IEC 60728-113

Edition 1.0 2018-07

INTERNATIONAL STANDARD

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Cable networks for television signals, sound signals and interactive services – Part 113: Optical systems for broadcast signal transmissions loaded with digital channels only

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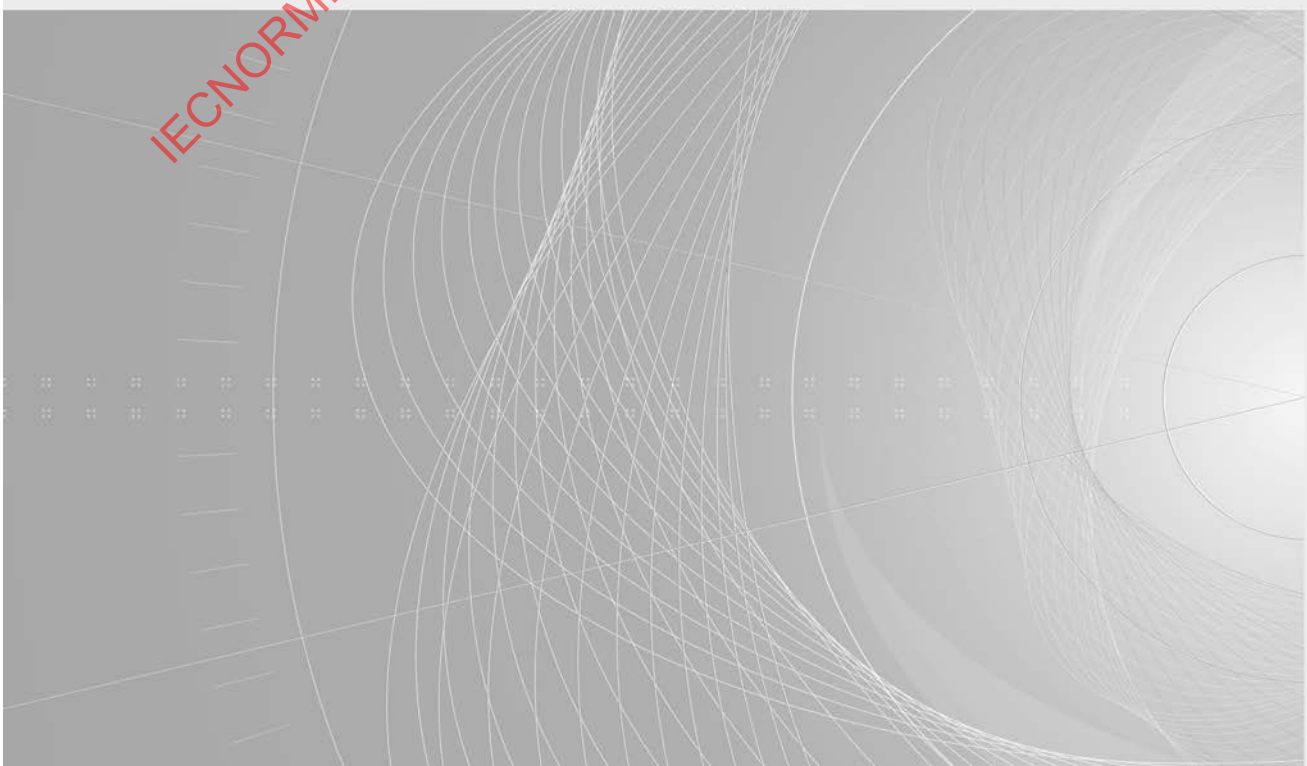

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 33.060.40

ISBN 978-2-8322-5844-6

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

Part 113: Optical systems for broadcast signal transmissions loaded with digital channels only

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

FDIS	Report on voting
100/3103/FDIS	100/3125/RVD

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

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

The list of all the parts of the IEC 60728 series, published 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 document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document 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- withdrawn,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 November 2018 have been included in this copy.

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INTRODUCTION

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

This includes, for instance:

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

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

The extent of this standardization work ranges from antennas and/or special interfaces to headends, or other interface points on the network up to any terminal interface of the equipment on the customer's premises.

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

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

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

Part 113: Optical systems for broadcast signal transmissions loaded with digital channels only

1 Scope

This part of IEC 60728 is applicable to optical transmission systems for broadcast signal transmission that consist of headend equipment, optical transmission lines, in-house wirings and system outlets. These systems are primarily intended for television and sound signals using digital transmission technology. This document specifies the basic system parameters and methods of measurement for optical distribution systems between headend equipment and system outlets in order to assess the system performance and its performance limits.

In this document, the upper signal frequency is limited at about 1 000 MHz. For systems requiring more bandwidth, refer to IEC 60728-13-1.

The purpose of this part of IEC 60728 is to describe the system specifications of FTTH (fibre to the home) networks for digitally modulated broadcast signal transmission. This document is also applicable to broadcast signal transmission using a telecommunication network if it satisfies the optical portion of this document. This document describes RF transmission for fully digitalized broadcast and narrowcast (limited area distribution of broadcast) signals over FTTH, and introduces xPON system as a physical layer media. The detailed description of the physical layer is out of the scope of this document. 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 the telecommunication system and the broadcast system are addressed in Clause 7.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60068-1:2013, *Environmental testing – Part 1: General and guidance*

IEC 60728-1:2014, *Cable networks for television signals, sound signals and interactive services – Part 1: System performance of forward paths*

IEC 60728-6:2011, *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 60728-101:2016, *Cable networks for television signals, sound signals and interactive services – Part 101: System performance of forward paths loaded with digital channels only*

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

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

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*

ITU-T Recommendation J.83, *Digital multi-programme systems for television, sound and data services for cable distribution*

ITU-T Recommendation J.382, *Advanced digital downstream transmission systems for television, sound and data services for cable distribution*

3 Terms, definitions, graphical symbols and abbreviated terms

3.1 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
optical transmitter
transmitting fibre optic terminal device accepting at its input port an electrical signal and providing at its output port an optical signal modulated by that input signal

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

Note 2 to entry: 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 the 1 530 nm to 1 625 nm range).

[SOURCE: IEC TR 61931:1998, 2.9.6, modified – Notes 1 and 2 have been added]

3.1.2
optical receiver
receiving fibre optic terminal device accepting at its input port a modulated optical signal, and providing at its output port the corresponding demodulated electrical signal (with the associated clock, if digital)

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

[SOURCE: IEC TR 61931:1998, 2.9.7, modified – Note 1 has been added]

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

Note 1 to entry: 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.

[SOURCE: IEC TR 61931:1998, 2.7.75, modified – Note 1 has been added.]

3.1.4
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 1 to entry: The ports can be connected to fibres, detectors, etc.

[SOURCE: IEC TR 61931:1998, 2.6.21, modified – The term "splitter" has been added, and "optical fibre branching device" and "optical fibre coupler" have been deleted.]

3.1.5
WDM filter
wavelength selecting device (used in WDM transmission systems) in which optical signals can be transferred between two predetermined ports, depending on the wavelength of the signal

3.1.6
WDM coupler
wavelength coupling device (used in WDM transmission systems) in which optical signals in different wavelengths can be coupled between two predetermined ports

3.1.7
optical modulation index
optical modulation index of k^{th} RF signal, OMI_k is defined as

$$OMI_k = \frac{\varphi_{\text{h}} - \varphi_{\text{l}}}{\varphi_{\text{h}} + \varphi_{\text{l}}}$$

where

ϕ_{h} is the highest instantaneous optical power of the intensity modulated optical signal;

ϕ_{l} is the lowest instantaneous optical power of the intensity modulated optical signal;

k is the total number of RF signals.

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

[SOURCE: IEC 60728-6:2011, 3.1.10, modified – The definition has been clarified and Notes 1 and 2 to entry have been replaced by a new Note 1 to entry.]

3.1.8
total optical modulation index
resulting optical modulation index when more than one RF signal is transmitted, OMI_{tot}, which is defined as

$$OMI_{\text{tot}} = \sqrt{\sum_{k=1}^{K} OMI_k{}^2}$$

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where

OMI_k is the optical modulation index of the k-th RF signal;

K is the total number of RF signals.

3.1.9
RIN
relative intensity noise
ratio of the mean square of the intensity fluctuations in the optical power of a light source to the square of the mean of the optical output power

Note 1 to entry: The RIN is usually expressed in dB(Hz-1) resulting in negative values.

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

[SOURCE: IEC 60728-6:2011, 3.1.12, modified – Note 2 has been added]

3.1.10
responsivity
ratio of an optical detector's electrical output to its optical input at a given wavelength

Note 1 to entry: The responsivity is generally expressed in ampere per watt or volt per watt of incident radiant power.

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

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

[SOURCE: IEC 60728-6:2011, 3.1.15]

3.1.11
wavelength
distance covered in a period by the wavefront of a harmonic plane wave

Note 1 to entry: 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 × 10^8 m/s);

f is the optical frequency.

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

[SOURCE: IEC TR 61931:1998, 2.2.9, modified – Notes 1 and 2 to entry have been added.]

3.1.12
central wavelength
average of those wavelengths at which the amplitude of a light source reaches or last falls to half of the maximum amplitude

[SOURCE: IEC 60728-6:2011, 3.1.26, modified – The term "centre wavelength" has been replaced by "central wavelength".]

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

[SOURCE: IEC 60050-702:1992, 702-06-63]

3.1.14
OFDM signal
orthogonal frequency division multiplexing
multiplexing scheme used for the transportation of terrestrial digital broadcasting SDTV and HDTV signals based on the idea of frequency-division multiplexing

Note 1 to entry: 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
signal level
strength of a digitally modulated signal given by the RMS power of the signal within the channel bandwidth (S)

Note 1 to entry: 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
QAM signal	RMS value	S	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		

Note 2 to entry: The level of digitally modulated signal can be expressed in dB(mW) or in dB(µV) referred to 75 Ω.

3.1.16
S/N ratio
signal-to-noise ratio (S/N) is given by

$$S/N \text{ (dB)} = S - N_{\text{rms}} \quad \text{(digital signals)}$$

where,

S is the signal level;

N_{rms} is the RMS level of the noise in the equivalent noise bandwidth of the RF channel.

Note 1 to entry: The level 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.

Note 2 to entry: In this document only digital modulated carriers are considered. The term S/N used in this document is the same as the term $S_{\text{D,RF}}/N$ defined in IEC 60728-1:2014, 3.1.72.

3.1.17
D/U ratio
single or multiple frequency interference ratio of desired signal level to undesired signal level

Note 1 to entry: The ratio of desired signal level, D(dB(µV)), to undesired signal level, U(dB(µV)) is given by

$$D/U \text{ (dB)} = D - U$$

Note 2 to entry: The desired and the undesired signals can also be expressed both in dB(mW).

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Note 3 to entry: The D/U ratio is generally used for multiple frequency interference as CSO and CTB, for single frequency interference as CCR.

Note 4 to entry: Note the similarity of the definition to the definition of "S/N ratio".

3.1.18
OLT
optical line terminal
central office-terminal equipment that is linked with the optical network unit (ONU) in customer premises

Note 1 to entry: OLT usually connects with headend equipment.

3.1.19
ONU
optical network unit
device at the customer premises that is linked with the optical line terminal (OLT)

Note 1 to entry: the ONU usually connects with customer premises equipment.

3.1.20
V-ONU
video-optical network unit
terminal unit that changes the optical signal of a broadcast system into an electric signal

Note 1 to entry: The term V-ONU is used as the synonym of optical receiver (O/E) in this standard.

3.1.21
SBS
stimulated Brillouin scattering
non-linear scattering of optical radiation characterized by a frequency shift

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

Note 2 to entry: SBS results in loss of optical level and affects the performance of optical system.

3.1.22
SPM
self-phase modulation
non-linear phase modulation caused by a device or a system itself due to excessive optical power launched into the fibre causing an increase of the refractive index of optical fibres

Note 1 to entry: Modulated optical signal induces modulation of refractive index, which means that the phase of optical signal varies in time.

Note 2 to entry: SPM affects the distortion properties of an optical transmission.

3.1.23
SRS
stimulated Raman scattering
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

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

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

Note 3 to entry: Frequency downshift is about 13 THz and gain bandwidth about 20 GHz

[SOURCE: IEC 61931:1998, 2.1.87, modified – Notes 1 to 3 to entry have been added]

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3.1.24
XPM
cross-phase modulation
modulation caused by the nonlinear refractive index of the fibre material

Note 1 to entry: XPM has a relationship with the wavelength spacing in optical transmission system. The more spacing becomes broader, 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 to entry: XPM affects the performance of the wavelength division multiplex system.

3.1.25
Rayleigh scattering
light scattering in a medium due to inhomogeneity in material density or composition of that medium which are small with respect to wavelength

Note 1 to entry: The scattered power is inversely proportional to the fourth power of the wavelength.

[SOURCE: IEC 60050-731:1991, 731-03-37 and IEC 61931:1998, 2.1.76]

3.1.26
SCR
signal to crosstalk ratio
level difference between CATV broadcast signal level and single frequency crosstalk level by other services in worst case measured at RF output port of optical receiver for CATV broadcast service

$$SCR = D_{CATV} - U_{OS}$$

where

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

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

SCR is the signal to crosstalk ratio expressed in dB.

3.1.27
BER
bit error ratio
ratio between erroneous bit and the total number of transmitted bits

[SOURCE: IEC 60728-1:2014, 3.1.60]

3.1.28
MER
modulation error ratio
sum of the sequence of the squares of the magnitudes of the ideal symbol vector divided by the sum of the squares of magnitudes of the symbol error vectors of a sequence of symbols

[SOURCE: IEC 60728-1:2014, 3.1.61]

3.2 Graphical symbols

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

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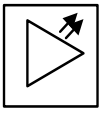
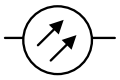
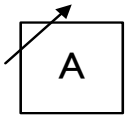
Optical transmitter based on IEC 60617-S00213-2001-07.



Optical amplifier based on IEC 60617-S01239-2001-07.



Optical fibre, IEC 60617-S01318-2001-07.

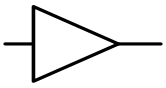


Variable attenuator, IEC 60617-S01245-2001-07

Optical receiver based on IEC 60617-S00213-2001-07.

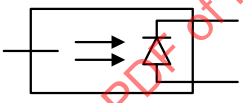
Power meter, IEC 60617-S00059-2001-07, IEC 60617-S00910-2001-07.

Electrical spectrum analyser, IEC 60617-S00059-2001-07, IEC 60617-S00910-2001-07.

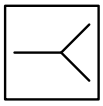


Amplifier, IEC 60617-S01239-2001-07.

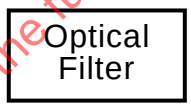
Ammeter based on IEC 60617-S00059-2001-07, IEC 60617-S00910-2001-07.



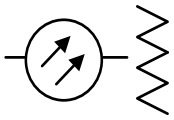
Photodiode with fibre pigtail, IEC 60617-S01327-2001-07.



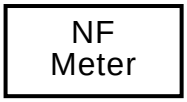
Coupler, IEC 60617-S00059-2001-07, IEC 60617-S01188-2001-07.



Optical filter



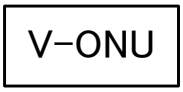
Optical terminator, IEC 60617-S01389, IEC 60617-S01318-2001-07.



NF meter

Optical splitter based on IEC TR 61930:1998 3.33.1.

Television set



Video optical network unit

Attenuator, IEC 60617-S01244-2001-07.

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3.3 Abbreviated terms

ADS	active double star	AGC	automatic gain control
BER	bit error ratio	APC	angled physical contact optical connector
BCH	Bose-Chaudhuri-Hocquenghem multiple error correction binary block code	CATV	community antenna television (network)

COFDM	coded orthogonal frequency division multiplex	CPE	customer premises equipment
CW	continuous wave		
DVB-C	digital video broadcasting baseline system for digital cable television(ETSI EN 300 429)	DVB-C2	digital video broadcasting baseline system for digital cable television second generation (ETSI EN 302 769)
DVB-T	digital video broadcasting baseline system for digital terrestrial television (ETSI EN 300 744)	DVB-T2	digital video broadcasting baseline system for digital terrestrial television second generation (ETSI EN 302 755)
DS	downstream or double star	DSF	dispersion shifted fibre
D/U	desired to undesired signal ratio	EDFA	erbium-doped fibre amplifier
EVM	error vector magnitude	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	ISDB-C	integrated services digital broadcasting – cable
ISDB-C2	integrated services digital broadcasting – cable second generation	ISDB-T	integrated services digital broadcasting – terrestrial
LD	laser diode	LDPC	low-density parity check (codes)
MC	Media Converter	MDU	multiple dwelling unit
MER	modulation error ratio	NF	noise figure
NM	noise margin		
O/E	optical receiver (optical to 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
SCR	signal-to-crosstalk ratio	S/IN	signal-to-intermodulation noise ratio
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
SW	switch	SS	single star
US	up stream	VBW	video bandwidth
V-ONU	video optical network unit	TMCC	transmission and multiplexing configuration control information
WDM	wavelength division multiplexing	XPM	cross-phase modulation
RFoG	radio frequency over glass	PSCS	polarization state change system

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4 Optical system reference model

Figure 1 shows the FTTH system reference model for broadcast signal transmission. Although the numbers of optical amplifiers and optical splitters depend on the scale of the optical system, or on the number 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 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. The reference model as shown Figure 1 includes the broadcast signal transmission system and the data signal transmission system. A data 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 shall consist of passive optical components such as optical fibres and optical power splitters only, considering maintenance and future system expansion. Although the data signal transmission system can transmit any IP datagram to subscriber premises through IO networks, such a system is out of the scope of this document.

In some cases, a one-fibre solution triple-play ONU (integral ONU for V-ONU, data-ONU and telephone terminal) is used. And in some cases, ONUs are located outside of subscribers' houses.

There are several ways to connect multi-dwelling units (MDU) with FTTH systems (see Figure 1). One is connected by an electrical port after V-ONU output and another one is connected by an optical port connected from outside plant.

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.

In this document, the optical wavelengths and electrical frequency bands listed in Table 2 and Table 3 are considered to be used.

