TECHNICAL REPORT

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Fibre optic communication system design guides –

Part 8: Calculating dispersion penalty from measured time-resolved chirp data

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 8: Calculating dispersion penalty from measured time-resolved chirp data

FOREWORD

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IEC 61282-8, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86C/686/DTR	86C/721/RVC

Full information on the voting for the approval of this technical report 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 61282 series, published under the general title *Fibre optic communication system design guides,* 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- withdrawn,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.

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

INTRODUCTION

Dispersion penalty is a commonly used parameter of laser transmitters and is usually included as a specification for transmitters designed for 2,5 Gb/s and higher data rates. The value of the dispersion penalty is a function of the interaction of laser chirp, spectral width and fibre dispersion and will depend on the particular type of fibre.

Because the type and length of the fibre specified for a particular transmitter is fixed, the dispersion penalty is determined by the temporal characteristics of the transmitter chirp, which include the spectral characteristics of the laser.

As developers and manufacturers of laser transmitters are attempting to go to higher rates and longer distances, they are finding that chirp is limiting their ability to achieve a required dispersion penalty. Direct measurement of dispersion penalty requires two *BER* measurements over a reference receiver input range that yields *BER* values typically from 10^{-4} to 10^{-12}. This is typically a long measurement. Measuring time-resolved chirp (TRC) and calculating dispersion penalty can be a considerably shorter measurement.

This technical report describes the procedure for calculating dispersion penalty from TRC data.

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 8: Calculating dispersion penalty from measured time-resolved chirp data

1 Scope

This part of IEC 61282 provides definitions of dispersion penalty and other related penalties. It describes the direct measurement of these penalties using a *BER* test set and the calculation of the penalties from time-resolved chirp (TRC) data. Annex A provides the theory for power penalty calculations.

The calculations are valid for all types of single longitudinal mode (SLM) laser transmitters intended for use in telecommunications applications at data rates of 2,5 Gbit/s and higher with NRZ modulation format. These include but are not limited to directly modulated DFB lasers, DFB lasers with integrated electro-absorption modulators, and DFB lasers with external Mach-Zehnder modulators. This technique is not suitable for multiple longitudinal mode (MLM) lasers or LEDs.

Chromatic dispersion induced power penalty values in this technical report are characteristics of the transmitter, which is considered to be the device-under-test (DUT). Other power penalty sources, such as nonlinear effects and amplifier noise are not covered by this document.

Since dispersion penalty for a transmission link depends on the transmitter, receiver and fibre, the dispersion penalty parameter for a transmitter is based on a specified fibre dispersion and receiver characteristic, which should be reported with the test results.

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 61280-2-8, *Fibre optic communication subsystem test procedures – Digital systems – Part 2-8: Determination of low BER using Q-factor measurements*

IEC 61280-2-10, *Fibre optic communication subsystem test procedures – Digital systems – Part 2-10: Time-resolved chirp and alpha-factor measurement of laser transmitters*

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

3 Terms and definitions

Power penalty measurements compare *BER* versus received power curves for two conditions. The first condition is a reference condition. The second condition introduces impairment. Changing the received power influences *BER* by altering the ratio of optical signal power to the receiver noise. Therefore it is useful, but equivalent, to express *BER* versus received power curves as *BER* versus *OSNR* curves, where this “optical signal to noise ratio” compares average optical signal power to all noise including the electrical noise of the receiver. Generally, the *OSNR*, based on average signal power, differs from the *SNR* of a digital signal, which is based on the average difference between the signal of the ‘1’ and ‘0’ bits, as described in IEC 61280-2-8.

3.1
dispersion penalty
apparent change in receiver sensitivity due to distortion of the signal waveform during its transmission over a path with a specified chromatic dispersion and minimal PMD. It is manifested as a shift of the system's *BER* curves from the fibre path to a no-fibre path:

– reference condition: DUT without dispersive fibre;

– impaired condition: DUT with specified fibre path

NOTE 1 It is normal that the impaired condition will shift the *BER* to a higher received power and yield a dispersion penalty that is a positive value. Under some conditions, for example, when fibre dispersion compensates for transmitter chirp, in the impaired condition, the *BER* curve will be shifter to a lower received power and yield a negative dispersion penalty.

NOTE 2 Minimal PMD is a necessary condition because, for example, 0,6 ps PMD causes 0,1 dB power penalty for 40 Gb/s NRZ.

