International Telecommunication Union

ITU-T

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

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

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10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification

Recommendation ITU-T G.987.2

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Recommendation ITU-T G.987.2

10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification

Summary

Recommendation ITU-T G.987.2 describes a flexible optical fibre access network capable of supporting the bandwidth requirements of business and residential services, and covers one type of 10-Gigabit-capable passive optical network (XG-PON) system with asymmetric nominal line rate of 9.95328 Gbit/s in the downstream direction and 2.48832 Gbit/s in the upstream direction, hereinafter referred to as XG-PON1.

This Recommendation describes the physical layer requirements and specifications for the XG-PON physical media dependent (PMD) layer, together with XG-PON reach extender boxes and wavelength enhancement band for XG-PON. The transmission convergence (TC) layer and ONT management are described in other Recommendations in the ITU-T G.987.x-series of Recommendations. The control interface (OMCI) specifications are described in the ITU-T G.987.x-series of Recommendations.

This Recommendation describes a system that represents an evolutionary development from the systems described in the ITU-T G.984 series. To the greatest extent possible, this Recommendation maintains the requirements of Rec. ITU-T G.984.1 to ensure maximal continuity with existing systems and optical fibre infrastructure.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.987.2	2010-01-13	15

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

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

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Recommendation ITU-T G.987.2

10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification

1 Scope

This Recommendation pertains to flexible access networks using optical fibre technology. The focus is primarily on a network supporting services with bandwidth requirements ranging from that of voice to data services running at up to 10 Gbit/s. Also included are broadcast services.

This Recommendation describes characteristics of the PMD layer of an optical access network (OAN) with the capability of transporting various services between the user-network interface and the service node interface. Described in this Recommendation are also reach extender boxes, providing extension of the system reach beyond that supported by XG-PON PMDs. Additionally, this Recommendation describes the wavelength enhancement band for XG-PON, which allows for the coexistence of XG-PON with GPON (see [ITU-T G.984.5]).

The OAN dealt with this Recommendation enables the network operator to provide a flexible upgrade to meet future customer requirements, in particular, in the area of the optical distribution network (ODN). The ODN considered is based on a point-to-multipoint tree and branch option.

2 References

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

[ITU-T G.652] Recommendation ITU-T G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.657] Recommendation ITU-T G.657 (2006), *Characteristics of a bending loss insensitive single mode optical fibre and cable for the access network*.

[ITU-T G.694.1] Recommendation ITU-T G.694.1 (2002), *Spectral grids for WDM applications: DWDM frequency grid*.

[ITU-T G.783] Recommendation ITU-T G.783 (2006), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.

[ITU-T G.825] Recommendation ITU-T G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH).*

[ITU-T G.957] Recommendation ITU-T G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2008), *Optical transport network physical layer interfaces.*

[ITU-T G.982] Recommendation ITU-T G.982 (1996), *Optical access networks to support services up to the ISDN primary rate or equivalent bit rates*.

[ITU-T G.984.1] Recommendation ITU-T G.984.1 (2008), *Gigabit-capable passive optical networks (GPON): General characteristics*.

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

[ITU-T G.984.5] Recommendation ITU-T G.984.5 (2007), *Gigabit-capable Passive Optical Networks (G-PON): Enhancement band*, plus Amendment 1 (2009).

[ITU-T G.987] Recommendation ITU-T G.987 (2010), *10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms.*

[ITU-T G.987.1] Recommendation ITU-T G.987.1 (2010), *10-Gigabit-capable passive optical networks (XG-PON): General Requirements.*

[ITU-T G.987.3] Recommendation ITU-T G.987.3 (20XX), *10-Gigabit-capable Passive Optical Networks (XG-PON): TC Layer Specification.*

[ITU-T G.987.4] Recommendation ITU-T G.987.4 (20XX), *10-Gigabit-capable Passive Optical Networks (XG-PON):ONU management and control interface specification (OMCI).*

[ITU-T G-Sup.39] ITU-T G-series Recommendations – Supplement 39 (2008), *Optical system design and engineering considerations.*

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

3 Definitions

See clause 3 of [ITU-T G.987].

4 Abbreviations and acronyms

See clause 4 of [ITU-T G.987].

5 Conventions

See clause 5 of [ITU-T G.987].

6 Architecture of the optical access network

See [ITU-T G.984.1]. For convenience, Figure 1 of [ITU-T G.984.2] is reproduced below.

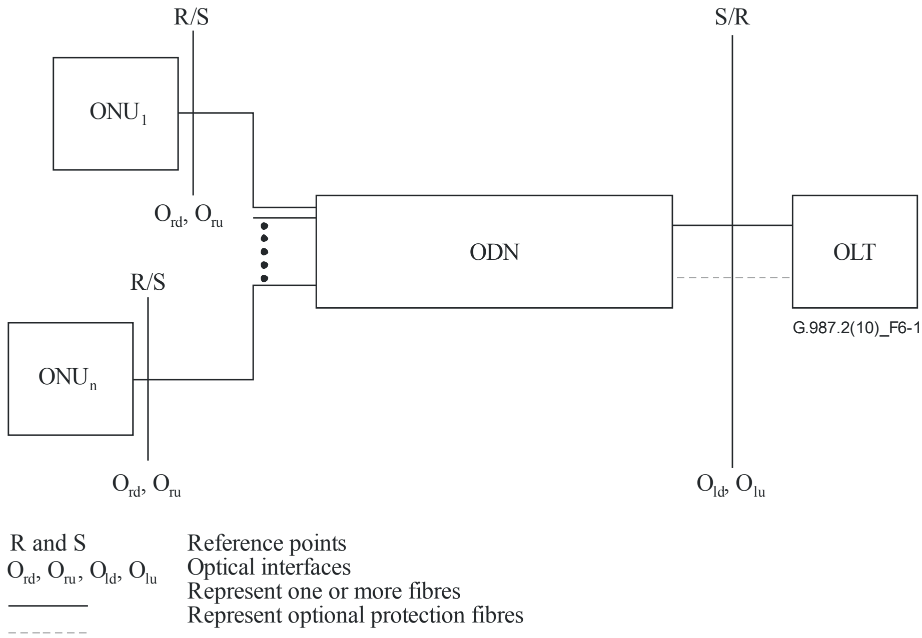


Figure 6-1 – Generic physical configuration of the optical distribution network (reproduced from Figure 1 of [ITU-T G.984.2])

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

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

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

Transmission in downstream and upstream directions can take place on the same fibre and components (duplex/diplex configuration).

