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INTERNATIONAL STANDARD

colour inside

Cable networks for television signals, sound signals and interactive services – Part 13: Optical systems for broadcast signal transmissions

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 13: Optical systems for broadcast signal transmissions

FOREWORD

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International Standard IEC 60728-13 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
100/1623/FDIS	100/1646/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.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

The contents of the corrigendum of August 2010 have been included in this copy.

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

INTRODUCTION

Standards of the IEC 60728 series deal with cable networks including equipment and associated methods of measurement for headend reception, processing and distribution of television signals, sound signals and their associated data signals and for processing, interfacing and transmitting all kinds of signals for interactive services using all applicable transmission media.

This includes

- CATV [1]-networks;
- MATV-networks and SMATV-networks;
- individual receiving networks;

and all kinds of equipment, systems and installations installed in such networks.

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.

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.

1 This word encompasses the HFC (Hybrid Fibre Cable) networks used nowadays to provide telecommunications services, voice, data, audio and video both broadcast and narrowcast.

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

Part 13: Optical systems for broadcast signal transmissions

1 Scope

This part of IEC 60728 is applicable to optical transmission system for broadcast signal transmission that consists of a head-end equipment, optical transmission lines, in-house wirings and a system outlet. The system is primarily intended for television and sound signals using analogue and/or digital transmission technology. This standard specifies the basic system parameters and methods of measurement for optical distribution system having a system outlet in order to assess the system performance and its performance limits.

The purpose of this part of IEC 60728 is to describe the system specification of FTTH (fibre to the home) network for broadcast signal transmission. This standard is also applicable to the broadcast signal transmission using telecommunication network if it satisfies the optical portion of this standard. This standard describes RF transmission for broadcast and narrowcast (limited area distribution of broadcast) signals over FTTH, and introduces xPON system as a physical layer media. The detailed description of physical layer is out of the scope of this standard. The scope is limited to RF signal transmission over FTTH, thus, it does not include IP transport technologies, such as IP Multicast and associate protocols. Some interference descriptions between telecommunication system and broadcast system addressed in Clause 7 and Annex D should be referred to for detailed explanations. Annex A describes actual service systems with design consideration based on this standard. Annex B gives an overview of the optical transmission systems applicable for broadcast signal transmission.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 60728-1:2007, *Cable networks for television signals, sound signals and interactive services – Part 1: System performance of forward paths*

IEC 60728-6:2003, *Cable networks for television signals, sound signals and interactive services – Part 6: Optical equipment*

IEC/TR 60728-6-1:2006, *Cable networks for television signals, sound signals and interactive services – Part 6-1: System guidelines for analogue optical transmission systems*

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

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

IEC 60825-12, *Safety of laser products – Part 12: Safety of free space optical communication systems used for transmission of information*

IEC 61291-1:2006, *Optical amplifiers – Part 1: Generic specification*

IEC 61755-1:2005, *Fibre optic connector optical interfaces – Part 1: Optical interfaces for single mode non-dispersion shifted fibres – General and guidance*

IEC 61930:1998, *Fibre optic graphical symbology*

IEC 61931:1998, *Fibre optic – Terminology*

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

ITU-T Recommendation G.694.2, *Spectral grids for WDM applications: CWDM wavelength grid*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

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

3.1.1
optical transmitting unit
optical transmitter
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

[IEC 61931, definition 2.9.6]

NOTE 1 For the purposes of this document, optical transmitters may have more than one input port accepting electrical RF signals.

NOTE 2 This piece of equipment amplifies frequency multiplexed electrical signals and converts these electrical signals into optical signals. The optical wavelength is a 1 500 nm band (1 550 ± 10 nm in 1 530 nm to 1 625 nm region).

3.1.2
optical receiving unit
optical receiver
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)

[IEC 61931, definition 2.9.7]

NOTE For the purposes of this document, optical receivers may have more than one output port providing electrical RF signals.

3.1.3
optical amplifier
optical waveguide device containing a suitably pumped, active medium which is able to amplify an optical signal

[IEC 61931, definition 2.7.75]

NOTE 1 In this document, Erbium Doped Fibre Amplifier (EDFA) is used for amplification in the 1 550 nm band.

NOTE 2 There are several methods based on wavelength to be used for amplification. The term “Erbium Doped Fibre Amplifier (EDFA)” is the synonym of optical amplifier in this document.

3.1.4
fibre optic branching device
optical fibre coupler
splitter
optical fibre 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 The ports may be connected to fibres, detectors, etc.

[IEC 61931, definition 2.6.21, modified]

3.1.5
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

[IEC 61931, definition 2.6.51]

3.1.6
optical modulation index
optical modulation index of k^{th} RF carrier, m_k is defined as

$$m_k = \frac{\phi_h - \phi_l}{\phi_h + \phi_l}$$

total optical modulation index, M is defined as

$$M = \sqrt{\sum_{k=1}^{K} m_k^{\ 2}}$$

where

ϕ_h is the highest and

ϕ_l is the lowest instantaneous optical power of the intensity modulated optical signal,

K is the total number of RF carriers and

M is the total optical modulation index.

NOTE This term is mainly used for analogue systems.

[IEC 60728-6, definition 3.1.10, modified]

3.1.7
noise figure
decrease of the signal-to-noise ratio (SNR), at the output of an optical detector with unitary quantum efficiency and zero excess noise, due to the propagation of a shot noise-limited signal through the optical fibre amplifier, expressed in dB

[IEC 61291-1, definition 3.2.38]

NOTE The noise figure of optical amplifiers depends on the optical input power and on the wavelength used.

3.1.8
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 The RIN is usually expressed in dB(Hz^{-1}) resulting in negative values.

[IEC 60728-6, definition 3.1.12, modified]

NOTE 2 The value of RIN can also be calculated from the results of a carrier-to-noise measurement for the system.

3.1.9
responsivity
ratio of an optical detector's electrical output to its optical input at a given wavelength

NOTE 1 The responsivity is generally expressed in Ampere per Watt or Volt per Watt of incident radiant power.

NOTE 2 Sensitivity is sometimes used as an imprecise synonym for responsivity.

NOTE 3 The wavelength interval around the given wavelength may be specified.

[IEC 60728-6, definition 3.1.15]

3.1.10
wavelength
distance covered in a period by the wavefront of a harmonic plane wave

NOTE The wavelength λ of light in vacuum is given by

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

where

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

f is the optical frequency

Although the wavelength in dielectric material, such as fibres, is shorter than in vacuum, only the wavelength of light in vacuum is used.

[IEC 60728-6, definition 3.1.17, modified]

3.1.11
central wavelength
the average of those wavelengths at which the amplitude of a light source reaches or last falls to half of the maximum amplitude

[IEC 60728-6, definition 3.1.26]

3.1.12
AM-VSB signal
sideband in which only the spectral components corresponding to the lower frequencies of the modulating signals are preserved, the other components being strongly attenuated

[IEV 702-06-28, modified]

NOTE This is the abbreviation for the vestigial sideband amplitude modulated signal used in the terrestrial broadcasting and CATV transmission system.

3.1.13
QAM signal
quadrature amplitude modulation
QAM
amplitude modulation by two separate signals of two sinusoidal carriers having the same amplitude and frequency but being in phase quadrature, the modulated signals being added for transmission in a single channel

[IEV 702-06-63, modified]

3.1.14
OFDM signal
orthogonal frequency division multiplexing is one of the multiplexing schemes used for the transportation of terrestrial digital broadcasting SDTV and HDTV signals

NOTE OFDM is based on the idea of frequency-division multiplexing, where each frequency channel is modulated with a simpler modulation, and the frequencies and modulation of FDM are arranged to be orthogonal with each other, which almost eliminates the interference between channels.

3.1.15
RF signal level definition
level of an RF signal is defined in Table 1; it is expressed in microvolt or in dB(μV) or in dB(mW)

3.1.16
AM-VSB analogue signals
vision carrier signal level is the RMS value of the vision carrier at the peak of the modulation envelope (C_{rms}), expressed in dB(μV) and measured across a 75 Ω termination or referred to 75 Ω

NOTE This will correspond, in negative modulation systems, to the carrier amplitude during synchronizing pulses and, in positive modulation systems, to that at peak white level without a chrominance signal, as shown in ITU-R Recommendation BT.470, Figure 1.

3.1.17
FM radio or FM audio carrier of a TV signals
level of an FM radio or of an FM audio carrier of a TV signal is the RMS value of the carrier expressed in dB(μV) and measured across a 75 Ω termination or referred to 75 Ω

3.1.18
digitally modulated signals
level of a digitally modulated signal is given by the RMS power of the signal within the channel bandwidth ($S_{D,RF}$) and can be expressed in dB(mW) or in dB(μV) referred to 75 Ω

NOTE The level of an OFDM signal is the average electrical power of the overall signal comprised of multi-carriers and is not the individual carrier level of the multi-carrier signal, as shown in Table 1.

Table 1 – Level of RF signals

Signal		Level detection	Symbol	Remarks
Analogue TV signal	**AM-VSB video carrier**	peak value	C_{rms}	RMS value of the carrier at the peak of the modulation envelope.
	FM audio carrier	RMS value	C_{rms}	The carrier level is a constant value.
QAM signal		RMS value	$S_{D,RF}$	The value is averaged over a sufficiently long period of time compared to period of the lowest frequency used for the modulation.
OFDM signal		RMS value		

3.1.19
carrier-to-noise ratio
C/N
signal-to-noise ratio
$S_{D,RF}/N$
ratios are given by

$$C/N \text{ (dB)} = C_{rms} - N_{rms} \qquad \text{(for analogue signals)}$$

$$S_{D,RF}/N \text{ (dB)} = S_{D,RF} - N_{rms} \qquad \text{(for digital signals)}$$

where N_{rms} is the RMS level of the noise in the equivalent noise bandwidth of the RF channel, expressed in dB(mW) or in dB(µV) referred to 75 Ω

NOTE The level of the analogue modulated carrier or of the RF digitally modulated signal and the level of the noise shall be expressed in the same units, in dB(mW) or in dB(µV) measured across a 75 Ω termination or referred to 75 Ω.

3.1.20
***D*/*U* ratio**
ratio of desired signal level, *D*[dB(µV)], to undesired signal level, *U*[dB(µV)]

NOTE The *D*/*U* ratio is generally used for multiple frequency interference as CSO and CTB, for single frequency interference as CCR.

3.1.21
single or multiple frequency interference
besides the *C*/*N* and $S_{D.RF}/N$ ratios, single or multiple frequency interference to video signal is defined as the ratio of desired signal level and undesired signal level

NOTE 1 The ratio of desired signal level, *D*(dB(µV)), to undesired signal level, *U*(dB(µV)) is given by

D/U (dB) = $D - U$

NOTE 2 The desired and the undesired signals can also be expressed both in dB(mW).

3.1.22
optical line terminal
OLT
central office-terminal equipment that is linked with the Optical Network Unit (ONU) in customer premises

NOTE OLT usually connects with headend equipment.

3.1.23
optical network unit
ONU
terminal equipment linked with OLT

3.1.24
video-optical network unit
V-ONU
terminal unit that changes the optical signal of a broadcast system into an electric signal

NOTE The term V-ONU is used as the synonym of optical receiver (O/E) in this standard.

3.1.25
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

[IEC 61931, definition 2.1.88]

NOTE 1 In silica fibres the frequency shift is typically around 10 GHz.

NOTE 2 *SBS* results in loss of optical level and affects the performance of analogue optical system.

NOTE 3 The frequency shift is characterized by a frequency downshift (that is to a longer wavelength) due to a GHz frequency acoustical vibration (frequency downshift is 10 or 11 GHz, and gain bandwidth 20 MHz).

3.1.26
self-phase modulation
SPM
increase of the refractive index of optical fibres due to excessive optical power launched into the fibre

NOTE 1 Modulated optical signal induces modulation of refractive index, which means that the phase of optical signal varies in time. The nonlinear phase modulation is caused by a device or a system itself, therefore it is called self-phase modulation.

NOTE 2 *SPM* affect the distortion properties of an analogue optical transmission.

3.1.27
stimulated Raman scattering
SRS
non-linear scattering of optical radiation characterized by a wavelength shift and accompanied by very high frequency vibration of the medium lattice, strongly enhanced by the presence of already scattered radiation

[IEC 61931, definition 2.1.87]

NOTE 1 In silica fibres the wavelength shift is typically around 100 nm for an exciting radiation with a wavelength around 1 550 nm.

NOTE 2 Stimulated Raman scattering can occur in both forward and backward directions and can cause crosstalk between optical signals of different wavelengths.

NOTE 3 Frequency downshift is about 13 THz and gain bandwidth about 20 GHz.

3.1.28
cross-phase modulation
XPM
caused by the nonlinear refractive index of the fibre material

NOTE 1 *XPM* has a relationship with the wavelength spacing in an optical transmission system. The more the spacing increases, the more the *XPM* value decreases. In such a WDM system having 1 490 nm (communication signal) and 1 550 nm (broadcast signal) wavelengths, *XPM* becomes negligibly small compared to *SRS* due to this relationship.

NOTE 2 *XPM* affects the performance of the wavelength division multiplex system.

3.1.29
Rayleigh scattering
light scattering in a medium due to in-homogeneity in material density or composition of that medium which are small with respect to wavelength

NOTE The scattered power is inversely proportional to the fourth power of the wavelength.

[IEV 731-03-37] and [IEC 61931, definition 2.1.76]

3.1.30
crosstalk
carrier-to-crosstalk ratio
CCR
level difference of CATV broadcast carrier level and worst case of other services single frequency crosstalk signal measured at RF output port of optical receiver for CATV broadcast service

$$CCR = D_{CATV} - U_{OtherService}$$

where

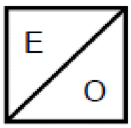
D_{CATV} is the nominal level of CATV broadcast signal in dB(μV) at RF output port of optical CATV broadcast receiver,

$U_{\text{OtherService}}$ is the worst case level of another service's single frequency crosstalk in dB(μV) at RF output port of optical CATV broadcast receiver. *The value of* $U_{\text{OtherService}}$ is mainly due to the Raman scattering effect.

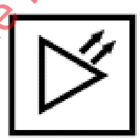
CCR is expressed in dB.

3.2 Symbols

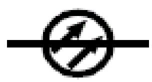
The following graphical symbols are used in the figures of this standard. These symbols are either listed in IEC 60617 or based on symbols defined in IEC 60617.



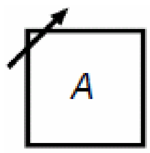
Optical transmitter based on [IEC 60617-S01231 (2001-07)]



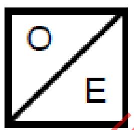
Optical amplifier [IEC 60617-S00127 and IEC 60617-S01239 (2001-07)]



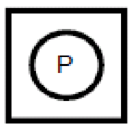
Optical fibre [IEC 60617-S01318 (2001-07)]



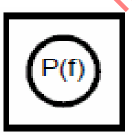
Variable attenuator [IEC 60617-S01245, modified (2001-07)]



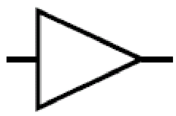
Optical receiver based on [IEC 60617-S00213 (2001-07)]



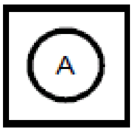
Power meter [IEC 60617-S00059, IEC 60617-S00910 (2001-07)]



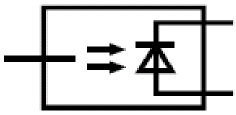
Electrical spectrum analyzer based on [IEC 60617-S00059 and IEC 60617-S00910 (2001-07)]



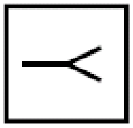
Amplifier [IEC 60617-S01239 modified (2001-07)]



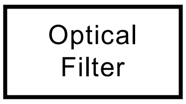
Ammeter
based on
[IEC 60617-S00059
and
IEC 60617-S00910
(2001-07)]



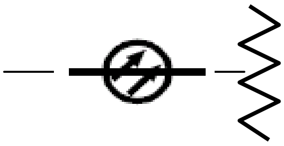
Photodiode with fibre
pigtail
[IEC 60617-S01327
(2001-07)]



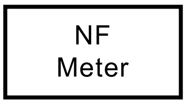
Coupler
[IEC 60617-S00059
and
IEC 60617-S01188
(2001-07)]



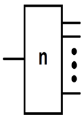
Optical filter



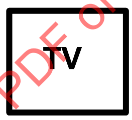
Optical terminator
[IEC 60617-S01389
and
IEC 60617-S01318 [2]]



NF meter



Optical splitter
[3.33.1 of IEC 61930]



Television set

Video optical network
unit

3.3 Abbreviations

ADS	Active Double Star	AGC	Automatic Gain Control
AM	Amplitude Modulation	APC	Angled Physical Contact optical connector
BCH	Bose-Chaudhuri-Hocquenghem multiple error correction binary block code	CATV	Community Antenna Television (network)
CODFM	Coded Orthogonal Frequency Division Multiplex	*CCR*	Carrier-To-Crosstalk ratio
C/N	Carrier-to-Noise ratio	CPE	Customer Premises Equipment
CSO	Composite Second Order	*CTB*	Composite Triple Beat
		CW	Continuous Wave
DS	Down Stream or Double Star	DSF	Dispersion Shifted Fibre
D/U	Desired to Undesired signal ratio	EDFA	Erbium-Doped Fibre Amplifier
E/O	Optical transmitter (Electrical-to-Optical transducer)	FM	Frequency Modulation
FTTB	Fibre To The Building	FTTH	Fibre To The Home
HDTV	High Definition Television	H/E	Headend
HFC	Hybrid Fibre Coaxial	ITU-T	International Telecommunication Union – Telecommunication sector
LD	Laser Diode	LDPC	Low-Density Parity Check (codes)

2 IEC 60617-S01318 is for reference only, obsolete since 1996-05.

MC	Media Converter	MDU	Multiple Dwelling Unit
MER	Modulation Error Ratio	*NF*	Noise Figure
O/E	Optical Receiver (OpticaltTo Electrical transducer)	OFCS	Optical Fibre Communication System
OFDM	Orthogonal Frequency Division Multiplex	OLT	Optical Line Terminal
OMI	Optical Modulation Index	ONU	Optical Network Unit
PD	Photo Diode	PDS	Passive Double Star
PER	Packet Error Ratio	PON	Passive Optical Network
QAM	Quadrature Amplitude Modulation	QPSK	Quaternary Phase Shift Keying
RIN	Relative Intensity Noise	RBW	Resolution Bandwidth
RF	Radio Frequency	SBS	Stimulated Brillouin Scattering
SDTV	Standard Definition Television	SDU	Single Dwelling Unit
SMF	Single Mode Fibre	*S/N*	Signal-to-Noise ratio
		SPM	Self-Phase Modulation
SRS	Stimulated Raman Scattering	SS	Single Star
US	Up Stream	*VBW*	Video Bandwidth
V-ONU	Video Optical Network Unit	AM-VSB	Amplitude Modulation-Vestigial Side Band
WDM	Wavelength Division Multiplexing	*XPM*	Cross-Phase Modulation
SW	Switch		

4 Optical system reference model

Figure 1 and Figure 2 show the optical system reference model for broadcast signal transmission. Although numbers of optical amplifiers and optical splitters depend on the scale of the optical system, or on the numbers of subscribers to be connected, the fundamental network configuration shall follow the system reference model. In addition the optical levels in operation required for the system are relatively high, and hence, special attention for human safety shall be paid in accordance with IEC 60825-1, IEC 60825-2 and IEC 60825-12.

