Optical Signal to Noise Ratio (OSNR)

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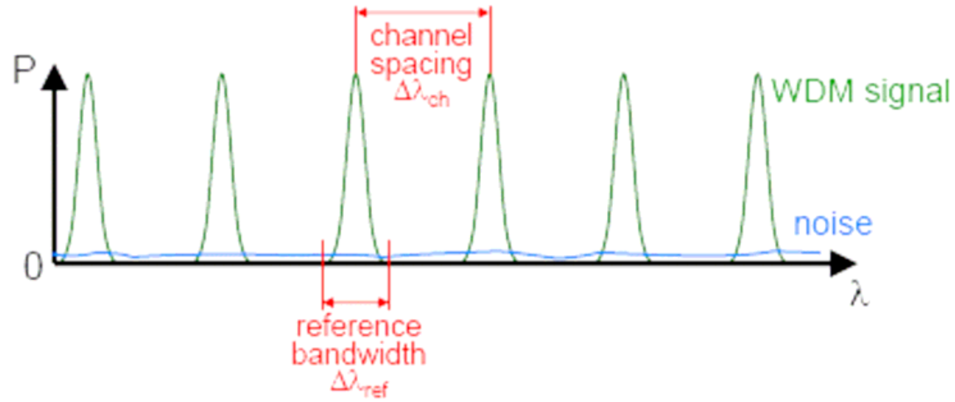
Overview of topics

- Optical Signal to Noise Ratio (OSNR)
- Bit Error Rate
- The Eye Diagram
- Q Factor

OSNR Definition



$$OSNR = 10dB \cdot Log_{10}\left(\frac{S}{N}\right)$$

Where
S represents the (linear) optical signal power and
N is the (linear) optical noise power

Optical Signal to Noise Ratio (OSNR) [dB] is the measure of the ratio of signal power to noise power in an optical channel.

OSNR is important because it suggests a degree of impairment when the optical signal is carried by an optical transmission system that includes optical amplifiers.

Problem: OSNR is a complex parameter

Optical signal suffers more than only attenuation. In amplitude, spectrally, temporally signal interaction with light-matter, light- light, light-matter-light leads to other signal disturbances such as :

- Power reduction
- Dispersion
- Polarization
- Unbalanced amplification

Thus leading to random noise, which causes misalignments, jitter and other disturbances resulting in erroneous bits, the rate of which is known as ***bit-error-rate***

Because of all possible influences outlined bits transmitted by source and bits arriving at the receiver may not have the same value. In actuality a threshold value is set at the receiver, above the threshold refers to a logic “one” and below threshold refers to a logic “zero”.

$$BER = \frac{\text{no. of incorrect received bits}}{\text{no. of transmitted bits}}$$

In order to measure BER in photonic regime, the optical signal is converted to electrical signal.

Example: Assuming a confidence level of 99%, BER threshold set at 10^{-10} and a bit rate of 2.5 Gb/s the required number n is 6.64×10^{10}

Co-relation between OSNR and BER

Given the OSNR, the empirical formula to calculate BER for single fiber is

$$\text{Log10 (BER)} = 10.7 - 1.45 \text{ (OSNR)}$$

Example:

Assume that OSNR = 14.5 dB
ThenLog10 (BER) = 10.7-1.45 (14.5) = -10.30

Therefore BER = $10^{(-10.30)}$
BER is approx 10^{-10}

Eye Diagram

In transmission, a quick and qualitative measure of the quality and integrity of the electronic signal (since optical has been converted to electrical) is a superposition of bit periods on an oscilloscope. This superposition is known as the "eye diagram"

If the signal has little noise and the amplitude is sufficient to be clearly recognized as "one" (marks) or "zero" (spaces) the superposition provides an "open eye", otherwise eye is corrupted and "fuzzy"

