BS EN 61290-10-1:2009

BSI British Standards

Optical amplifiers — Test methods —

Part 10-1: Multichannel parameters — Pulse method using an optical switch and optical spectrum analyzer

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British Standards

National foreword

This British Standard is the UK implementation of EN 61290-10-1:2009. It is identical to IEC 61290-10-1:2009. It supersedes BS EN 61290-10-1:2003 which is withdrawn.

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.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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EUROPEAN STANDARD

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EN 61290-10-1

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Supersedes EN 61290-10-1:2003

English version

Optical amplifiers -
Test methods -
Part 10-1: Multichannel parameters -
Pulse method using an optical switch and optical spectrum analyzer
(IEC 61290-10-1:2009)

Amplificateurs optiques -
Méthodes d'essai -
Partie 10-1: Paramètres
à canaux multiples -
Méthode d'impulsion utilisant
un interrupteur optique
et un analyseur de spectre optique
(CEI 61290-10-1:2009)

Prüfverfahren
für Lichtwellenleiter-Verstärker -
Teil 10-1: Mehrkanalparameter -
Pulsmethode bei Verwendung
eines optischen Schalters
und optischen Spektralanalysators
(IEC 61290-10-1:2009)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: Avenue Marnix 17, B - 1000 Brussels

Ref. No. EN 61290-10-1:2009 E

Foreword

The text of document 86C/778/CDV, future edition 2 of IEC 61290-10-1, prepared by SC 86C, Fibre optic systems and active devices, of IEC TC 86, Fibre optics, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61290-10-1 on 2009-04-01.

This European Standard supersedes EN 61290-10-1:2003.

It contains updated references and cautions on proper use of the procedure.

This European Standard is to be read in conjunction with EN 61291-1.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2010-01-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2012-04-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61290-10-1:2009 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60793-1	NOTE	Harmonized in EN 60793-1 series (partially modified).
IEC 60825-1	NOTE	Harmonized as EN 60825-1:2007 (not modified).
IEC 60825-2	NOTE	Harmonized as EN 60825-2:2004 (not modified).
IEC 60874-1	NOTE	Harmonized as EN 60874-1:2007 (not modified).
IEC 61290-1-1	NOTE	Harmonized as EN 61290-1-1:2006 (not modified).
IEC 61290-3	NOTE	Harmonized as EN 61290-3:2008 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 61291-1	- [1]	Optical amplifiers - Part 1: Generic specification	EN 61291-1	2006 [2]

[1] Undated reference.

[2] Valid edition at date of issue.

IEC 61290-10-1

Edition 2.0 2009-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical amplifiers – Test methods –
Part 10-1: Multichannel parameters – Pulse method using an optical switch and optical spectrum analyzer

Amplificateurs optiques – Méthodes d'essai
Partie 10-1: Paramètres à canaux multiples – Méthode d'impulsion utilisant un interrupteur optique et un analyseur de spectre optique

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OPTICAL AMPLIFIERS – TEST METHODS –

Part 10-1: Multichannel parameters – Pulse method using an optical switch and optical spectrum analyzer

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61290-10-1 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2003. It is a technical revision with updated references and cautions on proper use of the procedure.

This International Standard is to be read in conjunction with IEC 61291-1.

The text of this standard is based on the following documents:

CDV	Report on voting
86C/778/CDV	86C/809/RVC

Full information on the voting for the approval of this standard 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 61290 series, published under the general title *Optical amplifiers – Test methods*[1)] 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.

1) The first editions of some of these parts were published under the general title *Optical fibre amplifiers – Basic specification* or *Optical amplifier test methods*.

INTRODUCTION

This International Standard is devoted to the subject of optical fibre amplifiers. The technology of optical fibre amplifiers is still rapidly evolving, hence amendments and new editions to this standard can be expected.

OPTICAL AMPLIFIERS – TEST METHODS –

Part 10-1: Multichannel parameters – Pulse method using an optical switch and optical spectrum analyzer

1 Scope and object

This part of IEC 61290 applies to optical amplifiers (OAs) using active fibres and waveguides, containing rare-earth dopants, currently commercially available.

The object of this standard is to establish uniform requirements for accurate and reliable measurements of the signal-spontaneous noise figure as defined in IEC 61291-1.

The test method independently detects amplified signal power and amplified spontaneous emission (ASE) power by launching optical pulses into the OA under test and synchronously detecting "on" and "off" levels of the output pulses by using an optical sampling switch and an optical spectrum analyzer (OSA).

Such measurement is possible because the gain response of the rare-earth doped OA is relatively slow, particularly in Er-doped OAs. However, since the OA gain dynamics vary with amplifier types, operating conditions and control schemes, the gain dynamics should be carefully considered when applying the present test method to various OA. The manufacturer of the OA should present data validating the required modulation frequency to limit the error to <1 dB. The measurements for obtaining this information are described in Annex C.

The test method is described basically for multichannel applications, which includes single channel applications as a special case of multichannel (wavelength-division multiplexed) applications.

NOTE All numerical values followed by (‡) are currently under study.

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 61291-1, *Optical amplifiers – Part 1: Generic specification*

3 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply:

AGC	automatic gain control
ALC	automatic level control
AOM	acousto-optic modulator
APC	automatic power control
ASE	amplified spontaneous emission
CW	continuous wave

DBR	distributed Bragg reflector (laser diode)
DC	direct current
DFB	distributed feed-back (laser diode)
ECL	external cavity laser (diode)
EDFA	erbium-doped fibre amplifier
ER	erbium
FWHM	full width at half maximum
LED	light emitting diode
LD	laser diode
NF	noise figure
OA	optical amplifier
OSA	optical spectrum analyzer
SW	switch

4 Apparatus

The basic measurement set-up is given in Figure 1.

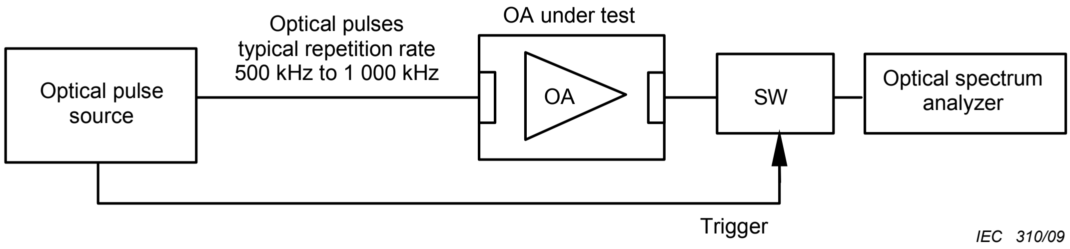


Figure 1 – Typical arrangement of the optical pulse test method

The test equipment needed, with the required characteristics, is listed below.

a) *Optical pulse source*: Two arrangements of the optical pulse source are possible as shown in Figure 2. Optical pulse source *a* (Figure 2a) consists of CW optical sources with an external optical switch and attenuator(s). Optical pulse source *b* (Figure 2b) consists of directly modulated optical sources and attenuator(s).

