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Recommendation

# ITU-T G.9805 (2022) Amd. 1 (06/2023)

SERIES G: Transmission systems and media, digital systems and networks

Access networks – Optical line systems for local and access networks

## Coexistence of passive optical network systems
**Amendment 1**

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 |
| 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 |
| Metallic access networks | G.9700-G.9799 |
| **Optical line systems for local and access networks** | **G.9800-G.9899** |
| In premises networks | G.9900-G.9999 |

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

# Recommendation ITU-T G.9805

## Coexistence of passive optical network systems

## Amendment 1


### Summary

Recommendation ITU-T G.9805 presents three methods for the coexistence of multiple passive optical network (PON) generations on a common optical distribution network (ODN): coexistence element (CE), multi-PON module (MPM), and splitter-based. These methods allow the reuse of already deployed fibre and splitters when evolving a legacy PON to a higher capacity. Methods for calculating required isolation for coexistence element, filter considerations for higher speed passive optical network (HSP) and asymmetric / symmetric 10-Gigabit passive optical network optical line termination or XG(S)-PON OLT, and optical interface parameters for gigabit-capable passive optical network (G-PON) and XG(S)-PON MPM supporting classes B+, C+ and D optical path loss (OPL) are also described.

Amendment 1 includes additional 3-gen PON systems coexistence methods, and crosstalk analysis between PON systems.



### History *

| Edition | Recommendation | Approval | Study Group | Unique ID |
|---|---|---|---|---|
| 1.0 | ITU-T G.9805 | 2022-02-13 | 15 | 11.1002/1000/14918 |
| 1.1 | ITU-T G.9805 (2022) Amd. 1 | 2023-06-13 | 15 | 11.1002/1000/15569 |

### Keywords

CEx, coexistence, MPM, PON.


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## Table of Contents

# Recommendation ITU-T G.9805

## Coexistence of passive optical network systems

## 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.9805 (2022).*

### 1 Scope

The purpose of this Recommendation is to establish the methods and parameters for passive optical network (PON) coexistence, where two or more PON systems share a common optical distribution network (ODN). For this purpose, this Recommendation defines and provides:

– a general reference diagram of coexistence element, and sample parameters of a discrete wavelength division multiplexing (WDM) filter that combines and isolates the gigabit-capable passive optical network (G-PON) up/down signals and enhancement bands of PON systems, radio frequency (RF) signal and optical time-domain reflectometer (OTDR) signal at the optical line termination (OLT) side;

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

– wavelength coexistence using M:N splitter;

– multi-PON module with integrated WDM;

– filter considerations for higher speed passive optical network (HSP) and XG(S)-PON/10G-EPON OLT.

Amendment 1 includes the following modifications:

1) 3-gen PON systems coexistence methods;

2) Crosstalk between PON systems.

### 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.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.9804.1] Recommendation ITU-T G.9804.1 (2020), *Higher speed passive optical networks – Requirements.*

[ITU-T G.9804.3] Recommendation ITU-T G.9804.3 (2021), *50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification*.

[ITU-T G.9807.1] Recommendation ITU-T G.9807.1 (~~2016~~2023), *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

## 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 optical distribution network (ODN)**: [ITU-T G.9804.1].

**3.1.2 optical line termination (OLT)**: [ITU-T G.9804.1].

**3.1.3 optical network unit (ONU)**: [ITU-T G.9804.1].

**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 10-Gigabit passive optical network (XGS-PON)**: [ITU-T G.9807.1].

**3.1.7 TWDM PON**: [ITU-T G.989].

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

**3.1.9 NG-PON2**: [ITU-T G.989].

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

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

**3.1.12 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 |
| FEC | Forward Error Correction |
| 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 |
| OOB | Out-Of-Band |
| OPL | Optical Path Loss |
| 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 |
| RSSI | Received Signal Strength Indication |
| SMSR | Side Mode Suppression Ratio |
| TC | Transmission Convergence |
| 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 of coexistence methods

When a passive optical network (PON) system is migrated from a legacy PON to a next generation PON (NG PON), coexistence and smooth migration are important requirements, to protect investment and guarantee user experience. There are three types of coexistence methods supporting multiple PON systems operating in the same optical distribution network (ODN) simultaneously, including wavelength coexistence using an external coexistence element (CEx) device, wavelength coexistence using multi-PON module (MPM), and wavelength coexistence using M:N splitter.

### 6.1 Wavelength coexistence using external CEx device

Figure 6-1 shows a reference diagram of multiple PON systems coexisting with an external CEx device.

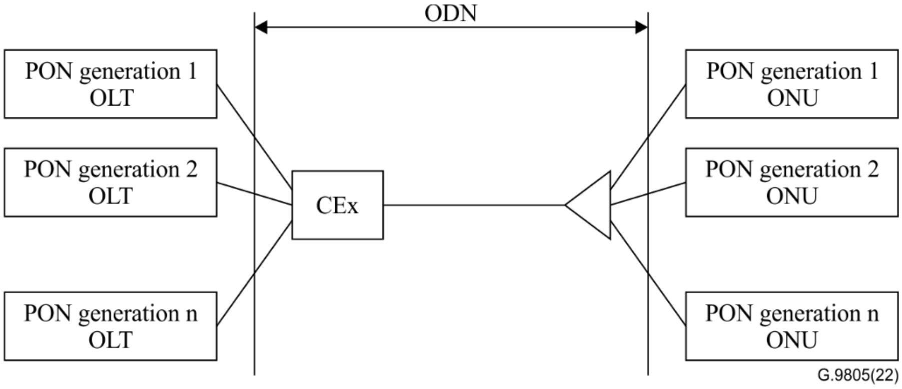


**Figure 6-1 – Reference diagram of multiple PON systems coexisting with an external CEx device**

The reference diagram of a generic coexistence CEx is shown in Figure 6-2. The insertion loss between the COM port and each optical line termination (OLT) port of the CEx device consumes the loss budget of the corresponding PON system. See Appendix I for examples of CEx in various coexistence scenarios.

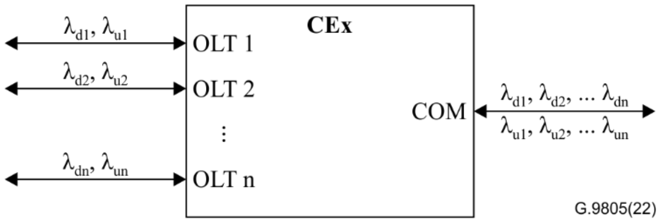


**Figure 6-2 – Reference diagram of a generic CEx**

### 6.2 Wavelength coexistence using MPM

For 2-generation coexistence, ~~An~~an architectural reference diagram using the optical line termination multi-PON module or OLT MPM is shown in Figure 6-3. The wavelength division multiplexing (WDM) function supporting multiple PON systems coexistence is integrated in the OLT MPM.

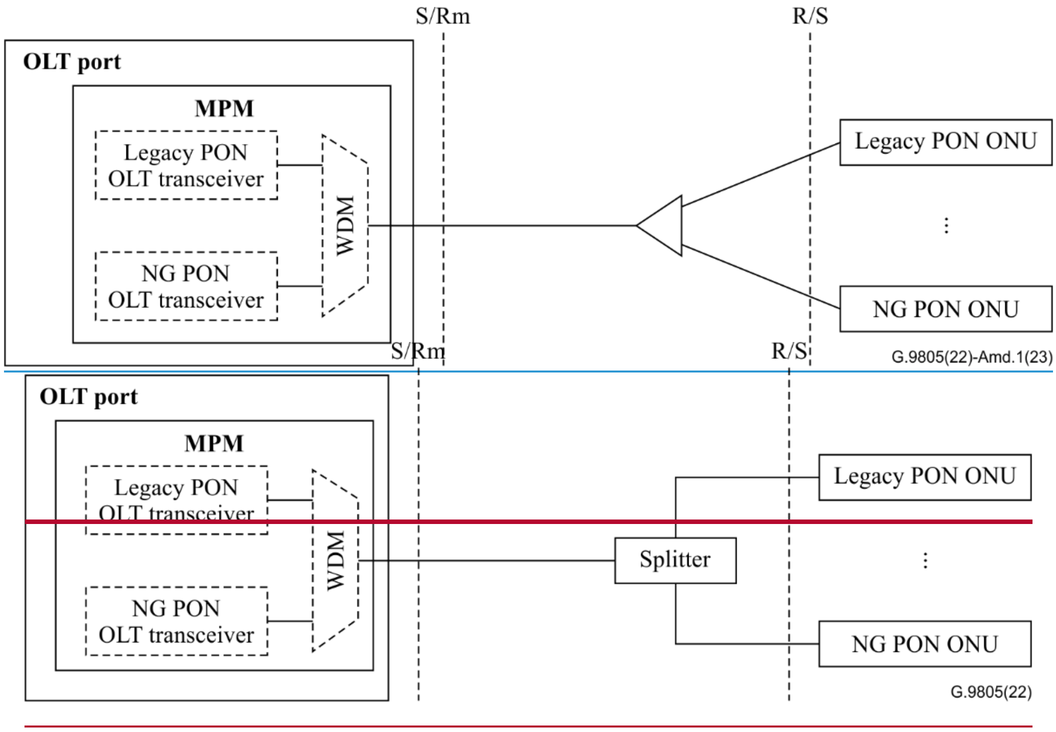


**Figure 6-3 – Reference diagram employing OLT MPM**

The physical media dependent (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.

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 transmission convergence (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~~support dual interfaces to the MPM~~.

For 3-generation coexistence, an architectural reference diagram using the OLT MPM is shown in Figure 6-3a. The WDM function supporting multiple PON system coexistence are integrated in the OLT MPM. Note the PONa and PONb indicate the legacy PON from two different generations (e.g., GPON and XG-PON).

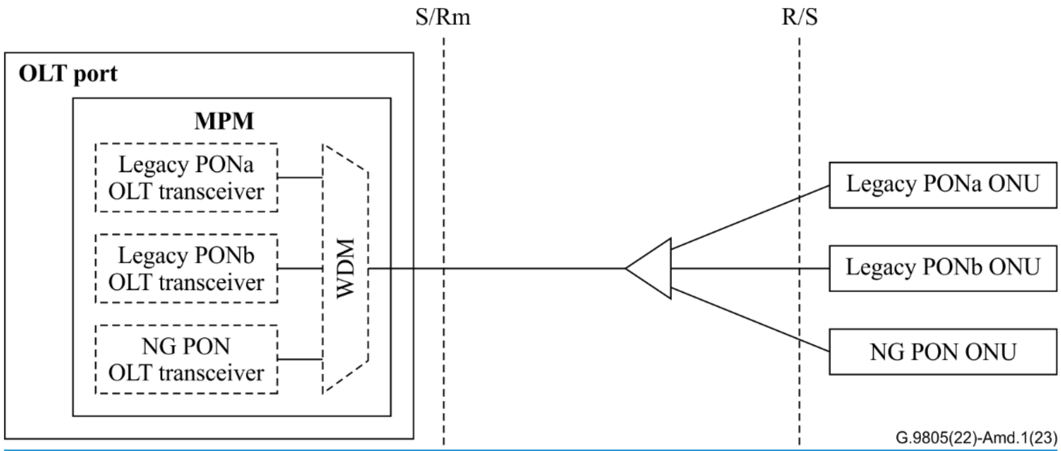


**Figure 6-3a – Reference diagram employing OLT MPM for 3-generation coexistence**

The PMD requirements for the optical interface between OLT MPM and ODN should be chosen accordingly for NG PON and both two legacy PON systems supported in the OLT MPM.

The classes for optical path loss G-PON/~~ and ~~XG(S)-PON MPM and GPON/XG(S)-PON/50G-PON MPM between S/Rm and R/S are specified in Table 6-1.

**Table 6-1 – Classes for optical path loss GPON/~~ & ~~XG(S)-PON MPM and GPON/XG(S)-PON/50G-PON MPM between S/Rm and R/S**

| OPL class | B+ | C+ | D |
|---|---|---|---|
| Minimum loss | 13 dB | 17 dB | 20 dB |
| Maximum loss | 28 dB | 32 dB | 35 dB |
| NOTE – Optical path loss classes B+, C+ and D are generally applicable for GPON~~ and~~/~~ ~~XG(S)-PON MPM and GPON/XG(S)-PON/50G-PON MPM from the S/Rm point, including ~~both ~~single~~ and~~, dual and triple receiver~~'s~~ configurations. | | | |

Key optical power parameters at the S/Rm reference point are given in Table 6-2, while all other PMD parameters are the same with corresponding values defined in [ITU-T G.984.2], [ITU-T G.987.2] ~~and~~, [ITU-T G.9807.1] and [ITU-T G.9804.3] respectively.

**Table 6-2 – Key optical power parameters at the S/Rm reference point**

| Source | Item | Unit | Value | | |
|---|---|---|---|---|---|
| | ODN class | ~~dBm~~ | B+ | C+ | D |
| GPON 2.488 Gbit/s downstream, 1.244 Gbit/s upstream | Mean launched power ~~MIN~~minimum | dBm | +1.5 | +3 | +6 |
| | Mean launched power ~~MAX~~maximum | dBm | +5 | +7 | +10 |
| | Minimum sensitivity | dBm | –28 (BER@1E-10) | –32 (BER@1E-4) | –35 (BER@1E-4) |
| | Minimum overload | dBm | –8 | –12 | –15 |
| XG-PON 9.95328 Gbit/s downstream, 2.48832 Gbit/s upstream | Mean launched power ~~MIN~~minimum | dBm | +1 | +5 | +8 |
| | Mean launched power ~~MAX~~maximum | dBm | +5 | +9 | +12 |
| | Minimum sensitivity@1E-4 | dBm | –26.5 | –30.5 | –33.5 |
| | Minimum overload | dBm | –6 | –10 | –13 |
| XGS-PON 9.95328 Gbit/s downstream, 9.95328 Gbit/s upstream | Mean launched power ~~MIN~~minimum | dBm | +1 | +5 | +8 |
| | Mean launched power ~~MAX~~maximum | dBm | +4 | +8 | +11 |
| | Minimum sensitivity@1E-3 | dBm | –25 | –29 | –32 |
| | Minimum overload | dBm | –4 | –8 | –11 |
| 50G-PON 49.7664 Gbit/s downstream | Mean launched power minimum (Note 1) | dBm | +4.5 (Note 2) | +8.5 (Note 3) | FFS |
| | Mean launched power maximum | dBm | +10 | +14 | FFS |

**Table 6-2 – Key optical power parameters at the S/Rm reference point**

| Source | Item | Unit | Value | | |
|---|---|---|---|---|---|
| | Launch power in OMA minus TDEC (min) (Note 4) | dBm | +3.75 | +7.75 | FFS |
| | Minimum extinction ratio (Note 5) | dB | 7 | 7 | FFS |
| Asymmetric 50G-PON 12.4416 Gbit/s upstream | Minimum sensitivity@1E-2 (Note 6) | dBm | –25 | –29 | FFS |
| | Minimum overload | dBm | –4 | –8 | FFS |
| Asymmetric 50G-PON 24.8832 Gbit/s upstream | Minimum sensitivity@1E-2 (Note 7) | dBm | –23.5 | –27.5 | FFS |
| | Minimum overload | dBm | –4 | –8 | FFS |
| Symmetric 50G-PON 49.7664 Gbit/s upstream | Minimum sensitivity@1E-2 | dBm | –21.7 (Note 8) | FFS | FFS |
| | Minimum OMA sensitivity @1E-2 | dBm | –21.53 | FFS | FFS |
| | Minimum overload | dBm | –1.2 | FFS | FFS |

NOTE 1 – A lower "mean launch power minimum" is allowed but will be compensated by a higher extinction ratio, within the limits of the "Launch power in OMA minus TDEC (min)" value. If the actual TDEC is worse than 2.0 dB, it will be compensated by increasing the transmitter mean launch power minimum specification by *X* dB for each *X* dB of extra TDEC allowance, where $X \leq 3.0$ dB, while meeting all other Tx specifications.

NOTE 2 – The mean launch power minimum value is consistent with a minimum "OMA minus TDEC" of +3.75 dBm when ER = 7 dB and TDEC = 2.0 dB. Even if the TDEC is lower than 2.0 dB, the mean launch power minimum should still exceed this value at 7 dB ER.

NOTE 3 – The mean launch power minimum value is consistent with a minimum "OMA minus TDEC" of +7.75 dBm when ER = 7 dB and TDEC = 2.0 dB. Even if the TDEC is lower than 2.0 dB, the mean launch power minimum should still exceed this value at 7 dB ER.

NOTE 4 – TDEC is measured, following the method in clause 9.2.7.8 in [ITU-T G.9804.3], using an appropriate fibre length to ensure the worst-case eye closure penalty over the full dispersion range.

NOTE 5 – This "minimum extinction ratio" is the minimum value required to meet the "mean launch power minimum" value in this table. A lower extinction ratio is allowed if compensated by a larger transmitter launch power within the limits of the "mean launch power maximum" value. In no case should the ER be lower than 5 dB. A lower "mean launch power minimum" is allowed if compensated by a higher extinction ratio. For quantitative treatment examples of these tradeoffs, see Appendix I in [ITU-T G.9804.3].

NOTE 6 – The sensitivity is based on ER = 6.0 dB received signal.

NOTE 7 – The sensitivity is based on ER = 5.0 dB received signal.

NOTE 8 – This Rx sensitivity is based on a transmitter with a transmitter eye closure (TEC) = 2.0 dB at 5 dB extinction ratio in back to back; it is equivalent to –21.53 dBm sensitivity in OMA. In addition, the Rx sensitivity in OMA with fibre, R(TDEC), should also comply with R(TDEC) ≤ maximum (–21.03, TDEC-23.53) dBm using an appropriate fibre length to ensure the worst-case eye closure within the dispersion range (for TDEC ≤ 5.0 dB).

## 6.3 Wavelength coexistence using M:N splitter

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 6-4 shows a reference diagram of coexistence with M:N splitter. 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 1, and the second PON system connected to input port M in the OLT side of M:N splitter.

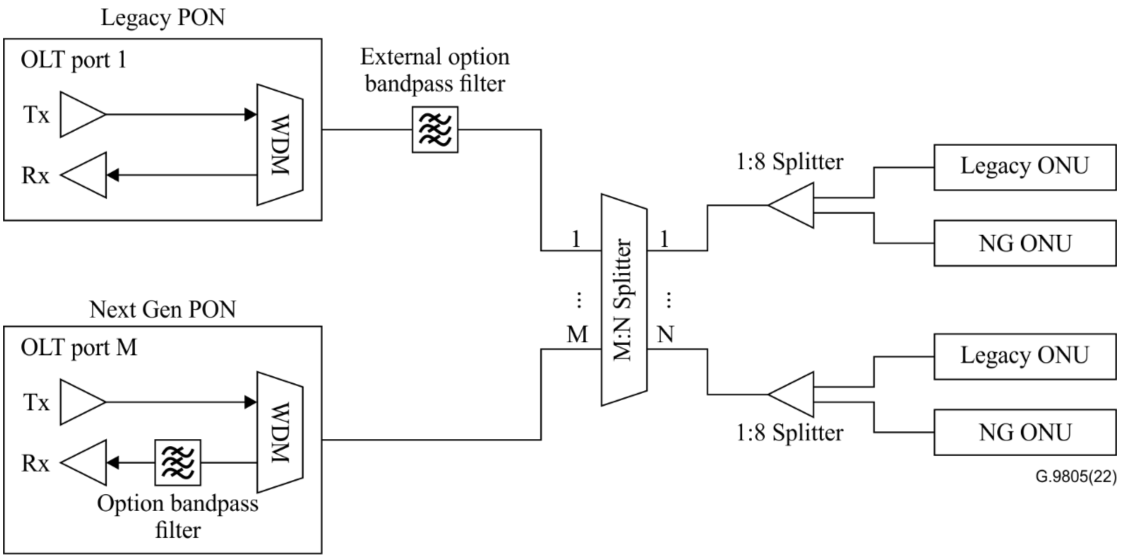


**Figure 6-4 – Example of architecture reference diagram employing 2:n splitter**

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 several 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 wavelength blocking filter (WBF) adapters. 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.

