

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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

**Réseaux de distribution par câbles pour signaux de télévision, signaux de
radiodiffusion sonore et services interactifs –
Partie 113: Systèmes optiques pour la transmission de signaux de radiodiffusion
soumis à une charge de porteuses exclusivement numériques**



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CONTENTS

FOREWORD.....	8
INTRODUCTION.....	10
1 Scope.....	11
2 Normative references	11
3 Terms, definitions, graphical symbols and abbreviated terms.....	12
3.1 Terms and definitions.....	12
3.2 Graphical symbols	19
3.3 Abbreviated terms.....	20
4 Optical system reference model.....	21
4.1 Overview.....	21
4.2 Over-all FTTH system reference model	21
4.3 Reference models for the optical systems for broadcast signal transmissions	24
4.3.1 Optical wavelength for FTTH system	24
4.3.2 Reference models.....	24
4.4 Specified performance points of the optical system	25
5 Preparation of measurement.....	25
5.1 Environmental conditions	25
5.1.1 Standard measurement conditions	25
5.1.2 Temperature and humidity	26
5.1.3 Setting up the measuring setup and system under test	26
5.1.4 AGC/ALC operation	26
5.1.5 Impedance matching between pieces of equipment	26
5.1.6 Standard operating condition	26
5.1.7 Standard signal and measuring equipment	26
5.2 Accuracy of measuring equipment	27
5.3 Source power.....	27
6 Methods of measurement	27
6.1 Measuring points and items	27
6.1.1 General	27
6.1.2 Measuring points	28
6.1.3 Measured parameters.....	28
6.2 General measurement requirement.....	29
6.2.1 General	29
6.2.2 Input specification.....	29
6.2.3 Standard measurement conditions	29
6.2.4 Precautions for measurements	30
6.3 Optical power.....	30
6.3.1 General	30
6.3.2 Measuring setup	30
6.3.3 Measuring method	31
6.3.4 Precautions for measurement	31
6.3.5 Presentation of the results	31
6.4 Optical wavelength.....	32
6.4.1 Introduction	32
6.4.2 Method of measurement	32
6.4.3 Presentation of the results	32

6.5	SINR (signal-to-intermodulation and noise ratio) below 1GHz	32
6.5.1	General	32
6.5.2	Measuring setup	33
6.5.3	Measuring conditions	33
6.5.4	Precautions for measurement	33
6.5.5	Presentation of the results	34
6.6	Relative intensity noise (RIN) of optical signal	34
6.6.1	General	34
6.6.2	Measuring setup	34
6.6.3	Measurement conditions	35
6.6.4	System RIN measuring method	35
6.6.5	SINR calculation based on RIN value	37
6.6.6	Component RIN calculation	37
6.6.7	Example for calculating of SINR	39
6.7	Optical modulation index	41
6.8	Signal-to-crosstalk ratio (SCR)	41
6.8.1	General	41
6.8.2	Equipment required	41
6.8.3	General measurement requirements	41
6.8.4	Procedure	41
6.8.5	Potential sources of error	42
6.8.6	Presentation of the results	42
6.9	RF signal-to-intermodulation and noise ratio (SINR) of satellite broadcast signals	42
6.9.1	General	42
6.9.2	Measuring setup	43
6.9.3	Equipment required	43
6.9.4	Measurement procedure	43
6.9.5	Presentation of the results	44
6.10	System BER (bit error ratio)	44
6.10.1	Overview	44
6.10.2	Connection of the equipment	44
6.10.3	Measurement procedure	45
6.10.4	Presentation of the results	45
6.11	SINR versus BER measurement	45
6.11.1	General	45
6.11.2	Connection of the equipment	45
6.11.3	Presentation of the results	46
6.12	System noise margins	47
6.12.1	General	47
6.12.2	Connection of the equipment	47
6.12.3	Measurement procedure	48
6.12.4	Presentation of the results	48
6.13	Modulation error ratio (MER)	49
6.13.1	General	49
6.13.2	Connection of the equipment	49
6.13.3	Measurement procedure	50
6.13.4	Presentation of the results	50
6.14	In-band frequency characteristics between optical transmitter and V-ONU	50

6.14.1	Overview	50
6.14.2	Measurement setup	50
6.14.3	Measuring method	51
6.14.4	Presentation of the results	51
7	Specification of the optical system for broadcast signal transmission.....	52
7.1	Digital broadcast system over optical network.....	52
7.2	RF signal levels at system outlet.....	52
7.3	RF signal-to-intermodulation and noise ratio and performance allocation	53
7.4	Relationship between RIN and SINR.....	58
7.4.1	Type of broadcast services	58
7.4.2	Types of broadcast services and relative signal level.....	59
7.4.3	RIN performance requirements	60
7.5	Optical wavelength.....	62
7.6	Frequency of source signal	63
7.7	Level difference between adjacent channels	63
7.8	BER at headend input	65
7.9	MER	65
7.10	SINR specification for in-house and in-building wirings	66
7.11	In-band frequency characteristics	68
7.12	Electrical signal interference	69
7.13	Crosstalk due to optical fibre non-linearity	71
7.14	Interference due to intermodulation noise caused by fibre non-linearity.....	72
7.15	Environmental conditions	72
Annex A	(informative) Actual service systems and design considerations	73
A.1	General.....	73
A.2	Multi-channel service system	73
A.2.1	General	73
A.2.2	Operating conditions.....	74
A.2.3	Operating environment	74
A.3	Re-transmission service system.....	75
A.3.1	General	75
A.3.2	Operating conditions.....	75
A.3.3	Operating environment	76
A.4	SINR calculation of optical network.....	76
A.5	System reference model	77
A.6	Hints for actual operation	81
A.6.1	Optimum operation	81
A.6.2	Key issues to be specified	81
Annex B	(informative) BER extrapolation method	82
Annex C	(informative) Optical system degradations	84
C.1	System degradation factors.....	84
C.2	Non-linear degradation	85
C.2.1	Degradation factors	85
C.2.2	Stimulated Brillouin scattering (SBS)	85
C.2.3	Stimulated Raman scattering (SRS).....	86
C.2.4	Self-phase modulation (SPM)	89
C.2.5	Cross-phase modulation (XPM)	89

Annex D (informative) Measurement of parameters (R , I_{d0} , I_{eq} and G) required for RIN calculation	90
D.1 Measurement of the responsivity (R)	90
D.2 Measurement of dark current (I_{d0})	90
D.3 Measurement of equivalent noise current density (I_{eq})	90
D.4 Measurement of gain (G)	91
Annex E (informative) Measurement of peak and average signal levels of digitally modulated signals	92
E.1 General	92
E.2 Peak and average power measurement using CCDF	92
E.3 Measurement method of CCDF	94
E.3.1 General	94
E.3.2 Measurement procedure	94
E.3.3 Estimation of BER from the CCDF measurement result	95
E.3.4 Examples of CCDF measurements	96
E.4 Performance evaluation of the FTTH system	97
E.4.1 General	97
E.4.2 Evaluation procedure	97
E.5 Potential sources of error	98
Annex F (informative) Clipping noise	99
Annex G (informative) Relation between SINR degradation and rain attenuation	100
G.1 Relation between SINR and G/T	100
G.2 SINR degradation of satellite receiving system due to rain attenuation	101
Bibliography	102
Figure 1 – Example of FTTH system for television and sound signal	23
Figure 2 – FTTH Cable TV system using one wavelength	25
Figure 3 – FTTH Cable TV system using two wavelengths	25
Figure 4 – Specified performance points of the optical system	25
Figure 5 – Typical optical video distribution system	28
Figure 6 – Test setup for optical power measurement using a wavelength filter	30
Figure 7 – Test setup for optical power measuring using a WDM coupler	31
Figure 8 – Measurement of optical wavelength without a WDM coupler	32
Figure 9 – Measurement of optical wavelength using a WDM coupler	32
Figure 10 – Test setup for RF signal to intermodulation and noise ratio measurement	33
Figure 11 – Test setup for RIN measurement	35
Figure 12 – Test setup for signal to crosstalk measurement	41
Figure 13 – Setup for the measurement of SINR for satellite broadcast signals	43
Figure 14 – Test setup for BER measurement	44
Figure 15 – Test setup for SINR versus BER measurement procedure	45
Figure 16 – Extrapolation method of BER measurement	46
Figure 17 – Example of SINR versus BER characteristics	47
Figure 18 – Test setup for system noise margin measurement	48
Figure 19 – Example of system noise margin characteristics	49
Figure 20 – Test setup for MER measurement	49

Figure 21 – Example of result of MER measurement (64-QAM modulation format).....	50
Figure 22 – Setup for the measurement of in-band frequency characteristics	51
Figure 23 – Measurement example of in-band frequency characteristics	51
Figure 24 – Performance specified points	52
Figure 25 – Permissible signal level of adjacent channels (ISDB-T, ISDB-C and ISDB-C2)	64
Figure 26 – Section SINR for SDU wiring (specified by electrical signal)	67
Figure 27 – Section SINR for MDU wiring (specified by electrical signal)	68
Figure 28 – Section SINR for MDU wiring (specified by optical signal)	68
Figure 29 – Signal level difference with 3rd order interference signal (ISDB-T)	69
Figure 30 – Signal level difference with 3rd order interference signal (ISDB-C 64QAM)	70
Figure 31 – Signal level difference with 3rd order interference signal (ISDB-C 256QAM)	70
Figure 32 – Level difference between signal and reflected (echo) signal (ISDB-T)	70
Figure 33 – Level difference between signal and reflected (echo) signal (ISDB-C 64QAM)	71
Figure 34 – Level difference between signal and reflected (echo) signal (ISDB-C 256QAM)	71
Figure A.1 – Example of a multi-channel service system of one million terminals	73
Figure A.2 – Example of a multi-channel service system of 2 000 terminals	74
Figure A.3 – Example of re-transmission service system of 72 terminals.....	75
Figure A.4 – Example of re-transmission service system of 144 terminals.....	75
Figure A.5 – Model 1 system performance calculation.....	79
Figure A.6 – Model 4 system performance calculation.....	80
Figure B.1 – Extrapolation method of BER measurement	82
Figure B.2 – BER characteristics for 256-QAM, 1 024-QAM and 4 096-QAM (extrapolation method)	83
Figure C.1 – Reflection model.....	84
Figure C.2 – Degradation factors of optical transmission system.....	85
Figure C.3 – SBS generation image	85
Figure C.4 – Interference between two wavelengths	87
Figure C.5 – Simulation of SRS (OLT transmission power versus D/U)	87
Figure C.6 – Simulation of SRS (D/U in arbitrary unit versus fibre length)	88
Figure C.7 – Fibre length of the first peak of SRS D/U versus frequency.....	88
Figure C.8 – GE-PON idle pattern spectrum (ISO/IEC/IEEE 8802-3:2017 1 000 Base-PX) (62,5 MHz = 1 250 Mbps/20 bit).....	89
Figure D.1 – Measurement of gain (G)	91
Figure E.1 – Typical CCDF curves for OFDM and M-QAM signals.....	93
Figure E.2 – CCDF measurement setup	94
Figure E.3 – CCDF measurement example	95
Figure E.4 – SER vs SINR performance in an AWGN channel	96
Figure E.5 – Example of CCDF measurements	96
Figure E.6 – Performance evaluation of digital optical signals in the FTTH system.....	97
Figure E.7 – CCDF measurement bandwidth.....	97
Figure F.1 – Clipping effects in laser diode static curve (IL curve).....	99
Figure F.2 – Clipping noise, zero span, sweep time 100 μ s.....	99

