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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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Gigabit-capable passive optical networks (GPON): Physical media dependent (PMD) layer specification

Recommendation ITU-T G.984.2

ITU-T

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Recommendation ITU-T G.984.2

Gigabit-capable passive optical networks (GPON): Physical media dependent (PMD) layer specification

Summary

Recommendation ITU-T G.984.2 describes a flexible optical fibre access network capable of supporting the bandwidth requirements of business and residential services, and covers systems with nominal line rates of 1 244.160 Mbit/s and 2 488.320 Mbit/s in the downstream direction and 155.520 Mbit/s, 622.080 Mbit/s, 1 244.160 Mbit/s and 2 488.320 Mbit/s in the upstream direction. Both symmetrical and asymmetrical (upstream/downstream) gigabit-capable passive optical network (GPON) systems are described. This Recommendation proposes the physical layer requirements and specifications for the physical media dependent (PMD) layer. The transmission convergence (TC) layer and ranging protocol for GPON systems are described in Recommendation ITU-T G.984.3.

This Recommendation describes a system that represents an evolutionary development from the system described in ITU-T G.983.1. To the greatest extent possible, this Recommendation maintains the requirements of ITU-T G.983.1 to ensure maximal continuity with existing systems and optical fibre infrastructure. In addition, it describes several enhanced optical budgets (B+, C+, and D) to extend that capability. The necessary parameters are defined to support optical layer supervision.

History

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GPON, PMD.

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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.

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

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Gigabit-capable passive optical networks (GPON): Physical media dependent (PMD) layer specification

1 Scope

This Recommendation describes 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 gigabit-per-second data services. Also included are distributive services.

This Recommendation describes characteristics of the physical media dependent (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 (SNI).

The OAN dealt within this Recommendation should enable 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.

This Recommendation concentrates on the fibre issues: the copper issues of hybrid systems are described elsewhere, e.g., in Recommendations on any type of digital subscriber line (xDSL) (ITU-T G.99x-series).

This Recommendation focuses on additions to and modifications of earlier members of the ITU-T G.983.x series, which describe an architecture based on the asynchronous transfer mode (ATM) over a passive optical network (PON). The purpose of the additions and modifications are to support higher data rates, especially for the transport of data services.

This Recommendation proposes the physical layer requirements and specifications for the PMD layer of a gigabit-capable passive optical network (GPON). The transmission convergence (TC) layer and ranging protocol specifications for GPON systems are specified in [ITU-T G.984.3].

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 G.652 (2016), *Characteristics of a single-mode optical fibre cable*.

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

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

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

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

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

[ITU-T G.984.5] Recommendation G.984.5 (2014), *Gigabit-capable passive optical networks (G-PON): Enhancement band*.

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 accuracy of a measuring system (accuracy): This is the ability of a measuring system to provide an indication value that is close to the true value being measured. This is normally expressed as an error range around the true value.

3.2.2 optical access network (OAN): The set of access links sharing the same network-side interfaces and supported by optical access transmission systems. The OAN may include a number of ODNs connected to the same OLT.

3.2.3 optical distribution network (ODN): In the pon context, a tree of optical fibres in the access network, supplemented with power or wavelength splitters, filters or other passive optical devices.

3.2.4 optical line supervision (OLS): A set of capabilities relating to the measurement and reporting of the state of the optical link.

3.2.5 optical line termination (OLT): A device that terminates the common (root) endpoint of an ODN, implements a PON protocol, such as that defined by [ITU-T G.984.3], and adapts PON PDUs for uplink communications over the provider service interface. The OLT provides management and maintenance functions for the subtended ODN and ONUs.

3.2.6 optical network termination (ONT): A single subscriber device that terminates any one of the distributed (leaf) endpoints of an ODN, implements a PON protocol, and adapts PON PDUs to subscriber service interfaces. An ONT is a special case of an ONU.

3.2.7 optical network unit (ONU): A generic term denoting a device that terminates any one of the distributed (leaf) endpoints of an ODN, implements a PON protocol, and adapts PON PDUs to subscriber service interfaces. In some contexts, an ONU implies a multiple subscriber device.

3.2.8 range of indications (range): This term can be either called as "range of indications" or "indication intervals". It is the set of quantity values bounded by the extreme possible indications of a measuring system.

3.2.9 repeatability of a measuring system (repeatability): This is the property of a measuring system to provide closely similar indications for replicated measurements of the same quantity under repeatable conditions. This is normally expressed as a range of indications that result from repeated measurements of identical conditions.

3.2.10 resolution of a measuring system (resolution): This is the smallest change in the value of the quantity being measured by a measuring system that causes a perceptible change in the corresponding indication.

3.2.11 response time (RT): For a measurement circuit, the time between test initiation and availability of a valid measurement. The RT does not include the delays associated with the transmission of the result to higher layers. The RT explains the real-time requirement for optical line supervision reasons.

3.2.12 time division multiple access (TDMA): Transmission technique involving the multiplexing of many time slots onto the same time payload.

3.2.13 wavelength division multiplexing (WDM): Bidirectional multiplexing using different optical wavelength for upstream and downstream signals.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APD	Avalanche Photodiode
ATM	Asynchronous Transfer Mode
BER	Bit Error Ratio
BPON	Broadband Passive Optical Network
CID	Consecutive Identical Digit
DFB	Distributed Feedback
EMS	Element Management System
EX	Extinction ratio
FEC	Forward Error Correction
FFS	For Further Study
GPON	Gigabit-capable Passive Optical Network
ISDN	Integrated Services Digital Network
MLM	Multi-Longitudinal Mode
MPN	Mode Partition Noise
NRZ	Non-Return to Zero
OAN	Optical Access Network
ODN	Optical Distribution Network
OLS	Optical Line Supervision
OLT	Optical Line Termination
ONT	Optical Network Termination
ONU	Optical Network Unit
ORL	Optical Return Loss
PIN	Photodiode without Internal Avalanche
PMD	Physical Media Dependent
PON	Passive Optical Network
p-p	peak to peak
RMS	Root Mean Square
R/S	Receive/Send
RT	Response Time
Rx	Receiver
SLM	Single-Longitudinal Mode

SNI	Service Node Interface
SOA	Semiconductor Optical Amplifier
S/R	Send/Receive
TC	Transmission Convergence
TDMA	Time Division Multiple Access
Tx	Transmission
UI	Unit Interval
WDM	Wavelength Division Multiplexing
xDSL	any type of Digital Subscriber Line

5 Architecture of the optical access network

See [ITU-T G.983.1]. For convenience, Figure 5 of [ITU-T G.983.1] is reproduced in Figure 1.

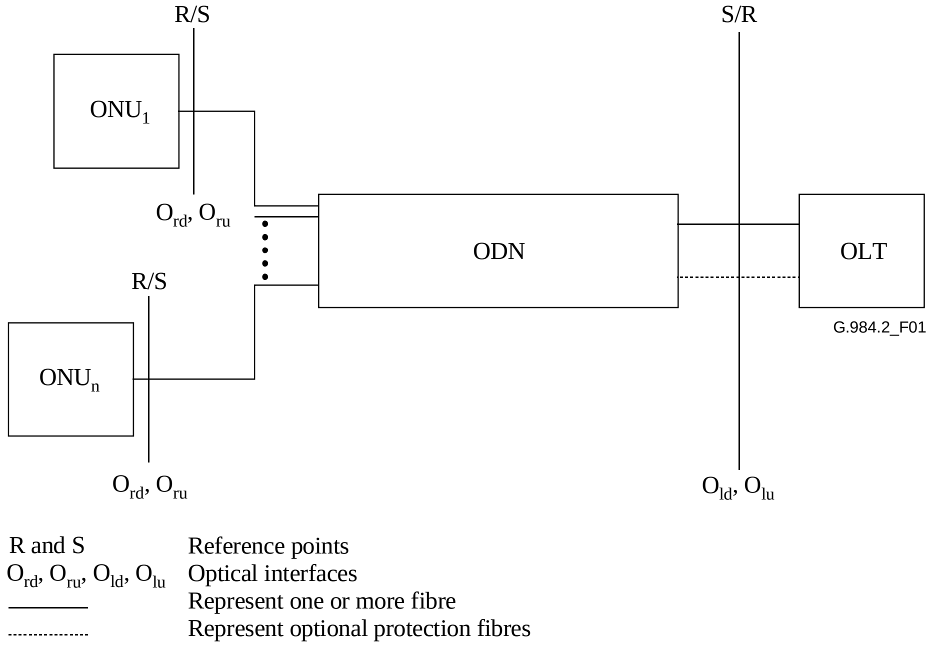


Figure 1 – Generic physical configuration of the optical distribution network

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

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

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

Transmission in downstream and upstream directions can take place on the same fibre and components (duplex/diplex working) or on separate fibres and components (simplex working).

6 Services

See [ITU-T G.984.1].

7 User network interface and service node interface

See [ITU-T G.984.1].

8 Optical network requirements

8.1 Layered structure of optical network

See [ITU-T G.983.1] and [ITU-T G.983.3].

8.2 Physical medium dependent layer requirements for the GPON

8.2.1 Digital signal nominal bit rate

The transmission line rate should be a multiple of 8 kHz. The target standardized system will have nominal line rates (downstream/upstream) of:

- 1 244.16 Mbit/s/155.52 Mbit/s,
- 1 244.16 Mbit/s/622.08 Mbit/s,
- 1 244.16 Mbit/s/1 244.16 Mbit/s,
- 2 488.32 Mbit/s/155.52 Mbit/s,
- 2 488.32 Mbit/s/622.08 Mbit/s,
- 2 488.32 Mbit/s/1 244.16 Mbit/s,
- 2 488.32 Mbit/s/2 488.32 Mbit/s.

