International Telecommunication Union

# ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

# G.984.6

**Amendment 2**
(05/2012)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Optical line systems for local and access networks

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# Gigabit-capable passive optical networks (G-PON): Reach extension

## Amendment 2

Recommendation ITU-T G.984.6 (2008) – Amendment 2

ITU-T

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ITU-T G-SERIES RECOMMENDATIONS

**TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS**

| | |
|---|---|
| INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS | G.100–G.199 |
| GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS | G.200–G.299 |
| INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES | G.300–G.399 |
| GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES | G.400–G.449 |
| COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY | G.450–G.499 |
| TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS | G.600–G.699 |
| DIGITAL TERMINAL EQUIPMENTS | G.700–G.799 |
| DIGITAL NETWORKS | G.800–G.899 |
| DIGITAL SECTIONS AND DIGITAL LINE SYSTEM | G.900–G.999 |
| General | G.900–G.909 |
| Parameters for optical fibre cable systems | G.910–G.919 |
| Digital sections at hierarchical bit rates based on a bit rate of 2048 kbit/s | G.920–G.929 |
| Digital line transmission systems on cable at non-hierarchical bit rates | G.930–G.939 |
| Digital line systems provided by FDM transmission bearers | G.940–G.949 |
| Digital line systems | G.950–G.959 |
| Digital section and digital transmission systems for customer access to ISDN | G.960–G.969 |
| Optical fibre submarine cable systems | G.970–G.979 |
| **Optical line systems for local and access networks** | **G.980–G.989** |
| Access networks | G.990–G.999 |
| MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS | G.1000–G.1999 |
| TRANSMISSION MEDIA CHARACTERISTICS | G.6000–G.6999 |
| DATA OVER TRANSPORT – GENERIC ASPECTS | G.7000–G.7999 |
| PACKET OVER TRANSPORT ASPECTS | G.8000–G.8999 |
| ACCESS NETWORKS | G.9000–G.9999 |

*For further details, please refer to the list of ITU-T Recommendations.*

# Recommendation ITU-T G.984.6

## Gigabit-capable passive optical networks (G-PON): Reach extension

## Amendment 2


**Summary**

Amendment 2 to Recommendation ITU-T G.984.6 (2008) is aimed at defining additional features, specifications, and/or types of gigabit-capable passive optical networks (G-PONs) compatible reach extender units, especially using a distributed Raman amplified G-PON reach extender. It also includes miscellaneous corrections to the Recommendation.


**History**

| Edition | Recommendation | Approval | Study Group |
|---|---|---|---|
| 1.0 | ITU-T G.984.6 | 2008-03-29 | 15 |
| 1.1 | ITU-T G.984.6 (2008) Amd. 1 | 2009-11-13 | 15 |
| 1.2 | ITU-T G.984.6 (2008) Amd. 2 | 2012-05-07 | 15 |

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## Table of Contents


Page

1) Changes to ITU-T G.984.6 as amended by ITU-T G.984.6 Amd.1 ............................ 1

1.1) Changes to clause 1, "Scope" ......................................................................... 1

1.2) Changes to clause 2, "References" ................................................................ 1

1.3) Changes to clause 3, "Definitions" ................................................................ 1

1.4) Changes to clause 4, "Abbreviations and acronyms" .................................... 2

1.5) New clause 6.6, "Raman amplified reach extenders" .................................... 2

1.6) Changes to clause 7.1, "Compatibility" ......................................................... 3

1.7) Changes to clause 7.2, "Management" .......................................................... 4

1.8) Modify clause 8.6.4, "Cyclic OTL wavelength allocation plan" .................. 4

1.9) New clause 8.7, "Specifications for Raman amplified reach extender" ......... 4

1.10) Add new Appendix IX, "General characteristics of reverse pumped distributed Raman amplifiers" ......................................................................... 5

1.11) Add new Appendix X, "General considerations and guidelines of safety procedure" ..................................................................................................... 7

1.12) Bibliography ................................................................................................... 8

## Recommendation ITU-T G.984.6

# Gigabit-capable passive optical networks (G-PON): Reach extension

## Amendment 2

*This amendment adds a Raman amplified reach extender to Recommendation ITU-T G.984.6 as amended. It defines the configuration, features, and specifications of the new type of G-PON reach extender using distributed Raman amplification in feeder fibre. It also includes miscellaneous corrections to the Recommendation.*

### 1) Changes to ITU-T G.984.6 as amended by ITU-T G.984.6 Amd.1

### 1.1) Changes to clause 1, "Scope"

*Add the following text after the last paragraph:*

"Optionally, Raman amplified type RE units are described in clause 6.6."