Table 2 – Optical wavelength for FTTH system

Optical signal	Wavelength	Document
Video transmission	1 550 nm	IEC 60728-13, IEC 60728-113
RF return (RFoG)	1 610 nm	IEC 60728-14
Data (Downstream)	1 490 nm / 1 577 nm	ISO/IEC/IEEE 8802-3
Data (Upstream)	1 310 nm / 1 270 nm	ISO/IEC/IEEE 8802-3

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Table 3 – Frequency range

Frequency band	Document
47 MHz to 862 MHz (only digitally modulated signals)	IEC 60728-101, IEC 60728-113
950 MHz to 3 300 MHz (satellite signal transmission)	IEC 60728-13-1

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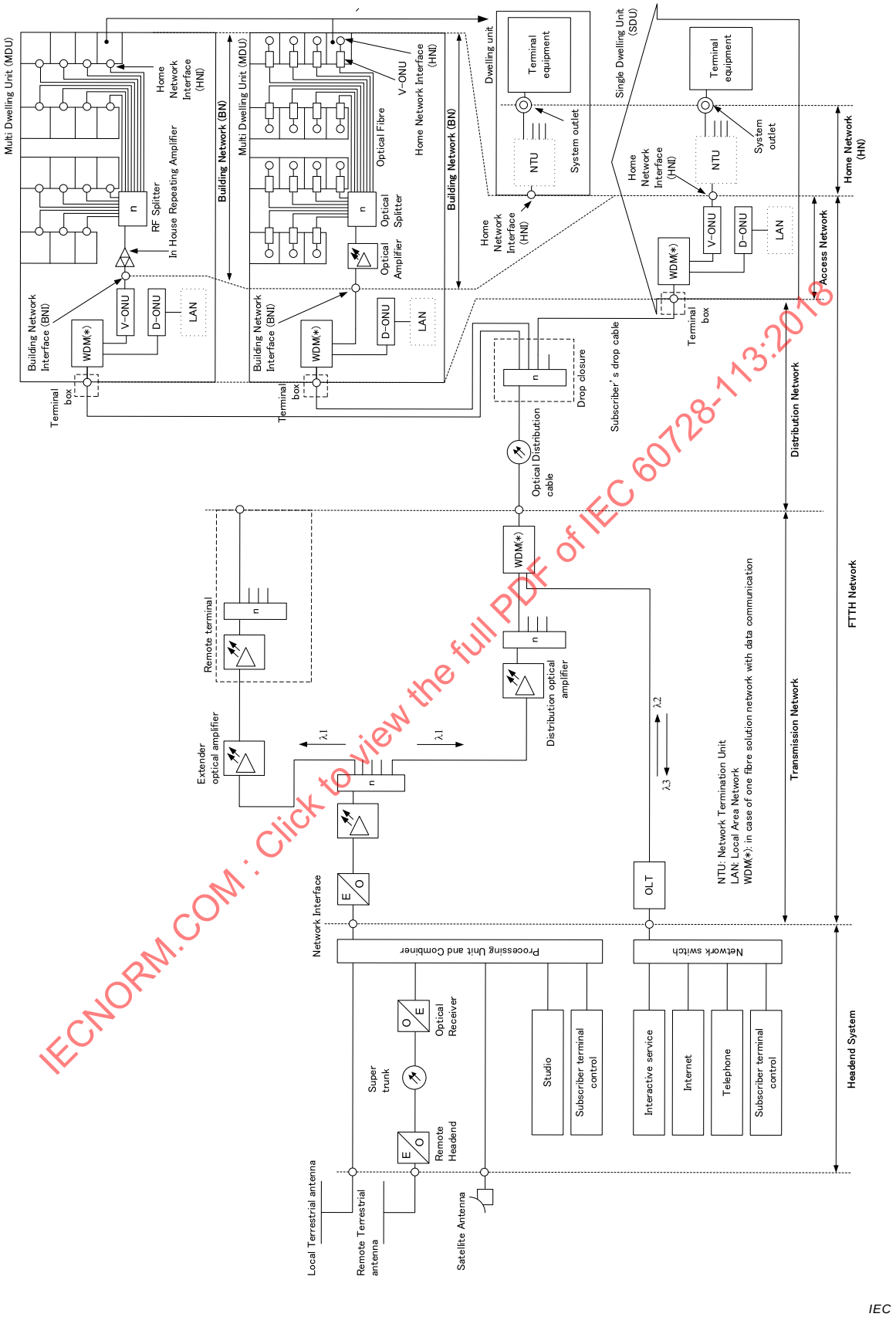

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Figure 1 – Example of FTTH system for television and sound signal

The points of performance specification of the optical system are shown in Figure 2.

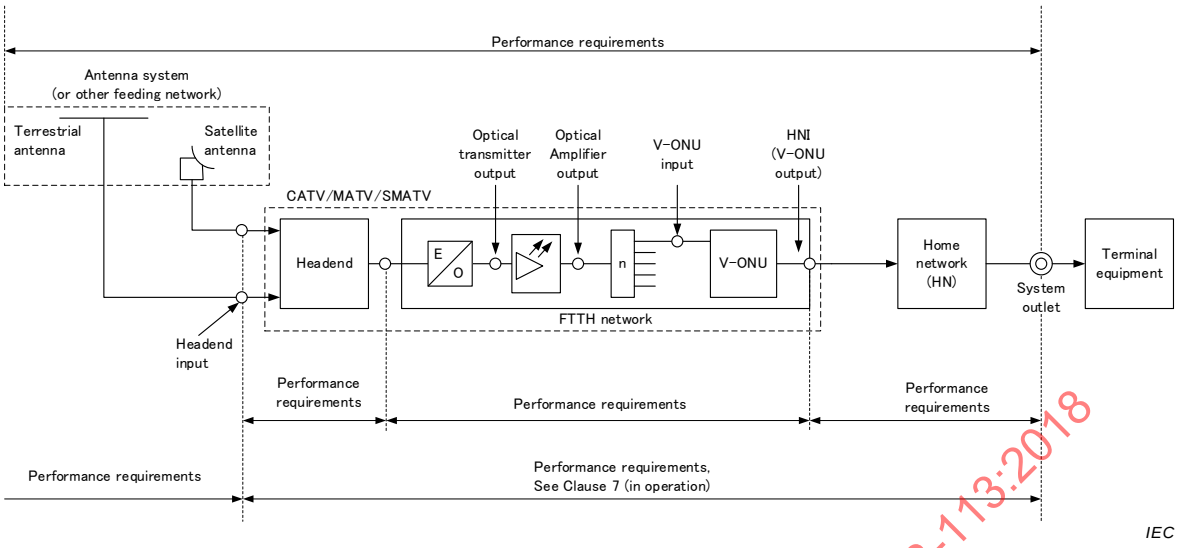

Figure 2 – Points of performance specification of the FTTH system

5 Preparation of measurement

5.1 Environmental conditions

5.1.1 Standard measurement conditions

Unless otherwise specified, all the measurement equipment shall be used in the following standard 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 60068-1:2013, 5.3.1). Nevertheless, the specification of the measurement equipment shall 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/ALC operation

Unless otherwise specified, all the pieces of equipment in the system shall be operated in the AGC (Auto Gain Control) or ALC (Auto Level Control) mode.

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.

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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 4 (passive pieces of equipment are excluded).

Table 4 – Measuring instruments

Name of instrument	Usage
Optical power meter	Instrument to measure the power of the optical signal.
Spectrum analyser	Instrument used for quantitative measurement of high frequency signals.
Signal generator	Instrument used to generate high frequency digital signals.
Digital signal analyser	Instrument used for quantitative measurement of digital modulated signals.
Noise figure (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 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 document 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 3 to ensure 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. The RIN should be measured at points (1) to (5) and S/N (electrical signal) at points (6) and (7).

6.1.3 Measured parameters

The following measurements shall be carried out.

a) Optical power

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The optical power shall be measured at points (1) to (5) in the optical system shown in Figure 3.

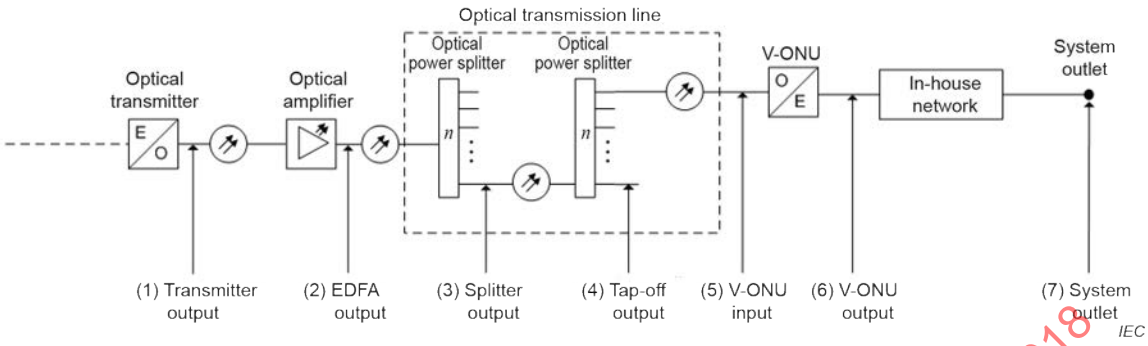

Figure 3 – Typical optical video distribution system

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

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

c) S/N ratio (RIN)

Estimation of the signal-to-noise ratio at the output of a 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.

Measuring points and measured parameters are summarized in Table 5.

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

Table 5 – 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	○	○	○	○	○	–	–
S/N (electrical)	–	–	–	–	–	○	○
S/N (RIN) (see NOTE 1)	○	○	Δ	Δ	Δ	–	–
BER,MER	–	–	–	–	–	○	○
○ Measurements are possible at these points.							
Δ Measurements are possible at these points when the optical power is higher than −3 dB (mW).							
NOTE Theoretical estimation of S/N at (6), at the output of V-ONU, is based on the measurement results of individual pieces of equipment.							

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6.2 Optical power

6.2.1 Introduction

The purpose of this measurement is to measure the average optical power at each measurement point in the optical system illustrated in Figure 4 or in Figure 5.

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 in accordance with 4.2 of IEC 60728-6:2011.

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 equipment as shown in Figure 4 or in Figure 5 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 60728-6:2011.

The optical power at the output of a WDM coupler shall be measured according to 4.2 of IEC 60728-6:2011.

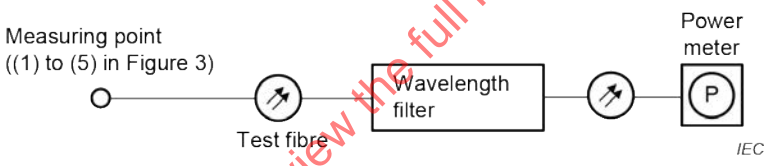

Figure 4 – Test set-up for optical power measurement using a wavelength filter

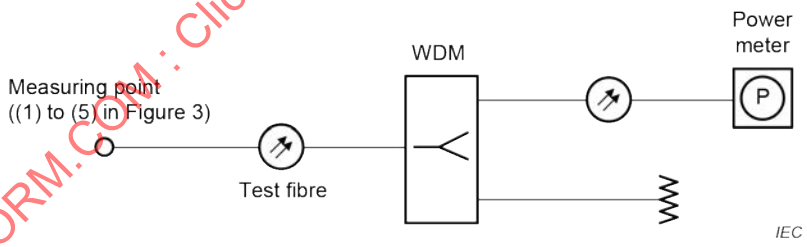

Figure 5 – Test set-up for optical power measurement using a WDM coupler

6.2.3 Measuring method

In addition to the requirements of IEC 60728-6:2011, 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.

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6.2.4 Precautions for measurement

The following considerations have to be taken into account.

a) The optical fibre end-face or the connector end-face shall not be viewed directly. Also, the end-face of the fibre shall 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 the entire 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 in CW mode. Ensure CW mode operation prior to the measurement.

g) If there is any instability in the measurement (the measured value fluctuates when the end-face of the 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 Signal level and RF signal to intermodulation and noise ratio S/IN

6.3.1 General

The purpose of this test method is to measure the signal level of the television broadcast signal. Also, the RF signal-to-intermodulation and 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 6. The method for measuring the RF signal to intermodulation and noise ratio of optical transmission systems is nearly the same as for cabled distribution systems (see IEC 60728-101:2016, 4.4) and as described in 6.7.

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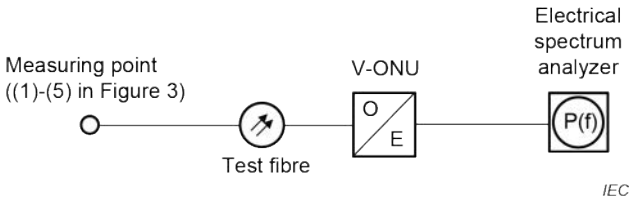

Figure 6 – Test setup for RF signal to intermodulation and noise ratio measurement

The test setup of Figure 6 is for simplified measurement of signal-to-noise ratio in the optical field. The correct measurement shall be carried out in the electrical field using an electrical spectrum analyser at points (6) and (7), described in Table 5.

6.3.3 Measuring conditions

The following measuring conditions apply.

a) The spectrum analyser used for the measurement shall 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 Precautions for measurement

The following considerations have to be taken into account.

a) Measurement accuracy: to obtain an accurate measurement of RF signal to intermodulation and 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 measurement error of the test method prescribed in this document.

b) Attenuation setup of the spectrum analyser: most of the spectrum analysers 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 analyser and by setting the centre frequency to 510 MHz, 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) at 75 Ω impedance on the voltage display, in order to avoid any distortion generated within the spectrum analyser, 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 analyser.

d) When the RF signal to intermodulation and noise ratio of the signal is very small, the noise within the signal will be larger than the measurement error and cannot be neglected. If a correction factor needs to be applied, this correction factor shall be subtracted from the spectrum analyser measured level (see Annex A of IEC 60728-101:2016).

e) This document recommends the test method using the electrical power measurement option of the spectrum analyser to deal with QAM and OFDM signals. This test method is preferred because any correction necessary within the spectrum analyser is automatically processed irrespective of the type of spectrum analyser used for the measurement. Also,

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the flatness of the signal over the transmission bandwidth does not influence the measurement results.

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

6.3.5 Presentation of the results

The signal level shall be expressed in dB(mW) or in dB(µV) and the RF signal to intermodulation and noise ratio shall be expressed in dB.

6.4 Signal-to-noise ratio of optical signals

6.4.1 General

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

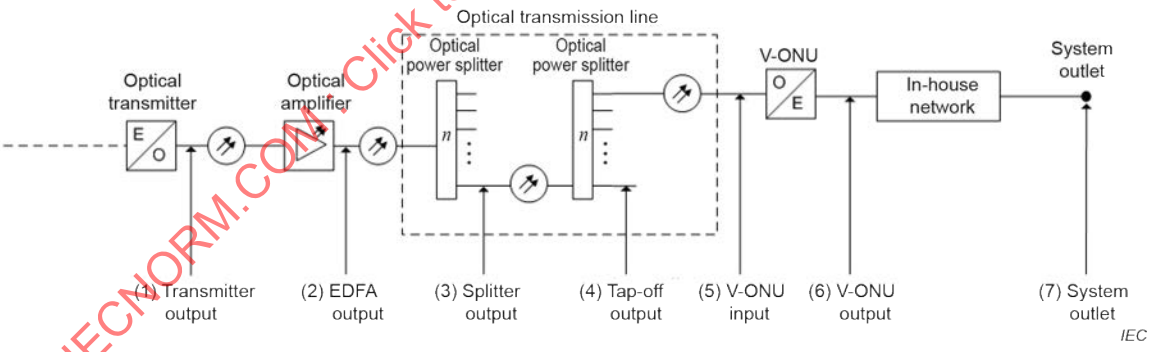
The RIN is the noise caused by fluctuations in optical output power with respect to time and is expressed as the ratio of average optical power to the average noise power measured in a 1-Hz bandwidth. It is difficult to measure the RIN directly in the optical domain and the measurement shall be carried out after converting the optical signal to an electrical signal. However, an accurate measurement of the RIN is not possible if the optical input to V-ONU is small, as in most practical systems. The 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) Measurement points

The measurement points in the cable TV network for optical signals are shown in Figure 7.



NOTE Figure 7 is identical to Figure 3, except that the figure title has changed to describe the measurement points.

Figure 7 – Measuring points in the optical cable TV network

- In order to calculate the signal-to-noise ratio at the V-ONU output, it is necessary to measure the RIN, as shown in Figure 7 at points (1) to (3), where the optical output power is sufficiently high to allow RIN measurements to be accurate.

NOTE RIN measurements are not accurate when the optical power is lower than −3 dB(mW).

- If no optical amplifier is employed in the system, the RIN shall be measured at point (1).
- If an outdoor type optical amplifier is employed and measurement can be carried out outdoors, the optical amplifier output shall be considered as a measurement point.

b) Measuring setup

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Figure 8 shows the RIN measurement setup.

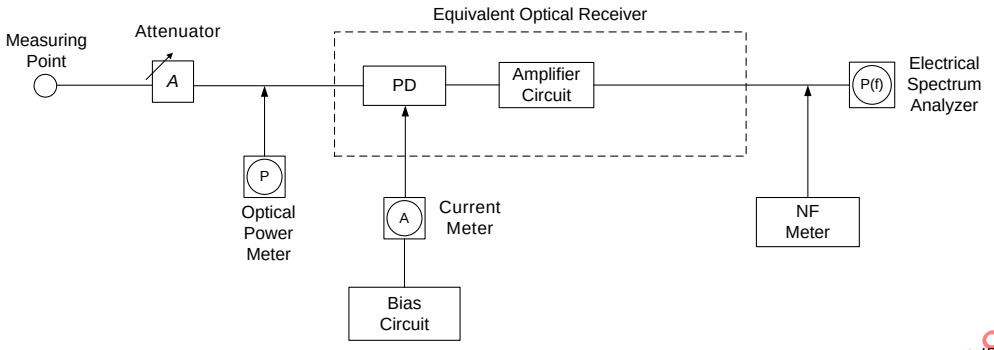

Figure 8 – Test setup for RIN measurement

6.4.3 Measurement conditions

The following measurement conditions apply.

- Only calibrated instruments (spectrum analyser, optical power meter, current meter, network analyser, NF meter and the optical attenuator) shall be used for the measurements.
- The spectrum analyser shall 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 shall have the provision to measure the photo diode current.
- A CW optical signal shall be used for the measurement. To avoid SBS interference, some technology shall be applied, such as the 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 to 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 a similar performance to the cable used in the actual optical network shall be inserted at the measurement point in Figure 8.

6.4.4 System RIN measuring method

6.4.4.1 General

This test method shall be applied to predict the signal-to-noise ratio at the output of a V-ONU from the RIN measurement using the setup shown in Figure 8. Subclause 6.4.4 contains several steps as shown below. If the parameters for R, I_{d0} , I_{eq} and G are unknown, refer to Annex D. The 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 the optical receiver (P_r) using a power meter.
- Connect the spectrum analyser 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 analyser set to 100 kHz):

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

where

Z_0 is the impedance of the measurement setup, expressed in Ω;

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

- The measured noise level (N_p) includes that of the measuring equipment (spectrum analyser) 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 the noise level (see Annex A of IEC 60728-101:2016).