Parameters to be determined are categorized by downstream and upstream, and nominal bit rate as shown in Table 1.

Table 1 – Relation between parameter categories and tables

Transmission direction	Nominal bit rate (Mbit/s)	Table
Downstream	1 244.16	Table 2b (downstream, 1 244 Mbit/s)
	2 488.32	Table 2c (downstream, 2 488 Mbit/s)
Upstream	155.52	Table 2d (upstream, 155 Mbit/s)
	622.08	Table 2e (upstream, 622 Mbit/s)
	1 244.16	Table 2f-1 (upstream, 1 244 Mbit/s) Table 2f-2 (upstream, 1 244 Mbit/s)
	2 488.32	Table 2g-1 (upstream, 2 488 Mbit/s) Table 2g-2 (upstream, 2 488 Mbit/s)

All parameters are specified as follows, and shall be in accordance with Table 2a (ODN) and Table 2b to g-2. There is a separate type of ONU for each combination of upstream bit-rate, downstream bit-rate and optical path loss class (class A, B, or C as specified in [ITU-T G.982]).

All parameter values specified are worst-case values, assumed to be met over the range of standard operating conditions (i.e., temperature and humidity ranges), 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 1×10^{-10} for the extreme case of optical path attenuation and dispersion conditions.

In particular, the values in this Recommendation, in Table 2b to g-2, are valid for the cases without an enhancement band, as described in [ITU-T G.983.3]. For GPONs with enhancement band applications, a new set of parameters must be defined, together with requirements for isolation between the different wavelength bands. This can be described in a separate Recommendation, having the same relation to this Recommendation as [ITU-T G.983.3] has to [ITU-T G.983.1]. However, the optical wavelength specified in this Recommendation for the downstream direction complies with [ITU-T G.983.3], in order to allow a smooth integration of the enhancement band in the future.

8.2.2 Physical media and transmission method

8.2.2.1 Transmission medium

This Recommendation is based on the fibre specified in [ITU-T G.652].

8.2.2.2 Transmission direction

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

8.2.2.3 Transmission methodology

Bidirectional transmission is accomplished by use of either the wavelength division multiplexing (WDM) technique on a single fibre or unidirectional transmission over two fibres (see clause 8.2.5).

8.2.3 Bit rate

This clause deals with bit-rate requirements for the GPON.

8.2.3.1 Downstream

The nominal bit rate of the OLT-to-ONU signal is 1 244.16, or 2 488.32 Mbit/s. When the OLT and the end office are in their normal operating state, this rate is traceable to a stratum-1 clock (accuracy of 1×10^{-11}). When the end office is in its free-running mode, the rate of the downstream signal is traceable to a stratum-3 clock (accuracy of 4.6×10^{-6}). When the OLT is in its free-running mode, the accuracy of the downstream signal is that of a stratum-4 clock (3.2×10^{-5}).

NOTE – The OLT may source 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.

8.2.3.2 Upstream

The nominal bit rate of the ONU-to-OLT signal is 155.52, 622.08, 1 244.16, or 2 488.32 Mbit/s. When in one of its operating states and given a grant, the ONU shall transmit its signal with an accuracy equal to that of the received downstream signal. The ONU shall not transmit any signal when not in one of its operating states or when not given a grant.

8.2.4 Line code

Downstream and upstream: non-return to zero (NRZ) coding.

Scrambling method not defined at the PMD layer.

Convention used for optical logic level is:

– high level of light emission for a binary "1";
– low level of light emission for a binary "0".

8.2.5 Operating wavelength

8.2.5.1 Downstream direction

The operating wavelength range for the downstream direction on single fibre systems shall be 1 480-1 500 nm.

The operating wavelength range for the downstream direction on two fibre systems shall be 1 260-1 360 nm.

8.2.5.2 Upstream direction

The operating wavelength range for the upstream direction shall be 1 260-1 360 nm.

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

All parameters are specified as follows, and shall be in accordance with Table 2.

8.2.6.1 Source type

See clause 8.2.6.1 of [ITU-T G.983.1].

8.2.6.2 Spectral characteristics

See clause 8.2.6.2 of [ITU-T G.983.1].

8.2.6.3 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 the operating state, the lower figure is the minimum power that shall be provided and the higher one is the power that 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.

8.2.6.3.1 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 that 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 Table 2d to g-1, 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 transmission (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 (EX) specified in Table 2d to g-1.

The specification of the maximum number of Tx enable and Tx disable bits for each upstream bit rate is provided in Table 2d to g-1.

8.2.6.4 Minimum extinction ratio

The convention adopted for the optical logic level is:

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

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

The EX is determined by:

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

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 EX 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 any procedures related to the optical power set-up.

8.2.6.5 Maximum reflectance of equipment, measured at transmitter wavelength

See clause 8.2.6.5 of [ITU-T G.983.1].

8.2.6.6 Mask of transmitter eye diagram

See clause 8.2.6.6 of [ITU-T G.983.1].

8.2.6.6.1 OLT transmitter

The parameters specifying the mask of the eye diagram are shown in Figure 2.

8.2.6.6.2 ONU transmitter

The parameters specifying the mask of the eye diagram are shown in Figure 3.

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 any procedures related to the optical power set-up.

8.2.6.7 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 Table 2.

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

8.2.7.1 Attenuation range

See clause 8.2.7.1 of [ITU-T G.983.1].

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

See clause 8.2.7.2 of [ITU-T G.983.1].

8.2.7.3 Maximum discrete reflectance between points S and R

See clause 8.2.7.3 of [ITU-T G.983.1].

8.2.7.4 Dispersion

See clause 8.2.7.4 of [ITU-T G.983.1].

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

All parameters are specified in clauses 8.2.8.1 to 8.2.8.12, and shall be in accordance with Table 2.

8.2.8.1 Minimum sensitivity

See clause 8.2.8.1 of [ITU-T G.983.1].

8.2.8.2 Minimum overload

See clause 8.2.8.2 of [ITU-T G.983.1].

8.2.8.3 Maximum optical path penalty

The receiver is required to tolerate an optical path penalty not exceeding 1 dB to account for total degradations due to reflections, intersymbol interference, mode partition noise (MPN), and laser chirp. In the upstream direction, the specified laser types in Table 2 produce less than 1 dB of optical path penalty over the ODN. As indicated in Note 5 of Table 2e and f-1, an increase in the upstream optical path penalty due to dispersion at bit rates of 622 Mbit/s or above is acceptable, provided that any increase in optical path penalty over 1 dB is compensated by an increase of the minimum transmitted launch power, or an increase of the minimum receiver sensitivity.

8.2.8.4 Maximum logical reach

The maximum logical reach is defined as the maximum length that can be achieved for a particular transmission system independently of the optical budget. It is measured in kilometres and is not limited by PMD parameters, but rather TC layer and implementation issues.

8.2.8.5 Maximum differential logical reach

The differential logical reach is the maximum difference in logical reach among all ONUs. It is measured in kilometres and is not limited by PMD parameters but rather TC layer and implementation issues.

8.2.8.6 Maximum reflectance of receiver equipment, measured at receiver wavelength

See clause 8.2.8.4 of [ITU-T G.983.1].

8.2.8.7 Differential optical path loss

See clause 8.2.8.5 of [ITU-T G.983.1].

8.2.8.8 Clock extraction capability

See clause 8.2.8.6 of [ITU-T G.983.1].

8.2.8.9 Jitter performance

This clause deals with jitter requirements for optical interfaces at the GPON.

8.2.8.9.1 Jitter transfer

Jitter transfer specification applies only to ONU.

The jitter transfer function is defined as:

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

The jitter transfer function of an ONU shall be under the curve given in Figure 4, when input sinusoidal jitter up to the mask level in Figure 5 is applied, with the parameters specified therein for each bit rate.

8.2.8.9.2 Jitter tolerance

See clause 8.2.8.7.2 of [ITU-T G.983.1].

8.2.8.9.3 Jitter generation

Jitter generation specification applies only to ONU.

An ONU shall not generate a peak to peak jitter more than 0.2 unit interval (UI) at bit rates of 155.52 Mbit/s or 622.08 Mbit/s, and not more than 0.33 UI peak to peak at 1 244.16 Mbit/s, with no jitter applied to the downstream input and with a measurement bandwidth as specified in Table 2d to g-1. The maximum peak-to-peak jitter allowed at 2 488.32 Mbit/s and the related measurement frequency range is for further study.

8.2.8.10 Consecutive identical digit immunity

The OLT and the ONU shall have a consecutive identical digit (CID) immunity as specified in Table 2b to g.

8.2.8.11 Tolerance to reflected power

See clause 8.2.8.9 of [ITU-T G.983.1].

8.2.8.12 Transmission quality and error performance

See clause 8.2.8.10 of [ITU-T G.983.1].

