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TECHNICAL REPORT

Fibre optic communication system design guides –
Part 12: In-band optical signal-to-noise ratio (OSNR)

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FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

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FOREWORD

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IEC 61282-12, 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/1341/DTR	86C/1364/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 in 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 stability date indicated on the IEC website 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- withdrawn,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.

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 12: In-band optical signal-to-noise ratio (OSNR)

1 Scope

The purpose of this part of IEC 61282, which is a Technical Report, is to provide a definition for in-band optical signal-to-noise ratio (OSNR) that is applicable to situations where the spectral noise power density is not independent of the optical frequency, as assumed in the OSNR definition of IEC 61280-2-9, but is significantly shaped across the optical bandwidth of the signal. Considering the development of multiple measurement methods for different use cases, as detailed below, it is desirable to establish a definition of in-band OSNR that is independent of the method used and, furthermore, is consistent with the OSNR definition of IEC 61280-2-9 in the case of frequency-independent noise power density.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61280-2-9:2009, *Fibre optic communication subsystem test procedures – Part 2-9: Digital systems – Optical signal-to-noise ratio measurement for dense wavelength-division multiplexed systems*

3 Terms and definitions

3.1
optical signal-to-noise ratio
OSNR
ratio of total signal power of an optical signal to the amplified spontaneous emission (ASE) noise power spectral density within the optical spectrum of the signal, wherein the power spectral density is normalized to a chosen reference bandwidth

Note 1 to entry: This definition is consistent with the one in subclause 3.1 of IEC 61280-2-9:2009, when the noise power spectral density is constant across the spectral range of the signal, but is used in this document as a generalized collective term for the following set of in-band OSNR definitions that have differing values when the noise power spectral density is not constant across the spectral range of the signal.

3.2
$OSNR_{int}$
spectrally-integrated in-band optical signal-to-noise ratiospectrally integrated ratio of time-averaged power spectral density of a signal to the power spectral density of the amplified spontaneous emission (ASE) noise, normalized to a chosen reference bandwidth

Note 1 to entry: The spectrally-integrated in-band OSNR, R_{int}, is calculated as

$$R_{\mathrm{int}} = \frac{1}{B_{\mathrm{r}}} \int_{\lambda_1}^{\lambda_2} \frac{s(\lambda)}{\rho(\lambda)} d\lambda \qquad (1)$$

where:

$s(\lambda)$ is the time-averaged signal power spectral density, not including ASE, expressed in W/nm;

$\rho(\lambda)$ is the ASE power spectral density, independent of polarization, expressed in W/nm;

B_r is the reference bandwidth expressed in nm (usually 0,1 nm if not otherwise stated);

and the integration range in nm from λ_1 to λ_2 is chosen to include the total signal spectrum.

Note 2 to entry: $OSNR_{int}$ is usually expressed in dB as 10 log(R_{int}).

3.3
$OSNR_{avg}$
weighted-average in-band optical signal-to-noise ratio

ratio of time-averaged optical signal power to the spectrally weighted average power spectral density of the amplified spontaneous emission (ASE) noise, where the weighting is proportional to the normalized signal power spectral density, and the weighted average power spectral density is normalized to a chosen reference bandwidth

Note 1 to entry: The weighted-average in-band OSNR, R_{avg}, is calculated as

$$R = \frac{1}{B_r}\frac{s}{\frac{\int_{\lambda_1}^{\lambda_2}\rho(\lambda)s(\lambda)\,d\lambda}{s}} = \frac{1}{B_r}\frac{s^2}{\int_{\lambda_1}^{\lambda_2}\rho(\lambda)s(\lambda)\,d\lambda} R = \frac{1}{B_r}\int_{\lambda_1}^{\lambda_2}\frac{s(\lambda)}{\rho(\lambda)}d\lambda$$

where:

$s(\lambda)$	is the time-averaged signal power spectral density, not including ASE, expressed in W/nm;
s	is the total signal power, i.e. the wavelength integral of $s(\lambda)$, expressed in W;
$\rho(\lambda)$	is the ASE power spectral density, independent of polarization, expressed in W/nm;
ρ_{avg}	is the spectrally weighted average noise power density, expressed in W/nm, where the weighting is proportional to the normalized signal power spectral density;
B_r	is the reference bandwidth expressed in nm (usually 0,1 nm if not otherwise stated);

and the integration range in nm from λ_1 to λ_2 is chosen to include the total signal spectrum.

Note 2 to entry: $OSNR_{avg}$ is usually expressed in dB as 10 log(R_{avg}).