Table 1 – Level of RF signals.....	16
Table 2 – Optical wavelength for FTTH system	24
Table 3 – Frequency range	24
Table 4 – Measuring equipment	27
Table 5 – Measuring points and measured parameters	29
Table 6 – Parameters used for the calculation of SINR	39
Table 7 – RF signal noise bandwidth	40
Table 8 – Digital signal levels at the system outlet	53
Table 9 – Minimum SINR (SDU case)	54
Table 10 – Minimum SINR (MDU case)	55
Table 11 – Minimum RF SINR requirements in operation	56
Table 12 – Types of broadcast services	58
Table 13 – Types of broadcast services and relative signal level	60
Table 14 – Minimum operational RIN values for digital broadcast services using the frequency band below 1 000 MHz	60
Table 15 – Type of service and minimum operational RIN values for satellite services	61
Table 16 – Performance of optical wavelength and power	62
Table 17 – Minimum MER Performance ^a for FTTH systems	66
Table 18– Section SINR for in-house/in-building wiring	67
Table 19 – In-band frequency characteristics specification.....	68
Table 20 – Limits for in-channel electrical signal interference	69
Table 21 – Interference level due to fibre non-linearity	72
Table 22 – Environmental conditions	72
Table A.1 – Operating conditions of a multi-channel service system	74
Table A.2 – Operating conditions of re-transmission service system	76
Table A.3 – Basic system parameters for multi-channel and re-transmission service systems	78
Table C.1 – Disturbance parameter of Raman crosstalk.....	86

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**CABLE NETWORKS FOR TELEVISION SIGNALS,
SOUND SIGNALS AND INTERACTIVE SERVICES –****Part 113: Optical systems for broadcast signal
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IEC 60728-113 has been prepared by technical area 5: Cable networks for television signals, sound signals and interactive services, of IEC technical committee 100: Audio, video and multimedia systems and equipment. It is an International Standard.

This second edition cancels and replaces the first edition published in 2018 and IEC 60728-13-1:2017. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) IEC 60728-13-1, which deals with the bandwidth expansion for broadcast signal over FTTH systems, has been merged with this document;
- b) a table containing the digital signal level at the system outlet (Table 8) has been added.

The text of this International Standard is based on the following documents:

Draft	Report on voting
100/3900/FDIS	100/3920/RVD

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

The language used for the development of this International Standard is English.

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

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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INTRODUCTION

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

This includes, for instance:

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

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

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

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

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

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

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

1 Scope

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

In this document, the upper signal frequency is limited to about 3 300 MHz.

The purpose of this part of IEC 60728 is to describe the system specifications of FTTH (fibre to the home) networks for digitally modulated broadcast signal transmission. This document is also applicable to broadcast signal transmission using a telecommunication network if it satisfies the performance of the optical portion of the system defined in this document. This document describes RF transmission for fully digitalized broadcast and narrowcast (limited area distribution of broadcast) signals over FTTH, and introduces the xPON system as a physical layer media. The detailed description of the physical layer is out of scope of this document. The scope is limited to downstream RF video signal transmission over FTTH; IP transport technologies, such as IP Multicast and associate protocols, which require a two-way optical transmission system, are out of scope of this document.

Some interference effects occurring between the telecommunication system and the broadcast system are addressed in Clause 7.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-1:2013, *Environmental testing – Part 1: General and guidance*

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

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

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

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

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

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

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

IEC 61280-1-1:2013, *Fibre optic communication subsystem basic test procedures – Part 1-1: Test procedures for general communication subsystems – Transmitter output optical power measurement for single-mode optical fibre cable*

IEC 61280-1-3, *Fibre optic communication subsystem test procedures – Part 1-3: General communication subsystems – Measurement of central wavelength, spectral width and additional spectral characteristics*

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

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

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

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

ITU-T Recommendation J.183, *Time-division multiplexing of multiple MPEG-2 transport streams and generic formats of transport streams over cable television systems*

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

3 Terms, definitions, graphical symbols and abbreviated terms

3.1 Terms and definitions

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

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

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

3.1.1

BER

bit error ratio

ratio between erroneous bits and the total number of transmitted bits

[SOURCE: IEC 60728-1:2014, 3.1.9]

3.1.2**central wavelength**

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

[SOURCE: IEC 60728-6:2011, 3.1.23, modified – The term "centre wavelength" has been replaced by "central wavelength".]

3.1.3**D/U ratio**

single or multiple frequency interference ratio of desired signal level to undesired signal level

Note 1 to entry: The ratio of desired signal level, $D(\text{dB}(\mu\text{V}))$, to undesired signal level, $U(\text{dB}(\mu\text{V}))$ is given by

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

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

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

Note 4 to entry: Note the similarity of the definition to the definition of SINR (3.1.20).

3.1.4**MER****modulation error ratio**

sum of the sequence of the squares of the magnitudes of the ideal symbol vectors divided by the sum of the squares of magnitudes of the symbol error vectors of a sequence of symbols, the result being expressed as a power ratio in dB

[SOURCE: IEC 60728-1:2014, 3.1.61, modified – Note 1 to entry has been deleted, and "the result being expressed as a power ratio in dB" has been added to the end of the definition.]

3.1.5**OFDM signal****orthogonal frequency division multiplexing**

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

Note 1 to entry: OFDM is based on the idea of frequency-division multiplexing, where each frequency subcarrier 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 subcarriers.

3.1.6**optical amplifier**

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

Note 1 to entry: There are several methods based on wavelength to be used for amplification. The term "Erbium Doped Fibre Amplifier (EDFA)" is the synonym of optical amplifier in this document.

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

3.1.7**optical modulation index**

optical modulation index of k -th RF signal, m_k is defined as

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

where

ϕ_h is the highest instantaneous optical power of the intensity modulated optical signal;

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

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

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

3.1.8

optical receiver

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

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

[SOURCE: IEC TR 61931:1998, 2.9.7, modified – Note 1 has been added, and the terms "optical receiving unit" and "Rx" have been omitted.]

3.1.9

optical transmitter

transmitting 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

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

Note 2 to entry: This piece of equipment amplifies frequency multiplexed electrical signals and converts these electrical signals into optical signals. The optical wavelength is a 1 500 nm band ($1\,550 \pm 10$ nm in the 1 530 nm to 1 625 nm range).

[SOURCE: IEC TR 61931:1998, 2.9.6, modified – Notes 1 and 2 to entry have been added, and the terms "optical transmitting unit" and "Tx" have been omitted.]

3.1.10

OLT

optical line terminal

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

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

3.1.11

ONU

optical network unit

device at the customer premises that is linked with the optical line terminal (OLT)

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

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 60050-702:1992, 702-06-63]

3.1.13**Rayleigh scattering**

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

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

[SOURCE: IEC 60050-731:1991, 731-03-37]

3.1.14**responsivity**

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

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

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

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

[SOURCE: IEC TR 61931:1998, 2.7.56]

3.1.15**RIN****relative intensity noise**

ratio of the mean square of the intensity fluctuations in the optical power of a light source to the square of the mean of the optical output power

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

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

[SOURCE: IEC 60728-6:2011, 3.1.12, modified – In Note 2 to entry, "carrier-to-noise" replaced with "signal-to-noise".]

3.1.16**SBS****stimulated Brillouin scattering**

non-linear scattering of optical radiation characterized by a frequency shift

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

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

3.1.17**SCR****signal-to-crosstalk ratio**

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

$$R_{SC} = D_{CATV} - U_{OS}$$

where

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

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

R_{SC} is the signal-to-crosstalk ratio, expressed in dB.

3.1.18**signal level**

strength of a digitally modulated signal given by the RMS power of the signal within the channel bandwidth ($S_{D,RF}$)

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

Table 1 – Level of RF signals

Signal	Level detection	Symbol	Remarks
QAM signal	RMS value	$S_{D,RF}$	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		

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

3.1.19**splitter**

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

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

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

3.1.20**SINR**

signal-to-intermodulation and noise ratio for a digitally modulated signal in the RF band

signal-to-intermodulation and noise ratio(R_{SIN}) is given by

$$R_{SIN} \text{ (dB)} = S_{D,RF} - N_{IN,rms} \text{ (digital signals)}$$

where,

$S_{D,RF}$ is the signal level;

$N_{IN,rms}$ is the RMS level of the intermodulation and noise in the equivalent noise bandwidth of the RF channel.

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

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

3.1.21

SPM

self-phase modulation

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

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

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

3.1.22

SRS

stimulated Raman scattering

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

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

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

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

[SOURCE: IEC 61931:1998, 2.1.87, modified – Notes 2 and 3 to entry have been added]

3.1.23

total optical modulation index (total OMI)

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

$$M_{\text{total}} = \sqrt{\sum_{k=1}^K m_k^2}$$

where

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

K is the total number of RF signals.

3.1.24

V-ONU

video-optical network unit

terminal unit that changes the optical signal of a broadcast system into an electrical signal

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

3.1.25

WDM filter

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

3.1.26**WDM coupler**

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

3.1.27**wavelength**

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

Note 1 to entry: The wavelength λ of light in vacuum is given by

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

where

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

f is the optical frequency in Hz.

