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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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A broadband optical access system with increased service capability by wavelength allocation

ITU-T Recommendation G.983.3

(Formerly CCITT Recommendation)

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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ITU-T Recommendation G.983.3

A broadband optical access system with increased service capability by wavelength allocation

Summary

This Recommendation defines new wavelength allocations to distribute ATM-PON signals and additional service signals simultaneously. New wavelength bands for additional services are made available by constraining the current ATM-PON downstream wavelength to a portion of downstream optical spectrum originally specified in ITU-T G.983.1. The new bands have potential to provide unidirectional and bidirectional services. The wavelength allocation defined in this Recommendation enables the distribution of video broadcast services or data services. The general optical characteristics of these services are taken into account. However, the detailed specifications of these services, such as modulation scheme, signal format, and so on are beyond the scope of this Recommendation.

Source

ITU-T Recommendation G.983.3 was prepared by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 15 March 2001.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

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, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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NOTE – This Recommendation uses the term "ONU" to refer to both ONTs and ONUs. Any reference to ONUs includes ONTs as well within this Recommendation.

ITU-T Recommendation G.983.3

A broadband optical access system with increased service capability by wavelength allocation

1 Scope

This Recommendation describes some extended functions for the ATM-PON system defined in ITU-T G.983.1.

This Recommendation describes the Broadband Passive Optical Network (BPON) system that uses wavelength division multiplexing techniques (WDM). These WDM techniques allow operators to provide additional services without disturbing the basic ATM-PON system.

This Recommendation defines new wavelength allocations to distribute ATM-PON signals and additional service signals simultaneously. New wavelength bands for additional services are made available by constraining the current ATM-PON downstream wavelength to a portion of downstream optical spectrum originally specified in ITU-T G.983.1. The new bands have potential to provide unidirectional and bidirectional services. The wavelength allocation defined in this Recommendation enables the distribution of video broadcast services or data services, and the general optical characteristics of these services are taken into account. However, the detailed specifications of these services, such as modulation scheme, signal format, and so on are beyond the scope of this Recommendation.

This Recommendation defines new reference points and optical interface parameters because of the new WDM and/or optical power splitter/combining functions needed at OLT and/or ONU sites.

However, the reference points and Optical Access Network (OAN) described in this Recommendation will remain compatible with the existing ITU-T G.982 and G.983.1.

This Recommendation also defines new environmental conditions required for the ONU equipment. These conditions are required for outside plant applications of the ATM-PON system.

This Recommendation describes the relevant differences from ITU-T G.983.1. However, sections that specify the TC layer are not included in this Recommendation, because they are not relevant to WDM enhancements. The specifications of the TC layer are given by other Recommendations, such as ITU-T G.983.1.

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; all 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. References cited in ITU-T G.983.1 also apply to this Recommendation but are not reproduced here to avoid redundancy.

[1] ITU-T G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.

[2] ITU-T G.983.1 (1998), *Broadband optical access systems based on Passive Optical Networks (PON), plus* Corrigendum 1 (1999).

[3] ITU-T G.983.2 (2000), *ONT management and control interface specification for ATM PON*.

[4] ITU-T G.959.1 (2001), *Optical transport network physical layer interfaces*.

3 Abbreviations

This Recommendation uses the following abbreviations:

AF	Adaptation Function
AM-VSB	Amplitude Modulation-Vestigial Side Band
APS	Automatic Protection Switching
ATM	Asynchronous Transfer Mode
BER	Bit Error Ratio
BIP	Bit Interleaved Parity
B-ISDN	Broadband Integrated Services Digital Network
BPON	Broadband Passive Optical Networks
CID	Consecutive Identical Digit
CNR	Carrier-to-Noise Ratio
CPE	Cell Phase Error
CRC	Cyclic Redundancy Check
DSL	Digital Subscriber Line
DWDM	Dense Wavelength Division Multiplexing
E/O	Electrical/Optical
E-OLT	Enhancement Band-Optical Line Termination
E-ONU	Enhancement Band-Optical Network Unit
FP-LD	Fabry-Perot Laser Diode
FTTB/C	Fibre to the Building/Curb
FTTCab	Fibre to the Cabinet
FTTH	Fibre to the Home
HEC	Header Error Control
IEC	International Electrotechnical Commission
ISDN	Integrated Services Digital Network
LAN	Local Area Network
LCD	Loss of Cell Delineation
LCF	Laser Control Field
LSB	Least Significant Bit
LT	Line Terminal
MAC	Media Access Control
MLM	Multi-Longitudinal Mode
MSB	Most Significant Bit
NRZ	Non Return to Zero
NT	Network Termination
O/E	Optical/Electrical

OAM	Operation, Administration and Maintenance
OAN	Optical Access Network
ODF	Optical Distribution Frame
ODN	Optical Distribution Network
OLT	Optical Line Termination
ONT	Optical Network Termination
ONU	Optical Network Unit
OpS	Operations System
ORL	Optical Return Loss
PLOAM	Physical Layer OAM
PON	Passive Optical Network
PRBS	Pseudo-Random Bit Sequence
PST	PON Section Trace
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAU	Request Access Unit
RIN	Relative Intensity Noise
RMS	Root Mean Square
RXCF	Receiver Control Field
SCM	Sub-Carrier Mulitiplexing
SDH	Synchronous Digital Hierarchy
SLM	Single-Longitudinal Mode
SN	Serial Number
SNI	Service Node Interface
TC	Transmission Convergence
TDMA	Time Division Multiple Access
UI	Unit Interval
UNI	User Network Interface
UPC	Usage Parameter Control
VC	Virtual Channel
VP	Virtual Path
VPI	Virtual Path Identifier
WDM	Wavelength Division Multiplexing
WF1	Wavelength division multiplexing and/or optical combining functions 1
WF2	Wavelength division multiplexing and/or optical splitting functions 2

4 Definitions

This Recommendation defines the following terms:

4.1 diplex working: Bidirectional communication using a different wavelength for each direction of transmission over a single fibre.

4.2 duplex working: Bidirectional communication using the same wavelength for both directions of transmission over a single fibre.

4.3 logical reach: The logical reach is defined as the maximum length that can be achieved for a particular transmission system independent of optical budget.

4.4 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.

4.5 Optical Distribution Network (ODN): An ODN provides the optical transmission means from the OLT towards the users, and vice versa. It utilizes passive optical components.

4.6 Optical Line Termination (OLT): An OLT provides the network-side interface of the OAN, and is connected to one or more ODNs.

4.7 Optical Network Termination (ONT): An ONU used for FTTH and includes the User Port function.

4.8 Optical Network Unit (ONU): An ONU provides (directly or remotely) the user-side interface of the OAN, and is connected to the ODN.

4.9 user port function: The User Port Function (UPF) adapts the specific UNI requirements to the core and management functions. The AN may support a number of different accesses and user network interfaces which require specific functions according to the relevant interface specification and the access bearer capability requirements, i.e. bearers for information transfer and protocols.

4.10 verification: It is possible for a malicious user to masquerade as other ONU and use the network if the user knows that the ONU is power-off. Verification is a function to check whether the connected ONU is masqueraded by a malicious user.

4.11 Wavelength Division Multiplexing (WDM): Bidirectional multiplexing using different optical wavelength for up and downstream signals and multiplexing using different optical wavelength for Basic Band, Enhancement Band and Future Band signals.

4.12 basic band: Wavelength region allocated for the ATM-PON downstream capabilities.

4.13 enhancement band: Wavelength region allocated for new additional service capabilities, which include at least video services and Dense Wavelength Division Multiplexing (DWDM) services.

4.14 future band: Reserved wavelength region for future use.

4.15 E-OLT: OLT, which provides additional service capabilities including video services and DWDM services in Enhancement Band.

4.16 E-ONU: ONU, which provides additional service capabilities including video services and DWDM services in Enhancement Band.

4.17 WF1: WDM and/or optical combining/splitting functions, which separate/combine wavelength and/or split/combine optical power for ATM-PON transport service and additional services. It is located between ODN and the OLT.

4.18 WF2: WDM and/or optical combining/splitting functions, which separate/combine wavelength and/or split/combine optical power for ATM-PON transport service and additional services. It is located between ODN and the ONU.

4.19 WDM-L: WDM, which separate/combine 1.3 µm region and 1.5 µm region, and is located in OLT side.

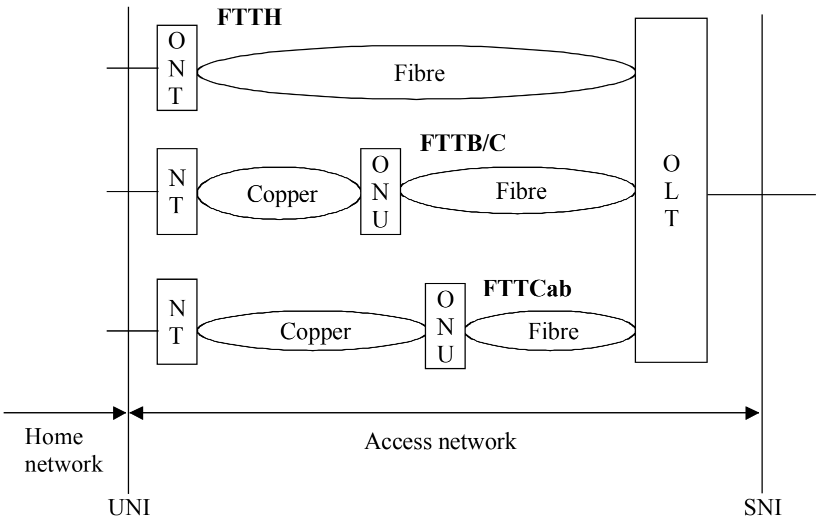
4.20 WDM-N: WDM, which separate/combine 1.3 µm region and 1.5 µm region, and is located in ONU side.

4.21 BPON: Broadband Passive Optical Network (BPON). BPONs are one-to-n broadband optical transmission systems. BPONs can transparently transport any type of data, for example voice, video, IP data, etc. The BPON is able to carry data regardless of the type of data link frame (i.e. not only native ATM but also HDL Ethernet frame, etc.).

5 Architecture of the optical access network

5.1 Network architecture

The optical section of a local access network system could be either a point-to-point, active, or passive point-to-multipoint architecture. Figure 1 shows the architectures considered, which range from Fibre to the Home (FTTH), through Fibre to the Building/Curb (FTTB/C) to Fibre to the Cabinet (FTTCab). The Optical Access Network (OAN) is common to all architectures shown in Figure 1, hence commonality in this system has the potential to generate large worldwide volumes. The FTTB/C and FTTCab network options are predominantly different only as a result of implementation, as a result they can be treated the same in this Recommendation.



ONU Optical Network Unit
ONT Optical Network Termination
OLT Optical Line Termination
NT Network Termination

Figure 1/G.983.3 – Network architecture

5.1.1 FTTCab/C/B scenario

See 5.1.1/G.983.1.

5.1.2 FTTH scenario

FTTH; Fibre to the Home service drivers are similar to those of the previous scenarios and are determined by:

– Indoor ONUs can be considered, resulting in more favourable environmental conditions.
– Some changes of intermediate ONU may be required to upgrade access network capabilities to accommodate future evolution of broadband and multimedia services.
– Maintenance is easy, because it requires maintenance only for fibre systems, and all fibre systems are regarded as more reliable than hybrid fibre-metallic ones.
– FTTH is a driver for the development of advanced optoelectronics technologies. The greater volume in production of optical modules will also accelerate the reduction in cost.

When these factors can be fully exploited they may counterbalance a slightly higher per line cost. In that situation the FTTH scenario may be regarded as economically feasible even in the short term.

5.2 Reference configuration

The general reference configuration from ITU-T G.983.1 is shown in Figure 2a.

The specific reference configuration for this Recommendation is shown in Figure 2b which provides clarification of the new specification based on the revised wavelength allocation.

The ODN offers one or more optical paths between one OLT and one or more ONUs. Each optical path is defined between reference points S and R in a specific wavelength window. The two directions for optical transmission in the ODN are identified as follows:

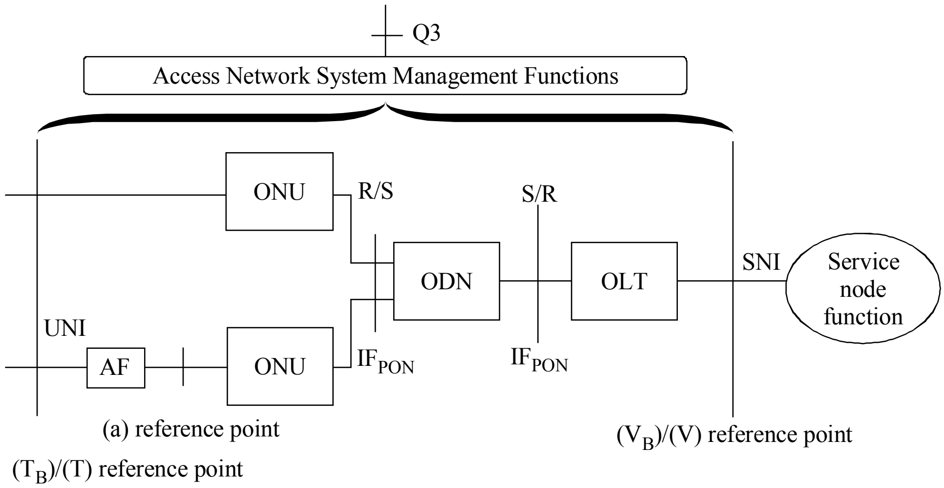
– downstream direction for signals travelling from the OLT to the ONU(s);
– upstream direction for signals travelling from the ONU(s) to the OLT.

This clause describes the reference architecture for supporting Broadband transmission over a PON. This system consists of Optical Line Termination (OLT), Optical Network Unit (ONU), Wavelength division multiplexing and/or optical combining/splitting functions (WF1 and WF2) for the new wavelength allocation plan defined in this Recommendation and fibre cable which has a Passive Optical Network (PON) configuration with a passive optical splitter.

One fibre is passively split between multiple ONUs who share the capacity of one fibre. Because of the passive splitting, special actions are required with respect to privacy and security. Moreover, in the upstream direction a TDMA protocol is required.

WF1 and WF2 are used for separating/combining wavelengths and/or splitting/combining optical power for ATM-PON transport service and additional services such as video broadcast. These may be integrated into or provided as external optical component parts connected to the OLT and the ONU. Therefore, WF1 and WF2 could be regarded as a part of the OLT and the ONU. In the case of integration into the OLT or the ONU, reference points (c) and (e) in Figure 2b are regarded as internal reference points of the OLT and the ONU respectively.

Functionality required for WF1 and WF2 will vary depending upon the particular system configuration, regulations, service strategy, and geographic conditions for each telecom operator. These configurations based on scenarios by operators are described in Appendix II.



ONU	Optical Network Unit
ODN	Optical Distribution Network
OLT	Optical Line Termination
AF	Adaptation Function
S	Point on the optical fibre just after the OLT[Downstream]/ONU[Upstream] optical connection point (i.e. optical connector or optical splice).
R	Point on the optical fibre just before the ONU[Downstream]/OLT[Upstream] optical connection point (i.e. optical connector or optical splice).
(a)	Reference point – This reference point is added to differentiate the AF from the ONU.

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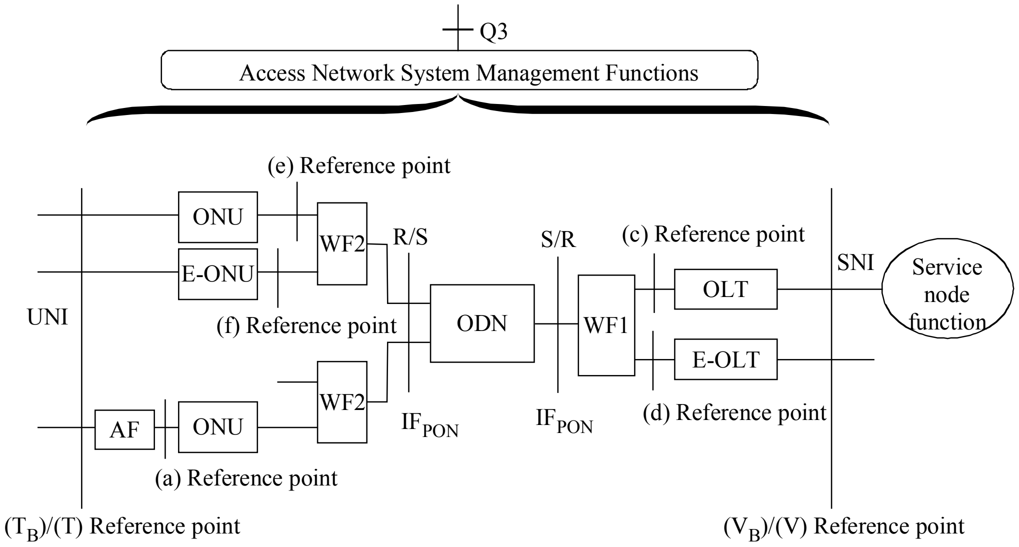
Figure 2a/G.983.3 – Reference configuration for an ATM based PON



ONU	Optical Network Unit (which may include WF2 and/or E-ONU)
E-ONU	Optical Network Unit for Enhancement Band usage (which may be integrated into ONU)
ODN	Optical Distribution Network
OLT	Optical Line Termination (which may include WF1 and/or E-OLT)
E-OLT	Optical Line Termination for Enhancement Band usage (which may be integrated into OLT)
AF	Adaptation Function
WF1	Wavelength division multiplexing and/or optical power splitting/combining Function at OLT side
WF2	Wavelength division multiplexing and/or optical power splitting/combining Function at ONU side
S	Point on the optical fibre just after the OLT[Downstream]/ONU[Upstream] optical connection point (i.e. optical connector or optical splice), assuming that WF1 and WF2 are included in the OLT and the ONU respectively.
R	Point on the optical fibre just before the ONU[Downstream]/OLT[Upstream] optical connection point (i.e. optical connector or optical splice), assuming that WF1 and WF2 are included in the OLT and the ONU respectively.
(a)	Reference point – This reference point is added to differentiate the AF from the ONU.
(b)	Intentionally not used to avoid confusion with the index of broadband.
(c)	Reference point – This reference point is added to differentiate the WF1 from the OLT.
(d)	Reference point – This reference point is added to differentiate the WF1 from the E-OLT.
(e)	Reference point – This reference point is added to differentiate the WF2 from the ONU.
(f)	Reference point – This reference point is added to differentiate the WF2 from the E-ONU.

