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INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

Procédures d'essai des sous-systèmes de télécommunications à fibres optiques – 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 third edition cancels and replaces the second edition published in 2005 and constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

a) The necessity of DC coupling for extinction ratio measurement is clarified.
b) The definition of extinction ratio has been revised to better harmonize with ITU-T.
c) The definition of OMA has been clarified.

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

CDV	Report on voting
86C/768/CDV	86C/801/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 of 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 maintenance result 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- withdrawn;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.

FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

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

1 Scope and object

The purpose of this part of IEC 61280 is to describe a test procedure to measure the eye pattern and waveform parameters such as rise time, fall time, overshoot, and extinction ratio. Alternatively, the waveform may be tested for compliance with a predetermined waveform mask.

2 Normative references

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

ITU-T Recommendation G.957, *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*

3 Apparatus

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.

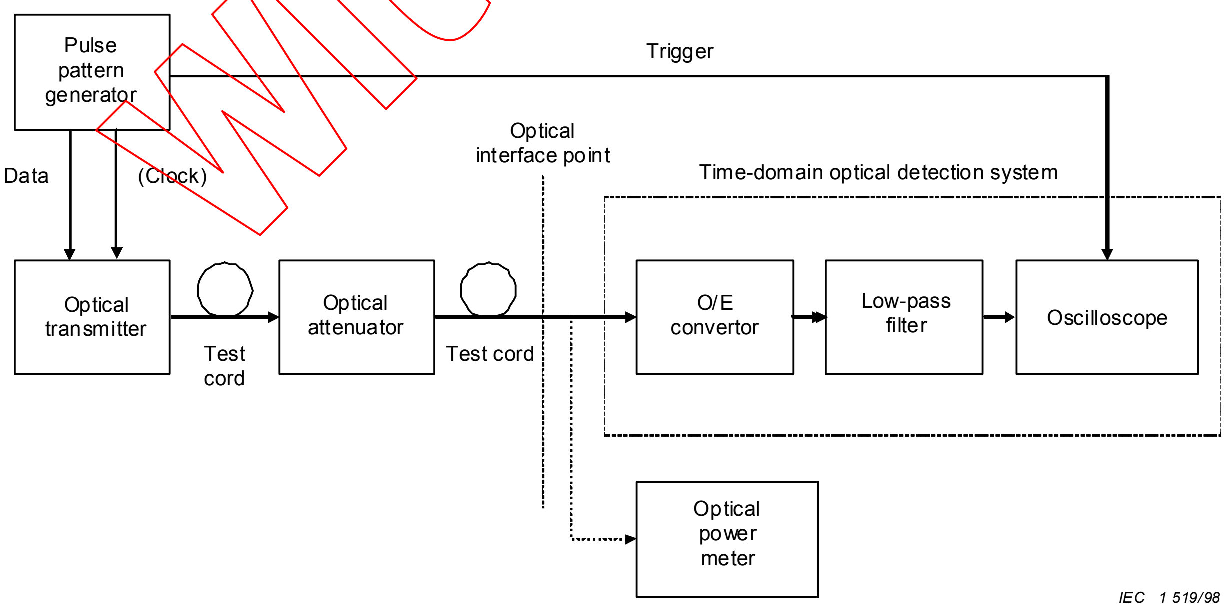

Figure 1 – Optical eye pattern, waveform, and extinction ratio measurement configuration

3.1 Time-domain optical detection system

The time-domain optical detection system displays the intensity of the optical waveform as a function of time. The optical detection system is comprised primarily of an optical-to-electrical (O/E) converter, a linear-phase low-pass filter and an oscilloscope. The detection system is shown in Figure 2. More complete descriptions of the equipment are listed in the following subclauses.