6.1 Classes for optical path loss

Recommended classes for optical path loss are shown in Table 6-1.

Table 6-1 – Classes for optical path loss defined in this Recommendation

	'Nominal1' class (N1 class)	'Nominal2' class (N2 class)	'Extended' class (E class)
Minimum loss	14 dB	16 dB	FFS dB
Maximum loss	29 dB	31 dB	FFS dB

Additional classes are for further study.

For single-star architectures, the absence of optical branching devices may result in optical path losses of less than 5 dB. In such a case, the ODN must contain additional optical attenuators guaranteeing minimum channel insertion loss for the given class to prevent potential damage to receivers.

7 Services

See clause 7 of [ITU-T G.987.1].

8 User network interface and service node interface

See Appendix I of [ITU-T G.987.1].

9 Optical network requirements

9.1 Layered structure of optical network

See clause 5.3 of [ITU-T G.987.1].

9.2 Physical media dependent layer requirements for the XG-PON

All parameters are specified as follows, and shall be in accordance with Table 9-3 (ODN) and Tables 9-4 through 9-6.

There could be a separate type of ONU for each optical path loss class (N1 class, N2 class and E class, as defined in clause 6.1).

All parameter values specified are worst-case values, to be met over the range of standard operating conditions (i.e., temperature and humidity), and they include ageing effects. The parameters are specified relative to an optical section design objective of a bit error ratio (BER) not worse than the values specified in Tables 9-4 through 9-6, for the extreme case of optical path attenuation and dispersion conditions.

In particular, the values given in Tables 9-4 through 9-6, are valid for the cases of an enhancement band, as described in clause 10.

9.2.1 Line rate

The transmission line rate should be a multiple of 8 kHz. The target standardized XG-PON system supports the following variant: XG-PON1 with a downstream line rate of 9.95328 Gbit/s and an upstream line rate of 2.48832 Gbit/s.

Parameters to be defined are categorized by downstream and upstream, and the nominal line rate as shown in Table 9-1.

Table 9-1 – Relation between parameter categories and tables

Variant	Transmission direction	Nominal line rate [Gbit/s]	Reference table
XG-PON1	Downstream	9.95328	Table 9-4
	Upstream	2.48832	Table 9-5 Table 9-6

9.2.1.1 Downstream accuracy

When the OLT and the end office are in their normal operating state, this line rate is typically traceable to a stratum-1 clock (accuracy of 1×10^{-11}). When the OLT is in its free-running mode, the accuracy of the downstream signal is at least that of a stratum-4 clock (3.2×10^{-5}). When the end office is in its free-running mode, the line rate of the downstream signal is traceable to a stratum-3 clock (accuracy of 4.6×10^{-6}).

NOTE – The OLT may derive its timing from either a dedicated timing signal source or from a synchronous data interface (line timing). A packet-based timing source may also be used.

9.2.1.2 Upstream accuracy

When in one of its operating states and granted an allocation, the ONU shall transmit its signal with frequency accuracy equal to that of the received downstream signal.

9.2.2 FEC code selection for XG-PON

XG-PON supports two different families of FEC codes, i.e., RS(25a, 22b, 32) (hereinafter referred to as strong *FEC*) and RS(25c, 23d, 16) (hereinafter referred to as weak *FEC*), the use of which depends on the transmission direction and the target power budget supported by the given optical link.

Table 9-2 – Selection of FEC code

Variant	Transmission direction	FEC code family	Implementation	Use
XG-PON1	Downstream	strong FEC	mandatory	mandatory
	Upstream	weak FEC	mandatory	optional

9.2.3 Physical media and transmission method

9.2.3.1 Transmission medium

This Recommendation is based on the fibre described in [ITU-T G.652]. Other fibre types may be compatible with this Recommendation, e.g., [ITU-T G.657] used for example for in-building cabling, drop section.

9.2.3.2 Transmission direction

The signal is transmitted both upstream and downstream through the transmission medium.

9.2.3.3 Transmission methodology

Bidirectional transmission is accomplished by use of wavelength division multiplexing (WDM) technique on a single fibre.

9.2.4 Line code

The scrambling method is not defined at the PMD layer:

The convention used for optical logic levels is:

– high level of light emission for a binary ONE;

– low level of light emission for a binary ZERO.

9.2.4.1 Downstream

Downstream line coding for XG-PON1: NRZ.

9.2.4.2 Upstream

Upstream line coding for XG-PON1: NRZ.

9.2.5 Operating wavelength

9.2.5.1 Downstream wavelength allocation

The operating wavelength range for XG-PON1 for the downstream direction on single fibre systems shall be as defined in Table 9-4.

9.2.5.2 Upstream wavelength allocation

The operating wavelength range for XG-PON1 for the upstream direction shall be as defined in Table 9-5.

9.2.6 XG-PON PMD parameters

9.2.6.1 XG-PON compatible ODN

XG-PON shall operate over an ODN whose parameters are described by Table 9-3.

Table 9-3 – Physical parameters of a simple ODN (ODS)

Item	Unit	Specification
Fibre type (Note 1)	–	[ITU-T G.652], or compatible
Attenuation range (as defined in clause 6.1)	dB	N1 class: 14-29 N2 class: 16-31 E class: FFS-FFS
Maximum fibre distance between S/R and R/S points (Note 2)	km	20
Minimum fibre distance between S/R and R/S points	km	0
Bidirectional transmission	–	1-fibre WDM
Maintenance wavelength	nm	See [ITU-T L.66]
NOTE 1 – See clause 9.2.3.1 NOTE 2 – The maximum fibre distance between S/R and R/S can optionally be longer than 20 km, for example 40 km. In this case, the maximum differential fibre distance will be increased from the traditional 20 km of [ITU-T G.984.2].		

