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INTERNATIONAL STANDARD

colour inside

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

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

Part 13-1: Bandwidth expansion for broadcast signal over FTTH system

FOREWORD

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International Standard IEC 60728-13-1 has been prepared by technical area 5: Cable networks for television signals, sound signal and interactive services, of IEC technical committee 100: Audio, video and multimedia systems and equipment.

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

CDV	Report on voting
100/1801/CDV	100/1931/RVC

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

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

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

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

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- withdrawn,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

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

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

INTRODUCTION

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

This includes

- CATV networks,
- MATV networks and SMATV networks,
- individual receiving networks

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

NOTE CATV encompasses the Hybrid Fibre Coaxial (HFC) networks used nowadays to provide telecommunications services, voice, data, audio and video both broadcast and narrowcast.

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

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

In this standard, informative Annex A describes the system composition and model system based on this standard, and Annex B describes basic concepts for optical wavelength division multiplexing and adds notes for system configuration. Annex C gives the minimum wavelength separation, and Annex D explains the relationship between C/N degradation and rain attenuation.

This standard describes the pass-through method of satellite broadcast signals over the FTTH system which uses AM-FDM (SCM) transmission. For an FTTH system below 1 GHz refer to IEC 60728-13. This standard contains descriptions of the measurement methods and specifications for optical wavelength division multiplex and for PSK modulation systems. It specifies the downstream video signal transmission and thus the two-way optical transmission system is out of the scope of this standard.This standard applies to the FTTH system of broadband broadcast signal transmission which conveys satellite broadcast signals using one or multiple optical wavelengths. It is provided for cable/satellite operators to extend their broadband services in order to avoid interference between optical wavelengths based on the technologies described in IEC 60728-13.

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

Part 13-1: Bandwidth expansion for broadcast signal over FTTH system

1 Scope

The purpose of this part of IEC 60728 is the precise description of the fibre to the home (FTTH) system for expanding broadband broadcast signal transmission from CATV services only, towards CATV plus broadcast satellite (BS) plus communication satellite (CS) services, additionally to other various signals such as data services.

The scope is limited to the RF signal transmission over the FTTH (fibre to the home) system. Thus, this part of IEC 60728 does not include IP transport technologies.

2 Normative references

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

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

IEC 60728-1:2007, *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 60728-13:2010, *Cable networks for television signals, sound signals and interactive services – Part 13: Optical systems for broadcast signal transmissions*

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

ITU-T Recommendation G.694.1, *Spectral grids for WDM applications: CWDM wavelength grid*

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

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

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

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

[SOURCE: IEC 61931:1998, definition 2.9.6]

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

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 1 530 nm to 1 625 nm region).

Note 3 to entry: The wavelength and necessary wavelength separation are described in Annexes B and C, respectively.

[SOURCE: IEC 60728-13:2010, definition 3.1.1, modified – Note 3 has been added]

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

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

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

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

Note 2 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 standard.

[SOURCE: IEC/TR 61931:1998, definition 2.7.75, modified – Notes 1 and 2 have been added]

3.1.4
fibre optic branching device
optical fibre coupler
splitter
optical fibre device, possessing three or more optical ports, which shares optical power among its ports in a predetermined fashion, at the same wavelength or wavelengths, without wavelength conversion

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

[SOURCE: IEC/TR 61931:1998, definition 2.6.21, modified – The term has been clarified]

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

[SOURCE: IEC 61931:1998, definition 2.6.51]

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

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

total optical modulation index, M is defined as

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

where

ϕ_h is the highest and

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

K is the total number of RF carriers and

M is the total optical modulation index.

Note 1 to entry: This term is mainly used for analogue systems.

[SOURCE: IEC 60728-13:2010, definition 3.1.6]

3.1.7
relative intensity noise
RIN
ratio of the mean square of the intensity fluctuations in the optical power of a light source to the square of the mean of the optical output power

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

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

[SOURCE: IEC 60728-13:2010, definition 3.1.8]

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

3.1.8
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 may be specified.

[SOURCE: IEC 60728-6:2011, definition 3.1.14]

3.1.9
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 ($c \approx 2{,}997\ 92 \times 10^8$ m/s)

f is the optical frequency

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

[SOURCE: IEC 60728-6:2011, definition 3.1.16]

3.1.10
centre 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, definition 3.1.23]

3.1.11
vestigial sideband
AM-VSB signal
sideband in which only the spectral components corresponding to the lower frequencies of the modulating signals are preserved, the other components being strongly attenuated

[SOURCE: IEC 60050-702:1992, definition 702-06-28, modified – The abbreviation has been completed]

Note 1 to entry: This is the abbreviation for the vestigial sideband amplitude modulated signal used in the terrestrial broadcasting and CATV transmission system.

[SOURCE: IEC 60728-13:2010, definition 3.1.12]

3.1.12
QAM signal
quadrature amplitude modulation
QAM
amplitude modulation by two separate signals of two sinusoidal carriers having the same amplitude and frequency but being in phase quadrature, the modulated signals being added for transmission in a single channel

[SOURCE: IEC 60728-13:2010, definition 3.1.13]

3.1.13
OFDM signal
orthogonal frequency division multiplexing is one of the multiplexing schemes used for the transportation of terrestrial digital broadcasting SDTV and HDTV signals

Note 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.

[SOURCE: IEC 60728-13:2010, definition 3.1.14]

3.1.14
phase shift keying
PSK signal
angle modulation in which each significant condition in a modulating discretely-timed signal is represented by a specified phase of a periodic sinusoidal oscillation

[SOURCE: IEC 60050-721:1991, definition 721-06-07, modified – One term has been deleted and one term has been modified.]

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

[SOURCE: IEC 60728-13:2010, definition 3.1.15]

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

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

[SOURCE: IEC 60728-13:2010, definition 3.1.16]

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

[SOURCE: IEC 60728-13:2010, definition 3.1.17]

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

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

[SOURCE: IEC 60728-13:2010, definition 3.1.18, modified – Table 1 has been improved.]

3.1.19
carrier-to-noise ratio
signal-to-noise ratio
if the noise level is expressed as

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

the carrier-to-noise ratio (C/N) or the signal to noise ratio ($S_{D,RF}/N$) is given by

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

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

Note 1 to entry: The level of the analogue modulated carrier or of the RF digitally modulated signal and the level of the noise is expressed in the same units, in dB(mW) or in dB(μV) measured across a 75 Ω termination or referred to 75 Ω.

[SOURCE: IEC 60728-13:2010, definition 3.1.19, modified – The definition has been revised.]

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

Note 1 to entry: The D/U ratio is generally used for multiple frequency interference as CSO and CTB, for single frequency interference as CCR.

[SOURCE: IEC 60728-13:2010, definition 3.1.20, modified]

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

Note 1 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).

[SOURCE: IEC 60728-13:2010, definition 3.1.21]

3.1.22
optical line terminal
OLT
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.

[SOURCE: IEC 60728-13:2010, definition 3.1.22]

3.1.23
optical network unit
ONU
terminal equipment linked with OLT

[SOURCE: IEC 60728-13:2010, definition 3.1.23]

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

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

[SOURCE: IEC 60728-13:2010, definition 3.1.24]

3.1.25
stimulated Brillouin scattering
SBS
non-linear scattering of optical radiation characterized by a frequency shift as for the Raman scattering, but accompanied by a lower frequency (acoustical) vibration of the medium lattice; the light is scattered backward with respect to the incident radiation

[SOURCE: IEC 61931:1998, definition 2.1.88]

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 analogue optical system.

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

[SOURCE: IEC 60728-13:2010, definition 3.1.25]

3.1.26
stimulated Raman scattering
SRS
non-linear scattering of optical radiation characterized by a wavelength shift and accompanied by very high frequency vibration of the medium lattice, strongly enhanced by the presence of already scattered radiation

[SOURCE: IEC 61931:1998, definition 2.1.87]

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 60728-13:2010, definition 3.1.27]

3.1.27
cross-phase modulation
XPM
cross-phase modulation is caused by the nonlinear refractive index of the fibre material

Note 1 to entry: It has a relationship with the wavelength spacing in optical transmission system. The more spacing becomes broader, the more XPM value decreases. In such WDM system having 1 490 nm (communication signal) and 1 550 nm (broadcast signal) wavelengths, XPM becomes negligible small compared with SRS due to this relationship-

Note 2 to entry: XPM affects the performance of the wavelength division multiplex system.

[SOURCE: IEC 60728-13:2010, definition 3.1.28]

3.1.28
crosstalk
carrier-to-crosstalk ratio
CCR
level difference of CATV broadcast carrier level and worst case of other services single frequency crosstalk signal measured at RF output port of optical receiver for CATV broadcast service

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

where

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

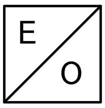
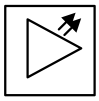
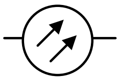
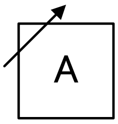
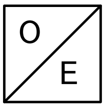
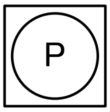
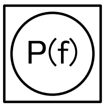
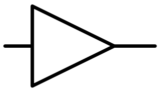
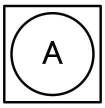
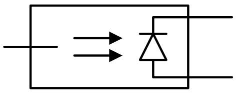
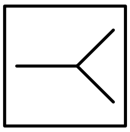
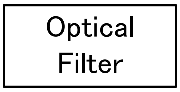
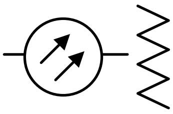
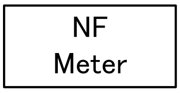
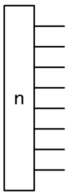
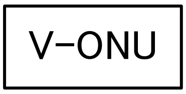
$U_{\mathrm{OtherService}}$ is the worst case level of another service's single frequency crosstalk in dB(μV) at RF output port of optical CATV broadcast receiver. The value of $U_{\mathrm{OtherService}}$ is mainly due to the Raman scattering effect.

Note 1 to entry: CCR is expressed in dB.

[SOURCE: IEC 60728-13:2010, definition 3.1.30]

3.2 Symbols

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

	Optical transmitter [IEC 60617-S002131 (2001-07)]		Optical amplifier [IEC 60617-S01239 (2001-07)]
	Optical fibre [IEC 60617-S01318 (2001-07)]		Variable attenuator [IEC 60617-S01245, modified (2001-07)]
	Optical receiver [IEC 60617-S00213 (2001-07)]		Power meter [IEC 60617-S00059, IEC 60617-S00910 (2001-07)]
	Electrical spectrum analyzer based on [IEC 60617-S00059, IEC 60617-S00910 (2001-07)]		Amplifier [IEC 60617-S01239 (2001-07)]
	Ammeter based on [IEC 60617-S00059, IEC 60617-S00910 (2001-07)]		Photodiode with fibre pigtail [IEC 60617-S01327 (2001-07)]
	Coupler [IEC 60617-S00059, IEC 60617-S01188 (2001-07)]		Optical filter
	Optical terminator [IEC 60617-S01389, IEC 60617-S01318 (2001-07)]		NF meter
	Optical splitter [3.33.1 of IEC 61930]		Television set
	Video optical network unit		WDM filter

3.3 Abbreviations

AGC	automatic gain control
AM	amplitude modulation
AM-VSB	amplitude modulation-vestigial side band
APC	angled physical contact optical connector
ATC	automatic temperature control
BS	broadcast satellite
CATV	community antenna television (network)
CCR	carrier-to-crosstalk ratio
C/N	carrier-to-noise ratio
CS	communication satellite
CSO	composite second order
CTB	composite triple beat
D/U	desired to undesired signal ratio
EDFA	erbium-doped fibre amplifier
E/O	optical transmitter (electrical to optical transducer)
FM	frequency modulation
FTTH	fibre to the home
GPON	gigabit passive optical network
GEPON	gigabit ethernet passive optical network
HDTV	high definition television
H/E	headend
HFC	hybrid fibre coaxial
ISDB-T	integrated services digital broadcasting – terrestrial
ISDB-S	integrated services digital broadcasting – satellite
ITU-T	International Telecommunication Union – Telecommunication sector
LD	laser diode
MDU	multiple dwelling unit
NF	noise figure
O/E	optical receiver (optical to electrical transducer)
OFDM	orthogonal frequency division multiplex
OLT	optical line terminal
OMI	optical modulation index
ONU	optical network unit
PD	photo diode
QAM	quadrature amplitude modulation
QPSK	quaternary phase shift keying
RIN	relative intensity noise
RBW	resolution bandwidth
RF	radio frequency
SBS	stimulated Brillouin scattering
SCM	single carrier modulation
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
TC8PSK	trellis coded 8PSK
VBW	video bandwidth
V-ONU	video optical network unit
WDM	wavelength division multiplexing
XPM	cross-phase modulation

4 Optical system reference model

This clause specifies bandwidth expansion of the system described in IEC 60728-13, the expansion contains a conversion method which transfers broadcast signals to optical transmitter after bandwidth expansion (i.e. one-wavelength system) or another conversion method which adds optical transmitter to cover the expanded bandwidth (i.e. two-wavelength system). It is desirable to apply either one or the other of these systems as a migration from the original system, as follows.

- An FTTH Cable TV system using one wavelength is shown in Figure 1.
- An FTTH Cable TV system using two wavelengths is shown in Figure 2.
- In the case of separate optical fibre transmission in broadcast and communication signals, the WDM filter in Figure 1 or Figure 2 should be removed and the system should use separated fibres for each signal.
- The two-wavelength system (Figure 2) should contain two optical transmitters and receive the two wavelengths (λ_1, λ_2) signals simultaneously. The WDM filter at receiving side for the separation of λ_1 and λ_2 signals is not necessary. However, the WDM filter for the separation of broadcast and communication signals is necessary at the receiving side.
- The FTTH system below 1 000 MHz is specified in IEC 60728-13.

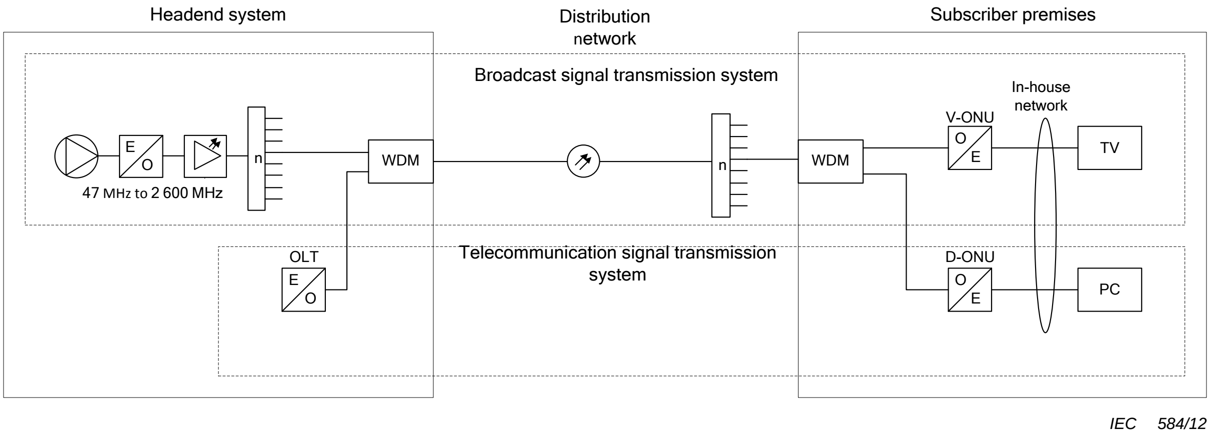


Figure 1 – FTTH Cable TV system using one-wavelength

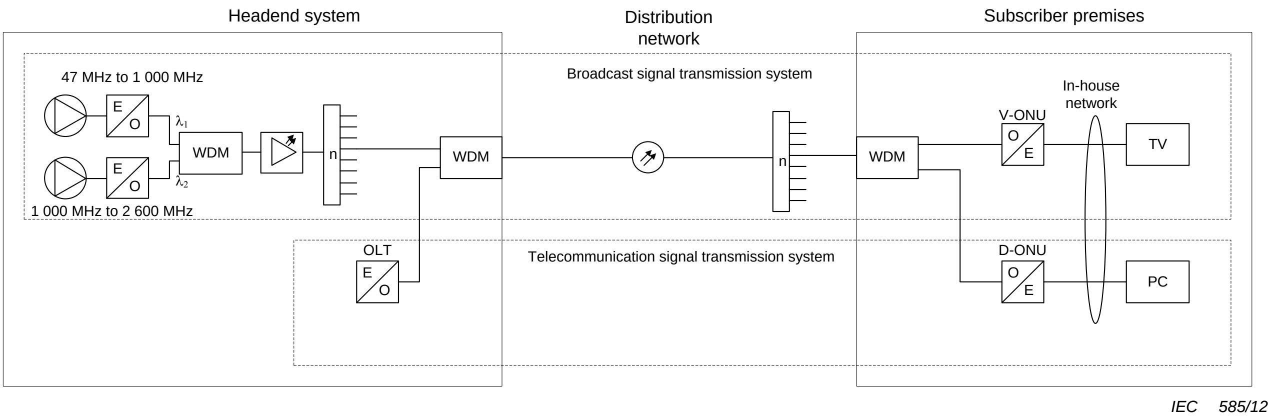


Figure 2 – FTTH Cable TV system using two wavelengths

Figure 3 shows the performance specified points of the optical system.

