BS EN 60728-14:2014

BSI Standards Publication

# Cable networks for television signals, sound signals and interactive services

## Part 14: Optical transmission systems using RFoG technology

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## National foreword

This British Standard is the UK implementation of EN 60728-14:2014. It is identical to IEC 60728-14:2014.

The UK participation in its preparation was entrusted to Technical Committee EPL/100, Audio, video and multimedia systems and equipment.

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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**Compliance with a British Standard cannot confer immunity from legal obligations.**

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EUROPEAN STANDARD

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**EN 60728-14**

May 2014

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English Version

# Cable networks for television signals, sound signals and interactive services - Part 14: Optical transmission systems using RFoG technology (IEC 60728-14:2014)

Réseaux de distribution par câbles pour signaux de télévision, signaux de radiodiffusion sonore et services interactifs - Partie 14: Systèmes de transmission optique appliquant la technologie RFoG
(CEI 60728-14:2014)

Kabelnetze für Fernsehsignale, Tonsignale und interaktive Dienste - Teil 14: Optische Übertragungssysteme mit RFoG-Technik
(IEC 60728-14:2014)

This European Standard was approved by CENELEC on 2014-04-11. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

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

**CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels**

## Foreword

The text of document 100/2248/FDIS, future edition 1 of IEC 60728-14, prepared by Technical Area 5 “Cable networks for television signals, sound signals and interactive services” of IEC/TC 100 “Audio, video and multimedia systems and equipment" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60728-14:2014.

The following dates are fixed:

| | | |
|---|---|---|
| • latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2015-01-11 |
| • latest date by which the national standards conflicting with the document have to be withdrawn | (dow) | 2017-04-11 |

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

## Endorsement notice

The text of the International Standard IEC 60728-14:2014 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 60068 Series | NOTE | Harmonized as EN 60068 Series (not modified). |
| IEC 60169-24 | NOTE | Harmonized as EN 60169-24. |
| IEC 60728-5 | NOTE | Harmonized as EN 60728-5. |
| IEC 60793-2-50 | NOTE | Harmonized as EN 60793-2-50. |
| IEC 60825-2 | NOTE | Harmonized as EN 60825-2. |
| IEC 61281-1:1999 | NOTE | Harmonized as EN 61281-1:1999 (not modified). |
| IEC 61280-2-2 | NOTE | Harmonized as EN 61280-2-2. |
| IEC 61280-4-2 | NOTE | Harmonized as EN 61280-4-2. |
| IEC 61290-1-1 | NOTE | Harmonized as EN 61290-1-1. |
| IEC 61290-1-2 | NOTE | Harmonized as EN 61290-1-2. |
| IEC 61290-6-1 | NOTE | Harmonized as EN 61290-6-1. |
| IEC 61291-4 | NOTE | Harmonized as EN 61291-4. |
| IEC 80416 Series | NOTE | Harmonized as EN 80416 Series (not modified). |

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# Annex ZA
(normative)

## Normative references to international publications with their corresponding European publications

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.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

| Publication | Year | Title | EN/HD | Year |
|---|---|---|---|---|
| IEC 60068-1 | 1988 | Environmental testing - Part 1: General and guidance | EN 60068-1 | 1994 [1)] |
| IEC 60068-2-1 | - | Environmental testing - Part 2-1: Tests - Test A: Cold | EN 60068-2-1 | - |
| IEC 60068-2-2 | - | Environmental testing - Part 2-2: Tests - Test B: Dry heat | EN 60068-2-2 | - |
| IEC 60068-2-6 | 2007 | Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal) | EN 60068-2-6 | 2008 |
| IEC 60068-2-14 | - | Environmental testing - Part 2-14: Tests - Test N: Change of temperature | EN 60068-2-14 | - |
| IEC 60068-2-27 | - | Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock | EN 60068-2-27 | - |
| IEC 60068-2-30 | - | Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle) | EN 60068-2-30 | - |
| IEC 60068-2-31 | - | Environmental testing - Part 2-31: Tests - Test Ec: Rough handling shocks, primarily for equipment-type specimens | EN 60068-2-31 | - |
| IEC 60068-2-40 | - | Basic environmental testing procedures - Part 2: Tests - Test Z/AM: Combined cold/low air pressure tests | EN 60068-2-40 | - |
| IEC 60529 | - | Degrees of protection provided by enclosures (IP Code) | EN 60529 | - |
| IEC 60728-1 | - | Cable networks for television signals, sound signals and interactive services - Part 1: System performance of forward paths | EN 60728-1 | - |

[1)] Superseded by EN 60068-1:2014 (IEC 60068-1:2013).

| Publication | Year | Title | EN/HD | Year |
|---|---|---|---|---|
| IEC 60728-2 | - | Cable networks for television signals, sound signals and interactive services - Part 2: Electromagnetic compatibility for equipment | EN 50083-2 | - |
| IEC 60728-3 | - | Cable networks for television signals, sound signals and interactive services - Part 3: Active wideband equipment for cable networks | EN 60728-3 | - |
| IEC 60728-6 | 2011 | Cable networks for television signals, sound signals and interactive services - Part 6: Optical equipment | EN 60728-6 | 2011 |
| IEC 60728-10 | 2014 | Cable networks for television signals, sound signals and interactive services - Part 10: System performance of return paths | EN 60728-10 | 2014 |
| IEC 60728-11 | - | Cable networks for television signals, sound signals and interactive services - Part 11: Safety | EN 60728-11 | - |
| IEC 60728-13 | 2010 | Cable networks for television signals, sound signals and interactive services - Part 13: Optical systems for broadcast signal transmissions | EN 60728-13 | 2010 |
| IEC 60728-13-1 | 2012 | Cable networks for television signals, sound signals and interactive services - Part 13-1: Bandwidth expansion for broadcast signal over FTTH system | EN 60728-13-1 | 2012 |
| IEC 60793-2-50 | 2012 | Optical fibres - Part 2-50: Product specifications - Sectional specification for class B single-mode fibres | EN 60793-2-50 | 2013 |
| IEC 60794-3-11 | 2010 | Optical fibre cables - Part 3-11: Outdoor cables - Product specification for duct, directly buried and lashed aerial single-mode optical fibre telecommunication cables | EN 60794-3-11 | 2010 |
| IEC 60825-1 | - | Safety of laser products - Part 1: Equipment classification and requirements | EN 60825-1 | - |
| IEC 61169-2 | - | Radio-frequency connectors - Part 2: Sectional specification - Radio frequency coaxial connectors of type 9,52 | EN 61169-2 | - |
| IEC 61169-24 | - | Radio-frequency connectors - Part 24: Sectional specification - Radio frequency coaxial connectors with screw coupling, typically for use in 75 ohm cable networks (type F) | EN 61169-24 | - |

| Publication | Year | Title | EN/HD | Year |
|---|---|---|---|---|
| IEC 61280-1-1 | - | Fibre optic communication subsystem basic test procedures - Part 1-1: Test procedures for general communication subsystems - Transmitter output optical power measurement for single-mode optical fibre cable | EN 61280-1-1 | - |
| IEC 61280-1-3 | - | Fibre optic communication subsystem test procedures - Part 1-3: General communication subsystems - Central wavelength and spectral width measurement | EN 61280-1-3 | - |
| IEC 61754-4 | - | Fibre optic interconnecting devices and passive components - Fibre optic connector interfaces - Part 4: Type SC connector family | EN 61754-4 | - |
| IEC/TR 61931 | 1998 | Fibre optic - Terminology | - | - |
| IEEE 802.3 | 2008 | IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part-3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications | - | - |
| IEEE 802.3av | 2009 | IEEE Standard for Information technology - Local and metropolitan area networks - Specific requirements - Part 3: CSMA/CD Access Method and Physical Layer Specifications - Amendment 1: Physical Layer Specifications and Management Parameters for 10 Gb/s Passive Optical Networks | - | - |

CONTENTS

# INTRODUCTION

Standards and other deliverables of the IEC 60728 series deal with cable networks including equipment and associated methods of measurement for headend reception, processing and distribution of television and sound signals and for processing, interfacing and transmitting all kinds of data signals for interactive services using all applicable transmission media. These signals are typically transmitted in networks by frequency-multiplexing techniques.

- regional and local broadband cable networks,
- extended satellite and terrestrial television distribution systems,
- individual satellite and terrestrial television receiving systems,

and all kinds of equipment, systems and installations used in such cable networks, distribution and receiving systems.

The extent of this standardization work is from the antennas and/or special signal source inputs to the headend or other interface points to the network up to the terminal input of the customer premises equipment.

The standardization work will consider coexistence with users of the RF spectrum in wired and wireless transmission systems.

The standardization of any user terminals (i.e., tuners, receivers, decoders, multimedia terminals, etc.) as well as of any coaxial, balanced and optical cables and accessories thereof is excluded.

The Annexes provide the following information.

| | |
|---|---|
| Annex A | describes implementation notes with design consideration based on this standard |
| Annex B | describes the system loss specification |
| Annex C | describes multiple CMTS operation |
| Annex D | contains specifications for an optional remote control system |
| Annex E | gives a design guideline of housings for R-ONU protection |
| Annex F | contains information on the effect of off-state optical power on $C/N$ ratio of transmission signal |

# CABLE NETWORKS FOR TELEVISION SIGNALS, SOUND SIGNALS AND INTERACTIVE SERVICES –

## Part 14: Optical transmission systems using RFoG technology

## 1 Scope

This part of IEC 60728 describes the system and equipment specification of FTTH/FTTB (fibre to the home/fibre to the building) networks where information is transmitted in both, forward and return path directions using RF subcarrier multiplexing technology, and where the return path transmission uses additionally time division multiple access technique imposed by the transmission of the return path signals using a TDMA (e.g. TDMA mode of DOCSIS) protocol. Such systems are called RF over Glass (RFoG) and consist of an RFoG optical network unit (R-ONU), an optical distribution network based on xPON structure, and an RFoG optical return path receiver. This standard specifies the basic system parameters and methods of measurement for RFoG systems in order to assess the system performance and its performance limits.

The detailed description of physical layer is out of the scope of this standard and it does not include IP transport technologies.

## 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 60068-1:1988, *Environmental testing – Part 1: General and guidance*

IEC 60068-2-1, *Environmental testing – Part 2-1: Tests – Test A: Cold*

IEC 60068-2-2, *Environmental testing – Part 2-2: Tests – Test B: Dry heat*

IEC 60068-2-6:2007, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-14, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60068-2-30, *Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60068-2-31, *Environmental testing – Part 2-31: Tests – Test Ec: Rough handling shocks, primarily for equipment-type specimens*

IEC 60068-2-40, *Environmental testing – Part 2-40: Tests – Test Z/AM: Combined cold/low air pressure tests*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60728-1, *Cable networks for television signals, sound signals and interactive services – Part 1: System performance of forward paths*

IEC 60728-2, *Cable networks for television signals, sound signals and interactive services – Part 2: Electromagnetic compatibility of equipment*

IEC 60728-3, *Cable networks for television signals, sound signals and interactive services – Part 3: Active wideband equipment for cable networks*

IEC 60728-6:2011, *Cable networks for television signals, sound signals and interactive services – Part 6: Optical equipment*

IEC 60728-10:2014, *Cable networks for television signals, sound signals and interactive services – Part 10: System performance of return path*

IEC 60728-11, *Cable networks for television signals, sound signals and interactive services – Part 11: Safety*

IEC 60728-13:2010, *Cable networks for television signals, sound signals and interactive services – Part 13: Optical systems for broadcast signal transmissions*

IEC 60728-13-1:2012, *Cable networks for television signals, sound signals and interactive services – Part 13-1: Bandwidth expansion for broadcast signal over FTTH system*

IEC 60793-2-50:2012, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60794-3-11:2010, *Optical fibre cables – Part 3-11: Outdoor cables – Product specification for duct, directly buried, and lashed aerial single-mode optical fibre telecommunication cables*

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 61169-2, *Radio-frequency connectors – Part 2: Sectional specification – Radio frequency coaxial connectors type 9,52*

IEC 61169-24, *Radio-frequency connectors – Part 24: Sectional specification – Radio-frequency coaxial connectors with screw coupling, typically for use in 75 ohm cable distribution systems (Type F)*

IEC 61280-1-1, *Fibre optic communication subsystem basic test procedures – Part 1-1:Test procedures for general communication subsystems – Transmitter output optical power measurement for single-mode optical fibre cable*

IEC 61280-1-3, *Fibre optic communication subsystem test procedures – Part 1-3: General communication subsystems – Central wavelength and spectral width measurement*

IEC 61754-4, *Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces – Part 4: Type SC connector family*

IEC/TR 61931:1998, *Fibre optics – Terminology*

IEEE Standard 802.3-2008, *Carrier sense multiple access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications (Includes the EPON standard). See also subsequent corrigenda*

IEEE Standard 802.3av-2009, *IEEE Standard for Information Technology-Part 3: Amendment 1: Physical Layer Specifications and Management Parameters for 10Gb/s Passive Optical Networks, October 2009*

# 3 Terms, definitions, symbols and abbreviations

## 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60728-1 and IEC/TR 61931 as well as the following apply.

### 3.1.1
**carrier-to-crosstalk ratio**
**CCR**
level difference of desired signal carrier level and worst case of other services single frequency crosstalk signal measured at RF output port of optical receiver

Note 1 to entry: *CCR* is defined by the following equation:

$$CCR = D - U_{\mathrm{OtherService}} \qquad (1)$$

where

| | |
|---|---|
| $D$ | is the nominal level of the desired signal in dB(μV) at RF output port of optical receiver; |
| $U_{\mathrm{OtherService}}$ | is the worst case level of another service's single frequency crosstalk in dB(μV) at RF output port of the optical receiver. |

Note 2 to entry: *CCR* is expressed in dB.

### 3.1.2
**equivalent input noise current density**
notional input noise current density which, when applied to the input of an ideal noiseless device, produces an output noise current density equal in value to that observed at the output of the actual device under consideration

Note 1 to entry: It can be calculated from the carrier-to-noise ratio $C/N$ (see IEC 60728-6) of a device or system using:

$$I_{\mathrm{r}} = \sqrt{\frac{C}{Z\, 10^{\frac{1}{10} C/N}}} \qquad (2)$$

where

| | |
|---|---|
| $C$ | is the power of the carrier at the input of the device or system, in W/Hz; |
| $Z$ | is its input impedance, in Ω. |

Note 2 to entry: The equivalent input noise current density is expressed in A/√Hz.

### 3.1.3
**extended satellite television distribution network or system**
distribution network or system designed to provide sound and television signals received by satellite receiving antenna to households in one or more buildings

Note 1 to entry: This kind of network or system can be combined with terrestrial antennas for the additional reception of TV and/or radio signals via terrestrial networks.

Note 2 to entry: This kind of network or system can also carry control signals for satellite switched systems or other signals for special transmission systems (e.g. MoCA or WiFi) in the return path direction.

**3.1.4**
**extended terrestrial television distribution network or system**
distribution network or system designed to provide sound and television signals received by terrestrial receiving antenna to households in one or more buildings

Note 1 to entry: This kind of network or system can be combined with a satellite antenna for the additional reception of TV and/or radio signals via satellite networks.