Eye Diagram

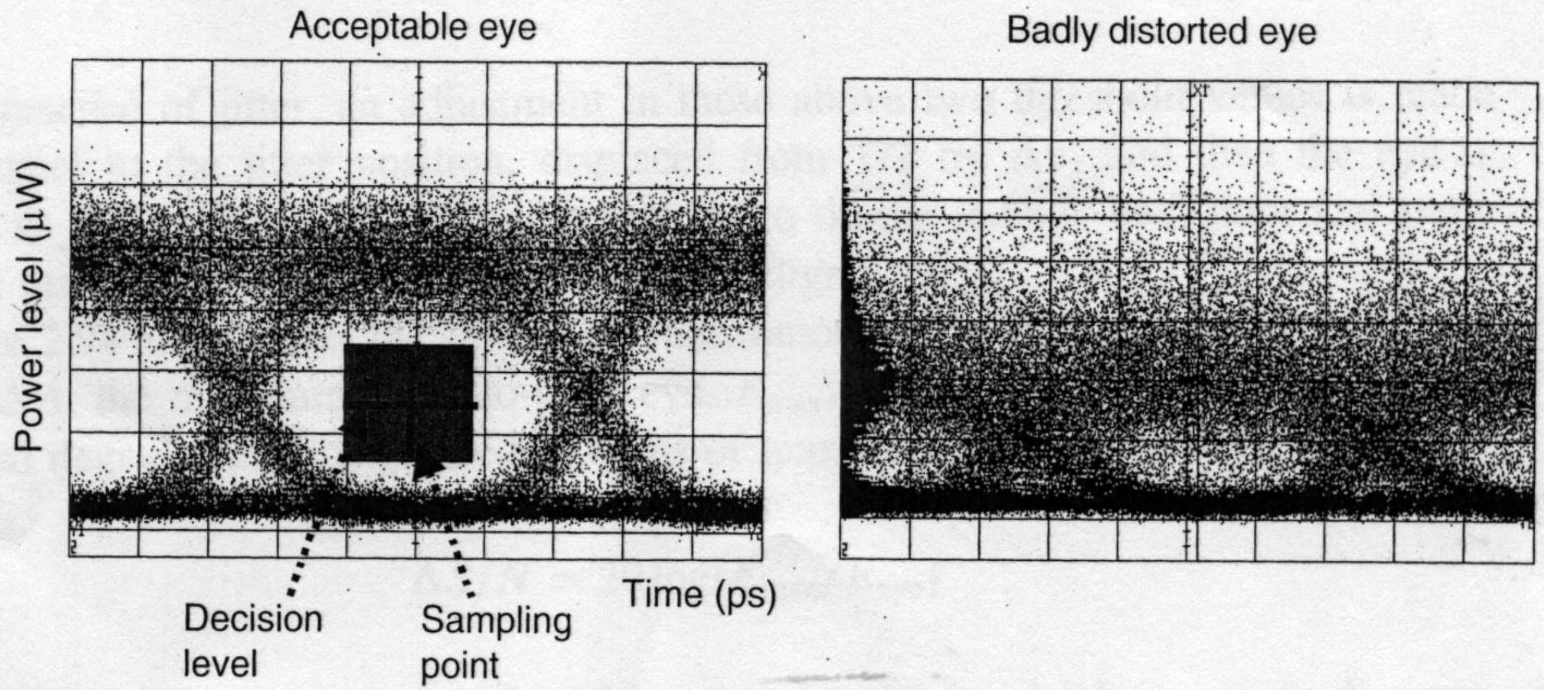


Figure 2.93 Eye diagrams provide a quick and qualitative measure of the quality and integrity of the signal at the receiver (optical has already been converted to electrical).

BER and the 'Open' Eye

Based on the expected eye diagram, decision levels have been determined:

- Sampling point in time
- Threshold power levels for logic "one" and logic "zero"

Minimum current threshold for logic 1 is set to $I_{1,min}$
Maximum current threshold for logic 0 is set to $I_{0,max}$

