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INTERNATIONAL STANDARD

Fibre optic active components and devices – Test and measurement procedures –
Part 4: Relative intensity noise using a time-domain optical detection system

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CONTENTS

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FIBRE OPTIC ACTIVE COMPONENTS AND DEVICES – TEST AND MEASUREMENT PROCEDURES –

Part 4: Relative intensity noise using a time-domain optical detection system

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

FDIS	Report on voting
86C/918/FDIS	86C/931/RVD

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 the parts in the IEC 62150 series, under the general title *Fibre optic active components and devices – Test and measurement procedures*, can be found on the IEC website.

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- reconfirmed,
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INTRODUCTION

Laser intensity noise can be one of the limiting factors in the transmission of analogue or digital signals. It can reduce the signal-to-noise ratio and increase the bit error rate, therefore degrading system performance. Laser intensity noise can vary significantly depending on the properties of the laser and back reflections. In order to optimize communication links, it is essential to accurately characterize the laser intensity noise, compare it with the signal strength, and if necessary allow an appropriate power budget.

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FIBRE OPTIC ACTIVE COMPONENTS AND DEVICES – TEST AND MEASUREMENT PROCEDURES –

Part 4: Relative intensity noise using a time-domain optical detection system

1 Scope

This part of IEC 62150 specifies test and measurement procedures for relative intensity noise (RIN). It applies to lasers, laser transmitters, and the transmitter portion of transceivers. This procedure examines whether the device or module satisfies the appropriate performance specification. The procedure is applicable to single longitudinal mode (SLM). An optional section of the procedure presents a controlled return loss to the device-under-test, but is only applicable to devices coupled to SMF.

The method described in this standard, using a time-domain detection system, provides a single value for RIN that averages the noise over the transmission bandwidth. The measurement is made on a modulated laser capturing the RIN value under normal operating conditions. It also measures RIN_{OMA}, an alternative definition, as described in IEEE 802.3-2005.

An alternative RIN measurement method uses a photoreceiver and electrical spectrum analyzer and provides RIN vs. electrical frequency. This method provides a RIN value averaged over particular electrical band determined by a filter. For a filter bandwidth and characteristic that duplicates the filtering in a transmission system, this technique provides a result that is appropriate to determine the noise for such a system.

This method is based on the measurement of total intensity noise including and does attempt to subtract the effects of thermal and shot noise.

Background on laser intensity noise is given in Annex A.

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.

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

IEC 61300-3-6, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examinations and measurements – Return loss*

IEC 62007-2, *Semiconductor optoelectronic devices for fibre optic system applications – Part 2: Measuring methods*

IEEE 802.3™-2005, *Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*

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

3 Terms, definitions and abbreviations

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

3.1 Terms and definitions

3.1.1
intersymbol interference
distortion of the received signal, which is manifested in the temporal spreading and consequent overlap of individual pulses to the degree that the receiver cannot reliably distinguish between changes of state, i.e., between individual signal elements

3.1.2
optical modulation amplitude
difference of the power in the “1” level to the power in the “0” level on a digital transmission signal

3.1.3
relative intensity noise
ratio of the mean-square optical intensity fluctuations over a specified frequency range, normalized to a 1-Hz bandwidth, to the square of the average optical power

$$RIN = \frac{< \Delta P_N^2 >}{P_1^2 B_N} \qquad RIN_{dB} = 10 \log_{10} RIN \tag{1}$$

where

$< P_N^2 >$ is the mean-square optical intensity fluctuations;

B_N is the measurement noise equivalent bandwidth;

P_1 is the optical power.

NOTE 1 The optical power, P_1, is derived from a measurement of photocurrent and includes means to calibrate non-ideal photodetector parameters including dark current and frequency response.

NOTE 2 The noise equivalent bandwidth of a filter is such that it would pass the same total noise power as a rectangular passband that has the same area as the actual filter, and the height of which is the same as the height of the actual filter at its centre wavelength.

3.1.4
RIN_{OMA}
ratio of the photodetected electrical noise power, N, normalized in a 1-Hz bandwidth to the optical modulation amplitude, P_{MOD} , of a square-wave modulated laser source

$$RIN_{OMA} = \frac{< \Delta P_N^2 >}{P_{MOD} B_N} \qquad (RIN_{OMA})_{dB} = 10 \log_{10} RIN_{OMA} \tag{2}$$

3.2 Abbreviations

FFT	fast Fourier transform
ISI	inter-symbol interference
MPI	multipath interference
OMA	optical modulation amplitude
PRBS	pseudo-random binary sequence
RIN	relative intensity noise
SLM	single longitudinal mode
SMF	single mode fibre
VOA	variable optical attenuator

4 Apparatus

4.1 General

The primary components of the measurement system are shown in Figure 1. The controlled return loss subsystem consists of a polarization controller, single-mode coupler, variable optical attenuator and fixed reflector. This clause is required to present a variable return loss to the transmitter-under-test and is only applicable to devices coupled to single-mode fibre. The modulation source enables digital modulation for the laser transmitter and a trigger for the time-domain detection system. Details of the elements are given in the following subclauses.