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

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

3.1.28**XPM****cross-phase modulation**

modulation caused by the nonlinear refractive index of the fibre material

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

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

3.2 Graphical symbols

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

	optical transmitter based on IEC 60617-S00213-2001-07.		optical amplifier based on IEC 60617-S01239-2001-07.
	optical fibre, IEC 60617-S01318-2001-07.		variable attenuator, IEC 60617-S01245-2001-07
	optical receiver based on IEC 60617-S00213-2001-07.		power meter, IEC 60617-S00059-2001-07, IEC 60617-S00910-2001-07.
	electrical spectrum analyser, IEC 60617-S00059-2001-07, IEC 60617-S00910-2001-07.		amplifier, IEC 60617-S01239-2001-07.
	ammeter based on IEC 60617-S00059-2001-07, IEC 60617-S00910-2001-07.		photodiode with fibre pigtail, IEC 60617-S01327-2001-07.
	coupler, IEC 60617-S00059-2001-07, IEC 60617-S01188-2001-07.		optical filter
	optical terminator, IEC 60617-S01180:2001-07		NF meter
	Optical splitter based on IEC TR 61930:1998 3.33.1.		Television set
	Video optical network unit		Attenuator, IEC 60617-S01244-2001-07.
	selective voltmeter, IEC 60617-S01429-2001-07		optical spectrum analyser based on [IEC 60617-S00059 (2001-07) and IEC 60617-S00910 (2001-07)]

3.3 Abbreviated terms

ADS	active double star	AGC	automatic gain control
ALC	automatic level control	APC	angled physical contact optical connector
BCH	Bose-Chaudhuri-Hocquenghem multiple error correction binary block code	BER	bit error ratio
BNI	building network interface	CATV	community antenna television (network)
CCDF	complementary cumulative distribution function	CPE	customer premises equipment
CW	continuous wave	CWDM	coarse wavelength division multiplexing
D/U	desired to undesired signal ratio	DM	coded orthogonal frequency division multiplex
DS	downstream or double star	DSF	dispersion shifted fibre
DVB-C	digital video broadcasting baseline system for digital cable television (ETSI EN 300 429)	DVB-C2	digital video broadcasting baseline system for digital cable television second generation (ETSI EN 302 769)
DVB-S	digital video broadcasting baseline system for digital satellite television (ETSI EN 300 421)	DVB-S2	digital video broadcasting baseline system for digital satellite television second generation (ETSI EN 302 307)
DVB-T	digital video broadcasting baseline system for digital terrestrial television (ETSI EN 300 744)	DVB-T2	digital video broadcasting baseline system for digital terrestrial television second generation (ETSI EN 302 755)
EDFA	erbium-doped fibre amplifier	END	equivalent noise degradation
E/O	optical transmitter (electrical-optical transducer)	EVM	error vector magnitude
FTTB	fibre to the building	FTTH	fibre to the home
GEAPON	gigabit ethernet passive optical network	GPON	gigabit passive optical network
G/T	gain to noise temperature ratio	HDTV	high-definition television
H/E	headend	HFC	hybrid fibre coaxial
HNI	home network interface	ISDB-C	integrated services digital broadcasting – cable
ISDB-C2	integrated services digital broadcasting – cable second generation	ISDB-S	integrated services digital broadcasting – satellite
ISDB-S3	integrated services digital broadcasting – satellite third generation	ISDB-T	integrated services digital broadcasting – terrestrial
ITU-T	International Telecommunication Union – Telecommunication sector	LD	laser diode
LDPC	low-density parity check (codes)	MC	media converter
MDU	multiple dwelling unit	MER	modulation error ratio
NF	noise figure	NM	noise margin
O/E	optical receiver (optical to electrical transducer)	OFCS	optical fibre communication system
OFDM	orthogonal frequency division multiplex	OLT	optical line terminal
OMI	optical modulation index	ONU	optical network unit
PC	physical contact	PD	photo diode
PDS	passive double star	PER	packet error ratio
PON	passive optical network	PSCS	polarization state change system
QAM	quadrature amplitude modulation	QPSK	quaternary phase shift keying
RBW	resolution bandwidth	RF	radio frequency
RFoG	radio frequency over glass	RIN	relative intensity noise
RS	Reed-Solomon	SBS	stimulated Brillouin scattering

SCR	signal-to-crosstalk ratio	SDTV	standard definition television
SDU	single dwelling unit	SER	symbol error rate
SINR	signal-to-intermodulation and noise ratio	SMF	single mode fibre
SPM	self-phase modulation	SRS	stimulated Raman scattering
SS	single star	SW	switch
TMCC	transmission and multiplexing configuration control information	US	up stream
VBW	video bandwidth	V-ONU	video optical network unit
WDM	wavelength division multiplexing	XPM	cross-phase modulation

4 Optical system reference model

4.1 Overview

This document describes the FTTH system reference model for broadcast signal transmission. The pass-through method of satellite broadcast signals over the FTTH system which uses AM-FDM (SCM) transmission is included in it. This document contains descriptions of the measurement methods and specifications for optical wavelength division multiplex and for xPSK (QPSK, 8PSK, TC-8PSK) and 16APSK modulation systems. It specifies the downstream video signal transmission and thus the two-way optical transmission system is out of the scope of this document. This document applies to FTTH systems of broadband broadcast signal transmission which conveys satellite broadcast signals using one or multiple optical wavelengths.

This document also includes technical descriptions for new transmission signals, such as 4K video content, which require more bandwidth expansion than the system described in the previous edition of this document. Furthermore, it is assumed that the 4K original video content and other new services expected in the future (such as 8K, 3D-hologram, and/or video on demand (VOD) etc.) will be transmitted on cable platforms via satellite link.

4.2 Over-all FTTH system reference model

Figure 1 depicts an over-all FTTH system reference model for broadcast signal transmission. Although the numbers of optical amplifiers and optical splitters depend on the scale of the optical system, or on the number of subscriber terminals to be connected, the fundamental network configuration shall follow this system reference model. The FTTH system consists of three network sections, (1) a transmission network, (2) a distribution network and (3) an access network.

The headend system and the home network are connected using the FTTH network. "In-building optical system" is defined as being between the BNI and the HNI in this document. The BNI is defined as an interface point between cable operator and building owner. The HNI is defined as an interface point between the in-building network and the home network owned by end-user.

In addition, the optical levels in operation required for the system are relatively high, and hence, special attention for safety shall be paid in accordance with IEC 60825-1, IEC 60825-2 and IEC 60825-12.

The reference model shown in Figure 1 includes the broadcast signal transmission system and the data signal transmission system. The broadcast signal transmission system uses one-way transmission while the data signal transmission system uses both ways of transmission over the optical fibre with different optical wavelengths. Both systems are combined by WDM filters at input and output of the distribution network. The distribution network shall consist of passive optical components such as optical fibres and optical power splitters only, considering simple maintenance and easiness of future system expansion. Although the data signal transmission system can transmit any IP signal to subscriber premises through the same networks, such a system is out of the scope of this document.

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

There are two ways for connecting multi-dwelling units (MDU) with FTTH systems (see Figure 1). One is connected by an electrical port after the V-ONU output and the other one is connected by an optical port connected directly to the outdoor closure through an optical drop cable as illustrated in Figure 1.

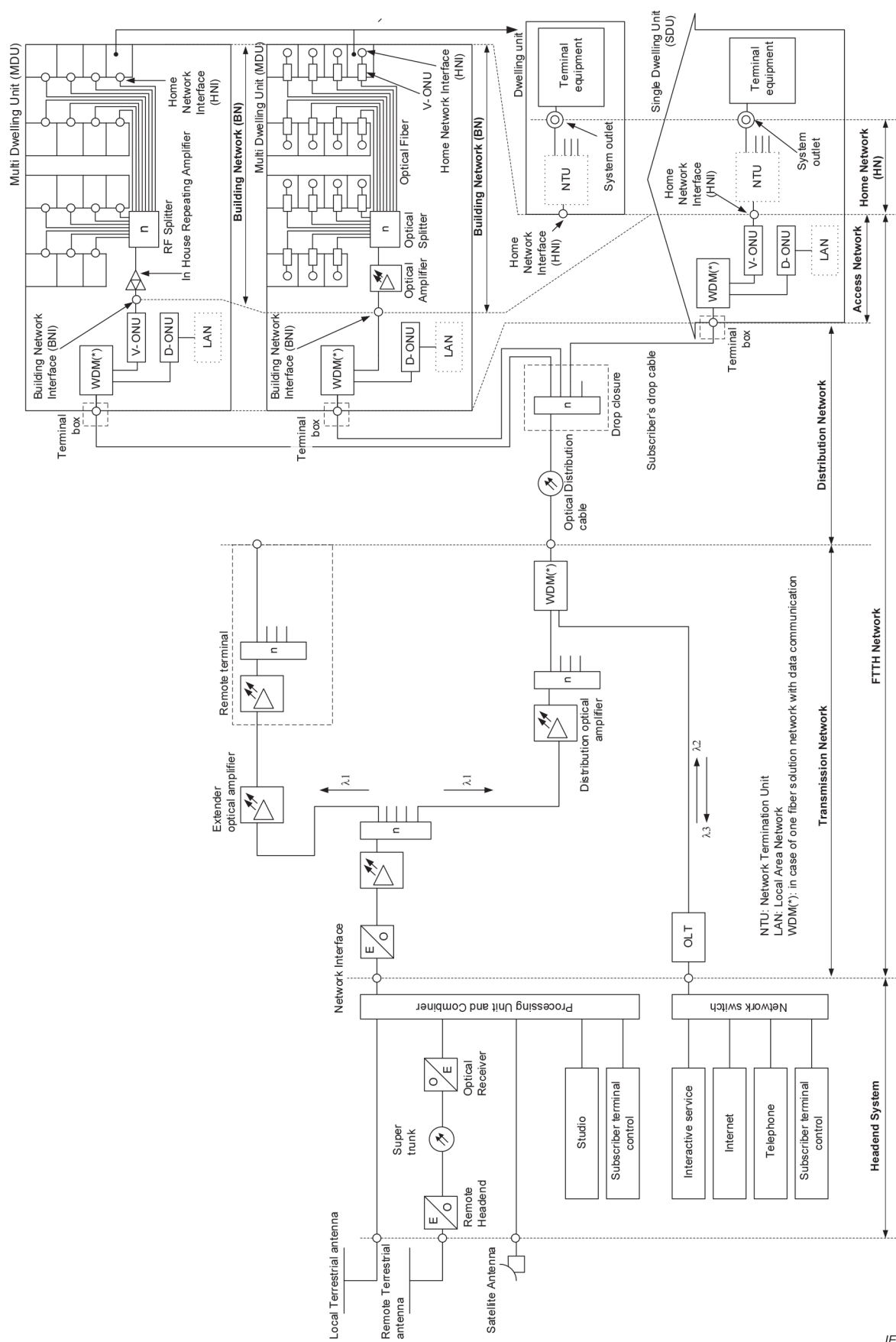


Figure 1 – Example of FTTH system for television and sound signal

4.3 Reference models for the optical systems for broadcast signal transmissions

4.3.1 Optical wavelength for FTTH system

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

Table 2 – Optical wavelength for FTTH system

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

Table 3 – Frequency range

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

4.3.2 Reference models

This clause shows two basic optical reference models for transmitting broadcast signals.

The expansion contains a conversion method that transfers broadcast signals to optical signals using a single optical transmitter with an expanded bandwidth in a one-wavelength system or by expanding the bandwidth by adding a second optical transmitter (i.e. a two-wavelength system). Migrating from the original system, the following options exist.

a) Reference model using one wavelength

An FTTH CATV system using one wavelength is shown in Figure 2. In the one-fibre solution, it is required to avoid optical and electrical crosstalk. Optical crosstalk between the downstream data signal transmitted on 1 490 nm wavelength and the CATV downstream signal is generated if the 1 550 nm WDM does not provide sufficient isolation for the 1 490 nm signal.

Electrical crosstalk between the 1 310 nm data driver signal and the 1 550 nm CATV PD receiver input signal is due to electromagnetic radiation in a very compact triplexer housing.

b) Reference model using two wavelengths

An FTTH CATV system using two wavelengths is shown in Figure 3. In the case of separate optical fibre transmission of the broadcast and the communication signals, the WDM filter in Figure 2 or Figure 3 should be removed and the system should use separated fibres for each signal.