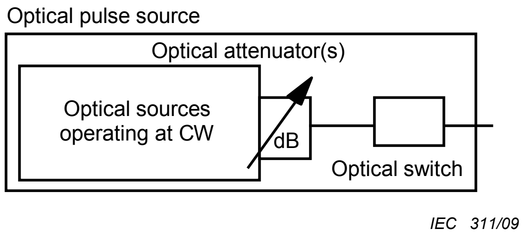


Figure 2a – Arrangement with external optical switch

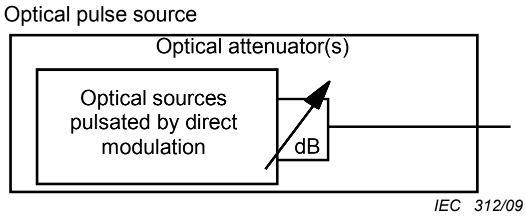


Figure 2b – Arrangement with directly modulated optical source

Figure 2 – Two arrangements of the optical pulse source

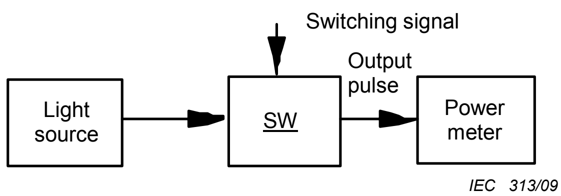
Unless otherwise specified, the full width at half maximum (FWHM) of the output spectrum of optical pulse source *a* or *b* shall be narrower than 0,1 nm (‡) so as not to cause any interference to adjacent channels. In the case of a single-channel source, it shall be narrower than 1 nm (‡). Distributed feedback (DFB) lasers, distributed Bragg reflection (DBR) lasers, and external cavity lasers (ECLs), for example, are applicable. The suppression ratio of the side modes of these DFB lasers shall be higher than 30 dB (‡). The output power fluctuation shall be less than 0,05 dB (‡), which may be more easily attainable with an optical isolator placed at the output port of each source.

Optical pulse source *a* simultaneously pulsates wavelength-division multiplexed light with an optical switch, where the switching time is common to all the channels; timing adjustment is not needed. Moreover, frequency chirping and spontaneous emission can be minimum; the extinction ratio of the "on" versus "off" stages can be uniquely determined at a high level if a high extinction-ratio switch is used. An acousto-optic modulator (AOM) is typically used as the switch.

For optical pulse source *b*, the leakage power at the off-state should be as small as possible to minimize the measurement error, although calibration is possible by subtracting the leaked power. This may demand a zero-bias operation of laser diode sources. Moreover, care must be taken in synchronizing optical pulses because the pulse timing may differ from one source to another.

b) *Variable optical attenuator:* The attenuation range and stability shall be over 40 dB (‡) and better than ± 0,1 dB (‡), respectively. The reflectance from this device shall be smaller than −40 dB (‡) at each port. The variable optical attenuator may be incorporated in the optical pulse source.

c) *Optical switch*: This device shall have a polarization sensitivity less than ± 0,1 dB (‡), static isolation better than 65 dB (‡), transition time less than 50 ns (‡), and switching delay time less than 2 ms (‡). The reflectance from this device shall be smaller than –40 dB (‡) at each port. Figure 3 defines the optical switch static isolation. The optical switch is not required for optical pulse source *b*.



$$ISO_{\text{static}} = \frac{P_{\text{off-state}}}{P_{\text{on-state}}}$$

Figure 3 – Static isolation of an optical switch

d) *Pulse generator:* This device is used to drive optical pulse sources and the optical sampling switch. When using an internally modulated optical pulse source, an independent pulse generator is not required. Pulse train(s) shall be generated with a pulse interval of, typically, 1 µs to 2 µs (‡). The pulse widths shall be adjustable from 100 ns to 2 ms (‡) with a step of 5 ns or finer. The delay shall be adjustable at least from 100 ns to 4 µs (‡) in steps of 5 ns or finer. The rise time and fall time, t_r and t_f, of the output optical pulse shall be less than 10 ns (‡). Definitions of t_r and t_f are given in Figure 4.

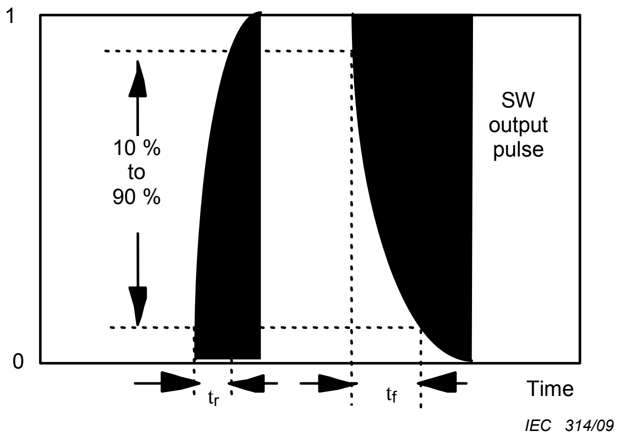


Figure 4 – Definitions of rise time and fall time, t_r and t_f of optical pulses

e) *Optical spectrum analyzer:* This device shall have polarization sensitivity less than 0,1 dB (‡), stability better than ±0,1 dB (‡),wavelength accuracy better than ±0,5 nm (‡), and wavelength reproducibility better than 0,01 nm (‡). The device shall have a measurement range at least from –75 dBm to +20 dBm (‡) with a resolution better than 0,1 nm (‡). The reflectance from this device shall be smaller than –40 dB (‡) at its input port.

f) *Optical power meter:* This device shall have a measurement accuracy better than ±0,2 dB (‡), irrespective of the state of the input light polarization, within the operational wavelength band of the OA and within a power range from –40 dBm to +20 dBm (‡).

g) *Optical connectors*: The connection loss repeatability shall be better than ±0,1 dB (‡). The reflectance from this device shall be smaller than –40 dB (‡).

h) *Optical fibre jumpers*: The mode field diameter of the optical fibre jumpers shall be as close as possible, so as not to cause excessive loss and reflectance, to that of fibres used as input and output ports of the OA. The reflectance from optical fibre jumpers shall be smaller than –40 dB (‡), and the device length shall be short (<2 m).

5 Test sample

The OA shall operate at nominal operating conditions. If the OA is likely to cause laser oscillations due to unwanted reflections, optical isolators should be used to bracket the OA under test. This will minimize the signal instability and the measurement inaccuracy.

Care shall be taken in the state of polarization of the input light during the measurement. Changes in the polarization state of the input light may result in input optical power changes because of the slight polarization dependency expected from all the optical components used, leading to measurement errors.

6 Procedure

The test procedure consists of four parts:

a) initial system setting and calibration;

b) sampling window adjustment;

c) OA measurement and

d) calculation.

The measurement flow is given in Figure 5. This procedure enables self-consistent calculation of not only OA noise factor but also ASE power and signal gain.