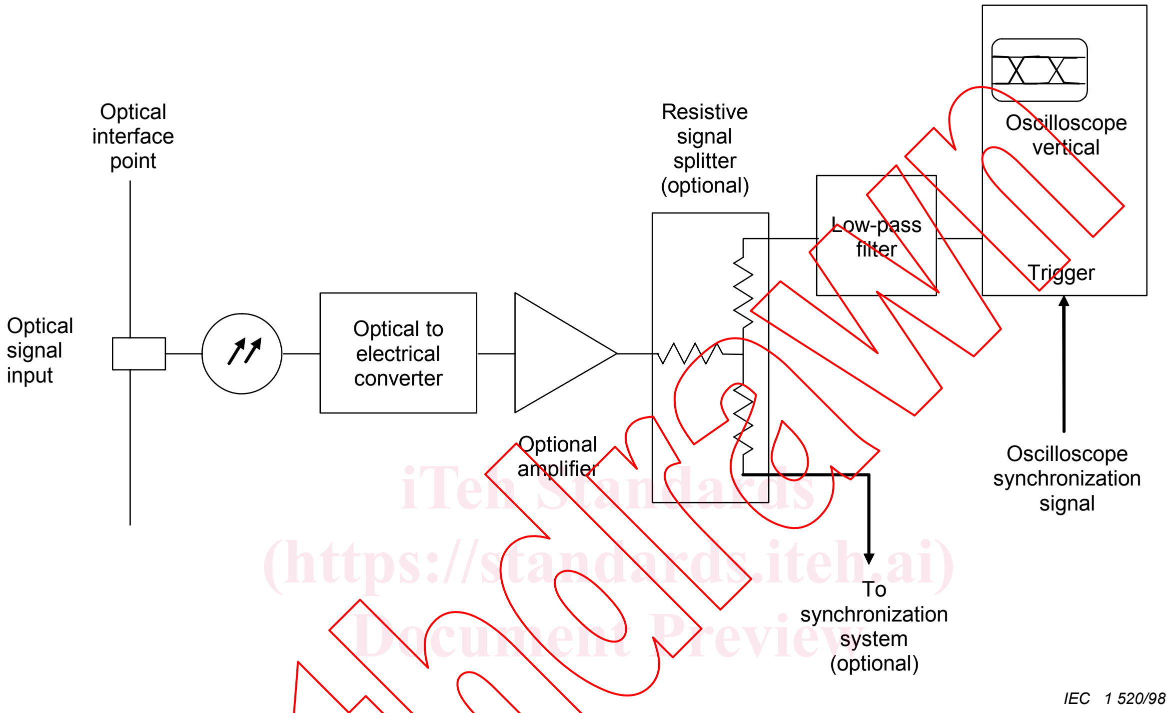

Figure 2 – Time-domain optical detection system

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

The O/E converter is typically a high-speed photodiode followed by electrical amplification. 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.

The O/E converter (including any optional amplification following the O/E converter) shall be able to reproduce the optical waveform with sufficient fidelity to ensure a meaningful measurement. 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;

   For example, assume that an optical transmitter is specified to tolerate –24 dB reflectance maximum. If the input reflectance of the O/E converter is –30 dB, the converter can be directly connected to the transmitter. If, however, the input reflectance of the O/E converter is –14 dB, a common value, the effective reflectance can be lowered to –24 dB (or less) by inserting either an optical isolator or a low-reflectance attenuator of 5 dB (or more) between the transmitter and the O/E converter.

c) responsivity, adequate to produce a readable display on the oscilloscope;

For example, assume that a non-return-to-zero (NRZ) optical data stream with an average optical power of –15 dBm is to be measured. If the sensitivity of the oscilloscope is 10 mV per division, a responsivity of 790 V/W is required in order to produce a display of 50 mV peak-to-peak (that is, five divisions peak-to-peak).

d) optical noise-equivalent power, low enough to result in an accurately measurable display on the oscilloscope;

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

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

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 via amplitude modulation of the detected waveform.

f) upper cut-off (–3 dB) frequency, greater than the bandwidth of the low-pass filter following the O/E converter;

In order to ensure repeatability and accuracy, a low-pass filter of known characteristics is inserted in the signal path before the oscilloscope. This filter alone should primarily determine the effective system bandwidth. However, the response of the entire measurement system should conform to the desired frequency response.

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

The low-pass filter following the O/E converter should primarily determine the system transient response.

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.

A time-domain measurement may be very inaccurate if significant multiple reflections are present. Many passive, low-loss, low-pass filters, in addition to being reflective in the stop band, have frequency responses that are strongly dependent on the termination impedances at the input and output. A minimum value of 15 dB for the return loss is recommended when passive low-pass filters are employed following the O/E converter. The effective output return loss of the O/E converter may be improved with in-line electrical attenuators, at the expense of reduced signal levels. Finally, the return loss specification extends to d.c., since otherwise, a d.c. shift in the waveform will occur, causing extinction ratio measurements to be in error.

3.1.2 Resistive signal splitter (optional)

If the trigger signal for the oscilloscope is to be derived from the optical waveform itself, it is necessary to tap into the signal path at some point. A resistive signal splitter (power divider) at the location indicated in Figure 2 provides a branch from which to derive the trigger signal.