The two-wavelength system (Figure 3) should contain two optical transmitters and receive the two wavelength (λ_1 , λ_2) signals with a single receiver. The WDM filter at the 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.

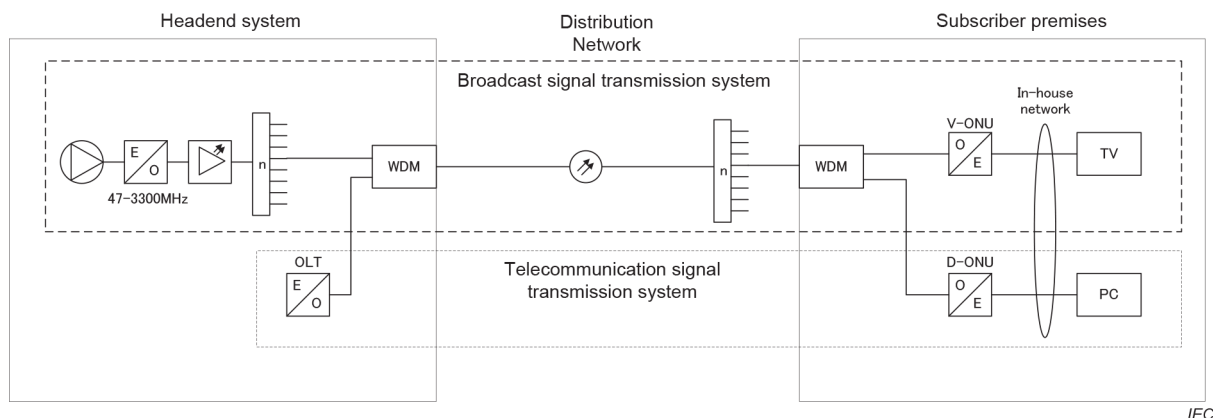


Figure 2 – FTTH Cable TV system using one wavelength

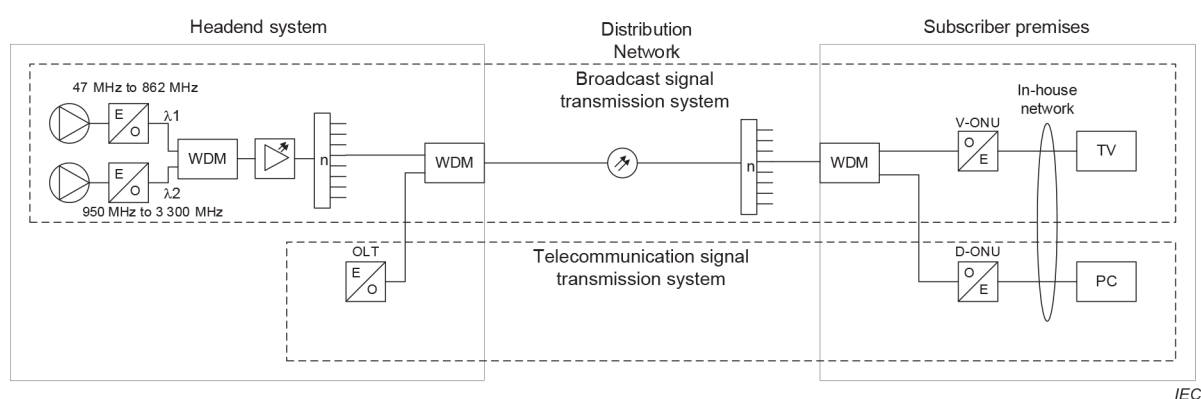


Figure 3 – FTTH Cable TV system using two wavelengths

4.4 Specified performance points of the optical system

The specified performance points of the optical system are shown in Figure 4. The specified performance points are the same for one wavelength and two wavelengths.

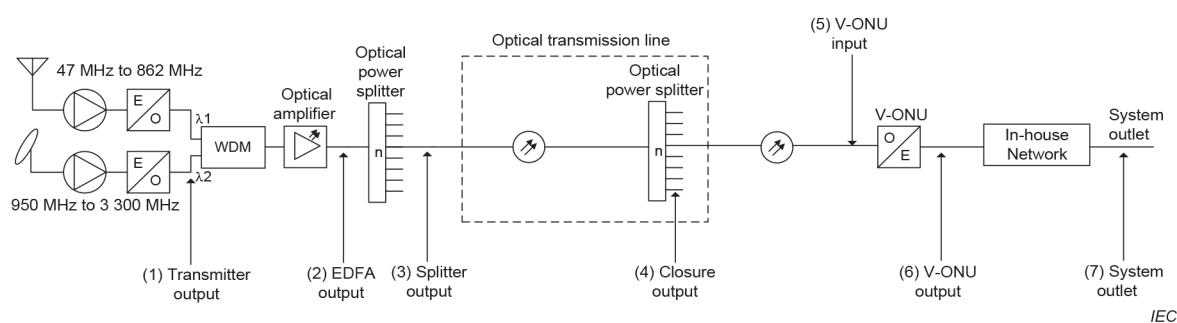


Figure 4 – Specified performance points of the optical system

5 Preparation of measurement

5.1 Environmental conditions

5.1.1 Standard measurement conditions

Unless otherwise specified, all the measurement equipment shall be used in the following standard conditions.

5.1.2 Temperature and humidity

The ambient temperature and relative humidity shall be in the range of 15 °C to 35 °C and 25 % to 75 %, respectively (see IEC 60068-1:2013, 4.3). Nevertheless, the specification of the measurement equipment shall be taken into account.

5.1.3 Setting up the measuring setup and system under test

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

5.1.4 AGC/ALC operation

Unless otherwise specified, all pieces of equipment in the system shall be operated in the AGC (automatic gain control) or ALC (automatic level control) mode.

5.1.5 Impedance matching between pieces of equipment

The impedance of the pieces of equipment and the test setup shall match, and measurement error shall be avoided by introducing components such as attenuators.

5.1.6 Standard operating condition

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

5.1.7 Standard signal and measuring equipment

For measurement purposes, the standard signals used in the measuring equipment, as well as in the system under test, shall be set according to the prescribed standard signal format of the individual system. The measuring equipment to be used is described in Table 4 (passive pieces of equipment are excluded).

Table 4 – Measuring equipment

Name of equipment	Usage
Optical power meter	Instrument to measure the power of the optical signal.
Optical spectrum analyser or Optical wavelength meter	Instrument to measure the wavelength of the optical signal.
Spectrum analyser	Instrument used for quantitative measurement of high-frequency signals.
Signal generator	Instrument used to generate high-frequency digital signals.
Digital signal analyser	Instrument used for quantitative measurement of digital modulated signals and error vector.
Noise figure (NF) meter ^a	Instrument used to measure the noise figure (NF).
Constellation analyser	Instrument used for visually knowing the state such as the orthogonality of the I signal and the Q signal of the modulated signal and the imbalance of gain. MER is a numerical value of the variation of the constellation.
Current meter (ammeter) ^a	Instrument used to measure electrical current.
Voltmeter	Instrument used to measure voltage.
Noise source	Instrument used to generate Gaussian noise signal. (flat within the required measurement range)
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.
Selective voltmeter	Instrument used for quantitative voltage measurement covering the frequency range of the broadcast service. A spectrum analyser can also be used for this purpose.
^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 the measurement.

5.3 Source power

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

6 Methods of measurement

6.1 Measuring points and items

6.1.1 General

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

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

6.1.2 Measuring points

Typical optical video distribution system is shown in Figure 5. It is required to measure the optical power at points (1) to (5), and the electrical signal level at points (6) and (7) of Figure 5 to ensure total system performance. Points (5), (6) and (7) shall be measured to guarantee the system performance at the end point of the optical section and at the interface point to the customer premises. The RIN should be measured at points (1) to (5) and SINR (electrical signal) at points (6) and (7).

6.1.3 Measured parameters

The following measurements shall be carried out.

a) Optical power

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

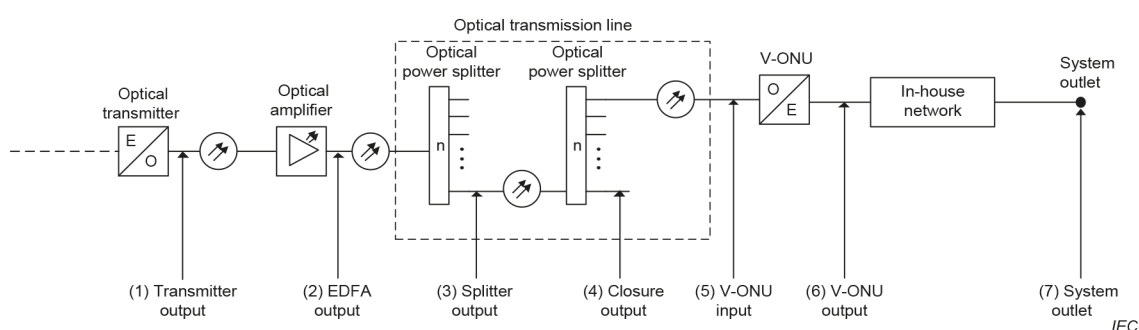


Figure 5 – Typical optical video distribution system

b) Signal-to-intermodulation and noise ratio (SINR) (electrical signal)

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

c) Measuring RIN (relative intensity noise)

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

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

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

Measuring points and measured parameters are summarized in Table 5.

The measurements at points (5), (6) and (7) are mandatory, while measurements at other points are required to ensure system performance.

Table 5 – Measuring points and measured parameters

Measured parameters	Measuring points						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Transmitter output	EDFA output	Power splitter output	Closure output	V-ONU input	V-ONU output	System outlet
Optical power	○	○	○	○	○	–	–
Optical wavelength	○	●	●	●	●	–	–
SINR (electrical)	–	–	–	–	–	○	○
SINR (RIN) (see NOTE)	○	○	Δ	Δ	Δ	–	–
BER, MER	–	–	–	–	–	○	○
Key ○ Measurements are possible at these points ● Wavelength measured at 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) – Measurements are not possible at these points. The measurements at points (5), (6) and (7) are mandatory, while measurement at other points is required to ensure the system performance. NOTE Theoretical estimation of SINR at point (6), at the output of the V-ONU, is based on the measurement results of individual equipment.							

6.2 General measurement requirement

6.2.1 General

Unless otherwise specified, for all the measurements described in Clause 6, the requirements in 6.2.2, 6.2.3 and 6.2.4 shall be considered.

6.2.2 Input specification

The following conditions shall be obtained from the specification of the device, instrument or system under test:

- a) supply voltage(s);
- b) control signal(s), if any, with correct impedance, level, and frequency.

6.2.3 Standard measurement conditions

Unless otherwise specified, all the measurements shall be carried out under the following conditions:

- a) The ambient temperature and relative humidity shall be in the range of 15 °C to 35 °C and 25 % to 75 %, respectively [see IEC 60068-1:2013, 4.3]. Nevertheless, the specification of the measurement equipment shall be taken into account.
- b) The device, instrument or system under test shall be in normal operating condition and shall be mounted and tuned according to the designed level diagram prior to the measurement.
- c) The normal operating condition refers to the condition in which the CATV/MATV/SMATV system under test is fully functional at a given facility.
- d) The impedance-matching between pieces of equipment and the test setup shall be aligned, and any measurement error shall be avoided by introducing components such as attenuators.