### 1.2) Changes to clause 2, "References"

*Add the following references to the list:*

[ITU-T G.664] Recommendation ITU-T G.664 (2006), *Optical safety procedures and requirements for optical transport systems*.

[ITU-T G.665] Recommendation ITU-T G.665 (2005), *Generic characteristics of Raman amplifiers and Raman amplified subsystems*.

[ITU-T G.698.3] Recommendation ITU-T G.698.3 (2012), *Multichannel seeded DWDM applications with single-channel optical interfaces*.

[IEC 60825-1] International Standard IEC 60825-1 (2007), *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] International Standard IEC 60825-2 (2000), *Safety of laser products – Part 2: Safety of optical fibre communication systems.*

### 1.3) Changes to clause 3, "Definitions"

*Add the following to clause 3:*

**3.2 maximum pump power** (based on [ITU-T G.665]): The highest pump power(s) available at $RP_i$ (as defined in Appendix I) for reverse pumping.

**3.3 minimum pump power** (based on [ITU-T G.665]): The lowest pump power(s) available at $RP_i$ (as defined in Appendix I) for reverse pumping for which the operation of the Raman amplifier is usable.

**3.4 net gain** (based on [ITU-T G.665]): Net gain is defined as the Raman On-Off gain with the loss between the input and output reference points of the amplifier subtracted from it.

**3.5 Raman on-off gain** (based on [ITU-T G.665]): The increase in signal optical power at the gain measurement point (GMP) defined in Appendix I when the Raman pump is activated compared to the signal optical power at the GMP when the Raman pump is de-activated.

*This Recommendation uses the following terms defined elsewhere:*

**automatic power reduction (APR)** [ITU-T G.664]: A technique (procedure) to automatically reduce the output power of laser and optical amplifiers to avoid exposure to hazardous levels.

**DOP of pump laser** [ITU-T G.665]: The degree of polarization of the pump laser.

**loss of continuity (of an optical link)** [ITU-T G.664]: Any event which may cause hazardous optical power levels to be emitted from some point along the path of an optical transmission system. Common causes of loss of continuity of an optical link are a fibre cable break, equipment failure, connector unplugging, etc.

**reverse pumped Raman amplifier** [ITU-T G.665]: The pump energy and signal propagate in opposite directions in the transmission fibre.

**RIN of pump laser** [ITU-T G.665]: Relative Intensity Noise of pump energy.

### 1.4) Changes to clause 4, "Abbreviations and acronyms"

*Add the following items to the list:*

AEL Accessible Emission Limit

APR Automatic Power Reduction

GMP Gain Measurement Point

R"/S" Optical trunk line interface to ODN

$RP_i$ Reverse-Pumped signal input reference point

$RP_o$ Reverse-Pumped signal output reference point

S"/R" Optical line termination interface to Raman reach extender

### 1.5) New clause 6.6, "Raman amplified reach extenders"

*Add the following clause 6.6:*

### 6.6 Schemes and architectures on Raman amplified reach extenders

The general architecture of a Raman RE is shown in Figure 7c. The Raman RE device is inserted between the OLT and the optical trunk line (OTL), which is optical fibre. The OLT and ONU are compliant with existing G-PON Recommendations, i.e., ITU-T G.984-series. This approach extends the reach of the PON by increasing the allowable length of the OTL, and may also increase the split ratio of the PON. Note the Raman-RE device can be co-located with the OLT at the central office (CO) and therefore it keeps the ODN passive (no electrical power required in R'/S' to R/S section).

