International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.984.5

(02/2022)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Optical line systems for local and access networks

Gigabit-capable passive optical networks (G-PON): Enhancement band

Recommendation ITU-T G.984.5

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
General	G.900–G.909
Parameters for optical fibre cable systems	G.910–G.919
Digital sections at hierarchical bit rates based on a bit rate of 2048 kbit/s	G.920–G.929
Digital line transmission systems on cable at non-hierarchical bit rates	G.930–G.939
Digital line systems provided by FDM transmission bearers	G.940–G.949
Digital line systems	G.950–G.959
Digital section and digital transmission systems for customer access to ISDN	G.960–G.969
Optical fibre submarine cable systems	G.970–G.979
Optical line systems for local and access networks	**G.980–G.989**
Metallic access networks	G.990–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.984.5

Gigabit-capable passive optical networks (G-PON): Enhancement band

Summary

Recommendation ITU-T G.984.5 defines wavelength ranges reserved for additional service signals to be overlaid via wavelength division multiplexing (WDM) in gigabit-capable passive optical networks (G-PONs) for maximizing the value of optical distribution networks (ODNs).

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.984.5	2007-09-22	15	11.1002/1000/9185
1.1	ITU-T G.984.5 (2007) Amd.1	2009-10-09	15	11.1002/1000/10543
2.0	ITU-T G.984.5	2014-05-14	15	11.1002/1000/12184
2.1	ITU-T G.984.5 (2014) Amd. 1	2018-05-07	15	11.1002/1000/13527
2.2	ITU-T G.984.5 (2014) Amd. 2	2020-10-29	15	11.1002/1000/14490
3.0	ITU-T G.984.5	2022-02-13	15	11.1002/1000/14927

Keywords

Coexistence element, enhancement band, G-PON, wavelength blocking filter, WDM filter.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Table of Contents

Recommendation ITU-T G.984.5

Gigabit-capable passive optical networks (G-PON): Enhancement band

1 Scope

The purpose of this Recommendation is to define wavelength ranges reserved for additional service signals to be overlaid via wavelength division multiplexing (WDM) in gigabit-capable passive optical networks (G-PONs) for maximizing the value of optical distribution networks (ODNs).

For this purpose, this Recommendation defines and provides:

– wavelength ranges to be reserved; and

– X/S tolerance in PON optical network units (ONUs).

Appendices I and II provide:

– a general reference diagram of coexistence elements, and sample parameters of a discrete WDM filter that combines and isolates up/down signals of passive optical network (PON) systems, radio frequency (RF) signals and optical time-domain reflectometer (OTDR) signals at the optical line termination (OLT) side;

– examples of wavelength allocation for next generation access (NGA) services and video distribution services.

The physical media dependent (PMD) layer specification for G-PON in the absence of an enhancement band is defined in [ITU-T G.984.2]. PMD layer specifications for G-PON in the presence of enhancement bands are defined by the combination of [ITU-T G.984.2] and this Recommendation. Whenever a parameter specified in [ITU-T G.984.2] is not explicitly mentioned in this Recommendation, its value given in [ITU-T G.984.2] remains valid. Whenever a parameter is specified in both this Recommendation and [ITU-T G.984.2], the specification in this Recommendation takes precedence.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.671] Recommendation ITU-T G.671 (2019), *Transmission characteristics of optical components and subsystems*.

[ITU-T G.983.1] Recommendation ITU-T G.983.1 (2005), *Broadband optical access systems based on Passive Optical Networks (PON)*.

[ITU-T G.983.3] Recommendation ITU-T G.983.3 (2001), *A broadband optical access system with increased service capability by wavelength allocation*.

[ITU-T G.984.2] Recommendation ITU-T G.984.2 (2019), *Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification.*

[ITU-T G.987] Recommendation ITU-T G.987 (2012), *10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms.*

[ITU-T G.987.2] Recommendation ITU-T G.987.2 (2016), *10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification.*

[ITU-T G.989] Recommendation ITU-T G.989 (2014), *40-Gigabit-capable passive optical network (NG-PON2) systems: Definitions, abbreviations and acronyms*.

[ITU-T G.989.1] Recommendation ITU-T G.989.1 (2013), *40-Gigabit-capable passive optical networks (NG-PON2): General requirements.*

[ITU-T G.9805] Recommendation ITU-T G.9805 (2022), *Coexistence of passive optical network systems.*

[ITU-T G.9807.1] Recommendation ITU-T G.9807.1 (2016), *10-Gigabit-capable symmetric passive optical network (XGS-PON).*

[ITU-T L.313] Recommendation ITU-T L.313/L.66 (2007), *Optical fibre cable maintenance criteria for in-service fibre testing in access networks.*

3 Definitions

This Recommendation makes frequent use of the terms defined in [ITU-T G.983.1], [ITU-T G.983.3] and [ITU-T G.984.2]. For purposes of convenience, the main definitions related to the G-PON enhancement bands are reported in this clause.

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 10-Gigabit-capable passive optical network (XG-PON): [ITU-T G.987].

3.1.2 coexistence element (CE): [ITU-T G.989].