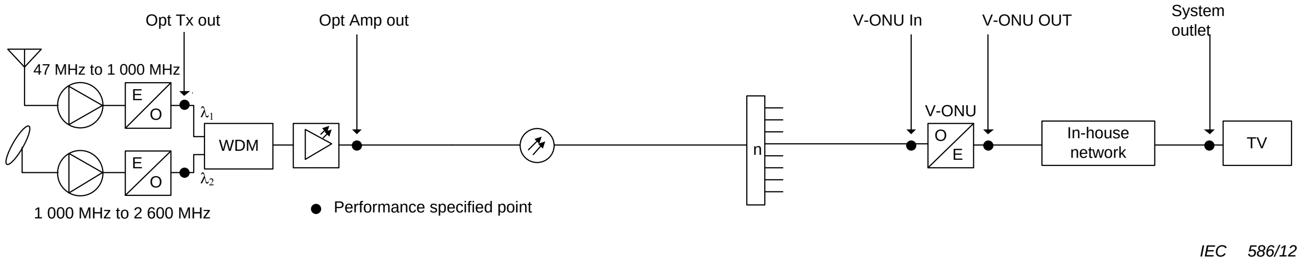


Figure 3 – Performance specified points of the optical system

5 Preparation of measurement

5.1 Environmental conditions

5.1.1 Standard measurement conditions

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

a) 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 60068-1:1988, 5.3.1) nevertheless, the specification of the measurement equipment has to be taken into account.

b) 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.

c) AGC operation

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

d) 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.

5.1.2 Standard operating condition

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

5.1.3 Standard signal and measuring equipment

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

Table 2 – Measuring instruments

Name of instrument	Usage
Optical power meter	Instrument to measure the power of the optical signal.
Spectrum analyzer	Instrument used for quantitative measurement of high frequency signals.
Optical spectrum analyzer or wavelength meter	Instrument used for optical wavelength measurement.
Signal generator	Instrument used to generate high frequency signals (sine-waves).
Network analyzer[a]	Instrument used to measure the high frequency performance of equipment.
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.
WDM Filter	Instrument used to separate the wavelength for measuring optical power and wavelength.

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

5.2 Accuracy of measuring equipment

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

5.3 Source power

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

6 Methods of measurement

6.1 Measuring points and parameters

6.1.1 General

This clause describes methods of measurement specifically designed for satellite broadcast signal transmission over the FTTH system.

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

6.1.2 Measuring points

This subclause describes measuring points of the FTTH system for satellite broadcast transmission in consistency with IEC 60728-13.

- The measuring points of the FTTH system for satellite broadcast transmission are illustrated in Figure 4. The methods of measurement described in this subclause are applied to the WDM system model and are basically similar to the system using single wavelength.
- The measurements carried out at the tap-off output can be used to predict the system performance at the output of V-ONU. Accordingly, it becomes easier for the system operators to monitor and control the performance of subscriber terminals.

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 4 to assure the total system performance. Points (5), (6) and (7) shall be measured to guarantee the system performance at the end point of the optical section and at the interface point to the customer premises. Relative intensity noise (RIN) shall be measured at points (1) through (5) and C/N (electrical signal) at points (6) and (7). Estimation of carrier-to-noise ratio at the output of V-ONU is calculated from the measured RIN value of the optical input signal to V-ONU at point (5).

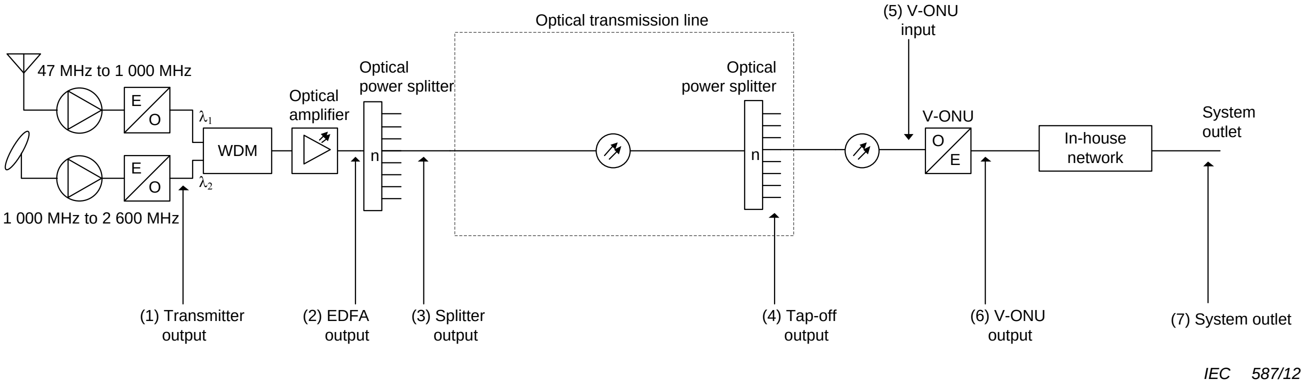


Figure 4 – Measuring points in a typical video distribution system

6.1.3 Measuring parameters

The measuring points and parameters are listed in Table 3.

For measuring the RIN it is preferable to maintain the optical power at the measuring point higher than –3 dB(mW), a limitation imposed by the noise performance of the measurement setup. If the optical power at the measuring point (5) is lower than –3 dB(mW), the measurement error may become significant and the measurement at this point is not recommended.

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

Table 3 – Measuring points and measured parameters

Measuring parameters	Measuring points						
	(1) Transmitter output	(2) EDFA output	(3) Splitter output	(4) Tap-off output	(5) V-ONU input	(6) V-ONU output	(7) System outlet
Optical power	○	○	○	○	○	—	—
Optical wavelength	○	●	●	●	●	—	—
C/N (electrical)	—	—	—	—	—	○	○
C/N (RIN) See NOTE	○	○	Δ	Δ	Δ	—	—
The measurement at points (5), (6) and (7) is mandatory, while measurement at other points is required to assure the system performance.							
NOTE Theoretical estimation of C/N at point (6), at the output of V-ONU, is based on the measurement results of individual pieces of equipment.							

○	:	Measurements are possible at these points.
●	:	Wavelength measured at the transmitter output, it can represent the entire system.
Δ	:	Measurements are possible at these points when the optical power is higher than –3 dB (mW).

6.2 Optical power

The measurement of optical power at single wavelength shall be carried out according to 4.2 of IEC 60728-6:2011. For measuring the total average optical power of multiple wavelengths emanating from the end of a test fibre, the method described in IEC 60728-13 shall be used.

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

6.3 Optical wavelength

The optical wavelength, in the FTTH system for satellite broadcast signal transmission, shall be measured following the descriptions given below.

If a single V-ONU is used to receive multiple wavelengths simultaneously without any WDM filter, a test WDM filter shall be used to measure the individual optical wavelength at the input of V-ONU. The measurement setup is shown in Figure 5.

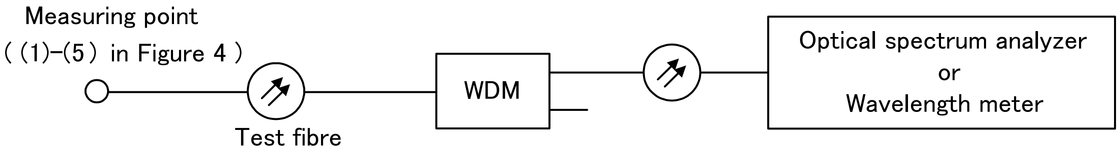


Figure 5 – Measurement of optical wavelength using WDM coupler

To measure the central wavelength λ_0 of the spectrum of an optical signal under modulation, the method described in IEC 61280-1-3 shall be used. The central wavelength shall be expressed in nm.

6.4 Carrier level and carrier-to-noise ratio

6.4.1 General

The purpose of this test method is to measure the carrier level of the satellite broadcast signal (TC8PSK, QPSK). Also, carrier-to-noise ratio is measured using the measured noise level within the transmission bandwidth of the broadcast signal. This test method performs the measurement in the electrical domain.

6.4.2 Measurement setup

Setup for the measurement of carrier level and carrier-to-noise ratio is shown in Figure 6.

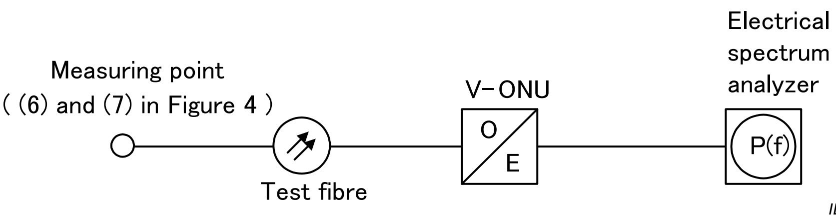


Figure 6 – Measurement of carrier level and carrier-to-noise ratio

6.4.3 Measurement conditions

The following measurement conditions apply.

a) The spectrum analyzer used for the measurement has to be calibrated before the measurement. The supply voltage of all the pieces of equipment used for the measurements shall be switched on at least 30 min before the start of the measurement.
b) If the measuring instrument has any calibration function, it shall be executed prior to the measurement.
c) Suitable coaxial cables and connectors shall be used to maintain proper impedance matching within the measurement system.

6.4.4 Measurement method for xPSK signals

For the measurement of the average level of carrier and carrier-to-noise ratio for digitally modulated signals, the methods described in IEC 60728-1 shall be followed.

6.4.5 Presentation of the results

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

6.5 Carrier-to-noise ratio defined by optical signal

6.5.1 General

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

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

6.5.2 Measuring points and measurement setup

6.5.2.1 Measuring points

The measuring points for the *RIN* measurement in a typical FTTH system for satellite broadcast signal transmission are illustrated in Figure 7.

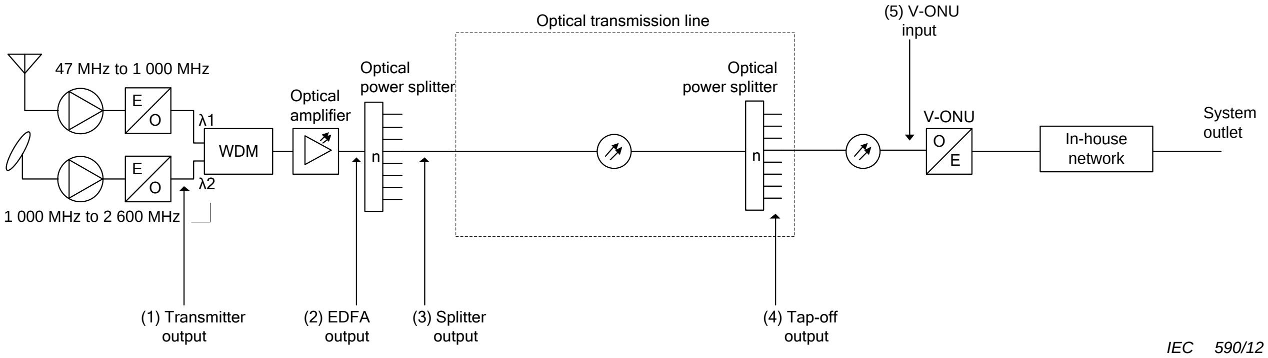


Figure 7 – Measuring points in a typical FTTH system

Following bullets indicate notes for actual measurement and calculation.

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

NOTE *RIN* measurements will not be accurate when the optical power is lower than –3 dB(mW).

- If an optical amplifier is not employed in the system, *RIN* shall be measured at point (1).
- If an outdoor type optical amplifier is employed and measurement can be carried out outdoor, the optical amplifier output shall be considered as a measuring point.
- If the optical power at points (4) and (5) is sufficiently high, these points shall also be used for measuring the *RIN* value.

6.5.2.2 Measurement setup

Figure 8 shows the *RIN* measurement setup.

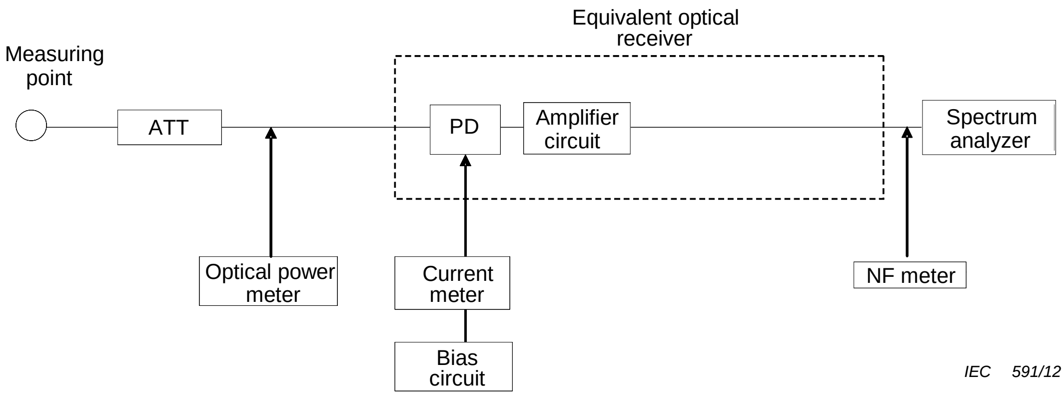


Figure 8 – *RIN* measurement setup

6.5.3 Measurement conditions

The measurement conditions of *RIN* measurement are the same as those given in 6.4.3 of IEC 60728-13:2010.

6.5.4 System *RIN* measurement method

6.5.4.1 General

This test method shall be used to predict the carrier-to-noise ratio at the output of V-ONU from the *RIN* measurement using the setup shown in Figure 8. If multiple wavelengths are used in the system, *RIN* shall be measured at all the individual wavelengths. In order to measure the *RIN* at individual wavelengths, either an optical wavelength filter shall be inserted at the measuring point or the transmitters of other wavelengths shall be turned off. Ensure that only the wavelength of interest is entered into the measurement setup.

This subclause contains several steps as described below. If the parameters, R, I_{d0}, I_{eq} and G are unknown, refer to Annex D of IEC 60728-13:2010 for methods to measure these parameters. *RIN* can be calculated using these parameters.

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

For step A proceed as follows.

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

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

where

Z_0 is the impedance of the measurement setup,

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

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

$$N_p = N_L + 10\ \mathrm{lg}\left(\frac{B_n}{B}\right) + K_1 + K_2 \tag{2}$$

where

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

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

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

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

NOTE The measured noise level (N_p) includes that of the measuring equipment (spectrum analyzer) which should be at least 20 dB lower than the noise level displayed outside the channel band in order not to affect the results. Otherwise, the contribution of noise (due to the system or the equipment under test and to the measuring equipment) should be taken into account in the measurement of noise level (see Annex F of IEC 60728-1:2007).

6.5.4.3 STEP B: *RIN* calculation

For step B proceed as follows.

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

$$RIN_n = 10\ \lg\left(\frac{\frac{I_{\mathrm{bn}}^2}{G}}{\left(R \times P_{\mathrm{r}\,n}\right)^2} - \frac{2e}{\left(R \times P_{\mathrm{r}\,n}\right)^2}\left(I_{\mathrm{d0}} + R \times P_{\mathrm{r}\,n}\right) - \frac{I_{\mathrm{eq}}^2}{\left(R \times P_{\mathrm{r}\,n}\right)^2} \right) \left[\mathrm{dB}(\mathrm{Hz}^{-1})\right] \qquad (3)$$

where

R	is the responsivity of the photodiode (A/W),
I_{d0}	is the dark current of the photodiode (A),
I_{eq}	is the preamplifier equivalent input noise current density (A/$\sqrt{\mathrm{Hz}}$),
I_{bn}	is the total noise current within 1 Hz bandwidth at the optical receiver output (A/$\sqrt{\mathrm{Hz}}$),
G	is the amplifier gain of the optical receiver (including gain of matching circuit),
$P_{\mathrm{r}\,n}$	is the n-th input power to the optical receiver (W),
e	is the charge of an electron 1,602 $\times$ 10^{-19}(C).