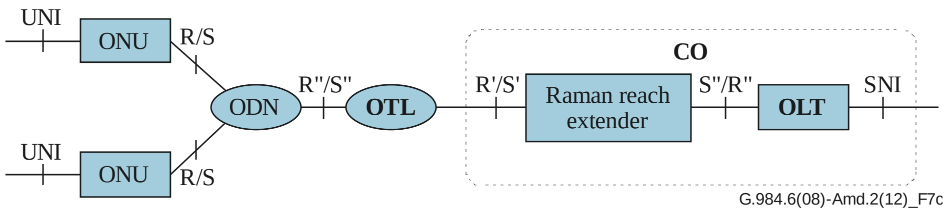


**Figure 7c – Raman G-PON reach extension**

The generic configuration of a Raman-RE is shown in Figure 7d by way of example. The Raman pumps at appropriate wavelengths are coupled into the OTL to provide reverse pumped distributed Raman gain for the G-PON upstream (US) signals. An optional optical amplifier (OA) may be used to boost the G-PON downstream (DS) signal power before launching into the OTL. The OA could be a semiconductor optical amplifier (SOA), discrete Raman amplifier, and EDFA, or any other suitable optical amplifier providing gain over the 1480-1500 nm wavelength range. The OA may be omitted if the G-PON DS power is high enough to accommodate the high loss for long reach or higher split ratio. Furthermore, the OA may also be replaced by an opto-electronic repeater providing improved launch power to overcome increased losses in the OTL and ODN. A Raman pump at the appropriate wavelength may also optionally be used to couple into the OTL to provide forward pumped distributed Raman gain for the G-PON DS signal. A WDM combiner is used to combine the G-PON DS signals with the Raman pump and separate the G-PON US signals. The pass bands of the WDM combiner are designed to ensure compatibility with the wavelength band specifications for G-PON signals as defined in [ITU-T G.984.5]. The WDM combiner may optionally act as an optical bandpass filter (OBF) to remove amplified spontaneous emission (ASE) noise outside of the signal bands in order to improve transmission performance.

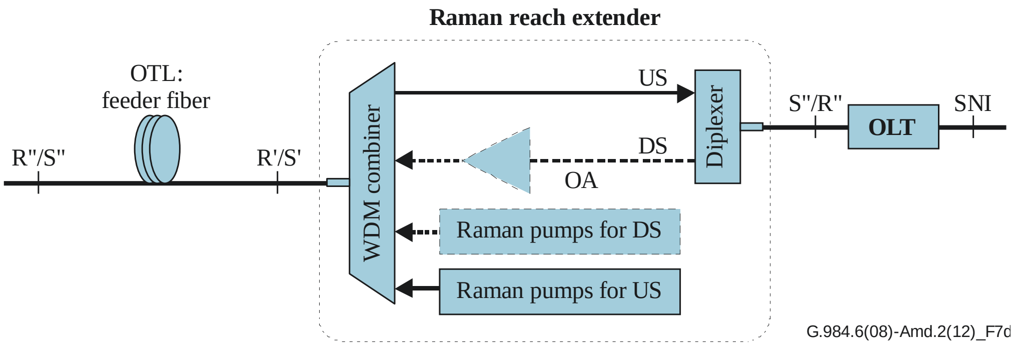


**Figure 7d – Example configuration for Raman RE; OA and Raman pumps for DS are optional**

Due to the nature of the Raman RE system, the equipment should be specified for a defined application range taking into account applicable penalties due to ASE and any non-linear penalties. The equipment should also be specified with the key parameters for Raman pumps, such as the Raman pump wavelength, maximum power, and the expected Raman on-off gain for the specified OTL fibre type. Other parameters for reverse pumped distributed Raman amplifiers defined in [ITU-T G.665] may also be included in the equipment specifications. It is recommended to refer to [ITU-T G.665] on "Generic characteristics of Raman amplifiers and Raman amplified subsystems". The key performance parameters and test methods used for Raman RE, as defined in [ITU-T G.665], are summarized in Appendix I. In addition, the equipment may be specified with the key parameters for the OA including, for example, the saturated output power, linear gain and noise figure.

### 1.6) Changes to clause 7.1, "Compatibility"

*Add the following text at the end of clause 7.1:*

The Raman-RE will be compatible with both narrow wavelength band option (US: 1300-1320 nm) and the reduced wavelength band option (US: 1290-1330 nm) as defined in [ITU-T G.984.5]. Due to the limited Raman gain bandwidth and laser safety considerations, support is not intended for the regular wavelength band option (US: 1260-1360 nm) as defined in [ITU-T G.984.5].