Note 2 to entry: This kind of network or system can also carry other signals for special transmission systems (e.g. MoCA or WiFi) in the return path direction.

**3.1.5**
**fibre optic branching device**
**<optical> <fibre> branching device**
**<optical> splitter**
DEPRECATED: <optical> <fibre> coupler
device, possessing three or more optical ports, which shares optical power among its ports in a predetermined fashion, at the same wavelength or wavelengths, without wavelength conversion

Note 1 to entry: The ports may be connected to fibres, sources, detectors, etc.

[SOURCE: IEC/TR 61931:1998, definition 2.6.21]

**3.1.6**
**flatness**
difference between the maximum and the minimum RF gain or attenuation not taking into account the slope within the specified modulation frequency range of a device or system

**3.1.7**
**headend system**
system comprising modulators, demodulators, CMTS, an optical transmitter with optional optical amplifiers and a WDM for the transmission of analogue video as well as digitally modulated signals located at the central office side of the optical network

Note 1 to entry: The headend system is equipped with an optical return path receiver receiving digitally modulated signals of data in the return path direction to enable e.g. VoIP, VOD and internet services.

Note 2 to entry: V-OLT is a part of the headend system and deals with video transmission in the forward path only.

**3.1.8**
**individual satellite television receiving system**
system designed to provide sound and television signals received from satellite(s) to an individual household

Note 1 to entry: This kind of system can also carry control signals for satellite switched systems or other signals for special transmission systems (e.g. MoCA or WiFi) in the return path direction.

**3.1.9**
**individual terrestrial television receiving system**
system designed to provide sound and television signals received via terrestrial broadcast networks to an individual household

Note 1 to entry: This kind of system can also carry other signals for special transmission systems (e.g. MoCA or WiFi) in the return path direction.

**3.1.10**
**local broadband cable network**
network designed to provide sound and television signals as well as signals for interactive services to a local area (e.g. one town or one village)

**3.1.11**
**multiplexing device**
**WDM device**
wavelength selective branching device (used in WDM transmission systems) in which optical signals can be transferred between two predetermined ports, depending on the wavelength of the signal

[SOURCE: IEC/TR 61931:1998, definition 2.6.51]

**3.1.12**
**noise power ratio**
***NPR***
ratio of the signal power density to the power density of the combined noise and intermodulation distortion

**3.1.13**
**off-state optical power**
residual optical output power emitted from the fibre of the R-ONU when the laser is switched to off-state

Note 1 to entry: In a typical burst mode transmitter, for fast switching operation, the laser bias may be kept near the threshold bias level to avoid turn-on and turn-off delays. The off-state optical power affects the system performance when a large number of transmitters are connected to the same distribution network.

**3.1.14**
**optical amplifier**
**OA**
optical waveguide device containing a suitably pumped, active medium which is able to amplify an optical signal

[SOURCE: IEC/TR 61931:1998, definition 2.7.75]

**3.1.15**
**optical distribution network**
**ODN**
passive optical network (PON) mainly consisting of optical fibres and splitters

**3.1.16**
**optical receiving unit**
**optical receiver**
**Rx**
receive fibre optic terminal device accepting at its input port a modulated optical carrier, and providing at its output port the corresponding demodulated electrical signal (with the associated clock, if digital)

[SOURCE: IEC/TR 61931:1998, definition 2.9.7]

Note 1 to entry: For the purposes of this standard, optical receivers may have more than one output port providing electrical RF signals.

**3.1.17**
**optical modulation index**
index defined as

$$m = \frac{\phi_h - \phi_l}{\phi_h + \phi_l} \qquad (3)$$

where $\phi_h$ is the highest and $\phi_l$ is the lowest instantaneous optical power of the intensity modulated optical signal

Note 1 to entry: This definition does not apply to systems where the input signals are converted and transported as digital baseband signals. In this case, the terms modulation depth or extinction ratio defined in 2.6.79 and 2.7.46 of IEC/TR 61931:1998 are used. A test procedure for extinction ratio is described in IEC 61280-2-2.

[SOURCE: IEC 60728-6:2011, definition 3.1.10, modified – repetition of "optical modulation" has been deleted.]

**3.1.18**
**optical return loss**
**return loss**
**ORL**
ratio of the total reflected power to the incident power from an optical fibre, optical device, or optical system, and defined as:

$$-10\lg\frac{P_r}{P_i} \qquad (4)$$

where

$P_r$ is the reflected power;

$P_i$ is the incident power

Note 1 to entry: When referring to a reflected power from an individual component, reflectance is the preferred term.

[SOURCE: IEC/TR 61931:1998, definition 2.6.49]

Note 2 to entry: For the purposes of this standard, the term reflectance is used for optical amplifiers only. The term optical return loss is used for ports of all other types of equipment.

Note 3 to entry: The term return loss is also used for electrical ports. The definition relates to electrical powers in this case.

Note 4 to entry: The ratio is expressed in dB.

**3.1.19**
**optical transmitting unit**
**optical transmitter**
**Tx**
transmit fibre optic terminal device accepting at its input port an electrical signal and providing at its output port an optical carrier modulated by that input signal

[SOURCE: IEC/TR 61931:1998, definition 2.9.6]

Note 1 to entry: For the purposes of this standard, optical transmitters may have more than one input port accepting electrical RF signals.

**3.1.20**
**radio frequency over glass**
**RFoG**
transmission technology on optical networks where information is transmitted in both, forward and return path directions, using RF subcarrier multiplexing technology, and where the return path transmission uses additionally time division multiple access technique imposed by the transmission of the return path signals using a TDMA (e.g. TDMA mode of DOCSIS) protocol

**3.1.21**
**reference output level of an optical receiver**
offset $x$ by which the electrical output level of an optical receiver can be calculated from the optical input level at a modulation index of $m$ = 0,05 using the following equation:

$$U = 2\,P_{\mathrm{opt,RX}} + x \ \mathrm{dB(\mu V)} \qquad (5)$$

where

$U$ is the electrical output level in dB(μV)

$P_{\mathrm{opt,RX}}$ is the optical input level in dB(mW)

$x$ is the reference output level in dB(μV)

**3.1.22**
**responsivity**
ratio of an optical detector's electrical output to its optical input at a given wavelength

Note 1 to entry: The responsivity is expressed in ampere per watt (A/W) or volts per watt (V/W) of incident radiant power.

Note 2 to entry: Sensitivity is sometimes used as an imprecise synonym for responsivity.

[SOURCE: IEC 60050-731:1991, 731-06-36, modified – "given wavelength" has been added and Note 1 has been clarified.]

Note 3 to entry: The wavelength interval around the given wavelength may be specified.

[SOURCE: IEC/TR 61931:1998, definition 2.7.56]

**3.1.23**
**relative intensity noise**
***RIN***
ratio of the mean square of the intensity fluctuations in the optical power of a light source to the square of the mean of the optical output power

Note 1 to entry: The *RIN* is usually expressed in dB($\mathrm{Hz}^{-1}$) resulting in negative values.

Note 2 to entry: The value for the *RIN* can be calculated from the results of a carrier-to-noise measurement for the system.

[SOURCE: IEC 60728-6:2011, 3.1.12]

**3.1.24**
**RFoG optical network unit**
**R-ONU**
fibre optic terminal comprising an optical receiver for reception of analogue signals and an optical transmitter for the transmission of analogue signals originating from the customer side of the optical network and a coaxial interface for the transmission of analogue signals to the customer network and reception of analogue signals from the customer network generally consisting of digital data using a TDMA (e.g. TDMA mode of DOCSIS) protocol

**3.1.25**
**slope**
gain or attenuation difference at two defined frequencies between two ports of a device or system

Note 1 to entry: In this standard the term slope relates only to the electrical gain or attenuation of equipment.

Note 2 to entry: In equipment for cable networks a line of best fit of the amplitude frequency response is considered at the band limits (see IEC 60728-6).

[SOURCE: IEC 60728-6:2011, 3.1.29]

**3.1.26**
**<stimulated> Brillouin scattering**
**SBS**
non-linear scattering of optical radiation characterized by a frequency shift as for the Raman scattering, but accompanied by a lower frequency (acoustical) vibration of the medium lattice; the light is scattered backward with respect to the incident radiation

Note 1 to entry: In silica fibres the frequency shift is typically around 10 GHz.

[SOURCE: IEC/TR 61931:1998, definition 2.1.88]

**3.1.27**
**video optical network unit**
**V-ONU**
terminal unit that changes the forward path optical signal into an electrical signal

Note 1 to entry: This functionality of this device is a part of an R-ONU.

**3.1.28**
**wavelength**
distance covered in a period by the wavefront of a harmonic plane wave

[SOURCE: IEC/TR 61931:1998, definition 2.2.9]

Note 1 to entry: The wavelength $\lambda$ of light in vacuum is given by

$$\lambda = \frac{c}{f} \tag{6}$$

where

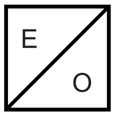
$c$ is the speed of light in vacuum ($c \approx 2{,}997\ 92 \times 10^8$ m/s);

$f$ is the optical frequency.

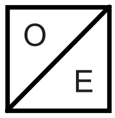
Note 2 to entry: Although the wavelength in dielectric material such as fibres is shorter than in vacuum, only the wavelength of light in vacuum is used.

### 3.2 Symbols

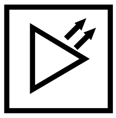
The following graphical symbols are used in the figures of this standard. These symbols are either listed in IEC 60617 or based on symbols defined in IEC 60617.



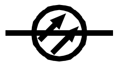

Optical transmitter based on [IEC 60617-S00213 (2001-07)]



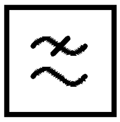

Optical receiver based on [IEC 60617-S00213 (2001-07)]



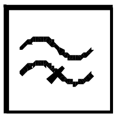
Optical amplifier based on [IEC 60617-S00127 (2001-07) and IEC 60617-S01239 (2001-07)]



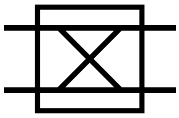
Optical fibre [IEC 60617-S01318 (2001-07)]



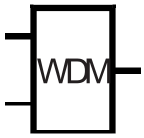
Low-pass filter [IEC 60617-S01248 (2001-07)]



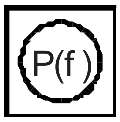
High-pass filter [IEC 60617- S01247 (2001-07)]



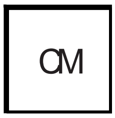
Directional coupler based on [IEC 60617-S00059 (2001-07) and IEC 60617-S01193 (2001-07)]




WDM

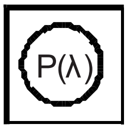



Electrical spectrum analyzer based on [IEC 60617-S00059 (2001-07) and IEC 60617-S00910 (2001-07)]

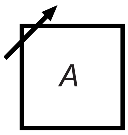



Cable modem

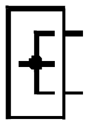

TV set



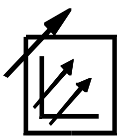

Optical spectrum analyzer based on [IEC 60617-S00059 (2001-07) and IEC 60617-S00910 (2001-07)]




Variable attenuator [IEC 60617-S01245 (2001-07)]



splitter/combiner



Polarisation control device [IEC 60617-S001430 (under consideration)]

### 3.3 Abbreviations

The following abbreviations are used in this standard:

| | | | |
|---|---|---|---|
| AC | alternating current | AGC | automatic gain control |
| CATV | community antenna television (network) | *C*/*N* | carrier-to-noise ratio |
| CCR | carrier-to-crosstalk ratio | CM | cable modem |
| CMTS | cable modem termination system | CSO | composite second order |
| CTB | composite triple beat | CW | continuous wave |

| | | | |
|---|---|---|---|
| DOCSIS | data over cable service interface specification | DS | downstream |
| EINC | equivalent input noise current | EMC | electromagnetic compatibility |
| EPON | Ethernet passive optical network (defined in IEEE Standard 802.3-2008) | FSK | frequency shift keying |
| FTTB | Fibre to the building | FTTH | fibre to the home |
| GEPON | Gigabit Ethernet passive optical network (defined in IEEE Standard 802.3-2008) | GPON | Gigabit-capable passive optical networks (defined in ITU-T Recommendation G.984) |
| HFC | hybrid fibre coaxial | MDU | multiple dwelling unit |
| MTBF | mean time between failure | $NPR$ | noise power ratio |
| OBI | optical beat interference | ODN | optical distribution network |
| OFDM | orthogonal frequency division multiplex | OMI | optical modulation index |
| ONU | optical network unit | PON | passive optical network |
| QAM | quadrature amplitude modulation | QPSK | quadrature phase shift keying |
| RF | radio frequency | RFoG | RF over glass |
| $RIN$ | relative intensity noise | R-ONU | RFoG optical network unit |
| Rx | (optical) receiver | SBS | stimulated Brillouin scattering |
| SDU | single dwelling unit | Tx | (optical) transmitter |
| US | upstream | V-ONU | video optical network unit |
| WDM | wavelength division multiplexing | XG-PON | 10-Gigabit-capable passive optical network (defined in ITU-T Recommendation G.987) |

## 4 System reference model

Figure 1 shows the optical system reference model for forward path signal transmission and return path signal transmission. The forward path signal transmission system is the subject of IEC 60728-13. Compared to Figure 1 in IEC 60728-13:2010 the V-ONU has been replaced by an R-ONU which adds a WDM and a burst mode return path transmitter to the V-ONU. The R-ONU is capable of transmitting interactive signals and is therefore connected to a cable modem (CM) as well.

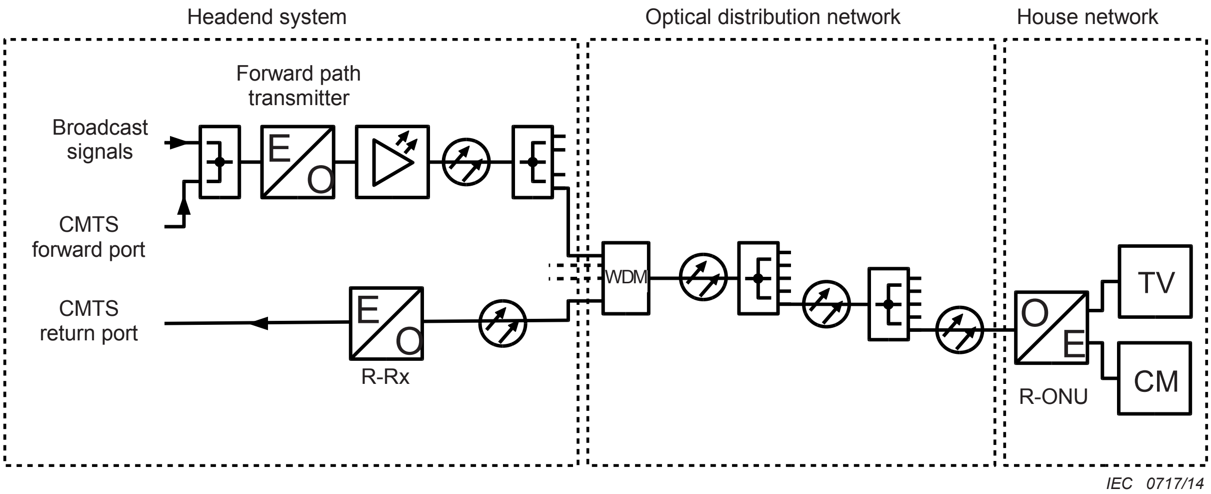



**Figure 1 – Optical system reference model for RFoG**

Figure 1 illustrates the reference architecture of the system. In the reference architecture, the headend system, the start of the RFoG system, comprises an optical forward path transmitter operating nominally on 1 550 nm, optical amplification and splitting as appropriate, and an optical return path receiver which receives optical return path signals on $\lambda_{up}$ (defined below), and converts them to RF form. The wavelength division multiplexer used to combine and separate the two wavelengths is a part of the headend system. For the purpose of optical loss budget calculation the WDM optical loss shall be included in the total loss of ODN, consistent with the ODN definition in EPON and GPON.