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

The carrier-to-noise ratio $(C/N)_{sk}$, C/N calculation value of the k-th RF carrier in s-th optical signal contained in n (1 to N_{T}) optical signals, at the V-ONU output can be calculated using the following relation:

$$\left(C/N\right)_{sk} = 10\ \lg\left(\frac{1}{B_{\mathrm{N}}} \cdot \frac{\frac{1}{2}\cdot\left(m_{sk}\cdot R\cdot P_{\mathrm{r}\,s}\right)^2}{\sum_{n=1}^{N_T}\left\{RIN_n\cdot\left(R\cdot P_{\mathrm{r}\,n}\right)^2\right\} + 2\cdot e\cdot\left(I_{\mathrm{d0}} + \sum_{n=1}^{N_{\mathrm{T}}} R\cdot P_{\mathrm{r}\,n}\right) + {I_{\mathrm{eq}}}^2} \right)[\mathrm{dB}] \qquad (4)$$

where

$$M_s = \sqrt{\sum_{k=1}^{Ks} {m_{sk}}^2} \qquad (5)$$

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

Table 4 – Parameters used to calculate the *C/N* when signals of multiple wavelengths are received by a single V-ONU

Symbol	Description	Remarks
B_N	Noise bandwidth NTSC-VSB-AM: 4,0 × 10^6 (Hz) 64-QAM: 5,6 × 10^6 (Hz) QPSK, TC8PSK: 28,86 × 10^6 (Hz)	Depends on the modulation format
K_s	Total number of RF carriers in s-th optical signal	
M_s	Total optical modulation index of s-th optical signal	These parameters depend on optical transmitter, transmission signal, etc.
m_{sk}	Optical modulation index of k-th RF carrier transmitted using s-th optical signal	
P_{rs}	Optical power of the s-th optical signal for optical signal level calculation(W)	To measure the optical power at individual wavelength, either turn off the transmitters of other wavelengths, or insert an optical wavelength filter at the measuring point, and ensure that only the wavelength of interest is input to the power meter.
P_{rn}	Optical power of n-th optical signal for optical noise level calculation (W)	This parameter depends on transmission line design.
RIN_n	*RIN* of the n-th optical signal for optical noise level calculation (dB(Hz^{-1}))	This parameter depends on optical transmitter, optical amplifier and transmission line. If these parameters are unknown, the following values may be used to calculate the *RIN* of optical signal input to the V-ONU. *RIN* of optical transmitter for multi-channel transmission is –155 dB(Hz^{-1}). *RIN* of optical transmitter for retransmission: –150 dB(Hz^{-1}). *NF* of optical amplifier: 6,5 dB *RIN* due to optical transmission line: –161 dB(Hz^{-1}).
e	Charge of an electron (1,602 × 10^{-19} C)	Physical constant.
R	Responsivity of V-ONU (A/W)	Depends on the performance of V-ONU. If these parameters are unknown, the following values may be used in the calculation of *RIN*. R: 0,89 (A/W) I_{d0}: 0,1 (nA) I_{eq}: $7\ \text{pA}/\sqrt{\text{Hz}}$
I_{d0}	Dark current of V-ONU (A)	
I_{eq}	V-ONU equivalent input noise current density $\left(\text{A}/\sqrt{\text{Hz}}\right)$	
N_T	Number of transmitted optical signals simultaneously.	

6.5.6 Calculation of component *RIN*

To calculate the *RIN* degradation due to optical amplifier and optical transmission line, the methods described in 6.4.6 of IEC 60728-13:2010 shall be used.

6.6 Optical modulation index

The optical modulation index (*OMI*) of broadcast satellite signals shall be measured according to the method described in 4.9 of IEC 60728-6:2011. In this standard it is assumed that power AGC function, if available in the transmitter, shall be off during the measurements.

6.7 Carrier-to-crosstalk ratio (*CCR*)

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

7 Specification of optical system for broadcast signal transmission

7.1 Analogue and digital broadcast system over optical network

VSB-AM, PAL, SECAM, OFDM and QAM (47 MHz to 1 000 MHz) systems are described in IEC 60728-13. This standard describes broadcast satellite (BS) and communication satellite (CS) signals (1 000 MHz to 2 600 MHz) modulated by TC8PSK and QPSK. C/N allocation shown in Figure 9 is applied only to these signals. The overall system C/N shall be allocated based on the analogue signals in which the more stringent condition is required. (Refer to IEC 60728-13).

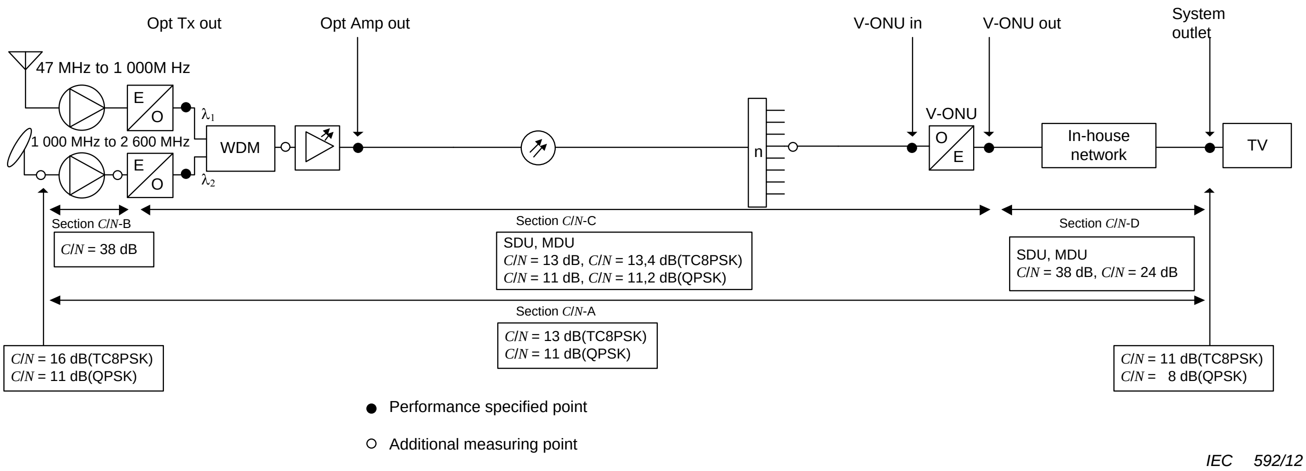


Figure 9 – Performance allocation and measuring points

7.2 International TV systems

Minimum RF signal-to-noise requirement in operation is shown in Table 5.

Table 5 – Minimum RF signal-to-noise ratio requirements in operation

System	Modulation	Code rate	Minimum RF signal-to-noise ratio at headend input $S_{D,RF}/N$ dB	Minimum RF signal-to-noise ratio at system outlet $S_{D,RF}/N$ dB
ISDB-S	TC8PSK	2/3	16 (See NOTE)	11
	QPSK	3/4	11 (See NOTE)	8

NOTE It shows the subtraction of corresponding C/N degradation of the rain attenuation of 99 % in time at the worst month from C/N of the headend input signal. Refer to Annex D for details of the relation between C/N degradation and rain attenuation.

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

The CATV broadcast service within the scope of this standard can be classified into three types:

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

The broadcast channels can be transmitted using either a single or dual (WDM) wavelengths.

Table 6 shows the types of broadcast services with the typical number of carriers. Annex A should be referred to for the combination of analogue and digital carriers in actual system design.

Multi-channel service system, for longer transmission distance and larger number of subscribers, uses transmitter with external intensity modulation method for the transmission of mixture of analogue and digital signals. In multi-channel service with CS supplementary service, the BS/CS-IF channels are transmitted using the direct intensity modulation method.

The re-transmission service system is a small-sized receiving facility with poor reception of broadcast TV programs. Ten carriers in each analogue and digital signal are assumed for the re-transmission service. Most of the re-transmission service system does not require an EDFA, or requires one EDFA only, and the optical system uses direct intensity modulation method in general.

Table 6 – Types of broadcast services

Type of service	Number of Wavelengths		Analogue (NTSC)	Digital	Satellite
a) **Multi-channel service with mixture of analogue and digital signals**	1		11 carriers	80 carriers (64 QAM, OFDM)	12 carriers (TC8PSK)
	2	λ_1	11 carriers	80 carriers (64 QAM, OFDM)	—
		λ_2	—	—	12 carriers (TC8PSK)
b) **Multi-channel with CS supplementary service**	1		11 carriers	11 carriers (64 QAM, OFDM)	24 carriers (TC8PSK, QPSK)
	2	λ_1	11 carriers	11 carriers (64 QAM, OFDM)	—
		λ_2	—	—	24 carriers (TC8PSK, QPSK)
c) **Re-transmission service for poor signal reception**	1		9 carriers	9 carriers (OFDM)	12 carriers (TC8PSK)
	2	λ_1	9 carriers	9 carriers (OFDM)	—
		λ_2	—	—	12 carriers (TC8PSK)

Performance of transmission line can be defined by the value of relative intensity noise (*RIN*) for optical signal, and the *C*/*N* ratio at V-ONU output for electrical signal. The term V-ONU is used as the synonym of optical receiver (O/E) device in this standard, and in the case of services employing dual-wavelength, the multiplexed signal is assumed to be received by a single V-ONU. Details on actual parameters are described in Annex A. *RIN* values required for the three service types are shown in Table 7. The intensity modulation method is applied to the optical system in all service types.

The following tables are applied only to the broadcasting satellite signal band using the digital modulation (TC8PSK and QPSK). The RIN value is calculated based on necessary *C*/*N* ratio for the transmission of enhanced broadcasting signal (broadcast satellite digital signal). The overall system *C*/*N* shall be allocated based on the analogue signals in which the more stringent condition is required (refer to IEC 60728-13).

Table 7 – Type of service and minimum operational *RIN* values for Satellite services

Type of service	Number of wavelengths	OMI %	V-ONU minimum input level dB(mW)	System *RIN* minimum value dB(Hz^{-1})	Corresponding *C/N* value (NOTE 1) dB
a) Multi-channel service with mixture of analogue and digital signals	1	2,2	–8	–124 –125	13(SDU) 14(MDU)
	2	—	–8 (λ_1, NOTE 2)	–124 (NOTE 3) –125 (NOTE 3)	13(SDU) 14(MDU)
		8,8	–14 (λ_2, NOTE 2)		
b) Multi-channel with CS supplementary service	1	2,2	–8	–124 –125	13(SDU) 14(MDU)
	2	—	–8 (λ_1, NOTE 2)	–124 (NOTE 3) –125 (NOTE 3)	13(SDU) 14(MDU)
		8,8	–14 (λ_2,NOTE 2)		
c) Re-transmission service for poor signal reception	1	2,9	–12	–122 –123	13(SDU) 14(MDU)
	2	—	–12 (λ_1, NOTE 2)	–125 (NOTE 3) –126 (NOTE 3)	13(SDU) 14(MDU)
		2,9	–12 (λ_2, NOTE 2)		

NOTE 1 The *C/N* value is calculated for TC8PSK system.

NOTE 2 λ_1: wavelength of 47 MHz to 1 000 MHz transmission band, λ_2: wavelength of 1 000 MHz to 2 600 MHz transmission band.

NOTE 3 Total *RIN* value for two-wavelength system.

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

7.4 Optical wavelength

Table 8 shows the performance of optical wavelength and power for the FTTH system defined by this standard.

Table 8 – Performance of optical wavelength and power

Optical wavelength		Refer to IEC 60728-13
Optical power	**Optical transmission power**	When FTTH system operates two wavelengths, optical power of the first wavelength refers to IEC 60728-13 and the second wavelength is –6 dB of first wavelength.
	V-ONU input power	
Interval of wavelengths (two wavelength system)		The wavelengths shall be selected in accordance with the ITU-T G.694.1 for DWDM case and the ITU-T G.694.2 for CWDM case. If it is not so, at least 0,3 nm wavelength-separation shall be kept in any case to avoid interference to broadcast signals.

Avoiding the influence to the first wavelength from the second one, the level of the second wavelength shall be sufficiently less than the first one. This means –6 dB level difference when the OMI of the second signal is quadrupled. Refer to Clause A.5.

7.5 Frequency of source signal

The frequency range of source signals considered here is 47 MHz to 2 600 MHz. However, regional frequency plans can be used for the operating frequency range of the optical system.

7.6 Optical system specification for satellite signal transmission

The major parameters of the optical system are shown in Table 9. Refer to IEC 60728-13 for VSB-AM, OFDM, and the QAM signals.

Table 9 – Optical system specification

<table>
<tr><th colspan="2">Parameter</th><th>TC8PSK</th><th>QPSK</th></tr>
<tr><td colspan="2">Optical wavelength</td><td colspan="2">1 530 nm to 1 625 nm
((1 555 ± 5) nm is strongly recommended.)</td></tr>
<tr><td colspan="2">Frequency of source signal</td><td colspan="2">1 000 MHz to 2 600 MHz</td></tr>
<tr><td colspan="2">Fluctuation of carrier-wave level</td><td colspan="2">under consideration</td></tr>
<tr><td colspan="2">Noise bandwidth of electronic signal</td><td>28,86 MHz</td><td>28,86 MHz</td></tr>
<tr><td colspan="2">Min. optical section C/N
(Between Head-end Output and System Outlet)</td><td>15 dB</td><td>9 dB</td></tr>
<tr><td rowspan="2">Min. C/N</td><td>At Head-end Input</td><td>16 dB (NOTE 1)</td><td>11 dB (NOTE 1)</td></tr>
<tr><td>At System Outlet (NOTE 2)</td><td>11 dB (NOTE 2)</td><td>8 dB (NOTE 2)</td></tr>
<tr><td colspan="4">NOTE 1 It shows the subtraction of corresponding C/N degradation of the rain attenuation of 99 % in time at the worst month from C/N of the headend input signal. Refer to Annex D for details of the relation between C/N degradation and rain attenuation.

NOTE 2 It corresponds to BER = 1 × 10^{–8}.</td></tr>
</table>

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

The *C*/*N* ratio can be specified outside of the system outlet if the performance of the in-house/in-building wiring section is maintained properly. Based on current installation methods, *C*/*N* ratio allocation for the in-house/in-building wiring section is specified in Table 10. *C*/*N* ratio allocation is different between Single Dwelling Unit (SDU) and Multiple Dwelling Unit (MDU) as shown in Figure 10 and Figure 11, considering the difference of network composition.

