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G.984.5

Amendment 1
(05/2018)

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

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

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Gigabit-capable passive optical networks (GPON): Enhancement band

Amendment 1

Recommendation ITU-T G.984.5 (2014) – Amendment 1

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Recommendation ITU-T G.984.5

Gigabit-capable passive optical networks (GPON): Enhancement band

Amendment 1

Summary

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

Amendment 1 presents three methods for the coexistence of multiple PON generations on a common ODN, which allow the reuse of already deployed fibre and splitters when evolving an operator’s network to a higher capacity. Amendment 1 includes a new Appendix IV for a multi-PON module (MPM) with integrated WDM within the optical line termination (OLT). Appendix III provides a method for CEx isolation and directivity calculations in multi-interferer scenarios. Appendix I has been revised with new isolation values and directivity values derived using the method in Appendix III for a 4-port CEx with GPON, XG(S)-PON, NGPON2, and an OTDR. Appendix V provides a method to have PON coexistence using a 2:N splitter.

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

* 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.

FOREWORD

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The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

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As of the date of approval of this Recommendation, ITU [had/had not] received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Gigabit-capable passive optical networks (GPON): Enhancement band

Amendment 1

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T G.984-5 (2014).

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 future gigabit-capable passive optical networks (G-PON) for maximizing the value of optical distribution networks (ODNs). Other PON systems, such as B-PON, have wavelength plans based on [ITU-T G.983.3], which includes existing options for enhancement bands. This Recommendation also defines further wavelength ranges reserved for additional service signals to be overlaid via WDM in future PONs whose wavelength allocations are based on [ITU-T G.983.3].

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, II and III provide:

– sample parameters of a discrete WDM filter that combines and isolates the G-PON up/down signals and enhancement bands at the OLT side;

– examples of wavelength allocation for NGA services and video distribution services;

– methods for calculating required isolation for WDM/CE/CEM devices.

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 (2009), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.671] Recommendation ITU-T G.671 (2012), *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 (2003), *Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification*.

[ITU-T G.984.2 Amd.1] Recommendation ITU-T G.984.2 (2003) Amd.1, (2006), *Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification*; Amendment 1: *New Appendix III – Industry best practice for 2.488 Gbit/s downstream, 1.244 Gbit/s upstream G-PON.*

[ITU-T G.984.2 Amd.2] Recommendation ITU-T G.984.2 (2003) Amd.2, (2008), *Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification*; Amendment 2.

[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 (2010), *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.9807.1] Recommendation ITU-T G.9807.1 (2016), *10-Gigabit-capable symmetric passive optical network (XGS-PON).*

[ITU-T L.66] Recommendation ITU-T 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 optical distribution network (ODN): [ITU-T G.984.2].

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

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

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

3.1.5 10-Gigabit-capable passive optical network (XG-PON): [ITU-T G.987].

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

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

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

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

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 G-PON on the same 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

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

OSA Optical Sub-Assembly

OTDR Optical Time Domain Reflectometer

PMD Physical Media Dependent

PON	Passive Optical Network
PtP WDM	Point-to-Point Wavelength Division Multiplexing
RF	Radio Frequency
TIA	Trans-Impedance Amplifier
TWDM	Time and Wavelength Division Multiplexing
WBF	Wavelength Blocking Filter
WDM	Wavelength Division Multiplexing
WM	Wavelength Multiplexer
XG-PON	10-Gigabit-capable Passive Optical Network.

5 Conventions

None.

6 Reference architecture

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

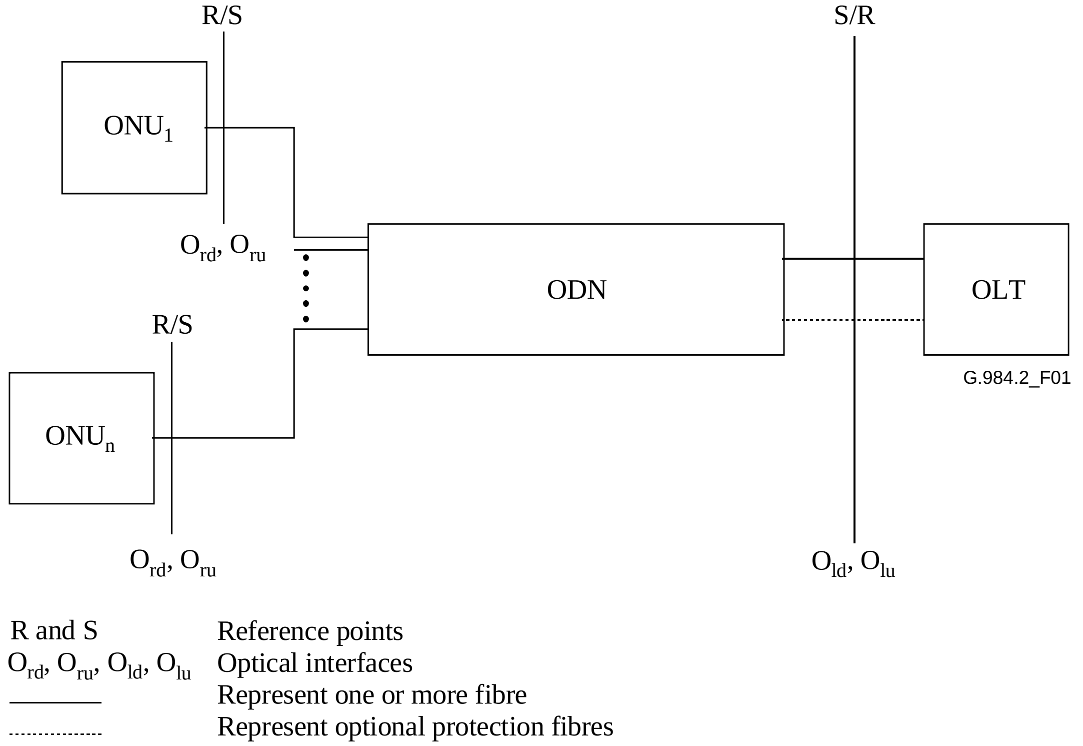


Figure 1 – Generic physical configuration of the optical access network
(Reproduced from Figure 5 of [ITU-T G.983.1])

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

– downstream direction for signals travelling from the OLT to the ONU(s);

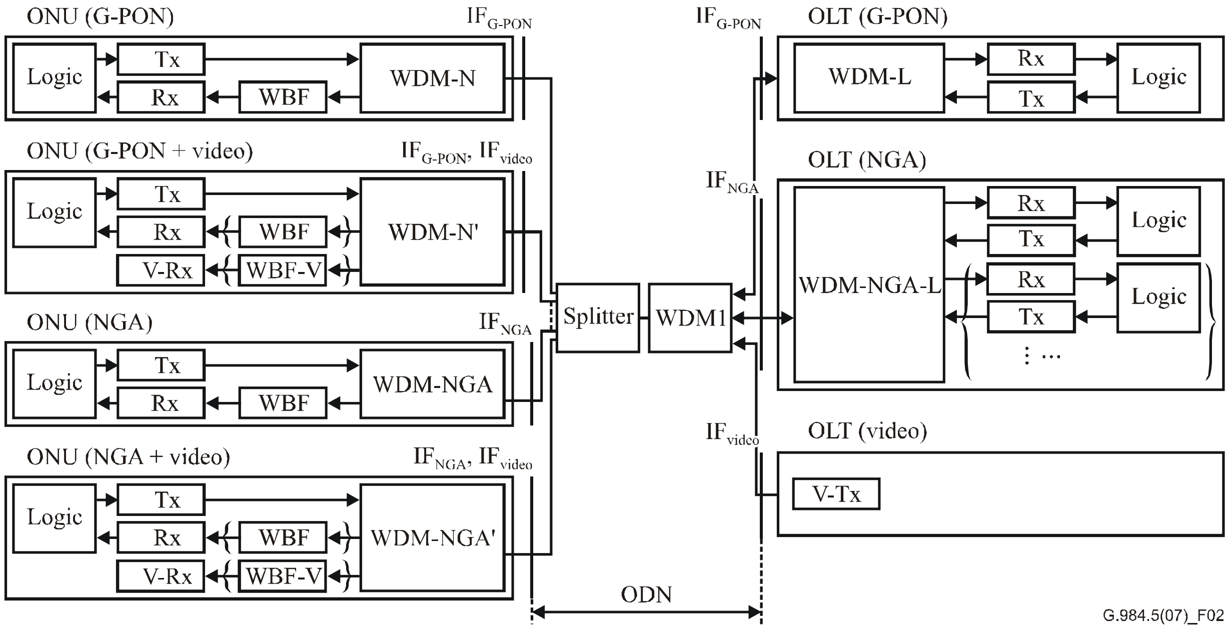
– upstream direction for signals travelling from the ONU(s) to the OLT.

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 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 (WBF) 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

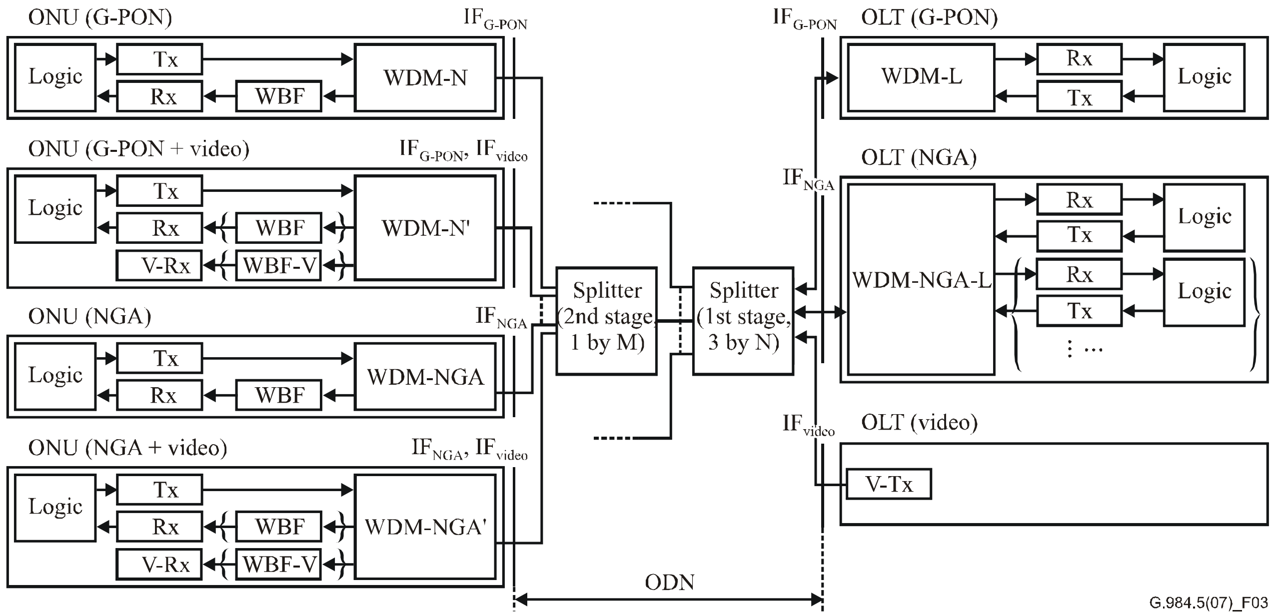


Figure 3 – Optical access network architecture reference diagram 2

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 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.

