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INTERNATIONAL STANDARD

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Optical amplifiers – Test methods
Part 4-3: Power transient parameters – Single channel optical amplifiers in output power control

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FOREWORD

International Standard IEC 61290-4-3 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This International Standard is to be used in conjunction with IEC 61291-1:2012, on the basis of which it was established.

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

FDIS	Report on voting
86C/1310/FDIS	86C/1329/RVD

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 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- withdrawn,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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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*.

OPTICAL AMPLIFIERS – TEST METHODS

Part 4-3: Power transient parameters – Single channel optical amplifiers in output power control

1 Scope

This part of IEC 61290 applies to output power controlled optically amplified, elementary sub-systems. It applies to optical fibre amplifiers (OFA) using active fibres containing rare-earth dopants, presently commercially available, as indicated in IEC 61291-1, as well as alternative optical amplifiers that can be used for single channel output power controlled operation, such as semiconductor optical amplifiers (SOA).

The object of this standard is to provide the general background for optical amplifier (OA) power transients and its measurements and to indicate those IEC standard test methods for accurate and reliable measurements of the following transient parameters:

a) Transient power response
b) Transient power overcompensation response
c) Steady-state power offset
d) Transient power response time

The stimulus and responses behaviours under consideration include:

1) Channel power increase (step transient)
2) Channel power reduction (inverse step transient)
3) Channel power increase/reduction (pulse transient)
4) Channel power reduction/increase (inverse pulse transient)
5) Channel power increase/reduction/increase (lightning bolt transient)
6) Channel power reduction/increase/reduction (inverse lightning bolt transient)

These parameters have been included to provide a complete description of the transient behaviour of an output power transient controlled OA. The test definition defined here are applicable if the amplifier is an OFA or an alternative OA. However, the description in Annex A of this document concentrates on the physical performance of an OFA and provides a detailed description of the behaviour of OFA; it does not give a similar description of other OA types.

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 61291-1:2012, *Optical amplifiers – Part 1: Generic specification*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1
input signal
optical signal that is input to the OA

3.1.2
input power excursion
relative input power difference in dB before, during and after the input power stimulus event that causes an OA transient power excursion.

3.1.3
input power rise time
time it takes for the input optical signal to rise from 10 % to 90 % of the total difference between the initial and final signal levels during an increasing power excursion event

Note 1 to entry: see Figure A.2

3.1.4
input power fall time
time it takes for the input optical signal to fall from 10 % to 90 % of the total difference between the initial and final signal levels during a decreasing power excursion event

Note 1 to entry: see Figure A.2

3.1.5
slew rate
maximum rate of change of the input optical signal during a power excursion event

3.1.6
transient power response
maximum or minimum deviation (overshoot or undershoot) in dB between the OA's target power and the observed power excursion induced by a change in an input channel power excursion

Note 1 to entry: Once the output power of an amplified channel deviates from its target power, the control electronics in the OA should attempt to compensate for the power difference or transient power response, bringing the OA output power back to its original target level.

3.1.7
transient power settling time
amount of time taken to restore the power of the OA to a stable power level close to the target power level

Note 1 to entry: This parameter is measured from the time when stimulus event that created the power fluctuation to the time at which the OA power response is stable and within specification.

3.1.8
transient power overcompensation response
maximum deviation in dB between the amplifier's target output power and the power resulting from the control electronics instability

Note 1 to entry: Transient power overcompensation response occurs after a power excursion, when an amplifier's control electronics attempts to bring the power back to the amplifier's target level. The control process is iterative, and control electronics may initially overcompensate for the power excursion until subsequently reaching the desired target power level.

Note 2 to entry: The transient power overcompensation response parameter is generally of lesser magnitude than the transient power response and has the opposite sign.

3.1.9
steady state power offset
difference in dB between the final and initial output power of the OA, prior to the power excursion stimulus event

Note 1 to entry: Normally, the steady state power level following a power excursion differs from the OA power before the input power stimulus event. The transient controller attempts to overcome this offset using feedback.

3.2 Abbreviations

AFF	ASE flattening filter
AGC	automatic gain controller
APC	automatic power control
ASE	amplified spontaneous emission
ASEP	amplified spontaneous emission power
BER	bit error ratio
DFB	distributed feedback (laser)
DWDM	dense wavelength division multiplexing
EDF	Erbium-doped fibre
EDFA	Erbium-doped fibre amplifier
GFF	gain flattening filter
NEM	network equipment manufacturers
NSP	network service providers
O/E	optical-to-electrical
OA	optical amplifier
OD	optical damage
OFA	optical fibre amplifier
OSA	optical spectrum analyser
OSNR	optical signal-to-noise ratio
PDs	photodiodes
PID	proportional integral derivative
SOA	semiconductor optical amplifier
SAR	signal-to-ASE ratio
SigP	signal power
SOP	state of polarization
VOA	variable optical attenuator
WDM	wavelength division multiplexing

4 Apparatus

4.1 Test set-up

Figure 1 shows a generic set-up to characterise the transient response properties of output power controlled single channel OAs.

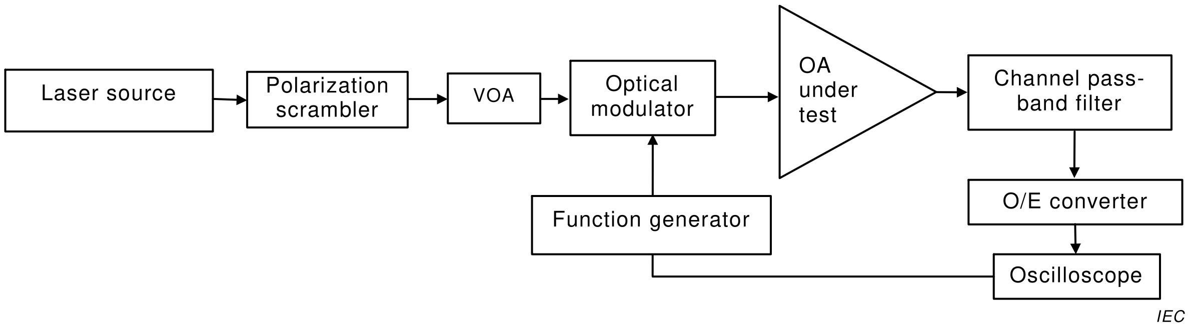


Figure 1 – Power transient test set-up

4.2 Characteristics of test equipment

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

a) Laser source for supplying the OA input signal with the following characteristics:
   – Ability to support the range of signal wavelengths for which the OA under test is to be tested. This could be provided for example by a tuneable laser, or a bank of distributed feedback (DFB) lasers.
   – An achievable average output power such that at the input to the OA under test the power will be above the maximum specified input power of the OA, including loss of any subsequent test equipment between the laser source and OA under test.

b) Polarization scrambler to randomize the incoming polarization state of the laser source, or to control it to a defined state of polarization (SOP). The polarization scrambler is optional.

c) Variable optical attenuator (VOA) with a dynamic range sufficient to support the required range of surviving signal levels at which the OA under test is to be tested.

