to allow connection to the optical interface point, either directly or via an optical test cord. When low power signals are to be measured, the photodetector may be followed by electrical amplification. The frequency response of the amplification must be considered as it may impact the overall frequency response of the test system.

Precise specifications are precluded by the large variety of possible implementations, but general guidelines are as follows:

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

b) input optical reflectance, low enough to avoid excessive back-reflection into the transmitter being measured;

c) responsivity and low noise, adequate to produce an accurately measureable display on the oscilloscope. The photodetector responsivity influences the magnitude of the displayed signal. The photodetector and oscilloscope electronics generate noise. The noise of the test system must be small compared to the observed signal. If the noise is significant relative to the detected optical waveform, some measurements such as eye-mask margin can be degraded. When the photodetector is integrated within the test system oscilloscope, noise performance is specified directly as an RMS optical power level (e.g. 5 mW). The responsivity of the photodetector is used to calibrate the vertical scale of the instrument. Further discussion on the impact of noise is found in 6.1;

d) lower cut-off (–3 dB) frequency, 0 Hz;

e) DC coupling is necessary for two reasons. First, extinction ratio measurements cannot otherwise be performed. Second, if AC-coupling is used, low-frequency spectral components of the measured signal (below the lower cut-off frequency of the O/E converter) may cause significant distortion of the detected waveform;

f) upper cut-off (–3 dB) frequency, greater than the bandwidth required to achieve the desired reference receiver response. Note that –3dB represents a voltage level within the oscilloscope that is 0,707 of the level seen in the filter passband;

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

h) output electrical return loss, high enough that reflections from the low-pass filter following the O/E converter are adequately suppressed from 0 Hz to a frequency significantly greater than the bandwidth of the low-pass filter.

4.3.3 Linear-phase low-pass filter

A reference receiver is commonly implemented by placing a low-pass filter of known characteristics in the signal path prior to the oscilloscope sampling electronics. The bandwidth and transfer function characteristics of the low-pass filter are designed so that the combined response of the entire signal path including the O/E converter and oscilloscope meets reference receiver specification.

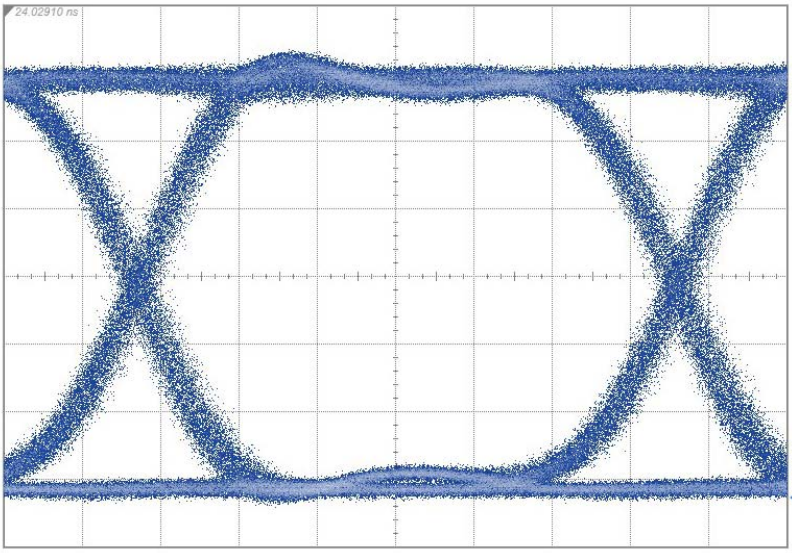
Some measurements of optical waveform parameters are best made without an intentionally reduced bandwidth. Measurements of risetime, falltime, overshoot etc. may be improved with removal of the low-pass filter (see 4.3.4 and 7.11). This may be achieved with electronic switching. The –3 dB bandwidth of the measurement system in this case shall be high enough to allow verification of minimum rise and fall times (for example, one-third of a unit interval), but low enough to eliminate unimportant high-frequency waveform details. For NRZ signals, a bandwidth of 300 % of the signalling rate is a typical compromise value for this type of measurement. RZ signals can require a bandwidth of 500 % of the signalling rate as a typical compromise.

4.3.4 Oscilloscope

The oscilloscope which displays the optical eye pattern typically will have a bandwidth well in excess of the bandwidth of the low-pass filter, so that the oscilloscope is not the bandwidth-limiting item of the measurement system. As signalling rates become very high, the oscilloscope bandwidth may become a more significant contributor to the overall reference receiver response.

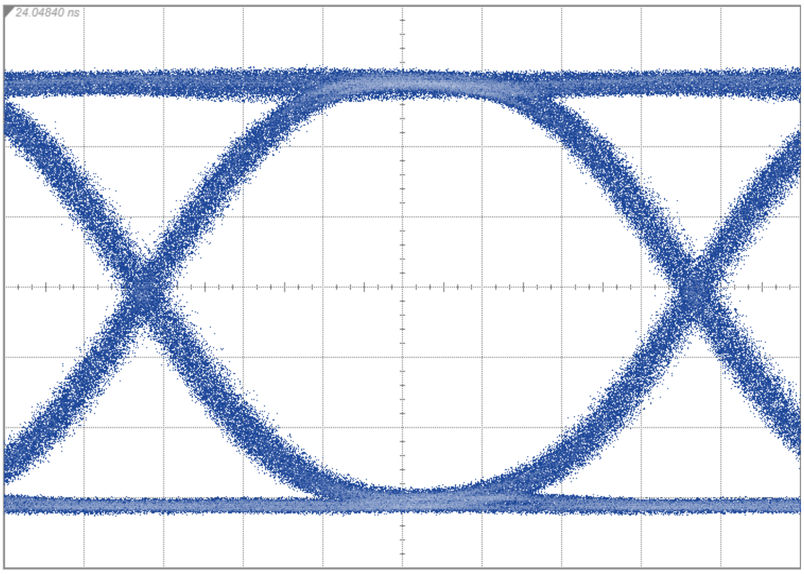
The oscilloscope is triggered either from a local clock signal which is synchronous with the optical eye pattern or from a synchronization signal derived from the optical waveform itself (see 4.5).

Figure 2 illustrates oscilloscope bandwidths that are commonly used in eye pattern measurements. Figure 2(a) displays a 10 GBd waveform when the measurement system filter is switched out and the bandwidth exceeds 20 GHz. Figure 2B shows the same signal when measured with the 10 GBd reference receiver in place (~7,5 GHz bandwidth). Note how rise and fall times and eye shape are dependent on measurement system bandwidth.



IEC 1898/12

Figure 2(a) – 10 GBd signal measured without filtering



IEC 1899/12

Figure 2(b) – 10 GBd signal measured with a 10 GBd reference receiver

Figure 2 – Oscilloscope bandwidths commonly used in eye pattern measurements

4.4 Overall system response

Regardless of the type of eye pattern measurement, the system should have a linear phase response at frequencies up to and somewhat beyond the –3 dB bandwidth. If the phase response is linear (the group delay is constant) up to frequencies of high attenuation, slight variations in frequency response should not significantly affect the displayed waveform and subsequent measurements.