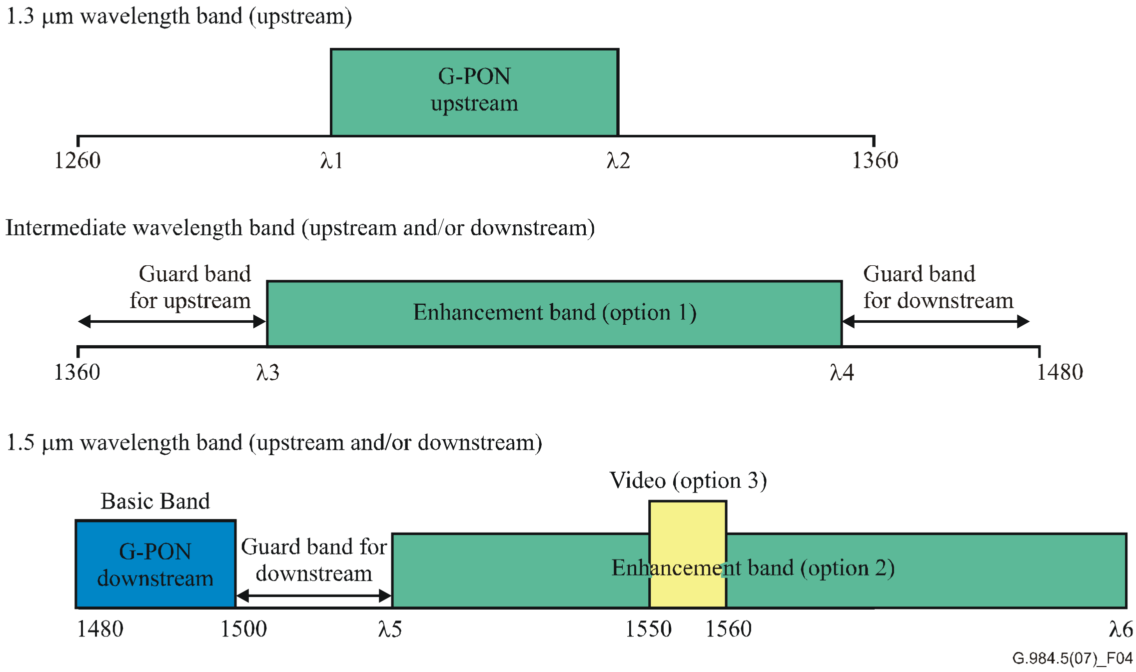


Figure 4 – Wavelength allocation

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).

Table 1 – Parameters for wavelength allocation

Items	Notation	Unit	Nominal value	Application examples
Lower limit	λ3	nm	1 400 *(Informative)*	Applicable for low-water-peak fibre only. (See Note 3)
Upper limit	λ4	nm	1 450 *(Informative)*	
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.

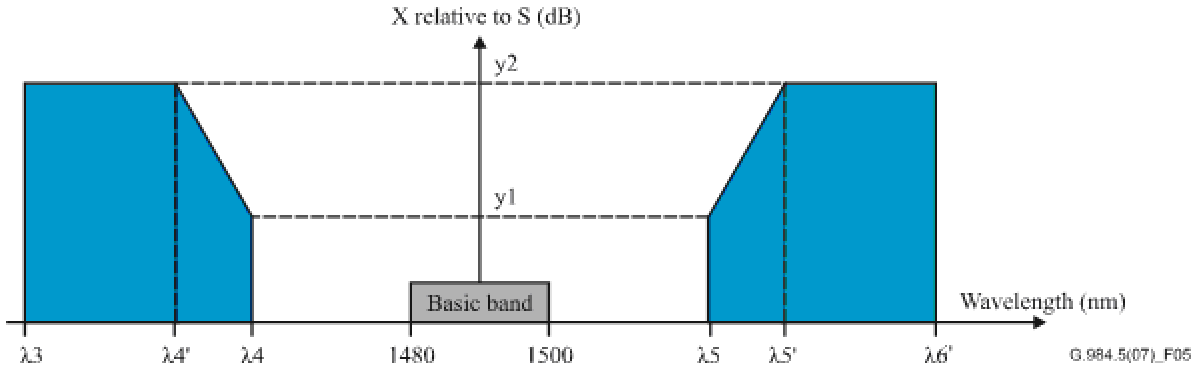
– Loss of a filter that separates/combines a monitoring signal and NGA signal(s) (if an optical monitoring system is used).

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 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. This appendix presents several examples of device characteristics.

The first example given of a WDM1 filter was defined in the first approved version of this Recommendation (released in September 2007). This WDM1 filter is hereby obsoleted, as the wavelength plan for NGA systems has become incompatible with its definition. Its description is retained below for historical reference.

The subsequent examples of filters (from Table I.2 to Table I.6 and Figure I.2 to Figure I.7) are termed "WDM1r" to signify that they are revised specifications that reflect the approved newer wavelength plan for NGA systems. There are two examples of the NGA interface: a single-fibre NGA interface and a deprecated dual-fibre NGA interface. There are four examples of added wavelength service ports: none, video, OTDR and video+OTDR. There are two upstream wavelength plans for the G-PON interface that allow coexistence with NGA.

The next examples of devices (from Table I.7 to Table I.10 and Figure I.8 to Figure I.11) are termed "CEx", and support the coexistence of NG-PON2 with legacy PON systems.

The final examples of devices (from Table I.11 to Table I.14 and Figure I.12 to Figure I.15) are termed "CEM" to signify that they include the functions of CEx and partial wavelength multiplexer (WM) which combine/isolate the TWDM PON and PtP WDM PON bands.

The isolation values in the following tables may be determined depending on the application and they can be calculated using the methods described in Appendix III.

In the following tables (except for Table I.3), G-PON with reduced upstream band is considered as an example. The values of insertion loss for G-PON with narrow upstream band are expected to be the same.

Table I.1 shows sample parameters of the deprecated WDM1 filter that combines (downstream) and isolates (upstream) the G-PON up/down signals and enhancement band. Figure I.1 shows the reference diagram of WDM1.

Table I.1 – Parameters for WDM1 (deprecated)

Specification	Value
Loss without connectors – G-PON wavelength span	< 0.7 dB (1260-1500 nm)
Loss without connectors for enhancement bands	< 1.0 dB (1524-1625 nm)
Isolation – COM – OLT (1524-1625 nm)	To be determined (> 30 dB (higher values may be required depending on the application))
Isolation – COM – UPGRADE (1480-1500 nm, 1260-1360 nm)	> 30 dB
Maximum optical power	+23 dBm

Table I.1 – Parameters for WDM1 (deprecated)

Specification	Value
Return loss	> 50 dB
Directivity	> 50 dB
NOTE 1 – The wavelength range of 1524-1530 nm should not be used by NGA downstream signals. NOTE 2 – The specification of WDM1 in the range of 1625-1660 nm for applications such as inserting an OTDR signal onto the PON is for future study.	

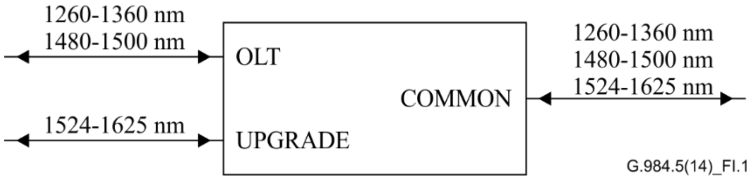


Figure I.1 – Reference diagram of WDM1 (deprecated)

Table I.2 shows sample parameters of the single-fibre WDM1r filter that combines (downstream) and isolates (upstream) the G-PON up/down signals and NGA bands. Figure I.2 shows the reference diagram of the single-fibre WDM1r.

Table I.2 – Parameters for a WDM1r with G-PON and NGA ports

Specification	Value
Loss without connectors for G-PON bands	< 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for NGA bands	< 1.0 dB (1260-1280 nm and 1524-1625 nm)
Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1625 nm)	DBA (see Appendix III)
Isolation – COM – NGA OLT (1290-1500 nm)	DBA (see Appendix III)
Maximum optical power	+23 dBm
Return loss	> 50 dB
Directivity	> 50 dB

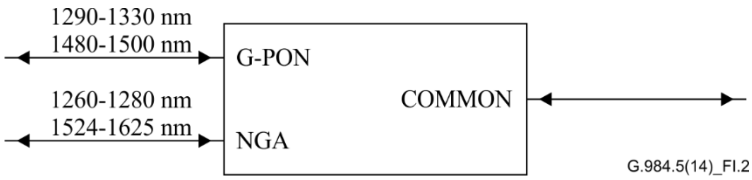


Figure I.2 – Reference diagram of a WDM1r with G-PON and NGA support

Table I.3 shows sample parameters of the single-fibre WDM1rn filter that combines (downstream) and isolates (upstream) the G-PON up/down signals and NGA bands. The WDM1rn can be used when all of the G-PON ONUs comply with the narrow upstream wavelength option. Figure I.3 shows a reference diagram of a single-fibre WDM1rn.

Table I.3 – Parameters for a WDM1rn with narrow upstream wavelength G-PON and NGA ports

Specification	Value
Loss without connectors for G-PON bands	< 0.8 dB (1300-1320 nm and 1480-1500 nm)
Loss without connectors for NGA bands	< 1.0 dB (1260-1280 nm and 1524-1625 nm)
Isolation – COM – G-PON OLT (1260-1280 and 1524-1625 nm)	DBA (see Appendix III)
Isolation – COM – NGA OLT (1300-1500 nm)	DBA (see Appendix III)
Max optical power	+23 dBm
Return loss	> 50 dB
Directivity	> 50 dB

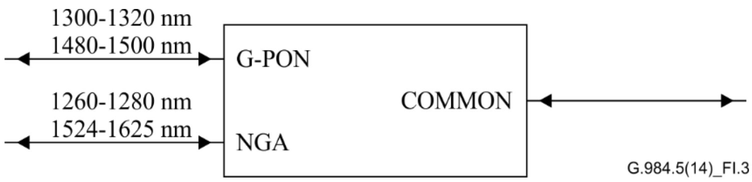


Figure I.3 – Reference diagram of a WDM1rn with narrow upstream wavelength G-PON and NGA support

Table I.4 shows sample parameters of the deprecated dual-fibre WDM1r filter that combines (downstream) and isolates (upstream) the G-PON up/down signals and NGA bands. Figure I.4 shows the reference diagram of the dual-fibre WDM1r.

Table I.4 – Parameters for a dual-fibre WDM1r with G-PON and NGA ports (deprecated)

Specification	Value
Loss without connectors for G-PON bands	< 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for NGAd band	< 0.8 dB (1575-1581 nm)
Loss without connectors for NGAu band	< 0.8 dB (1260-1280 nm)
Isolation – COM – G-PON OLT (1260-1280 and 1524-1625 nm)	To be determined (> 30 dB (higher values may be required depending on the application))
Isolation – COM – NGAd OLT (1480-1500 nm, 1260-1360 nm)	N/A
Isolation – COM – NGAu OLT (1480-1625 nm, 1290-1360 nm)	To be determined (> 30 dB (higher values may be required depending on the application))
Maximum optical power	+23 dBm
Return loss	> 50 dB
Directivity	> 50 dB

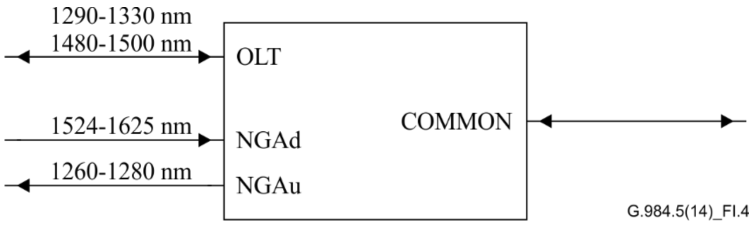


Figure I.4 – Reference diagram of a dual-fibre WDM1r with G-PON and NGA support (deprecated)

Table I.5 shows sample parameters of the single-fibre WDM1r filter supporting OTDR capability. The wavelength range assumed for the OTDR is referred from [ITU-T L.66]. Note that the wavelength range of the NGA port changes when these optional ports are present. Figure I.5 shows the reference diagram of this filter.

Table I.5 – Parameters for a WDM1r with G-PON, NGA and OTDR ports

Specification	Value
Loss without connectors for G-PON bands	≤ 1.0 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for NGA bands	≤ 1.2 dB (1260-1280 nm and 1524-1581 nm)
Loss without connectors for OTDR band	≤ 1.1 dB (1625-1675 nm)
Isolation – COM – G-PON OLT (1260-1280 and 1524-1675 nm)	DBA (see Appendix III)
Isolation – COM – NGA OLT (1290-1500 nm and 1600-1675 nm)	DBA (see Appendix III)
Isolation – COM – OTDR (1260-1581 nm)	DBA (see Appendix III)
Maximum optical power for G-PON or NGA ports	+23 dBm
Maximum optical power for OTDR port	For further study
Return loss	> 50 dB
Directivity	> 50 dB

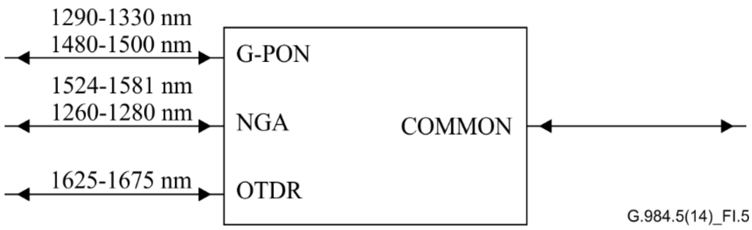


Figure I.5 – Reference diagram of a WDM1r with G-PON, NGA and OTDR support

Figure I.6 shows the reference diagram of the deprecated dual-fibre WDM1r with video support.

