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Q-factor basics

Pocket Guide

ACTERNA™
The Keepers of Communications

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Introduction

Dense Wavelength Division Multiplex (DWDM) is the technology currently deployed to increase transmission bandwidth in optical networks. With bit rates of 2.5 Gigabit per second (Gbps) and 10 Gbps per channel currently being used, products with increasingly higher bit rates of 40 Gbps are beginning to appear on the horizon of optical systems. Transparent DWDM systems have the advantage of being independent of data format and bit rate so they are able to transport different protocols such as Synchronous Digital Hierarchy (SDH), Synchronous Optical Network (SONET), Internet Protocol over Wavelength Division Multiplex (IP over WDM), Gigabit Ethernet (GE) etc.

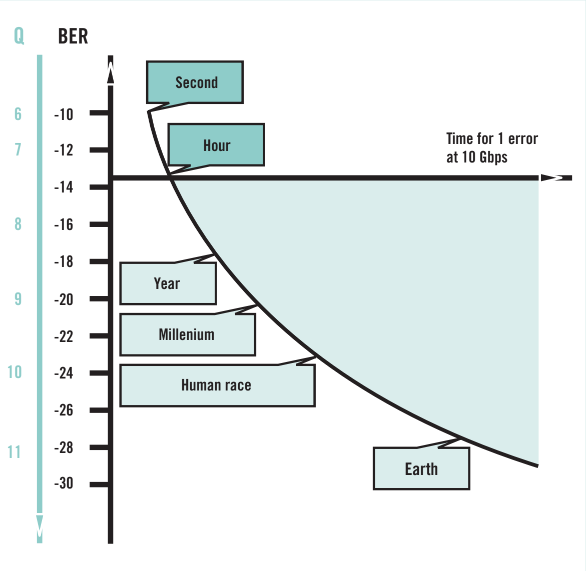
Increased bandwidth means more data per unit time but also more impairments through higher power and increased channel counts. The higher the power and channel counts the more impairments become analog characteristics. To get a measure of the influence through these impairments it is necessary to evaluate the Quality of Service (QoS) of the optical transmission channels.

Today, the standard method used in the field is Bit Error Ratio (BER) testing. BER testing is an out-of-service and often time consuming test particularly when low BERs are to be measured. Figure 1 shows the statistical time for one bit error to occur at a bit rate of 10 Gbps. Standard testing today may have 24 or 72 hours test time per channel.

The challenge is to find a way to determine the QoS of an optical transmission channel independent of data format and bit rate within a short time frame. The Q-factor itself significantly reduces measurement time and is thus more cost-effective.

This pocket guide aims to equip the reader with a sound foundational understanding of the application of Q-factor measurement by explaining the theory and practice behind the Q-factor and how it differs from traditional BER testing and applications.

figure 1 *Time for one error to occur at ultra low BER*



What is the Q-factor?

The Q-factor is a parameter that directly reflects the quality of a digital optical communications signal. The higher the Q-factor, the better the quality of the optical signal.

Q-factor measurement is related to the analog signal and in this respect differs from traditional BER tests. Assuming signal impairments follow a stochastic distribution, the Q-factor can theoretically be related to a BER. As the Q-factor is related to the analog signal it gives a measure of the propagation impairments caused by optical noise, non-linear effects, polarization effects and chromatic dispersion.

What are the impairments for optical transmission?

Impairments for optical systems can be categorized into linear and non-linear effects. The following linear and non-linear effects all have an effect on the optimal signal quality (see figure 2). There is some relation between limiting effects in optical systems and the optical power or number of wavelengths used (figure 3). With less optical power and a lower number of channels the system performance suffers mainly linear effects (linear effects include: attenuation, noise and dispersion effects like Polarization Mode Dispersion (PMD) and Chromatic Dispersion (CD)). With higher optical power and more channels however, non-linear effects are evident and become increasingly important.

figure 2 *Pulse degradation by impairments*

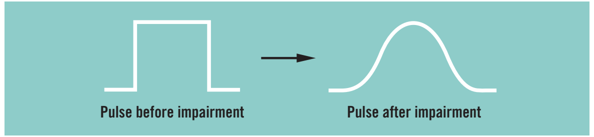
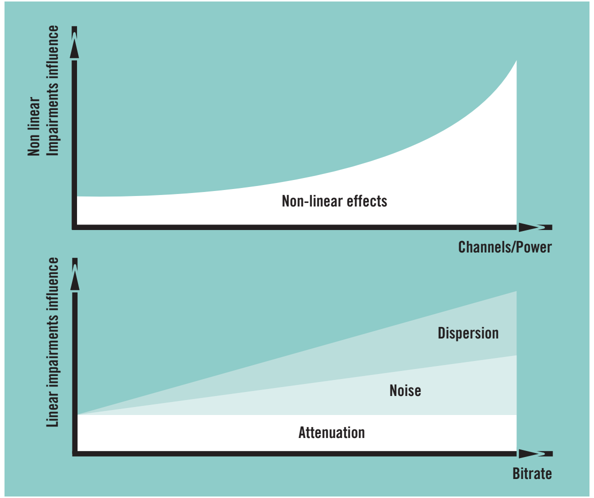


figure 3 *Impairments for optical systems*



Attenuation and noise (figure 4) – Attenuation is the loss of signal power caused by material absorption, impurities, waveguide geometry and scattering. Noise is the unwanted power in an optical or electrical system. Noise power is caused by circuit components or natural disturbances. For optical systems the main noise generating components are Optical Fiber Amplifiers (OFA), producing Amplified Spontaneous Emission (ASE) noise, and Optical-to-Electrical (O/E) converters.

