

# Fibre optic communication subsystem test procedures — Digital systems —

## Part 2-8: Determination of low BER using Q-factor measurements

The European Standard EN 61280-2-8:2003 has the status of a  
British Standard

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# National foreword

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The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/3, Fibre optic systems and active devices, which has the responsibility to:

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**Fibre optic communication subsystem test procedures -  
Digital systems**  
**Part 2-8: Determination of low BER using Q-factor measurements**  
(IEC 61280-2-8:2003)

Procédures d'essai des sous-systèmes  
de télécommunications à fibres optiques -  
Systèmes numériques  
Partie 2-8: Détermination du faible  
Taux d'Erreur Binaire (TEB)  
en utilisant les mesures du facteur Q  
(CEI 61280-2-8:2003)

Prüfverfahren für Lichtwellenleiter-  
Kommunikationsuntersysteme -  
Digitale Systeme  
Teil 2-8: Bestimmung von geringen  
Bitfehlerverhältnissen (BERs)  
mit Hilfe von Q-Faktormessungen  
(IEC 61280-2-8:2003)

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## **Foreword**

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with the EN have to be withdrawn (dow) 2006-03-01

Annexes designated "normative" are part of the body of the standard.  
Annexes designated "informative" are given for information only.  
In this standard, annex A is normative and annex B is informative.

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## **Endorsement notice**

The text of the International Standard IEC 61280-2-8:2003 was approved by CENELEC as a European Standard without any modification.

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## FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES – DIGITAL SYSTEMS –

### Part 2-8: Determination of low BER using Q-factor measurements

#### 1 Scope

This part of IEC 61280 specifies two main methods for the determination of low BER values by making accelerated measurements. These include the variable decision threshold method (Clause 4) and the variable optical threshold method (Clause 5). In addition, a third method, the sinusoidal interference method, is described in Annex B.

#### 2 Definitions and abbreviated terms

##### 2.1 Definitions

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

###### 2.1.1

**amplified spontaneous emission**

**ASE**

impairment generated in optical amplifiers

###### 2.1.2

**bit error ratio**

**BER**

the number bits in error as a ratio of the total number of bits

###### 2.1.3

**intersymbol interference**

**ISI**

mutual interference between symbols in a data stream, usually caused by non-linear effects and bandwidth limitations of the transmission path

###### 2.1.4

**Q-factor**

**Q**

ratio of the difference between the mean voltage of the 1 and 0 rails, and the sum of their standard deviation values

##### 2.2 Abbreviations

|      |                                                                |
|------|----------------------------------------------------------------|
| cw   | Continuous wave (normally referring to a sinusoidal wave form) |
| DC   | Direct current                                                 |
| DSO  | Digital sampling oscilloscope                                  |
| DUT  | Device under test                                              |
| PRBS | Pseudo-random binary sequence                                  |

### 3 Measurement of low bit-error ratios

#### 3.1 General considerations

Fibre optic communication systems and subsystems are inherently capable of providing exceptionally good error performance, even at very high bit rates. The mean bit error ratio (BER) may typically lie in the region  $10^{-12}$  to  $10^{-20}$ , depending on the nature of the system. While this type of performance is well in excess of practical performance requirements for digital signals, it gives the advantage of concatenating many links over long distances without the need to employ error correction techniques.

The measurement of such low error ratios presents special problems in terms of the time taken to measure a sufficiently large number of errors to obtain a statistically significant result. Table 1 presents the mean time required to accumulate 15 errors. This number of errors can be regarded as statistically significant, offering a confidence level of 75 % with a variability of 50 %.