Table 2a – Physical medium dependent layer parameters of ODN

Items	Unit	Specification
Fibre type (Note 1)	–	[ITU-T G.652]
Attenuation range [ITU-T G.982]	dB	Class A: 5-20 Class B: 10-25 Class C: 15-30
Differential optical path loss	dB	15
Maximum optical path penalty	dB	1 (see Note 5 in Table 2e and f-1)
Maximum logical reach	km	60 (Note 2)
Maximum differential logical reach	km	20
Maximum fibre distance between send/receive (S/R) and receive/send (R/S) points	km	20 (10 as option)
Minimum supported split ratio	–	Restricted by path loss PON with passive splitters (16, 32 or 64 way split)
Bidirectional transmission	–	1-fibre WDM or 2-fibre
Maintenance wavelength	nm	to be defined
NOTE 1 – For future extended reach (> 20 km), the use of different types of fibre is for further study, for a future PMD specification. NOTE 2 – This is the maximum distance managed by the higher layers of the system (MAC, TC, Ranging), in view of a future PMD specification.		

Table 2b – Optical interface parameters of 1 244 Mbit/s downstream direction

Items	Unit	Single fibre			Dual fibre		
		OLT transmitter (optical interface O_{ld})					
Nominal bit rate	Mbit/s	1 244.16			1 244.16		
Operating wavelength	nm	1 480-1 500			1 260-1 360		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 2			Figure 2		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA			NA		
Minimum optical return loss (ORL) of ODN at O_{lu} and O_{ld} (Notes 1 and 2)	dB	more than 32			more than 32		
ODN Class		A	B	C	A	B	C
Mean launched power MIN	dBm	–4	+1	+5	–4	+1	+5
Mean launched power MAX	dBm	+1	+6	+9	+1	+6	+9
Launched optical power without input to the transmitter	dBm	NA			NA		
Extinction ratio	dB	more than 10			more than 10		
Tolerance to the transmitter incident light power	dB	more than –15			more than –15		

Table 2b – Optical interface parameters of 1 244 Mbit/s downstream direction

Items	Unit	Single fibre			Dual fibre		
If multi-longitudinal mode (MLM) laser – Maximum root mean square (RMS) width	nm	NA			NA		
If single-longitudinal mode (SLM) laser – Maximum –20 dB width (Note 3)	nm	1			1		
If SLM laser – Minimum side mode suppression ratio	dB	30			30		
ONU receiver (optical interface O_{rd})							
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20			less than –20		
Bit error ratio	–	less than 10^{-10}			less than 10^{-10}		
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	–25	–25	–26	–25	–25	–25
Minimum overload	dBm	–4	–4	–4 (Note 4)	–4	–4	–4
Consecutive identical digit immunity	bit	more than 72			more than 72		
Jitter tolerance	–	Figure 5			Figure 5		
Tolerance to the reflected optical power	dB	less than 10			less than 10		

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases that are described in Appendix I of [ITU-T G.983.1].

NOTE 2 – The values of ONU transmitter reflectance if the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II of [ITU-T G.983.1].

NOTE 3 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in [b-ITU-T G.957].

NOTE 4 – While only –6 dBm overload is required to support the class C ODN, a –4 dBm overload value has been chosen here for ONU receiver uniformity across all ODN classes.

Table 2c – Optical interface parameters of 2 488 Mbit/s downstream direction

Items	Unit	Single fibre			Dual fibre		
OLT transmitter (optical interface O_{ld})							
Nominal bit rate	Mbit/s	2 488.32			2 488.32		
Operating wavelength	nm	1 480-1 500			1 260-1 360		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 2			Figure 2		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA			NA		
Minimum ORL of ODN at O_{lu} and O_{ld} (Notes 1 and 2)	dB	more than 32			more than 32		
ODN Class		A	B	C	A	B	C

Table 2c – Optical interface parameters of 2 488 Mbit/s downstream direction

Items	Unit	Single fibre			Dual fibre		
Mean launched power MIN	dBm	0	+5	+3 (Note 4)	0	+5	+3 (Note 4)
Mean launched power MAX	dBm	+4	+9	+7 (Note 4)	+4	+9	+7 (Note 4)
Launched optical power without input to the transmitter	dBm	NA			NA		
Extinction ratio (Note 5)	dB	more than 8.2			more than 8.2		
Tolerance to the transmitter incident light power	dB	more than –15			more than –15		
If MLM laser – Maximum RMS width	nm	NA			NA		
If SLM laser – Maximum –20 dB width (Note 3)	nm	1			1		
If SLM laser – Minimum side mode suppression ratio	dB	30			30		
ONU receiver (optical interface O_{rd})							
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20			less than –20		
Bit error ratio	–	less than 10^{-10}			less than 10^{-10}		
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	–21	–21	–28 (Note 4)	–21	–21	–28 (Note 4)
Minimum overload	dBm	–1	–1	–8 (Note 4)	–1	–1	–8 (Note 4)
Consecutive identical digit immunity	bit	more than 72			more than 72		
Jitter tolerance	–	Figure 5			Figure 5		
Tolerance to the reflected optical power	dB	less than 10			less than 10		

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I of [ITU-T G.983.1].

NOTE 2 – The values of ONU transmitter reflectance if the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II of [ITU-T G.983.1].

NOTE 3 – Values of maximum −20 dB width, and minimum side mode suppression ratio are referred to in [b-ITU-T G.957].

NOTE 4 – These values assume the use of a high-power distributed feedback (DFB) laser for the OLT transmitter and of a receiver based on an avalanche photodiode (APD) for the ONU. Taking future developments of semiconductor optical amplifier (SOA) technology into account, a future alternative implementation could use a DFB laser + SOA or a higher power laser diode for the OLT transmitter, allowing a receiver based on a photodiode without internal avalanche (PIN) for the ONU. The assumed values would then be conditional on eye-safety regulations and practice:

Mean launched power MAX OLT transmitter: +12 dBm

Mean launched power MIN OLT transmitter: +8 dBm

Minimum sensitivity ONU receiver: –23 dBm

Minimum overload ONU receiver: –3 dBm

NOTE 5 – The extinction ratio of 8.2 dB was a relaxation of the former value of 10 dB. The new value does imply an improvement in the ONU receiver of 0.5 dB optical modulation amplitude.

Table 2d – Optical interface parameters of 155 Mbit/s upstream direction

Items	Unit	Single fibre			Dual fibre		
ONU transmitter (optical interface O_{ru})							
Nominal bit rate	Mbit/s	155.52			155.52		
Operating wavelength	nm	1 260-1 360			1 260-1 360		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 3			Figure 3		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	less than –6			less than –6		
Minimum ORL of ODN at O_{ru} and O_{rd} (Notes 1 and 2)	dB	more than 32			more than 32		
ODN Class		A	B	C	A	B	C
Mean launched power MIN	dBm	–6	–4	–2	–6	–4	–2
Mean launched power MAX	dBm	–0	+2	+4	–1	+1	+3
Launched optical power without input to the transmitter	dBm	less than Min sensitivity –10			less than Min sensitivity –10		
Maximum Tx enable (Note 3)	bits	2			2		
Maximum Tx disable (Note 3)	bits	2			2		
Extinction ratio	dB	more than 10			more than 10		
Tolerance to the transmitter incident light power	dB	more than –15			more than –15		
If MLM laser – Maximum RMS width	nm	5.8			5.8		
If SLM laser – Maximum –20 dB width (Note 4)	nm	1			1		
If SLM laser – Minimum side mode suppression ratio	dB	30			30		
Jitter transfer	–	Figure 4			Figure 4		
Jitter generation from 0.5 kHz to 1.3 MHz	UI peak to peak (p-p)	0.2			0.2		
OLT receiver (optical interface O_{lu})							
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20			less than –20		
Bit error ratio	–	less than 10^{-10}			less than 10^{-10}		
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	–27	–30	–33	–27	–30	–33
Minimum overload	dBm	–5	–8	–11	–6	–9	–12

Table 2d – Optical interface parameters of 155 Mbit/s upstream direction

Items	Unit	Single fibre	Dual fibre
Consecutive identical digit immunity	bit	more than 72	more than 72
Jitter tolerance	–	NA	NA
Tolerance to reflected optical power	dB	less than 10	less than 10
NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I of [ITU-T G.983.1]. NOTE 2 – The values of ONU transmitter reflectance if the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II of [ITU-T G.983.1]. NOTE 3 – As defined in clause 8.2.6.3.1. NOTE 4 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in [b-ITU-T G.957].			

Table 2e – Optical interface parameters of 622 Mbit/s upstream direction

Items	Unit	Single fibre			Dual fibre		
		ONU transmitter (optical interface O_{ru})					
Nominal bit rate	Mbit/s	622.08			622.08		
Operating wavelength (Note 5)	nm	MLM type 1 or SLM: 1 260~1 360 MLM type 2: 1 280~1 350 MLM type 3: 1 288~1 338			MLM type 1 or SLM: 1 260~1 360 MLM type 2: 1 280~1 350 MLM type 3: 1 288~1 338		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 3			Figure 3		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	less than –6			less than –6		
Minimum ORL of ODN at O_{ru} and O_{rd} (Notes 1 and 2)	dB	more than 32			more than 32		
ODN Class		A	B	C	A	B	C
Mean launched power MIN	dBm	–6	–1	–1	–6	–1	–1
Mean launched power MAX	dBm	–1	+4	+4	–1	+4	+4
Launched optical power without input to the transmitter	dBm	less than Min sensitivity –10			less than Min sensitivity –10		
Maximum Tx enable (Note 3)	bits	8			8		
Maximum Tx disable (Note 3)	bits	8			8		
Extinction ratio	dB	more than 10			more than 10		
Tolerance to transmitter incident light power	dB	more than –15			more than –15		
MLM laser – Maximum RMS width (Note 5)	nm	MLM type 1: 1.4 MLM type 2: 2.1 MLM type 3: 2.7			MLM type 1: 1.4 MLM type 2: 2.1 MLM type 3: 2.7		

Table 2e – Optical interface parameters of 622 Mbit/s upstream direction

Items	Unit	Single fibre			Dual fibre		
SLM Laser – Maximum –20 dB width (Note 4)	nm	1			1		
If SLM Laser – Minimum side mode suppression ratio	dB	30			30		
Jitter transfer	–	Figure 4			Figure 4		
Jitter generation from 2.0 kHz to 5.0 MHz	UI p-p	0.2			0.2		
OLT receiver (optical interface O_{lu})							
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20			less than –20		
Bit error ratio	–	less than 10^{-10}			less than 10^{-10}		
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	–27	–27	–32	–27	–27	–32
Minimum overload	dBm	–6	–6	–11	–6	–6	–11
Consecutive identical digit immunity	bit	more than 72			more than 72		
Jitter tolerance	–	NA			NA		
Tolerance to the reflected optical power	dB	less than 10			less than 10		

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I of [ITU-T G.983.1].