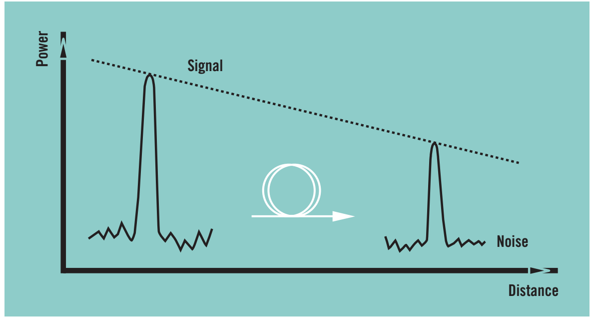


figure 4 *Attenuation and noise*

PMD (Polarization Mode Dispersion, figure 5) – Signal energy at a given wavelength is resolved into two orthogonal polarization modes of slightly differing propagation velocity. The resulting difference in propagation time leads to pulse broadening of the signal. The time difference of the two wave components is called Differential Group Delay (DGD). This may vary with temperature and other environmental circumstances like mechanical stress. The PMD characteristic of a fiber link is important for high bit rate optical transmission.

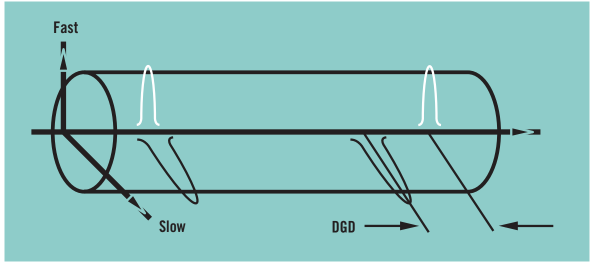


figure 5 *Polarization Mode Dispersion*

CD (Chromatic Dispersion, figure 6) – Signal pulses consist of a range of wavelengths which travel at different velocities. A positive dispersion constant means that shorter wavelengths travel faster. Thus causing a broadening of the pulse. CD is dependent upon the spectral width of the light source, the fiber cable length and the type of fiber.

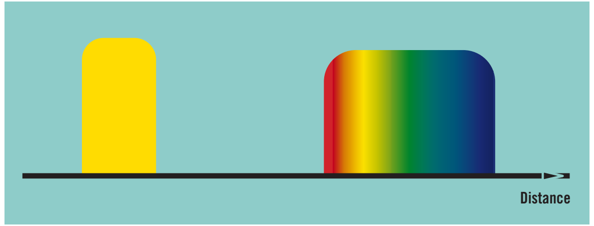


figure 6 *Chromatic Dispersion*

In times of single channel systems with lower power requirements, the non-linear effects have not been a main limiting factor for optical transmission. However with higher power and an increasing number of optical channels per single fiber, these kind of analog effects play an increasingly significant role. Non-linear effects are Self-phase Modulation (SPM), Cross-phase Modulation (XPM), Four Wave Mixing (FWM) and scattering effects like Stimulated Raman Scattering (SRM) and Stimulated Brillouin Scattering (SBS).

SPM (Self-phase Modulation, figure 7) – An optical signal causes a time-varying intensity in the optical fiber. A characteristic of the optical fiber is that intensity changes cause a change in the refractive index (Kerr effect). High optical intensities above certain thresholds also cause a phase modulation of the transmitted wavelength and broaden the wavelength spectrum of the transmitted optical pulse. The broadened spectrum may also interfere with adjacent channels in a DWDM system (see also XPM).

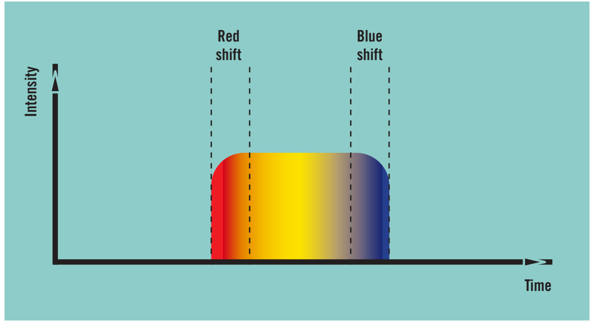


figure 7 *Self-phase Modulation*

XPM (Cross-phase Modulation, figure 8) – The interaction of a pulse with the phases of pulses in adjacent channels is called XPM. This is generated by refractive index perturbations of the signal in the channel itself as well as from adjacent channels. XPM is also dependent on channel spacing and is therefore critical for multi-channel DWDM. XPM can be reduced by allowing small amounts of CD on the fiber which has the effect of reducing interaction times (walk-off effect) between signal pulses of different wavelengths.

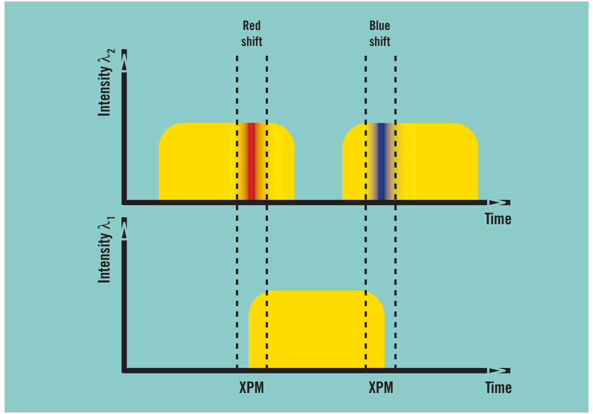


figure 8 *Cross-phase Modulation*

FWM (Four Wave Mixing, figure 9) – Interference between channels leads to FWM. Wavelengths, which co-propagate (f_1 and f_2 in figure 9), generate new wavelengths ($2f_1$-f_2 and $2f_2$-f_1 in figure 9). The creation of new wavelengths also transfers power from the original signal to the new signal.

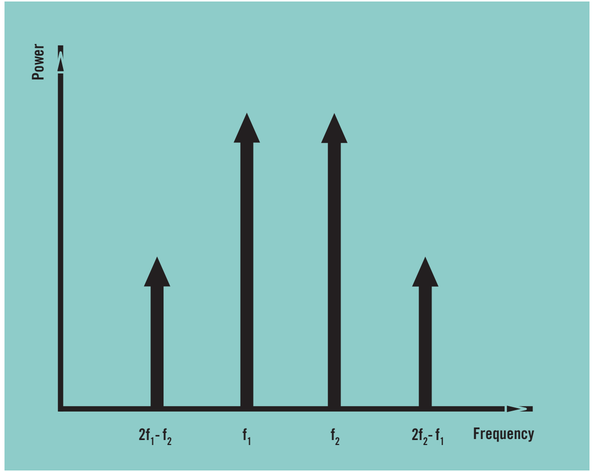


figure 9 *Four Wave Mixing*

SBS (Stimulated Brillouin Scattering, figure 10) – Brillouin scattering is an effect which is generated by the interaction of light and acoustic waves. The effect has its maximum in the backward direction. SBS has a low threshold compared to other non-linear effects but can also be easily overcome with spectral broadening of the light source (dithering).