3.4
$OSNR_{max}$
maximal-noise in-band optical signal-to-noise ratio

ratio of time-averaged optical signal power to the maximal power spectral density of the amplified spontaneous emission (ASE) noise within the wavelength range of the total signal spectrum, normalized to a chosen reference bandwidth

Note 1 to entry: The maximal-noise in-band OSNR, R_{max}, is calculated as

$$R_{max} = \frac{\int_{\lambda_1}^{\lambda_2} s(\lambda)d\lambda}{B_r\ \rho_{max}} = \frac{s}{B_r\ \rho_{max}} \tag{3}$$

where:

$s(\lambda)$	is the time-averaged signal power spectral density, not including ASE, expressed in W/nm;
s	is the total signal power, i.e. the wavelength integral of $s(\lambda)$, expressed in W;
ρ_{max}	is the maximal ASE power spectral density within the spectral range of the signal, independent of polarization, expressed in W/nm;
B_r	is the reference bandwidth expressed in nm (usually 0,1 nm if not otherwise stated);

and the integration range in nm from λ_1 to λ_2 is chosen to include the total signal spectrum.

Note 2 to entry: $OSNR_{max}$ is usually expressed in dB as 10 log(R_{max}).

3.5
subcarrier OSNR
$OSNR_{sub}$
in-band OSNR determined for a single modulated subcarrier of a signal consisting of multiple modulated subcarriers at different wavelengths, calculated with only the signal power density of the selected subcarrier

3.6
$OSNR_{sup}$
superchannel OSNR
in-band OSNR determined by including the signal power density of all modulated subcarriers in a multiple-carrier optical signal

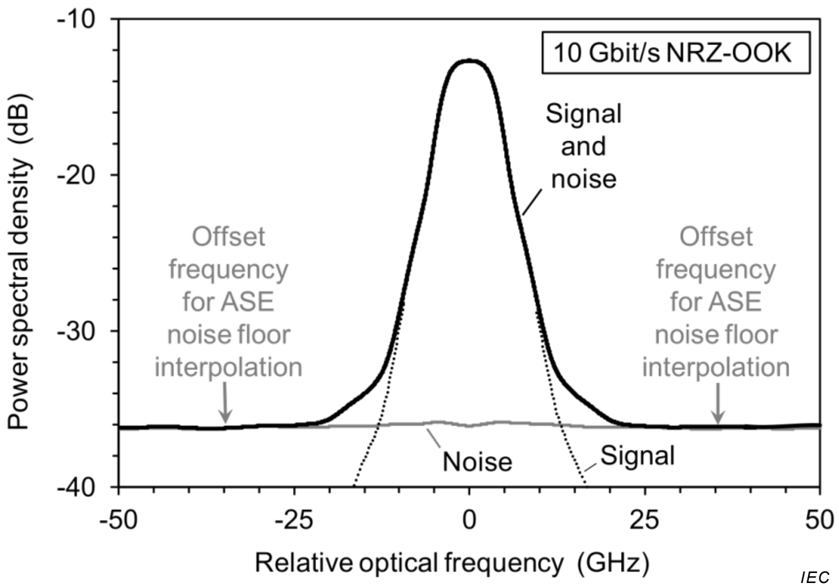
Note 1 to entry: If the signal is polarization-multiplexed, then each polarization tributary of the signal carries only a fraction of the signal power and thus, by itself, has a lower OSNR than the combined signal. This means that for the case of equal power in the two polarization tributaries, the OSNR of a polarization-multiplexed signal is 3 dB higher than that of the two components taken separately. Thus, polarization-multiplexed signals are typically assigned an OSNR value that is 3 dB higher than that for single-polarization signals of the same SNR quality, as if the total power were in a single polarization mode and only interfering with the ASE in that mode. This convention has been widely adopted by the industry, especially because it is supported by the existing measurement functionality of optical spectrum analyzer instruments.

4 Background

4.1 General

In fibre optic communication systems with in-line optical amplification, OSNR is a key parameter to assess system performance. As described in IEC 61280-2-9, OSNR is defined as the ratio of total signal power to the amplified spontaneous emission (ASE) noise power spectral density within the optical spectrum of the signal. In other words, the OSNR is a measure of the signal strength relative to the strength of the underlying ASE noise. However, this widely-used and well-established definition of OSNR assumes that the ASE noise spectrum is essentially flat across the spectrum of the transmitted signals, so that the noise power level can be characterized by a single parameter, i.e. the noise power spectral density.