NOTE 2 – The values of ONU transmitter reflectance if the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II of [ITU-T G.983.1].

NOTE 3 – As defined in clause 8.2.6.3.1.

NOTE 4 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in [b-ITU-T G.957].

NOTE 5 – Transmitter types meeting narrower spectral width specifications are allowed wider central wavelength ranges. The specified laser types produce less than 1 dB of optical path penalty over the ODN. Lasers with different optical parameters may be substituted provided that: 1) the total wavelength range does not exceed 1 260~1 360 nm, and 2) any increase in optical path penalty over 1 dB is compensated by an increase of the minimum transmitted launch power or an increase of the minimum receiver sensitivity.

Table 2f-1 – Optical interface parameters of 1 244 Mbit/s upstream direction

Items	Unit	Single fibre			Dual fibre		
ONU transmitter (optical interface O_{ru})							
Nominal bit rate	Mbit/s	1 244.16			1 244.16		
Operating wavelength	nm	1 260-1 360			1 260-1 360		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 3			Figure 3		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	less than –6			less than –6		
Minimum ORL of ODN at O_{ru} and O_{rd} (Notes 1 and 2)	dB	more than 32			more than 32		
ODN Class		A	B	C	A	B	C
Mean launched power MIN	dBm	–3 (Note 5)	–2	+2	–3 (Note 5)	–2	+2
Mean launched power MAX	dBm	+2 (Note 5)	+3	+7	+2 (Note 5)	+3	+7
Launched optical power without input to the transmitter	dBm	less than Min sensitivity –10			less than Min sensitivity –10		
Maximum Tx enable (Note 3)	bits	16			16		
Maximum Tx disable (Note 3)	bits	16			16		
Extinction ratio	dB	more than 10			more than 10		
Tolerance to transmitter incident light power	dB	more than –15			more than –15		
MLM laser – Maximum RMS width	nm	(Note 5)			(Note 5)		
SLM Laser – Maximum –20 dB width (Note 4)	nm	1			1		
If SLM Laser – Minimum side mode suppression ratio	dB	30			30		
Jitter transfer	–	Figure 4			Figure 4		
Jitter generation from 4.0 kHz to 10.0 MHz	UI p-p	0.33			0.33		
OLT receiver (optical interface O_{lu})							
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20			less than –20		
Bit error ratio	–	less than 10^{-10}			less than 10^{-10}		
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	–24 (Note 6)	–28	–29	–24 (Note 6)	–28	–29
Minimum overload	dBm	–3 (Note 6)	–7	–8	–3 (Note 6)	–7	–8

Table 2f-1 – Optical interface parameters of 1 244 Mbit/s upstream direction

Items	Unit	Single fibre	Dual fibre
Consecutive identical digit immunity	Bit	more than 72	More than 72
Jitter tolerance	–	NA	NA
Tolerance to the reflected optical power	dB	less than 10	less than 10

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I of [ITU-T G.983.1].

NOTE 2 – The values of ONU transmitter reflectance if the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II of [ITU-T G.983.1].

NOTE 3 – As defined in clause 8.2.6.3.1.

NOTE 4 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in [b-ITU-T G.957].

NOTE 5 – While MLM laser types are not applicable to support the full ODN fibre distance of Table 2a, such lasers can be used if the maximum ODN fibre distance between R/S and S/R is restricted to 10 km. The MLM laser types of Table 2e can be employed to support this restricted fibre distance at 1 244.16 Mbit/s. These laser types are subject to the same conditions as indicated in Note 5 of Table 2e.

NOTE 6 – These values assume the use of a PIN-based receiver at the OLT for Class A. Depending on the number of ONUs connected to the OLT, an alternative implementation from a cost point of view could be based on an APD-based receiver at the OLT, allowing it to use more economical lasers with lower fibre-coupled emitted power at the ONUs. In this case, the values for class A would be:

Mean launched power MIN ONU transmitter: –7 dBm

Mean launched power MAX ONU transmitter: –2 dBm

Minimum sensitivity OLT receiver: –28 dBm

Minimum overload OLT receiver: –7 dBm

Table 2f-2 – Optical interface parameters of 1 244 Mbit/s upstream direction, using power levelling mechanism at ONU transmitter

Items	Unit	Single fibre			Dual fibre		
ONU transmitter (optical interface O_{ru})							
ODN Class		A	B	C	A	B	C
Mean launched power MIN	dBm	–2 (Note 2)	–2	+2	–2 (Note 2)	–2	+2
Mean launched power MAX	dBm	+3 (Note 2)	+3	+7	+3 (Note 2)	+3	+7
OLT receiver (optical interface O_{lu})							
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	–23 (Note 2)	–28	–29	–23 (Note 2)	–28	–29
Minimum overload	dBm	–8 (Note 2)	–13	–14	–8 (Note 2)	–13	–14

NOTE 1– This table only indicates the parameters of Table 2f-1 that change due to the application of the power levelling mechanism at ONU transmitter, namely the launched powers of the ONU transmitter and the sensitivity and overload of the OLT receiver. All other parameters and notes are identical to those in Table 2f-1.

NOTE 2 – These values assume the use of a PIN-based receiver at the OLT for Class A. Depending on the number of ONUs connected to the OLT, an alternative implementation from a cost point of view could be based on an APD-based receiver at the OLT, allowing it to use more economical lasers with lower fibre-coupled emitted power at the ONUs. In this case, the values for class A would be:

Mean launched power MIN ONU transmitter: –7 dBm

Mean launched power MAX ONU transmitter: –2 dBm

Minimum sensitivity OLT receiver: –28 dBm

Minimum overload OLT receiver: –10 dBm

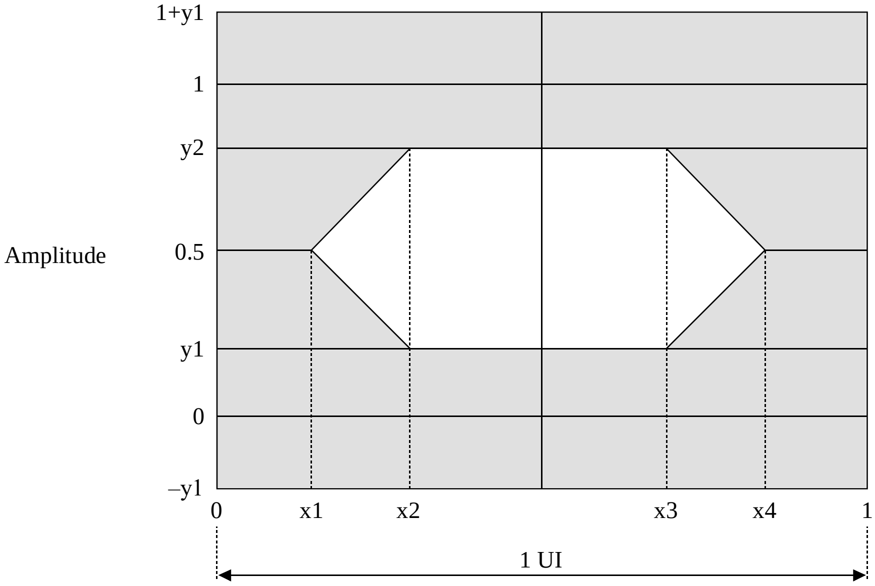
The impact of power levelling is less, due to the restriction on the minimal power to be emitted to guarantee the eye-diagram.

Table 2g-1 – Optical interface parameters of 2 488 Mbit/s upstream direction

Items	Unit	Single fibre			Dual fibre		
ONU transmitter (optical interface O_{ru})							
Nominal bit rate	Mbit/s	2 488.32			2 488.32		
Operating wavelength	nm	1 260-1 360			1 260-1 360		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 3			Figure 3		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	FFS			FFS		
Minimum ORL of ODN at O_{ru} and O_{rd}	dB	FFS			FFS		
ODN Class		A	B	C	A	B	C
Mean launched power MIN	dBm	FFS	FFS	FFS	FFS	FFS	FFS
Mean launched power MAX	dBm	FFS	FFS	FFS	FFS	FFS	FFS
Launched optical power without input to the transmitter	dBm	FFS			FFS		
Maximum Tx enable (Note 2)	bits	32			32		
Maximum Tx disable (Note 2)	bits	32			32		
Extinction ratio	dB	FFS			FFS		
Tolerance to the transmitter incident light power	dB	FFS			FFS		
If MLM laser – Maximum RMS width	nm	FFS			FFS		
If SLM laser – Maximum –20 dB width	nm	FFS			FFS		
If SLM Laser – Minimum side mode suppression ratio	dB	FFS			FFS		
Jitter transfer	–	Figure 4			Figure 4		
Jitter generation (measurement frequency range is FFS)	UI p-p	FFS			FFS		
OLT receiver (optical interface O_{lu})							
Maximum reflectance of equipment, measured at receiver wavelength	dB	FFS			FFS		
Bit error ratio	–	FFS			FFS		
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	FFS	FFS	FFS	FFS	FFS	FFS
Minimum overload	dBm	FFS	FFS	FFS	FFS	FFS	FFS
Consecutive identical digit immunity	Bit	FFS			FFS		
Jitter tolerance	–	FFS			FFS		
Tolerance to the reflected optical power	dB	FFS			FFS		
NOTE 1 – FFS: for further study. NOTE 2 – As defined in clause 8.2.6.3.1.							