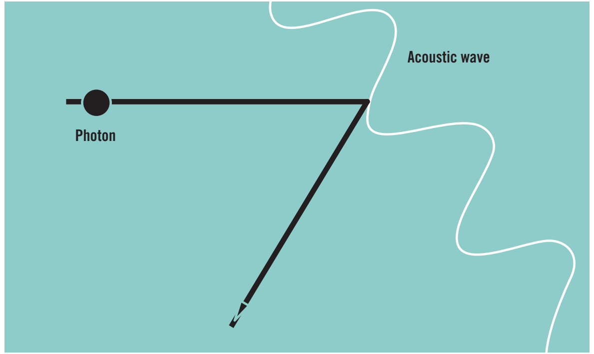


figure 10 *Stimulated Brillouin Scattering*

SRS (Stimulated Raman Scattering, figure 11) – Raman scattering is caused by interaction of molecular vibrations with photons to generate a new higher wavelength. SRM also causes a gain tilt over the overall DWDM spectrum.

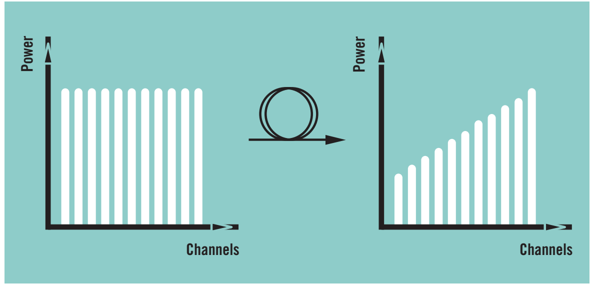


figure 11 *Stimulated Raman Scattering*

The Q-factor in more detail

Definition of the Q-factor

As mentioned before, the Q-factor is a measure for the quality of the analog signal, which is usually defined by its signal-to-noise ratio (this is also the mathematical definition of the Q-factor). The Q-factor is defined by the difference of the mean values of the two signal levels divided by the sum of the noise rms values (standard deviations) at the two signal levels. This can be expressed by the following equation.

$$Q = \frac{\text{mean "1" - mean "0"}}{\text{standard deviation "1" + standard deviation "0"}}$$

The analog representation of a digital signal on the time scale toggles between the states "0" and "1" depending on the data pattern to be sent. To make the data stream visible however the time scale can only show a "snapshot" with a restricted number of bits as theoretically it would go to infinity. If the data signal is triggered to the bit rate and superimposed into the same picture, the so called 'eye diagram' or 'eye pattern' is generated (figure 12).

figure 12 *Eye pattern generation*

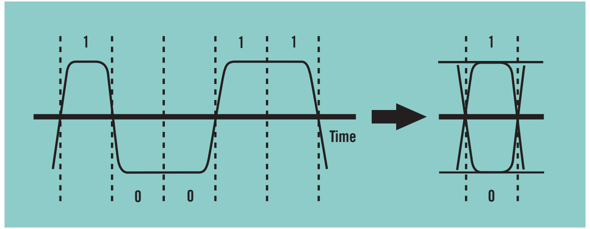
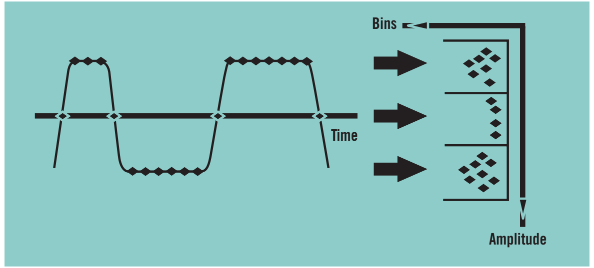


figure 13 *Signal sampling into bins*



As the illustrations show the signal is more likely to be at the “0” or “1” level rather than in a transient state. The likelihood of certain signal level occuring can be described in a diagram, derived from sampling the data stream and collecting the sampling points for certain amplitude levels

in bins (figure 13). Real signals are also influenced by noise which causes the most likely amplitude levels to spread out.

The higher the sampling rate (samples per second) and smaller the bins, the more accurate the diagram generated by this method. Assuming an infinitely high sampling rate and small bin size, the filling level of the bins can be normalized and represented by a single curve (figure 14). The normalized curve is known as the Probability Density Function (PDF).

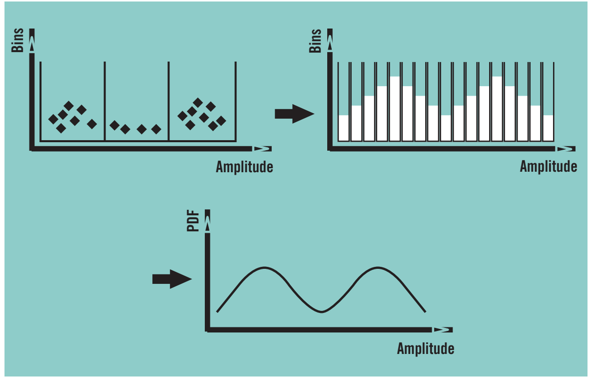


figure 14 *Deriving the PDF from the bins*

Only the sample values at the detection time are of importance when detecting a binary signal. A PDF can be derived from the "bin" method – but only for detection samples (figure 15).