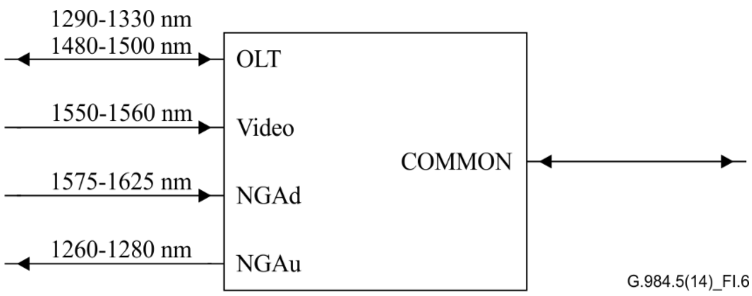


Figure I.6 – Reference diagram of a dual-fib~~e~~re WDM1r with G-PON, video and NGA support (deprecated)

Table I.6 shows sample parameters of a single-fibre WDM1r filter supporting OTDR and video capability. Note that the wavelength range of the NGA port changes when these optional ports are present. Figure I.7 shows the reference diagram of this filter.

Table I.6 – Parameters for WDM1r with G-PON, RF video, NGA and OTDR ports

Specification	Value
Loss without connectors for G-PON bands	≤ 1.0 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for NGA bands	≤ 1.5 dB (1260-1280 nm and 1575-1581 nm)
Loss without connectors for OTDR band	≤ 1.1 dB (1625-1675 nm)
Loss without connectors for RF video band	≤ 1.7 dB (1550-1560 nm)
Isolation – COM – G-PON OLT (1260-1280 and 1550-1675 nm)	DBA (See Appendix III)
Isolation – COM – NGA OLT (1290-1560 nm and 1625-1675 nm)	DBA (see Appendix III)
Isolation – COM – OTDR (1260-1581 nm)	DBA (see Appendix III)
Isolation – COM – RF video (1260-1500 nm, 1575-1675 nm)	NA (RF is downstream only)
Maximum optical power for G-PON or NGA ports	+23 dBm
Maximum optical power for OTDR port	For further study
Maximum optical power for RF video port	+23 dBm
Return loss	> 50 dB
Directivity	> 50 dB

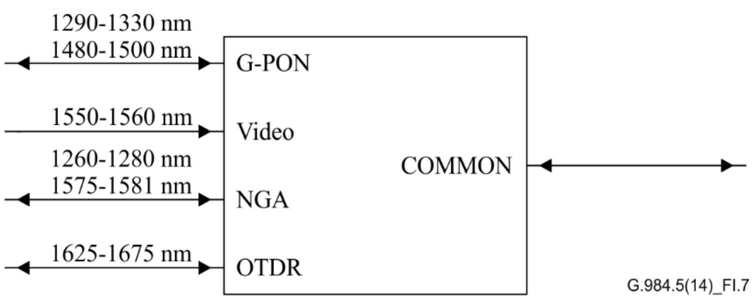


Figure I.7 – Reference diagram of a WDM1r with G-PON, RF video, NGA and OTDR support

Table I.7 shows sample parameters of a CEx supporting G-PON (reduced upstream band as an example), XG-PON1 and NG-PON2 (wide range TWDM PON upstream band and shared spectrum PtP WDM PON as an example). Figure I.8 shows the reference diagram of this device.

Table I.7 – Parameters for a CEx with G-PON, XG-PON1 and NG-PON2 ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for XG-PON1 bands	≤ 1.1 dB (1260-1280 nm and 1575-1581 nm)
Loss without connectors for NG-PON2 bands	≤ 1.0 dB (1524-1544 nm and 1596-1625 nm)
Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1675 nm)	DBA (see Appendix III)
Isolation – COM – XG-PON1 OLT (1290-1560 nm and 1596-1675 nm)	DBA (see Appendix III)
Isolation – COM – NG-PON2 (1260-1500 nm, 1550-1581 nm and 1640-1675 nm)	DBA (see Appendix III)
Maximum optical power	+23 dBm
Return loss	> 50 dB
Directivity	> 50 dB

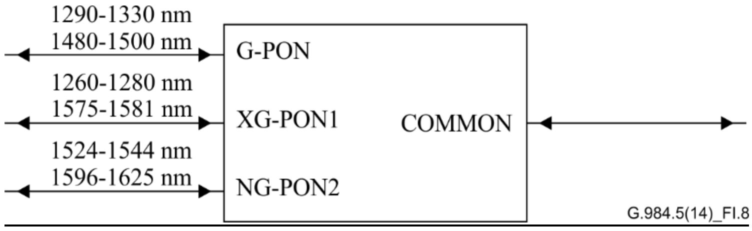


Figure I.8 – Reference diagram of a CEx with G-PON, XG-PON1 and NG-PON2 support

Table I.8 shows sample parameters of a CEx supporting G-PON (reduced upstream band as an example), XG-PON1 and NG-PON2 (wide range TWDM PON upstream band and shared spectrum PtP WDM PON as an example) and OTDR (with wavelength range of 1640-1660 nm as an example) capability. Figure I.9 shows the reference diagram of this device.

Table I.8 – Parameters for a CEx with G-PON, XG-PON1, NG-PON2 and OTDR ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1290-1330 nm and 1 480-1 500 nm)
Loss without connectors for XG-PON1 bands	≤ 1.1 dB (1260-1280 nm and 1575-1581 nm)
Loss without connectors for NG-PON2 bands	≤ 1.2 dB (1524-1 544 nm and 1596-1625 nm)
Loss without connectors for OTDR band	≤ 1.4 dB (1640-1660 nm)
Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1675 nm)	DBA (see Appendix III) or see application case below

Table I.8 – Parameters for a CEx with G-PON, XG-PON1, NG-PON2 and OTDR ports

Specification	Value
Isolation – COM – XG-PON1 OLT (1290-1560 nm and 1596-1675 nm)	DBA (see Appendix III) or see application case below
Isolation – COM – NG-PON2 (1260-1500 nm, 1550-1581 nm and 1640-1675 nm)	DBA (see Appendix III) or see application case below
Isolation – COM – OTDR (1260-1625 nm)	DBA (see Appendix III) or see application case below
Maximum optical power for G-PON, XG-PON1 or NG-PON2 ports	+23 dBm
Maximum optical power for OTDR port	For further study
Return loss	> 50 dB
Directivity	> 50 dB or see application case below

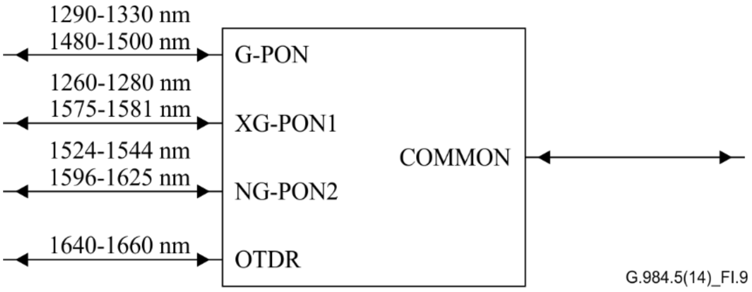


Figure I.9 – Reference diagram of a CEx with G-PON, XG-PON1, NG-PON2 and OTDR support

The assumptions for application case 1 are listed below. Isolation and directivity values are provided in Table I.8a.

Application case 1

- Total tolerated penalty (caused by finite isolation and directivity) = 0.5 dB
- ODN maximum differential loss = 15 dB
- ODN Class = C+
- Number of NG-PON2 channels = 8 TWDM + 8 PTP WDM
- I_{BiDi} = 30 dB for the case when the interferer is located in the blocking band of the diplexer; I_{BiDi} = 0 dB in all other cases
- No isolation is assumed to be provided by the NG-PON2 WM
- ρ (photodiode responsivity) = 0.8 A/W in O band, 0.9A/W in C band
- NG-PON2 OPP values corresponding to the 8 ch, 20 km case
- OTDR equipment is assumed to include an input filtering device providing 30 dB of isolation
- OTDR pulse power = +23 dBm, ER=10 dB, Rate = 100 Mbit/s[1]

[1] For the purpose of these calculations, the fact that the OTDR signal is normally pulsed and unmodulated is neglected.

Table I.8a – Isolation and directivity for Application Case 1

Specification		Value [dB]
Isolation [dB]	COM – GPON (1260-1280 nm; 1524-1675 nm)	35
	COM – XG(S)-PON (1290-1560 nm; 1596-1675 nm)	35
	COM – NG-PON2 (1260-1500 nm; 1550-1581nm; 1640-1675 nm)	40[2]
	COM – OTDR (1260-1625 nm)	10
Directivity (to port) [dB]	GPON	40
	XG(S)-PON	45
	NG-PON2	55[2]
	OTDR	25
Directivity (port-to-port) [dB]	GPON / XG(S)-PON	45
	GPON / NG-PON2	55[2]
	GPON / OTDR	40
	XG(S)-PON / NG-PON2	55[2]
	XG(S)-PON / OTDR	45
	NG-PON2 / OTDR	55[2]
NOTE – directivity figures can be specified equivalently per port or between ports.		

Table I.9 shows sample parameters of a CEx supporting G-PON (reduced upstream band as an example), RF video and NG-PON2 (wide range TWDM PON upstream band and shared spectrum PtP WDM PON as an example). Figure I.10 shows the reference diagram of this device.

[2] This level is sufficient for a NG-PON2 TWDM system; if the NG-PON2 port is used (also) for a PTP WDM PON system, a much higher value (isolation >55 dB, directivity >70 dB) would be necessary or interference onto this system should be mitigated using additional means.

Table I.9 – Parameters for a CEx with G-PON, RF video and NG-PON2 ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for RF video band	≤ 0.8 dB (1550-1560 nm)
Loss without connectors for NG-PON2 bands	≤ 1.0 dB (1524-1544 nm and 1596-1625 nm)
Isolation – COM – G-PON OLT (1260-1280 and 1524-1675 nm)	DBA (see Appendix III)
Isolation – COM – RF video (1260-1544 nm, 1575-1675 nm)	NA (RF is downstream only)
Isolation – COM – NG-PON2 OLT (1260-1500 nm, 1550-1581 nm and 1640-1675 nm)	DBA (see Appendix III)
Maximum optical power for G-PON or NG-PON2 ports	+23 dBm
Maximum optical power for RF video port	+23 dBm
Return loss	> 50 dB
Directivity	> 50 dB

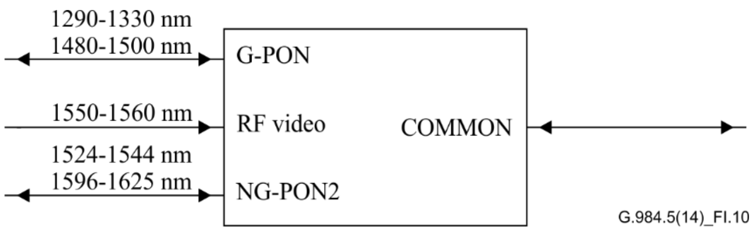


Figure I.10 – Reference diagram of a CEx with G-PON, RF video and NG-PON2 support

Table I.10 shows sample parameters of a CEx supporting G-PON (reduced upstream band as an example), RF video, NG-PON2 (wide range TWDM PON upstream band and shared spectrum PtP WDM PON as an example) and OTDR (with a wavelength range of 1640-1660 nm as an example) capability. Figure I.11 shows the reference diagram of this device.