3.1.3 Linear-phase low-pass filter

Generally, one of the primary purposes of measuring the optical eye pattern is to verify certain performance requirements such as rise and fall time, overshoot, etc. If the measurement system bandwidth is much greater than needed, high frequency (and probably insignificant) details of the waveform will tend to obscure the desired measurement. Also, since different measurement setups would have different bandwidths, repeatability between setups would be almost impossible to achieve.

In order to ensure repeatability and accuracy, a low-pass filter of known characteristics is inserted in the signal path prior to the oscilloscope. This filter alone should primarily determine the effective system bandwidth. The type of measurement being performed determines the bandwidth of the low-pass filter. The bandwidth and transfer function characteristics of the low-pass filter should be explicitly stated in the detail specifications.

One type of eye pattern measurement effectively simulates the signal that would result at the output of a bit-rate-specific optical receiver. For NRZ format signals, this type of receiver typically has a bandwidth that is somewhat less than the clock frequency. For this type of measurement, a low-pass filter of –3 dB bandwidth of 0,75/T (where T is the bit interval, in seconds, of the data signal) is often used. The resulting eye pattern is compared to a "mask" to verify compliance with specification. For RZ format signals, spectral content may be significantly higher than the NRZ signal at the same optical bit rate. This may require the reference bandwidth to be in excess of the clock frequency.

A different type of eye pattern measurement involves measuring the rise time, fall time, pulse width and other time-domain parameters of an optical transmitter unit. For this type of measurement, the system bandwidth shall be greater than described above. The –3 dB bandwidth of the low-pass filter in this case needs to be high enough to allow verification of maximum rise and fall times (for example, one-third of a bit intervals), but low enough to eliminate unimportant high-frequency waveform details. For NRZ signals, a low-pass filter bandwidth of 3,0/T is a typical compromise value for this type of measurement. RZ signals can require a bandwidth of 5,0/T as a typical compromise.

Regardless of the type of eye pattern measurement, the filter should have a linear phase response at frequencies up to and somewhat beyond the filter –3 dB bandwidth. If the phase response is linear (implying that the group delay is constant) up to frequencies of high attenuation, slight variations in filter bandwidths should not significantly affect the waveform measurements (see Table 1).

Example low-pass filter specifications for a 0,75/T filter are as follows (exact filter specifications are typically found within the communication standard defining transmitter performance):

– characteristic impedance: 50 Ω nominal;
– –3 dB bandwidth: 0,75/T, Hz; (RZ ffs);
– filter type: fourth-order Bessel-Thompson (RZ ffs).

Table 1 – Frequency response characteristics

Frequency divided by bit rate	**Nominal attenuation** dB	**Attenuation tolerance** dB	**Maximum group delay distortion** s
0,15	0,1	0,3	–
0,30	0,4	0,3	–
0,45	1,0	0,3	–
0,60	1,9	0,3	0,002 T
0,75	3,0	0,3	0,008 T
0,90	4,5	0,3	0,025 T
1,00	5,7	0,3	0,044 T
1,05	6,4	0,39	0,055 T
1,20	8,5	0,64	0,100 T
1,35	10,9	0,90	0,140 T
1,50	13,4	1,15	0,190 T
2,00	21,5	2,0	0,300 T

3.1.4 Oscilloscope

The oscilloscope that displays the optical eye pattern should 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. The oscilloscope is triggered either from a local clock signal that is synchronous with the optical eye pattern or from a synchronization signal derived from the optical waveform itself.

Figures 4 and 5 illustrate oscilloscope bandwidths that are commonly used in eye pattern measurements.

The oscilloscope shall have a vertical-channel histogram function for extinction ratio measurement.

3.1.5 Overall system response

The eye pattern measurement is obviously a time-domain measurement and needs to accurately represent the optical waveform. This should be done without introducing undesirable overshoot, ringing and other waveform aberrations. While the individual components of the measurement system are most conveniently specified in the frequency-domain, the final assembled system may also be required to meet certain time-domain performance limits.

Even an ideal fourth-order Bessel-Thompson filter will have an overshoot of about 1 % and a rise time (10 % to 90 %) of about 0,35/B, where B is the bandwidth in Hertz. In view of this, the overall measurement system shall be required to demonstrate performance similar to the following when stimulated by an ideal step function signal:

– rise time, fall time (10 % – 90 %): 0,43/B maximum, 0,29/B minimum;

– rise time, fall time (20 % – 80 %): 0,35/B maximum, 0,23/B minimum;

– overshoot, undershoot: 5 % maximum.

3.2 Oscilloscope synchronization system

A stable synchronization signal is essential for accurate eye pattern measurement. Ideally, the optical transmitter unit provides the synchronization signal. However, since this synchronization signal may not be present at an optical interface point, it may be necessary to derive the signal from the optical waveform itself.