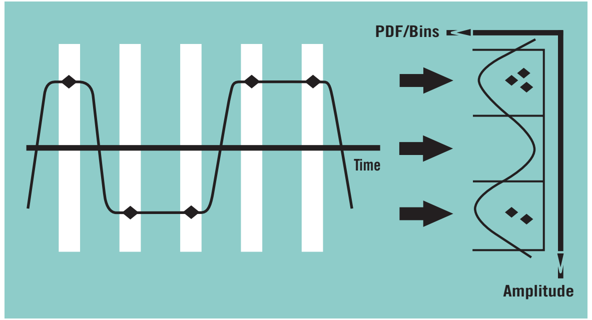


figure 15 *Deriving the PDF from detection point samples*

It can be assumed that the PDF deriving from the "bin" method is the sum of two separate PDFs representing the two binary states "0" and "1". Each binary state has a Gaussian distribution known as a 'bell curve'.

The signal distributions show the two most likely or mean values which are related to the binary "0" and binary "1" levels (figure 16). As the real signal is affected by noise it shows slight deviations from the most likely amplitude values. The spreading through noise power is called standard deviation. The more noise a signal level contains, the broader the standard deviation. The mean value is often denoted as μ and the standard deviation as σ in mathematical equations.

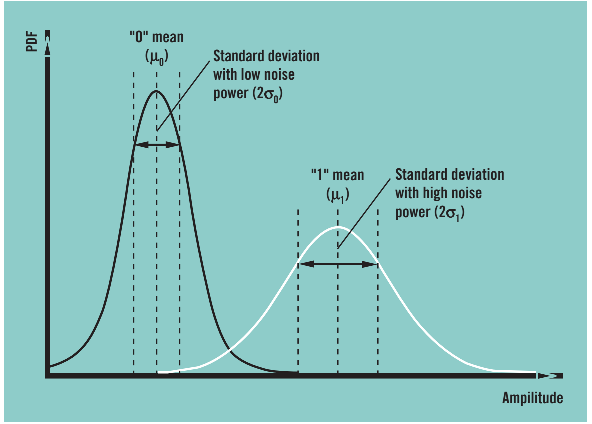


figure 16 *PDF with Gaussian distributions*

To determine whether a binary “0” or “1” has been sent, one must first ascertain whether the signal is on the “0” level or “1” level. The threshold level for decision lies between the two mean values of the PDF shapes. There is a small probability however of a binary level becoming distorted by noise for example and jumping over the threshold level. In this case, the detection point will be misinterpreted. There are two possibilities whereby a misinterpretation can be made:

- “0” is detected as “1” or
- “1” is detected as “0”

The probability of this particular type of misinterpretation is reflected in figure 17. An optimum threshold can be found when looking for the smallest area covered thus providing lowest probability of misinterpretation. One could assume that the optimum threshold lies at the intersection of the two PDF shapes. This is only true when both bell curves are identical. Real systems however always have slightly different shapes for the two signal levels. In this case the optimum threshold level does not necessarily cross the intersection point.

The probability of misinterpretation or error probability can also be expressed as bit errors per total transmitted number of bits – the so called Bit Error Ratio or BER.

$$\text{BER} = \frac{\text{bit errors}}{\text{total number of bits}}$$

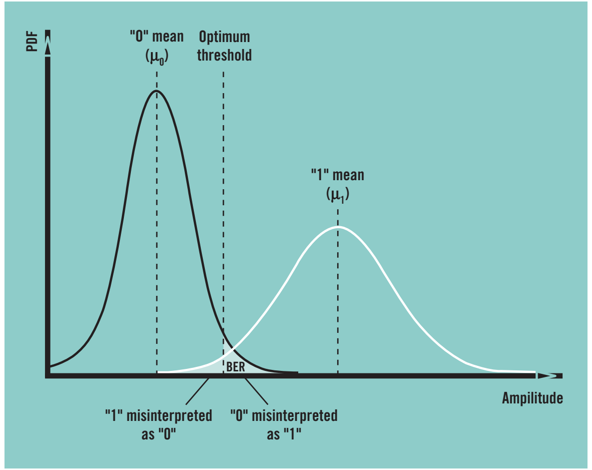


figure 17 BER in the PDF diagram

The detection of the binary level during the pulse width is not only dependent on the detection threshold but also on the detection time. The detection time is often expressed as sampling phase. This comes from the definition of the pulse width in radians. The pulse width itself may be defined to cover the range from 0 to 2π (see in figure 18).

The center of the eye opening provides optimal conditions for the detection of the binary signal and is defined as the sampling phase with the highest vertical eye opening (figure 18).

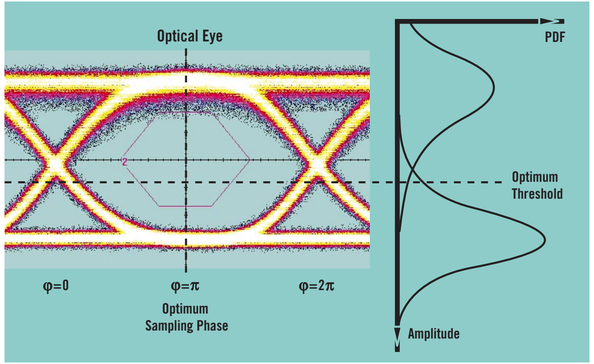


figure 18 *Optical eye with optimum detection point*

Assuming that the signal distributions are Gaussian, the Q-factor can also be expressed as BER and vice versa.

Let's go back to the initial definition of the Q-factor to understand how it relates to the BER. The difference in the mean values produces the vertical eye opening. The higher the difference, the better the BER will be as the two bell curves drift away from each other and have less overlap. This difference is divided by the sum of the noise distributions which are represented by the width of the bell curves. Increases in noise result in more overlap in the two bell curves resulting in a higher BER.

Methods to determine the Q-factor

There are two fundamental methods for determining the Q-factor; the histogram method and the Pseudo-BER method. Though the processes behind each method differ, the intention of them is to estimate the BER for the optimum threshold which is directly related to the Q-factor.