Table I.10 – Parameters for a CEx with G-PON, RF video, NG-PON2 and OTDR ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for RF video band	≤ 1.0 dB (1550-1560 nm)
Loss without connectors for NG-PON2 bands	≤ 1.1 dB (1524-1544 nm and 1596-1625 nm)
Loss without connectors for OTDR band	≤ 1.3 dB (1640-1660 nm)
Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1675 nm)	DBA (see Appendix III)
Isolation – COM – RF video (1260-1544 nm, 1575-1675 nm)	NA (RF is downstream only)
Isolation – COM – NG-PON2 OLT (1260-1500 nm, 1550-1581 nm and 1640-1675 nm)	DBA (see Appendix III)
Isolation – COM – OTDR (1260-1625 nm)	DBA (see Appendix III)

Table I.10 – Parameters for a CEx with G-PON, RF video, NG-PON2 and OTDR ports

Specification	Value
Maximum optical power for G-PON or NG-PON2 ports	+23 dBm
Maximum optical power for RF video port	+23 dBm
Maximum optical power for OTDR port	For further study
Return loss	> 50 dB
Directivity	> 50 dB

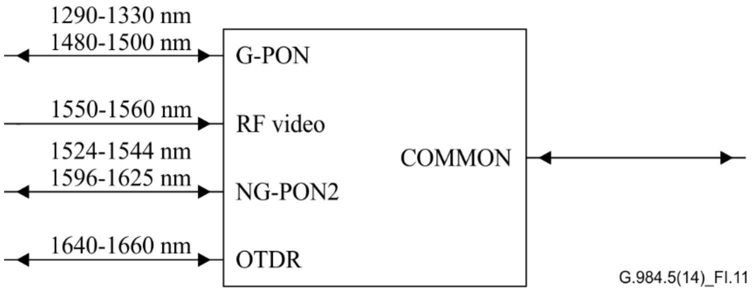


Figure I.11 – Reference diagram of a CEx with G-PON, RF video, NG-PON2 and OTDR support

Table I.11 shows sample parameters of a CEMx supporting G-PON (reduced upstream band as an example), XG-PON1, TWDM PON (wide range upstream band as an example) and PtP WDM PON (shared spectrum as an example) capability. Figure I.12 shows the reference diagram of this device.

Table I.11 – Parameters for a CEMx with G-PON, XG-PON1, TWDM PON and PtP WDM PON ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1 290-1 330 nm and 1 480-1 500 nm)
Loss without connectors for XG-PON1 bands	≤ 1.1 dB (1 260-1 280 nm and 1 575-1 581 nm)
Loss without connectors for TWDM PON bands	≤ 1.2 dB (1 524-1 544 nm and 1 596-1 603 nm)
Loss without connectors for PtP WDM PON band	≤ 1.3 dB (1 606-1 625 nm)
Isolation – COM – G-PON OLT (1 260-1 280 nm and 1 524-1 675 nm)	DBA (see Appendix III)
Isolation – COM – XG-PON1 OLT (1 290-1 560 nm and 1 596-1 675 nm)	DBA (see Appendix III)
Isolation – COM – TWDM PON OLT (1 260-1 500 nm, 1 550-1 581 nm and 1 606-1 675 nm)	DBA (see Appendix III)
Isolation – COM – PtP WDM PON OLT (1 260-1 603 nm and 1 640-1 675 nm)	DBA (see Appendix III)
Maximum optical power	+23 dBm
Return Loss	> 50 dB
Directivity	> 50 dB

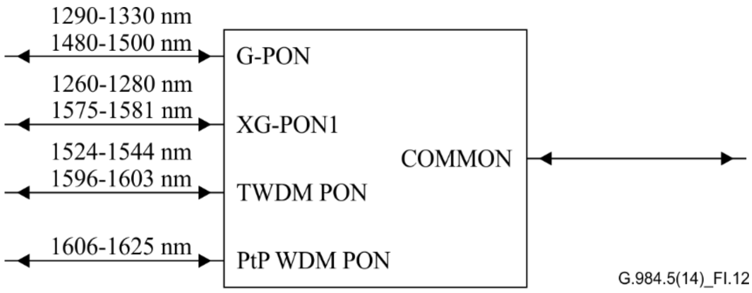


Figure I.12 – Reference diagram of a CEMx with G-PON, XG-PON, TWDM PON and PtP WDM PON support

Table I.12 shows sample parameters of a CEMx supporting G-PON (reduced upstream band as an example), XG-PON1, TWDM PON (wide range upstream band as an example), PtP WDM PON (shared spectrum as an example) and OTDR (with wavelength range of 1640-1660 nm as an example) capability. Figure I.13 shows the reference diagram of this device.

Table I.12 – Parameters for a CEMx with G-PON, XG-PON, TWDM PON, PtP WDM PON and OTDR ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for XG-PON1 bands	≤ 1.1 dB (1260-1280 nm and 1575-1581 nm)
Loss without connectors for TWDM PON bands	≤ 1.4 dB (1524-1544 nm and 1596-1603 nm)
Loss without connectors for PtP WDM PON band	≤ 1.3 dB (1606-1625 nm)
Loss without connectors for OTDR band	≤ 1.6 dB (1640-1660 nm)
Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1675 nm)	DBA (see Appendix III)
Isolation – COM – XG-PON1 OLT (1290-1560 nm and 1596-1675 nm)	DBA (see Appendix III)
Isolation – COM – TWDM PON OLT (1260-1500 nm, 1550-1581 nm and 1606-1675 nm)	DBA (see Appendix III)
Isolation – COM – PtP WDM PON OLT (1260-1603 nm and 1640-1675 nm)	DBA (see Appendix III)
Isolation – COM – OTDR (1260-1625 nm)	DBA (see Appendix III)
Maximum optical power for G-PON, XG-PON, TDM PON or PtP WDM PON ports	+23 dBm
Maximum optical power for OTDR port	For further study
Return loss	> 50 dB
Directivity	> 50 dB

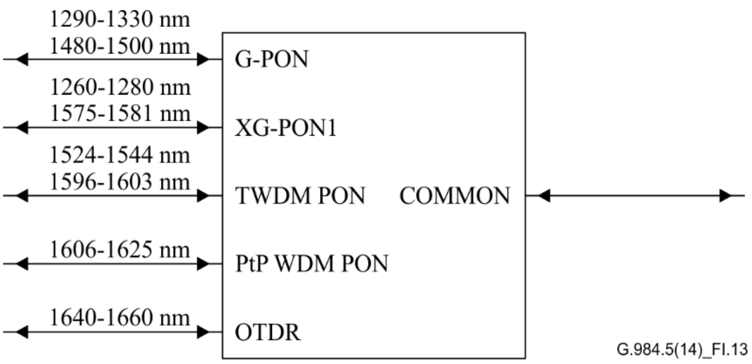


Figure I.13 – Reference diagram of a CEMx with G-PON, XG-PON, TWDM PON, PtP WDM PON and OTDR support

Table I.13 shows sample parameters of a CEMx supporting G-PON (reduced upstream band as an example), RF video, TWDM PON (wide range upstream band as an example) and PtP WDM PON (shared spectrum as an example) capability. Figure I.14 shows the reference diagram of this device.

Table I.13 – Parameters for a CEMx with G-PON, RF video, TWDM PON and PtP WDM PON ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for RF video band	≤ 1.2 dB (1550-1560 nm)
Loss without connectors for TWDM PON bands	≤ 1.1 dB (1524-1544 nm and 1596-1603 nm)
Loss without connectors for PtP WDM PON band	≤ 0.9 dB (1606-1625 nm)
Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1675 nm)	DBA (see Appendix III)
Isolation – COM – RF video (1260-1544 nm and 1575-1675 nm)	NA (RF is downstream only)
Isolation – COM – TWDM PON OLT (1260-1 500 nm, 1550-1581 nm and 1606-1675 nm)	DBA (see Appendix III)
Isolation – COM – PtP WDM PON OLT (1260-1603 nm and 1640-1675 nm)	DBA (see Appendix III)
Maximum optical power for G-PON, TWDM PON or PtP WDM PON ports	+23 dBm
Maximum optical power for RF video port	+23 dBm
Return loss	> 50 dB
Directivity	> 50 dB

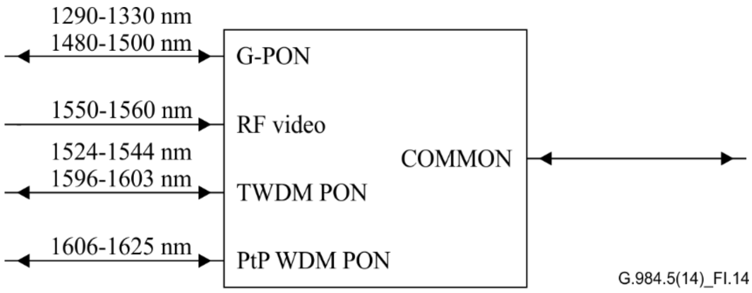


Figure I.14 – Reference diagram of a CEMx with G-PON, RF video, TWDM PON and PtP WDM PON support

Table I.14 shows sample parameters of a CEMx supporting G-PON (reduced upstream band as an example), RF video, TWDM PON (wide range upstream band as an example), PtP WDM PON (shared spectrum as an example) and OTDR (with a wavelength range of 1640-1660 nm as an example) capability. Figure I.15 shows the reference diagram of this device.

Table I.14 – Parameters for a CEMx with G-PON, RF video, TWDM PON, PtP WDM PON and OTDR ports

Specification	Value
Loss without connectors for G-PON bands	≤ 0.8 dB (1290-1330 nm and 1480-1500 nm)
Loss without connectors for RF video band	≤ 1.2 dB (1550-1560 nm)
Loss without connectors for TWDM PON bands	≤ 1.3 dB (1524-1544 nm and 1596-1603 nm)
Loss without connectors for PtP WDM PON band	≤ 0.9 dB (1606-1625 nm)
Loss without connectors for OTDR band	≤ 1.5 dB (1640-1660 nm)
Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1675 nm)	DBA (see Appendix III)
Isolation – COM – RF video (1260-1544 nm, 1575-1675 nm)	NA (RF is downstream only)
Isolation – COM – TWDM PON OLT (1260-1500 nm, 1550-1581 nm and 1606-1675 nm)	DBA (see Appendix III)
Isolation – COM – PtP WDM PON OLT (1260-1603 nm and 1640-1675 nm)	DBA (see Appendix III)
Isolation – COM – OTDR (1260-1625 nm)	DBA (see Appendix III)
Maximum optical power for G-PON, TWDM PON or PtP WDM PON ports	+23 dBm
Maximum optical power for RF video port	+23 dBm
Maximum optical power for OTDR port	For further study
Return loss	> 50 dB
Directivity	> 50 dB

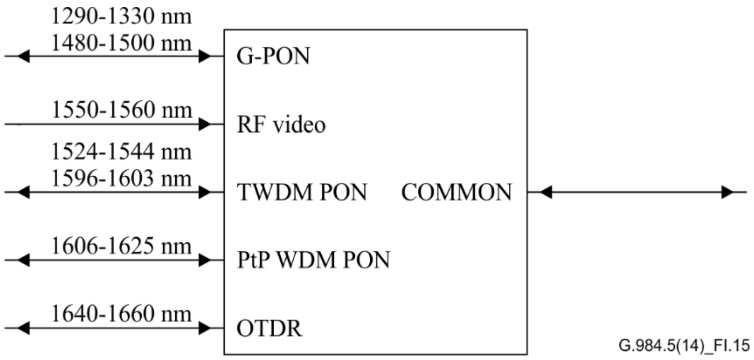


Figure I.15 – Reference diagram of a CEMx with G-PON, RF video, TWDM PON, PtP WDM PON and OTDR support

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 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 below.

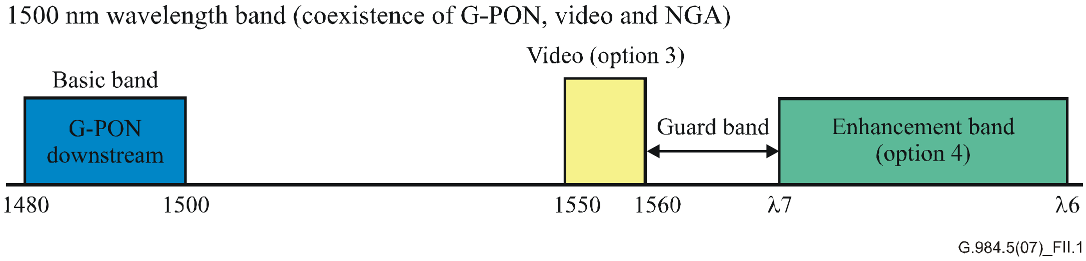


Figure II.1 – Wavelength allocation

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 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.