Table 1 shows example reference receiver specifications for a 0,75/T response, where T is the time of one unit interval (exact specifications are typically found within the communication standard defining transmitter performance, with this example showing typical attenuation tolerances for a 10 GBd test system). Reference receiver bandwidth and design for RZ signalling is for further study:

- –3 dB bandwidth: 0,75/T, Hz;
- filter response type: fourth-order Bessel-Thomson.

Table 1 – Frequency response characteristics

Frequency divided by signalling rate	Nominal attenuation dB	Attenuation tolerance dB	Maximum group delay distortion s
0,15	0,1	0,85	–
0,30	0,4	0,85	–
0,45	1,0	0,85	–
0,60	1,9	0,85	0,002 T
0,75	3,0	0,85	0,008 T
0,90	4,5	1,68	0,025 T
1,00	5,7	2,16	0,044 T
1,05	6,4	2,38	0,055 T
1,20	8,5	2,99	0,100 T
1,35	10,9	3,52	0,140 T
1,50	13,4	4	0,190 T
2,00	21,5	5,7	0,300 T

Intermediate attenuation values beyond the –3 dB frequency should be interpreted linearly on a logarithmic frequency scale.

It is common to define the 0 dB amplitude of a low-pass filter response at DC. However, a frequency response measurement of an optical receiver at DC is impractical. Thus the 0 dB level can be associated with the response at a very low frequency such as 3 % of the signalling rate. All other attenuation levels are then relative to the response at 0,03/T. If the frequency response of the reference receiver is accurately known, deviation from ideal can be compensated using port-processing techniques.

4.5 Oscilloscope synchronization system

4.5.1 General

Measurements of optical transmitters are typically performed using equivalent time digitising oscilloscopes commonly referred to as sampling oscilloscopes. This class of oscilloscope requires a triggering signal that is synchronous to the signal being observed. All timing information derived from the waveform will be relative to this trigger signal.

4.5.2 Triggering with a clean clock

The most common trigger signal is a system clock and can be used if allowed by governing standards. Ideally, this is the same clock used to generate the data stream being observed (see Figure 1). Synchronous subrate clocks are also valid except when testing repeating patterns where the ratio of the data pattern length to the clock divide ratio is an integer other than 1. Integer pattern-to- clock divide ratios result in incomplete eye diagrams in which specific bits of the test pattern will systematically not be observed. For example, if the pattern length is 128 bits, clock divide ratios such as 4, 8 and 32 should be avoided. However, these divide ratios are appropriate if the pattern length is 127 bits.

4.5.3 Triggering using a recovered clock

It is common for governing standards to require the synchronizing clock signal to be generated from the signal under test through clock recovery. Clock recovery systems are typically achieved with some form of phase-locked loop (PLL) which synchronizes itself to a tapped portion of the transmitter signal. Triggering the oscilloscope with a clock that has been derived from the signal being observed creates some important measurement issues. If the transmitter signal suffers from significant timing instability (jitter), this would be important to observe. However, if the timing reference (trigger) for the oscilloscope has been derived from the transmitter signal, it will include some of the same jitter properties. The displayed jitter can be dramatically reduced as the jitter is common to both the trigger and the signal being observed.

The amount of jitter present on the extracted clock trigger is dependent on the loop bandwidth of the PLL within the clock recovery system. If the loop bandwidth is narrow, only very low frequency jitter will be transferred to the recovered clock, which is then used to trigger the oscilloscope. If the loop bandwidth is wide, both low and high frequency jitter is transferred to the recovered clock trigger. This is described by the jitter transfer function (JTF) which is the ratio of the jitter on the recovered clock to the jitter on the signal under test. JTF is typically characterized as a function of jitter frequency and follows a low-pass filter response (see Figure 3).

Jitter common to both the trigger and the test signal will not be displayed on the oscilloscope. If the clock recovery loop bandwidth is narrow, low frequency jitter will be suppressed from the displayed eye, but high frequency jitter will be displayed. If the loop bandwidth is wide, both low and high frequency jitter will be suppressed. This leads to the concept of the observed jitter transfer function (OJTF). OJTF is mathematically the complement of the clock recovery JTF (see Figure 3). In effect, triggering with a recovered clock results in a high-pass filtering of displayed jitter. The filter bandwidth is approximated by the bandwidth of the PLL. The actual OJTF response is a complex function of frequency and depends on both the PLL design and any trigger-to-sample delay in the test system.

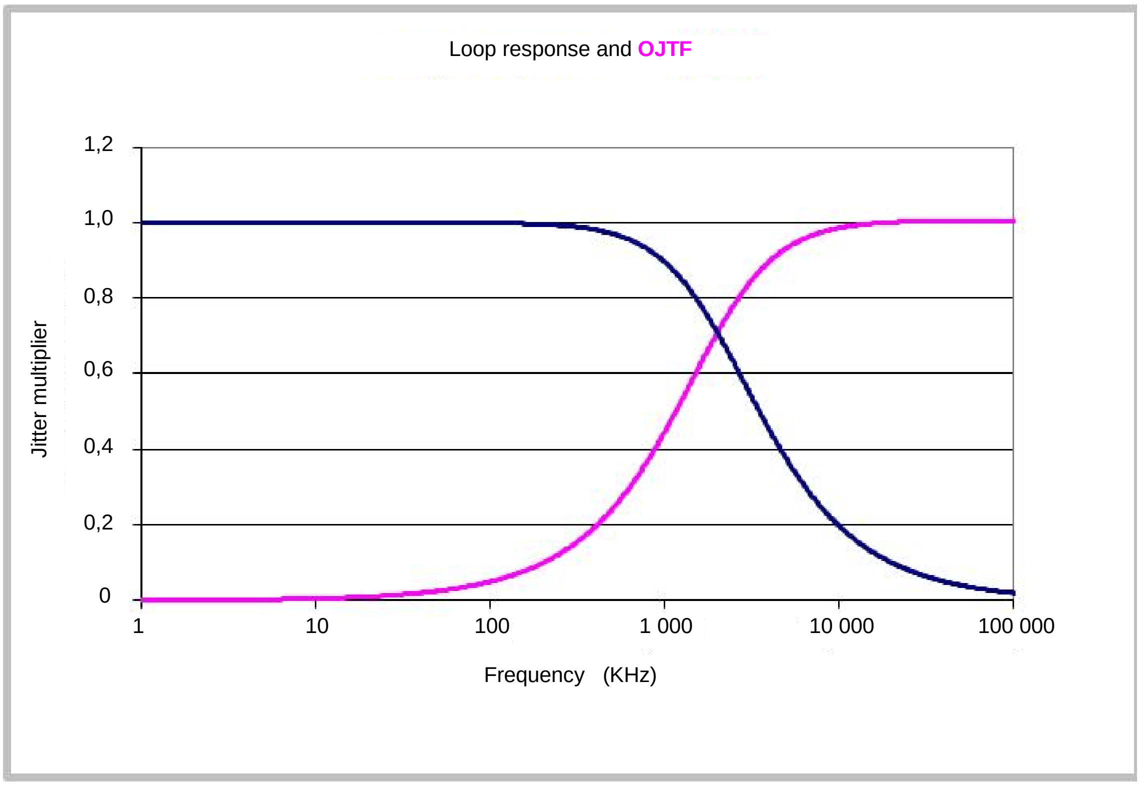


Figure 3 – PLL jitter transfer function and resulting observed jitter transfer function