The histogram method samples the signal and collects the sampling points into bins as shown in the previous chapter. The Pseudo-BER method, however, determines the BER for different threshold levels representing different areas under the PDF curve. With the BERs at different threshold levels, an extrapolation can be made for the estimated BER at the optimum threshold.

table 1 Methods to determine Q

Fundamental Method	Sampling	Description
Histogram method	Asynchronous	Voltage histogram
	Synchronous	Digital sampling scope
Pseudo-BER method	Synchronous	Single threshold method
	Synchronous	Dual threshold method

Asynchronous sampling (voltage histogram) – All the amplitude values of the eye diagram (including the amplitude values of the transient regions) are sampled asynchronously resulting in a histogram representing the PDF of the complete signal including the transient regions (figure 19).

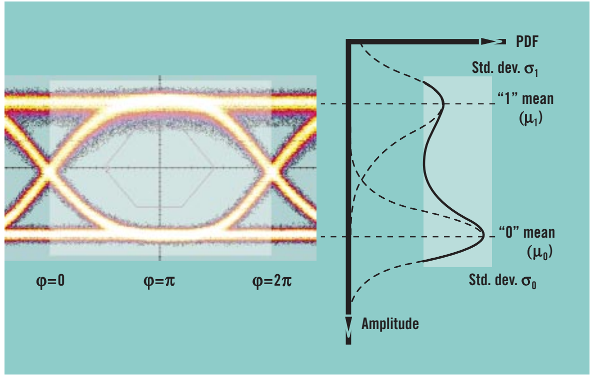
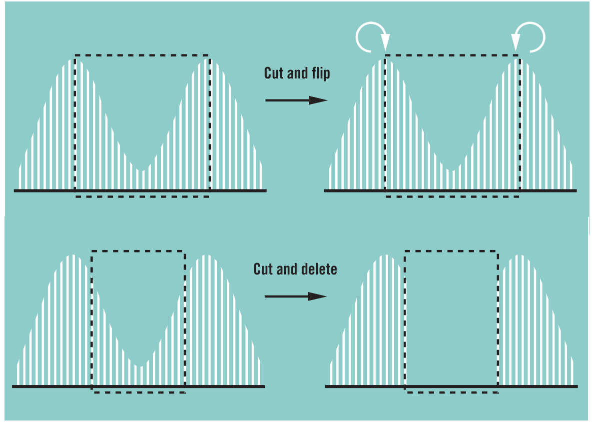


figure 19 Asynchronous sampling

The main objective in acquiring an evaluation of the performance is to determine the PDF of the optimum sampling phase which would be π (in this particular case). The contribution of the transient regions to the overall PDF is to "hide" the PDF of the sampling phase. The transient region samples fill up the center between the two means. Two possible solutions for correction are the "cut & flip" or the "cut & delete" methods (figure 20). The idea behind this is that the histogram's edges are influenced only by the noise distributions but not by the transient. In the first case, the edges representing noise distributions are flipped inside to get a more appropriate model of the PDF. In the second case, the center (which is affected by the transient samples) is omitted leaving the edges for evaluation.

figure 20 *"Cut & flip" and "cut & delete" method*



The characteristics of the asynchronous sampling method make it very difficult to fit the Gaussian functions to the measurement results which are necessary for the BER calculation. The BER calculation for the signal will not give a high accuracy for the optimum sampling phase as the PDF needs to be prepared to provide a better estimation.

Until now, the exact estimation of the Q-factor from the asynchronous sampling histogram could not be accurately proved. Although this technique has restrictions for performance monitoring, it remains a very powerful tool for detecting small signal degradations.

Synchronous sampling (digital sampling scope) – The main restriction of asynchronous sampling is that the transient regions affect the result. To overcome this restriction and gain higher accuracy, synchronous sampling must be performed. Synchronous sampling needs a clock recovery and is therefore more complex. The sampling phase is locked to the optimum phase and can therefore give a more accurate result of the BER estimation. Synchronous sampling concentrates more on the detection phase rather than the whole signal (figure 21).

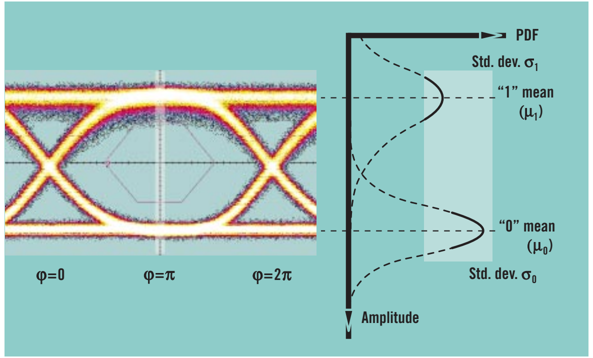


figure 21 *Synchronous sampling histogram method*

One disadvantage of this method is that the digital sampling scopes used often do not have the sampling rate needed for Q-factor measurements. A typical sampling rate would be 100,000 samples per second. Assuming a 10 Gbps signal (10,000,000,000 bits per second) is received, only one bit out of 100,000 would be sampled.

An additional disadvantage is that due to the low statistical probability of a sample being affected during measurement occuring at the tail of the Gaussian function, the samples tend to be concentrated at the "0" and "1" levels.

This gives a good estimation around the mean values of the two Gaussian distribution functions although the estimation of the correct standard deviations and hence the bell curve is difficult to determine. The shape of the bell curve however contributes greatly to the BER estimation as the evaluation takes place mostly at the tail of the bell curve.

Although this method gives a higher degree of accuracy than the asynchronous histogram method, it is still not very accurate and mostly shows lower Q- factor values (higher BER) than the more accurate synchronous Pseudo-BER methods which are described next.

Synchronous sampling method (single decision threshold method) – Rather than taking the histogram to determine the shape of the PDF (and thus the estimated BER), BER measurements at different decision threshold levels can be taken to extrapolate the estimated BER.

The BER measurement method described in ITU-T standards can be time consuming given that the measurement time must fulfill the requirement of a certain statistical confidence.

By taking decision threshold levels which are correlated to BERs of 10^{-4} to 10^{-8}, the measurement can be completed much quicker (table 2). Assuming the distribution of the PDFs are Gaussian, the BER of the optimum threshold level can be evaluated giving an estimated BER as opposed to an actual measured value.