Generally, there are two solutions for constructing an optical transmission system: one-fibre and two-fibre solutions. One-fibre solution is suitable for deployment of both broadcast and telecommunication services cost-effectively using Wave Division Multiplex (WDM) technology. However, special attention shall be paid to the selection of the transmission parameters to avoid mutual interference over single optical fibre transmission. The two-fibres solution is suitable for segregation of service areas for broadcast and telecommunications and is free from mutual signal interference. However, the installation cost is not competitive compared with the one-fibre solution.

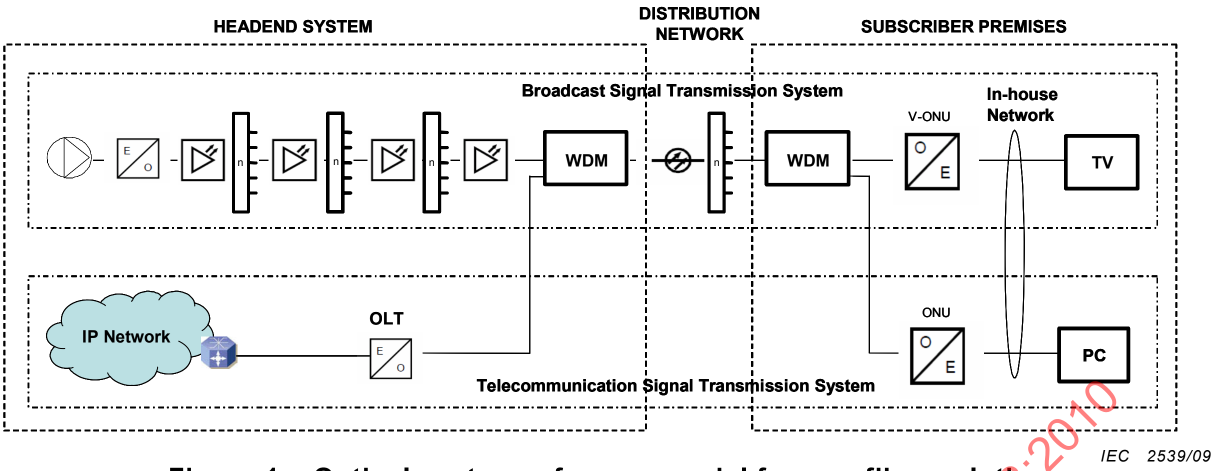


Figure 1 – Optical system reference model for one-fibre solution

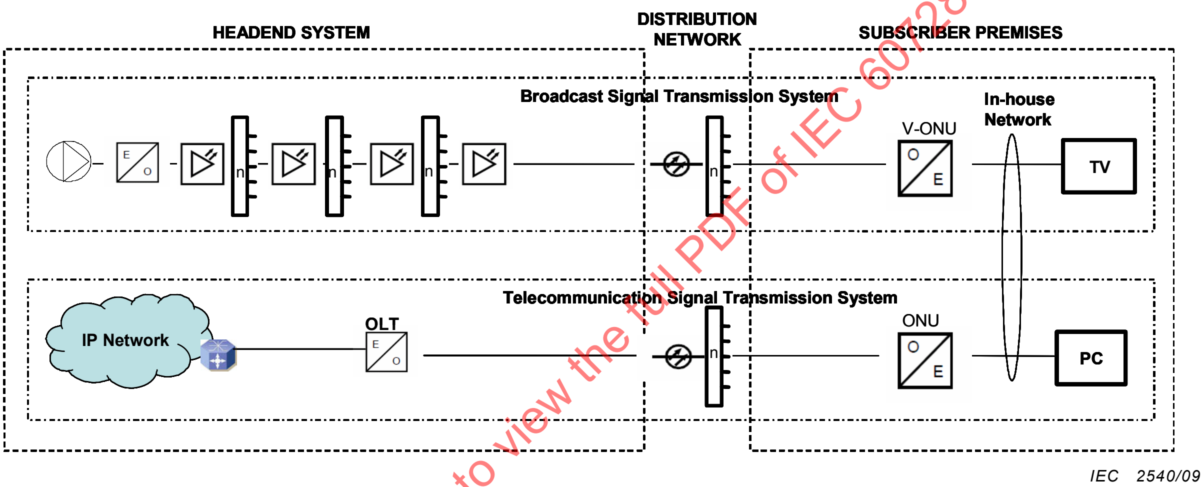


Figure 2 – Optical system reference model for two-fibres solution

In this standard the one-fibre solution is used as the reference model.

The reference model as shown in Figure 1 includes the broadcast signal transmission system and the telecommunication signal transmission system. A telecommunication signal transmission system uses both ways of transmission over the optical fibre with different optical wavelengths. Both systems are combined by WDM filters at input and output of the distribution network as an example. The distribution network must be passive optical components such as optical fibre and optical power splitters, considering maintenance and future system expansion. Although the telecommunication signal transmission system can transmit any IP datagram to subscriber premises through IP networks, this system is out of the scope of this standard.

In some cases a one-fibre solution triplexer is used. The schematics of the PON triplexer is given in Figure 3.

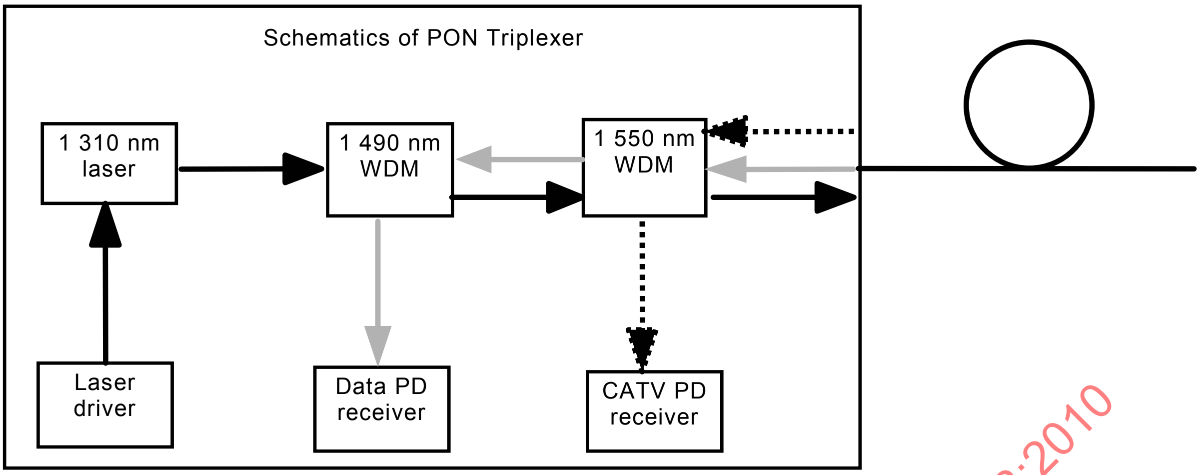


Figure 3 – Example of PON triplexer

In the one-fibre solution it is required to avoid optical and electrical crosstalk.

- Optical crosstalk between the downstream data signal transmitted on 1 490 nm wavelength and the CATV downstream signal is generated if the 1 550 nm WDM does not provide sufficient isolation for the 1 490 nm signal.
- Electrical crosstalk between the 1 310 nm data driver signal and the 1 550 nm CATV PD receiver input signal due to electromagnetic radiation in the very compact triplexer housing. Example: Typical laser driver currents of the 1 310 nm laser are in the order of 10 dB(mA). The input receiver current of one TV signal is in the order of −36 dB(mA), that means 46 dB lower. In order to have less than −60 dB crosstalk between the IP transmitter and the CATV receiver signal, the isolation of the IP driver signal respect to the CATV receiver has to be greater than 100 dB. This is quite difficult to achieve in compact housings for a wide frequency range from about 45 MHz to 1 000 MHz.

Therefore in some systems, PON diplexers with separate 1 550 nm WDMs are used instead of PON triplexers to achieve better performance for CATV transmission.

The performance specified points of the optical system are described in Figure 4. Some of the performance check point in the optical distribution network should be provided in accordance with maintenance policy of cable operator.

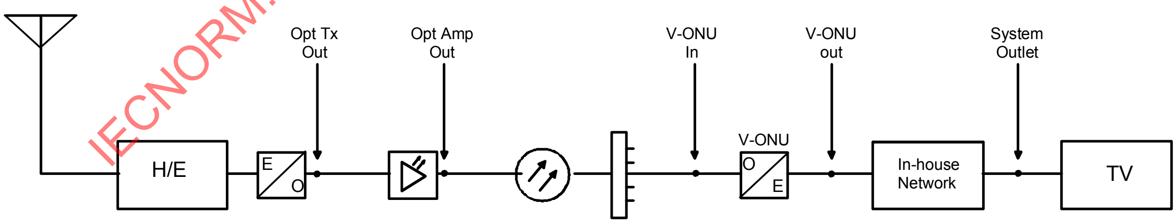


Figure 4 – Performance specified points of the optical system

5 Preparation of measurement

5.1 Environmental conditions

5.1.1 Standard measurement conditions

Unless otherwise specified, all the measurements shall be carried out under the following standard measurement conditions.

5.1.2 Temperature and humidity

The ambient temperature and relative humidity shall be in the range of 15 °C to 35 °C and 25 % to 75 %, respectively, see IEC 60068-1, 5.3.1] nevertheless the specification of the measurement equipment has to be taken into account.

5.1.3 Setting up the measuring setup and system under test

The system under test shall be in the normal operating condition, and all the pieces of equipment in the system shall be mounted and tuned according to the designed level diagram prior to the measurement.

5.1.4 AGC operation

Unless otherwise specified, all the pieces of equipment in the system shall be operated in the AGC mode if available.

5.1.5 Impedance matching between pieces of equipment

Attention shall be paid on the impedance matching between pieces of equipment and the test setup, and sufficient care shall be taken to avoid any measurement error by introducing components such as attenuators.

5.1.6 Standard operating condition

The standard operating condition refers to the condition in which the cable TV system under test is fully functional at a given facility. All the input and output of individual pieces of equipment shall be tuned according to the designed level diagram before any measurement is carried out.

5.1.7 Standard signal and measuring equipment

For measurement purposes, the standard signals used in the measuring instruments as well as in the system under test shall be set according to the prescribed standard signal format of the individual system. The measuring instruments to be used are described in Table 2 (passive pieces of equipment are excluded).

Table 2 – Measuring instruments

Name of instrument	Usage
Optical power meter	Instrument to measure the power of the optical signal.
Spectrum analyzer	Instrument used for quantitative measurement of high frequency signals.
Signal generator	Instrument used to generate high frequency signals (sine-waves).
Network analyzer[a]	Instrument used to measure the high frequency performance of equipments.
NF meter[a]	Instrument used to measure Noise Figure (*NF*).
Current meter (Ammeter)[a]	Instrument used to measure electrical current.
V-ONU	Optical receiver unit used to convert an optical video signal to an electrical signal.

[a] If the *RIN* calculation parameters of ONU, responsivity (*R*), dark current (I_{d0}) and equivalent noise current density (I_{eq}) are known beforehand, these instruments are not necessary.

5.2 Accuracy of measuring equipment

All the devices and instruments used for the measurement shall be accurately calibrated. The standard sources used for calibration shall be calibrated within 6 months before the day of measurement.

5.3 Source power

The supply voltage and frequency for the measuring instruments and the equipment of the system under test shall be obtained from the corresponding instrument/equipment specifications.

6 Methods of measurement

6.1 Measuring points and items

6.1.1 General

This clause describes methods of measurement specifically designed for FTTH system.

The measurement points described in this standard are limited to the part of the system, that is ranging from the output terminal of the optical transmitter to the system outlet.

6.1.2 Measuring points

It is required to measure the optical power at points (1) to (5), and the electrical signal level at points (6) and (7) of Figure 5 to assure the total system performance. Points (5), (6) and (7) shall be measured to guarantee the system performance at the end point of the optical section and at the interface point to the customer premises. *RIN* should be measured at points (1) to (5) and *C*/*N* (electrical signal) at points (6) and (7).

6.1.3 Measured parameters

The following measurements have to be carried out.

a) Optical power

The optical power shall be measured at points (1) to (5) in the optical system shown in Figure 5.

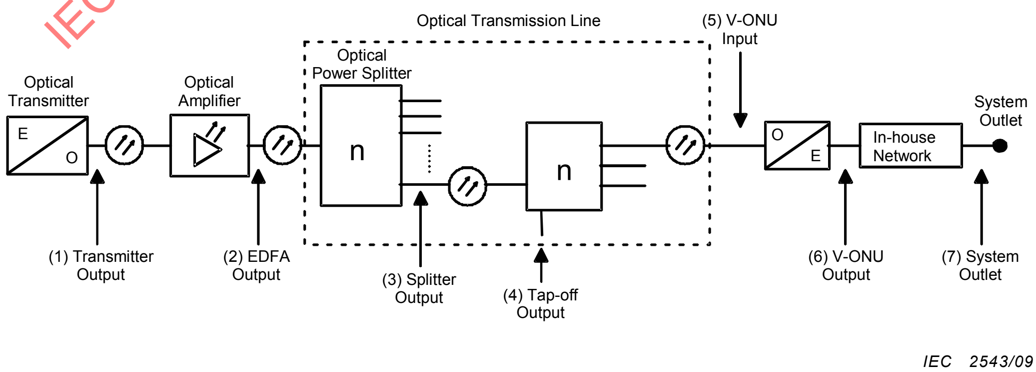


Figure 5 – Typical optical video distribution system

b) Carrier-to-noise ratio (electrical signal)

The carrier-to-noise ratio is measured after the optical signal is converted into an electrical signal, and it shall be carried out at measurement points (6) and (7).

c) *C/N* ratio (*RIN*)

Estimation of the carrier-to-noise ratio at the output of V-ONU is calculated from the measured *RIN* (relative intensity noise) of the optical input signal of V-ONU at point (5).

It is preferable to measure the *RIN* when the optical power at the measuring point is higher than –3 dB(mW), a limitation imposed by the noise performance of the measuring setup. Similarly, since the optical power at the measuring point (5) in a typical system is lower than −3 dB(mW), the measurement error becomes large and the measurement of *RIN* at this point is not recommended.

However, since the above limitation is due only to the noise performance of the measuring system, this can be exempted if the accuracy of measurement improves in future.

For measuring points and measured parameters see Table 3.

Table 3 – Measuring points and measured parameters

Measured parameters	Measuring points						
	(1) Transmitter output	(2) EDFA output	(3) Power splitter output	(4) Tap-off output	(5) V-ONU input	(6) V-ONU output	(7) System outlet
Optical power	○	○	○	○	○	—	—
C/N (electrical)	—	—	—	—	—	○	○
C/N (*RIN*) (see NOTE 1)	○	○	△	△	△	—	—

○ : Measurements are possible at these points.

△ : Measurements are possible at these points when the optical power is higher than –3 dB (mW).

NOTE 1 Theoretical estimation of *C/N* at (6), at the output of V-ONU, is based on the measurement results of individual pieces of equipment.

NOTE 2 The measurement at points (5), (6) and (7) is mandatory, while measurement at other points is required to assure the system performance.

6.2 Optical power

6.2.1 General

The purpose of this measurement is to measure the average optical power at each measurement point in the optical system illustrated in Figure 6 or in Figure 7.

6.2.2 Measuring setup

6.2.2.1 Measurement of the optical power at single wavelength

The measurement of optical power at single wavelength shall be carried out according to 4.2 of IEC 60728-6.

6.2.2.2 Measurement of the optical power of a WDM signal

When multiple wavelengths are multiplexed, either by using an optical filter or a WDM coupler, the optical power of the specified wavelength shall be measured. The directivity and isolation performance of the WDM coupler used for the measurement shall be the same or better than the filter used inside the V-ONU. Connect the equipments as shown in Figure 6 or in Figure 7 depending on whether a WDM coupler or a wavelength filter is used.

NOTE Methods of measurement for the optical power of single wavelength are described in IEC 60728-6.

The optical power at the output of a WDM coupler shall be measured according to 4.2 of IEC 60728-6.