The OJTF phenomenon can be used strategically. In a communications system a transmitter is paired with a receiver that has its own clock recovery system to time its decision circuit. Such a receiver can track and thus tolerate jitter within its loop bandwidth and may be present on the incoming signal. Thus if low frequency jitter is present on the signal, it will not degrade system level communications. If this jitter remained on the observed signal during test, it would result in eye diagram closure and a viable transmitter could appear unusable. A test system that uses a clock recovery process that has a loop bandwidth similar to the communications system receiver will suppress the display of unimportant low frequency jitter. Communications standards typically define the observed jitter transfer bandwidth for receivers in use and for eye and waveform measurement. Acceptable signals are defined by the relevant communications standards and should consider both the JTF and OJTF concept when specifying allowable transmitter jitter.

4.5.4 Triggering directly on data

A sampling oscilloscope can be triggered by splitting the test signal after the photodetector and routing some signal to the trigger input. A data trigger is problematic. For any two bit sequence, only one of the possible four combinations will generate the edge required to be a valid trigger event. Thus, approximately 75 % of typical test patterns are systematically not observed on any single eye diagram. As discussed above, jitter will be common to both the data and the trigger. Observed jitter is reduced by the removal of the transmitters' clock jitter. There is no control over the OJTF of the transmitter's clock jitter, much of it increased by the signals' high frequency jitter. This method is not recommended except for OMA measurements (see 7.4).

Some oscilloscopes acquire data and derive an effective trigger through a post-processing 'software' clock recovery. Algorithms must consider the same issues that exist with hardware triggering and clock recovery.

4.6 Pattern generator

The pattern generator shall be capable of providing bit sequences and programmable word patterns to the system consistent with the signal format (pulse shape, amplitude, etc.) required at the system input electrical interface of the transmitter device and as defined by the appropriate communications standard.

4.7 Optical power meter

The optical power meter shall be used which has a resolution better than 0,1 dB and which has been calibrated for the wavelength of operation for the equipment to be tested. Optical power meters can also be integrated within an optical reference receiver through monitoring the DC component of the photodetector output current.

4.8 Optical attenuator

The attenuator shall be capable of attenuation in steps less than or equal to 0,1 dB and should be able to adjust the input level to suit the acceptable range of the O/E converter.

The attenuator should not alter the mode structure of the signal under test. The total attenuation of the attenuator must be accounted for in any measurements that require absolute amplitude information. Care should be taken to avoid back reflection into the transmitter.

4.9 Test cord

Unless otherwise specified, the test cords shall have physical and optical properties normally equal to those of the cable plant with which the equipment is intended to operate. The test cords can be 2 m to 5 m long. Appropriate connectors shall be used. Single-mode test cords shall be deployed with two 90 mm diameter loops. If the equipment is intended for multimode operation and the intended cable plant is unknown, the fibre size shall be 62,5 μm/125 μm.

5 Signal under test

The test sample shall be a specified fibre optic transmitter. The system inputs and outputs shall be those normally seen by the user of the system. The test transmitter shall be installed in the measurement configuration as shown in Figure 1.

6 Instrument set-up and device under test set-up

6.1 Unless otherwise specified, standard operating conditions apply. The ambient or reference point temperature and humidity shall be recorded. A filtered response using the appropriate reference receiver described in 4.2 is used except where noted. Allow sufficient warm-up time for the test instrumentation. Perform any instrument calibrations recommended by the manufacturer. Of particular importance to eye-diagram extinction ratio testing is a “dark cal” or dark level calibration. Any residual signal present within the oscilloscope when there is no optical signal present at the input is known as the dark level. Measuring and removing the dark level ‘b_{dark}’ will enhance the accuracy of the extinction ratio measurement. Dark levels are determined by placing a vertical histogram about the signal trace observed on the oscilloscope when absolutely no signal is present at the oscilloscope input. ‘b_{dark}’ is the mean level of the histogram. For best accuracy, dark calibrations should be performed at the oscilloscope vertical scale and offset setting at which extinction ratio measurements are made. Thus, a dark cal may need to be repeated after the transmitter signal levels have been observed. Apply appropriate terminal input voltage/power to the system under test. Follow appropriate operating conditions. Allow sufficient time for the terminal or transmitter under test to reach steady-state temperature and performance conditions.

6.2 As part of standard operating conditions, all transmitter inputs are fully loaded with a signal at the full signalling rate and with a pattern that has spectral content representative of actual operation. Acceptable signals are defined by the relevant communications standards, otherwise this is often achieved with pseudo-random data (typically 2^{31} –1). Test patterns can be constructed that represent actual communications signals, yet are much shorter than pseudo-random 2^{31} –1 sequences. These can be appropriate for test scenarios where extremely long test patterns are problematic for some oscilloscope architectures.

6.3 Use appropriate optical fibre cables; if necessary connect the input of the O/E converter to the optical interface point being tested.

6.4 Adjust the trigger setup and level of the oscilloscope to achieve a stable waveform display

6.5 Determine the signalling rate of the optical signal to be tested. Select the appropriate reference receiver frequency response corresponding to the signalling rate and controlling specification.

6.6 Connect the test equipment, as shown in Figure 1. Verify that the waveform shape is not corrupted through averaging or excess power into the oscilloscope. As necessary, adjust the optical attenuator to set the reference receiver input power within the input power level range specified by the manufacturer.

6.7 Set the horizontal timebase of the oscilloscope to display approximately 1,2 or more unit intervals, with at least one complete eye displayed. Unless the test system is capable of using data outside of a single unit interval, displays of multiple unit intervals lead to inefficient data acquisition, as only one unit interval (or one eye diagram) is analyzed in most automatic measurement systems.

6.8 Set the vertical scale of the oscilloscope such that the entire waveform is observed on the screen. Typically, measurement accuracy is improved if the majority of the vertical scale is used. (Example, if the vertical scale is eight divisions, the waveform is displayed across six or seven divisions.) It is common for automatic sampling oscilloscopes to achieve optimal horizontal and vertical scaling of the eye diagram through an ‘autoscale’ function, which should display the eye pattern across most of the available vertical scale.

7 Measurement procedures

7.1 Overview

Several eye diagram parameters are presented including definitions and measurement procedures. (In some cases, the complexity of the measurement algorithm is beyond the scope of the document.)

7.2 Extinction ratio measurement

7.2.1 Configure the test equipment

Configure the test equipment as described in Clause 6. Unless otherwise specified, standard operating conditions apply. The ambient or reference point temperature and humidity shall be recorded.