BER	10^{-4}	10^{-8}	10^{-14}	10^{-15}	10^{-16}	10^{-18}	10^{-20}
STM-16/ OC-48	0.004 ms	0.04 s	11 h	6 days	46 days	13 y	1268 y
STM-64/ OC-192	0.001 ms	0.01 s	3 h	28 h	12 days	3 y	317 y

table 2 *Time for one error to occur at different bit rates*

By using the Pseudo-BER method, the number of samples is the same as those given by the bit rate: For example, a 10 Gbps signal results in 10,000,000,000 samples per second, which when compared to a sampling scope gives a much higher rate.

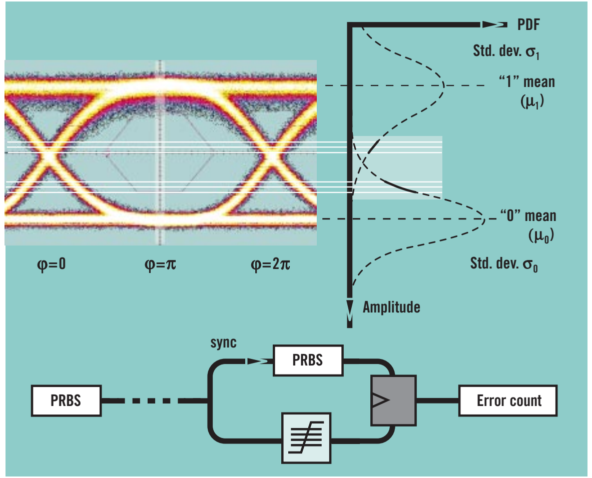


figure 22 *Single decision threshold method*

The principle block diagram shows how the single decision threshold method works (figure 22). On the transmitter side a known data pattern which can be realized by a Pseudo-Random Binary Sequence (PRBS) is sent. On the receiver side the signal is detected with variable decision threshold levels.

A second path is required to provide the known data pattern (PRBS) as a reference signal. The detected signal and the reference signal are compared with each other to identify the bit errors. The errors are then counted over a certain time frame to determine the BER. This process is repeated at different threshold levels.

Once the BERs have been measured, an extrapolation can be made for the optimum decision threshold level. The different threshold levels also allow a better evaluation at the tail of the PDF as the area investigated is much closer to the tail than it is with the histogram method. This results in a better fitting of the Gaussian curve and in turn a higher confidence and accuracy of the BER estimation at the optimum detection point. A BER estimation with this method may be completed in just under 1 minute.

Synchronous sampling method (dual decision threshold method) –
The single decision threshold method is based on the traditional BER testing with a known bit pattern (PRBS). This of course has the drawback that the single decision threshold method can only be performed in out-of-service mode.

To overcome this disadvantage the dual decision threshold method is applied. The receiver has two signal paths, one set to the assumed optimum threshold (used as reference path or signal), the other operating with variable decision threshold levels (figure 23). The two paths are compared to count bit errors thus making the known data pattern at the receiver side obsolete.

Being independent of the bit rate and a specific test pattern, this method clearly shows its benefits as an in-service performance measurement. If not otherwise stated, the Q-factor measurement always refers to the synchronous sampling method with dual decision threshold in this pocket guide.

The results of the Q-factor measurement can be graphically displayed in a diagram with the x-axis representing the threshold level and the y-axis representing the BER (error count with regard to the reference threshold level and estimated BER).

Each threshold level generates a data point in the range of 10^{-4} to 10^{-8} in order to receive short measurement time. An extrapolation using the measured BERs (light area in figure 24) allows for an estimation of the BER of the optimum threshold level (Q-factor point in figure 24). The estimated BER can be expressed as Q-factor.

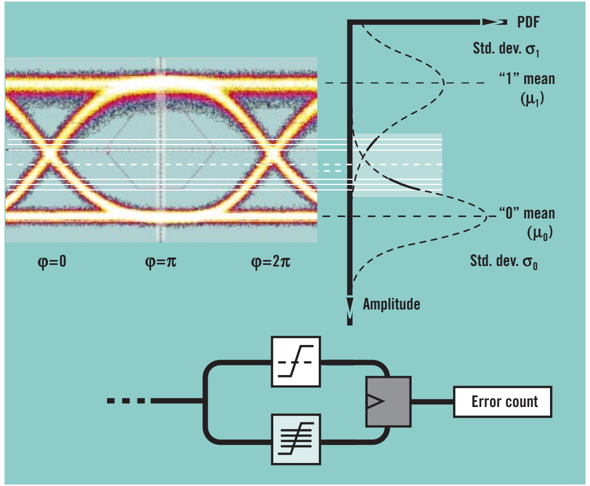
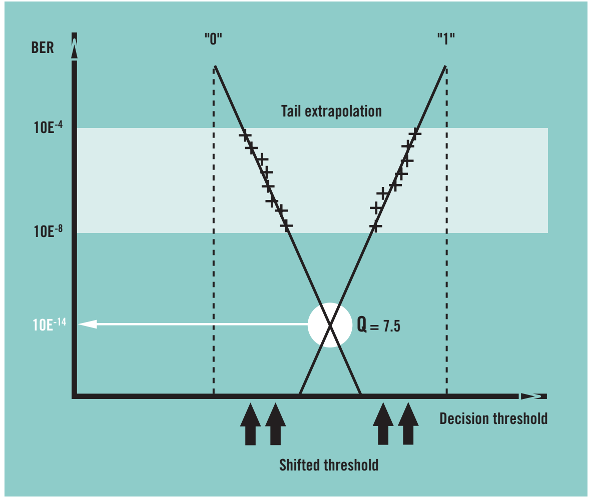


figure 23 *Dual decision threshold method*

figure 24 *Q-factor extrapolation*



Q-factor applications

- **Manufacturing** system components must be checked after manufacturing
- **Installation** functionality of equipment set up at network operator sites must be verified
- **Optimization** systems currently in operation must be optimized for best system performance
- **Maintenance & Troubleshooting** covering tasks where the Q-factor meter can be used as a measuring tool
- **Monitoring** Q-factor can show the smallest of signal degradations

System test during manufacturing

During manufacturing a final system test must be performed in order to verify the technical specifications of systems. DWDM implies multi-channel systems of which every channel must be thoroughly checked. Systems able to handle 40 or 80 channels are common with some higher channel systems currently emerging in the market place.