   NOTE If the output power of the laser source can be varied over the required dynamic range, then a VOA is not needed.

d) Optical modulator to modify the OA input signal to the defined power excursion with the following characteristics.
   – Extinction ratio at rewrite without putting number higher than the maximum drop level for which the OA under test is to be tested.
   – Switching time fast enough to support the fastest slew rate for which the OA under test is to be tested.

e) Channel pass-band filter: an optical filter designed to distinguish the signal wavelength with the following characteristics. Note the use of a channel pass-band filter is optional.
   – Ability to support the range of signal wavelengths for which the OA under test is to be tested. This could be provided for example by a tuneable filter, or a series of discrete filters.
   – 1dB pass-band of at least ±20 GHz centred around the signal wavelength.
   – At least 20 dB attenuation level below the minimum insertion loss across the entire specified transmission band of the OA under test except within a range of ±100 GHz centred around the signal wavelength.

f) Opto-electronic (O/E) convertor to detect the filtered output of the OA under test with the following characteristics.
   – A sufficiently wide optical and electrical bandwidth to support the fastest slew rate for which the OA is to be tested.
   – A linear response within a ±5 dB range of all signal levels for which the OA under test is to be tested.

g) Oscilloscope to measure and capture the transient response of the optically filtered output of the OA under test, with a sufficiently wide electrical bandwidth to support the fastest slew rate for which the OA is to be tested.

h) Function generator to generate the input power transient waveforms to drive the optical modulator, with electrical pulse width short enough and electrical slew rate high enough to support the fastest slew rate for which the OA under test is to be tested.

5 Test sample

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

6 Procedure

6.1 Test preparation

In the set-up shown in Figure 1, the input optical signal power injected into the amplifier being tested is generated from a suitable laser source. The optical power is passed through an optional polarization scrambler to allow randomization or control of the signal polarization state and is subsequently adjusted with a VOA to the desired optical input power levels. The signal then passes through an optical modulator driven by a function generator that provides the desired input power test waveform to stimulate the transient input power excursions. The signal is then injected into the amplifier being tested. A channel pass-band filter (such as a tuneable optical filter, fixed optical filter or similar component) may be used to select only the relevant channel wavelength under test, followed by an O/E converter and an oscilloscope at the output of the amplifier. The output channel selected by the optional channel pass-band filter and its transient response is monitored with the O/E converter and oscilloscope. Waveforms similar to those shown in Figure A.3 are captured via the oscilloscope for subsequent computer processing.

Prior to measurement of the transient response, the input power waveform trace shall be recorded. Use the set-up of Figure 1 without the OFA under test. The input optical connector from the optical modulator is connected to the channel pass filter.

For this test to stimulate a power excursion at the input of the OA under test, the source laser power at the OA input is set at some typical power level. The function generator waveform is chosen to increase or decrease the input power to the OA under test with power excursions and slew rate relevant to the defined test condition. For example, for a typical number in the case of an optical receiver, the input power to the OA could be increased by 7 dB in a timeframe of 50 μs and then held at this power value to simulate a power increase transient power response (step transient) condition as shown in Figure A.1(1). For alternative transient control measurements, the signal generator waveform is controlled appropriately, and the VOA is adjusted accordingly.

6.2 Test conditions

Several sequential transient control measurements can be performed according to the optical amplifier's specified operating conditions. Examples of power excursion scenarios are shown in Table 1. These measurements are typically performed over a broad range of input power levels.

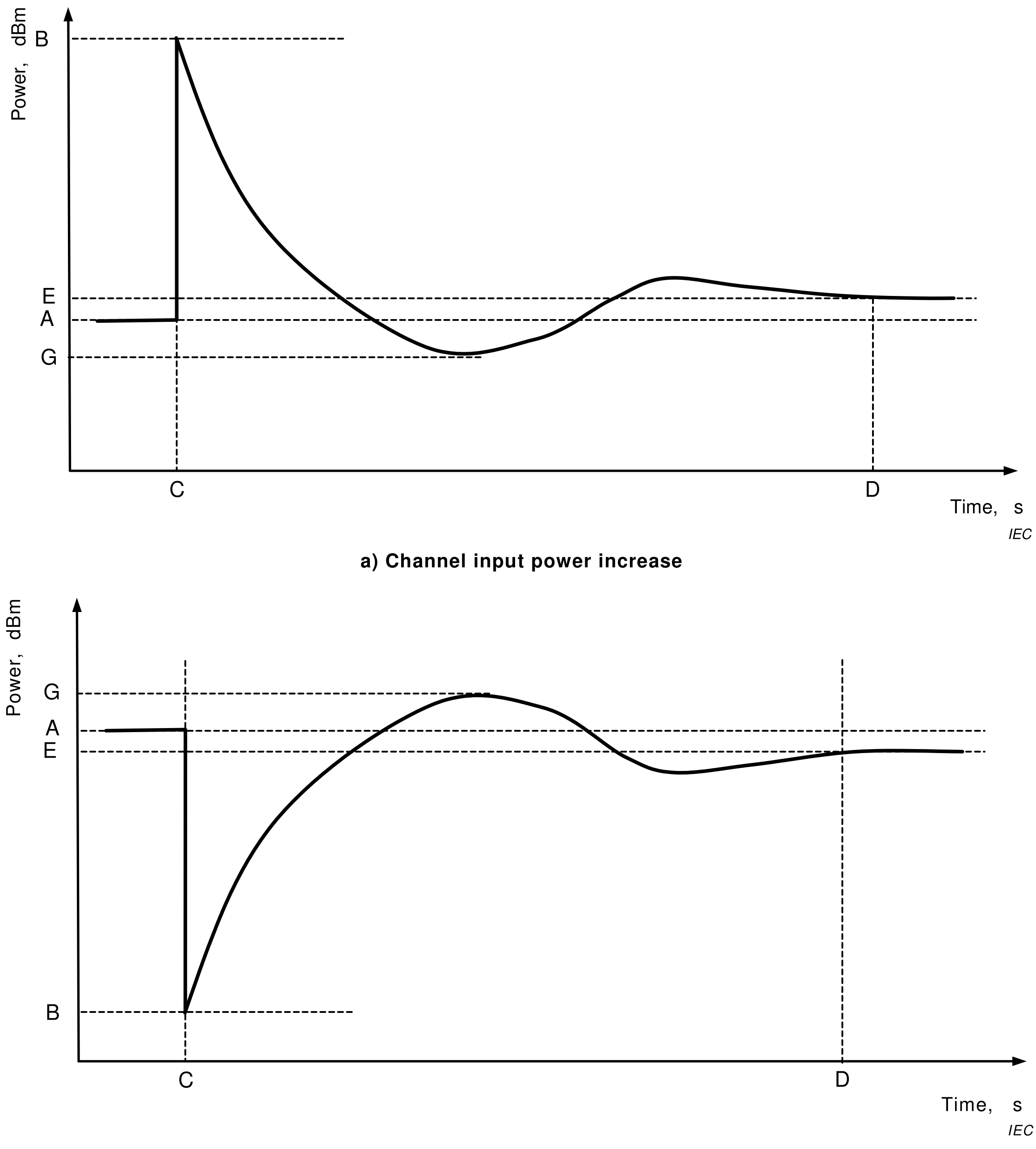
Table 1 – Examples of transient control measurement test conditions