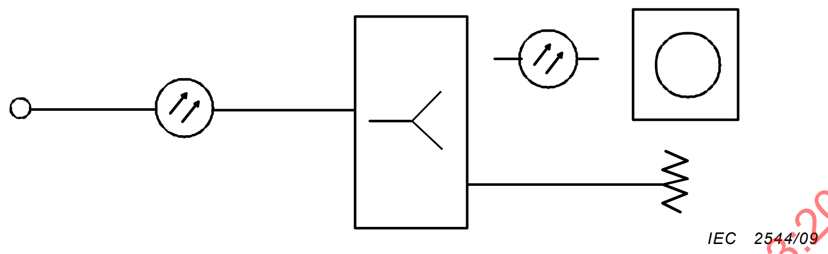


Figure 6 – Measurement of optical power using a WDM coupler

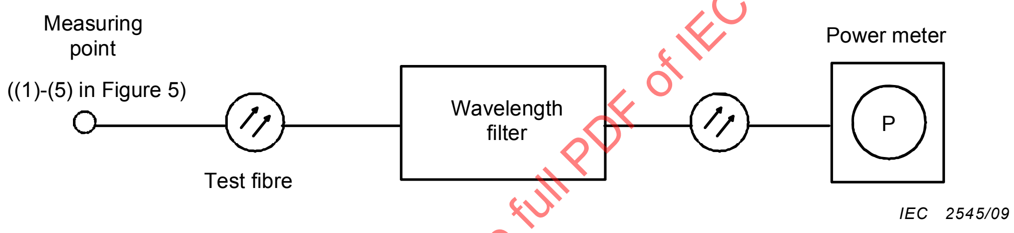


Figure 7 – Measurement of optical power using a wavelength filter

6.2.3 Measuring method

In addition to the requirements of IEC 60728-6, the following points shall be considered.

a) Connect the test fibre to the power meter and ensure that the power meter is switched to the specified single wavelength and only the specified wavelength signal is applied to the power meter.

b) Measure and record the power of the output signal using the power meter.

c) If a WDM coupler or a wavelength filter is used to measure the WDM signals, the pre-determined insertion loss of the WDM coupler or the wavelength filter shall be added to the measured optical power.

6.2.4 Precaution for measurement

The following considerations have to be taken into account.

a) Optical fibre end-face or the connector end-face should not be viewed directly. Also, the end-face of the fibre should not be pointed towards any person. If there are unterminated single or multiple fibres, they shall be covered together to avoid any radiation hazard. Any unconnected optical connector shall be covered with a cap during all the measuring time.

b) Ensure that the power meter has a measuring range suitable for the expected power, and is capable of measuring the expected signal wavelength. The detector system of the power meter shall have a sufficiently large area to collect all the radiation from the test fibre and a spectral sensitivity compatible with the light source. A minimum accuracy of ±10 % is recommended.

c) The sensor portion of the power meter shall be shut off and zero offset adjustment shall be carried out before the measurement.

d) Test fibres and connectors shall have clean and unscratched ends in order to prevent losses of power and reflections.

e) If the measurement bandwidth and the measuring range of the power meter can be set independently, they shall be set in the auto mode prior to the measurement.

f) The measurement shall be carried out in the CW mode. If the power meter has a selectable measurement mode (CW / 270 Hz / 1 kHz / 2 kHz), CW mode shall be selected. Power meters without any measurement mode function, normally operate with in CW mode and ensure CW mode of operation prior to the measurement.

g) If there is any instability in the measurement (measured value may fluctuate when end-face of fixed attenuator is directly connected to the power meter), a suitable patch cord shall be used and the measurement shall be repeated.

h) The potential sources of error are the following:

   1 the inaccuracy of the power meter, for example if its dark current is not sufficiently low;

   2 the attenuation of the test fibre and the specified coupling means.

6.2.5 Presentation of the results

The optical power shall be expressed in dB(mW).

6.3 Carrier level and carrier-to-noise ratio

6.3.1 General

The purpose of this test method is to measure the carrier level of the television broadcast signal. Also, carrier-to-noise ratio is measured using the measured noise level within the transmission bandwidth of the television signal. This test method performs the measurement in the electrical domain.

6.3.2 Measuring setup

Connect the pieces of equipment as shown in Figure 8. The method for measuring the carrier-to-noise ratio of analogue optical transmission systems is nearly the same as for cabled distribution systems (see IEC 60728-1, 4.6)

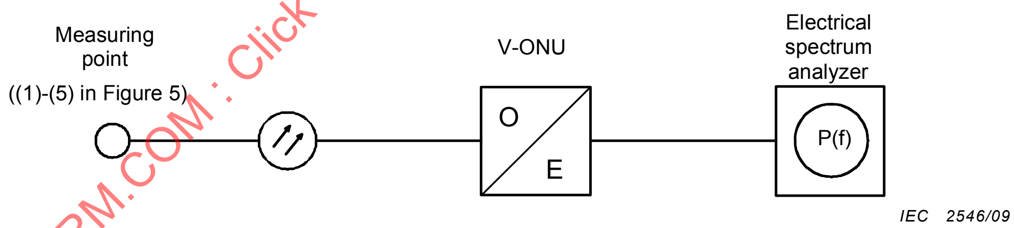


Figure 8 – Arrangement of test equipment for carrier-to-noise ratio measurement

6.3.3 Measuring conditions

The following measuring conditions apply.

a) The spectrum analyzer used for the measurement has to be calibrated before the measurement. The supply voltage of all the pieces of equipment used for the measurements shall be switched on at least 30 min before the start of the measurement.

b) If the measuring instrument has any calibration function, it shall be executed prior to the measurement.

c) Suitable coaxial cables and connectors shall be used to maintain proper impedance matching within the measurement system.

6.3.4 Measuring method for analogue signals (AM-VSB)

Methods of measurement for the carrier level and carrier-to-noise ratio (*C*/*N*) are described in 4.6 and 4.8 of IEC 60728-1.

6.3.5 Measuring method for digitally modulated signals (64 QAM, OFDM)

Methods of measurement for the carrier level and carrier-to-noise ratio for digitally modulated signals are described in IEC 60728-1.

6.3.6 Precautions for measurement

The following considerations have to be taken into account.

a) Measurement accuracy: To obtain accurate measurement of carrier-to-noise ratio, it is necessary to turn off the channel under test and measure the noise level within the channel bandwidth. Depending on the situation, it is expected that the arbitrary broadcast channel cannot be turned off during network operation. Therefore, attention shall be paid on the inaccuracy and measuring error of the test method prescribed in this standard.

b) Attenuation setup of the spectrum analyzer: Most of the spectrum analyzers have a default input attenuation of 10 dB when powered on. It is possible to carry out the measurement with this default value when the total electrical input power does not exceed 0 dB(mW). Total electrical power is measured using the electrical power measurement option of the spectrum analyzer and by setting the centre frequency to 510 MHz and the frequency span to 1 GHz and the channel power measurement bandwidth to 1 GHz. There shall not be any signal outside the above frequency span. If the total power (P_T) exceeds 0 dB(mW) (109 dB(µV) on the voltage display), in order to avoid any distortion generated within the spectrum analyzer, adjust the input attenuation (ATT_{IN}) setting to satisfy the following relation:

$$P_T - ATT_{IN} < -10 \text{ dB(mW)}.$$

c) Measure the output of the digital signal generator using a calibrated power meter with a thermo-coupled sensor and, taking this as the true value, calibrate the measurement level of the spectrum analyzer.

d) When the carrier-to-noise ratio of the signal is very small, the noise within the signal will be larger than the measuring error and cannot be neglected. If a correction factor needs to be applied, this correction factor shall be subtracted from the spectrum analyzer measured level (see Annex F of IEC 60728-1).

e) This standard recommends the test method using the electrical power measurement option of the spectrum analyzer to deal with QAM and OFDM signals. This test method is preferred because any correction necessary within the spectrum analyzer is automatically processed irrespective of the type of spectrum analyzer used for the measurement. Also, the flatness of the signal over the transmission bandwidth does not influence the measurement results.

NOTE The noise level per unit frequency may be expressed in dB(µV/$\sqrt{\text{Hz}}$) or in dB(µV/Hz).

6.3.7 Presentation of the results

The carrier level shall be expressed in dB(mW) or in dB(µV) and the carrier-to-noise ratio shall be expressed in dB.

6.4 Carrier-to-noise ratio defined by optical signal

6.4.1 General

This measurement method has the purpose to predict the carrier-to-noise ratio at the output of V-ONU from the measured relative intensity noise (*RIN*) of the optical input signal to the V-ONU.

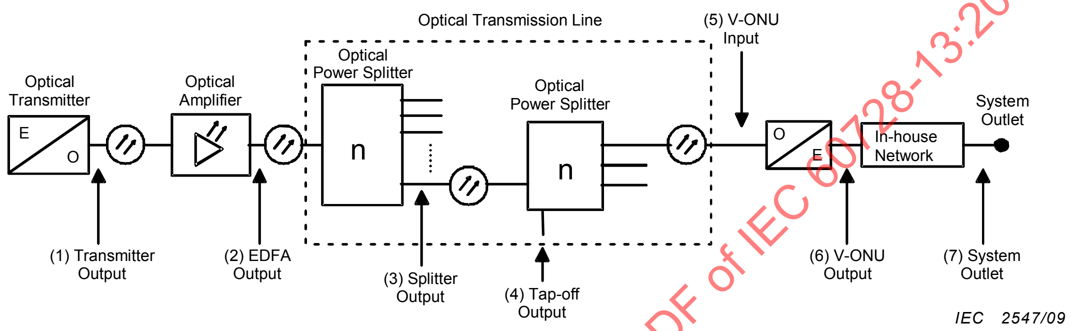
RIN is the noise caused by fluctuations in optical output power with respect to time and is expressed as the ratio of average optical power to the average noise power measured in 1 Hz bandwidth. It is difficult to measure the *RIN* directly in the optical domain and the measurement shall be carried out after converting the optical signal to an electrical signal. However, an accurate measurement of *RIN* is not possible if the optical input to V-ONU is small as in most of the practical systems. *RIN* may also be calculated from the measured performance of individual components constituting the system. However, it is necessary to measure the *RIN* on a near side measurement point.

6.4.2 Measuring setup

The measuring setup is the following.

a) Measuring points

Measuring points in the Cable TV network for optical signals are shown in Figure 9.



NOTE Figure 9 is identical to Figure 5, except that the Figure title has changed to describe the measurement points.

Figure 9 – Measuring points in the optical cable TV network

- In order to calculate the carrier-to-noise ratio at the V-ONU output, it is necessary to measure the *RIN*, as shown in Figure 9 at points (1) to (3), where the optical output power is sufficiently high to allow *RIN* measurements to be accurate.
- NOTE *RIN* measurements will not be accurate when the optical power is lower than –3 dB(mW).
- If an optical amplifier is not employed in the system, *RIN* shall be measured at point (1).
- If an outdoor type optical amplifier is employed and measurement can be carried out outdoor, the optical amplifier output shall be considered as a measuring point.
- If the optical power at point (4) or (5) is sufficiently high, these points shall also be used for measuring *RIN*.

b) Measuring setup

Figure 10 shows the *RIN* measurement set-up.

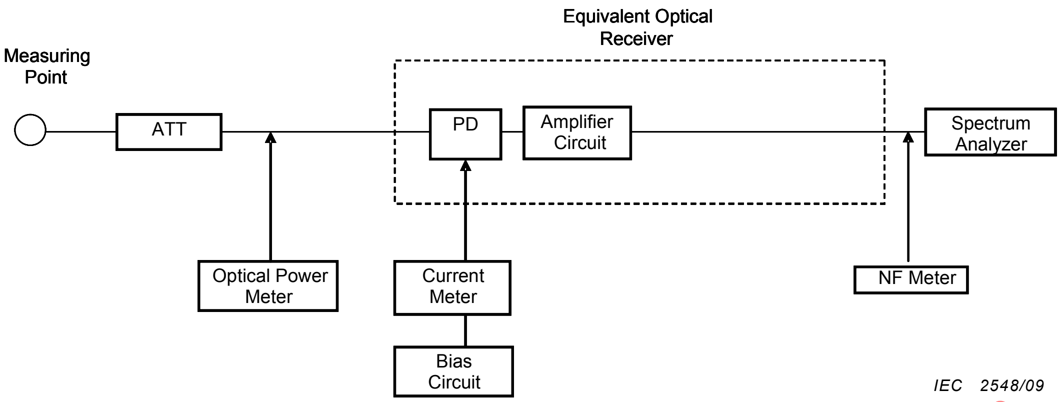


Figure 10 – *RIN* measurement setup

6.4.3 Measuring conditions

The following measuring conditions apply.

- Only calibrated instruments (spectrum analyzer, optical power meter, current meter, network analyzer, *NF* meter and the optical attenuator) shall be used for the measurements.
- The spectrum analyzer must have the option to measure the noise power density. The optical receiver part is constituted by a photo diode (PD), a low-noise preamplifier and a matching circuit. The photo diode must have the provision to measure the photo diode current.
- A CW optical signal shall be used for the measurement. To avoid the SBS interference some technology shall be applied such as SBS suppression carrier method.
- The optical input level to the optical receiver shall be around 0 dB(mW), and shall not be lower than –3 dB(mW).

The *RIN* degradation due the Rayleigh scattering and multiple optical reflections within the transmission line cannot be neglected. Therefore, if the *RIN* measurement is carried out within the head-end, an equivalent optical cable having similar performance to the cable used in the actual optical network, shall be inserted at the measuring point in Figure 10.

6.4.4 System *RIN* measuring method

6.4.4.1 General

This test method shall be applied to predict the carrier-to-noise ratio at the output of V-ONU from the *RIN* measurement using the setup shown in Figure 10. This subclause contains several steps as shown below. If the parameters for R, I_{d0} , I_{eq} and G are unknown, refer to Annex D. *RIN* can be calculated using these parameters.

6.4.4.2 STEP A: Input power of optical receiver and system noise (noise current density)

For step A proceed as follows.

- Measure the input power of optical receiver (P_r) using a power meter.
- Connect the spectrum analyzer at the output of the optical receiver and select the measurement mode to measure the noise power density. Measure the noise power density per unit frequency, N_p expressed in dB(mW/Hz). The total noise current per Hz, I_{bn} of the optical receiver can be calculated using Equation (1) with RBW of the spectrum analyzer set to 100 kHz)

$$I_{bn} = \sqrt{\frac{10^{\frac{N_p}{10}} \times 10^{-3}}{Z_0}} \quad \left[A/\sqrt{Hz}\right] \tag{1}$$

where

Z_0: is the impedance of the measurement setup,

N_p is the noise power density, expressed in dB(mW/Hz).

The following correction shall be applied if the noise level (N_L) is measured with the spectrum analyzer:

$$N_p = N_L + 10 \log (B_n/B) + K_1 + K_2$$

where

B_n is the measurement bandwidth of noise power (N_p) 1 Hz,

B is the noise bandwidth, $RBW \times 1{,}2$(noise bandwidth correction factor) = 120 000 Hz,

K_1 is the correction factor for conversion to effective voltage level = 10 log(2/ $\sqrt{\pi}$)=1,05 dB,

K_2 is the correction factor for the logarithmic amplifier of spectrum analyzer = 1,45 dB.

NOTE The measured noise level (N_p) includes that of the measuring equipment (spectrum analyzer) which should be at least 20 dB lower than the noise level displayed outside the channel band in order not to affect the results. Otherwise, the contribution of noise (due to the system or the equipment under test and to the measuring equipment) should be taken into account in the measurement of noise level (see Annex F of IEC 60728-1).

6.4.4.3 STEP B: *RIN* calculation

For step B proceed as follows.

- From the above measurement results, *RIN* can be calculated from the following relation:

$$RIN = 10 \lg \left(\frac{\frac{I_{bn}^2}{G}}{(R \times P_r)^2} - \frac{2e}{(R \times P_r)^2}(I_{d0} + R \times P_r) - \frac{I_{eq}{}^2}{(R \times P_r)^2} \right) \quad [dB(Hz^{-1})] \tag{2}$$

where

R is the responsivity of the photodiode (A/W),

I_{d0} is the dark current of the photodiode (A),

I_{eq} is the preamplifier equivalent input noise current density (A/ $\sqrt{Hz}$),

I_{bn} is the total noise current within 1 Hz bandwidth at the optical receiver output (A/ $\sqrt{Hz}$),

G is the amplifier gain of the optical receiver (Including gain of matching circuit)

P_r is the input power to the optical receiver (W),

e is the charge of the electron $1{,}602 \times 10^{-19}$(C).

6.4.5 *C/N* calculation based on *RIN* value

The carrier-to-noise ratio (C/N) at the V-ONU output can be calculated using the following relation.

$$C/N = 10\ \lg\left(\frac{1}{B_N}\cdot\frac{\frac{1}{2}\cdot(m_k\cdot R\cdot P_r)^2}{RIN(R\cdot P_r)^2+2\cdot e\cdot(I_{d0}+R\cdot P_r)+I_{eq}{}^2}\right)\ [\text{dB}] \tag{3}$$

where

$$M=\sqrt{\sum_{k=1}^{K}m_k{}^2} \tag{4}$$

The other parameters for the calculation are listed in Table 4.

6.4.6 Component *RIN* calculation

The following method shall be applied to calculate the component *RIN* of the optical signal at input of the V-ONU when 6.4.4 is not applicable. If the *RIN* of the first EDFA (*RIN* of optical transmitter) is expressed as RIN_{in}, then the *RIN* of the nth EDFA, RIN_{out} is given by

$$RIN_{out} = 10\ \lg\left(\sum\frac{2\cdot E\cdot 10^{\frac{NF_n}{10}}}{10^{\frac{P_n}{10}}}+10^{\frac{RIN_{in}}{10}}\right) \tag{5}$$

where

E is the photon energy, $E = hf$,
h is the Planck's constant, 6,62 $\times 10^{-34}$[Js],
f is the frequency.
If the optical wavelength is 1 555 nm, then E = 1,278$\times 10^{-16}$[mJ].

