

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Cable networks for television signals, sound signals and interactive services –
Part 14: Optical transmission systems using RFoG technology**

**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**



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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX

XA

ICS 33.060.40; 33.160; 33.180

ISBN 978-2-8322-1439-8

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**CABLE NETWORKS FOR TELEVISION SIGNALS,
SOUND SIGNALS AND INTERACTIVE SERVICES –****Part 14: Optical transmission systems using RFoG technology**

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International Standard IEC 60728-14 has been prepared by technical area 5: Cable networks for television signals, sound signals and interactive services, of IEC technical committee 100: Audio, video and multimedia systems and equipment.

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

FDIS	Report on voting
100/2248/FDIS	100/2284/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The list of all the parts of the IEC 60728 series, under the general title *Cable networks for television signals, sound signals and interactive services*, can be found on the IEC website.

This standard follows closely (where applicable) the ANSI/SCTE 174 2010 standard “Radio Frequency over Glass / Fiber-to-the-Home Specification”. In agreement with SCTE¹ major parts of ANSI/SCTE 174:2010 have been copied into this standard.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

reconfirmed,
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amended.

¹ SCTE = Society of Cable Telecommunications Engineers

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:

$$CCR = D - U_{\text{OtherService}} \quad (1)$$

where

D is the nominal level of the desired signal in dB(μV) at RF output port of optical receiver;

$U_{\text{OtherService}}$ 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:

$$I_r = \sqrt{\frac{C}{Z 10^{\frac{1}{10} C/N}}} \quad (2)$$

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

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

where ϕ_h is the highest and ϕ_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:

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

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:

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

where

U is the electrical output level in dB(μV)

$P_{\text{opt,RX}}$ 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(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 λ of light in vacuum is given by

$$\lambda = \frac{c}{f} \quad (6)$$

where

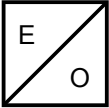
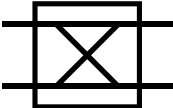
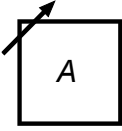
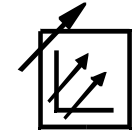
c is the speed of light in vacuum ($c \approx 2,997\,92 \times 10^8$ m/s);

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
GEAPON	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	<i>NPR</i>	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
<i>RIN</i>	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.

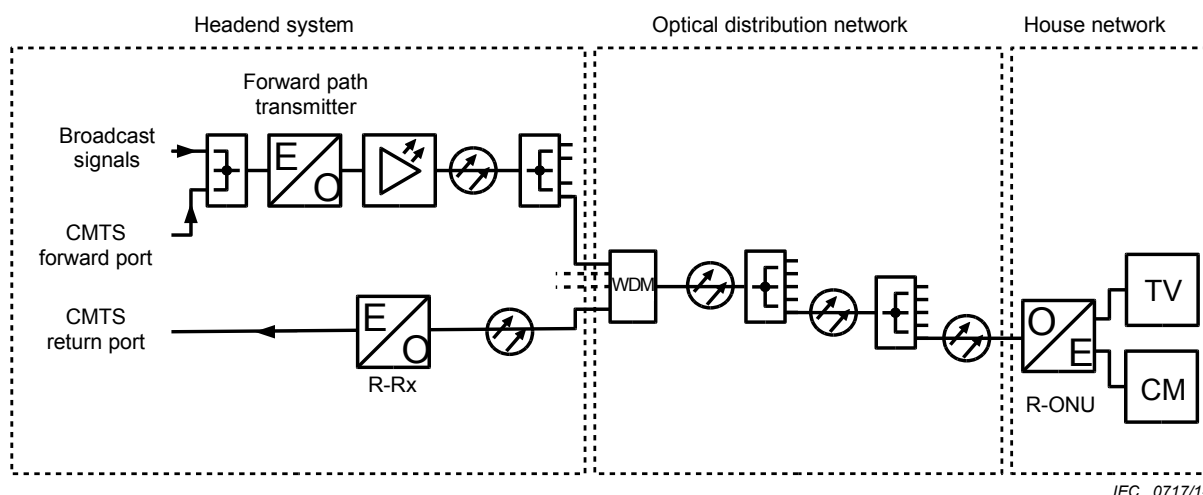


Figure 1 – Optical system reference model for RFoG

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 λ_{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 λ_{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.