3.2
transmitter and dispersion penalty
TDP
apparent change in receiver sensitivity due to distortion of the signal waveform during its transmission over a path with a specified chromatic dispersion for a transmitter with a defined extinction ratio. It is manifested as a shift of the system's *BER*-curves for these two cases:

– reference condition: ideal transmitter (specified with maximum rise and fall times only) with the same extinction ratio as the actual DUT with no dispersive fibre in the path;

– impaired condition: DUT with specified fibre path

NOTE This parameter is defined in IEEE 802.3ae-2002, *10Gb/s Ethernet*. The IEEE standard does not specify a transmitter with the same ER as the DUT, but accomplishes the equivalent by specifying a measurement of optical modulation amplitude (OMA) as opposed to average power.

3.3
total transmitter power penalty

apparent change in receiver sensitivity due to distortion of the signal waveform during its transmission over a path with a specified chromatic dispersion for a transmitter with an infinite extinction ratio. It is manifested as a shift of the system's *BER*-curves for these two cases:

– reference condition: ideal transmitter with infinite extinction ratio;

– impaired condition: DUT with specified fibre path

4 Measuring dispersion penalty using a bit-error-ratio test set

Directly measuring dispersion penalty requires the setup of Figure 1. This figure is introduced to provide a context for the calculation of dispersion induced power penalty, which is the main topic of this document.

NOTE When dispersion induced power penalty is measured directly, care should be taken to use power levels that are low enough to avoid introducing penalties that can be induced by nonlinear effects.

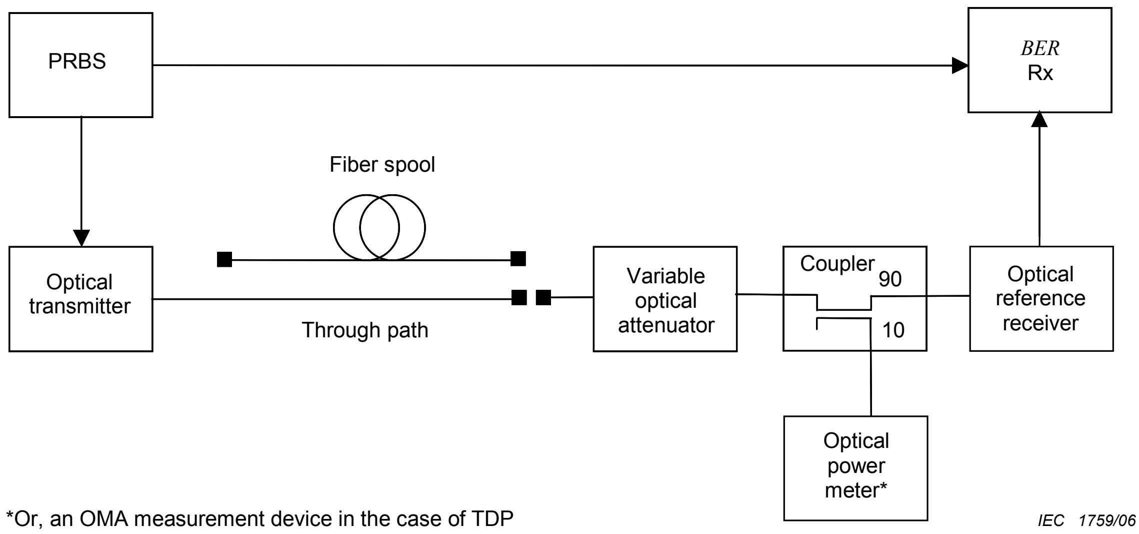

Figure 1 – Equipment setup for direct power penalty measurements

As described in Annex A, two sets of *BER* versus received power data are taken by varying the variable optical attenuator. The received power (or, equivalently, the *OSNR*) for the specified *BER* for the reference and impaired conditions, expressed in dB, are subtracted to obtain the penalty value. The particular reference and impaired conditions are given in 3.1.

5 Obtaining time-resolved chirp data

The measurement of time-resolved chirp is described in IEC 61280-2-10. As described in that standard, the measured result is an array of instantaneous optical power versus time, *P(t)*, and of instantaneous optical frequency versus time, $\Delta f(t)$. The transmitter stimulus is a pseudo-random binary sequence, PRBS, to simulate transmitter behaviour with actual data.