NF_n is the noise factor of the *n*th EDFA (dB),

P_n is the optical input power of the *n*th EDFA (dB(mW)).

NOTE "1/*G*" term in Equation (12) of IEC/TR 60728-6-1 is very small compared to other terms and hence can be neglected.

- Also, even though the *RIN* degradation due to Rayleigh scattering and other reflections within the fibre is small, this cannot be ignored if an optical transmitter with *RIN* smaller than –160 dB(Hz^{-1}) and EDFAs with low *NF* are used. The following relation shall be used to calculate the *RIN*, RIN_f due to the fibre transmission.

$$RIN_f = 10\ \lg\left[\frac{s^2}{4}\left(2\alpha L-1+e^{-2\alpha L}\right)\cdot\frac{\Delta\nu}{\pi\left(f_{RF}{}^2+\Delta\nu^2\right)}\right]\quad (\text{dB/Hz}) \tag{6}$$

where

S is the ratio of scattered optical power that is propagated in the reverse direction,

$$s=\frac{1{,}5}{(\pi\cdot W\cdot \eta_1)^2}$$

α is the fibre transmission loss. If the transmission loss is α_{dB}(dB/km), then $\alpha = \alpha_{dB}/4{,}343$.

L is the transmission distance (km),
$\Delta\nu$ is the spectral width of the optical signal when modulated (Hz),
f_{RF} is the measurement frequency (Hz),
W is the fibre mode field diameter (μm),
η_l is the refractive index of fibre core.

- The *RIN* of the optical signal at the input of V-ONU is given by

$$RIN = -10 \lg \left[10^{-(RIN_{out}/10)} + 10^{-(RIN_f/10)} \right] \quad \text{(dB/Hz)} \qquad (7)$$

Based on the *RIN* value above, *C/N* can be calculated by Equation (3).

Table 4 – Parameters used for the calculation of carrier-to-noise ratio (*C/N*)

Parameter	Remarks	
B_N	Noise bandwidth AM-VSB: 4,00 MHz (NTSC) 5,08 MHz (I) 4,75 MHz (B, G, D1) 5,00 MHz (L) 5,75 MHz (D, K) QAM: Table H.1 of Part-1 Annex H OFDM: Table H.1 of Part-1 Annex H	This parameter depends on transmission signal format.
K	Number of transmission carriers	
M	Total optical modulation index	These parameters depend on optical transmitter, transmission signal, etc.
m_k	Optical modulation index of k^{th} carrier (modulated RF carriers)	
P_r	Received optical power (W)	This parameter depends on transmission line design.
RIN	*RIN* of the optical signal input to the V-ONU (dB(Hz^{-1}))	This parameter depends on optical transmitter, amplifier and transmission line. If the parameter is unknown, the following values may be used to calculate the *RIN* of optical signal input to the V-ONU. *RIN* of optical transmitter for multi-channel transmission is −155 dB(Hz^{-1}). *RIN* of optical transmitter for retransmission is −150 dB(Hz^{-1}). *NF* of optical amplifier is 6,5 dB *RIN* due to optical transmission line is −161 dB(Hz^{-1}).
e	Charge of an electron (1,602 × 10^{-19} C)	Physical constant.
R	Responsivity of V-ONU (A/W)	,,,
I_{d0}	Dark current of V-ONU (A)	

Example for calculating carrier-to-noise ratio (*C/N*)

Carrier-to-noise-ratio (*C/N*) may be calculated as follows with the following typical parameters:

Noise bandwidth	4 MHz
Number of carriers	Analogue (AM-VSB)
	K = 57 channels
Total modulation index	0,264
RIN of optical signal at the input of V-ONU	−148 dB(Hz^{-1})
Response of V-ONU	0,89 A/W
Dark current of V-ONU	0,1 nA
Equivalent input noise current density of pre-amplifier before V-ONU	7 pA/$\sqrt{\text{Hz}}$

NOTE *RIN* of optical signal at the input of V-ONU is calculated when *RIN* of optical transmitter is −155 dB(Hz^{-1}), *NF* of optical amplifier is 6,5 (single stage, optical input 0 dB(mW)). Then the *RIN* due to optical transmission line is −161 dB(Hz^{-1}).

If the optical modulation index of all the carriers is assumed to be the same, then the optical modulation index per carrier is given by,

$$m_k = \frac{0,264}{\sqrt{57}} \cong 0,035$$

If the optical input to the V-ONU is −9,6dB(mW), from Equation (3), the carrier-to-noise-ratio is calculated to be 43,0 dB.

6.5 Optical modulation index

The optical modulation index (*OMI*) of analogue signals shall be measured according to the method described in 4.9 of IEC 60728-6. In this standard it is assumed that the power AGC function in the transmitter shall be off.

6.6 Carrier-to-crosstalk ratio (CCR)

6.6.1 General

This method of measurement is applicable when other services (i.e. digital communication signals like GPON, GEPON or Ethernet-point-to-point) besides CATV broadcast transmission (i.e. AM-VSB and 64/256QAM broadcast signals) are transmitted in the optical network. Other services may produce crosstalk effects in optical fibres and in optical receiver devices with high linearity.

Crosstalk effects may arise when other service transmissions are applied by wavelength division multiplexing (WDM) on the same fibre and there is either insufficient optical wavelength filtering or relevant presence of non-linear fibre optical effects or both. Insufficient optical wavelength filtering may be due to low triplexer quality. Important non-linear fibre optical effects may be stimulated Raman scattering (SRS), self-phase modulation (SPM) and cross phase modulation (XPM). Among these causes SRS induced crosstalk is typically dominant, when analogue CATV broadcasting is transmitted on 1 550 nm wavelength and digital service signals use the 1 490 nm wavelength due to the fixed wavelength spacing.

6.6.2 Equipment

The following equipment is required:

- running system with implemented CATV broadcast service and other service(s);
- a selective voltmeter (or spectrum analyser) covering the frequency range of CATV broadcast service;

- sufficient length of fibre for connecting the transmitters, optical WDM filters, optical amplifiers, optical attenuators, optical polarization state change systems and receivers.

6.6.3 General measurements

The following measurements are required:

- unless otherwise required, the reference levels used in the measurements shall be the normal operating levels;
- where the receiver to be measured includes automatic level control (ALC) pilot signals of the correct type, frequency and level shall be maintained throughout the tests.

6.6.4 Procedure

Proceed as follows.

a) Set the supply voltage(s) and any control input signal(s) to the specified value(s).

b) Connect the equipment as shown in Figure 11.

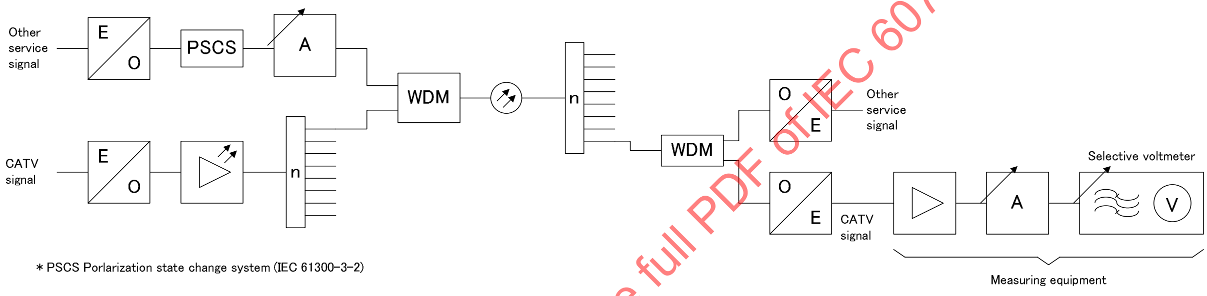


Figure 11 – Arrangement of test equipment for measuring other services crosstalk

c) Carry out measurements with the service signals in operation widely and closely spaced over each band of interest.

d) Carry out measurements over the full specified range, optical power at optical fibre input by adjusting optical attenuators A.

e) Carry out measurements over the full specified range of optical transmission distance by applying various fibre lengths. Figure C.6 shall be referred to.

f) Carry out measurements with various other services' communication signal patterns. For example measurements should be performed with and without digital idle signals (with and without payload), because signal pattern characteristics will the influence crosstalk intensity.

g) Connect the variable RF attenuator A and selective voltmeter to the RF output port of optical receiver for CATV broadcast service. Tune the meter to each CATV carrier and note the attenuator A value a_1 required to obtain a convenient meter reading R for the reference signal. The attenuator value a_1 should be slightly greater than other services crosstalk *CCR* expected at the point of measurement.

h) Tune the meter to the other services' crosstalk product to be measured and tune the optical polarization state change system (PSCS) to the other services' crosstalk product to be measured at maximum level. Reduce the RF attenuator A by setting to the value a_2 required to obtain the same meter reading R.

NOTE It may be necessary to temporarily switch off one CATV carrier occupying the frequency band of local interest during measurements of other services' crosstalk single frequency level in order to obtain an accurate value a_2.

i) The other services' crosstalk, in dB, is given by

$$CCR = a_1 - a_2$$

where

a_1 is the RF attenuator A value when measuring the test signal used as reference, in dB;

a_2 is the RF attenuator A value when measuring the crosstalk product, in dB.

6.6.5 Potential sources of error

Sources of error are the following:

- the inaccuracy of the selective voltmeter;
- the inaccuracy of the variable attenuators.

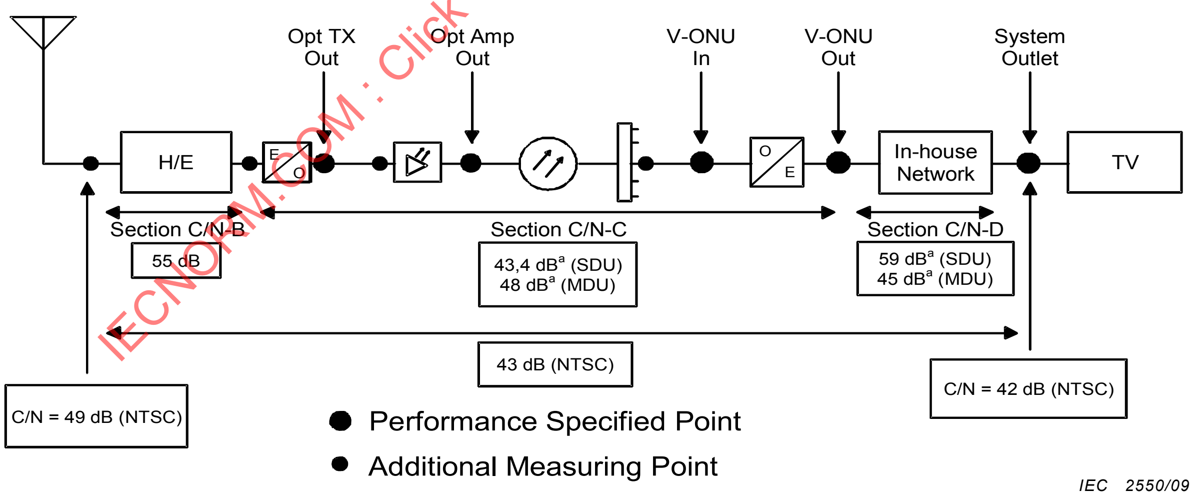
6.6.6 Presentation of the results

The other services' crosstalk (*CCR*) shall be expressed in dB.

7 Specification of optical system for broadcast signal transmission

7.1 Analogue and digital broadcast system over optical network

NTSC, PAL or SECAM systems are commonly used in analogue broadcast system with AM–VSB modulation systems. In digital broadcast systems over optical networks the 64 QAM system and the OFDM system are mainly used. The minimum *C/N* ratio at the headend input and system outlet for NTSC, PAL or SECAM systems are indicated in Table 5. These values shall be obtained on section *C/N* indicated in Figure 12, where the values for the NTSC system only are showed. For digitally modulated signals the Bit Error Ratio (*BER*) must be used as the specification parameter at system outlet: 1×10^{-4} is required for 64 QAM signals while 2×10^{-4} for OFDM signals. Figure 12 also depicts the measuring points (performance specified points) in order to guarantee the operating performance of the optical system. Additional measuring points are indicated for maintenance purposes. The measuring methods of Clauses 5 and 6 shall be used.



[a] Appropriate optical level at V-ONU input shall be considered in the system design for MDU and SDU systems in the in-house network.

NOTE 1 All the values indicate the minimum requirement.

NOTE 2 Section C/N-D is not identical to the home network defined in IEC 60728-1.

NOTE 3 In the case of 51 dB C/N (IEC 60728-1-1) for Section C/N-D, the C/N for Section C/N-C should be 44 dB.

Figure 12 – Performance allocation and measuring points

For other system parameters Table 5 shall be referred to.

7.2 International TV systems

Table 5 and Table 6 can be applied to the FTTH systems covered by this standard for commercial use.

Table 5 – Minimum *C/N* requirements in operation

Systems	Modulation	Minimum C/N at headend input dB	Minimum C/N at system outlet dB
NTSC	AM-VSB FM	49 20	42 13
I **B, G, D1** **L** **D, K**	AM-VSB	50 50 48,5 50	43 43 44,5 43
PAL **SECAM**	FM	21	14

Table 6 – Minimum RF signal-to-noise ratio requirements in operation

System	Modulation	Code rate	Minimum RF signal-to-noise ratio at headend input $S_{D,RF}/N$ dB				Minimum RF signal-to-noise ratio at system outlet $S_{D,RF}/N$ dB			
DVB-S	QPSK	1/2	8,6				6,6			
		2/3	10,5				8,5			
		3/4	11,5				9,6			
		5/6	12,6				10,6			
		7/8	13,3				11,3			
DVB-S2	QPSK 8PSK 16APSK 32APSK [c]		QPSK	8PSK	16APSK	32APSK	QPSK	8PSK	16APSK	32APSK
		1/4	3,7	–	–	–	1,7	–	–	–
		1/3	4,8	–	–	–	2,8	–	–	–
		2/5	5,7	–	–	–	3,7	–	–	–
		1/2	7,0	–	–	–	5,0	–	–	–
		3/5	8,2	11,5	–	–	6,2	9,5	–	–
		2/3	9,1	12,6	15,0	–	7,1	10,6	13,0	–
		3/4	10,0	13,9	16,2	18,7	8,0	11,9	14,2	16,7
		4/5	10,7	–	17,0	19,6	8,7	–	15,0	17,6
		5/6	11,2	15,4	17,6	20,3	9,2	13,4	15,6	18,3
		8/9	12,2	16,7	18,9	21,2	10,2	14,7	16,9	19,4
		9/10	12,4	17,0	19,1	22,1	10,4	15,0	17,1	20,1
DVB-C	16 QAM		25,9				19 [a]			
	64 QAM		31,9				25 [a]			
	256 QAM		37,9				31 [a]			
DVB-T COFDM	QPSK [b]		2k mode and 8k mode				2k mode		8k mode	
		1/2	6,1				4,9		5,1	
		2/3	8,2				7,2		7,4	
		3/4	9,3				8,5		8,6	
		5/6	10,5				9,9		10,0	
		7/8	11,3				10,9		11,0	
	16 QAM [b]		2k mode and 8k mode				2k mode		8k mode	
		1/2	12,2				11,0		11,2	
		2/3	14,2				13,2		13,4	
		3/4	15,6				14,7		14,9	
		5/6	17,1				16,4		16,6	
		7/8	17,7				17,3		17,3	

System	Modulation	Code rate	Minimum RF signal-to-noise ratio at headend input $S_{D,RF}/N$ dB			Minimum RF signal-to-noise ratio at system outlet $S_{D,RF}/N$ dB		
	64 QAM b	 1/2 2/3 3/4 5/6 7/8	2k mode and 8k mode 17,4 20,0 21,6 23,3 24,5			2k mode 16,1 19,0 20,7 22,5 23,8		8k mode 16,3 19,2 20,9 22,6 23,9
ISDB-T (OFDM)	16QAM	 1/2 2/3 3/4 5/6 7/8	Mode 1 d	Mode 2 d	Mode 3 d	Mode 1 24 24 24 24 24	Mode 2 24 24 24 24 24	Mode 3 24 24 24 24 24
	64QAM	 1/2 2/3 3/4 5/6 7/8	Mode 1 d	Mode 2 d	Mode 3 d	Mode 1 24 24 24 24 24	Mode 2 24 24 24 24 24	Mode 3 24 24 24 24 24
	QPSK	 1/2 2/3 3/4 5/6 7/8	Mode 1 d	Mode 2 d	Mode 3 d	Mode 1 24 24 24 24 24	Mode 2 24 24 24 24 24	Mode 3 24 24 24 24 24
	DQPSK	 1/2 2/3 3/4 5/6 7/8	Mode 1 d	Mode 2 d	Mode 3 d	Mode 1 24 24 24 24 24	Mode 2 24 24 24 24 24	Mode 3 24 24 24 24 24

a The above values take into account simultaneous distribution of analogue and digital signals. These values assume that intermodulation noise is not present or can be neglected and a *BER* of 10^{-4} before Reed-Solomon decoder is achieved. For CATV networks intermodulation has to be considered in the time domain as clipping noise and a margin of 6 dB should be added even if the signal is regenerated in the headend.

b These values take into account white noise and impulse noise.

c These values are calculated according to ETSI EN 302 307, Tables 13 and H.1, and are intended for a *PER* of 10^{-7} after LDPC and BCH decoders.

d Every value is defined in *BER* 1×10^{-4} before Reed-Solomon decoder, not S/N.

Remark: The values for the system outlet were taken from IEC 60728-1-2, first edition The values for the headend input were calculated using the system outlet values and the system performance specified in Table 11 of IEC 60728-1-2.

7.3 Relationship between *RIN* and *C*/*N*

The CATV broadcast service can be classified into three types:

– multi-channel service with a mixture of analogue and digital signals,
– digital only multi-channel service and
– re-transmission service for poor signal reception.