- e) Use calibrated measurement equipment. Refer to the specifications of the measurement equipment for instructions related to calibration.

6.2.4 Precautions for measurements

- a) Optical reflection shall not impair the accuracy of the measurement.
- b) During measurement, the input signal and control signal (if used) shall be kept constant within 0,5 dB.
- c) Test fibres shall have clean and unscratched ends in order to prevent losses of power and reflections.
- d) Accurately calibrated measurement equipment shall be used to ensure the accuracy of measurement results.
- e) All the test equipment and test environment shall comply to human safety against laser radiation as specified in IEC 60825-2 and IEC 60825-12.

6.3 Optical power

6.3.1 General

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

6.3.2 Measuring setup

6.3.2.1 Measurement of the optical power at single wavelength

The measurement of optical power at single wavelength shall be carried out in accordance with IEC 61280-1-1:2013, Clause 5.

6.3.2.2 Measurement of the optical power of a WDM signal

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

NOTE Methods of measurement for the optical power of single wavelength are described in IEC 61280-1-1.

The optical power at the output of a WDM coupler shall be measured in accordance with IEC 61280-1-1:2013, Clause 5.

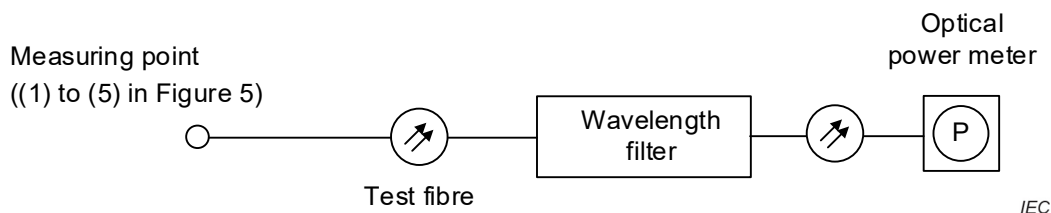


Figure 6 – Test setup for optical power measurement using a wavelength filter

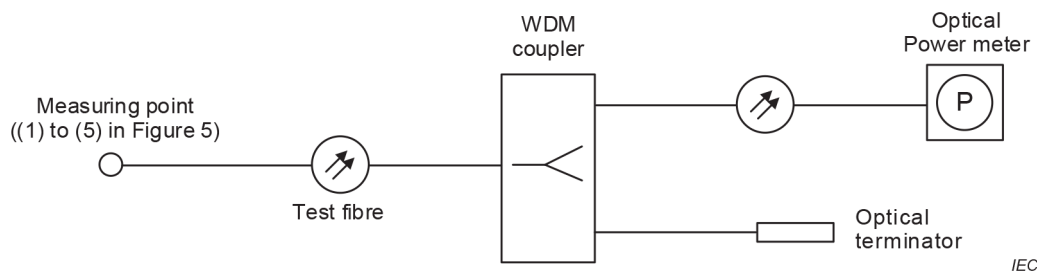


Figure 7 – Test setup for optical power measuring using a WDM coupler

6.3.3 Measuring method

In addition to the requirements of IEC 61280-1-1, the following points shall be considered.

- a) Connect the test fibre to the power meter and ensure that the power meter is switched to the specified single wavelength and only the specified wavelength signal is applied to the power meter.
- b) Measure and record the power of the output signal using the power meter.
- c) If a WDM coupler or a wavelength filter is used to measure the WDM signals, the pre-determined insertion loss of the WDM coupler or the wavelength filter shall be added to the measured optical power.

6.3.4 Precautions for measurement

The following considerations shall be taken into account.

- a) The optical fibre end-face or the connector end-face shall not be viewed directly. Also, the end-face of the fibre shall not be pointed towards any person. If there are unterminated single or multiple fibres, they shall be covered together to avoid any radiation hazard. Any unconnected optical connector shall be covered with a cap during the entire measuring time.
- b) Ensure that the power meter has a measuring range suitable for the expected power, and is capable of measuring the expected signal wavelength. The detector system of the power meter shall have a sufficiently large area to collect all the radiation from the test fibre and a spectral sensitivity compatible with the light source. A minimum accuracy of $\pm 10\%$ is recommended.
- c) The sensor portion of the power meter shall be shut off and zero offset adjustment shall be carried out before the measurement.
- d) Test fibres and connectors shall have clean and unscratched ends in order to prevent losses of power and reflections.
- e) If the measurement bandwidth and the measuring range of the power meter can be set independently, they shall be set in the auto mode prior to the measurement.
- f) The measurement shall be carried out in the CW mode. If the power meter has a selectable measurement mode (CW / 270 Hz / 1 kHz / 2 kHz), CW mode shall be selected. Power meters without any measurement mode function normally operate in CW mode. Ensure CW mode operation prior to the measurement.
- g) If there is any instability in the measurement (the measured value fluctuates when the end-face of the fixed attenuator is directly connected to the power meter), a suitable patch cord shall be used, and the measurement shall be repeated.
- h) The potential sources of error are the following:
 - 1) the inaccuracy of the power meter, for example if its dark current is not sufficiently low;
 - 2) the attenuation of the test fibre and the specified coupling means.

6.3.5 Presentation of the results

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

6.4 Optical wavelength

6.4.1 Introduction

The purpose of this measurement is to measure the central wavelength or peak wavelength at each measurement point listed in Clause 7.

6.4.2 Method of measurement

The optical wavelength, in the FTTH system for 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 the V-ONU. The measurement setup is shown in Figure 8 and Figure 9.

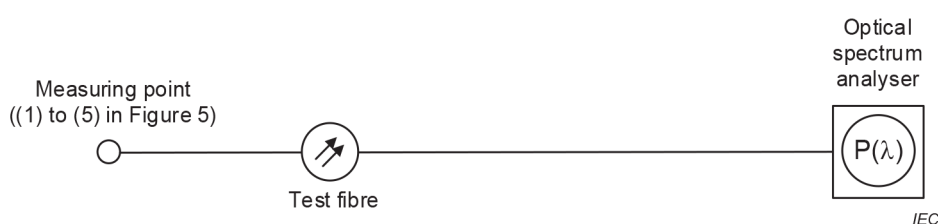


Figure 8 – Measurement of optical wavelength without a WDM coupler

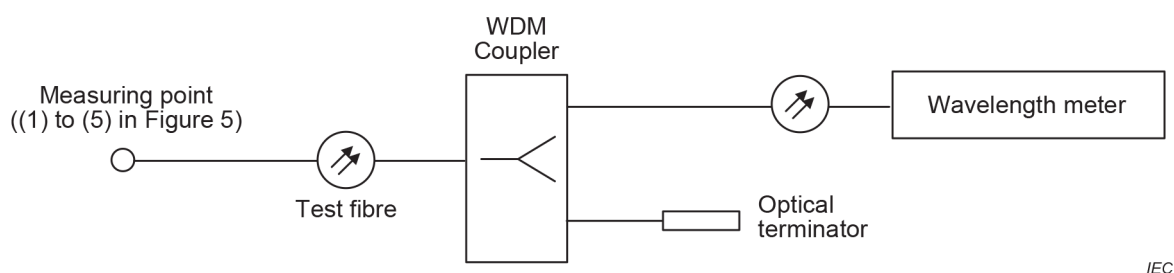


Figure 9 – Measurement of optical wavelength using a WDM coupler

For measuring the central wavelength λ_0 of the spectrum of an optical signal under modulation, the method described in IEC 61280-1-3 shall be used.

6.4.3 Presentation of the results

The central optical wavelength shall be expressed in nm.

6.5 SINR (signal-to-intermodulation and noise ratio) below 1GHz

6.5.1 General

The purpose of this test method is to measure the signal level of a television broadcast signal of less than 1 GHz. Also, the RF signal-to-intermodulation and noise ratio is measured using the measured noise level within the transmission bandwidth of the television signal. This test method performs the measurement in the electrical domain.

6.5.2 Measuring setup

Connect the pieces of equipment as shown in Figure 10. The method for measuring the RF signal-to-intermodulation and noise ratio of optical transmission systems is the same as that for cabled distribution systems (see IEC 60728-101:2016, 4.4).

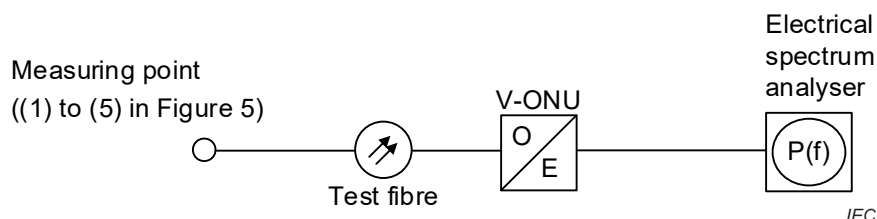


Figure 10 – Test setup for RF signal to intermodulation and noise ratio measurement

The test setup of Figure 10 is for simplified measurement of signal-to-intermodulation and noise ratio in the optical domain. The correct measurement shall be carried out in the electrical domain using an electrical spectrum analyser at points (6) and (7), described in Table 5.

6.5.3 Measuring conditions

The following measuring conditions apply.

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

6.5.4 Precautions for measurement

The following considerations shall be taken into account.

- Measurement accuracy: to obtain an accurate measurement of RF signal to intermodulation and noise ratio, it is necessary to turn off the channel under test and measure the noise level within the channel bandwidth. Depending on the situation, it is expected that the arbitrary broadcast channel cannot be turned off during network operation. Therefore, the inaccuracy and measurement error of the test method prescribed in this document shall be observed.
- Attenuation setup of the spectrum analyser: most spectrum analysers have a default input attenuation of 10 dB when powered on. It is possible to carry out the measurement with this default value when the total electrical input power does not exceed 0 dB(mW). Total electrical power is measured using the electrical power measurement option of the spectrum analyser and by setting the centre frequency to 510 MHz, the frequency span to 1 GHz, and the channel power measurement bandwidth to 1 GHz. There shall not be any signal outside the above frequency span. If the total power (P_T) exceeds 0 dB(mW) (109 dB(μV) at 75 Ω impedance) on the voltage display, in order to avoid any distortion generated within the spectrum analyser, adjust the input attenuation (A_{in}) setting to satisfy the following relation:

$$P_T - A_{in} < -10 \text{ dB(mW)}.$$

- Measure the output of the digital signal generator using a calibrated power meter with a thermocoupled sensor and taking this as the true value, calibrate the measurement level of the spectrum analyser.

- d) When the RF signal-to-intermodulation and noise ratio of the signal is very small, the noise within the signal will be larger than the measurement error and cannot be neglected. If a correction factor needs to be applied, this correction factor shall be subtracted from the spectrum analyser measured level (see IEC 60728-101:2016, Annex A).
- e) This document recommends the test method using the electrical power measurement option of the spectrum analyser to deal with QAM and OFDM signals. This test method is preferred because any correction necessary within the spectrum analyser is automatically processed irrespective of the type of spectrum analyser used for the measurement. Also, the flatness of the signal over the transmission bandwidth does not influence the measurement results.