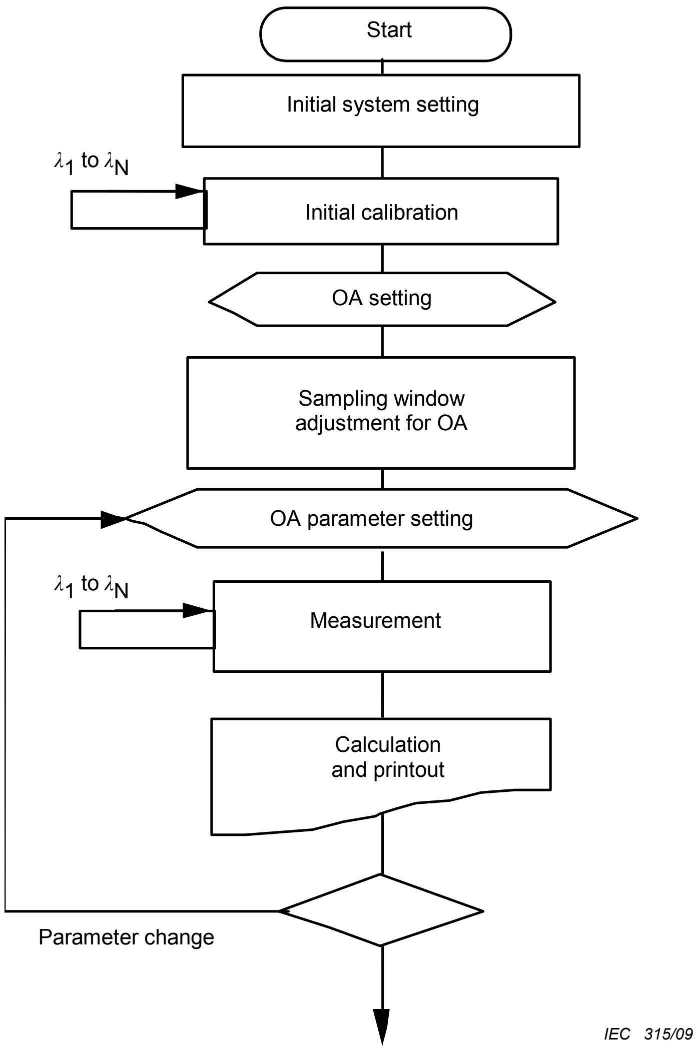


Figure 5 – Measurement flow chart

6.1 Calibration

6.1.1 Calibration of OSA power measurement

Calibrate the OSA power measurement by using a calibrated power meter.

NOTE The calibrated optical power meter detects all the optical power including source spontaneous emission, whereas the OSA measurement detects just the optical power within the resolution bandwidth of the OSA. Therefore, use of an optical filter with a FWHM passband of 1 nm to 3 nm is recommended at the output of the optical pulse source to increase the calibration accuracy.

6.1.2 Calibration of the pulse duty ratio

Follow the steps below to calibrate the pulse duty ratio.

a) Activate any one channel of the optical pulse source at CW and the specified power and wavelength.

b) Set the pulse width T_{source} and the pulse interval T of the optical pulse source output as specified in the product specification. T_{source} and T shall be sufficiently shorter than the gain-response time of the OA under test. For EDFAs, T_{source} and T are typically 0,4 µs (‡)

and 1 μs (‡), respectively. These values, however, depend on the amplifier saturation condition.

NOTE Measurement accuracy versus pulse rates is given in informative Annex B. EDFA output waveforms for various EDFAs are given in informative Annex A.

c) Measure the average output power, $P_{\text{pulse-ave}}$, with a power meter.

d) Drive the optical pulse source with 100 % duty pulse (DC drive), and measure the output power, P_{DC}, with a power meter.

e) Calculate the equivalent duty ratio by using Equation (1).

$$DR_{\text{source}} = \frac{P_{\text{pulse-ave}}}{P_{\text{DC}}} \qquad (1)$$

NOTE For the optical pulse source using an external optical switch, the calibration result is applicable to the other channels.

For the optical pulse source using direct modulation, the calibration shall be repeated for all the channels, because the optical-pulse shape generated by each source can be different.

6.1.3 Calibration of the sampling module

Follow the steps below to calibrate the sampling module.

a) Arrange the optical pulse source, sampling SW, OSA and calibrated power meter as shown in Figure 6.

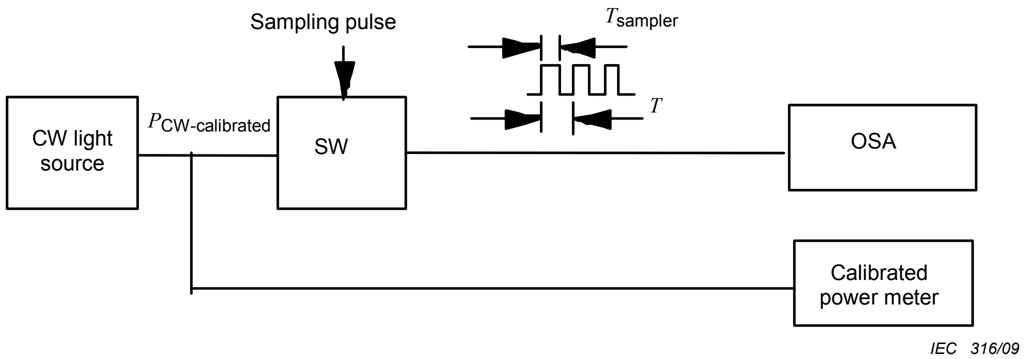


Figure 6 – Arrangement for the sampling switch calibration

b) Activate the optical pulse source to emit CW light at a channel wavelength to be tested.

c) Set the OSA optical bandwidth, B_{o}, in a way to accommodate the spectral bandwidth of the pulse signal.

d) Adjust the OSA centre wavelength to the wavelength selected at step b).

e) Set the sampling pulse width, T_{sampler}, as specified in the product specification. The sum of the duty ratios, the source duty ratio plus sampler duty ratio, shall be less than 100 % while still keeping some margin, e.g., 80 % to 90 %. T_{sampler} shall be smaller than T_{source}. Measure the average output power, $P_{\text{OSA-pulse-ave}}$ with the OSA.

f) Drive the sampling switch with a 100 % duty pulse (DC drive).

g) Measure $P_{\text{OSA-DC}}$ with the OSA.

h) Calculate the equivalent sampling switch duty ratio by using Equation (2).

$$DR_{\text{sampler}} = \frac{P_{\text{OSA-pulse-ave}}}{P_{\text{OSA-DC}}} \qquad (2)$$

NOTE The value of DR_{sampler} thus obtained at one channel wavelength is applicable to the other channel wavelengths.

i) Measure the input power to the sampling switch, $P_{\text{CW-calibd}}$, with a calibrated power meter.

j) Activate the optical pulse source to emit CW light at the next channel wavelength to be tested. Repeat steps g) through i) for the next channel wavelength to be measured.

k) Calculate the calibration factor, $CAL(\lambda_k)$, of the sampler including the OSA by using Equation (3).

$$CAL(\lambda_k) = \frac{P_{\text{OSA-DC}}}{P_{\text{CW-calibd}}} \tag{3}$$

6.1.4 Calibration of dynamic isolation

6.1.4.1 Timing adjustment of the sampling switch (SW)

Follow the steps below for timing adjustment of the sampling switch.

a) Connect the optical pulse source and the sampling switch plus OSA with a fibre cord as shown in Figure 7, in which optical pulse source *a* is illustrated as the optical pulse source. Optical pulse source *b* is also applicable here.