4.2 Time-domain 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 and a complete description of the equipment is given in IEC 61280-2-2. Included in this apparatus are means for calibration so that the dark current and frequency response of the photodetector are removed. Methods for calibrating the O/E converter are described in IEC 62007-2. The combined frequency response of the O/E converter and filter are designed to meet the requirements in ITU-T Recommendation G.957 for the particular transmission rate.

The input to the time-domain optical system is single-mode. The wavelength range of the O/E converter is compatible with the wavelength of the device under test.

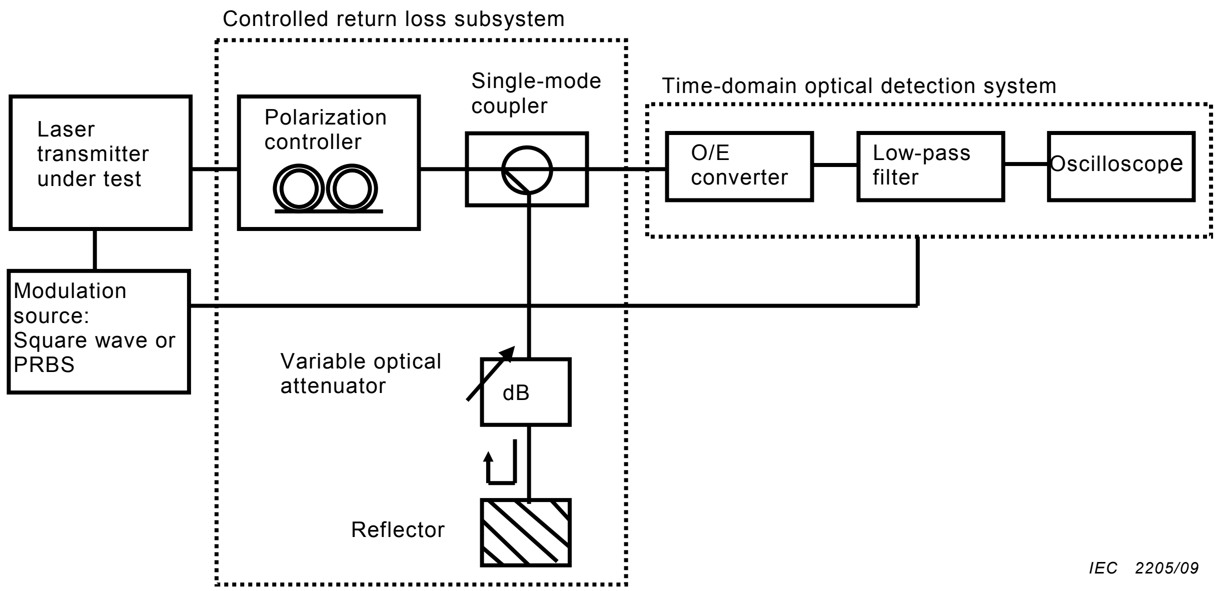

Figure 1 – Equipment setup for *RIN* measurement

Care must be taken to eliminate reflection between the variable return loss subsystem and the laser that cause multipath interference (MPI) and convert phase noise to intensity noise.

4.3 Polarization controller

This device shall be able to convert any state of polarization of a signal to any other state of polarization. The polarization controller may consist of an all-fibre polarization controller or a quarter-wave plate rotatable by a minimum of 90 degrees followed by a half-wave plate rotatable by a minimum of 180 degrees. It is a SMF device.

4.4 Optical coupler

The optical coupler is a 3-dB, 2 X 2 device. It shall have an insertion loss lower than 3,5 dB and a directivity greater than 60 dB. Its input connectors shall have return loss greater than 60 dB. The polarization dependent loss of the optical coupler shall be less than 0,5 dB. It is a SMF device with a wavelength range compatible with the device under test.

4.5 Variable optical attenuator

The variable optical attenuator (VOA) shall be capable of attenuation in steps less than or equal to 1 dB in order to set the appropriate return loss to the laser transmitter under test. It is a SMF device with a wavelength range compatible with the device under test.

4.6 Fixed reflector

The fixed reflector is a highly reflective mirror to reflect the power pack into the system. It is a SMF device with a wavelength range compatible with the device under test.

4.7 Modulation source

The modulation sources shall be capable of providing a pseudo random binary sequence (PRBS) and a square-wave pattern to the system consistent with the signal format (pulse shape, amplitude, etc.) required at the system input electrical interface of the laser transmitter.