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

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

where

B_n is the measurement bandwidth of noise power (Np) 1 Hz;

B is the noise bandwidth, RBW × 1,2 (noise bandwidth correction factor) = 120 000 Hz;

K_1 is the correction factor for conversion to effective voltage level = 20 lg(2/ $\sqrt{\pi}$) = 1,05 dB;

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

6.4.4.3 Step B: RIN calculation

For step B, proceed as follows.

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

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

where

R is the responsivity of the photodiode, expressed in A/W;

I_{d0} is the dark current of the photodiode, expressed in A;

I_{eq} is the preamplifier equivalent input noise current density, expressed in A $\sqrt{Hz}$;

I_{bn} is the total noise current within a 1-Hz bandwidth at the optical receiver output, expressed in A/ $\sqrt{Hz}$;

G is the amplifier gain of the optical receiver (including gain of matching circuit), expressed in true value;

P_r is the input power to the optical receiver, expressed in W;

e is the charge of the electron 1,602 × 10^{-19}, expressed in C.

6.4.5 S/N calculation based on RIN value

The signal-to-noise ratio (S/N) at the V-ONU output can be calculated using the following relation:

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$$S/N = 10\,\lg\left(\frac{1}{B_N}\cdot\frac{\frac{1}{2}\cdot\left(OMI_k\cdot R\cdot P_r\right)^2}{\mathrm{RIN}\cdot\left(R\cdot P_r\right)^2+2\cdot e\cdot\left(I_{d0}+R\cdot P_r\right)+I_{eq}^2}\right)\,[\mathrm{dB}] \quad (3)$$

The other parameters for the calculation are listed in Table 6.

6.4.6 Component RIN calculation

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

$$RIN_{out} = 10\,\lg\left(\sum\frac{2\cdot E\cdot 10^{\frac{NF_n}{10}}}{10^{\frac{P_n}{10}}}+10^{\frac{RIN_{in}}{10}}\right) \quad (4)$$

where

E is the photon energy, $E = hf$;

h is Planck's constant, 6,62 × 10^{-34} [J·s];

f is the frequency, expressed in Hz.

If the optical wavelength is 1 555 nm, then E = 1,278 × 10^{-16} mJ.

NF_n is the noise factor of the nth EDFA in dB;

P_n is the optical input power of the nth EDFA in dB(mW).

NOTE The term "1/G" in Equation (12) of IEC TR 60728-6-1:2006 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:

$$RIN_f = 10\,\lg\left[\frac{s^2}{4}\left(2\alpha L-1+e^{-2\alpha L}\right)\cdot\frac{\Delta\nu}{\pi\left(f_{RF}{}^2+\Delta\nu^2\right)}\right] \quad (5)$$

where

s is the ratio of scattered optical power that is propagated in the reverse direction, $s = \frac{1{,}5}{\left(\pi\cdot W\cdot\eta_1/\lambda\right)^2}$;

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, expressed in km;

$\Delta\nu$ is the spectral width of the optical signal when modulated, expressed in Hz;

f_{RF} is the measurement frequency, expressed in Hz;

W is the fibre mode field diameter, expressed in µm;

η_1 is the refractive index of fibre core;

λ is the wavelength, expressed in µm.

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

$$RIN = -10 \lg \left[10^{-(RIN_{\text{out}}/10)} + 10^{-(RIN_{\text{f}}/10)} \right] \frac{\Delta y}{\Delta x} \quad (6)$$

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

Table 6 – Parameters used for the calculation of signal-to-noise ratio (S/N)

Parameter	Remarks		
B_N	ISDB-C ISDB-C2 ISDB-T	See Table 7	This parameter depends on the transmission signal format. QAM: BW in Table H.1 of IEC 60728-1:2014 OFDM: BW in Table H.1 of IEC 60728-1:2014
	DVB-C DVB-C2 DVB-T DVB-T2	See Table 7	
K	Number of transmission signals		
OMI_{total}	Total optical modulation index		These parameters depend on the optical transmitter, transmission signal, etc.
OMI_k	Optical modulation index of k^{th} signal (modulated RF signals)		
P_r	Received optical power (W)		This parameter depends on the transmission line design.
RIN	RIN of the optical signal input to the V-ONU (dB(Hz^{-1}))		This parameter depends on the 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 the optical transmitter for multi-channel transmission is −155 dB(Hz^{-1}). RIN of the optical transmitter for retransmission is −150 dB(Hz^{-1}). NF of the optical amplifier is 6,5 dB RIN due to the optical transmission line is −161 dB(Hz^{-1}).
e	Charge of an electron (1,602 × 10^{-19} C)		Physical constant.
R	Responsivity of the V-ONU (A/W)		Typical values of these parameters are listed in 6.4.7.
I_{d0}	Dark current of the V-ONU (A)		

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6.4.7 Example for calculating signal-to-noise ratio S/N

The signal-to-noise ratio S/N may be calculated with the following typical parameters:

Parameter	Japan	Europe
Noise bandwidth	5,3 MHz	8 MHz
Number of signals	K = 57 channels	K = 50 channels
Total modulation index	0,264	0,264
RIN of optical signal at the input of a V-ONU	−148 dB(Hz^{-1})	−148 dB(Hz^{-1})
Responsivity of the V-ONU	0,89 A/W	0,9 A/W
Dark current of the V-ONU	0,1 nA	0,1 nA
Equivalent input noise current density of pre-amplifier before V-ONU	7 pA/ $\sqrt{Hz}$	7 pA/ $\sqrt{Hz}$

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

If the optical modulation index of all the signals is assumed to be the same, then the optical modulation index per signal is given by:

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

If the optical input to the V-ONU is −9,6 dB(mW), from Equation (3), the signal-to-noise ratio is calculated to be 40,6 dB.

6.5 Optical modulation index

The optical modulation index (OMI) of digital signals shall be measured in accordance with the method described in 4.9 of IEC 60728-6:2011. In this document, the power AGC function in the transmitter shall be off.

6.6 Signal-to-crosstalk ratio (SCR)

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. 64/256 or higher QAM broadcast signals) are transmitted in the optical network. Other services can produce crosstalk effects in optical fibres and in optical receiver devices with high linearity.

Crosstalk effects can arise when the broadcast signals are multiplexed with signals of other services on the same fibre through wavelength division multiplexing (WDM) and there is either insufficient optical wavelength filtering or relevant presence of non-linear fibre optical effects or both. Insufficient optical wavelength filtering can be due to low triplexer quality. Important non-linear fibre optical effects can be stimulated Raman scattering (SRS), self-phase modulation (SPM) and cross-phase modulation (XPM).

6.6.2 Equipment required

The following equipment is required for the measurement:

a) a running system with implemented CATV broadcast service with other service(s), i.e. telecommunication services;

b) a selective voltmeter (or spectrum analyser) covering the frequency range of the CATV broadcast service;

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c) lengths of fibre for connecting the transmitters, optical WDM filters, an optical amplifier, optical attenuators, an optical polarization state change system and the receivers.

6.6.3 General measurement requirements

The measurement shall be carried out following the steps described in 6.6.4.

a) Unless otherwise required, the reference levels used in the measurements shall be the normal operating levels.

b) 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

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 9.

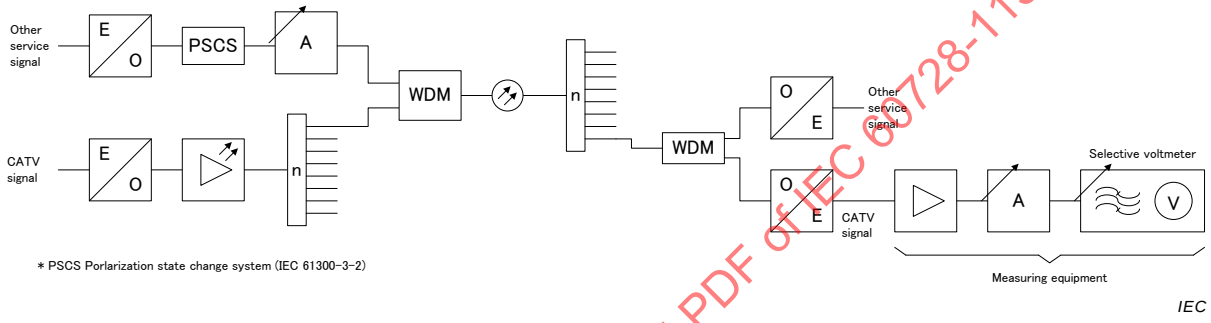

Figure 9 – Test setup for signal to crosstalk measurement

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 optical power range at the optical fibre input by adjusting the 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.

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

g) Connect the variable RF attenuator A and selective voltmeter to the RF output port of the optical receiver for CATV broadcast service. Tune the meter to each CATV signal 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 SCR from other services 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 the maximum level. Reduce the RF attenuator A setting to the value a_2 required to obtain the same meter reading R.

It can be necessary to temporarily switch off one CATV signal occupying the frequency band of local interest during measurement of other services crosstalk in order to obtain an accurate value a_2.

i) The SCR from other services , in dB, is given by

$$SCR = a_1 - a_2 \tag{7}$$

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where

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

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

6.6.5 Potential sources of error

Sources of error are the following:

a) the inaccuracy of the selective voltmeter;

b) the inaccuracy of the variable attenuators.

6.6.6 Presentation of the results

The SCR from other services shall be expressed in dB.

6.7 RF signal-to-intermodulation and noise ratio S/IN

6.7.1 General

In a cable network, two distortion signals occur: thermal noise and intermodulation products associated with the non-linear behaviour of equipment and components. In a single measurement of the noise signal, the two distortion signals cannot be distinguished. Therefore, in this subclause, they are taken together as intermodulation and noise signals (IN). The interference by 3rd order frequency, single frequency and signal reflection described in Table 10 is included in the S/IN ratio category.

For this measuring method, the composite network load of all input channels as used during normal service conditions shall be applied. The intermodulation signal will depend on the signal level throughout the cascade. Therefore, a measured S/IN ratio is meaningful only when all signal levels are specified.

This measurement method applies to the measurement of the RF signal-to-intermodulation and noise ratio S/IN of digitally modulated signals using PSK, APSK, QAM, OFDM formats.

Because the modulated signal is similar to the intermodulation and noise signal distributed in the bandwidth of the channel, the measurement is based on the use of a suitable spectrum analyser that is able to tune the frequency range of the channel and to display the whole bandwidth in order to measure spectral power densities of both the signal and the noise.

NOTE A vector signal analyser can also be used.

The measurement can be performed at the system outlet, at the output of a piece of distribution equipment (passive or active), at the output of the headend or at the output of an outdoor unit (SHF receiver) for satellite reception.

The measured S/IN will depend on the signal-to-noise (S/N) of the composite input signal and on the ratio of the signal to the intermodulation noise added by the cable network. Using a standard network input load of carriers can thus limit the measurement range of the method of measurement up to the S/N ratio of the input load. As an alternative, an input source with notch filters to reduce the S/N of the measurement carriers can be used, similar to the source signal used in IEC 60728-3:2017.

6.7.2 Equipment required

The equipment required is a spectrum analyser having a calibrated display of the tuned signal.

The equipment shall be able to tune the nominal frequency range of the system under test.

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6.7.3 Connection of the equipment

Connect the measuring equipment to the system outlet or to the point where the measurement shall be performed, using suitable cable and connectors, taking care to maintain correct impedance matching.

6.7.4 Measurement procedure

The measurement shall be carried out following the procedures described below.

a) Tune the spectrum analyser on the channel that shall be measured (selecting the centre frequency of the spectrum analyser) and select the span and level settings to show the whole channel whose bandwidth depends on the type of modulation used. Examples of the equivalent signal bandwidth (BW) for digitally modulated signals are indicated in Table 7.

b) Set the resolution bandwidth of the spectrum analyser to 100 kHz and the video bandwidth low enough to obtain a smooth display (100 Hz, if available). If a different setting is used, this shall be the same when measuring the signal level and the intermodulation and noise level.

c) Measure the maximum level S of the flat top of the displayed signal in dB(µV) or in dB(mW) using the display line cursor if this feature is available.

NOTE If the spectrum of the signal is not flat, due to echoes, measure the signal level at the centre frequency of the channel.

d) Switch off the channel at the input of the system or at the input of the device under test, terminating the input port with a matched impedance (or depointing the antenna, if the measurement is performed at the output of an outdoor unit for satellite reception) and measure the intermodulation and noise level IN in the same units as the signal level (in dB(µV) or in dB(mW) or in dB(mW)/Hz).

e) When switching off the input signal, all equipment with built-in AGC will show a different behaviour. In this case, the intermodulation and noise level should be measured in-between the channels.

f) Calculate the signal to intermodulation and noise ratio S/IN with the following formula:

$$S/IN = S - IN \quad (8)$$

where

S/IN is the signal to intermodulation and noise ratio, expressed in dB;

S is the signal level in dB(µV), expressed in dB(mW) or in dB(mW)/Hz;

IN is the intermodulation and noise level in dB(µV), expressed in dB(mW) or in dB(mW)/Hz.

This method of measurement actually measures the (S + IN)/IN ratio. The measuring equipment (spectrum analyser) should have a noise level at least 10 dB lower than the intermodulation and noise level displayed outside the channel band in order not to affect the results. Otherwise, the contribution of the measuring equipment noise in the measurement of the intermodulation and noise level (IN) should be taken into account.

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Table 7 – RF signal noise bandwidth

Broadcast signal			RF signal noise bandwidth
System	Modulation	Sub-carrier	MHz
ISDB-T	OFDM	64 QAM	5,60
ISDB-C (J.83)	64 QAM	–	5,30
	256 QAM	–	5,30
ISDB-C2 (J.382)	OFDM	256 QAM	5,71
		1 024 QAM	5,71
		4 096 QAM(4/5)	5,71
		4 096 QAM(5/6)	5,71
DVB-T	COFDM	64 QAM (2/3)	7,61
DVB-T2	COFDM	256 QAM (2/3)	7,61
DVB-C	64 QAM	–	6,96
	256 QAM	–	6,96
DVB-C2	COFDM	256 QAM	7,61
		1 024 QAM	7,61
		4 096 QAM(5/6,9/10)	7,61
Table 7 presents noise bandwidths for various signal types. The bandwidth refers to one channel (sub-carrier).			

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6.7.5 Presentation of the results

The measured signal to intermodulation and noise ratio S /IN shall be expressed in dB.

6.8 Bit error ratio (BER)

6.8.1 General

The purpose of this test method is to measure the bit error ratio (BER) of the digital modulated RF signal at each measurement point.

The measurement of the BER described in 6.8 is carried out by demodulating the broadcast signal with the digital signal analyser. The BER can also be estimated through an RF measurement of the complementary cumulative distribution function (CCDF) of the noise within a transmission channel. Refer to Annex E for the details of the measurement of the CCDF and BER estimation.

6.8.2 Connection of the equipment

The measuring setup for BER measurement is shown in Figure 10.

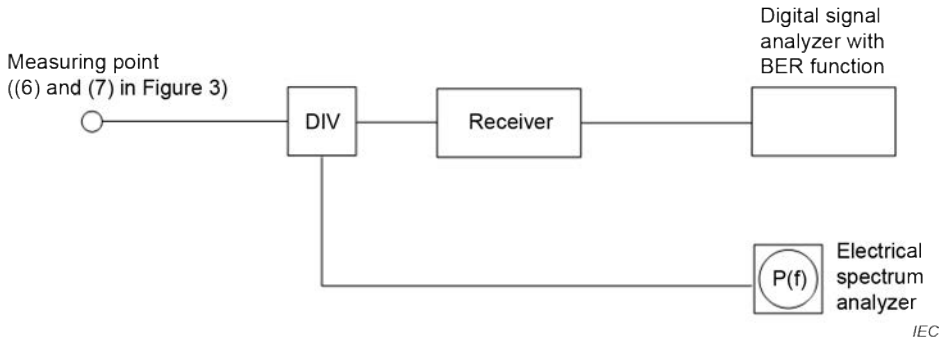

Figure 10 – Test setup for BER measurement

6.8.3 Measurement procedure

The measurement shall be carried out following the procedures described below.

a) First, measure the signal level and signal-to-noise ratio (S/N) of the desired signal channel by spectrum analyser.

b) Adjust the desired channel on the digital signal tuner or digital signal analyser. The FEC condition should be off.

c) Measure BER with a BER measurement instrument or with a digital signal analyser. The BER should be measured several times, and the average value should be calculated and recorded.

6.8.4 Presentation of the results

The measured signal-to-noise ratio S/N shall be expressed in dB and BER shall be expressed without a unit.

6.9 BER versus S/N

6.9.1 General

The purpose of this test method is to measure relationship between bit error ratio (BER) and signal-to-noise ratio (S/N) of the digital modulated RF signal at each measurement point.

6.9.2 Connection of the equipment

The measuring setup for the BER versus S/N measurement is shown in Figure 11.

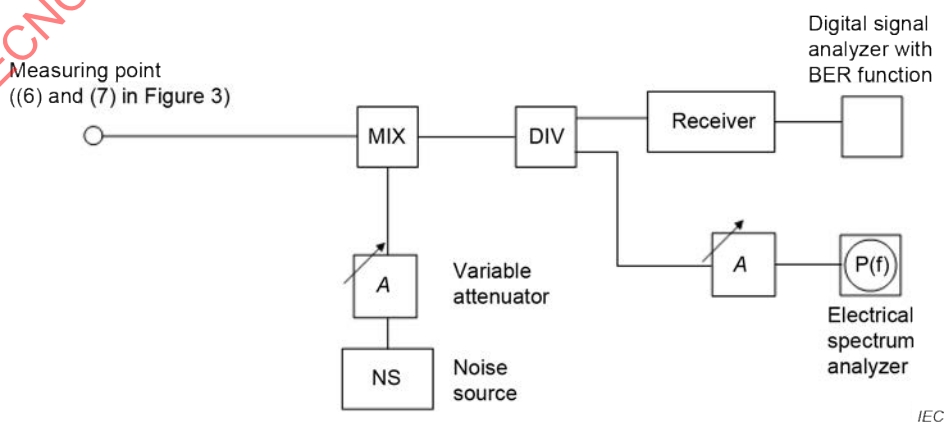

Figure 11 – Test setup for BER versus S/N measurement

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6.9.3 Measurement procedure

The measurement shall be carried out following the procedures described below.

a) This measurement can be performed under operation conditions.

b) Instruments are connected as shown in the measurement block diagram.

c) Measure the signal-to-noise ratio.

Turn off any RS error correction and measure the BER with the digital signal analyser with the BER measurement function or with a BER measurement instrument.

d) If the error correction can't be turned off, or when LDPC error correction is used, it will generally take a long time to measure low error conditions like BER = 10^{-11}. In this case, the extrapolation method can be applied as described below.