An important task of measuring OSNR, therefore, is to determine the power spectral density of the ASE noise within the spectrum of the signal. The standard procedure for determining the in-band noise power spectral density is based on out-of-band ASE noise measurements, as described in IEC 61280-2-9 and illustrated in Figure 1. This procedure requires that the optical spectrum of the signal be confined to a relatively small wavelength range of the DWDM channel allocated to the signal, so that the ASE noise power level can be measured on both sides of the signal spectrum. Under the assumption that the ASE noise spectrum is essentially flat, the in-band ASE noise power spectral density can be determined by interpolation of the two noise power measurements on either side of the signal spectrum. The definition of OSNR from IEC 61280-2-9 is given in terms of this out-of-band noise measurement method. This method is especially convenient for DWDM systems because the OSNR of multiple signals can be measured simultaneously in a relatively short time. Furthermore, these measurements can be performed while the system is in service (in-service OSNR measurement).



NOTE The signal power is the integral of the power density after subtracting the ASE density. When the spectrum is measured with an optical spectrum analyzer, the resolution bandwidth is often chosen wider than the complete signal, so that the peak of the measurement trace represents this integral.

Figure 1 – Optical power spectrum composed of a modulated signal and ASE noise

However, three recent developments in optical transmission technology have now added complications to the OSNR measurement defined in IEC 61280-2-9, two of which have already been noted in Annex B of IEC 61280-2-9:2009.

4.2 Higher spectral density of signals

To increase the overall transmission capacity of fibre optic links, the transmitted signals are spaced closer together in wavelength and/or are modulated at higher symbol rates, where the latter results in broader signal spectra [3-4][1]. Faster modulation rates and closer channel spacing often cause significant overlap of adjacent signal spectra, as illustrated in Figure 2, so that it becomes very difficult – if not impossible – to determine the ASE level between adjacent signals from a simple spectral analysis. Transmission of densely spaced DWDM signals, therefore, greatly reduces the usefulness of the interpolation method described in IEC 61280-2-9. Hence, there is a rising need for alternative methods to measure the in-band noise power spectral density (in-band OSNR measurements).

1 Numbers in square brackets refer to the Bibliography

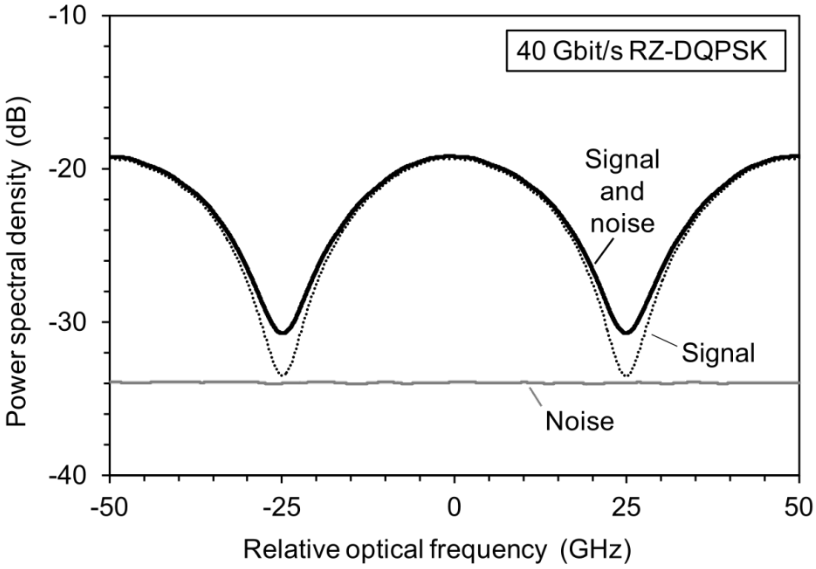


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Figure 2 – Optical power spectrum of 50-GHz spaced 40 Gbit/s RZ-DQPSK signals with significant spectral overlap

4.3 Spectral filtering in wavelength-routing elements

The introduction of reconfigurable optical add-drop multiplexers (ROADM) in optical networks gives rise to spectral filtering of the transmitted signals and noise along the fibre optic link [5-6]. This filtering generally attenuates the optical power level between adjacent signal channels, as shown in Figure 3. As a result, power level measurements on either side of the signal spectrum may not be indicative of the ASE noise power spectral density at the signal wavelength. A further consequence of this filtering is that the transmitted ASE noise spectrum is no longer flat, as assumed in IEC 61280-2-9, but spectrally shaped by the transfer function of the ROADMs. Furthermore, the spectral shaping of ASE noise is usually different from the corresponding spectral shaping of the signal because noise is added at intermediate stages along the transmission link. Thus, spectral filtering in ROADMs not only greatly reduces the usefulness of the interpolation method described in IEC 61280-2-9 but also introduces substantial ambiguity in the OSNR measurement, because IEC 61280-2-9 does not define the OSNR of signals with spectrally shaped noise.