7.2.2 Measurement procedure

7.2.2.1 General

Modern sampling oscilloscopes perform extinction ratio measurements automatically and should adhere to the following measurement procedure.

7.2.2.2 Construct an amplitude histogram, method 1

Construct an amplitude histogram that includes all samples present on the logic one level within the central 20 % of the eye diagram unit interval. b_1 is the mean value of the histogram (see Figure 4). The centre of the eye is defined as midway between the crossing times. The exact definition may be given by the governing standards; otherwise 0,5 UI from the mean crossing time is suitable. It is important that histogram means rather than peak values are used for the following reasons: Extinction ratio should be measured for the aggregate logic one and zero levels. Eye diagram pattern dependencies can result in distributions that are asymmetric and/or contain multiple modes. Also, if two or more modes dominate and are close in magnitude, the peak value may switch between modes as data is collected leading to an extinction ratio measurement that is unstable.

7.2.2.3 Construct an amplitude histogram, method 2

Similar to 7.2.2.2 construct an amplitude histogram that includes all samples present on the logic zero level within the central 20 % of the eye diagram unit interval. b_0 is the mean value of the histogram (see Figure 4).

7.2.2.4 Construct an amplitude histogram

For RZ (return to zero) signals, the procedure of 7.2.2.2 and 7.2.2.3 are used, but histograms are constructed over the central 5 % of the RZ eye. The centre of the eye is defined as the time location of the peak of the eye.

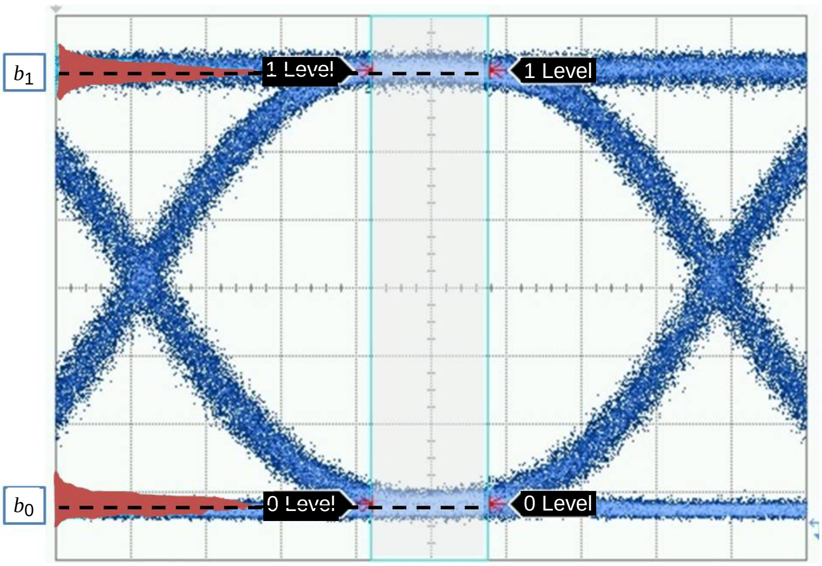


Figure 4 – Histograms centred in the central 20 % of the eye used to determine the mean logic one and 0 levels, b_1 and b_0

7.2.3 Extinction ratio calculation

Extinction ratio definition: the ratio of the average optical energy in the centre of a logic one to the average optical energy in the centre of a logic zero.

For non-return-to-zero (NRZ) and return-to-zero (RZ) optical line coding, the extinction ratio may be determined as the ratio:

Extinction ratio (linear): $(b_1 - b_{dark}) / (b_0 - b_{dark})$

Extinction ratio in decibels: $10 \log_{10}((b_1 - b_{dark}) / (b_0 - b_{dark}))$

Extinction ratio as a percentage: $100\ (b_0 - b_{dark})/(b_1 - b_{dark})$

Note that when extinction ratio is expressed as a percentage, the higher the “on to off ratio” the smaller the extinction ratio percentage will be.

Extinction ratio results can be adversely impacted by reference receivers exhibiting deviation from an ideal frequency response. Systematic measurement errors can occur due to this non-ideal response particularly at low frequencies. This error can be quantified as an extinction ratio correction factor (ERCF) and used to improve the extinction ratio measurement result. ERCF values are determined by providing a signal of known extinction ratio to the test system. The ERCF is the difference between the known extinction ratio and the measured extinction ratio (both expressed as a percentage). If the true extinction ratio is 1 %, but the measured value is 1,5 %, the ERCF is -0,5 %. Subsequent measurements of extinction ratio are improved by adding the ERCF to the measured value. In general, ERCF values are unique for a specific optical reference receiver based test system. When a test system is capable of being configured with reference receivers for multiple data rates, it is likely that a unique ERCF will be required for each configuration. Once the measured extinction ratio has been corrected, it can be expressed in linear terms or in decibels as follows:

Corrected extinction ratio (percentage): $100\ (b_0 - b_{dark})/(b_1 - b_{dark})+\text{ERCF}$

Corrected extinction ratio (linear): $1/((100\ (b_0 - b_{dark})/(b_1 - b_{dark})+\text{ERCF})/100)$

Extinction ratio (decibels): $10\ \log_{10} 1/((100\ (b_0 - b_{dark})/(b_1 - b_{dark})+\text{ERCF})/100)$

7.3 Eye amplitude

7.3.1 Eye amplitude is similar to OMA (see 7.4).

7.3.2 Eye amplitude is the difference in the b_1 and b_0 values from 7.2.

7.4 Optical modulation amplitude (OMA) measurement using the square wave method

7.4.1 General

Some communication system standards require an OMA value that is not impacted by inter-symbol interference. The logic one amplitude b_1 is obtained within a consecutive sequence of logic ones and the logic zero amplitude b_0 is obtained within a consecutive sequence of logic zeros. The most common scheme is to have the transmitter produce a repeating sequence of five logic ones followed by five logic zeros. Eight ones and eight zeros are also used.

7.4.2 Oscilloscope triggering

Triggering of the oscilloscope is achieved by using a signal edge that occurs once per N repetitions of the square wave sequence. This can be achieved with a divided clock signal (signalling rate divided by N times the pattern length) or by triggering directly on the signal under test. For example, if the signal is five ones followed by five zeros, a clock signal with a frequency of the signalling rate divided by 10, 20, 30 etc. is valid. Although triggering directly on the signal under test is generally discouraged, for the OMA measurement triggering on either the rising edge or the falling edge of the data will yield the correct waveform display.

7.4.3 Amplitude histogram, step 1

An amplitude histogram is constructed over the full bit interval of the central bit (or region specified by the communications standard) in the sequence of ones. b_1 is the mean of this histogram.

7.4.4 Amplitude histogram, step 2

An amplitude histogram is constructed over the full bit interval of the central bit (or region specified by the communications standard) in the sequence of zeros. b_0 is the mean of this histogram.

7.4.5 Calculate OMA

See Figure 5. OMA is the difference between b_1 and b_0.

