INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.959.1

(02/2001)

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

Digital sections and digital line system – Digital line systems

Optical transport network physical layer interfaces

ITU-T Recommendation G.959.1

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ITU-T Recommendation G.959.1

Optical transport network physical layer interfaces

Summary

This Recommendation focuses on optical parameter values for pre-OTN single channel and multichannel inter-domain interfaces, and provides a framework for OTN physical interfaces.

Source

ITU-T Recommendation G.959.1 was prepared by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 9 February 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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Optical transport network physical layer interfaces

1 Scope

This Recommendation provides pre-OTN physical layer inter-domain interface (IrDI) specifications for optical networks employing wavelength division multiplexing (WDM). The physical layer specifications are valid for pre-OTN IrDIs, while also allowing application on OTN IrDIs according to ITU-T G.709. In the case of a pre-OTN IrDI, OTN management capabilities are not required. The IrDIs within the optical transport network (OTN) are provided by unidirectional, point-to-point, single and multichannel line systems. Their primary purpose is to enable transversely compatible interfaces to span the boundary between two administrative domains. The IrDI specifications include intra-office, short-haul and long-haul applications, without line amplifiers.

NOTE – For the purposes of this Recommendation, the term "Administrative domain" is understood to mean the extent of resources which belong to a single player, such as a network operator, a service provider, or an end-user. Administrative domains of different players do not overlap among themselves.

In order to provide a framework for the definition of IrDI specifications, this Recommendation includes general aspects of physical layer OTN considerations. A generic reference model is presented that defines physical layer interfaces between optical network elements. The specifications are organized according to application codes, which take into account the many possible combinations of channel counts, optical tributary signal types, span distances, fibre types and system configurations. The reference configuration and application codes form the foundation for specifying the optical networking physical layer parameters.

While this initial Recommendation focuses on pre-OTN point-to-point IrDIs, it can also be applied to IrDIs as specified in ITU-T G.709. In this Recommendation, however, any possible gain due to the use of forward error correction or the use of an optical supervisory channel has not been considered. Future versions and other new Recommendations will further address these aspects of the OTN, possibly involving an arrangement of optical network elements on either side of an optical subnetwork interface that is more complex than point-to-point. For these applications, different parameters beyond those specified for a point-to-point configuration may be required.

This Recommendation presumes that the optical tributary signals transported within Optical Channels are digital rather than analogue. Specifications for systems enabling transport of analogue optical tributary signals are for further study.

2 References

2.1 Normative references

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

– ITU-T G.652 (2000), *Characteristics of a single-mode optical fibre cable*.

– ITU-T G.653 (2000), *Characteristics of a dispersion-shifted single-mode optical fibre cable*.

- ITU-T G.655 (2000), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre cable*.
- ITU-T G.664 (1999), *Optical safety procedures and requirements for optical transport systems*.
- ITU-T G.691 (2000), *Optical interfaces for single-channel STM-64, STM-256 and other SDH systems with optical amplifiers*.
- ITU-T G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.
- ITU-T G.709/Y.1331 (2001), *Interfaces for the optical transport network (OTN)*.
- ITU-T G.872 (1999), *Architecture of optical transport networks*.
- ITU-T G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.
- IEC 60825-1 (2001), *Safety of laser products – Part 1: Equipment classification, requirements and user's guide*.
- IEC 60825-2 (2000), *Safety of laser products – Part 2: Safety of optical fibre communication systems*.

2.2 Informative references

The following ITU-T Recommendations contain provisions which, through reference in this text, constitute other relevant information:

- ITU-T G.7077/Y.1322 (2000), *Network node interface for the synchronous digital hierarchy (SDH)*.
- ITU-T G.8711/Y.1301 (2000), *Framework for optical transport network Recommendations*.

3 Terms and definitions

3.1 Definitions

This Recommendation defines the following terms:

3.1.1 optical tributary signal: A single channel signal that is placed within an Optical Channel for transport across the optical network.

3.1.2 optical tributary signal class NRZ 2.5G: Applies to continuous digital signals with non-return to zero line coding, from nominally 622 Mbit/s to nominally 2.67 Gbit/s. In the case of OTN optical tributary signals, NRZ 2.5G includes a signal with OTU1 bit rate according to ITU-T G.709.

3.1.3 optical tributary signal class NRZ 10G: Applies to continuous digital signals with non-return to zero line coding, from nominally 2.4 Gbit/s to nominally 10.71 Gbit/s. In the case of OTN optical tributary signals, NRZ 10G includes a signal with OTU2 bit rate according to ITU-T G.709.

3.1.4 optical transmission section of order 1 (OTS1): A single channel signal that provides transport of an Optical Channel between two Optical Network Elements.

3.1.5 optical transmission section of order n (OTSn): A multichannel signal that provides transport of an Optical Multiplex section, which in turn provides transport of up to n (n > 1) Optical Channels between two optical network elements.

3.1.6 pre-OTN: This term refers to systems deployed in advance of future systems compliant with the suite of OTN Recommendations indicated in ITU-T G.871. In particular, pre-OTN systems may rely on client-specific overhead information for performance monitoring, management, and protection switching/restoration of the single channel client signals.

3.2 Terms defined in other Recommendations

This Recommendation uses the following term defined in ITU-T G.692:

– Optical Supervisory Channel (OSC).

This Recommendation uses the following term defined in ITU-T G.709:

– Completely standardized OTUk (OTUk).

This Recommendation use the following terms defined in ITU-T G.872:

– Intra-domain interface (IaDI);
– Inter-domain interface (IrDI);
– Optical Channel (OCh);
– Optical Multiplex Section (OMS);
– Optical Transmission Section (OTS);
– 3R regeneration.