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

<table>
<tr><th colspan="2">Category of house</th><th>Minimum C/N ratio for in-house/ in-building wiring
dB</th></tr>
<tr><td>Single dwelling unit (SDU)</td><td>–</td><td>38</td></tr>
<tr><td rowspan="2">Multiple dwelling unit (MDU)</td><td>O/E conversion at MDU entrance, coaxial cable distribution to TV set</td><td>24</td></tr>
<tr><td>No O/E conversion at MDU entrance, optical cable distribution to TV set</td><td>24</td></tr>
</table>

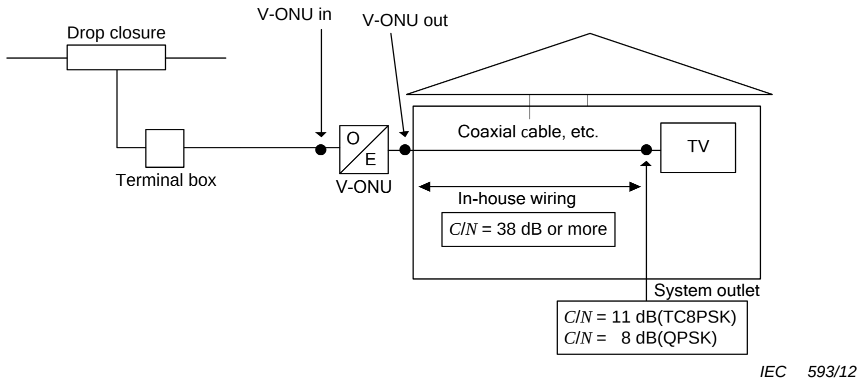


Figure 10 – Section of *C*/*N* ratio specification (38 dB) for in-house wiring

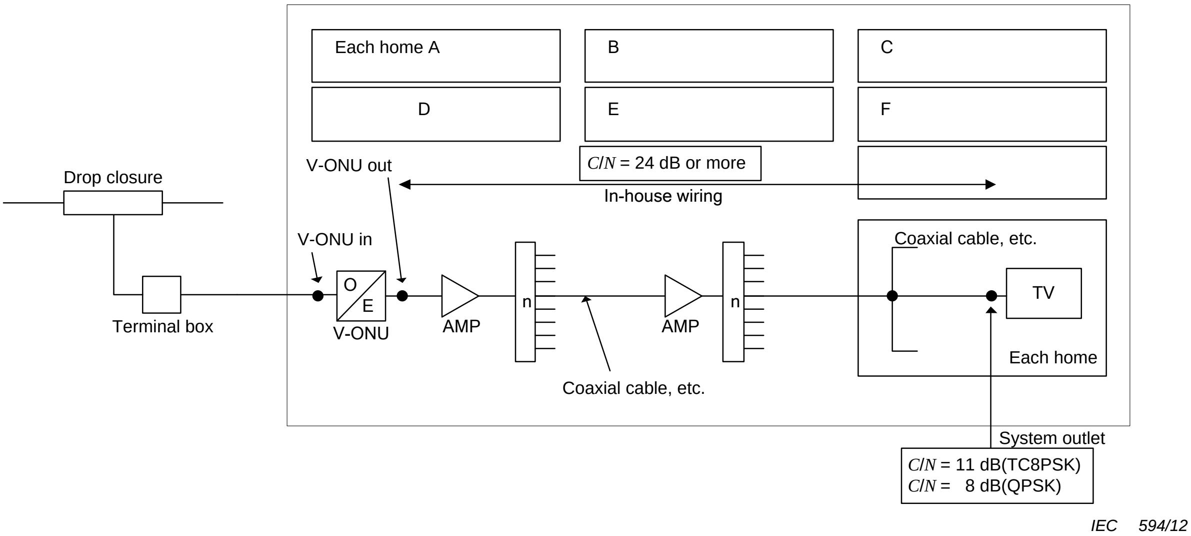


Figure 11 – Section of *C*/*N* ratio specification (24 dB) for in-building wiring (in case of coaxial cable distribution after V-ONU)

7.8 Crosstalk due to optical fibre non-linearity

Refer to IEC 60728-13.

7.9 Single frequency interference level due to fibre non-linearity

The single frequency interference level caused by fibre non-linearity shall meet the following values shown in Table 11. All the parameters of optical broadcast transmission systems shall be set appropriately to satisfy the interference level. The measuring points shall be point (6) shown in Figure 4.

Table 11 – Interference level due to fibre non-linearity

Broadcast system	*D*/*U* ratio dB
Broadcast satellite (TC8PSK)	More than 13
Communication satellite (QPSK)	More than 13

7.10 Environment condition

Refer to IEC 60728-13.

Annex A
(informative)

Actual service systems and design considerations

A.1 General

As described in Clause 7, the CATV broadcast service under the scope of this standard can be classified into the following three types:

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

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

A.2 Multi-channel service with mixture of analogue and digital signals

CATV operator currently provides multi-channel services for mixed analogue and digital broadcasting. Analogue and/or digital multi-channel services are classified as multi-channel services in this standard. This sub-clause describes the following two reference models for the multi-channel services over an optical network using single optical wavelength and dual optical wavelength, respectively. In both cases, the transmitter is used direct intensity modulation method.

Model(A) λ_1:Analogue 11 carriers + Digital 80 carriers + Satellite (BS) 12 carriers

Model(B) λ_1: Analogue 11 carriers + Digital 80 carriers, λ_2: Satellite (BS) 12 carriers

Model (A) is selected as a reference model that is used single optical wavelength, and Model (B), two optical wavelengths. “Analogue” here means NTSC signals, “Digital” means either 64QAM or OFDM signals, and “Satellite“, TC8PSK signals.

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

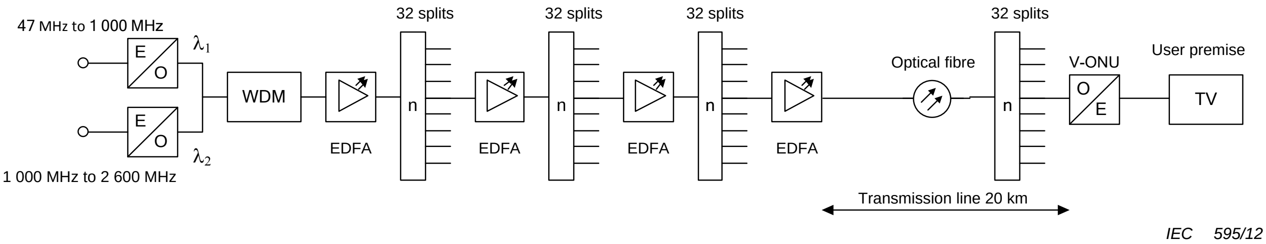


Figure A.1 – Example of a multi-channel service system of one million terminals

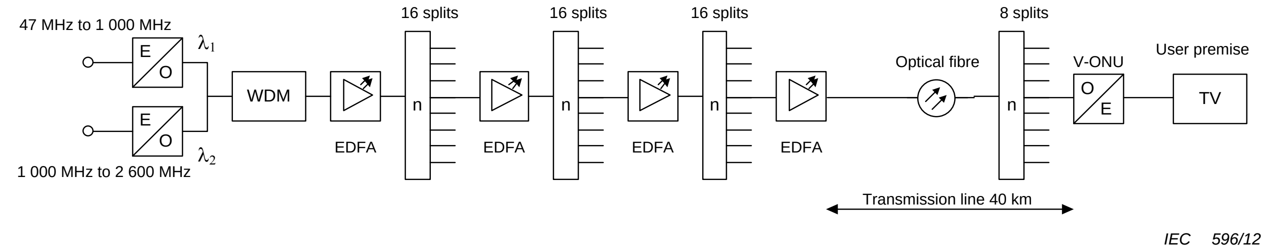


Figure A.2 – Example of a multi-channel service system of 2 000 terminals

A.3 Multi-channel with CS supplementary service

This subclause describes the following two reference models for the multi-channel services with CS supplementary service over an optical network using single optical wavelength and dual optical wavelength, respectively. If a single optical wavelength is used, the transmitter uses the direct intensity modulation method. And in the case of the dual optical method, one transmitter adopts external modulation for the signal below 1 000 MHz and the other uses direct modulation for the signal above 1 000 MHz, see Figure A.3.

Model (C) λ_1: Analogue 11 carriers + Digital 11 carriers + Satellite (BS and CS) 24 carriers

Model (D) λ_1: Analogue 11 carriers + Digital 11 carriers, λ_2: Satellite 24 (BS and CS) carriers

Model (C) is selected as a reference model applied to a single optical wavelength. In this case, the transmitter uses a direct intensity modulation method. On the other hand, model (D), contains two optical wavelengths. In this case, the transmitter uses an external modulation method for frequencies below 1 000 MHz and direct modulation method for frequencies above 1 000 MHz. Analogue in this case represents a NTSC signal and digital represents either a 64QAM or a OFDM signal and a satellite signal, either TC8PSK or QPSK.

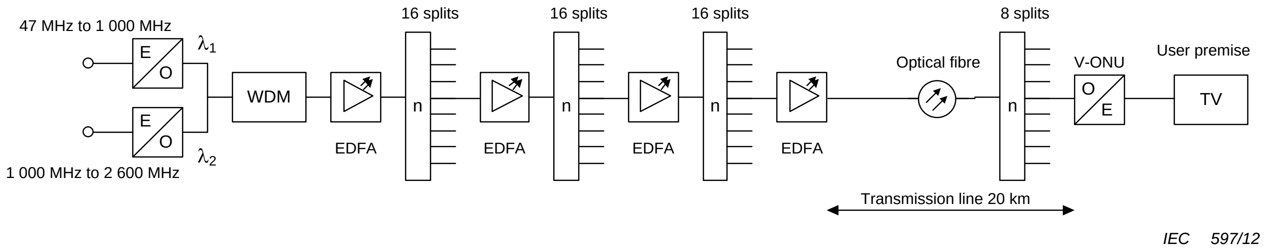


Figure A.3 – Example of a multi-channel with CS supplementary service system of 2 000 terminals

A.4 Retransmission service for poor signal reception

The retransmission service system is a small-sized receiving facility for the poor reception area to receive broadcast TV programs. Nine carriers in each analogue, and digital signal, and twelve carriers in satellite signals are assumed for the retransmission service. In general, retransmission service systems have an about 2 km trunk line and 70 terminals. In this case, one EDFA at its maximum is enough for this network size, see Figure A.4. Most of the retransmission service system does not require an EDFA, see Figure A.5.

Model(E) λ_1:Analogue 9 carriers + Digital 9 carriers + Satellite (BS) 12 carriers

Model(F) λ_1: Analogue 9 carriers + Digital 9 carriers, λ_2: Satellite (BS) 12 carriers

Model (E) is selected as the reference model of a single optical wavelength system, and model (F), of a dual optical wavelength system. In both cases, the transmitter is used as the direct intensity modulation method.

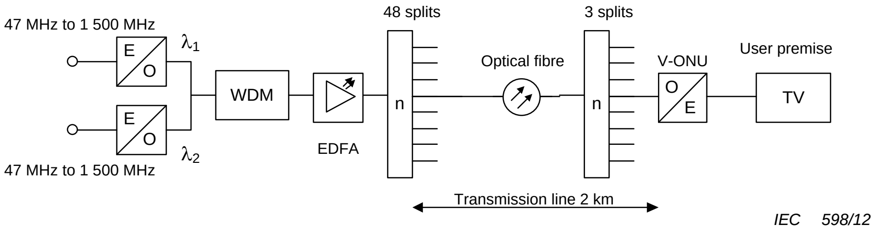


Figure A.4 – Example of retransmission service system with 144 terminals

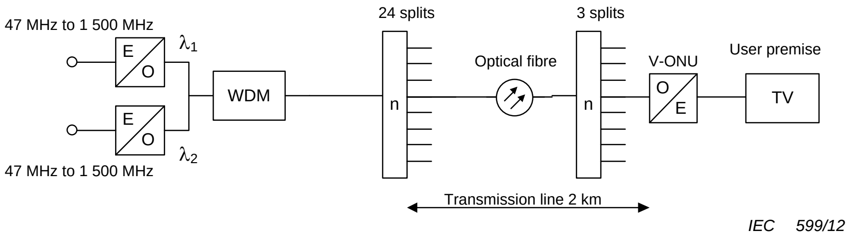


Figure A.5 – Example of retransmission service system with 72 terminals

A.5 System reference model

A.5.1 System parameters

Table A.1 summarizes the basic system parameters verified for the above service systems.

Table A.1 – Basic system parameters

Type of service	Number of wave-lengths	Number of carriers	OMI (%)	EDFA stage	Remark	Ref. model No.
Multi-channel service with mixture of analogue and digital signals, multi-channel	1	Analogue: 11 carriers Digital: 80 carriers Satellite (BS): 12 carriers	Analogue: 7,0 Digital: 2,2 Satellite(BS): 2,2	4	**Direct modulation method** (90 MHz to 2 600 MHz)	**Model No.1** Figure A.6
	2		Analogue: 7,0 Digital: 2,2 Satellite(BS): 8,8	4	**External modulation method** (90 MHz to 1 000 MHz) **Direct modulation method** (1 000 MHZ to 2 600 MHz)	**Model No.2** Figure A.7
Multi-channel with CS supplementary service	1	Analogue: 11 carriers Digital: 11 carriers Satellite (BS and CS): 24 carriers	Analogue: 7.0 Digital: 2,2 Satellite (BS and CS): 2,2	3	**Direct modulation method** (90 MHz to 2 600 MHz)	**Model No.3** Figure A.8
	2		Analogue: 7,0 Digital: 2,2 Satellite (BS and CS): 8,8	3	**External modulation method** (90 MHz to 1 000 MHz) **Direct modulation method** (1 000 MHz to 2 600 MHz)	**Model No.4** Figure A.9
Retransmission service for poor signal reception	1	Analogue: 9 carriers Digital: 9 carriers Satellite (BS): 12 carriers	Analogue: 9,0 Digital: 2,9 Satellite(BS): 2,9	1	**Direct modulation method** (90 MHz to 2 600 MHz)	**Model No.5** Figure A.10
	2	Analogue: 9 carriers Digital: 9 carriers Satellite (BS): 12 carriers	Analogue: 9,0 Digital: 2,9 Satellite(BS): 2,9	1	**Direct modulation method** (90 MHz to 2 600 MHz)	**Model No.6** Figure A.11

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

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

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

A.5.2 Operating environment

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

a) Optical transmitter

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

b) Optical amplifier

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

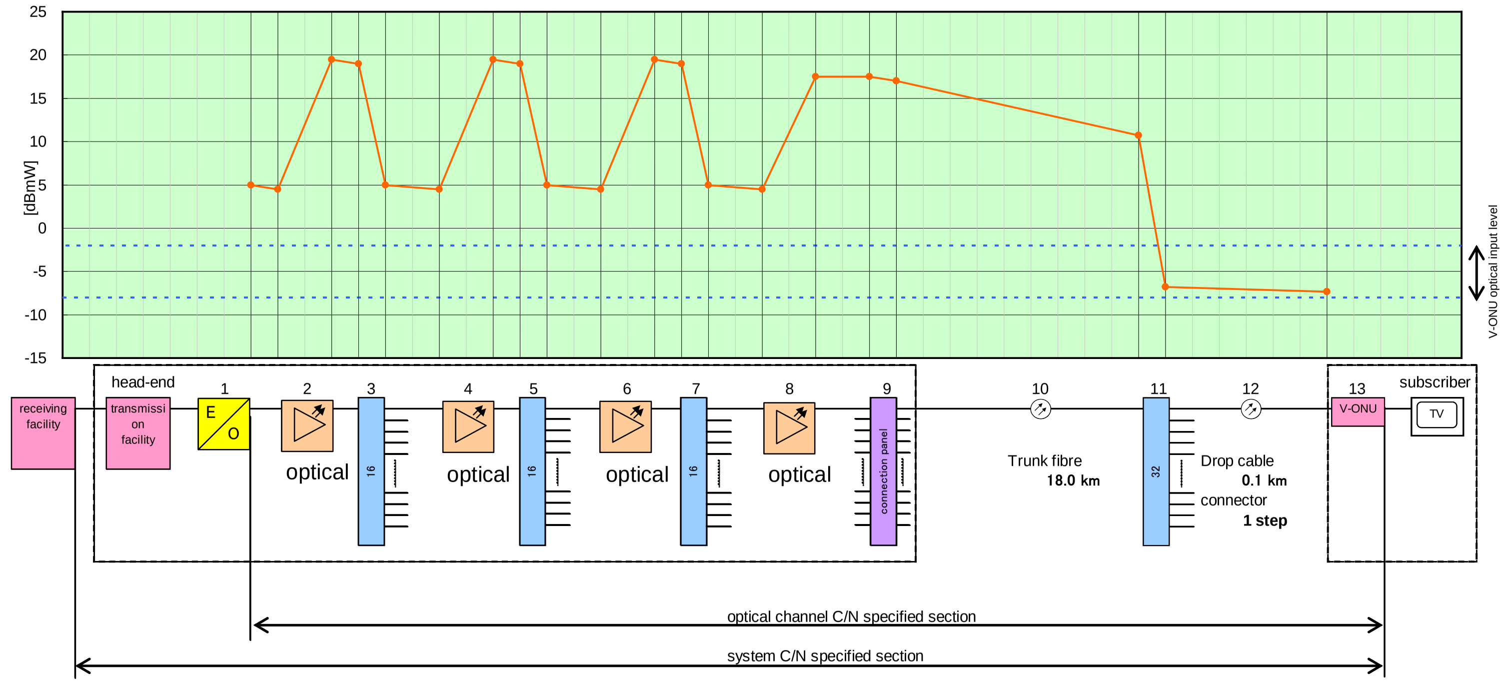
c) V-ONU

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

NOTE 1 Except for the rising temperature due to solar radiation.