BER performance of better than 10^{-12} is a common requirement, though this can be a time consuming task especially for multi-channel systems. Assuming a single 10 Gbps channel needs to stand the requirement for a BER of better than 10^{-13}, the test time is 28 hours to get a statistically correct result. With DWDM systems able to carry up to 100 channels, the overall test time will be in a range where it is no longer economical

to apply this kind of test method. 28 hours multiplied by 100 channels results in a testing time of approximately 4 months.

An alternative option is to apply new test methods which do not allow direct proof of the performance but deliver a performance estimation with a high degree of confidence. The Q-factor method is an ideal solution for this (figure 25). The fast BER estimation checks all system channels quickly, thus lowering test time and costs. Typically an 'out-of-service' application, factory calibration and optimization can now be performed efficiently and economically especially in multi-channel-systems.

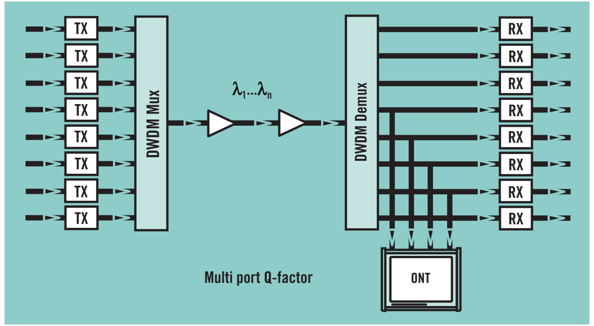


figure 25 *System test during manufacturing*

Installation of optical networks

Another 'out-of service' application in which the Q-factor can be utilized is during installation of optical networks at a network operators site (figure 26). Here the Q-factor measurement allows for the functional verification of the optical network elements. Typical questions arising at installation include:

Question:

- Has the installation of the subsystem been successfully completed?
- Will the performance of a subsystem be good enough to support the overall performance requirements?
- Are there certain parts or components of the system which could be problematic?

Answer:

The Q-factor meter allows a fast BER estimation during installation to answer these questions. Time consuming traditional BER tests can be avoided before final commissioning. An Optical Spectrum Analyzer (OSA) can also be used to monitor various parameters such as power, Optical Signal-to-Noise Ratio (OSNR) and wavelength.

It should be noted that the Q-factor does not replace the final commissioning with a BER tester to determine the overall QoS. For final commissioning the whole link needs to be seen as a Device Under Test (DUT) (including system transmitter and system receiver). The system transmitter is then replaced by a pattern generator and the output of the system receiver fed into a BER tester. ITU-T considers this the only test method valid today to determine the QoS of a digital channel.

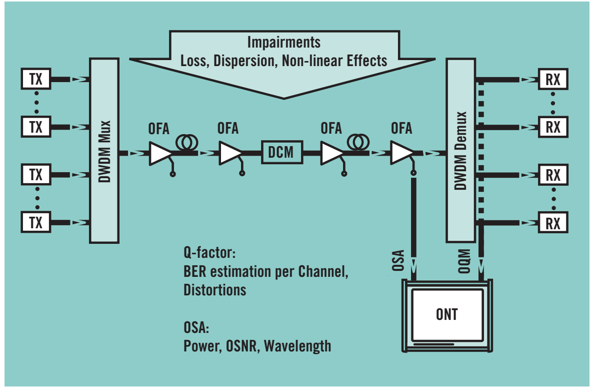


figure 26 *Possible setup during installation*

System optimization

Installed systems include components which can be adjusted for optimum performance. Although this is part of the installation process, it may also be a factor to be resolved during operation. A common question at this stage:

Question:

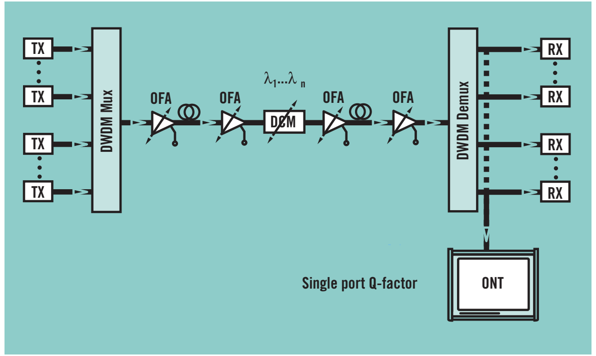
- Have the system parameters such as channel power level and chromatic dispersion been adjusted for optimum performance?

Answer:

The Q-factor meter allows direct monitoring of the performance as it provides fast BER estimation. System optimization can be easily achieved through the adjustment of network elements with results which can be seen immediately (figure 27). The proper settings for Optical Fiber Amplifier (OFA) output levels for example can be checked very quickly as the settings have a direct impact on signal quality.

A significant advantage with the Q-factor meter is that it also operates in the in-service mode when the appropriate tap points are provided. This is made possible as the Q-factor meter is independent of bit rate and data format.

figure 27 *Q-factor used for system optimization*



Maintenance and troubleshooting

During maintenance and troubleshooting one of the main objectives is to gather as much information as possible on the system in-service. To take the system out-of-service costs time and money. A performance estimation with a Q-factor meter is therefore an ideal solution. Tapped signals provided in systems allow for these measurements to be made. Questions raised relating to these measurement tasks include:

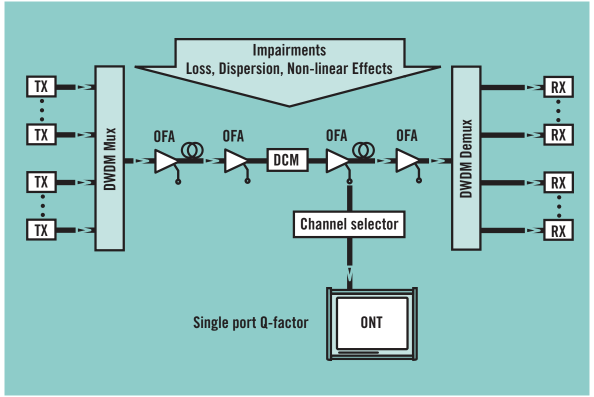
Question:

– Are there system degradations which make it necessary to switch to an alternative transmission path?
– Are there crosstalk or non-linear effects present due to added channels during a system upgrade?