4 Abbreviations

This Recommendation uses the following abbreviations:

2R	(Regeneration) Re-amplification, reshaping
3R	(Regeneration) Re-amplification, reshaping, retiming
APD	Avalanche photodiode
ATM	Asynchronous transfer mode
BER	Bit error ratio
DGD	Differential group delay
DWDM	Dense wavelength division multiplexing
EA	Electro-absorption
EX	Extinction ratio
ffs	For further study
IaDI	Intra-domain interface
IP	Internet protocol
IrDI	Inter-domain interface
MLM	Multi-longitudinal mode
MPI	Main path interface
MPI-R_M	Multichannel receive main path interface reference point
MPI-S_M	Multichannel source main path interface reference point
NA	Not applicable
NE	Network element
NRZ	Non-return to zero

OA	Optical amplifier
OADM	Optical add-drop multiplexer
OCh	Optical channel
OD	Optical demultiplexer
OEO	Optical-to-electrical-to-optical
OM	Optical multiplexer
OMS	Optical multiplex section
ONE	Optical network element
OSC	Optical supervisory channel
OSNFR	Optical signal-to-noise floor ratio
OTN	Optical transport network
OTS	Optical transmission section
OTS1	Optical transmission section of level 1
OTSn	Optical transmission section of level n
OTUk	Completely standardized optical channel transport unit – k
PIN	P type-intrinsic-n type
PDH	Plesiochronous digital hierarchy
PMD	Polarization Mode Dispersion
RMS	Root mean square
RZ	Return to zero
R_M	Multichannel receive reference point (for line OAs)
R_{S-M}	Single channel (to multichannel) receive reference point
R_S	Single channel receive reference point
S_M	Multichannel source reference point (for line OAs)
S_{M-S}	Single channel (from multichannel) source reference point
S_S	Single channel source reference point
SDH	Synchronous digital hierarchy
SLM	Single-longitudinal mode
SONET	Synchronous Optical Network
VSR	Very short reach
WDM	Wavelength division multiplexing

5 Classification of optical interfaces

5.1 Applications

This Recommendation addresses pre-OTN single and multichannel optical systems within the Optical Transport Network (OTN) and provides optical interface parameters and values for a range of inter-domain interface applications.

As described in ITU-T G.872, a standardized interconnection is required for interconnecting administrative domains in a point-to-point configuration.

Interworking between different administrative domains also requires the specification of the characteristic information that is transferred across the inter-domain interface (IrDI) as described in ITU-T G.707, ITU-T G.709 or other specifications. The definition of this characteristic information, which includes signal bit rate, format and byte assignment, is outside the scope of this Recommendation.

The current state of technology development and deployment of optical transport systems provides somewhat limited opportunities for interworking between administrative domains compared to the target architecture described in ITU-T G.872. In particular, it is anticipated that initially OTN islands will be deployed within a single administrative domain. Interconnection between domains and interconnection of the OTN with existing transport networks (e.g. PDH and SDH networks) will be achieved through a simplified type of IrDI interface called pre-OTN within this Recommendation. Clause 8/G.872 describes a foreseen evolution from this initial stage toward the target OTN.

From the transmission viewpoint, an optical connection shows analogue behaviour (e.g. the optical transmission impairments due to attenuation, dispersion, fibre nonlinearity, amplified spontaneous emission, etc., accumulate in a manner similar to the accumulation of noise and other impairments in analogue networks). Within digital networks, mitigation of such impairments is achieved at 3R regeneration points, located in the transmission path according to engineering guidelines designed to achieve the required link error performance objective. Similarly, within the OTN, 3R regeneration is required at certain locations to maintain the OTN error performance objectives. Currently, the 3R process typically relies on electro-optic conversion. The use of 2R regeneration, as an alternative solution to 3R regeneration for particular applications in pre-OTN IrDIs is left for further study. The use of all-optical 2R/3R regeneration is also for further study.

The IrDI may be realized as either a single-channel interface or a multichannel interface. Multichannel IrDIs require additional wavelength multiplexing and demultiplexing equipment and possibly optical amplifiers but use fewer fibres as compared with multiple single channel IrDIs having equivalent optical channel capacity. Figure 5-7 indicates a single channel IrDI. Figures 5-4, 5-5 and 5-6 indicate three types of multichannel IrDI.

This Recommendation provides the physical layer parameters and values for application codes corresponding both to the single-channel and multichannel pre-OTN IrDIs with 3R regenerators on both sides of the interface as shown in Figures 5-4, 5-5, 5-6 and 5-7.

The specification method used in this Recommendation is a "Black-Box" approach, which means that within the scope of this Recommendation only the optical interfaces to the IrDI are specified. It is not intended to restrict or specify the internal elements and/or the connections between the elements within the black-box. There are however functional requirements for the black-box, the most important being the inclusion of 3R regeneration.

Specifications are given for single-channel inter-domain interfaces with the following characteristics: channel bit rates corresponding to NRZ 2.5G and NRZ 10G, intra-office, short-haul and long-haul span distances, and unidirectional transmission. In the future, specifications are also anticipated for single channel IrDIs with approximately 40 Gbit/s bit rate. Parameters and optical line coding for that bit rate are for further study.

Appendix I contains a further description of single-channel client interfaces.

Specifications are also given for a multichannel inter-domain interface. This interface accommodates up to 16 channels with central frequencies conforming to the ITU-T G.692 grid, with channel bit rates corresponding to NRZ 2.5G, and NRZ 10G, intra-office and short-haul (40 km) Optical Multiplex Section single span distances, unidirectional transmission, and point-to-point configuration.

In the future, specifications are anticipated for a further multichannel application. It accommodates up to 16 channels with central frequencies conforming to the ITU-T G.692 grid, with channel bit rates corresponding to NRZ 2.5G, and NRZ 10G, a long-haul (80 km) Optical Multiplex Section span distance without line amplifiers, unidirectional transmission, and point-to-point configuration.

In the future, specifications are also anticipated for multichannel IrDIs with approximately 40 Gbit/s (OTU3) channel bit rate. Parameters and optical line coding for that channel bit rate are for further study.

5.2 Reference points

Figure 5-1 shows a set of "generic" reference points for optical network elements (ONEs) in the future OTN.