The Raman-RE must be compatible with existing G-PON 2.4/1.2 Gbit/s class B+ rated ONT equipment and class B+ ODN [ITU-T G.984.2 Amd.1]. It is also possible for the extender to support a more capable ODN, such as the class C+ defined in Amendment 2 to [ITU-T G.984.2].

As the Raman-RE uses the OTL fibre to provide gain, the system gain is dependent on the length of the OTL. A typical OTL length greater than 20 km will be employed before optical splitting (see "specification for Raman amplified reach extender"). OTL lengths shorter than 20 km are possible but will result in a reduction of the Raman on-off gain and thus the supported loss budget.

### 1.7) Changes to clause 7.2, "Management"

*Add the following text at the end of clause 7.2:*

The Raman-RE shall support full management functions for configuration, performance monitoring, and fault reporting. This will include the configuration and provision of the output power level of Raman pumps.

Considering that the Raman-RE will most likely operate at optical power levels well in excess of the Hazard Level 1 limit, as specified by [IEC 60825-2], it should provide optical safety features for automatic power reduction (APR) of the Raman pump lasers when a loss of continuity occurs in the OTL. General requirements for, and considerations on, APR with respect to "safety considerations for avoiding damage to the human eye and skin" and consideration to keep fibres damage-free are provided in [ITU-T G.664].

### 1.8) Modify clause 8.6.4, "Cyclic OTL wavelength allocation plan"

*Replace the entire contents of clause 8.6.4 with the following text:*

"The cyclic OTL wavelength plan is defined in [ITU-T G.698.3]."

### 1.9) New clause 8.7, "Specifications for Raman amplified reach extender"

*Add the following clause 8.7:*

### 8.7 Specifications for Raman amplified reach extender

An illustrative specification for the OTL and ODN with a Raman-RE is shown in Table 6. Note that the actual performance achieved will need to be defined by engineering rules that consider the actual fibre plant configuration as the Raman gain is highly sensitive to losses from connectors and splices in the vicinity of the R'/S' interface.

**Table 6 – Physical medium dependent layer parameters of OTL and ODN (Note 1)**

| Parameter | Unit | Specifications |
|---|---|---|
| Fibre type | – | [ITU-T G.652] (Note 2) |
| Maximum fibre length of OTL | km | 60 (minus the distance used in the distribution fibre) |
| Minimum fibre length of OTL | km | 20 |
| Maximum attenuation at ODN | dB | 21 (Note 3) |
| Maximum attenuation between R/S and R'/S' points at 1300-1320 nm | dB | 39 (Note 4) |
| NOTE 1 – Assuming B+ optics with narrow wavelength band option (US: 1300-1320 nm) as defined in [ITU G.984.5].<br>NOTE 2 – Other fibre types may be used but the performance of other types will vary.<br>NOTE 3 – Assuming losses for 64-way split, but if the fibre length of OTL is short, this may increase to 128-way split.<br>NOTE 4 – Total losses of OTL and ODN. | | |

Example optical parameters of the Raman reach extender are given in Table 7.

**Table 7 – The optical parameters of the Raman reach extender (Note 1)**

| Items | Unit | Specifications |
|---|---|---|
| Passband for US | nm | 1300-1320 |
| Passband for DS | nm | 1480-1500 |
| Wavelength range of Raman pump laser | nm | 1240 (±0.5) (Note 2) |
| Output power of Raman pump laser | mW | 100-750 |
| RIN | dB/Hz | < –90 |
| Range of Raman on-off gain | dB | 5-15 |
| Saturated output power of SOA | dBm | > 16 (Note 3) |
| Minimum linear gain of SOA | dB | 10 (Note 3) |
| Maximum polarization dependent gain (PDG) | dB | 1 (Note 3) |
| Noise figure (NF) of SOA | dB | 6.5 (Note 3) |
| Maximum transmission penalty for US | dB | 2.5 (Note 4) |
| Maximum transmission penalty for DS | dB | 1.5 (Note 5) |

NOTE 1 – For B+ optics G-PON OLT and ONU.