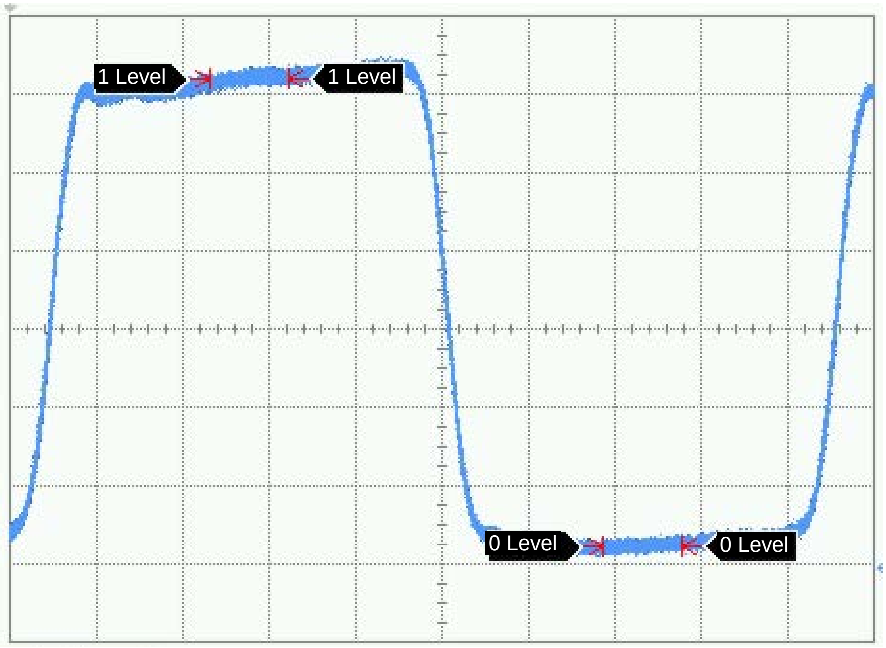


Figure 5 – OMA measurement using the square wave method

7.5 Contrast ratio (for RZ signals)

Contrast ratio (RZ format signals) definition: the ratio of the signal level of the logic one at its full on state to the level of the logic one at its off state where it returns to zero before transitioning to another logic one.

$$(b_{1\text{on}} - b_{\text{dark}}) \,/\, (b_{1\text{off}} - b_{\text{dark}})$$

The general logic one off level is composed of data from logic one pulses including those preceded or followed by logic zeros. Care should be taken to reduce the influence of the logic zero signal in the construction of the measurement of the logic one off level.

7.6 Jitter measurements

7.6.1 As described in 3.9, jitter is the deviation of the logical transitions of a digital signal from their ideal positions in time manifested in the eye diagram as the time width or spread of the crossing point. For the NRZ eye diagram a jitter measurement can be made at the crossing point, where the rising and falling edges of the eye diagram intersect. This provides a useful assessment of the overall jitter of the signal when making transitions to both logic zero levels and logic one levels and the effective eye closure specifically caused by that jitter.

7.6.2 This measurement is performed by placing a vertically thin histogram positioned at the eye diagram crossing point. The histograms statistics such as peak-to-peak spread and standard deviation can be used to quantify the jitter (Jitter p-p and Jitter RMS respectively). Note that when jitter is measured at the eye diagram crossing point, it does not include duty-cycle-distortion (DCD), which can be considered an element of jitter, but is defined and measured as an individual parameter in this procedure (see 7.8). Also, some communications standards prefer to assess jitter at the mean amplitude of the eye, which will not be the same level as the crossing point when DCD is present. In this scenario, the histogram statistics will include the DCD contribution.

7.6.3 While the full width of the histogram can provide a peak-to-peak jitter value, realize that as more data samples are acquired the width of the histogram and the jitter value will increase. Thus, it is a coarse assessment of the jitter and may not provide a precision estimate of total jitter used to estimate bit-error-ratio (see IEC 61280-2-3).

7.6.4 While the standard deviation of the histogram can be used to provide a root-mean-square estimate of the jitter, it may not be an accurate measure of random jitter, as the histogram can be composed of both random and deterministic jitter elements.

7.6.5 For the RZ eye, rising and falling edges do not intersect at a location that provides useful timing information. A jitter measurement is made on either the rising edge or the falling edge, typically at the 50 % level. An aggregate measurement can be made through combining the jitter measurements made using histograms on both the rising and falling edges. As the jitter is an assessment of horizontal (time) eye closure, the right half of the rising edge jitter histogram is combined with the left half of the falling edge jitter histogram to approximate the equivalent jitter measurement of the crossing point of the NRZ eye.

7.7 Eye width

7.7.1 A complementary measurement to jitter is eye width. From 7.6, jitter causes the eye to close in time. The eye width of an ideal jitter-free NRZ eye would be one unit interval. For practical signals eye width is a measure of the residual eye opening after accounting for jitter and mathematically is the time difference between the unit interval and the measured jitter.

7.7.2 Eye width= 1 unit interval – 6 $\text{jitter}_{\text{rms}}$. Note this assumes that the jitter distribution is the same on each crossing point as well as symmetric about the ideal crossing point. In addition, some standards may define the eye closure using 7 $\text{jitter}_{\text{rms}}$.

7.7.3 Eye width %= 100 (1 unit interval -6 $\text{jitter}_{\text{rms}}$)/1 unit interval.

7.8 Duty cycle distortion (DCD)

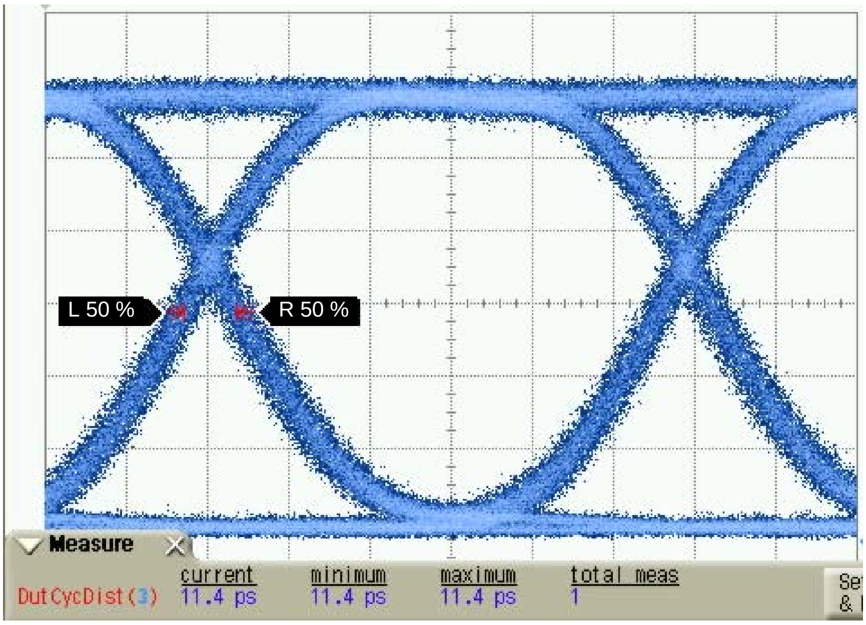
7.8.1 DCD occurs when the width of the logic one pulses are different from the width of the logic zero pulses. This is seen as an eye diagram crossing point, which occurs at a level that is not midway between the logic one level (b_1) and the logic zero level (b_0). DCD can be measured as the time separation between the average position of the falling edge and the average position of the rising edge, both measured at the average level of the signal.