Specifications contained in this standard apply between the electrical signal terminal of the headend system and the RF electrical terminal from the R-ONU. The system designer is responsible for making sure that the effects of any signal degradation are properly accounted for in the network design. Return path system performance will vary by choice of optical return path receiver hardware. Receiver noise performance and technology choice determines interoperability. The ODN is defined to start at the input of the WDM at the optical headend system and to end at the pigtail on the R-ONU at the home.

The ODN is shown with a single point splitter. However, the ODN may also be implemented as a series of optical taps or as a multi-layer splitter, such as a 1:4 split followed by a set of 1:8 splitters at a different location. So long as the maximum distance, loss budget, and split ratio are respected, the architecture of the splitting is at the discretion of the operator.

## 5 RFoG ONU reference architecture

Figure 2 illustrates the ONU reference architecture. The ONU comprises a wave division multiplexer (WDM) which separates the optical forward path signal at 1 550 nm nominal and the optical return path signal at $\lambda_{up}$. The forward path receiver recovers RF forward path signals from the 1 550 nm (nominal) forward path optical carrier and supplies them to the output via a diplexer.

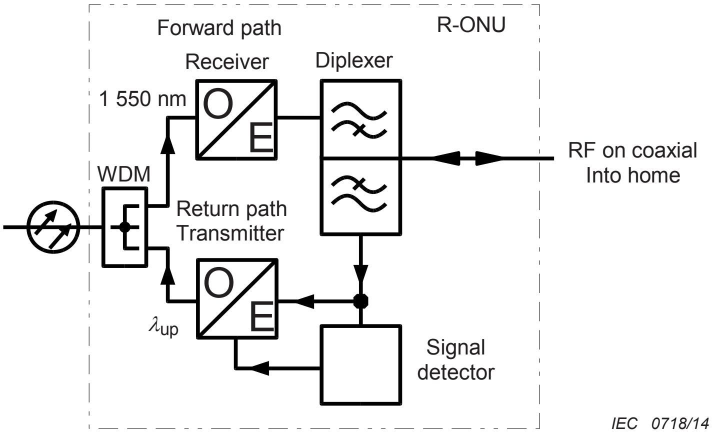



**Figure 2 – Principle schematics of R-ONU**

The low port of the diplexer supplies return path signals to a return path transmitter whose output is at $\lambda_{up}$. It also supplies signals to a signal detector, whose job it is to turn on the return path transmitter when RF signals in the return path band are detected at a level exceeding a specified minimum threshold.

The specification permits either of two return path wavelengths $\lambda_{up}$. One permitted wavelength is 1 310 nm nominal, and the other is 1 610 nm nominal. Use of 1 610 nm permits an optional overlay of an RFoG system with either an IEEE 802.3-2008 / IEEE 802.3av-2009 (EPON) system or an ITU G.984 / ITU G.987 (GPON) system. Both systems use 1 310 nm or lower wavelengths for return path data communications. Both return path wavelengths work with the same physical network. Note that if the 1 310 nm return path wavelength is used for RFoG, then neither EPON nor GPON will coexist in the same physical passive optical network.

For compatibility with 10G-EPON or XG-PON systems, the 1 610 nm return path option may be used, but will need an external optical trap at 1 577 nm (nominal) to eliminate that forward path carrier. Alternatively, a manufacturer may offer an R-ONU with a built-in optical trap, or the operator may choose to deploy RFoG and 10G-EPON or XG-PON on separate networks with co-located splitting.

## 6 Method of measurements

### 6.1 Optical power

The measurement of optical power at single wavelength shall be carried out according to IEC 61280-1-1. For measuring the total average optical power of multiple wavelengths emanating from the end of a test fibre, the method described in IEC 60728-13 shall be used.

NOTE In general, there is no wavelength selectivity in the optical power meter that is calculated and is displayed as total optical power. Therefore, it is necessary to separate wavelength by the WDM coupler or WDM filter. In that case, it is necessary to compensate the loss of the WDM filter used.

### 6.2 Centroidal wavelength and spectral width under modulation

For measuring the centroidal wavelength $\lambda_0$ of the spectrum and the spectral width $\Delta\lambda$ of a transmitter under modulation, the method described in IEC 61280-1-3 shall be used. The centroidal wavelength and the spectral width shall be expressed in nanometres. This method is not suitable for light sources and transmitters with very narrow spectral width (single mode laser) or for measuring the chirping of transmitters.

## 6.3 Optical wavelength

The optical wavelength, in the RFoG system, shall be measured following the description given below.

If a single R-ONU is used to receive multiple wavelengths simultaneously without any WDM filter, a test WDM filter shall be used to measure the individual optical wavelength at the input of R-ONU. The measurement setup is shown in Figure 3.

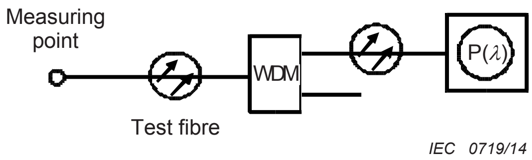



**Figure 3 – Measurement of optical wavelength using WDM coupler**

For measuring the central wavelength $\lambda_0$ of the spectrum of an optical signal under modulation, the method described in IEC 61280-1-3 shall be used. The central wavelength shall be expressed in nm.

## 6.4 Linewidth and chirping of transmitters with single mode lasers

The measurement of linewidth and chirping of transmitter with single mode lasers shall be carried out according to 4.7 of IEC 60728-6:2011.

## 6.5 Optical modulation index

The measurement of optical modulation index shall be carried out according to 4.8 of IEC 60728-6:2011.

## 6.6 Reference output level of an optical receiver

The measurement of reference output of an optical receiver shall be carried out according to 4.9 of IEC 60728-6:2011.

## 6.7 Noise parameters of optical transmitters and optical receivers

The measurement of noise parameters of optical transmitters and optical receivers shall be carried out according to 4.16 of IEC 60728-6:2011.

## 6.8 Relative intensity noise (*RIN*), optical modulation index and equivalent input noise current (EINC)

The method of measurement for relative intensity noise (*RIN*), optical modulation index (OMI) and equivalent input noise current (EINC) shall be carried out according to 4.17 of IEC 60728-6:2011.

## 6.9 Carrier level and carrier-to-noise ratio

The method of measurement for carrier level and carrier-to-noise ratio in the electrical domain shall be carried out according to 6.3 of IEC 60728-13:2010.

## 6.10 Noise power ratio (*NPR*)

The measurement of noise power ratio (*NPR*) shall be carried out according to 4.12 of IEC 60728-10:2014.

### 6.11 Carrier-to-noise ratio defined by optical signal

The measurement method for carrier level and carrier-to-noise ratio in the optical domain shall be carried out according to 6.4 of IEC 60728-13:2010.

### 6.12 Carrier-to-crosstalk ratio (CCR)

This method of measurement is applicable when other services (i.e. digital communication signals like GPON, GEPON or Ethernet-Point-to-Point) besides forward path signals of regional and local broadband cable networks (i.e. AM-VSB, 64/256QAM, OFDM, TC8PSK and QPSK) are transmitted in the optical network. Other services may produce crosstalk effects in optical fibres and in optical receiver devices with high linearity. The carrier-to-crosstalk ratio (CCR) of broadcast signals shall be measured according to the method described in 6.6 of IEC 60728-13:2010.

## 7 System performance requirements

### 7.1 Digital data system

#### 7.1.1 ODN

The optical distribution network shall meet the requirements in Table 1.

**Table 1 – ODN Specifications**

| Specification | Value |
|---|---|
| Operating distance, optical hub to R-ONU (D) for 1:32 split ratio [a,b] | 0 km to 20 km |
| Highest loss budget under which the system shall operate (L) | 25 dB [c] |
| Lowest loss budget under which the system shall operate | 5 dB lower than the highest loss. If the system design has even less loss (e.g., if the split ratio is low) then the system design shall make up the loss. See Annex A, for a discussion of the minimum loss budget. |
| Assumed optical fibre type | IEC 60794-3-11 cable standard using B1.3 or B6 category optical fibres (IEC 60793-2-50) [d] |

[a] Longer distances may be possible, but the designer should keep the distance limits of EPON and GPON in mind if migration to either standard is contemplated.

[b] Any ratio may be used so long as the total loss budget is respected. Depending on the splitting architecture, stimulated Brillouin scattering (SBS) may limit operation to a lower split ratio (see Annex B for more information). Typical PON implementations normally use split ratios of 32 and, rarely, 64, limited by available optics, so using a higher split ratio may make use of those standards infeasible unless an intermediate interface is used.

[c] Operation with loss budgets greater than 25 dB is optional. See Annex B for a discussion.

[d] A cross-reference between IEC fibre categories and ITU-T G.65x Recommendations can be found in either IEC 60793-2-50:2012 (Table I.1) or in IEC 60794-3-11:2010 (Table A.1)

#### 7.1.2 Performance allocation

The general system specification for the forward path transmission is specified in Table 9 of IEC 60728-13:2010 and/or in Table 7, of IEC 60728-13-1:2012.

The general system specification for the return path transmission is specified in Table 6 of IEC 60728-10:2014. An example for the return path performance allocation is given in Clause B.3.

The required values for minimum system *RIN* and corresponding *C/N* are laid down in 7.3 of IEC 60728-13:2010.

### 7.2 Forward path and return path frequency split

The crossover between return path and forward path RF frequencies shall meet the requirements of one of the options in Table 2. The frequencies given in Table 2 are the values that the R-ONU shall be specified to support. The inequalities are given to allow for R-ONU implementations that are manufacturer-specified to include a maximum return path and/or minimum forward path frequency that provides a wider passband than the listed value.

**Table 2 – RF frequencies**

| Option | Upper limit of return path frequency band $f_{US,max}$ MHz | Lower limit of forward path frequency band $f_{DS,min}$ MHz |
|---|---|---|
| Option 42/54 | ≥42 | ≤54 |
| Option 55/70 | ≥55 | ≤70 |
| Option 65/85 | ≥65 | ≤85 |
| Option 85/105 | ≥85 | ≤105 |

## 8 RFoG equipment specifications

### 8.1 General specifications

#### 8.1.1 Safety

The relevant safety requirements of all equipment shall conform to IEC 60728-11, where applicable. Concerning laser safety, optical transmitters and optical amplifiers shall additionally fulfil the requirements of IEC 60825-1.

#### 8.1.2 Electromagnetic compatibility (EMC)

The limits of radiation and susceptibility to interference for all equipment covered by this standard are laid down in IEC 60728-2.

#### 8.1.3 Environmental conditions

##### 8.1.3.1 Requirements

Manufacturers shall publish relevant environmental information on their products in accordance with the requirements of the relevant parts of IEC 60068 as specified below:

##### 8.1.3.2 Storage

Climatic category of component or equipment for storage and operation IEC 60068-1

#### 8.1.3.3 Transportation

| | |
|---|---|
| Air freight (combined cold and low pressure) | IEC 60068-2-40 |
| Road transport (shock test) | IEC 60068-2-27 |

#### 8.1.3.4 Installation or maintenance

| | |
|---|---|
| Rough handling test | IEC 60068-2-31 |

#### 8.1.3.5 Operation

| | |
|---|---|
| IP Class: Protection provided by enclosures | IEC 60529 |
| Climatic category of component or equipment for storage and operation as defined in | Appendix A of IEC 60068-1:1988 |
| Cold | IEC 60068-2-1 |
| Dry heat | IEC 60068-2-2 |
| Damp heat | IEC 60068-2-30 |
| Change of temperature (test Nb) | IEC 60068-2-14 |
| Vibration (sinusoidal) | Annex B of IEC 60068-2-6:2007 |

This will enable users to judge the product's suitability with regard to four main requirements: storage, transportation, installation and operation.

### 8.1.4 Marking

Equipment shall be legibly and durably marked with the manufacturer's name and type number.

It is recommended that symbols in accordance with IEC 80416 and IEC 60417 are used when marking ports.

## 8.2 R-ONU

### 8.2.1 Indicators

The R-ONU shall provide visual indication of the presence of DC power and of forward path optical power.

The visual indication of forward path optical power shall be on at levels above −13 dB(mW).

### 8.2.2 R-ONU forward path receiver specifications

Optical receivers for various applications are specified in 6.3 of IEC 60728-6:2011. Classes A to D in Table 3 correspond with these types. Additionally classes H to J are introduced, class J reflects the requirements on forward path receivers for applications as specified in IEC 60728-13-1:2012.

**Table 3 – Classification of R-ONU optical receivers**

| Class | Characteristics |
|---|---|
| A | High electrical output level 1GHz |
| B | Low electrical output level 1 GHz |
| D | Fibre to the building 1 GHz FTTB |
| H | Low electrical output level 1 GHz RFoG |
| I | High electrical output level 1 GHz RFoG |
| J | Low electrical output level 2,6 GHz RFoG |

The manufacturer shall at least publish information on the parameters listed in Table 4. Given figures are recommended values.

**Table 4 – Data publication requirements for R-ONU optical receivers**

| Parameter | Class A | Class B | Class D | Class H | Class I | Class J |
|---|---|---|---|---|---|---|
| Equivalent input noise current density in pA/√Hz | <6 | <6 | <5 | <6 | <6 | <8 |
| Reference output level at 862 MHz and OMI = 5 % | – | | | (80±3) dB(μV) | (98±3) dB(μV) | (80±3) dB(μV) |
| Receiver intermodulation at OMI = 3,5 %<br>– second order<br>– triple beat | <br>>60 dB<br>>70 dB | | | <br>>60 dB<br>>60 dB | <br>>60 dB<br>>60 dB | <br>>60 dB<br>>60 dB |
| Fibre connection | Connector/splice type and type of fibre | | | High return loss connector according to IEC 61754-4 | High return loss connector according to IEC 61754-4 | High return loss connector according to IEC 61754-4 |
| Power consumption | – | | | | | |

The manufacturer shall additionally publish information on parameters deviating from the recommendations as specified in Table 5.