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

6.5.5 Presentation of the results

The signal level shall be expressed in $\text{dB}(\text{mW})$ or in $\text{dB}(\mu\text{V})$ and the RF signal-to-intermodulation and noise ratio shall be expressed in dB .

6.6 Relative intensity noise (RIN) of optical signal

6.6.1 General

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

The RIN is the noise caused by fluctuations in optical output power with respect to time and is expressed as the ratio of average optical power to the average noise power measured in a 1-Hz bandwidth. It is difficult to measure the RIN directly in the optical domain and the measurement shall be carried out after converting the optical signal to an electrical signal. The RIN can also be calculated from the measured performance of individual components constituting the system. However, it is necessary to measure the RIN on a near-side measurement point where the optical signal is converted to an electrical signal, for instance, at the V-ONU input.

6.6.2 Measuring setup

The measuring setup is the following.

a) Measurement points

The measurement points in the cable TV network for optical signals are shown in Figure 5.

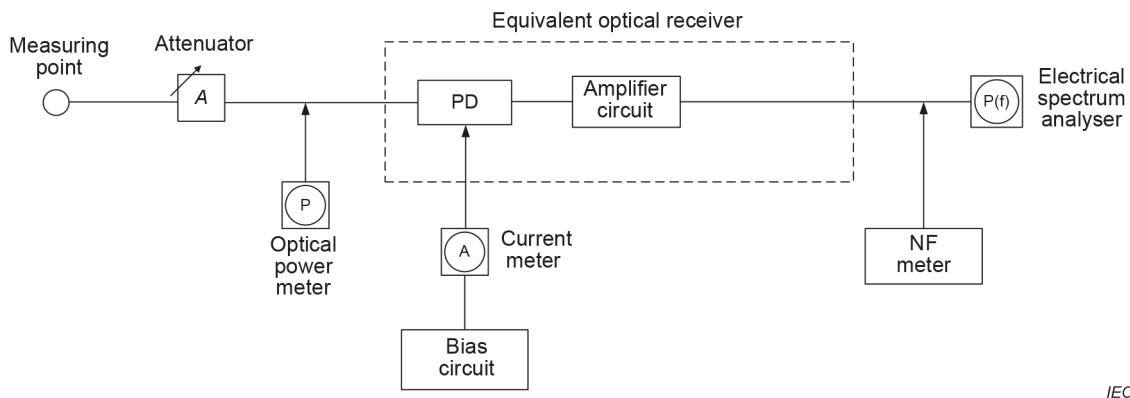
- In order to calculate the signal-to-intermodulation and noise ratio at the V-ONU output, it is necessary to measure the RIN, as shown in Figure 5 at points (1) to (3), where the optical output power is sufficiently high to allow RIN measurements to be accurate.

NOTE RIN measurements are not accurate when the optical power is lower than $-3 \text{ dB}(\text{mW})$.

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

b) Measuring setup

Figure 11 shows the RIN measurement setup.



IEC

Figure 11 – Test setup for RIN measurement

6.6.3 Measurement conditions

The following measurement conditions apply.

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

The RIN degradation due to Rayleigh scattering and multiple optical reflections within the transmission line cannot be neglected. Therefore, if the RIN measurement is carried out within the headend, an equivalent optical cable having a similar performance to the cable used in the actual optical network shall be inserted at the measurement point in Figure 5.

6.6.4 System RIN measuring method

6.6.4.1 General

This test method shall be applied to predict the signal-to- intermodulation and noise ratio at the output of a V-ONU from the RIN measurement using the setup shown in Figure 11. Subclause 6.6.4 contains several steps, as outlined in 6.6.4.2 and 6.6.4.3. If the parameters for R , I_{d0} , I_{eq} and G are unknown, refer to Annex D. The RIN can be calculated using these parameters.

6.6.4.2 Step A: input power of optical receiver and system noise (noise current density)

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

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

where

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

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

- The measured noise level (N_p) includes that of the measuring equipment (spectrum analyser), which should be at least 20 dB lower than the noise level displayed outside the channel band in order not to affect the results. Otherwise, the contribution of noise (due to the system or the equipment under test and to the measuring equipment) should be taken into account in the measurement of the noise level (see IEC 60728-101:2016, Annex A).

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

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

where

B_n is the measurement bandwidth of noise power (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 = $20 \lg(2/\sqrt{\pi}) = 1,05$ dB;

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

6.6.4.3 Step B: RIN calculation

- From the above measurement results, the N_{RIN} can be calculated using Equation (2):

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

where

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

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

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

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

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

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

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

6.6.5 SINR calculation based on RIN value

The signal-to-intermodulation and noise ratio (R_{SIN}) at the V-ONU output can be calculated using Equation (3):

$$R_{\text{SIN}} = 10 \lg \left(\frac{1}{B_{\text{N}}} \cdot \frac{\frac{1}{2} \cdot (m_k \cdot R \cdot P_r)^2}{N_{\text{RIN}} \cdot (R \cdot P_r)^2 + 2 \cdot e \cdot (I_{\text{d0}} + R \cdot P_r) + I_{\text{eq}}^2} \right) [\text{dB}] \quad (3)$$

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

6.6.6 Component RIN calculation

The following method can be applied to calculate the component RIN of the optical signal at the input of a V-ONU when 6.6.4 is not applicable. If the input RIN of the first EDFA (the RIN of the optical transmitter) is expressed as $N_{\text{RIN,in}}$, then the output RIN of the n th EDFA, $N_{\text{RIN,out}}$, is given by Equation (4):

$$N_{\text{RIN,out}} = 10 \lg \left(\sum \frac{2 \cdot E \cdot 10^{\frac{N_{\text{FACT},n}}{10}}}{10^{\frac{P_n}{10}}} + 10^{\frac{N_{\text{RIN,in}}}{10}} \right) \quad (4)$$

where

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

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

f is the frequency, expressed in Hz.

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

$N_{\text{FACT},n}$ is the noise factor of the n th EDFA, in dB;

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

NOTE The term " $1/G$ " in Equation (12) of IEC TR 60728-6-1:2006 is very small compared to other terms and hence can be neglected.

Also, even though the RIN degradation due to Rayleigh scattering and other reflections within the fibre is small, this cannot be ignored if an optical transmitter with RIN smaller than -160 dB(Hz $^{-1}$) and EDFAs with low NF are used. The following Equation (5) shall be used to calculate the RIN, $N_{\text{RIN,f}}$ due to the fibre transmission:

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

where

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

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

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

L is the transmission distance, expressed in km;

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

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

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

η_1 is the refractive index of fibre core;

λ is the wavelength, expressed in μm .

The RIN of the optical signal at the input of V-ONU is given by Equation (6)

$$N_{\text{RIN}} = -10\lg\left[10^{-(N_{\text{RIN,out}}/10)} + 10^{-(N_{\text{RIN,f}}/10)}\right] \quad (6)$$

Based on the RIN value above, the SINR can be calculated with Equation (3).

Table 6 – Parameters used for the calculation of SINR

Parameter	Remarks		
B_N	ISDB-C ISDB-C2 ISDB-T ISDB-S ISDB-S3	See Table 7	This parameter depends on the transmission signal format. QAM: BW in IEC 60728-1:2014, Table I.1 OFDM: BW in IEC 60728-1:2014, Table I.1
	DVB-C DVB-C2 DVB-T DVB-T2 DVB-S DVB-S2	See Table 7	
K	Number of transmission signals		
M_{total}	Total optical modulation index		These parameters depend on the optical transmitter, transmission signal, etc.
m_k	Optical modulation index of k^{th} signal (modulated RF signals)		
P_r	Received optical power (W)		This parameter depends on the transmission line design.
N_{RIN}	N_{RIN} of the optical signal input to the V-ONU (dB(Hz ⁻¹))		This parameter depends on the optical transmitter, amplifier and transmission line. If the parameter is unknown, the following values can be used to calculate the RIN of optical signal input to the V-ONU. RIN of the optical transmitter for multi-channel transmission is –155 dB(Hz ⁻¹). RIN of the optical transmitter for retransmission is –150 dB(Hz ⁻¹). NF of the optical amplifier is 6,5 dB RIN due to the optical transmission line is –161 dB(Hz ⁻¹).
e	Charge of an electron (1,602 × 10 ⁻¹⁹ C)		Physical constant.
R	Responsivity of the V-ONU (A/W)		Typical values of these parameters are listed in 6.6.7.
I_{d0}	Dark current of the V-ONU (A)		

6.6.7 Example for calculating of SINR

The signal-to-intermodulation and noise ratio (SINR) can be calculated with the following typical parameters:

Parameter	ISDB-C	DVB-C
Noise bandwidth	5,3 MHz	6,96 MHz
Number of signals	$K = 57$ channels	$K = 50$ channels
Total modulation index	0,264	0,264
RIN of optical signal at the input of a V-ONU	–148 dB(Hz ⁻¹)	–148 dB(Hz ⁻¹)
Responsivity of the V-ONU	0,89 A/W	0,9 A/W
Dark current of the V-ONU	0,1 nA	0,1 nA
Equivalent input noise current density of pre-amplifier before V-ONU	7 pA/√Hz	7 pA/√Hz

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

If the optical modulation index of all the signals is assumed to be the same, then the optical modulation index (m_k) per signal is given by Equation (7):

$$m_k = \frac{0,264}{\sqrt{57}} \cong 0,035 \quad (7)$$

If the optical input to the V-ONU is $-9,6 \text{ dB(mW)}$, from Equation (3), the signal-to-intermodulation and noise ratio is calculated to be 40,6 dB.

Table 7 shows the RF signal noise bandwidth of the broadcasting systems.

Table 7 – RF signal noise bandwidth

Broadcast signal			RF signal noise bandwidth MHz
System	Modulation	Sub-carrier	
ISDB-T	OFDM	64-QAM / QPSK	5,572 4
ISDB-C (J.83, J.183)	64-QAM	—	5,274
	256-QAM	—	5,274
ISDB-C2 (J.382)	OFDM	256-QAM	5,71
		1 024-QAM	5,71
		4 096-QAM (4/5)	5,71
		4 096-QAM (5/6)	5,71
ISDB-S	QPSK, TC-8PSK:	—	28,86
ISDB-S3	16APSK:	—	33,756 1
DVB-T	COFDM	64-QAM (2/3)	7,61
DVB-T2	COFDM	256-QAM (2/3)	7,61
DVB-C	64-QAM	—	6,96
	256-QAM	—	6,96
DVB-C2	COFDM	256-QAM	7,61
		1 024-QAM	7,61
		4 096-QAM (5/6, 9/10)	7,61
DVB-S	QPSK	— —	27,5
DVB-S2	QPSK,8PSK 16APSK,32APSK	Roll-off factor (0,35) Roll-off factor (0,25) Roll-off factor (0,2)	1-45 MS/s
This table presents noise bandwidths for various signal types. The bandwidth refers to one channel (sub-carrier).			