9.2.6.2 Optical interface parameters of 9.95328 Gbit/s downstream direction

Table 9-4 – Optical interface parameters of 9.95328 Gbit/s downstream direction

Item	Unit	Value			
OLT transmitter (optical interface O_{ld})					
Nominal line rate	Gbit/s	9.95328			
Operating wavelength (Note 1)	nm	1575-1580			
Line code	–	NRZ			
Mask of the transmitter eye diagram	–	see clause 9.2.7.6.1			
Maximum reflectance at S/R, measured at transmitter wavelength	dB	NA			
Minimum ORL of ODN at O_{lu} and O_{ld} (Notes 2 and 3)	dB	more than 32			
ODN Class		N1	N2		E
			N2a	N2b	
Mean launched power MIN	dBm	+2.0	+4.0	+10.5	FFS
Mean launched power MAX	dBm	+6.0	+8.0	+12.5	FFS
Launched optical power without input to the transmitter	dBm	NA			
Minimum extinction ratio	dB	8.2			
Tolerance to the transmitter incident light power	dB	more than –15			
Dispersion range (Note 6)	ps/nm	0-400			
Minimum side mode suppression ratio	dB	30			

Table 9-4 – Optical interface parameters of 9.95328 Gbit/s downstream direction

Item	Unit	Value			
Maximum optical path penalty at 20 km (Note 7)	dB	1.0			
Differential optical path loss	dB	15			
ONU receiver (optical interface O_{rd})					
Maximum reflectance at R/S, measured at receiver wavelength	dB	less than –20			
Bit error ratio reference level	–	10^{-3} (Note 4)			
ODN Class		N1	N2		E
			N2a	N2b	
Minimum sensitivity at BER reference level (Note 5)	dBm	–28.0	–28.0	–21.5	FFS
Minimum overload at BER reference level	dBm	–8.0	–8.0	–3.5	FFS
Consecutive identical digit immunity	bit	more than 72			
Jitter tolerance	–	see clause 9.2.10.7.2			
Tolerance to reflected optical power	dB	less than 10			

NOTE 1 – In the case of outdoor OLT deployment, it is allowed for the operating wavelength to span between 1575-1581 nm.

NOTE 2 – The value of "minimum ORL of ODN at O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases.

NOTE 3 – The value of ONU transceiver reflectance for the case that the value of "minimum ORL of ODN at O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is –20 dB.

NOTE 4 – See [ITU-T G-Sup.39], clause 9.4.1 for additional details.

NOTE 5 – This sensitivity shall be met in the presence of G-PON and video overlay on the same ODN. If either G-PON, or video overlay, or both of them are absent, the sensitivity may be different (precise value is FFS).

NOTE 6 – The maximum fibre distance between S/R and R/S can optionally be longer than 20 km, for example 40 km, where the resulting dispersion range would be from 0-800 ps/nm.

NOTE 7 – The maximum fibre distance between S/R and R/S can optionally be longer than 20 km, for example 40 km, where the resulting maximum optical path penalty should remain at 1 dB for devices that support distances above 20 km.

9.2.6.3 Optical interface parameters of 2.48832 Gbit/s upstream direction

Table 9-5 – Optical interface parameters of 2.48832 Gbit/s upstream direction

Item	Unit	Value
ONU transmitter (optical interface O_{ru})		
Nominal line rate	Gbit/s	2.48832
Operating wavelength	nm	1260-1280
Line code	–	NRZ
Mask of the transmitter eye diagram	–	see clause 9.2.7.6.2
Maximum reflectance at R/S, measured at transmitter wavelength	dB	less than –6
Minimum ORL of ODN at O_{ru} and O_{rd} (Notes 1 and 2)	dB	more than 32

Table 9-5 – Optical interface parameters of 2.48832 Gbit/s upstream direction

Item	Unit	Value		
ODN Class		N1	N2	E
Mean launched power MIN	dBm	+2.0	+2.0	FFS
Mean launched power MAX	dBm	+7.0	+7.0	FFS
Launched optical power without input to the transmitter	dBm	less than MIN sensitivity – 10		
Maximum Tx enable (Note 3)	bits	32		
Maximum Tx disable (Note 3)	bits	32		
Minimum extinction ratio	dB	8.2		
Tolerance to transmitter incident light power	dB	more than –15		
Dispersion range (Notes 4, 6 and 8)	ps/nm	0 to –140		
Minimum side mode suppression ratio	dB	30		
Jitter transfer	–	see clause 9.2.10.7.1		
Jitter generation	–	see clause 9.2.10.7.3		
Maximum optical path penalty at 20 km (Notes 5 and 9)	dB	0.5		
OLT receiver (optical interface O_{lu})				
Maximum reflectance at S/R, measured at receiver wavelength	dB	less than –20		
Bit error ratio reference level	–	10^{-4} (Note 7)		
ODN Class		N1	N2	E
Minimum sensitivity at BER reference level	dBm	–27.5	–29.5	FFS
Minimum overload at BER reference level	dBm	–7.0	–9.0	FFS
Consecutive identical digit immunity	bit	more than 72		
Jitter tolerance	–	see clause 9.2.10.7.2		
Tolerance to the reflected optical power	dB	less than 10		

NOTE 1 – The value of "minimum ORL of ODN at O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases.

NOTE 2 – The value of ONU transceiver reflectance for the case that the value of "minimum ORL of ODN at O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is –20 dB.

NOTE 3 – As defined in clause 9.2.7.3.1.

NOTE 4 – Dispersion range is considered to be the most appropriate method of specifying a laser's spectral characteristic. These values are considered to be compatible with the older method of specifying values using maximum –20 dB width, for line rates below 2.5 Gbit/s.

NOTE 5 – This value may be sufficient for longer distances.

NOTE 6 – The equivalent maximum –20 dB width value is specified as less than 1 nm.

NOTE 7 – See [ITU-T G-Sup.39], clause 9.4.1 for additional details.

NOTE 8 – The maximum fibre distance between S/R and R/S can optionally be longer than 20 km, for example 40 km, where the resulting dispersion range would be from 0 to –280 ps/nm.

NOTE 9 – The maximum fibre distance between S/R and R/S can optionally be longer than 20 km, for example 40 km, where the resulting maximum optical path penalty would remain at 0.5 dB for devices that support distances above 20 km.

9.2.6.4 Optical interface parameters of 2.48832 Gbit/s upstream direction with power levelling mechanism at ONU transmitter

Table 9-6 – Optical interface parameters of 2.48832 Gbit/s upstream direction, using power levelling mechanism at ONU transmitter

Items	Unit	Single fibre		
ONU transmitter (optical interface O_{ru})				
ODN Class		N1 class	N2 class	E class
Mean launched power MIN	dBm	FFS	FFS	FFS
Mean launched power MAX	dBm	FFS	FFS	FFS
OLT receiver (optical interface O_{lu})				
ODN Class		N1 class	N2 class	E class
Minimum sensitivity	dBm	FFS	FFS	FFS
Minimum overload	dBm	FFS	FFS	FFS

9.2.7 Transmitter at O_{ld} and O_{ru}

All parameters are specified as follows, and shall be in accordance with Tables 9-4 through 9-6.