7.8.2 Construct a time histogram at the average of the b_1 and b_0 levels, positioned to include both the rising and falling edge of the eye diagram crossing point.

7.8.3 Locate the mean time position of the falling edges t_f.

7.8.4 Locate the mean position of the rising edges t_r.

7.8.5 DCD= $| t_f - t_r |$. See Figure 6.



IEC 1903/12

Figure 6 – Construction of the duty cycle distortion measurement

7.8.6 Alternatively, DCD can be expressed as a percentage of a unit interval.

7.8.7 DCD %= 100 (DCD/unit interval).

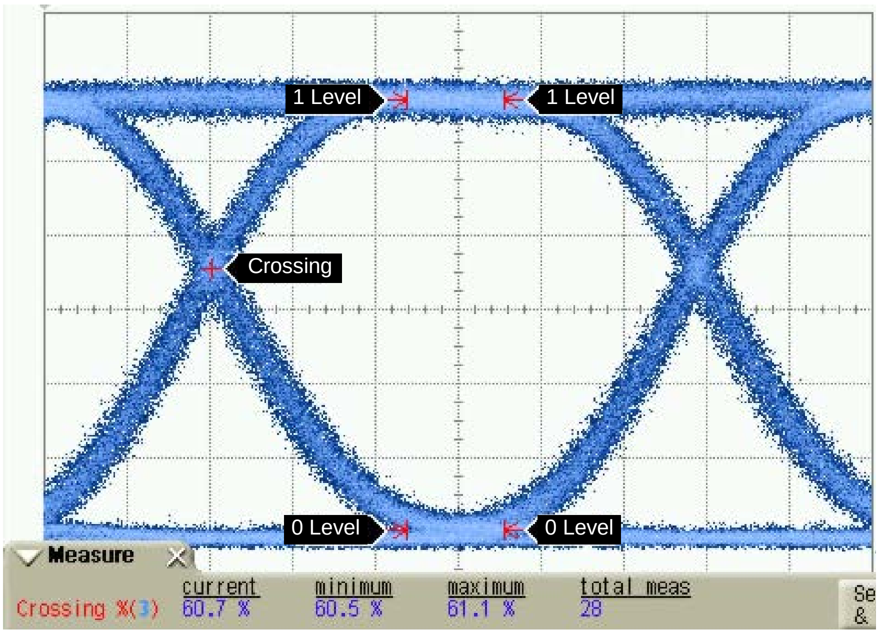
7.9 Crossing percentage

7.9.1 Crossing percentage is used to measure the relative amplitude position where falling edges intersect with the rising edges of the eye diagram.

7.9.2 Construct histograms to locate the time position where the mean of the falling edge population intersects the mean of the rising edge population.

7.9.3 Construct a histogram to determine the amplitude b_x at the mean intersection point.

7.9.4 Crossing percentage = 100 $(b_x – b_0)/(b_1 - b_0)$. See Figure 7.



IEC 1904/12

Figure 7 – Construction of the crossing percentage measurement

7.10 Eye height

7.10.1 Eye height describes the vertical opening of the eye diagram and accounts for deviation of the signal from its ideal amplitude levels

7.10.2 Histograms are constructed in the same fashion as described in 7.2.2.2 and 7.2.2.3.

7.10.3 In addition to determining b_1 and b_0, the standard deviation of each histogram (s_1 and s_0) is also calculated.

7.10.4 Eye height is calculated as the $(b_1\text{-}3s_1) – (b_0+3s_0)$.

7.11 Q-factor/signal-to-noise ratio (SNR)

7.11.1 SNR compares the amplitude of the transmitter signal to the combined 'noise' on both the logic one and zero levels. Note that in this procedure the measured 'noise' includes any amplitude deviations from ideal, both random and deterministic. Generally, noise is due only to random mechanisms. Thus this is not a precision method to determine a true signal to noise ratio that could be used to estimate bit-error-ratio. Note that this measurement definition is equivalent to that used for Q-Factor. Similarly, Q-factor analysis assumes that signal deviation from ideal amplitudes is dominated by random mechanisms.

7.11.2 SNR is calculated using the same parameters as eye height.

7.11.3 SNR = $(b_1 - b_0)/(s_1 + s_0)$.

7.12 Rise time

Rise time is the time required for the optical signal to rise from 20 % to 80 %, or from a value of

$$b_0 + 0{,}2\ (b_1 – b_0)$$

to a value of

$$b_0 + 0{,}8\ (b_1 - b_0)$$

Because optical waveforms may exhibit distortion in the initial turn-on region and in reaching a steady state amplitude, the 10 % and 90 % levels sometimes used to describe edge speed in electrical systems may be difficult to resolve with sufficient accuracy. Therefore, 20 % to 80 % rise times are preferred by this standard. See Figure 8. This value is typically measured without a low-pass Bessel-Thomson filter. If the filter is in place, the rise time measured will be larger than that measured without the filter. The observed risetime may be correlated by the root-sum-of-squares method to the risetime in the bandwidth specified by the governing standard.

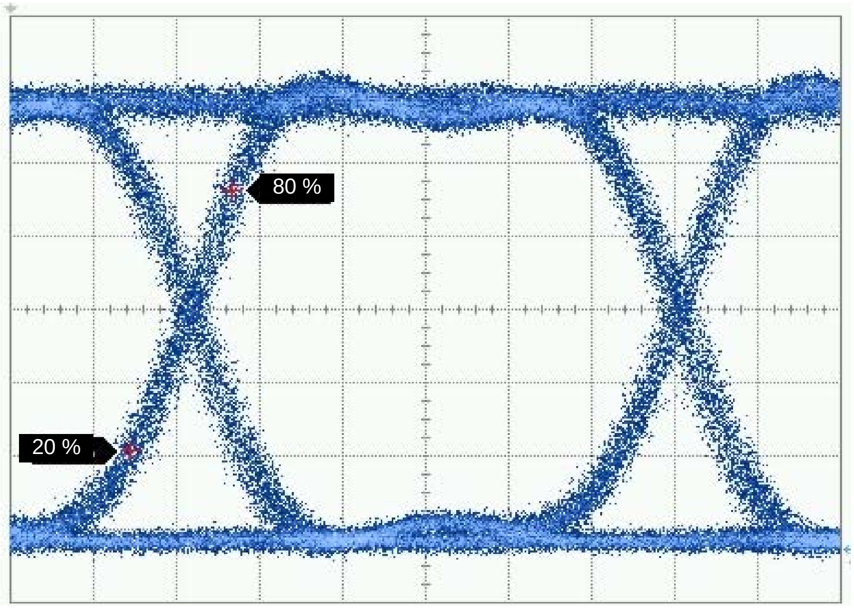


Figure 8 – Construction of the risetime measurement with no reference receiver filtering

7.13 Fall time

Fall time is the time required for the optical pulse to fall from 80 % to 20 %, or from a value of

$$b_0 + 0{,}8\ (b_1 - b_0)$$

to a value of

$$b_0 + 0{,}2\ (b_1 - b_0)$$

For clarity, Figure 9 indicates definition and construction of measurements for an RZ waveform.