6.7 Optical modulation index

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

6.8 Signal-to-crosstalk ratio (SCR)

6.8.1 General

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

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

6.8.2 Equipment required

The following equipment is required for the measurement:

- a running system with implemented CATV broadcast service with other service(s), i.e. telecommunication services;
- a selective voltmeter (or spectrum analyser) covering the frequency range of the CATV broadcast service;
- lengths of fibre for connecting the transmitters, optical WDM filters, an optical amplifier, optical attenuators, an optical polarization state change system and the receivers.

6.8.3 General measurement requirements

The measurement shall be carried out following the steps described in 6.8.4 .

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

6.8.4 Procedure

- Set the supply voltage(s) and any control input signal(s) to the specified value(s).
- Connect the equipment as shown in Figure 12.

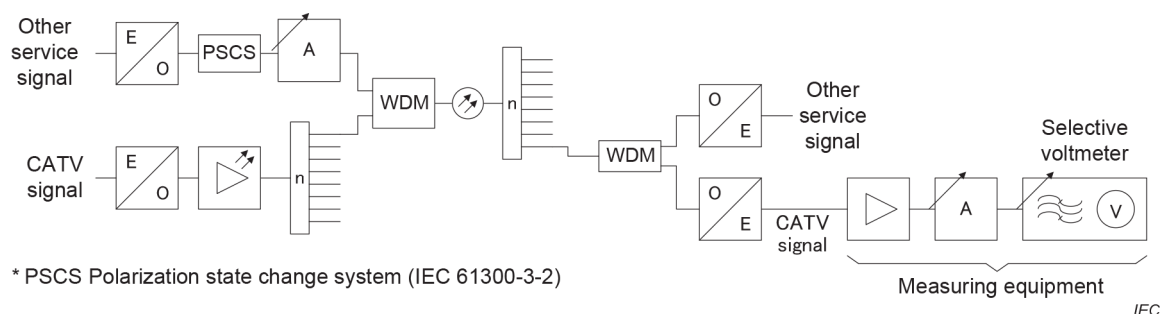


Figure 12 – Test setup for signal to crosstalk measurement

- c) Carry out measurements with the service signals in operation widely and closely spaced over each band of interest.
- d) Carry out measurements over the full specified optical power range at the optical fibre input by adjusting the optical attenuators A.
- e) Carry out measurements over the full specified range of optical transmission distance by applying various fibre lengths; refer to Figure C.6.
- f) Carry out measurements with various other services' communication signal patterns. For example, measurement should be performed with and without digital idle signals (with and without payload) because signal pattern characteristics will influence the crosstalk intensity.
- g) Connect the variable RF attenuator A and selective voltmeter to the RF output port of the optical receiver for the CATV broadcast service. Tune the meter to each CATV signal and note the attenuator A value a_1 required to obtain a convenient meter reading R for the reference signal. The attenuator value a_1 should be slightly greater than R_{SC} from other services expected at the point of measurement.
- h) Tune the meter to the other services' crosstalk product to be measured and tune the optical polarization state change system (PSCS) to the other services' crosstalk product to be measured at the maximum level. Reduce the RF attenuator A setting to the value a_2 required to obtain the same meter reading.

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

- i) The R_{SC} from other services, in dB, is given by Equation (8).

$$R_{SC} = a_1 - a_2 \quad (8)$$

where

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

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

6.8.5 Potential sources of error

Sources of error are the following:

- a) the inaccuracy of the selective voltmeter;
- b) the inaccuracy of the variable attenuators.

6.8.6 Presentation of the results

The SCR from other services shall be expressed in dB.

6.9 RF signal-to-intermodulation and noise ratio (SINR) of satellite broadcast signals

6.9.1 General

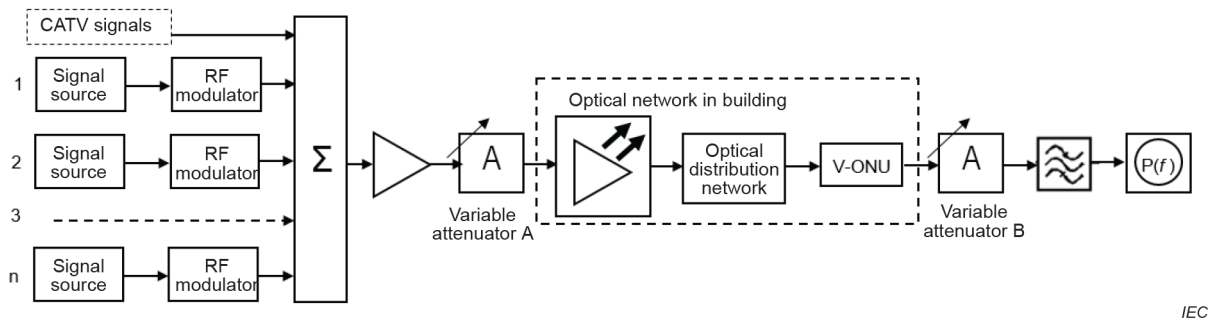
This measurement method applies to the measurement of the RF signal-to-intermodulation and noise ratio SINR of digitally modulated signals using formats such as 16APSK, TC-8PSK, 8PSK, QPSK.

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

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

6.9.2 Measuring setup

The measuring setup is shown in Figure 13. The signal source and RF modulators are chosen in such a way to generate signals with the desired number of signals with the modulation format expected to be used in the actual operation of the system.



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Figure 13 – Setup for the measurement of SINR for satellite broadcast signals

6.9.3 Equipment required

The equipment required is listed below:

- baseband video signal sources;
- RF modulators for appropriate modulation format;
- other CATV video signal (optional);
- RF amplifier with appropriate gain;
- a combiner for the output signals of the modulators with negligible distortion;
- variable attenuators;
- reference optical receiver;
- band pass filter;
- spectrum analyser able to tune to the nominal frequency range of the system.

6.9.4 Measurement procedure

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

- All applied channels (channel load and measurement channels) shall have the same output level within a deviation of maximum $\pm 0,5$ dB as measured at the input of the RF amplifier.
- Adjust the input to the RF amplifier to obtain the nominal RF output. The SINR of the signal input to the RF amplifier shall not affect the measurement accuracy.
- Measure the signal power of the measurement signal (choose the measurement bandwidth according to the modulation format, for example 28,86 MHz for TC-8PSK, 33,7561 MHz for 16APSK)
- Turn off the measurement signal and the adjacent signal on either side of the measurement signal and measure the noise power within the measurement bandwidth. When switching off the input signal, the signal operated AGC systems may not function correctly and, in this case, the AGC shall be turned off and manual gain control shall be used during these tests.

The total noise power within the measurement bandwidth shall be measured. For this measurement, appropriate band pass filters shall be used to filter all the signal out of the measurement bandwidth to avoid any signal distortion within the spectrum analyser.

- e) Calculate the signal to intermodulation and noise ratio SINR using the following Equation (9):

$$R_{\text{SIN}} \text{ (dB)} = S_{\text{D, RF}} - N_{\text{IN}} \quad (9)$$

where

R_{SIN} is the signal-to-intermodulation and noise ratio, expressed in dB;

$S_{\text{D, RF}}$ is the signal level expressed in dB(μV), dB(mW) or dB(mW)/Hz;

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

- f) Repeat the procedure c) to e) to measure the SINR for other measurement signals.

NOTE 1 For the measurement of satellite signals, a total number of 50 signals (TC-8PSK/16APSK) is preferred.

NOTE 2 Set the measurement conditions on the spectrum analyser as follows:

- frequency span: 50 MHz;
- resolution bandwidth: 300 kHz;
- video bandwidth: 3 MHz;
- detection mode: sample;
- average: 30 times or more;

6.9.5 Presentation of the results

The measured signal-to-intermodulation and noise ratio (SINR) shall be expressed in dB.

6.10 System BER (bit error ratio)

6.10.1 Overview

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

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

6.10.2 Connection of the equipment

The measuring setup for BER measurement is shown in Figure 14.

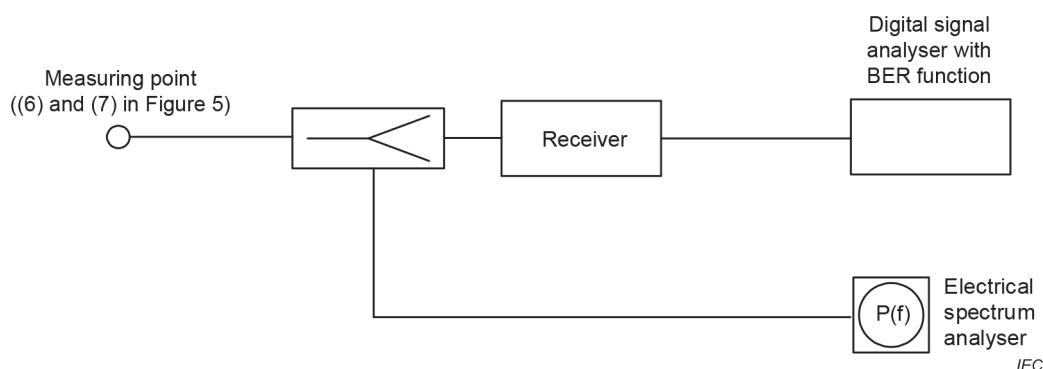


Figure 14 – Test setup for BER measurement

6.10.3 Measurement procedure

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

- First, measure the signal level and signal-to-intermodulation and noise ratio (SINR) of the desired signal channel by spectrum analyser.
- Adjust the desired channel on the digital signal tuner or digital signal analyser. The FEC condition should be off.
- Measure BER with a BER measurement instrument or with a digital signal analyser. The BER should be measured several times, and the average value should be calculated and recorded.

6.10.4 Presentation of the results

The measured signal-to-intermodulation and noise ratio (SINR) shall be expressed in dB and BER shall be expressed without a unit.

6.11 SINR versus BER measurement

6.11.1 General

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

6.11.2 Connection of the equipment

The measuring setup for the BER versus SINR measurement is shown in Figure 15.