9.2.7.1 Source type

Considering the attenuation/dispersion characteristics of the target fibre channel, feasible transmitter devices include only single-longitudinal mode (SLM) lasers. The indication of a nominal source type in this Recommendation is not a requirement though it is also expected that only SLM lasers meet all the distance and line rate requirements of the XG-PON systems both for the downstream and upstream links.

The use of multi-longitudinal mode (MLM) lasers is not contemplated in this Recommendation, due to their practical distance/line rate limitations.

9.2.7.2 Spectral characteristics

For SLM lasers operating at a nominal line rate of 2.5 Gbit/s or below, the laser is specified as its fibre dispersion range, the range over which the laser characteristics and fibre dispersion result in a defined penalty at a specified fibre distance, under standard operating conditions. Additionally, for control of mode partition noise in SLM systems, a minimum value for the laser side-mode suppression ratio is specified. The actual spectral characteristics are limited by the maximum amount of optical path penalty (OPP) produced with the worst-case optical dispersion in the data channel.

For SLM lasers operating at a nominal line rate greater than 2.5 Gbit/s, the laser is specified as its fibre dispersion range, the range over which the laser characteristics and fibre dispersion result in a defined penalty at a specified fibre distance, under standard operating conditions. Additionally, for control of mode partition noise in SLM systems, a minimum value for the laser side-mode suppression ratio is specified. The actual spectral characteristics are limited by the maximum amount of OPP produced with the worst-case optical dispersion in the data channel.

The use of MLM lasers is not contemplated in this Recommendation.

9.2.7.3 Mean launched power

The mean launched power at O_{ld} and O_{ru} is the average power of a pseudo-random data sequence coupled into the fibre by the transmitter. It is given as a range to allow for some cost optimization and to cover all allowances for operation under standard operating conditions, transmitter connector degradation, measurement tolerances, and ageing effects.

In operating state, the lower figure is the minimum power which shall be provided and the higher one is the power which shall never be exceeded.

NOTE – The measurement of the launched power at the O_{ru} optical interface shall take into account the bursty nature of the upstream traffic transmitted by the ONUs.

9.2.7.3.1 Launched optical power without input to the transmitter

In the upstream direction, the ONU transmitter should launch no power into the fibre in all slots which are not assigned to that ONU. However, an optical power level less than or equal to the launched power without input to the transmitter, specified in Tables 9-4 through 9-6, is allowed. The ONU shall also meet this requirement during the guard time of slots that are assigned to it, with the exception of the last Tx Enable bits which may be used for laser pre-bias, and the Tx Disable bits immediately following the assigned cell, during which the output falls to zero. The maximum launched power level allowed during laser pre-bias is the zero level corresponding to the extinction ratio specified in Tables 9-4 through 9-6.

The specification of the maximum number of Tx Enable and Tx Disable bits, for each upstream line rate, is provided in the series of Tables 9-4 through 9-6.

9.2.7.4 Minimum extinction ratio

The convention adopted for optical logic level is:

– high level of light emission for a logical "1";

– low level of light emission for a logical "0".

The extinction ratio (ER) is defined as:

$$ER = 10 \log_{10} (A/B)$$

where A is the average optical power level at the centre of the logical "1" and B is the average optical power level at the centre of the logical "0".

The extinction ratio for the upstream direction burst mode signal is applied from the first bit of the preamble to the last bit of the burst signal inclusive. This does not apply to eventual procedures related to the optical power set-up.

9.2.7.5 Maximum reflectance of equipment, measured at transmitter wavelength

Reflections from equipment (ONU/OLT) back to the cable plant are specified by the maximum permissible reflectance of equipment measured at O_{ld}/O_{ru}. It shall be in accordance with Tables 9-4 through 9-6.

9.2.7.6 Mask of transmitter eye diagram

In this Recommendation, general transmitter pulse shape characteristics, including rise time, fall time, pulse overshoot, pulse undershoot, and ringing, all of which should be controlled to prevent excessive degradation of the receiver sensitivity, are specified in the form of a mask of the transmitter eye diagram at O_{ld}/O_{ru}. For the purpose of an assessment of the transmit signal, it is important to consider not only the eye opening, but also the overshoot and undershoot limitations.

9.2.7.6.1 OLT transmitter

The parameters specifying the mask of the eye diagram (see Figure 9-1) for the OLT transmitter are shown in Table 9-7. The test set-up for the measurement of the mask of the eye diagram is shown in Figure 9-2.

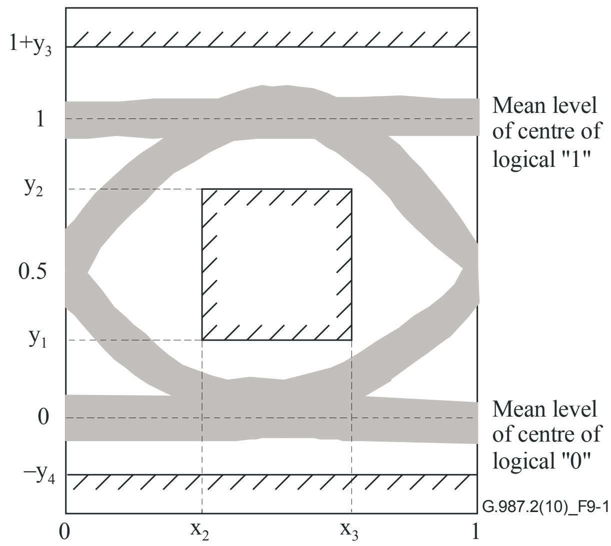
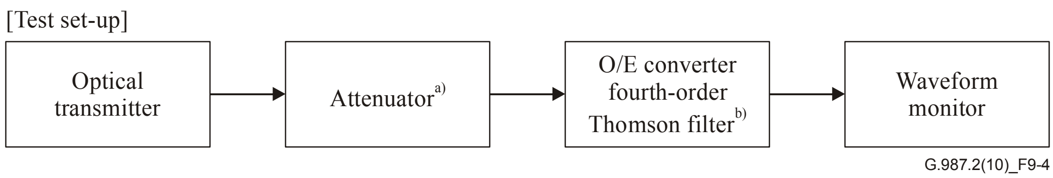


Figure 9-1 – Mask of the eye diagram for OLT transmitter

Table 9-7 – Mask of the eye diagram for OLT transmitter – Numeric values

	9.95328 Gbit/s
x3-x2 (Note 1)	0.2
y1	0.25
y2	0.75
y3	0.25
y4	0.25
NOTE 1 – x2 and x3 of the rectangular eye mask need not be equidistant with respect to the vertical axes at 0 UI and 1 UI. NOTE 2 – The values were extracted from [ITU-T G.959.1], clause 7.2.2.14.	



a) Attenuator is used if necessary.

b) Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

Figure 9-2 – Test set-up for mask of the eye diagram for OLT transmitter

9.2.7.6.2 ONU transmitter

The parameters specifying the mask of the eye diagram (see Figure 9-3) for the ONU transmitter are shown in Table 9-8. The test set-up for the measurement of the mask of the eye diagram is shown in Figure 9-4.