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Figure 2b/G.983.3 – Reference configuration for a Broadband PON

5.2.1 Service Node Interface

See ITU-T G.902.

5.2.2 Interface at the reference points S/R and R/S

This interface at the reference points S/R and R/S is defined as IF$_{PON}$ This is a PON-specific interface that supports all the protocol elements necessary to allow the transmission between OLT and ONUs.

5.3 Functional blocks

See 5.3/G.983.1.

5.4 ONU functional block

As an example, the FTTH ONU is active and decouples the access network delivery mechanism from the in-house distribution. The ONU consists of ODN interface, User Port, Transmission, Services, Customers Multiplexing (MUX)/demultiplexing functions and powering, which is described in Figure 3.

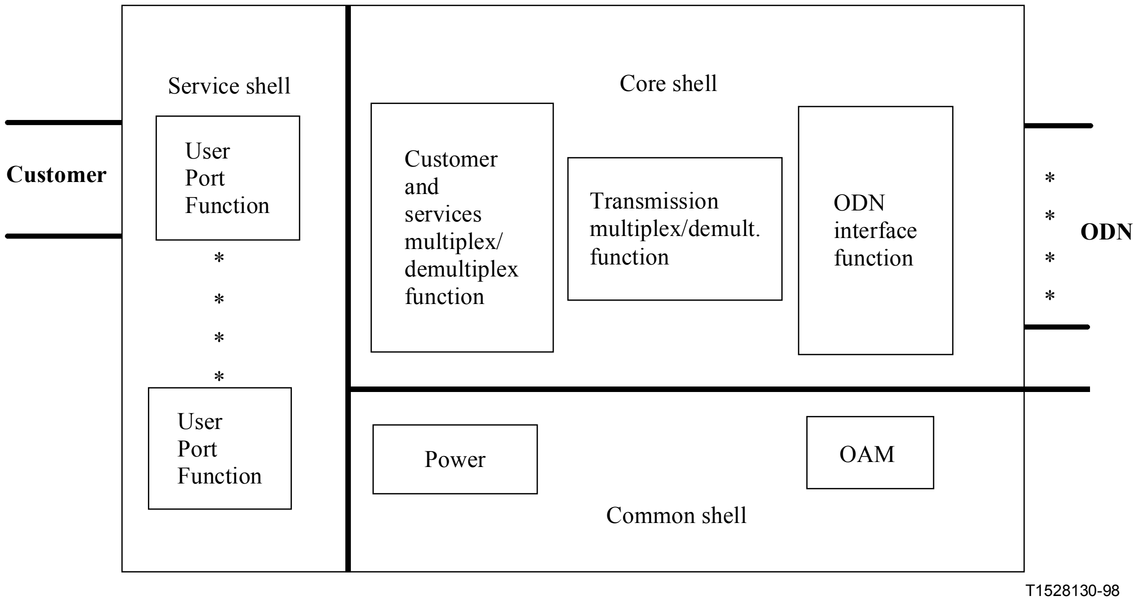


Figure 3/G.983.3 – Example of ONU functional blocks

5.4.1 Optical Distribution Network interface

The ODN interface handles the optoelectronic conversion process. The ODN interface extracts ATM cells from the downstream PON payload and inserts ATM cells into the upstream PON payload based on synchronization acquired from the downstream frame timing.

The ODN interface may handle the separation/combination of designated wavelengths and/or the optical splitter/combiner.

5.4.2 Multiplexing

Multiplexer (MUX) multiplexes service interfaces to ODN interface. Only valid ATM cells can be passed through the MUX, so many VPs can share the assigned upstream bandwidth effectively.

5.4.3 User Port

The User Port interfaces over UNI to a terminal. The User Port may handle inserting ATM cells into the upstream payload and extracting ATM cells from the downstream payload. In addition, the User Port may interface for video delivery and/or additional service from the OLT to customers.

5.4.4 ONU powering

ONU powering may be implementation dependent.

5.5 Optical Line Termination functional block

The OLT is connected to the switched networks via standardized interfaces (VB5.x, V5.x, NNI's). At the distribution side, it presents optical accesses according to the agreed requirements, in terms of bit rate, power budget, etc.

The OLT consists of three parts: the service port function; ODN interface; and MUX for VP grooming (see Figure 4). This combination is not intended to preclude the Virtual Channel (VC) layer function in the OLT. VC layer function is for further study.

1) *Service port function*

The function interfaces to service nodes. The service port function may handle inserting ATM cells into the upstream SDH payload and extracting ATM cells from the downstream SDH payload. The function may be duplicated, then a protection switching function is necessary.

2) *MUX*

The MUX provides VP connections between the service port function and the ODN interface and different VPs are assigned to different services at IF_{PON}. Various information such as main contents, signalling, and OAM flows are exchanged by using VCs of the VP.

3) *ODN interface*

The ODN interface handles the optoelectronic conversion process. The ODN interface handles inserting ATM cells into the downstream PON payload and extracting ATM cells from the upstream PON payload. In addition, the ODN interface may handle the separation/combination of designated wavelengths and/or the optical splitter/combiner.

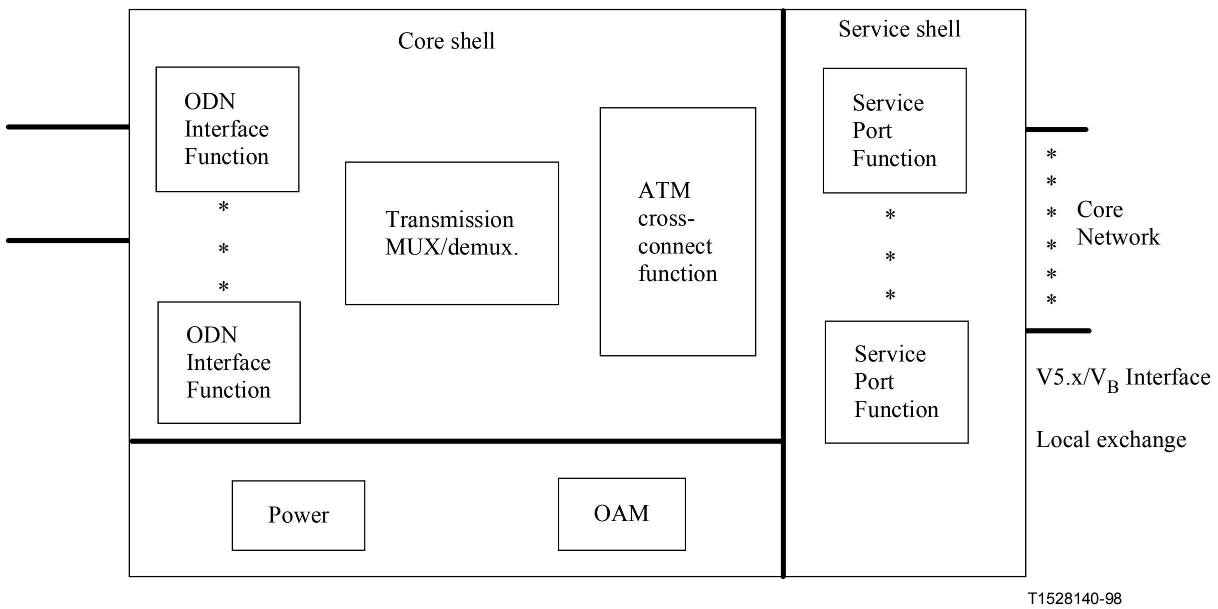


Figure 4/G.983.3 – Example of OLT functional blocks

5.6 Optical Distribution Network functional block

See 5.6/G.983.1.

6 Services

Such a high speed access system could provide the complete range of all currently known and new services being discussed for the residential subscribers and business customers. Here transmission system's service independence has to be regarded.

These services cover a broad range of network requirements like bit rate, symmetry/asymmetry or delay, and range from video distribution, with varying degrees of interactivity, to electronic data transfer, LAN interconnection, transparent Virtual Paths, and so on.

What specific services should be provided is clearer to some operators than to others and depends heavily on the particular regulatory conditions of each operators' markets, as well as on the own markets potential. How these services are delivered in a cost effective way is a function not only of legal conditions, but also of factors including existing telecommunications infrastructure, dwelling distribution and residential and business customers mix.

In spite of this varied market background there are some features which have been perceived as common to all parties. They can be summarized as follows:

– some services require bit rates higher than those supported by PSTN and basic ISDN. These services are best delivered on fibre-based or fibre hybrid networks;
– as the services evolve and newer services are introduced, the bandwidth and management requirements will increase. This requires the access network to be flexible and easily upgradable;
– additional services, such as video distribution service overlaid ATM-PON, can be provided in an appropriate manner using the WDM scheme, where necessary. The choice of video modulation type will have an impact on the system requirements, but the video modulation system is beyond the scope of this Recommendation.

7 User Network Interface and Service Node Interface

The location of UNI and SNI is preliminary given in the reference configuration (see Table 1).

Other types of services such as video broadcast are for further study.

Table 1/G.983.3 – UNI and SNI

Service type	UNI standard	SNI standard
Defined in ITU-T G.982	ITU-T G.902	ITU-T G.902
– Digital broadband video system – Multimedia services – VP leased line – ATM SVC	ITU-T I.432 IEEE 802.3	ITU-T G.967.1 ITU-T G.967.2

8 Optical network requirements

8.1 Layered structure of optical network

See 8.1/G.983.1.

8.2 Physical medium dependent layer requirements for the wavelength allocation

The wavelength of the ATM-PON downstream signal (single fibre system) is in the 1.5 μm band and that of the ATM-PON upstream signal is in the 1.3 μm band in ITU-T G.983.1. This Recommendation defines the new wavelength allocation to enable additional new services using the wavelength band defined in ITU-T G.983.1. The ATM-PON downstream wavelength band shall be compressed within the original 1.5 μm band and new wavelength bands shall be assigned for new additional services.

Figure 5 and Table 2 define the new wavelength allocation. This reduces the ATM-PON downstream allocation currently defined in ITU-T G.983.1 to a portion of the available downstream optical spectrum. This portion for the ATM-PON shall be referred to as the "Basic Band". An additional wavelength band will then be made available and be referred to as the "Enhancement Band." Uses for the Enhancement Band include at least video services and Wavelength Division Multiplexing (WDM) services. A guardband separates the Basic Band from the Enhancement Band. The interference between signals in these two bands causes signal degradation to each other, which shall be kept negligible. Required isolation between these bands depends on optical power level, modulation scheme and so on. An example of WDM filters is described in Appendix III.

The specifications for Future L Band in the 1.5 µm band, and the "Reserved for Allocation by ITU-T" band in the Intermediate region, are for further study.

NOTE – Wavelengths in Enhancement Band may be used not only for downstream but also for upstream signal transmission in the WDM scheme.

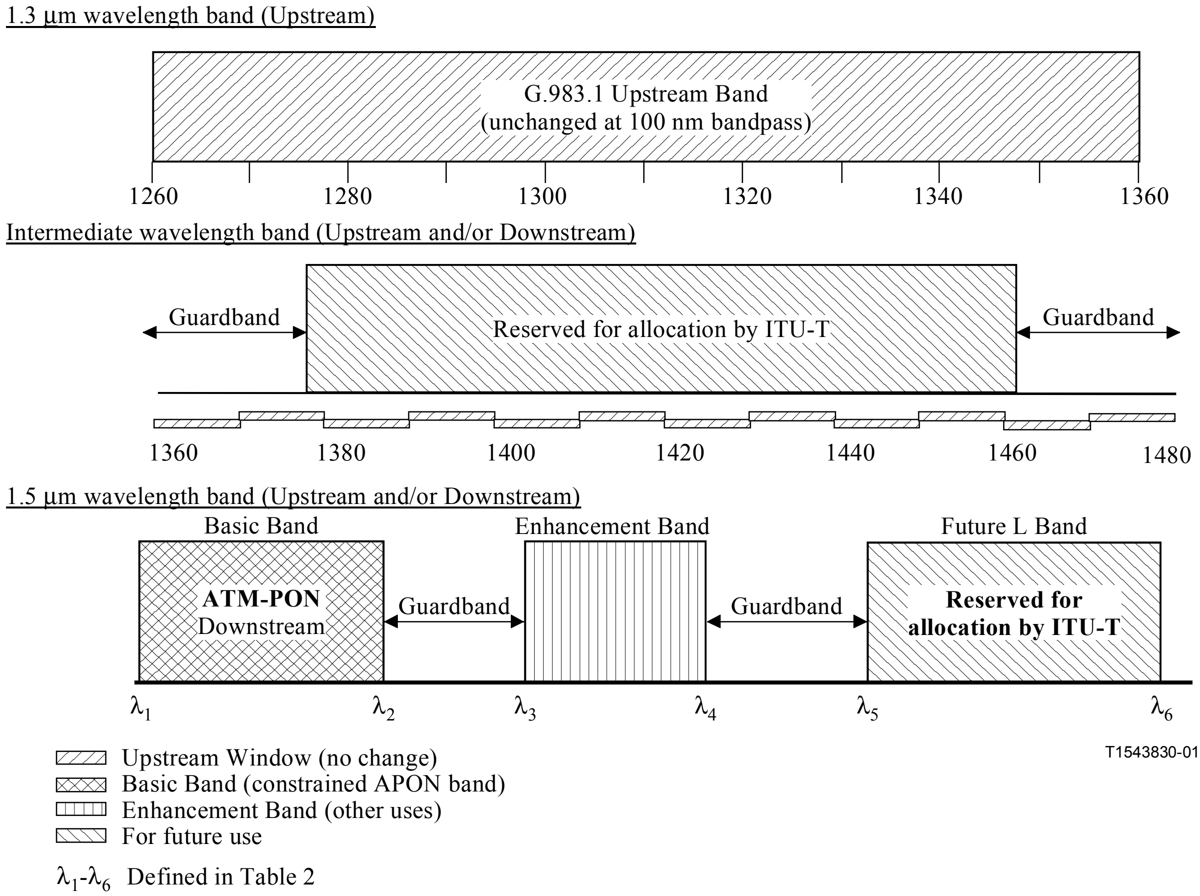


Figure 5/G.983.3 – Wavelength allocation

Table 2/G.983.3 – Parameters for wavelength allocation in Figure 5

Items	Notation	Unit	Nominal value	Application examples
1.3 µm wavelength band				For use in ATM-PON upstream.
Lower limit	–	nm	1260	
Upper limit	–	nm	1360	
Intermediate wavelength band				For future use – Reserved band including guardbands for allocation by ITU-T.
Lower limit	–	nm	1360	
Upper limit	λ1	nm	1480	
Basic Band				For use in ATM-PON downstream.
Lower limit	λ1	nm	1480	
Upper limit	λ2	nm	1500	
Enhancement Band (Option 1)				For additional digital service use.
Lower limit	λ3	nm	1539	
Upper limit	λ4	nm	1565	
Enhancement Band (Option 2)				For video distribution service.
Lower limit	λ3	nm	1550	
Upper limit	λ4	nm	1560	
Future L Band				For future use – Reserved band for allocation by ITU-T.
Lower limit	λ5	nm	For further study	
Upper limit	λ6	nm		

NOTE 1 – The central frequencies in the Enhancement Band for DWDM application shall be based on the frequency grid given in ITU-T G.959.1 and G.692.

NOTE 2 – The value of isolation between the Basic Band signal and the Enhancement Band signal is not decided uniquely, because system configuration varies by regulations, service strategy, and geographic conditions as well as offered services in the Enhancement Band.

Here, isolation should be interpreted as both the ratio of leaked Basic Band signal to E-ONU or E-OLT from Basic Band signal and the ratio of leaked Enhancement Band signal to ONU or OLT from Enhancement Band signal at WF1 or WF2. Both types of isolation should be defined separately.

Common use of WDM filters is expected for cost reduction through large volume production. The isolation examples required in typical cases are described in Appendix III.