Scenario	Power excursion	Slew rate
Input power step transient increase/reduction	3 dB, 7 dB	500 μs, 200 μs, 50 μs
Input power pulse transient	3 dB, 7 dB	500 μs, 200 μs, 50 μs
Input power lightning bolt transient	±3 dB, ±7 dB	500 μs, 200 μs, 50 μs

7 Calculations

Transient parameters can be calculated by processing amplifier output power transient waveforms shown in Figure 2, using the following criteria.

– Transient power response (dB) = B – A
– Transient power overcompensation response (dB) = G – A
– Steady state power offset (dB) = E – A
– Transient power response time (μs) = D – C



b) Channel input power decrease

Figure 2 – OA output power transient response of a) input power increase

8 Test results

8.1 Test settings

The following test setting conditions shall be recorded.

a) Arrangement of the test set-up
b) Details (make and model) of each piece of test equipment
c) Set-up condition of each piece of test equipment (e.g. operating speed of polarization scrambler, resolution bandwidth of optical spectrum analyzer (OSA))
d) Mounting method of test sample
e) Ambient conditions for the test sample

f) Input optical wavelength λ_{in}

8.2 Test data

The following test data shall be recorded.

a) Input optical power, P_{in} trace
b) Output optical power P_{out} trace
c) Signal-to-ASE ratio (SAR) at operating condition before and after excursion
d) OFA laser pump power before and after excursion
e) OA reported input power before and after input excursion (where available)
f) OA reported output power before and after input excursion
g) OA reported internal temperature (where available)
h) Measurement accuracy of each piece of test equipment
i) Temperature of test sample
j) Transient power response
k) Transient power overcompensation
l) Steady state power offset
m) Transient power response time

Annex A
(informative)

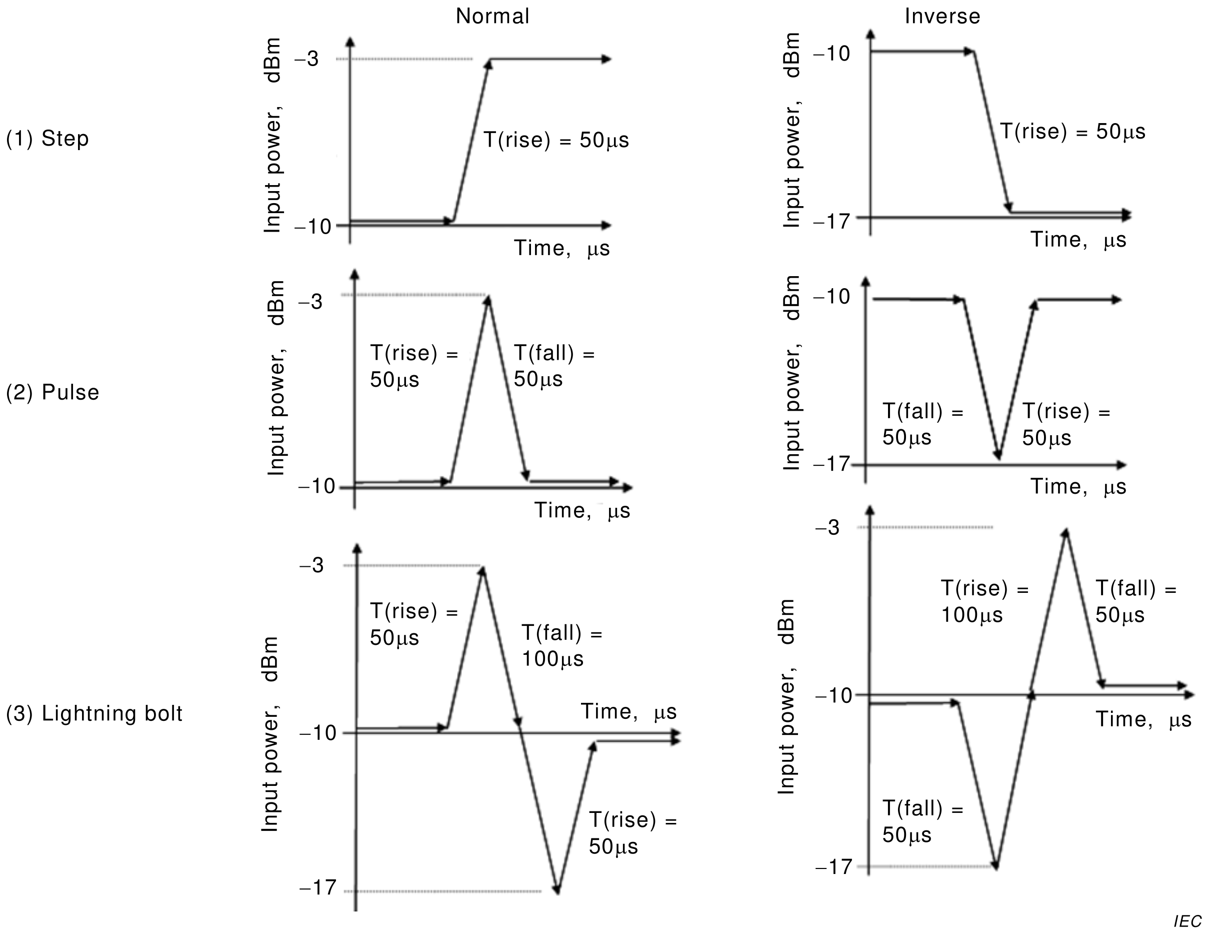
Overview of power transient events in single channel EDFA