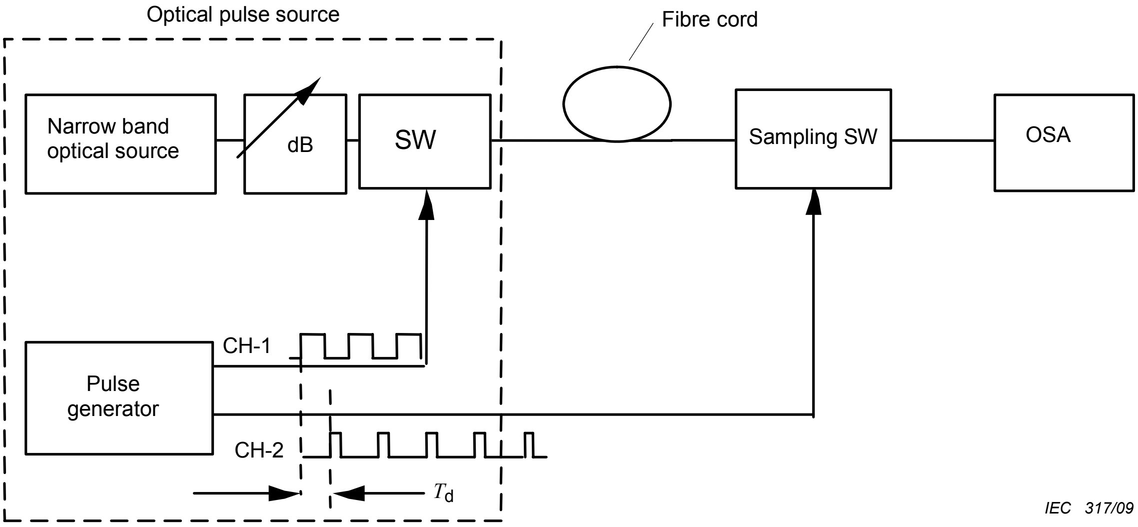


Figure 7 – Arrangement for timing adjustment

b) Activate the optical pulse source to emit light at all channel wavelengths.

NOTE Although the delay time can be determined by using just one channel, the present test procedure activates all the channels at this stage so that the multichannel optical pulse source can be better stabilized for later stages of the measuring procedure.

c) Adjust the OSA centre wavelength to one arbitrary channel wavelength.

d) Set the drive pulse timing for the optical pulse source and the sampling switch as shown in Figure 8. DR_{sampler} shall be smaller than DR_{source}.

e) Find the delay time, $T_{\text{d-min}}$, that minimizes the received optical power with the OSA by tuning the CH2 delay time T_d.

f) Calculate the delay time $T_{\text{d-max}}$ that maximizes the received optical power with the OSA by using Equation (4).

$$T_{\text{d-max}} = T_{\text{d-min}} - \frac{T_p}{2} \tag{4}$$

NOTE The delay time thus obtained at one channel wavelength is applicable to the other channel wavelengths.

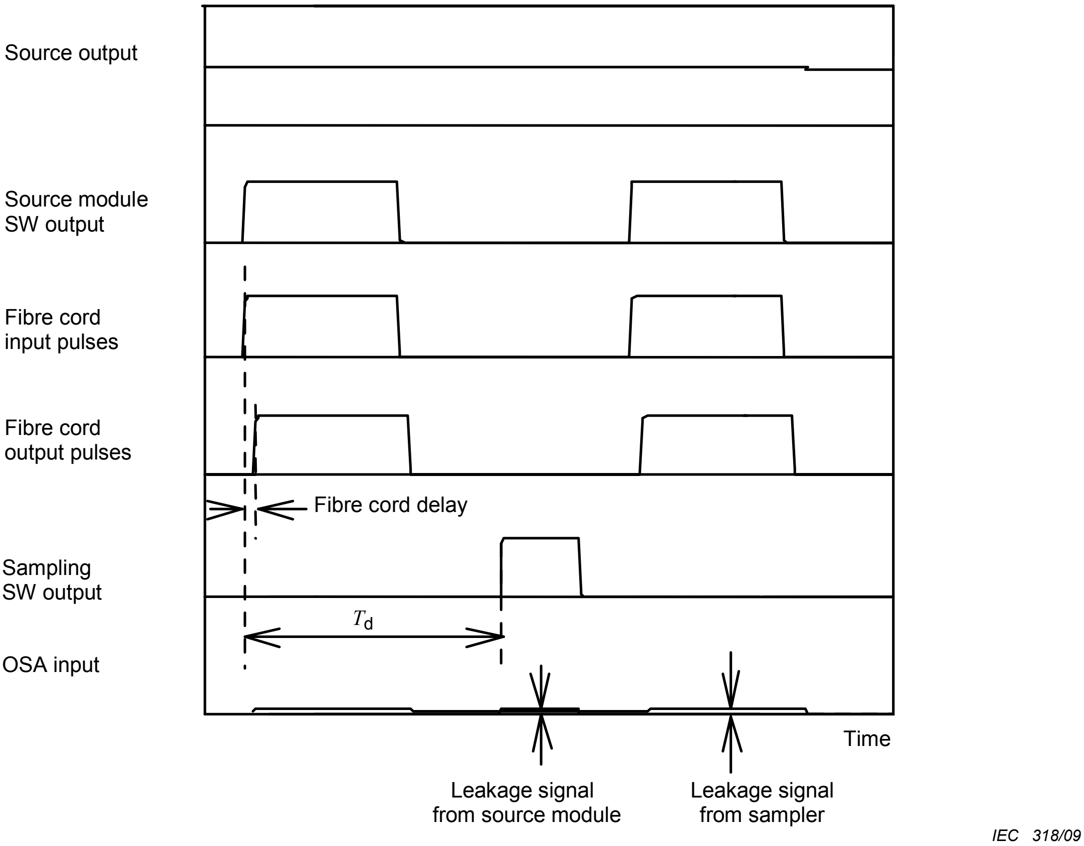


Figure 8 – Timing adjustment of the sampling switch

6.1.4.2 Dynamic isolation

Follow the steps below to calculate the dynamic isolation.

a) Keep activating the optical pulse source to emit light pulses at all channel wavelengths.