**Table 5 – Recommendations for R-ONU optical receivers**

| Parameter | Class A | Class B | Class D | Class H | Class I | Class J |
|---|---|---|---|---|---|---|
| Wavelength range [a] | 1 540 nm to 1 560 nm | | | | | |
| Optical input power [b] | (–7 to 0) dB(mW) | (–4 to 3) dB(mW) | (–10 to –1) dB(mW) | (–8 to 0) dB(mW) | (–8 to 0) dB(mW) | (–12 to –6) dB(mW) |
| Output level adjustment range | >10 dB | | | | N/A | |
| Slope ($f_{DSmin}$ to 1 006 MHz) | (0 to 12) dB | (0 to 6) dB | 0 | (5±2) dB | (5±2) dB | (5±2) dB |
| Flatness<br>($f_{DSmin}$ to 1 006 MHz)<br>($f_{DSmin}$ to 2 400 MHz) | <br><3 dB<br>– | <br><2 dB<br>– | <br><4 dB<br>– | <br><4 dB<br>– | <br><4 dB<br>– | <br><4 dB<br>8 dB |
| Frequency range $f_{DSmin}$ to | 1 006 MHz | | | 1 006 MHz | 1 006 MHz | 2 600 MHz |

| | | | | | |
|---|---|---|---|---|---|
| Supply voltage | One of the following: DC 48 V / 120 V or AC 65 V / 230 V | | At least one of the following: DC (10,5 to 18) V (12 V nominal) or AC 100 V or AC 230 V [c] | At least one of the following: DC (10,5 to 18) V (12 V nominal) or AC 100 V or AC 230 V | At least one of the following: DC (10,5 to 18) V (12 V nominal) or AC 100 V or AC 230 V [c] |
| DC monitor output for optical input power | 10 V/mW | 1 V/mW | 1 V/mW | 1 V/mW | 1 V/mW |
| Mechanical dimensions | For operation in buildings: 19″ (482,6 mm) rack mountable | | Outdoor use / Indoor use | Outdoor use / Indoor use | Outdoor use / Indoor use |

[a] Refer to Annex A for comments on 10 Gbit/s compatibility.

[b] Received optical power over which RF output level, slope, and frequency response specifications shall be met. At optical powers below specified optical input power range AGC may not be effective. Thus, the RF output level is allowed to decrease 2 dB for every 1 dB decrease in optical power.

[c] DC powering shall be capable to be fed through the RF connector with centre conductor positive with respect to ground. Additional power connection methods may be supplied.

The forward path receiver of the R-ONU shall meet all the requirements in Table 6.

**Table 6 – Performance requirements for R-ONU optical receivers**

| Parameter | Classes A and B | Class D | Class H and I | Class J |
|---|---|---|---|---|
| Responsivity of the internal photo diode | ≥0,9 A/W for the whole wavelength range | | | |
| Electrical output port | Impedance: 75 Ω<br>Connector: IEC 60169-2 female or IEC 61169-24<br>Return loss: according to category B defined in IEC 60728-3 | | Impedance: 75 Ω<br>Connector: IEC 61169-24<br>Return loss: according to category B defined in IEC 60728-3 | |
| Optical return loss | >45 dB | >40 dB | >40 dB | |
| Indicators | Optical input level failure | | | |
| Alarms | Optical input level failure<br>Out of AGC range (if AGC available) | | N/A | |

### 8.2.3 Return path performance of R-ONU

#### 8.2.3.1 Classification

Two wavelength options, as classified in Table 7, are provided in the return path. The return path wavelength may be 1 310 nm for maximum cost effectiveness, or 1 610 nm in order to allow the same PON to be used for RFoG and GPON or EPON applications. The return path band shall be specified in purchase documents, and a corresponding WDM and return path receiver shall be used at the optical hub.

**Table 7 – Classes of optical return path transmitters**

| Class | Application |
|---|---|
| R1R | Secondary wavelength, only for systems not needing compatibility with EPON or GPON |
| R2R | Primary wavelength, compatible with EPON or GPON. |

#### 8.2.3.2 Data publication requirements

Manufacturers shall at least publish information on the parameters listed in Table 8. Given figures are recommended values.

**Table 8 – Data publication requirements for optical return path transmitters**

| Parameter | Class R1R | Class R2R |
|---|---|---|
| Type of light source | FP or DFB | DFB |
| Fibre connection | High return loss connector according to IEC 61754-4 | |
| Power consumption | – | |
| Test point output attenuation | if test point provided | |

#### 8.2.3.3 Optical performance requirements

Optical return path transmitters of the R-ONU according to this standard shall meet the requirements of one of the following classes as listed in Table 9. All specifications shall be met when the same fibre is carrying either EPON or GPON signalling. This does not necessarily include 10 Gbit/s systems unless the R-ONU manufacturer claims coexistence with 10 Gbit/s systems. Otherwise, coexistence with 10 Gbit/s systems may require a blocking filter (see Annex A for more information).

**Table 9 – Performance requirements for optical parameters and interfaces**

| Parameter | Class R1R | | Class R2R | |
|---|---|---|---|---|
| Wavelength in nm | 1 310 | | 1 610 | |
| Wavelength tolerance in nm (includes effects of temperature) | ±50 | | ±10 | |
| Output power in dB(mW) | Indoor units | Outdoor units | Indoor units | Outdoor units |
| Low power version | 1,5 ± 1 | 1,5 ± 1,5 | 1,5 ± 1 | 1,5 ± 1,5 |
| Medium power version | 3 ± 1 | 3 ± 1,5 | 3 ± 1 | 3 ± 1,5 |
| High power version | 6 ± 1 (DFB only) | 6 ± 1,5 (DFB only) | 6 ± 1 | 6 ± 1,5 |
| Maximum “off state” optical power in dB(mW) | –30 | | | |
| *RIN* in dB($Hz^{-1}$) | < –130 | | < –145 | |
| Minimum optical return loss of the system to be tolerated (discrete reflections only) in dB | –45 | | | |
| Fibre connection | Connector/splice type and type of fibre | | | |
| Coexistence with EPON or GPON | not required | | required | |

#### 8.2.3.4 Performance requirements for electrical parameters and interfaces

Optical return path transmitters according to this standard shall fulfil the requirements on the electrical properties of one of the following classes, see Table 10.

**Table 10 – Electrical properties requirements for R-ONU optical return path transmitters**

| Parameter | Class R1R | Class R2R |
|---|---|---|
| RF input level for obtaining m = 0,35 | +99 dB(μV) | +99 dB(μV) |
| Variation of OMI for constant RF input level over full rated temperature range [a] | ±3 dB | |
| Nominal channel capacity [b] | Four 6,4 MHz wide channels | |
| Nominal RF input level per channel (return path RF into R-ONU) | 93 dB(μV) per carrier | |
| Flatness | ±2 dB, 5 MHz to $f_{\mathrm{US,max}}$ MHz | |
| Noise Power Ratio (*NPR*) [c] | ≥38 dB over a ≥10 dB dynamic range | |
| Maximum power level (total power, continuous, no damage) | 120 dB(μV) | |
| Electrical input port<br>(for stand-alone equipment only) | Impedance: 75 Ω<br>Connector: IEC 61169-2 female or IEC 61169-24<br>Return loss: according to category B defined in IEC 60728-3 | |
| Supply voltage | One of the following: DC 48 V / 120 V or AC 65 V / 100 V / 230 V (if used as stand-alone equipment) | |
| Indicators | Laser “on” indicator, indicating when light is emitted | |
| dBc = decibel referred to carrier signal level | | |

[a] The OMI is measured with a CW carrier inserted at the specified carrier amplitude. The specified OMI and carrier amplitude are the recommended design level for total composite RF power at the R-ONU coaxial port when fully loaded. If a four channel operation is used, the level of each channel at the R-ONU coaxial port will be 6 dB lower. See Annex A for guidance on channel characteristics.

[b] The nominal channel capacity is used to derive the nominal RF input level per channel specification and to estimate the performance of a return path channel in a typical deployment. These values are suggested and are not mandatory. R-ONUs should function with higher channel loads, but performance may be reduced. See Annex A for guidance on channel characteristics and additional considerations.

[c] R-ONU return path *NPR* cannot easily be measured in a link with high optical loss. To measure *NPR*, it is necessary to use a link with relatively low optical loss. The noise loading for the *NPR* test shall be 37 MHz of broadband noise from 5 MHz to 42 MHz with a nominally centred notch. *NPR* shall be tested with 20 km of fibre and additional attenuation resulting in –10 dB(mW) optical power into the test receiver. The test receiver shall have an EINC over the return band of 5 MHz to 42 MHz of no greater than 2,5 pA√Hz and two tone IM2 and IM3 products better than –60 dBc at 20 % OMI per tone and 0 dB(mW) total optical received power. The test setup should have the optical attenuation placed between the transmitter and the fibre.

#### 8.2.3.5 Dynamical properties of the R-ONU return path transmitter

The R-ONU shall meet the turn-on and turn-off characteristics specified in Table 11. The characteristics are illustrated in Figure 4. The turn-on and turn-off characteristics shall be tested with a single continuous wave (CW) RF carrier.

**Table 11 – R-ONU turn-on and turn-off specifications**

| Interval | Specification | Value |
|---|---|---|
| N/A | Power at which R-ONU shall not turn on | ≤67 dB(μV) |
| N/A | Power at which R-ONU shall turn on [a] | ≥76 dB(μV) |
| N/A | Power at which R-ONU should turn on [a] | ≥73 dB(μV) |
| N/A | Power of “on” level at which R-ONU laser should not turn on with pulsed on/off RF input (50 % duty cycle, 100 ns period) | ≤70 dB(μV) |

| Interval | Specification | Value |
|---|---|---|
| N/A | Power of "on" level at which the R-ONU laser should turn on within time T1 (defined below and in Figure 4), when tested using a continuous 50 % duty cycle pulsed on/off RF input, 50 ns on and 50 ns off. | ≥76 dB(μV) |
| N/A | Power at which R-ONU shall not turn off [b] | ≥61 dB(μV) |
| N/A | Power at which R-ONU should not turn off [b] | ≥58 dB(μV) |
| N/A | Power at which R-ONU shall turn off | ≤52 dB(μV) |
| T1: Don't turn on too late | Maximum time from application of RF to 90 % optical power (read to late-side mask) | 1,3 μs |
| T2: Don't turn on too fast | Minimum 10 % to 90 % optical power rise time (read from late-side mask 10 % to early-side mask 90 %) | 100 ns |
| T3: Don't turn on too slow | Maximum optical power rise time (read from early-side mask 10 % to late-side mask 90 %). If there is overshoot on the optical power, use the value after the overshoot has dissipated. | 1,0 μs |
| Don't turn on by mistake | Power at which a single isolated pulse ≤90 ns long should not turn on the laser | ≤125 dB(μV) |
| T11: Don't turn off too late | Maximum time from removal of RF (defined as RF dropping to 52 dB(μV)) to the time the optical carrier falls to 10 % of its steady-state amplitude (read to late-side mask) | 1,6 μs |
| T12: Don't turn off too fast | Minimum (90 to 10) % optical power fall time | 100 ns |
| T13: Don't turn off too slow | Maximum (90 to 10) % optical power fall time | 1,0 μs |
| T14: Don't turn off by mistake | When the turn-off threshold is >58 dB(μV), the R-ONU shall not drop the laser power below 90 % for a sudden drop in RF input power to ≤52 dB(μV) that lasts ≤600 ns. For the same turn-off threshold, the R-ONU may allow the laser power to remain above 90 % for a sudden drop in RF input power to ≤52 dB(μV) that lasts >600 ns.<br><br>When turn-off threshold is ≤58 dB(μV), the R-ONU shall not drop the laser power below 90 % for a sudden drop in RF input power to ≤52 dB(μV) that lasts ≤400 ns. For the same turn-off threshold, the R-ONU may allow the laser power to remain above 90% for a sudden drop in RF input power to ≤52 dB(μV) that lasts >400 ns [c]. | See left column |
| Should maintain turn on with ramp up input | Upon reaching 90 % optical power during turn on, subsequent time during which optical power should not drop below 90 % of its steady-state amplitude | ≤12 μs |
| Should reach and maintain steady-state stability upon turn on | Maximum time after application of a valid turn on RF input in which the optical modulator should achieve and maintain RF signal level stability within ±0,1 dB, observed at the output of a reference optical-to-electrical converter (also reach and maintain *NPR* required performance) | 1,3 μs |

[a] To allow flexibility in the laser activation implementation and provide greater noise immunity in the RFoG system, the "shall turn on" level may be increased by up to 3 dB relative to the "should turn on" level. This will delay the absolute start of laser activation by less than 1/3 of a symbol period.

[b] To allow flexibility in the laser de-activation implementation and provide greater noise immunity in the RFoG system, the "shall not turn off" level may be increased by up to 3 dB relative to the "should not turn off" level.

[c] For a sudden drop in RF input power to 52 dB(μV), a valid input signal will remain below the higher threshold (61 dB(μV) ) for more time than below the lower threshold (58 dB(μV)).

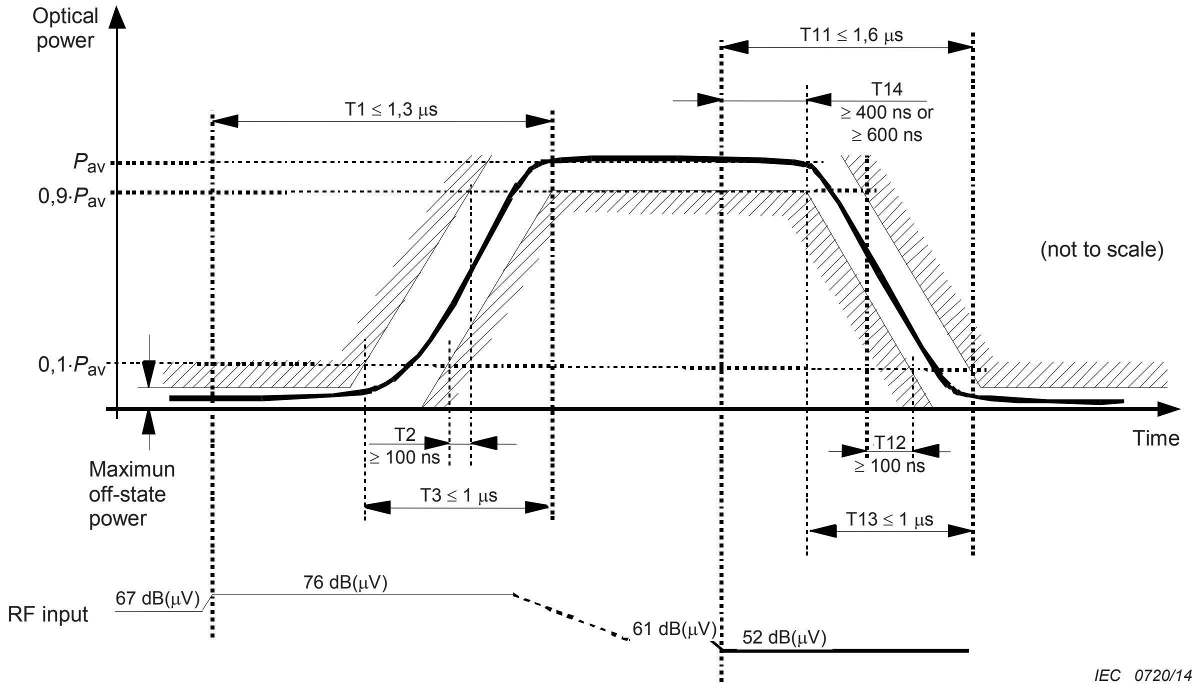



**Figure 4 – R-ONU turn-on and turn-off diagram**

Note that the turn-on and turn-off characteristics shown in Figure 4 apply for transitions between any RF power within the "off" power range and any RF power within the normal operating range of the R-ONU.