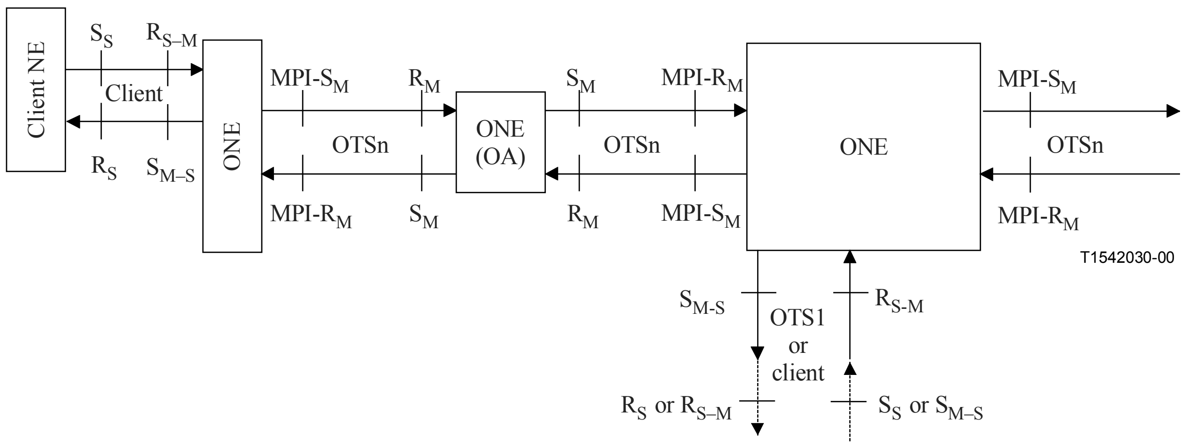

Figure 5-1/G.959.1 – Generic reference points for optical network elements

The reference points in Figure 5-1 are defined as follows:

– S_S is a (single channel) reference point on the optical fibre just after a single channel client NE transmitter optical connector;

– R_S is a (single channel) reference point just before a single channel client NE receiver optical connector;

– S_{M-S} is a (single channel) reference point just after each of the optical network element tributary interface output optical connectors (the "M-S" subscript indicating a single channel output from a multichannel system);

– R_{S-M} is a (single channel) reference point on the optical fibre just before each of the optical network element tributary interface input optical connectors (the "S-M" subscript indicating a single channel input to a multichannel system);

– MPI-S_M is a (multichannel) reference point on the optical fibre just after the optical network element transport interface output optical connector;

– MPI-R_M is a (multichannel) reference point on the optical fibre just before the optical network element transport interface input optical connector;

– S_M is a reference point just after the line multichannel OA output optical connector;

– R_M is a reference point on the optical fibre just before the line multichannel OA input optical connector.

Client interfaces at reference points S_S, R_S, and line amplifiers with reference points S_M and R_M are not within the scope of this Recommendation.

The term "Optical Network Element" (ONE) serves to illustrate the general case of a generic network element within the optical transport network. In general, an ONE may have:

1) only multichannel interfaces;

2) only single channel interfaces; or

3) any combination of single- and multichannel interfaces (i.e., the ONEs found in Figure 5-1 are not meant to imply any particular configuration).

For the purpose of this Recommendation, specifying the pre-OTN IrDI, the relevant reference points applicable to the multichannel IrDI and the single channel IrDI are shown in Figures 5-2 and 5-3 respectively.

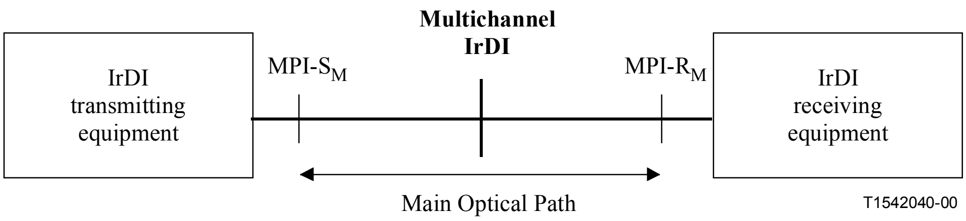

Figure 5-2/G.959.1 – Multichannel IrDI reference configuration

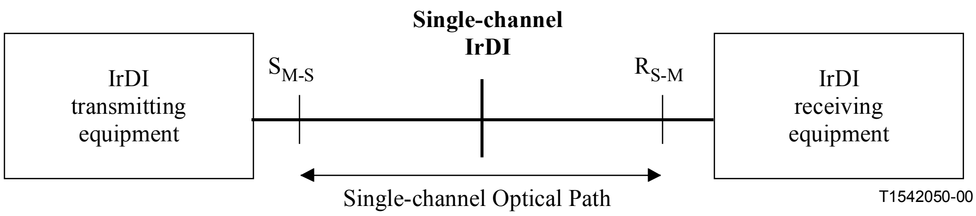

Figure 5-3/G.959.1 – Single-channel IrDI reference configuration

A further clarification of the reference points defined in this Recommendation and their application to the IrDI and IaDI, as specified in ITU-T G.872, is given in Appendix II.

5.3 Nomenclature

The application code identifies the network, implementation, and architectural characteristics of an application.

The application code notation is constructed as follows:

PnWx-ytz

where

P when present, indicates a pre-OTN application code applying to an IrDI

n is the maximum number of channels supported by the application code

W is a letter indicating the span distance/attenuation, such as:

– **VSR** indicating very short reach (span attenuation for further study);

– **I** indicating intra-office (up to 7 dB span attenuation);

– **S** indicating short-haul (11 dB span attenuation);

– **L** indicating long-haul (22 dB span attenuation);

– **V** indicating very long-haul (33 dB span attenuation).

x is the maximum number of spans allowed within the application code

y indicates the highest class of optical tributary signal supported:

– **1** indicating NRZ 2.5G;

– **2** indicating NRZ 10G.

t is a letter indicating configuration supported by the application code, such as:

– **A** indicating one OA used as a booster amplifier in the originating ONE and a second OA used as a preamplifier in the terminating ONE;

– **B** indicating only the booster amplifier is used;

– **C** indicating only the pre-amplifier is used;

– **D** indicating neither amplifier is used.

z is the source and fibre type, as follows:

– **1** indicating nominally 1310 nm sources on G.652 fibre;

– **2** indicating nominally 1550 nm sources on G.652 fibre;

– **3** indicating nominally 1550 nm sources on G.653 fibre;

– **5** indicating nominally 1550 nm sources on G.655 fibre.