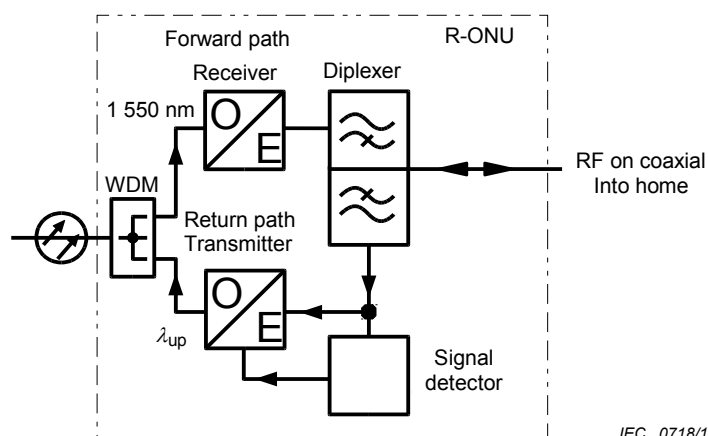


Figure 2 – Principle schematics of R-ONU

The low port of the diplexer supplies return path signals to a return path transmitter whose output is at λ_{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 λ_{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 λ_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.

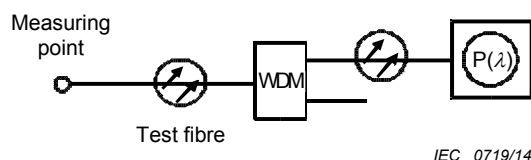


Figure 3 – Measurement of optical wavelength using WDM coupler

For measuring the central wavelength λ_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, GEAPON 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
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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 %						
– second order	>60 dB			>60 dB	>60 dB	>60 dB
– triple beat	>70 dB			>60 dB	>60 dB	>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 (f_{DSmin} to 1 006 MHz)	<3 dB	<2 dB	<4 dB	<4 dB	<4 dB	<4 dB
(f_{DSmin} to 2 400 MHz)	–	–	–	–	–	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 Connector: IEC 60169-2 female or IEC 61169-24 Return loss: according to category B defined in IEC 60728-3		Impedance: 75 Ω Connector: IEC 61169-24 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 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			
<i>RIN</i> 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(μ V)	+99 dB(μ V)
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(μ V) per carrier	
Flatness	± 2 dB, 5 MHz to $f_{US,max}$ MHz	
Noise Power Ratio (<i>NPR</i>) ^c	≥ 38 dB over a ≥ 10 dB dynamic range	
Maximum power level (total power, continuous, no damage)	120 dB(μ V)	
Electrical input port (for stand-alone equipment only)	Impedance: 75 Ω Connector: IEC 61169-2 female or IEC 61169-24 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 <i>NPR</i> cannot easily be measured in a link with high optical loss. To measure <i>NPR</i> , it is necessary to use a link with relatively low optical loss. The noise loading for the <i>NPR</i> test shall be 37 MHz of broadband noise from 5 MHz to 42 MHz with a nominally centred notch. <i>NPR</i> 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 $\sqrt$ 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(μ V)
N/A	Power at which R-ONU shall turn on ^a	≥ 76 dB(μ V)
N/A	Power at which R-ONU should turn on ^a	≥ 73 dB(μ V)
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(μ V)