Table 7 shows the types of broadcast services with the typical number of carriers. For combination of analogue and digital carriers in actual system design, Annex A should be referred to.

Table 7 – Types of broadcast services

	Analogue (NTSC) system	Digital system
a) Multi-channel service with mixture of analogue and digital signals	40 carriers	30 carriers (64 QAM, OFDM)
b) Digital only multi-channel service	–	110 carriers (64 QAM, OFDM)
c) Re-transmission service for poor signal reception	10 carriers	10 carriers (OFDM)

Performance of transmission line can be defined by the value of relative intensity noise (*RIN*) for optical signal, and the *C*/*N* ratio at V-ONU output for electrical signal. The term V-ONU is used as the synonym of optical receiver (O/E) device in this document. Details on *RIN* measurement are described in Annex A. *RIN* values required for the three service types are shown in Table 8. The Intensity Modulation method is applied to the optical system in all service types.

Table 8 – Type of service and minimum operational *RIN* values

Type of service	V-ONU minimum input level dB(mW)	System RIN minimum value dB(Hz^{-1})	Corresponding *C/N* value dB
Multi-channel service with mixture of analogue and digital signals	–8	–149	44
Digital only multi-channel service	–12	–146	28
Re-transmission service for poor signal reception	–5	–134	44
	–8	–134	44
	–10	–136	44

Multiple optical reflections over transmission line may degrade *RIN* values. In order to minimize this degradation, the use of Grade 2 cnnectors of IEC 61755-1 or APC optical connectors is recommended.

7.4 Optical wavelength

In accordance with ITU-T Recommendation G.983.3, a wavelength within the range of 1 555 nm ± 5 nm is strongly recommended for the combined system of broadcast and telecommunication systems over single fibre. For DWDM systems wavelengths according to the grid defined in ITU-T Recommendation G.692 shall be used.

In CWDM systems ITU-T Recommendation G.694.2 shall be taken into account.

NOTE Considering the availability of EDFA and appropriate allocation of wavelengths, the wavelength range of 1 530 nm to 1 625 nm (edge of C-band and L-band of ITU-T RecommendationG.694.2) can be used for actual and economical video transmission.

7.5 Frequency of source signal

The frequency range of source signals considered here is 47 MHz to 862 MHz. However, regional frequency plans can be used for the operating frequency range of the optical system.

7.6 Optical system specification for broadcast signal transmission

The specification of the most important parameters of the optical system is shown in Table 9.

Table 9 – Optical system specification

Parameter		Analogue TV NTSC	Analogue TV PAL, SECAM	Digital TV 64QAM [d]	Digital TV OFDM
Optical wavelength		1 530 nm to 1 625 nm			
Frequency of source signal		90 MHz to 770 MHz (NTSC) 47 MHz to 862 MHz (PAL, SECAM)			
Fluctuation of carrier-wave level		Within 4 dB for a duration of 1 min [b]	–	Within 3 dB for a duration of 1 min	
Noise bandwidth of electronic signal		4 MHz	5 MHz [c]	5,3 MHz	5,6 MHz
Minimum section *C/N* (Between head-end input and system outlet)		44 dB	46,5 dB	28 dB	27 dB
Minimum *C/N*	**At head-end input**	51 dB	53 dB	–	–
	At system outlet [a]	43 dB	44,5 dB	26 dB	24 dB
Minimum *BER*	**At head-end input**	–	–	1×10^{-4}	1×10^{-4}
	At system outlet [a]	–	–	1×10^{-4}	2×10^{-4}

[a] Minimum *C/N* must be specified at system outlet. However, it may allow to specify the *C/N* at the input of V-ONU which is the interface point to customer premises, as an alternative way. In such a case additional 2 dB are required to the minimum *C/N* in Table 9. Minimum *BER* shall remain unchanged in Table 9.

[b] Such transients may be observed in the electrical section of Headend which has AGC functions to absorb unexpected fluctuations including fading, and such a fluctuation is a rare event, not a permanent one.

[c] Noise bandwidth of each system shall be referred to Table 4.

[d] ITU-T Recommendation J.83, Annex C.

7.7 *C/N* ratio specification for in-house and in-building wirings

The *C/N* ratio can be specified outside of the system outlet if the performance of the in-house/in-building wiring section is maintained properly. Based on current installation methods, *C/N* ratio allocation for the in-house/in-building wiring section is specified in Table 10. *C/N* ratio allocation is different between Single Dwelling Unit (SDU) and Multiple Dwelling Unit (MDU) as shown in Figure 13 and Figure 14. The coaxial distribution network after V-ONU shall be designed in such a manner that the *C/N* ratio of in-house wiring should be not lower than 59 dB in SDU, while it should be not lower than 45 dB in MDU, taking into account the *C/N* degradation due to the distribution network only, therefore assuming an unimpaired input signal to the in-home distribution network.

Table 10 – Section of *C/N* ratio specification for in-house/in-building wiring

Category of house		Minimum *C/N* ratio for in-house/ in-building wiring dB
Single dwelling unit (SDU)	–	59
Multiple dwelling unit (MDU)	O/E conversion at MDU entrance, coaxial cable distribution to TV set (see Figure 13)	45
	No O/E conversion at MDU entrance, optical cable distribution to TV set (see Figure 14)	45
NOTE The 59 dB is not a requirement for the IEC 60728-1 home-network interface, but a practical specification for the RF amplifier that is built-in the optical receiver of the analogue RF wavelength of the PON.		

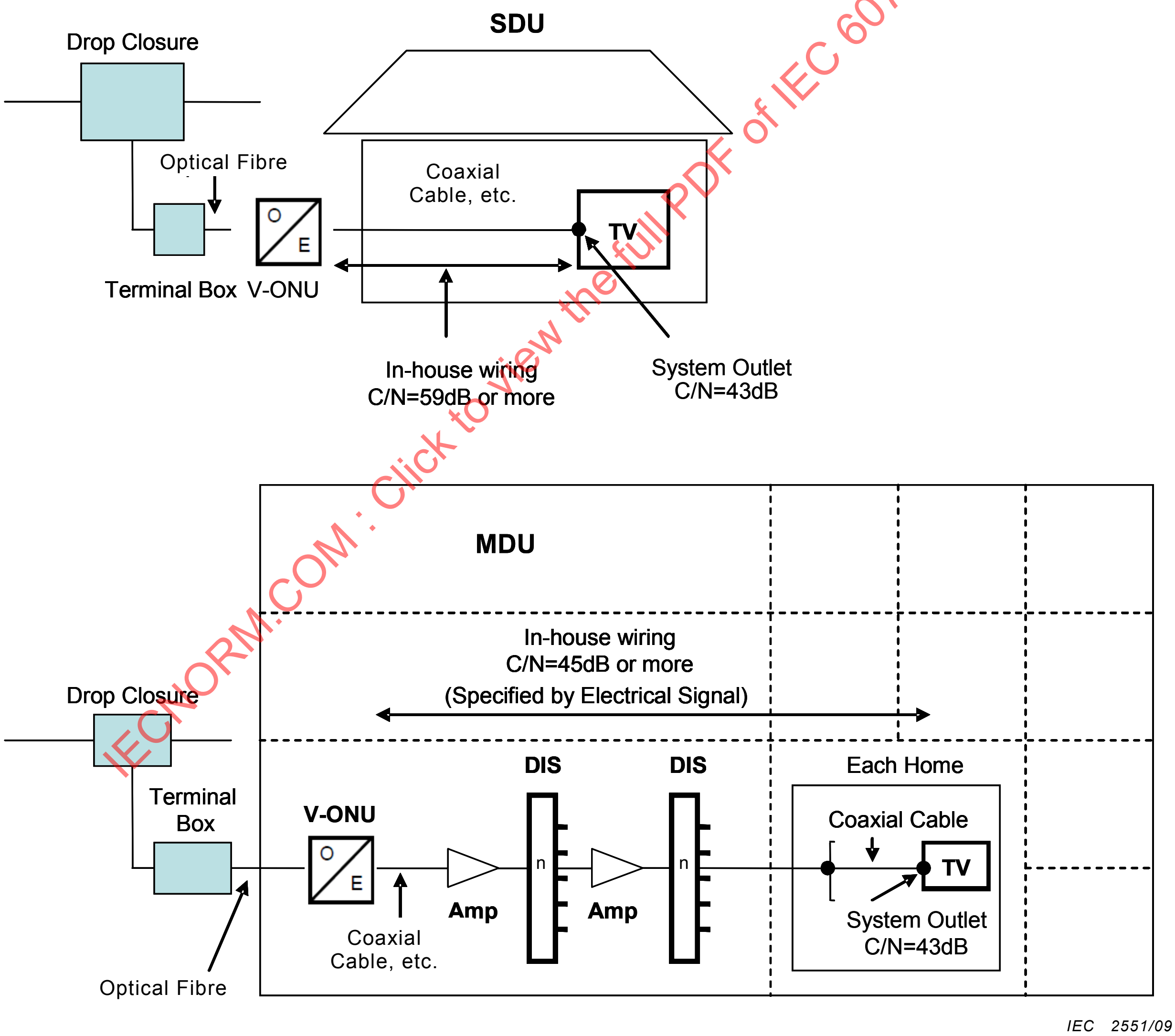


Figure 13 – Section of *C/N* ratio specification (45 dB) for in-house wiring (specified for electrical signals)

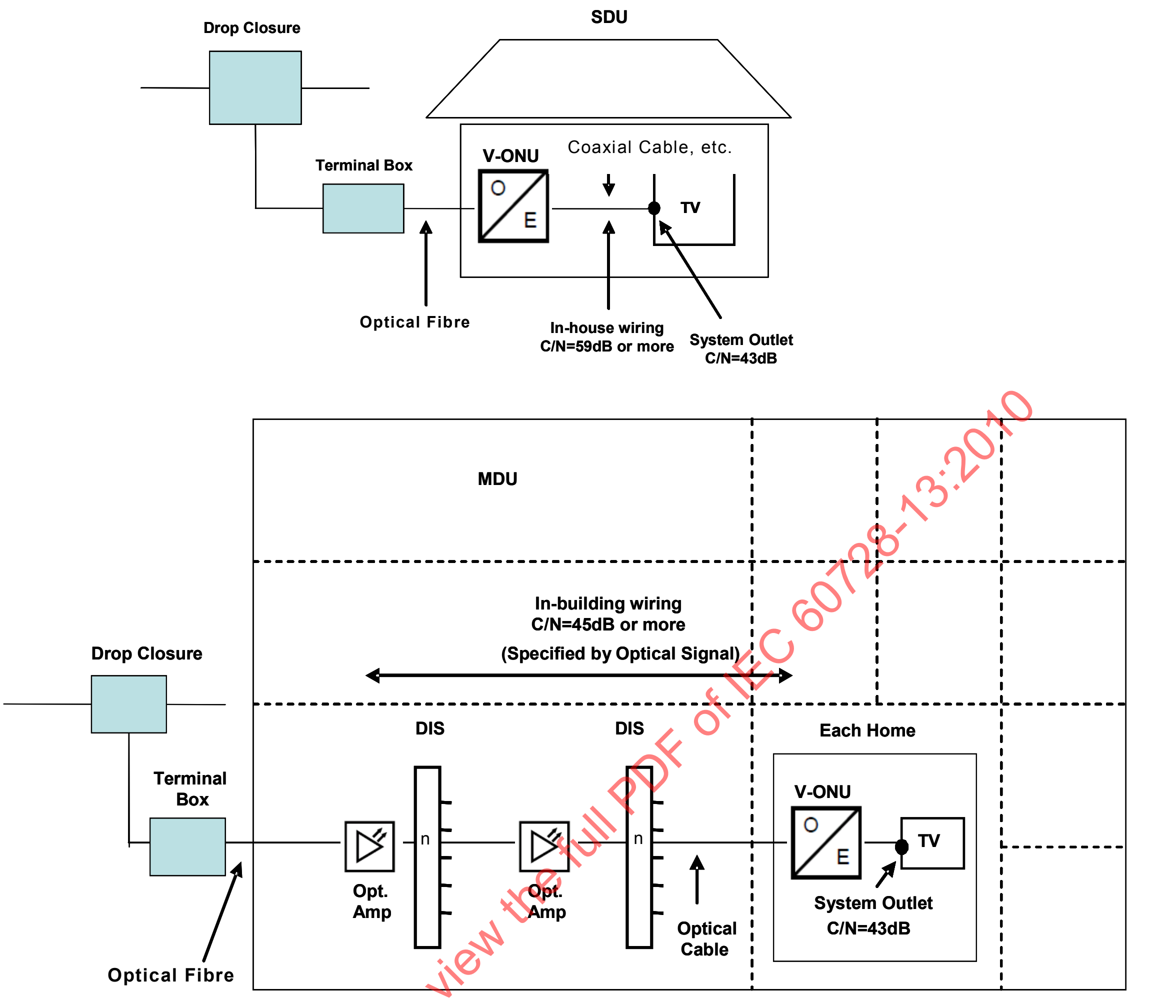


Figure 14 – Section of *C/N* ratio specification for in-house wiring (specified for optical signals)

7.8 Crosstalk due to optical fibre non-linearity

In a hybrid WDM transmission system in which broadcast signal and telecommunication signal are both incorporated, crosstalk between the two signals due to optical fibre non-linearity shall be taken into consideration. As described in Clause D.2, important parameters of optical crosstalk are stimulated Raman scattering (SRS), self-phase modulation (SPM), and Cross phase modulation (XPM). Among these parameters only SRS-induced crosstalk is dominant and it is difficult to reduce interference based on the Raman effect (change of optical wavelength) and the fixed wavelength spacing between the two signals (1 550 nm and 1 490 nm). XPM is not dominant in the case of this kind of wavelength spacing. SPM is caused by non-linear refractive index of fibre materials and reduced significantly when the input power is decreased.

Considering the above features of crosstalk, the following points shall be maintained as a minimum guideline for reducing SRS-induced crosstalk caused by optical fibre non-linearity.

- Optical level of telecommunication signal at trunk line fibre input: Less than 0 dB(mW).
- Optical level of broadcast signal at trunk line fibre input: Less than 18 dB(mW).
- Optical modulation index of broadcast signal: More than 3 %/Carrier, total optical modulation index shall be in accordance with the description in IEC/TR 60728-6-1.
- Randomization of telecommunication signal pattern: Recommended.

NOTE 1 Annex D contains additional descriptions of SRS.

NOTE 2 Table A.3 should be referred to for the description of the optical modulation index and the number of combinations of analogue and digital carriers.

7.9 Single frequency interference level due to fibre non-linearity

The single frequency interference level caused by fibre non-linearity shall meet the following values shown in Table 11. All the parameters of optical broadcast transmission systems shall be set appropriately to satisfy the interference level. The measuring points shall be point (6) shown in Figure 5.

Table 11 – Interference level due to fibre non-linearity

Broadcast system	D/U ratio dB
AM-VSB (NTSC)	More than 52
64QAM (Japan)	More than 39
64QAM (DVB)	More than 33
OFDM (ISDB-T)	More than 45

7.10 Environmental conditions

Equipment used for FTTH systems shall meet the environmental condition requirements of Table 12.

Table 12 – Environmental conditions

	Optical Tx (In-house)	EDFA (In-house)	V-ONU (In-house)	V-ONU (Outdoor)
Temperature °C	0 to +40	0 to +40	0 to +40	–20 to +40 (Notes 1, 2)
Humidity %	20 to 90	20 to 90	20 to 90	20 to 100

NOTE 1 Except the rising temperature due to solar radiation.
NOTE 2 To be applied in normal climate conditions in extra-tropical zones, not in extremely cold and hot temperatures.
NOTE 3 Refer to IEC 60068-1, IEC 60050-191 and ETSI 3000019-1-4 when used in other climate conditions.

Annex A
(informative)

Actual service systems and design considerations

A.1 Multi-channel service system

A.1.1 General

This annex describes actual service systems and design considerations based on the specifications stated in this standard.

CATV operator currently provides multi-channel services for mixed analogue and digital broadcasting. Analogue and/or digital multi-channel services are classified as multi-channel services in this standard. Since the actual number of carriers in CATV network varies, this annex describes the following two reference models for the multi-channel services over an optical network.

(1) Analogue 57 carriers + Digital 40 carriers

(2) Analogue 11 carriers + Digital 80 carriers

Model (1) is selected as a reference model that has the maximum number of both analogue and digital transmission carriers at present. Model (2) is the reference model that can carry up to 80 digital carriers, with a small number of analogue carriers. In both cases, the maximum number of carriers is assumed. “Analogue” here means NTSC signals, and “digital”, either 64 QAM or OFDM signals, regardless of the presence of digital carriers. Refer to Clause H.1 of IEC 60728-1.

The system size of CATV multi-channel services is mostly from 1 500 to 340 000 terminals, the transmission line length is up to 40 km, and 4 stages of EDFA in general. Term EDFA is the synonym of optical amplifier in this standard. In the optical network system, the relationship between transmission distance and the number of branches is in inverse proportion. If the number of branches is reduced, optical line is extendable up to 40 km, and one million or more subscriber terminals become available by stacking splitters. Figure A.1 and Figure A.2 show the examples of the multi-channel service system of one million terminals, and of 2 000 terminals, respectively.