**Table 1 – Mean time for the accumulation of 15 errors  
as a function of BER and bit rate**

| BER<br>Bits/s | $10^{-6}$   | $10^{-7}$   | $10^{-8}$ | $10^{-9}$ | $10^{-10}$ | $10^{-11}$ | $10^{-12}$ | $10^{-13}$ | $10^{-14}$ | $10^{-15}$ |
|---------------|-------------|-------------|-----------|-----------|------------|------------|------------|------------|------------|------------|
| 1,0M          | 1,5 s       | 15 s        | 2,5 min   | 25 min    | 4,2 h      | 1,7d       | 17 d       | 170 d      | 4,7 years  | 47 years   |
| 2,0M          | 750 ms      | 7,5 s       | 75 s      | 750 s     | 2,1 h      | 21 h       | 8,8 d      | 88 d       | 2,4 years  | 24 years   |
| 10M           | 150 ms      | 1,5 s       | 15 s      | 2,5 min   | 25 min     | 4,2 h      | 1,7 d      | 17 d       | 170 d      | 4,7 years  |
| 50M           | 30 ms       | 300 ms      | 3,0 s     | 30 s      | 5,0 min    | 50 min     | 8,3 h      | 3,5 d      | 35 d       | 350 d      |
| 100M          | 15 ms       | 150 ms      | 1,5 s     | 15 s      | 2,5 min    | 25 min     | 4,2 h      | 1,7 d      | 17 d       | 170 d      |
| 500M          | 3 ms        | 30 ms       | 300 ms    | 3,0 s     | 30 s       | 5,0 min    | 50 min     | 8,3 h      | 3,5 d      | 35 d       |
| 1,0G          | 1,5 ms      | 15 ms       | 150 ms    | 1,5 s     | 15 s       | 2,5 min    | 25 min     | 4,2 h      | 1,7 d      | 17 d       |
| 10G           | 150 $\mu$ s | 1,5 ms      | 15 ms     | 150 ms    | 1,5 s      | 15 s       | 2,5 min    | 25 min     | 4,2 h      | 1,7 d      |
| 40G           | 38 $\mu$ s  | 380 $\mu$ s | 3,8 ms    | 38 ms     | 380 ms     | 3,8 s      | 38 s       | 6,3 min    | 63 min     | 10,4 h     |
| 100G          | 15 $\mu$ s  | 150 $\mu$ s | 1,5 ms    | 15ms      | 150 ms     | 1,5 s      | 15 s       | 2,5 min    | 25 min     | 4,2 h      |

The times given in Table 1 show that the direct measurement of the low BER values expected from fibre optic systems is not practical during installation and maintenance operations. One way of overcoming this difficulty is to artificially impair the signal-to-noise ratio at the receiver in a controlled manner, thus significantly increasing the BER and reducing the measurement time. The error performance is measured for various levels of impairment, and the results are then extrapolated to a level of zero impairment using computational or graphical methods according to theoretical or empirical regression algorithms.

The difficulty presented by the use of any regression technique for the determination of the error performance is that the theoretical BER value is related to the level of impairment via the inverse error function (*erfc*). This means that very small changes in the impairment lead to very large changes in BER; for example, in the region of a BER value of  $10^{-15}$  a change of approximately 1 dB in the level of impairment results in a change of three orders of magnitude in the BER. A further difficulty is that a method based on extrapolation is unlikely to reveal a levelling off of the BER at only about 3 orders of magnitude below the lowest measured value.

It should also be noted that, in the case of digitally regenerated sections, the results obtained apply only to the regenerated section whose receiver is under test. Errors generated in upstream regenerated sections may generate an error plateau which may have to be taken into account in the error performance evaluation of the regenerator section under test.

As noted above, two main methods for the determination of low BER values by making accelerated measurements are described. These are the variable decision threshold method (Clause 4) and the variable optical threshold method (Clause 5). In addition, a third method, the sinusoidal interference method, is described in Annex B.

It should be noted that these methods are applicable to the determination of the error performance in respect of amplitude-based impairments. Jitter may also affect the error performance of a system, and its effect requires other methods of determination. If the error performance is dominated by jitter impairments, the amplitude-based methods described in this standard will lead to BER values which are lower than the actual value.