# 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 examples of filters termed as "WDM1r" are to signify that they are specifications that reflect the approved newer wavelength plan for next generation access (NGA) systems. 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 examples of devices are termed "CEx", and support the coexistence of multiple PON systems.

The examples of devices are termed "CEM" for coexistence element/multiplexer to signify that they include the functions of CEx and partial wavelength multiplexer (WM) which combine/isolate the time and wavelength division multiplexing (TWDM) PON and point-to-point wavelength division multiplexing (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 II.

In the following tables (except for Table I.2), 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 single-fibre WDM1r filter that combines (downstream) and isolates (upstream) the G-PON up/down signals and NGA bands. Figure I.1 shows the reference diagram of the single-fibre WDM1r.

**Table I.1 – 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<br>(1260-1280 nm and 1524-1625 nm) | DBA (see Appendix II) |
| Isolation – COM – NGA OLT<br>(1290-1500 nm) | DBA (see Appendix II) |
| Maximum optical power | +23 dBm |
| Return loss | > 50 dB |
| Directivity | > 50 dB |

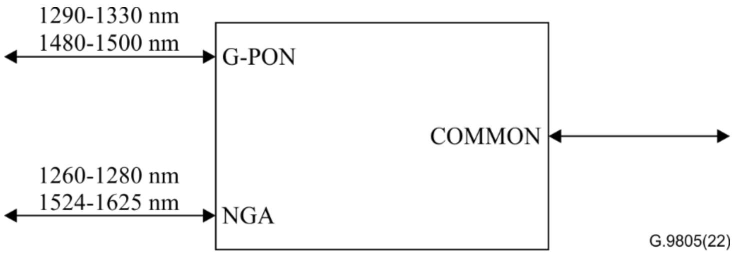


**Figure I.1 – Reference diagram of a WDM1r with G-PON and NGA support**

Table I.2 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.2 shows a reference diagram of a single-fibre WDM1rn.

**Table I.2 – 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 II) |
| Isolation – COM – NGA OLT (1300-1500 nm) | DBA (see Appendix II) |
| Max optical power | +23 dBm |
| Return loss | > 50 dB |
| Directivity | > 50 dB |

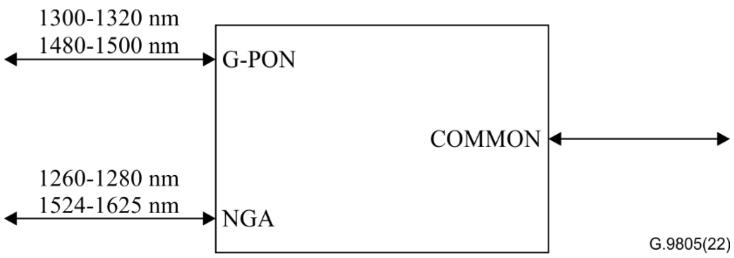


**Figure I.2 – Reference diagram of a WDM1rn with narrow upstream wavelength G-PON and NGA support**

Table I.3 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.313]. Note that the wavelength range of the NGA port changes when these optional ports are present. Figure I.3 shows the reference diagram of this filter.

**Table I.3 – 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 II) |
| Isolation – COM – NGA OLT (1290-1500 nm and 1600-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – OTDR (1260-1581 nm) | DBA (see Appendix II) |
| 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 |

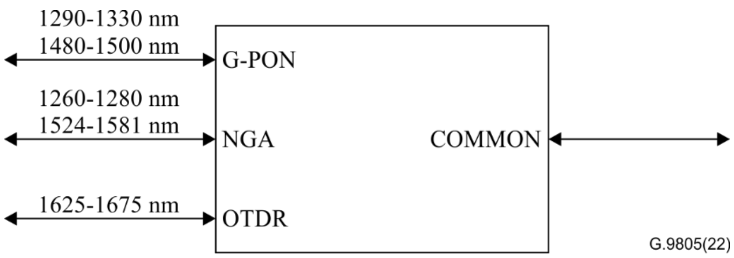


**Figure I.3 – Reference diagram of a WDM1r with G-PON, NGA and OTDR support**

Table I.4 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.4 shows the reference diagram of this filter.

**Table I.4 – 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 II) |
| Isolation – COM – NGA OLT (1290-1560 nm and 1625-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – OTDR (1260-1581 nm) | DBA (see Appendix II) |
| Isolation – COM – RF video (1260-1500 nm, 1575-1675 nm) | NA (RF is downstream only) |

**Table I.4 – Parameters for WDM1r with G-PON, RF video, NGA and OTDR ports**

| Specification | Value |
|---|---|
| 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 |

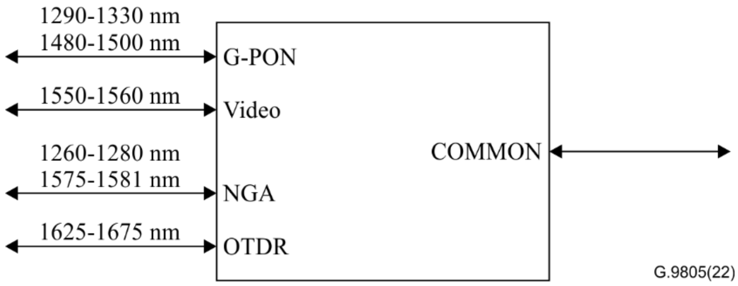


**Figure I.4 – Reference diagram of a WDM1r with G-PON, RF video, NGA and OTDR support**

Table I.5 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.5 shows the reference diagram of this device. (Note that as XG-PON1 is a deprecated name for the XG-PON system that operates at a nominal line rate of 10 Gbit/s downstream and 2.5 Gbit/s upstream, the term XG-PON1 can be regarded as the term XG-PON hereafter in the following text in Appendix I).

**Table I.5 – 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 II) |
| Isolation – COM – XG-PON1 OLT (1290-1560 nm and 1596-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – NG-PON2 (1260-1500 nm, 1550-1581 nm and 1640-1675 nm) | DBA (see Appendix II) |
| Maximum optical power | +23 dBm |
| Return loss | > 50 dB |
| Directivity | > 50 dB |

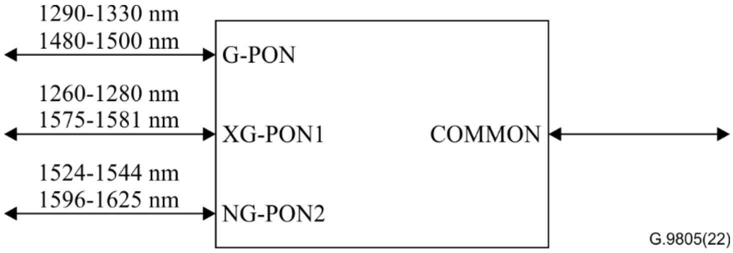


**Figure I.5 – Reference diagram of a CEx with G-PON, XG-PON1 and NG-PON2 support**

Table I.6 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.6 shows the reference diagram of this device.

**Table I.6 – 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 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 | ≤ 1.2 dB (1524-1544 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 II) or see application case below |
| Isolation – COM – XG-PON1 OLT (1290-1560 nm and 1596-1675 nm) | DBA (see Appendix II) or see application case below |
| Isolation – COM – NG-PON2 (1260-1500 nm, 1550-1581 nm and 1640-1675 nm) | DBA (see Appendix II) or see application case below |
| Isolation – COM – OTDR (1260-1625 nm) | DBA (see Appendix II) 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 |

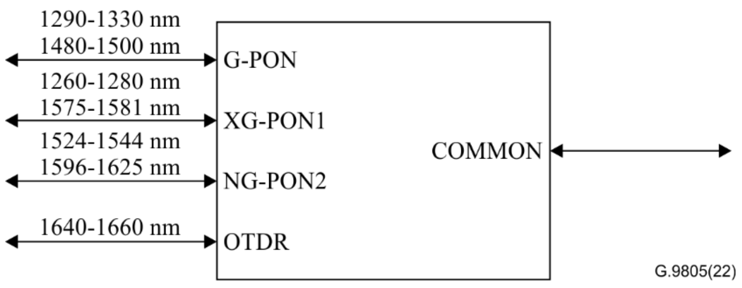


**Figure I.6 – Reference diagram of a CEx with G-PON, XG-PON1, NG-PON2 and OTDR support**

The assumptions for application case 1 are listed below. Isolation and directivity values are provided in Table I.6a.

**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, 0.9 A/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[2].

**Table I.6a – Isolation and directivity for application case 1**

| **Specification** | | **Value [dB]** |
|---|---|---|
| **Isolation [dB]** | COM – G-PON<br>(1260-1280 nm; 1524-1675 nm) | 35 |
| | COM – XG(S)-PON<br>(1290-1560 nm; 1596-1675 nm) | 35 |
| | COM – NG-PON2<br>(1260-1500 nm; 1550-1581 nm; 1640-1675 nm) | 40[2] |
| | COM – OTDR<br>(1260-1625 nm) | 10 |

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

**Table I.6a – Isolation and directivity for application case 1**

| Specification | | Value [dB] |
|---|---|---|
| **Directivity (to port) [dB]** | G-PON | 40 |
| | XG(S)-PON | 45 |
| | NG-PON2 | 55[3] |
| | OTDR | 25 |
| **Directivity (port-to-port) [dB]** | G-PON / XG(S)-PON | 45 |
| | G-PON / NG-PON2 | 55[2] |
| | G-PON / 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.7 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.7 shows the reference diagram of this device.

**Table I.7 – 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<br>(1260-1280 and 1524-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – RF video<br>(1260-1544 nm, 1575-1675 nm) | NA (RF is downstream only) |
| Isolation – COM – NG-PON2 OLT<br>(1260-1500 nm, 1550-1581 nm and 1640-1675 nm) | DBA (see Appendix II) |
| 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 |

[3] 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.

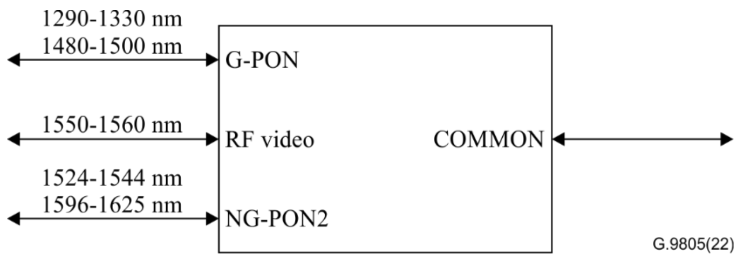


**Figure I.7 – Reference diagram of a CEx with G-PON, RF video and NG-PON2 support**

Table I.8 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.8 shows the reference diagram of this device.

**Table I.8 – 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<br>(1260-1280 nm and 1524-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – RF video<br>(1260-1544 nm, 1575-1675 nm) | NA (RF is downstream only) |
| Isolation – COM – NG-PON2 OLT<br>(1260-1500 nm, 1550-1581 nm and 1640-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – OTDR<br>(1260-1625 nm) | DBA (see Appendix II) |
| 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 |

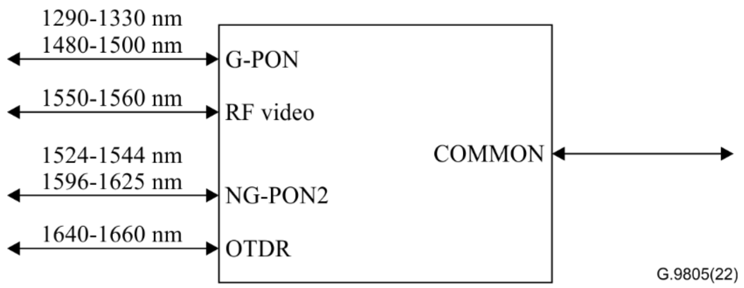


**Figure I.8 – Reference diagram of a CEx with G-PON, RF video, NG-PON2 and OTDR support**

Table I.9 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.9 shows the reference diagram of this device.

**Table I.9 – 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 (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 | ≤ 1.2 dB (1524-1544 nm and 1596-1603 nm) |
| Loss without connectors for PtP WDM PON band | ≤ 1.3 dB (1606-1625 nm) |
| Isolation – COM – G-PON OLT<br>(1260-1280 nm and 1524-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – XG-PON1 OLT<br>(1290-1560 nm and 1596-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – TWDM PON OLT<br>(1260-1500 nm, 1550-1581 nm and 1606-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – PtP WDM PON OLT<br>(1260-1603 nm and 1640-1675 nm) | DBA (see Appendix II) |
| Maximum optical power | +23 dBm |
| Return Loss | > 50 dB |
| Directivity | > 50 dB |

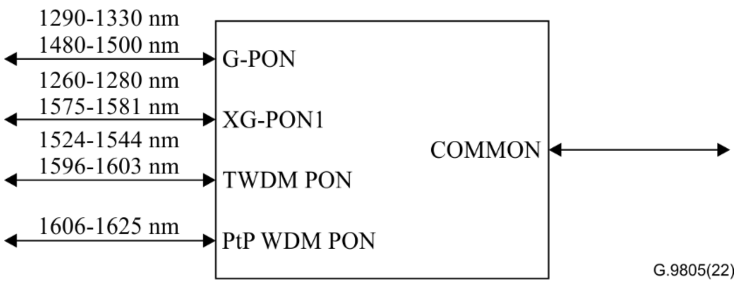


**Figure I.9 – Reference diagram of a CEMx with G-PON, XG-PON, TWDM PON and PtP WDM PON support**

Table I.10 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.10 shows the reference diagram of this device.

**Table I.10 – 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 II) |
| Isolation – COM – XG-PON1 OLT (1290-1560 nm and 1596-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – TWDM PON OLT (1260-1500 nm, 1550-1581 nm and 1606-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – PtP WDM PON OLT (1260-1603 nm and 1640-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – OTDR (1260-1625 nm) | DBA (see Appendix II) |
| 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 |

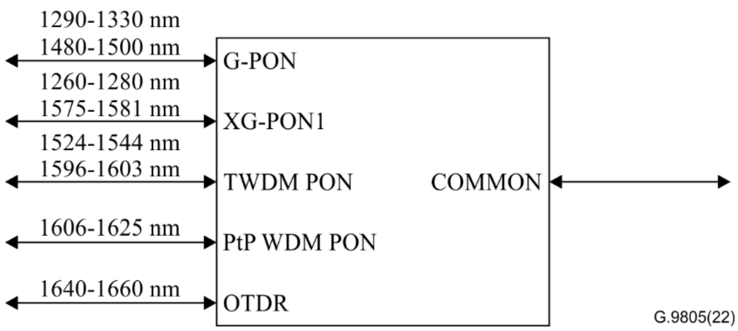


**Figure I.10 – Reference diagram of a CEMx with G-PON, XG-PON, TWDM PON, PtP WDM PON and OTDR support**

Table I.11 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.11 shows the reference diagram of this device.

**Table I.11 – 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<br>(1260-1280 nm and 1524-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – RF video<br>(1260-1544 nm and 1575-1675 nm) | NA (RF is downstream only) |
| Isolation – COM – TWDM PON OLT<br>(1260-1500 nm, 1550-1581 nm and 1606-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – PtP WDM PON OLT<br>(1260-1603 nm and 1640-1675 nm) | DBA (see Appendix II) |
| 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 |

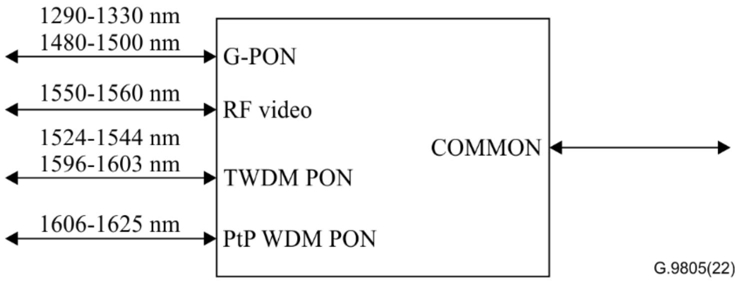


**Figure I.11 – Reference diagram of a CEMx with G-PON, RF video, TWDM PON and PtP WDM PON support**

Table I.12 shows sample parameters of a CEMx supporting G-PON (reduced upstream band as an example), 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.12 shows the reference diagram of this device.

**Table I.12 – 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) |

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

| Specification | Value |
|---|---|
| Isolation – COM – G-PON OLT (1260-1280 nm and 1524-1675 nm) | DBA (see Appendix II) |
| 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 II) |
| Isolation – COM – PtP WDM PON OLT (1260-1603 nm and 1640-1675 nm) | DBA (see Appendix II) |
| Isolation – COM – OTDR (1260-1625 nm) | DBA (see Appendix II) |
| 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 |

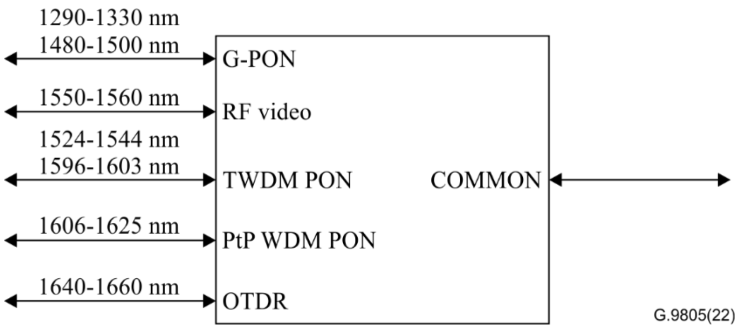


**Figure I.12 – Reference diagram of a CEMx with G-PON, RF video, TWDM PON, PtP WDM PON and OTDR support**

The reference diagram of a generic ~~2~~n-port coexistence CEx is shown in Figure I.13. ~~Table I.13 shows parameter specifications for the 2-port CEx with OLT1 and OLT2 ports. Table I.14 and Table I.15 show sample parameters for port isolation requirements and port directivity requirements of the 2-port CEx with OLT1 and OLT2 ports.~~

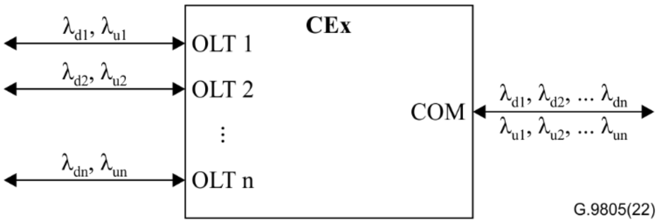


**Figure I.13 – Reference diagram of a generic 2-port coexistence CEx**

Table I.13 shows parameter specifications for the 2-port CEx with OLT1 and OLT2 ports. Table I.14 and Table I.15 show sample parameters for port isolation requirements and port directivity requirements of the 2-port CEx with OLT1 and OLT2 ports.

