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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

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

Recommendation ITU-T G.984.2

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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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FOREWORD

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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.

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Recommendation ITU-T G.984.2

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.

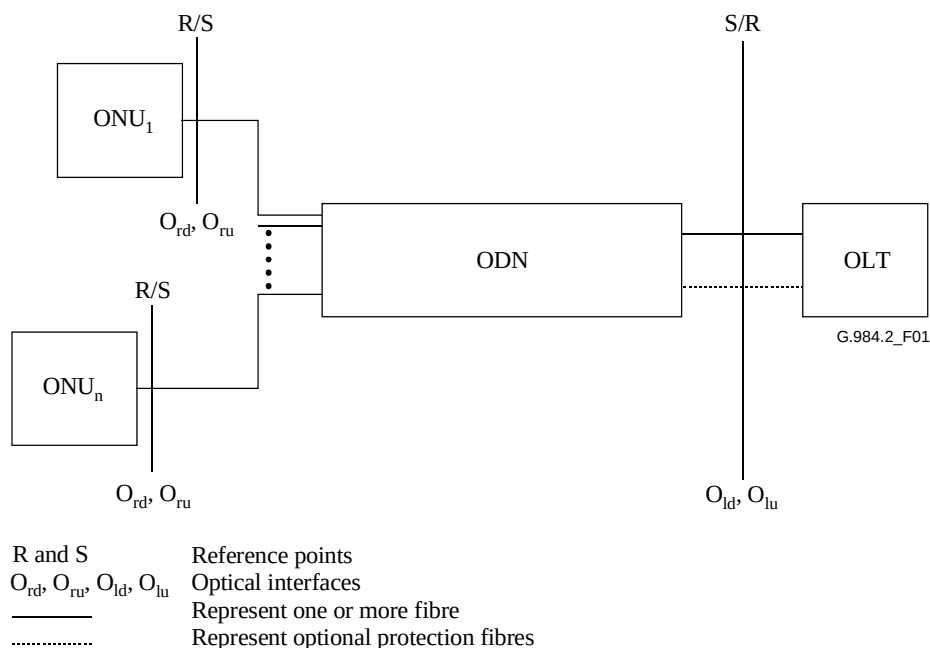


Figure 1 – Generic physical configuration of the optical distribution network

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/duplex 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].