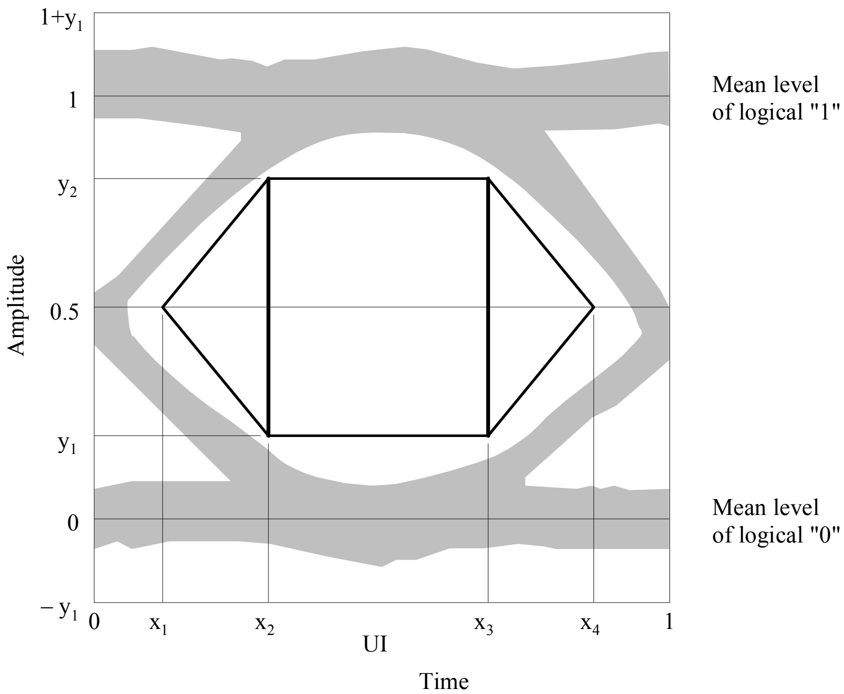
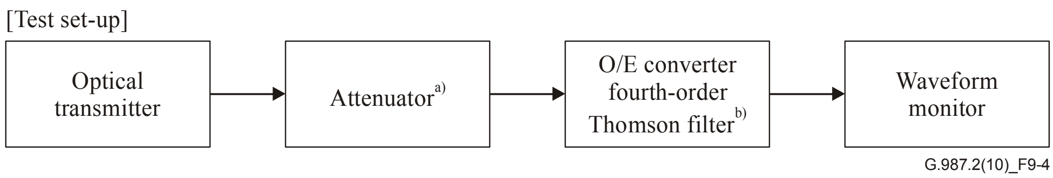


Figure 9-3 – Mask of the eye diagram for ONU transmitter

Table 9-8 – Mask of the eye diagram for ONU transmitter – numeric values

	2.48832 Gbit/s
x3-x2	0.2
y1/y2	0.25/0.75
x3/x4	(Note 1)
NOTE 1 – These points need not be equidistant with respect to the vertical axes at 0 UI and 1 UI. NOTE 2 – The values were extracted from [ITU-T G.957], clause 6.2.5.	



a) Attenuator is used if necessary.

b) Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

Figure 9-4 – Test set-up for mask of the eye diagram for ONU transmitter

The mask of the eye diagram for the upstream direction burst mode signal is applied from the first bit of the preamble to the last bit of the burst signal inclusive. This does not apply to eventual procedures related to the optical power set-up.

9.2.7.7 Tolerance to the reflected optical power

The specified transmitter performance must be met in the presence at S of the optical reflection level specified in Tables 9-4 through 9-6.

9.2.8 Optical path between O_{ld}/O_{ru} and O_{rd}/O_{lu}

9.2.8.1 Attenuation range

Three classes of attenuation ranges are specified in clause 6.1:

– N1 class: 14-29 dB;

– N2 class: 16-31 dB;

– E class: FFS-FFS dB.

Attenuation specifications are assumed to be worst-case values including losses due to splices, connectors, optical attenuators (if used) or other passive optical devices, and any additional cable margin to cover allowances for:

1) future modifications to the cable configuration (additional splices, increased cable lengths, etc.);

2) fibre cable performance variations due to environmental factors; and

3) degradation of any connector, optical attenuators (if used) or other passive optical devices between points S and R, when provided.

9.2.9 Minimum optical return loss of the cable plant at point R/S, including any connectors

Overall minimum optical return loss (ORL) specification at point R/S in the ODN is specified in Tables 9-4 and 9-5.

Optionally, minimum ORL specification at point S in the ODN is specified in Note 2 of Tables 9-4 and 9-5.

NOTE – The overall reflectance at the S/R point for an ODN model is dominated by the optical connectors at the optical distribution frame (ODF). The maximum reflectance of a single discrete element within [ITU-T G.982] is −35 dB. The reflectance from the two ODF connectors leads to a figure of −32 dB. However, based on another network model, the overall reflectance may become worse than −20 dB.

9.2.9.1 Maximum discrete reflectance between points S and R

All discrete reflectances in the ODN shall be better than −35 dB as defined in [ITU-T G.982].

9.2.9.2 Dispersion

Systems considered limited by dispersion have maximum values of dispersion (ps/nm) specified in Tables 9-4 through 9-6. These values are consistent with the maximum optical path penalties specified. They take into account the specified transmitter type, and the fibre dispersion coefficient over the operating wavelength range.

Systems considered limited by attenuation do not have maximum dispersion values specified and are indicated in Tables 9-4 through 9-6 with the entry "NA" (not applicable).

9.2.10 Receiver at O_{rd} and O_{lu}

All parameters are specified as follows, and shall be in accordance with Tables 9-4 through 9-6.