3.1.3 NG-PON2: [ITU-T G.989].

3.1.4 optical distribution network (ODN): [ITU-T G.984.2].

3.1.5 optical line termination (OLT): [ITU-T G.984.2].

3.1.6 optical network unit (ONU): [ITU-T G.984.2].

3.1.7 PtP WDM PON: [ITU-T G.989].

3.1.8 TWDM PON: [ITU-T G.989].

3.1.9 wavelength division multiplexing (WDM): [ITU-T G.984.2].

3.1.10 wavelength multiplexer (WM): [ITU-T G.989].

3.1.11 XGS-PON: [ITU-T G.9807.1].

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 next generation access (NGA): A possible new optical access system that coexists with gigabit-capable passive optical network (G-PON) on the same optical distribution network (ODN).

3.2.2 wavelength blocking filter (WBF): An optical filter to prevent an optical receiver from receiving unwanted optical signals with different wavelengths.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APD	Avalanche Photo Diode
BER	Bit Error Rate
BM	Burst Mode
B-PON	Broadband Passive Optical Network
CDR	Clock Data Recovery
CE	Coexistence Element
CEM	Coexistence Element/Multiplexer
CNR	Carrier-to-Noise Ratio
DBA	Determined By Application
DFB	Distributed Feedback Laser
G-PON	Gigabit-capable Passive Optical Network
HSP	Higher Speed Passive Optical Network
LA	Limiting Amplifier
MPM	Multi-PON Module
NRZ	Non Return to Zero
NG-PON2	Next Generation Passive Optical Network phase 2
NGA	Next Generation Access
OAN	Optical Access Network
ODN	Optical Distribution Network
OLT	Optical Line Termination
ONU	Optical Network Unit
OPL	Optical Path Loss
OSA	Optical Sub-Assembly
OTDR	Optical Time-Domain Reflectometer
PLC	Planar Lightwave Circuit
PMD	Physical Media Dependent
PON	Passive Optical Network
PtP WDM	Point-to-Point Wavelength Division Multiplexing
RF	Radio Frequency
TIA	Trans-Impedance Amplifier
TDM	Time Division Multiplexing
TWDM	Time and Wavelength Division Multiplexing
WBF	Wavelength Blocking Filter
WDM	Wavelength Division Multiplexing
WM	Wavelength Multiplexer

XG-PON Asymmetric 10-Gigabit Passive Optical Network

XGS-PON Symmetric 10-Gigabit Passive Optical Network

XG(S)-PON XG-PON or XGS-PON

5 Conventions

None.

6 Reference architecture

Figure 1, reproduced here for convenience from Figure 5 of [ITU-T G.983.1], shows the generic physical configuration of an optical access network (OAN).

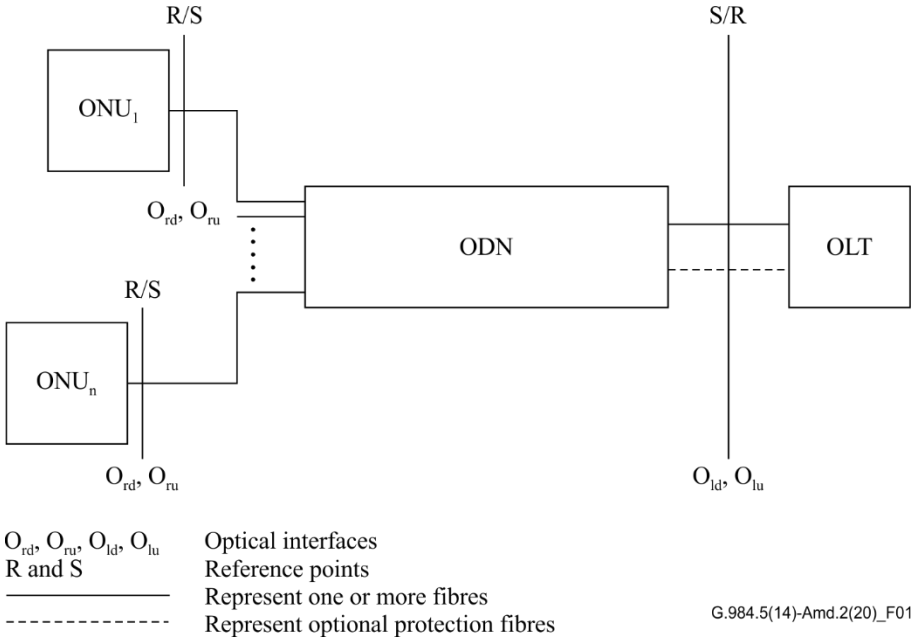


Figure 1 – Generic physical configuration of the optical access network
(Reproduced from Figure 5 of [ITU-T G.983.1])

The two directions for optical transmission in the optical distribution network ODN are identified as follows:

– downstream direction for signals travelling from the optical line termination (OLT) to the optical network unit(s) (ONU);