Figure 12 shows the extrapolation method for BER.

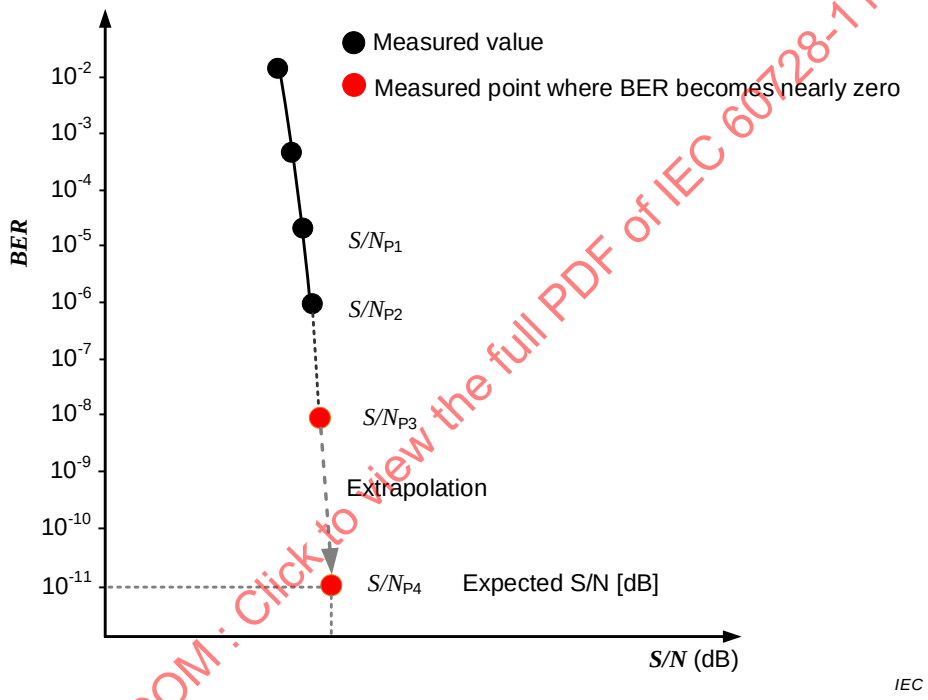

Figure 12 – Extrapolation method of BER measurement

Measure three S/N values for S/N_{P1}, S/N_{P2} and S/N_{P3} as shown in Figure12 and find S/N_{P4} that crosses the line of BER = 10^{-11} and the slope line between the points of P2 and P3. S/N_{P4} can be calculated with the following equation. For a more detailed method and obtained results, see Annex B.

$$S/N_{P4} = 2 \cdot \frac{\lg(10^{-11}) - \lg(BER_{P3})}{\dfrac{\lg(BER_{P2}) - \lg(BER_{P1})}{S/N_{P2} - S/N_{P1}} + \dfrac{\lg(BER_{P3}) - \lg(BER_{P2})}{S/N_{P3} - S/N_{P2}}} + S/N_{P3} \quad (9)$$

Measure the S/N at the input of the measurement instrument and the BER by changing the value of the attenuator.

6.9.4 Presentation of the results

An example of a measurement of BER versus S/N is shown in Figure 13. The measured signal-to-noise ratio S/N shall be expressed in dB and the BER shall be expressed without a unit.

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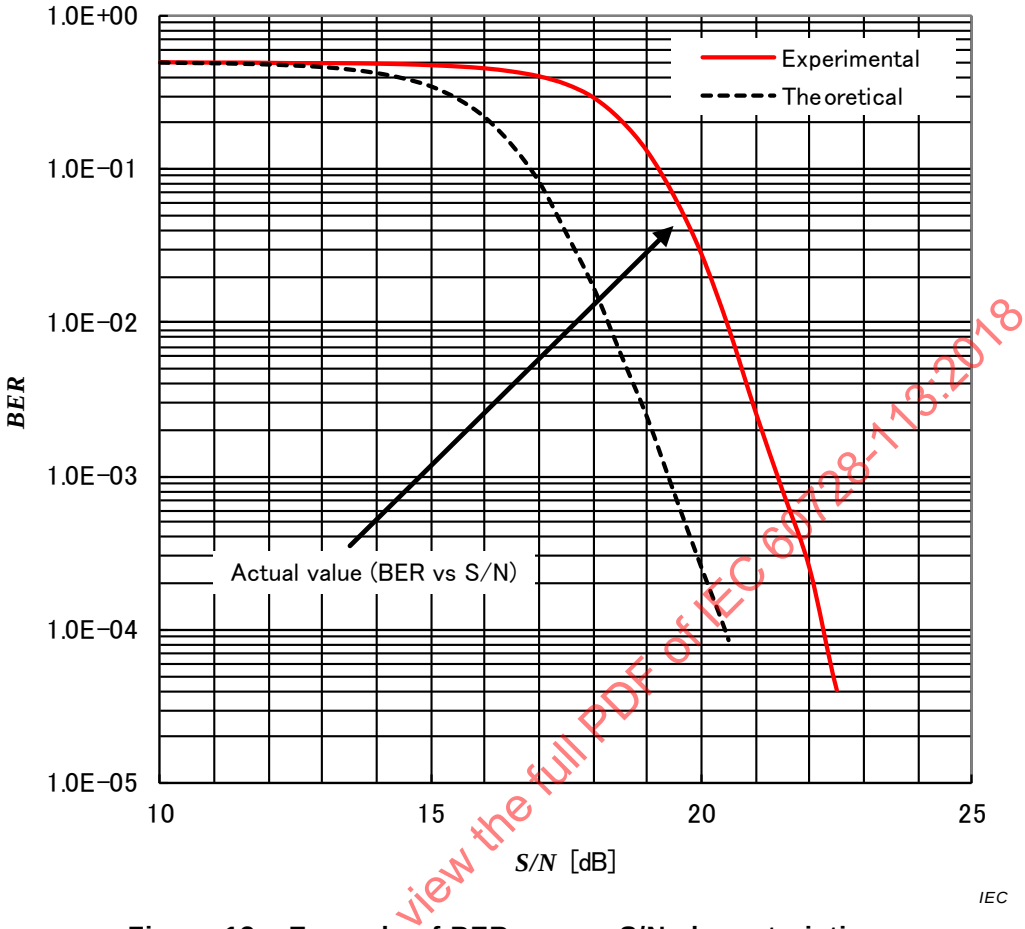

Figure 13 – Example of BER versus S/N characteristics

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6.10 System noise margins

6.10.1 General

The purpose of this test method is to measure the difference value (noise margin) between the value of S/N where BER = 1×10^{-4} and the system S/N, in case of RS error correction. In case of LDPC error correction, the calculation shall be carried out for BER = 1×10^{-11}; in this case, the S/N measurement method should follow the extrapolation method described in 6.9.3. The measurement shall be carried out at measurement points (6) and (7) as shown in Figure 3, where the S/N of the complete system is measured.

6.10.2 Connection of the equipment

The measuring setup for system noise margin measurement is shown in Figure 14.

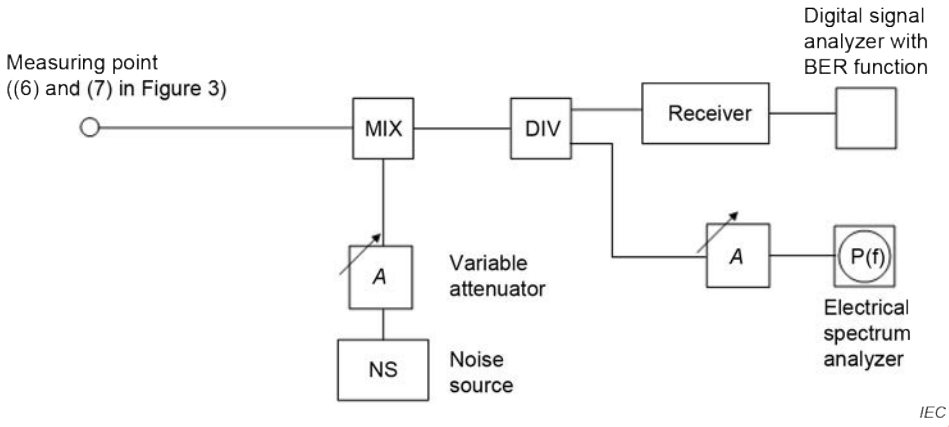

Figure 14 – Test setup for system noise margin measurement

6.10.3 Measurement procedure

The measurement shall be carried out following the procedures described below.

a) Prepare the measurement system as shown in Figure 14.

b) The spectrum analyser and the digital signal analyser (or digital tuner + BER measurement instrument) are connected at each measurement point.

c) Adjust the measurement frequency on the measurement instrument.

d) Measure the BER before RS error correction with the digital signal analyser or the digital tuner + BER measurement instrument.

e) Measure S/N_1 at the measurement frequency.

f) Add noise by changing the attenuation level until the BER before RS error correction becomes 1×10^{-4}.

g) Measure S/N_2.

h) Calculate the noise margin as follows:

$$NM = S/N_1 - S/N_2 \text{ in dB} \quad (10)$$

6.10.4 Presentation of the results

An example of measurement for the system noise margin is shown in Figure 15.

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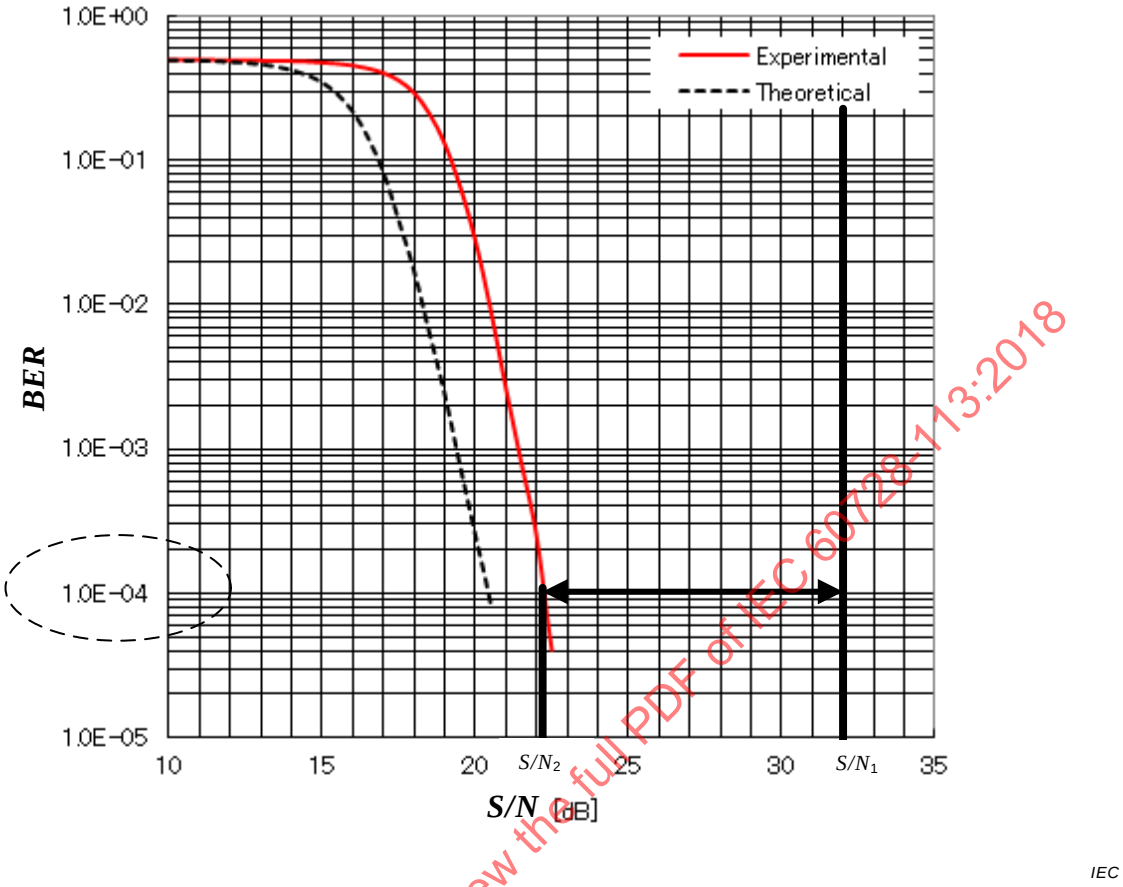

Figure 15 – Example of system noise margin characteristics

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6.11 Modulation error ratio (MER)

6.11.1 General

The purpose of this test method is to measure the modulation error ratio (MER) at each measurement point of the FTTH system.

6.11.2 Connection of the equipment

The measuring setup for MER measurement is shown in Figure 16.

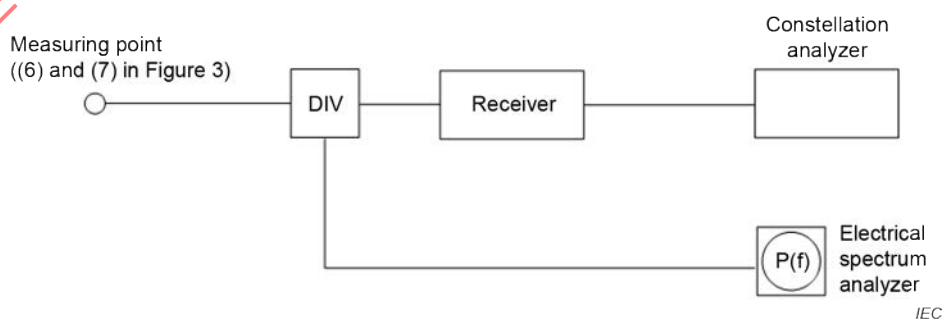

Figure 16 – Test setup for MER measurement

6.11.3 Measurement procedure

The measurement shall be carried out following the procedures described below.

a) The digital signal analyser is connected at each measurement point.
b) Configure each parameter of the digital signal analyser.
c) Adjust the signal frequency and the reference level.
d) Adjust mode, guard interval, TMCC parameter if it is necessary.
e) Measure MER.

6.11.4 Presentation of the results

An example of measurement for system noise margin is shown in Figure 17. The measured MER shall be expressed in dB.

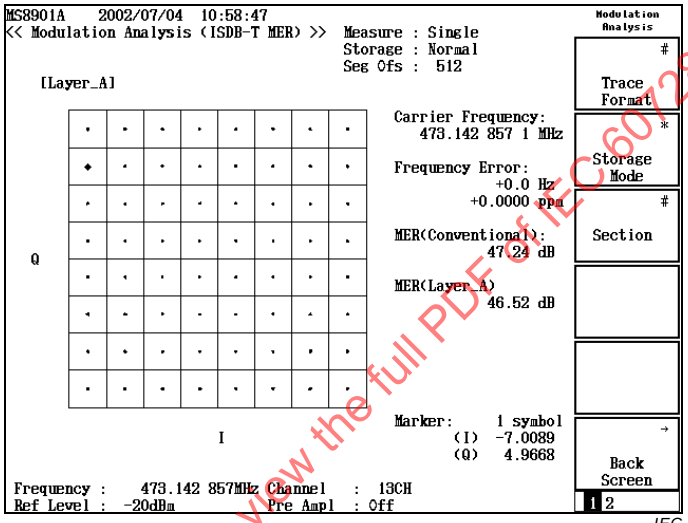

Figure 17 – Example of result of MER measurement (64 QAM modulation format)

7 Specification of the optical system for broadcast signal transmission

7.1 Digital broadcast system over optical network

For digital broadcast services over optical networks, the modulation methods 64/256 QAM or OFDM with 256, 1 024, and 4 096 QAM are mainly used. Figure 18 shows the performance specified points in this document. It also depicts the measuring points (same as performance specified points) and additional measuring points in order to check the operating performance of the optical system. The minimum S/N ratio at the headend output, V-ONU output and system outlet with section S/N ratio for transmission line and in-house network are indicated in Table 8 and Table 9. Table 8 is for the SDU case while Table 9 is for the MDU case. The measurement methods of Clauses 5 and 6 shall be applied.

For digitally modulated signals, the bit error ratio (BER) shall be used as a specification parameter at the headend input only. 1×10^{-4} is required for digitally modulated broadcast signals before FEC in the case of RS (204, 188). In the case of other FEC methods, 1×10^{-11} is required after FEC. As supplementary parameters at the headend input, equivalent noise degradation (END), noise margin (NM), modulation error ratio (MER) and error vector magnitude (EVM) can be used.