NOTE 3 – Isolation value recommended for between the Basic Band signal and the Enhancement Band signals (Option 1) is for further study.

NOTE 4 – Isolation value recommended for between the Basic Band signal and the Enhancement Band signals (Option 2) is for further study.

NOTE 5 – Applied filter has appropriate loss characteristics to achieve required isolation. However, loss characteristics outside the 1480-1580 nm range (e.g. in the future L Band) is for further study.

8.3 Physical medium dependent layer requirements for the ATM-PON

8.3.1 Digital signal nominal bit rate

The transmission line rate should be a multiple of 8 kHz. The target standardized system will have the following nominal line rates:

– Option 1: Symmetric 155.52 Mbit/s for FTTCab/C/B/H.

– Option 2: Asymmetric 155.52 Mbit/s upstream/622.08 Mbit/s downstream for FTTCab/C/B.

Parameters to be defined are categorized by downstream and upstream, and nominal bit rate as shown in Table 3.

Table 3/G.983.3 – Relation between parameter categories and tables

Transmission direction	Nominal bit rate	Table
Downstream	155.52 Mbit/s	Table 4b (downstream, 155 Mbit/s)
	622.08 Mbit/s	Table 4c (downstream, 622 Mbit/s)
Upstream	155.52 Mbit/s	Table 4d (upstream, 155 Mbit/s)

All parameters are specified as follows, and shall be in accordance with Table 4a (ODN), Table 4b (downstream, 155 Mbit/s), Table 4c (downstream, 622 Mbit/s) and Table 4d (upstream, 155 Mbit/s). These tables will be globally referred to as Table 4 in this Recommendation unless more precision is needed. There are 6 kinds of ONUs and they are distinguished by bit rates of 155.52 Mbit/s and 622.08 Mbit/s and by optical path loss of Class A, Class B, and Class C (defined in ITU-T G.982). Some parameters described in Table 4 are described in Appendix I as examples for implementation.

The specification in Table 4 does not include the Maximum reflectance of equipment measured at transmitter wavelength and the Maximum reflectance of equipment measured at receiver wavelength for the E-ONU and E-OLT. Reflection from E-ONU and E-OLT may cause signal degradation in the ATM-PON transmission. The specifications for E-ONU and E-OLT reflectances at the 1.3 μm upstream and at the Basic Band downstream wavelengths are for further study.

All parameter values specified are worst-case values, assumed to be met over the range of standard operating conditions (e.g. 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.

All parameters are specified for IF_{PON} and relevant optical parameters for reference points of (c) and (e) in Figure 2b are described in Appendix V.

Attenuation range in the ODN may be reduced for some application area such as new-built field or limited area. In this case, required optical parameters will be relaxed and enhance applicability of optical modules compliant to ITU-T G.983.1. Appendix V also describes the example case of reduced attenuation range of the ODN.

Table 4a/G.983.3 – Physical medium dependant layer parameters of ODN

Items	Unit	Specification
Fibre type	–	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
Max differential logical reach	km	20
Maximum fibre distance between S/R and R/S points	km	20
Minimum supported split ratio	–	Restricted by path loss and ONU addressing limits. PON with passive splitters (16 or 32 way split)
Bidirectional transmission	–	1-fibre WDM (2-fibre system is beyond the scope of this Recommendation)
Maintenance wavelength	nm	to be defined

Table 4b/G.983.3 – Optical interface parameters of 155 Mbit/s downstream direction for the Basic Band

Items	Unit	Specifications		
OLT Transmitter (optical interface O_{ld})				
Nominal bit rate	Mbit/s	155.52		
Operating wavelength	nm	1480-1500		
Line code	–	Scrambled NRZ		
Mask of the transmitter eye diagram	–	See Figure 6/G.983.1		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA		
Minimum ORL of ODN at O_{ld} and O_{lu} (Notes 1 and 2)	dB	more than 32		
ODN Class		Class A	Class B	Class C
Mean launched power MIN	dBm	Note 4	Note 4	Note 4
Mean launched power MAX	dBm	Note 4	Note 4	Note 4
Launched optical power without input to the transmitter	dBm	NA		
Extinction ratio	dB	more than 10		
Tolerance to the transmitter incident light power	dB	more than −15		
If MLM Laser – Maximum RMS width	nm	1.8		
If SLM Laser – Maximum −20 dB width (Note 3)	nm	1		
If SLM Laser – Minimum side mode suppression ratio	dB	30		

Table 4b/G.983.3 – Optical interface parameters of 155 Mbit/s downstream direction for the Basic Band *(concluded)*

Items	Unit	Specifications		
ONU Receiver (optical interface O_{rd})				
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20		
Bit error ratio	–	less than 10^{-10}		
ODN Class		Class A	Class B	Class C
Minimum sensitivity	dBm	Note 4	Note 4	Note 4
Minimum overload	dBm	Note 4	Note 4	Note 4
Consecutive identical digit immunity	bit	more than 72		
Jitter tolerance	–	See Figure 9/G.983.1		
Tolerance to the reflected optical power	dB	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/G.983.1.

NOTE 2 – The values on ONU transmitter reflectance for the case that 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 IV.

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

NOTE 4 – Tentative parameters are described in Appendix I.

Table 4c/G.983.3 – Optical interface parameters of 622 Mbit/s downstream direction for the Basic Band

Items	Unit	Specifications		
OLT Transmitter (optical interface O_{ld})				
Nominal bit rate	Mbit/s	622.08		
Operating wavelength	nm	1480-1500		
Line code	–	Scrambled NRZ		
Mask of the transmitter eye diagram	–	See Figure 6/G.983.1		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA		
Minimum ORL of ODN at O_{lu} and O_{ld} (Notes 1 and 2)	dB	more than 32		
ODN Class		Class A	Class B	Class C
Mean launched power MIN	dBm	Note 4	Note 4	Note 4
Mean launched power MAX	dBm	Note 4	Note 4	Note 4
Launched optical power without input to the transmitter	dBm	NA		
Extinction ratio	dB	more than 10		
Tolerance to the transmitter incident light power	dB	more than –15		
If MLM Laser – Maximum RMS width	nm	NA		

Table 4c/G.983.3 – Optical interface parameters of 622 Mbit/s downstream direction for the Basic Band *(concluded)*

Items	Unit	Specifications		
If SLM Laser – Maximum −20 dB width (Note 3)	nm	1		
If SLM Laser – Minimum side mode suppression ratio	dB	30		
ONU Receiver (optical interface O_{rd})				
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than −20		
Bit error ratio	–	less than 10^{-10}		
ODN Class		Class A	Class B	Class C
Minimum sensitivity	dBm	Note 4	Note 4	Note 4
Minimum overload	dBm	Note 4	Note 4	Note 4
Consecutive identical digit immunity	bit	more than 72		
Jitter tolerance	–	See Figure 9/G.983.1		
Tolerance to the reflected optical power	dB	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/G.983.1. NOTE 2 – The values on ONU transmitter reflectance for the case that 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 IV. NOTE 3 – Values of maximum −20 dB width, and minimum side mode suppression ratio are referred to in ITU-T G.957. NOTE 4 – Tentative parameters are described in Appendix I.				

Table 4d/G.983.3 – Optical interface parameters of 155 Mbit/s upstream direction

Items	Unit	Specifications		
ONU Transmitter (optical interface O_{ru})				
Nominal bit rate	Mbit/s	155.52		
Operating wavelength	nm	1260-1360		
Line code	–	Scrambled NRZ		
Mask of the transmitter eye diagram	–	See Figure 7/G.983.1		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	less than −6		
Minimum ORL of ODN at O_{ru} and O_{rd} (Notes 1 and 2)	dB	more than 32		
ODN Class		Class A	Class B	Class C
Mean launched power MIN	dBm	Note 4	Note 4	Note 4
Mean launched power MAX	dBm	Note 4	Note 4	Note 4
Launched optical power without input to the transmitter	dBm	less than Min sensitivity −10		
Extinction ratio	dB	more than 10		

Table 4d/G.983.3 – Optical interface parameters of 155 Mbit/s upstream direction *(concluded)*

Items	Unit	Specifications		
Tolerance to the transmitter incident light power	dB	more than −15		
If MLM Laser – Maximum RMS width	nm	5.8		
If SLM Laser – Maximum −20 dB width (Note 3)	nm	1		
If SLM Laser – Minimum side mode suppression ratio	dB	30		
Jitter transfer	–	See Figure 8/G.983.1		
Jitter generation from 0.5 kHz to 1.3 MHz	UI p-p	0.2		
OLT Receiver (optical interface O_{lu})				
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than −20		
Bit error ratio	–	less than 10^{-10}		
ODN Class		Class A	Class B	Class C
Minimum sensitivity	dBm	Note 4	Note 4	Note 4
Minimum overload	dBm	Note 4	Note 4	Note 4
Consecutive identical digit immunity	bit	more than 72		
Jitter tolerance	–	NA		
Tolerance to the reflected optical power	dB	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/G.983.1.

NOTE 2 – The values of ONU transmitter reflectance for the case that 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 IV.

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

NOTE 4 – Tentative parameters are described in Appendix I.

8.3.2 Physical media and transmission method

8.3.2.1 Transmission medium

This specification is based on the fibre described in ITU-T G.652.

8.3.2.2 Transmission direction

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

8.3.2.3 Transmission methodology

Bidirectional transmission is accomplished by use of Wavelength Division Multiplexing (WDM) technique of 1310 nm region and Basic Band (1480-1500 nm) region wavelengths on a single fibre.

8.3.3 Bit rate

See 8.2.3/G.983.1.

8.3.4 Line code

See 8.2.4/G.983.1.

8.3.5 Operating wavelength

8.3.5.1 Downstream direction

The operating wavelength range for the downstream direction on single fibre systems shall be 1480-1500 nm.

8.3.5.2 Upstream direction

The operating wavelength range for the upstream direction shall be 1260-1360 nm.

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

All parameters are specified as follows, and shall be in accordance with Table 4.

See the following clauses in ITU-T G.983.1 for each item:

8.2.6.1 for Source type;

8.2.6.2 for Spectral characteristics;

8.2.6.3 for Mean launched power;

8.2.6.3.1 for Launched optical power without input to the transmitter;

8.2.6.4 for Minimum extinction ratio;

8.2.6.6 for Mask of transmitter eye diagram;

8.2.6.6.1 for OLT transmitter; and

8.2.6.6.2 for ONU transmitter.

8.3.6.1 Maximum reflectance of equipment, measured at transmitter wavelength

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

8.3.6.2 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 4.

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

See the following clauses in ITU-T G.983.1 for each item:

8.2.7.2 for Minimum optical return loss of the cable plant at point R/S, including any connector; and

8.2.7.3 for Maximum discrete reflectance between points S and R.

8.3.7.1 Attenuation range

Three classes of attenuation ranges are being specified as defined in ITU-T G.982:

– 5-20 dB: Class A;

– 10-25 dB: Class B;

– 15-30 dB: Class C.

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

1) future modifications to the cable configuration (additional splices, increased cable lengths, etc.);
2) fibre cable performance variations due to environmental factors; and
3) degradation of any connector, optical attenuators (if used) or other passive optical devices between points S and R, when provided.

8.3.7.2 Dispersion

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

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

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

All parameters are specified as follows, and shall be in accordance with Table 4.

See the following clauses in ITU-T G.983.1 for each item:

8.2.8.1 for Minimum sensitivity;

8.2.8.2 for Minimum overload;

8.2.8.3 for Maximum optical path penalty;

8.2.8.5 for Differential optical path loss;

8.2.8.6 for Clock extraction capability;

8.2.8.7 for Jitter performance;

8.2.8.7.1 for Jitter transfer;

8.2.8.7.2 for Jitter tolerance;

8.2.8.7.3 for Jitter generation;

8.2.8.8 for Consecutive identical digit (CID) immunity;

8.2.8.9 for Tolerance to reflected power; and

8.2.8.10 for Transmission quality and error performance.

8.3.8.1 Maximum reflectance of receiver equipment, measured at receiver wavelength

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

8.4 Physical medium dependent layer requirements for the Enhancement Band

Optical parameters, line code, modulation scheme and so on for the Enhancement Band are out of scope of this Recommendation.

However, reflection from ONU and OLT may cause signal degradation in the Enhancement Band services. Therefore the Maximum reflectance of equipment measured at transmitter wavelength and the Maximum reflectance of equipment measured at receiver wavelength for the ONU and the OLT should be specified in the Enhancement Band wavelength. The specification for reflectance of the ONU and OLT are for further study.

9 Operations Administration and Maintenance (OAM) functionality

See clause 9/G.983.1.

10 Performance

See clause 10/G.983.1.

11 Environmental condition

For the OLT and indoor ONU, the conditions of IEC 60721-3-3 are recommended. For the outdoor ONU, the conditions of IEC 60721-3-4, with the expanded environmental range (4.1E) specified in ETS 300 019-1-4, are recommended.

The conditions of IEC 60801-2 and 60801-3 for electro magnetic compatibility are recommended.

Examples of the applied environmental conditions for the OLT and ONU temperature and relative humidity are described in Table 5. The other environmental conditions such as environmental pollutants and chemicals are for further study.

Table 5/G.983.3 – Examples of environmental conditions

Applied example	Temperature (C)		Relative humidity (%)		Remarks
	Normal	Short term	Normal	Short term	
OLT	5 to 40	0 to 50 (Note 1)	5 to 85	5 to 90 (Note 1)	IEC 60721-3-3 class 3k3
Indoor ONU	−5 to 45	–	5 to 95	–	IEC 60721-3-3 class 3k5
Outdoor ONU (Note 2)	−45 to 45 (Note 3)	–	8 to 100	–	ETS 300 019-1-4 class 4.1E

NOTE 1 – Option 1: short term refers to a period of not more than 72 consecutive hours and a total of not more than 15 days in one year.

Option 2: short term refers to a period of not more than 12 consecutive hours and a total of not more than four days in one year.

NOTE 2 – The environmental conditions for the ONU are environmental conditions outside the ONU enclosure, and assume that the ONU (including housing/cabinet) is provided by a single supplier and is located in a conventional indoor or outdoor setting. Environmental conditions for ONUs that are located in other settings (e.g. inside an operator-provided cabinet or a non-conditioned indoor environment such as an attic or garage) are for future study.

NOTE 3 – In many instances, network operators are willing to relax the low temperature requirement to −40 degrees.

12 Safety

Safety is defined in ITU-T G.983.1.

APPENDIX I

Optical interface parameters examples for ODN

I.1 Introduction

Tentative optical parameters for ODN are described below (see Table 4) and are given in this Appendix I as examples for implementation. If appropriate parameters are approved and entered into Table 4, this Appendix will be removed.

I.2 Examples

Specified numerical values described in the following table indicate tentative values for items described in Table 4.

Table I.1/G.983.3 – Optical interface parameters of 155 Mbit/s downstream direction for the Basic Band

Items	Unit	Specifications		
OLT Transmitter (optical interface O_{ld})				
ODN Class		Class A	Class B	Class C
Mean launched power MIN	dBm	–7.5	–2.5	–0.5
Mean launched power MAX	dBm	–3	+2	+4
ONU Receiver (optical interface O_{rd})				
ODN Class		Class A	Class B	Class C
Minimum sensitivity	dBm	–28.5	–28.5	–31.5
Minimum overload	dBm	–8	–8	–11

Table I.2/G.983.3 – Optical interface parameters of 622 Mbit/s downstream direction for the Basic Band

Items	Unit	Specifications		
OLT Transmitter (optical interface O_{ld})				
ODN Class		Class A	Class B	Class C
Mean launched power MIN	dBm	–5.5	–0.5	–0.5
Mean launched power MAX	dBm	–1	+4	+4
ONU Receiver (optical interface O_{rd})				
ODN Class		Class A	Class B	Class C
Minimum sensitivity	dBm	–26.5	–26.5	–31.5
Minimum overload	dBm	–6	–6	–11

Table I.3/G.983.3 – Optical interface parameters of 155 Mbit/s upstream direction

Items	Unit	Specifications		
ONU Transmitter (optical interface O_{ru})				
ODN Class		Class A	Class B	Class C (Note)
Mean launched power MIN	dBm	–7.5	–5.5	–3.5
Mean launched power MAX	dBm	0	+2	+4
OLT Receiver (optical interface O_{lu})				
ODN Class		Class A	Class B	Class C (Note)
Minimum sensitivity	dBm	–28.5	–31.5	–34.5
Minimum overload	dBm	–5	–8	–11
NOTE – The values proposed for the upstream Class C are best estimates. They are therefore subject to change in the future.				

APPENDIX II

Deployment scenarios

II.1 Introduction

It is assumed that various system configurations or scenarios will be introduced by telecom operators. These system configurations or scenarios are influenced by regulations, service strategy, and the geographic conditions for each telecom operator. These configurations include pure WDM-based overlays and those which rely on FDM techniques to separate the Basic Band and Enhancement Band signals.

Configuration examples are described below.