Answer:

To bring the system back to the guaranteed QoS it is necessary to have the right tools for fault identification and location. The Q-factor meter can be used for maintenance as well as for troubleshooting to view when and where a system degradation might occur (figure 28).

figure 28 *Q-factor in a maintenance and troubleshooting environment*



System monitoring

To check the system performance over a certain period of time or within specific time intervals, monitoring needs to be performed. Monitoring may also imply that the user handles equipment remotely from a central location such as a Network Operations Center (NOC) for example (figure 29).
Typical questions which arise include:

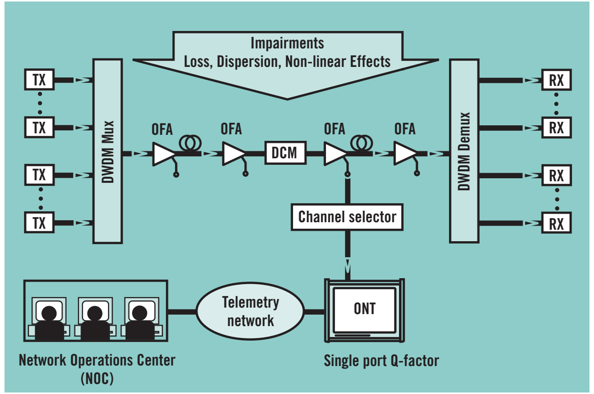
Question:

- Is it possible to perform monitoring as preventive maintenance in an in-service mode?
- Can system degradations be identified during preventive maintenance monitoring which is independent of bit rate and protocols used (e.g. SDH with and without digital wrappers, ATM , IP, etc.)?

Answer:

Monitoring is possible when tapped signals are provided by the system. Pre-maintenance monitoring shows even small degradations in QoS and the network operator can react quickly to this. Degradation effects can occur through aging and mechanical stress.

figure 29 *Setup of ONT with Q-factor during system monitoring*



Standardization

The principle of the Q-factor measurement with variable decision thresholds has already been adopted in the **ITU-T Recommendation G.976** “Test methods applicable to optical fibre submarine cable systems”. The Q-factor measurement is proposed for use in fast end-to-end testing in this recommendation.

Future US standard **TIA/EIA-526-12** will also give details on the Q-factor measurement evaluation procedure. The proposal is named “Q-factor Measurement Procedure for Optical Transmission Systems”.

The **IEC (TC 86 A, B, C)** is expected to define the principle of the Q-factor method as well as the parameters involved, evaluation procedure and presentation of results by adopting **TIA/EIA-526-12**. The IEC does not give any recommendations related to measurement equipment as this will be addressed by the ITU-T.

It is of critical importance in the case of Q-factor measurement to standardize precisely the test equipment and evaluation process to ensure that test equipment from different vendors yields comparable results. In response to this an O-series recommendation **O.qfm** "Q-factor test equipment for measuring the transmission performance of transparent optical channels” was initiated in January 2001 in ITU-T SG4.

Summary

The Q-factor meter is a tool which can be used during:

- **Manufacturing** for system test
- **Installation** for a fast BER estimation (BER pre-qualification)
- **Installation and operation** for system optimization
- **Maintenance, troubleshooting** and monitoring.

The Q-factor meter estimates the BER for optimum threshold level and sampling phase in less than 1 minute, making the Q-factor measurement faster than traditional BER testing.

The Q-factor measurement is independent of bit rate and data format and as such is a ‘universal tool’ in systems carrying different bit rates and protocols. As DWDM systems are transparent for different data formats the Q-factor meter is an ideal solution.

In addition to this, the Q-factor does not require a known bit pattern to be sent thus allowing in-service monitoring when appropriate tapped signals are provided.

Although traditional BER testing is still considered the only method for final commissioning of digital channels (according to standards) the Q-factor measurement brings some significant advantages especially for high bit rate systems. A standardization process for the Q-factor measurement is currently in progress.

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Abbreviations

Abbreviation	Description
ATM	Asynchronous Transfer Mode
BER	Bit Error Ratio
CD	Chromatic Dispersion
DCM	Dispersion Compensation Module
Demux	Demultiplexer
DUT	Device Under Test
DWDM	Dense Wavelength Division Multiplex
FEC	Forward Error Correction
FWM	Four Wave Mixing
Gbps	Gigabit per second
IEC	International Engineering Consortium
IP	Internet Protocol
ITU-T	International Telecommunications Union – Telecommunications Services Sector
Mux	Multiplexer
NOC	Network Operations Center
O/E converter	Optical-to-electrical converter
OC	Optical Container
OFA	Optical Fiber Amplifier
ONT	Optical Network Tester
OQM	Optical Q-factor Meter
OSA	Optical Spectrum Analyzer

Abbreviation	Description
OSNR	Optical Signal-to-noise Ratio
PDF	Probability Density Function
PMD	Polarization Mode Dispersion
PRBS	Pseudo-random Binary Sequence
QoS	Quality of Service
RX	Receiver
SBS	Stimulated Brillouin Scattering
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
SPM	Self-phase Modulation
SRS	Stimulated Raman Scattering
STM-x	Synchronous Transport Module
TIA/EIA	Telecommunications Industry Association/ Electronic Industries Alliance
TX	Transmitter
WDM	Wavelength Division Multiplex
XOR	Exclusive Or
XPM	Cross-phase Modulation