Table I.16 shows parameter specifications for the 3-port CEx with OLT1, OLT2 and OLT3 ports. Table I.17 and Table I.18 show sample parameters for port isolation requirements and port directivity requirements of the 3-port CEx with OLT1, OLT2 and OLT3 ports.

**Table I.13 – Parameter specifications for a 2-port CEx with OLT1 and OLT2 ports**

| Specification | Value |
|---|---|
| Loss w/o connectors for OLT1 band | < 0.8 dB (1290-1500 nm) |
| Loss w/o connectors for OLT2 bands | < 1.0 dB (1260-1280 nm and 1524-1625 nm) |
| Isolation COM – OLT1 port (1260-1280 nm and 1524-1625 nm) | See Table I.14~~6~~ |
| Isolation COM – OLT2 port (1290-1500 nm) | See Table I.14~~6~~ |
| Maximum optical power | +23 dBm |
| Return loss | > 50 dB |
| Directivity | See Table I.18~~7~~ |

**Table I.14 – Isolation requirements for different PON pairings of a generic 2-port coexistence CEx**

| **OLT1** | | **OLT2** | | **Isolation *[dB]* (Note 1)** | | |
|---|---|---|---|---|---|---|
| **System** | **OPL Class** | **System** | **OPL Class** | **[COM to OLT1]** | **[COM to OLT2]** | |
| | | | | | **OLT 2 w/o defined X/S tolerance** | **OLT2 w/ defined X/S tolerance (Note 2)** |
| GPON | C+ | XG-PON | E1 | 36.29 | 36.45 | 21.70 |
| GPON | C+ | XGS-PON | E1 | 32.27 | 35.86 | 22.20 |
| 50G TDM PON (50G 12.5G) | N1 | XG-PON | N1 | 24.80 | 34.06 | 26.30 |
| 50G TDM PON (50G 25G) | N1 | XG-PON | N1 | 26.22 | 31.05 | 26.30 |
| 50G TDM PON (50G 50G) | N1 | XG-PON | N1 | 26.05 | 30.84 | 29.10 |
| 50G TDM PON (50G 12.5G) | N1 | XGS-PON | N1 | 26.80 | 39.49 | 26.80 |

**Table I.14 – Isolation requirements for different PON pairings of a generic 2-port coexistence CEx**

| OLT1 | | OLT2 | | Isolation *[dB]* (Note 1) | | |
|---|---|---|---|---|---|---|
| | | | | | [COM to OLT2] | |
| System | OPL Class | System | OPL Class | [COM to OLT1] | OLT 2 w/o defined X/S tolerance | OLT2 w/ defined X/S tolerance (Note 2) |
| 50G TDM PON (50G 25G) | N1 | XGS-PON | N1 | 28.22 | 36.48 | 26.80 |
| 50G TDM PON (50G 50G) | N1 | XGS-PON | N1 | 28.05 | 36.27 | 29.60 |
| 50G TDM PON (50G 12.5G) | N1 | 10G-EPON | PR30 | 25.80 | 38.84 | |
| 50G TDM PON (50G 25G) | N1 | 10G-EPON | PR30 | 27.22 | 35.83 | |
| 50G TDM PON (50G 50G) | N1 | 10G-EPON | PR30 | 27.25 | 35.62 | |

NOTE 1 – Here it is assumed that the CEx has a maximum insertion loss of 0.8 dB and 1.0 dB for COM-to-OLT-1 and COM-to-OLT-2, respectively. Furthermore, the tolerable crosstalk penalty assumption is 0.1 dB (this is considered negligible for implementation).

NOTE 2 – In compliance with the optional (but recommended to implement) XG(S)-PON OLT X/S tolerance masks as defined in clause 10.1 of [ITU-T G.987.2 Amd2] and Annex B.10.3 in [ITU-T G.9807.1], respectively.

| ~~OLT1~~ | | ~~OLT2~~ | | ~~Isolation *[dB]* (Note 1)~~ | | |
|---|---|---|---|---|---|---|
| | | | | | ~~[COM to OLT2]~~ | |
| ~~System~~ | ~~OPL class~~ | ~~System~~ | ~~OPL class~~ | ~~[COM to OLT1]~~ | ~~OLT 2 w/o defined X/S tolerance~~ | ~~OLT2 w/ defined X/S tolerance (Note 2)~~ |
| ~~G-PON~~ | ~~C+~~ | ~~XG-PON~~ | ~~E1~~ | ~~36.29~~ | ~~36.45~~ | ~~21.70~~ |
| ~~G-PON~~ | ~~C+~~ | ~~XGS-PON~~ | ~~E1~~ | ~~32.27~~ | ~~35.86~~ | ~~22.20~~ |
| ~~50G TDM PON (50G 10G)~~ | ~~N1~~ | ~~XG-PON~~ | ~~N1~~ | ~~24.80~~ | ~~34.06~~ | ~~26.30~~ |
| ~~50G TDM PON (50G 25G)~~ | ~~N1~~ | ~~XGS-PON~~ | ~~N1~~ | ~~26.22~~ | ~~31.05~~ | ~~26.30~~ |
| ~~50G TDM PON (50G 10G)~~ | ~~N1~~ | ~~XG-PON~~ | ~~N1~~ | ~~26.80~~ | ~~39.49~~ | ~~26.80~~ |
| ~~50G TDM PON (50G 25G)~~ | ~~N1~~ | ~~XGS-PON~~ | ~~N1~~ | ~~28.22~~ | ~~36.48~~ | ~~26.80~~ |
| ~~50G TDM PON (50G 10G)~~ | ~~N1~~ | ~~10G-EPON~~ | ~~PR30~~ | ~~25.80~~ | ~~38.84~~ | |

| | | | | | |
|---|---|---|---|---|---|
| ~~50G TDM PON (50G 25G)~~ | ~~N1~~ | ~~10G-EPON~~ | ~~PR30~~ | ~~27.22~~ | ~~35.83~~ |
| ~~NOTE 1 – Here it is assumed that the CEx has a maximum insertion loss of 0.8 dB and 1.0 dB for COM-to-OLT-1 and COM-to-OLT-2, respectively. Furthermore, the tolerable crosstalk penalty assumption is 0.1 dB (this is considered negligible for implementation).~~<br>~~NOTE 2 – In compliance with the optional (but recommended to implement) XG(S)-PON OLT X/S tolerance masks as defined in clause 10.1 of [ITU-T G.987.2] and Annex B.10.3 in [ITU-T G.9807.1], respectively.~~ | | | | | |

**Table I.15 – Directivity requirements for different PON pairings of a generic 2-port coexistence CEx**

| **OLT1** | | **OLT2** | | **Directivity *[dB]* (Note 1)** | | |
|---|---|---|---|---|---|---|
| **System** | **OPL Class** | **System** | **OPL Class** | **[OLT2 to OLT1]** | **[OLT1 to OLT2]**<br>**OLT 2 w/o defined X/S tolerance** | **[OLT1 to OLT2]**<br>**OLT 2 w/ defined X/S tolerance (Note 2)** |
| GPON | C+ | XG-PON | E1 | 50.27 | 55.45 | 40.70 |
| GPON | C+ | XGS-PON | E1 | 49.27 | 54.86 | 41.20 |
| 50G TDM PON (50G 12.5G) | N1 | XG-PON | N1 | 37.00 | 43.24 | 41.50 |
| 50G TDM PON (50G 25G) | N1 | XG-PON | N1 | 38.42 | 43.24 | 41.50 |
| 50G TDM PON (50G 50G) | N1 | XG-PON | N1 | 38.25 | 43.24 | 41.50 |
| 50G TDM PON (50G 12.5G) | N1 | XGS-PON | N1 | 36.00 | 48.67 | 42.00 |
| 50G TDM PON (50G 25G) | N1 | XGS-PON | N1 | 37.42 | 48.67 | 42.00 |
| 50G TDM PON (50G 50G) | N1 | XGS-PON | N1 | 37.25 | 48.67 | 42.00 |
| 50G TDM PON (50G 12.5G) | N1 | 10G-EPON | PR30 | 36.00 | 48.82 | |
| 50G TDM PON (50G 25G) | N1 | 10G-EPON | PR30 | 37.42 | 48.82 | |
| 50G TDM PON (50G 50G) | N1 | 10G-EPON | PR30 | 37.25 | 48.82 | |
| NOTE 1 – Here it is assumed that the CEx has a maximum insertion loss of 0.8 dB and 1.0 dB for COM-to-OLT-1 and COM-to-OLT-2, respectively. Furthermore, the tolerable crosstalk penalty assumption is 0.1 dB (this is considered negligible for implementation).<br>NOTE 2 – In compliance with the optional (but recommended to implement) XG(S)-PON OLT X/S tolerance masks as defined in clause 10.1 of [ITU-T G.987.2] and clause B.10.3 in [ITU-T G.9807.1], respectively. | | | | | | |

| ~~OLT1~~ | | ~~OLT2~~ | | ~~Directivity *[dB]* (Note 1)~~ | | |
|---|---|---|---|---|---|---|
| | | | | | ~~[OLT1 to OLT2]~~ | |
| ~~System~~ | ~~OPL class~~ | ~~System~~ | ~~OPL class~~ | ~~[OLT2 to OLT1]~~ | ~~OLT 2 w/o defined X/S tolerance~~ | ~~OLT 2 w/ defined X/S tolerance (Note 2)~~ |
| ~~G-PON~~ | ~~C+~~ | ~~XG-PON~~ | ~~E1~~ | ~~50.27~~ | ~~55.45~~ | ~~40.70~~ |
| ~~G-PON~~ | ~~C+~~ | ~~XGS-PON~~ | ~~E1~~ | ~~49.27~~ | ~~54.86~~ | ~~41.20~~ |
| ~~50G-TDM-PON (50G-10G)~~ | ~~N1~~ | ~~XG-PON~~ | ~~N1~~ | ~~37.00~~ | ~~43.24~~ | ~~41.50~~ |
| ~~50G-TDM-PON (50G-25G)~~ | ~~N1~~ | ~~XGS-PON~~ | ~~N1~~ | ~~38.42~~ | ~~43.24~~ | ~~41.50~~ |
| ~~50G-TDM-PON (50G-10G)~~ | ~~N1~~ | ~~XG-PON~~ | ~~N1~~ | ~~36.00~~ | ~~48.67~~ | ~~42.00~~ |
| ~~50G-TDM-PON (50G-25G)~~ | ~~N1~~ | ~~XGS-PON~~ | ~~N1~~ | ~~37.42~~ | ~~48.67~~ | ~~42.00~~ |
| ~~50G-TDM-PON (50G-10G)~~ | ~~N1~~ | ~~10G-EPON~~ | ~~PR30~~ | ~~36.00~~ | ~~For further study~~ | |
| ~~50G-TDM-PON (50G-25G)~~ | ~~N1~~ | ~~10G-EPON~~ | ~~PR30~~ | ~~37.42~~ | ~~For further study~~ | |

~~NOTE 1 – Here it is assumed that the CEx has a maximum insertion loss of 0.8 dB and 1.0 dB for COM-to-OLT-1 and COM-to-OLT-2, respectively. Furthermore, the tolerable crosstalk penalty assumption is 0.1 dB (this is considered negligible for implementation).~~

~~NOTE 2 – In compliance with the optional (but recommended to implement) XG(S)-PON OLT X/S tolerance masks as defined in clause 10.1 of [ITU-T G.987.2] and clause B.10.3 in [ITU-T G.9807.1], respectively.~~

**Table I.16 – Parameter specifications for a 3-port CEx with OLT1 and OLT2 ports**

| Specification | Value |
|---|---|
| Loss w/o connectors for OLT1 band | < 1.0 dB (1290 – 1330 nm and 1480 – 1500 nm) |
| Loss w/o connectors for OLT2 bands | < 1.5 dB (1284 – 1288 nm and 1340 – 1344 nm) |
| Loss w/o connectors for OLT3 band | < 1.2 dB (1260 – 1280 nm and 1524 – 1625 nm) |
| Isolation COM – OLT1 port (1260-1280 nm, 1284-1288 nm, 1340-1344 nm and 1524-1625 nm) | See Table I.17 |
| Isolation COM – OLT2 port (1260-1280 nm, 1290-1330 nm, 1480-1500 nm and 1524-1625 nm) | See Table I.17 |
| Isolation COM – OLT3 port (1284-1288 nm, 1290-1330 nm, 1340-1344 nm and 1480-1500 nm) | See Table I.17 |
| Maximum optical power | +23 dBm |
| Return loss | > 50 dB |
| Directivity | See Table I.18 |

**Table I.17 – Isolation requirements for different PON pairings of a generic 3-port coexistence CEx**

| OLT1 | | OLT2 | | OLT3 | | Isolation *[dB]* (Note) | | |
|---|---|---|---|---|---|---|---|---|
| **System** | **OPL Class** | **System** | **OPL Class** | **System** | **OPL Class** | **[COM to OLT1]** | **[COM to OLT2]** | **[COM to OLT3]** |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | XG-PON | N1 | 33.76 | 32.03 | 31.93 |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | XGS-PON | N1 | 30.57 | 33.36 | 32.58 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | XG-PON | N1 | 34.32 | 32.75 | 32.73 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | XGS-PON | N1 | 31.66 | 34.08 | 34.34 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | XG-PON | N1 | 33.74 | 32.06 | 31.89 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | XGS-PON | N1 | 30.51 | 33.39 | 32.47 |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | 10G/1G-EPON | PR30 | 34.19 | 30.24 | 35.99 |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | 10G/10G-EPON | PR30 | 29.46 | 32.36 | 32.46 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | 10G/1G-EPON | PR30 | 34.59 | 30.96 | 36.45 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | 10G/10G-EPON | PR30 | 30.57 | 33.08 | 34.25 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | 10G/1G-EPON | PR30 | 34.17 | 30.27 | 35.97 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | 10G/10G-EPON | PR30 | 29.40 | 32.39 | 32.35 |
| NOTE – Here it is assumed that the CEx has a maximum insertion loss of 1.0 dB, 1.5 dB and 1.2 dB for COM-to-OLT-1, COM-to-OLT-2 and COM-to-OLT-3, respectively. Furthermore, the tolerable crosstalk penalty assumption is 0.1dB (this is considered negligible for implementation). | | | | | | | | |

**Table I.18 – Directivity requirements for different PON pairings of a generic 3-port coexistence CEx**

| OLT1 | | OLT2 | | OLT3 | | Directivity *[dB]* (Note) | | |
|---|---|---|---|---|---|---|---|---|
| **System** | **OPL Class** | **System** | **OPL Class** | **System** | **OPL Class** | **OLT1** | **OLT2** | **OLT3** |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | XG-PON | N1 | 46.32 | 44.44 | 45.41 |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | XGS-PON | N1 | 42.24 | 43.92 | 46.69 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | XG-PON | N1 | 47.25 | 45.16 | 46.50 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | XGS-PON | N1 | 44.32 | 44.63 | 48.77 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | XG-PON | N1 | 45.76 | 44.47 | 44.75 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | XGS-PON | N1 | 40.65 | 43.95 | 45.10 |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | 10G/1G-EPON | PR30 | 47.91 | 43.92 | 50.27 |
| GPON | B+ | 50G TDM PON (50G 25G) | N1 | 10G/10G-EPON | PR30 | 42.18 | 43.92 | 47.59 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | 10G/1G-EPON | PR30 | 48.58 | 44.63 | 50.93 |
| GPON | B+ | 50G TDM PON (50G 12.5G) | N1 | 10G/10G-EPON | PR30 | 44.29 | 44.63 | 49.70 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | 10G/1G-EPON | PR30 | 47.53 | 43.95 | 49.89 |
| GPON | B+ | 50G TDM PON (50G 50G) | N1 | 10G/10G-EPON | PR30 | 40.56 | 43.95 | 45.97 |
| NOTE – Here it is assumed that the CEx has a maximum insertion loss of 1.0 dB, 1.5 dB and 1.2 dB for COM-to-OLT-1, COM-to-OLT-2 and COM-to-OLT-3, respectively. Furthermore, the tolerable crosstalk penalty assumption is 0.1dB (this is considered negligible for implementation). | | | | | | | | |

# Appendix II

## 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, CEx and CEMx 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 II.1 shows the assumed network topology for calculating the required isolation for the G-PON port of a WDM device enabling coexistence with XG(S)-PON. The G-PON ONUs are assumed to be at the maximum differential loss expected in the deployment and the XG(S)-PON 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], [ITU-T G.987.2] and [ITU-T G.9807.1] 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.

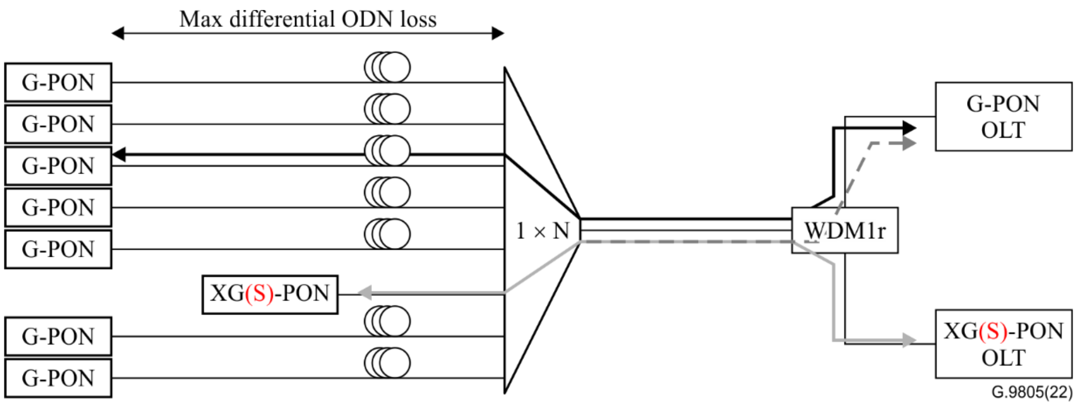


**Figure II.1 – Network topology assumed for calculating the required isolation for the G-PON port of a WDM device enabling coexistence with XG-PON**

In addition to being at the highest loss, the G-PON ONUs are assumed to be transmitting at the lowest power permitted in [ITU-T G.984.2]. The XG(S)-PON ONU is transmitting at the highest power permitted in [ITU-T G.987.2] or [ITU-T G.9807.1].

On the OLT side, the internal diplexer of the G-PON OLT transceiver may also add some isolation that could be taken into account if known by the implementer. This is illustrated in Figure II.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.

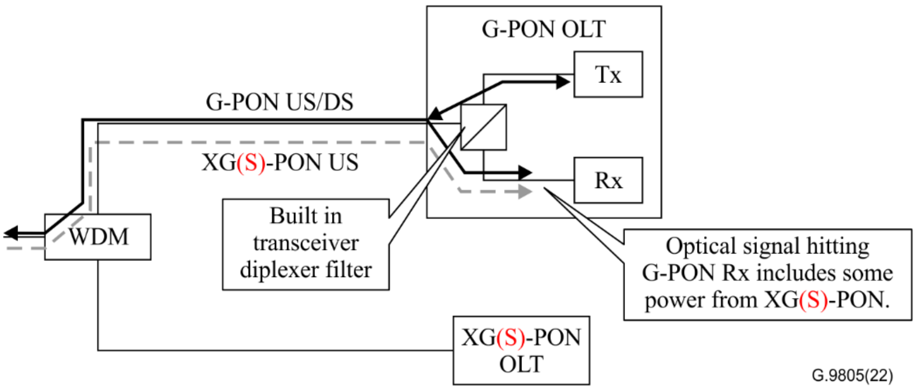


**Figure II.2 – Isolation factors to consider at the OLT**

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 [b-ITU-T G-Sup.39], for inter-channel crosstalk power penalty may be used to derive the allowed crosstalk.