In the present version of this Recommendation only physical parameter values of single span IrDIs (i.e. for x = 1) have been defined.

A bidirectional system, if introduced, will be indicated by the addition of the letter B at the front of the application code. For an OTN application this would be:

BnWx-ytz

For some single-channel application codes, a suffix is added to the end of the code. Three suffixes are defined as follows:

– **r** to indicate a reduced target distance. These application codes are dispersion limited. The same target distances can also be achieved by means of other technical solutions, which are for further study (e.g. parallel interface approach).

– **a** to indicate that this code has transmitter power levels appropriate to APD receivers.

– **b** to indicate that this code has transmitter power levels appropriate to PIN receivers.

This notation level may have to be augmented when other architectural and implementation alternatives are identified. Table 5-1 provides examples of application codes:

Table 5-1/G.959.1 – Application code examples

Example application code	Pre-OTN or OTN	Maximum number of channels	Maximum span attenuation	Maximum number of spans	Highest class of optical tributary Signal	ONE type	Fibre type
P1I1-1D1	Pre-OTN	1	6 dB	1	NRZ 2.5G	No amplifier	G.652
P16S1-2C5	Pre-OTN	16	11 dB	1	NRZ 10G	Preamplifier only	G.655
16S1-2B5	OTN	16	11 dB	1	NRZ 10G (OTU2)	Booster only	G.655

5.4 Multichannel inter-domain interfaces

The multichannel IrDI interfaces described in 5.4.1, 5.4.2 and 5.4.3 are intended to enable transverse (multivendor) compatibility. These interfaces may operate on G.652, G.653 or G.655 fibre, simultaneously transporting up to 16 optical channels, using either NRZ 2.5G or NRZ 10G optical tributary signals, depending on the particular application code. The same optical parameters apply to all the application codes listed in each individual column of Table 8-1.

Further requirements related to transverse compatibility can be found in clause 6.

Table 5-2 summarizes the multichannel IrDI application codes, which are structured according to the nomenclature in 5.3.

Table 5-2/G.959.1 – Classification of multichannel inter-domain interfaces based on application and showing application codes

Application	Intra-office			Short-haul		
Source nominal wavelength (nm)	1550 (G.692 grid)[b)]			1550 (G.692 grid)[b)]		
Type of fibre	G.652	G.653	G.655	G.652	G.653	G.655
Target distance (km)[a)]	20	2	20	40	40	40
Optical tributary signal class NRZ 2.5G	–	–	–	P16S1-1D2	–	P16S1-1D5
Optical tributary signal class NRZ 10G	P16I1-2D2	P16I1-2D3	P16I1-2D5	P16S1-2B2 P16S1-2C2	P16S1-2C3	P16S1-2B5 P16S1-2C5
a) – These target distances are for classification and not for specification. b) – See Table 8-1.						

5.4.1 Amplified short-haul multichannel inter-domain interfaces

The amplified short-haul multichannel pre-OTN IrDIs in this Recommendation are specified in Table 8-1. These amplified short-haul multichannel interface specifications permit an optical path loss of 11 dB. Such an optical path loss is intended to cover a target distance of 40 km, however, this target distance is for classification only and not for specification.

Applications P16S1-2C2, P16S1-2C3, and P16S1-2C5 are each amplified short-haul multichannel IrDI specifications using preamplifiers illustrated in Figure 5-4. Applications P16S1-2B2 and P16S1-2B5 are each amplified short-haul multichannel IrDI specifications using booster amplifiers, and are illustrated in Figure 5-5.