Model No.1

Multi-channel service with mixture of analogue and digital signals Multi-channel system, 4 stage EDFA(s), OMI: 7,0 %
Direct modulation optical transmitter: 1 Wavelength (analogue 11 carriers, digital 80 carriers, Satellite(BS) 12 carriers)



item		
amplifier NF	**6.2 dB**	
OMI/ch (NTSC/BS)	**7.0 %**	**2.2 %**
receiving point C/N(NTSC/BS)	**53.0 dB**	**20.0 dB**
transmitter RFout C/N	**55.0 dB**	

	1	2	3	4	5	6	7	8	9	10	11	12	13
equipment	transmitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	32 splitter	drop cable	V-ONU
input level [dBmW]	RF:80dBuV	4.50	19.00	4.50	19.00	4.50	19.00	4.50	17.50	17.00	10.70	-6.80	-7.34
gain or loss [dB]	-	**15.00**	-14.00	**15.00**	-14.00	**15.00**	-14.00	**13.00**	-0.50	-6.30	-17.50	-0.54	-
output level [dBmW]	**5.00**	19.50	5.00	19.50	5.00	19.50	5.00	17.50	17.00	10.70	-6.80	-7.34	RF:80dBuV
output RIN[dB(Hz-1)]	**-155.00**	-151.58	←	-149.70	←	-148.39	←	-147.38	←	←	←	←	-
channel C/N_1 [dB]	-	-	-	-	-	-	-	-	-	-	-	-	48.81
channel C/N_2 [dB]	-	-	-	-	-	-	-	-	-	-	-	-	30.18
system C/N [dB]	-	-	-	-	-	-	-	-	-	-	-	-	46.71

note 1: optical channel C/N at the V-ONU RF output, which is calculated from RIN of the optical transmitter and the amplifier
note 2: C/N（NTSC:C/N_1 ,BS:C/N_2) at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*

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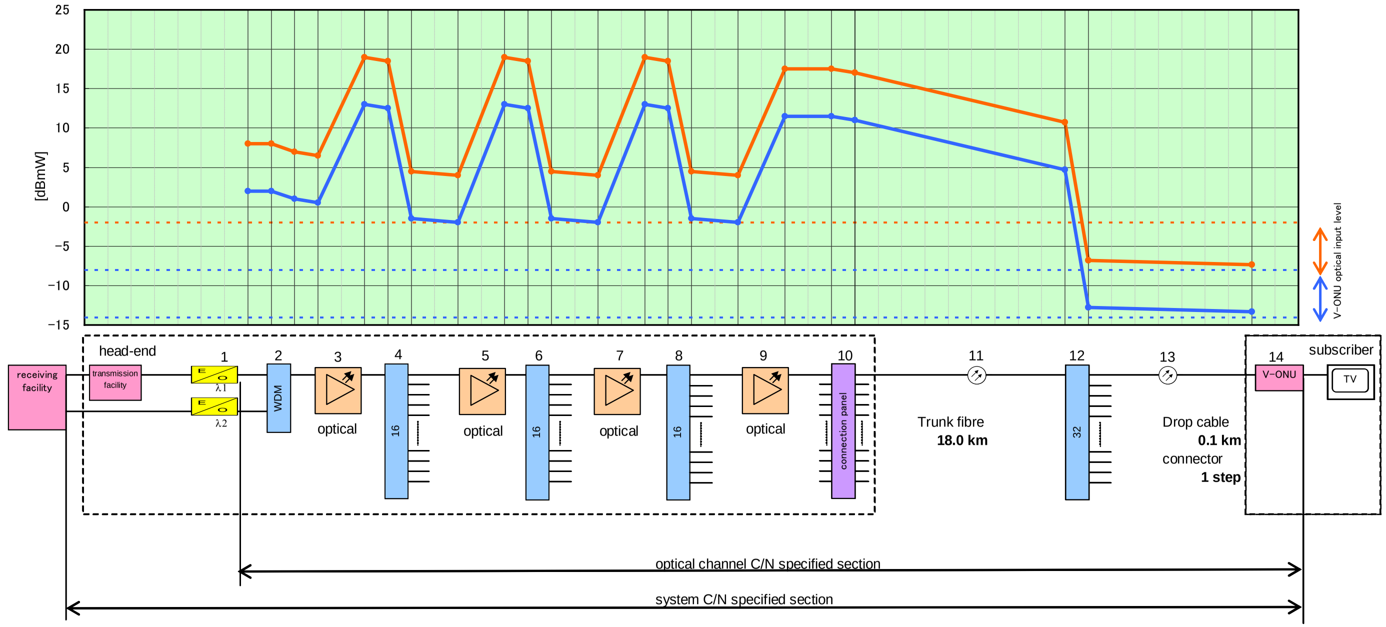
Figure A.6 – System performance calculation Model No.1

Model No.2 Multi-channel service with mixture of analogue and digital signals Multi-channel system, 4 stage EDFA(s), OMI: 7,0 %
External and direct modulation optical transmitters: 2 Wavelengths (analogue 11 carriers, digital 80 carriers, Satellite(BS) 12 carriers)



item		
amplifier NF	**6.2 dB**	
OMI/ch (NTSC/BS)	**7.0 %**	**8.8 %**
receiving point C/N(NTSC/BS)	**53.0 dB**	**19.5 dB**
transmitter RFout C/N	**55.0 dB**	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
equipment	transmitter	WDM	amplifier	16 splitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	32 splitter	drop cable	V-ONU
input level λ_1[dBmW]	RF:80dBuV	8.00	6.50	18.50	4.00	18.50	4.00	18.50	4.00	17.50	17.00	10.70	-6.80	-7.34
input level λ_2[dBmW]		2.00	0.50	12.50	-2.00	12.50	-2.00	12.50	-2.00	11.50	11.00	4.70	-12.80	-13.34
gain or loss [dB]	-	-1.00	**12.50**	-14.00	**15.00**	-14.00	**15.00**	-14.00	**13.50**	-0.50	-6.30	-17.50	-0.54	
output level λ_1[dBmW]	**8.00**	7.00	19.00	4.50	19.00	4.50	19.00	4.50	17.50	17.00	10.70	-6.80	-7.34	RF:80dBuV
output level λ_2[dBmW]	**2.00**	1.00	13.00	-1.50	13.00	-1.50	13.00	-1.50	11.50	11.00	4.70	-12.80	-13.34	
output RIN λ_1[dB(Hz-1)]	**-158.10**	←	-154.05	←	-150.87	←	-149.06	←	-147.78	←	←	←	←	
output RIN λ_2[dB(Hz-1)]	**-153.00**	←	-148.38	←	-145.03	←	-143.16	←	-141.86	←	←	←	←	
channel C/N_1 [dB] note1	-	-	-	-	-	-	-	-	-	-	-	-	-	48.42
channel C/N_2 [dB] note1	-	-	-	-	-	-	-	-	-	-	-	-	-	29.82
system C/N_1 [dB] note2	-	-	-	-	-	-	-	-	-	-	-	-	-	46.47
system C/N_2 [dB] note2	-	-	-	-	-	-	-	-	-	-	-	-	-	19.11

note 1: optical channel C/N at the V-ONU RF output, which is calculated from RIN of the optical transmitter and the amplifier.(RIN degradation when λ1 and λ2 are received is considered.
note 2: C/N(NTSC:C/N_1,BS:C/N_2) at V-ONU RF output, which is calculated from the receiving point *C/N* , transmitter *C/N* and optical channel *C/N* .
Receiving antenna C/N (BS-D) is the C/N in 99% hour rate of the month with the most precipitation when 75cm φ BS antenna is used.
note 3: Gain tilt depending on input power and wave length of the optical amplifier is NOT considered in the above calculation.

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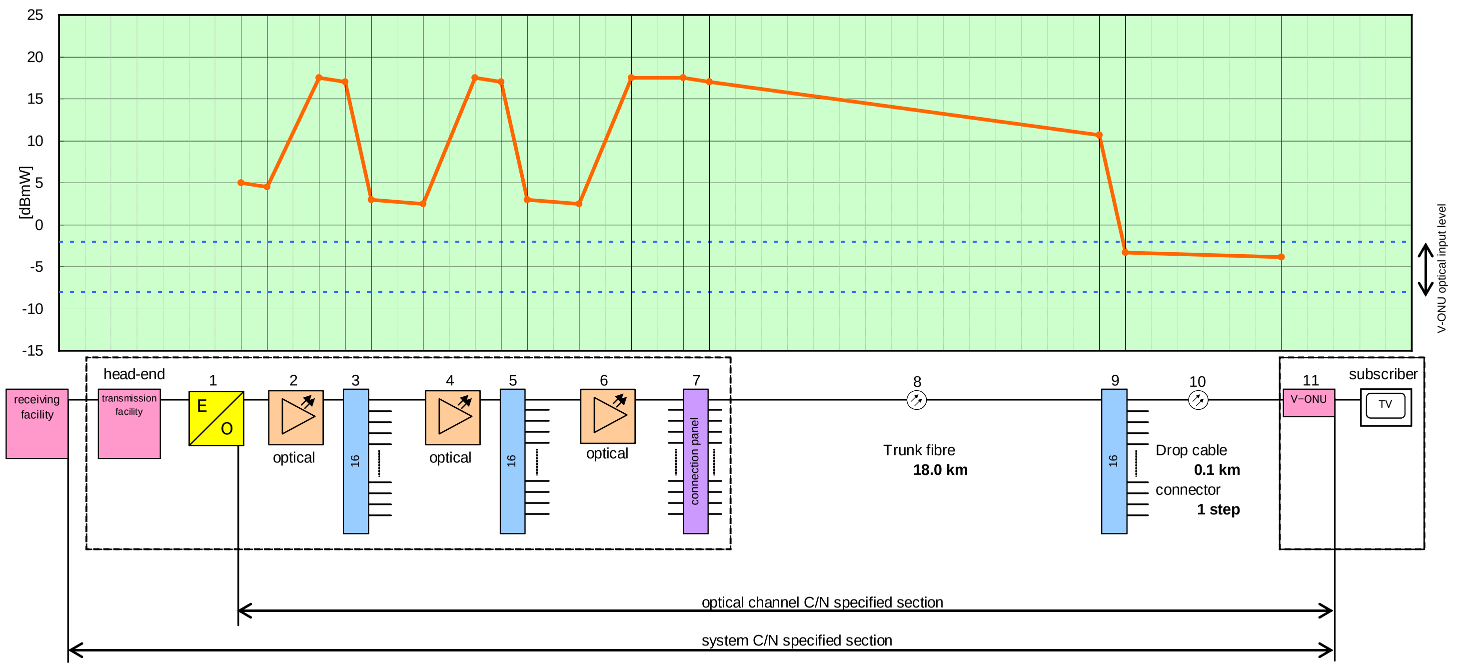
Figure A.7 – System performance calculation Model No.2

Model No.3

Multi-channel with CS supplementary service system, 3 stage EDFA(s), OMI: 7,0 %
Direct modulation optical transmitter: 1 Wavelength (analogue 11 carriers, digital 11 carriers, Satellite((BS/CS) 24 carriers)



item		
amplifier NF	**6.2 dB**	
OMI/ch (NTSC/BS)	**7.0 %**	**2.2 %**
receiving point C/N(NTSC/BS)	**53.0 dB**	**19.5dB**
transmitter RFout C/N	**55.0 dB**	

	1	2	3	4	5	6	7	8	9	10	11
equipment	transmitter	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	16 splitter	drop cable	V-ONU
input level [dBmW]	RF:80dBuV	4.50	17.00	2.50	17.00	2.50	17.50	17.00	10.70	-3.30	-3.84
gain or loss [dB]	-	**13.00**	-14.00	**15.00**	-14.00	**15.00**	-0.50	-6.30	-14.00	-0.54	-
output level [dBmW]	**5.00**	17.50	3.00	17.50	3.00	17.50	17.00	10.70	-3.30	-3.84	RF:80dBuV
output RIN[dB(Hz-1)]	**-155.00**	-151.58	←	-148.88	←	-147.23	←	←	←	←	-
channel C/N_1 [dB] note1	-	-	-	-	-	-	-	-	-	-	52.26
channel C/N_2 [dB] note1	-	-	-	-	-	-	-	-	-	-	33.62
system C/N_1 [dB] note2	-	-	-	-	-	-	-	-	-	-	48.50
system C/N_2 [dB] note2	-	-	-	-	-	-	-	-	-	-	19.33

note 1: optical channel C/N at the V-ONU RF output, which is calculated from RIN of the optical transmitter and the amplifier
note 2: C/N（NTSC:C/N_1 ,BS:C/N_2 ）at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*
Receiving antenna C/N (BS-D) is the C/N in 99% hour rate of the month with the most precipitation when 75cm φ BS antenna is used

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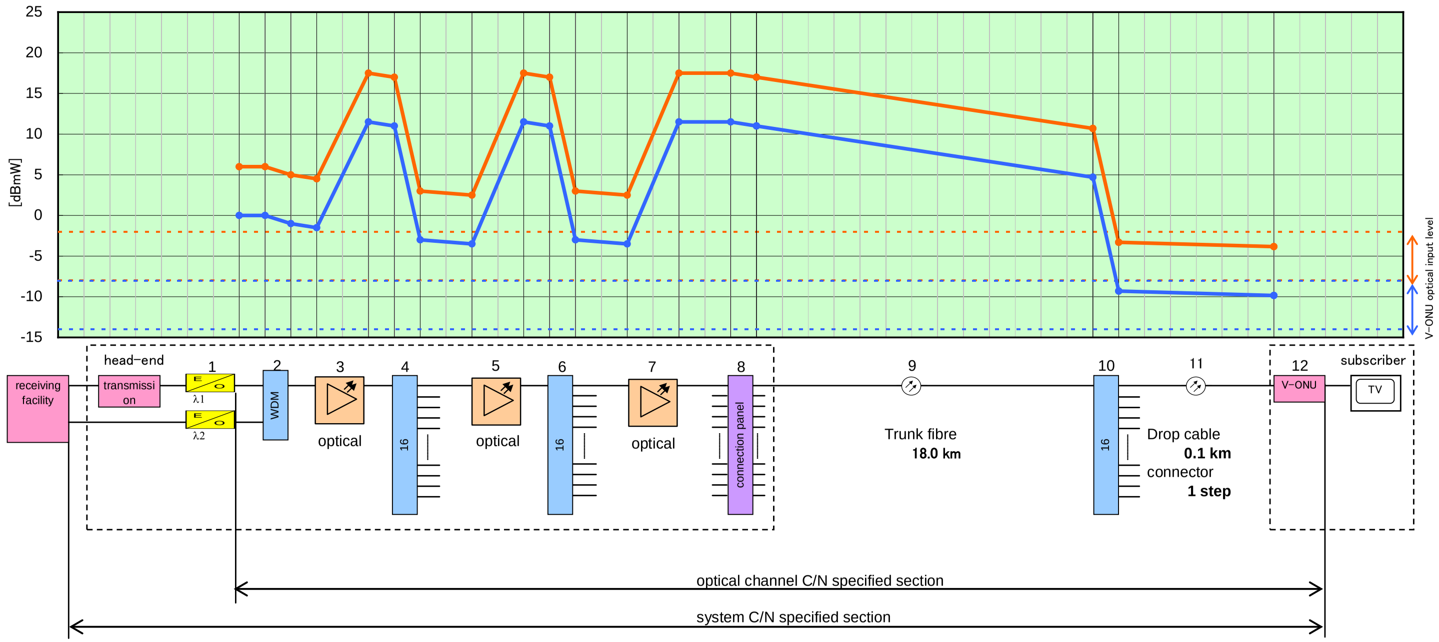
Figure A.8 – System performance calculation Model No.3

Model No.4

Multi-channel with CS supplementary service system, 3 steps of EDFA(s), OMI: 7,0 %
External and direct modulation optical transmitter: 2 Wavelengths, (analogue 11 carriers, digital 11 carriers, Satellite((BS/CS) 24 carriers)



item		
amplifier NF	**6.2 dB**	
OMI/ch (NTSC/BS)	**7.0 %**	**8.8 %**
receiving point C/N(NTSC/BS)	**53.0 dB**	**19.5dB**
transmitter RFout C/N	**55.0 dB**	

	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫
equipment	transmitter	WDM	amplifier	16 splitter	amplifier	16 splitter	amplifier	conn.	trunk	16 splitter	drop cable	V-ONU
input level I_1[dBmW]	RF:80dBuV	6.00	4.50	17.00	2.50	17.00	2.50	17.50	17.00	10.70	-3.30	-3.84
input level I_2[dBmW]	RF:70dBuV	0.00	-1.50	11.00	-3.50	11.00	-3.50	11.50	11.00	4.70	-9.30	-9.84
gain or loss [dB]	-	-1.00	**13.00**	-14.00	**15.00**	-14.00	**15.00**	-0.50	-6.30	-14.00	-0.54	-
output level I_1[dBmW]	**6.00**	5.00	17.50	3.00	17.50	3.00	17.50	17.00	10.70	-3.30	-3.84	RF:80dBuV
output level I_2[dBmW]	**0.00**	-1.00	11.50	-3.00	11.50	-3.00	11.50	11.00	4.70	-9.30	-9.84	
output RIN I_1[dB(Hz-1)]	**-158.10**	←	-152.73	←	-149.46	←	-147.62	←	←	←	←	-
output RIN I_2[dB(Hz-1)]	**-153.00**	←	-146.98	←	-143.57	←	-141.69	←	←	←	←	
channel C/N_1 [dB] note1	-	-	-	-	-	-	-	-	-	-	-	69.60
channel C/N_2 [dB] note1	-	-	-	-	-	-	-	-	-	-	-	#NUM!
channel C/N_2 [dB] note3	-	-	-	-	-	-	-	-	-	-	-	7.00
channel C/N_2 [dB] note4	-	-	-	-	-	-	-	-	-	-	-	#NUM!

note 1: optical channel C/N at the V-ONU RF output, which is calculated from RIN of the optical transmitter and the amplifier.(RIN degradation when λ1 and λ2 are received is considered.
note 2: C/N (NTSC:C/N_1 ,BS:C/N_2) at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N* .
Receiving antenna C/N (BS-D) is the C/N in 99% hour rate of the month with the most precipitation when 75cm φ BS antenna is used.
note 3: Gain tilt depending on input power and wave length of the optical amplifier is NOT considered in the above calculation.