NOTE All the channels need to be active when measuring the dynamic isolation. This is because, although the dynamic isolation is measured by tuning the OSA to one channel, the OSA should receive all the optical powers including those from adjacent channels.

b) Connect the optical pulse source and the sampling switch plus OSA with a fibre cord as shown in Figure 7.

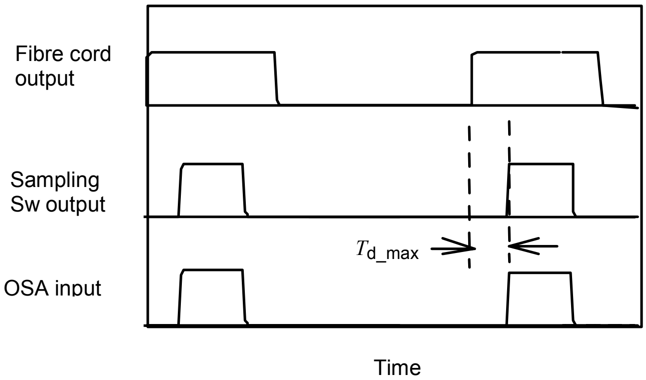
c) Set the sampling switch timing as shown in Figure 9a. Measure $P^{\mathrm{Sig}}{}_{\mathrm{OSA\text{-}ave}}$ with the OSA tuned to the channel to be tested.

d) Set the sampling switch timing as shown in Figure 9b. Measure $P^{\mathrm{Leak}}{}_{\mathrm{OSA\text{-}ave}}$ with the OSA tuned to the same channel as in step c).

e) Repeat steps c) and d) for the different channels to be tested.

f) Calculate the average dynamic isolation of each channel, $ISO(\lambda_k)_{\mathrm{dyna\text{-}ave}}$, by using Equation (5).

$$ISO(\lambda_k)_{\mathrm{dyna\text{-}ave}} = \frac{P^{\mathrm{Leak}}{}_{\mathrm{OSA-ave}}}{P^{\mathrm{Sig}}{}_{\mathrm{OSA-ave}}} \qquad (5)$$



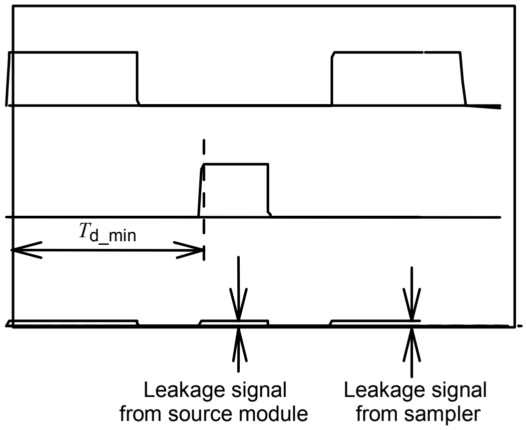


Figure 9a – Measurements of $P_{OSA\text{-}ave}^{Sig}$

Figure 9b – Measurements of $P_{OSA\text{-}ave}^{Leak}$

Figure 9 – Timing chart for dynamic isolation calibration

6.2 OA measurement

6.2.1 Timing adjustment for ASE and amplified signal power measurement

Follow the steps below to adjust the timing for ASE and amplified signal power measurement.

a) Keep activating the optical pulse source to emit pulsed light at all channel wavelengths.

NOTE Although the timing can be adjusted by using just one channel, all the channels are kept activated so that the multichannel optical pulse source can be stable.

b) Connect the optical pulse source, the OA under test, the sampling switch and the OSA as shown in Figure 10, in which optical pulse source *a* is illustrated. Optical pulse source *b* is also applicable instead.

c) Activate the OA under test as specified in the detail specification while avoiding surge generation.

d) Tune the OSA to one arbitrary channel wavelength.

e) Set the drive pulse timing to the optical pulse source and the sampling switch as shown in Figure 10, in which the sampling switch is driven out of phase with the optical pulse source for ASE measurement.

f) Find the delay time of $T_{d\text{-ASE}}$ that minimizes $P^{ASE}{}_{OSA\text{-ave}}$ by tuning the CH2 delay time T_d.

g) Calculate the delay time $T_{d\text{-sig}}$, that maximizes $P^{Sig\text{-}OA\text{-}out}{}_{OSA\text{-ave}}$ by using Equation (6).

$$T_{d\text{-sig}} = T_{d\text{-ASE}} - \frac{T_p}{2} \qquad (6)$$

NOTE The delay time thus obtained at one channel wavelength is applicable to the other channel wavelengths.

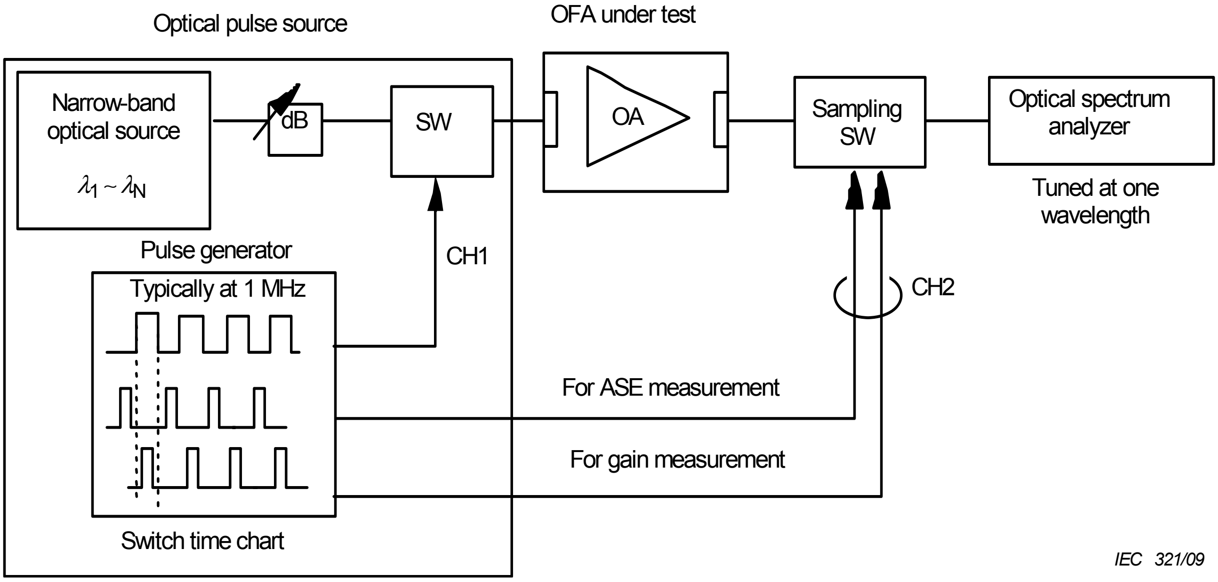


Figure 10 – Arrangement for OA measurement

6.2.2 ASE measurement

Follow the steps below to measure the ASE.