A.1 Background

The input signal to a terminal OFA is normally a single channel erbium doped fibre amplifier (EDFA) with a wide dynamic range as a result of channel power excursions throughout the network. The input signal will accumulate fast power variations which are caused by concatenation of transient overshoot/undershoot excursions from the preceding chain of imperfect EDFA that transport channels. Those well-known gain transients arise as a result of add/drop events throughout the network, even though each EDFA is operated in constant gain mode with state of the art gain transient suppression (typically, less than ±1 dB gain overshoot/undershoot from each EDFA). The temporal steepness and over/undershoot magnitude of those transients will accumulate with the number of EDFAs passed, and eventually a transient event with considerable power variations will arrive at the input of the terminal EDFA. The shape of this single-channel power transient event is directly dependent on the transient output power shape of the preceding inline EDFAs.

A.2 Characteristic input power behaviour

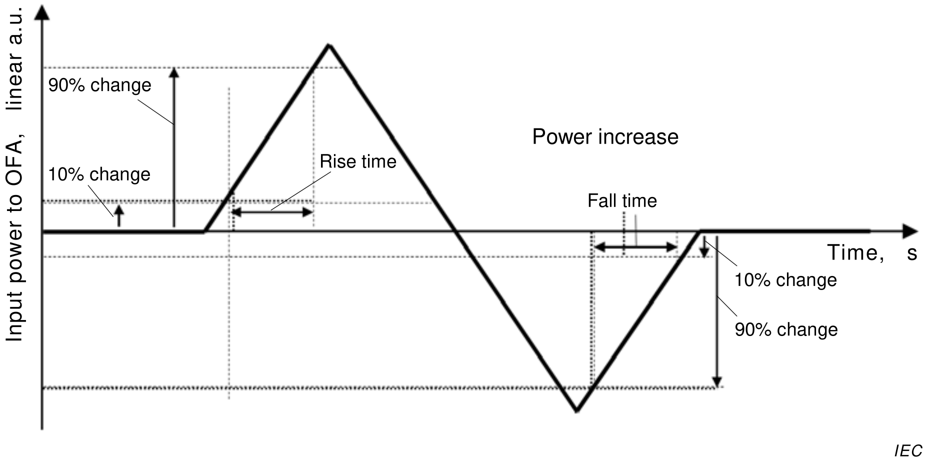
The characteristic input power behaviour of a single channel terminal OFA is shown in Figure A.1, which is a consequence of add/drop events in the preceding amplifier chain. The figure specifically represents time dependence of the input power changes with example timings. The step, pulse and lightning bolt transient power response, and power offset response are particularly critical to carriers and network equipment manufacturers (NEM), given that the terminal OA is immediately followed by a channel receiver. A properly designed OA will have small values for these transient parameters.



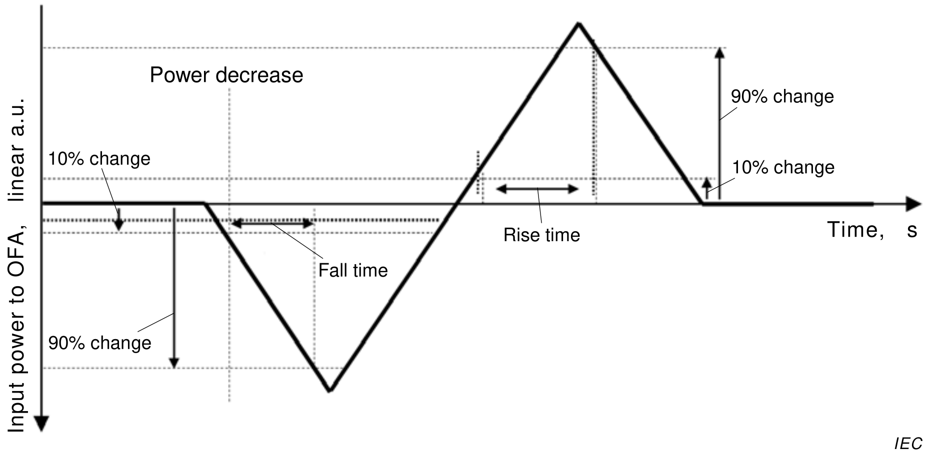
NOTE As an example of receivers, these are example numbers.

Figure A.1 – Example OA input power transient cases for a receiver application

Specific measurement parameters of the input power changes are detailed in Figure A.2 with reference to the lightning bolt scenario.



a) Input power increase



b) Input power decrease

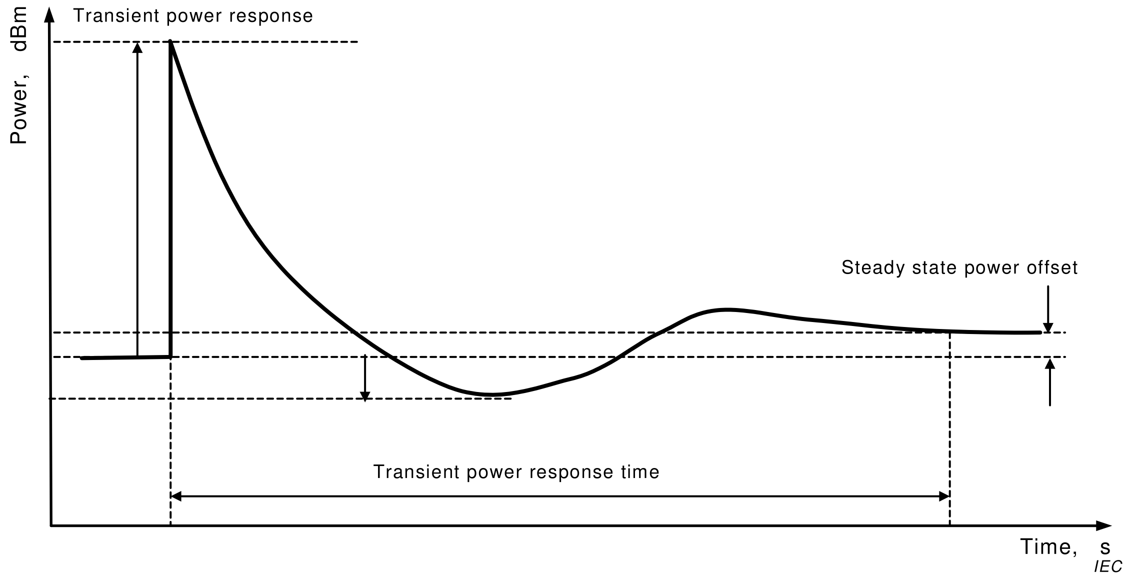
Figure A.2 – Input power measurement parameters for a) input power increase and b) input power decrease

It is important that a single channel OA placed next to a receiver is operated in automatic power control (APC) mode in order to suppress these input power transient excursions. This is referred to as output power transient controlled operation. Moderate transient power excursions incident on the receiver are manageable, depending on the receiver dynamic range and the bandwidth of the receiver automatic gain controller (AGC). However, excessive optical powers at the receiver either can result in data miss-readings giving unwanted bit errors or can permanently damage the receiver.