II.2 Configuration examples

II.2.1 Case 1: Reception of Basic Band only

If customers do not require additional services such as video service etc. over the Enhancement Band under the wavelength allocation of Figure 5, then two system configurations would be as shown in Figures II.1 and II.2. In the case of Figure II.1, the WDM blocking filter may be needed to prevent the signal in the Enhancement Band from reaching the ONU. In the case of Figure II.2, an FDM-based approach, newer version ONUs, which are equipped with an electrical bandsplit filter, are required.

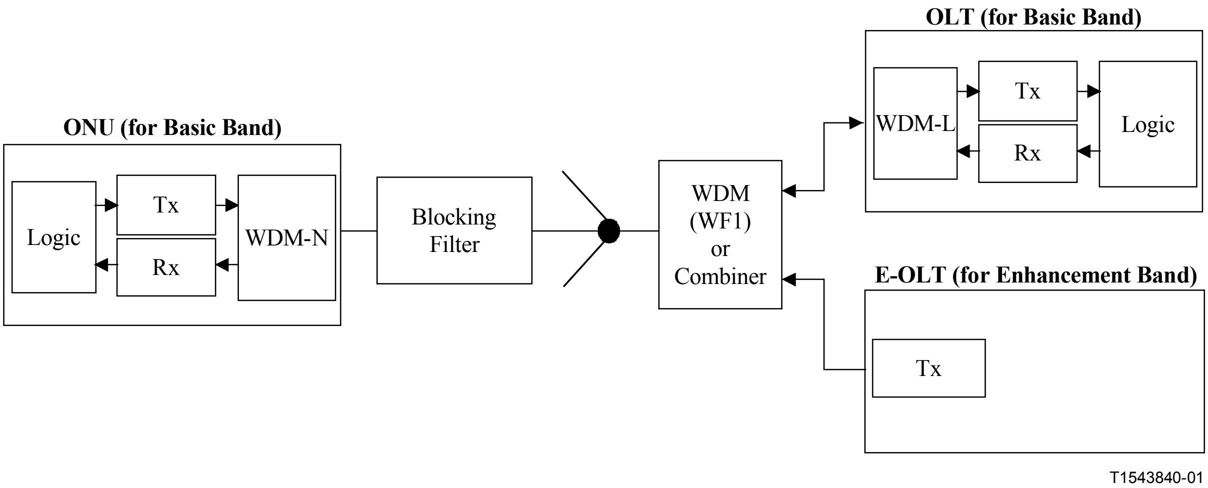


Figure II.1/G.983.3 – Reception of Basic Band only by blocking filter

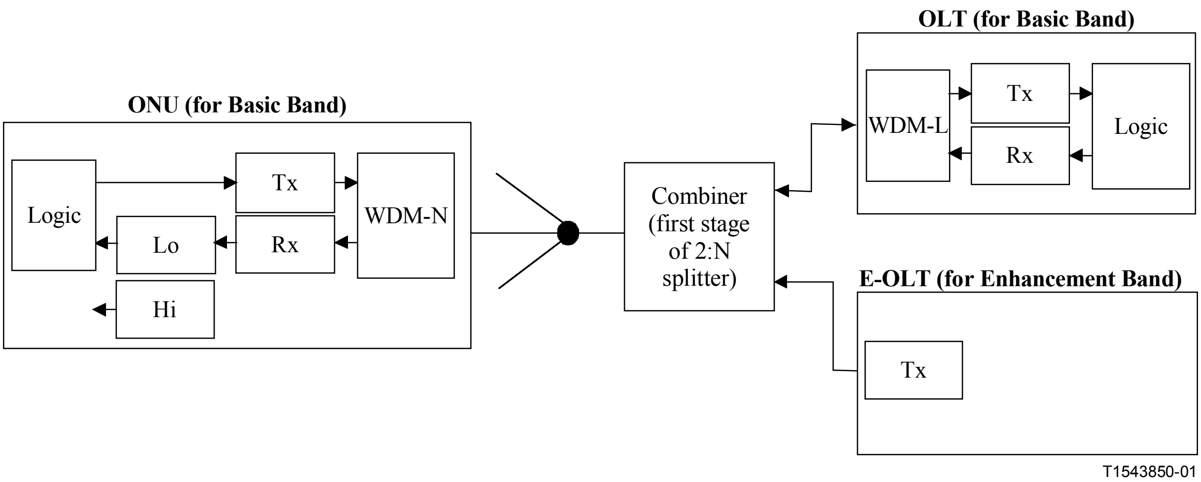


Figure II.2/G.983.3 – Reception of Basic Band only by FDM-based approach

II.2.2 Case 2: Reception of Basic Band and Enhancement Band signals by separate ONUs

If operators provide both ATM-PON and additional services such as video service etc. in separate equipment modules, the WDM-based system configuration would be Figure II.3.

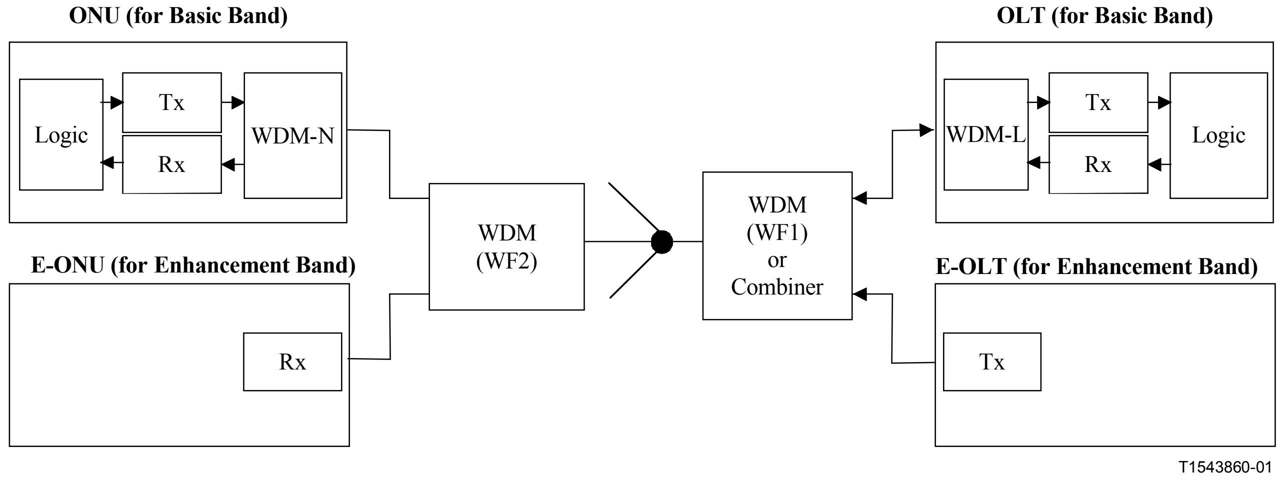


Figure II.3/G.983.3 – Reception of Basic Band and Enhancement Band signals by separate ONUs

II.2.3 Case 3: Reception of Basic Band and Enhancement Band signals by integrated ONUs

If operators provide both ATM-PON and additional services such as video service etc. in the same equipment, then two system configurations would be as shown in Figures II.4 and II.5. Figure II.4 shows a WDM-based approach. This type's ONUs are equipped with WDM filter. Figure II.5 shows FDM-based approach. This type's ONUs are equipped with electrical bandsplit filter.

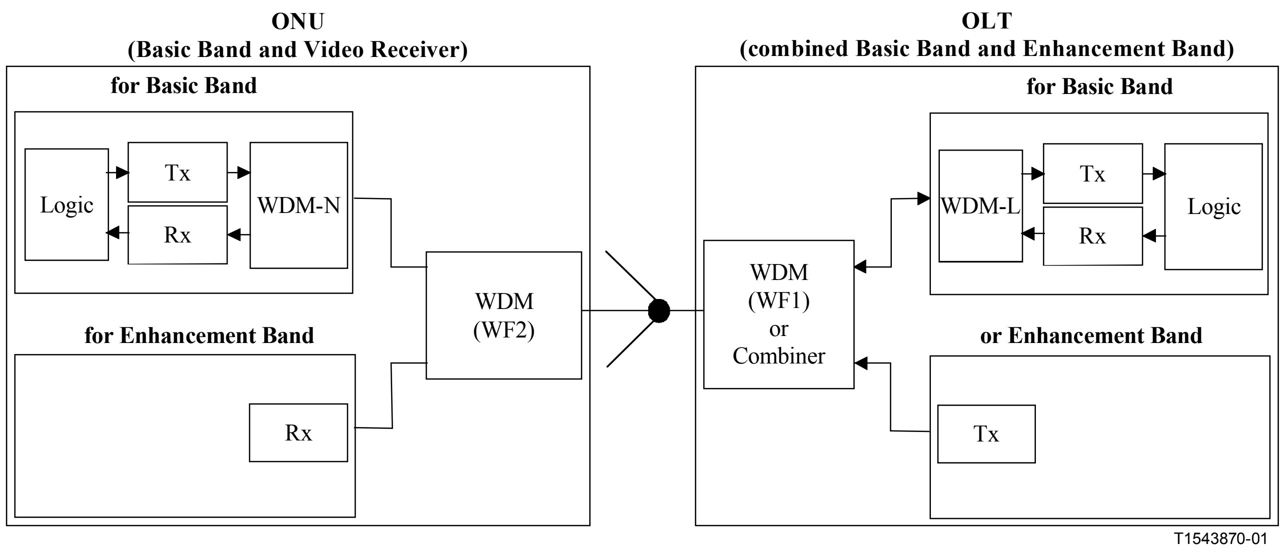


Figure II.4/G.983.3 – Reception of Basic Band and Enhancement Band signals by integrated ONUs (WDM-based approach)

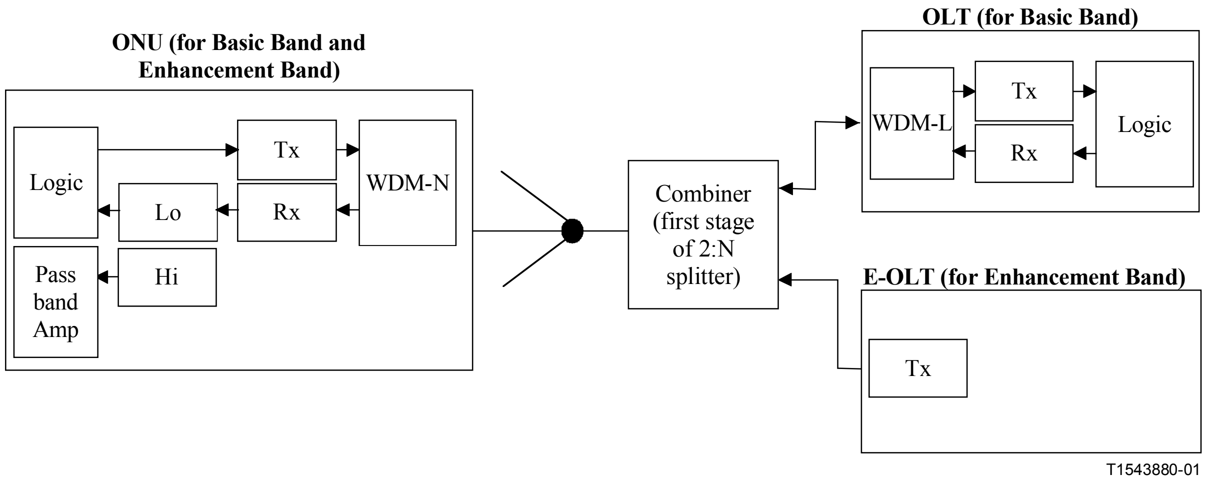


Figure II.5/G.983.3 – Reception of Basic Band and Enhancement Band signals by integrated ONUs (FDM-based approach)

II.2.4 Case 4: Arrangement of WDMs to minimize upstream path loss

This arrangement is aimed at minimizing the upstream path loss (at 1300 nm) when an Enhancement Band is added. In this case WDM-L and WDM-N separate the 1300 nm and 1500 nm bands and WF1 and WF2 split the 1500 nm band. This allows existing upstream transmitters and receivers to be used without a change in the end-to-end loss. The performance of WF1 and WF2 needs only to be specified in the 1500 nm band since 1300 nm signals are eliminated. It avoids the problem of near-end crosstalk when the Enhancement Band carries a downstream-only service. It avoids problems of reflections in the Basic Band being a problem to the Enhancement Band receivers. A disadvantage of this approach is that it is unsuitable for use with Basic Band electro-optic modules that incorporate G.983.1 WDMs.

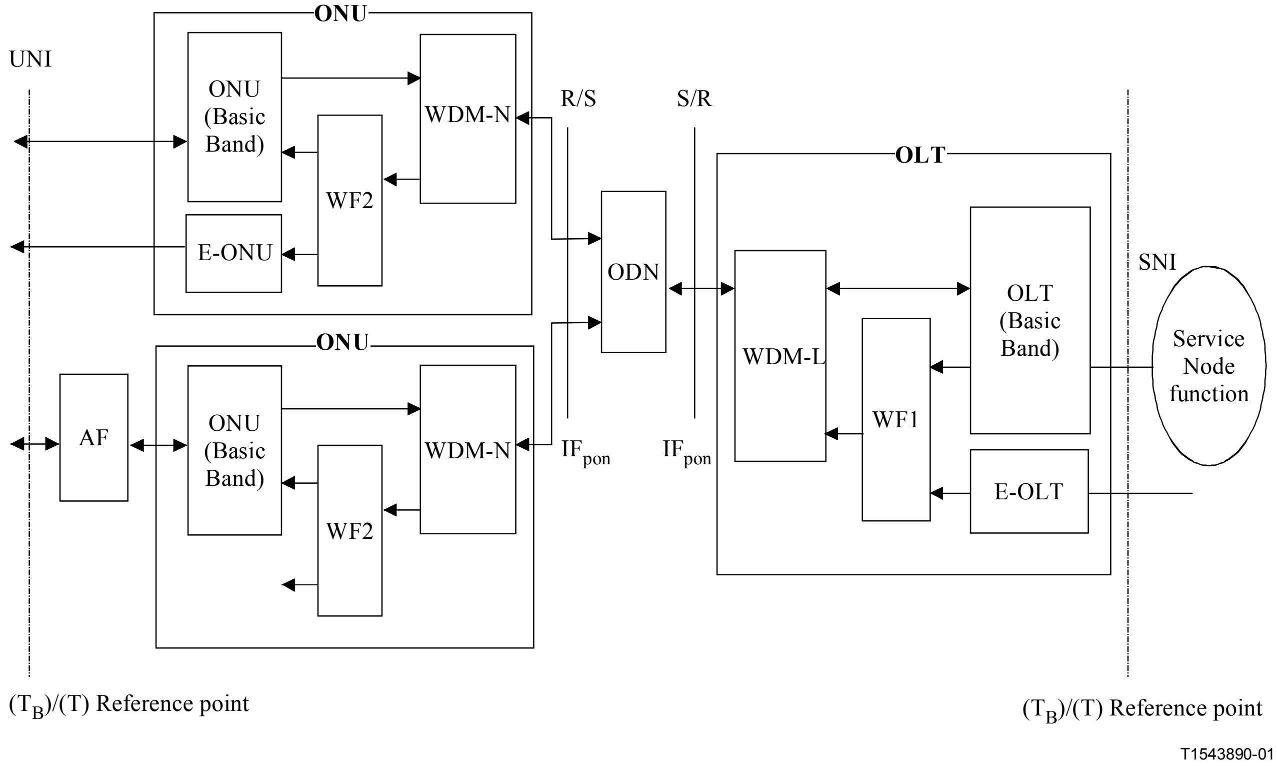


Figure II.6/G.983.3 – Arrangement of WDMs to minimize upstream path loss

II.2.5 Case 5: ODNs with reduced attenuation range for Enhancement Band

A problem for some operators arises when an existing Class C ODN is deployed. This is specified to have 30 dB path loss in both the 1300 and 1500 nm windows. Existing Basic Band transceivers will not have sufficient power budget when WDM components are added externally.

Case 4 could avoid this problem for the upstream path when the upstream and downstream transmitters and receivers are available as separate modules.

The downstream path will have additional losses for the WDMs in the 1500 nm band which could be as high as 1.5 dB at each end. This means that the 1500 nm transmitters and receivers need 3 dB extra power budget. One way of compensating this 3 dB is to apply a modified Class C, which takes into account the differential losses of the fibre in the 1300 and 1500 nm windows. The maximum loss at 1300 nm is 30 dB and the maximum loss at 1500 nm is 27 dB. Many existing Class C ODNs and all Class C with reduced attenuation range could meet a specification having less than 27 dB loss in the 1480-1580 nm band and less than 30 dB loss in the 1260-1360 nm band.

II.2.6 Example in case of insufficiency of loss budget between E-ONU and E-OLT

In case of insufficiency of loss budget between E-ONU and E-OLT, it is possible to shorten the distance between E-ONU and E-OLT. Figure II.7 shows an example. In that case, output from E-OLT is inputted to second stage of splitter.