a) Keep activating the optical pulse source to emit pulsed light at all channels.

b) Set the average signal power of each channel into the OA, $P_{\text{OA-in-ave}}$, as specified in a detail specification. $P_{\text{OA-in-ave}}$ can be adjusted by using an OSA as follows:

1) Connect the optical pulse source and the sampling switch with a fibre cord.
2) Set the sampling switch timing: $T_{\text{d-max,}}$ as given in Equation (4)
3) Measure $P^{\text{Sig}}{}_{\text{OSA-ave}}$ with the OSA at the wavelength under test.
4) $P_{\text{OA-in-ave}}$ is given in Equation (7).

$$P(\lambda_k)\text{OA-in-ave} = \frac{DR_{\text{source}}}{CAL\,(\lambda_k)\times DR_{\text{sampler}}}\,P(\lambda_k)^{\text{sig-OA-in}}{}_{\text{OSA-ave}} \tag{7}$$

c) For single-channel applications, instead of following the above steps 1) to 4), $P_{\text{OA-in-ave}}$ can be adjusted by using the calibrated power meter.

d) Set the sampling module timing, as determined by item e) of 6.2.1, to measure the ASE power. The timing chart is given in Figure 11.

e) Measure $P^{\text{ASE}}{}_{\text{OSA-ave}}$ with the OSA at the channel under test.

NOTE This power depends on the resolution bandwidth of the OSA.

f) Measure $P^{\text{ASE}}{}_{\text{OSA-ave}}$ with the OSA at the next channel to be tested while keeping other conditions unchanged.

6.2.3 Amplified signal power measurement

a) Keep activating the optical pulse source to emit pulsed light at all channels.

b) Set the sampling switch timing as determined by step g) of 6.2.1 to measure the signal power. The timing chart is given in Figure 12.

c) Keep $P_{\text{OA-in-ave}}$ for all the channels at the same levels as for the ASE measurement.

d) Measure $P^{\text{sig-OA-out}}{}_{\text{OSA-ave}}$ with the OSA at the wavelength under test.

e) Measure $P^{\text{sig-OA-out}}{}_{\text{OSA-ave}}$ with the OSA at the next channel to be tested while keeping other conditions unchanged.

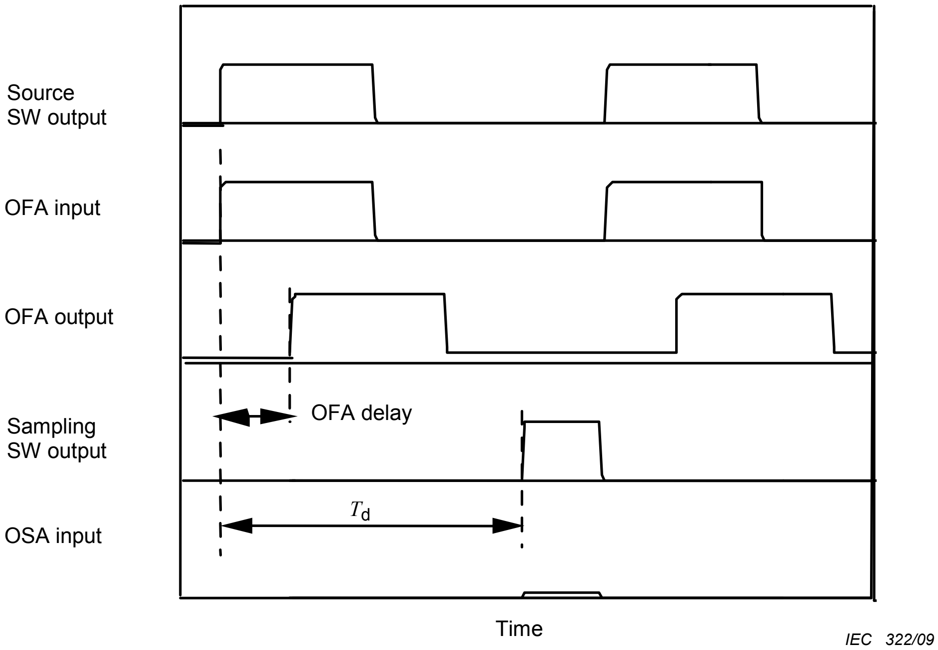


Figure 11 – Timing chart for ASE measurement

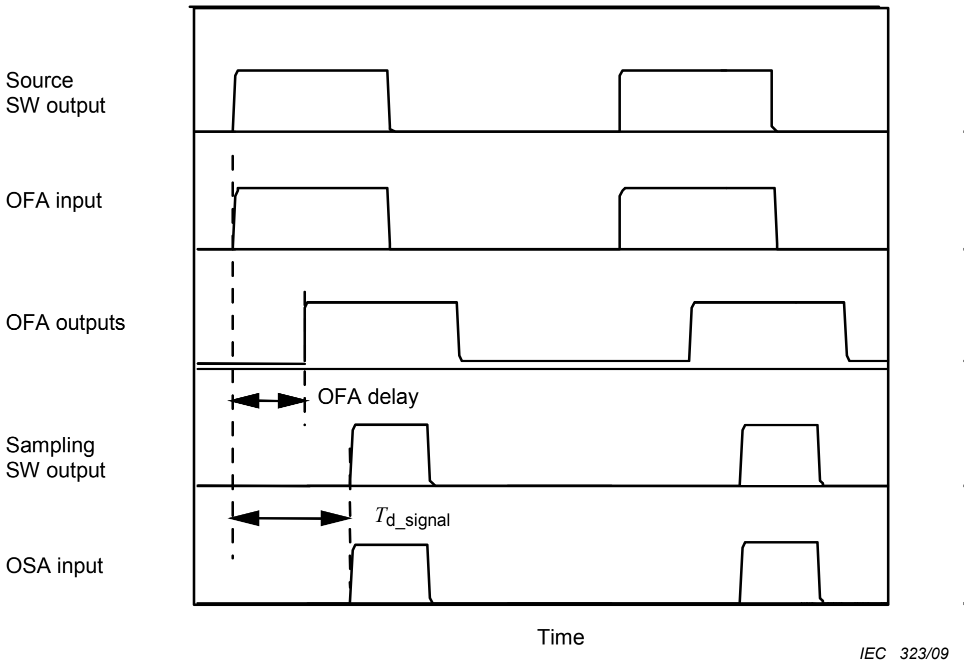


Figure 12 – Timing chart for amplified signal power measurement

7 Calculation

7.1 General

Since the following parameter values differ depending on the channel under test, the calculation needs to be conducted at each channel by using the parameter values specific to each channel.