Some oscilloscopes will allow triggering from transitions in the detected data pattern, either internally (from the vertical channel) or externally (from a separate trigger input). While conveniently simple, this method is not recommended for performing accurate measurements. Optical waveforms are usually fairly "noisy," and by triggering on transitions in the data pattern, the observed eye pattern will be changed by the precise adjustment of the trigger threshold. An oscilloscope typically will trigger on either a rising or a falling edge (but not both). For a Pseudo-random binary sequence (PRBS) data pattern only one of every four bit transitions will produce a trigger event. Thus 75 % of the data is never measured, even if the pattern repeats. Also, jitter in the optical waveform itself will be difficult to observe, since the triggering process may mask jitter. Jitter on the signal being measured is common to the trigger signal and can be effectively eliminated. Finally, the bandwidth of the transition detector in many oscilloscopes may be insufficient to allow reliable, repeatable triggering.

When a stable synchronization signal is not available, a more reliable method of using the optical waveform for oscilloscope synchronization is to use an external oscillator which is "locked" to the optical signal. This is similar to the method used to recover the clock in an optical receiver, but is accomplished with commercially available test equipment rather than with custom circuitry. This method provides a very stable trigger signal, and allows jitter in the optical waveform to be viewed directly. A detailed description of an oscilloscope synchronization system and associated equipment is given in Annex A. Care must be taken in choosing the response bandwidth of the trigger extraction system to achieve an accurate jitter measurement.

3.3 Pulse pattern generator

The pulse pattern generator shall be capable of providing a pseudo random bit sequence 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.

3.4 Optical power meter

The optical power meter shall be used which has a resolution of at least 0,1 dB and which has been calibrated for the wavelength of operation for the equipment to be tested.

3.5 Optical attenuator

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

Care should be taken to avoid back reflection into the transmitter.

3.6 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 shall be 2 m to 5 m long and shall contain fibres with coatings which remove cladding light. 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 62,5/125 µm.

4 Test sample

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.

5 Procedure

In measuring an optical eye pattern, a synchronization signal for triggering the oscilloscope may or may not be available. Many measurement systems include the ability to derive a synchronization signal from the signal being measured. Measurement considerations, as well as a scheme for building a synchronization system when one is not integrated into the test equipment, are discussed in Annex A.

5.1 Method 1: Basic waveform measurement

5.1.1 Unless otherwise specified, standard operating conditions apply. The ambient or reference point temperature and humidity shall be specified.

5.1.2 Apply appropriate terminal input voltage/power to the system under test. Follow appropriate operating conditions. Allow sufficient time (30 min, unless otherwise specified by the manufacturer) for the terminal under test to reach steady-state temperature and performance conditions.

Determine the data rate of the optical signal to be tested. Select the appropriate low-pass filter corresponding to the data rate and controlling specification. Connect the test equipment, as shown in Figure 1, and apply power. If a sampling oscilloscope is used, verify that the waveform shape is not corrupted through averaging or smoothing and that the sampling loop gain is properly adjusted, if applicable. Set the horizontal display of the oscilloscope to approximately 0,2 T per division, where T is as defined in 3.1.3, and the oscilloscope timebase is displayed in 10 divisions. Allow sufficient warm-up time for the test equipment.

As part of standard operating conditions, all terminal inputs are fully loaded with a signal at the full data rate and with a pattern that has spectral content representative of actual operation. This is often achieved with pseudo random data (maximum word length, typically $2^{23}-1$).

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

5.1.6 Adjust the vertical position and sensitivity of the oscilloscope to obtain a centred display covering about half of the vertical screen dimension.

5.1.7 Oscilloscope synchronization: adjust the trigger level, if necessary, to obtain a stable waveform display.

5.1.8 Adjust the vertical and horizontal controls of the oscilloscope to produce the desired eye pattern display.

5.1.9 If desired, photograph, print or store in a memory device the displayed waveform for later calculations. Otherwise, measurements shall be performed on screen.

5.1.10 Disconnect or otherwise block the optical signal input to the O/E converter by using the optical attenuator. Observe or record the oscilloscope trace under this condition to determine the dark level. This information is necessary for extinction ratio calculations.

5.2 Method 2: Extinction measurement method using the histogram function

5.2.1 Unless otherwise specified, standard operating conditions apply. The ambient or reference point temperature and humidity shall be specified.

5.2.2 Apply appropriate terminal input voltage/power to the system under test. Follow appropriate operating conditions. Allow sufficient time (30 min, unless otherwise specified by