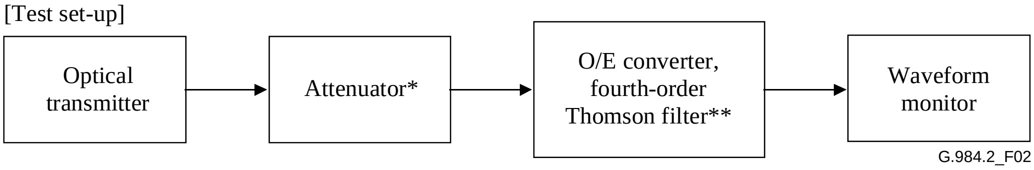
Table 2g-2 – Optical interface parameters of 2 488 Mbit/s upstream direction, using power levelling mechanism at ONU transmitter

Items	Unit	Single fibre			Dual fibre		
		ONU transmitter (optical interface O_{ru})					
ODN Class		A	B	C	A	B	C
Mean launched power MIN	dBm	FFS	FFS	FFS	FFS	FFS	FFS
Mean launched power MAX	dBm	FFS	FFS	FFS	FFS	FFS	FFS
		OLT receiver (optical interface O_{lu})					
ODN Class		A	B	C	A	B	C
Minimum sensitivity	dBm	FFS	FFS	FFS	FFS	FFS	FFS
Minimum overload	dBm	FFS	FFS	FFS	FFS	FFS	FFS
NOTE – This table only indicates the parameters of Table 2g-1 that change due to the application of the power levelling mechanism at the ONU transmitter, namely the launched powers of the ONU transmitter and the sensitivity and overload of the OLT receiver. All other parameters and notes are identical to those of Table 2g-1.							



	1244.16 Mbit/s	2488.32 Mbit/s
x1/x4	0.28/0.72	---
x2/x3	0.40/0.60	---
x3 – x2	---	0.2
y1/y2	0.20/0.80	0.25/0.75

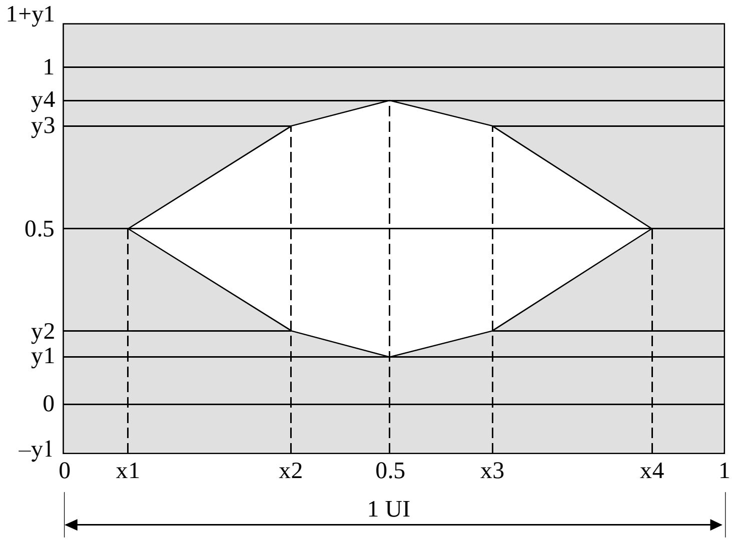
[Test set-up]



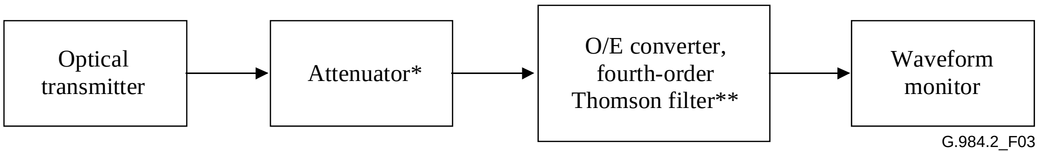
* Attenuator is used if necessary.
** Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

NOTE – In the case of 2488.32 Mbit/s, x2 and x3 of the rectangular eye mask need not be equidistant with respect to the vertical axes at 0 UI and 1 UI. The extent of this deviation is for further study.

Figure 2 – Mask of the eye diagram for the downstream transmission signal



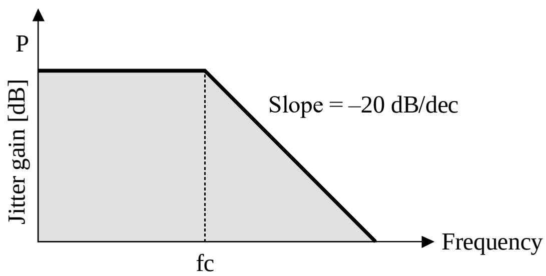
	155.52 Mbit/s	622.08 Mbit/s	1244.16 Mbit/s	2488.32 Mbit/s
x1/x4	0.10/0.90	0.20/0.80	0.22/0.78	For further study
x2/x3	0.35/0.65	0.40/0.60	0.40/0.60	For further study
y1/y4	0.13/0.87	0.15/0.85	0.17/0.83	For further study
y2/y3	0.20/0.80	0.20/0.80	0.20/0.80	For further study



* Attenuator is used if necessary.

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

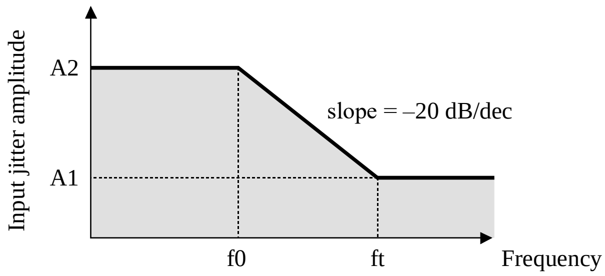
Figure 3 – Mask of the eye diagram for the upstream transmission signal



Downstream bit rate (Mbit/s)	fc [kHz]	P [dB]
1244.16	1000	0.1
2488.32	2000	0.1

G.984.2_F04

Figure 4 – Jitter transfer for ONU



Downstream bit rate (Mbit/s)	ft [kHz]	f0 [kHz]	A1 [UIp-p]	A2 [UIp-p]
1244.16	500	50	0.075	0.75
2488.32	1000	100	0.075	0.75

G.984.2_F05

Figure 5 – Jitter tolerance mask for ONU

8.3 Interaction between GPON PMD layer and TC layer

As previously stated, this Recommendation describes characteristics of the PMD layer of an OAN with the capability of transporting various services between the user network interface and the SNI. However, some GPON functionalities belong to or have impact on both the PMD layer and TC layer. Clauses 8.3.1 to 8.3.3 describe those functionalities and explain the relation between the GPON PMD layer and TC layer. The latter is specified in [ITU-T G.984.3].

8.3.1 Forward error correction

Systems employing forward error correction (FEC) will be able to support the ODN attenuation ranges of Table 2a with lower performance transmitters and receivers than indicated in Table 2b to g-2.

The effective optical gain *G* of systems employing FEC is defined as the difference of optical power at the receiver input, with and without FEC, for a BER of 1×10^{-10}.

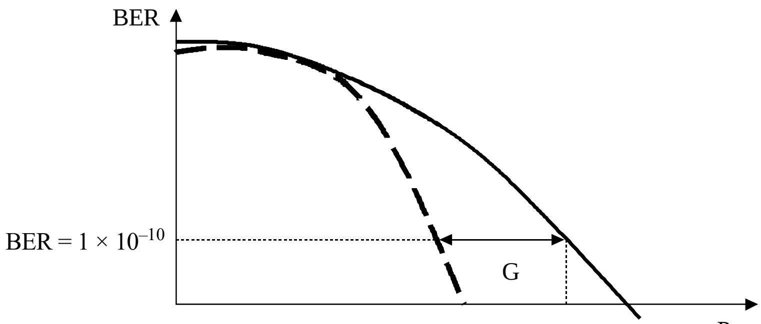


Figure 6 – Effective optical gain *G* achieved with FEC

In systems employing FEC with an effective optical gain, *G*, expressed in decibels, either of the two following performance variations from Table 2 are acceptable (but not both, to facilitate interoperability):

i) minimum and maximum transmitter power may be reduced by *G*; or

ii) minimum receiver sensitivity may be decreased by *G*.

Alternatively, while maintaining the same performance of transmitters and receivers indicated in Table 2b to g-2, the effective optical coding gain *G* can be used to achieve a longer physical reach or a higher split ratio when using an MLM laser in the ONU. In this case, FEC is used to reduce the penalty due to MPN.

FEC is implemented at the TC layer, therefore, it is not described in this Recommendation.