For a single interfering channel:

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

where $r$ is the linear extinction ratio.

Using this formula, the chart shown in Figure II.3 can be plotted from which the allowed crosstalk for the system design penalty assumption can be extracted. This chart shows the calculation for G-PON, XG-PON 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 G-PON, XG-PON/NG-PON2(2.5G) and NG-PON2(10G) respectively.

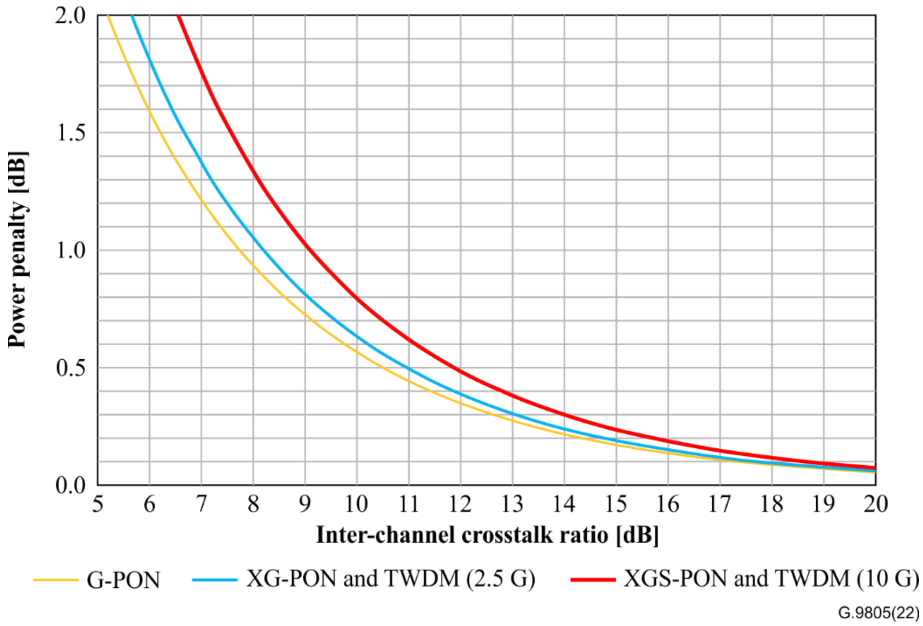


**Figure II.3 – Power penalty as a function of inter-channel crosstalk ratio**

The following formula (II-2) may be derived for calculating the required isolation in terms of the allowed crosstalk, differential ODN loss, launch power difference between ONUs (G-PON (min) – XG-PON (max)), diplexer (or other WDM to Rx path) isolation and bandwidth ratio. All parameters are in dB.

$$I_{WDM} = XT(dB) - \Delta P + \Delta ODN - I_{BiDi} - B_{comp} \tag{II-2}$$

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

$XT$: Allowed inter-channel crosstalk power ratio in dB

$\Delta P$: ONU launch power ratio in dB between the target signal (minimum) and the interfering signal (maximum)

$\Delta ODN$: 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:

$$B_{comp}(dB) = 10\log\left( R_{int} / R_{target} \right) \tag{II-3}$$

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

**Example 1**

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

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

The designed ODN loss differential ($\Delta ODN$) 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 G-PON port for the XG-PON US wavelength is:

10 − (−6.5) + 5 − 2 − 3= <u>16.5 dB.</u>

**Example 2**

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

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

The designed ODN loss differential ($\Delta ODN$) 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 G-PON port for the XG-PON US wavelength is:

17 − (−6.5) + 10 − 0 − 3 = <u>30.5 dB.</u>

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.

$$I_{WDM} = XT - \Delta P + \Delta ODN - I_{BiDi} - B_{comp} + 10\log(N) \quad \text{(II-4)}$$

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., G-PON, XG-PON and NG-PON2) are to coexist, the analysis becomes more complex.

[b-ITU-T G-Sup.39] addresses the multi-interferer case (eq. 9-30 of [b-ITU-T G-Sup.39]), 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 (eq. 9.28 of [b-ITU-T G-Sup.39]), 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 II.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.

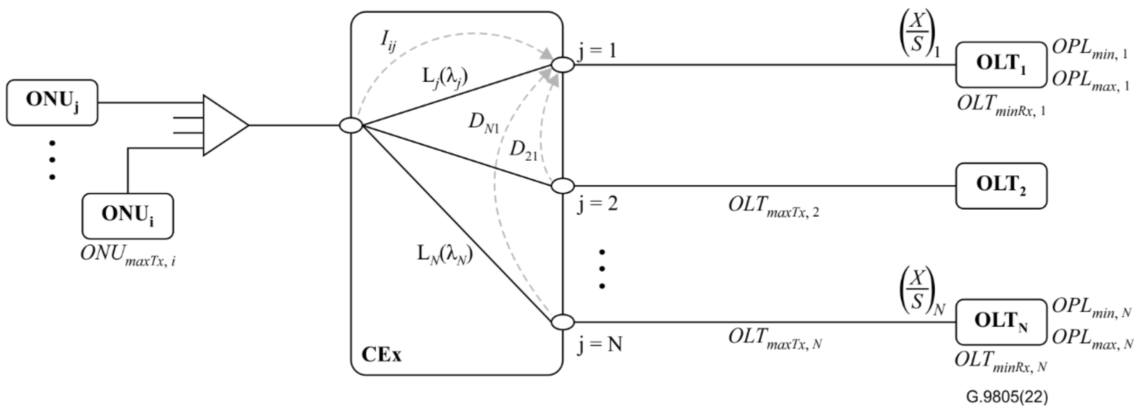


**Figure II.4 – CEx model for isolation and directivity calculations**

$N$ : 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 $j$)

$L_{min/max,j}(\lambda_j)$ : Maximum (and minimum) insertion (pass band) loss of (common port to) port $j$ at the victim wavelength $\lambda_j$

$L_j(\lambda_i)$ : Insertion (pass band) loss of (common port to) port $j$ at the interferer wavelength $\lambda_i$; (equivalent to the isolation $I_{ij}$)

$\rho_i, \rho_j$ : Photodiode responsivities at the interferer and victim signal wavelengths respectively

$R_i$, $R_j$ : Bit rates of the interferer and victim signals respectively

$ONU_{maxTX,i}$ : Maximum $ONU_i$ transmitter power of interfering signal

$OLT_{minRX,j}$ : Sensitivity of victim signal OLT Rx at port $j$

$OLT_{maxTX,i}$ : Maximum OLT transmitter power of interfering signal from port $i$

$OPL_{min,j}$ : Minimum Optical Path Loss supported by the OPL class of the OLT transceiver at port $j$

$OPL_{max,j}$ : Maximum Optical Path Loss supported by the OPL class of the OLT transceiver at port $j$

$C_j$ : Crosstalk to (victim signal) port $j$

$r_j$ : Extinction ratio of victim signal $j$

$P_c$ : Tolerated crosstalk penalty on victim signal $j$.

**Isolation formulas**

For the condition of uniform isolation: $I_{ij} = I_j$, $\forall j \neq i$ :

(i) For OLT ports without wavelength blocking filters for which the tolerable crosstalk ratio ($C_j$) for a given power penalty must be calculated for the victim port:

$$I_{ij} = L_j(\lambda_i) = \frac{1}{OLT_{minRx,j} \cdot OPL_{max,j}} \cdot \frac{min\left[\left(\frac{OPL_{max,j}}{L_{max,j}(\lambda_j)}\right)_{j=1\ to\ N}\right]}{max\left[\left(\frac{OPL_{min,j}}{L_{min,j}(\lambda_j)}\right)_{j=1\ to\ N}\right]} \cdot \frac{L_{max,j}(\lambda_j)}{C_j} \cdot \sum_{i=1,(i\neq j)}^{N} \frac{ONU_{maxTx,i}}{max\left[1,\frac{R_i}{R_j}\right]} \cdot \frac{\rho_i}{\rho_j} \quad \text{(III-5)}$$

(ii) For OLT ports with wavelength blocking filters (see Appendix IV) for which the X/S tolerance of the victim port is known:

$$I_{ij} = L_j(\lambda_i) = \frac{1}{OLT_{minRx,j} \cdot OPL_{max,j}} \cdot \frac{min\left[\left(\frac{OPL_{max,j}}{L_{max,j}(\lambda_j)}\right)_{j=1\ to\ N}\right]}{max\left[\left(\frac{OPL_{min,j}}{L_{min,j}(\lambda_j)}\right)_{j=1\ to\ N}\right]} \cdot \frac{L_{max,j}(\lambda_j)}{\left(\frac{X}{S}\right)_j} \cdot \sum_{i=1,(i\neq j)}^{N} ONU_{maxTx,i} \quad \text{(III-6)}$$

**Directivity formulas**

For the condition of uniform directivity: $D_{ij} = D_j$, $\forall j \neq i$

(i) For OLT ports without wavelength blocking filters for which the tolerable crosstalk ratio ($C_j$) for a given power penalty must be calculated for the victim port:

$$D_{ij} = \frac{1}{OLT_{minRx,j} \cdot OPL_{max,j}} \cdot min\left[\left(\frac{OPL_{max,j}}{L_{max,j}(\lambda_j)}\right)_{j=1\ to\ N}\right] \cdot \frac{L_{max,j}(\lambda_j)}{C_j} \cdot \sum_{i=1,(i\neq j)}^{N} \frac{OLT_{maxTx,i}}{max\left[1,\frac{R_i}{R_j}\right]} \cdot \frac{\rho_i}{\rho_j} \quad \text{(III-7)}$$

(ii) For OLT ports with wavelength blocking filters (see Appendix IV) for which the X/S tolerance of the victim port is known:

$$D_{ij} = \frac{1}{OLT_{minRx,j} \cdot OPL_{max,j}} \cdot min\left[\left(\frac{OPL_{max,j}}{L_{max,j}(\lambda_j)}\right)_{j=1\ to\ N}\right] \cdot \frac{L_{max,j}(\lambda_j)}{\left(\frac{X}{S}\right)_j} \cdot \sum_{i=1,(i\neq j)}^{N} OLT_{maxTx,i} \quad \text{(III-8)}$$

The tolerated crosstalk $C_j$ in the above formulas can be calculated by inverting the single interferer formula, eq. 9.28 of [b-ITU-T G-Sup.39]): and with an additional change of the sign (–Pc):

$$C_j = \frac{r_j - 1}{r_j + 1}\left(1 - 10^{\frac{-P_c}{10}}\right) \quad \text{(III-9)}$$

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 eq. 9.29 of [b-ITU-T G-Sup.39], must not be used here.

To illustrate the application of the above isolation and directivity equations, worked examples are given below:

**Example 1**

For a penalty $P_c$ = 0.1 dB in a B+ G-PON and N1 XGS-PON coexistence scenario, the maximum inter-channel crosstalk ($C_j$) is –17.3 dB for G-PON.

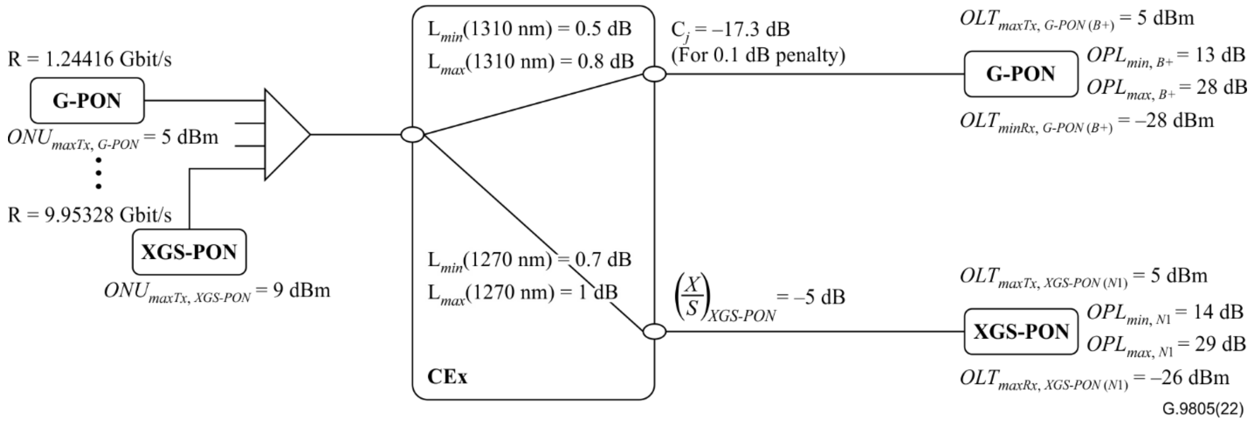


**Figure II.5 – 2-port CEx worked example**

The relevant parameters for this example scenario are shown in Table II.1. It is assumed that the responsivity of the victim Rx is the same at both the victim and interferer wavelengths as both are in the O-band.

**Table II.1 – 2-port CEx worked example parameters**

| Parameter | Value | Unit | Comment |
|---|---|---|---|
| Bit rate of victim | 1.24416 | Gbit/s | G-PON US line-rate (Note 1) |
| Bit rate of interferer | 9.95328 | Gbit/s | XGS-PON US line-rate (Note 2) |
| Victim OLT Rx sensitivitye | –28.0 | dBm | min for B+ G-PON OLT (Note 1) |
| Max OPL of victim OLT port | 28.0 | dB | max ODN loss of B+ OPL class (Note 1) |
| Max OPL of interferer OLT port | 29.0 | dB | max ODN loss of N1 OPL class (Note 2) |
| Min OPL of victim OLT port | 13.0 | dB | min ODN loss of B+ OPL class (Note 1) |
| Min OPL of interferer OLT port | 14.0 | dB | min ODN loss of N1 OPL class (Note 2) |
| Min loss of victim OLT port | 0.5 | dB | G-PON port of CEx (Note 3) |
| Min loss of interferer OLT port | 0.7 | dB | XGS-PON port of CEx (Note 3) |
| Max loss of victim OLT port | 0.8 | dB | G-PON port of CEx (Note 3) |
| Max loss of interferer OLT port | 1.0 | dB | XGS-PON port of CEx (Note 3) |
| Max allowed X/S of the victim OLT port | –17.3 | dB | As calculated as no X/S defined for G-PON OLT (Note 4) |
| Launch power max interfering ONU | 9.0 | dBm | Max for XGS-PON ONU (Note 2) |
| NOTE 1 – See [ITU-T G.984.2].<br>NOTE 2 – See [ITU-T G.9807.1].<br>NOTE 3 – Estimated values for the purpose of this worked example.<br>NOTE 4 – See equation 9.28 of [b-ITU-T G-Sup.39]. | | | |

The equation for isolation can be expressed in dB for a 2 port CEx as follows:

$$
\begin{aligned}
I_{21}(dB) = & -OLT_{minRx,1}(dBm) - OPL_{max,1}(dB) \\
& + min\left[\left(OPL\_max_j\ (dB) - L_{max,j}\left(\lambda_j\right)dB\right)_{j=1\ to\ 2}\right] \\
& - max\left[\left(OPL\_min_j\ (dB) - L_{min,j}\left(\lambda_j\right)dB\right)_{j=1\ to\ 2}\right] + L_{max,1}(\lambda_1)\ \ dB - C_1(dB) \\
& + ONU_{maxTx,2}(dBm) - max\left[1, \frac{R_2}{R_1}\right](dB)\ + 10log\left(\frac{\rho_2}{\rho_1}\right)
\end{aligned}
$$

For G-PON as the victim at port 1:

$$
\begin{aligned}
I_{21}(dB) = & -(-28\ dBm) - 28\ dB + min[(28\ dB - 0.8\ dB)\,, (29\ dB - 1\ dB)] \\
& - max[(13\ dB - 0.5\ dB)\,, (14\ dB - 0.7\ dB)] + 0.8\ dB - (-17.3\ dB) + 9\ dBm \\
& - max\left[0, {\scriptstyle 10log}\left(\frac{9.95328}{1.24416}\right)\right](dB) + 0\ dB
\end{aligned}
$$

$$
I_{21}(dB) = 28\ dBm - 28\ dB + 27.2\ dB - 13.3\ dB + 0.8\ dB + 17.3\ dB + 9d\ Bm\ - 9\ dB = \boldsymbol{32\ dB}
$$

For the XGS-PON port of the CEx, in the case that a blocking filter has been implemented with (X/S) = –5 dB, the required isolation in dB is given as follows:

$$
\begin{aligned}
I_{21}(dB) = & -OLT_{minRx,1}(dBm) - OPL_{max,1}(dB) \\
& + min\left[\left(OPL\_max_j\ (dB) - L_{max,j}\left(\lambda_j\right)dB\right)_{j=1\ to\ 2}\right] \\
& - max\left[\left(OPL\_min_j\ (dB) - L_{min,j}\left(\lambda_j\right)dB\right)_{j=1\ to\ 2}\right] + L_{max,1}(\lambda_1)\ \ dB - \left(\frac{X}{S}\right)_1(dB) \\
& + ONU_{maxTx,2}(dBm)
\end{aligned}
$$

$$
\begin{aligned}
I_{21}(dB) = & -(-26\ dBm) - 29dB + min[(29\ dB - 1\ dB)\,, (28\ dB - 0.8\ dB)] \\
& - max[(14\ dB - 0.7\ dB)\,, (13\ dB - 0.5\ dB)] + 1\ dB - (-5\ dB) + 5\ dBm
\end{aligned}
$$

$$
I_{21}(dB) = 26\ dBm - 29\ dB + 27.2\ dB - 13.3\ dB + 1\ dB + 5\ dB + 5\ dBm = \boldsymbol{21.9\ dB}
$$

In the case of directivity, the dB form of the equation is given as follows for this 2-port CEx example:

$$
\begin{aligned}
D_{21}(dB) = & -OLT_{minRx,1}(dB) - OPL_{max,1}(dB) + min\left[\left(OPL_{max,j}\ (dB) - L_{max,j}\left(\lambda_j\right)dB\right)_{j=1\ to\ 2}\right] \\
& + L_{max,1}(\lambda_1)\ \ dB - C_1(dB) + OLT_{maxTx,2}(dBm)) - max\left[0,10log\left(\frac{R_2}{R_1}\right)\right] \\
& + 10log\left(\frac{\rho_2}{\rho_1}\right)
\end{aligned}
$$

The interference to the G-PON signal comes from the N1 OPL class XGS-PON OLT Tx at +5 dBm (max).

$$
\begin{aligned}
D_{21}(dB) = & -(-28\ dBm) - 28\ dB + min[(28\ dB - 0.8\ dB), (29\ dB - 1\ dB)] + 0.8\ dB \\
& - (-17.3\ dB) + 5\ dBm - max\left[0, {\scriptstyle 10log}\left(\frac{9.95328}{1.24416}\right)\right](dB) + 0\ dB
\end{aligned}
$$

$D_{21}(dB) = 28\ dBm - 28\ dB + 27.2\ dB + 0.8\ dB + 17.3\ dB + 5\ dBm - 9\ dB + 0\ dB$ = **41.3 *dB***

In this scenario the G-PON upstream victim signal is in the 1300 nm spectral region and the interferer is at 1577 nm and, for such a wide wavelength separation, it is likely that the responsivity of the victim receiver will be different at these wavelengths. If the receiver module responsivity difference is purely due to the absorption coefficient in the photodiode (i.e., not due to other wavelength dependent losses in between the S/R reference point and the detector), then one might expect about 10% higher responsivity at the longer wavelength for InGaAs based detectors. This would result in about 0.5 dB additional directivity requirement. However, the exact responsivity difference must be determined by application.