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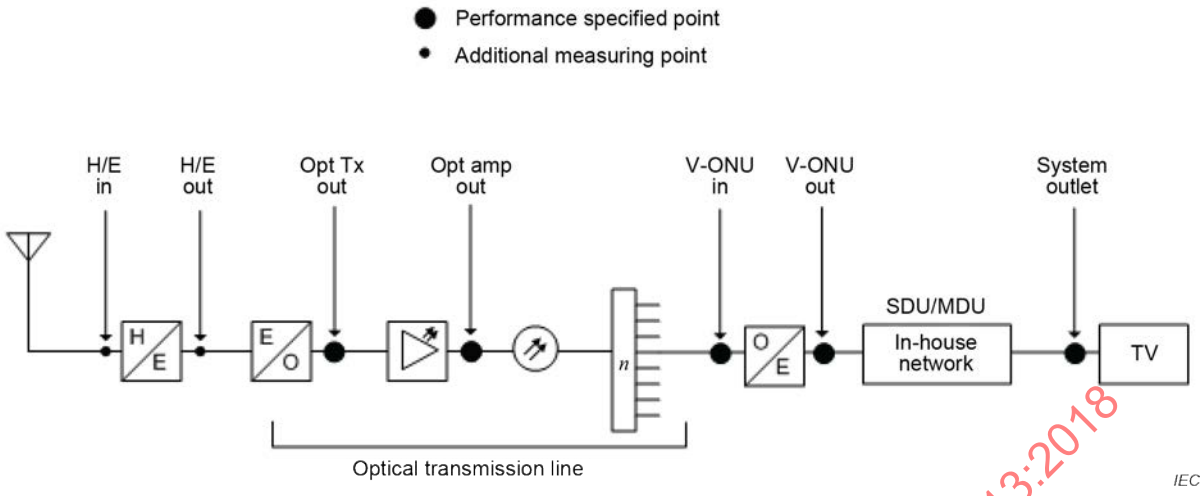

Figure 18 – Performance specified points

Table 8 – Minimum S/N ratio (SDU case)

Broadcast signal			S/N at H/E output	S/N at optical transmission line	S/N at V-ONU output	S/N at in-house network interface	S/N at system outlet
System	Modulation	Sub-carrier	dB	dB	dB	dB	dB
ISDB-T	OFDM	64 QAM	27	30	25	45	24
ISDB-C (J.83)	64 QAM	–	35	28	27	45	26
	256 QAM	–	43	37	36	51	34
ISDB-C2 (J.382)	OFDM	256 QAM	35	28	27	45	26
		1 024 QAM	42	36	35	51	33
		4 096 QAM(4/5)	46	39	38	53	37
		4 096 QAM(5/6)	49	42	41	55	40
DVB-T	COFDM	64 QAM	27	–	25	–	24
DVB-T2	COFDM	256 QAM	33	–	31	–	30
DVB-C	64 QAM	–	36	–	29	–	28
	256 QAM	–	42	–	35	–	34
DVB-C2	COFDM	256 QAM	35	–	29	–	28
		1 024 QAM	42	–	35	–	34
		4 096 QAM(5/6)	46	–	38	–	37
		4 096 QAM(9/10)	49	–	41	–	40

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Table 9 – Minimum S/N ratio (MDU case)

Broadcast signal			S/N at H/E output	S/N at opt transmission line	S/N at V-ONU output	S/N at in-house network interface	S/N at system outlet
System	Modulation	Sub-carrier	dB	dB	dB	dB	dB
ISDB-T	OFDM	64 QAM	27	30	25	33	24
ISDB-C (J.83)	64 QAM	–	35	28	27	33	26
	256 QAM	–	43	37	36	39	34
ISDB-C2 (J.382)	OFDM	256 QAM	35	28	27	33	26
		1 024 QAM	42	36	35	39	33
		4 096 QAM(4/5)	46	42	40	41	37
		4 096 QAM(5/6)	49	45	44	43	40
DVB-T	COFDM	64 QAM	27	–	25	–	24
DVB-T2	COFDM	256 QAM	33	–	31	–	30
DVB-C	64 QAM	–	36	–	29	–	28
	256 QAM	–	42	–	35	–	34
DVB-C2	COFDM	256 QAM	35	–	29	–	28
		1 024 QAM	42	–	35	–	34
		4 096 QAM(5/6)	46	–	38	–	37
		4 096 QAM(9/10)	49	–	41	–	40
An appropriate optical level at the V-ONU input shall be chosen in the system design for MDU and SDU systems in the in-house network. NOTE All the values indicate the minimum requirement.							

Table 10 shows minimum RF signal-to-noise ratio requirement for broadcast systems that are applicable to this document.

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Table 10 – Minimum RF signal to noise ratio requirements in operation

System	Mode	Code rate	Minimum RF signal-to-noise ratio at headend input dB	Minimum RF signal-to-noise ratio at system outlet dB	
DVB-C	16 QAM		25,9	19 [a]	
	64 QAM		31,9	25 [a]	
	256 QAM		37,9	31 [a]	
DVB-C2	16 QAM	4/5	u.c.	13	
		9/10	u.c.	15	
	64 QAM	2/3	u.c.	16	
		4/5	u.c.	18	
		9/10	u.c.	21	
	256 QAM	3/4	u.c.	22	
		5/6	u.c.	24	
		9/10	u.c.	27	
	1 024 QAM	3/4	u.c.	28	
		5/6	u.c.	31	
		9/10	u.c.	33	
	4 096 QAM	5/6	u.c.	40	
		9/10	u.c.	42	
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	2Kmode	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
	64 QAM [b]		2K mode and 8K mode	2Kmode	8K mode
		1/2	17,4	16,1	16,3
		2/3	20,0	19,0	19,2
		3/4	21,6	20,7	20,9
		5/6	23,3	22,5	22,6
		7/8	24,5	23,8	23,9
DVB-T2 COFDM	QPSK		LDPC b. l.: 64 800 bits [c]	LDPC b.l. 16 200 bits	LDPC b. l.: 64 800 bits
		1/2	5,2	4,2	4,4
		3/5	6,5	5,5	5,7
		2/3	7,4	6,4	6,6
		3/4	8,4	7,4	7,6
		4/5	9,1	8,1	8.3
		5/6	9,6	8,6	8,8
	16 QAM		LDPC b. l.: 64 800 bits [c]	LDPC b.l. 16 200 bits	LDPC b. l.: 64 800 bits
		1/2	10,2	9,2	9,4
		3/5	11,8	10,8	11,0
		2/3	13,1	12,1	12,3

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System	Mode	Code rate	Minimum RF signal-to-noise ratio at headend input dB	Minimum RF signal-to-noise ratio at system outlet dB	
		3/4	14,4	13,4	13,6
		4/5	15,2	14,2	14,4
		5/6	15,8	14,8	15,0
	64 QAM		LDPC b. l.: 64 800 bits [c]	LDPC b.l. 16 200 bits	LDPC b. l.: 64 800 bits
		1/2	14,2	13,2	13,4
		3/5	16,3	15,3	15,5
		2/3	17,8	16,8	17,0
		3/4	19,4	18.4	18,6
		4/5	20,6	19,6	19,8
		5/6	21,2	20,2	20,4
	256 QAM		LDPC b. l.: 64 800 bits [c]	LDPC b.l. 16 200 bits	LDPC b. l.: 64 800 bits
		1/2	17,6	16,6	16,8
		3/5	20,3	19,3	19,5
		2/3	22,1	21,1	21,3
		3/4	24,3	23,3	23,5
		4/5	25,7	24,7	24,9
		5/6	26,4	25,4	25,6
ISDB-C (J.83)	64 QAM		35	26	
	256 QAM		43	34	
ISDB-T (OFDM)	64 QAM	3/4	(27) [d]	24	
ISDB-C2 (J.382) (OFDM)	256 QAM [c]	3/4 5/6 9/10	35	26	
	1 024 QAM [c]	3/4 5/6 9/10	42	33	
	4 096 QAM [c]	4/5	46	37	
	4 096 QAM [c]	5/6	49	40	

[a] The above values take simultaneous distribution of digital signals into account. These values assume that intermodulation noise is not present or can be neglected and a BER of 10^{-4} before the 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 white noise and impulse noise into account.

[c] *These values are calculated according to ETSI TS 102 991 document Table 4 and 18 and are intended for* 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.

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7.2 Relationship between RIN and S/N

Table 11 show types of broadcast services and recommended relative carrier level. For the combination of digital signals in actual system design, Annex A should be taken into account.

The optical sub-carrier modulation index depends on the number of sub-carriers and its relative carrier level. In Europe, various kinds of channel allocations with different system/modulation constellations (different modulations selected, different number of carriers per modulation selected) are used. For a given channel allocation, the optical sub-carrier modulation index OMI_k can be calculated in dependence of the total numbers n_i of each sub-carrier type i= 1, 2, ... N and the relative carrier level l_i of each sub-carrier type:

$$OMI_k = \frac{OMI_{tot} \cdot 10^{l_k/20}}{\sqrt{\sum_{i=1}^{N} n_i \cdot 10^{l_i/10}}} \quad (11)$$

Table 11 – Types of broadcast services and relative carrier level

Broadcast Signal			(Recommended) relative carrier level *l* dB
System	**Modulation**	**Sub-carrier**	
DVB-T	COFDM	64 QAM (2/3)	−10
ISDB-T	OFDM	64 QAM (2/3)	−6
DVB-T2	COFDM	256 QAM (2/3)	−5
DVB-C / ISDB-C	64 QAM	—	−6
	256 QAM	—	0
DVB-C2	COFDM	256 QAM	−6
		1 024 QAM	0
		4 096 QAM(4/5)	+3
		4 096 QAM(9/10)	+6
ISDB-C2	OFDM	256 QAM	−6
		1 024 QAM	0
		4 096 QAM(4/5)	+2
		4 096 QAM(5/6)	+4
Transmission bandwidth: 47 MHz to 862 MHz (in the case of a European system)			

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The performance of the transmission system can be expressed by the relative intensity noise (RIN) of the optical signal at the V-ONU input, and by the S/N of the electrical signal at the V-ONU output. 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 D. RIN values required for the two service types are shown in Table 12. The intensity modulation method is used for all service types.

Table 12 – Type of service and minimum operational RIN values

Type of service	**Minimum V-ONU input level** dB(mW)	**Minimum system RIN value** dB(Hz^{-1})	**Corresponding S/N value** dB
Multi-channel service	−12	−146	28
Re-transmission service	−5	−134	44
	−8	−134	44
	−10	−136	44

As a general approach, it is recommended to equalize the noise contribution of the optical receiver on the one side and noise contribution caused by the headend, optical transmitter and optical fibre effects on the other side. Both noise effects together shall result in the minimum S/N_{min} given by Table 8 and Table 9.

$$S/N_{\text{V-ONU},k} \geq S/N_{\text{min},k} + 3\ \text{dB} \quad (12)$$

$$10 \cdot \lg\left(\frac{(OMI_k)^2}{2 \cdot RIN_{\text{V-ONU-In},k} \cdot B_N}\right) \geq S/N_{\text{min},k} + 3 \text{ dB} \quad (13)$$

Then, RIN at the V-ONU optical receiver input can be calculated as follows.

$$RIN_{\text{V-ONU-In},k} \leq 10 \cdot \lg\left(\frac{(OMI_k)^2}{4 \cdot B_N}\right) - S/N_{\text{min},k} \quad (14)$$

The requirement for the V-ONU noise results from Equation (15). The equation contains both the optical input power and the optical receiver's characteristic. With known characteristics and required minimum S/N_{min} of Table 8 and Table 9, Equation (15) can be solved for the minimum required optical input power P_r.

$$S/N_{\text{V-ONU},k} = 10 \cdot \lg\left(\frac{1}{B_N} \cdot \frac{(OMI_k \cdot R \cdot P_r)^2}{2 \cdot e \cdot (I_{do} + R \cdot P_r) + I_{eq}^2}\right) \geq S/N_{\text{min},k} + 3 \text{ dB} \quad (15)$$

where

OMI_k is the modulation index of the k-th RF signal;

R is the optical-electrical conversion efficiency of an optical receiver device;

P_r is the optical input power, expressed in W;

B_N is the noise bandwidth (64 QAM, 256 QAM: 5,3 × 10^6 Hz);

e is the charge of an electron (1,602 × 10^{-19} C);

I_{d0} is the dark current of the optical receiver device, expressed in A;

I_{eq} is the equivalent input noise current density of an optical receiver, expressed in A/$\sqrt{\text{Hz}}$.

7.3 Optical wavelength

In accordance with ITU-T Recommendation G.983.3, a wavelength within the range of 1 555 nm ± 5 nm is recommended for the combination of a broadcast and a telecommunication system over a single fibre. For DWDM systems, wavelengths in accordance with 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 wavelength, the wavelength range of 1 530 nm to 1 625 nm (edge of C-band and L-band of ITU-T Recommendation G.694.2) can be used for actual and economical video transmission.

7.4 Frequency of source signal

The frequency range of source signals considered here is 85 MHz to 1 006 MHz. However, regional frequency plans can be used for the operating frequency range of the optical system.

7.5 Level difference between adjacent channels

The difference in level between adjacent channels (of equal channel bandwidth) shall be less than 10 dB.

The permissive signal level difference between adjacent channels shall be kept as shown in Figure 19 (in the case of Japan).

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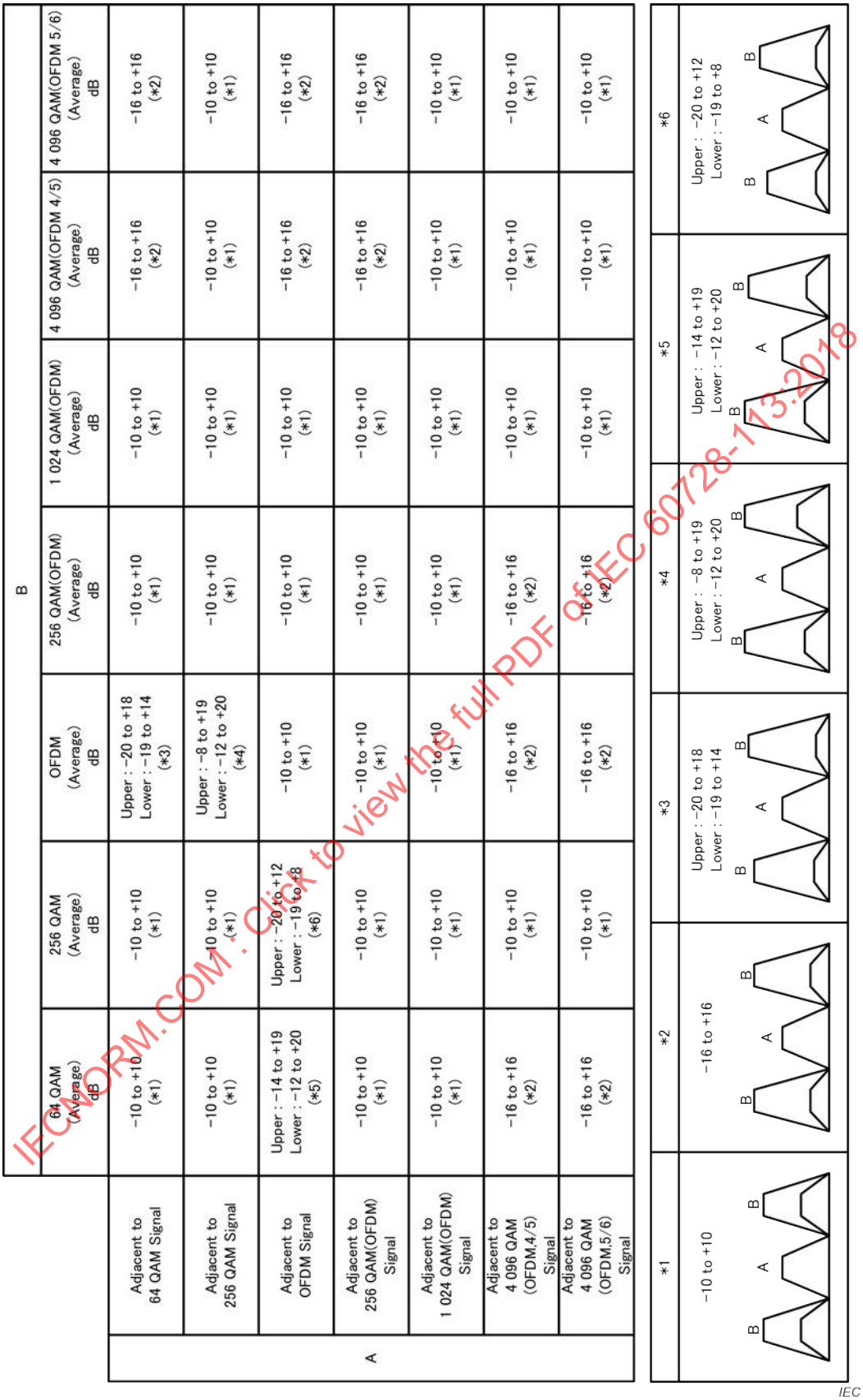

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Figure 19 – Permissible signal level of adjacent channels (in the case of Japan)

7.6 BER at headend input

The BER at the headend inputs shall not exceed the following values:

- COFDM signals (LDPC decoding): BER < 1×10^{-4}
- (Single) QAM signals (block decoding): BER < 1×10^{-10}

7.7 MER

The MER shall be measured averaged for at least 1 000 symbols. In the case of COFDM, the average MER over all data sub-carriers shall be measured.

The MER is recommended to be at least 2 dB better than the specified S/N.

7.8 S/N specification for in-house and in-building wirings

The S/N can be specified at the output of a V-ONU instead of the system outlet if the performance of the in-house/in-building wiring section is maintained properly. Based on current installation methods, the S/N for the in-house/in-building wiring section is specified in Table 13. The S/N ratio values for Multiple Dwelling Unit (MDU) are shown in Figure 20 (specified by electrical signal) and Figure 21 (specified by optical signal).

Table 13 – Section S/N ratio for in-house/in-building wiring (Japan)

Category of house	Method of distribution	Minimum S/N ratio for in-house/ in-building wiring						
		Terrestrial (OFDM)	64 QAM	256 QAM	OFDM (256 QAM)	OFDM (1 024 QAM)	OFDM (4 096 QAM, 4/5)	OFDM (4 096 QAM, 5/6)
Single Dwelling Unit (SDU)	O/E conversion at entrance or inside of SDU, coaxial cable distribution to TV set	45 dB	45 dB	51 dB	45 dB	51 dB	53 dB	55 dB
Multiple Dwelling Unit (MDU)	O/E conversion at MDU entrance, coaxial cable distribution to TV set (Figure 20)	33 dB	33 dB	39 dB	33 dB	39 dB	41 dB	43 dB
	O/E conversion at each home entrance, coaxial cable distribution to TV set (Figure 21)	33 dB	33 dB	39 dB	33 dB	39 dB	41 dB	43 dB

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Note that the section S/N is not a requirement for the IEC 60728-1 home-network interface, but a practical specification for the RF amplifier that is built into the optical receiver of the RF wavelength of the PON.