The variable decision threshold method is the procedure which can most accurately measure the Q-factor and the BER for optical systems with unknown or unpredictable noise statistics. A key limitation, however, to the use of the variable threshold method to measure Q-factor and BER is the need to have access to the receiver electronics in order to manipulate the decision threshold. For systems where such access is not available it may be useful to utilize the alternative variable optical threshold method. Both methods are capable of being automated in respect of measurement and computation of the results

### 3.2 Background to Q-factor

The Q-factor is the signal-to-noise ratio (SNR) at the decision circuit and is typically expressed as [3]<sup>1</sup>:

$$Q = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0} \quad (1)$$

where  $\mu_1$  and  $\mu_0$  are the mean voltage levels of the "1" and "0" rails, respectively, and  $\sigma_1$  and  $\sigma_0$  are the standard deviation values of the noise distribution on the "1" and "0" rails, respectively.

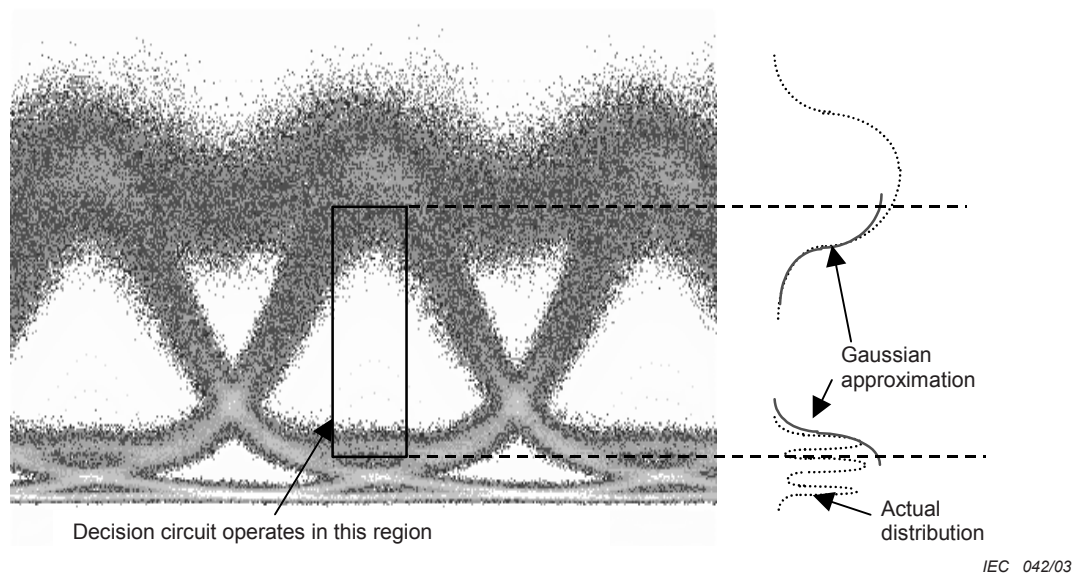
An accurate estimation of a system's transmission performance, or Q-factor, must take into consideration the effects of all sources of performance degradation, both fundamental and those due to real-world imperfections. Two important sources are amplified spontaneous emission (ASE) noise and intersymbol interference (ISI). Additive noise originates primarily from ASE of optical amplifiers. ISI arises from many effects, such as chromatic dispersion, fibre non-linearities, multi-path interference, polarization-mode dispersion and use of electronics with finite bandwidth. There may be other effects as well, for example, a poor impedance match can cause impairments such as long fall times or ringing on a waveform.

One possible method to measure Q-factor is the voltage histogram method in which a digital sampling oscilloscope is used to measure voltage histograms at the centre of a binary eye to estimate the waveform's Q-factor [4]. In this method, a pattern generator is used as a stimulus and the oscilloscope is used to measure the received eye opening and the standard deviation of the noise present in both voltage rails. As a rough approximation, the edge of visibility of the noise represents the  $3\sigma$  points of an assumed Gaussian distribution. The advantage of using an oscilloscope to measure the eye is that it can be done rapidly on real traffic with a minimum of equipment.