In order to adequately describe the transmitter behaviour, the PRBS must be sufficiently long to include strings of consecutive ones and zeros adequate to measure any intersymbol effects of the transmitter. For example, a maximal length sequence of $2^7 - 1$ bits sufficiently represents intersymbol interference effects up to ±3 bits, and is available in all standard pattern generators. Shorter patterns can be used as long as they satisfy the criteria of equal probability of occurrence of each bit pattern within the range of the intersymbol interference. Additionally, the time resolution must be sufficient to capture the transient nature of *P(t)* and $\Delta f(t)$. Typically, a resolution that provides more than 30 points per bit period is adequate.

Figure 2 shows a plot of data that is suitable for calculating the power penalties described in Clause 6. This data is for a 9,95328 Gbit/s NRZ signal. The time range is 12,8 ns and there are 4 096 points of display resolution. This provides 32 points per bit period.

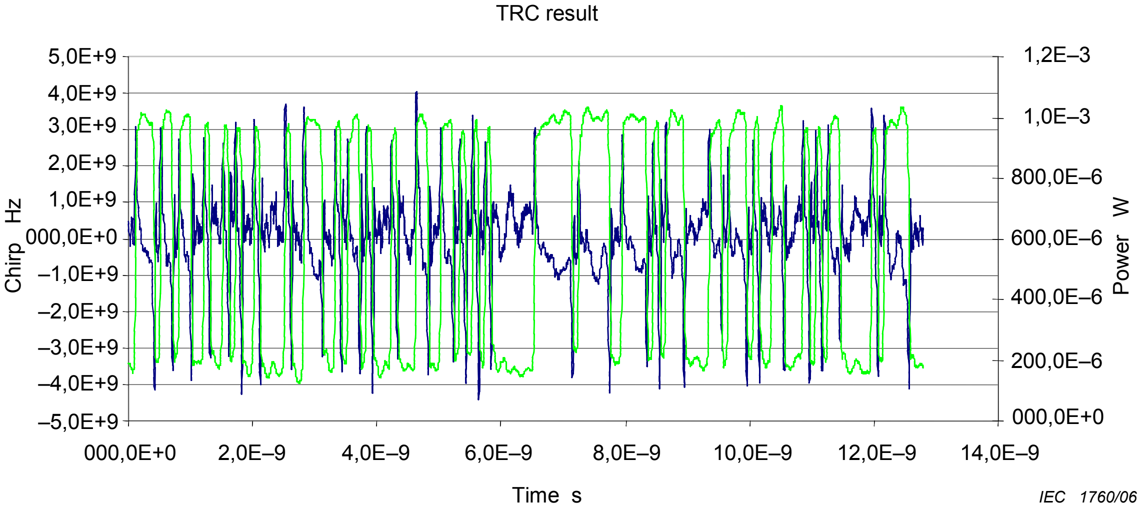

Figure 2 – Typical TRC data suitable for dispersion penalty calculations

6 Calculating dispersion penalty from time-resolved chirp data

The TRC data, as represented in Figure 2, is a complete description of the transmitted signal. By Fourier transforming, adding the effect of chromatic dispersion, inverse-Fourier transforming, and analysing the *BER* by adding noise, the dispersion penalty may be calculated. The following is a detailed description of the algorithm.

6.1 Calculate *BER* for a particular condition

(1) Integrate $\Delta f(t)$ to obtain phase, $\phi(t)$.

$$\phi(t) = \int 2\pi\Delta f(t)dt \qquad (1)$$

(2) Calculate complex electric field array

$$E(t) = \sqrt{P(t)}e^{j\phi(t)} \qquad (2)$$

(3) Perform fast Fourier, transform, *FFT*.

$$S_{\text{in}}(f) = FFT[E(t)] \qquad (3)$$

(4) Add chromatic dispersion.

$$S_{\text{out}}(f) = S_{\text{in}}\text{e}^{j\pi d^2} \qquad (4)$$

where d is dispersion in s/Hz, related to D in ps/nm by

$$d(\text{s/Hz}) = -D(\text{ps/nm}) * 10^{-3} * \frac{\lambda_0{}^2}{c}$$

where λ_0 is in meters, the 10^{-3} converts the ps/nm to s/m, and the final term converts 1/m to –1/Hz.

(5) Perform inverse *FFT* and compute signal magnitude.

$$P(t) = \left|FFT^{-1}S_{\text{out}}(f)\right|^2 \qquad (5)$$