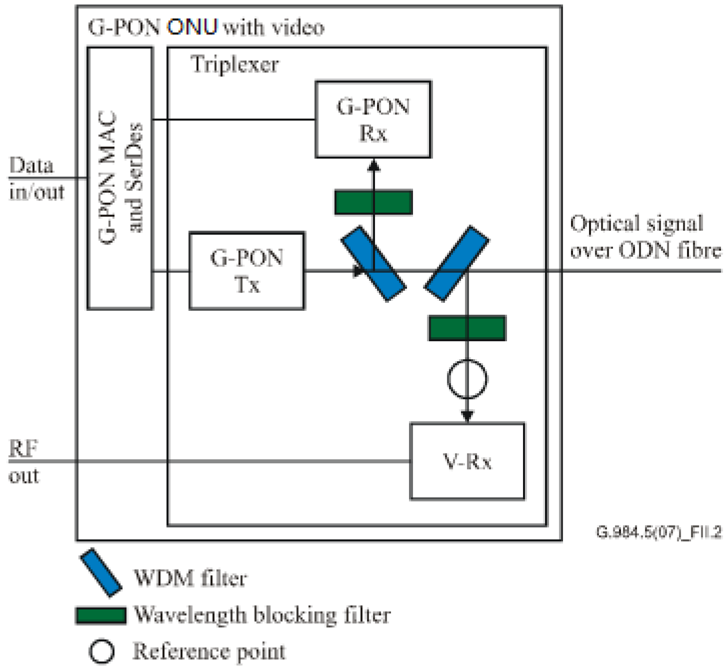


Figure II.2 – Example configuration of G-PON ONU with video (Case 1)

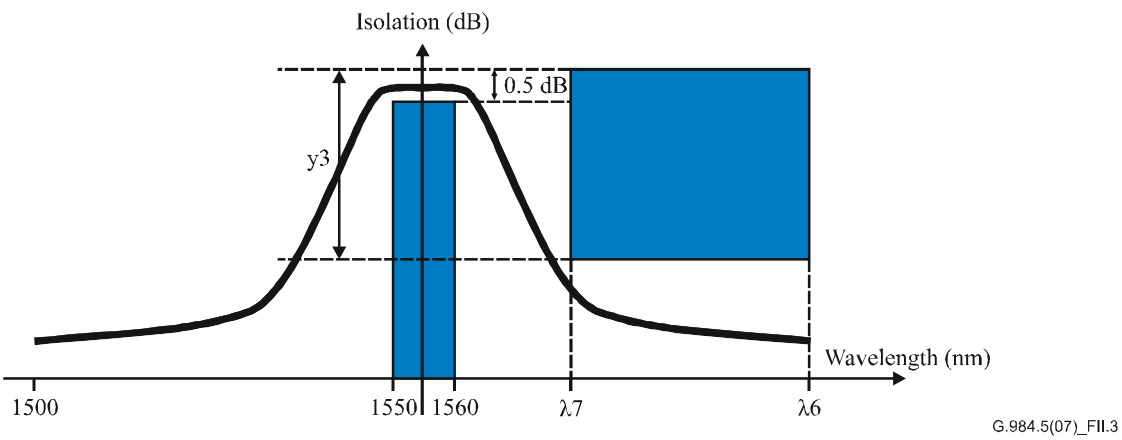


Figure II.3 – Example of integrated filter characteristics for video

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.

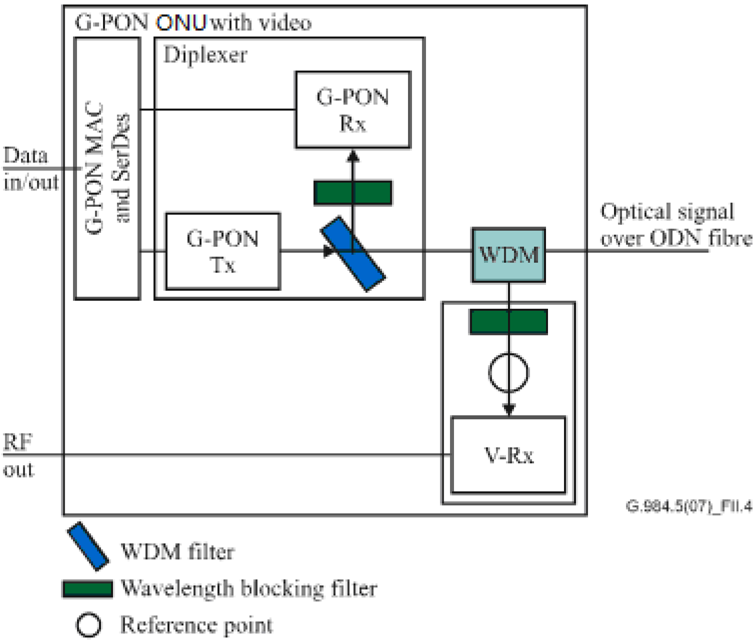


Figure II.4 – Example configuration of G-PON ONU with video (Case 2)

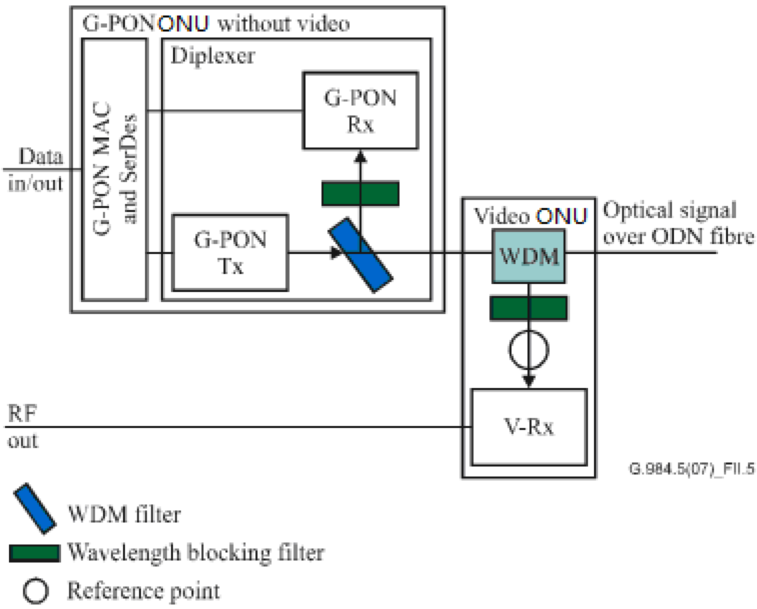


Figure II.5 – Example configuration of G-PON ONU and video ONU (Case 2)

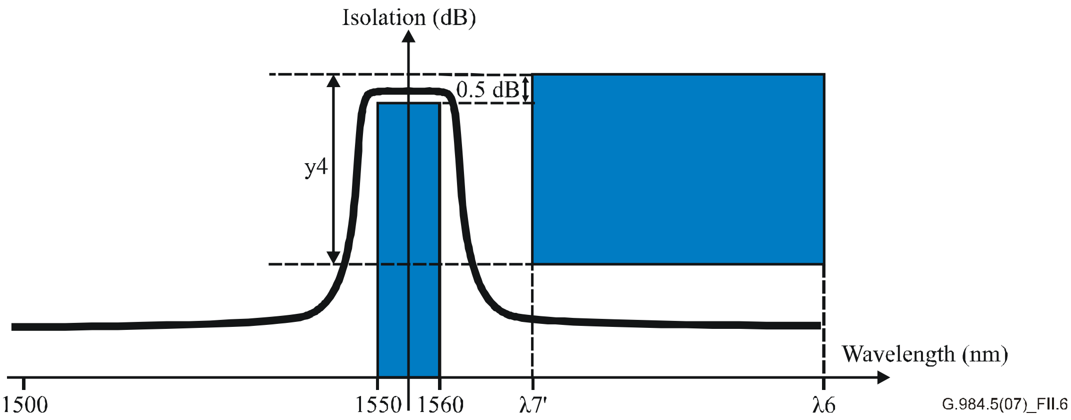


Figure II.6 – Example of discrete filter characteristics for video ONU

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	

Appendix III

Methods for calculating required isolation for WDM/CE/CEM devices

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

This appendix provides guidance to implementers of WDM1r, CE and CEM components concerning the isolation requirements. It is not appropriate to specify a single value for the isolation requirement for each WDM1r, CE and CEM device, as it depends on the particular operational use case, so a simple formula is provided below to enable implementers to derive indicative isolation values.

By way of example, Figure III.1 shows the assumed network topology for calculating the required isolation for the GPON port of a WDM device enabling coexistence with XG-PON1. The GPON ONUs are assumed to be at the maximum differential loss expected in the deployment and the XG-PON1 ONU is at the minimum loss i.e., their relative ODN losses are equal to the maximum expected differential loss in the ODN. Note that this does not need to be the same as the maximum differential loss supported in [ITU-T G.984.2] and [ITU-T G.987.2] if the ODN design is such that it limits the expected differential loss. The expected differential loss may be limited for example by ODN component specification or by limiting drop fibre lengths.

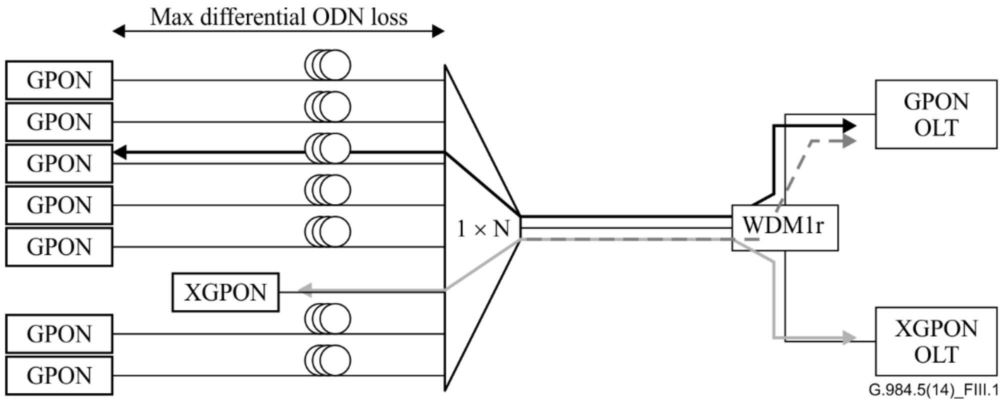


Figure III.1 – Network topology assumed for calculating the required isolation for the GPON port of a WDM device enabling coexistence with XG-PON1

In addition to being at the highest loss, the GPON ONUs are assumed to be transmitting at the lowest power permitted in [ITU-T G.984.2]. The XG-PON1 ONU is transmitting at the highest power permitted in [ITU-T G.987.2].

On the OLT side, the internal diplexer of the GPON OLT transceiver may also add some isolation that could be taken into account if known by the implementer. This is illustrated in Figure III.2. Other sources of intrinsic OLT isolation may also be considered e.g., any additional filtering in the Rx path or additional filtering inserted between the WDM and the OLT. If the isolation is not known, or if a worse case assumption is preferred, then the isolation of this diplexer (and other elements after the WDM) may be set to zero.

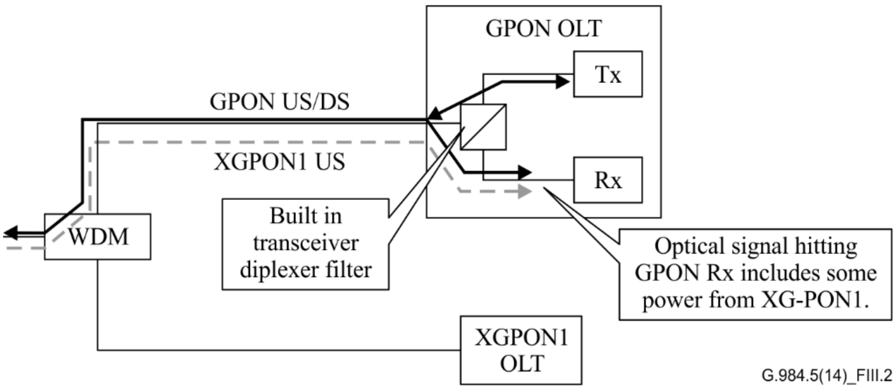


Figure III.2 – Isolation factors to consider at the OLT

To derive the required isolation, the allowed crosstalk ratio is to be calculated at the tolerable penalty in the particular deployment scenario being considered (this is a design choice for the implementer and is not specified by ITU-T Recommendations). The following equation, taken from [ITU-T G.Sup39], for inter-channel crosstalk power penalty may be used to derive the allowed crosstalk.