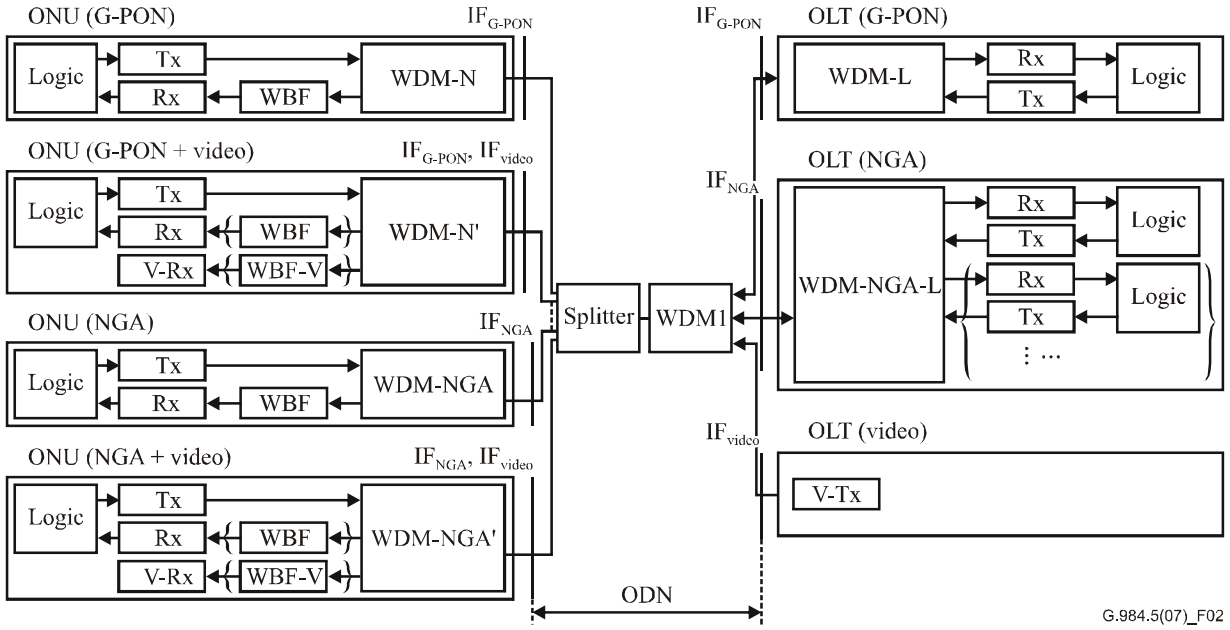
– upstream direction for signals travelling from the ONU(s) to the OLT.

According to [ITU-T G.983.1], transmission in downstream and upstream directions can take place on the same fibre and components (duplex/diplex working) or on separate fibres and components (simplex working). This Recommendation covers only diplex working, i.e., bidirectional transmission using different wavelengths over a single fibre.

There can be several types of ODN architectures to achieve the coexistence of gigabit-capable passive optical network (G-PON) and additional services including next generation access (NGA) and video distribution services.

Figures 2 and 3 are reference diagrams of optical access network (OAN) architectures and assume that wavelength blocking filters (WBFs) are used when G-PON, video and NGA share the same ODN.

Note that these reference diagrams only provide reference configurations of the ODN and WBF and are not intended to limit future designs and implementations.



(NOTE – WDM1 can be replaced by WDM1r, CE or CEM.)

Figure 2 – Optical access network architecture reference diagram 1

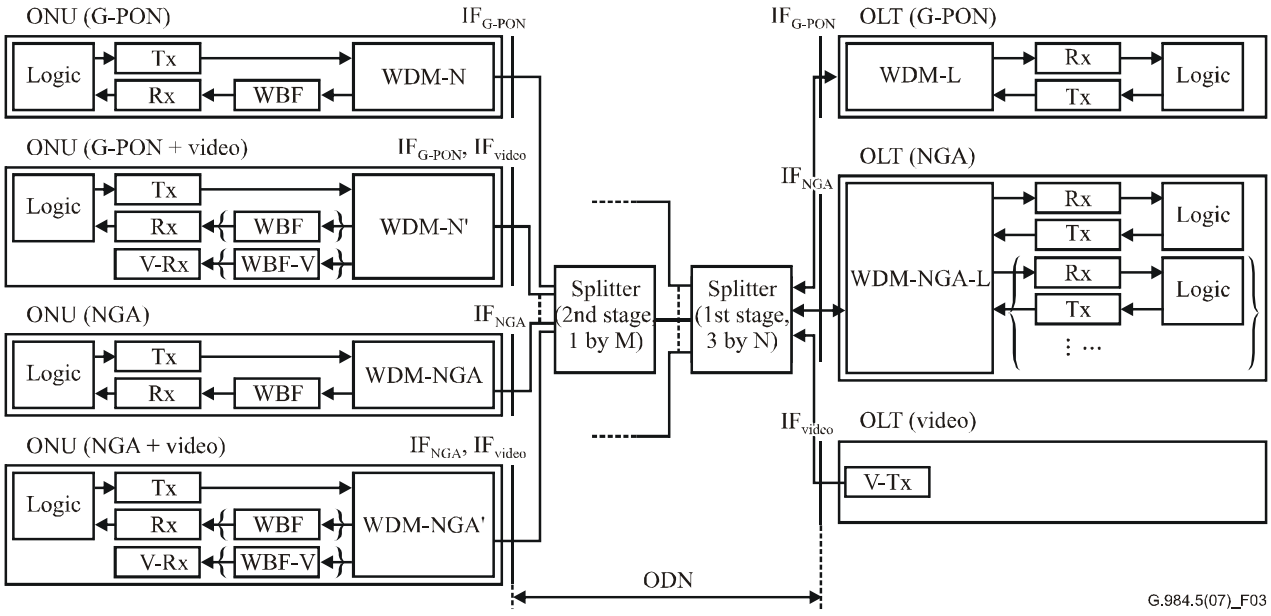


Figure 3 – Optical access network architecture reference diagram 2

The following abbreviations are used in Figures 2 and 3:

CE Coexistence element that may be located in the central office to combine/isolate the wavelengths of next generation passive optical network phase 2 (NG-PON2) and legacy PON signals and which occasionally combines the video signals and/or OTDR signals

CEM Coexistence element that may be located in the central office to combine/isolate the wavelengths of TWDM PON, PtP WDM PON and legacy PON signals and which occasionally combines the video signals and/or OTDR signals

Rx	Optical receiver
Tx	Optical transmitter
V-Rx	Video receiver
V-Tx	Video transmitter
WBF	Wavelength blocking filter for blocking interference signals to Rx
WBF-V	Wavelength blocking filter for blocking interference signals to V-Rx
WDM-N	WDM filter in G-PON ONU to combine/isolate the wavelengths of G-PON upstream and downstream
WDM-N'	WDM filter in G-PON ONU to combine/isolate the wavelengths of G-PON upstream and downstream and isolate the video signal(s)
WDM-NGA	WDM filter in NGA ONU to combine/isolate the wavelengths of NGA upstream and downstream
WDM-NGA'	WDM filter in NGA ONU to combine/isolate the wavelengths of NGA upstream and downstream and isolate the video signal(s)
WDM-L	WDM filter in G-PON OLT to combine/isolate the wavelengths of G-PON upstream and downstream
WDM-NGA-L	WDM filter in NGA OLT to combine/isolate the wavelengths of NGA upstream and downstream of one or more channels
WDM1	WDM filter that may be located in the central office to combine/isolate the wavelengths of G-PON and NGA signals and which occasionally combines the video signals and/or OTDR signals
WDM1r	WDM filter that may be located in the central office to combine/isolate the wavelengths of G-PON and XG-PON signals and which occasionally combines the video signals and/or OTDR signals.

7 Operating wavelength

The wavelength range of the G-PON downstream signal (single fibre system) is specified in [ITU-T G.984.2] as 1480 nm to 1500 nm and that of the G-PON upstream signal as 1260 nm to 1360 nm. This Recommendation redefines the reserved wavelength range and specifies the tolerance for interference signals of G-PON ONUs to enable the coexistence of G-PON and additional services including NGA and video services.

Figure 4 and Table 1 define the wavelength allocation plan including the wavelength bands reserved for additional services. The wavelength range of the G-PON downstream signal is referred to as the "basic band". Reserved bands are referred to as the "enhancement band". Applications for the enhancement band include video services and NGA services. The wavelength range for video services remains as defined in [ITU-T G.983.3].

A guard band separates the G-PON upstream and/or basic band from the enhancement band. Interference between signals in these two bands causes signal degradation to each. This signal degradation must be kept to a negligible level. Wavelength blocking filters (WBFs) are used to obtain the required isolation outside the guard band. The wavelength values specified in Table 1 take into account guard bands that may be achievable by commercially available low-cost WBFs.

NOTE – Wavelengths in the enhancement band may be used not only for downstream but also for upstream signal transmission in the WDM scheme.