$P(\lambda_k)_{\text{OA-in-ave}}$	Average input signal power, mW
$P(\lambda_k)^{\text{ASE}}{}_{\text{OSA-ave}}$	Average ASE power measured with the OSA, mW
$P(\lambda_k)^{\text{sig-OA-out}}{}_{\text{OSA-ave}}$	Average output signal power from OA measured with the OSA, mW
$ASE(\lambda_k, B_0)$	ASE power within the optical bandwidth of the OSA, mW
$CAL(\lambda_k)$	Calibration factor of the sampler plus OSA
$ISO(\lambda_k)_{\text{dyna-ave}}$	Average dynamic isolation, dB
$G(\lambda_k)$	Linear gain
$F(\lambda_k)_{\text{sig-sp}}$	Signal-spontaneous noise factor (expressed in linear form)
$NF(\lambda_k)_{\text{sig-sp}}$	Signal-spontaneous noise figure, dB

7.2 Noise factor calculation

Noise factor, $F_{\text{sig-sp}}$, at each channel at a wavelength, λ, is given by using the following equations:

$$F_{\text{sig-sp}} = \frac{P^{\text{ASE}}_{\text{OSA-ave}}}{CAL \times Ghvh_0 DR_{\text{sampler}}} - \frac{ISO_{\text{dyna-ave}} \times P_{\text{OA-in-ave}}}{hv_0 B_0 DR_{\text{source}}} \quad (8)$$

or

$$F_{\text{sig-sp}} = \frac{1}{CAL \times GhvB_0 DR_{\text{sampler}}} \left(P^{\text{ASE}}{}_{\text{OSA-ave}} - ISO_{\text{dyna-ave}} \times P^{\text{sig-OA-out}}{}_{\text{OSA-ave}}\right) \quad (9)$$

where

B_0 is the OSA resolution bandwidth, in Hz,

h is Planck's constant,

v is the optical signal frequency, in Hz.

NOTE The second terms in Equations (8) and (9) are used to cancel the effect of the signal leakage in ASE measurement.

By measuring the ASE power distribution around the signal wavelength, the ASE power excluding the signal leakage at the signal wavelength can be estimated by an interpolation technique. $F_{\text{sig-sp}}$ can be given by using Equation (10)

$$F_{\text{sig-sp}} = \frac{P^{\text{ASE}}\text{OSA - ave - interpolated}}{CAL \times GhvB_0 DR_{\text{sampler}}} \quad (10)$$

7.3 ASE power

ASE power at the OA output is given by using Equation (11) or (12).

$$ASE(B_o) = \frac{P^{\text{ASE}}{}_{\text{OSA-ave}}}{CAL \times DR_{\text{sampler}}} - \frac{ISO_{\text{dyna-ave}}}{DR_{\text{source}}} G \times P_{\text{OA}}\text{-in-ave} \quad (11)$$

or

$$ASE(B_o) = \frac{1}{CAL \times DR_{sampler}} (P^{ASE}{}_{OSA\text{-}ave} - ISO_{dyna\text{-}ave} \times P^{sig\text{-}OFA\text{-}out}{}_{OSA\text{-}ave} \qquad (12)$$

7.4 Gain calculation

Signal linear gain is given by using the following equations;

$$G = \frac{\left\{P^{sig\text{-}OFA\text{-}out}{}_{OSA\text{-}ave}(1 + ISO_{dyna\text{-}ave}) - P^{ASE}{}_{OSA\text{-}ave}\right\} DR_{source}}{CAL \times P_{OFA\text{-}in\text{-}ave} \times DR_{sampler}} \qquad (13)$$

or

$$G = \frac{P^{sig\text{-}OFA\text{-}out}{}_{OSA\text{-}ave}(1 + ISO_{dyna\text{-}ave}) - P^{ASE}{}_{OSA\text{-}ave}}{P^{sig\text{-}OFA\text{-}IN}{}_{OSA\text{-}ave}} \qquad (14)$$

7.5 Average output signal power

Average output signal power is given by using Equation (15).

$$P_{OA\text{-}out\text{-}ave} = \frac{\left\{P^{sig\text{-}OFA\text{-}out}{}_{OSA\text{-}ave}(1 + ISO_{dyna\text{-}ave}) - P^{ASE}{}_{OSA\text{-}ave}\right\} DR_{source}}{CAL \times DR_{sampler}} \qquad (15)$$

7.6 Noise figure calculation

Noise figure NF is obtained from noise factor F by using Equation (16).

$$NF = 10 \log(F) \qquad (16)$$

8 Test results

The following details shall be presented for each channel:

a) Wavelength range of the measurement
b) Spectral linewidth (FWHM) of the optical source
c) Input signal wavelength: λ_k
d) OSA optical bandwidth: B_o
e) Indication of the optical pump power (if applicable)
f) Ambient temperature
g) Pulse interval: $T_,$ Signal pulse width: T_{source}, Sampler width: T_{sample}
h) Average input signal power: $P_{OA\text{-}in\text{-}ave}$
i) Average output signal power: $P_{OA\text{-}out\text{-}ave}$
j) Linear gain, G
k) ASE power: $ASE(B_o)$
l) Noise factor: $F_{SIG\text{-}SP}$ or Noise figure: $NF_{SIG\text{-}SP}$

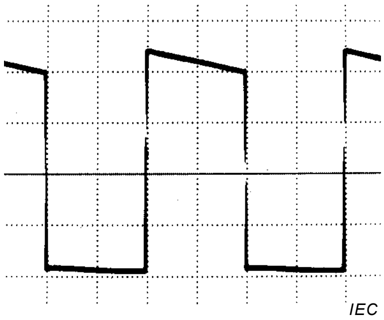
Annex A
(informative)

Output waveforms for various EDFAs at 25 kHz and 500 kHz pulse rates

Figure A.1 shows examples of the output waveform for various types of EDFAs (see NOTE). It is seen from a) to c) of Figure A.1, in which the pulse rate is 25 kHz, that the EDFA gain changes within one pulse waveform and also varies with EDFA types of A, B and C.

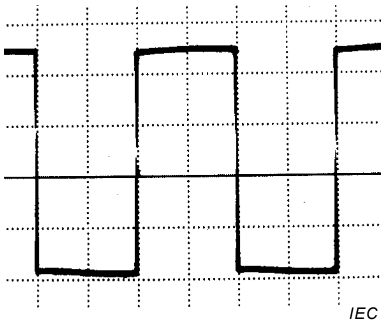
NOTE Type A EDFA is operated at a constant pump power under saturated regime. Type B EDFA has a relatively slow automatic power control (APC), whereas type C EDFA has a quick APC with an operating band >25 kHz.

The gain change disappears for type C EDFA when the pulse rate is increased to 500 kHz as is seen from c) and d) of Figure A.1. Thus, the gain measurement and, accordingly, the NF measurement are accurate at > 500 kHz.