The receiver overload specification is not altered by FEC gain.

8.3.2 Power levelling mechanism at ONU transmitter

The OLT receiver requirements dictate the use of APD-based implementations at 1 244.16 Mbit/s and above. Such receivers must provide both a high sensitivity and a large dynamic range for a burst-mode reception at high bit rates. This imposes a compromise for the multiplication factor *M* of the APD-based receiver, which is not straightforward, particularly for GPON supporting the enhancement band where the requirements rise further due to the losses and loss variations of the extra WDM components.

In order to relax the dynamic range of the OLT receiver, the transmitter power level of the ONUs experiencing a low ODN loss should be reduced in order to avoid overload of the OLT receiver. For this reason, a suitable power levelling mechanism has to be implemented.

The power levelling mechanism requires functionalities belonging to the TC layer, such as the ONU capability to increase/reduce the transmitted power on the basis of downstream messages sent by the OLT. Such functionalities, as well as the capability to perform power levelling during initialization or also during operation, are not described in this Recommendation.

The requirements at the PMD layer to allow a suitable power levelling mechanism for GPON systems are reported in the following. The background for the requirements is described in Appendix II.

a) The ONU output power can have three modes. The PMD can be locally directed to operate in any mode. Upon such a control input, the PMD will perform whatever actions it needs to take in order to achieve an output power that lies within the range specified in the following:

   Mode 0: Normal (mean launched MIN/MAX as stated in Table 2f-2 and g-2)

   Mode 1: Low 1 = Normal − 3 dB

   Mode 2: Low 2 = Normal − 6dB

b) The OLT measures the average optical power, *P*, of each ONU burst. The OLT compares this measurement to one or two thresholds (TL (threshold low) and TH (threshold high)), and issues one of three indications as shown:

   P > TH: power_high indication

   P < TL: power_low indication

   TL < P <TH: power_ok indication

   NOTE – TL is required (single threshold operation), TH is an optional requirement (double threshold operation).

   The uncertainty range on the threshold comparison must be maximum 4 dB.

c) Taking into account the values of the optical power corresponding to the OLT receiver (Rx) minimum sensitivity P_{ms} and minimum overload P_{mo} stated in Table 2f-2 and g-2, the values of TH and TL must satisfy the following conditions:

   Double threshold operation:

   R1: P_{mo} > TH > (P_{mo} − 4 dB)

   R2: (P_{ms} + 5 dB) > TL > (P_{ms} + 1 dB)

   R3: TH − TL > 8 dB.

   Single threshold operation:

R2: (P_{ms} + 7 dB) > TL > (P_{ms} + 1 dB).

d) The OLT Rx must be able to measure the burst power (but not reliably read the data) at sensitivity − 5 dB (see Table 2f-2 and g-2).

The benefits of the power levelling mechanism are as follows.

- Reduced dynamic range requirement at the OLT receiver, as an ONU at low ODN loss will be set at a low transmitter power.
- Increase of laser lifetime and reduction of power consumption when an ONU is working in low-power mode.

The power levelling mechanism allows the relaxation of the requirements for the OLT receiver, as indicated in Table 2f-2 and g-2.

8.3.3 Upstream physical layer overhead

The GPON frame structure is described in [ITU-T G.984.3], 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 GPON. Table 3 shows the length of the physical layer overhead for all the upstream bit rates specified in this Recommendation.

Table 3 – GPON upstream physical layer overhead

Upstream bit rate Mbit/s	**Overhead bytes**
155.52	4
622.08	8
1 244.16	12
2 488.32	24

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

Annex A

Industry best practice for 2.488 Gbit/s downstream, 1.244 Gbit/s upstream GPON class B+

(This annex forms an integral part of this Recommendation.)

A.1 Introduction

The widespread interest in the 2.4 Gbit/s downstream, 1.2 Gbit/s upstream GPON system has provided increased visibility into the feasibility of loss budgets for this system. This annex describes industry best practices for this rate combination.

The notable variations from the loss budgets found elsewhere in this Recommendation include:

- overall loss budgets midway between class B and class C;
- different value of optical path penalties;
- the OLT must support FEC in the downstream.

These variations can provide increased capabilities for operation of GPON systems. Therefore, the budgets contained in this annex are recommended over and above all others in this Recommendation for the 2.4/1.2 Gbit/s rate PON. This budget is named B+.

A.2 System applications

There are currently two major applications for the GPON system. The first is a full-service system with a video overlay. The second is a digital-only system without a video overlay. These two applications are illustrated in Figure III.1.

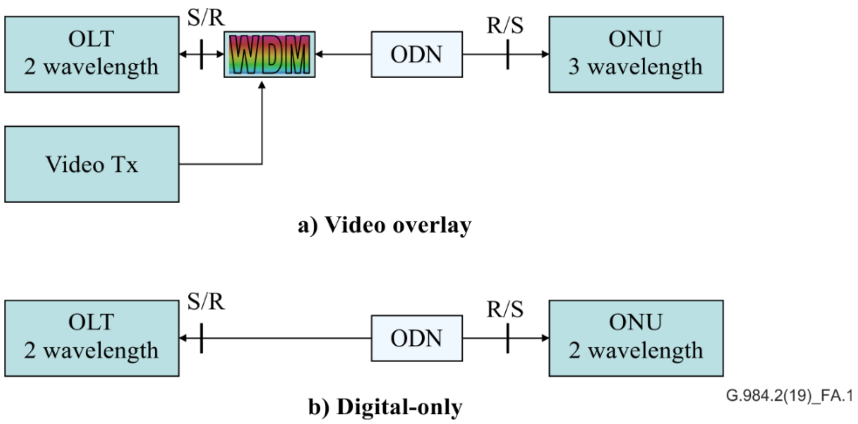


Figure A.1 – GPON applications

A.3 Optical specifications

The optical specifications for the OLT and ONU optics are given in Table A.1, which refers to power levels measured at the interface points shown in Figure A.1, i.e., both types a (video overlay) and b (digital-only) systems. Specifically, any WDM filters external to the OLT or ONU equipment are considered part of the ODN. These specifications are meant to augment similar specifications found in Table 2. All other specifications found elsewhere in Table 2 still apply.

The ONU sensitivity can be achieved either using an APD without FEC or a PIN with FEC. The choice is a matter of ONU implementation. The APD solution is seen as an immediately available option, while the PIN with FEC solution is a longer-term option that depends on the introduction of higher performance receiver circuitry. The OLT must support FEC in the downstream by having the capability of calculating and transmitting the FEC parity bytes in the downstream signal. The OLT equipment must also have the ability to activate or deactivate the downstream FEC feature by operations system command. The ONU can optionally support FEC decoding in the downstream, and in any specific instance the ONU can use the FEC parity at its own discretion.

The optical penalty does not include any Raman impairment in the downstream wavelength. Any penalty due to this effect must be accounted for out of the link budget. However, any system with an appreciable Raman effect will also have a significant length of fibre. Because of the loss differential between 1 490 nm and 1 310 nm, it is anticipated that the Raman impairment will be compensated by the lower fibre loss at 1 490 nm.

Table A.1 – B+ Optical power levels for the 2.4 Gbit/s downstream, 1.2 Gbit/s upstream system

Items	Unit	Single fibre
OLT:		**OLT**
Mean launched power MIN	dBm	+1.5
Mean launched power MAX	dBm	+5
Minimum sensitivity	dBm	−28
Minimum overload	dBm	−8
Downstream optical penalty	dB	0.5
ONU:		**ONU**
Mean launched power MIN	dBm	+0.5
Mean launched power MAX	dBm	+5
Minimum sensitivity	dBm	−27
Minimum overload	dBm	−8
Upstream optical penalty	dB	0.5

A.4 Link budget

The link budget is given in Table A.2. This budget covers all optical components between the OLT and ONU, including non-integrated WDM filters for the multiplex of video overlays and other enhancement band services, and must include any Raman impairment from the overlay signal.

Table A.2 – B+ loss budgets for the GPON system

Items	Unit	Single fibre
Minimum optical loss at 1 490 nm	dB	13
Minimum optical loss at 1 310 nm	dB	13
Maximum optical loss at 1 490 nm	dB	28
Maximum optical loss at 1 310 nm	dB	28

In comparison, the broadband passive optical network (BPON) class B+ budgets recommended in [ITU-T G.983.3] are shown in Table A.3. The GPON budget is similar to the video overlay system in that it supports a 13 dB minimum loss, and it is similar to the digital-only budget in that it is symmetric and it supports a 28 dB maximum loss. It is theoretically possible that a PON that complies with the BPON B+ budgets might not comply with the GPON budget; however, such cases should be very rare in the actual deployed base of PONs. Therefore, the GPON budget should be compatible with practically all deployed PONs.

Table A.3 – Loss budgets for the BPON [ITU-T G.983.3] systems

Items	Unit	Single fibre
Video overlay system (OLT1-ONT)		
Minimum optical loss at 1 490 nm	dB	9
Minimum optical loss at 1 310 nm	dB	13
Maximum optical loss at 1 490 nm	dB	27
Maximum optical loss at 1 310 nm	dB	29
Digital-only system (OLT2-ONT)		
Minimum optical loss at 1 490 nm	dB	10
Minimum optical loss at 1 310 nm	dB	10
Maximum optical loss at 1 490 nm	dB	28
Maximum optical loss at 1 310 nm	dB	28

Annex B

Description of physical layer measurements to support optical layer supervision

(This annex forms an integral part of this Recommendation.)