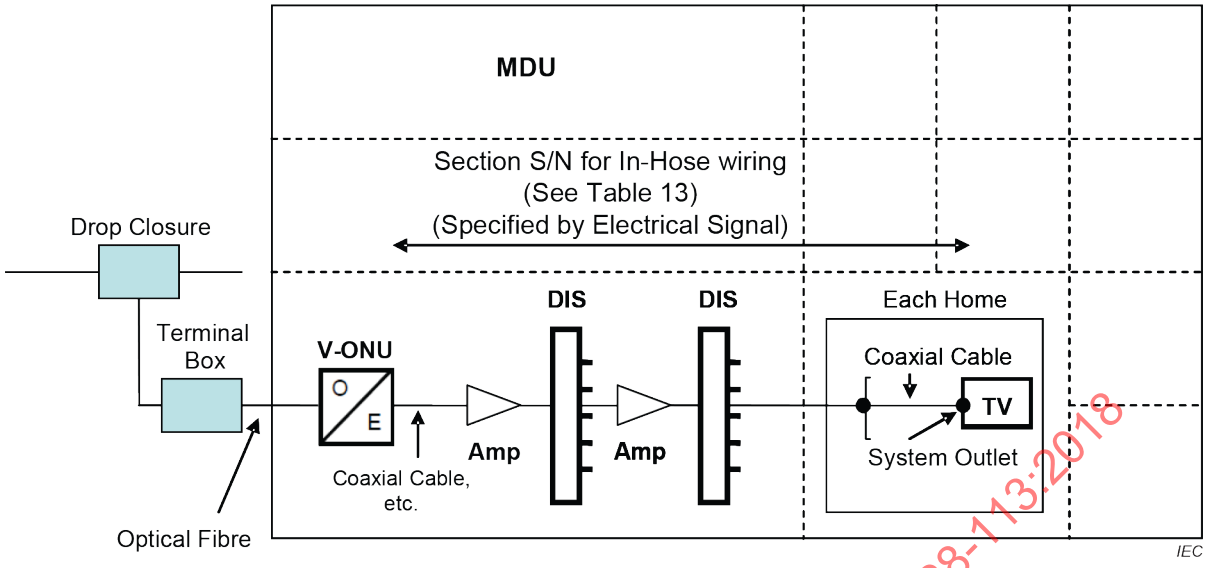

Figure 20 – Section S/N for MDU wiring (specified by electrical signal)

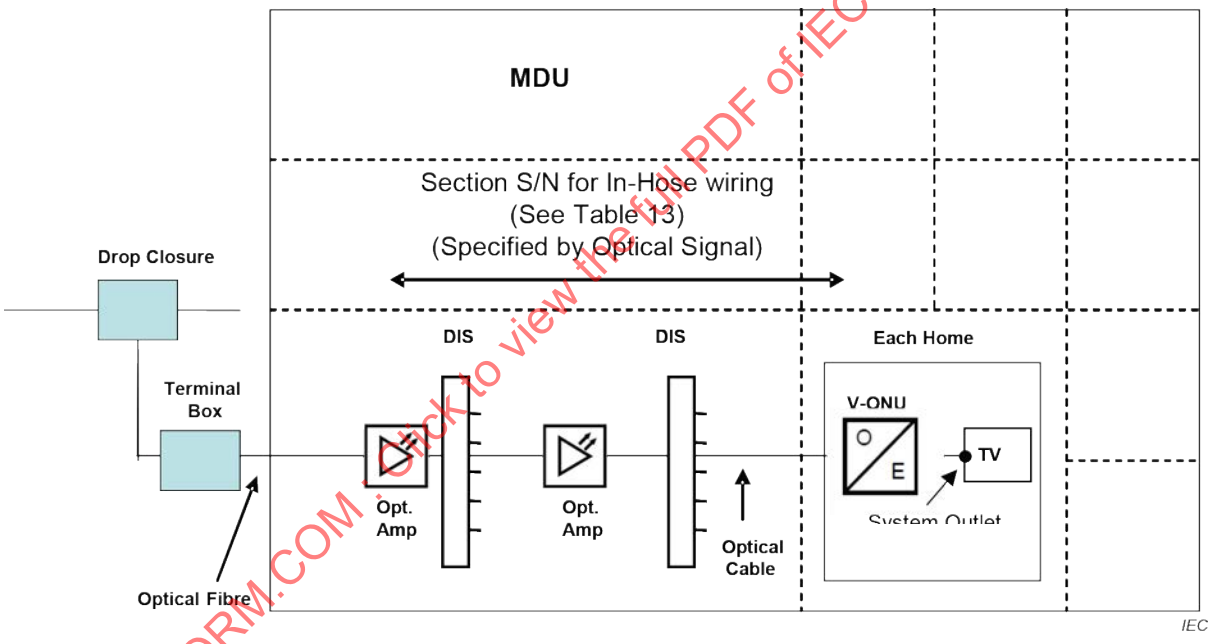

Figure 21 – Section S/N for MDU wiring (specified by optical signal)

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7.9 Electrical signal interference

Table 14 presents limits for several in-channel electrical signal interference types.

Table 14 – Limits for in-channel electrical signal interference

Broadcast signal			Multi frequency interference	Single frequency interference	Signal reflection
System	Modulation	Sub-carrier			
ISDB-T	OFDM	64 QAM (2/3)	See Figure 22 (3rd)	35 dB	See Figure 23
ISDB-C	64 QAM	–	See Figure 24 (3rd)	26 dB	See Figure 26
	256 QAM	–	See Figure 25 (3rd)	34 dB	See Figure 27
ISDB-C2	OFDM	256 QAM	26dB	33 dB	See Figure 26
		1 024 QAM	33dB	39 dB	
		4 096 QAM(4/5)	37dB	39 dB	
		4 096 QAM(5/6)	40dB	40 dB	
DVB-T	COFDM	64 QAM (2/3)	27 dB	u.c.	Max. –15 dB echo amplitude Max. 1,5 µs echo delay
DVB-T2	COFDM	256 QAM (2/3)	27 dB	u.c.	
DVB-C	64 QAM	–	33 dB	u.c.	
	256 QAM	–	39 dB	u.c.	
DVB-C2	COFDM	256 QAM	27 dB	u.c.	
		1 024 QAM	27 dB	u.c.	
		4 096 QAM (5/6,9/10)	27 dB	u.c.	

Interference by 3rd order intermodulation product for OFDM, 64 QAM and 256 QAM broadcast signals shall be below the mask of Figure 22, Figure 24 and Figure 25, respectively.

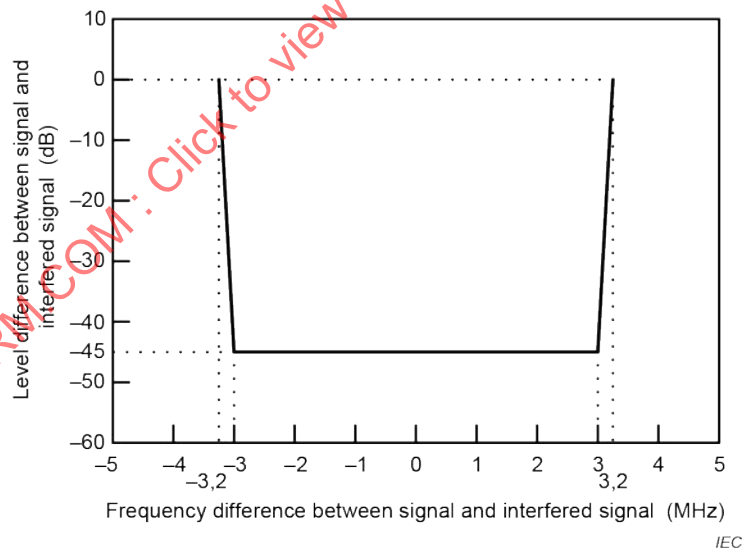

Figure 22 – Signal level difference with 3rd order interference signal (ISDB-T)

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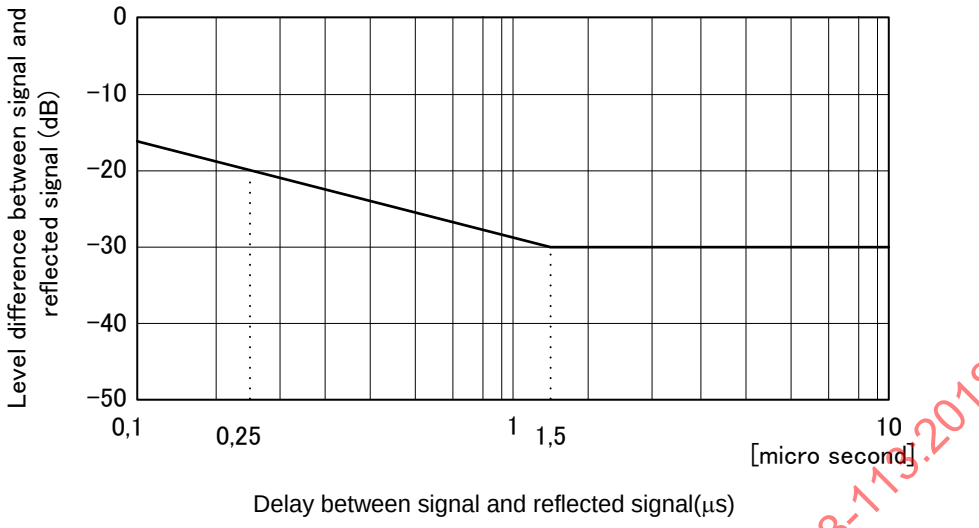

Figure 23 – Level difference between signal and reflected (echo) signal (ISDB-T)

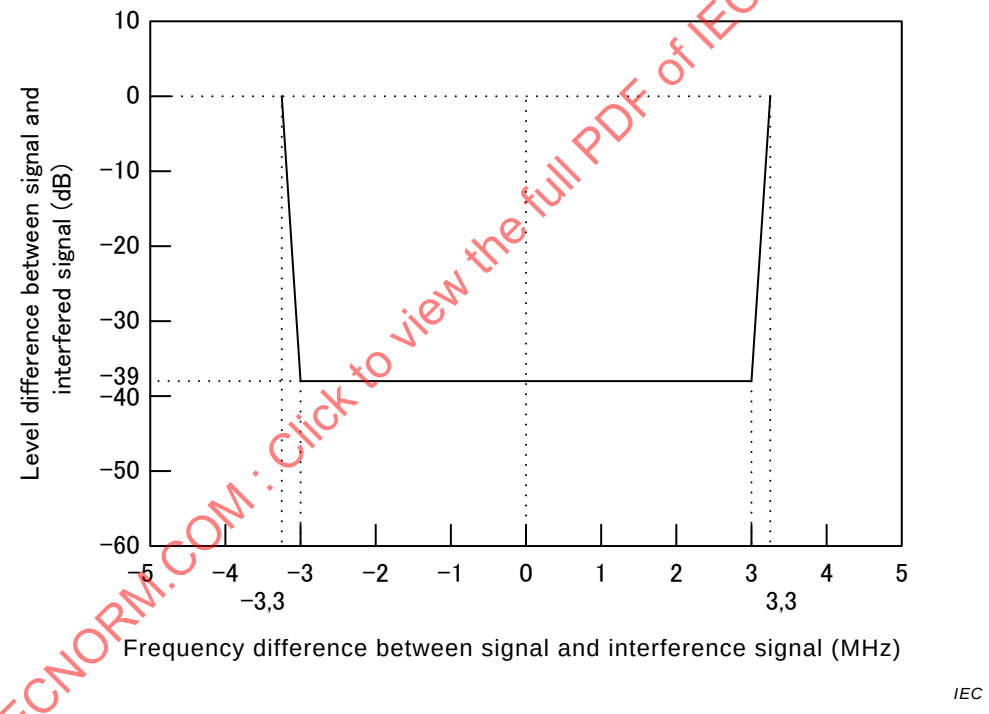

Figure 24 – Signal level difference with 3rd order interference signal (ISDB-C 64 QAM)

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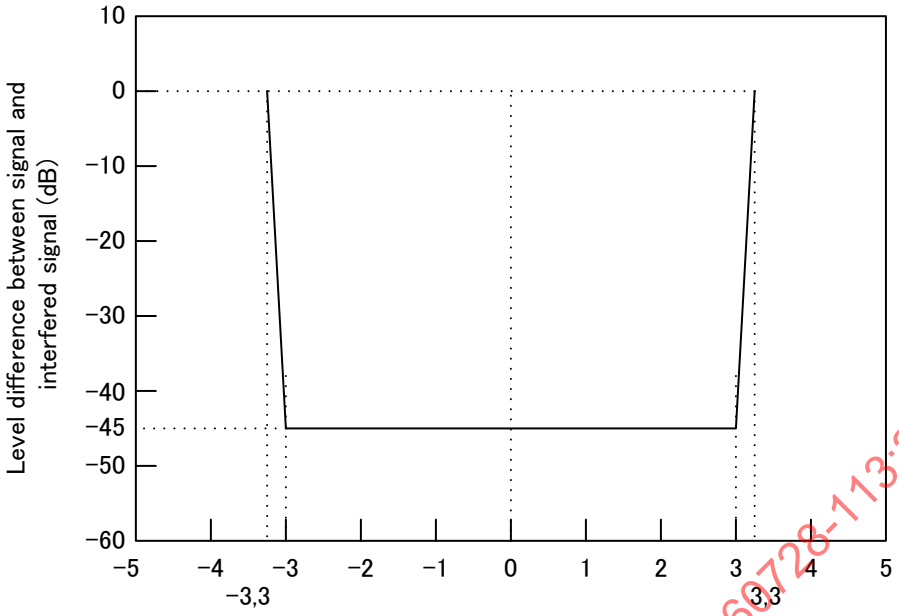

Figure 25 – Signal level difference with 3rd order interference signal (ISDB-C 256 QAM)

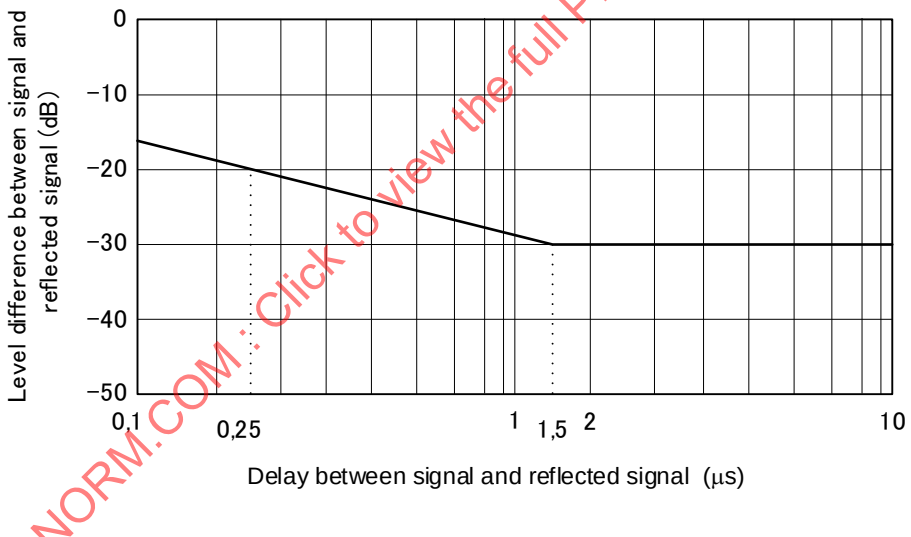

Figure 26 – Level difference between signal and reflected (echo) signal (ISDB-C 64 QAM, ISDB-C2 256 QAM to 4 096 QAM)

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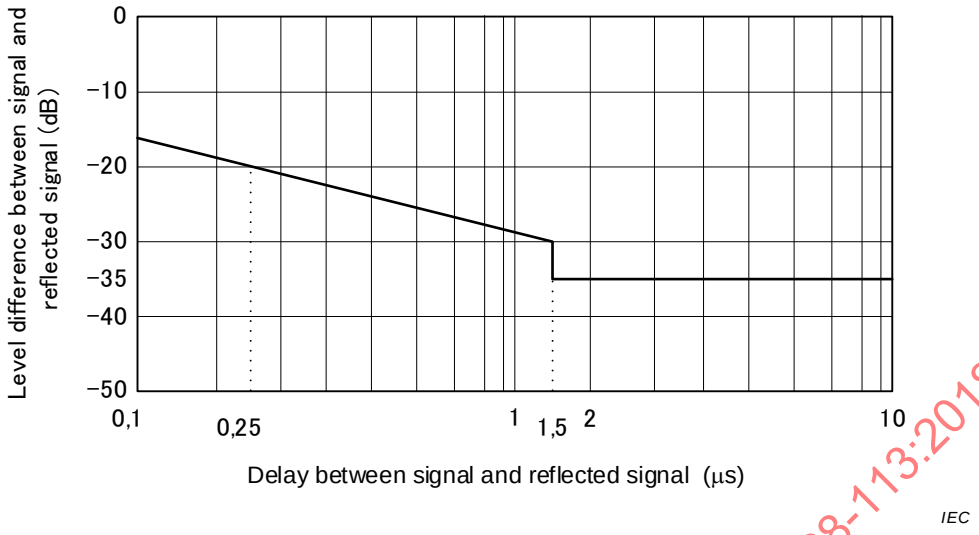

Figure 27 – Level difference between signal and reflected (echo) signal (ISDB-C 256 QAM)

7.10 Crosstalk due to optical fibre non-linearity

In a hybrid WDM transmission system in which broadcast signals and telecommunication signals are both incorporated, crosstalk between the two signals due to optical fibre non-linearity shall be taken into consideration. As described in Clause C.2, important parameters of optical crosstalk are stimulated Raman scattering (SRS), self-phase modulation (SPM), and cross-phase modulation (XPM). Among these parameters, 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 %/signal; the 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 C contains additional descriptions of SRS.

NOTE 2 Refer to Clause A.4 for the description of the optical modulation index and the number of combinations of digital signals.

7.11 Interference due to intermodulation noise caused by fibre non-linearity

Interference level due to intermodulation noise caused by fibre non-linearity shall meet the values shown in Table 15. All the parameters of optical broadcast transmission systems shall be set appropriately to satisfy the interference level. The measurement point shall be point (6) shown in Figure 3.

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Table 15 – Interference level due to fibre non-linearity

System	Modulation	Sub-carrier (code rate)	D/U ratio dB
ISDB-T	OFDM	64 QAM	More than 35
ISDB-C	64 QAM	—	More than 26
(J.83)	256 QAM	—	More than 34
ISDB-C2	OFDM	256 QAM	More than 33
(J.382)		1 024 QAM	More than 39
		4 096 QAM(4/5)	More than 39
		4 096 QAM(5/6)	More than 40

7.12 Environmental conditions

Equipment used for FTTH systems shall meet the environmental condition requirements of Table 16.

Table 16 – 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 [a] [b]
Humidity (%)	20 to 90	20 to 90	20 to 90	20 to 100

[a] To be applied in normal climate conditions in extra-tropical zones, not in extremely cold and hot temperatures. Refer to IEC 60068-1 and ETSI 3000019-1-4 when used in other climate conditions.

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

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Annex A
(informative)

Actual service systems and design considerations

A.1 General

This annex describes actual service system and design consideration based on the specification described in this document.

Many CATV operators currently provide multi-channel services and re-transmission services for digital broadcasting. Since the actual number of signals in CATV network varies, this annex describes a reference model for the multi-channel services and re-transmission services over an optical network.

A.2 Multi-channel service system

A.2.1 General

This model has in total 112 digital signals (6 MHz bandwidth) over the 90 MHz to 770 MHz cable system, comprising 12 signals for ISDB-T, 56 signals for 64 QAM, 20 signals for 256 QAM and 24 signals for 4 096 QAM (OFDM, 4/5).

The system size of CATV multi-channel services is mostly from 1 500 to 340 000 terminals, the transmission line length is up to 20 km, and 4 stages of EDFA are provided for one million terminals. For a few thousand terminal systems only, the line length can be extended up to 40 km with up to three stages of EDFA. 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, the 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.