For XGS-PON, in the case that a blocking filter has been implemented with (X/S) = –5 dB, the required directivity in dB is given as follows:

$$D_{21}(dB) = -OLT_{minRx,1}(dBm) - OPL_{max,1}(dB) + min\left[\left(OPL_{max,j}\ (dB) - L_{max,j}(\lambda_j)dB\right)_{j=1\ to\ 2}\right] + L_{max,1}(\lambda_1)\ dB - \left(\frac{X}{S}\right)_1 (dB) + OLT_{maxTx,2}(dBm)$$

$$D_{21}(dB) = -(-26\ dBm) - 29\ dB + min[(29\ dB - 1\ dB), (28\ dB - 0.8\ dB)] + 1\ dB - (-5\ dB) + 5\ dBm$$

$$D_{21}(dB) = 26\ dBm - 29\ dB + 27.2\ dB + 1\ dB + 5\ dB + 5\ dBm = \mathbf{35.2\ dB}$$

**Example 2**

For a penalty $P_c$ = 0.1 dB in a N1 50G/25G HS-PON and N1 XGS-PON coexistence scenario, the HS-PON has a mandatory X/S for OLT as −5 dB (wavelength option 2), for the XGS-PON, there are two cases:

a) No OLT X/S tolerance specification: XGS-PON tolerates –18.66 dB maximum crosstalk (Ci) to achieve 0.1 dB penalty

b) With OLT X/S tolerance specification as defined in [ITU-T G.9807.1]: X/S = −5 dB

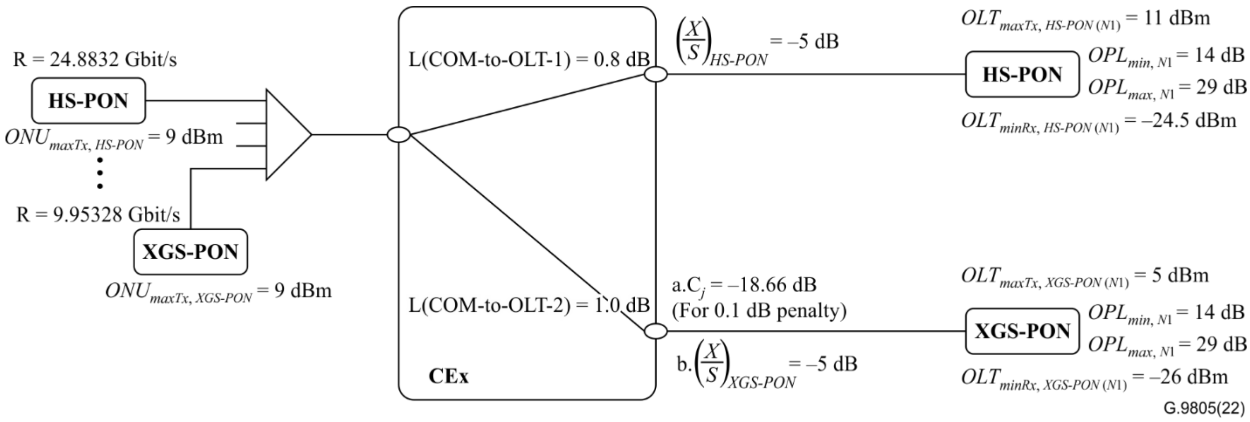


**Figure II.6 – 2-port CEx worked example**

The relevant parameters for this example scenario are shown in Table II.2.

**Table II.2 – 2-port CEx worked example parameters**

| Parameter | Value | Unit | Comment |
|---|---|---|---|
| Bit rate of victim | 24.8832 | Gbit/s | HS-PON US line-rate (Note 1) |
| Bit rate of interferer | 9.95328 | Gbit/s | XGS-PON US line-rate (Note 2) |
| Victim OLT Rx sensitivitye | –24.5 | dBm | min for N1 HS-PON OLT (Note 1) |
| Max OPL of victim OLT port | 29.0 | dB | max ODN loss of N1 OPL class (Note 1) |
| Max OPL of interferer OLT port | 29.0 | dB | max ODN loss of N1 OPL class (Note 2) |
| Min OPL of victim OLT port | 14.0 | dB | min ODN loss of N1 OPL class (Note 1) |
| Min OPL of interferer OLT port | 14.0 | dB | min ODN loss of N1 OPL class (Note 2) |
| Min Loss of victim OLT port | 0.8 | dB | HS-PON port of CEx (Note 3) |
| Min Loss of interferer OLT port | 1.0 | dB | XGS-PON port of CEx (Note 3) |
| Max Loss of victim OLT port | 0.8 | dB | HS-PON port of CEx (Note 3) |

**Table II.2 – 2-port CEx worked example parameters**

| Parameter | Value | Unit | Comment |
|---|---|---|---|
| Max Loss of interferer OLT port | 1.0 | dB | XGS-PON port of CEx (Note 3) |
| X/S of the victim OLT port | –5 | dB | X/S defined for HS-PON OLT (Wavelength option 2) (Note 1) |
| X/S of the interferer OLT port | –5 | dB | X/S defined for XGS-PON OLT (Note 2) |
| Launch power max interfering ONU | 9.0 | dBm | Max for XGS-PON ONU (Note 2) |
| NOTE 1 – See [ITU-T G.9804.3].<br>NOTE 2 – See ~~Amendment 2 to~~ [ITU-T G.9807.1].<br>NOTE 3 – Estimated values for the purpose of this worked example. | | | |

The equation for isolation can be expressed in dB for a 2 port CEx as follows:

$$I_{21}(dB) = -OLT_{minRx,1}(dBm) - OPL_{max,1}(dB) + min\left[\left(OPL\_max_j\ (dB) - L_{max,j}(\lambda_j)dB\right)_{j=1\ to\ 2}\right] - max\left[\left(OPL\_min_j\ (dB) - L_{min,j}(\lambda_j)dB\right)_{j=1\ to\ 2}\right] + L_{max,1}(\lambda_1)\ dB - C_1(dB) + ONU_{maxTx,2}(dBm) - max\left[1,\frac{R_2}{R_1}\right](dB)\ + 10log\left(\frac{\rho_2}{\rho_1}\right)$$

For HS-PON as the victim at port 1 that a blocking filter has been implemented with (X/S) = –5 dB, the required isolation in dB is given as follows:

$$I_{21}(dB) = -OLT_{minRx,1}(dBm) - OPL_{max,1}(dB) + min\left[\left(OPL\_max_j\ (dB) - L_{max,j}(\lambda_j)dB\right)_{j=1\ to\ 2}\right] - max\left[\left(OPL\_min_j\ (dB) - L_{min,j}(\lambda_j)dB\right)_{j=1\ to\ 2}\right] + L_{max,1}(\lambda_1)\ dB - \left(\frac{X}{S}\right)_1(dB) + ONU_{maxTx,2}(dBm)$$

$$I_{21}(dB) = -(-24.5\ dBm) - 29\ dB + min[(29\ dB - 0.8\ dB)\,,(29\ dB - 1\ dB)] - max[(14\ dB - 0.8\ dB)\,,(14\ dB - 1\ dB)] + 0.8\ dB - (-5\ dB) + 9\ dBm$$

$$I_{21}(dB) = 24.5\ dBm - 29\ dB + 28\ dB - 13.2\ dB + 0.8\ dB + 5\ dB + 9\ dBm = \mathbf{25.10\ dB}$$

a) For the XGS-PON port of the CEx without OLT X/S tolerance specification, the required isolation in dB is given as follows:

$$I_{21}(dB) = -(-26\ dBm) - 29\ dB + min[(29\ dB - 0.8\ dB)\,,(29\ dB - 1\ dB)] - max[(14\ dB - 1\ dB)\,,(14\ dB - 0.8\ dB)] + 1\ dB - (-18.66\ dB) + 9\ dBm - max\left[0,10log\left(\frac{24.8832}{9.95328}\right)\right](dB) + 0\ dB$$

$$I_{21}(dB) = 26\ dBm - 29\ dB + 28\ dB - 13.2\ dB + 1\ dB + 18.66\ dB + 9\ dBm - 3.98\ dB = \mathbf{36.48\ dB}$$

b) For the XGS-PON port of the CEx with OLT X/S tolerance specification (X/S) = –5 dB, the required isolation in dB is given as follows:

$$I_{21}(dB) = -(-26\ dBm) - 29\ dB + min[(29\ dB - 0.8\ dB)\,,(29\ dB - 1\ dB)] - max[(14\ dB - 1\ dB)\,,(14\ dB - 0.8\ dB)] + 1\ dB - (-5\ dB) + 9\ dBm$$

$$I_{21}(dB) = 26\ dBm - 29\ dB + 28\ dB - 13.2\ dB + 1\ dB + 5\ dB + 9\ dBm = \mathbf{26.80\ dB}$$

In the case of directivity, the dB form of the equation is given as follows for this 2-port CEx example:

$$D_{21}(dB) = -OLT_{minRx,1}(dB) - OPL_{max,1}(dB) + min\left[\left(OPL_{max,j}\ (dB) - L_{max,j}(\lambda_j)dB\right)_{j=1\ to\ 2}\right] + L_{max,1}(\lambda_1)\ dB - C_1(dB) + OLT_{maxTx,2}(dBm)) - max\left[0,10log\left(\frac{R_2}{R_1}\right)\right] + 10log\left(\frac{\rho_2}{\rho_1}\right)$$

For HS-PON, a blocking filter has been implemented with (X/S) = –5 dB, the required directivity in dB is given as follows:

$$D_{21}(dB) = -OLT_{minRx,1}(dBm) - OPL_{max,1}(dB) + min\left[\left(OPL_{max,j}\ (dB) - L_{max,j}(\lambda_j)dB\right)_{j=1\ to\ 2}\right] + L_{max,1}(\lambda_1)\ dB - \left(\frac{X}{S}\right)_1 (dB) + OLT_{maxTx,2}(dBm)$$

$$D_{21}(dB) = -(-24.5\ dBm) - 29\ dB + min[(29\ dB - 0.8\ dB)\,,(29\ dB - 1\ dB)]\ + 0.8\ dB - (-5\ dB) + 5\ dBm$$

$$D_{21}(dB) = 24.5\ dBm - 29\ dB + 28\ dB + 0.8\ dB + 5\ dB + 5\ dBm = \mathbf{34.30\ dB}$$

a) For XGS-PON without OLT X/S tolerance specification, the required directivity in dB is given as follows:

$$D_{21}(dB) = -(-26\ dBm) - 29\ dB + min[(29\ dB - 0.8\ dB), (29\ dB - 1\ dB)] + 1\ dB - (-18.66\ dB) + 11\ dBm - max\left[0, 10log\left(\frac{49.7664}{9.95328}\right)\right](dB) + 0\ dB$$

$$D_{21}(dB) = 26\ dBm - 29\ dB + 28\ dB + 1\ dB + 18.66\ dB + 11\ dBm - 6.99\ dB = \mathbf{48.67\ dB}$$

b) For the XGS-PON port with OLT X/S tolerance specification (X/S) = –5 dB, the required directivity in dB is given as follows:

$$D_{21}(dB) = -(-26\ dBm) - 29\ dB + min[(29\ dB - 0.8\ dB), (29\ dB - 1\ dB)] + 1\ dB - (-5\ dB) + 11\ dBm$$

$$D_{21}(dB) = 26\ dBm - 29\ dB + 28\ dB + 1\ dB + 5\ dB + 11\ dBm = \mathbf{42.00\ dB}$$

**Example 3**

For a penalty $P_C$ = 0.1 dB in a B+ GPON, N1 50/25G HS-PON, N1 XG-PON coexistence scenario, with no OLT X/S tolerance specification: GPON tolerates −14.135dB allowed maximum crosstalk, 50/25G HS-PON tolerates −8.982 dB allowed maximum crosstalk, XG-PON tolerates −12.258 dB allowed maximum crosstalk to achieve 0.1 dB penalty.

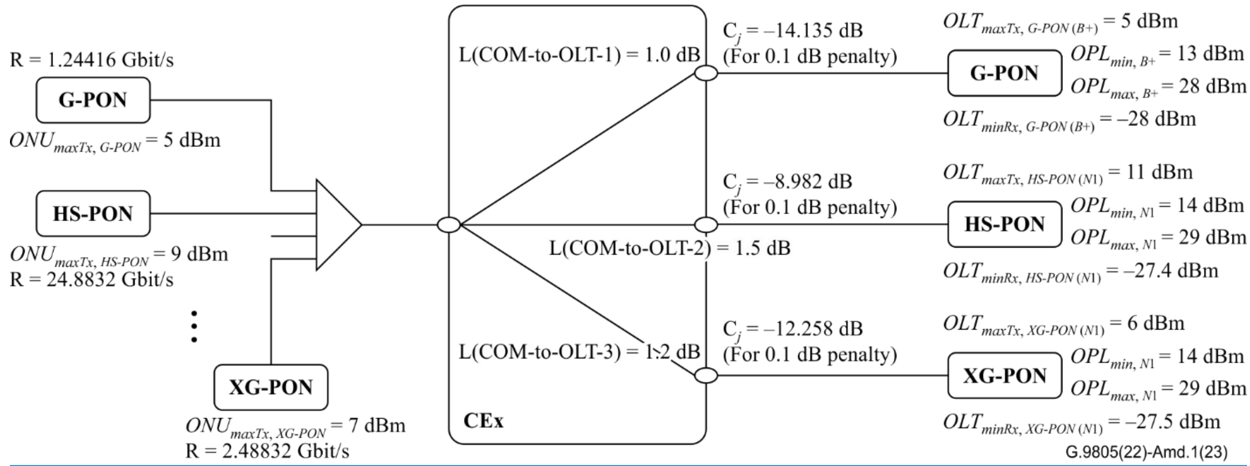


**Figure II.7 – 3-port Cex worked example**

The relevant parameters for this example scenario are shown in Table II.7. Note that the OLT-1, OLT-2 and OLT-3 indicate the GPON, HS-PON and XG-PON respectively.

**Table II.3 – 3-port Cex worked example parameters**

| Parameter | Value | Unit | Comment |
|---|---|---|---|
| Bit rate of OLT-1 | 1.24416 | Gb/s | GPON US line-rate (Note 1) |
| Bit rate of OLT-2 | 24.8832 | Gb/s | HS-PON US line-rate (Note 3) |
| Bit rate of OLT-3 | 2.48832 | Gb/s | XG-PON US line-rate (Note 2) |

## Table II.3 – 3-port Cex worked example parameters

| Parameter | Value | Unit | Comment |
|---|---|---|---|
| OLT-1 Rx sensitivity | –28.0 | dBm | min for B+ GPON OLT (Note 1) |
| OLT-2 Rx sensitivity | –27.4 (Note 5) | dBm | min for N1 HS-PON OLT (Note 3) |
| OLT-3 Rx sensitivity | –27.5 | dBm | min for N1 XG-PON OLT (Note 2) |
| Max OPL of OLT-1 port | 28.0 | dB | max ODN loss of B+ OPL class (Note 1) |
| Max OPL of OLT-2 port | 29.0 | dB | max ODN loss of N1 OPL class (Note 3) |
| Max OPL of OLT-3 port | 29.0 | dB | max ODN loss of N1 OPL class (Note 2) |
| Min OPL of OLT-1 port | 13.0 | dB | min ODN loss of B+ OPL class (Note 1) |
| Min OPL of OLT-2 port | 14.0 | dB | min ODN loss of N1 OPL class (Note 3) |
| Min OPL of OLT-3 port | 14.0 | dB | min ODN loss of N1 OPL class (Note 2) |
| Min Loss of OLT-1 port | 0.8 | dB | GPON port of Cex (Note 4) |
| Min Loss of OLT-2 port | 1.0 | dB | HS-PON port of Cex (Note 4) |
| Min Loss of OLT-3 port | 1.0 | dB | XG-PON port of Cex (Note 4) |
| Max Loss of OLT-1 port | 1.0 | dB | GPON port of Cex (Note 4) |
| Max Loss of OLT-2 port | 1.5 | dB | HS-PON port of Cex (Note 4) |
| Max Loss of OLT-3 port | 1.2 | dB | XG-PON port of Cex (Note 4) |
| Launch power max ONU (GPON) | 5.0 | dBm | Max for GPON ONU (Note 1) |
| Launch power max ONU (HS-PON) | 9.0 | dBm | Max for HS-PON ONU (Note 3) |
| Launch power max ONU (XG-PON) | 7.0 | dBm | Max for XG-PON ONU (Note 2) |

NOTE 1 – See [ITU-T G.984.2].
NOTE 2 – See [ITU-T G.987.2].
NOTE 3 – See [ITU-T G.9804.3].
NOTE 4 – Estimated values for the purpose of this worked example.
NOTE 5 – HS-PON ONU supports flexible Tx power and ER. The "ONU_Tx_min" value will be 3.1 dBm when ER is reasonably high as 20 dB and OP P=1.5 dB. In this case the "OLT Rx sensitivity" can be calculated as −27.4 dBm using ONU_Tx_min – OPPmax – OPLmax.