B.1 Introduction

This annex describes physical layer parameter measurements that are required to provide the GPON system with a basic optical layer supervision capability. The quantities to be measured are enumerated, along with the desired range, accuracy and resolution. These measurements can be obtained by different practical and cost-effective monitoring methods, and the method of measurement is left to implementation choice.

B.2 Transceiver parameters monitoring

In PON systems, physical monitoring for OLS may be used for the following.

1) Normal status monitoring: Get and buffer "historic" data as a reference in a normally working system.
2) Degradation detection: Find the potential faults before they become service-affecting, and identify the source of the problem (e.g., ODN, OLT or ONT).
3) Fault management: Detect, localize and diagnose faults.

In order to achieve these objectives, the following performance items should be monitored in a PON system.

– Transceiver temperature (OLT and ONT);
– Transceiver voltage (OLT and ONT);
– Laser bias current (OLT and ONT);
– OLT transmit power;
– OLT receive power (per ONT);
– ONT transmit power;
– ONT receive power.

Clause B.3 specifies recommended measurement performance parameters for each of these transceiver performance measurements.

NOTE – These are obtainable using currently available detection and monitoring technology.

B.3 Measurement table for transceiver parameters

Table B.1 gives information on the standard measurement performance that should be obtainable with measurement equipment embedded in the OLT or ONTs.

NOTE – The values specified in Table B.1 pertain to the measurement, and not the reporting, of data. Therefore, the resolution mainly refers to the intrinsic quantization size of the measurement circuit, and not the message field format of the report. The typical RT refers to the timeliness of the measurement circuit in the optical module, and not to the actual reporting of data over the PON or to the element management system (EMS).

Table B.1 – Optical line supervision-related measurement specifications

	Typical range [Note 1]	Resolution	Accuracy	Repeatability	Typical response time
Temperature – OLT and ONT	–45 to +90 C	0.25 C	±3 C	±1 C	1 s
Voltage – OLT and ONT [Note 4]	0 to 6.55 V	0.5% of nominal	±3% of nominal	±1% of nominal	1 s
Bias current – OLT and ONT [Note 4]	0 to 131 mA	1% of nominal	±10% of nominal	±5% of nominal	1 s
ONT transmit power	–10 to +8 dBm	0.1 dB	±3 dB	±0.5 dB [Note 2]	300 ns
ONT receive power	–34 to –8 dBm	0.1 dB	±3 dB	±0.5 dB [Note 2]	300 ns
OLT transmit power	–10 to +9 dBm	0.1 dB	±2 dB	±0.5 dB [Note 2]	300 ns
OLT receive power [Note 3]	–34 to –8 dBm	0.1 dB	±2 dB	±0.5 dB [Note 2]	300 ns

NOTE 1 – The typical range attempts to capture the most common range of parameters of an operational optical module. If a module has a different operational range, then the measurement range should follow that range, augmented by the measurement inaccuracy on either end.

NOTE 2 – ONT and OLT optical repeatability refers to multiple measurements taken when the true values of the ONT or OLT temperature and voltage are the same at the time of measurement. However, the normal range of those parameters should be exercised in between tests as a means to gauge their aging effects.

NOTE 3 – The measurement of the OLT should reflect the average power received during a burst. This requires the OLT to perform the measurement at the proper time with respect to the incoming burst, and that said burst is long enough to support the response time of the detector. The deviation due to non-50% duty cycle in the upstream data pattern is not to be charged against the measurement accuracy or repeatability specifications.

NOTE 4 – Nominal refers to the design value of the quantity being measured (i.e., voltage or bias current) for the particular device implementation.

B.4 OLS physical layer performance measurements requirements

All parameters in clauses B.2 and B.3 should be monitored continuously in real time in order to reflect the actual quality of physical links and operational status of optical modules. Moreover, the monitoring process should not significantly degrade the normal service transmissions.

Appendix I

Allocation of the physical layer overhead time

(This appendix forms an integral part of this Recommendation.)

The physical layer overhead (T_{plo}) time 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 with which the OLT must comply, and suggests values for the discretionary values.

As shown in Table I.2, specific values for T_{on}, T_{off}, and T_{plo} are given for the different data rates. T_{plo} can be divided into three sections with respect to what ONT data pattern is desired. For simplicity, these times can be referred to as the guard time (T_g), the preamble time (T_p) and the delimiter time (T_d). During T_g, the ONT will transmit no more power that the nominal zero level. During T_p, the ONT will transmit a preamble pattern that provides maximal transition density for fast level and clock recovery functions. Lastly, during T_d, the ONT 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 (T_u). This uncertainty arises from variations of the time of flight caused by fibre and component variations with temperature and other environmental factors.

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

$$T_g > T_{on} + T_u \text{, and}$$

$$T_g > T_{off} + T_u$$

T_d 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:

$$E = \text{int}\left(N/4\right) - 1 \tag{I-1}$$

Equation I-1 has been empirically verified by a numerical search of all the delimiters of sizes ranging from 8 to 20 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 0s and 1s. The Hamming distance, D, of the best delimiter from all shifted patterns of itself and the preamble was found to be $D = \text{int}(N/2) - 1$; yielding the error tolerance shown.

Given a certain bit error rate (BER), the probability of a severely errored burst (P_{seb}) is given by:

$$P_{seb} = \left(\frac{N}{E+1}\right)\text{BER}^{E+1} \tag{I-2}$$

Substituting Equation I-1 into Equation I-2, the resultant P_{seb} is given by:

$$P_{seb} = \left[\frac{N}{\text{int}\left(N/4\right)}\right]\text{BER}^{\text{int}(N/4)} \tag{I-3}$$

If the BER equals $1E-4$, the resultant P_{seb} for various delimiter lengths, N, are given in Table I.1. Inspection of Table I.1 shows that, in order to suppress this kind of error, the delimiter length must be at least 16 bits, if not more.

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

N	P_{seb}
8	$2.8E-07$
12	$2.2E-10$
16	$1.8E-13$
20	$1.5E-16$
24	$1.3E-19$

With these considerations taken into account, the recommended allocations of the physical layer overhead are given in Table I.2, which also lists the normative values for the ONT Tx enable time and Tx disable time, as well as the total physical layer overhead time for reference.

Table I.2 – Recommended allocation of burst mode overhead time for OLT functions

Upstream data rate (Mbit/s)	**Tx enable** (bits)	**Tx disable** (bits)	**Total time** (bits)	**Guard time** (bits)	**Preamble time** (bits)	**Delimiter time** (bits)
155.52	2	2	32	6	10	16
622.08	8	8	64	16	28	20
1 244.16	16	16	96	32	44	20
2 488.32	32	32	192	64	108	20
Notes	Maximum	Maximum	Mandatory	Minimum	Suggested	Suggested

Appendix II

Description and examples of power levelling mechanism

(This appendix forms an integral part of this Recommendation.)

II.1 Introduction

This appendix illustrates the different considerations that have to be taken into account in order to perform a stable and efficient power levelling mechanism. They lead to the requirements of clause 8.3.2.

II.2 ONU levels

The ONU transmitter power (mean launched MIN and MAX) is described in Table 2f-2 and g-2. These values correspond to mode 0. The values corresponding to mode 1 and mode 2 are 3 dB and 6 dB lower, respectively. As an example, a class B ONU for 1 244 Mbit/s with power levelling capability will comply to the following output power ranges:

Mode 0: MIN = −2 dBm ≤ mean launched power ≤ MAX = +3 dBm

Mode 1: MIN = −5 dBm ≤ mean launched power ≤ MAX = 0 dBm

Mode 2: MIN = −8 dBm ≤ mean launched power ≤ MAX = −3 dBm

The power levelling mechanism is under control of the OLT and determines the necessary level changes. When an ONU receives an order to change from one mode to another, it will be able to set its emitted power to the corresponding range of the new mode and will then resume sending upstream data. Note that as long as the ranges are respected, the effective change of ONU power from one mode to another does not necessarily have to be equal to the 3 dB or 6 dB step.

Example 1

- An ONU in mode 1 is emitting at −1 dBm.
- This ONU receives a message to go to mode 0 (increase setting by +3 dB).
- The effective emitted power is now +1 dBm, not exactly 3 dB higher, but within the range of mode 0.

Example 2

- An ONU in mode 2 is emitting at −4 dBm.
- The ONU receives a message to go to mode 1 (increase setting by +3 dB).
- The effective emitted power is now −5 dBm, lower than the previous power, but within the range of mode 1.
- The OLT will measure a lower power while it expected a higher power. The algorithm in the OLT will therefore send another command to increase by 3 dB (go to mode 0).
- The ONU will now emit within the range of mode 0, which is min. −2 dBm.

II.3 Thresholds at OLT

The OLT receiver measures the incoming power level for a particular ONU and compares it to thresholds. There will be an uncertainty on this measurement, due to implementation-specific inaccuracies (current sources, linearity of receiver at high power, supply voltage variations, temperature effects on the electrical amplifier stages, etc.). This translates into uncertainties on the effective threshold value when compared to its setting. These uncertainties have to be taken into account to guarantee a comprehensive and stable power levelling mechanism. The uncertainty range over which the threshold can vary over the full operational range of the OLT is required to be max. 4 dB.

Taking into account the values of the optical power corresponding to the OLT Rx minimum sensitivity P_{ms} and minimum overload P_{mo} stated in Table 2f-2 and g-2, the allowed power range at the OLT receiver for correct operation is then (P_{ms} + 1 dB) through P_{mo}. Note that P_{ms} includes a 1 dB penalty (see clause 8.2.8.3), which does not have to be considered for the minimal optical power. A correct power at the OLT receiver must be guaranteed by the power levelling mechanism. There are two cases for the mechanism: single threshold and double threshold.