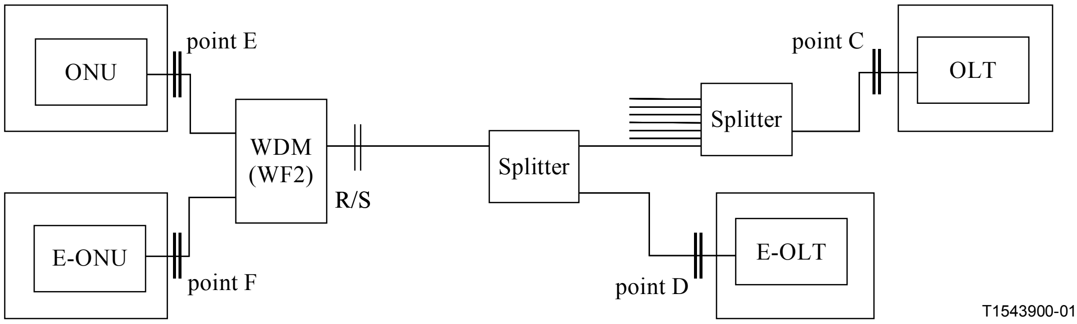


Figure II.7/G.983.3 – Arrangement in case of insufficiency of loss budget between E-ONU and E-OLT

APPENDIX III

Isolation between the Basic Band and the Enhancement Band

III.1 Introduction

The Enhancement Band can be used for many different types of services, such as video distribution and digital high bit-rate services.

Each service (characterized by modulation format or bit rate, the amount of carriers or amount of wavelengths) will require its own Enhancement Band receiver sensitivity and allowable cross-talk from the Basic Band signal.

These parameters, together with the total optical power in the Enhancement Band, will in turn determine the necessary isolation value at the Enhancement Band receiver from the Basic Band signal, and the necessary isolation value at the Basic Band receiver from the Enhancement Band signal.

In general, "Isolation" is defined as the loss difference between two wavelengths measured at the same port. Required Isolation for WDM filter such as WF1 and WF2 should be estimated considering reflections of equipment and/or ODN. The effect of reflections is described in Appendix IV.

This appendix provides some initial calculations of the optical characteristics of the Enhancement Band services. These are used to find example isolation values of the Basic Band from the Enhancement Band. Such examples may be useful to vendors in guiding their development efforts. However, the exact requirements of the isolation values, and the isolation required by the enhancement signals from the Basic Band depend on many factors that are out of the scope of this Recommendation. Any system design will need to do a complete accounting of all these factors to arrive at a complete optical isolation specification.

Isolation to be considered is schematically shown in Figure III.1.

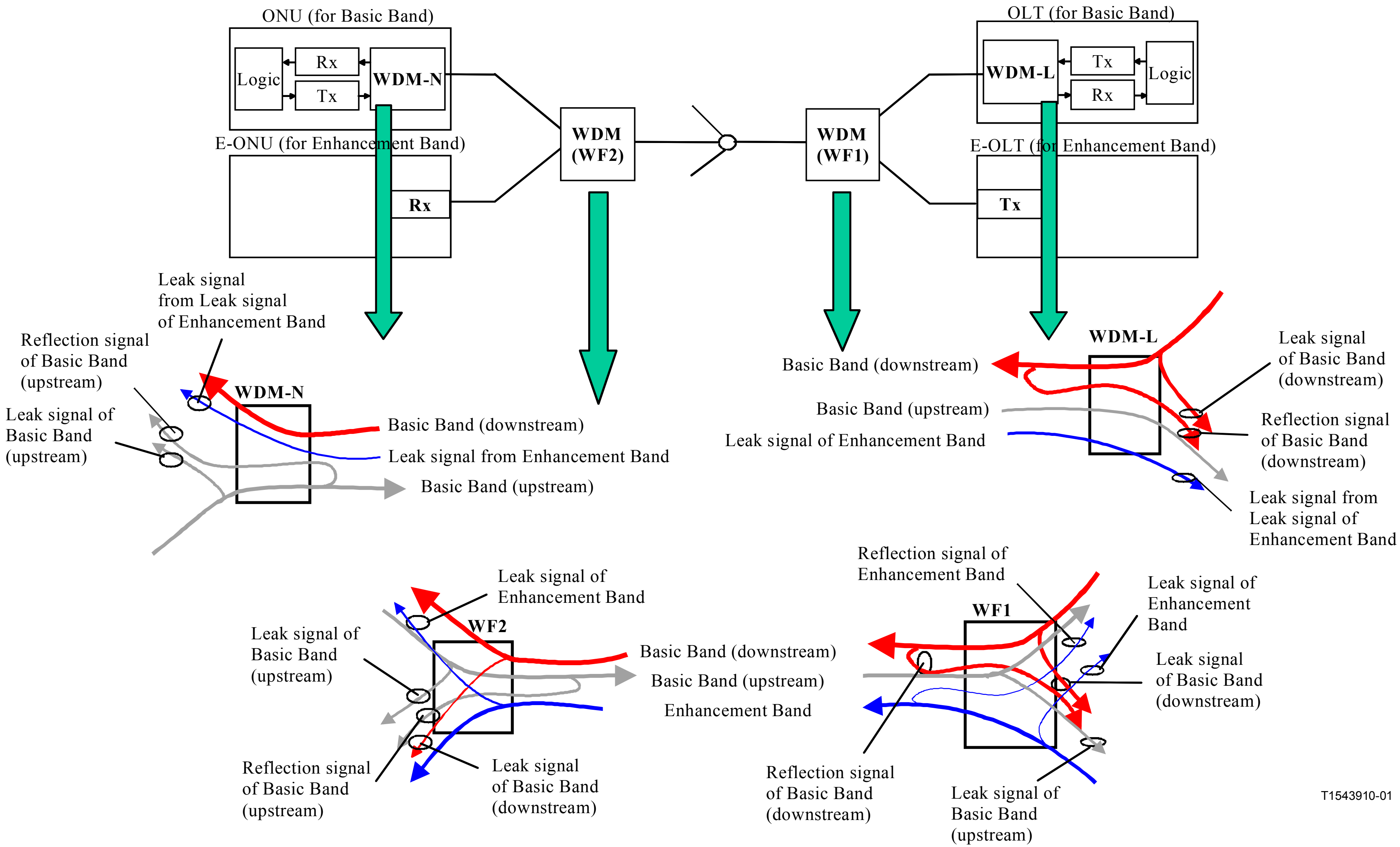


Figure III.1/G.983.3 – Isolation at WDM-L, WDM-N, WF1 and WF2

The type of service and its characteristics will determine isolation performances of WF1 and WF2. As the optical power of the Basic Band signal will vary with the PON system class (A, B, C), the isolation values will also be different for the different ODN classes.

Out of the many different service and class scenarios, several isolation classes could then be defined.

The following tables illustrate several service scenarios. The scenarios have to be analysed for each PON Class.

The following notations are used in this appendix:

L_{ODN-BB} Optical loss of Basic Band in the ODN

L_{ODN-EB} Optical loss of Enhancement Band in the ODN

P_{BB} Optical power of Basic Band signal at the input to the ONU

P_{EB} Optical Power of Enhancement Band signal at the input to the E-ONU

F.F.S for further study

The following assumptions are taken for the examples:

– $L_{ODN-BB} = L_{ODN-EB}$.

– The allowable cross-talk at the Basic Band receiver [at reference points (c) and (e)] from the Enhancement Band signal is assumed to be at least 10 dB lower than the lowest Basic Band signal.

  NOTE – This assumption should be modified to some higher value than 10 dB, for example to 13 dB, because the total optical noise to the receiver consists of multiple reflections as well as leak optical power. Permissible total noise may be 10 dB lower than the lowest signal level, but permissible noise power for each noise component is for further study. Therefore, the following are tentatively described on the assumption that each noise component be at least 10 dB lower than the signal.

– Assuming following WF1 and WF2 insertion losses: 0 dB – 1.5 dB.

III.2 Example for required isolation at Basic Band receiver from Enhancement Band signal

III.2.1 Video services

Required isolation depends on the minimum power required by the receiver to produce a usable signal plus the total amount of system tolerance (transmitter, fibre, and optical component loss variations). For subcarrier multiplexed video systems, the carrier-to-noise ratio (CNR) is given by Equation (III-1).

$$CNR = \frac{1}{2B} \cdot \frac{m^2}{RIN + \frac{2e}{i} + \frac{4kT}{i^2 R}} \qquad \text{(III-1)}$$

Here *B* is the channel bandwidth, *m* is the per-channel modulation index, *RIN* is the relative intensity noise of the transmitter, *e* is the charge of the electron, *i* is the detected photocurrent, *kT* is the Boltzman factor, and *R* is the receiver impedance. The assumed values for all these parameters are given in the following table:

RIN (dB/Hz)	–150.0
Receiver Temperature (K)	300.0
Receiver Impedance (Ω)	75.0
Receiver Responsivity (A/W)	0.85
RMS OMI	25%

The required SNR depends on the signal format being considered. The values assumed here are given in the following table:

Channel Format	(dB)
QPSK	16
16-QAM	22
64-QAM	28
256-QAM	34
AM-VSB	44 (Note)
NOTE – The value given for AM-VSB is the CNR.	

The RMS optical modulation index (*OMI*), along with *N*, the number of channels, can be used to compute *m*, by using Equation (III-2). The responsivity is used to convert the photocurrent to optical power.

$$m = OMI\sqrt{\frac{2}{N}} \tag{III-2}$$

Equation (III-1) can be re-arranged as shown in Equation (III-3). This gives a quadratic in photocurrent, and the solution to this equation then can be converted into the required optical power, P_{EB}, at the point between the E-ONU and WF2, shown in Table III.1.

$$\left(RIN - \frac{m^2}{2B \cdot CNR}\right)i^2 + 2ei + \frac{4kT}{R} = 0 \tag{III-3}$$

Table III.1/G.983.3 – P_{EB}, minimal power of Enhancement Band signal at the input to the E-ONU

Transmission System	Carrier Format	Number of carriers	Carrier BW (MHz)	Required Power (dBm)
SCM	AM-VSB	40	4.5	–7.7
			6.5	–6.7
	QPSK	60	18	–18.3
	64-QAM	110	5.2	–13.6
			7.0	–13.0
	256-QAM	110	5.2	–10.5
			7.0	–9.8
FM Conversion	AM-VSB	40	4.5	–14.1
			6.5	–11.5
	64-QAM	110	5.2	–16.7
			7.0	–14.3
	256-QAM	110	5.2	–13.3
			7.0	–10.1

The isolation values at WF2 (the ratio of leaked Enhancement Band signal to ONU from Enhancement Band signal at common port of WF2) are obtained from:

Isolation of WF2 = P_{EB} req + $R_{x\Delta}$ + $T_{x\Delta}$ – P_{BB} min + 13 dB,

where $R_{x\Delta}$ and $T_{x\Delta}$ are the dynamic range tolerances of the receiver and transmitter. We assume values of $R_{x\Delta}$ = 2 dB, and $T_{x\Delta}$ = 1 dB.

For example, if the minimum required enhancement power at the E-ONU receiver, P_{EB} req = –10 dBm and P_{BB} min = –30 dBm, then required isolation = 36 dB.

The resulting isolation at WF2 is specified in Table III.2. These are assuming that P_{BB} min = –30 dBm, which is true for class B equipment. Note that the above calculation assumes that the enhancement and Basic Band signals suffer the same insertion loss through WF2.

Table III.2/G.983.3 – Isolation requirements at Basic Band receiver from Enhancement Band

Transmission System	Carrier Format	Number of carriers	Carrier BW (MHz)	Required Isolation (dB)
SCM	AM-VSB	40	4.5	38.3
			6.5	39.3
	QPSK	60	18	27.7
	64-QAM	110	5.2	32.4
			7.0	33.0
	256-QAM	110	5.2	35.5
			7.0	36.2
FM Conversion	AM-VSB	40	4.5	31.9
			6.5	34.5
	64-QAM	110	5.2	29.3
			7.0	31.7
	256-QAM	110	5.2	32.7
			7.0	35.9

The isolation required at WF1 is driven by the reflections in the PON, which can be either –32 dB or –20 dB. The video transmitter will most likely be operating near the SBS limit of the fibre, implying a maximum launch power of +17 dBm. With a reflection loss of –20 dB, the reflection can be as high as –3 dBm. If the signal must be 13 dB higher than the interference, then the combined isolation of the WF1 and diplexer must be 40 dB. If PON reflectance of –32 dB is assumed, then the isolation of WF1 and diplexer must be 28 dB.

Note that the above isolations assume that the video and Basic Band signals overlap in electrical frequency. This is not necessarily true, and in some notable cases, such as the QPSK video, the video signal is entirely out of band. In these cases, the video signal only impairs the Basic Band signal via increased shot and relative intensity noise. This can reduce the required isolation greatly, in some cases to the point where no optical isolation is required at all.

III.2.2 DWDM services

The provision of DWDM services over the PON will also place requirements on the isolation of filters WF1 and WF2. The starting point again is the sensitivities of the receivers that would be used for the DWDM upgrade. Table III.3 below gives the typical values for optical receivers, and also for the filters that are required to demultiplex the individual channels.

Table III.3/G.983.3 – The typical values for optical receivers and filters

Table a – Data Rate	SDH-1	SDH-4	GbE	SDH-16
Maximum overload (PIN photodiode) (dBm)	–8	–7	–6	–4
Minimum sensitivity (PIN photodiode) (dBm)	–36	–31	–25	–20
Maximum overload (APD) (dBm)	NA	–10	–9	–9
Minimum sensitivity (APD) (dBm)	NA	–38	–33	–29

Table b – Number of Channels	1	8	16	32
200 GHz Filter max loss (dB)	2	3.5	5	NA
100 GHz Filter Max loss (dB)	2.5	4.5	6.5	8.5
Basic/Enhancement Filter max loss (dB)	1	NA	NA	NA

By building hypothetical loss budgets using these numbers, one can derive the maximum launched powers (per channel) at both ends of the PON. The result depends on the speed and number of channels, as shown in Table III.4. Note that the upstream launch powers are higher than the downstream powers because the upstream channels must pass through the lossy multichannel WDM demultiplexer, while the downstream channels only pass through a single WDM filter.

Table III.4/G.983.3 – The maximal Tx power of Enhancement Band signal at IF_{PON}

a – just after the WF1 going downstream

	PIN (dBm)		APD (dBm)	
Channels	SDH-1	SDH-4	GbE	SDH-16
4	–4.5	0.5	–1.5	2.5
8	–4.5	0.5	–1.5	2.5
16	–4.0	1.0	–1.0	3.0

b – just after WF2 going upstream

	PIN (dBm)		APD (dBm)	
Channels	SDH-1	SDH-4	GbE	SDH-16
4	–2.0	3.0	1.0	4.8
8	–1.5	3.5	1.5	5.0
16	2.0	7.0	5.0	6.8

The isolation values are obtained by first computing the maximum Enhancement Band power entering either WF1 or WF2. The two sources of this power are the forward path power (upstream in the case of WF1) and the reflection path power (downstream in the case of WF1). These powers are summed arithmetically, including the multiplier for the number of channels involved, and produce the interfering power. The worst case of this interfering power is then compared with the worst case of the Basic Band power. Their difference plus 13 dB is then the required isolation. The isolations for WF1 and WF2 are specified in Table III.5 assuming a class B PON. Note that the isolation stated for WF1 also includes whatever isolation that the diplexer provides inside the OLT, hence the actual isolation required of WF1 is actually less.

Table III.5/G.983.3 – Isolation requirements at Basic Band receiver from Enhancement Band

a – for WF1

	PIN (dB)		APD (dB)	
Channels	**SDH-1**	**SDH-4**	**GbE**	**SDH-16**
4	37.3	42.3	40.3	44.0
8	40.7	45.7	43.7	47.3
16	47.1	52.1	50.1	52.0

b – for WF2

	PIN (dB)		APD (dB)	
Channels	**SDH-1**	**SDH-4**	**GbE**	**SDH-16**
4	20.8	25.8	23.8	27.8
8	24.0	29.0	27.0	30.8
16	28.6	33.6	31.6	34.6

III.3 Example of isolation classes

Possible isolation classes for the ONU WF2 filter are shown in Table III.6. It would appear that 30 dB of isolation is sufficient for most all of the DWDM upgrades, and some of the video upgrades. Hence, this could define the first class of isolation. For exceptional cases of DWDM upgrade, or for many of the video upgrades, 40 dB of isolation is required. This could define the second class of isolation.

Table III.6/G.983.3 – Isolation Classes

		Guaranteed Isolation	
		at EB from BB (dB)	**at BB from EB (dB)**
Isolation Class	Case 1	F.F.S	30
	Case 2	F.F.S	40
	Case 3	F.F.S	F.F.S

III.4 Deployment examples

This clause shows examples of WDM filters' characteristics such as power loss and isolation in deploying this system.

III.4.1 Model to be considered

Figure III.2 shows an example of model.

In order to calculate the value of isolation, the SNR of three receivers such as OLT-Rx, ONU-Rx and E-Rx should be considered. For that, each amount of interference optical power and the power of signal should be considered.