Opening of the Eye, $E_{Eye} = I_{1,min} - I_{0,max}$

Eye Diagram Threshold Levels

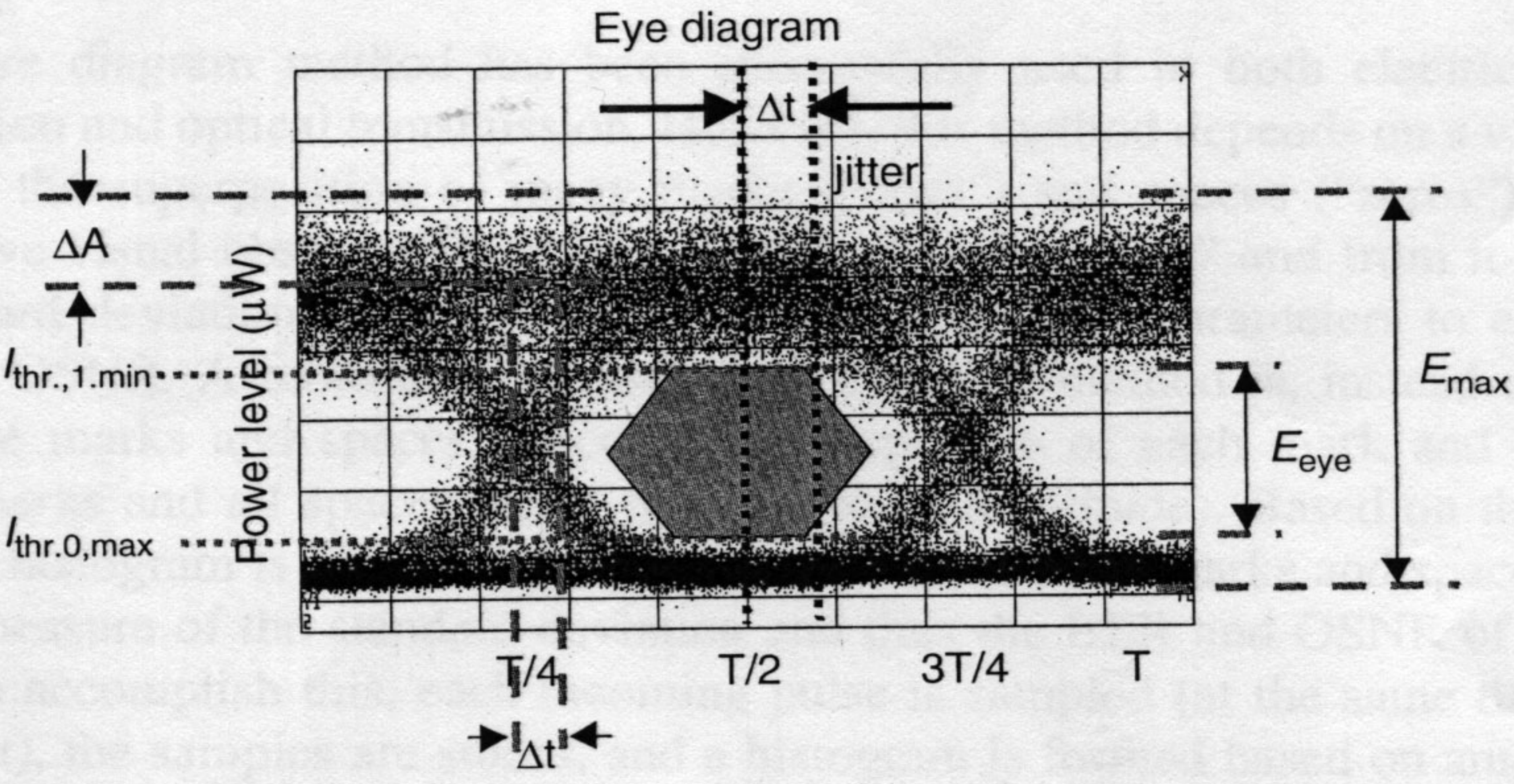


Figure 2.94 Threshold levels (power and jitter) mapped on eye diagram.

The Q factor and BER

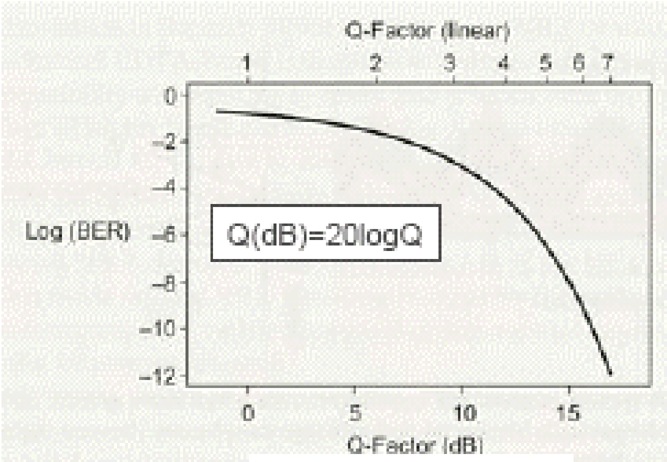
If the standard diviation for logic "one" bit is σ_1
And the standard diviation for logic "zero" bit is σ_0

The quality factor, $$Q = \frac{E_{Eye}}{\sqrt{\left|\sigma_0^2 - \sigma_1^2\right|}}$$