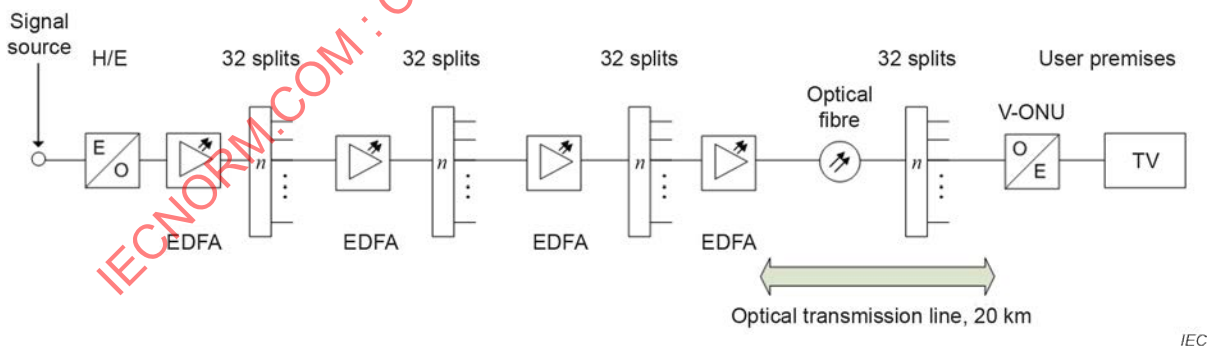

Figure A.1 – Example of a multi-channel service system of one million terminals

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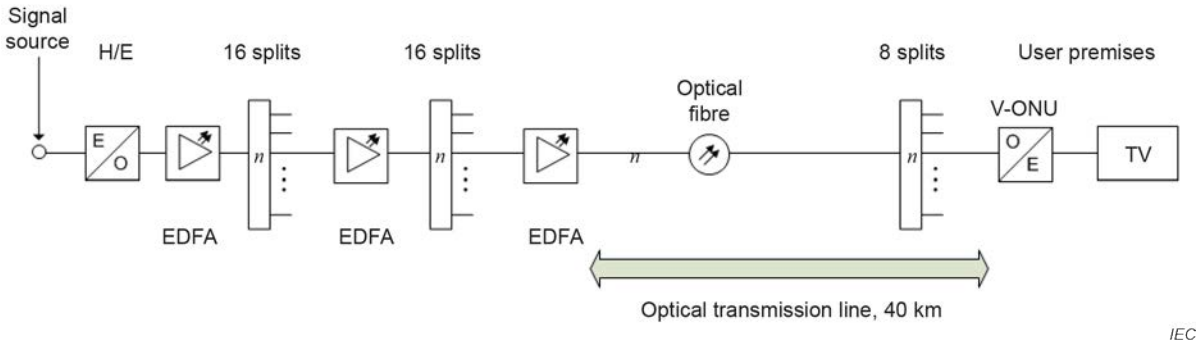

Figure A.2 – Example of a multi-channel service system of 2 000 terminals

A.2.2 Operating conditions

Table A.1 shows the operating condition for the multi-channel service system with its typical optical modulation index. The optical system uses the external intensity modulation method.

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

Service model	Modulation method	System	Number of signals	Typical optical modulation index (m_k)/signal
Multi-channel service system model	External intensity modulation		112 signals in total	Total modulation index:
			Composed of the following signals	Less than 30 %
		ISDB-T	12 signals, OFDM	2,5 %
		ISDB-C	56 signals, 64 QAM	2,5 %
		ISDB-C	20 signals, 256 QAM	5,0%
		ISDB-C2	24 signals, 4 096 QAM (OFDM, 4/5)	4,75%

In the case of 4 096 QAM (OFDM) signal transmission, the optical modulation index and the number of signals shall be carefully chosen in order to avoid optical clipping effects.

Refer to Annex F for a brief description on the origin of distortion due to clipping effects.

A.2.3 Operating environment

The optical transmitters and optical amplifiers are assumed to be installed in an office building as headend equipment with the following environmental conditions. V-ONUs are assumed to be installed indoors or outdoors, for instance, under eaves. Unless otherwise specified, the following range should be applied.

(1) Optical transmitter

- Ambient temperature 0 °C to +40 °C
- Humidity 20 % to 90 % without dew condensation[1]

(2) Optical amplifier

- Ambient temperature 0 °C to +40 °C
- Humidity 20 % to 90 % without dew condensation[1]

(3) V-ONU

- Ambient temperature −20 °C to +40 °C (outdoor installation)

[1] Except rising temperatures due to solar radiation.

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- Ambient temperature 0 °C to +40 °C (indoor installation)
- Humidity 20 % to 100 % without dew condensation[1]

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

A.3 Re-transmission service system

A.3.1 General

The re-transmission service system is a small-sized receiving facility of terrestrial digital broadcast signals. Twelve OFDM digital signals are assumed for the re-transmission service. In general, it has a transmission line of about 2 km with one EDFA. Figure A.3 and Figure A.4 show examples of system configurations for 72 terminals and 144 terminals, respectively.

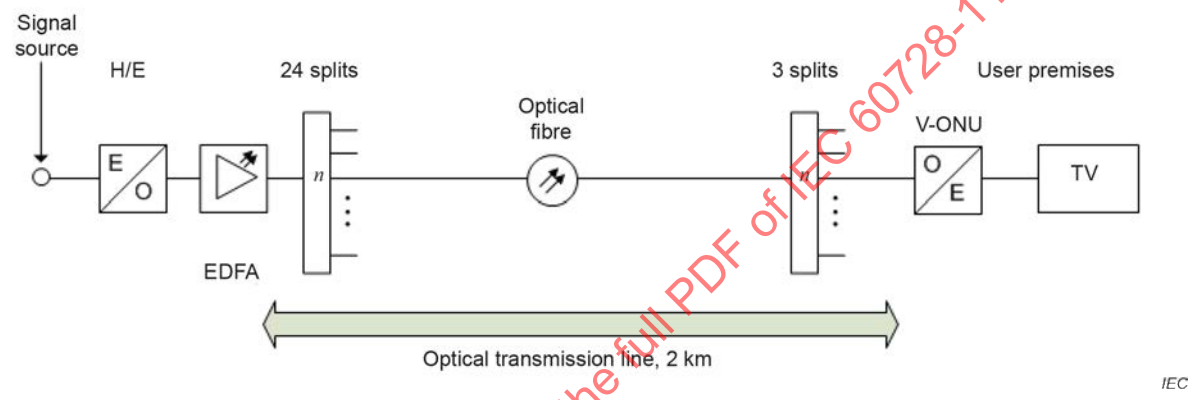

Figure A.3 – Example of re-transmission service system of 72 terminals

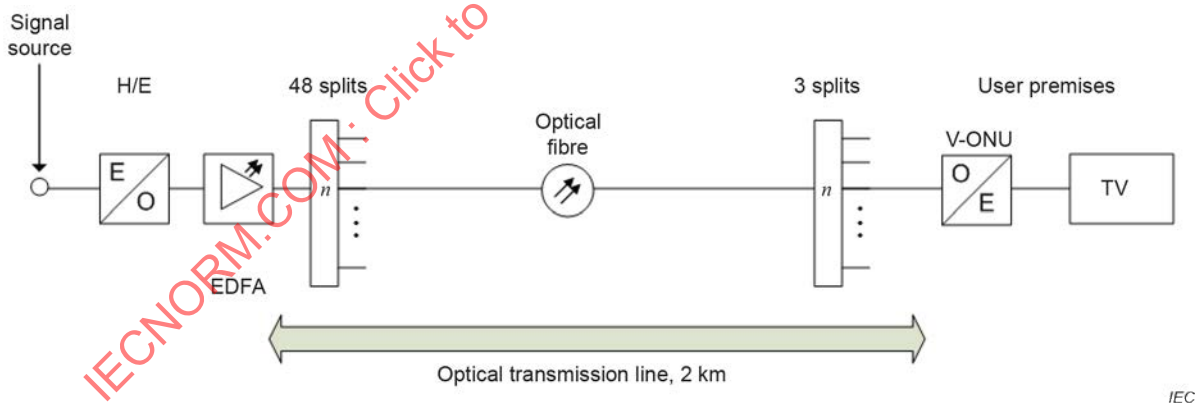

Figure A.4 – Example of re-transmission service system of 144 terminals

A.3.2 Operating conditions

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

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

Service model	System	Number of signals	Modulation method	Typical optical modulation index (m_k)/signal
Re-transmission service system	ISDB-T	12 signals (Terrestrial OFDM)	Direct intensity modulation	6,4 %

A.3.3 Operating environment

The optical transmitter and optical amplifier are assumed to be installed in an office building as headend equipment, with the following environmental conditions. V-ONUs are supposed to be installed indoors or outdoors, for instance, under eaves. Unless otherwise specified, the following ranges should be met.

(1) Optical transmitter

- Ambient temperature −20 °C to +40 °C
- Humidity 20 % to 90 % without dew condensation[2]

(2) Optical amplifier

- Ambient temperature −20 °C to +40 °C
- Humidity 20 % to 90 % without dew condensation[2]

(3) 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[2]

A.4 S/N ratio calculation of optical network

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

(1) RIN degradation by optical amplifier

RIN degradation by multi-stage connection of the optical amplifiers is given by Formula (A.1):

$$RIN_{\text{out}} = 10 \lg\left[\sum_{k} \frac{2 \cdot E \cdot 10^{NF_k/10}}{10^{P_k/10}} + 10^{RIN_{\text{in}}/10}\right] \quad \text{(A.1)}$$

where

RIN_{in} is the *RIN* at input of the first optical amplifier, expressed in dB(Hz^{-1});

RIN_{out} is the *RIN* at input of the k-th optical amplifier, expressed in 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, expressed in dB;

P_k is the optical input power of the k-th optical amplifier, expressed in dB(mW).

(2) S/N ratio in the case of intensity modulation system

[2] Except rising temperatures due to solar radiation.

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$$S/N = 10 \lg \left(\frac{1}{B_N} \cdot \frac{\frac{1}{2} \cdot \left(OMI_k \cdot R \cdot P_r \right)^2}{RIN \cdot \left(R \cdot P_r \right)^2 + 2 \cdot e \cdot \left(I_{d0} + R \cdot P_r \right) + I_{eq}^2} \right) [\text{dB}] \quad \text{(A.2)}$$

where

B_N is the noise bandwidth (64 QAM, 256 QAM: 5,3x10^6 Hz);

OMI_k is the optical modulation index of the k-th carrier;

R is the optical-electrical conversion efficiency of an optical receiver device;

P_r is the input optical power, expressed in W;

RIN is the relative intensity noise of optical input signal, expressed in $1/\sqrt{\text{Hz}}$;

e is the charge of an electron (1,602 × 10^{-19} C);

I_{d0} is the dark current of the optical receiver device, expressed in A;

I_{eq} is the equivalent input noise current density of an optical receiver, expressed in $\text{A}/\sqrt{\text{Hz}}$.

The total optical modulation index OMI_{total} depends on the optical modulation indexes OMI_k as shown in Formula (A.3):

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

where

K is the number of electrical channels;

OMI_k is the optical modulation index of the k-th carrier.

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.5 System reference model

Table A.3 summarizes the basic system parameters verified for multi-channel and re-transmission service systems. Examples of reference models are shown in Figure A.5 and Figure A.6.

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

Ref. model No.	Broadcast service	Number of terminals	Number of signals				Optical modulation index %/signal	Remark
			System	Type of modulation		Total		
Model 1	Multi-channel service	1 000 000	ISDB-T	OFDM	68	112	1,5	See Figure A5
			ISDB-C	64 QAM			1,5	
			ISDB-C	256 QAM	20		3,0	
			ISDB-C2	OFDM(4 096 QAM)	24		4,7	
Model 2		2 000	ISDB-T	OFDM	68	112	1,5	–
			ISDB-C	64 QAM			1,5	
			ISDB-C	256 QAM	20		3,0	
			ISDB-C2	OFDM(4 096 QAM)	24		4,7	
Model 3	Re-transmission service	72	ISDB-T	OFDM	12	12	6,4	–
Model 4		144	ISDB-T	OFDM	12	12	6,4	See Figure A6

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

(1) Multi-channel service system

- 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/$\sqrt{Hz}$
- V-ONU receiving device dark current (I_{d0}) 1,3 nA
- V-ONU optical-electrical conversion efficiency (R) 0,84 A/W

(2) Re-transmission service system

- 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/$\sqrt{Hz}$
- V-ONU receiving device dark current (I_{d0}) 1,0 nA
- V-ONU optical-electrical conversion efficiency (R) 0,9 A/W

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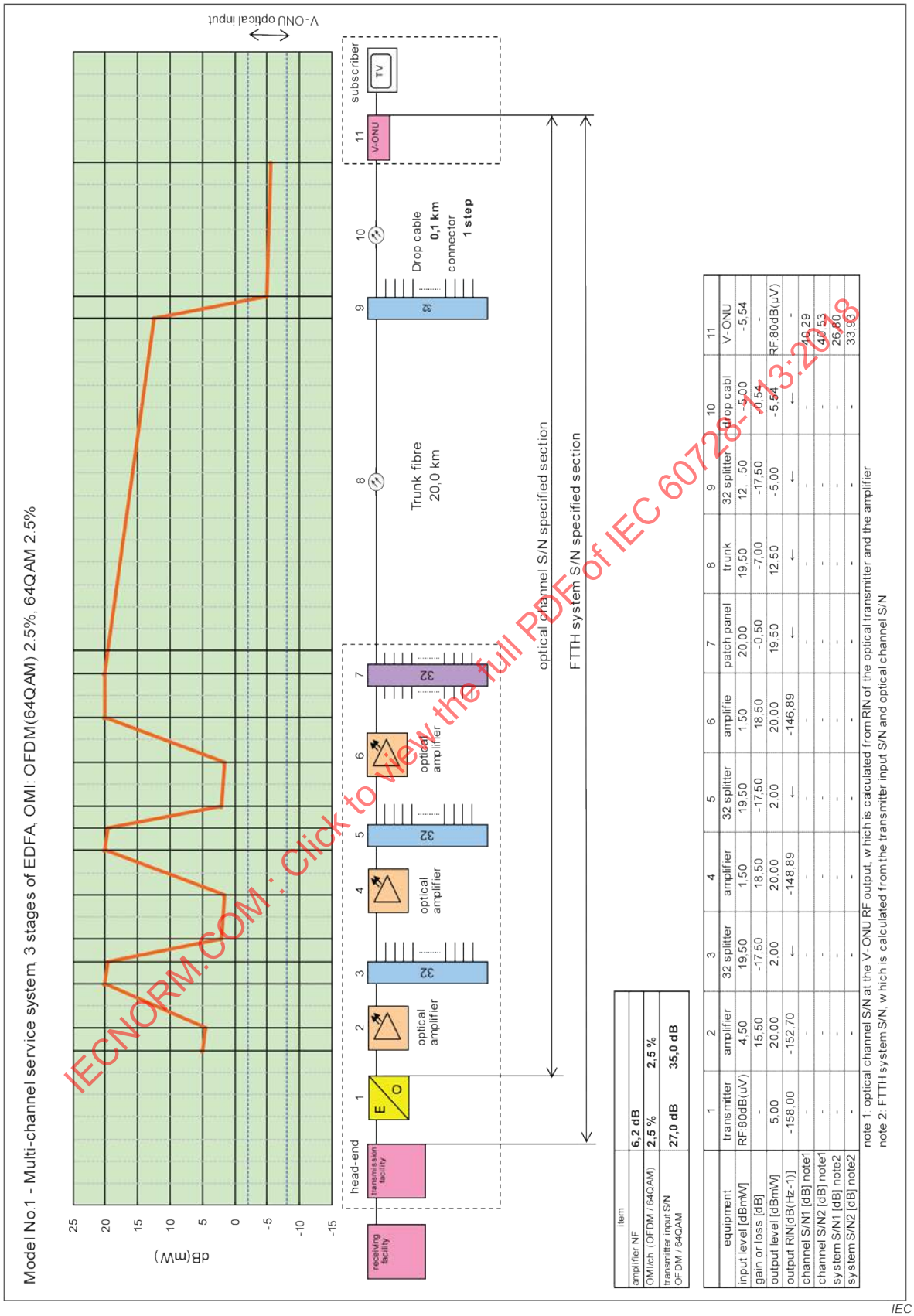

item	
amplifier NF	6,2 dB
OMI/ch (OFDM / 64QAM)	2,5 % 2,5 %
transmitter input S/N OFDM / 64QAM	27,0 dB 35,0 dB

	1	2	3	4	5	6	7	8	9	10	11
equipment	transmitter	amplifier	32 splitter	amplifier	32 splitter	amplifie	patch panel	trunk	32 splitter	drop cabl	V-ONU
input level [dBmW]	RF:80dB(uV)	4.50	19.50	1.50	19.50	1.50	20.00	19.50	12. .50	-5.00	-5.54
gain or loss [dB]	-	15.50	-17.50	18.50	-17.50	18.50	-0.50	-7.00	-17.50	-0.54	-
output level [dBmW]	5.00	20.00	2.00	20.00	2.00	20.00	19.50	12.50	-5.00	-5.54	RF:80dB(uV)
output RIN[dB(Hz-1)]	-158.00	-152.70	←	-148.89	←	-146.89	←	←	←	←	-
channel S/N1 [dB] note1	-	-	-	-	-	-	-	-	-	-	40.29
channel S/N2 [dB] note1	-	-	-	-	-	-	-	-	-	-	40.53
system S/N1 [dB] note2	-	-	-	-	-	-	-	-	-	-	26.80
system S/N2 [dB] note2	-	-	-	-	-	-	-	-	-	-	33.90

note 1: optical channel S/N at the V-ONU RF output, which is calculated from RIN of the optical transmitter and the amplifier
note 2: FTTH system S/N, which is calculated from the transmitter input S/N and optical channel S/N