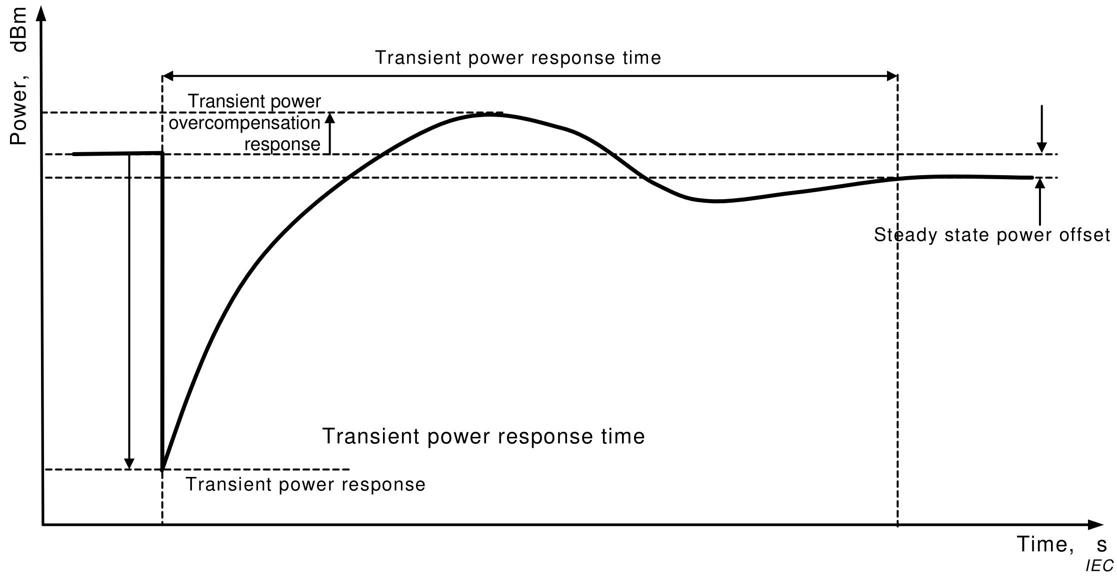
A.3 Parameters for characterizing transient behaviour

The parameters generally used to characterize the transient behaviour of a power controlled OA for the case of channel step increase/reduction are defined in Figure A.3. Figure A 3a) specifically represents the time dependence of the output power of the OA when the input power is rapidly increased. Likewise, the transient power behaviour for the case when the input power is rapidly decreased is shown in Figure A.3b).

The important transient parameters are transient power overshoot/undershoot, transient power response settling time and steady state power offset. For a power-controlled amplifier, a reduction in input power results in an output power undershoot, and an increase in output results in an output power overshoot. This is in contrast to a gain-controlled amplifier, where a reduction in input power results in a gain overshoot, and an increase in input power results in a gain undershoot.



a) Channel input power increase



b) Channel input power decrease

Figure A.3 – OA output power transient response of a) input power increase and b) input power decrease

Annex B
(informative)

Background on power transient phenomena in a single channel EDFA

B.1 Amplifier chains in optical networks

Optical networks commonly incorporate a chain of optical amplifiers to manage fibre loss as well as losses incurred by optical components providing functions such as dispersion compensation or channel add/drop. As the network is developing into a mesh structure, channels may pass through a number of different optical paths before arriving at a receiver with a consequential impact of unexpected power variations due to compounded compensation of channel add-drops within networks components, especially transient control of in-line optical amplifiers. The resilience of the receiver to these unexpected optical power variations is key to a correctly functioning optical network.

It is common in existing 10 Gb/s systems for the last line amplifier in the WDM link to be a preamplifier with the entire dense wavelength division multiplexing (DWDM) comb being amplified collectively. Nevertheless, there is an increasing need for amplifiers on each channel to pre-amplify further the optical channel prior to the receiver. This single channel OFA is inserted to help meet the stringent optical signal-to-noise ratio (OSNR) requirements of modern modulation formats and overcome the losses of specialized optical components, including optical discriminators or demodulators, polarization demultiplexers, tuneable dispersion compensators, and tuneable filters in the receiver chain. The total output power of this single-channel OFA is composed of signal power and amplified spontaneous emission (ASE) noise. The signal power and ASE power is sometimes unfiltered and not attenuated by an optical band-pass filter, demultiplexer or specialized components downstream of the OFA. This is particularly true for colourless receivers, which are broadband and not wavelength specific.

B.2 Typical optical amplifier design

The typical design of an optically amplified receiver consists of a channel selector, an OFA, a photon detector, a limiting amplifier, and an electrical low pass filter. Pre-amplifier OFAs have become an integral part of optical receivers since their performance boosts the sensitivity of the receiver photon detector. However, noise is generated within a pre-amp EDFA as a result of spontaneous de-excitation of the excited erbium ions. As the ions have a finite excited state lifetime, some return spontaneously to the ground state emitting a photon that is incoherent with respect to the incoming optical signal, as opposed to a photon generated by stimulated emission. This background noise is known as amplified spontaneous emission (ASE), and it is the dominant noise element in pre-amplifier EDFAs.