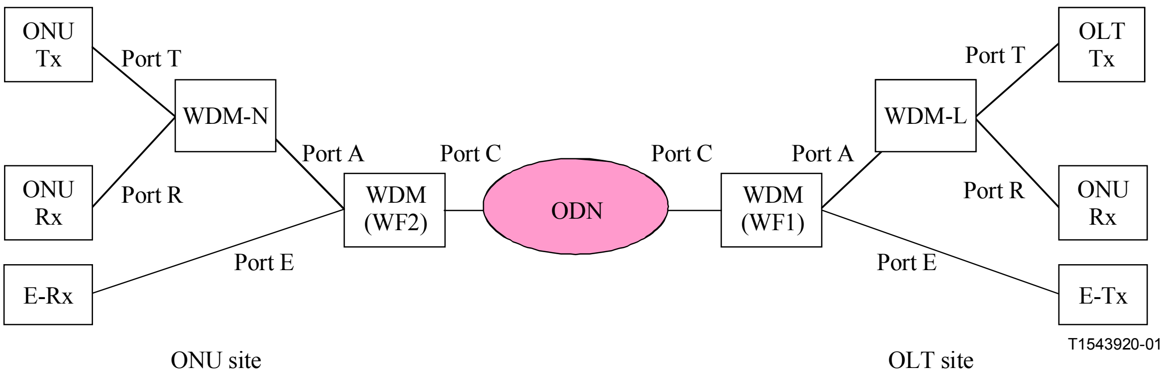
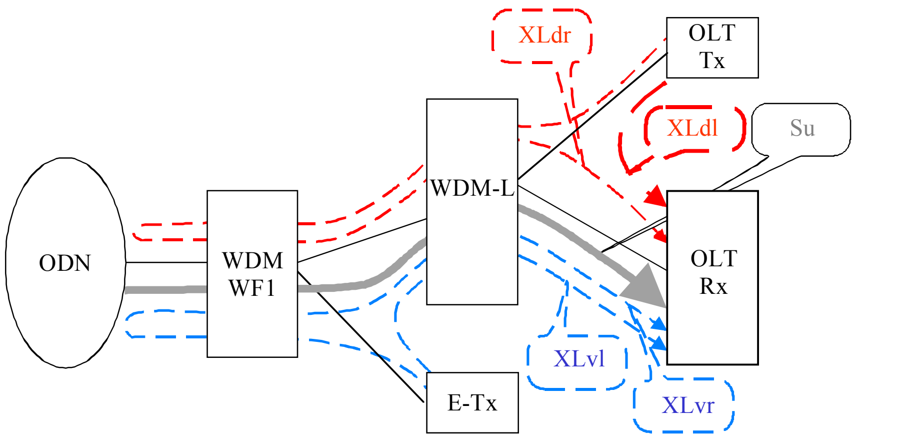


Figure III.2/G.983.3 – Model for calculation

III.4.1.1 SNR of OLT-Rx

Figure III.3 shows the noise signals received at OLT-Rx receiver.



Su	Basic Band Signal (upstream)
XL	Amount of interference optical power for OLT Receiver
XLdl	Leak signal of downstream
XLdr	Reflection signal of downstream
XLvl	Leak signal of video
XLvr	Reflection signal of video

Figure III.3/G.983.3 – Noise signals at OLT-Rx

Then, amount of Interference optical power is given by Equation (III-4).

$$XL[dBm] = 10 \times \log(XL[mW]) \quad \text{(III-4)}$$

where:

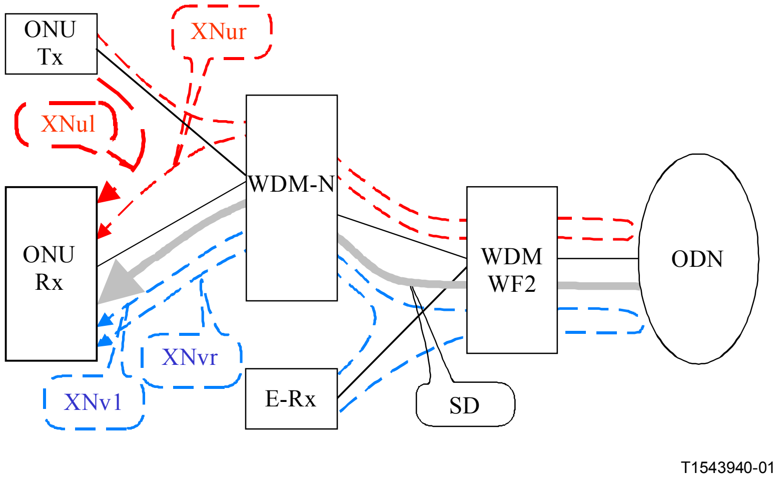
$$XL[mW] = XLdl[mW] + XLdr[mW] + XLvl[mW] + XLvr[mW]$$

So, if the reflected optical power is at least 10 dB lower than the signal power, then Equation (III-5) is satisfied.

$$Su[dBm] - XL[dBm] \geq 10[dB] \quad \text{(III-5)}$$

III.4.1.2 SNR of ONU-Rx

Figure III.4 shows the noise signals received at ONU-Rx receiver.



Sd	Basic Band (downstream)
XN	Amount of interference optical power for ONU Receiver
XNul	Leak signal of upstream
XNur	Reflection signal of upstream
XNvl	Leak signal of video
XNvr	Reflection signal of video

Figure III.4/G.983.3 – Noise signals at ONU-Rx

Then, amount of Interference optical power is given by Equation (III-6).

$$XN[dBm] = 10 \times \log(XN[mW]) \quad \text{(III-6)}$$

where:

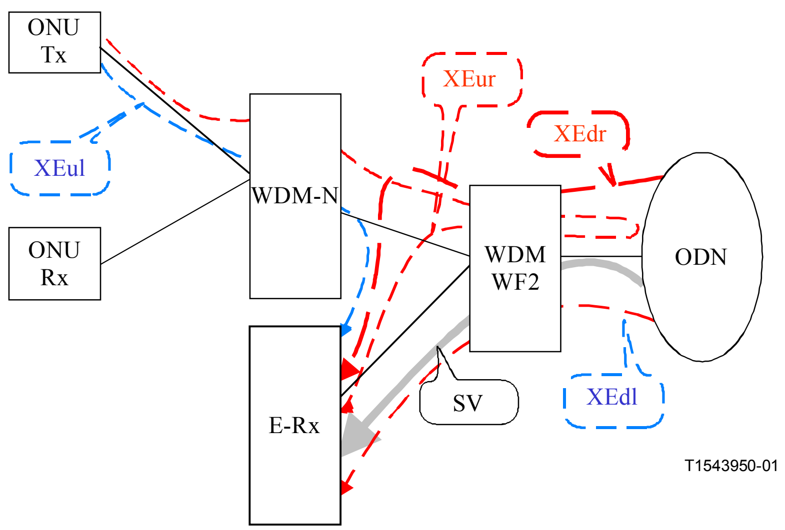
$$XN[mW] = XNul[mW] + XNur[mW] + XNvl[mW] + XNvr[mW]$$

So, if the reflected optical power is at least 10 dB lower than the signal power, then Equation (III-7) is satisfied.

$$Sd[dBm] - XN[dBm] \geq 10[dB] \quad \text{(III-7)}$$

III.4.1.3 SNR of E-Rx

Figure III.5 shows the noise signals received at E-Rx receiver.



Sv Video signal
XE Amount of interference optical power for E-ONU Receiver
XEul Leak signal of upstream
XEur Reflection signal of upstream
XEdl Leak signal of downstream
XEdr Reflection signal of downstream

Figure III.5/G.983.3 – Noise signals at E-Rx

Then, amount of Interference optical power (XE) is given by Equation (III-8).

$$XE[dBm] = 10 \times \log(XE[mW]) \qquad \text{(III-8)}$$

where:

$$XE[mW] = XEul[mW] + XEur[mW] + XEdl[mW] + XEdr[mW]$$

So, Equation (III-9) is satisfied.

$$Sv[dBm] - XE[dBm] \geq (*)[dB] \qquad \text{(III-9)}$$

(*) It depends on the specification of video signal. Refer to III.4.2.3.

III.4.2 In case of 64-QAM

– Assumption of the Basic Band signal
  - 155 Mbit/s Class B

    Pout(ATM-OLT) = –2.5 to +2 [dBm] @ODN-I/F

    Pin(ATM-OLT) = –8 to –31.5 [dBm] @ODN-I/F

    Pout(ATM-ONU) = –5.5 to +2 [dBm] @ODN-I/F

    Pin(ATM-ONU) = –8 to –28.5 [dBm] @ODN-I/F
  - All WDM insertion loss of through port for all wavelengths is 0 to 1.5 dB
  - ORL of ODN is 32 dB, ORL of Equipment at receiver wavelength is 20 dB

– Assumption of the 64-QAM signal:

- 64-QAM modulation and 40 carriers for video (27.4 dB SNR is required)
  Pout(video) = +7 to +10 [dBm] @ODN I/F
  Pin(video) = 0 to −18 [dBm] @ODN I/F
- Frequency Range: 54 MHz ~ 750 MHz
- Carrier Spacing: 6 MHz
- Required SNR: 28 dB

III.4.2.1 Calculation of OLT-Rx

Su [dBm] = –31.5 [dBm] – 1.5 [dB] – 1.5 [dB]

XLdl [dBm] = +2 [dBm] – LLTRd [dB]

XLdr [dBm] = +2 [dBm] – 32 [dB] – 0 [dB] – LLARd [dB]

XLvl [dBm] = +10 [dBm] – LWF1EAv [dB] – LLARv [dB]

XLvr [dBm] = +10 [dBm] – 32 [dB] – LWF1CAv [dB] – LLARv [dB]

From Equation III-4 and Equation III-5, an example of WDM characters are as follows:

LLTRd = 50 [dB] (Loss of downstream in WDM-L from Port T to port R)

LLARd = 20 [dB] (Loss of downstream in WDM-L from Port A to port R)

LWF1EAv = 50 [dB] (Loss of video in WDM-WF1 from Port E to port A)

LLARv = 20 [dB] (Loss of video in WDM-L from Port A to port R)

LWF1CAv = 20 [dB] (Loss of video in WDM-WF1 from Port C to port A)

III.4.2.2 Calculation of ONU-Rx

Sd [dBm] = –28.5 [dBm] – 1.5 [dB] – 1.5 [dB]

XNul [dBm] = +2 [dBm] – LNTRu [dB]

XNur [dBm] = +2 [dBm] – 32 [dB] – 0 [dB] – LNARu [dB]

XNvl [dBm] = (–18 [dBm] + 3 [dB]) – LWF2CAv [dB] – 0 [dB]

XNvr[dBm] = (–18 [dBm] + 3 [dB]) – 0 [dB] – 20 [dB] – LWF2EAv [dB] – 0 [dB]

3 [dB] = +10 [dBm] – (+7 [dBm])

From Equation III-6 and Equation III-7, examples of WDM characteristics are as follows:

LNTRu = 50 [dB] (Loss of upstream in WDM-N from Port T to port R)

LNARu = 20 [dB] (Loss of upstream in WDM-N from Port A to port R)

LWF2CAv = 29 [dB] (Loss of video in WDM-WF2 from Port C to port A)

LWF2EAv = 20 [dB] (Loss of video in WDM-WF2 from Port E to port A)

III.4.2.3 Calculation of E-Rx

S/X for video receiver requires 27.4 dB to transmit 40 carriers with –18 dBm received power. So, Equation (III-9 *bis*) is satisfied.

$$Sv[dBm] - XE[dBm] \geq 27.4 \text{ dB} \qquad \text{(III-9 } bis\text{)}$$

Sv [dBm] = –18 [dBm] – 1.5 [dB]

XEul [dBm] = +2 [dBm] – LWF2AEu [dB]

XEur [dBm] = +2 [dBm] – 32 [dB] – LWF2CEu [dB]

XEdl [dBm] = (–27.5 [dBm] + 4.5 [dB]) – LWF2CEd [dB]

XEdr [dBm] = (–27.5 [dBm] + 4.5 [dB]) – 0 [dB] – 20 [dB] – LWF2AEd [dB]

4.5 [dB] = +2 [dBm] – (–2.5 [dBm])

From Equation (III-8) and Equation (III-9 *bis*), examples of WDM characters are as follows:

LWF2AEu = 50 [dB] (Loss of upstream in WDM-WF2 from Port A to port E)

LWF2CEu = 31.5 [dB] (Loss of upstream in WDM-WF2 from Port C to port E)

LWF2CEd = 31.5 [dB] (Loss of downstream in WDM-WF2 from Port C to port E)

LWF2AEd = 20 [dB] (Loss of downstream in WDM-WF2 from Port A to port E)

III.4.3 Filter characteristics

From an estimation of III.4.2.1, III.4.2.2 and III.4.2.3, required filter characteristics are shown in Tables III.7 and III.8.

Table III.7/G.983.3 – Required filter characteristics (OLT side)

WF1					WDM-L				
	Port	**Wavelength**	**Min**	**Max**		**Port**	**Wavelength**	**Min**	**Max**
LWF1Acd	A→C	Down	0	1.5	LLTAd	T→A	Down	0	1.5
LWF1CAu	C→A	Up	0	1.5	LLARu	A→R	Up	–	1.5
LWF1CEv	C→E	Video	0	1.5	LLATv	A→T	Video	–	–
LWF1CEd	C→E	Down	–	–	LLARd	A→R	Down	20	–
LWF1CEu	C→E	Up	–	–	LLATu	A→T	Up	–	–
LWF1CAv	C→A	Video	20	–	LLARv	A→R	Video	20	–
LWF1AEd	A→E	Down	–	–	LLTRd	T→R	Down	50	–
LWF1AEu	A→E	Up	–	–	LLRTu	R→T	Up	–	–
LWF1EAv	E→A	Video	50	–	LLTRv	T→R	Video	–	–

Table III.8/G.983.3 – Required filter characteristics (ONU side)

WF2					WDM-N				
	Port	**Wavelength**	**Min**	**Max**		**Port**	**Wavelength**	**Min**	**Max**
LWF2Acu	A→C	Up	0	1.5	LNTAu	T→A	Up	0	1.5
LWF2CAd	C→A	Down	0	1.5	LNARd	A→R	Down	–	1.5
LWF2CEv	C→E	Video	0	1.5	LNARv	A→T	Video	0	–
LWF2CEu	C→E	Up	31.5	–	LNARu	A→R	Up	20	–

Table III.8/G.983.3 – Required filter characteristics (ONU side) *(concluded)*

WF2					WDM-N				
	Port	**Wavelength**	**Min**	**Max**		**Port**	**Wavelength**	**Min**	**Max**
LWF2CEd	C→E	Down	31.5	–	LNATd	A→T	Down	–	–
LWF2CAv	C→A	Video	29	–	LNATv	A→R	Video	–	–
LWF2AEu	A→E	Up	50	–	LNTRu	T→R	Up	50	–
LWF2AEd	A→E	Down	20	–	LNRTd	R→T	Down	–	–
LWF2EAv	E→A	Video	20	–	LNTTv	T→R	Video	–	–

Isolation is defined as the loss difference between two wavelengths measured at the same port. Therefore, we can calculate "Isolation" using Tables III.7 and III.8.

Isolation at WDM-WF1: Isolate Basic Band upstream signal from Enhancement band signal.

LWF1CAv(min) [dB] – LWF1CAu(max) [dB] = 20 [dB] – 1.5 [dB] = **18.5 [dB]**

Isolation at WDM-WF2: Isolate Enhancement Band signal from Basic band upstream signal.

LWF2CEu(min) [dB] – LWF2CEv(max) [dB] = 31.5 [dB] – 1.5 [dB] = **30 [dB]**

Isolation at WDM-WF2: Isolate Enhancement Band signal from Basic Band downstream signal.

LWF2CEd(min) [dB] – LWF2CEv(max) [dB] = 31.5 [dB] – 1.5 [dB] = **30 [dB]**

Isolation at WDM-WF2: Isolate Basic Band downstream signal from Enhancement Band signal.

LWF2CAv(min) [dB] – LWF2CAd(max) [dB] = 29 [dB] – 1.5 [dB] = **27.5 [dB]**

APPENDIX IV

Effect of optical return loss of ODN

IV.1 Introduction

Each network model has its own optical return loss (ORL) of ODN and BPON is sensitive to the ORL of ODN. This appendix describes the relationship among some types of reflectance to be considered, WDM isolation of ONU and OLT, and ONU equipment reflectance for transmitter and receiver for each case that ORL of ODN is 32 dB and 20 dB.

The fundamental consideration has already been described in Appendix II/G.983.1. Similar consideration is applicable and extended for BPON ODN including effects by Enhancement Band, E-ONU, and E-OLT.

In the calculation of optical parameters, we assume that ONU and E-ONU equipment reflectance for receiver is −20 dB and OLT and E-OLT equipment reflectance for receiver is −20 dB. This appendix describes condition equations and calculation results for the reflectance, which restrict the parameters.

NOTE – Permissible total noise to the receiver, which consists of multiple reflections as well as leaked optical power, may be 10 dB lower than the lowest signal level. Since the permissible noise power for each noise component is for further study, thus the following clauses IV.2 and IV.3 are tentatively described on the assumption that each noise component be at least 10 dB lower than the signal. This assumption should be modified and interpreted to some higher value than 10 dB, for example to 13 dB, according to the permissible noise power assigned to each noise component such as reflections and leaked power.