The oscilloscope method for measuring the Q-factor has several shortcomings. When used to measure the eye of high-speed data (of the order of several Gbit/s), the oscilloscope's limited digital sampling rate (often in the order of a few hundred kilohertz) allows only a small minority of the high-speed data stream to be used in the Q-factor measurement. Longer observation times could reduce the impact of the slow sampling. A more fundamental shortcoming is that the  $Q$  estimates derived from the voltage histograms at the eye centre are often inaccurate. Various patterning effects and added noise from the front-end electronics of the oscilloscope can often obscure the real variance of the noise.

<sup>1</sup> Figures in square brackets refer to the bibliography.

Figure 1 shows a sample eye diagram made on an operating system. It can be seen in this figure that the vertical histograms through the centre of the eye show patterning effects (less obvious is the noise added by the front-end electronics of the oscilloscope). It is difficult to predict the relationship between the  $Q$  measured this way and the actual BER measured with a test set.



NOTE The data for measuring the  $Q$ -factor is obtained from the tail of the Gaussian distributions.

**Figure 1 – A sample eye diagram showing patterning effects**

Figure 2 shows another possible way of measuring Q-factor using an oscilloscope. The idea is to use the centre of the eye to estimate the eye opening and use the area between eye centres to estimate the noise. Pattern effect contributions to the width of the histogram would then be reduced. A drawback to this method is that it relies on measurements made on a portion of the eye that the receiver does not really ever use.

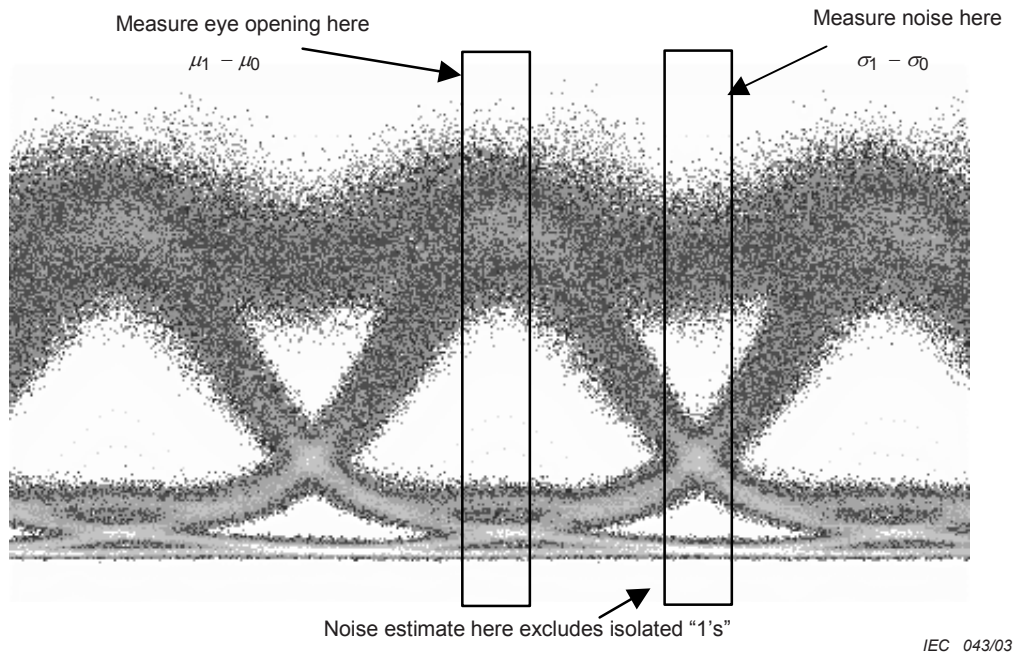


**Figure 2 – A more accurate measurement technique using a DSO that samples the noise statistics between the eye centres**