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(μ V)
N/A	Power at which R-ONU shall not turn off ^b	≥ 61 dB(μ V)
N/A	Power at which R-ONU should not turn off ^b	≥ 58 dB(μ V)
N/A	Power at which R-ONU shall turn off	≤ 52 dB(μ V)
T1: Don't turn on too late	Maximum time from application of RF to 90 % optical power (read to late-side mask)	1,3 μ s
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 μ s
Don't turn on by mistake	Power at which a single isolated pulse ≤ 90 ns long should not turn on the laser	≤ 125 dB(μ V)
T11: Don't turn off too late	Maximum time from removal of RF (defined as RF dropping to 52 dB(μ V)) to the time the optical carrier falls to 10 % of its steady-state amplitude (read to late-side mask)	1,6 μ s
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 μ s
T14: Don't turn off by mistake	When the turn-off threshold is >58 dB(μ V), the R-ONU shall not drop the laser power below 90 % for a sudden drop in RF input power to ≤ 52 dB(μ V) 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(μ V) that lasts >600 ns. When turn-off threshold is ≤ 58 dB(μ V), the R-ONU shall not drop the laser power below 90 % for a sudden drop in RF input power to ≤ 52 dB(μ V) 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(μ V) 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 μ s
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 $\pm 0,1$ dB, observed at the output of a reference optical-to-electrical converter (also reach and maintain <i>NPR</i> required performance)	1,3 μ s
^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(μ V), a valid input signal will remain below the higher threshold (61 dB(μ V)) for more time than below the lower threshold (58 dB(μ V)).		

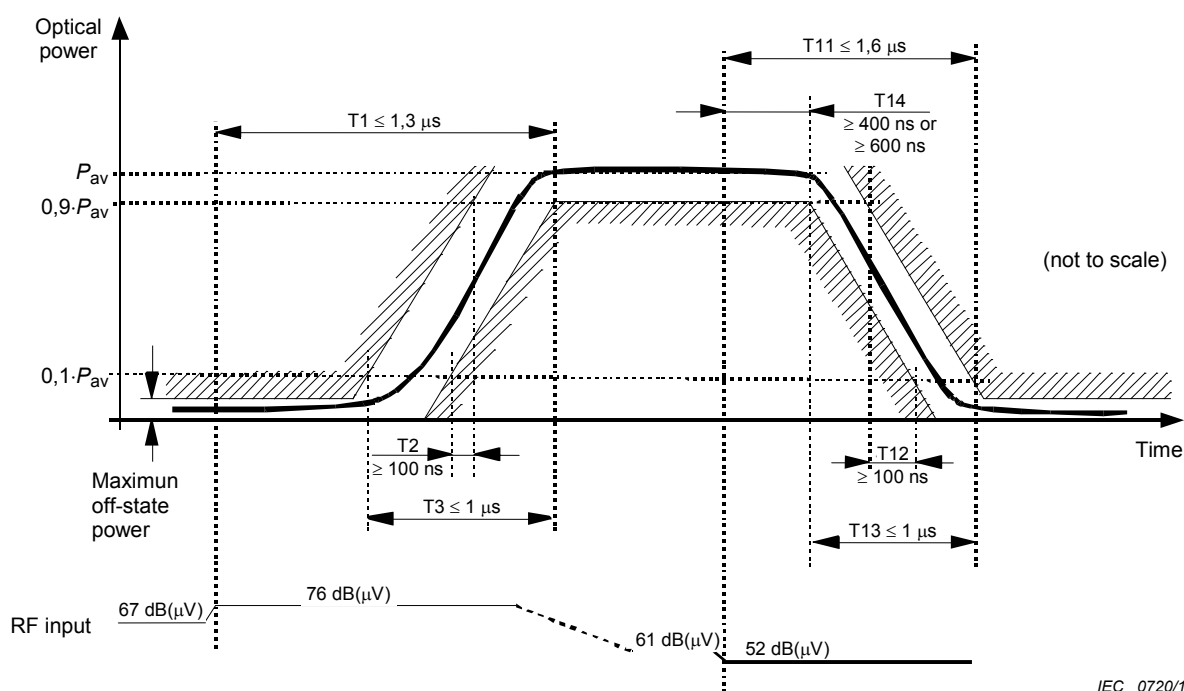


Figure 4 – R-ONU turn-on and turn-off diagram

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.