9.2.10.1 Receiver sensitivity

Receiver sensitivity is defined in [ITU-T G.987]. The values are specified in Tables 9-4 through 9-6, accordingly. It takes into account power penalties caused by the use of a transmitter under standard operating conditions with worst-case values of extinction ratio, pulse rise and fall times, optical return loss at point S, receiver connector degradation and measurement tolerances. The receiver sensitivity does not include power penalties associated with dispersion, jitter, or reflections from the optical path; these effects are specified separately in the allocation of maximum optical path penalty.

9.2.10.2 Receiver overload

Receiver overload is defined in [ITU-T G.987]. The values are specified in Tables 9-4 through 9-6, accordingly. The receiver should have a certain robustness against increased optical power level due to start-up or potential collisions during ranging, for which a BER, specified in Tables 9-4 through 9-6 accordingly, is not guaranteed.

9.2.10.3 Maximum optical path penalty

Optical path penalty is defined in [ITU-T G.987]. The receiver is required to tolerate an optical path penalty not exceeding a target value specified for the given optical link as defined in Tables 9-4 through 9-6.

9.2.10.4 Maximum reflectance of transceiver, measured at receiver wavelength

Reflections from equipment (ONU/OLT) back to the cable plant are specified by the maximum permissible reflectance of equipment measured at O_{rd} and O_{lu}. It shall be in accordance with Tables 9-4 through 9-6.

9.2.10.5 Differential optical path loss

Differential optical path loss means the optical path loss difference between the highest and lowest optical path loss in the same ODN. The maximum differential optical path loss is defined in Tables 9-4 through 9-6.

9.2.10.6 Clock extraction capability

NOTE – The clock of the upstream transmission signal is extracted rapidly from several bits alternating continuous code (preamble) of the positive logic "1", "0". The clock extracted from the preamble is maintained at least during the reception of the signal from the delimiter through the end of the upstream cell, or is continuously extracted from the signal after the preamble during the reception of the cell.

9.2.10.7 Jitter performance

This clause deals with jitter requirements for optical interfaces at the XG-PON.

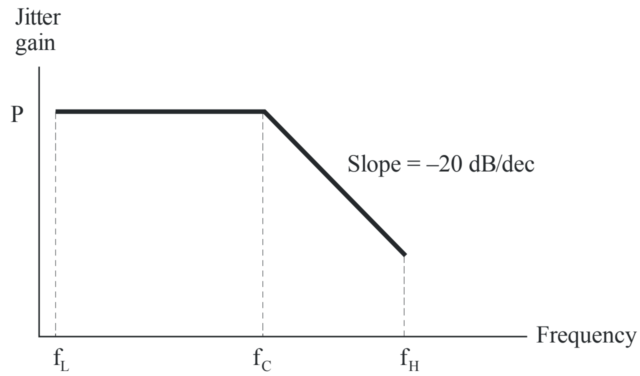
9.2.10.7.1 Jitter transfer

The jitter transfer specification applies only to ONU.

The jitter transfer function is defined as:

$$jitter\ transfer = 20\log_{10}\left[\frac{jitter\ on\ upstream\ signal\ UI}{jitter\ on\ downstream\ signal\ UI} \times \frac{down\ stream\ bit\ rate}{upstream\ bit\ rate}\right]$$

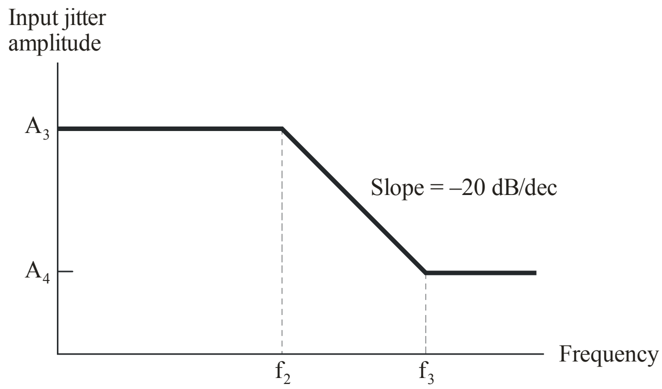
The jitter transfer function of an ONU shall be under the curve given in Figure 9-5, when input sinusoidal jitter up to the mask level in Figure 9-6 is applied, with the parameters specified in this figure for each line rate.



Upstream line rate (Gbit/s)	f_L (kHz)	f_C (kHz)	f_H (kHz)	P (dB)
2.48832	20	2 000	20 000	0.1
NOTE – These values come from [ITU-T G.783]				

G.987.2(10)_F9-5

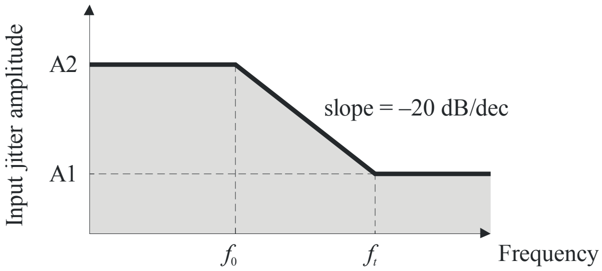
Figure 9-5 – Jitter transfer for ONU



Downstream line rate (Gbit/s)	A_3 (UI)	A_4 (UI)	f_2 (kHz)	f_3 (kHz)
9.95328	1.5	0.15	400	4000
NOTE – These values come from [ITU-T G.783]				

G.987.2(10)_F9-6

Figure 9-6 – High-band portion of sinusoidal jitter mask for jitter transfer



Line rate (Gbit/s)	f_t [kHz]	f_0 [kHz]	A1 [UIp-p]	A2 [UIp-p]
2.48832	1000	100	0.075	0.75
9.95328	4000	400	0.075	0.75
NOTE – These values are derived from [ITU-T G.984.2]				

G.987.2(10)_F9-7

Figure 9-7 – Jitter tolerance mask for ONU

9.2.10.7.2 Jitter tolerance

Jitter tolerance is defined as the peak-to-peak amplitude of sinusoidal jitter applied on the input XG-PON signal that causes a 1-dB optical power penalty at the optical equipment. Note that it is a stress test to ensure that no additional penalty is incurred under operating conditions.

ONU shall tolerate, as a minimum, the input jitter applied according to the mask in Figure 9-7, with the parameters specified in that figure for each downstream line rate. OLT should tolerate, as a minimum, the input jitter applied according to the mask in Figure 9-7, with the parameters specified in that figure for each upstream line rate. The jitter tolerance specification for the OLT is informative as it can only be measured in a setting that permits continuous operation of the upstream.