For a single interfering channel:

$$P_C = 10\log_{10}\left(1 - 10^{\frac{C_C}{10}}\frac{r+1}{r-1}\right) \qquad \text{dB} \qquad (9\text{-}28)$$

where r is the linear extinction ratio.

Using this formula, the chart shown in Figure III.3 can be plotted from which the allowed crosstalk for the system design penalty assumption can be extracted. This chart shows the calculation for GPON, XG-PON1 and NG-PON2 (both 2.5G and 10G US). The source of the difference between each system is the minimum extinction ratio specification in each case i.e., 10 dB, 8.2 dB and 6 dB for GPON, XG-PON1/NG-PON2(2.5G) and NG-PON2(10G) respectively.

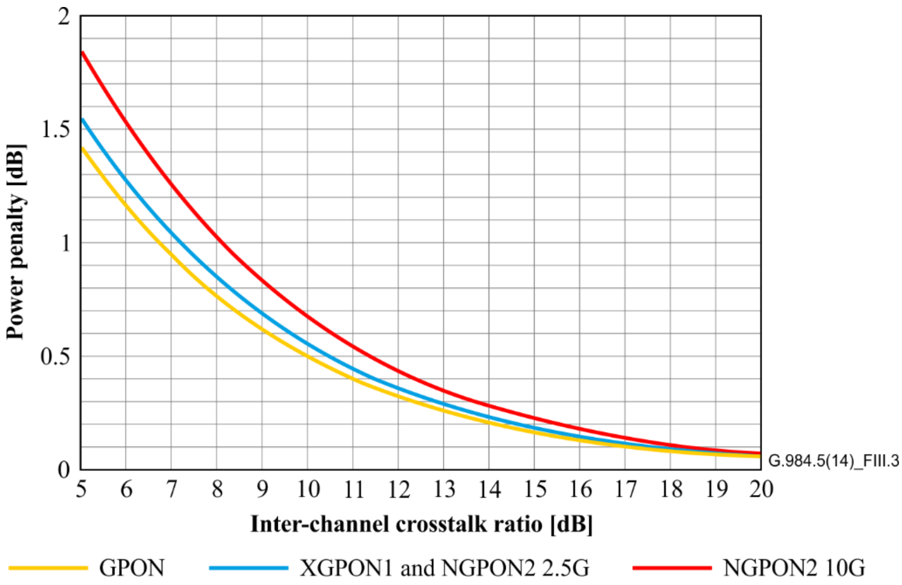


Figure III.3 – Power penalty as a function of inter-channel crosstalk ratio

The following formula may be derived for calculating the required isolation in terms of the allowed crosstalk, differential ODN loss, launch power difference between ONUs (GPON(min) – XG-PON1(max)), diplexer (or other WDM to Rx path) isolation and bandwidth ratio. All parameters are in dB.

$$I_{WDM} = XT(dB) - \Delta P + \Delta ODN - I_{BiDi} - B_{comp}$$

I_{WDM}: Port isolation at the interferer wavelength for the WDM device enabling coexistence

XT: Allowed inter-channel crosstalk power ratio in dB

ΔP: ONU launch power ratio in dB between the target signal (minimum) and the interfering signal (maximum)

ΔODN: ODN loss difference in dB for the target signal (minimum) and the interfering signal (maximum)

I_{BiDi}: Isolation in the receive path (external to the WDM used for coexistence) at the interferer wavelength e.g., from the internal transceiver diplexer (BiDi)

B_{comp}: Relative bandwidth compensation factor to account for signal bandwidth difference between the target signal and the interfering signal as given by:

$$B_{comp}(dB) = 10\log\left(R_{\text{int}} / R_{target} \right)$$

To illustrate the application of the formula, worked examples are given below:

Example 1

For a 0.5 dB penalty to GPON in a GPON and XG-PON1 coexistence scenario the permitted inter-channel crosstalk (XT) is approximately 10 dB (from Figure III.3).

For a B+/N1 class ODN, the power ONU launch difference (ΔP) is 0.5 dBm − 7 dBm = −6.5 dB.

The designed ODN loss differential (ΔODN) is 5 dB.

The post WDM isolation (I_{BiDi}) is assumed to be 2 dB.

The bit-rate compensation factor (B_{comp}) is 10log(2.5/1.25) = 3 dB.

So, the required WDM isolation (I_{WDM}) at the GPON port for the XG-PON1 US wavelength is:

$$10 - (-6.5) + 5 - 2 - 3 = \underline{16.5\text{ dB.}}$$

Example 2

For a 0.1 dB penalty to GPON in a GPON and XG-PON1 coexistence scenario, the permitted inter-channel crosstalk (XT) is approximately 17 dB (from Figure III.3).

For a B+/N1 class ODN The power ONU launch difference (ΔP) is 0.5 dBm − 7 dBm = −6.5 dB.

The designed ODN loss differential (ΔODN) is 10 dB.

The post WDM isolation (I_{BiDi}) is assumed to be 0 dB.

The bit-rate compensation factor (B_{comp}) is 10log(2.5/1.25) = 3 dB.

So, the required WDM isolation (I_{WDM}) at the GPON port for the XG-PON1 US wavelength is:

$$17 - (-6.5) + 10 - 0 - 3 = \underline{30.5\text{ dB.}}$$

To extend the above equation for the required WDM isolation to include multichannel systems (e.g., NG-PON2) acting as the interferer, the number of interfering channels (N) can be included as a parameter.

$$I_{WDM} = XT - \Delta P + \Delta ODN - I_{BiDi} - B_{comp} + 10\log(N)$$

The simple analysis above assumes there is one interfering system where all the interferers are at the same line rate and power. In the event that the three systems (e.g., GPON, XG-PON1 and NG-PON2) are to coexist, the analysis becomes more complex and the details are for further study. In general terms the total interfering power needs to be carefully apportioned among the various interfering systems and wavelength channels based on their transmitter characteristics.

To extend the above equation for the required WDM isolation to include multichannel systems (e.g., NG-PON2) acting as the interferer, the number of interfering channels (N) can be included as a parameter.

$$I_{WDM} = XT - \Delta P + \Delta ODN - I_{BiDi} - B_{comp} + 10\log(N)$$

The simple analysis above assumes there is one interfering system where all the interferers are at the same line rate and power. In the event that the three systems (e.g., GPON, XG-PON1 and NG-PON2) are to coexist, the analysis becomes more complex.

[b-ITU-T G-Suppl.39] addresses the multi-interferer case (eq. 9-30), but only for a high number of equal power interferers, hence the multi-interferer formula is clearly not applicable to the PON coexistence scenario, in which the number of interferers is limited and the power differences may be high.

As a first approximation, the single interferer formula is therefore used ([b-ITU-T G-Suppl.39], eq.9.28), assuming the interferers add in power (for multi-channel systems, like NG-PON2, each channel is considered as a separate interferer). Although this approach may require further validation, consideration can be taken of the fact that most practical scenarios result in a single dominant interferer, hence the approximation error should be limited. More rigorous approaches are left for further study.

With the above assumptions and referring to the CEx model (see Figure III.4) and definitions listed below, a simple mathematical derivation leads to the following formulas that can be used to calculate the required per port isolation and directivity figures, once a tolerated penalty value has been defined. The formulas have been derived assuming either an equal isolation/directivity of each port against each interferer or an equal crosstalk level from each interferer. Note that linear quantities are used in all formulas, unless otherwise stated.

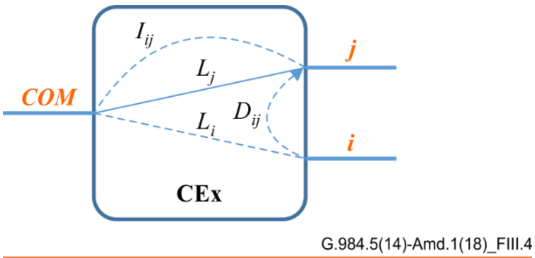


Figure III.4 – CEx model for isolation and directivity calculations

N = Number of coexisting systems;

j, i = CEx ports corresponding to victim signal j and interfering signal i ;

I_{ij} = Isolation (blocking band loss) of port j against band i (i.e., the loss encountered by interferer i when it traverses the CEx from common port to port j);

D_{ij} = Directivity of port i to port j (i.e., the loss encountered by interferer i when it traverses the CEx from port i to port j);

L_i, L_j = Insertion (pass band) loss of (common port to) port i , port j;

$I_{B,ij}$ = BiDi isolation to (interferer) band *i* of the transceiver connected to port j of the CEx;

ρ_i, ρ_j = Photodiode responsivities at the interferer and victim signal wavelengths respectively;

R_i, R_j = Bit rates of the interferer and victim signals respectively;

OPP_j = *Optical path penalty affecting the victim signal*;

$ONU_{minTX,j}$ = *Minimum ONU transmitter power of victim signal*;

$ONU_{maxTX,i}$ = *Maximum ONU transmitter power of interfering signal*;

$OLT_{minRX,j}$ = *Sensitivity of victim signal OLT Rx*;

$OLT_{maxTX,i}$ = *Maximum OLT transmitter power of interfering signal*;

Cj = *Crosstalk to (victim signal) port j*;

rj = *Extinction ratio of victim signal j*;

Pc = *Tolerated crosstalk penalty on victim signal j.*

Isolation formulas

Uniform isolation: $I_{ij} = I_j, \forall j \neq i$:

$$I_j = \frac{1}{C_j} \cdot \frac{1}{ONU_{minTx,j}} \cdot \frac{max\ ODN\ loss}{\min ODN\ loss} \cdot OPP_j \cdot \sum_{i=1,\ (i \neq j)}^{N} ONU_{maxTx,i} \cdot \frac{L_i}{I_{B,ij}} \cdot \frac{\rho_i}{\rho_j} / \max\left[1,\ \frac{R_i}{R_j}\right]$$

$$or \quad I_j = \frac{1}{C_j} \cdot \frac{1}{OLT_{minRx,j}} \cdot \frac{1}{\min ODN\ loss} \cdot \sum_{i=1,\ (i \neq j)}^{N} ONU_{maxTx,i} \cdot \frac{L_i}{I_{B,ij}} \cdot \frac{\rho_i}{\rho_j} / \max\left[1,\ \frac{R_i}{R_j}\right]$$

Uniform crosstalk: $C_{ij} = C_j, \forall j \neq i$:

$$I_{ij} = (N-1) \cdot \frac{1}{C_j} \cdot \frac{ONU_{maxTx,i}}{ONU_{minTx,j}} \cdot \frac{max\ ODN\ loss}{\min ODN\ loss} \cdot OPP_j \cdot \frac{L_i}{I_{B,ij}} \cdot \frac{\rho_i}{\rho_j} / \max\left[1,\ \frac{R_i}{R_j}\right]$$

$$or \quad I_{ij} = (N-1) \cdot \frac{1}{C_j} \cdot \frac{ONU_{maxTx,i}}{OLT_{minRx,j}} \cdot \frac{1}{\min ODN\ loss} \cdot \frac{L_i}{I_{B,ij}} \cdot \frac{\rho_i}{\rho_j} / \max\left[1,\ \frac{R_i}{R_j}\right]$$

Directivity formulas

Uniform directivity: $D_{ij} = D_j, \forall j \neq i$

$$D_j = \frac{1}{C_j} \cdot \frac{1}{OLT_{minRx,j}} \cdot \sum_{i=1,\ (i \neq j)}^{N} \frac{OLT_{maxTx,i}}{I_{B,ij}} \cdot \frac{\rho_i}{\rho_j} / \max\left[1,\ \frac{R_i}{R_j}\right]$$

Uniform crosstalk: $C_{ij} = C_j, \forall j \neq i$

$$D_{ij} = (N-1) \cdot \frac{1}{C_j} \cdot \frac{1}{OLT_{minRx,j}} \cdot \frac{OLT_{maxTx,i}}{I_{B,ij}} \cdot \frac{\rho_i}{\rho_j} / \max\left[1,\ \frac{R_i}{R_j}\right]$$

The tolerated crosstalk C_j in the above formulas can be calculated by inverting the single interferer formula ([b-ITU-T G.Sup39], eq.9.28): and with an additional change of the sign (-Pc):

$$C_j = \frac{r_j - 1}{r_j + 1}\left(1 - 10^{\frac{-P_c}{10}}\right)$$

where r_j is the extinction ratio of the victim signal and P_c is the tolerated crosstalk penalty expressed in decibels. Note that penalty caused by eye opening reduction is already included in the isolation and directivity formulas through the OPP or receiver sensitivity terms, hence the effective value of *r* defined by [b-ITU-T G-Suppl.39], eq. 9.29 must not be used here.