4.8 Low-pass filter

The filter should have a linear phase response at frequencies up to and somewhat beyond the filter's –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 measurement. Refer to IEC 61280-2-2 and ITU-T Recommendation G.957 for more detail on the low-pass filter.

5 Test procedure

5.1 Return loss calibration (optional)

This procedure shall be carried out as follows:

a) With reference to Figure 1, connect return loss apparatus as described in IEC 61300-3-6 to in place of the DUT.
b) Measure and record the return loss while varying the setting of the VOA.
c) The result is a table of return loss vs. VOA settings.

NOTE Return loss calibration is necessary if the performance specification requires a RIN value for a particular return loss presented to the device under test.

5.2 RIN measurement – Direct method

5.2.1 General

This method requires square-wave modulation of the laser transmitter with a period sufficiently long such that intersymbol interference is negligible and only the random (Gaussian) parts of the levels are measured. The square wave period is at least five "1"s followed by five "0"s at the system transmission rate.

If the performance specification does not require measurement for a particular return loss, steps 5.2.2 f) and g) are omitted.

5.2.2 Procedure

This procedure shall be carried out as follows:

a) Set up equipment as shown in Figure 1.

b) Select a low-pass filter bandwidth that is appropriate for the transmission rate. Guidance on the selection of the filter bandwidth is provided in IEC 61280-2-2 and ITU-T Recommendation G.957.

c) With no input to the time-domain detection system, measure the photodetector dark current. The time-domain detection will subtract the dark current from the photocurrent measured in the steps below.

d) Connect the laser transmitter and turn the modulation on. Use a square wave with a period of at least 5 “1”s followed by 5 “0”s at the system transmission rate.

e) Set the trigger and amplitude settings on the time-domain optical detection system to achieve a stable eye pattern as in Figure 2.

f) Adjust the VOA to achieve the required return loss at the laser transmitter port.

g) Adjust the polarization controller to maximize the noise on the “1” level.

h) Measure the rms value of the noise on the “1” level, ΔP_1. This value is obtained by analyzing the data over the centre 20 % of the signal as shown in Figure 2. The noise value is the standard deviation and is equivalent to the rms value.

i) Measure the average value of “1” level, P_1, over the centre 20 % of the signal as shown in Figure 2.

j) Calculate RIN from Equation (1) by squaring the value of ΔP_N measured in h) and P_1 measured in i). The value for B_N is the filter bandwidth set in b).

NOTE The low-pass filter bandwidth is typically given as the –3 dB bandwidth, which constitutes a reasonable approximation of the noise equivalent bandwidth.

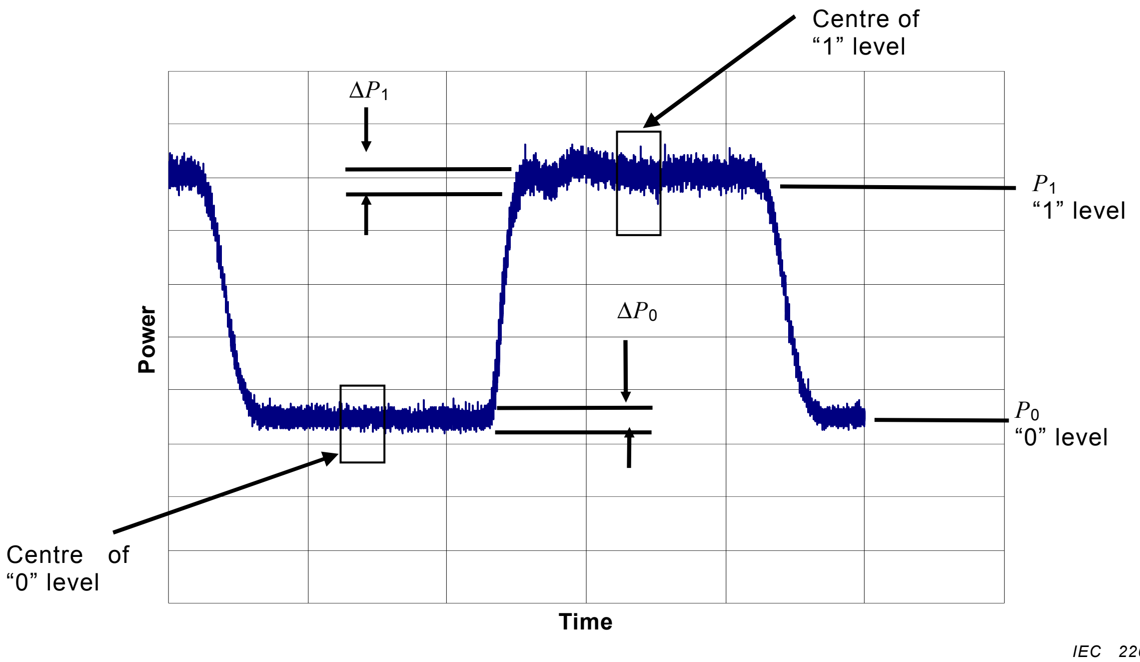

Figure 2 – Diagram for measuring RIN and RIN_{OMA}

5.3 RIN_{OMA} measurement – Direct method

5.3.1 General

This method requires square-wave modulation of the laser transmitter with a period sufficiently long such that intersymbol interference is negligible and only the random (Gaussian) parts of the levels are measured. The square wave period is at least 5 "1"s followed by 5 "0"s at the system transmission rate.