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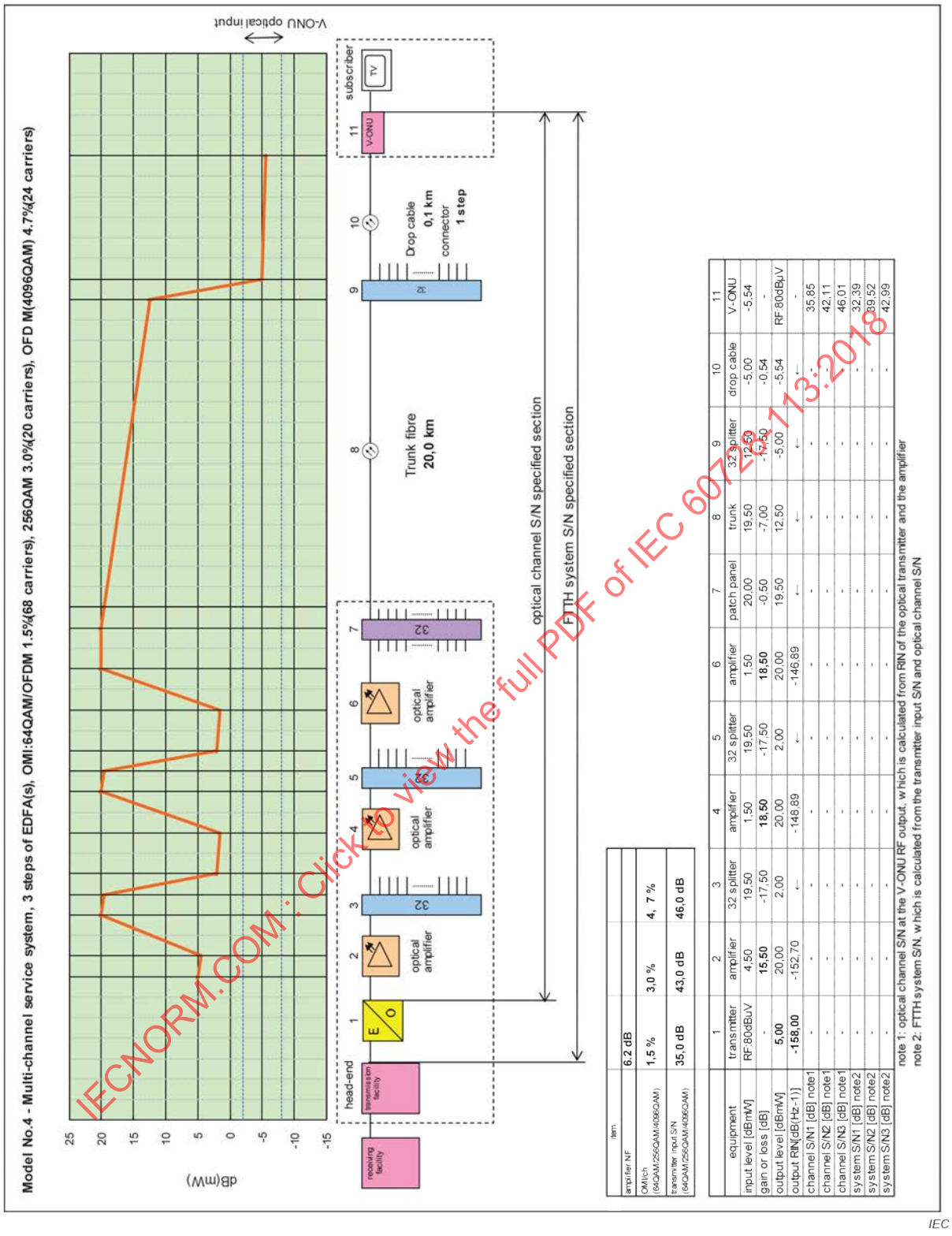
Figure A.5 – Model 1 system performance calculation



	1	2	3	4	5	6	7	8	9	10	11
equipment	transmitter	amplifier	32 splitter	amplifier	32 splitter	amplifier	patch panel	trunk	32 splitter	drop cable	V-ONU
input level [dBmV]	RF:80dBuV	4,50	19,50	1,50	19,50	1,50	20,00	19,50	-12,69	-5,00	-5,54
gain or loss [dB]	-	**15,50**	-17,50	**18,50**	-17,50	**18,50**	-0,50	-7,00	-17,50	-0,54	-
output level [dBmW]	**5,00**	20,00	2,00	20,00	2,00	20,00	19,50	12,50	-5,00	-5,54	RF:80dBµV
output RIN[dB(Hz-1)]	**-158,00**	-152,70	←	-148,89	←	-146,89	←	←	←	←	-
channel S/N1 [dB] note1	-	-	-	-	-	-	-	-	-	-	35,85
channel S/N2 [dB] note1	-	-	-	-	-	-	-	-	-	-	42,11
channel S/N3 [dB] note1	-	-	-	-	-	-	-	-	-	-	46,01
system S/N1 [dB] note2	-	-	-	-	-	-	-	-	-	-	32,39
system S/N2 [dB] note2	-	-	-	-	-	-	-	-	-	-	89,52
system S/N3 [dB] note2	-	-	-	-	-	-	-	-	-	-	42,99

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Figure A.6 – Model 4 system performance calculation

A.6 Hints for actual operation

A.6.1 Optimum operation

This clause describes neither a system performance nor device parameters, but the systems shall be optimized with the number of transmit channels, modulation indexes as long as they satisfy the permissible ranges of RIN, NF, S/N ratio and the interferences described in this

document. Combined operation can be allowed with different modulated signals that have own modulation indexes, if the system performance is well maintained.

A.6.2 Key issues to be specified

The key issues with respect to the design of an optical system and the operating conditions are as follows.

a) Optical wavelength

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

b) Optical modulation system

In systems for re-transmission service direct intensity modulation is used due to its short trunk line length. For multi-channel service systems usually external intensity modulation transmitters are employed in order to bridge long spans (up to approx. 40 km). In the case of short spans in a multi-channel service system, direct intensity modulation can also be utilized.

c) Optical modulation index

Present optical transmitters in the market have the function to adjust the modulation index automatically according to the number of signals by its AGC function. As mentioned in A.6.1, the operation with other adequate modulation indexes can be allowed as long as the system performance is reached.

d) Distortion performance

Since it is difficult to describe system performance separately for the optical transmitter and the V-ONU, it is recommended to specify the performance with a pair of optical transmitters and V-ONUs. The distortion performance of the optical system can change its optical characteristics in actual operation. This factor is especially significant when direct intensity modulation is used in a 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

V-ONUs with AGC function detect the optical input level and control the electric power sum of the output signal. This document 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) S/N ratio (SNR)

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

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Annex B
(informative)

BER extrapolation method

This annex describes the extrapolation method of BER measurement. Unless the error correction can be turned off, mostly like LDPC error correction, it will generally take a very long time to measure low error conditions such as BER = 10^{-11} and the obtained data will fluctuate. In such a case, the extrapolation method can be applied as depicted in Figure B.1.

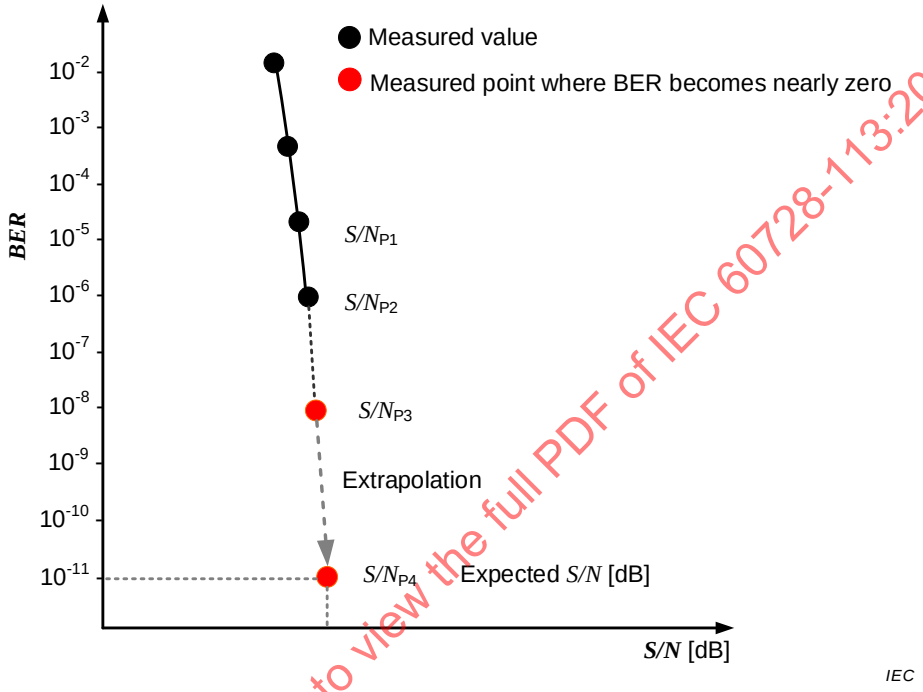

Figure B.1 – Extrapolation method of BER measurement

Expected S/N by extrapolation method

1) Get measured values for P1$(S/N)_1$, P2$(S/N)_2$ and P3$(S/N)_3$
2) Determine averaged slope between P1 and P2, between P2 and P3
3) Find P4$(S/N)_4$ where the line from BER=10^{-11} intercepts with the extrapolated Curve

The expected S/N at P4, $(S/N)_4$ can be expressed as follows

$$(S/N)_4 = 2 \cdot \frac{\lg(10^{-11}) - \lg(BER_3)}{\dfrac{\lg(BER_2) - \lg(BER_1)}{(S/N)_2 - (S/N)_1} + \dfrac{\lg(BER_3) - \lg(BER_2)}{(S/N)_3 - (S/N)_2}} + (S/N)_3$$

Where S/N and BER at P1, P2, P3 and P4 are $((S/N)_1, BER_1)$, $((S/N)_2, BER_2)$, $((S/N)_3, BER_3)$, $((S/N)_4, BER_4)$ respectively.

The obtained BER characteristics for 256 QAM, 1 024 QAM and 4 096 QAM signals by this method are shown in Figure B.2. The dotted line shows the extrapolation.

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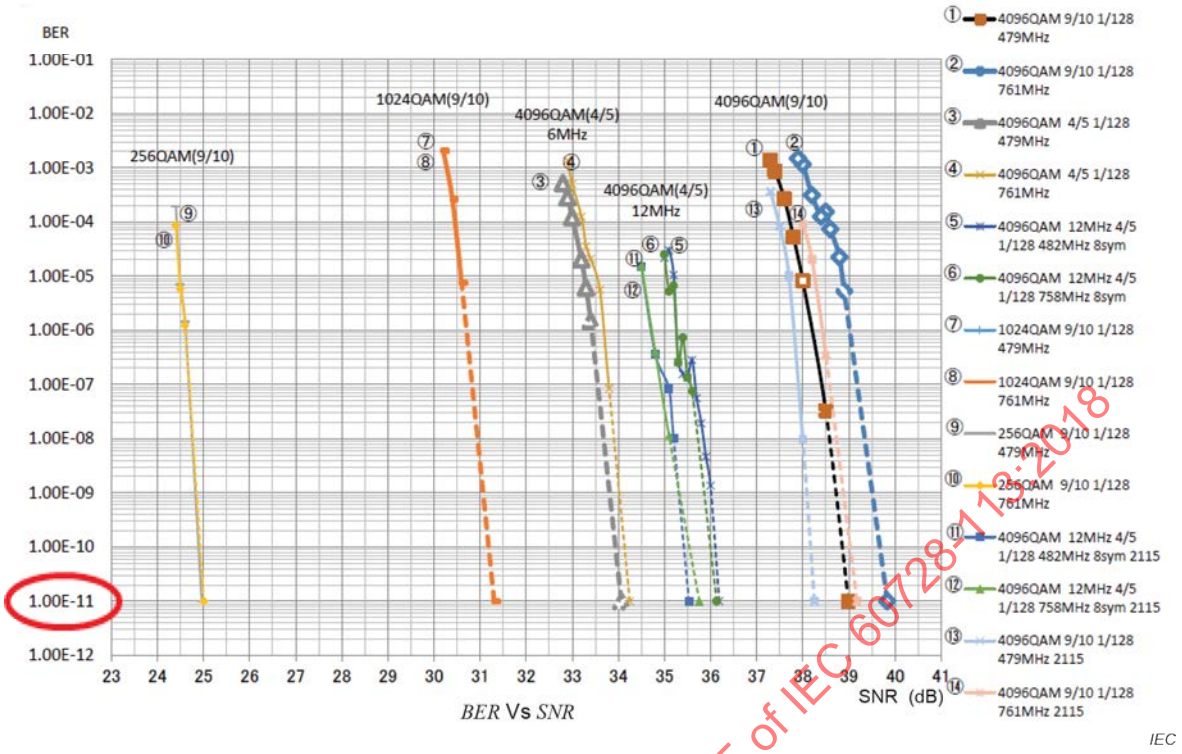

Figure B.2 – BER characteristics for 256 QAM, 1 024 QAM and 4 096 QAM (Extrapolation method)

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Annex C
(informative)

Optical system degradations

C.1 System degradation factors

The transmission quality of digital signals in telecommunication can be evaluated by BER. However, in the case of broadcast signals that contain a mixture of analogue and digital signals, the performance evaluation can include S/N ratio, BER, MER, signal distortion and subjective picture quality. Subjective picture quality evaluation is outside the scope of this document. Generally, a broadcast system should also consider various non-linear degradation factors due to higher optical level usage. Furthermore, in the case of a three-wavelength multiplex transmission system, no interference among services (video and data) can appear. With video transmission, the optical reflection over transmission line should be specifically considered as a keen degradation factor. Relative intensity noise (RIN) is used as a parameter for the noise property of optical signals. Although RIN originally describes the time fluctuations of laser power, it can also represent the noise caused by optical reflections in the system. Figure C.1 shows a transmission line with two reflection points. A beat arises between the twice-reflected light (delayed signal) and direct signal (original signal), resulting in noise.

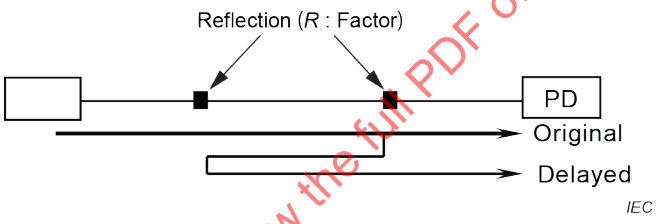

Figure C.1 – Reflection model

When the laser diode (LD) is directly modulated by the multi-channel signal, the additional RIN can be calculated as follows:

$$RIN_{\text{ref(f)}} = \frac{2\alpha R_1 R_2}{\sqrt{\pi \sigma_f}} \cdot \exp\left[-\frac{f^2}{4\sigma_f^2}\right] \quad \text{(C.1)}$$

where

R_1, R_2 is the reflective index for the first and the second reflection point;

α is the optical loss between the two reflection points;

σ_f is the optical frequency shift of the laser diode.

On a transmission line, reflection can occur at any point of the fibre connection or connector. For example, if in the observing point σ_f is set to 1,3 GHz, α to 5 dB, R_1 and R_2 to 40 dB each (in the case of normal polished Grade 2 Connectors of IEC 61755-1, the RIN obtained at f = 100 MHz will be −175 dB(Hz^{-1}). If R_1 and R_2 are 20 dB (in case of PC polish), the RIN will be −135 dB(Hz^{-1}). Therefore, in this case, the system will be deteriorated significantly. Generally, since RIN of an optical laser is about −160 dB(Hz^{-1}), the former Grade 2 Connectors of IEC 61755-1 polish case will cause no significant interference, while the latter PC polish case will affect the system performance. Therefore, in the case of CATV, Grade 2 Connectors of IEC 61755-1 are recommended, and it is better to use an angled-PC polish type having a reflection loss of 60 dB or more.

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C.2 Non-linear degradation

C.2.1 Degradation factors

Various degradation factors over an optical transmission system are shown in Figure C.2. Important parameters are stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), self-phase modulation (SPM), cross-phase modulation (XPM). These types of degradation are caused by a high-level optical power input into optical fibres. It is not enough to specify these parameters only for the optical transmitter or the optical receiver. As a total cable system, it is necessary to design complete systems with the appropriate optical power level, as described in Annex A.

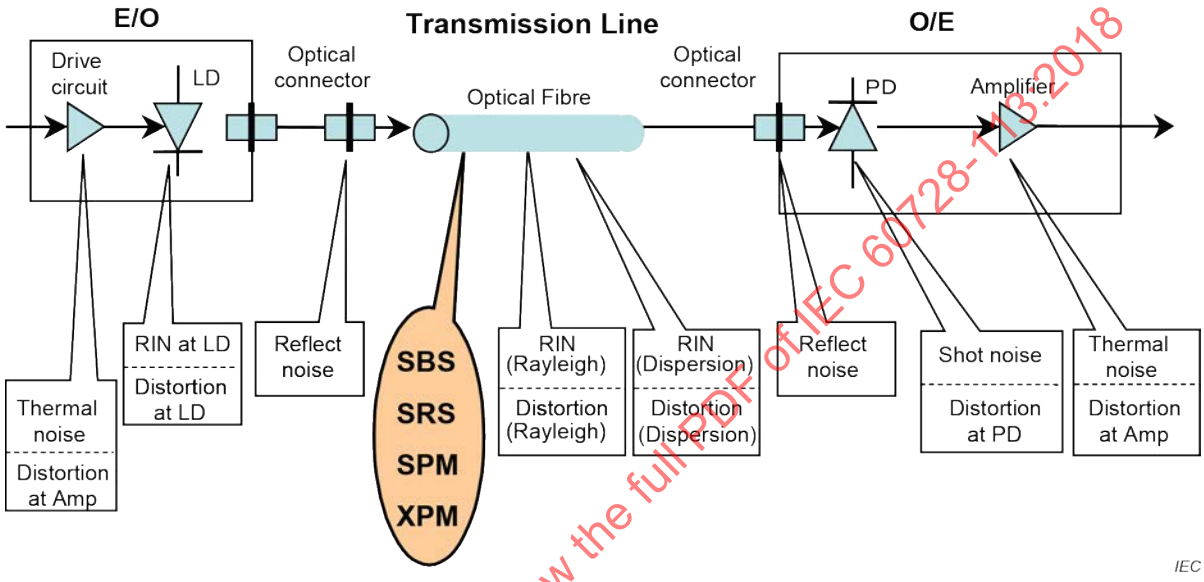

Figure C.2 – Degradation factors of optical transmission system

C.2.2 Stimulated Brillouin scattering (SBS)

SBS is a scattering effect of silica fibre due to its non-linear characteristics and caused by an excessive optical input power over some threshold. In this case, transmitted light cannot reach the receiving side but returns to the sending side. Figure C.3 shows an SBS generation image. In order to expand the threshold level range, a relaxing method of energy density is used by applying frequency modulation or phase modulation to the optical source of the transmitter. Currently a +20 dB(mW) power class is available as a maximum.

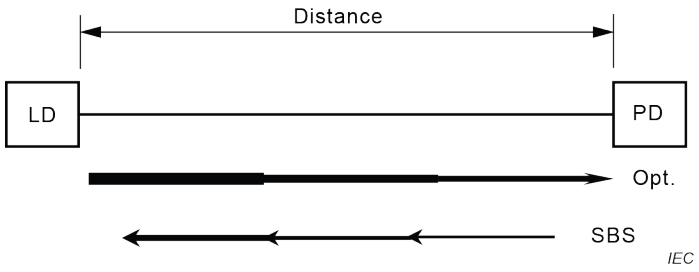

Figure C.3 – SBS generation image

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