Optical power transients are sub-millisecond fluctuations in network power levels that are caused by events such as planned or accidental channel loading changes, passive loss variations, or network protection switching. In a dynamic networking environment, optical amplifiers need to be able to compensate for such power variations in order to avoid potential degradation of quality of service. For instance, in a network reconfiguration scenario, the number of DWDM channels at the input of an OFA may suddenly decrease, increasing the amplifier's population inversion with a corresponding increase in gain, in a matter of microseconds. This gain change results in channel power overshoot which is detrimental to network service providers (NSPs), given that their networks will no longer operate at the gain level for which they were optimized, potentially impacting service quality. Power fluctuations accumulate with each OFA in the system and, if left unabated, will enter a single channel OFA upstream of a receiver and will be amplified, causing the transient to enter the receiver. This can result in a cumulative transient overshoot or undershoot at the receiver that can grow to exceed the dynamic range of the receiver. The subsequent increase in bit error ratio (BER) results in quality of service degradation or, in some circumstances, can even damage a receiver as a result of excessive optical power.

Line OFA in the optical repeaters along the transmission system typically operate in constant gain mode. An OFA that is operating with constant gain will replicate and amplify channel power transients entering the input at the output, which is detrimental for a single channel amplifier in an amplified receiver.

It is imperative that any single channel OFA situated close to a receiver be operated in constant output power mode in order to suppress transients. This is referred to as power transient controlled operation. Moderate transient power excursions incident on the receiver are manageable, depending on the receiver dynamic range and the bandwidth of the receiver automatic gain controller (AGC), but an excessively large power excursion can:

a) exceed the absolute maximum optical power rating of the receiver, leading to potential catastrophic optical damage (OD) (particularly resulting from power overshoot);
b) exceed the maximum operating optical power rating of the receiver, leading to eye opening penalty and a burst of errors leading to an outage (particularly resulting from power overshoot waveforms);
c) drop below the minimum operating optical power rating of the receiver, leading to eye opening penalty and a burst of errors, leading to an outage (particularly resulting from power undershoot waveforms);
d) rapidly oscillate between cases b) and c) above, causing an outage (particularly resulting from lightning bolt power waveforms).

In addition to amplifying optical channels carrying data, an OFA generates and transmits ASE noise. The optical data signal is typically centred on one or more wavelengths corresponding to the channels standardised by the International Telecommunications Union (ITU). In contrast, the ASE is typically generated across a much broader wavelength range, for example around 40 nm, which is substantially within the gain bandwidth region of the OFA. The level of ASE depends upon the optical signal channel gain, the overall population inversion and temperature of the erbium doped fibre (EDF). Further, the level of ASE produced by the OFA will also vary due to the loss variability of other optical components within the OFA, since passive losses affect the gain required in the EDF to attain a target gain in the OFA.

A measure of the amount of ASE relative to the signal power entering a single channel receiver is defined as the signal to ASE ratio (SAR). This is calculated as:

$$SAR = \frac{SigP}{ASEP} \quad \text{(dB)}$$

where

SAR is the signal to ASE ratio in dB;

$SigP$ is the signal power exiting the OFA in dBm;

$ASEP$ is the total ASE power exiting the OFA in dBm.

Ideally, the SAR of an amplifier is always positive because the signal power is greater than the sum of the ASE power exiting the OFA. It is preferred that higher levels of SAR are achieved as this is beneficial to low bit error rate detection of signal data, and single channel pre-amplifier OFA are designed to maximize SAR. Since operational conditions affect the amount of ASE, the value of SAR will also be operational.

Since the OFA is employed as a single channel amplifier, the gain shape with respect to wavelength of the OFA may or may not be gain flattened. Even with ideal gain flattening, the gain of the EDF varies with input channel wavelength. Therefore, ASE generated by the OFA varies widely over operational conditions. Signal wavelength discrimination is not inherently incorporated in the OFA because OFA control PDs are unable to discriminate signal channel power from ASE and are, ideally, relatively wavelength insensitive to ensure the OFA is adapted for operation at a range of ITU channels. The presence of an unpredictable amount of ASE due to OFA input power or channel wavelength variation leads to transient power gain offset errors, and so the output channel power of the OFA will not have the ideal power level at the receiver, which consequently increases detection errors in an associated optical network.

B.3 Approaches to address detection errors

A number of approaches are known to address this problem. One common method employed in DWDM OFA is to estimate, through calibration, the amount of ASE for any operational condition. Since signal gain, temperature, EDF population inversion, and channel wavelength all impact the amount of ASE, the calibration routine to achieve an accurate estimate is prohibitive in test time and cost. Alternatively, in a fixed, single channel optical amplifier, it is known that inserting a fixed wavelength discriminating filter into the OFA can filter out the ASE at and beyond wavelengths a few nanometres above and below the bandwidth of the optical data signal. However, this approach is inflexible and impractical because the OFA becomes coloured by a fixed filter and can only be used for a fixed, defined channel wavelength matching the filter, requiring a different OFA to be manufactured for each signal channel wavelength. Using a fixed wavelength ASE discriminating filter cannot be applied to OFAs in systems that handle more than one channel over lifetime, for example in optical networks comprising transmitters that use tuneable laser sources. Use of an ASE flattening filter (AFF), similar to a gain-flattening filter (GFF), can increase the OFA SAR, as it will reduce the wavelength dependence of ASE; but it can only be optimized at a single gain and temperature, and thus does not eliminate the need for ASE calibration. Additionally, the use of an AFF adds cost to the OFA. Insertion of a tuneable optical filter in the OFA can provide ASE suppression with the required flexibility. Although tuneable filters with requisite optical performance are available, they are physically large, costly and require additional controls, making them less attractive for deployment in applications where cost or size is key.

As a result of the limitations of fixed filters and the cost and size of tuneable filters, many single channel OFA employ no gain flattening ASE flattening or tuneable filters. Thus, the OFA controller will only have total output power at the output PD available as a control signal parameter, as the output PD is exposed to the total output power comprised of both amplified signal channel and ASE power.

Four factors determine the power output of a single channel erbium-doped optical fibre amplifiers: input optical power, input optical channel wavelength, optical pump power, and the population inversion level of the optical amplifier. The inversion level of an OFA characterizes the fraction of erbium atoms that are available to provide energy to the input optical signal, resulting in optical gain. Typically, the inversion level increases with the increase in optical pump power and decreases with the increase in input optical power. For that reason, if channel power increases at the OFA input, the optical power of the pumps will also need to be increased in order to maintain the output power. Similarly, if the channel power drops at the OFA input, the pumps will need to be rapidly decreased in order to maintain a constant power.

The output power of an OFA can be set by controlling the pump laser output power via pump current adjustments. The basic scheme for the pump control involves making measurement of input and output power of the OFA through signal taps and monitor photodiodes, computing an error signal from the monitor signals and driving the pump power via a high-speed proportional integral-derivative PID controller that might employ feed forward and feedback control.