Appendix IV

Multi-PON module with integrated WDM

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

When a PON system is migrated from a legacy PON to a next generation PON (NG PON), coexistence and smooth migration are important requirements. External WDM1, WDM1r, CEx and CEMx devices discussed in Appendix I provide a good way to support coexistence and smooth migration. However, these external WDM approaches introduce extra insertion loss in the ODN. For example, loss without connectors for G-PON bands is less than 0.8 dB in Table I.2 and Table I.3 of Appendix I, applied and counted in the ODN design. This is a challenge in ODN cases with tight optical margin. Furthermore, it is advantageous for some operators to have an upgrade approach that replaces existing line cards in the OLT chassis with new line cards in order to upgrade to multiple PON technologies integrated into the line card. The new line card can simplify the upgrade engineering and reduce the probability of manual operational error during migration.

To meet the engineering and operation requirements mentioned above, an OLT line card with an integrated WDM function is introduced. This card is called an OLT multi-PON module (MPM).

An architectural reference diagram using the OLT MPM is shown in Figure IV.1.

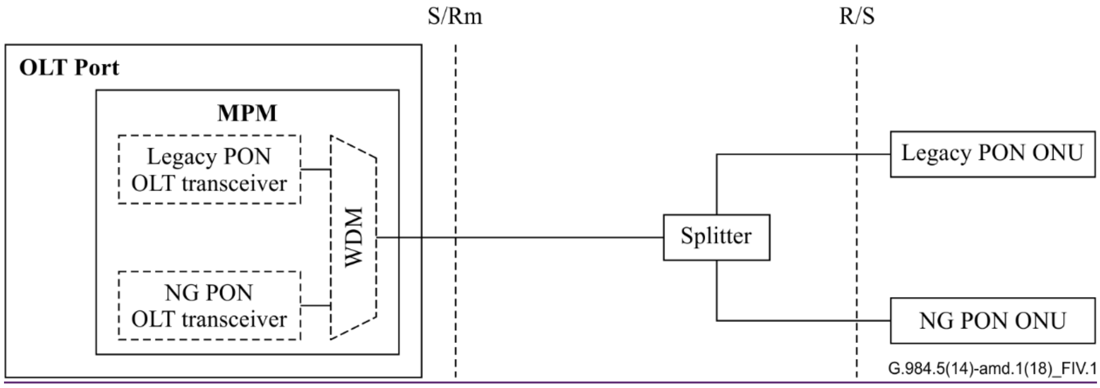


Figure IV.1 – Example of an architectural reference diagram employing OLT MPM

The PMD requirements for the optical interface between OLT MPM and ODN should be chosen accordingly for NG PON and legacy PON supported in the OLT MPM. The OPL class of NG PON should not be less than the OPL class of legacy PON as both PON systems share the same ODN ensuring the legacy PON system has sufficient optical budget over the legacy ODN network. Furthermore, the next generation PON system has sufficient link budget to work over the legacy ODN.

NOTE – The optical levels present at the interface point S/Rm may be different from standards based S/R levels depending on the PON family presented to the interface. New CE or CEM types may be required when a PON with MPM migrates to future PON systems. The CE or CEM would consist of one port to the MPM and another port to the future PON.

An example reference diagram for the OLT MPM function is shown in Figure IV.2.

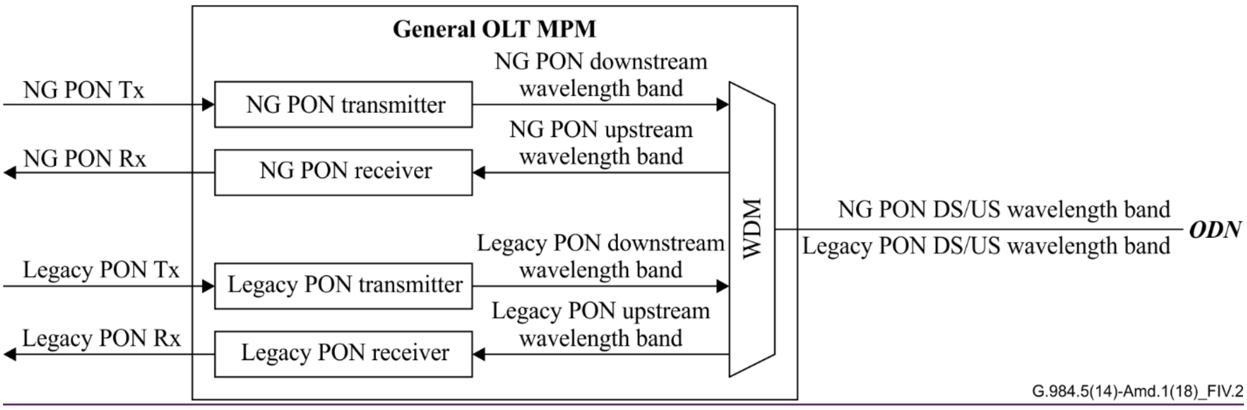


Figure IV.2 – Example reference diagram for OLT MPM with integrated WDM

In Figure IV.2, a WDM is used to accommodate two pairs of wavelength bands, for legacy PON and NG PON respectively.

When upgrading using an OLT MPM, no external coexistence element is necessary at the OLT side, since its function has been integrated inside the OLT optical module for each PON port. Hence no extra space or associated engineering operation are required to achieve coexistence.

To accompany the OLT MPM with an integrated WDM in an upgrade scenario, a TC chipset supporting both legacy PON and NG PON may be required in the OLT configuration, including specific MSA with dual interfaces to legacy PON and NG PON.

An example reference diagram of GPON/XG-PON OLT MPM with integrated WDM is shown in Figure IV.3.

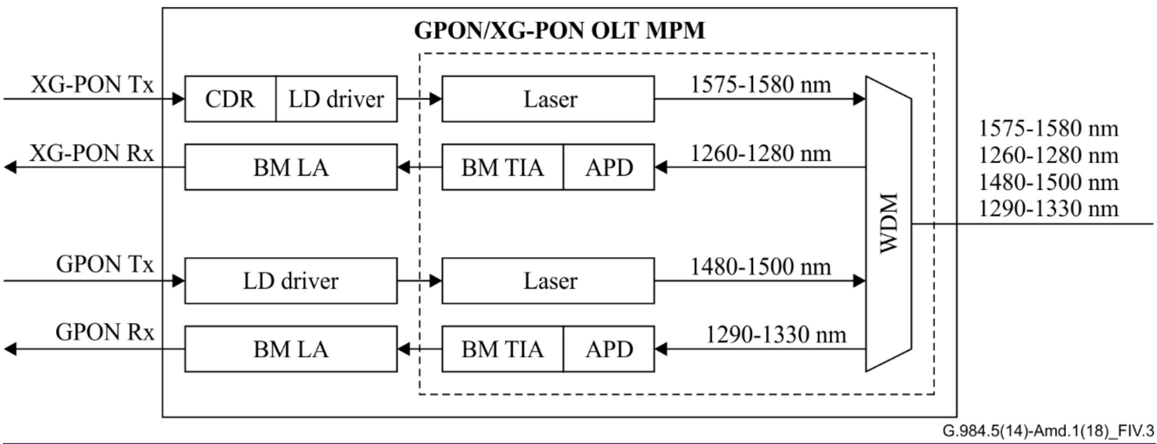


Figure IV.3 – Reference diagram of GPON/XG-PON OLT MPM with integrated WDM

By employing GPON/XG-PON OLT MPM in the migration scenario, GPON ONUs and XG-PON ONUs coexist in the same ODN and simultaneously operate with a common OLT in the corresponding standards-based wavelength bands. The narrow option can be supported as well as the reduced wavelength options of GPON shown in Figure IV.3.

An example reference diagram of GPON/XG-PON OLT MPM with dual-rate receiver and triplexer optical sub-assembly (OSA) is shown in Figure IV.4. The triplexer OSA is used to simplify the components assembly to make it easier and more compact. One GPON transmitter, one XG-PON transmitter and one GPON/XG-PON dual rate receiver are connected to the WDM (GPON and XG-PON share one receiver).

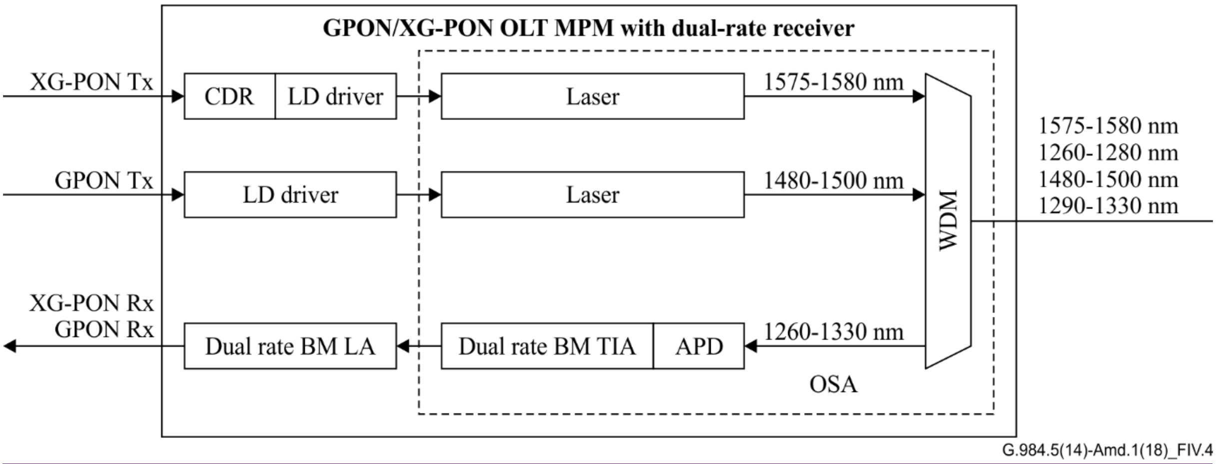


Figure IV.4 – Reference diagram of GPON/XG-PON OLT MPM with dual-rate receiver and WDM

The PMD requirements for the ODN optical interface should ensure that the legacy GPON and XG-PON ONUs can work on the legacy ODN.

An example reference diagram of GPON/XG-PON/XGS-PON OLT MPM with WDM is shown in Figure IV.5. The WDM is used to support all three types of ONU on the same ODN. The GPON transmitter and receiver, XGS-PON transmitter and dual rate receiver (also supporting XG-PON ONUs) are connected to the internal WDM.