### 8.2.4 Remote control functions

#### 8.2.4.1 General description

This standard defines the optional remote control function of an R-ONU (RFoG optical network unit) device. The R-ONU is a fibre node used in RFoG (RF over glass) networks to convert optical signals into RF signals for forward path signals and RF signals into optical signals for return path signals.

The remote control specified in this standard comprises forward and return path RF signal functions and the return path optical signal functions of the R-ONU device.

For remote control, an RFoG remote control manager device installed in the headend is required. The remote control manager provides the remote control commands, which are transmitted "in band" via RFoG network forward transmission path.

#### 8.2.4.2 Remote control system configuration

An example of the remote control system configuration is shown in Figure 5.

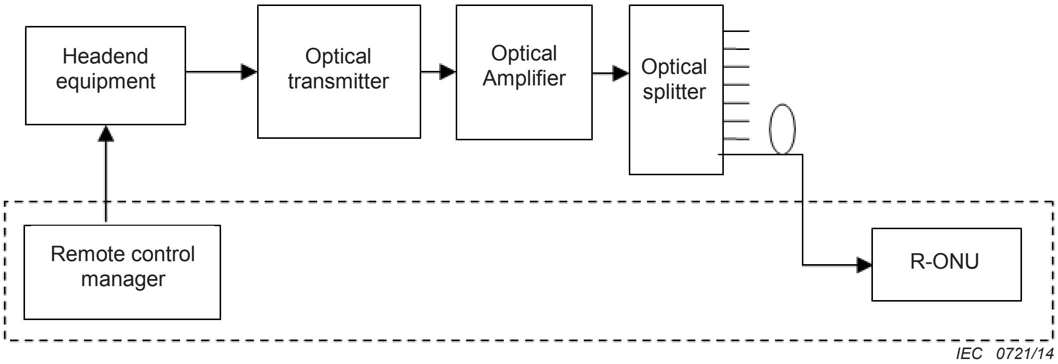



**Figure 5 – Example of the remote control system configuration**

The remote control signal is generated by the remote control manager situated in the headend, and is frequency-multiplexed with the forward path signals in the forward path. In the R-ONU, the remote control signal is demodulated and processed.

### 8.2.4.3 Remote control items

The remote control items defined in this standard are shown in Table 12.

Setting the RF output to ON in all R-ONUs should be performed simultaneously.

**Table 12 – Remote control items**

| Controlled item | Function |
|---|---|
| Forward path RF output signal | Control forward path RF output signal of R-ONU OFF / ON by the remote control manager, individually. |
| | Set RF output signal ON in all R-ONUs by the remote control manager, simultaneously. [a] |
| Return path optical signal | Control return path optical signal of R-ONU OFF / ON by the remote control manager, individually. |
| [a] When not performing the simultaneous control, control the R-ONU based on the information from the remote control manager. | |

#### 8.2.4.4 Specification of data communication

##### 8.2.4.4.1 Fundamental specification of data communication

The fundamental data communication is shown in Table 13.

**Table 13 – Fundamental specification of data communication**

| Item | Specification |
|---|---|
| Data transfer rate | 19,2 kbit/s ± 0,5 % |
| Synchronisation | Asynchronous mode |
| Communication mode | One-way communication |
| Data format | 1 start bit<br>8 data bits<br>1 stop bit<br>1 parity bit, even |
| Error check | BCC (XOR) |

##### 8.2.4.4.2 Data format

The data format of asynchronous mode is shown in Figure 6.

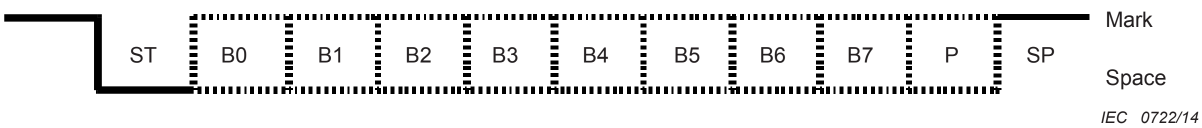



**Figure 6 – Data format**

##### 8.2.4.4.3 Data packet

The structure of data packet is shown in Figure 7 and its content is listed in Table 14 and Table 15.

| Header | R-ONU address | Control command | Error check |
|---|---|---|---|
| (1 B) | (6 B) | (1 B) | (1 B) |

**Figure 7 – Structure of data packet**

**Table 14 – Content of data packets**

| | |
|---|---|
| Header (1 B) | Used in combination with control command below |
| R-ONU address (6 B) | R-ONU address: 6 B, see Table 15 |
| Control command (1 B) | R-ONU control commands are implemented by combining the header byte and the control command byte, as defined in 8.2.4.5. |
| Error check (1 B) | The XOR calculation for each data from header to control command in the packet structure |

**Table 15 – R-ONU address**

| | | |
|---|---|---|
| 3 B | Vendor_ID | Vendor specific ID (same as IEEE standards OUI) |
| 3 B | Decoder_ID | R-ONU unique ID |

### 8.2.4.5 Control transfer process

The control transfer process is shown in Figure 8.

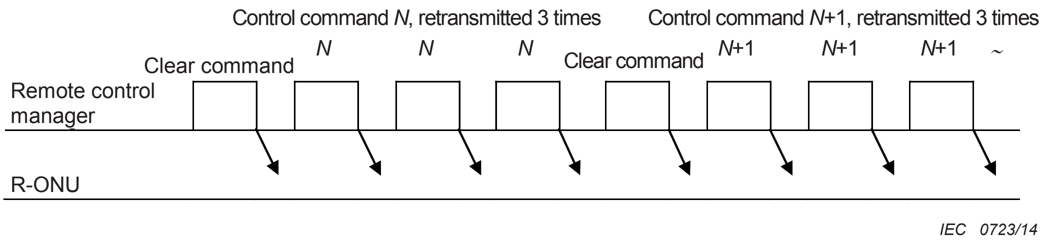



**Figure 8 – Control transfer process**

Each control transfer process from the remote manager to the R-ONU consists of 4 data packets. One "clear command" packet (defined in 8.2.4.7) followed by a control command packet retransmitted 3 times. The timing specification for a complete control transfer process is specified in 8.2.4.6.

The R-ONU has to receive a "clear command" packet followed by at least 2 (of 3) error free command packets of same content within the specified time window to execute the desired command.

### 8.2.4.6 Timing of control transfer process

The specification of the timing of the data transmission is shown in Figure 9 and Table 16.

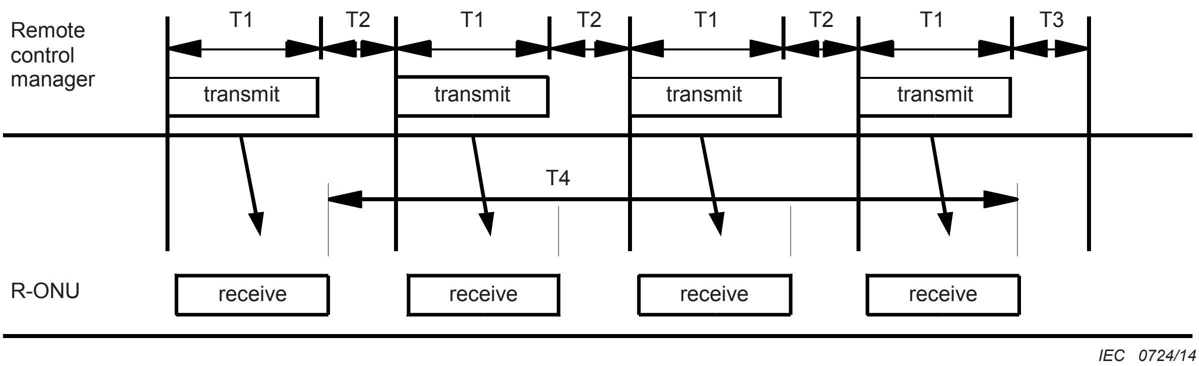



**Figure 9 – Timing of data transmission**

**Table 16 – Recommendation for timing of data transmission**

| Item | Time<br>ms | |
|---|---|---|
| T1: Transmitting time of control signal | (5,156 ± 0,5) % | Corresponding to the bit length, 99 bit |
| T2: Transmitting interval of control signal | 3 < T2 < 90 | 10 ms, typical |
| T3: Time before transmitting next control signal set after transmitting the third control signal | 3 < T3 < 90 | 10 ms, typical<br>In case the interrupt processing (updating the database, etc.) is not done by PC |
| T4: Waiting time per R-ONU | <300 | The buffer is cleared after 300 ms |

#### 8.2.4.7 Command bytes

The command bytes for the remote control system are listed in Table 17. For all command bytes the header shall be 0xF0.

**Table 17 – Remote control command codes**

| Command | Control command byte |
|---|---|
| Clear command | 0xF1 |
| Turn on RF forward path of R-ONU | 0xF2 |
| Turn off RF forward path of R-ONU | 0xF3 |
| Turn on RF return R-ONU | 0xF4 |
| Turn off RF return path of R-ONU | 0xF5 |
| Turn on 6 dB RF attenuator in the return path of R-ONU | 0xF6 |
| Turn on optical return path of R-ONU | 0xF7 |
| Turn off optical return path of R-ONU | 0xF8 |
| Reserved for future expansion | 0xF9 to 0xFF |
| NOTE In Japan different remote control command bytes are valid, which are protected by Japan Cable Labs IPR policy. | |

#### 8.2.4.8 Modulation for the remote control signal

The specification of the carrier signal of the remote control manager is shown in Table 18. The modulation is FSK.

**Table 18 – Specification of modulation for the remote control signal**

| Item | Specification |
|---|---|
| Modulation | FSK |
| Coding | NRZ |
| Data transfer rate in kbit/s | 19,2 ± 0,5 % |
| Carrier level in dB | 0 to 10 [a] |
| Carrier frequency in MHz | 70 to 120 [b] |
| Frequency accuracy in kHz | ±15 |
| Frequency shift in kHz | ± 75 [c] |
| Bandwidth in kHz | ± 250 [d] |

[a] Compared with the digital broadcast signal level

[b] Network operators shall define appropriate carrier frequency with vendors. In Japan, basically the carrier will be 75,5 MHz. In case this carrier interferes with other systems, Japanese network operators are likely to specify a frequency in the range of 70 MHz to 76 MHz instead of 75,5 MHz.

[c] Mark: –75 kHz, Space: +75 kHz

[d] Less than –45 dB against the peak level of FSK signal. In this case, the measurement conditions are as follows: SPAN 1 MHz, RBW 30 kHz, VBW 30 kHz, CF set to carrier frequency.

## 8.3 Headend specifications

### 8.3.1 Headend forward path specifications

A V-OLT in general consists of a forward path optical transmitter followed by one or several cascaded optical amplifiers to obtain the desired total optical output power to feed the ODN.

Optical forward path transmitters for various applications are specified in 6.1 of IEC 60728-6:2011. Class F1 is the one which requests specifications for the SBS threshold capability of this transmitter and therefore is the recommended class for RFoG systems. Additional information can be obtained from IEC 60728-13-1:2012 where frequency extensions of forward path optical transmitters up to 2 600 MHz are included. The optical wavelength range specification, however, has to be restricted to 1 555 nm ± 5 nm in order to obtain compatibility with the GPON and EPON specifications.

### 8.3.2 Headend return path specifications: R-RRX

Optical return path receivers are specified in 6.3 of IEC 60728-6:2011 in class E. For RFoG applications, however, significantly better noise performance is requested which leads to the definition of the classes E1R and E2R (Table 19). Class E1R receivers will be applied in extended reach applications with highest ODN loss budget. This subclause describes specifications for RFoG return path receivers (R-RRX) that, when used, should provide proper operation of the RFoG system. The requirement specifications suggest that DOCSIS 3.0 modems with four simultaneous return path carriers from one home shall operate, using the highest density modulation formats permitted under the DOCSIS 3.0 specification.

Manufacturers shall at least publish information on the parameters listed in Table 19. Given figures are recommended values.

**Table 19 – Data publication requirements for return path optical receivers**

| Parameter | Class E1R | Class E2R |
|---|---|---|
| Equivalent input noise current density in pA/√Hz [a] | <1 | <2,5 |
| Reference output level at OMI = 0,35 | >76 dB(µV) | |
| receiver *NPR* in dB [b] | >38 | |
| Fibre connection | Connector/splice type and type of fibre | |
| Power consumption | – | |
| Wavelength range | 1 250 nm to 1 650 nm | |
| Optical input power | (−25 to −16) dB(mW) | (−21 to −12) dB(mW) |
| Output level adjustment range | >18 dB | |
| Output level AGC range | no AGC | |
| Receiver turn-on time [c] | <0,25 µs | |
| Flatness | <2 dB | |
| Frequency range | 5 to $f_{US,max}$ MHz | |
| Supply voltage | One of the following: DC 48 V / 120 V or AC 65 V / 230 V<br>(class E: only for stand-alone equipment) | |
| Mechanical dimensions | For operation in buildings: 19″ (482,6 mm) rack mountable | |

[a] Measured at the lowest optical input power.

[b] For ≥5 dB optical input power variation at OMI = 0,35.

[c] Measured from when the optical input signal first reaches 90 % of its nominal value to when the electrical output signal reaches 90 % of its steady-state value.

Optical receivers according to this standard shall fulfil the requirements given in Table 20.