9.2.10.7.3 Jitter generation

An ONU shall not generate a peak-to-peak jitter amplitude more than shown in Table 9-9 at a line rate of 2.48832 Gbit/s, with no jitter applied to the downstream input and with a measurement bandwidth as specified in Table 9-9. An OLT shall not generate a peak-to-peak jitter amplitude more than shown in Table 9-9 at a line rate of 9.95328 Gbit/s, with no jitter applied to its timing reference input and with a measurement bandwidth as specified in Table 9-9.

Table 9-9 – Jitter generation requirements for XG-PON1

Line rate (Gbit/s)	Measurement band (–3 dB frequencies) (Note 1)		Peak-peak amplitude (UI) (Note 2)
	high-pass (kHz)	low-pass (MHz) –60 dB/dec	
2.48832	5	20	0.30
	1000	20	0.10
9.95328	20	80	0.30
	4000	80	0.10
NOTE 1 – The high-pass and low-pass measurement filter transfer functions are defined in clause 5 of [ITU-T G.825]. NOTE 2 – The measurement time and pass/fail criteria are defined in clause 5 of [ITU-T G.825]. NOTE 3 – This table comes from [ITU-T G.783].			

9.2.10.8 Consecutive identical digit (CID) immunity

The OLT and the ONU shall have a CID immunity as specified in Tables 9-4 through 9-6.

9.2.10.9 Tolerance to reflected power

The tolerance to reflected power is the allowable ratio of optical input average power of O_{rd} and O_{lu} to reflected optical average power when multiple reflected light is regarded as a noise light at O_{rd} and O_{lu} respectively.

The tolerance to reflected power is defined at minimum receiving sensitivity.

9.2.10.10 Transmission quality and error performance

For designing a frame structure, robustness of the overhead bytes for transmission bit errors approximately equal to the BER defined in Tables 9-4 through 9-6 for individual optical links should be considered to avoid system down or failures. Error characteristics of the optical physical medium dependent layer in the local field environment should be considered whether any error correction mechanism is required or not for the overhead bytes at the section level.

The average transmission quality should have a very low bit error ratio of less than the BER across the entire PON system, as defined in Tables 9-4 through 9-6 for individual optical links. An objective error ratio required for optical components should be better than the BER defined in Tables 9-4 through 9-6 for individual optical links, in the environment conditions as defined in [ITU-T G.957].

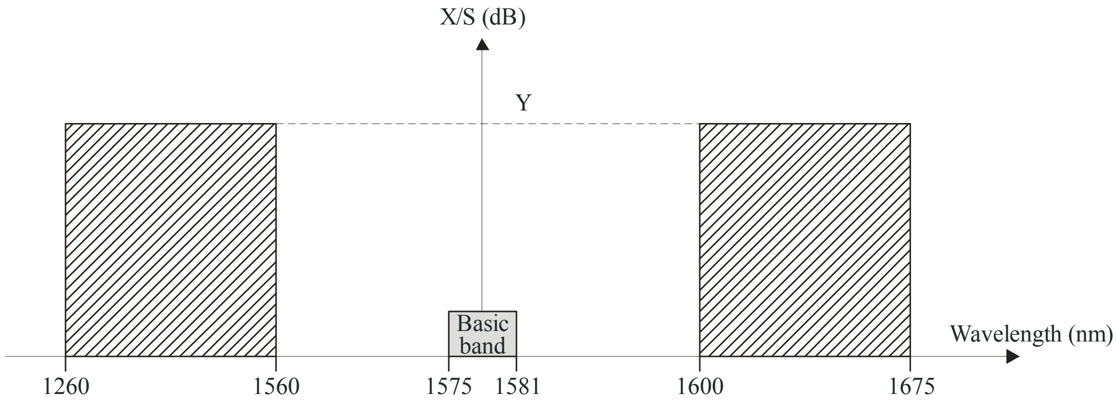
10 X/S tolerance of XG-PON ONU

The minimum optical sensitivity of an XG-PON ONU must be met while interference signals exist. Interference signals are caused by other services such as G-PON and/or video signals in the enhancement band specified in [ITU-T G.987.1]. To minimize the effect of interference signals, XG-PON ONUs need to isolate interference signals using an appropriate wavelength blocking filter (WBF) and WDM filter. This Recommendation does not specify the isolation characteristics of the WBF and WDM filters directly, but specifies the X/S tolerance of the XG-PON ONU. Here, S is the optical power of the basic band signal, and X is that of the interference signal(s). Both are measured at the point IF_{XGPON} of the ONU side specified in [ITU-T G.987.1].

The interference signal format for measuring X/S tolerance should be NRZ pseudo-random coded with the same line rate as the XG-PON downstream signal or a lower line rate within the bandwidth of the basic band receiver.

10.1 Versatile WDM configuration

This clause describes the X/S tolerance of XG-PON ONUs, which can adapt to versatile WDM configuration. It makes no definite assumption about additional services using the enhancement band specified in [ITU-T G.987.1]. Figure 10-1 shows the X/S tolerance mask that should not cause the sensitivity of the basic band receiver to fail to meet the specified limit. Implementers need to specify the isolation characteristics of the WBF and WDM filters to obtain enough isolation of the interference signal(s). This will allow the sensitivity requirement to be met while presence of this level of interference exists. On the other hand, the wavelengths and total optical launch power of additional services must be considered by referencing Figure 10-1 if there is coexistence with XG-PON.



Class	Y
N1	FFS
N2a	FFS
N2b	FFS
E	FFS

G.987.2(10)_F10-1

S: Received power of basic band.
X: Maximum total power of additional services received in the blocking wavelength range.
X/S: In the mask (hatching area) should not cause the sensitivity of the basic band receiver to fail to meet the specified limit.

Figure 10-1 – X/S tolerance mask for ONU (Versatile WDM configuration)

11 Upstream physical layer overhead

The XG-PON1 frame structure is described in [ITU-T G.987.3], devoted to the specification of the TC layer. However, the upstream bursts must be preceded by a suitable physical layer overhead, which is used to accommodate several physical processes in the XG-PON1. Table 11-1 shows the length of the physical layer overhead for the upstream line rate specified in this Recommendation.

Table 11-1 – XG-PON1 upstream physical layer overhead

Upstream line rate	Overhead bytes
2.48832 Gbit/s	256

Moreover, Appendix III provides information on the physical processes that have to be performed during the physical layer overhead (Tplo) time, and some guidelines for an optimized usage of such time.

12 Mid-span reach extenders for XG-PON

For further study.