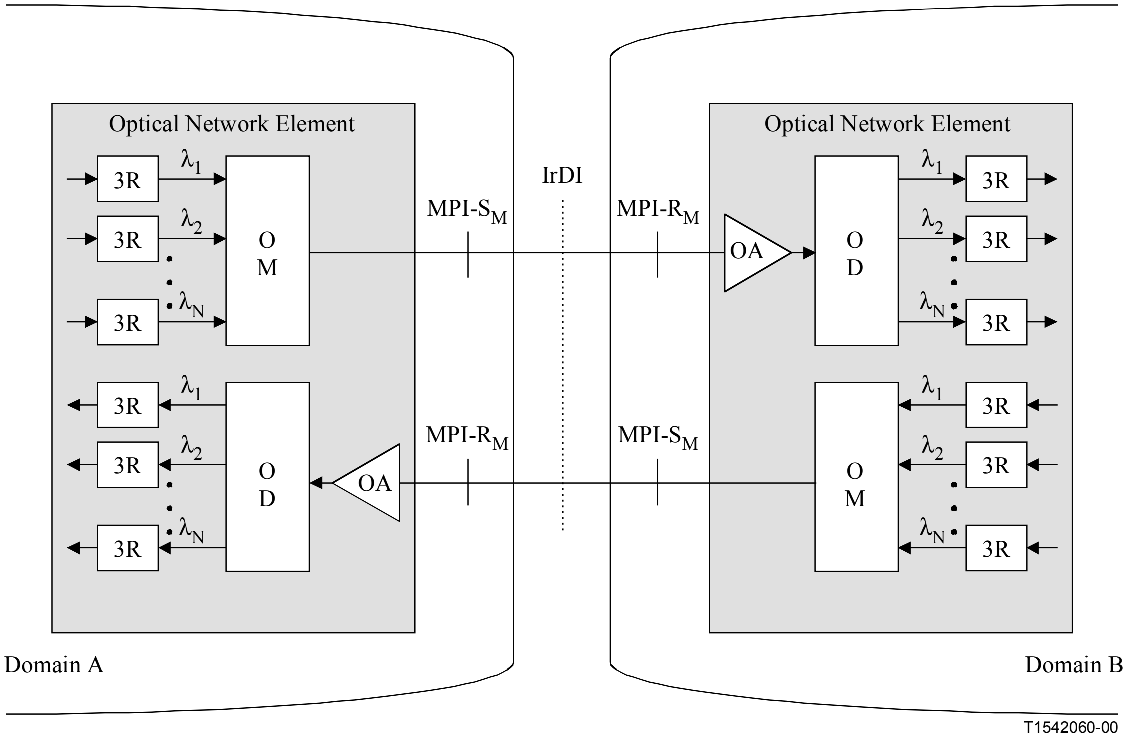

Figure 5-4/G.959.1 – Short-haul multichannel IrDI application using preamplifiers

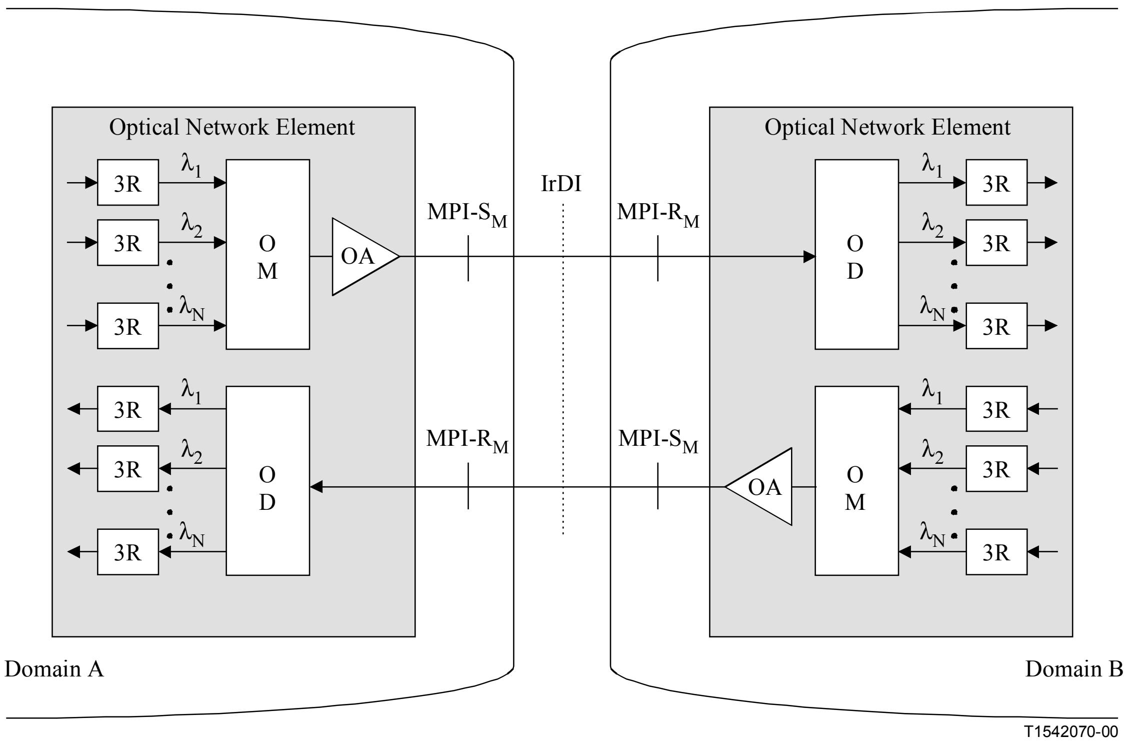

Figure 5-5/G.959.1 – Short-haul multichannel IrDI application using booster amplifiers

5.4.2 Non-amplified intra-office multichannel inter-domain interfaces

The non-amplified intra-office multichannel pre-OTN IrDIs in this Recommendation are specified in Table 8-1. These intra-office multichannel interfaces are specified for G.652, G.653 and G.655 fibres to permit an optical path loss of up to 6 dB. Transmission distance for the intra-office multichannel interface on G.653 fibre is recommended to be held within 2 km. If the distance on G.653 fibre is significantly longer than 2 km for this intra-office multichannel interface, a further penalty due to four wave mixing, in addition to the optical path penalty, may be observed.

Applications P16I1-2D2, P16I1-2D3, and P16I1-2D5 are each non-amplified intra-office multichannel IrDI specifications that are illustrated in Figure 5-6.