**Table 20 – Performance requirements for optical return path receivers**

| Parameter | Class E1R | Class E2R |
|---|---|---|
| Responsivity of the internal photo diode | ≥0,8 A/W for the whole wavelength range | |
| Electrical output port | Impedance: 75 Ω<br>Connector: IEC 61169-2 female or IEC 61169-24<br>Return loss: according to category B defined in IEC 60728-3 | |
| Optical return loss | >40 dB | |
| Indicators | Optical input level failure | |
| Alarms | Optical input level failure | |

# Annex A
(informative)

## Implementation notes

For implementing RFoG systems the following notes should be taken into account.

a) It is possible that, on the same PON or a group of PONs combined to one optical return path receiver, a combination of two devices (cable modem or set top) will transmit at the same time. If this happens, two optical transmitters will turn on at the same time. If they happen to be close enough in wavelength, it is possible that the two will generate mutual interference at the return path receiver, and neither transmission may get through.

b) Cable modems preferably should be restricted by the CMTS such that only one cable modem in a headend optical receiver group is transmitting at any given time. If several ODNs are combined to a single optical receiver, then the restriction should apply to all cable modems in the combined group.

c) For RFoG operation with burst profiles using 64-QAM modulation, preamble lengths of 32 symbols or more may be required. For lower orders of modulation, shorter preambles may work acceptably, but the CMTS vendor should be consulted. If CMTS default values of preamble length are to be changed, the CMTS vendor should also be consulted.

d) To assure proper operation of the R-ONU, the operating level of return path signals of special set top boxes at the R-ONU should be equal to the level of a DOCSIS channel.

e) If a return path wavelength of 1 310 nm is chosen, then it will not be possible to share the physical passive optical network with either an EPON or GPON standard network, as EPON and GPON both use 1 310 nm for return path signalling.

f) Compatibility with 10 Gbit/s PONs is optional due to the cost of blocking the 1 577 nm forward path data wavelength. An R-ONU manufacturer may choose to support it, or an external blocking filter may be used, or a separate 10 Gbit/s PON may be made available at the same splitting location.

g) Blocking filters may also be required if an optical carrier at 1 530 nm is used in the same fibre.

h) The minimum loss budget for any PON is set as 5 dB less loss than the maximum loss budget. The primary purpose is to minimize the variation in return path performance. In mixed RFoG and PON systems, there is an additional consideration of crosstalk from the PON into RFoG. If loss were to be added to an RFoG system, it may be added in the RFoG system only in the return path signal path. The forward path may be accommodated by simply supplying a lower amplitude 1 550 nm forward path optical carrier. For mixed RFoG and PON systems, additional loss will need to be added in the PON interface. See Figure A.1 for an explanation of where to add attenuation in order to place the entire plant within specification. Note that WDM loss is included in the system loss budget. Also note that covers two cases, with and without an xPON (either EPON or GPON). The 1 310 nm wavelength (if used) is handled in different ways with and without xPON.

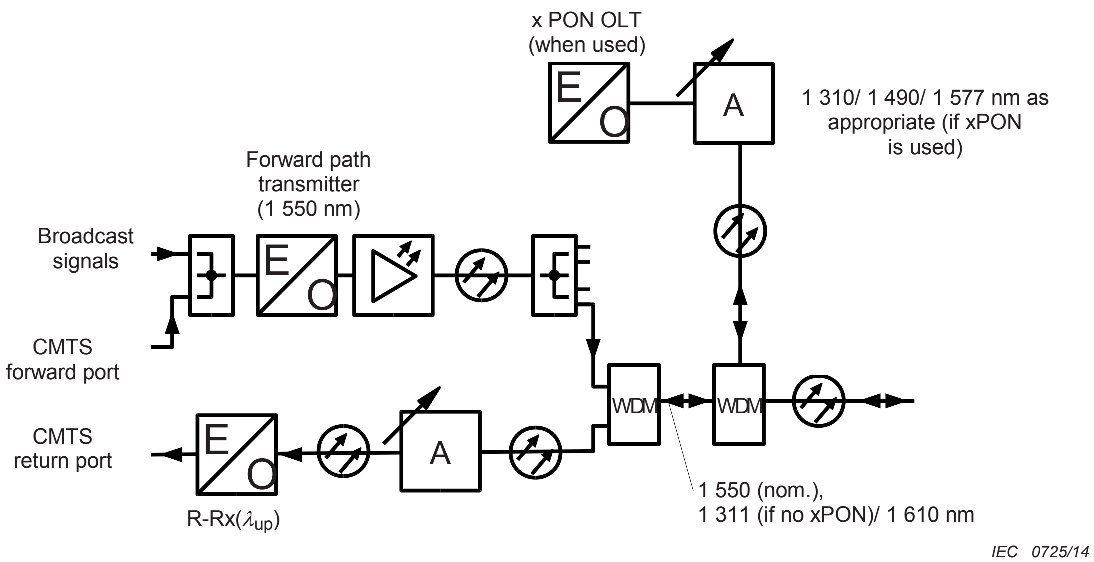
i) The return path channel capacity is assumed to be four 6,4 MHz wide DOCSIS channels, as shown in Table 10: return path R-ONU input level and response specifications.

   Table 10 also states the “nominal RF input level per channel” and the “RF input level for obtaining $m$ = 0,35”. Note that the per-carrier level is 6 dB lower than the total power level. This accounts for the assumption that the system is loaded with four channels. The link loss and performance assumptions are based on four-channel operation. The system could be designed for operation with fewer channels, which would result in a higher OMI and CNR for each channel, but less channel capacity for the system. Or, the system could be designed for operation with more channels, which would result in a lower OMI and CNR for each channel, but allow for more capacity in the system. The “nominal channel capacity” and “nominal RF input level per channel” are not mandatory specifications. The “RF input level for obtaining $m$ = 0,35” specification is a normative requirement. However, one shall be careful to not deviate too far from the nominal RF input level per channel specification or the turn-on and turn-off thresholds of the R-ONU may not operate correctly with the actual channel level.

j) The turn-on and turn-off characteristics specified in 8.2.3.5 shall be measured with a CW signal. The actual laser turn-on and turn-off times will be different when the R-ONU is fed with actual DOCSIS traffic. When consecutive bursts from different cable modems behind different R-ONUs exist with the minimum guard times allowed in the DOCSIS 3.0 specification, the specifications in 8.2.3.5 allow a second R-ONU to turn on before the first R-ONU is off, thus allowing for the possibility of optical beat interference.

k) The CMTS or other long loop AGC controller will command the return path RF transmitters in the premise to raise or lower their transmit level until the proper level is achieved at the input to the CMTS or other controller. It is important to align the RFoG return path network such that the RF level into the R-ONU is at the proper level when the input to the CMTS or other controller is also at the proper level.

   It is recommended that the alignment be conducted on an R-ONU with high optical loss between it and the return path receiver because R-ONUs that feed high optical loss budgets will require high RF input levels to compensate. As a result, R-ONUs with lower optical loss budgets will be driven with lower RF levels. If alignment were instead conducted on an R-ONU with a low optical loss budget, the RF input to R-ONUs with a high optical loss budget will have their return path transmitters driven into clipping. R-ONUs with a high optical loss budget will have lower than average *NPR* at the nominal RF input level but will be driven by higher than nominal RF levels. R-ONUs with a low optical loss budget will have a higher than average *NPR* at the nominal RF input level but will be driven by lower than normal RF levels.




NOTE The two WDMs may be located in either order on the signal path, or they may be in the same optical block.

**Figure A.1 – Placement of attenuators when system loss is too low**

# Annex B
(informative)

# System loss specification

## B.1 General

The RFoG system shall operate with a system loss in either direction of at least 25 dB. Note from Figure 1 that this loss is defined from the input to the WDM that combines the return path and optical forward path signals, to the input of any R-ONU. The RFoG system may work at higher loss levels. This annex is intended to provide guidance concerning the loss that can be tolerated. Both return path and forward path directions shall be considered, as either may be the limiting factor. Besides other considerations, one may want to keep in mind an ultimate conversion or overlay (to coexist with RFoG) to some other form of PON, looking at the loss budgets it will tolerate. One factor to be considered in an overlay would include additional system loss due to added WDM devices (added to or substituted for the original devices) and the potential impact on both the RFoG and PON system.

## B.2 Forward path considerations

Using conventional HFC optical transmitters, the maximum launch power into a long fibre may be 16 dB(mW), resulting in a tolerable loss budget of 16 dB − (−5 dB) = 21 dB, less than required. However, an operator can improve the loss budget in various ways:

a) Many optical transmitters today employ SBS-mitigating strategies, resulting in higher output power without encountering the SBS threshold. Typically, the SBS threshold might be raised by up to 4 dB, just getting to the 25 dB loss budget.
b) Shorter lengths of fibre permit higher launch powers. For example, if the distance from the headend to the splitter is 5 km, then the launch power can be approximately 4 dB higher than the launch power for a 20 km PON. Note that in calculating the effect on SBS, only the fibre distance to the first split needs to be included, as power usually will drop enough at that point to not be much of a problem. Also, note that the PON is defined to include the WDM, and typically the WDM is located so close to the transmitter that the launch power contributing to SBS is the optical power after the loss of the WDM. Thus, the power used in calculating SBS effects will be 1 dB or so lower than the actual launch power, reduced by the loss in the WDM.
c) Newer fibre types offer improved SBS limitation, so if new fibre is installed from the headend system, it might be considered using this fibre in order to improve performance.

Note that at higher optical power levels there may be additional safety regulations which shall be observed. Also, there are additional possibilities for damage to connectors and other components. A service provider contemplating operation at higher optical levels shall be aware of these issues.

Of course, if digital-only transmission is planned over the RFoG network, then the optical power at the R-ONU may be lower, and the above considerations modified accordingly. In this case, it may be possible to reduce the optical power by 3 dB to 5 dB compared with that needed if analogue signals are carried. This operation does not represent a violation of this standard.

For forward path considerations IEC 60728-13 and IEC 60728-13-1 should also be taken into account.

## B.3 Return path considerations

In the return path direction, the maximum tolerable loss is determined by the launch power of the R-ONU, the type of modulation of the return path carriers, the number of return path carriers, and the sensitivity of the return path receiver. Note that the tolerable return path loss budget is different from the calculation of return path levels from the RF sources in the home. Once the return path optical loss is set for a particular PON, the expected receive level at the headend system needs to be chosen such that the OMI of the return path transmitter is “correct”, as defined elsewhere in this standard.

As an example, consider a return path minimum launch power of 2 dB(mW), four 64-QAM signals, and a receiver that can provide 28 dB $C/N$ at an input level of −23 dB(mW). This yields a maximum system loss of 25 dB as suggested. There may be some ways to improve the loss, however.

a) Some manufacturers are providing optical receivers with greater sensitivity.
b) If only two return path carriers are planned to operate rather than four, a 3 dB higher OMI at the R-ONU may be used, improving the loss budget.
c) Some vendors are proposing optical amplifiers that can be strategically placed in the plant.
d) Use of the higher-powered 1 610 nm option will permit more system loss.

Some combination of these methods may be used to allow for optically combining two return path PONs, thus saving return path receivers. But a number of possible degrading issues should be allowed for, as listed below.

e) System loss may turn out to be higher than anticipated after a break that is repaired under adverse conditions. Standard design techniques provide a “repair margin” (at least 1 dB and up to 3 dB) to allow for this. This means that 25 dB available loss would allow the designer 24 dB of day-one loss.
f) There can be up to 1 dB degradation in optical budget due to dispersion issues in the plant.
g) There can be several decibels of variation in OMI at the home, depending on actual losses in the system, receiver output, loss between the receiver and the CMTS, accuracy of the CMTS level setting, etc.

An example for the performance allocation for the return path transmission system is specified as shown in Figure B.1.

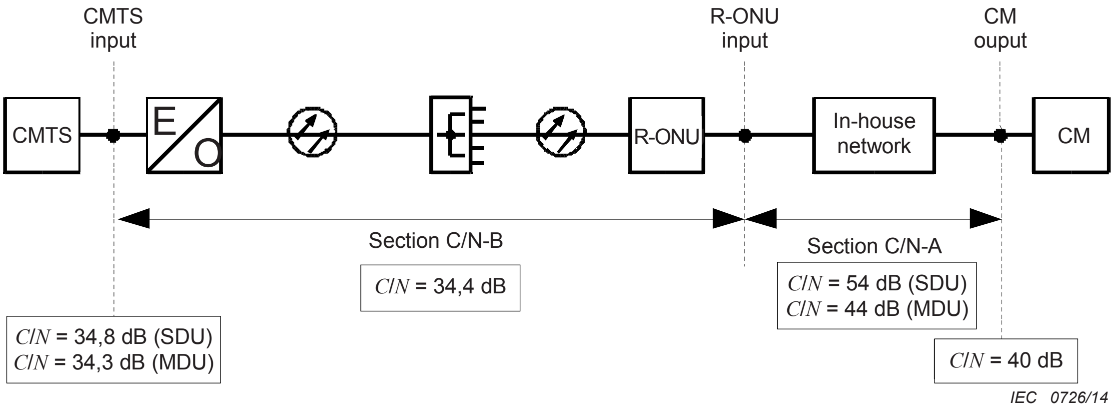



**Figure B.1 – Performance allocation of the return path transmission system**

The minimum carrier to noise ratio at the RF output of a cable modem is derived from the spurious emissions of the cable modem permitted under the DOCSIS physical layer specification.

The carrier-to-noise ratio of the in-house network (section C/N-A) is specified based on currently available installation methods and minimum RF output levels recommended in the DOCSIS physical layer specifications. $C/N$ allocation for in-house/in-building wiring section is illustrated in Figure B.1. The $C/N$ allocation for in-house wiring for a single dwelling unit (SDU) and a multiple dwelling unit (MDU) are 54 dB and 44 dB, respectively, as shown in Figure B.2. These values are specified taking into account the $C/N$ degradation due to only the distribution network.

With regard to optical distribution network, the carrier-to-noise ratio (section C/N-B) is specified assuming the following system parameters (refer to Clause 8 of this standard for detailed description).

Assuming an optical modulation index of **OMI** = 17,5 %, a $RIN$ of the return path optical transmitter of $RIN$ = –130 dB($Hz^{-1}$), an optical input power to the return path receiver of $P_{opt,in}$ = –23,5 dB(mW), a responsivity of the receiver photodiode of $r$ = 0,8 A/W, an equivalent input noise current density of the return path optical receiver of $I_r$ = 2,5 pA/√Hz and a Nyquist bandwidth of $B$ = 5,12 MHz, the section C/N-B can be calculated to 36,4 dB.

The $C/N$ ratio at the output of the return path optical receiver is 34,8 dB for SDUs and 34,3 dB for MDUs, which are derived by adding all the section $C/N$ values. These values are greater than the 26 dB, a minimum acceptable $C/N$ value for 64-QAM under DOCSIS operation.