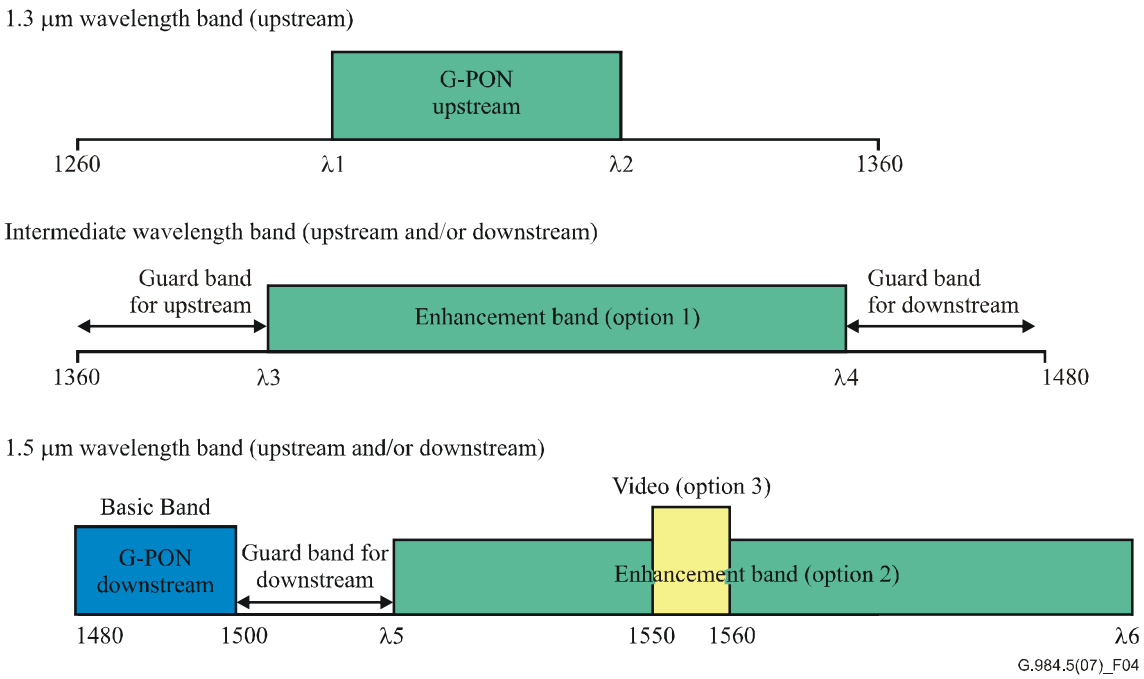


Figure 4 – Wavelength allocation

Table 1 – Parameters for wavelength allocation

Items	Notation	Unit	Nominal value	Application examples
1.3 μm wavelength band				For use in G-PON upstream.
– Regular wavelength band option				e.g., ONUs based on Fabry-Perot lasers.
Lower limit	λ1	nm	1 260	
Upper limit	λ2	nm	1 360	
– Reduced wavelength band option				e.g., ONUs based on ordinary DFB lasers.
Lower limit	λ1	nm	1 290	
Upper limit	λ2	nm	1 330	
– Narrow wavelength band option				e.g., ONUs based on wavelength selected lasers.
Lower limit	λ1	nm	1 300	
Upper limit	λ2	nm	1 320	
Enhancement band (option 1-1)				For next generation access (NGA). (See Note 2)
Lower limit	λ3	nm	1 415 *(Informative)*	
Upper limit	λ4	nm	1 450 *(Informative)*	
Enhancement band (option 1-2)				For next generation access (NGA). Applicable for low-water-peak fibre only. (See Note 3)
Lower limit	λ3	nm	1 400 *(Informative)*	
Upper limit	λ4	nm	1 450 *(Informative)*	

Table 1 – Parameters for wavelength allocation

Items	Notation	Unit	Nominal value	Application examples
Basic band				For use in G-PON downstream.
Lower limit	–	nm	1 480	
Upper limit	–	nm	1 500	
Enhancement band (option 2, see Note 1)				For next generation access (NGA). (See Note 4 and Note 5)
Lower limit	λ5	nm	1 530	
Upper limit	λ6	nm	1 580 to 1 625	
Enhancement band (option 3, see Note 1)				For video distribution service.
Lower limit	–	nm	1 550	
Upper limit	–	nm	1 560	

NOTE 1 – Additional guard bands are needed in the case of the coexistence of option 2 and option 3 (see Appendix II).

NOTE 2 – The values are informative. The loss in this band is not guaranteed in optical branching components for PON (i.e., power splitters) as specified in [ITU-T G.671] nor in optical fibres specified as G.652A and G.652B (non-low-water-peak fibres).

NOTE 3 – The values are informative. The loss in this band is not guaranteed in optical branching components for PON (i.e., power splitters) as specified in [ITU-T G.671].

NOTE 4 – The value of 1530 nm assumes use of the wavelength for downstream NGA transmission. If it is used for upstream transmission, the value can be smaller.

NOTE 5 – The upper-limit value is determined as an operator choice from 1580 to 1625 nm taking into account the following factors:

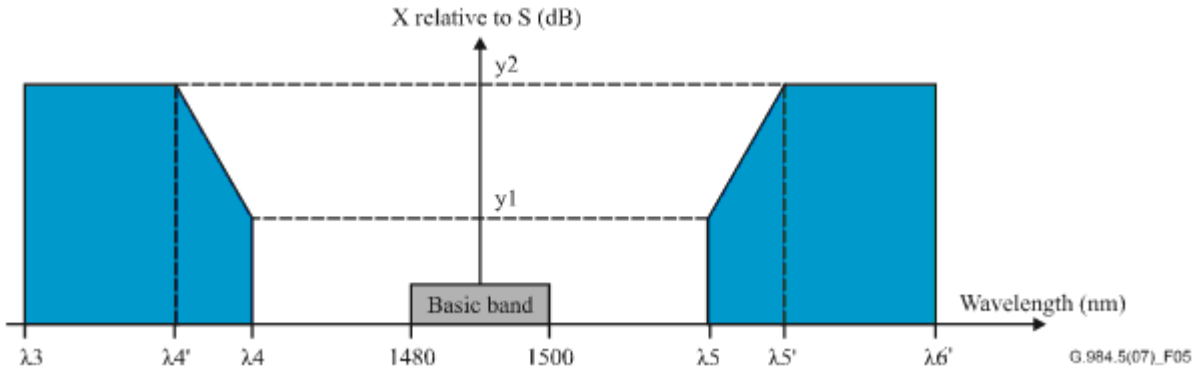
– Bending loss of optical fibre that increases at longer wavelengths.
– Loss of a filter that separates/combines a monitoring signal and NGA signal(s) (if an optical monitoring system is used).