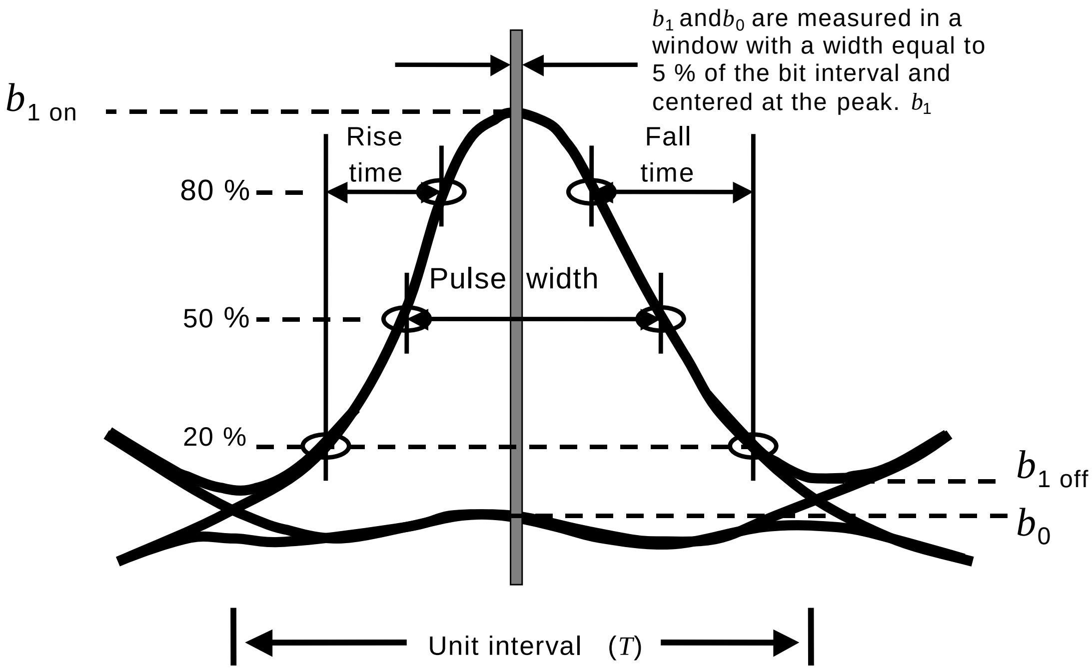


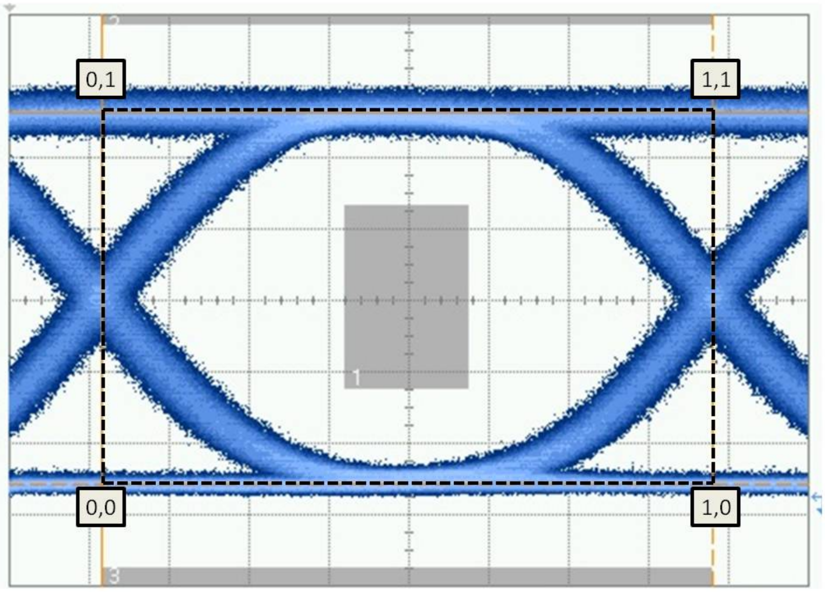
Figure 9 – Illustrations of several RZ eye-diagram parameters

8 Eye-diagram analysis using a mask

8.1 Eye mask testing using the 'no hits' technique

Many communications standards define the allowable shape of a transmitter output waveform through an eye mask. An eye mask typically consists of three polygons placed above, below, and within the eye-diagram (see Figure 10). Mask shapes are typically defined by specific communications standards. The alignment of the mask to the eye diagram generally is as follows:

The mask shapes are defined using a generic coordinate system where 0 and 1 on the time axis correspond to the left and right crossing points of the eye respectively although in some standards it is permissible to adjust the position of the eye in time. 0 on the amplitude axis is defined by the logic zero level of the eye. 1 on the amplitude axis is defined by the logic one level of the eye. Unless stated otherwise by the communication standard the 1 and 0 amplitude levels are defined according to 7.2.2.2 and 7.2.2.3 as b_1 and b_0 respectively.



IEC 1907/12

Figure 10 – Basic eye mask and coordinate system

Mask tests are typically performed using digitising oscilloscopes. A digitised waveform is composed of a fixed number of samples. Historically a transmitter with one or more samples falling on any mask polygon was considered non-complaint. Thus, results are dependent upon the population size of the sampled data. When a mask test is designed, the number of waveform samples required to produce an adequate assessment of the eye diagram, rather than the number of waveforms, should be considered. As the number of samples that make up a waveform can vary with different oscilloscope implementations, specifying a number of samples rather than waveforms will lead to comparable results. Typical values for the number of samples range from 50 000 to 1 000 000. It is important to note that the likelihood of mask test failures increases with increased sample size due to random elements such as noise and jitter in the signal and measurement equipment. For consistency in test results, the number of samples required for an adequate population should be set by the communication standard. The benefit of a large sample population is typically weak compared to the test time penalty incurred, thus populations in the 100 000 to 200 000 are recommended.

Mask test compliance can be quantified further through the use of mask margins to determine how well compliance is achieved. A positive mask margin is an expansion of the nominal mask while a negative margin is a contraction of the nominal mask. A mask margin is generally a proportional expansion of the mask polygons within the general coordinate system. A 0 % expansion represents the nominal mask dimension, while a 100 % mask expansion would be a mask that had been expanded to the 0 and 1 levels of the generic coordinate system. Note that a waveform with a 100 % mask margin is unrealizable when measured with a typical reference receiver using common eye mask shapes. The fastest rise and fall times that can pass through the reference receiver will still violate a 100 % mask expansion even if the transmitter is completely free of distortion, noise and jitter. A mask margin is generally not considered as part of a communications standard, as the standard defines the baseline capability required for system level communications performance. Mask margins are generally used for manufacturing process control and as a figure of merit for a transmitter design.