If the performance specification does not require measurement for a particular return loss, steps 5.2.2 f) and 5.2.2 g) are omitted.

5.3.2 Procedure

This procedure shall be carried out as follows:

a) Follow steps 5.2.2 a) through 5.2.2 i).

b) Measure the average value of "1" level, P_1, over the centre 20 % of the signal as shown in Figure 1.

c) Measure the rms value of the noise on the "0" level, ΔP_0. This value is obtained by analyzing the data at the centre of the signal as shown in Figure 2. The standard deviation is equivalent to the rms value.

d) Calculate the optical modulation amplitude, $P_{\text{MOD.}}$

$$P_{MOD} = P_1 - P_0 \tag{3}$$

e) Calculate $< \Delta P_N^2 >$.

$$< \Delta P_N^2 > = \left(\frac{\Delta P_1 + \Delta P_0}{2} \right)^2 \tag{4}$$

f) Calculate RIN_{OMA} from Equation (2).

5.4 RIN and RIN_{OMA} measurement – Using signal processing

5.4.1 General

It is sometimes not possible to modulate the laser transmitter with a square wave as described in 5.2.2 c), but instead, the modulation is a PRBS. In that case the "0" and "1" levels consist of two components: (1) the random (Gaussian) component that is required for the RIN and RIN_{OMA} calculations and (2) a deterministic component due to ISI. In this case, signal analysis is required separate the random component from the deterministic component.

If the performance specification does not require measurement for a particular return loss, steps 5.2.2 f) and 5.2.2 g) are omitted.

5.4.2 Procedure

This procedure shall be carried out as follows:

a) Follow steps 5.2.2 a) through 5.2.2 i).

b) If measuring RIN_{OMA}, also follow steps 5.3.2 b) through 5.3.2 f).

c) To obtain the power and noise values for the calculations, measure the pattern repeatedly and acquire histograms of the "0" and "1" levels. Fit the histogram data to a dual-Dirac model in order to separate random a deterministic components. Use only the random components to derive P_1, P_0, ΔP_1, and ΔP_0. Alternatively, the "0" and "1" levels can be processed through an FFT because they are repetitively sampled. The random component is separated by removing the spectral peaks and integrating the remainder.

6 Test results

The following information shall be reported for each test:

– data rate;

– low-pass filter bandwidth;

– return loss presented to laser transmitter (if required);

– RIN and RIN_{OMA} values.

Annex A
(informative)

Background on laser intensity noise

In a receiver, laser intensity fluctuations can create noise that exceeds the thermal noise of the load impedance and/or the shot noise of the photodetector. It therefore can become a limiting factor for the power budget of an optical link. If so, then careful characterization of such fluctuations becomes essential to optimize system performance.

Intensity fluctuations come primarily from the spectral properties of a laser. At very low power levels a laser emits mostly spontaneous emission, which, similar to the light coming from an LED, covers a range of wavelengths. Above its lasing threshold, a laser emits mostly stimulated emission and only a small amount of spontaneous emission. The stimulated emission is concentrated at or around one wavelength and contains most of the power used for sending information along an optical fibre. In a photodetector the stimulated emission interacts with any residual spontaneous emission, effectively creating noise that can be observed electrically. Photodetectors create an output current that is proportional to the optical power, which in turn is proportional to the square of the electric field. Because of this nonlinear relationship between optical field strength and photodetector current, photons with different optical frequencies create "beat signals."

The signal "beats" with the spontaneous emission and the spontaneous emission beats with itself. However, with today's semiconductor lasers and in the absence of optical amplifiers the spontaneous-spontaneous beat noise is much smaller than the signal-spontaneous beat noise and usually can be ignored. The amount of beat noise generated in the photodetector depends on the receiver's properties, particularly its bandwidth, and it matters only if it exceeds the noise in the electronics. Therefore, it makes more sense to characterize the effects of laser intensity fluctuations on the electrical signal after the optical/electrical (O/E) conversion.

Relative intensity noise (RIN) describes the contributions of the laser intensity fluctuations to the electrical noise in the receiver relative to the signal power observed electrically. In general, RIN is normalized to a 1-Hz bandwidth so that it becomes easier to compare laser intensity fluctuations when using receivers with different bandwidths.

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