The equation for isolation (condition of uniform isolation) can be expressed in dB for a 3-port CEx as follows:

$$I_j(dB) = L_j(\lambda_i) = -OLT_{minRx,j}(dBm) - OPL_{max,j}(dB) + min\left[\left(OPL_{max,j}(dB) - L_{max,j}(\lambda_j)dB\right)_{j=1\ to\ 3}\right] - max\left[\left(OPL_{min,j}(dB) - L_{min,j}(\lambda_j)dB\right)_{j=1\ to\ 3}\right] + L_{max,j}(\lambda_j)\ dB - C_j(dB) + \sum_{i=1,(i\neq j)}^{3}\left(\frac{ONU_{maxTx,i}}{max\left[1,\frac{R_i}{R_j}\right]}\cdot\left(\frac{\rho_i}{\rho_j}\right)\right)$$

For HS-PON as the victim at port 2, the required isolation in dB is given as follows:

$$I_2(dB) = -(-27.4\ dBm) - 29\ dB + min[(28\ dB - 1\ dB),(29\ dB - 1.5\ dB),(29\ dB - 1.2\ dB)] - max[(13\ dB - 0.8\ dB),(14\ dB - 1\ dB),(14\ dB - 1\ dB)] + 1.5\ dB - (-8.98\ dB) + 10\log\left(\frac{10^{\frac{5}{10}}}{max\left[1,\left(\frac{1.24416}{24.8832}\right)\right]}\cdot 1 + \frac{10^{\frac{7}{10}}}{max\left[1,\left(\frac{2.48832}{24.8832}\right)\right]}\cdot 1\right)$$

$$I_2(dB) = 27.4\ dBm - 29\ dB + 27\ dB - 13\ dB + 1.5\ dB + 8.98\ dB + 9.12\ dBm = \mathbf{32.00\ dB}$$

In the case of directivity, the dB form of the equation is given as follows for this 3-port CEx example:

$$D_j(dB) = -OLT_{minRx,1}(dB) - OPL_{max,1}(dB) + min\left[\left(OPL_{max,j}\,(dB) - L_{max,j}(\lambda_j)dB\right)_{j=1\ to\ 3}\right] + L_{max,\mathrm{j}}(\lambda_j)\ dB - C_j(dB) + \sum_{i=1,(i\neq j)}^{3}\left(\frac{OLT_{maxTx,\mathrm{i}}}{max\left[1,\frac{R_i}{R_j}\right]}\cdot\left(\frac{\rho_i}{\rho_j}\right)\right)$$

For HS-PON at port 2, the required directivity in dB is given as follows:

$$D_2(dB) = -(-27.4\ dBm) - 29\ dB + min[(28\ dB - 1\ dB), (29\ dB - 1.5\ dB), (29\ dB - 1.2\ dB)] + 1.5\ dB - (-8.98\ dB) + 10\log\left(\frac{10^{\frac{5}{10}}}{max\left[1,\left(\frac{1.24416}{24.8832}\right)\right]}\cdot 1 + \frac{10^{\frac{6}{10}}}{max\left[1,\left(\frac{2.48832}{24.8832}\right)\right]}\cdot 1\right)$$

$$D_2(dB) = 27.4\ dBm - 29\ dB + 27\ dB + 1.5\ dB + 8.98\ dB + 8.54\ dBm = \mathbf{44.42\ dB}$$

# Appendix III

## Multi-PON module with integrated WDM

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

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 margins. 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 MPM. The MPM method can simplify the upgrade engineering and reduce the probability of manual operational error during migration.

An example reference diagram for the OLT MPM function is shown in Figure III.1.

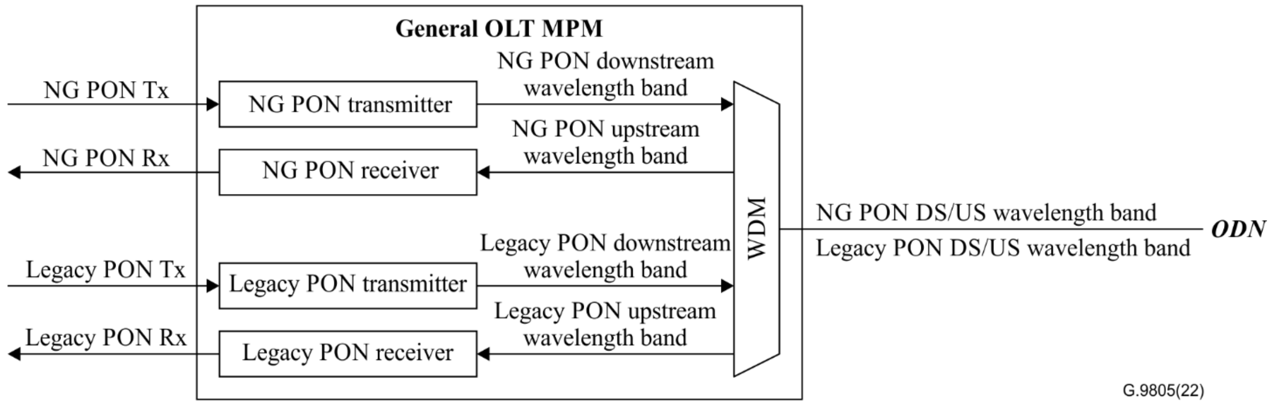


**Figure III.1 – Example reference diagram for OLT MPM with integrated WDM**

An example reference diagram of G-PON/XG-PON OLT MPM with integrated WDM is shown in Figure III.2.

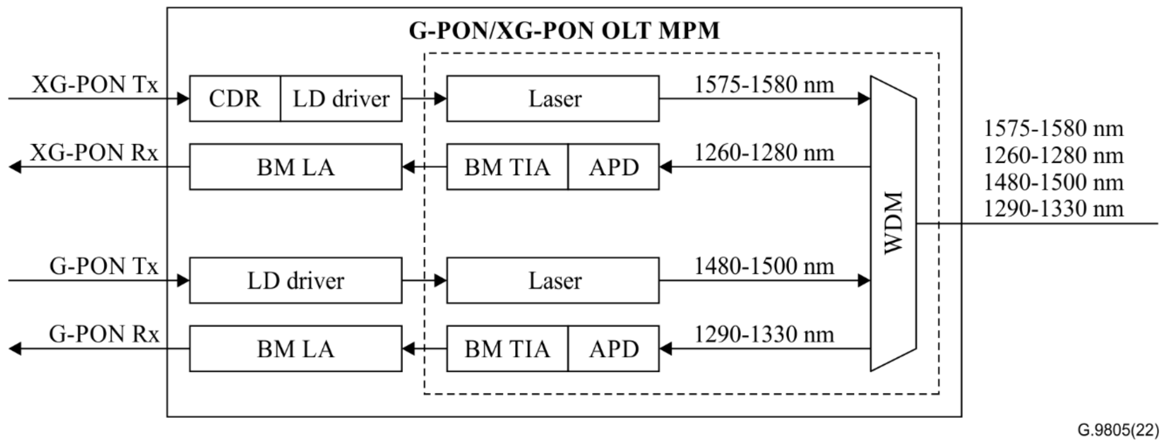


**Figure III.2 – Reference diagram of G-PON/XG-PON OLT MPM with integrated WDM**

By employing G-PON/XG-PON OLT MPM in the migration scenario, G-PON 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 G-PON shown in Figure III.2.

An example reference diagram of G-PON/XG-PON OLT MPM with dual-rate receiver and triplexer optical sub-assembly (OSA) is shown in Figure III.3. The triplexer OSA is used to simplify the components assembly to make it easier and more compact. One G-PON transmitter, one XG-PON transmitter and one G-PON/XG-PON dual rate receiver are connected to the WDM (G-PON and XG-PON share one receiver).

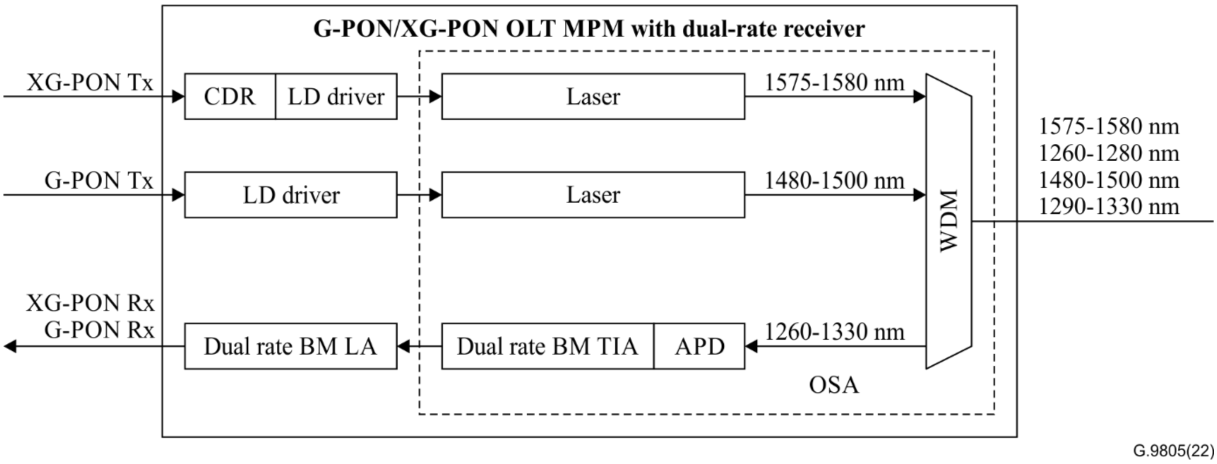


**Figure III.3 – Reference diagram of G-PON/XG-PON OLT MPM with dual-rate receiver and WDM**

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

An example reference diagram of G-PON/XG-PON/XGS-PON OLT MPM with WDM is shown in Figure III.4. The WDM is used to support all three types of ONU on the same ODN. The G-PON transmitter and receiver, XGS-PON transmitter and dual rate receiver (also supporting XG-PON ONUs) are connected to the internal WDM.

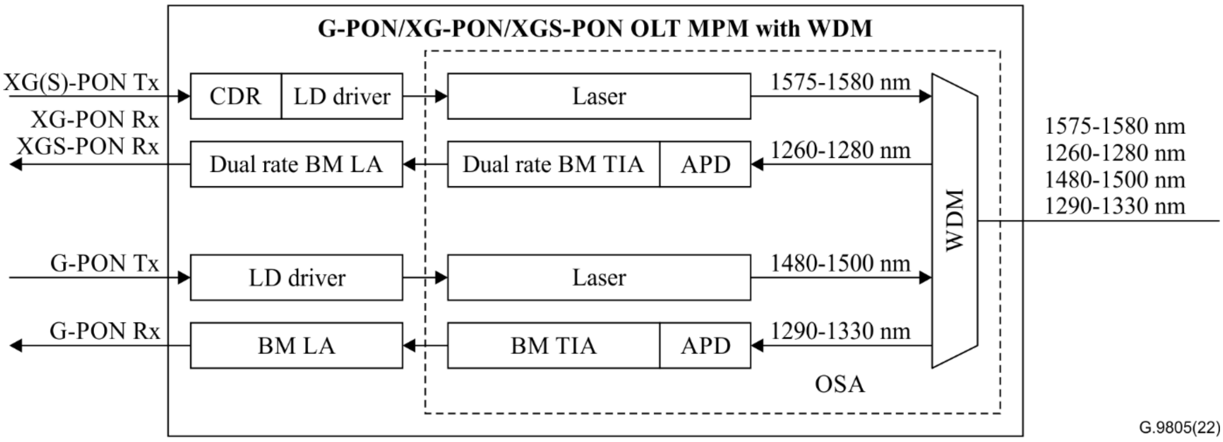


**Figure III.4 – Reference diagram of G-PON/XG-PON/XGS-PON OLT MPM with WDM**

The PMD requirements for the optical interface should ensure that the legacy G-PON, 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 G-PON/XG-PON/XGS-PON OLT MPM with triple-rate receiver is shown in Figure III.5. The OSA is used to make the components assembly easier and more compact. One G-PON transmitter, one XG-PON/XGS-PON transmitter, and one G-PON/XG-PON/XGS-PON triple rate receiver are connected to the WDM inside the OSA (GPON/XG-PON/XGS-PON share one receiver).

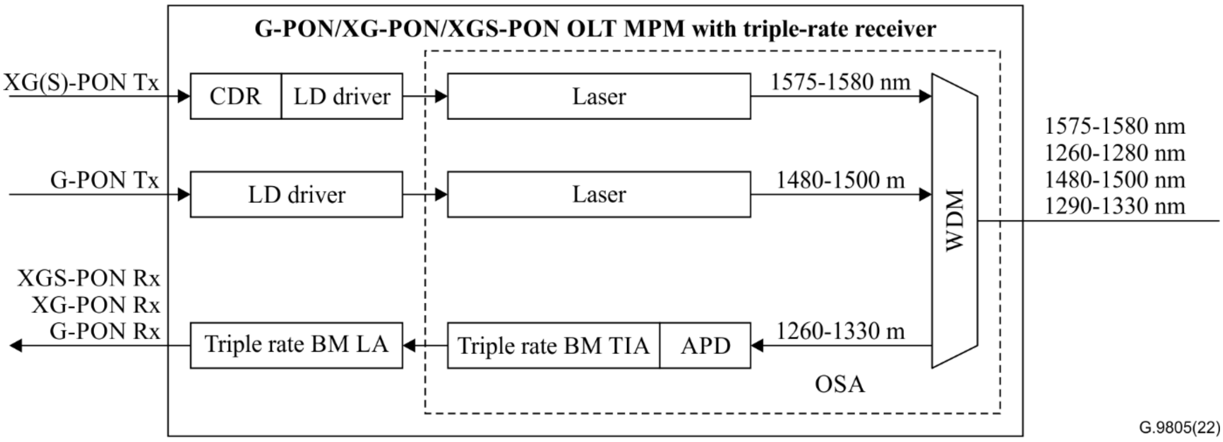


**Figure III.5 – Reference diagram of G-PON/XG-PON/XGS-PON OLT MPM with triple-rate receiver**

The PMD requirements for the ODN optical interface should ensure that the legacy G-PON, 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 G-PON/XGS-PON receiver.

One advantage of a single Rx MPM configuration is a reduction in the number of components. It also 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 G-PON 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 G-PON DBA and the XG(S)-PON DBA engines to construct each respective BWmap.

A 3-generation coexistence example reference diagram for the OLT MPM function is shown in Figure III.6. Note the PONa and PONb indicate the legacy PON from two different generations (e.g., GPON and XG-PON.

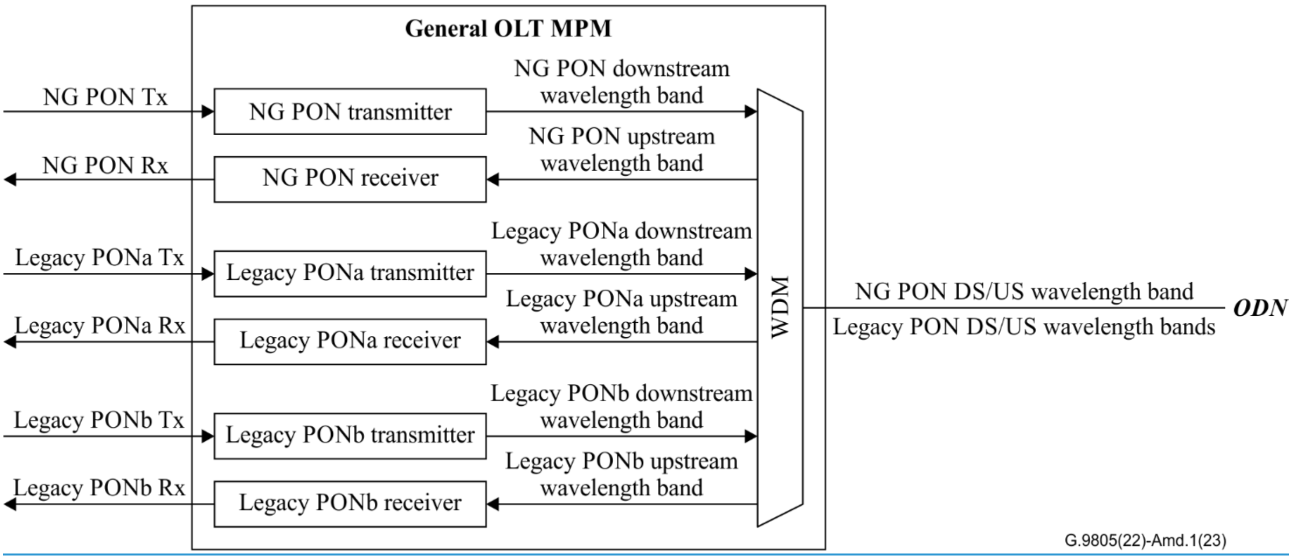


**Figure III.6 – Example reference diagram for 3-generation coexistence OLT MPM with integrated WDM**

According to the operating wavelength for 3-generation coexistence, an example reference diagram for common GPON/XG(S)-PON/50G PON OLT MPM with integrated WDM is shown in Figure III.7. The WDM is used to support all three types of ONU on the same ODN. The PMD requirements for optical interface should ensure that the legacy GPON and XG(S)-PON ONUs can work on the legacy ODN.

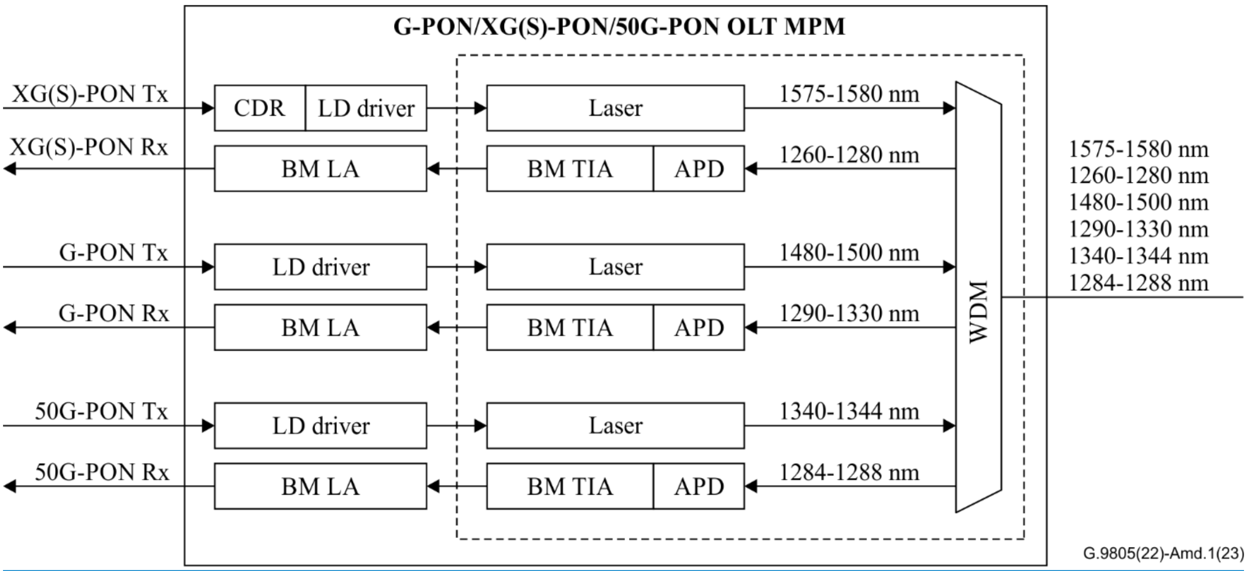


**Figure III.7 – Reference diagram of GPON/XG(S)-PON/50G PON OLT MPM**

# Appendix IV

## Filter considerations for XG(S)-PON OLT and HSP OLT

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

The minimum optical sensitivity requirements of a XG(S)-PON OLT or HSP OLT must be met in the presence of the interference signals caused by coexisting PON system and/or video signals. To minimize the effect of interference signals, XG(S)-PON OLT or HSP OLT need to isolate interference signals using an appropriate WBF and WDM filter. Figure IV.1 shows the optical reference diagram for XG(S)-PON and HSP.