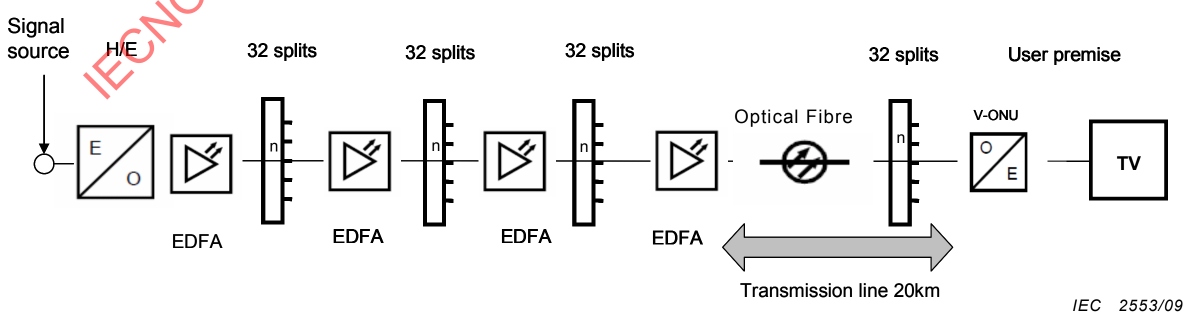


Figure A.1 – Example of a multi-channel service system of one million terminals

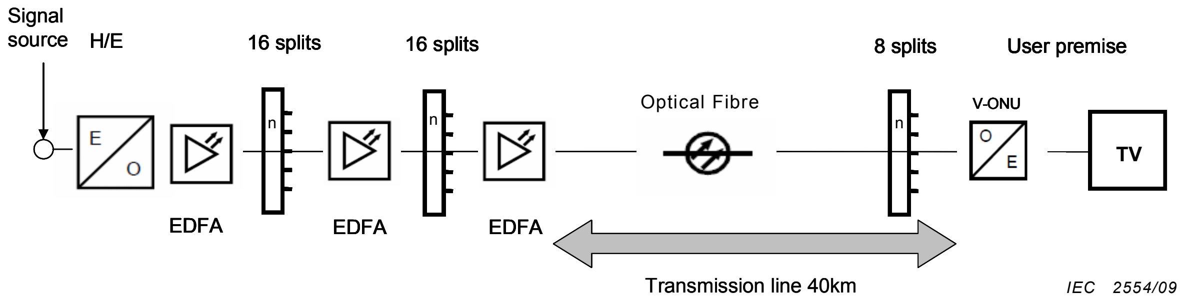


Figure A.2 – Example of a multi-channel service system of 2 000 terminals

A.1.2 Operating conditions

Table A.1 shows the two models of operating conditions for the multi-channel service system with its optical modulation index for each analogue or digital carrier. The optical system uses the external intensity modulation method.

Table A.1 – Operating conditions of a multi-channel service system

System	Number of carriers	Modulation method	Optical modulation index (m_k)/Carrier
Multi-channel service system model (1)	Analogue: 57 carriers Digital: 40 carriers	External intensity modulation	Analogue: 3,5 % Digital: 1,1 %
Multi-channel service system model (2)	Analogue: 11 carriers Digital: 80 carriers		Analogue: 7 % Digital: 2,2 %

A.1.3 Operating environment

The optical transmitter and optical amplifier are assumed to be installed in an office building as well as head end equipment, in the following environmental conditions. V-ONU is assumed to be installed indoors or outdoors like under eaves. Unless otherwise specified, the following range should be applied.

a) Optical transmitter

Ambient temperature	0 °C to +40 °C	
Humidity	20 % to 90 %	without dew condensation [a]

b) Optical amplifier

Ambient temperature	0 °C to +40 °C	
Humidity	20 % to 90 %	without dew condensation [a]

c) V-ONU

Ambient temperature	–20 °C to +40 °C	(outdoor installation)
Ambient temperature	0 °C to +40 °C	(indoor installation)
Humidity	20 % to 100 %	without dew condensation [a]

[a] Except the rising temperature due to solar radiation.

For optical safety, refer to IEC 60825-1 and IEC 60825-2 in addition to the relevant clauses of this standard.

A.2 Re-transmission service system

A.2.1 General

The re-transmission service system is a small-sized receiving facility with poor reception to measure broadcast TV programs, and does not support transmission of terrestrial digital broadcast signals. Nine carriers in each analogue and digital signal are assumed for the re-transmission service. General, re-transmission service systems have about 2 km trunk line and 70 terminals. In this case, one EDFA at its maximum is enough for this network size. Most of the re-transmission service system does not require an EDFA. It is enough to describe two types as shown in Figure A.3 and Figure A.4.

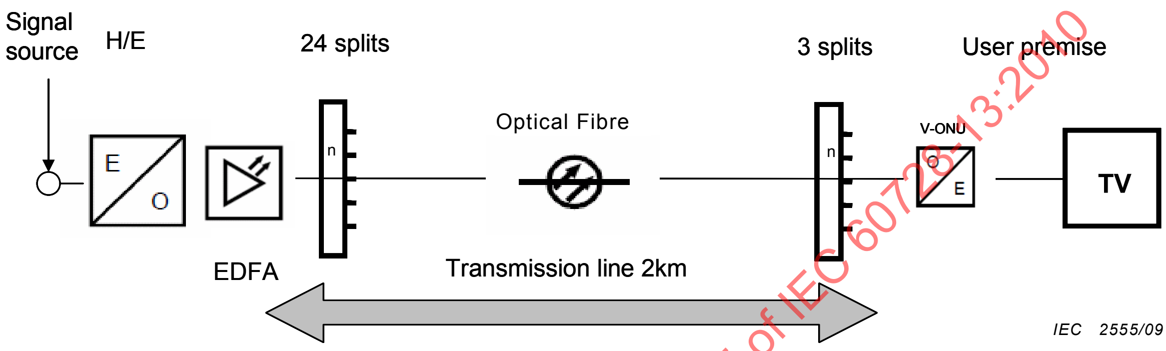


Figure A.3 – Example of re-transmission service system of 72 terminals

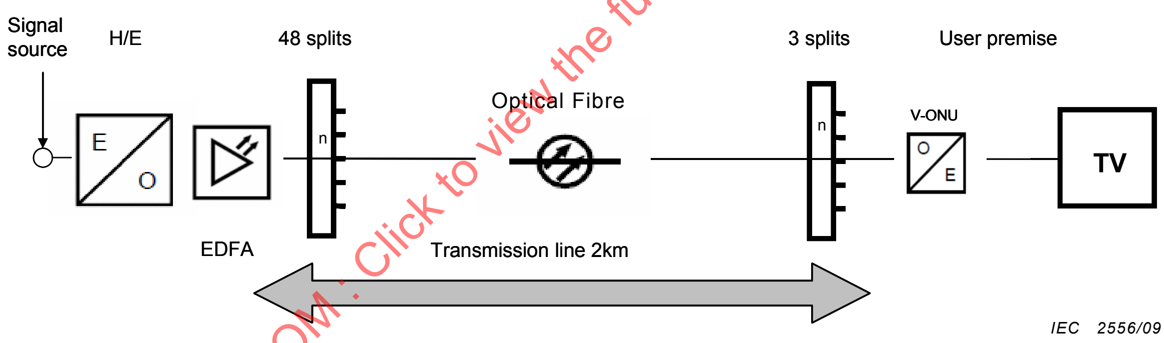


Figure A.4 – Example of re-transmission service system of 144 terminals

A.2.2 Operating conditions

Table A.2 shows the model of operating conditions for the re-transmission service system with its optical modulation index. The optical system uses the direct intensity modulation method.

Table A.2 – Operating conditions of re-transmission service system

System	Number of carriers	Modulation method	Optical modulation index (m_k)
Re-transmission service system	Analogue: 9 carriers Digital: 9 carriers	Direct intensity modulation	Analogue: 9 % Digital: 2,9 %

A.2.3 Operating environment

The optical transmitter and optical amplifier are assumed to be installed in an office building with head-end equipment, in the following environmental conditions. V-ONU is supposed to be installed indoors or outdoors like under eaves. Unless otherwise specified, the following range shall be applied.

a) Optical transmitter

Ambient temperature	–20 °C to +40 °C	
Humidity	20 % to 90 %	[a] without dew condensation

b) Optical amplifier

Ambient temperature	–20 °C to +40 °C	
Humidity	20 % to 90 %	[a] without dew condensation

c) V-ONU

Ambient temperature	–20 °C to +40 °C	(outdoor installation)
Ambient temperature	0 °C to +40 °C	(indoor installation)
Humidity	20 % to 100 %	[a] without dew condensation

[a] Except the rising temperature due to solar radiation.

A.3 *C*/*N* ratio calculation of optical network

In the case of optical intensity modulation, the *C*/*N* ratio of optical network can be calculated as follows.

a) *RIN* degradation by optical amplifier

RIN degradation by multi-stage connection of the optical amplifiers is given by the following formula:

$$RIN_{\text{out}} = 10\lg\left(\sum_k \frac{2\cdot E\cdot 10^{\frac{NF_k}{10}}}{10^{\frac{P_k}{10}}} + 10^{\frac{RIN_{\text{in}}}{10}}\right) \quad [\text{dB(Hz}^{-1})] \qquad \text{(A.1)}$$

where

RIN_{in} is the *RIN* at input of the first optical amplifier [dB(Hz^{-1})],
RIN_{out} is the *RIN* at input of the k-th optical amplifier [dB(Hz^{-1})],
E is the photon energy (in case of λ = 1 555 nm, E = 1,278 × 10^{-16} [mJ]),
NF_k is the noise figure of the k-th optical amplifier [dB],
P_k is the optical input power of the k-th optical amplifier [dB(mW)].

b) *C/N* ratio in the case of intensity modulation system

$$C/N = 10\lg\left(\frac{1}{B_{\text{N}}}\cdot\frac{\frac{1}{2}\cdot\left(m_{\text{k}}\cdot R\cdot P_{\text{r}}\right)^2}{RIN\left(R\cdot P_{\text{r}}\right)^2 + 2\cdot e\cdot\left(I_{\text{d0}} + R\cdot P_{\text{r}}\right) + I_{\text{eq}}^{\,2}}\right) \quad [\text{dB}] \qquad \text{(A.2)}$$

where

B_N is the noise bandwidth (AM-VSB: 4,0 × 10^6 [Hz], 64 QAM: 5,3 × 10^6 [Hz]),
m_k is the optical modulation index of the k-th carrier,
R is the optical-electrical conversion efficiency of an optical receiver device [A/W],

P_r	is the input optical power [W],
RIN	is the relative intensity noise of optical input signal (RIN) [1/Hz],
e	is the charge of electron (1,602x10^{-19} [C]),
I_{d0}	is the dark current of a optical receiver device [A],
I_{eq}	is the equivalent input noise current density of an optical receiver [A/√Hz].

The total optical modulation index "M" has the relationship with optical modulation index "m_k"at the k-th carrier, and the number of transmission carriers "K", as shown in the following formula:

$$M = \sqrt{\sum_{k=1}^{K} m_k^2} \quad \text{(A.3)}$$

Since the total optical modulation index affects the distortion characteristic of the total system, it is generally desirable to be 30 % or less in case of an external intensity modulation system.

A.4 System reference model

Table A.3 summarizes the basic system parameters verified for multi-channel and re-transmission service systems, the reference models are shown in Figure A.5 to Figure A.11.

Table A.3 – Basic system parameters for multi-channel and re-transmission service systems

Reference model	Type	Number of carriers	Modulation index (m_k)	EDFA stages	Remark
No. 1, 2	**Multi-channel service system**	Analogue: 57 carriers	Analogue: 3,5 %	4 steps	Figures
		Digital: 40 carriers	Digital: 1,1 %	3 steps	A.5, A.6
No. 3		Analogue: 40 carriers	Analogue: 4,3 %	4 steps	Figure A.7
		Digital: 30 carriers	Digital: 1,4 %		
No. 4, 5		Analogue: 11 carriers	Analogue: 7 %	4 steps	Figures
		Digital: 80 carriers	Digital: 2,2 %	4 steps	A.8, A.9
No. 6, 7	**Re-transmission service system**	Analogue: 9 carriers	Analogue: 9 %	None	Figures
		Digital: 9 carriers	Digital: 2,9 %	1 step	A.10, A.11

The parameters used for calculation of system performance are as follows.

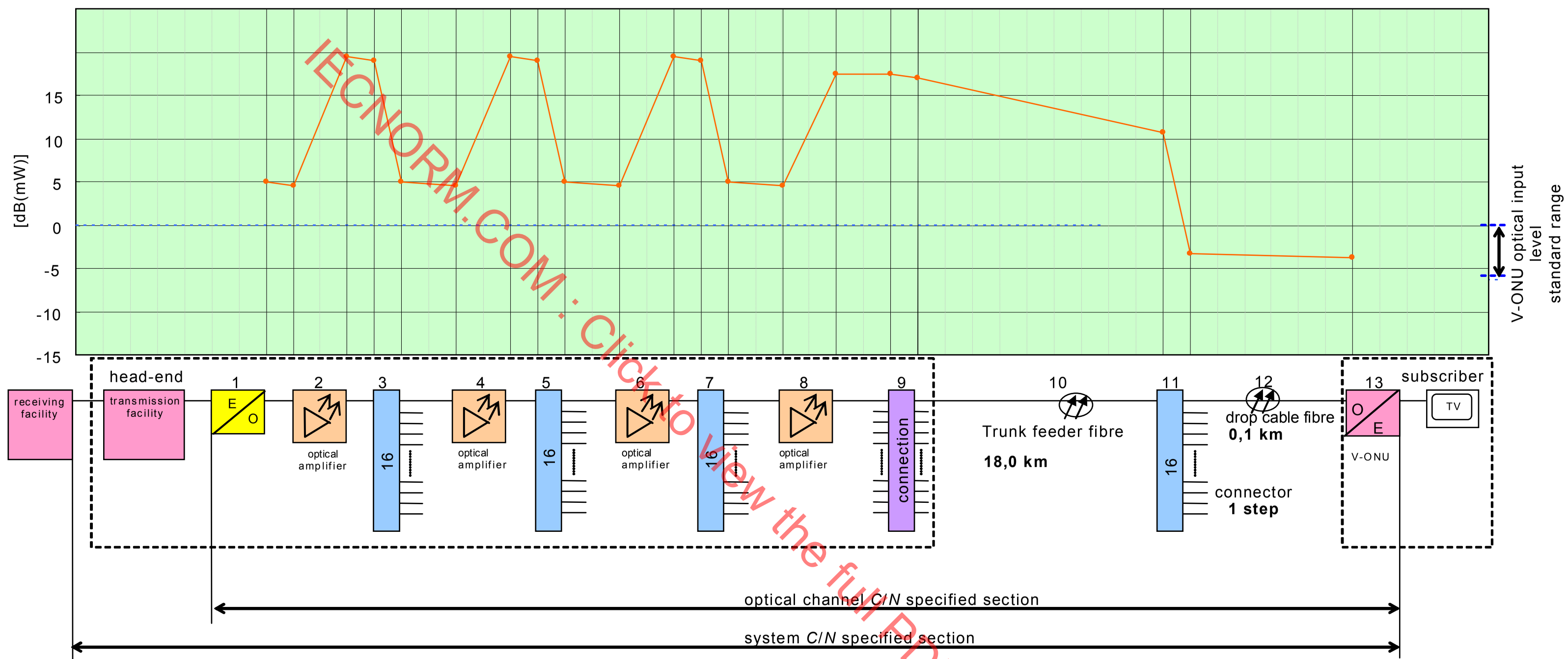
Multi-channel service system, reference models No. 1 to No. 5, Figures A.5 to A.9

Connection loss at connector	0,5 dB/point
Fibre loss including splicing loss	0,35 dB/km
V-ONU equivalent input noise current density (I_{eq})	10 pA/√Hz
V-ONU receiving device dark current (I_{d0})	1,3 nA
V-ONU optical-electrical conversion efficiency (R)	0,84 A/W

Re-transmission service system, reference models No. 6 and No. 7, Figures A.10 and A.11

Connection loss at connector	0,5 dB/point
Fibre loss including splicing loss	0,35 dB/km
V-ONU equivalent input noise current density (I_{eq})	8,3 pA/√Hz
V-ONU receiving device dark current (I_{d0})	1,0 nA
V-ONU optical-electrical conversion efficiency (R)	0,9 A/W

Model No.1 – Multi-channel service system, 4 steps of EDFA(s), OMI: analogue 3,5 % (57 carriers), digital 1,1 % (40 carriers)



item	
amplifier *NF*	**6,2 dB**
OMI/ch	**3,5%**
receiving point *C/N*	**53,0 dB**
transmitter RFout *C/N*	**55,0 dB**

	1	2	3	4	5	6	7	8	9	10	11	12	13
equipment	transmitter		16 splitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	16 splitter	drop cable	V-ONU
input level [dBmW]	RF80dBuv	4,5	19,0	4,5	19,0	4,5	19,0	4,5	17,5	17,0	10,7	–	–
gain or loss [dB]	–	15,0	–	**15,0**	–	**15,0**	–	**13,0**	–	–		–	–
output level [dBmW]	**5,00**	19,5	5,0	19,5	5,0	19,5	5,0	17,5	17,0	10,7	–		