8 X/S tolerance of G-PON ONU

The minimum optical sensitivity requirements of a G-PON ONU must be met in the presence of the interference signals caused by NGA and/or video signals in the enhancement bands specified in Table 1. To minimize the effect of interference signals, G-PON ONUs need to isolate interference signals using an appropriate WBF and WDM filter. This Recommendation does not specify the isolation characteristics of the WBF and WDM filters themselves, but does specify the X/S tolerance of the G-PON ONU.

In Figure 5, S is the optical power of the basic band signal, and X is the optical power of the interference signal(s). Both S and X are measured at the point $IF_{G\text{-}PON}$ on the optical network unit (ONU) side of the network shown in Figures 2 and 3. Figure 5 shows the X/S tolerance mask that should not cause the sensitivity of the basic band receiver to fail to meet the specified limit. Implementers need to specify the isolation characteristics of the WBF and WDM filter needed to obtain enough isolation of the interference signal(s) that will allow the sensitivity requirements to be respected in the presence of this level of interference. In the case of coexistence with G-PON, the wavelengths and total optical launch power of additional services including NGA and video services must be considered with reference to Figure 5.

The interference signal format for measuring X/S tolerance should be non-return to zero (NRZ) pseudo-random coded with the same bit rate as the G-PON downstream signal or with a lower bit rate within the bandwidth of the basic band receiver.



Wavelength (nm)	λ3	λ4'	λ4	λ5	λ5'	λ6'
	1415/1400 *(Informative)*	1441 *(Informative)*	1450 *(Informative)*	1530	1539	1675
X relative to S (dB)	y2	y2	y1	y1	y2	y2
	22 *(Informative)*	22 *(Informative)*	7 *(Informative)*	7	22	22

S Received power of basic band
X Maximum total power of NGA and video received in the blocking wavelength range
X/S Inside the mask (hatching area) should not cause the sensitivity of the basic band receiver to fail to meet the specified limit
NOTE – λ3 value of 1400 *(Informative)* may be applicable for low-water-peak fibre only.

Figure 5 – X/S tolerance mask for ONU

Appendix I

Example of WDM1, WDM1r, CEx and CEMx characteristics

(This appendix does not form an integral part of this Recommendation.)

The WDM1, WDM1r, CEx and CEMx devices can have several different configurations depending on whether a video overlay service or an optical time-domain reflectometer (OTDR) is provided. Appendix I of [ITU-T G.9805] presents several examples of device characteristics.

Appendix II

Examples of wavelength allocation for NGA services and video distribution services

(This appendix does not form an integral part of this Recommendation.)

II.1 Introduction

Considering the possible network scenarios that allow the coexistence of G-PON, NGA and video services, it is assumed that additional guard bands are needed at both sides of the video band to avoid interference which could cause the degradation of video carrier-to-noise ratio (CNR) performances of the video receiver. To take the guard bands for both basic band and video into account, the wavelength range between basic band and video may not be applicable for NGA downstream signals. Figure II.1 shows the wavelength plan of the 1.5 μm wavelength band for these scenarios. The ranges of the guard bands depend on the filter characteristics of the video band pass filter and the performance of the video receiver. In this clause, two types of filters are considered. One is the integrated filter within the G-PON ONU transceiver such as triplexer type transceiver and the other is the discrete filter outside of the G-PON diplexer type transceiver and the video receiver. The examples of wavelength allocation and filter characteristics for each case are provided in clauses II.2 and II.3.

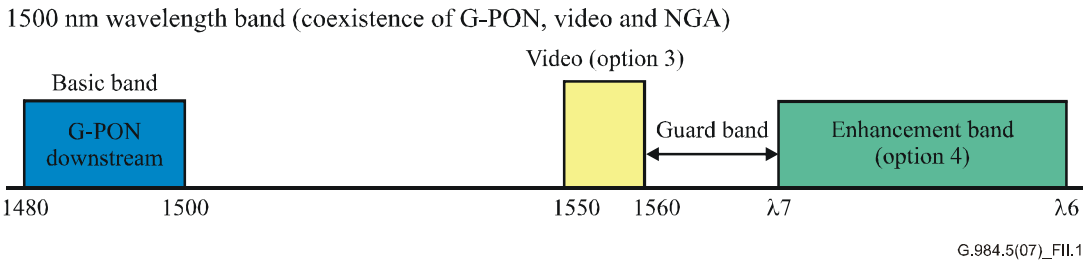


Figure II.1 – Wavelength allocation

II.2 Case 1: Integrated filter for video

Figure II.2 shows an example configuration of a G-PON ONU using a triplexer type transceiver including an integrated video filter. This figure does not intend to limit filter configurations of the triplexer. Filter configurations may be different in each implementation and also depend on the implementations of optics (e.g., micro-optics or planar lightwave circuit (PLC) based). In this figure, the isolation values at the reference point are the sum of the isolation values of the WDM filter and the wavelength blocking filter (WBF) in front of the V-Rx. Figure II.3 shows an example of isolation and Table II.1 shows an example of wavelength allocation including the tentative wavelength value of λ7 in Figure II.3. One of the example isolation values of y3 in Figure II.3 is 30 dB with reference to the realistic isolation performances of an integrated filter. Service operators and implementers should take the actual filter characteristics and performance of the video receiver into account when considering additional enhanced services.