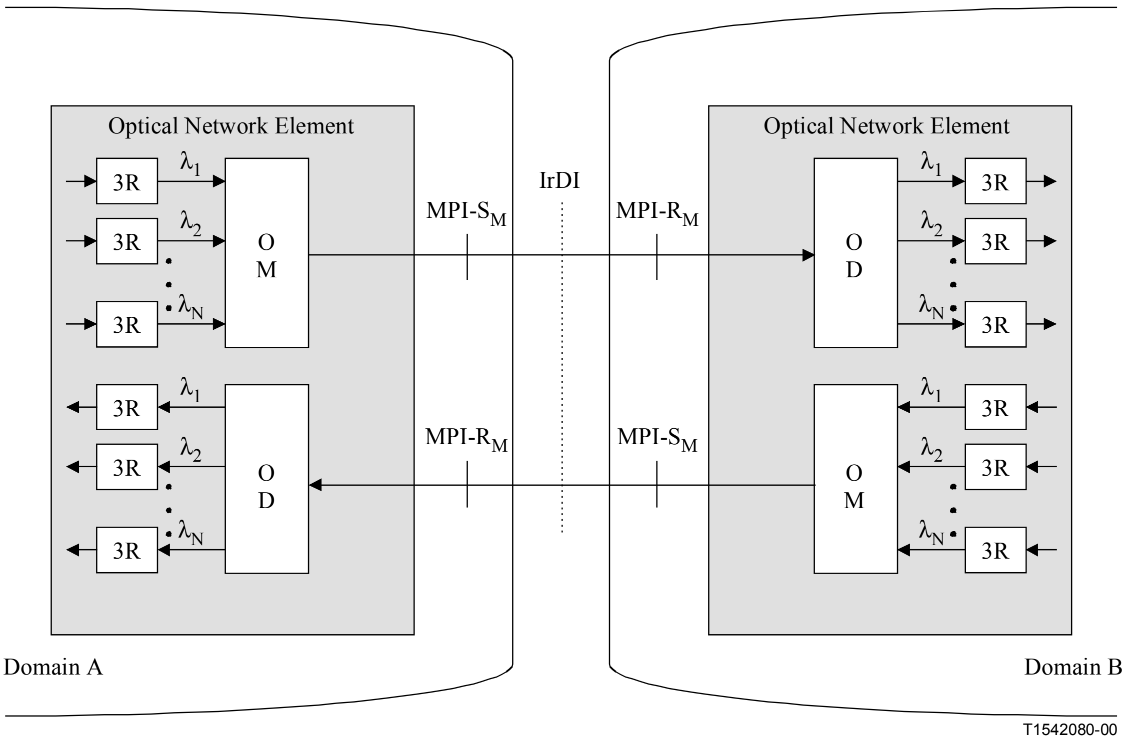

Figure 5-6/G.959.1 – Non-amplified intra-office or short-haul multichannel IrDI application

5.4.3 Non-amplified short-haul multichannel inter-domain interfaces

The non-amplified short-haul multichannel pre-OTN IrDIs in this Recommendation are specified in Table 8-1. These short-haul multichannel interface specifications permit an optical path loss of up to 11 dB. Such an optical path loss is intended to cover a target distance of 40 km, however, this target distance is for classification only and not for specification.

Applications P16S1-1D2 and P16S1-1D5 are each non-amplified short-haul multichannel IrDI specifications that are illustrated in Figure 5-6.

5.5 Single-channel inter-domain interfaces

Single-channel inter-domain interfaces are illustrated in Figure 5-7.

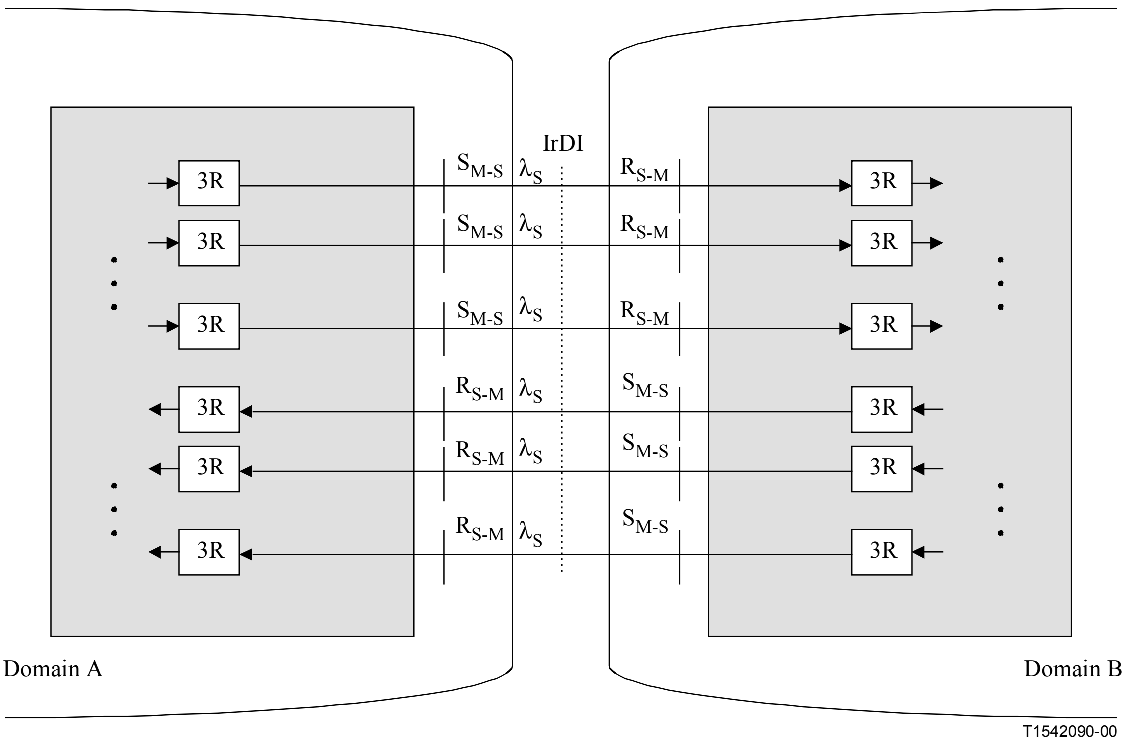

Figure 5-7/G.959.1 – Intra-office, short-haul or long-haul single channel IrDI application

Single-channel IrDI applications are specified for the following three distance categories:

– intra-office;

– short-haul inter-office;

– long-haul inter-office.

An additional distance category, very short reach, is defined. Specifications of very short reach IrDI applications are for further study. For each of these categories (intra-office, short-haul, long-haul) at least one application for optical tributary signal class NRZ 2.5G and one application for optical tributary signal class NRZ 10G is specified. Applications which use nominal 1310 nm sources on fibre complying with ITU-T G.652 and applications which use nominal 1550 nm sources on fibre complying with ITU-T G.652, ITU-T G.653 and ITU-T G.655 are included. The applications do not cover all possible combinations of distance category, optical tributary signal class, nominal source wavelength and fibre type. The included applications are intended to satisfy a broad range of network requirements with low-cost implementations. Table 5-3 summarizes the single-channel IrDI application codes, which are structured according to the nomenclature in 5.3.