8.2 Eye mask testing using the ‘hit-ratio’ technique

In general, an eye mask test that allows no mask hits is subject to inconsistent results. As indicated in 8.1, results are typically dependent on the population size. This is particularly true when mask margins are applied. A transmitter may easily achieve no hits for the standard test for even large sample sizes. When the mask dimensions are expanded for margin testing, the amount of expansion that can be achieved with no mask hits will fluctuate both from test to test as well as with different population sizes. A single sample that is a rare outlier in the overall population may significantly reduce the mask expansion in one test but not when a new sample population is acquired.

If a small percentage of samples are allowed to violate the mask compared to the total number of samples, mask testing is significantly less vulnerable to variation in results due to extreme outliers or changes in sample population size. For example, if 1 out of 10 000 samples are allowed to violate the mask, the mask margin will typically be the same for a sample population of 100 000, 1 000 000, or 10 000 000 samples. See Figure 11. The product of sample population and hit ratio should be greater than 5 for consistent results.

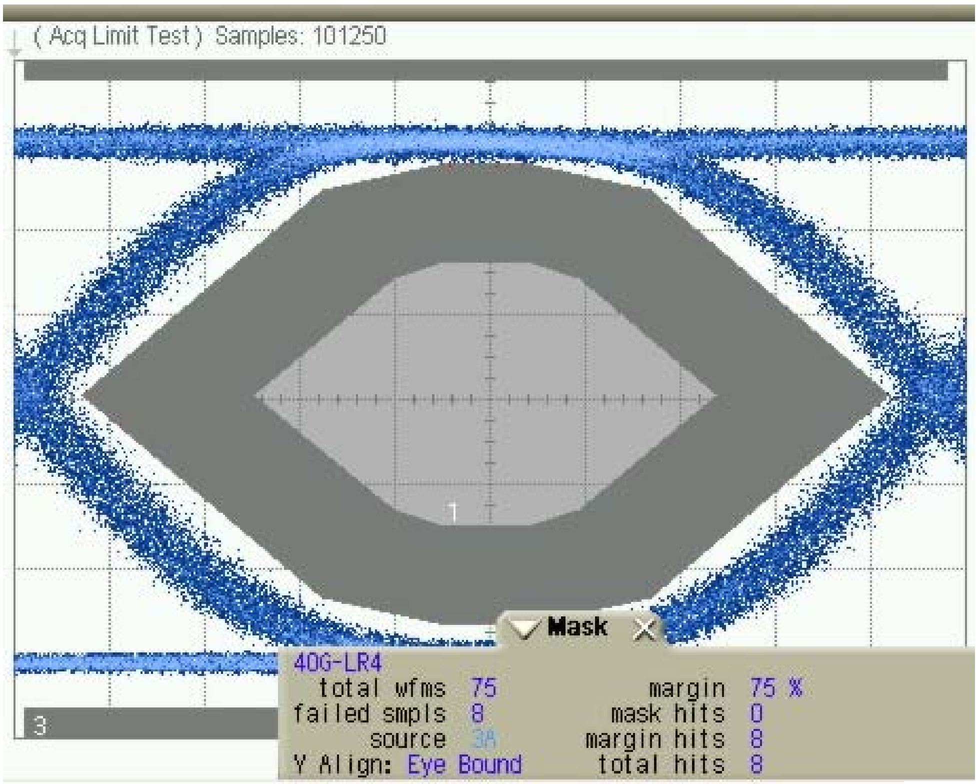
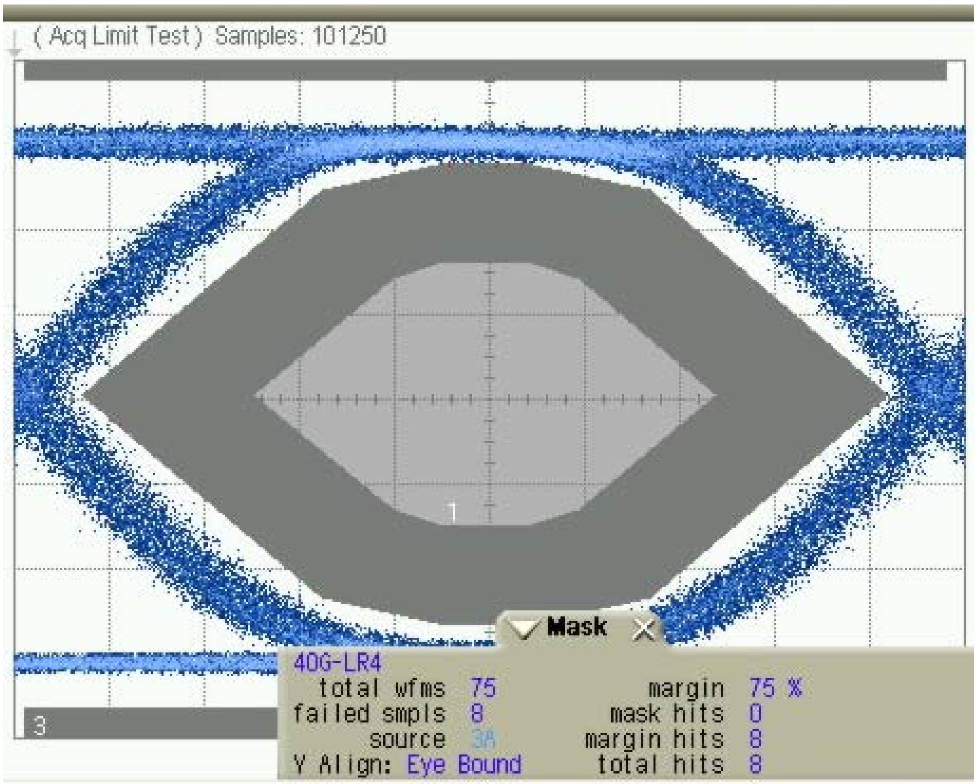


Figure 11(a) – Mask margin with ~ 100 000 samples tested at a 1:10 000 hit ratio: 75 %



IEC 1909/12

Figure 11(b) – Mask margin (76 %) with over 1 million samples and a 1:10 000 hit ratio

Figure 11 – Mask margins at different sample population sizes

For a communication standard using the hit ratio technique, mask dimensions and allowable hit ratio shall be designed concurrently to be compatible with link budgets. A hit ratio of 5 x 10^5 is common and gives reasonable correlation to link performance.

9 Test result

9.1 Required information

– Date, title of the test and test procedure number.

– Sample identification).

– Reference point temperature and humidity.

– Results of the test.

9.2 Available information

– Identification of the test equipment used, an estimate of the measurement uncertainty and the latest date of test equipment calibration.

– Names of test personnel.

9.3 Specification information

The following information shall be specified in the detail specification:

– a reference to this test procedure if it is to be used;

– acceptance or failure criteria;

– other requirements, if applicable.

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