Any error in post-transient output power is known as steady state power offset error and is related to the post transient ASE level, the channel wavelength and temperature. The time taken for the OFA to recover to the correct output power (called the power transient settling time) is determined by the time for the pump controller to respond and the pumping rate into the EDF, which is dependent upon monitoring response, controller bandwidth, algorithm latency, and the Er recovery and Er saturation time constants. The output power transient settling time is the sum of these parameters and is dependent upon the output power, channel wavelength and EDF temperature. Generally, a higher output power amplifier will have a faster output power transient response time. Raising the temperature of the EDF and lowering the channel wavelength will also decrease the output transient response time.

The inherent ability for an OFA to respond to input transients depends upon two time constants related to the EDF. First is the Er recovery time constant, which is the time it takes for pump power to create a change in the population inversion in the EDF. The second is the Er saturation time constant, which is related to the decay time of the EDF population inversion. Both these time constants decrease with increasing population inversion; however, the saturation rate can be much faster than the Er recovery rate in an operational OFA. Both recovery and saturation time constants are wavelength and temperature dependent. Longer channel wavelengths and cooler EDF temperatures result in the longest saturation time constant.

Any single channel OFA designed to suppress input power transients shall employ a controller that operates in constant output power mode with a power transient suppression controller algorithm in operation with its own controller time constant. When a single channel input power transient enters the OFA, the controller shall modify the pump power to attempt to set the output power level to the correct state.

Consider the OFA power transient response with no pump power controller, i.e. with the controller deactivated. When an inverse step input power transient excursion (reduced input power, Figure B.1a)) enters the OFA, the gain of the uncontrolled OFA instantaneously remains constant, and so the output power reduces concomitantly with the drop in input power (Figure B 1b)). After the input power has dropped at time t_0, the gain begins to grow as a result of a change in the amplifier saturation condition at the new lower input power and the output power rises. Eventually, the output power settles at time t_S at a new value corresponding to the new input power level and corresponding gain. Although the post-transient gain is higher, the post-transient output power is lower than that prior to the input power transient excursion/power drop, creating a steady state power offset error. The magnitude of power offset will depend upon the input power value prior to and post the step change, the temperature, ASE level and the relative saturation of the amplifier in these conditions.

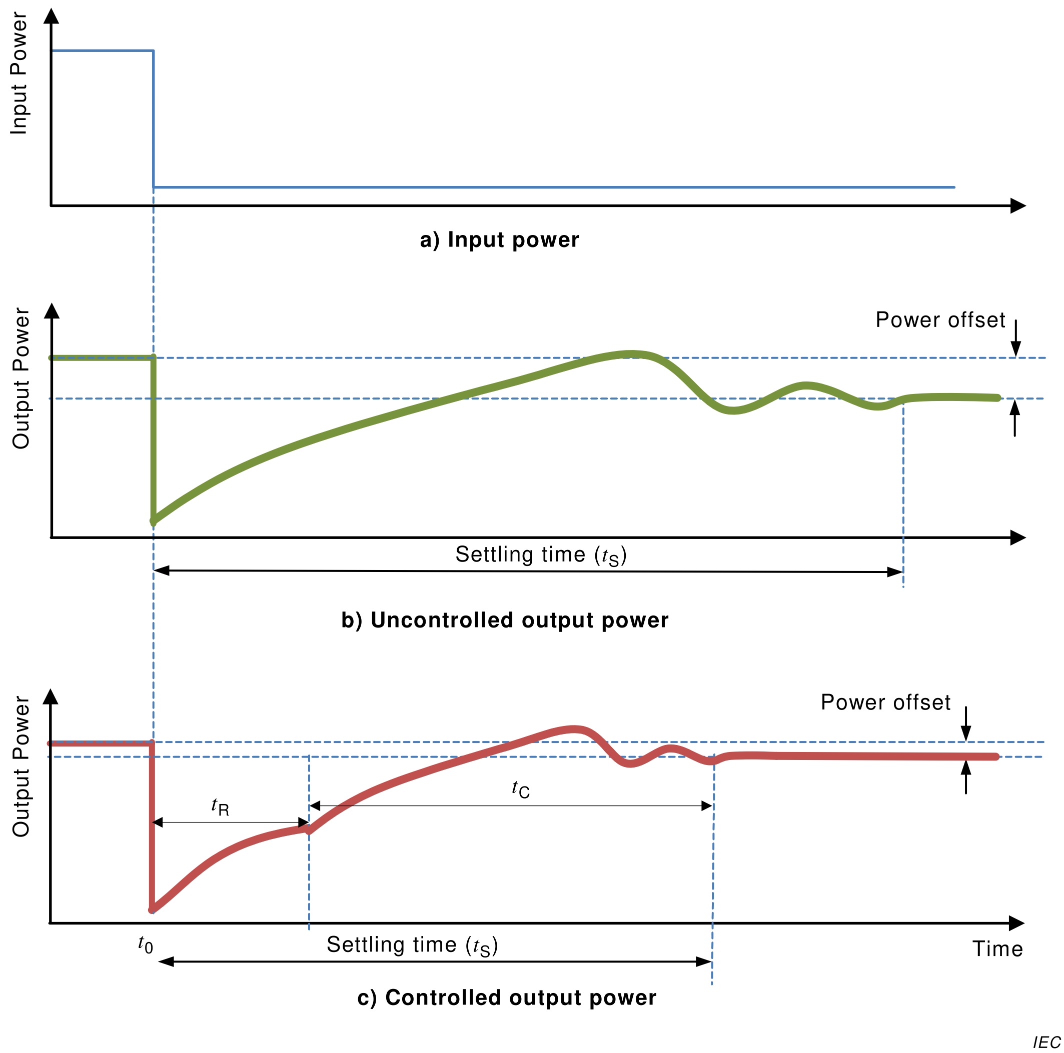


Figure B.1 – Transient response to a) input power drop (inverse step transient) with transient control, b) deactivated (constant pump power), and c) activated (power control)

Now consider the OFA transient response with the controller activated (see Figure B 1c)), where the pump controller is able to respond to changes in output power and thus attempt to maintain the same total output power target (since output $SigP$ and $ASEP$ cannot be differentiated). When the input power transient step excursion reduces the instantaneous input power at time t_0, the instantaneous gain of the OFA stays constant, so the output power drops. The magnitude of the output power change before the controller responds is called the output power transient undershoot. However, the OFA controller recognizes the output power has dropped and changes the pump power to increase the level of inversion of the EDF. During the Er recovery time (t_R), the inversion level is not changed significantly, so the gain rises slowly. After t_R, the controller is able to affect the output power, and the gain rises more quickly than in the uncontrolled case. The post-transient output power then returns to a magnitude close to the pre-transient level, with a smaller steady state power offset error and settling in a time quicker, t_C, than the uncontrolled case. If the control is not well damped, there may be over compensation of the output power before settling to the correct value, as shown in Figure B.1c).