IV.2 Effect of ODN optical return loss in the Basic Band

IV.2.1 Reflectance model to be considered

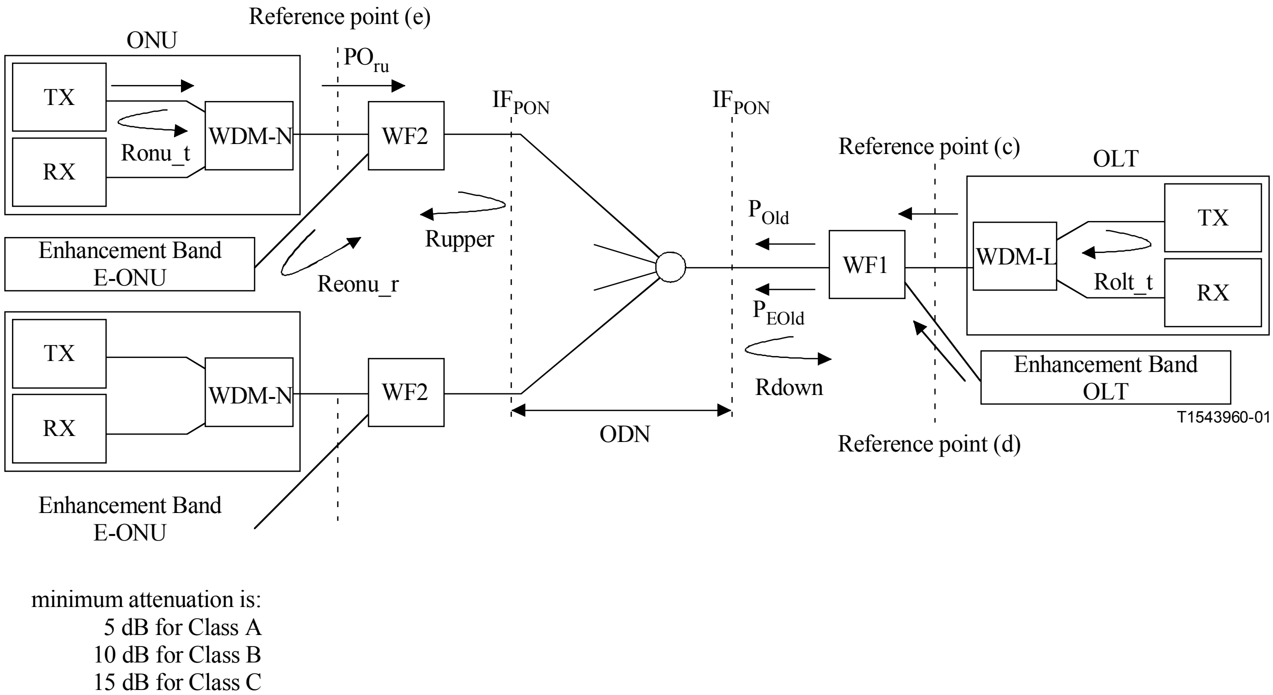


Figure IV.1/G.983.3 – Reflectance model to be considered

The following notations are used in this appendix:

P_{Oru_n}	Optical output power of ONU #n transmitter at O_{ru}
P_{Old}	Optical output power of OLT transmitter at O_{ld}
P_{EOld}	Optical output power of E-OLT transmitter at O_{ld}
Ronu_t	ONU transmitter equipment reflectance
Rolt_t	OLT transmitter equipment reflectance
Reonu_r	E-ONU receiver equipment reflectance
Rupper	ORL of ODN at O_{ru} and O_{rd}
Rdown	ORL of ODN at O_{ld} and O_{lu}
$L_{ODN\text{-}BB}$	Optical loss of Basic Band in the ODN
$L_{ODN\text{-}EB}$	Optical loss of Enhancement Band in the ODN
L_{WF1}	Insertion loss of WF1
L_{WF2}	Insertion loss of WF2
Iolt_t	WDM isolation for OLT transmitter
Iolt_r	WDM isolation for OLT receiver
Ionu_r	WDM isolation for ONU receiver
I_{WF1}	WF1 isolation for Basic Band
I_{WF2}	WF2 isolation for Basic Band

These values are all treated as positive in this appendix.

The following assumptions are taken for the examples:

– $L_{ODN\text{-}BB} = L_{ODN\text{-}EB}$

– Minimum insertion loss for WF1 and WF2 is equal to 0 dB.

– Insertion loss between the port at reference point (c) and the port at IF_{PON} side of WF1 is identical for upstream/downstream 1.3 µm, and upstream/downstream 1.5 µm Basic Band wavelengths.

– Insertion loss between the port at reference point (e) and the port at IF_{PON} side of WF2 is identical for upstream/downstream 1.3 µm, and upstream/downstream 1.5µm Basic Band wavelengths.

IV.2.2 Influence of reflectance into ONU receiver

Figure IV.2 shows the path of reflected signal to be considered. Equation (IV-1) must be satisfied:

$$P_{Oru\_1} - \text{Rupper} - \text{Ionu\_r} < \text{(permissible interference optical power)} \qquad \text{(IV-1)}$$

Assuming permissible interference optical power is equal to (minimum sensitivity –10 dB), permissible interference optical power = Pmin(A,B,C) – 10 dB. Pmin(A,B,C) means minimum sensitivity at reference point (e) for Class A, B, C described in Table V.1.

Then Ionu_r is estimated and summarized in Table IV.1.

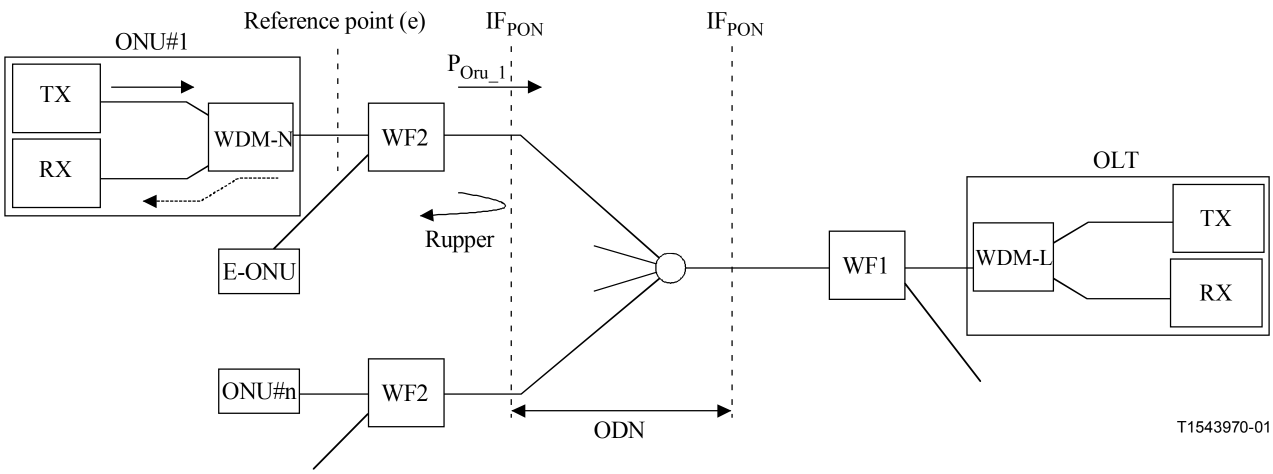


Figure IV.2/G.983.3 – Model for incidence into ONU receiver

IV.2.3 Influence of reflectance into OLT receiver (in the signal region)

The analysis for the influence of reflectance into OLT receiver is performed in two conditions; one is that the reflected signal overlaps the upstream burst signal region and the other is that the reflected signal is in the delay measurement window where there is no signal.

In the signal region, the following three cases are to be considered.

IV.2.3.1 Case 1

Figure IV.3 shows the path of reflectance signals. Equation (IV-2) must be satisfied:

$$(\text{maximum difference of burst signal optical levels}) - \text{Rupper} - 2L_{WF2} - \text{Ronu\_t} < (\text{permissible interference optical power ratio}) \quad \text{(IV-2)}$$

Assuming permissible interference optical power ratio is −10 dB, we obtain the results (see Table IV.1). Here, loss of L_{WF2} is assumed as 0 dB to estimate the worst case.

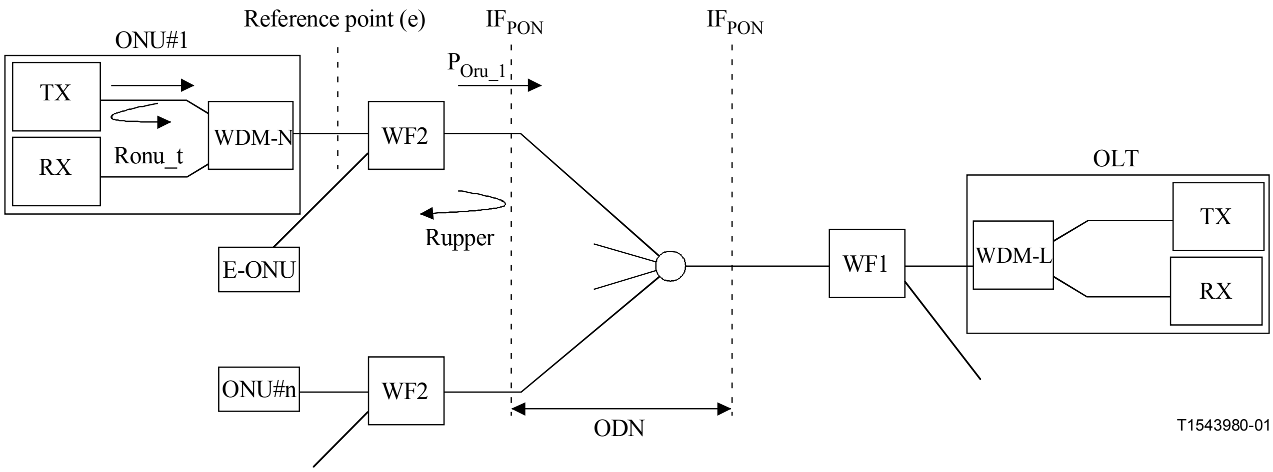


Figure IV.3/G.983.3 – Model 1 for incidence into OLT receiver

IV.2.3.2 Case 2

Figure IV.4 shows the path of reflectance signals. Equation (IV-3) must be satisfied:

$$(\text{maximum difference of burst signal optical levels}) - \text{Rolt\_t} - \text{Rdown} - 2\,L_{WF1} - 2\text{Iolt\_t} < (\text{permissible interference optical power}) \quad \text{(IV-3)}$$

Assuming permissible interference optical power is equal to −10 dB, we obtain the results (see Table IV.1). To estimate the worst case of Iolt_t, loss of L_{WF1} is assumed as 0 dB.

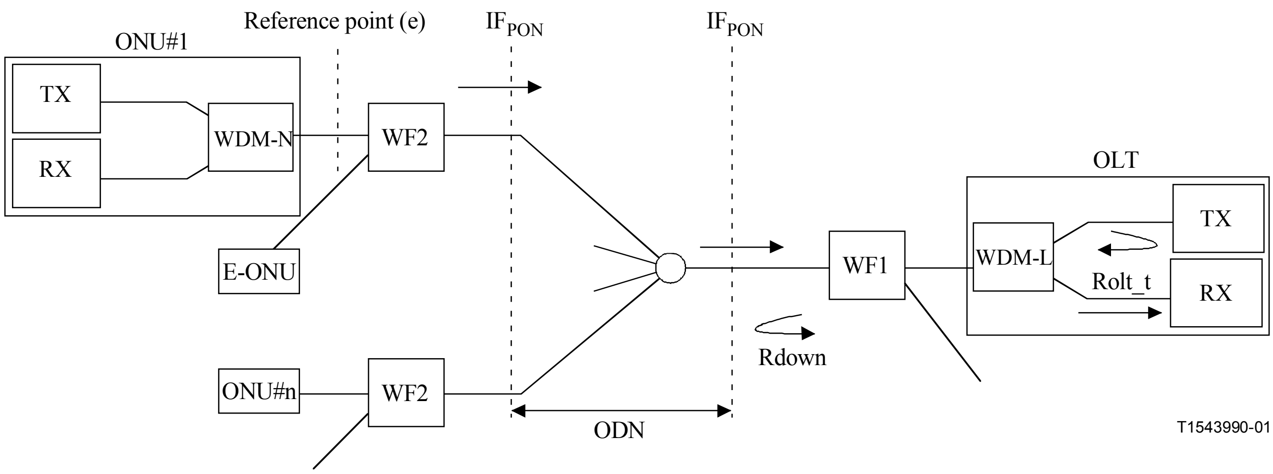


Figure IV.4/G.983.3 – Model 2 for incidence into OLT receiver

IV.2.3.3 Case 3

Figure IV.5 shows the path of reflectance signals. Equation (IV-4) must be satisfied:

$$P_{Old} - Rdown - Iolt\_r < (\text{permissible interference optical power}) \qquad \text{(IV-4)}$$

Assuming permissible interference optical power is equal to minimum sensitivity −10 dB, we obtain the results (see Table IV.1).

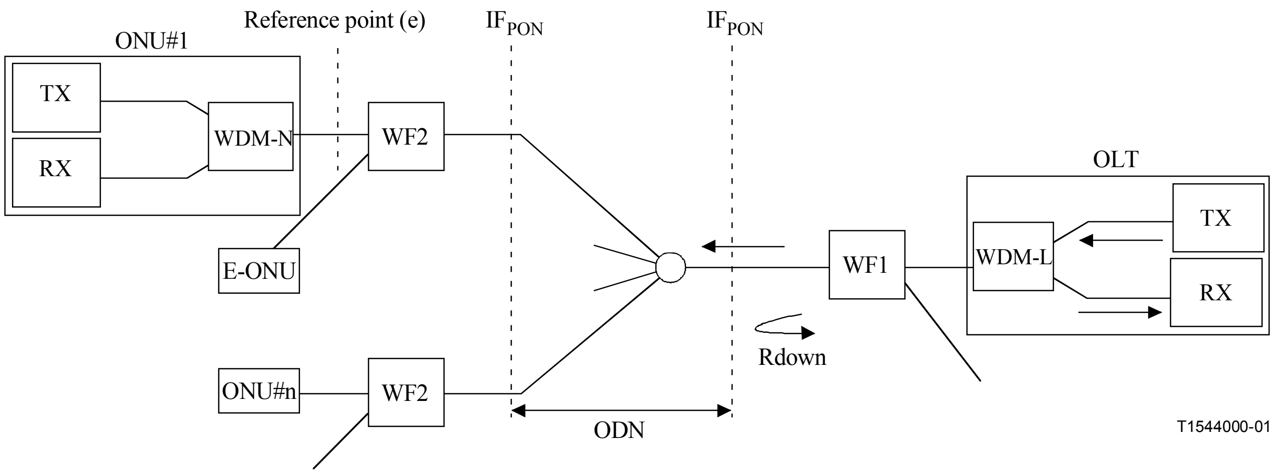


Figure IV.5/G.983.3 – Model 3 for incidence into OLT receiver

IV.2.4 Influence of reflectance into OLT receiver (in the no signal region)

In the no signal region, main cases of reflectance to be considered are the following two cases.

IV.2.4.1 Case 1

Figure IV.3 shows the path of reflectance signals. Equation (IV-5) must be satisfied:

$$P_{Oru\_n} - Rupper - 2L_{WF2} - Ronu\_t - (\text{minimum optical path attenuation}) < (\text{determination level as no signal}) \qquad \text{(IV-5)}$$

Assuming determination level as no signal is equal to minimum sensitivity −10 dB, we obtain the results (see Table IV.1). To estimate the worst case of Ronu_t, loss of L_{WF2} is assumed as 0 dB.

IV.2.4.2 Case 2

Figure IV.5 shows the path of reflectance signals. Equation (IV-6) must be satisfied:

$$P_{Old} - Rdown - Iolt\_r < (\text{determination level as no signal}) \qquad \text{(IV-6)}$$

Assuming determination level as no signal is equal to minimum sensitivity −10 dB, we obtain the results (see Table IV.1).

IV.2.5 Summary in effects of ODN optical return loss in the Basic Band

The calculation method mentioned above is available for the case that ODN reflectance is −20 dB. Table IV.1 shows the requirement for optical parameters when minimum ORL of ODN is 32 dB and 20 dB.

WDM isolation parameter is implementation matter, and values concerning WDM isolation parameters in Table IV.1 are just informative. This appendix includes ONU and OLT equipment reflectance. Considering the characteristic of the WDM, Ronu_t is equal to the reflectance of ONU measured at transmitter wavelength.

When ORL of ODN is 32 dB, ONU transmitter equipment reflectance must be less than incident optical power. It shall be 6 dB, which is available in an ordinary FP-LD module.

In the case that ORL of ODN is 20 dB, ONU transmitter equipment reflectance must be less than 13.5 dB.

As mentioned above, maximum ONU transmitter equipment reflectance is sensitive to the value of ORL of ODN, which depends on the network built by the common carrier. In the case that ORL of ODN is 32 dB and 20 dB, values of equipment reflectance for ONU transmitter in Table IV.1 are applicable. In the other case, the appropriate value is derived by means of the calculation method mentioned above.