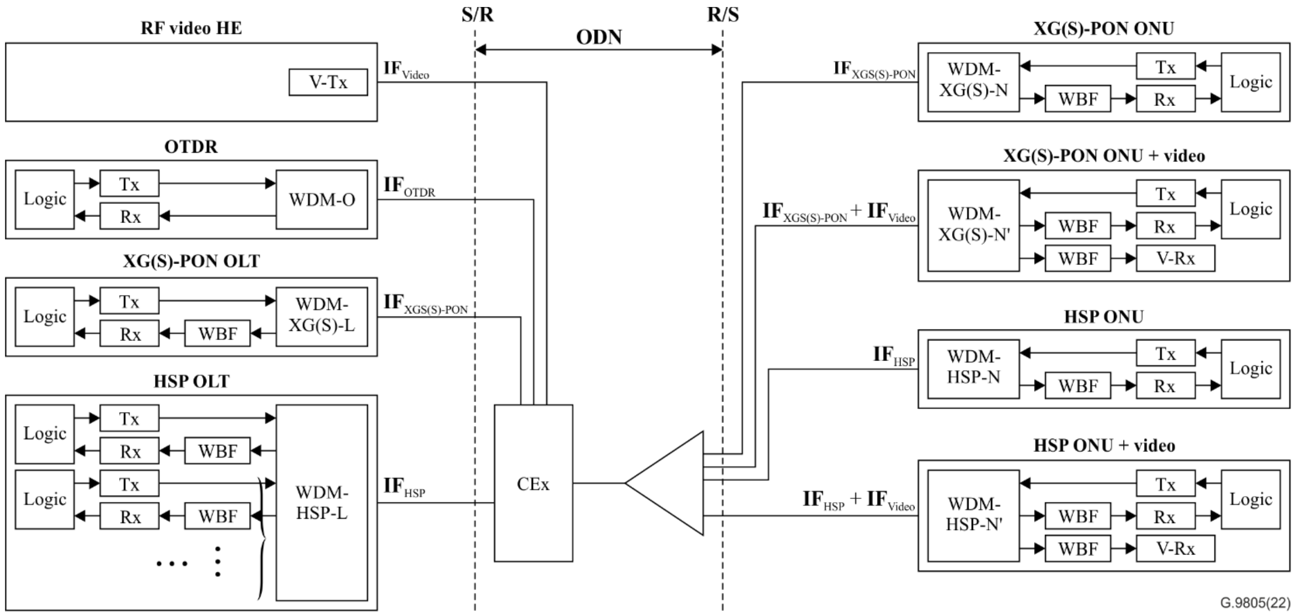


**Figure IV.1 – Optical reference diagram for XG(S)-PON and HSP**

The following abbreviations are used in Figure IV.1:

| | |
|---|---|
| CEx | Coexistence element, be used to combine/isolate the wavelengths of XG(S)-PON and HSP 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-XG(S)-L | WDM filter in XG(S)-PON OLT to combine/isolate the wavelengths of XG(S)-PON upstream and downstream |
| WDM-XG(S)-N | WDM filter in XG(S)-PON ONU to combine/isolate the wavelengths of XG(S)-PON upstream and downstream |
| WDM-XG(S)-N' | WDM filter in XG(S)-PON ONU to combine/isolate the wavelengths of XG(S)-PON upstream and downstream and isolate the video signal(s) |

| | |
|---|---|
| WDM-HSP-L | WDM filter in HSP OLT to combine/isolate the wavelengths of HSP upstream and downstream |
| WDM-HSP-N | WDM filter in HSP ONU to combine/isolate the wavelengths of HSP upstream and downstream |
| WDM-HSP-N' | WDM filter in HSP ONU to combine/isolate the wavelengths of HSP upstream and downstream and isolate the video signal(s) |
| WDM-HSP-O | WDM filter in HSP OLT to combine/isolate the wavelengths of HSP upstream and downstream. |

# Appendix V

## Crosstalk between PON systems

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

In case of coexistence of multiple PON systems on a single ODN, the equipment and the deployment should be designed such that both systems can operate without interference or disturbance. However, it has been found that there are situations where equipment that is fully compliant to the relevant Recommendations needs special care to coexist on the same ODN. This appendix provides guidance and describes techniques for how to mitigate the effect of crosstalk to facilitate the coexistence between two or more PON systems on the same ODN.

### V.1 Crosstalk between coexisting PON system

There are three types of possible crosstalk between coexisting PON systems: in-band crosstalk, nonlinear effects, and out-of-band (OOB) crosstalk. In-band crosstalk refers to the imperfect filtering of the coexistence element or blocking filter. There are specifications for the X/S that each system must tolerate, and if these specifications are met there should be no penalty. However, in the case of the OLT-side of the network, the necessary isolation is typically met through the combination of the CE and the OLT blocking filter. If these components are not correctly co-engineered, there can be an issue.

Nonlinear effects are the interactions between the PON signals that occur on the fibre, especially stimulated Raman scattering. These effects have been well known and partial allowance for them have been made in the [b-ITU-T G.989.2] PMD specifications (the self-induced Raman depletion becomes part of the OPP). Of course, Raman interactions between coexisting systems must be accounted for separately when engineering the system. Coexisting RF video overlay signals are particularly sensitive to Raman crosstalk. More information on possible remediation methods can be found in Appendix VI and Appendix IX of [b-ITU-T G.989.2].

In a coexistence scenario, it is important that both systems limit the generated OOB noise PSD at the operating wavelength band of the other system. Various PON Recommendations use different ways to specify the limit of the OOB noise. Some systems like NG-PON2 [b-ITU-T G.989.2] limit the OOB power spectral density of the transmitter, while other Recommendations, e.g., XGS-PON [ITU-T G.9807.1], specify the side mode suppression ratio (SMSR), which is defined as the ratio of the power of the largest peak of the transmitter spectrum to that of the second largest peak. The second largest peak may be next to the main peak or far away from it. In fact, the SMSR was never intended to protect against OOB crosstalk, and so this may lead to situations where the performance of another PON system operating in the same ODN is compromised.

The following example illustrates a hypothetical coexistence issue between an XGS-PON [ITU-T G.9807.1] and a GPON system [b-ITU-T G.984.3] in upstream direction. Without any relation to existing equipment, the following parameters for the XGS-PON and GPON equipment are assumed:

– XGS-PON ONU mean launch power: $P_{XGS-PON} = +7$ dBm (required range: +4 dBm to +9 dBm, see Table B.9.4 of [ITU-T G.9807.1])

– GPON ONU mean launch power: $P_{GPON} = +1.5$ dBm (required range for a B+ ODN class: 0.5 to 5 dBm, see Table A.1 of [ITU-T G.984.2])

– $\Delta ODN = 8$ dB differential ODN loss (PON recommendations allow 15 dB, see e.g., Table B.9.2 [ITU-T G.9807.1]): XGS-PON branch IL= 20 dB, GPON branch IL=28 dB.

For such case, the minimum side mode suppression ratio $SMSR_{min} = 30$ dB of XGS-PON, see [ITU T G.9807.1], can only guarantee an OSNR of

$$OSNR_{min} = P_{GPON} - \Delta ODN - (P_{XGS-PON} - SMSR_{min}) \quad \text{(V-1)}$$

$$OSNR_{min} = 1.5\ \text{dBm} - 8\ \text{dB} - (7\ \text{dBm} - 30\ \text{dB}) = 16.5\ \text{dB} \quad \text{(V-2)}$$

for the GPON upstream signal at the OLT. This will result in a significant power penalty to the GPON system.

## V.2 Preventing crosstalk

The best solution for crosstalk is to prevent it from becoming an issue in the first place. This can be done by designing the ODN to reduce the crosstalk effects or allow for crosstalk. Alternatively, the PON devices can comply with the necessary OOB requirements.

### V.2.1 ODN engineering (loss range or margin)

One way to resolve the issue described above is to limit the maximum differential ODN loss in a coexistence scenario:

$$\Delta ODN \leq P_{min,vic} - OSNR_{min} - \text{RxBW}_{vic} * P_{OOB,int} \quad \text{(V-3)}$$

$P_{vic}$: ONU minimum mean launch power in dBm of the victim system.

$OSNR_{min}$: Minimum OSNR in dB that should be guaranteed for the victim system.

$\text{Rx}BW_{vic}$: The optical bandwidth of the victim system receiver

$P_{OOB,int}$: ONU OOB noise in dBm/0.1 nm of the interferer ONU at the wavelength band of the victim system. This should be the maximum for the deployed interferer ONUs.

$\Delta ODN$: ODN loss difference in dB for the victim signal (maximum) and the interferer signal (minimum).

As a variation of the example given above, assume that XGS-PON ONUs are deployed which limit the OOB noise in the GPON upstream wavelength band to $P_{OOB,int} = -46.5\ \text{dBm/0.1 nm}$. Furthermore, assume that $OSNR_{min} = 20\ \text{dB}$ is needed to limit the penalty of the GPON system to a negligible value, and that the G-PON receiver has a bandwidth of 20 nm. With those assumptions the differential ODN loss should be limited to

$$\Delta ODN \leq 1.5\ \text{dBm} - 20\ \text{dB} - (-46.5 + 23\ \text{dBm}) = 5\ \text{dB} \quad \text{(V-4)}$$

An alternative method of reducing the OOB noise is to reduce the receiver bandwidth. Some G-PON OLT Rx bandwidths are excessively broad and can be reduced without impact to the desired signal. This can be done by installing a blocking filter on the OLT CT ports or improving the coexistence element.

Generally speaking, any PON deployment will be planned and engineered with some margin for reliable operation and to allow for increased link losses over the system life, for example, from cable repairs. In a coexistence scenario, penalties that may occur from OOB noise can be accommodated by:

- the existing margin in a deployed system;
- reengineering an existing link by, for example, cleaning connectors, replacing connectors with splices or removing any lossy fibre bends;
- an increased margin allowance in the design of a new deployment.

In all deployment scenarios, it will help to have a knowledge of the minimum OSNR required to achieve a particular penalty. The minimum upstream OSNR of a GPON system co-existing with XG(S)-PON will be given by equation V-5.

$$OSNR_{min} = P_{GPON} - \Delta ODN - P_{OOB,int} \quad \text{(V-5)}$$

The target for the system designer will then be to ensure that the penalty induced by the $OSNR_{min}$ in equation V-5 is within the total system margin considering all the other required margins included in the ODN design.

### V.2.2 ONU OOB emission specification

As outlined above, the treatment of OOB emission is different in different PON systems. From the ITU-T G.989 series onward, there were clear specifications of maximum OOB power spectral density from the start. However, earlier systems only had SMSR specifications, and these were intended to guard against mode partition noise impairment of the transmitted signal. SMSR has nothing to do with limiting OOB for coexistence, and it has been demonstrated that SMSR is inadequate to guard against crosstalk. To be clear, this was a missing specification in ITU-T G.984 and ITU-T G.987 series.

Later amendments to ITU-T G.987.2 and ITU-T G.9807 have added the necessary OOB power spectral density limitations. However, since they were added years after the initial consent of the base documents, there may still be ONUs that exceed the OOB specification. Given the widespread adoption of coexisting G-PON and XG(S)-PON, the crosstalk has been an infrequent occurrence, but still one that presents operational difficulties and must be addressed. Clauses V.3 and V.4 outline how to find crosstalk and how to ameliorate it.

## V.3 Detecting crosstalk

As a preliminary, optical crosstalk must be recognized as only one or several possible impairments. When presented with a faulty ONU connection, the operator must analyse the fault to determine what is the root cause. For example, the trouble could be in the ONU hardware, or in its configuration, or the fibre connection to that ONU, or a rogue ONU in that same PON system, or crosstalk between PON systems. A combination of historical and current data collection along with field measurements and corrective actions can lead to the correct diagnosis of the trouble.

Although the proportion is relatively small, crosstalk has been observed where XG(S)-PON ONUs interfere with GPON ONUs in the deployed network. It was found that the initial GPON faults were resolved after isolating or replacing these XG(S)-PON ONUs. Most of these issues are sporadic and intermittent, which can make locating and analysing the root cause to be time-consuming. There are two possible methods for crosstalk detection. The first is to make field measurements using optical instrumentation. The second is to use the measurement capabilities of the OLTs themselves.

### V.3.1 Field measurements

In the current network environment, when GPON and XG(S)-PON coexist by MPM, the measurement can be done at either the user side or the central office side. When measuring on the user side, a splitter can be installed at the drop fibre segment to which the suspected XG(S)-PON ONU is attached (assuming there is sufficient OPL margin, and the splitter can be a non-equal splitting ratio, e.g., 90% in the main branch and 10% in the side branch, shown in Figure V.1a), and an optical spectrum analyser (OSA) can be used to measure the spectrum of the optical signal output by the ONU to determine if there is a strong side lobe around 1300 nm. When measuring on the central office side, as shown in Figure V.1b, a WDM demultiplexer could be installed right before the OLT optical module, and all GPON ONUs should be controlled not to transmit in the upstream direction. The 1310 nm port is connected with an OSA to observe the side lobe around 1310 nm which comes from the suspected XG-PON ONU upstream optical signal. In this case, the live services of XG(S)-PON will not be affected.

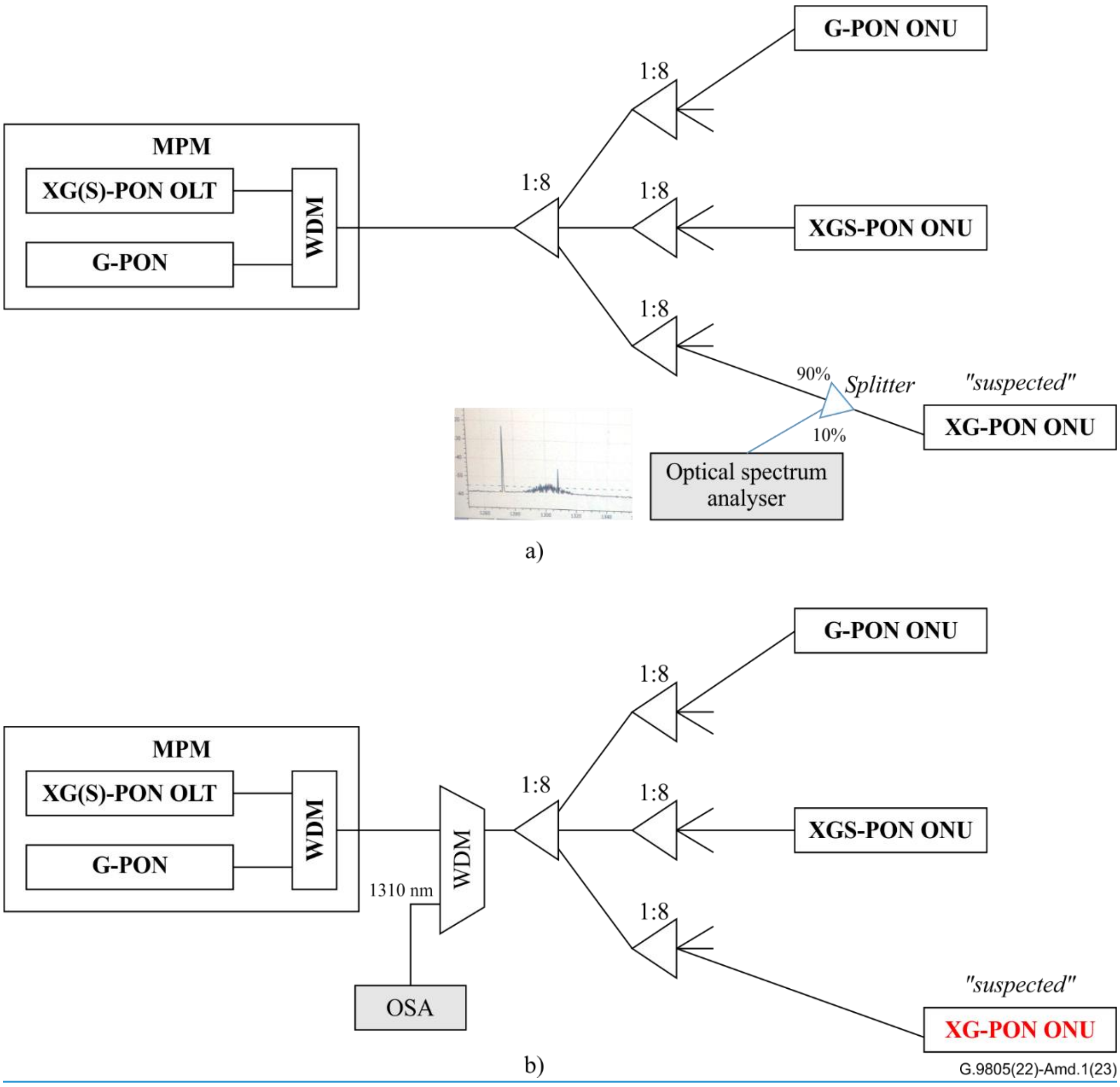


**Figure V.1 – Field measurement for the XG(S)-PON ONU with a strong side lobe around 1300 nm in MPM coexistence cases at (a) user side (b) central office side**

For the links that GPON and XG(S)-PON coexist by external CEx, measurements can be performed on the user side or central office side. When measuring on the user side, the method is exactly the same as the MPM case, shown in Figure V.2a. When measuring on the central office side, an OSA may be attached to the GPON OLT port of external Cex to accomplish the detection, as shown in Figure V.2b. In this case, the live stream of XG(S)-PON will not be disconnected while all GPON ONUs should be controlled not to transmit in the upstream direction.

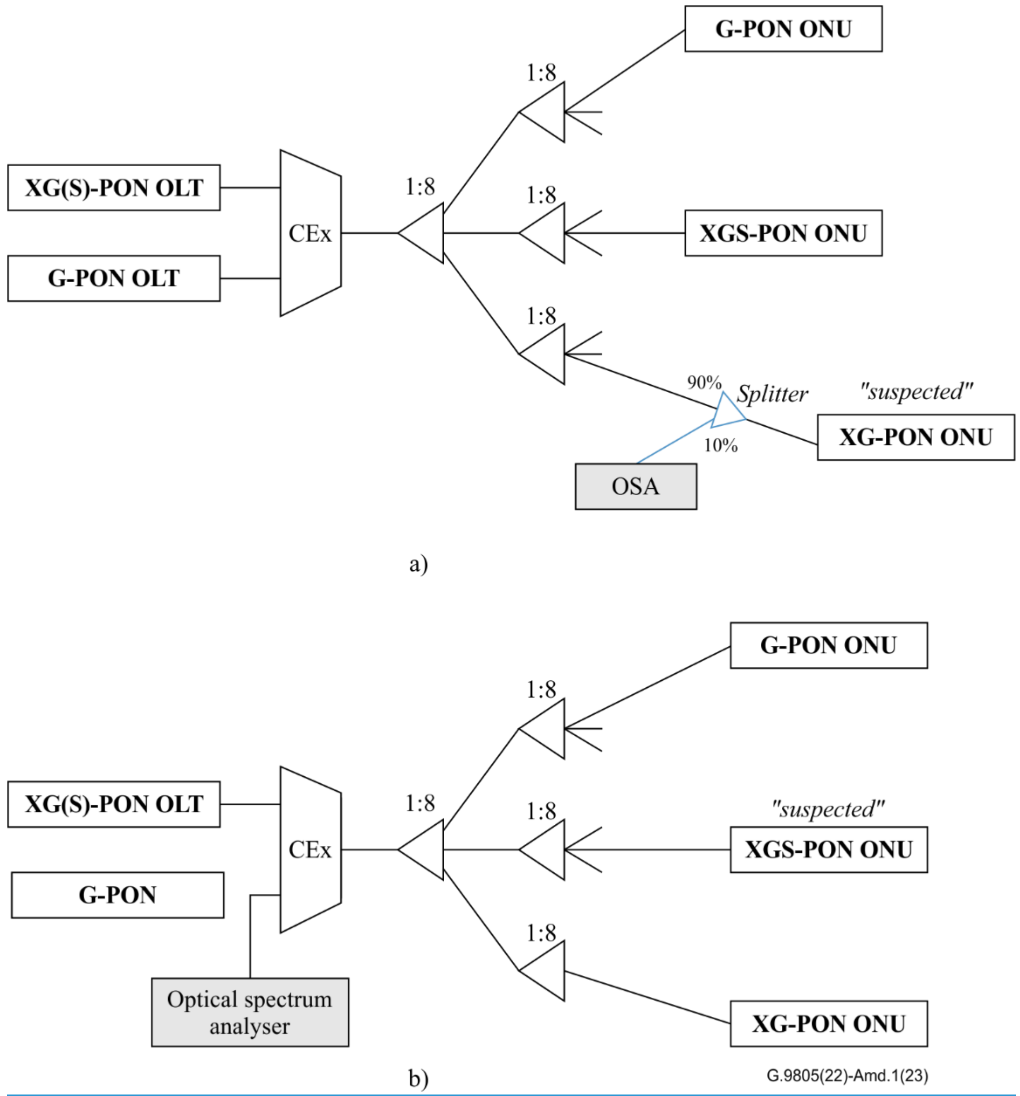


**Figure V.2 – Field Measurement for the XG(S)-PON ONU with a strong side lobe around 1300 nm in external Cex coexistence cases at (a) user side (b) central office side**

### V.3.2 Measurement of correlated errors

All PON systems have received error counting capabilities. These can be used to detect and diagnose instances of crosstalk. The error counts in the victim system (assumed to have N ONUs) need to be correlated to the transmission schedule of the interfering system (assumed to have M ONUs). This can be illustrated in the form of a BER matrix as shown in Table V.1. In this matrix, each row contains the bit error rates measured for a particular victim ONU, and each column contains the bit error rates for a particular interferer ONU transmitting. Organizing the data in this way allows us to identify which combinations of victim and interferer are generating excessive errors. This is obviously useful in diagnosis and also for performing targeted effective remediation.