NOTE 2 – For narrow wavelength band option (US: 1300-1320 nm) as defined in [ITU G.984.5].

NOTE 3 – If the OA is an SOA then this needs to be operated near the linear regime in order to reduce pattern-dependent distortion caused by gain dynamics of the SOA.

NOTE 4 – ASE noise induced receiver power penalty.

NOTE 5 – Receiver power penalty caused by pattern-dependent distortion and fibre dispersion and other non-linear penalty.

**1.10) Add new Appendix IX, "General characteristics of reverse pumped distributed Raman amplifiers"**

*Add the following Appendix IX:*

# Appendix IX

## General characteristics of reverse-pumped distributed Raman amplifiers

(This appendix does not form an integral part of this Recommendation.)

This appendix summarizes generic characteristics of reverse-pumped distributed Raman amplifiers for Raman RE.

As defined in [ITU-T G.665], a reference model is used to define the performance parameters and their test methods. This model is illustrated in Figure I.1, where the point labelled GMP is the gain measurement point, and at which two signal power measurements are made. One is the signal power measured when the Raman pumps are on ($P_{on}$) and the other is the signal power measured when the Raman pumps are off ($P_{off}$).

The Raman on-off gain is then defined as $10\text{Log}\left(\frac{P_{on}}{P_{off}}\right)$

$RP_i$ is the reverse-pumped signal input reference point

$RP_o$ is the reverse-pumped signal output reference point

The net gain is the on-off gain with the loss between the reference point $RP_i$ and $RP_o$ subtracted from it.

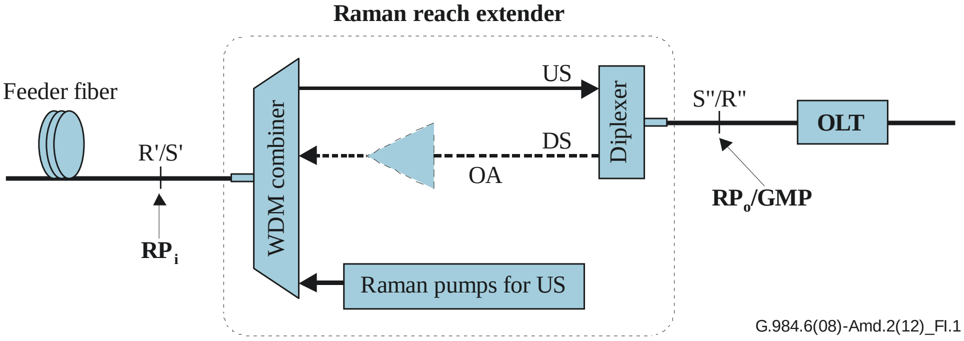


**Figure I.1 – Reverse pumped distributed Raman amplifier for Raman RE**

Table IX.1 outlines various measurement points at which the parameters are to be measured.

**Table IX.1 – Generic characteristics of reverse pumped Raman amplifier for the Raman RE**

| Parameters | Measurement points |
|---|---|
| Gain passband range | GMP |
| Raman on-off gain | GMP |
| Output signal power | $RP_o$ |
| Reflectance at signal input interface | $RP_i$ |
| Reflectance at signal output interface | $RP_o$ |
| Reflectance at pump output interface | $RP_i$ |
| Pump power | $RP_i$ |
| RIN of pump laser | $RP_i$ |
| DOP of pump laser | $RP_i$ |

A list of performance parameters and test methods for the Raman RE is contained in Table IX.2

**Table IX.2 – Performance and test parameters for the Raman RE**

| Functional parameters | Unit | Test method |
|---|---|---|
| Raman on-off gain | dB | [b-IEC 61290-1] |
| Net gain | dB | [b-IEC 61290-1] |
| Pump power | dBm | [b-IEC 61292-6] |
| RIN of pump laser | dB/Hz | [b-IEC 61292-2], or [b-IEC 61290-3] |
| DOP of pump laser | % | [b-IEC 61290-11] |
| Input signal power | dBm | Section 2.11 of [b-IEC 61292-6] |
| Output signal power | dBm | Section 2.12 of [b-IEC 61292-6] |

### 1.11) Add new Appendix X, "General considerations and guidelines of safety procedure"

*Add the following Appendix X:*

# Appendix X

# General considerations and guidelines of safety procedure

(This appendix does not form an integral part of this Recommendation.)