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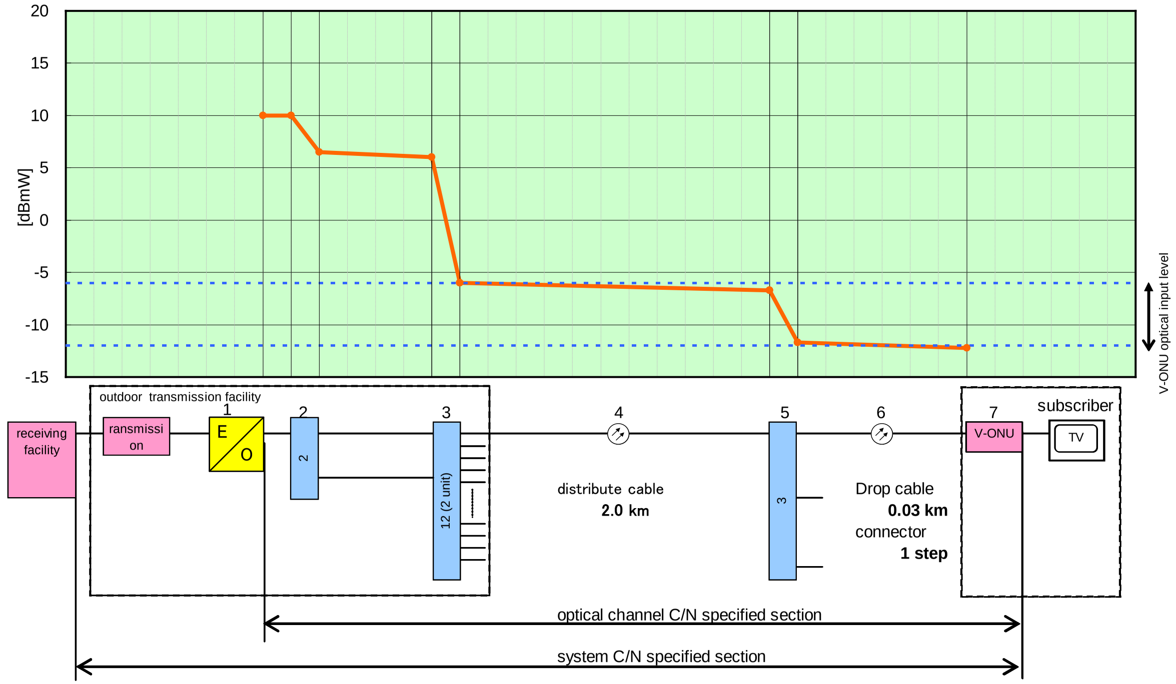
Figure A.9 – System performance calculation Model No.4

Model No.5 Re-transmission service for poor signal reception system without EDFA, OMI: 9,0 %
Direct modulation optical transmitter: 1 Wavelengths, (analogue 9 carriers, digital 9 carriers, BS 12 carriers)



	1	2	3	4	5	6	7
equipment	transmitter	2 to 2 splitter	12 splitter	DIS.	3 splitter	drop cable	V-ONU
input level [dBmW]	RF:80dBuV	10.00	6.00	-6.00	-6.70	-11.70	-12.21
gain or loss [dB]]	-	-3.50	-12.00	-0.70	-5.00	-0.51	-
output level [dBmW]	**10.00**	6.50	-6.00	-6.70	-11.70	-12.21	RF:80dBuV
output RIN [dB(Hz-1)	**-150.00**	←	←	←	←	←	-
channel C/N_1 [dB] note1	-	-	-	-	-	-	44.33
channel C/N_2 [dB] note1	-	-	-	-	-	-	25.91
system C/N_1 [dB] note2	-	-	-	-	-	-	42.52
system C/N_2 [dB] note2	-	-	-	-	-	-	17.69

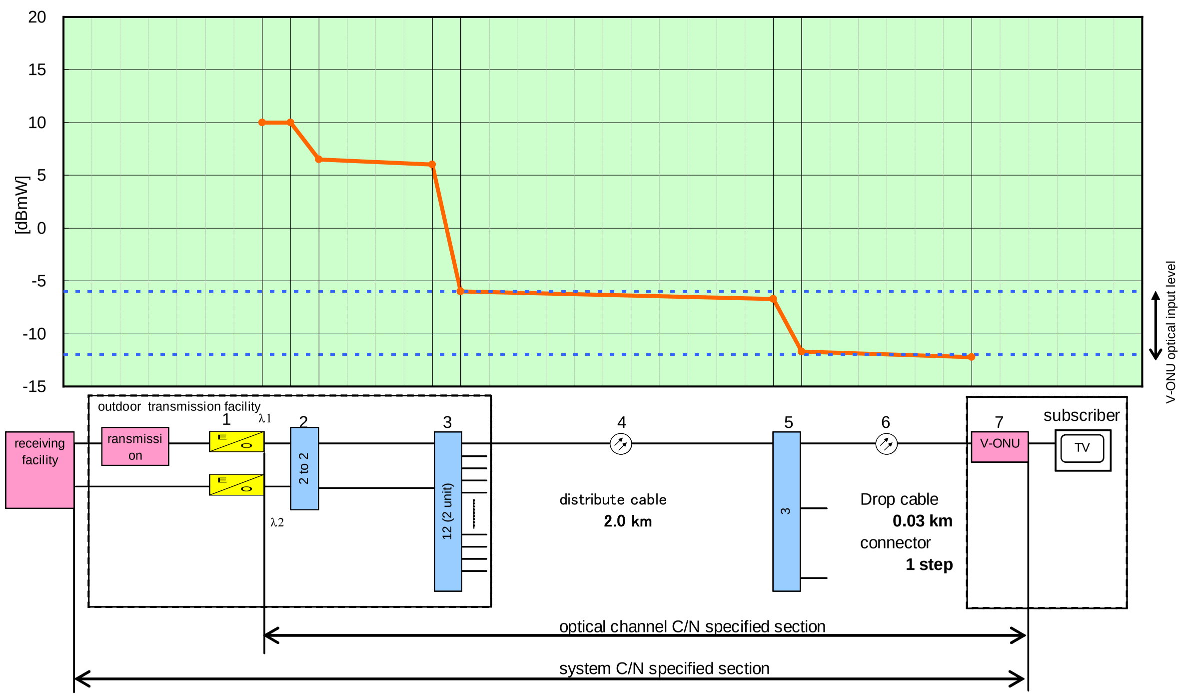
item		
amplifier NF	**6.2 dB**	
OMI/ch (NTSC/BS)	**9.0 %**	**2.9 %**
receiving point C/N(NTSC/BS	**48.0 dB**	**18.4 dB**
transmitter RFout C/N	**55.0 dB**	

note 1: optical channel *C/N* at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier.(RIN degradation when λ1 and λ2 are received is cons
note 2: C/N（NTSC:C/N_1 ,BS:C/N_2 ）at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*
Receiving antenna C/N (BS-D) is the C/N in 99% hour rate of the month with the most precipitation when 45cm φ BS antenna is used.
note 3:Level diagram shows 1-wavelength transmission as the level difference of the 2-wavelength transmission is 0.

IEC 604/12

Figure A.10 – System performance calculation Model No.5

Model No.6 Re-transmission service for poor signal reception system without EDFA, OMI: 9,0 %
Direct modulation optical transmitter: 2 Wavelengths, (analogue 9 carriers, digital 9 carriers, Satellite(BS) 12 carriers)



	1	2	3	4	5	6	7
equipment	transmitter	2 to 2 splitter	12 splitter	DIS.	3 splitter	drop cable	V-ONU
input level [dBmW]	RF:80dBuV	10.00	6.00	-6.00	-6.70	-11.70	-12.21
gain or loss [dB]]	-	-3.50	-12.00	-0.70	-5.00	-0.51	-
output level [dBmW]	**10.00**	6.50	-6.00	-6.70	-11.70	-12.21	RF:80dBuV
output RIN [dB(Hz-1)	**-150.00**	←	←	←	←	←	-
channel C/N_1 [dB] note1	-	-	-	-	-	-	44.33
channel C/N_2 [dB] note1	-	-	-	-	-	-	25.91
system C/N_1 [dB] note2	-	-	-	-	-	-	42.52
system C/N_2 [dB] note2	-	-	-	-	-	-	17.69

item		
amplifier NF	**6.2 dB**	
OMI/ch (NTSC/BS)	**9.0 %**	**2.9 %**
receiving point C/N(NTSC/BS	**48.0 dB**	**18.4 dB**
transmitter RFout C/N	**55.0 dB**	

note 1: optical channel *C/N* at the V-ONU RF output, which is calculated from *RIN* of the optical transmitter and the amplifier.(RIN degradation when λ1 and λ2 are received is considered.)
note 2: C/N（NTSC:C/N_1,BS:C/N_2) at V-ONU RF output, which is calculated from the receiving point *C/N*, transmitter *C/N* and optical channel *C/N*
Receiving antenna C/N (BS-D) is the C/N in 99% hour rate of the month with the most precipitation when 45cm φ BS antenna is used.
note 3:Level diagram shows 1-wavelength transmission as the level difference of the 2-wavelength transmission is 0.

IEC 605/12

Figure A.11 – System performance calculation model No.6

A.6 Tips for actual operation

A.6.1 Optical transmitter

It is necessary to operate with the CS supplementary service facilities to control the SBS (Stimulated Brillouin Scattering) effect. For that purpose a transmitter having the dummy carrier in the vicinity of 2 GHz in the direct intensity modulation method is used.

A.6.2 Optical amplifier

In case of multiple optical wavelength (i.e. WDM system) inputs to an amplifier, the gain tilt effect shall be considered. In general, the wider the wavelength spacing, the larger the gain tilt, and the operation level becomes different. Careful attention is necessary for the level difference between wavelengths in the cascade operation. A 6 dB level difference is assumed between two wavelengths at headend in this system, however, the gain tilt may impair the level difference and finally it becomes difficult to maintain the original level difference. This may degrade the C/N value.

Annex B
(informative)

Wavelength division multiplexing

B.1 Optical wavelength spacing (optical frequency)

The wavelength spacing is defined as follows.

a) DWDM frequency grid (ITU-T G.694.1)

A variety of channel spacing ranging from 12,5 GHz to 100 GHz and wider

b) CWDM wavelength grid (ITU-T G.694.2)

The wavelength spacing is regulated by the central wavelength of the filter, and the wavelength grid is provided at a 20 nm interval.

B.2 Nominal central frequencies and wavelengths

Wavelength (frequency) is defined as follows by two methods. (See ITU-T G.694.1.)

a) DWDM case

For channel spacings of 12,5 GHz on a fibre, the allowed channel frequencies (in THz) are defined by:

f = 193,1 + $n \times$ 0,0125 where n is a positive or negative integer including 0

For channel spacings of 25 GHz on a fibre, the allowed channel frequencies (in THz) are defined by:

f = 193,1 + $n \times$ 0,0250 where n is a positive or negative integer including 0

For channel spacings of 50 GHz on a fibre, the allowed channel frequencies (in THz) are defined by:

f = 193,1 + $n \times$ 0,0500 where n is a positive or negative integer including 0

For channel spacings of 100 GHz or more on a fibre, the allowed channel frequencies (in THz) are defined by:

f = 193,1 + $n \times$ 0,1000 where n is a positive or negative integer including 0

Wavelength can be calculated by the following equation.

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

where

λ [nm];	wavelength
f [GHz];	frequency [GHz]=[10^9 Hz]
c [m/s];	speed of light in vacuum (=2,997 924 58 $\times$ 10^8)

Approximate nominal central wavelengths (nm) are calculated as shown in Table B.1.

Table B.1 – Example nominal central frequencies of the DWDM grid

Approximate nominal central wavelengths nm	**Nominal central frequencies** (THz) **for spacing's of**		**Approximate nominal central wavelengths** nm	**Nominal central frequencies** (THz) **for spacing's of**	
	100 GHz	**200 GHz**		**100 GHz**	**200 GHz**
1 624,89	184,5	184,5	1 575,37	190,3	190,3
1 624,01	184,6		1 574,54	190,4	
1 623,13	184,7	184,7	1 573,71	190,5	190,5
1 622,25	184,8		1 572,89	190,6	
1 621,38	184,9	184,9	1 572,06	190,7	190,7
1 620,50	185,0		1 571,24	190,8	
1 619,62	185,1	185,1	1 570,42	190,9	190,9
1 618,75	185,2		1 569,59	191,0	
1 617,88	185,3	185,3	1 568,77	191,1	191,1
1 617,00	185,4		1 567,95	191,2	
1 616,13	185,5	185,5	1 567,13	191,3	191,3
1 615,26	185,6		1 566,31	191,4	
1 614,39	185,7	185,7	1 565,50	191,5	191,5
1 613,52	185,S		1 564,68	191,6	
1 612,65	185,9	185,9	1 563,86	191,7	191,7
1 611,79	186,0		1 563,05	191,8	
1 610,92	186,1	186,1	1 562,23	191,9	191,9
1 610,06	186,2		1 561,42	192,0	
1 609,19	186,3	186,3	1 560,61	192,1	192,1
1 608,33	186-4		1 559,79	192,2	
1 607,47	186,5	186,5	1 558,98	192,3	192,3
1 606,60	186,6		1 558,17	192,4	
1 605,74	186,7	186,7	1 557,36	192,5	192,5
1 604,88	186,8		1 556,55	192,6	
1 504,03	186,9	186,9	1 555,75	192,7	192,7
1 603,17	187,0		1 554,94	192,8	
1 602,31	187,1	187,1	1 554,13	192,9	192,9
1 601,46	187,2		1 553,33	193,0	
1 600,60	187,3	187,3	1 552,52	193,1	193,1
1 599,75	187,4		1 551,72	193,2	
1 598,89	187,5	187,5	1 550,92	193,3	193,3

Approximate nominal central wavelengths nm	**Nominal central frequencies** (THz) **for spacing's of**	
	100 GHz	**200 GHz**
1 598,04	187,6	
1 597,19	187,7	187,7
1 596,34	187,8	
1 595,49	187,9	187,9
1 594,64	188,0	
1 593,79	188,1	188,1
1 592,95	188,2	
1 592,10	188,3	188,3
1 591,26	188-4	
1 590,41	188,5	188,5
1 589,57	188,6	
1 588,73	188,7	188,7
1 587,88	188,8	
1 587,04	188,9	188,9
1 586,20	189,0	
1 585,36	189,1	189,1
1 584,53	189,2	
1 583,69	189,3	189,3
1 582,85	189,4	
1 582,02	189,5	189,5
1 581,18	189,6	
1 580,35	189,7	189,7
1 579,52	189,8	
1 578,69	189,9	189,9
1 577,86	190,0	
1 577,03	190,1	190,1

Approximate nominal central wavelengths nm	**Nominal central frequencies** (THz) **for spacing's of**	
	100 GHz	**200 GHz**
1 550,12	193,4	
1 549,32	193,5	193,5
1 548,51	193,6	
1 547,72	193,7	193,7
1 546,92	193,8	
1 546,12	193,9	193,9
1 545,32	194,0	
1 544,53	194,1	194,1
1 543,73	194,2	
1 542,94	194,3	194,3
1 542,14	194,4	
1 541,35	194,5	194,5
1 540,56	194,6	
1 539,77	194,7	194,7
1 538,98	194,8	
1 538,19	194,9	194,9
1 537,40	195,0	
1 536,61	195,1	195,1
1 535,82	195,2	
1 535,04	195,3	195,3
1 534,25	195,4	
1 533,47	195,5	195,5
1 532,68	195,6	
1 531,90	195,7	195,7
1 531,12	195,8	
1 530,33	195,9	195,9

b) **CWDM case**

Wavelength is defined as shown in Table B.2 (ITU-T G.694.2)

Table B.2 – Nominal central wavelength for spacing of 20 nm (ITU-T G.694.2)

Wavelength of laser diode nm	**Nominal central wavelengths** (nm) **for spacing of 20 nm**	**Channel spacing** nm
1 530 band	1 531	1 524,5 to 1 537,5
1 550 band	1 551	1 544,5 to 1 557,5
1 570 band	1 571	1 564,5 to 1 577,5
1 590 band	1 591	1 584,5 to 1 597,5
1 610 band	1 611	1 604,5 to 1 617,5

B.3 Notes of wavelength division multiplexing

B.3.1 Crosstalk between two wavelength

When multiple wavelength signals are transmitted in one fibre, crosstalk is generated. It is classified into linear and non-linear type.

a) **Linear cross talk**

Linear crosstalk is caused by the insufficient separation of wavelength of WDM filter. The residual frequency component of other wavelength signals appears at the receiving side due to insufficient separation.