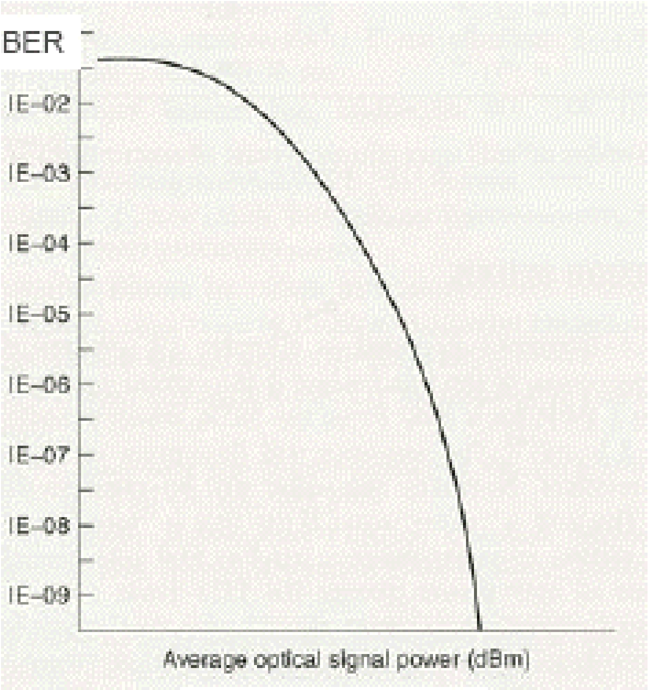
The BER is defined as, $$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right)$$

Where *erfc* is the error function

The Q factor and BER



BER vs. Q-factor

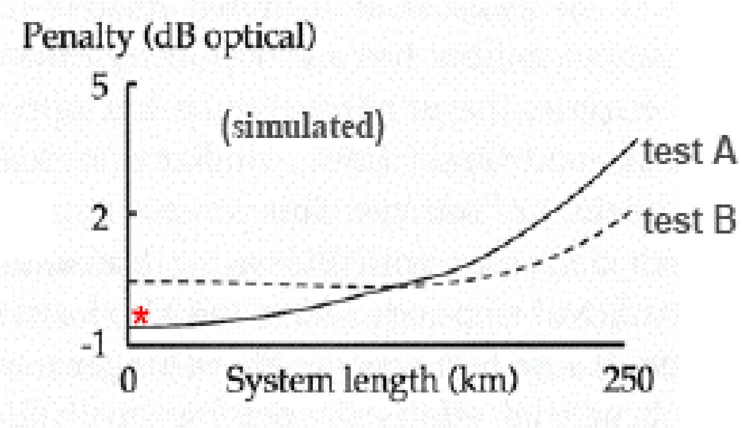


BER vs. $P_{received}$

Penalty ratio

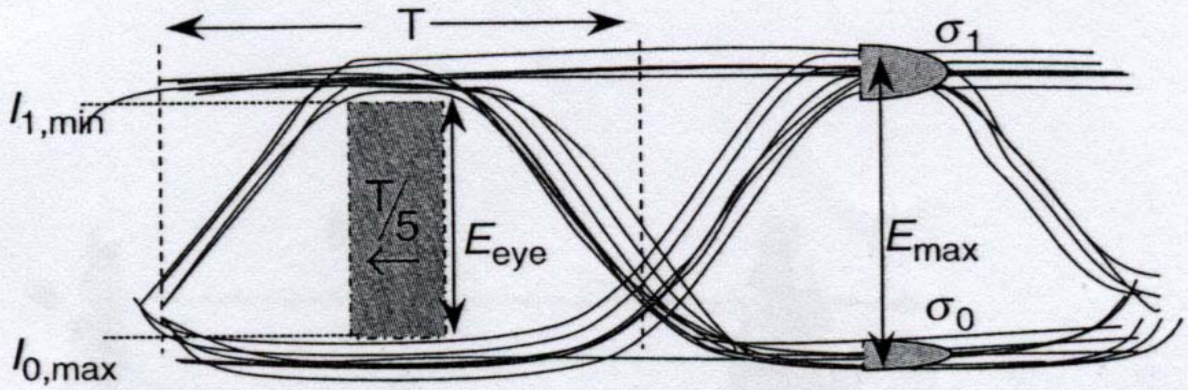
Based on the expected opening of the eye E_{Eye} and the actual average eye opening E_{Avg} a quantitative penalty is defined,

$$Penalty = \frac{E_{Eye}}{2E_{Avg}}$$



*note:
The eye opening penalty could be negative (EOP < 0 dB), which means the eye opens up and indicates an improvement of the system performance.

Eye Diagram BER and Penalty Estimation



1. Measure/estimate:

Variance for "0", Var_0

Variance for "1", Var_1

σ_0 = std deviation for "0"

$= \sqrt{Var_0}$

σ_1 = std deviation for "1"

$= \sqrt{Var_1}$

E_{eye}, E_{max}, E_{avg}

2. Calculate:

$E_{eye} = I_{1,min} - I_{0,max}$

$Q = E_{max} / \sqrt{\sigma_1^2 + \sigma_0^2}$

BER = ½ erfc $(Q/\sqrt{2})$

Penalty = $E_{eye}/2E_{avg}$

Figure 2.95 BER and penalty estimation based on eye diagram.