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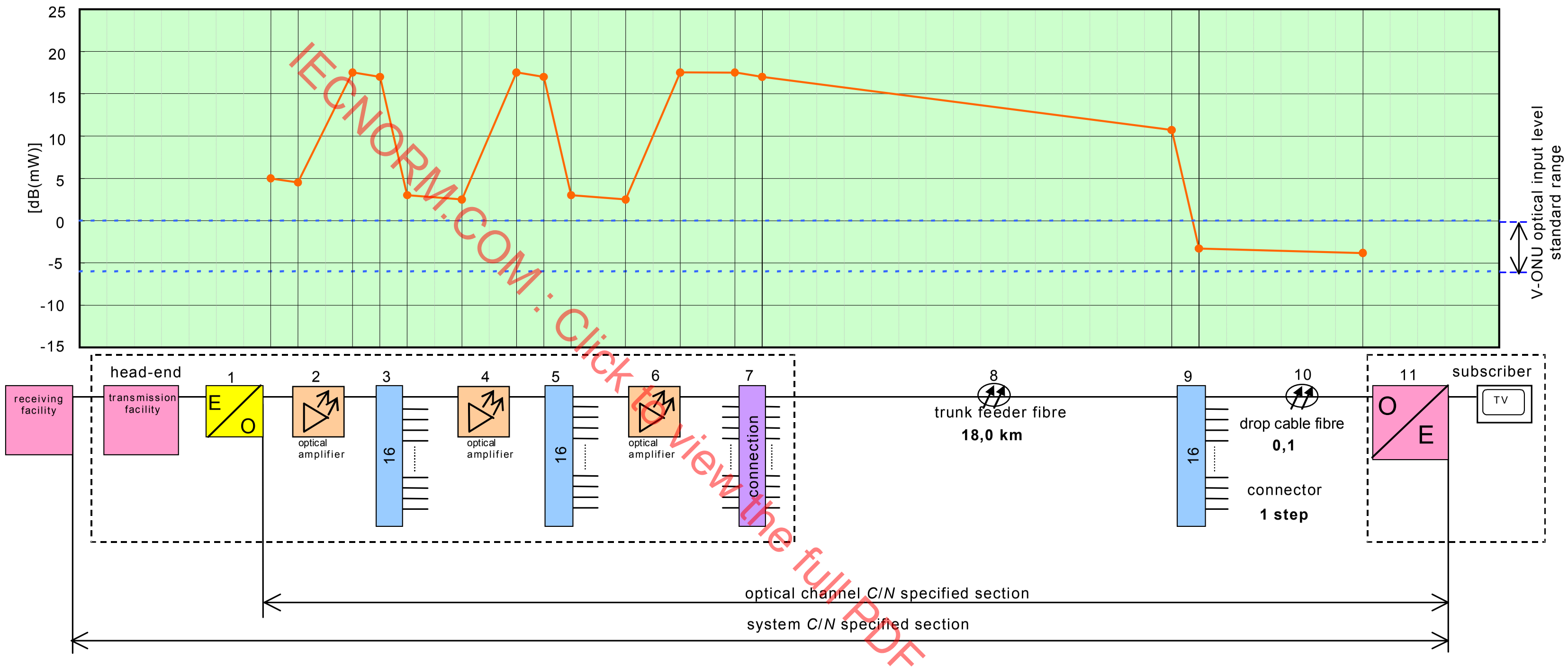
Figure A.5 – Model No.1 of a system performance calculation

Model No.2 – Multi-channel service system: 3 steps of EDFA(s); OMI: analogue 3,5 % (57 carriers), digital 1,1 % (40 carriers)



item	value
amplifier *NF*	**6,2 dB**
OMI /ch	**3,5%**
receiving point *C/N*	**53,0 dB**
transmitter RFout *C/N*	**55,0 dB**

	1	2	3	4	5	6	7	8	9	10	11
equipment	transmitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	16 splitter	drop cable	V-ONU
input level [dBmW]	RF80dBuv	**4,5**	17,0	2,5	17,0	2,5	17,5	17,0	10,7	–	–
gain or loss [dB]	–	**13,0**	–	**15,0**	–	**15,0**	–	–	–	–	–
output level [dBmW]	**5,00**	17,5	3,0	17,5	3,0	17,5	17,0	10,7	–	–	RF80dBuv
output RIN[dB(Hz-1)]	**–**	–	←	**–**	←	–	←	←	←	←	–
channel *C/N* [dB]	–	–	–	–	–	–	–	–	–	–	46,4
system *C/N* [dB]	–	–	–	–	–	–	–	–	–		45,1

NOTE 1 optical channel *C/N* at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier

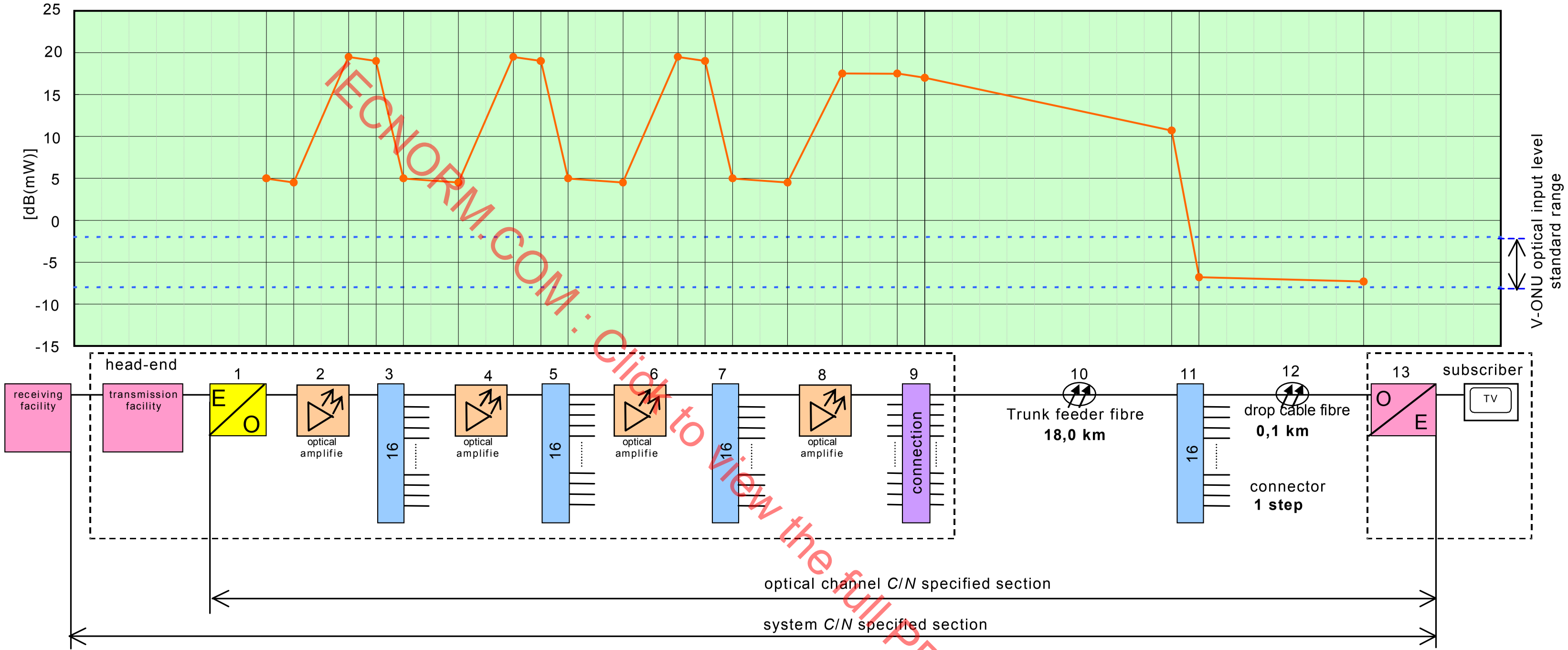
NOTE 2 *C/N* at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*

NOTE 3 connection loss between optical amplifier and connection panel is included in the loss of the connection panel

IEC 2558/09

Figure A.6 – Model No.2 of a system performance calculation

Model No.3 – Multi-channel service system: 4 steps of EDFA(s); OMI: analogue 4,3 % (40 carriers), digital 1,4 % (30 carriers)



item	value
amplifier *NF*	**6,2 dB**
OMI/ch	**4,31%**
receiving point *C/N*	**53,0 dB**
transmitter RFout *C/N*	**55,0 dB**

	1	2	3	4	5	6	7	8	9	10	11	12	13
equipment	transmitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	16 splitter	drop cable	V-ONU
Input level [dBmW]	RF80dBuV	4,50	19,00	4,50	19,00	4,50	19,00	4,50	17,50	17,00	10,70	–6,80	–7,34
gain or loss [dB]	–	**15,00**	–14,00	**15,00**	–14,00	**15,00**	–14,00	**13,00**	–0,50	–6,30	–17,50	–0,54	–
output level [dBmW]	**5,00**	19,50	5,00	19,50	5,00	19,50	5,00	17,50	17,00	10,70	–6,80	–7,34	RF80dBuV
output *RIN* [dB(Hz^{-1})]	**–158,10**	**–152,73**	←	–150,40	←	–148,90	←	–147,78	←	←	←	←	–
channel C/N [dB]	–	–	–	–	–	–	–	–	–	–	–	–	44,69
system C/N [dB]	–	–	–	–	–	–	–	–	–	–	–	–	43,75

NOTE 1 optical channel *C/N* at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier

NOTE 2 C/N at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*

NOTE 3 connection loss between optical amplifier and connection panel is included in the loss of the connection panel

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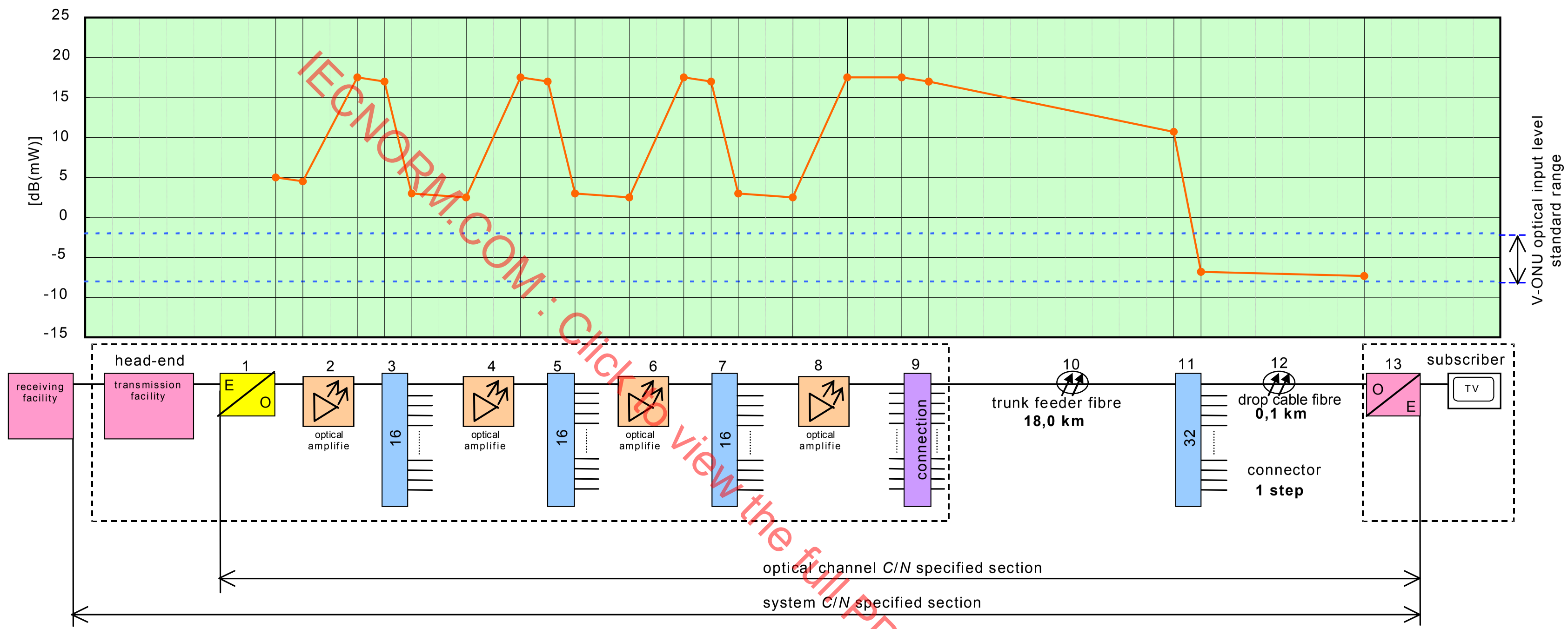
Figure A.7 – Model No.3 a of system performance calculation

Model No.4 – Multi-channel service system: 4 steps of EDFA(s); OMI: analogue 7 % (11 carriers), digital 2,2 % (80 carriers)



item	value
amplifier *NF*	**6,2 dB**
OMI/ch	**7,0 % %**
receiving point *C/N*	**53,0 dB**
Transmitter RFout C/N	**55,0 dB**

	1	2	3	4	5	6	7	8	9	10	11	12	13
equipment	transmitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	32 splitter	drop cable	V-ONU
input level [dBmW]	RF80dBuV	4,50	17,00	2,50	17,00	2,50	17,00	2,50	17,50	17,00	10,70	–6,80	–7,34
gain or loss [dB]	–	**13,00**	–14,00	**15,00**	–14,00	**15,00**	–14,00	**15,00**	–0,50	–6,30	–17,50	–0,54	–
output level [dBmW]	**5,00**	17,50	3,00	17,50	3,00	17,50	3,00	17,50	17,00	10,70	–6,80	–7,34	RF80dBuV
output *RIN* [dB(Hz^{-1})]	**–158,10**	–152,73	←	–149,46	←	–147,62	←	–146,33	←	←	←	←	–
channel *C/N* [dB]	–	–	–	–	–	–	–	–	–	–	–	–	48,55
system *C/N* [dB]	–	–	–	–	–	–	–	–	–	–	–	–	46,55

NOTE 1 optical channel *C/N* at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier
NOTE 2 *C/N* at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*
NOTE 3 connection loss between optical amplifier and connection panel is included in the loss of the connection panel

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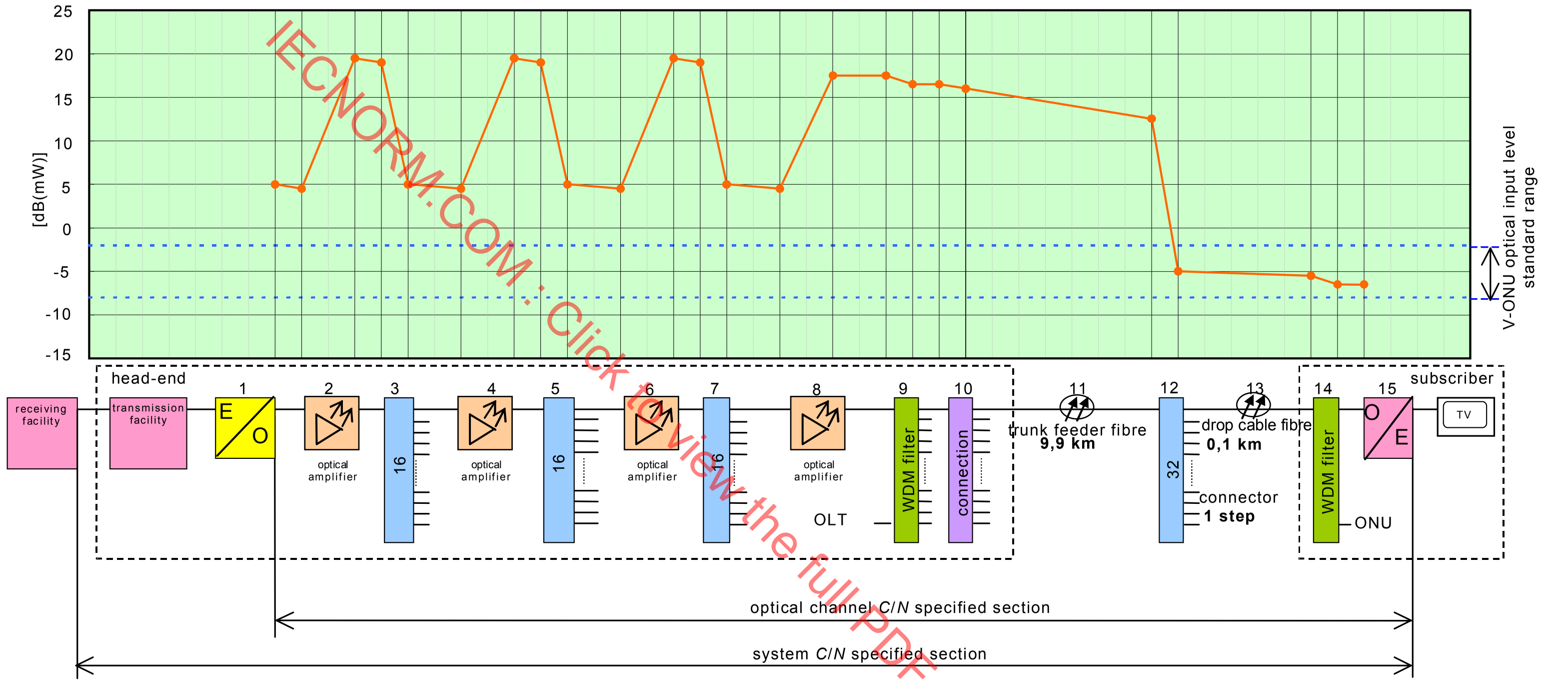
Figure A.8 – Model No.4 of a system performance calculation

Model No.5 – Multi-channel service system: 4 steps of EDFA(s); OMI: analogue 7 % (11 carriers), digital 2,2 % (80 carriers) with a WDM filter



item	value
amplifier *NF*	**6,2 dB**
OMI/ch	**7,0 %**
receiving point *C*/*N*	**53,0 dB**
transmitterRFout *C*/*N*	**55,0 dB**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
equipment	transmitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	WDM filter	conn.	trunk	32 splitter	drop	WDM filter	V-ONU
input level[dBmW]	RF80dBuV	4,50	19,00	4,50	19,00	4,50	19,00	4,50	17,50	16,50	16,00	12,54	–4,97	–5,50	–6,0
gain or loss [dB]	–	**15,00**	–14,00	**15,00**	–14,00	**15,00**	–14,00	**13,00**	–1,00	–0,50	–3,47	–17,50	–0,54	–1,00	–
output level[dBmW]	**5,00**	19,50	5,00	19,50	5,00	19,50	5,00	17,50	16,50	16,00	12,54	–4,97	–5,50	–6,50	RF80dBuV
output*RIN*[dB(Hz^{-1})]	**–158,10**	–	←	–	←	–	←	–	←	←	←	←	←	←	–
channel *C*/*N* [dB]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	49,95
system *C*/*N* [dB]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	47,38