In the same manner, consider the case of an increase in input power for the OFA transient response with no pump power control, i.e. with the controller deactivated. When a step increase in input power enters the OFA (see Figure B.2a)), the gain of the uncontrolled OFA prior to and immediately following the transient event is constant, and so the output power increases in response to the rise in input power, as seen in Figure B.2b). Immediately following the input power transient, the gain begins to decrease due to increased gain saturation. Eventually, the output power settles at time t_S at a new magnitude corresponding to the new input power level. Although the post-transient gain is lower, the post-transient output power is higher than that prior to the input power transient excursion, creating a gain offset error. The magnitude of the gain offset error is dependent upon the input power conditions and corresponding gain saturation level.

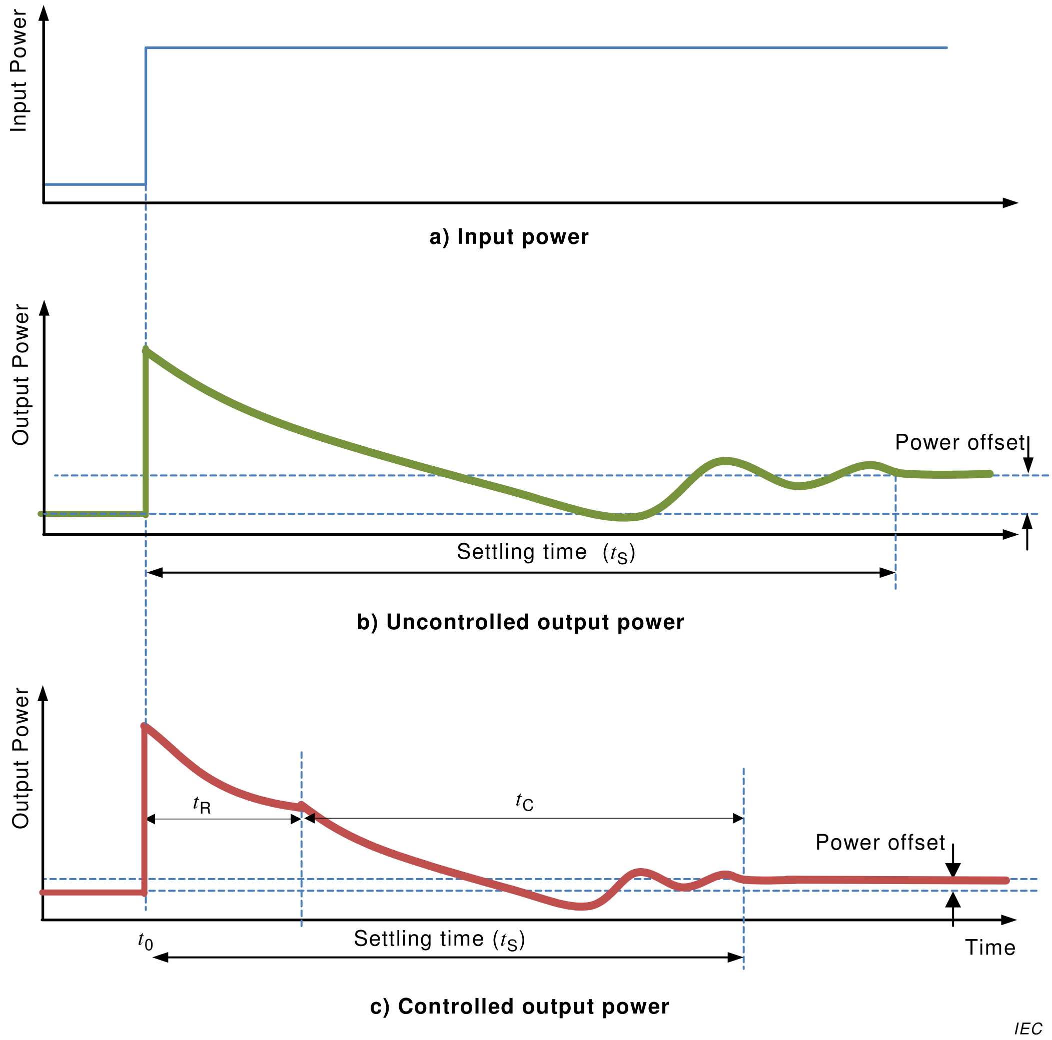


Figure B.2 – Transient response to a) input power rise (step transient) with transient control, b) deactivated (constant pump power), and c) activated (power control)

Now consider the OFA transient response with the controller activated (see Figure B.2c)), where the pump controller responds to changes in output power and attempts to maintain the same total output power target (since output *SigP* and *ASEP* cannot be differentiated). When the input power transient excursion (step transient) at time t_0, enters the controlled OFA, the instantaneous gain of the OFA stays constant so the output power rises. The magnitude of the output power change before the controller responds is called the output power transient overshoot. The OFA controller acts to reduce the output power, and after the saturation recovery time t_R, the output power drops quickly due to a reduced inversion of the EDF. The gain and pump power now fall faster than the uncontrolled case, and the post transient output power returns to a magnitude close to the pre-transient level with a smaller steady state power offset error and settles in a time t_C, more quickly than the uncontrolled case. If the control is not well damped, there may be over compensation of the output power before settling to the correct value.

Annex C
(informative)

Slew rate effect on transient gain response

When channel powers rise or fall, the speed of the input power transient shall be considered while measuring transient performance. Power transient control of OFA is generally realized by monitoring of input and output levels and through adjustment of the pump laser current. Optical design, monitor and controller bandwidth, and control algorithms affect transient response, as indicated in Annex A. However, the slew rate of the input power transient will also affect the OFA performance. Variation in the slew rate of the input transient waveform results from the speed of the transient event accumulated in the network or the switch speed used in testing apparatus.

If input power variations to the OFA change slowly, the power control system may be able to compensate transient phenomena adequately through pump power adjustment to minimize transient overshoot or undershoot. Thus, the transient response of the OFA will be minimized.

If input power to OFA changes rapidly (a faster slew rate or switch speed), the power control system may not be able to minimize over or undershoot adequately, since the control mechanism of the OFA may not be fast enough to track and compensate the rapid input power variation. The response of the OFA will degrade as a result.

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