Conclusions

The eye diagram method has been successfully used in both electrical and optical transmission. However, this method depends on the visual observation of the superposition of many marks (“ones”) and spaces (“zeroes”) to yield a quantitative observation of how well the “eye is open”, and from it to estimate the BER and OSNR.

Conclusions contd…

A more complex method would be to instead of superimposing the marks and spaces , to count the amplitude of each mark and each space. Based on these data statistical histogram is formed, which for a large number of marks and spaces provides a better measure of the standard deviation and thus BER and OSNR of the optical signal.

Each incoming pulse is sampled, samples are stored and histogram is formed based on amplitude and frequency of occurrence.

Conclusions contd …

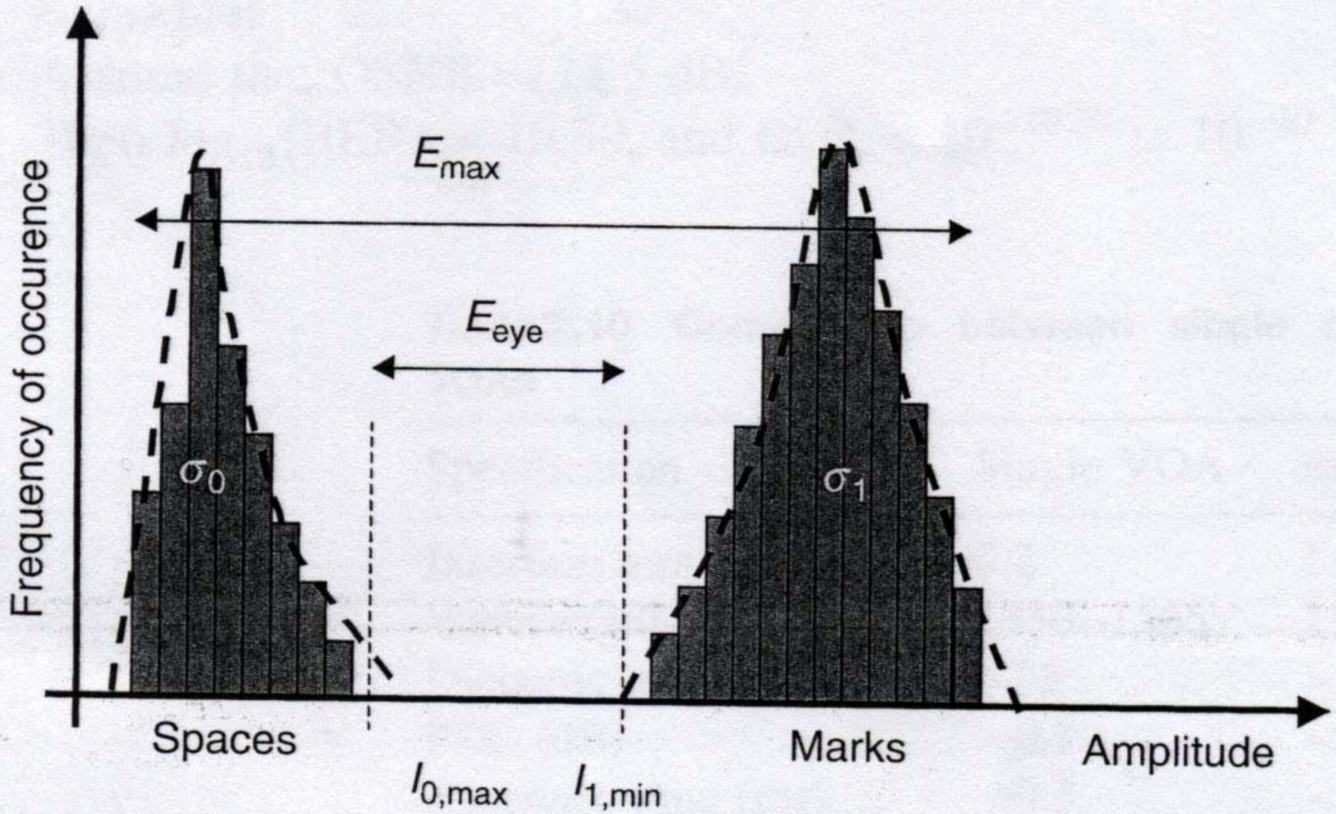


Figure 2.96 BER and penalty estimation based on the histogram diagram.