Table IV.1/G.983.3 – Values for ONU transmitter equipment reflectance

Min ORL of ODN	Class	Optical parameters	Required characteristics					
			A[a)]	B[a)]	C[a)]	D[a)]	E[a)]	F[a)]
32 dB	A	WDM isolation for ONU receiver	6.5					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				3.5		3.5
		WDM isolation for OLT transmitter			NA			
		Equipment reflectance for ONU transmitter		0.5			1.5	
	B	WDM isolation for ONU receiver	8.5					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				11.5		11.5
		WDM isolation for OLT transmitter			NA			
		Equipment reflectance for ONU transmitter		0.5			1.5	
	C	WDM isolation for ONU receiver	13.5					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				16.5		16.5
		WDM isolation for OLT transmitter			NA			
		Equipment reflectance for ONU transmitter		0.5			1.5	
20 dB	A	WDM isolation for ONU receiver	18.5					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				15.5		15.5
		WDM isolation for OLT transmitter			3.3			
		Equipment reflectance for ONU transmitter		12.5			13.5	
	B	WDM isolation for ONU receiver	20.5					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				23.5		23.5
		WDM isolation for OLT transmitter			3.3			
		Equipment reflectance for ONU transmitter		12.5			13.5	
	C	WDM isolation for ONU receiver	25.5					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				28.5		28.5
		WDM isolation for OLT transmitter			3.3			
		Equipment reflectance for ONU transmitter		12.5			13.5	

a) A, B, C, D, E and F represent Equation (IV-1), Equation (IV-2), Equation (IV-3), Equation (IV-4), Equation (IV-5) and Equation (IV-6), respectively.

IV.3 Influence of reflectance from Enhancement Band to Basic Band

IV.3.1 Influence of reflectance into OLT receiver from Enhancement Band

Service using Enhancement Band signals may degrade quality of the Basic Band (ATM-PON) service, and vice versa. Three types of reflection of Enhancement Band signals are considered. One is the reflection from the ODN, and the others are those from the E-ONU and the blocking filter.

IV.3.1.1 Case 1

Figure IV.6 shows the path of reflectance signals from ODN. Equation (IV-7) must be satisfied:

$$P_{EOld} - Rdown - Iolt\_r - I_{WF1} < \text{(determination level as no signal)} \qquad \text{(IV-7)}$$

Assuming determination level as no signal is equal to minimum sensitivity −10 dB, we obtain the condition for I_{WF1}. Example for required isolation of I_{WF1} is shown in Table IV.2. Example conditions refer to Table IV.1 and Table V.1.

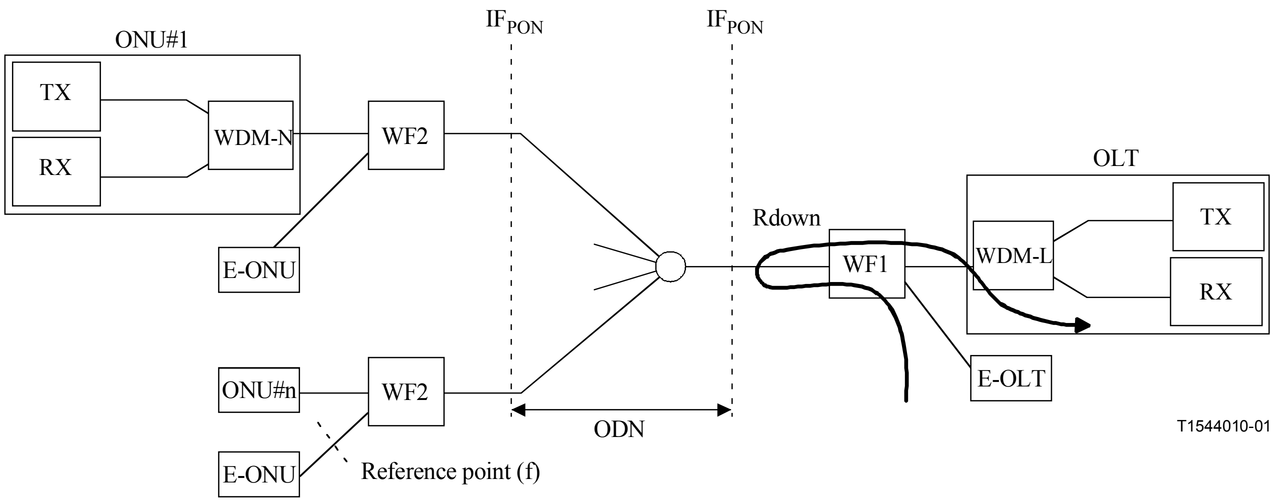


Figure IV.6/G.983.3 – Model 4 for incidence into OLT receiver

Table IV.2/G.983.3 – ORL versus Isolation at WF1

Min ORL of ODN	Class	Example conditions			Required I_{WF1} (dB)
		P_{Eold} (dBm)	Iolt_r (dB)	Pmin (dBm)	
32 dB	A	+16	3.5	–28.5	19
	B		11.5	–31.5	14
	C		16.5	–34.5	12
20 dB	A		15.5	–28.5	19
	B		23.5	–31.5	14
	C		28.5	–34.5	12

IV.3.1.2 Case 2

Figure IV.7 shows the path of reflectance signals from E-ONU. Equation (IV-8) must be satisfied:

$$\Sigma\,(P_{EOld} - 2\,L_{ODN\text{-}EB} - Reonu\_r\,) - Iolt\_r - I_{WF1} < \text{(determination level as no signal)} \quad \text{(IV-8)}$$

Here, the first Σ (summation) denotes reflection from all connected E-ONUs. In other words,

$P_{EOld} - 2\,L_{ODN\text{-}EB} - Reonu\_r + 10 \times \log N - Iolt\_r - I_{WF1} <$ (determination level as no signal).

Here, N shows the number of connected E-ONUs.

Assuming determination level as no signal is equal to minimum sensitivity −10 dB, we obtain the condition for I_{WF1}. Example for required isolation of I_{WF1} is shown in Table IV.3. Minimum loss of ODN and appropriate number of N is assumed. Example conditions refer to Tables IV.1 and V.1.

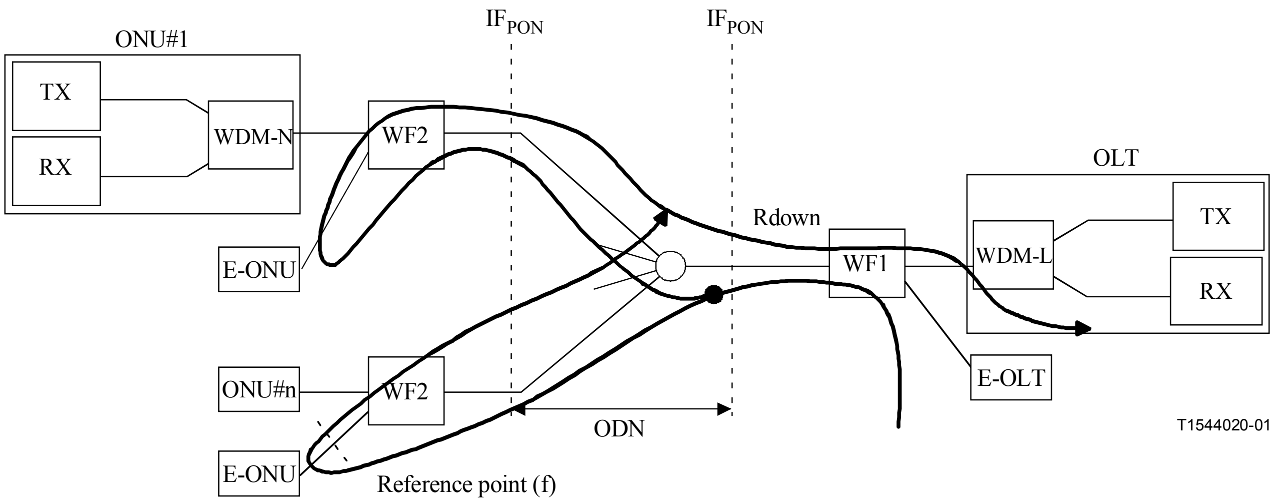


Figure IV.7/G.983.3 – Model 5 for incidence into OLT receiver

Table IV.3/G.983.3 – ORL versus Isolation at WF1

Min ORL of ODN	Assumption conditions							Required I_{WF1} (dB)
	ODN Class	Loss of ODN (dB)	No. of E-ONU N	P_{Eold} (dBm)	Iolt_r (dB)	Pmin (dBm)	Reonu_r (dB)	
32 dB	A	5	2	+16	3.5	–28.5	20	24
	B	10	8		11.5	–31.5		15
	C	15	32		16.5	–34.5		9
20 dB	A	5	2		15.5	–28.5		12
	B	10	8		23.5	–31.5		3
	C	15	32		28.5	–34.5		NA

IV.3.1.3 Case 3

Deployment scenarios described in Appendix II demonstrate configuration example of mixture in ONUs served by Basic Band only and ONUs served both by Basic Band and Enhancement Band. In this case, Blocking filters for Basic Band only users may be applied. Some type of Blocking filter may cause reflections to degrade signal quality.

Figure IV.8 shows the path of reflection signals from Blocking filters. Equation (IV-9) must be satisfied:

$$\Sigma\,(P_{EOld} - 2\,L_{ODN\text{-}EB} - R_{WF2\_}r\,) - Iolt\_r - I_{WF1} < \text{(determination level as no signal)} \quad \text{(IV-9)}$$

Here, $R_{WF2\_}r$ means the reflectance of the Blocking filter and the first Σ (summation) denotes reflection from all connected Blocking Filters. In other words,

$P_{EOld} - 2\,L_{ODN\text{-}EB} - R_{WF2\_}r + 10 \times \mathrm{Log}N - Iolt\_r - I_{WF1}$ < (determination level as no signal).

Here, N shows the number of connected blocking filters.

Assuming determination level as no signal is equal to minimum sensitivity −10 dB, we obtain the condition for $R_{WF2\_}r$. An example for required reflectance of $R_{WF2\_}r$ is shown in Table IV.4. Minimum loss of ODN and appropriate number of N is assumed. Isolation of I_{WF1} is assumed to be larger value among those in Tables IV.2 and IV.3. Example conditions refer to Tables IV.1 and V.1.

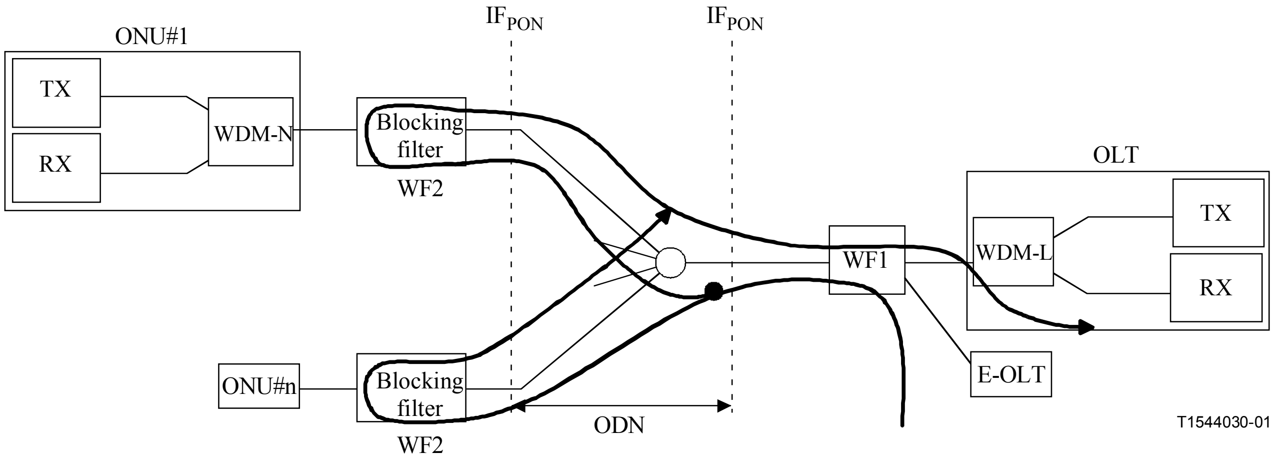


Figure IV.8/G.983.3 – Model 6 for incidence into OLT receiver

Table IV.4 – ORL versus Isolation at WF1

Min ORL of ODN	Assumption conditions							Required $R_{WF2\_}r$ (dB)
	ODN Class	Loss of ODN (dB)	No. of E-ONU N	P_{Eold} (dBm)	Iolt_r (dB)	Pmin (dBm)	I_{WF1} (dB)	
32 dB	A	5	2	+16	3.5	–28.5	24	20
	B	10	8		11.5	–31.5	15	20
	C	15	32		16.5	–34.5	12	17
20 dB	A	5	2		15.5	–28.5	19	13
	B	10	8		23.5	–31.5	14	9
	C	15	32		28.5	–34.5	12	5

APPENDIX V

Optical parameters for reference point (c) and (e) and two example deployment cases

V.1 Introduction

The optical power parameters for reference points of (c) and (e) shown here are examples to guide implementation.

V.2 Optical level diagram examples

V.2.1 Case 1: ODN centric view of optical parameters

Optical parameters examples for IF_{PON} are assumed to be the same as those described in Appendix I and the attenuation range of the ODN is compliant to ITU-T G.982.

In this case, example optical power level diagrams are shown below:

WDM loss of WF1 = 0 dB to 1.5 dB, WDM loss of WF2 = 0 dB to 1.5 dB.

Optical path penalty of 1 dB is included at the reference points of R/S and S/R at IF_{PON}.

Table V.1/G.983.3 – Optical power level diagram (example)

	Ref.(e)		IF_{PON} (O_{ru}, O_{rd})		ODN loss		IF_{PON} (O_{lu}, O_{ld})		Ref.(c)	
Unit	**dBm**		**dBm**		**dB**		**dBm**		**dBm**	
Range	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Downstream										
155M Class A	–30	–8	–28.5	–8	5	20	–7.5	–3	–6	–3
155M Class B	–30	–8	–28.5	–8	10	25	–2.5	2	–1	2
155M Class C	–33	–11	–31.5	–11	15	30	–0.5	4	1	4
622M Class A	–28	–6	–26.5	–6	5	20	–5.5	–1	–4	–1
622M Class B	–28	–6	–26.5	–6	10	25	–0.5	4	1	4
622M Class C	–33	–11	–31.5	–11	15	30	–0.5	4	1	4
Upstream										
155M Class A	–6	0	–7.5	0	5	20	–28.5	–5	–30	–5
155M Class B	–4	2	–5.5	2	10	25	–31.5	–8	–33	–8
155M Class C	–2	4	–3.5	4	15	30	–34.5	–11	–36	–11

V.2.2 Case 2: Equipment centric view of optical parameters

Optical parameters for reference points of (c) and (e) are same as those specified in ITU-T G.983.1 and the attenuation range of the ODN is reduced from that in ITU-T G.982.

The purpose of this clause is to survey the BPON applicability of optical modules compliant to ITU-T G.983.1. Maximum variation of the attenuation range in the ODN is reduced in order to compensate for the extra dynamic range induced by WF1 and WF2. Applied ODN parameters are shown in Table V.2.

With regards to ODN Class A, optical parameters are not specified in ITU-T G.983.1, thus the case of Class A is not described.

Table V.2/G.983.3 – Physical medium dependant layer parameters of ODN

Items	Unit	Specification
Fibre type	–	ITU-T G.652
Attenuation range	dB	Reduced Class B with attenuation range: 10-22 Reduced Class C with attenuation range: 15-27
Differential optical path loss	dB	12
Maximum optical path penalty	dB	1
Max differential logical reach	km	20
Maximum fibre distance between S/R and R/S points	km	20
Minimum supported split ratio	–	Restricted by path loss and ONU addressing limits. PON with passive splitters (16 or 32 way split)
Bidirectional transmission	–	1-fibre WDM (2-fibre system is beyond the scope of this Recommendation)
Maintenance wavelength	nm	To be defined

In this case, example optical power level diagrams are shown below:

WDM loss of WF1 = 0 dB to 1.5 dB, WDM loss of WF2 = 0 dB to 1.5 dB.

Optical path penalty of 1 dB is included at the reference points of R/S and S/R at IF_{PON}.

Table V.3/G.983.3 – Optical power level diagram (example)

	Ref.(e)		IF_{PON} (O_{ru}, O_{rd})		ODN loss		IF_{PON} (O_{lu}, O_{ld})		Ref.(c)	
Unit	**dBm**		**dBm**		**dB**		**dBm**		**dBm**	
Range	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Downstream										
155M reduced Class B	–30	–8	–28.5	–8	10	22	–5.5	2	–4	2
155M reduced Class C	–33	–11	–31.5	–11	15	27	–3.5	4	–2	4
622M reduced Class B	–28	–6	–26.5	–6	10	22	–3.5	4	–2	4
622M reduced Class C	–33	–11	–31.5	–11	15	27	–3.5	4	–2	4
Upstream										
155M reduced Class B	–4	2	–5.5	2	10	22	–28.5	–8	–30	–8
155M reduced Class C	–2	4	–3.5	4	15	27	–31.5	–11	–33	–11

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