Parameter values for intra-office, short-haul, and long-haul applications are given in 8.2. For optical tributary signal class NRZ 2.5G applications, in most instances the values in 8.2 are similar to or the same as values for applications found in ITU-T G.957, except that the ITU-T G.957 values have been modified, where necessary, to achieve a bit error ratio of less than or equal to 10^{-12}. For optical tributary signal class NRZ 10G applications, in most instances the values in 8.2 are the same as values for applications found in ITU-T G.691.

The intra-office specifications permit an optical path loss of up to 7 dB for single-channel interfaces.

Table 5-3/G.959.1 – Classification of single-channel inter-domain interfaces based on application and showing application codes

Application	**Very short reach**	**Intra-office**						**Short-haul**				**Long-haul**	
Source nominal wavelength (nm)	1310	1310		1550				1310	1550			1310	1550
Type of fibre	G.652	G.652		G.652		G.653	G.655	G.652	G.652	G.653	G.655	G.652	G.652, G.653, G.655
Optical tributary signal class NRZ 2.5G	P1VSR1-1D1	–	P1I1-1D1	–	–	–	–	P1S1-1D1	P1S1-1D2	–	–	P1L1-1D1	
Target distance for class NRZ 2.5G (km)[a)]	ffs	–	2	ffs	ffs	ffs	ffs	15	15	15	ffs	40	80
Optical tributary signal class NRZ 10G	P1VSR1-2D1	P1I1-2D1r	P1I1-2D1	P1I1-2D2r	P1I1-2D2	P1I1-2D3	P1I1-2D5	–	P1S1-2D2	P1S1-2D3	P1S1-2D5	P1L1-2D1	
Target distance for class NRZ 10G (km)[a)]	ffs	0.6	2	2	25	25	25	20	40	40	ffs	40	80
a) – These target distances are for classification and not for specification.													

5.6 Management signal implementations

Although no overhead implementation is required of the current pre-OTN IrDI, the need for signals to manage the Optical Channel, Optical Multiplex Section and Optical Transmission Section layers is foreseen for the future OTN realization. Considerations for physical implementations of such signals are presented in Appendix III.

6 Transverse compatibility

The goal for the IrDI in this Recommendation is to specify parameters in order to enable transverse (i.e. multivendor) compatible line systems for short-haul and long-haul point-to-point applications.

Inter-domain interfaces are intended to interconnect two different administrative domains. Such domains may consist of equipment from two different vendors. The two administrative domains may also belong to two different network operators.

– Transverse (multivendor) compatibility is enabled for all IrDIs having exactly the same application code nWx-ytz. As an example a P16S1-2B2 interface from one vendor – implemented in domain A – can be connected with a P16S1-2B2 interface of another vendor – installed in domain B. Care must also be taken to match the optical tributary signal bit rate and format.
– Interconnection of interfaces with different application codes is a matter of joint engineering. Care must be taken particularly with respect to critical parameters that must be matched, e.g. MPI-S_M output power, MPI-R_M power levels, maximum dispersion, minimum/maximum attenuation, etc. As an example, an interface P16S1-2B2 (booster amplifier type) in domain A should not be interconnected with an interface P16S1-2C2 (preamplifier type) in domain B without additional measures, e.g. adding an attenuator. In this example the booster amplifier output power may be +15 dBm (see Table 8-1) and the attenuation may be 0 dB. Thus, the input power to the preamplifier type interface is +15 dBm. However, the maximum receiver input power of the preamplifier type interface must not exceed +5 dBm (see Table 8-1) and the receiver is overloaded by up to 10 dB. Care must also be taken to match the optical tributary signal bit rate and format.

7 Parameter definitions

7.1 System operating wavelength range

The operating wavelength ranges for multichannel applications within this Recommendation are not necessarily restricted to those found within ITU-T G.692. Specifically, operating wavelength ranges may exceed those found in ITU-T G.692 (e.g. 1525-1625 nm).

In addition, future use of the 1285-1330 nm amplification range should not be precluded.

The operating wavelength ranges for single channel applications within this Recommendation are not necessarily restricted to those found within ITU-T G.957 or ITU-T G.691.

7.2 Parameters

The parameters in Tables 7-1 and 7-2 are defined at the interface points, and definitions are provided in the subclauses below. In addition, Appendix IV provides some further considerations on possible future IaDI specifications.

Table 7-1/G.959.1 – Physical layer parameters for multichannel IrDI

Proposed parameter	Units	Defined in
General information		
Maximum number of channels	–	7.2.1.1
Bit rate/line coding of optical tributary signals	–	7.2.1.2
Maximum bit error ratio	–	7.2.1.3
Fibre type	–	7.2.1.4
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	7.2.2.1
Minimum mean channel output power	dBm	7.2.2.2
Maximum mean total output power	dBm	7.2.2.3
Central frequency	THz	7.2.2.4
Channel spacing	GHz	7.2.2.5
Maximum central frequency deviation	GHz	7.2.2.6
Minimum channel extinction ratio	dB	7.2.2.7
Eye mask	–	7.2.2.8
Optical path (single span) from point MPI-S_M to MPI-R_M		
Maximum attenuation	dB	7.2.3.1
Minimum attenuation	dB	7.2.3.2
Maximum chromatic dispersion	ps/nm	7.2.3.3
Minimum optical return loss	dB	7.2.3.4
Maximum discrete reflectance	dB	7.2.3.5
Maximum differential group delay	ps	7.2.3.6
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	7.2.4.1
Minimum mean channel input power	dBm	7.2.4.2
Maximum mean total input power	dBm	7.2.4.3
Maximum channel power difference	dB	7.2.4.4
Maximum optical path penalty	dB	7.2.4.5
Maximum reflectance of optical network element	dB	7.2.4.6