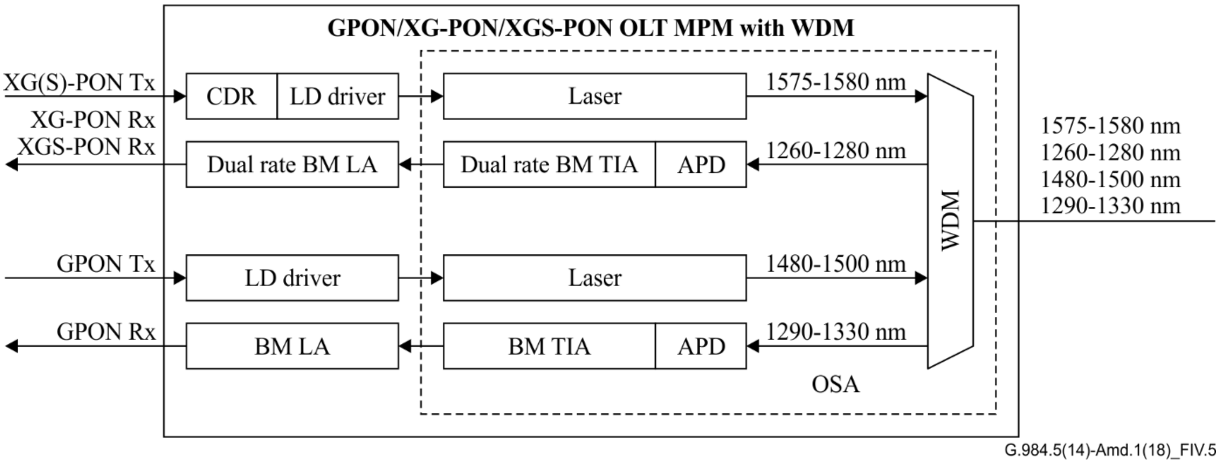


Figure IV.5 – Reference diagram of GPON/XG-PON/XGS-PON OLT MPM with WDM

The PMD requirements for optical interface should ensure that the legacy GPON, XG-PON and XGS-PON ONUs can work on the legacy ODN. If the support of XG-PON ONUs is not required on the ODN, then the dual rate receiver can be simplified to a single rate XGS-PON receiver.

An example reference diagram of GPON/XG-PON/XGS-PON OLT MPM with triple-rate receiver is shown in Figure IV.6. The OSA is used to make the components assembly easier and more compact. One GPON transmitter, one XG-PON/XGS-PON transmitter, and one GPON/XG-PON/XGS-PON triple rate receiver are connected to the WDM inside the OSA (GPON/XG-PON/XGS-PON share one receiver).

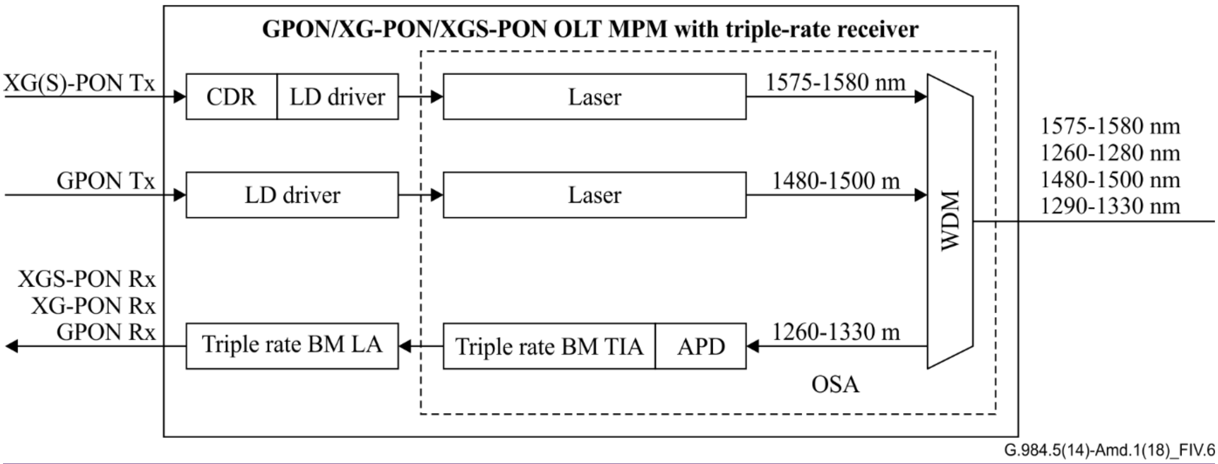


Figure IV.6 – Reference diagram of GPON/XG-PON/XGS-PON OLT MPM with triple-rate receiver

The PMD requirements for ODN optical interface should ensure that the legacy GPON, XG-PON and XGS-PON ONUs can work on the legacy ODN. If the XG-PON ONUs are not required, then the triple rate receiver can be simplified to a dual-rate GPON/XGS-PON receiver.

The advantages of a single Rx MPM configuration is a reduction in the number of components. It reduces the filtering losses and so enables higher OPL classes with lower power consumption. Moreover, there is no interoperability issue in using such modules and the key goal of co-existence (i.e. simultaneous operation of GPON and XG-PON in the same ODN) is still guaranteed. Other benefits of co-existence, such as more aggregate upstream bandwidth, are dependent on the use case of each operator. There is no change to the BWmap structure, but it does require co-ordination between the GPON DBA and the XG(S)-PON DBA engines to construct each respective BWmap.

Table IV.1 – Classes for optical path loss GPON & XG(S)-PON MPM between S/Rm and R/S

OPL class	**B+**	**C+**
Minimum loss	13 dB	17 dB
Maximum loss	28 dB	32 dB
NOTE – Optical path loss classes B+ and C+ are generally applicable for GPON and XG(S)-PON MPM from the S/Rm point, including both single and dual receiver's configuration.		

Classes for optical path loss GPON and XG(S)-PON MPM are shown in Table IV.1. Key optical power parameters at the S/Rm reference point are given in Table IV.2, while all other PMD parameters are same with corresponding values defined in [ITU-T G.984.2], [ITU-T G.987.2] and [ITU-T G.9807.1] respectively.

Table IV.2 – Key optical power parameters at the S/Rm reference point

<table>
<tr><th>Source</th><th>Item</th><th>Unit</th><th colspan="2">Value</th></tr>
<tr><td></td><td>ODN class</td><td>dBm</td><td>B+</td><td>C+</td></tr>
<tr><td rowspan="4">GPON
2.488 Gbit/s downstream, 1.244 Gbit/s upstream (Note 1)</td><td>Mean launched power MIN</td><td>dBm</td><td>+1.5</td><td>+3</td></tr>
<tr><td>Mean launched power MAX</td><td>dBm</td><td>+5</td><td>+7</td></tr>
<tr><td>Minimum sensitivity</td><td>dBm</td><td>–28
(BER@1E-10)</td><td>–32
(BER@1E-4)</td></tr>
<tr><td>Minimum overload</td><td>dBm</td><td>–8</td><td>–12</td></tr>
<tr><td rowspan="4">XG-PON
9.95328 Gbit/s downstream,
2.48832 Gbit/s upstream (Note 2)</td><td>Mean launched power MIN</td><td>dBm</td><td>+1</td><td>+5</td></tr>
<tr><td>Mean launched power MAX</td><td>dBm</td><td>+5</td><td>+9</td></tr>
<tr><td>Minimum sensitivity@1E-4</td><td>dBm</td><td>–26.5</td><td>–30.5</td></tr>
<tr><td>Minimum overload</td><td>dBm</td><td>–6</td><td>–10</td></tr>
<tr><td rowspan="4">XGS-PON
9.95328 Gbit/s downstream,
9.95328 Gbit/s upstream (Note 3)</td><td>Mean launched power MIN</td><td>dBm</td><td>+1</td><td>+5</td></tr>
<tr><td>Mean launched power MAX</td><td>dBm</td><td>+4</td><td>+8</td></tr>
<tr><td>Minimum sensitivity@1E-3</td><td>dBm</td><td>–25</td><td>–29</td></tr>
<tr><td>Minimum overload</td><td>dBm</td><td>–4</td><td>–8</td></tr>
<tr><td colspan="5">NOTE 1 – The parameters for GPON are same with class B+,C+ in [ITU-T G.984.2 Amd.1] and [ITU-T G.984.2 Amd.2], respectively.
NOTE 2 – Parameters for XG-PON are relaxed by 1dB compared with corresponding values defined in [ITU-T G.987.2].
NOTE 3 – Parameters for XGS-PON are relaxed by 1dB compared with corresponding values defined in [ITU-T G.9807.1].</td></tr>
</table>

Appendix V

Wavelength coexistence using M:N splitter

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

This appendix provides an alternative approach to wavelength coexistence to that provided by traditional WDM schemes as captured in Appendix I, and the multi-PON module (MPM) approach captured in Appendix IV. The term WDM will be used elsewhere in this appendix to reference the range of the external solutions (WDM1, WDM1r, CE and CEM).

This Recommendation contains two optical access network architecture reference diagrams, Figure 2 and Figure 3. Figure 2 provides the traditional scheme of combining WDM technologies, typically via external devices. Figure 3 provides for combining wavelengths using power splitters with the assumption that the needed wavelength isolation between wavelength bands is provided by wavelength blocking filters in the equipment. This appendix addresses a variant of this latter approach.

Different operators deploy PON using different schemes for the outside plant, some deploy a single splitter scheme and some deploy using cascaded splitter (2 or more splitters in tandem) schemes. Figure V.1 shows a possible architecture for this latter case. The first splitter could be used as an integral part of a wavelength combining architecture. Employing a M:N splitter (for instance 2:n) as the first splitter (often located in the central office), provides that the first PON (OLT) system can be connected to input port A, and the second PON system connected to input port B.

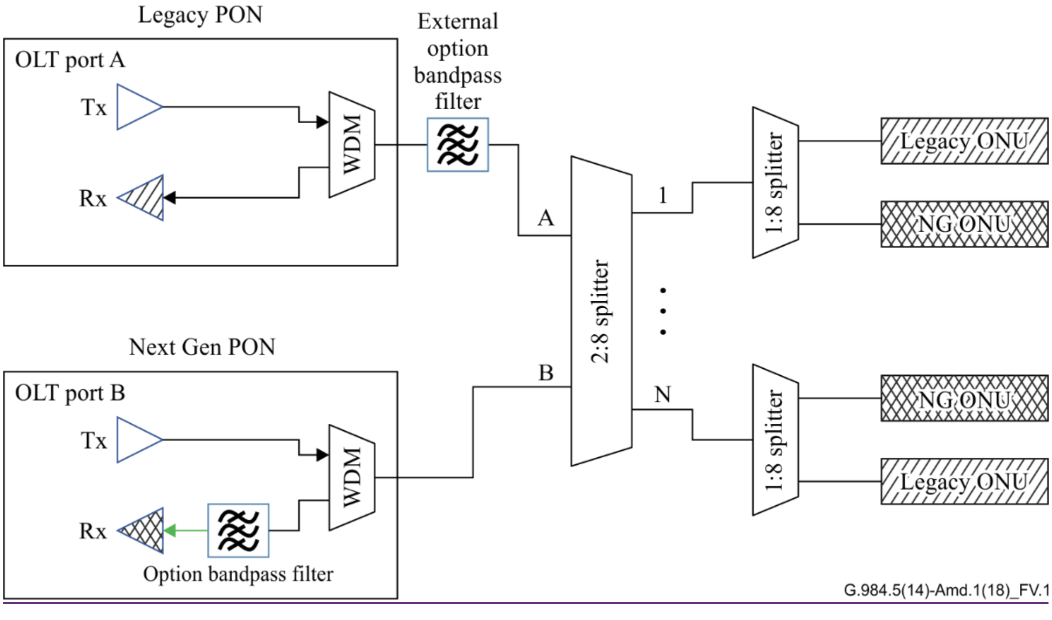


Figure V.1 – Example of architecture reference diagram employing 2:n splitter

In order for the splitter approach to work, the terminating (receiving) ports must have appropriate band to band filtering, providing sufficient isolation to the interfering wavelength bands. While nowadays a number of OLT's have wavelength blocking filters in their receivers, this may not be the case for older implementations. In that case, external wavelength blocking mechanisms would have to be considered, such as pluggable SC type WBF adapters. In this example, it is noted that as long as the OLT receiver has sufficient isolation to the interfering bands of interest, the M:N splitter scheme could even support three (3) PON coexistence by substituting the 2:n splitter with a 3:n splitter.

The M:N splitter has some of the same advantages, in that the existing fibre connections to/from the OLT equipment remain the same; however, the M:N approach require the addition of a second fibre from the new PON OLT equipment/port to the splitter's second input port. The extra loss for the addition of the second input port of the power splitter is minimal in most devices, typically less than 0.5 dB, resulting in a lower insertion loss solution to the traditional WDM approach.

Bibliography

[b-ITU-T G-Suppl.39] Recommendation ITU-T G-Suppl.39 (2016), *Optical system design and engineering considerations*.

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