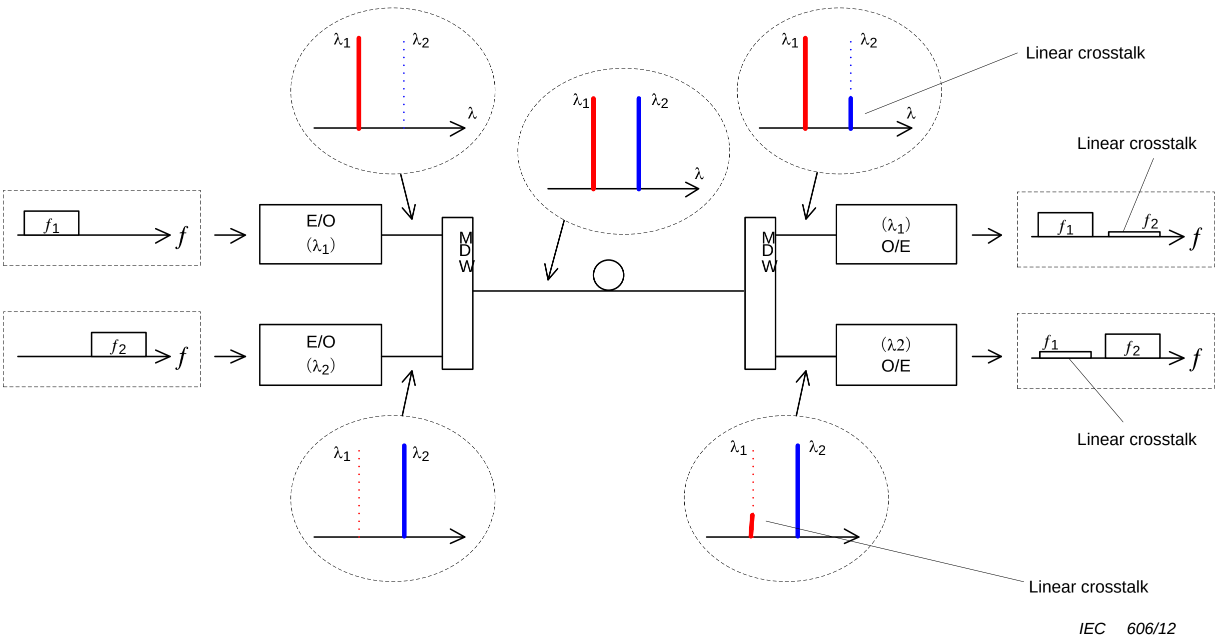


Figure B.1 – Linear crosstalk between two wavelengths

b) **Non-linear cross talk**

The typical non-linear crosstalk is the Raman crosstalk which appears in the fibre itself. SRS (Stimulated Raman Scattering) is the cause of this Raman crosstalk. The Raman crosstalk is worst when the wavelength spacing is 13 THz (100 nm), as shown in Figure B.2. This phenomenon occurs whenever the optical signals are transmitted in the optical fibre, and it is not possible to remove the residual frequency component of other wavelengths by the wavelength separation filter, as shown in Figure B.3. XPM (Cross Phase Modulation) is another cause of non-linear crosstalk between different wavelengths signals, and the interference level may become significant in the case of high frequency usage (or small $\Delta\lambda$ wavelength separation), as shown in Figure B.4. However, it is generally negligibly small for the FTTH system described in this standard in case of use of different frequencies, i.e. below and above 1 GHz.

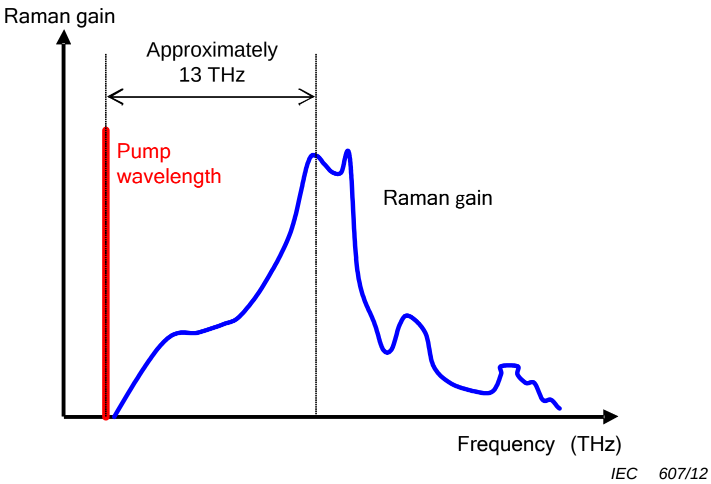


Figure B.2 – Wavelength dependency of Raman crosstalk

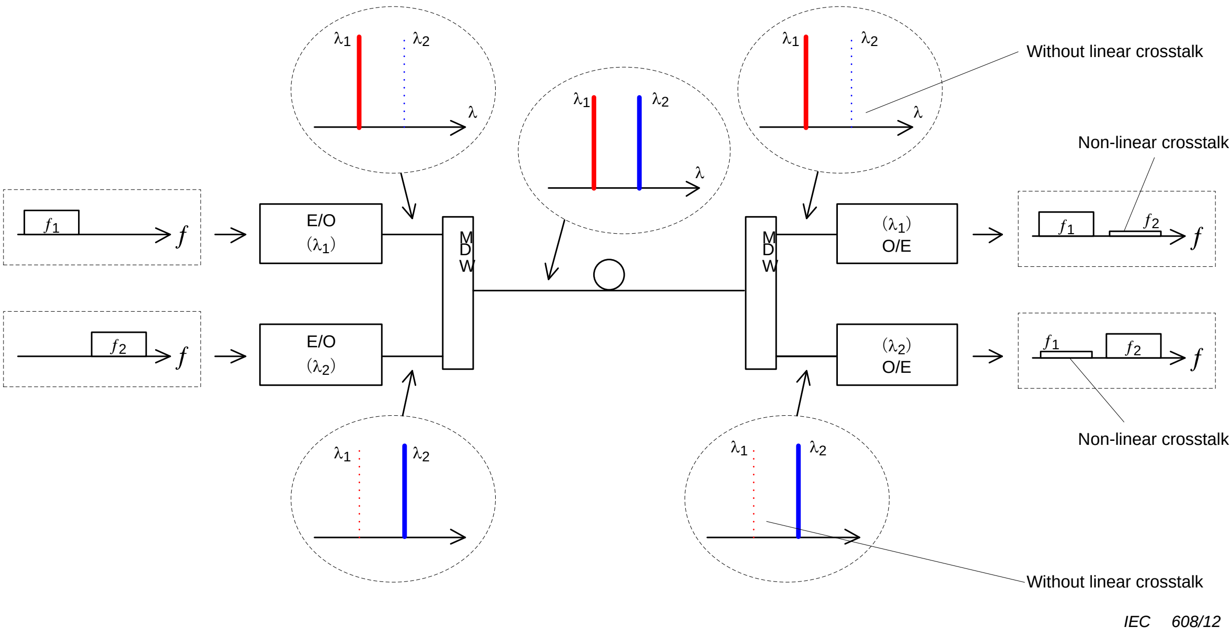
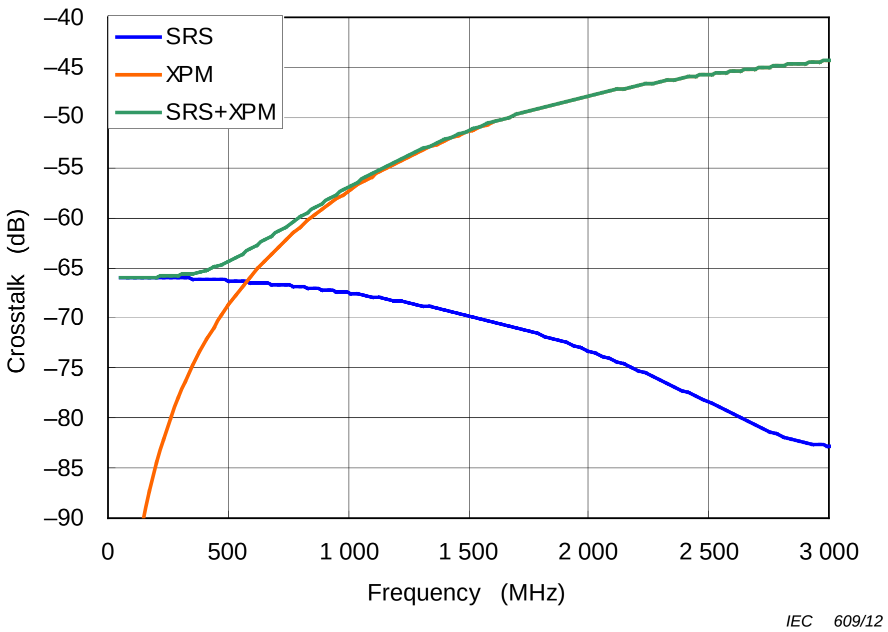


Figure B.3 – Nonlinear crosstalk between two wavelengths



NOTE Provided that wavelength λ_1 = 1 555,00 nm, λ_2 = 1 554,00 nm, fibre length = 20 km and optical input power to fibre = 10 dB(mW).

Figure B.4 – Frequency dependency of cross phase modulation

B.3.2 Receiving two wavelengths by single V-ONU

When optical signals on the different two wavelengths are received by single V-ONU, the level difference of two RF signals (ΔC in dB) can be described as follows.

$$\Delta C = 2 \cdot 10 \cdot \lg\left(\frac{P_2}{P_1}\right) + 20 \cdot \lg\left(\frac{m_2}{m_1}\right) \tag{B.1}$$

where

m_k is the optical modulation index of k_{th} wavelength,

P_k is the optical input level of k_{th} wavelength in watt (W).

Figure B.5 illustrates the C/N degradation when optical signals on the two wavelengths are received by one V-ONU. The noise is accumulated by not only each λ_1 and λ_2, but also by mutual interference between λ_1 and λ_2. The calculation method of these total C/N are described in 6.5.5.

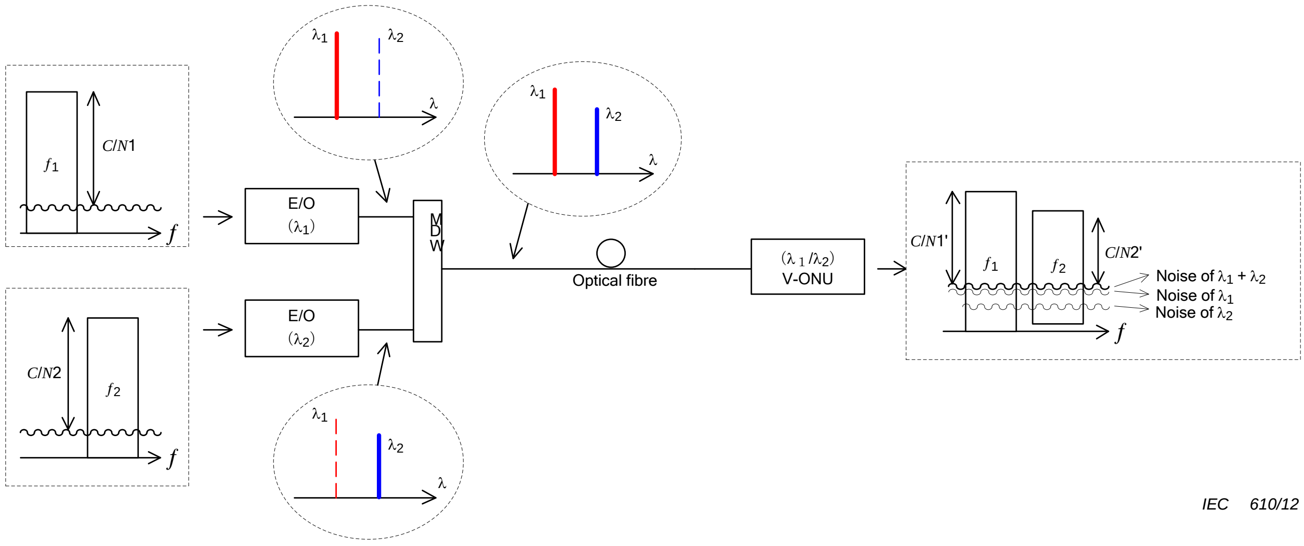


Figure B.5 – *C*/*N* degradation (two wavelengths into one V-ONU case)

Annex C
(informative)

Minimum wavelength separation

C.1 Optical beat interference

When multiplexed signals of two wavelengths are received by a single optical receiver, the optical beat interference component called beat noise ($RIN_{\Delta\lambda}$) will be generated at a frequency centered around the difference in wavelength (frequency) of the two signals. The centre frequency, f_{beat} of the optical beat noise is given by the following formula.

$$f_{\text{beat}} = \frac{c\left|\lambda_i - \lambda_{i+1}\right|}{\lambda_i \cdot \lambda_{i+1}} \tag{C.1}$$

where

c is the velocity of light in vacuum, 2,997 924 58 × 10^8 (m/s)

Also, the optical beat noise ($RIN_{\Delta\lambda}$) can be expressed using the following formula.

$$RIN_{\Delta\lambda} = 10 \text{ lg}\left\{\frac{2}{\pi}\cdot\frac{\Delta v}{(\Delta F - f)^2 + \Delta v}\right\}\text{(dB)} \tag{C.2}$$

where

ΔF is the frequency equivalent of wavelength difference,

Δv is the spectral width of the optical signal,

f is any frequency for the calculation of RIN.

In Figure C.1 experimental results of RIN degradation due to optical beat is plotted against the offset frequency (difference between centre frequency of optical beat and RF frequency transmitted through the optical signal). For example, if the optical signal is modulated by an RF frequency of 2,5 GHz (assuming the total optical modulation index = 30 %), and if the required RIN is –140 dB(Hz^{-1}), then the centre frequency of beat noise should be,

$$f_{\text{beat}} \geq 25 \text{ GHz} \tag{C.3}$$

25 GHz corresponds to 0,20 nm at 1 550 nm band. Therefore, it is sufficient that if the two wavelengths are separated by 0,20 nm to avoid the effect of noise due to optical beat interference. However, in a large scale FTTH system, such as satellite signal transmission, the RIN required value is less than –150 dB(Hz^{-1}). In this case, the wavelength separation required, including allowance, is at least 0,3 nm. In the actual DWDM wavelengths system (see ITU-T100GHz Grid), the wavelength separation will be approximately 0,8 nm, and there is no need to consider the optical beat interference. Similarly, for the CWDM wavelengths system, the wavelength separation will be 20 nm and again there is no need to take into account the optical beat interference.