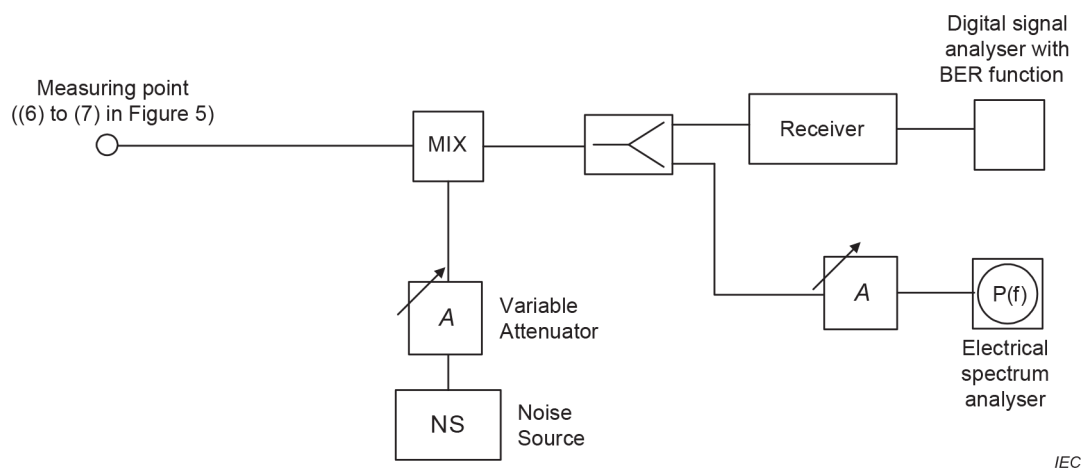


Figure 15 – Test setup for SINR versus BER measurement procedure

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

- This measurement can be performed under operating conditions.
- Instruments are connected as shown in the measurement block diagram.
- Measure the signal-to-intermodulation and noise ratio.
Turn off any RS error correction and measure the BER with the digital signal analyser with the BER measurement function or with a BER measurement instrument.
- If the error correction can't be turned off, or when LDPC error correction is used, it will generally take a long time to measure low error conditions like $BER = 10^{-11}$. In this case, the extrapolation method can be applied as described below.

Figure 16 shows the extrapolation method for BER.

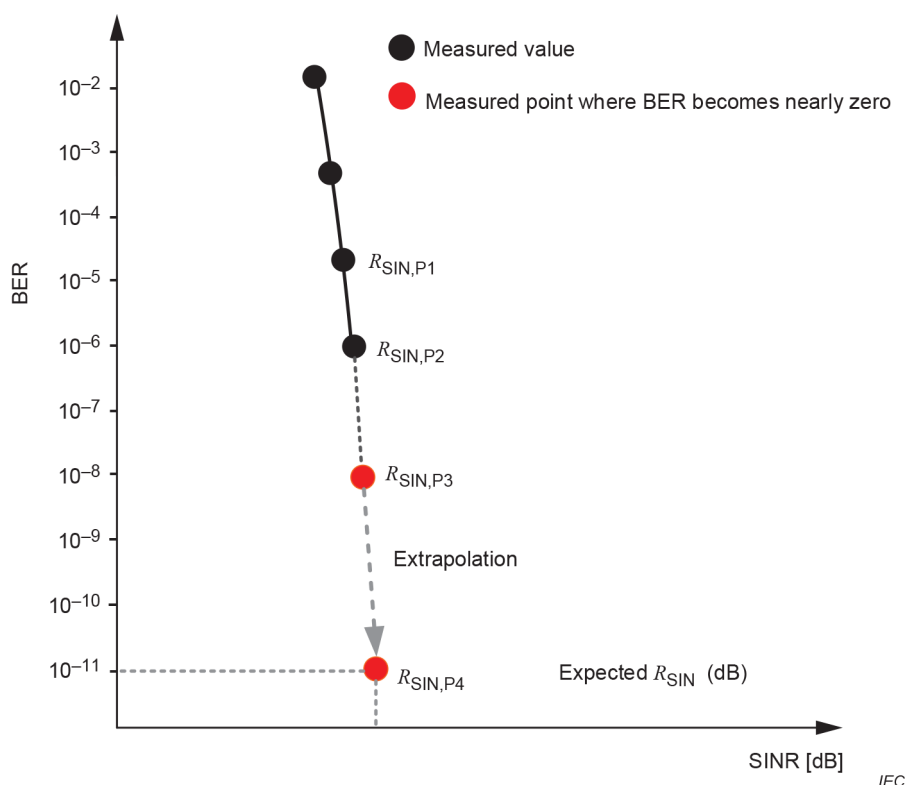


Figure 16 – Extrapolation method of BER measurement

Measure three SINR values for $R_{\text{SIN}, P1}$, $R_{\text{SIN}, P2}$ and $R_{\text{SIN}, P3}$ as shown in Figure 16 and find $R_{\text{SIN}, P4}$ that crosses the line of $\text{BER} = 10^{-11}$ and the slope line between the points of P2 and P3. $R_{\text{SIN}, P4}$ can be calculated with Equation (10). For a more detailed method and obtained results, see Annex B.

$$R_{\text{SIN}, P4} = 2 \cdot \frac{\lg(10^{-11}) - \lg(R_{\text{BER}, P3})}{\frac{\lg(R_{\text{BER}, P2}) - \lg(R_{\text{BER}, P1})}{R_{\text{SIN}, P2} - R_{\text{SIN}, P1}} + \frac{\lg(R_{\text{BER}, P3}) - \lg(R_{\text{BER}, P2})}{R_{\text{SIN}, P3} - R_{\text{SIN}, P2}}} + R_{\text{SIN}, P3} \quad (10)$$

Measure the SINR at the input of the measurement instrument and the BER by changing the value of the attenuator.

6.11.3 Presentation of the results

An example of a measurement of BER versus SINR is shown in Figure 17. The measured signal-to-noise ratio SINR shall be expressed in dB and the BER shall be expressed without a unit.

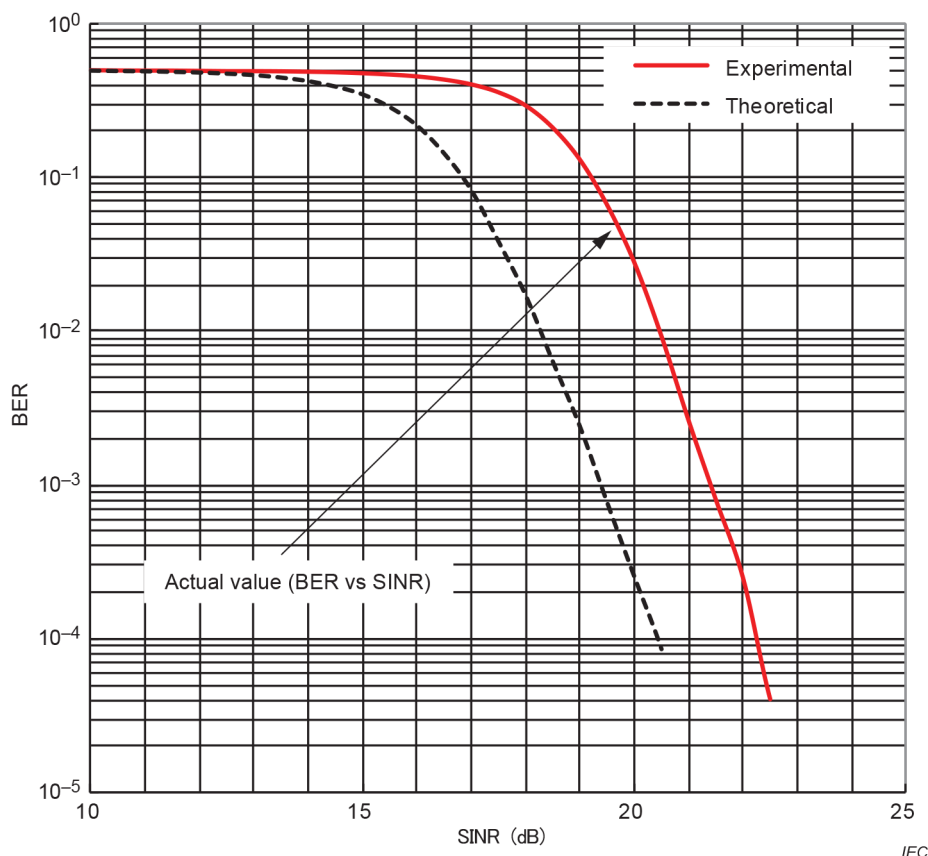


Figure 17 – Example of SINR versus BER characteristics

6.12 System noise margins

6.12.1 General

The purpose of this test method is to measure the difference value (noise margin) between the value of SINR where $BER = 1 \times 10^{-4}$ and the system SINR, in the case of RS error correction. In the case of LDPC error correction, the calculation shall be carried out for $BER = 1 \times 10^{-11}$; in this case, the SINR measurement method should follow the extrapolation method described in 6.11.2. The measurement shall be carried out at measurement points (6) and (7) as shown in Figure 5, where the SINR of the complete system is measured.

6.12.2 Connection of the equipment

The measuring setup for system noise margin measurement is shown in Figure 18.

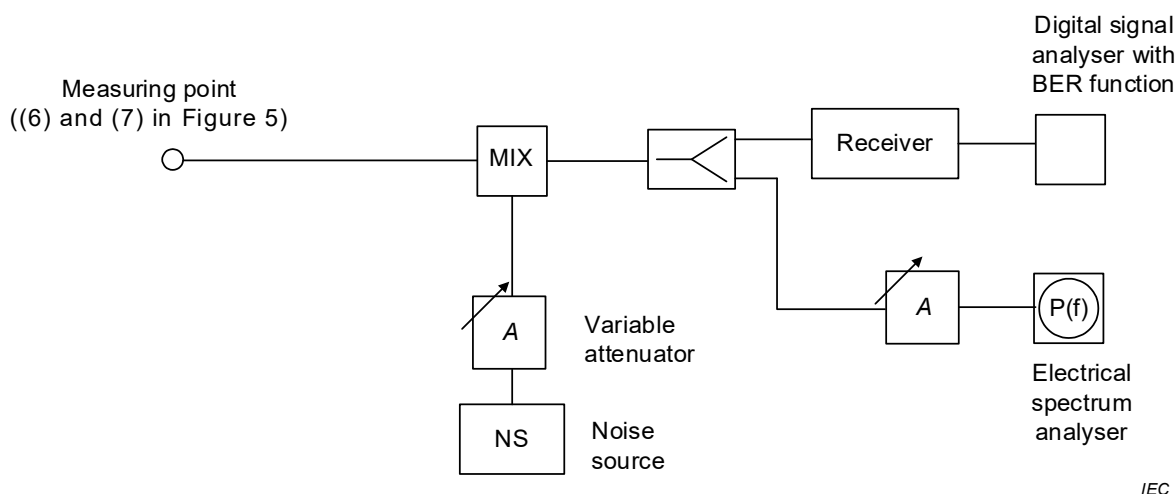


Figure 18 – Test setup for system noise margin measurement

6.12.3 Measurement procedure

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

- Prepare the measurement system as shown in Figure 18.
- The spectrum analyser and the digital signal analyser (or digital tuner + BER measurement instrument) are connected at each measurement point.
- Adjust the measurement frequency on the measurement instrument.
- Measure the BER before RS error correction with the digital signal analyser or the digital tuner + BER measurement instrument.
- Measure R_{SIN1} at the measurement frequency.
- Add noise by changing the attenuation level until the BER before RS error correction becomes 1×10^{-4} .
- Measure R_{SIN2} .
- Calculate the noise margin (M_{IN}) using Equation (11):

$$M_{\text{IN}} = R_{\text{SIN1}} - R_{\text{SIN2}} \quad \text{in dB} \quad (11)$$

6.12.4 Presentation of the results

An example of measurement for the system noise margin is shown in Figure 19.