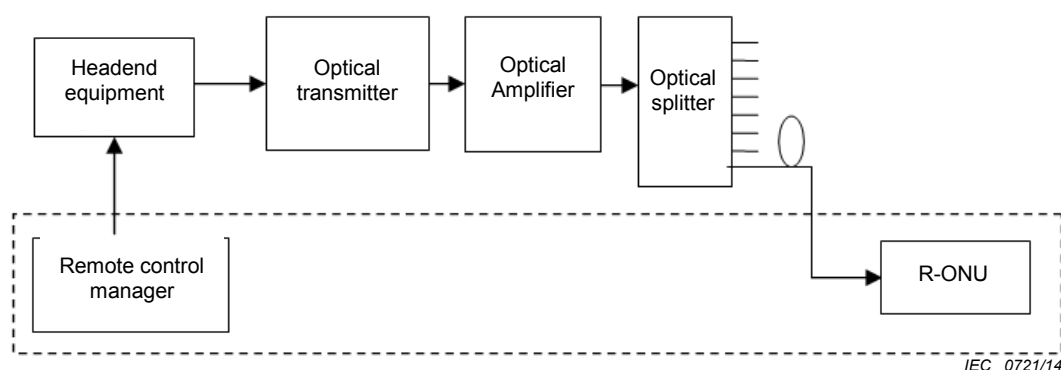


Figure 5 – Example of the remote control system configuration

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 $\pm$ 0,5 %
Synchronisation	Asynchronous mode
Communication mode	One-way communication
Data format	1 start bit 8 data bits 1 stop bit 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.

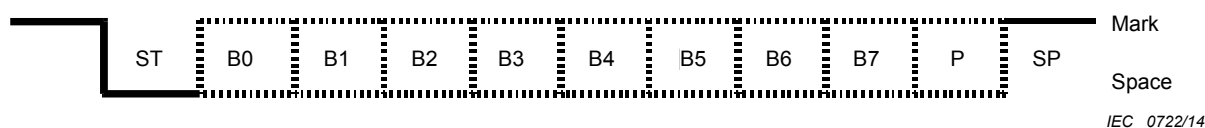


Figure 6 – Data format

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

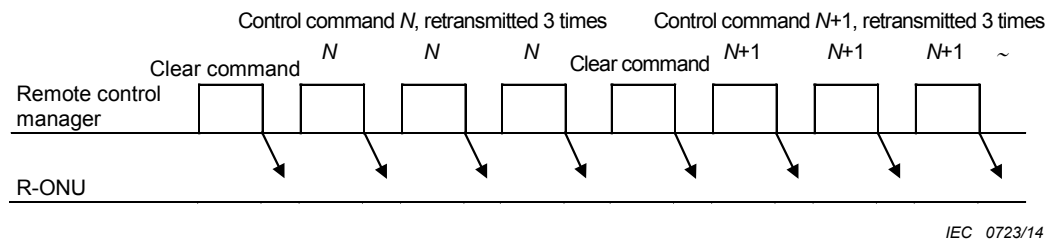


Figure 8 – Control transfer process

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.

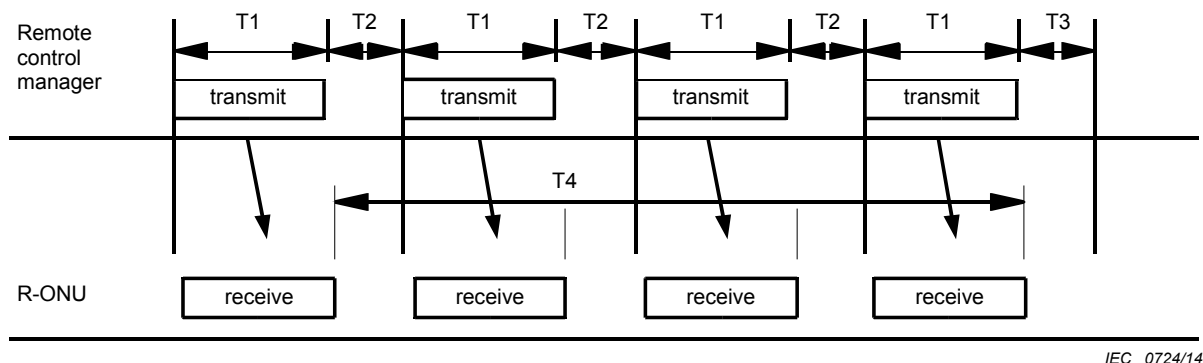


Figure 9 – Timing of data transmission

Table 16 – Recommendation for timing of data transmission

Item	Time ms	
T1: Transmitting time of control signal	$(5,156 \pm 0,5) \%$	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 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.