**Table V.1 – The victim system errors correlated to the interferer transmission**

| | X | X | X | X | X | X | X | X |
|---|---|---|---|---|---|---|---|---|
| G 1 | 1 | 1 | 2 | 7 | 1 | 4 | 0 | 0 |
| G 2 | 8 | 3 | 6 | 4 | 9 | 3 | 0 | 0 |

**Table V.1 – The victim system errors correlated to the interferer transmission**

| | X | X | X | X | X | X | X | X |
|---|---|---|---|---|---|---|---|---|
| G 3 | 6 | 7 | 3 | 7 | 5 | 1 | 2 | 7e- |
| G 4 | 8 | 3 | 7 | 1 | 2 | 3 | 3 | 0 |
| G 5 | 1 | 2 | 7 | 3 | 6 | 1 | 1 | 2e- |
| G 6 | 3 | 6 | 1 | 8 | 3 | 7 | 3 | 6e- |

One issue that arises in doing this correlated error counting is that the two PON systems need to share a great deal of information (such as the bandwidth maps). This data is not normally exposed, and typical OLTs do not have the facilities to do so easily. An illustration of this is given in Figure V.3, where two OLT CTs are interconnected so that they can be correlated and coordinated. Note that the figure indicates the superset of all the possible interconnection data (bandwidth allocations, error data, Received Signal Strength Indication (RSSI), and DBA requests. The specific algorithm used for crosstalk mitigation will determine which of these are needed. In an exemplary implementation, each PON MAC will need to send its error detection and RSSI data and the DBA requests that it receives to a common processing entity. That entity would do the necessary correlations between this data to attempt to determine the BER matrix entities. In addition, the timing of the two PON systems framing would have to be connected, either by forcing both OLTs to align their framing, or by determining what timing offset exists between the two systems. All of these interactions are made easier if the two PON systems are on the same line card or even better the same MPM. This is also similar to the TDMA coexistence method (see Appendix III).

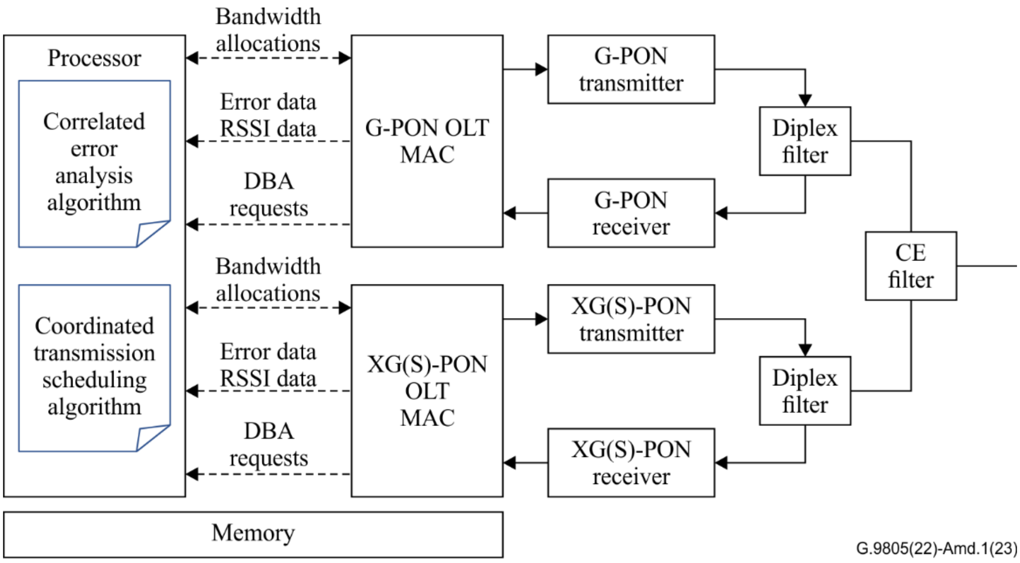


**Figure V.3 – Coordinating two coexisting OLT ports**

It is unlikely that the error data can be collected on an allocation by allocation basis, and so the algorithm must process error data collected on a much longer time scale (perhaps 1 second). For any error data collection, the correlation process can determine the fraction of overlap that a particular victim ONU had with each interferer ONU by considering the bandwidth maps. Then a statistical regression can be performed to estimate the error rate matrix entries. This method has the advantage that each OLT's DBA algorithm can operate independently, but the data obtained is randomized, and the regression analysis may take a long time.

One scheme that could avoid high speed signalling is to develop diagnostic modes for the DBA processes in the OLT CTs. A simple example would be to have the interferer OLT CT suppress transmission from some of its ONUs, and then observe the resulting errors on the G-PON system. This is reminiscent of a method to diagnose rogue ONU issues, as outlined in [b-ITU-T G-Sup.39].

The OLT CTs also can measure the received signal strength indication of each ONU. This gives a very direct way to estimate the crosstalk level at the OLT. Assuming the OOB emission from the typical interferer ONU is proportional to its launch power, then the OOB noise at the OLT receiver will be proportional to the RSSI of that interferer.

$$P_{OOB,int} \approx C_{OOB} \cdot P_{RSSI,int} \qquad \text{(V-6)}$$

The optical SNR ($OSNR$) due to a specific interferer noise for a victim upstream reception can be calculated as:

$$OSNR_{vic} = P_{RSSI,vic} - C_{OOB} \cdot P_{RSSI,int} \qquad \text{(V-7)}$$

The $OSNR_{vic}$ can be functionally related to the BER of that victim:

$$BER_{vic} = F(OSNR_{vic}) \qquad \text{(V-8)}$$

The function F is going to be similar to the erf() function, scaled such that at high OSNR the BER tends to zero, while at low OSNR the BER tends to 0.5. Using this approximation, the BER matrix (NxM elements) can be estimated from the N victim and M interferer RSSI measurements, which is obviously much easier to do. Of course, there are assumptions in this approximation, and so the results are not necessarily the most accurate.

## V.4 Managing crosstalk

Once an instance of crosstalk has been found, methods are needed to manage the crosstalk in some way. This could be a method to eliminate it, or a method that makes it less disruptive to the system. Some may involve field personnel going to the ONUs in question and performing an action, while some can be implemented by OLT configuration changes.

### V.4.1 ONU replacement

This method of managing crosstalk is unique because it does not require the exact diagnosis of whether or not there is crosstalk or even the location of the interfering ONU. In this scenario, XG(S)-PON ONUs share the same ODN as GPON ONUs, and an operator observes that upstream transmission from a GPON ONU becomes unstable (while there is normal operation on XG(S)-PON ONUs). For example, missing bursts or errored frames are observed, or customer complaints are received. A potential cause is a defective GPON ONU. Replacing that GPON ONU with another GPON ONU may solve the problem. However, if the cause is OOB crosstalk from one or more XG(S)-PON ONUs, this very likely will not solve the problem. One solution that solves both causes is to replace the GPON ONU with an XG(S)-PON ONU and to provide service to that customer via the XG(S)-PON system. This requires some level of coordination between both systems, e.g., managed by the same network operator. Attempting to troubleshoot the cause, that is, to distinguish between a failed GPON ONU and XG(S)-PON OOB interference, would likely be more complex and expensive than exchanging the ONU. So, while this method may turn out to replace a G-PON ONU that is perfectly OK, it may be the most cost effective and expeditious method.

### V.4.2 In-line filters /attenuators

In coexistence scenarios where it is expected that an ONU added to an ODN is likely to cause (or is causing) interference to deployed GPON ONUs in the upstream, then devices may be added to the ONU fibre output to control this.

As the OOB light that causes the interference is in the GPON wavelength band, it is possible to insert a filter element between the interferer ONU and the ODN. For example, a pluggable or patch-cord type of device with a blocking band in the 1290 nm –1330 nm wavelength range could be used. Take

GPON and XG-PON ONT coexistence as an example, when there is an XG-PON ONT with high OOB power emitting in the GPON upstream wavelength band. Here, a band blocking filter in the GPON upstream band but transparent to the XG-PON downstream/upstream signals can be inserted at the optical interface to the high OOB XG-PON ONT to mitigate the crosstalk on GPON ONT, as shown in Figure V.4.

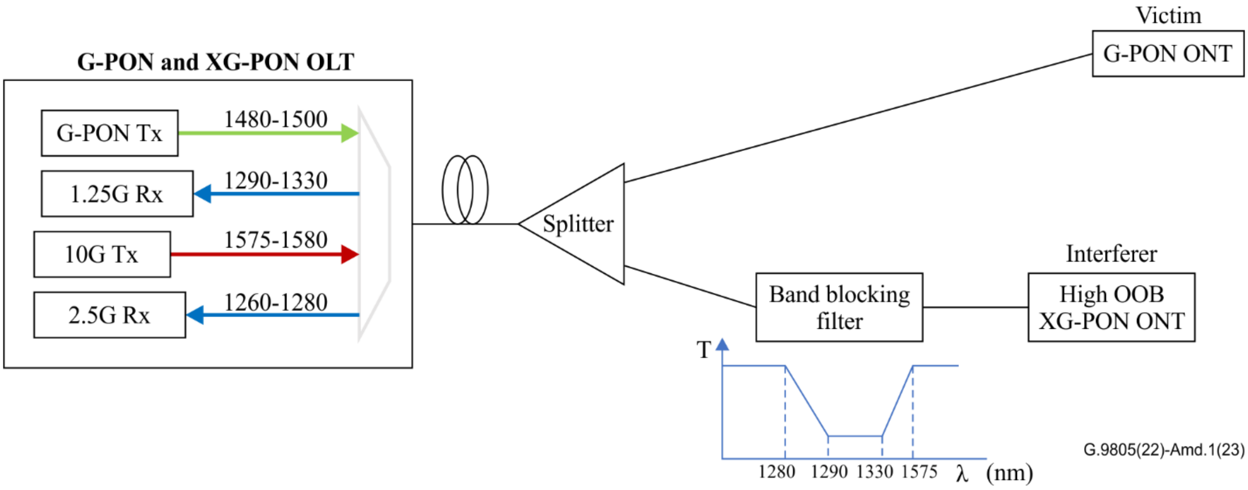


**Figure V.4 – OOB crosstalk mitigation method by inserting a band blocking filter at the interferer ONT optical interface**

The amount of rejection needed may be given by the following equation:

$$OSNR_{min} = P_{GPON} - \Delta ODN - P_{OOB,int} + R_{filter} \quad \text{(V-9)}$$

whereby, the filter rejection in dB, $R_{filter}$ is adjusted to ensure the required $OSNR_{min}$ is achieved.

Alternatively, if the interferer ONU is on a low loss ODN path, then the interfering power from that ONU can be reduced by the use of an attenuator at the ONU fibre output. This attenuation should be high enough to sufficiently reduce the OOB power in the GPON band but low enough to ensure that the maximum optical budget class loss is not exceeded.

Similarly, the attenuation required $L_{atten}$, may be derived from the required $OSNR_{min}$ as follows:

$$OSNR_{min} = P_{GPON} - \Delta ODN - P_{OOB,int} + L_{atten} \quad \text{(V-10)}$$

### V.4.3 Activate FEC on victim system

In coexistence scenarios where FEC (forward error correction) is not enabled for the victim system e.g., for the GPON B+ optical path loss class, it is possible to effectively add margin to the victim system by enabling FEC. By allowing the link to work at higher BER (e.g., pre-FEC, $10^{-4}$) the Rx sensitivity is in effect improved compared to working at $10^{-10}$ BER. The increase in system margin will be given by the difference between these two Rx sensitivities. However, this difference is something that is typically not defined in PON standards, but it may be known to the system vendor and/or operator from previous testing. As such, FEC activation may be used as a simple and opportunistic mitigation to OOB crosstalk penalty, or it may be implemented as part of a network planning and design process. It should be remembered that, enabling FEC will use a portion of the upstream data capacity to carry the FEC parity bits.

### V.4.4 Coordinated DBA scheduling

In a typical system, not all combinations of victim and interferer ONUs exhibit crosstalk. This opens the possibility to use coordinated transmission to avoid combinations of ONUs that cause penalty to the upstream reception of the victim system.

To accomplish this, the transmission of victim and interferer ONUs should be coordinated. For example, the transmission of an interferer ONU with a low ODN loss and a victim ONU with a high ODN loss should be scheduled to different intervals. It should be noted that simultaneous transmission is not an issue in case the differential loss does not exceed a certain threshold or the OOB noise in victim upstream wavelength band is low enough.

The only point in time when the OLT does not know the identification and/or properties of the transmitting ONU is during the serial number acquisition/ONU discovery phase and ranging phase. These phases are rather short and occur only during the activation of the ONU. The OLT may not grant any upstream transmission to interferer ONUs during the grants for serial number acquisition and ranging of victim ONUs. These periods of silence can be used by the transceiver to measure the OOB crosstalk from the other system at the OLT.

Assuming that the OLT systems will have estimated the BER matrix of the system, they can adjust their DBA behaviour to avoid the victim-interferer combinations that exceed the BER threshold. This can be visualized in a three-step process. The first step towards this is recognizing that the matrix can be transformed by exchanging either rows or columns without changing its meaning. In other words, the number order of the ONUs is an arbitrary choice, and we can interchange them freely. These transformations can be used to move all the troublesome combinations of ONUs to one corner of the matrix. In Table V.2, all the troubled combinations are coloured red, and they are concentrated in the upper right-hand corner of the matrix.

It should be noted that if the RSSI-derivation of the BER matrix is reasonably accurate, then the transformation of the matrix can be accomplished simply by sorting the RSSI values in ascending order for both the XG-PON and G-PON ONUs. This should work to move all the troubled combinations to the upper right corner of the matrix. Alternatively, one can sort both sets of ONUs in descending order, which should concentrate all the troubled combinations in the lower left corner of the matrix. Either way will tend to clear the diagonal of the matrix, which should then reduce the chances of crosstalk. Interestingly, the perverse sorting where one PON is ascending order and one PON is descending order will concentrate the errors in the upper left or lower right corners, and this will accentuate the crosstalk. This could have applications in crosstalk detection.

**Table V.2 – BER matrix reorganized such that the bad combinations are concentrated**

| | | **XG 3** | **XG 6** | **XG 8** | **XG 7** | **XG 2** | **XG 4** | **XG 5** | **XG 1** |
|---|---|---|---|---|---|---|---|---|---|
| | RSSI values | –26 | –24 | –23.5 | –20.5 | –18 | –17 | –14 | –14 |
| G 3 | –30 | 3e-4 | 1e-5 | 7e-6 | 2e-5 | 7e-4 | 7e-5 | 5e-3 | 6e-3 |
| G 2 | –29.5 | 6e-5 | 3e-6 | 0 | 0 | 3e-4 | 4e-4 | 9e-3 | 8e-3 |
| G 1 | –29 | 2e-4 | 4e-7 | 0 | 0 | 1e-5 | 7e-4 | 1e-2 | 1e-2 |
| G 4 | –26 | 7e-5 | 3e-4 | 0 | 3e-6 | 3e-4 | 1e-5 | 2e-4 | 8e-4 |
| G 5 | –20 | 7e-4 | 1e-4 | 2e-6 | 1e-5 | 2e-4 | 3e-4 | 6e-5 | 1e-5 |
| G 6 | –15 | 1e-4 | 7e-6 | 6e-5 | 3e-5 | 6e-5 | 8e-5 | 3e-4 | 3e-4 |

The second step is to perform the normal DBA process for both PON systems. The first iteration would be for each PON system to schedule its ONUs according to their bandwidth requests, but in the transformed matrix order. The result of the first iteration can be represented as a parametric curve (the red series of arrows in Table V.3). Each arrow represents the transmission changing from one ONU to the next. In this example, most of the combinations are operational; however, the combination of G-PON 1 and XG-PON 4 will cause errors. This is the result of the matrix transformation, since the DBA curve will run largely along the diagonal of the matrix and avoid all the troubled cells in the corner.

**Table V.3 – Cooperative DBA process in progress**

| | | XG 3 | XG 6 | XG 8 | XG 7 | XG 2 | XG 4 | XG 5 | XG 1 |
|---|---|---|---|---|---|---|---|---|---|
| | RSSI | -26 | -24 | -23.5 | -20.5 | -18 | -17 | -14 | -14 |
| G 3 | -30 | | | | | Error | | Error | Error |
| G 2 | -29.5 | | | | | | | Error | Error |
| G 1 | -29 | | | | | T1 | Error | Error | Error |
| G 4 | -26 | | | | | | T2 | | Error |
| G 5 | -20 | | | | | | | | |
| G 6 | -15 | | | | | | | | |

Once the problematic schedule entries are identified, the third step is to determine a way to avoid them. There are many different algorithms that could be devised; however, they all must balance the avoidance of errors with the fairness of the DBA algorithm. An extreme example would be to just suppress the transmissions of the victim ONUs so that they avoid the problem, or suppress the interferer ONUs so they do not create the problem. This is most unfair to either party; however, given the dynamic nature of the DBA process, it is unlikely that the same problem happens every time. The performance of the algorithm will also depend greatly on the number of errored combinations. If there are a moderate number of "red cells" in the matrix, then many simple methods will work. If there are too many red cells, then the scheduling problem becomes over-constrained, and more advanced methods would likely be required.

## Bibliography

[b-ITU-T G.984.3] Recommendation ITU-T G.984.3 (2014), *Gigabit-capable passive optical networks (G-PON): Transmission convergence layer specification*.

[b-ITU-T G.984.5] Recommendation ITU-T G.984.5 (2022), *Gigabit-capable passive optical networks (G-PON): Enhancement band.*

[b-ITU-T G.989.2] Recommendation ITU-T G.989.2 (2019), *40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification.*

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

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