NOTE 1 optical channel *C*/*N* at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier

NOTE 2 *C*/*N* at V-ONU RF output, which is calculated from the receiving point *C*/*N*, transmitter *C*/*N* and optical channel *C*/*N*

NOTE 3 connection loss between optical amplifier and connection panel is included in the loss of the connection panel

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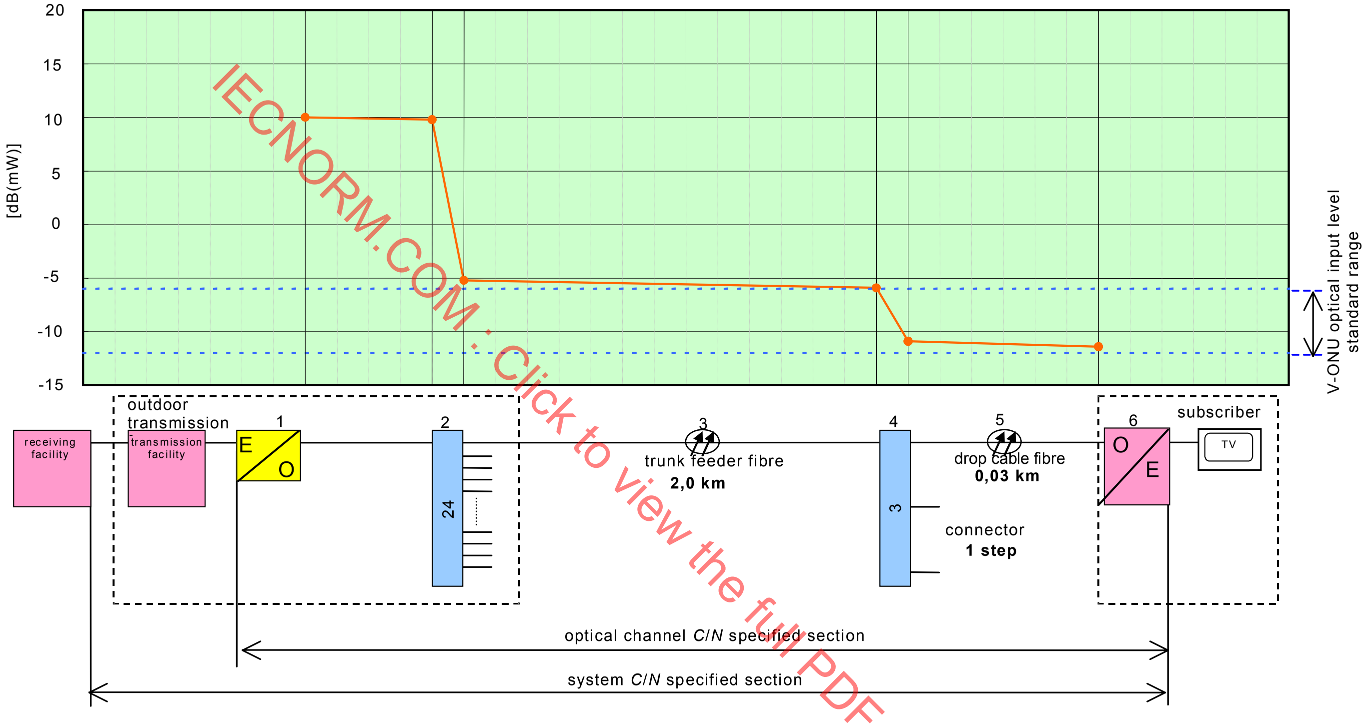
Figure A.9 – Model No.5 of a system performance calculation

Model No.6 – Re-transmission service system with no EDFA; OMI: analogue 9 % (9 carriers), digital 2,9 % (9 carriers)



	1	2	3	4	5	6
equipment	transmitter	24 splitter	trunk	3 splitter	drop cable	V-ONU
Input level [dBmW]	RF80dBuV	9,80	–5,20	–5,90	–10,90	–11,41
gain or loss [dB]	–	–15,00	–0,70	–5,00	–0,51	–
output level [dBmW]	**10,00**	–5,20	–5,90	–10,90	–11,41	RF:80dBuV
output *RIN* [dB(Hz^{-1})]	**–150,00**	←	←	←	←	–
channel *C/N* [dB]	–	–	–	–	–	46,59
system *C/N* [dB]	–	–	–	–	–	43,88

item	value
OMI /ch	**9,0 %**
receiving point *C/N*	**48,0 dB**
transmitter RF out	**55,0 dB**

NOTE 1 optical channel *C/N* at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier

NOTE 2 *C/N* at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*

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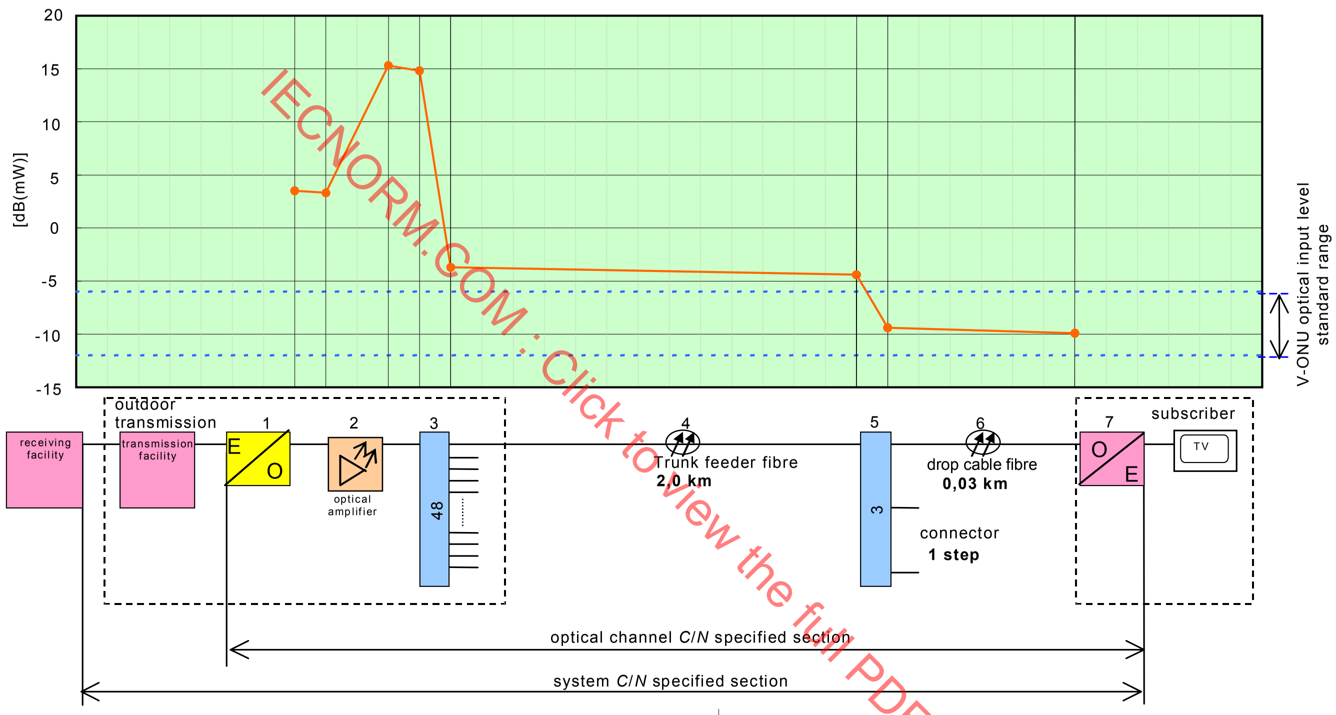
Figure A.10 – Model No.6 of a system performance calculation

Model No.7 – Re-transmission service system 1 step of EDFA; OMI: analogue 9 % (9 carriers), digital 2,9 % (9 carriers)



	1	2	3	4	5	6	7
equipment	transmitter	amplifier	48 splitter	trunk	3 splitter	drop cable	V-ONU
input level [dBmW]	RF80dBuV	3,30	14,80	–3,70	–4,40	–9,40	–9,91
gain or loss [dB]	–	**12,00**	–18,50	–0,70	–5,00	–0,51	–
output level [dBmW]	**3,50**	15,30	–3,70	–4,40	–9,40	–9,91	RF:80dBuV
output *RIN* [dB(Hz^{-1})]	**–150,00**	–148,24	←	←	←	←	–
channel *C/N* [dB]	–	–	–	–	–	–	48,87
system *C/N* [dB]	–	–	–	–	–	–	44,95

item	value
amplifier *NF*	**6,2 dB**
OMI/ch	**9,0 %**
receiving point *C/N*	**48,0 dB**
transmitter RF out	**55,0 dB**

NOTE 1 optical channel C/N at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier

NOTE 2 *C/N* at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*

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Figure A.11 – Model No.7 of system performance calculation

A.5 Tips for actual operation

A.5.1 Optimum operation

This clause describes neither a system performance nor device parameters. They may be optimized with the number of transmit channels as long as they satisfy the allowable ranges of *RIN*, *NF*, *C*/*N* ratio and the interferences described in this standard. Table A.4 shows an example of parameters verified in actual broadcast signal transmission. As long as the system performance is maintained, the operation with other modulation indexes can be allowed. Even if the modulation index is the same in this table and the number of carriers differs, the system is still considered to be satisfactory as long as the *RIN* value, the number of carriers and the *C*/*N* ratio at V-ONU output are maintained in adequate condition.

Table A.4 – Verified optimum operation

Service type	Analogue multi-channel system				Digital multi-channel system				Re-transmission system			
	Combination (1) ref. model 1, 2		Combination (2) ref. model 3		Combination (3) ref. model 4, 5		Combination (4)		Combination (5) ref. model 6, 7		Combination (6)	
	A [a]	D [a]	A	D	A	D	A	D	A	D	A	D
Number of carriers	57	40	40	30	11	80	-	110	9	9	10	10
Modulation index % m_k	3,5	1,1	4,3	1,4	7	2,2	-	2,7	9	2,9	8,6	2,7

[a] A = analogue; D = digital.

NOTE Combinations (1), (2), (3) and (5) correspond to the reference model of Clause A.4. Combinations (4) and (6) are for reference only.

A.5.2 Key issues to be specified

The key issues in order to design an optical system and operating conditions are shown below.

a) Optical wavelength

Although the wavelength of 1 530 nm to 1 625 nm is generally used, many commercially available systems use wavelengths of 1 540 nm to 1 560 nm. This band (i.e. 1 540 nm – 1 560 nm) is therefore chosen to limit the operating wavelength. Nevertheless, with the progress of WDM technology usage of wavelengths may vary.

b) Optical modulation system

As the optical modulation system in CATV network, only the intensity modulation system is specified in this standard. The re-transmission service system selects a direct intensity modulation system due to its short trunk line length, and a multi-channel service system introduces an external intensity modulation system considering its long span (approximately 40 km at maximum). In case of short span in a multi-channel service system, direct intensity modulation can also be utilized.

c) Optical modulation index

Optical modulation index in some system models are described in Table A.4. Many optical transmitters in the market have the function to adjust the modulation index automatically according to the number of carriers by its AGC function. As mentioned in A.5.1, the operation with other adequate modulation indexes can be allowed as long as system performance is satisfied.

d) Distortion performance

Since it is difficult to describe system performance separately between optical transmitter and V-ONU, it is recommended to specify the performance with a pair of optical transmitter and V-ONU. The distortion performance of optical system may change its optical characteristics in actual operation. Especially, this factor is significant when direct intensity modulation is used in re-transmission system. Careful selection of each distortion parameter is required for actual optical system design.

e) V-ONU optical input level

This specification does not limit the operation beyond parameters described in this document. It specifies the minimum range of specification. Hence, this specification can be used as a guideline of system design. The specified optical input level is assumed without WDM filters, the loss shall be compensated if it has WDM filters.

f) AGC function of V-ONU

There is a V-ONU having AGC function that detects optical input level and controls electric power sum of the output signal. This standard does not specify this type of control, but requires to keep the output level within the fixed range even if the optical input level of V-ONU varies.

g) *C*/*N* ratio (*CNR*: *C*/*N*)

The *C*/*N* ratio in CATV network generally shows lowest value at optical input of V-ONU. It is possible to increase input optical level to some extent to meet higher *C*/*N* ratio requirement.

Annex B
(informative)

Optical system overview

B.1 Optical system topology

B.1.1 Single star and double star system

This annex describes the optical system overview that is applicable to broadcast signal transmission.

The optical network is classified into Single Star (SS) and Double Star (DS) systems. An active Double Star (ADS) or Passive Double Star (PDS) system is a kind of DS system. PDS is also called Passive Optical Network (PON). The progress of wavelength division multiplex (WDM) technology allows its application to video signal transmission. Figure B.1 shows the topology of the optical system and Figure B.2 the network composition.

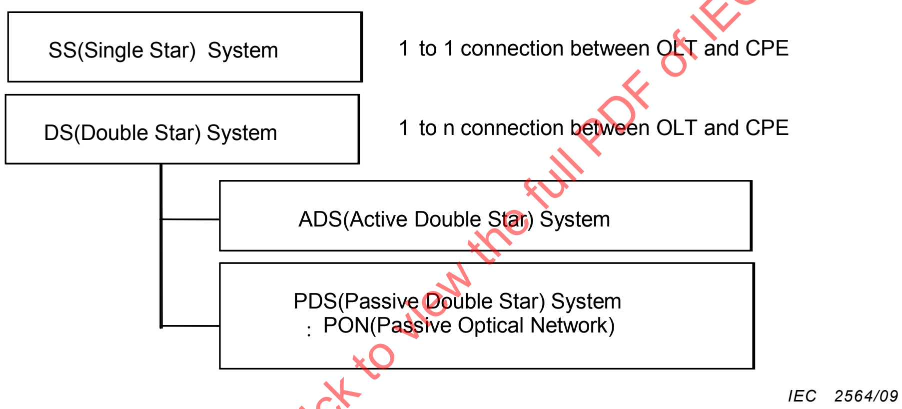

Figure B.1 – Topology of optical system

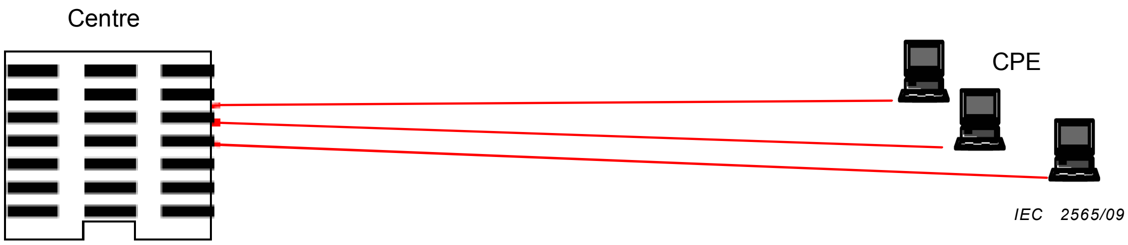

Figure B.2a – SS system

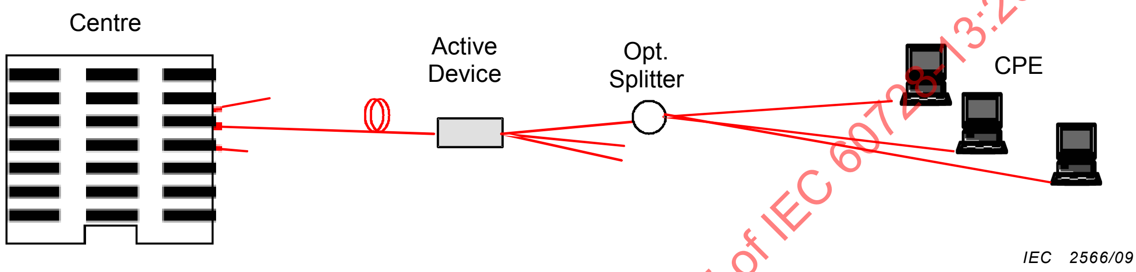

Figure B.2b – ADS system

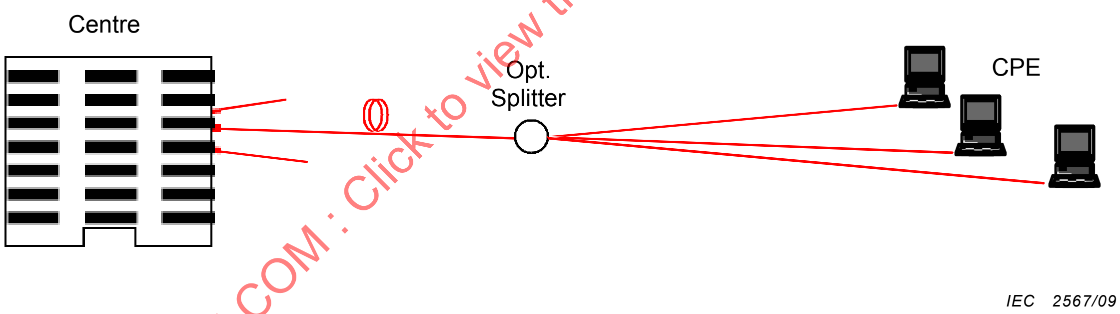

Figure B.2c – PDS system

Figure B.2 – Network composition

B.1.2 SS system

Single Star is a system containing one central terminal and one customer premises equipment (CPE) in a pair. Media Converter (MC) is installed in each centre office and CPE, and it converts an electrical signal to an optical signal and vice versa. There is a component type for individual CPE, and a consolidated type which has slots for media converter modules. It has also maintenance, failure detection and provisioning functions. High-speed services such as tenth of Mbps to Gbps are available. One or two optical fibres are used for this system. An example of an SS system is shown in Figure B.3.