II.3.1 Case 1: Comparison to two thresholds (TL, TH)

In this case, the power levelling mechanism is implemented by comparing the received average power at the OLT (P) to two different thresholds (TL and TH). When P < TL, the power at the OLT is considered too low and the ONU must go to a higher mode. When P > TH, the power at the OLT is considered too high and the ONU must go to a lower mode. When TH > P > TL, the power at the OLT is considered fine and the ONU can be kept at its current mode.

1) The effective value of TH must guarantee the following.
   - Any power level above the OLT receiver overload is detected: P_{mo} > TH.
   - If an ONU goes into a lower mode because P > TH, the OLT receiver may not go below sensitivity:

     $TH > P_{mo} - [(P_{mo} - P_{ms} - 1\ dB) - 3\ dB - (P_{ONU\ Tx\ MAX} - P_{ONU\ Tx\ MIN})]$.

     This is equal to: TH > P_{mo} −– 6 dB.
2) The effective value of TL must guarantee the following.
   - Any power level below OLT receiver sensitivity is detected: TL > P_{ms} + 1 dB.
   - If an ONU goes into a higher mode because P < TL, the OLT receiver may not go into overload:

     $(P_{ms} + 1\ dB) + [(P_{mo} - P_{ms} - 1\ dB) - 3\ dB - (P_{ONU\ Tx\ MAX} - P_{ONU\ Tx\ MIN})] > TL$.

     This is equivalent to: P_{ms} + 7 dB > TL.
3) The combined effective values of TL and TH must guarantee that:
   - the mechanism is stable (no repetitive toggling between modes). If an ONU changes to another mode because P < TL or P > TH, the new power level at the OLT receiver may not cross the opposite threshold. This is equivalent to defining a minimum spacing between TH and TL.

     $TH - TL > 3\ dB + (P_{ONU\ Tx\ MAX} - P_{ONU\ Tx\ MIN})$.

     This is equivalent to: TH – TL > 8 dB.

This last combined requirement tightens the individual requirements for TH and TL, as they should be spaced by at least 8 dB. Taking into account the requirement of the uncertainty margin of max. 4 dB, the best fit for the first and second requirements (largest spacing between TH and TL) then becomes:

R1: P_{mo} > TH > P_{mo} − 4 dB.

R2: P_{ms} + 5 dB > TL > P_{ms} + 1 dB.

As R1 and R2 only guarantee a spacing of 6 dB, the third requirement must also be kept:

R3: TH − TL > 8 dB.

R1, R2 and R3 together allow for a variation of TH and TL over 4 dB over the full operational range of the OLT (temperature, ...) but require at any moment that TH and TL be spaced by at least 8 dB.

If an OLT has a more precise power measurement than 4 dB, any combination of TH and TL can be chosen as long as R1, R2 and R3 are respected.

II.3.2 Case 2: Comparison to one threshold (TL)

The power levelling mechanism is implemented by starting all ONUs at mode 2 (during their initialization) and comparing the received average power at the OLT (P) to one threshold (TL). When P < TL, the power at the OLT is considered too low and the ONU must go to a higher mode. When P > TL, the power at the OLT is considered fine and the ONU can be kept in its current mode.

The effective value of TL must guarantee the following.

- Any power level under OLT receiver sensitivity is detected: TL > P_{ms} + 1 dB.
- If an ONU goes into a higher mode because P < TL, the OLT receiver may not go into overload:

  $(P_{ms} + 1\text{ dB}) + [(P_{mo} - P_{ms} - 1\text{ dB}) - 3\text{ dB} - (P_{ONU\ Tx\ MAX} - P_{ONU\ Tx\ MIN})] > \text{TL}$.

  This is equal to: P_{ms} + 7 dB > TL.

Therefore the requirement for the effective level TL is:

R2: P_{ms} + 7 dB > TL > P_{ms} + 1 dB.

With an uncertainty range of 4 dB, this leaves a choice for the TL setting:

Example 1 for class B at 1 244 Mbit/s: –23 dBm > TL > –27 dBm;

Example 2 for class B at 1 244 Mbit/s: –21 dBm > TL > –25 dBm.

II.4 Power detection

In order to initialize new ONUs, the OLT periodically opens ranging windows during which new ONUs can send upstream bursts. The OLT must be able to detect the presence of any new ONU. This implies that when new ONUs start at mode 2, the OLT must be capable to detect (but not necessarily read data at) an optical power as weak as (P_{ms} + 1 dB) − 6 dB = P_{ms} − 5 dB.

Appendix III

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

The material formerly in Appendix III is now contained in Annex A.

Appendix IV

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

The material formerly in Appendix IV is now contained in Annex B.

Appendix V

Industry best practice for single-sided extended 2.488 Gbit/s downstream, 1.244 Gbit/s upstream GPON (class C+ and class D)

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

V.1 Introduction

The single-sided extended 2.488/1.244 Gbit/s GPON is achieved by using a more capable OLT interface. This interface would have all the characteristics of the existing S/R interface, with the exception of certain OLT optical parameters, as listed in Table V.1 (for class C+) or Table V.2 (for class D). Note that the ONU specifications should be achievable with ONU optics that are substantially similar to those described in Annex A, except for the difference in upstream wavelength (described in [ITU-T G.984.5]) and operation with FEC (described in [ITU-T G.984.3]).

Table V.1 – Optical power levels for the 2.488 Gbit/s downstream, 1.244 Gbit/s upstream single-sided reach extended system (Class C+)

Item	Unit	Single fibre
Reach-extended OLT:		**OLT**
Mean launched power MIN	dBm	+3
Mean launched power MAX	dBm	+7
Downstream optical penalty	dB	1
Bit error ratio (pre-FEC) [Note 1]		10^{-4}
Minimum sensitivity [Note 1]	dBm	−32
Minimum overload	dBm	−12
Upstream wavelength range [ITU-T G.984.5]	nm	1 290-1 330
ONU:	–	ONU
Mean launched power MIN	dBm	+0.5
Mean launched power MAX	dBm	+5
Upstream optical penalty	dB	0.5
Upstream wavelength range [ITU-T G.984.5]	nm	1 290-1 330
Bit error ratio (pre-FEC) [Note 2]	–	10^{-4}
Minimum sensitivity [Note 2]	dBm	−30
Minimum overload [Note 3]	dBm	−8
NOTE 1 – The OLT sensitivity assumes the use of the optional RS (255,239) FEC capability of the GPON TC layer, as well as intrinsic detector technology improvements, e.g., SOA preamplification. NOTE 2 – The ONU sensitivity assumes the use of the optional RS (255,239) FEC capability of the GPON TC layer with the current class B+ ONU detector technology. NOTE 3 – The ONU overload is set at –8 dBm to be common with the class B+ value, even though in this application –10 dBm is sufficient.		

Table V.2 – Optical power levels for the 2.488 Gbit/s downstream, 1.244 Gbit/s upstream single-sided reach extended system (Class D)

Item	Unit	Single fibre
Reach-extended OLT:		**OLT**
Mean launched power MIN	dBm	+6
Mean launched power MAX	dBm	+10
Downstream optical penalty	dB	1
Bit error ratio (pre-FEC) [Note 1]		10^{-4}
Minimum sensitivity [Note 1]	dBm	−35
Minimum overload	dBm	−15
Upstream wavelength range [ITU-T G.984.5]	nm	1 290-1 330
ONU:	–	ONU
Mean launched power MIN	dBm	+0.5
Mean launched power MAX	dBm	+5
Upstream optical penalty	dB	0.5
Upstream wavelength range [ITU-T G.984.5]	nm	1 290-1 330
Bit error ratio (pre-FEC) [Note 2]	–	10^{-4}
Minimum sensitivity [Note 2]	dBm	−30
Minimum overload [Note 3]	dBm	−8
NOTE 1 – The OLT sensitivity assumes the use of the optional RS (255,239) FEC capability of the GPON TC layer, as well as intrinsic detector technology improvements, e.g., SOA preamplification. NOTE 2 – The ONU sensitivity assumes the use of the optional RS (255,239) FEC capability of the GPON TC layer with the current class B+ ONU detector technology. NOTE 3 – The ONU overload is set at –8 dBm to be common with the class B+ value, even though in this application –10 dBm is sufficient.		

The single-sided extended ODN link budget for class C+ is given in Table V.3, and for class D is given in Table V.4. These budgets covers all optical components between the extended OLT and ONU, including non-integrated WDM filters for the multiplex of video overlays and other enhancement band services, and must include any Raman impairment from the overlay signal.

Table V.3 – Loss budgets for the single-sided extended GPON system (class C+)

Items	Unit	Single fibre
Minimum optical loss at 1 490 nm	dB	17
Minimum optical loss at 1 310 nm	dB	17
Maximum optical loss at 1 490 nm	dB	32
Maximum optical loss at 1 310 nm	dB	32
Maximum fibre length	km	60

Table V.4 – Loss budgets for the single-sided extended GPON system (class D)

Items	Unit	Single fibre
Minimum optical loss at 1 490 nm	dB	20
Minimum optical loss at 1 310 nm	dB	20
Maximum optical loss at 1 490 nm	dB	35
Maximum optical loss at 1 310 nm	dB	35
Maximum fibre length	km	60

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

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