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INTERNATIONAL STANDARD

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inside

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

Procédures d’éssai des sous-systèmes de télécommunication fibroniques – Partie 2-2: Systèmes numériques – Mesure du diagramme de l’œil optique, de la forme d’onde et du taux d’extinction

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FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

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FOREWORD

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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- withdrawn,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.

The contents of the corrigendum of February 2015 have been included in this copy.

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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.

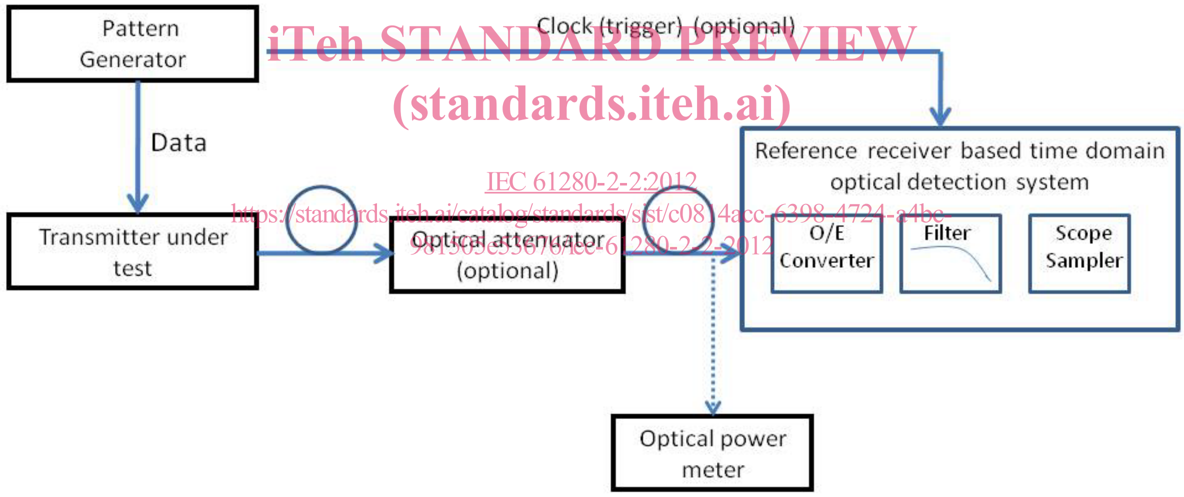

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Figure 1 – Optical eye pattern, waveform and extinction ratio measurement configuration

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.

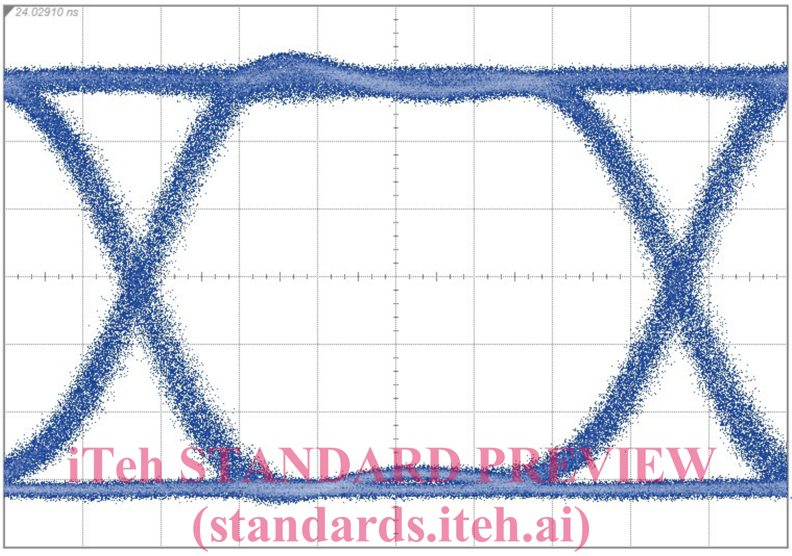

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Figure 2(a) – 10 GBd signal measured without filtering