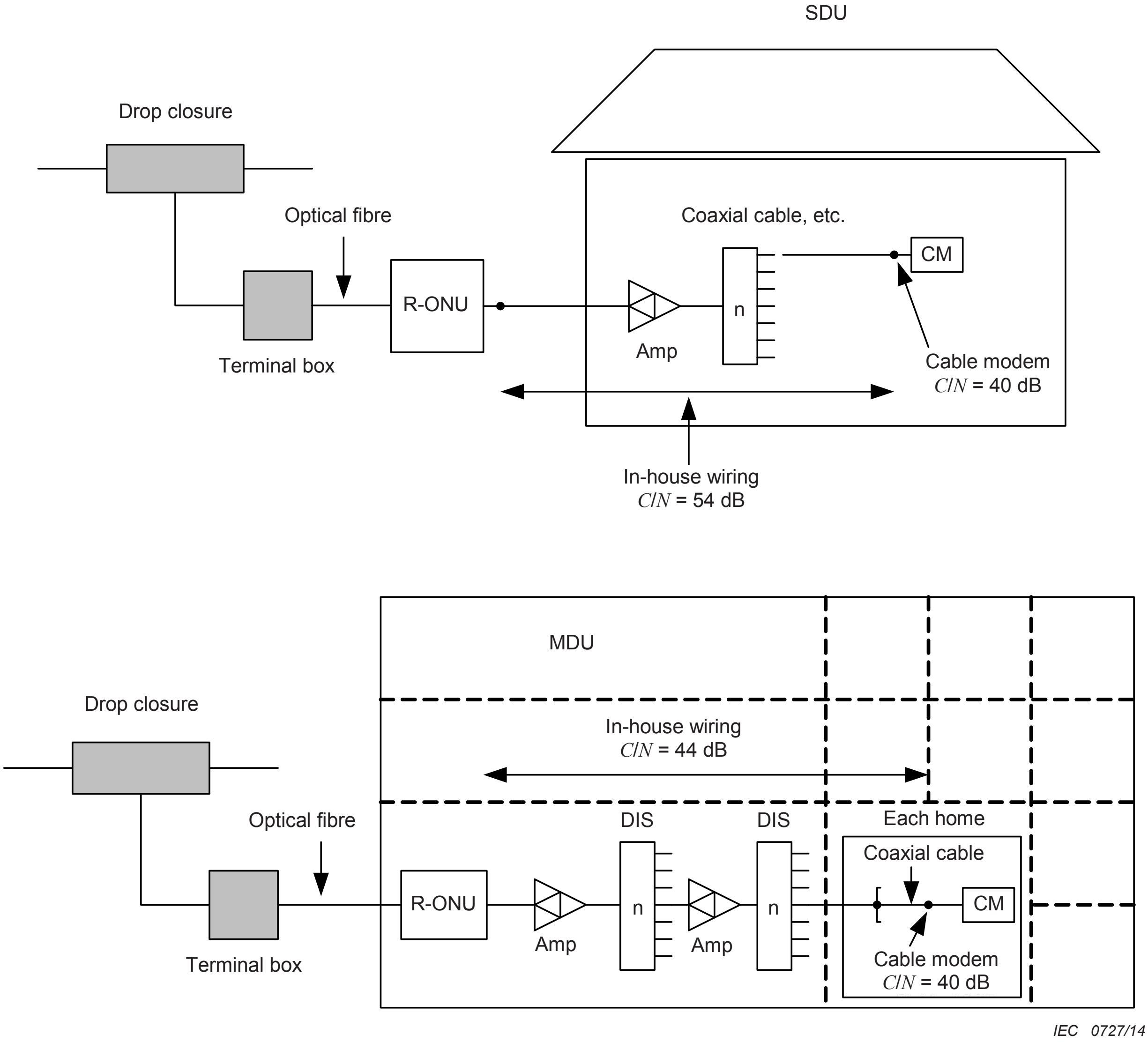



**Figure B.2 – Section *C*/*N* specification for SDU and MDU in-house wiring**

# Annex C
(informative)

# Optical beat interference

## C.1 General

In some cases, dedicated CMTSs are used for individual services within the same PON group or more than one return path input of a single CMTS is connected to the same PON. If the CMTSs used within the same PON group or the inputs of the single CMTS are not synchronized (i.e. coordinated / do not use a common scheduling), multiple R-ONUs may transmit return path signals simultaneously, and the return path optical signals interfere with each other if the optical wavelengths are not sufficiently separated. This phenomenon is called optical beat interference (OBI) and is caused by the heterodyne process within the optical receiver.

Occurrence of OBI results in generation of wideband noise within the return path bandwidth and deterioration of CNR performance. Maintaining the quality of an IP telephone service is of prime concern. To maintain the quality of IP telephone service, a guideline for the system design and operation, based on the results of experimental evaluations, is described in the following clauses.

## C.2 Operating conditions of ODN

The ODN parameters used for the experiments are listed in Table C.1.

**Table C.1 – Operating conditions related to ODN parameters**

| Parameter | Operating condition | Remark |
|---|---|---|
| Transmission distance | 0 km to 20 km | Transmission distance can be extended for systems with smaller distribution loss |
| Maximum optical loss of ODN (loss budget) | 25 dB [a]<br>29 dB (optional) [b] | |
| Number of split | 64 | |

[a] Optical output power of R-ONU is +3 dB(mW) and input to the optical receiver at the headend system is -22 dB(mW)

[b] Optical output power of R-ONU is +3 dB(mW) and input to the optical receiver at the headend system is -26 dB(mW) or optical output power of R-ONU is +6 dB(mW) and input to the optical receiver at the headend system is –23 dB(mW).

## C.3 Operating conditions of optical receiver at the headend system

Under the condition that the maximum optical system loss budget is 25 dB and multiple R-ONUs are connected in the same PON group, significant OBI has been observed if the optical output power of R-ONU is not well controlled and their optical signals are transmitted at the same time. When there is a difference in optical output power exceeding a tolerable limit among R-ONUs, the performance deterioration on the weaker channel due to OBI can be severe. It has been confirmed through experiments that an optical power difference of 4 dB among R-ONUs can be tolerated. The 4 dB tolerance is measured by adjusting the polarization states of interfering signals to determine the worst case performance.

In a practical network, it was confirmed that imperfect overlapping of polarization states relaxes the above tolerance by approximately 1 dB. Therefore, the optical output power level difference among R-ONUs between the interfering signals may be allowed to be within 5 dB as a practical limit.

## C.4 Operating conditions of CMTS

The effect of OBI is even more severe if the number of RF return path channels is increased. It has been confirmed through experimental evaluations that the quality of IP telephone service can be maintained even if three return path channels are used in the same PON group. The operating conditions used for the evaluations are listed in Table C.2.

**Table C.2 – Operating conditions related to ODN parameters**

| Parameter | Operating condition | Remark |
|---|---|---|
| Number of return channels | 3 channels or less [a] | Includes one channel for IP telephone service |
| Return path modulation profile used for IP telephone service | QPSK/3,2 MHz | |
| For operation with 4 channels or more, it is recommended to evaluate and confirm the system performance following the measurement method of OBI described below. | | |
| [a] Not synchronized by CMTS. | | |

## C.5 Environmental conditions

Unless otherwise mentioned, the evaluation of system performance is conducted under the environmental conditions stated in Table C.3.

**Table C.3 – Environmental conditions for system evaluation**

| Equipment | Environmental parameter | Condition |
|---|---|---|
| R-ONU | Ambient temperature | 0 °C to +40 °C (indoor installation)<br>−20 °C to +40 °C (outdoor installation) [a] |
| | Humidity | 20 % to 90 % non-condensing |
| Optical receiver at the headend system | Ambient temperature | 0 °C to +40 °C |
| | Humidity | 20 % to 90 % (non-condensing) |
| [a] Except the rising temperature due to solar radiation. | | |

## C.6 Relation between optical transmission loss and OMI

The optical transmission loss ($L$) and OMI ($m$) in a typical return path system is illustrated in Figure C.1. If there is any change in the return path RF input power, $P_{RF}$ due to change in the optical transmission loss, the CMTS controls the RF output of CM to maintain a preset RF input power, $P_{RF}$. The return path RF power, $P_{RF}$ is proportional to square of (OMI / transmission loss). Therefore, even if the constant RF input power, $P_{RF}$ is maintained, there will be a change in OMI.

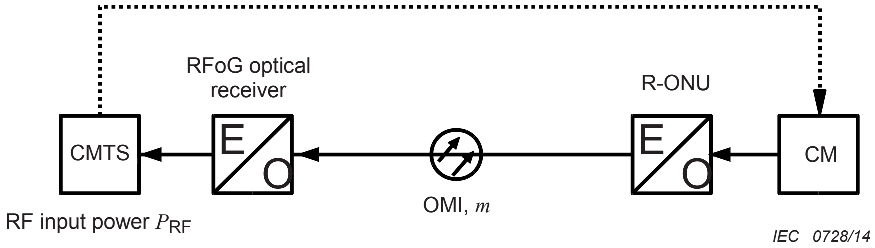



**Figure C.1 – Optical transmission loss and OMI**

## C.7 Design margin of ODN

The network should be designed with a design margin to support the optical power loss variation during the operation of the network. The factors that cause the power loss variation are

a) error in the output power of individual R-ONU,
b) fluctuation of the optical power of the individual R-ONU,
c) power fluctuation in the transmission line (temperature dependent and/or stress induced micro and macro-bending losses),
d) loss variation due to network alteration and repair margin, etc.

The factors that cause the variation of transmission loss of ODN are listed in Table C.4 and the overall loss variation, $K$ can be calculated using Equation (C.1), and can be assumed to be around 5 dB (refer to Figure C.2).

$$K = \sqrt{2^2 + 2^2 + 3^2 + 2{,}5^2} = 4{,}8 \qquad \text{(C.1)}$$

where

$K$ is the optical loss variation

Accordingly, OMI of the network should be designed by taking the loss variation in the range of +2 dB to –3 dB into account to support the 5 dB loss margin described above.

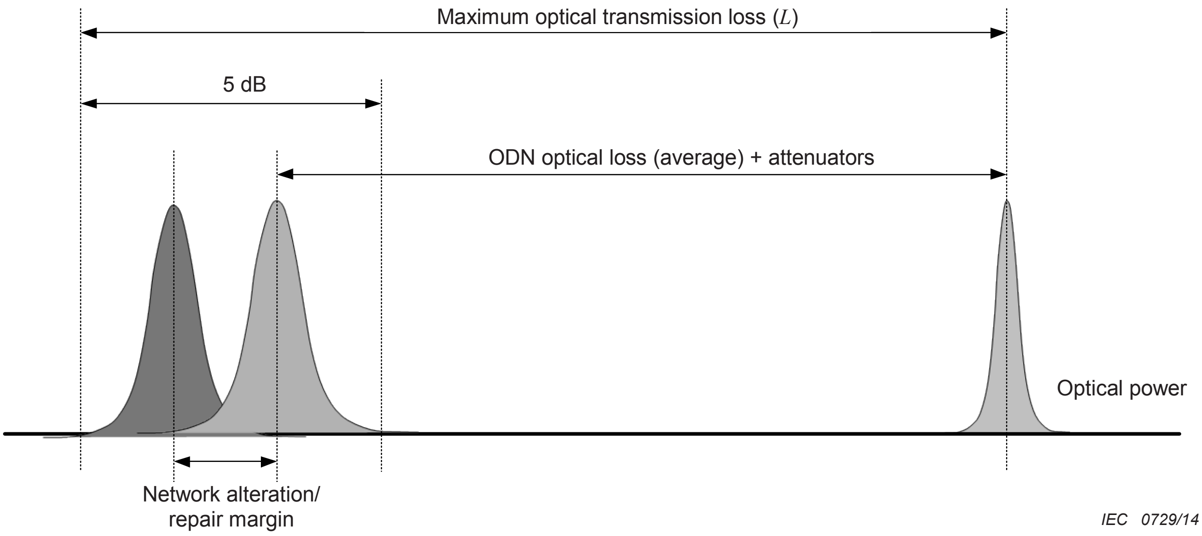



**Figure C.2 – ODN design margin**

**Table C.4 – Factors affecting the transmission loss of ODN**

| Parameter | Value |
|---|---|
| Deviation in ODN loss from different ONUs to the headend system | within ±1,0 dB |
| Fluctuation of optical power from individual R-ONU | within ±1,0 dB |
| Power fluctuation in the transmission line (temperature dependent micro and macro-bending losses) (Assuming a transmission length of 20 km) | within ±1,5 dB |
| Loss variation due to network alteration and repair margin | within 2,5 dB |

## C.8 Example of system design

If the transmission quality needs to be maintained even during the occurrence of OBI, an appropriate OMI should be kept. The CMTS controls the RF output power of CM and in turn the OMI of R-ONU, the OMI becomes maximum when the transmission loss becomes maximum. The total OMI of R-ONU depends on the number of carriers and the modulation format, clipping effect may cause intermodulation distortion among telephone lines which deal with all return path services.

In Clause C.6, a variation of optical power received at the headend system in the +2 dB to −3 dB range is described. Taking this variation into account, the OMI of individual channels and total OMI can be designed as described below.

In Table C.5, a system design example is given in which the OMI/channel is fixed at 20 %. In Table C.6, a similar example is given in which the OMI of channels others than IP telephone channel are modulated with lower OMI.

**Table C.5 – System design example 1**

| | +2 dB | 0 dB | –3 dB |
|---|---|---|---|
| Maximum number of interfering channels (Number of R-ONU simultaneously transmitting return path signals) | 3 channels or less | | |
| Modulation format of IP telephone channel | QPSK | | |
| Channel width for IP telephone channel | 3,2 MHz | | |
| OMI of IP telephone channel | 12,6 % | 20 % | 39,9 % |
| OMI of channels other than IP telephone channel | 12,6 % | 20 % | 39,9 % |
| Total OMI (Maximum) | 21,9 % | 34,6 % | 69,1 % |

**Table C.6 – System design example 2**

| | +2 dB | 0 dB | –3 dB |
|---|---|---|---|
| Maximum number of interfering channels (Number of R-ONU simultaneously transmitting return path signals) | 3 channels or less | | |
| Modulation format of IP telephone channel | QPSK | | |
| Channel width for IP telephone channel | 3,2 MHz | | |
| OMI of IP telephone channel | 12,6 % | 20 % | 39,9 % |
| OMI of channels other than IP telephone channel | 7,1 % | 11,2 % | 22,4 % |
| Total OMI (maximum) | 16,1 % | 25,6 % | 51 % |

## C.9 Method of measurement of OBI

### C.9.1 Purpose

This measurement is to evaluate the system performance when OBI is occurring due to multiple return path channels operating simultaneously in the same PON group.

### C.9.2 Measurement setup

The measurement setup is shown in Figure C.3.