Appendix I

Examples of wavelength allocation for XG-PON, G-PON and video distribution services

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

See Appendix II of [ITU-T G.984.5] for a generic consideration of this application.

Appendix II

Physical layer measurements required to support optical layer supervision

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

See Appendix IV in Amendment 2 of [ITU-T G.984.2].

Appendix III

Allocation of the physical layer overhead time

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

The physical layer overhead time (Tplo) is used to accommodate five physical processes in the PON. These are: laser on/off time, timing drift tolerance, level recovery, clock recovery, and start of burst delimitation. The exact division of the physical layer time to all these functions is determined partly by constraint equations, and partly by implementation choices. This appendix reviews the constraints that the OLT must comply with, and suggests values for the discretionary values.

As shown in Table III.2, specific values for Ton, Toff, and Tplo are given for the different line rates. Tplo can be divided into three sections with respect to what ONU data pattern is desired. For simplicity, these times can be referred to as the guard time (Tg), the preamble time (Tp) and the delimiter time (Td). During Tg, the ONU will transmit no more power than the nominal zero level. During Tp, the ONU will transmit a preamble pattern that provides the desired transition density and signal pattern for fast level and clock recovery functions. Lastly, during Td, the ONU will transmit a special data pattern with optimal autocorrelation properties that enable the OLT to find the beginning of the burst.

An additional parameter of the control logic on the PON is the total peak-to-peak timing uncertainty (Tu). This uncertainty arises from variations of the time of flight caused by the fibre and component variations with temperature and other environmental factors.

The constraint equations with which the OLT must comply are then:

$$\mathrm{Tg} > \mathrm{Ton} + \mathrm{Tu}, \text{and}$$
$$\mathrm{Tg} > \mathrm{Toff} + \mathrm{Tu}$$

These equations can be explained as follows. The first equation makes sure that the following burst's laser on ramp-up does not fall on top of the last burst's data. The second equation makes sure that the last burst's laser off tail-off does not fall on top of the following burst's preamble.

Tp must be sufficient for the physical layer to recover the signal level (essentially, setting the decision threshold), and the signal clock phase. There are many diverse design approaches to these two problems, each with its own benefits and costs. Some designs are very fast, but require an external trigger signal and produce sub-optimal error performance. Other designs are slower, but do not require a reset signal and produce bit errors that are normally distributed. In addition, each of these designs may have special requirements on the data pattern used for the preamble. Some designs prefer a maximum transition density pattern, while others prefer a pattern with a balance of transitions and controlled runs of identical digits.

Since the choice of design is up to the OLT implementer, it is the OLT that gets to configure the details of the preamble that is transmitted by the ONU. This will be discussed as a part of the burst profile discussion below.

Td must provide sufficient data bits to provide a robust delimiter function in the face of bit errors. The error resistance of the delimiter depends on the exact implementation of the pattern correlator, but a simple approximate relationship between the number of bits in the delimiter (N) and the number of bit errors tolerated (E) is:

$$E = \mathrm{int}(N/4) - 1 \quad \text{(III-1)}$$

Equation III-1 has been empirically verified by a numerical search of all the delimiters of sizes ranging from 8 to 32 bits. This search was performed under the assumption that the preamble pattern was a '1010' repeating pattern, and that the delimiter has an equal number of zeroes and ones. The Hamming distance, D, of the best delimiter from all shifted patterns of itself and the preamble was found to be D = int(N/2) – 1; yielding the error tolerance shown.

Given a certain bit error ratio (BER), the probability of a severely errored burst (Pseb) is given by:

$$Pseb = \binom{N}{E+1} BER^{E+1} \qquad \text{(III-2)}$$

Substituting equation III-1 into equation III-2, the resultant Pseb is given by:

$$Pseb = \binom{N}{\text{int}(N/4)} BER^{\text{int}(N/4)} \qquad \text{(III-3)}$$

If the BER equals 10^{-4}, the resultant Pseb for various delimiter lengths, N, is given in Table III.1. Inspection of this table shows that, in order to suppress this kind of error, the delimiter length must be at least 16 bits, if not more. The choice of delimiter length and pattern is made by the OLT, as part of the burst profile.

Table III.1 – Probability of a severely errored burst as a function of delimiter length

N	Pseb
8	2.8×10^{-7}
12	2.2×10^{-10}
16	1.8×10^{-13}
20	1.5×10^{-16}
24	1.3×10^{-19}
32	1.1×10^{-25}
64	4.9×10^{-50}

With these considerations taken into account, the worst case and objective allocations of the physical layer overhead are given in Table III.2. This table also lists the values for the ONU Tx enable time and Tx disable time, and the total physical layer overhead time for reference. The worst-case values are intended to provide a reasonable bound for easy implementation, and the objective values are intended to be the design target for more efficient implementation with optimized components. Note that these values are for a simple ODN without reach extenders. Reach extenders may require their own guard and preamble time allowances, making the total overhead larger.

Table III.2 – Recommended allocation of burst mode overhead time for XG-PON1 OLT functions

	Tx enable	Tx disable	Total time	Guard time	Preamble time	Delimiter time
Worst-case (bit times)	32	32	2048	128	1856	64
Objective (bit times)	32	32	256	64	160	32

In addition to the design dependent aspects of the burst overhead, there can be operationally dependent factors. For example, detecting an ONU's ranging burst is a more difficult problem than receiving an ONU's regular transmission. For another example, some ONUs may have higher power and are easier to detect, therefore they do not need FEC. For these reasons, the OLT may request different burst parameters depending on the context.

The concept of a burst profile captures all the aspects of burst overhead control. A burst profile specifies the preamble pattern and length, the delimiter pattern and length, and whether FEC parity should be sent. The OLT establishes one or more burst profiles, and then requests a particular burst profile for each burst transmission.

The OLT has considerable latitude in setting up the profiles, because the OLT's burst receiver is far more sensitive to the profile parameters. Therefore, the OLT should use profiles that insure adequate response in its burst mode receiver. However, some basic requirements from the ONU side must be met. Namely, the preamble and delimiter patterns should be balanced and they should have a reasonable transition density. If not, then the ONU transmitter driver circuitry may be adversely affected. Also note that the preamble and delimiter patterns can be different in each profile, and this difference can be used by the OLT receiver as an in-band indication of the format of each burst (e.g., FEC active or not).

The details of distributing the burst profiles and signalling their use are described in [ITU-T G.987.3], the XG-PON XGTC layer Recommendation.

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