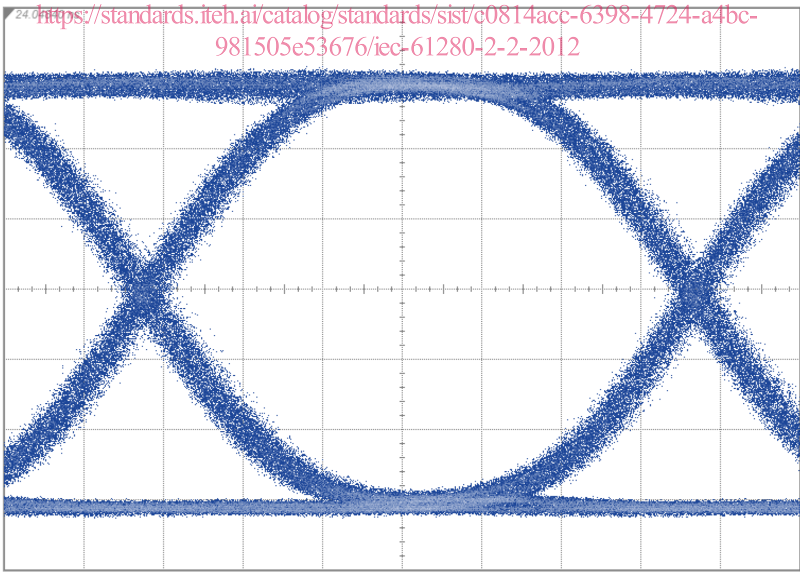

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Figure 2(b) – 10 GBd signal measured with a 10 GBd reference receiver

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.

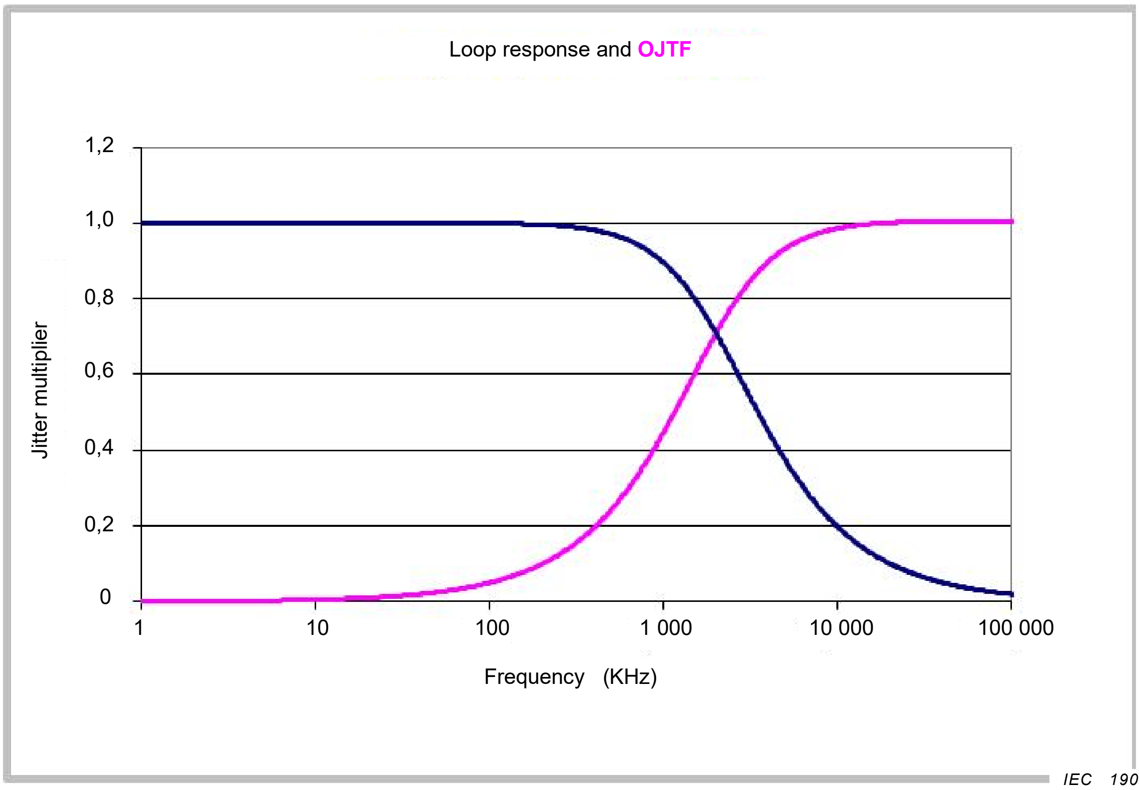

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Figure 3 – PLL jitter transfer function and resulting observed jitter transfer function

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.