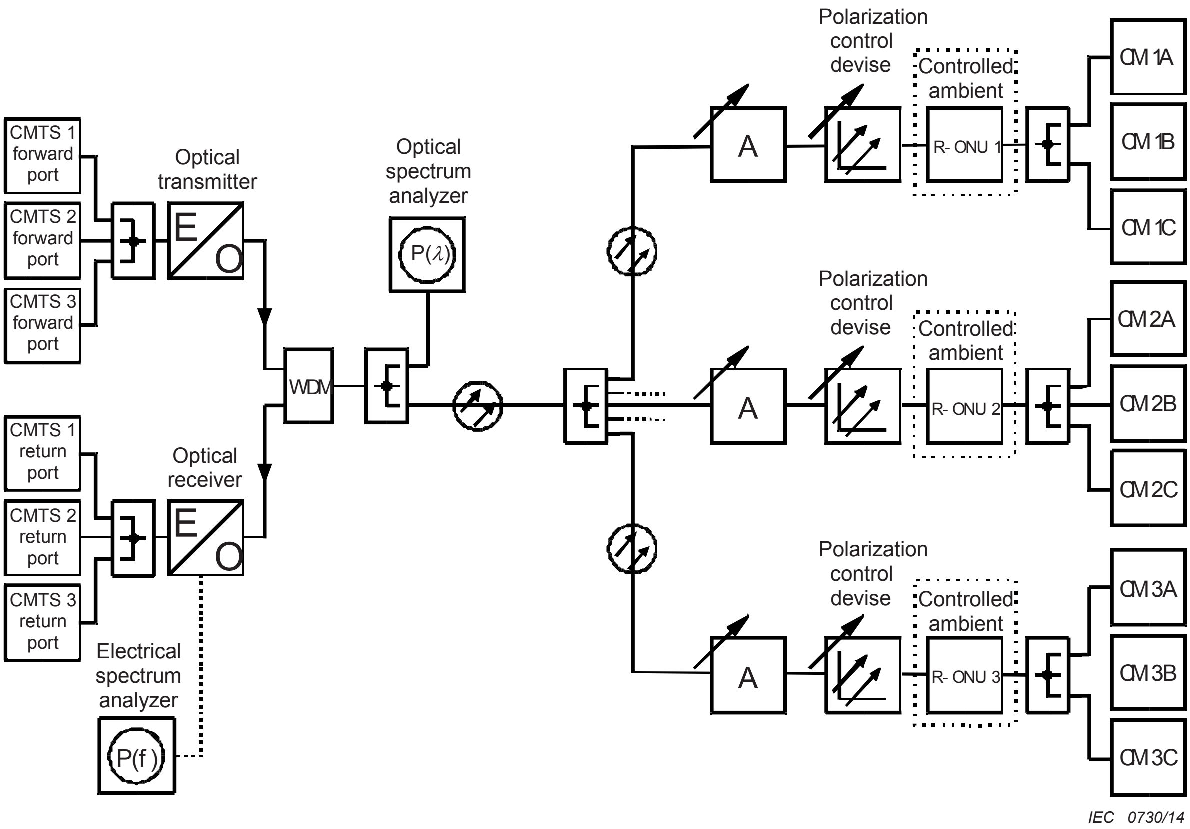



**Figure C.3 – Setup used for the measurement of OBI**

### C.9.3 Example of measurement conditions

An example of measurement conditions is indicated in Table C.7.

**Table C.7 – Example of list of measurement conditions**

| | Frequency in MHz | Bandwidth in MHz | Modulation format |
|---|---|---|---|
| CM 1 Measurement signal | | | |
| CM 2 Interfering signal 1 | | | |
| CM 3 Interfering signal 2 | | | |
| CPE setup:Measurement signal (1 460 + 42) byte x_____ F/S UDP packet<br>Interfering signal (1 460 + 42) byte x_____ F/S UDP packet | | | |

### C.9.4 Procedure

For the measurement proceed as follows.

a) Ensure the optical inputs to the receiver from the individual R-ONU are equal by adjusting the optical attenuators.
b) By controlling the ambient temperature of R-ONU, adjust the wavelengths of all the three interfering signals so that they overlap each other.
c) Adjust the polarization controller in order to create worst case CNR at the output of the headend system optical receiver.
d) Observe the SNR and FEC counter values through the MIB information of CMTS and simultaneously record the CNR measured at the RF output of the headend system optical receiver.
e) Repeat the procedure d) by increasing the optical power of interfering signals in steps of 1 dB.

### C.9.5 Presentation of results

The measuring results should be presented as shown in Table C.8.

**Table C.8 – Presentation of OBI measurement results**

| | | | | **Spectrum analyser** | | | **CMTS** | | |
|---|---|---|---|---|---|---|---|---|---|
| Optical input power to headend system receiver in dB(mW) | | | Optical power difference | Carrier level | Noise level | CNR | Forward path SNR | FEC corrected | FEC uncorrected |
| Meas ure-ment signal | Inter-fering signal 1 | Inter-fering signal 2 | dB | dB(μV) | dB(μV) | dB | dB | | |
| | | | | | | | | | |
| | | | | | | | | | |

## C.10 Method of measurement of OBI (measurement with CW signals)

### C.10.1 Purpose

This measurement is to evaluate the system performance when OBI is occurring due to multiple CMTS operating in the same PON group. The measurement is carried out using un-modulated RF carriers.

### C.10.2 Measurement setup

The setup for measurement of OBI with CW signals is shown in Figure C.4.

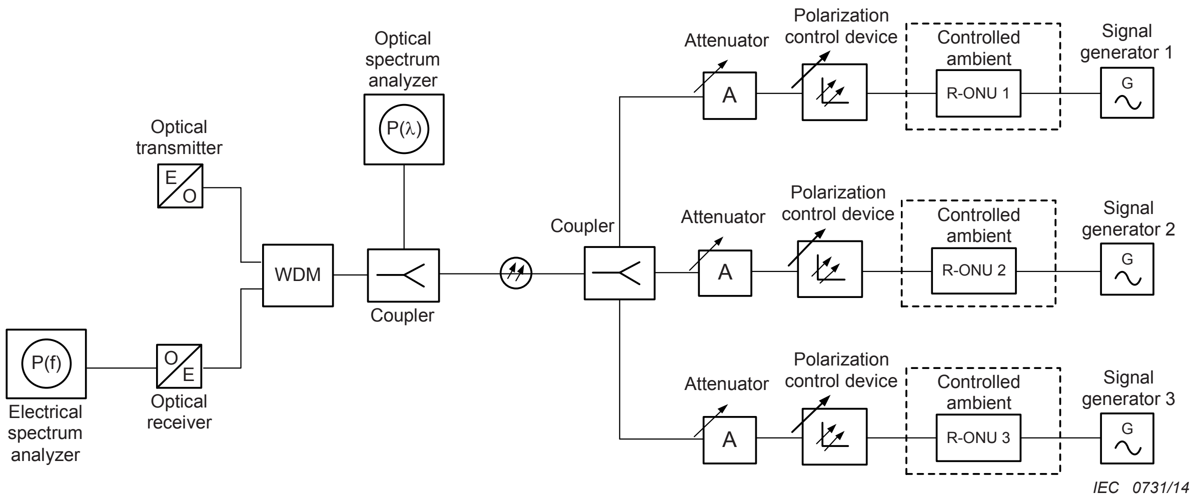



**Figure C.4 – Setup used for the measurement of OBI (CW method)**

### C.10.3 Procedure

For the measurement proceed as follows.

a) Ensure the optical input to the receiver from the individual R-ONU are equal by adjusting the optical attenuators.

b) By controlling the ambient temperature of R-ONU, adjust the wavelengths of all the three interfering signals so that they overlap each other.

c) Adjust the polarization controller in order to create worst case CNR at the output of headend system optical receiver.

d) Adjust the signal generators to obtain the specified OMI, and record the CNR measure at the RF output of the headend system optical receiver.

e) Repeat the procedure d) by increasing the optical power of interfering signal in steps of 1 dB.

The measuring results should be presented as shown in Table C.9.

**Table C.9 – Presentation of OBI measurement results**

| **Optical input power to headend system receiver in dB(mW)** | | | **Optical power difference** | **Carrier level** | **Noise level** | **CNR** |
|---|---|---|---|---|---|---|
| Measurement signal | Interfering signal 1 | Interfering signal 2 | dB | dB(μV) | dB(μV) | dB |
| | | | | | | |

# Annex D
(normative)

## Optional remote control manager

This annex describes the performance requirement for the connection and interoperability tests in the laboratory by an optional remote control equipment. Requirement values are indicated not as specification but as reference values here.

The performance requirements listed in Table D.1 are dedicated to the FSK transmitter part of the remote control manager being the primary part of the manager.

**Table D.1 – Performance requirements for the FSK transmitter**

| Item | Unit | Specification | Remark |
|---|---|---|---|
| Modulation | | FSK | |
| Encoding | | NRZ | |
| Data transfer rate | kbit/s | 19,2 ± 0,5 % | |
| Carrier frequency | MHz | 70 to 120 | Network operator shall define appropriate carrier frequency with vendors.<br>In Japan, basically the carrier will be 75,5 MHz. In case this carrier interferes with other systems, Japanese network operators are likely to specify a frequency in the range of 70 MHz to 76 MHz instead of 75,5 MHz. |
| Frequency accuracy | ppm | ±50 | |
| Bandwidth | kHz | ±250 | |
| Max. RF output level | dB(μV) | >100 | |
| RF output adjustment range | dB | > −10 | Against the maximum output level |
| RF output stability | dB | < ±1,5 | |
| Output impedance | Ω | 75 | |
| Spurious | dB | < −60 | Against FSK Carrier in whole forward frequency range |

# Annex E
(informative)

## Outdoor housings for R-ONU protection

R-ONUs should be deployed inside weather-resistant housings for the purpose of environmental/physical protection as well as to store cable slack, prevent tampering, facilitate access for network testing and the like. Housings used for this purpose should follow these guidelines:

Minimum features:

- The housing should be designed to prevent the ingress of water, wind-driven rain, sand and dust, according to IP54 (IEC 60529).
- The standard entry/exit port size should accommodate optical drop cables as well as electrical power, optical, coaxial and twisted pair cables that run to/from the customer premises.
- The housing should allow for a minimum bend radius of 10× the cable outside diameter, or as recommended by the cable manufacturer.
- Any metallic housing should provide suitable means for grounding and bonding of the R-ONU, cable shielding and other devices according to building codes and manufacturer recommendations.
- The housing should provide a suitable means (such as a backplane or substrate) for mounting and securing the R-ONU.

Additional features:

- The housing may permit storage of drop cable slack.
- The housing may support pigtail splicing and/or optical adapters necessary to interconnect the drop cable and the R-ONU or inside optical cables to the drop or R-ONU.
- The housing may allow for coaxial splitters, power inserters and similar devices needed to complete the installation.

# Annex F
(informative)

## Effect of off-state optical power on *C/N* ratio of transmission signal

The laser inside the R-ONU is basically kept in the off-state when there is no RF signal at the input of R-ONU. However, due to implementation difficulties, a minimum amount of optical power is allowed to be emitted from the laser even when switched to off-state. If the off-state optical power is large, it will affect the system performance when a large number of transmitters are connected to the same distribution network.

The off-state optical power is specified in this standard in such a way that the transmission characteristics of a specific R-ONU will not be affected due to the residual optical power from the rest of R-ONUs in the same PON group. This can be clarified through the following discussion.

The $C/N$ ratio of the main transmitted signal at the output of an optical receiver can be calculated from equation E.1.

$$(C/N) = 10 \text{ lg}\left( \frac{1}{B_\text{N}} \cdot \frac{\frac{1}{2}\cdot\left(m \cdot R \cdot P_{\text{r}1}\right)^2}{\sum_{n=1}^{N_\text{T}}\left\{RIN_n \cdot \left(R \cdot P_{\text{r}n}\right)^2\right\} + 2 \cdot e \cdot \left(I_{\text{d}0} + \sum_{n=1}^{N_T} R \cdot P_{\text{r}n}\right) + I_\text{eq}{}^2} \right) [\text{dB}] \qquad \text{(E.1)}$$

where

| | |
|---|---|
| $B_\text{N}$ | noise bandwidth (5,12 MHz) |
| $m$ | optical modulation index of the main optical signal (17,5 %) |
| $P_{\text{r}1}$ | received optical power of the main optical signal (−23,5 dB(mW)) |
| $P_{\text{r}n}$ | received optical power of $n$-th optical signal (−55 dB(mW)) |
| $RIN_n$ | $RIN$ of the $n$-th optical signal for optical noise level calculation (−130 dB(Hz$^{-1}$) |
| $e$ | charge of an electron (1,602·10$^{-19}$ As) |
| $R$ | responsivity of V-ONU (0,8 A/W) |
| $I_{\text{d}0}$ | dark current of V-ONU (1 nA) |
| $I_\text{eq}$ | optical receiver equivalent input noise current density (2,5 pA/√Hz) |
| $N_\text{T}$ | number of simultaneously transmitted optical signals (32) |

NOTE The $RIN$ of a laser turned on differs from the $RIN$ of a laser turned off. This may lead to results deviating from measured $C/N$ figures. The numerator and denominator of Equation (E.1) correspond to carrier and noise power respectively.

If the off-state optical power is zero, then the noise power is generated only by the main optical signal, and is calculated to be 4,44·10$^{-17}$ A$^2$.

When an off-state optical power of −30 dB(mW) is assumed to be emitted from individual R-ONUs, the combined noise level is calculated to be 4,45 × 10$^{-17}$ A$^2$. The total noise level due to interfering signals is about four hundred times smaller than the noise level generated due only to the main optical signal.

Therefore, the effect of off-state optical power can be ignored as long as it is kept within the values specified in this standard.

# Bibliography

The following documents may provide valuable information to the reader but are not required when complying with this standard.

IEC 60050-731:1991, *International Electrotechnical Vocabulary – Chapter 731: Optical fibre communication*

IEC 60068 (all parts), *Environmental testing*

IEC 60169-24, *Radio-frequency connectors – Part 24: Radio-frequency coaxial connectors with screw coupling, typically for use in 75 ohm cable distribution systems (Type F)*

IEC 60417, *Graphical symbols for use on equipment*

IEC 60617, *Graphical symbols for diagrams*

IEC 60728-5, *Cable networks for television signals, sound signals and interactive services – Part 5: Headend equipment*

IEC/TR 60728-6-1, *Cable networks for television signals, sound signals and interactive services – Part 6-1: System guidelines for analogue optical transmission systems*

IEC 60793-2-50, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

IEC 61281-1:1999, *Fibre optic communication subsystems – Part 1:Generic specification*

IEC 61280-2-2, *Fibre optic communication subsystem test procedures – Part 2-2: Digital systems – Optical eye pattern, waveform and extinction ratio measurement*

IEC 61280-4-2, *Fibre optic communication subsystem basic test procedures – Part 4-2: Fibre optic cable plant – Single-mode fibre optic cable plant attenuation*

IEC 61282-4, *Fibre optic communication system design guides – Part 4: Accommodation and utilization of non-linear effects*

IEC 61290-1-1, *Optical amplifiers – Test methods – Part 1-1: Power and gain parameters – Optical spectrum analyzer method*

IEC 61290-1-2, *Optical amplifiers – Test methods – Part 1-2: Power and gain parameters – Electrical spectrum analyzer method*

IEC 61290-6-1, *Optical fibre amplifiers – Basic specification – Part 6-1: Test methods for pump leakage parameters – Optical demultiplexer*

IEC 61291-4, *Optical amplifiers – Part 4: Multichannel applications – Performance specification template*

IEC/TR 61292-4, *Optical amplifiers – Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers*

IEC 80416 (all parts), *Basic principles for graphical symbols for use on equipment*

ITU G.692, *Optical interfaces for multichannel systems with optical amplifiers*

ITU J.186, *Transmission equipment for multi-channel television signals over optical access networks by sub-carrier multiplexing (SCM)*

ANSI/SCTE 96 2008, *Cable Telecommunications Testing Guidelines*

GR-49-CORE, Issue 2, *Generic Requirements for Outdoor Telephone Network Interface Devices*

GR-487-CORE, Issue 3, *Generic Requirements for Electronic Equipment Cabinets*

Multimedia over Coax Alliance (MoCA), http://www.mocalliance.org

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