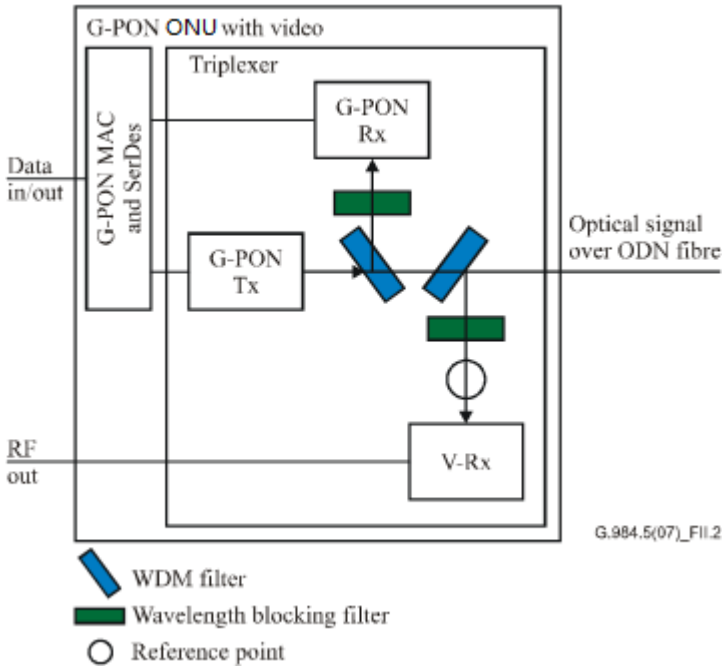


Figure II.2 – Example configuration of G-PON ONU with video (Case 1)

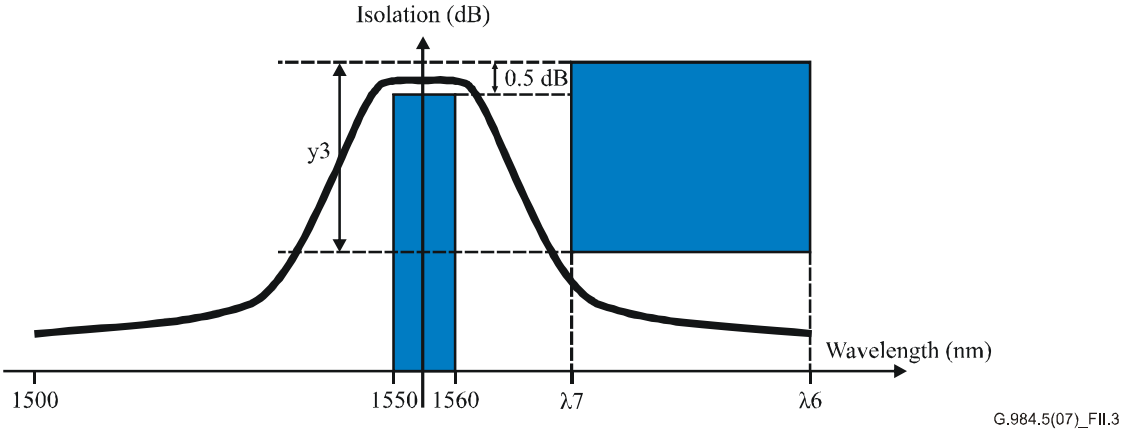


Figure II.3 – Example of integrated filter characteristics for video

Table II.1 – Example of wavelength allocation (Case 1)

Items	Notation	Unit	Nominal value	Application examples
Enhancement band (option 3)				For video distribution service
Lower limit	–	nm	1550	
Upper limit	–	nm	1560	
Enhancement band (option 4)				For next generation access (NGA)
Lower limit	λ7	nm	To be determined (1574 or 1575)	
Upper limit	λ6	nm	1580 to 1625	
NOTE – Typically applied to the integrated filters inside the triplexer type optical transceiver.				

II.3 Case 2: Discrete WDM filter for video

Figures II.4 and II.5 show example configurations of a G-PON ONU (and a video ONU) using discrete WDM filters. These figures do not intend to limit filter configurations. In these figures, the isolation values at the reference point are the sum of the isolation values of the discrete WDM filter and the WBF in front of the V-Rx. Figure II.6 shows an example of isolation and Table II.2 shows an example of wavelength allocation. One of the example isolation values of y4 in Figure II.6 is 35 dB with reference to the realistic isolation performances of a discrete filter. Service operators and implementers should take actual filter characteristics and performance of the video receiver into account when considering additional enhanced services.