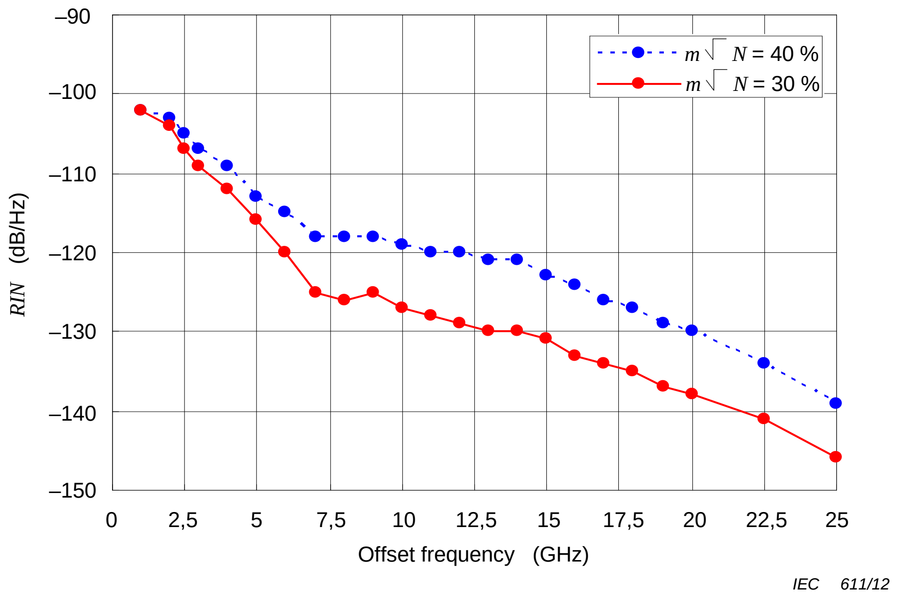


Figure C.1 – Experimental results of *RIN* degradation due to optical beat

Another type of optical WDM system may contain transmitters with automatic temperature control (ATC) function. The 100 GHz ITU-T grid system requires the wavelength separation between the multiplexed optical signals at at least 0,8 nm. In order to meet this requirement, the wavelengths variation is assumed to be 0,2 nm for an ATC circuit, 0,3 nm for long-term usage and 0,3 nm for general tolerance in an actual system.

C.2 Range of wavelengths variation

Optical transmitters may contain an ATC device to control the variation of optical wavelengths against temperature. A DWDM transmitter usually has ATC to minimize the wavelength variation. However, a typical CWDM transmitter does not employ ATC, as a result, the wavelength may shift 0,1 nm to the longer (or shorter) wavelength side if the temperature increases (or decreases) by 1 °C.

Experimental results on the variation of optical wavelengths in DWDM transmitters is shown in Figure C.2, and for CWDM transmitters, in Figure C.3.

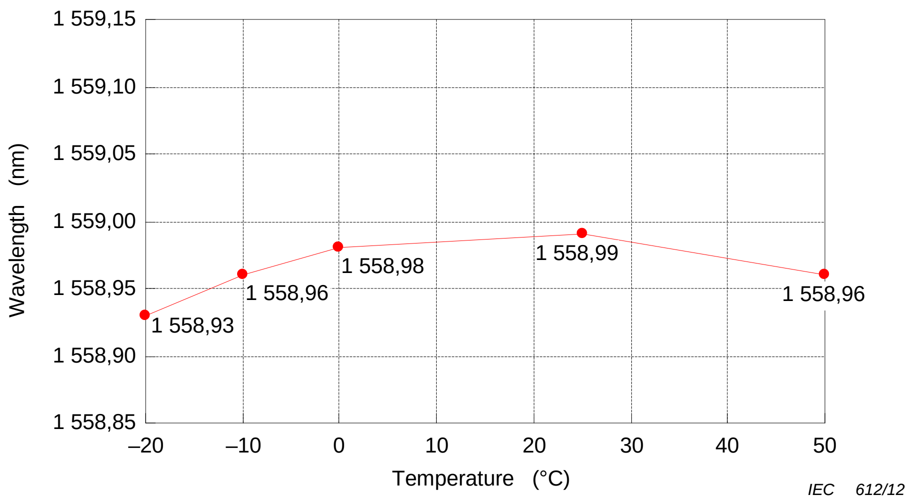


Figure C.2 – Wavelength variation of DWDM transmitter against ambient temperature

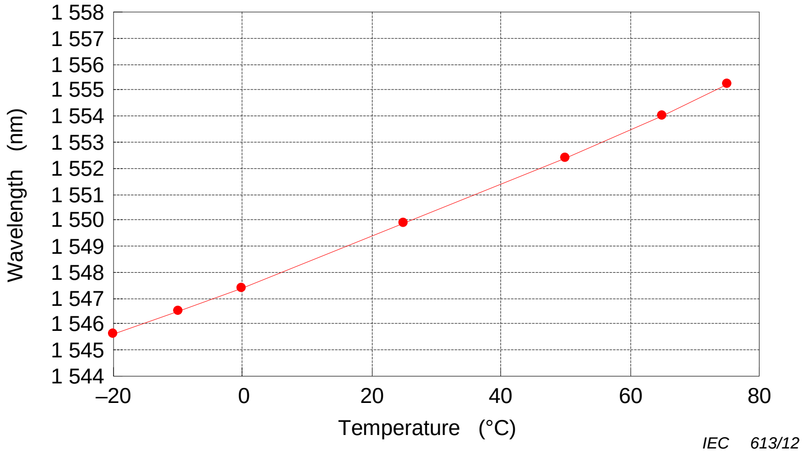


Figure C.3 – Wavelength variation of CWDM transmitter against ambient temperature

C.3 WDM system using optical filters and couplers

A WDM system can be designed with a WDM filter or an optical coupler. For a WDM system with a WDM filter, care shall be taken that the wavelengths variation does not exceed the pass bandwidth of the WDM filter, as illustrated in Figure C.4. Figure C.5 shows a CWDM filter design taking the temperature and LD wavelengths variation into account. Figure C.6 shows an example of a wavelength division multiplex system using an optical coupler. The wavelength separation shall be kept at at least 0,3 nm.

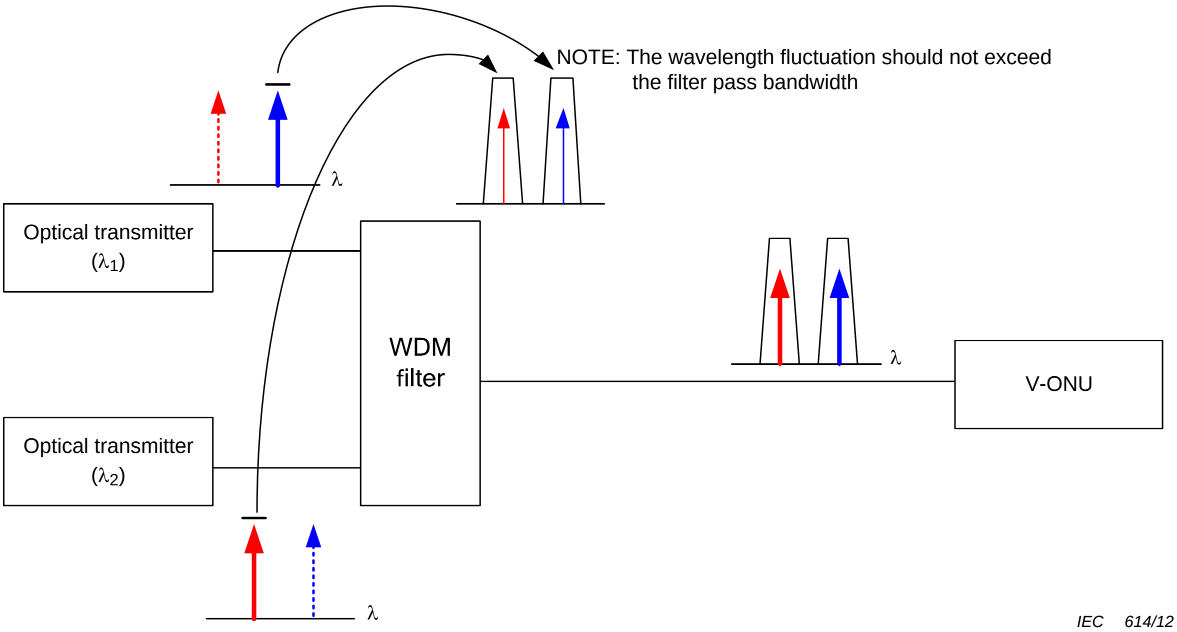


Figure C.4 – Example of wavelength division multiplexing using WDM filter

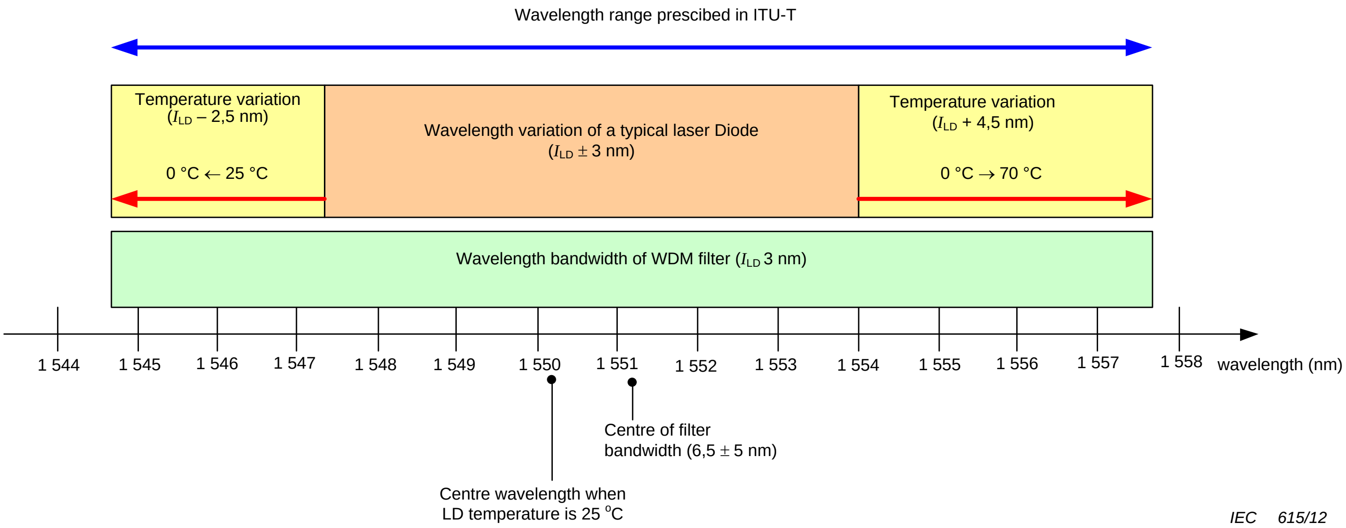


Figure C.5 – Example of CWDM filter design

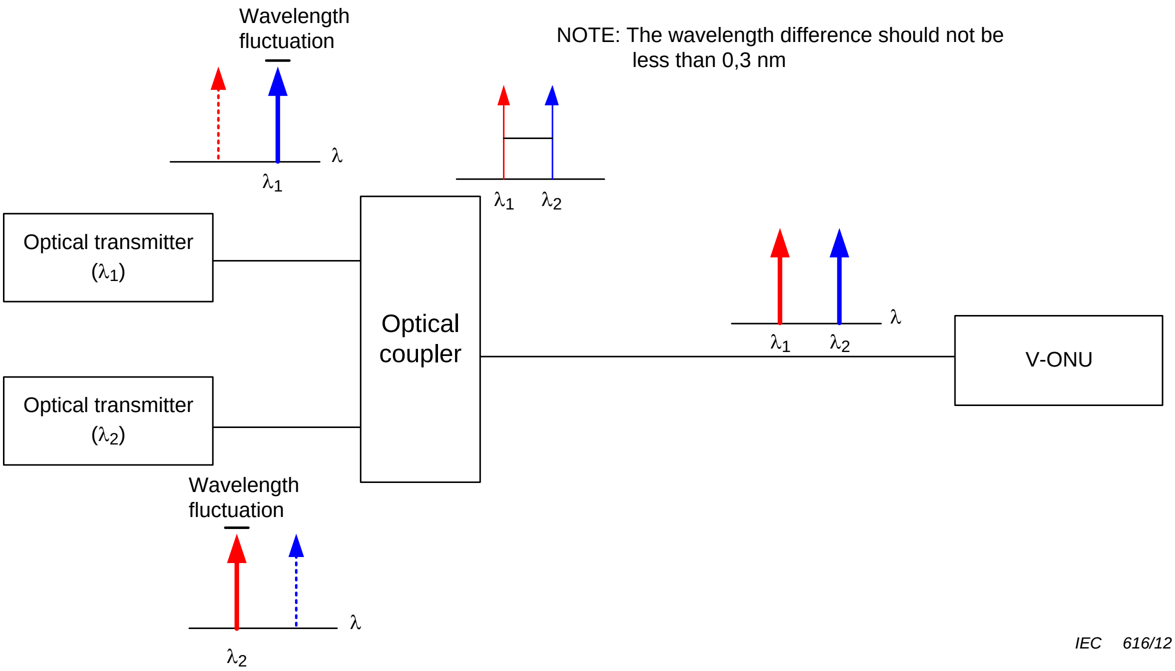


Figure C.6 – Example of wavelength division multiplexing using optical coupler

Annex D
(informative)

Relation between *C*/*N* degradation and rain attenuation

The ratio of antenna aerial gain to the noise temperature of receiving system, *G*/*T* is related to *C*/*N* by the following formula.

$$G/T = \left[\frac{C/N \times k \times B}{EIRP \times L_\mathrm{S} \times R \times N_\mathrm{U}}\right] \tag{D.1}$$

and the *C*/*N* is given by,

$$C/N = \left[\frac{G/T \times EIRP \times L_\mathrm{S} \times R \times N_\mathrm{U}}{k \times B}\right] \tag{D.2}$$

where

k	Boltzmann's constant
B	channel bandwidth
$EIRP$	equivalent isotropically radiated power
L_S	propagation loss in the free space
R	rain attenuation
N_U	receiving *C*/*N* degradation due to uplink *C*/*N*

G/*T* can be expressed by the following expression.

$$\begin{aligned} G/T &= \left[\frac{\alpha \times \beta \times G_\mathrm{r}}{\alpha \times T_\mathrm{a} + (1-\alpha) \times T_0 + (F-1) \times T_0}\right] \\ &= \left[\frac{\alpha \times \beta \times G_r}{\alpha \times T_\mathrm{a} + (F-\alpha) \times T_0}\right] \end{aligned} \tag{D.3}$$

where

α	coupling loss
β	pointing loss
G_r	gain of receiving antenna
T_a	noise temperature of receiving antenna
T_0	reference temperature
F	noise temperature of the receiving system

C/*N* degradation due to rain attenuation is defined as the difference between *C*/*N* during clear weather and *C*/*N* during rainy weather.

$$C/N \text{ degradation } = C/N_1 - C/N_2$$

$$= 10\lg\left[\frac{G/T_1 \times EIRP \times L_\mathrm{S} \times N_\mathrm{U}}{k \times B}\right] - 10\lg\left[\frac{G/T_2 \times EIRP \times L_\mathrm{S} \times R \times N_\mathrm{U}}{k \times B}\right]$$

$$= 10\lg[G/T_1] - 10\lg[G/T_2] - 10\lg[R]$$

$$= 10\lg\left[\frac{\alpha \times Ta_2 + (F-\alpha) \times T_0}{\alpha \times Ta_1 + (F-\alpha) \times T_0}\right] - 10\lg[R] \text{(dB)} \qquad \text{(D.4)}$$

where

C/N_1 *C*/*N* value during clear weather

C/N_2 *C*/*N* value during rainy weather

G/T_1 *G*/*T* value during clear weather

G/T_2 *G*/*T* value during rainy weather

Assuming the noise temperature, Ta_1 of the receiving antenna during clear weather to be 50 K, the noise temperature, Ta_2 of the receiving antenna during rainy weather can be expressed by the following relation.

$$Ta_2 = 50 \times R + (1 - R) \times T_0 \qquad \text{(D.5)}$$

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