## X.1 General consideration

[ITU-T G.664] and [IEC 60825-2] provide optical safety procedures and requirements for optical transport systems, and classifications of laser class and hazard level. Based upon the description and classification of Laser Class by [IEC 60825-1], [IEC 60825-2], and [ITU-T G.664], the complete G-PON reach extension system using distributed Raman amplification as described in this Recommendation can be regarded as a Class 1 laser product because, under normal conditions, the emissions from all pump lasers and transmitters are completely enclosed and no light should be emitted outside the protective housing.

However, by the classification described in the accessible emission limit (AEL) Tables in [IEC 60825-1], the Raman pump power from the laser itself exceeds Class 1 limits (sometimes at Class 3b or Class 4 levels depending on the pump power used for Raman G-PON reach extender). This can be potentially hazardous when the pump light escapes from the optical system, for example, if a fibre break occurs in the feeder fibre and/or an optical connector is unplugged. These hazardous conditions can cause not only risks of human eye damage but also skin and perhaps even other bodily damage. Hence safety procedures for avoiding damage to the human eye and skin should be considered.

In addition, when optical fibres are being operated at such high optical power levels, fibre and optical connectors could be damaged by imperfect connections. These imperfect connections may be caused, for example, by imperfect mating of the fibre or by surface contamination on the fibre connections at R'/S' point (e.g., oils, dust, or dirt) that can absorb some of the optical pump power and cause a hot spot. Some aspects of this high power operation in fibres and connectors are also related to safety. For example, fires may be started by local heating in contaminated connectors carrying high optical power.

[b-IEC/TR 61292-4] provides extensive guidance on the following topics:

– Fibre fuse and its propagation;

– Loss-induced heating at connectors or splices;

– Connector end-face damage induced by dust/contamination;

– Fibre-coat burn/melt induced by tight fibre bending.

It is recommended to refer to the above guidance and other best practices for optical power safety when operating the Raman RE.

Because high pump power being injecting into the feeder fibre at OLT when the Raman G-PON RE is deployed, it is also necessary to provide for a capability for automatic (optical) power reduction (APR) in the case of loss of optical power within one section of the main optical path. This loss of power can be caused by fibre break and connector unplugging, etc., as described above. This condition can be generically referred to as a loss of continuity within a fibre link.

### X.2 APR issues for the Raman G-PON extender

Many known APR systems that detect failures in optical communication systems detect the loss of signal (LOS) on the data channel (for example, that being described in [ITU-T G.664]). Other APR systems detect loss of frame (LOF) on the optical supervisory channel (OSC). In G-PON, there is no OSC. Some APR systems detect both LOS on the data channels and LOF on the OSC. After APR systems detect LOS on the data channel and/or LOF on OSC, they reduce the power of lasers and other active components to the level that is below safety level. Because the 1310 nm upstream data signal operates in burst mode for Raman G-PON extension systems, and because the PON is a point-to-multipoint topology, the use of the G-PON loss of signal needs to be addressed with some care. For further information, refer to [ITU-T G.664].

### 1.12) Bibliography

*Add the following bibliography after Appendix X:*


[b-IEC 61290-1] IEC 61290-1-1 ed2.0 (2006), *Optical amplifiers – Test methods – Part 1-1: Power and gain parameters – Optical spectrum analyzer method*

[b-IEC 61290-3] IEC 61290-1-3 ed2.0 (2005), *Optical amplifiers – Test methods – Part 1-3: Power and gain parameters – Optical power meter method.*

[b-IEC 61290-11] IEC 61290-1-11, *Optical amplifiers – Test methods – Part 11: Polarization mode dispersion parameter.*

[b-IEC 61292-2] IEC/TR 61292-2 ed1.0 (2003), *Optical amplifier technical reports – Part 2: Theoretical background for noise figure evaluation using the electrical spectrum analyzer.*

[b-IEC 61292-6] IEC/TR 61292-6 ed1.0 (2010), *Optical amplifiers – Part 6: Distributed Raman amplification.*

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