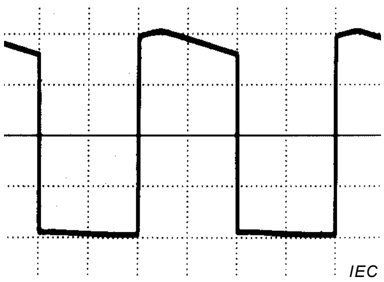
IEC 324/09

a) EDFA type A at 25 kHz



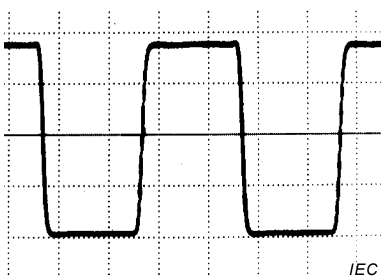
IEC 325/09

b) EDFA type B at 25 kHz



IEC 326/09

c) EDFA type C at 25 kHz



IEC 327/09

d) EDFA type C at 500 kHz

Figure A.1 – EDFA output waveforms for various EDFAs

Annex B
(informative)

Measurement accuracy versus pulse rate

Examples of the NF measurement accuracy versus pulse rate are shown in Figure B.1, where optical pulse source *a* (see Clause 4, Figure 2) was used. The AOM switches were used for source pulsation and sampling, respectively. Measurement conditions were AOM switches: 1 MHz; pulse duty ratios: 0,4 for pulsation and 0,2 for sampling; wavelength-division multiplexed channels: 1 550,4 nm, 1 551,2 nm, 1 552,0 nm and 1 552,8 nm; Total OA input power: 0 dBm; OA gain: 9 dB to 17 dB.

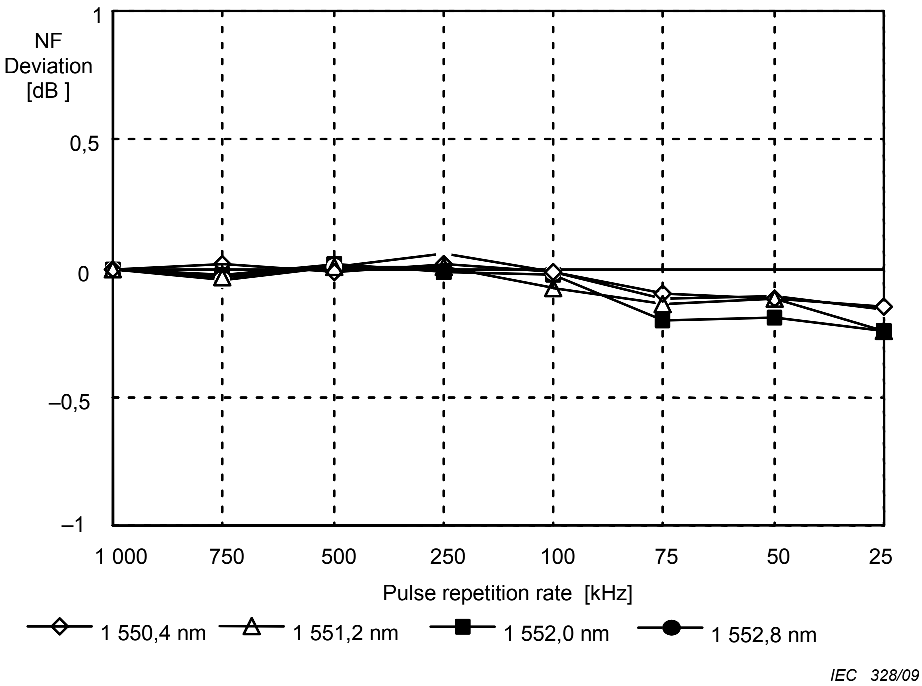


Figure B.1 – NF measurement accuracy versus pulse rate

The NF value was stable for pulse rates higher than about 250 kHz, where the effect of the waveform distortion due to the slow gain dynamics of EDFAs, as seen in Figure A.1, no longer exists. Figure B.1 indicates that high measurement accuracy is achieved at a pulse rate >250 kHz.

Annex C
(informative)

Pulse repetition frequency measurements

The measurements described in this annex are possible because the gain response of the rare-earth doped fibre amplifier is relatively slow, that is >100 µs for Er-doped fibre amplifiers. Currently, the gain recovery times allow pulse repetition rates in the 25 kHz to 100 kHz range. A simple set-up to evaluate OA gain response versus modulation frequency is shown in Figure C.1. An optical source with variable modulation frequency is applied to the OA. The average output power of the OA is measured on an optical power meter. As the modulation frequency is increased, the power meter reading asymptotically approaches a final value. At low modulation frequencies there is an increasing error due to non-linear gain recovery of the OA.

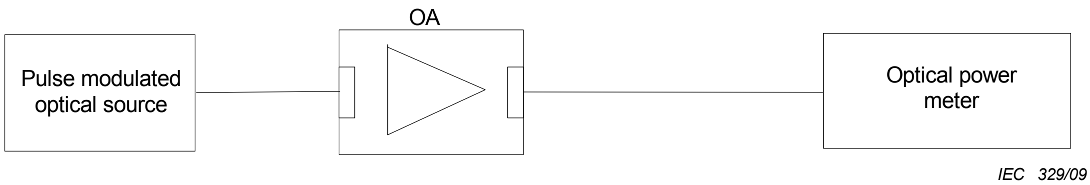


Figure C.1 – Set-up to evaluate gain recovery error versus modulation rate

Figure C.2 shows a measurement on a 980 nm pumped Er-doped fibre amplifier with three values of pump current. As pump power increases, the gain recovery time constant becomes shorter, resulting in a larger deviation from the high-frequency value. For this particular amplifier, a modulation frequency above 20 kHz is required to give <0,1 dB error in measured gain at 500 mA pump current.

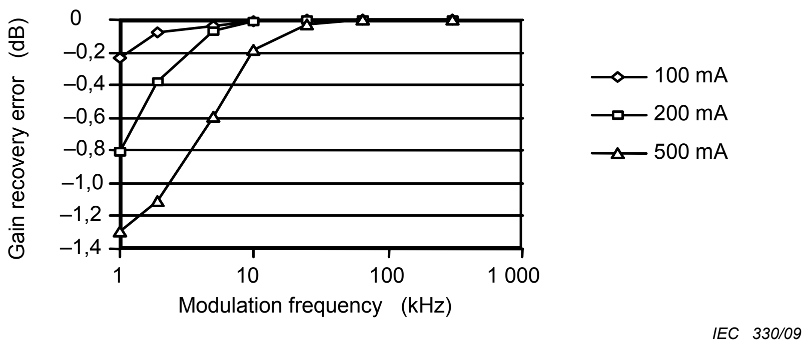


Figure C.2 – Gain recovery error versus modulation frequency with pump current as a parameter

However, there are two situations that require careful consideration of modulation frequency. First, as indicated in Figure C.2, higher pump current shortens the recovery time. Secondly, in some situations it is necessary to test OAs when automatic gain control (AGC) or automatic level control (ALC) circuitry is operational. The bandwidths of these AGC and ALC control loops will impose limitations on the modulation rate. It is recommended that this test be performed to qualify the appropriate modulation rate for a particular amplifier design.

NOTE In performing the above test, modulation rates below about 10 kHz should not be used. A large output power transient could destroy OA or test system components.

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