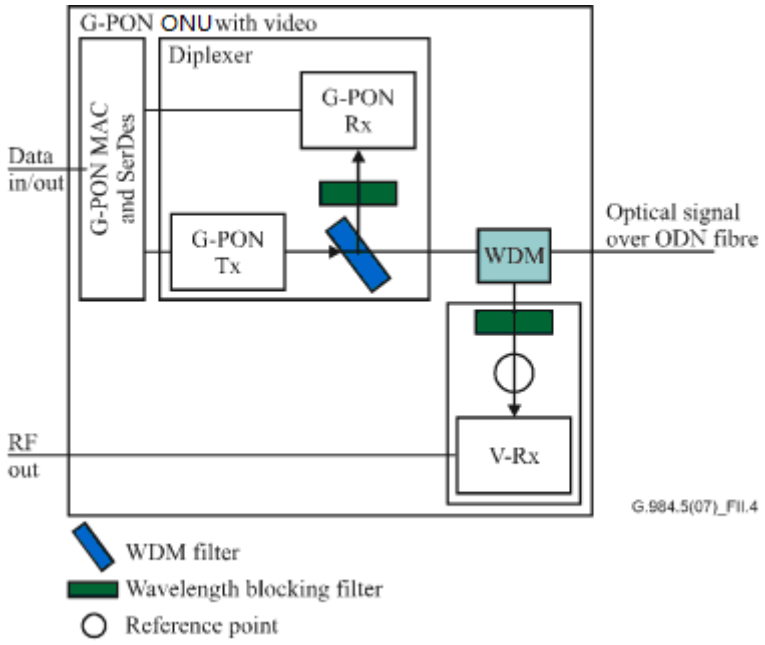


Figure II.4 – Example configuration of G-PON ONU with video (Case 2)

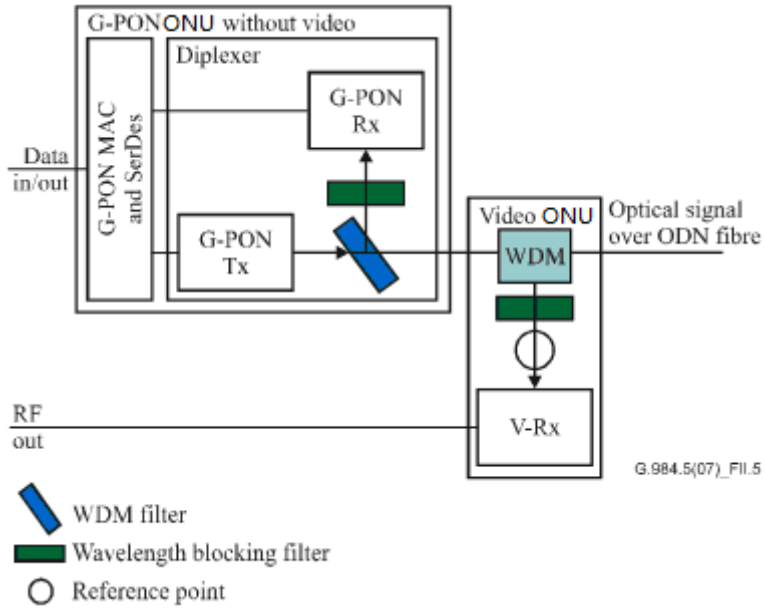


Figure II.5 – Example configuration of G-PON ONU and video ONU (Case 2)

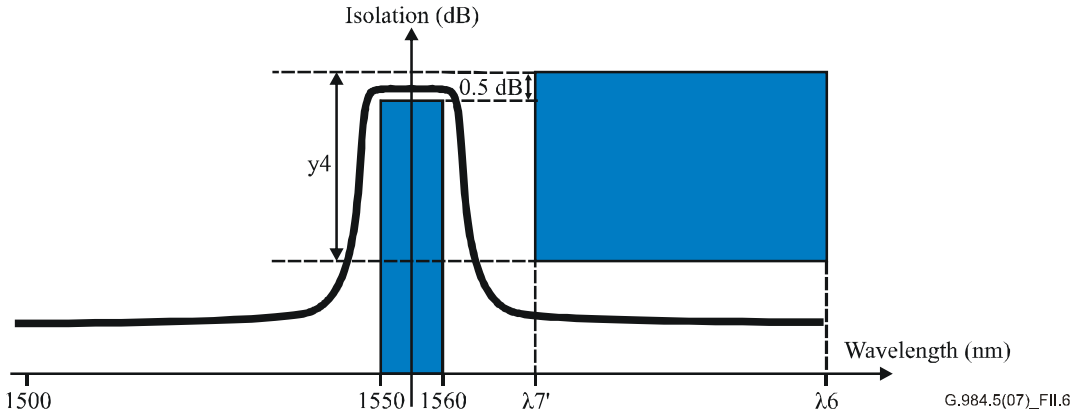


Figure II.6 – Example of discrete filter characteristics for video ONU

Table II.2 – Example of wavelength allocation (Case 2)

Items	Notation	Unit	Nominal value	Application examples
Enhancement band (option 3)				For video distribution service
Lower limit	–	nm	1550	
Upper limit	–	nm	1560	
Enhancement band (option 5)				For next generation access (NGA)
Lower limit	λ7'	nm	For further study	
Upper limit	λ6	nm	1580 to 1625	

Bibliography

[b-ITU-T G-Sup.39] ITU-T G-series Recommendations – Supplement 39 (2016), *Optical system design and engineering considerations*.

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Printed in Switzerland
Geneva, 2022