Table 7-2/G.959.1 – Physical layer parameters for single channel IrDI

Proposed Parameter	Units	Defined in
General information		
Maximum number of channels	–	7.2.1.1
Bit rate/line coding of optical tributary signals	–	7.2.1.2
Maximum bit error ratio	–	7.2.1.3
Fibre type	–	7.2.1.4
Interface at point S_{M-S}		
Operating wavelength range	nm	7.2.5.1
Source type		7.2.5.2
Maximum RMS width (σ)	nm	7.2.5.3
Maximum −20 dB width	nm	7.2.5.4
Minimum side mode suppression ratio	dB	7.2.5.5
Maximum mean output power	dBm	7.2.5.6
Minimum mean output power	dBm	7.2.5.7
Minimum extinction ratio	dB	7.2.5.8
Optical path from point S_{M-S} to R_{S-M}		
Maximum attenuation	dB	7.2.6.1
Minimum attenuation	dB	7.2.6.2
Maximum chromatic dispersion	ps/nm	7.2.6.3
Minimum optical return loss at S_{M-S}	dB	7.2.6.4
Maximum discrete reflectance between S_{M-S} and R_{S-M}	dB	7.2.6.5
Maximum differential group delay	ps	7.2.6.6
Interface at point R_{S-M}		
Maximum mean input power	dBm	7.2.7.1
Minimum sensitivity	dBm	7.2.7.2
Maximum optical path penalty	dB	7.2.7.3
Maximum reflectance	dB	7.2.7.4

7.2.1 General information

7.2.1.1 Maximum number of channels

The maximum number of Optical Channels that may be simultaneously present at a multichannel interface.

7.2.1.2 Bit rate/line coding of optical tributary signals

Optical tributary signal class NRZ 2.5G applies to continuous digital signals with non-return to zero line coding, from nominally 622 Mbit/s to nominally 2.67 Gbit/s. Optical tributary signal class NRZ 10G applies to continuous digital signals with non-return to zero line coding, from nominally 2.4 Gbit/s to nominally 10.71 Gbit/s. For OTN optical tributary signals, NRZ 2.5G includes the OTU1 bit rate and NRZ 10G includes the OTU2 bit rate defined in ITU-T G.709.

NOTE – While this Recommendation currently deals with NRZ coding only, future versions may contain other line codes, e.g. RZ.

7.2.1.3 Maximum bit error ratio

The parameters are specified relative to an optical section design objective of a Bit Error Ratio (BER) not worse than the value specified by the application code. This value applies to each Optical Channel under the extreme case of optical path attenuation and dispersion conditions in each application. The possible effect on the definition of this parameter due to the presence of forward error correction (e.g. in an OTUk) has not been considered in the present version of this Recommendation.

7.2.1.4 Fibre type

Single mode optical fibre types are chosen from those defined in ITU-T G.652, ITU-T G.653, and ITU-T G.655.

7.2.2 Interface at point MPI-S_M

7.2.2.1 Maximum mean channel output power

The mean launched power of each Optical Channel at reference point MPI-S_M is the average power of a pseudo-random data sequence coupled into the fibre from the ONE. It is given as a range (maximum and minimum) to allow for some cost optimization and to cover allowances for operation under the standard operating conditions, connector degradations, measurement tolerances, and aging effects.

7.2.2.2 Minimum mean channel output power

See 7.2.2.1.

7.2.2.3 Maximum mean total output power

The maximum value of the mean launched optical power at point MPI-S_M.

7.2.2.4 Central frequency

The nominal single channel frequencies on which the digital coded information of the particular optical wavelength channels are modulated by use of the NRZ line code as defined in ITU-T G.957 and ITU-T G.691.

The central frequencies are based on the frequency grid given in Annex A/G.692. The allowed central frequencies for the multichannel IrDI are specified in Table 8-1.

Note that the value of "c" (speed of light in vacuum) that should be used for converting between frequency and wavelength is 2.99792458×10^8 m/s.

7.2.2.5 Channel spacing

The nominal difference in frequency between two adjacent channels. All possible tolerances of actual frequencies are considered in 7.2.2.6.

7.2.2.6 Maximum central frequency deviation

The difference between the nominal central frequency and the actual central frequency. Included in the central frequency deviation are all the processes that affect the instantaneous value of the source central frequency over a measurement interval appropriate to the channel bit-rate. These processes include source chirp, information bandwidth, broadening due to self-phase modulation, and effects due to temperature and aging.

7.2.2.7 Minimum channel extinction ratio

The convention adopted for optical logic levels is

– emission of light for a logical "1";

– no emission for a logical "0".

The extinction ratio (EX) is defined as:

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

where

A is the average optical power level at the centre of the logical "1"; and

B is the average optical power level at the centre of the logical "0".

This definition can be directly applied to single-channel systems. In the case of the multichannel IrDI, two alternative methods can be used.

– Method A can be used when single-channel reference points are accessible at the transmit end of the link for verification. For this method the procedures described in ITU-T G.957 and ITU-T G.691 are used. The configuration for this method is contained in Annex A.

– Method B employs a reference optical bandpass filter to isolate the individual transmitted signals, followed by a reference receiver. The characteristics of the reference optical bandpass filter and the reference receiver are contained in Annex B.

7.2.2.8 Eye mask

The definition and limits for this parameter are found in ITU-T G.691. This definition can be directly applied to single-channel systems. In the case of the multichannel IrDI, two alternative methods can be used.

– Method A can be used when single-channel reference points are accessible at the transmit end of the link for verification. For this method the procedures described in ITU-T G.957 and ITU-T G.691 are used. The configuration for this method is contained in Annex A.

– Method B employs a reference optical bandpass filter to isolate the individual transmitted signals, followed by a reference receiver. The characteristics of the reference optical bandpass filter and the reference receiver are contained in Annex B.

7.2.3 Optical path (single span) from point MPI-S_M to MPI-R_M

7.2.3.1 Maximum attenuation

The maximum path attenuation where the system in question operates under end-of-life conditions at a BER of 10^{-12} (or as given by the application code), under worst-case transmit-side signal and dispersion. The definition of effects included in the maximum attenuation is given in 6.3.1/G.691. The maximum attenuation values required for the IrDI target distances are based on the assumption of 0.275 dB/km installed fibre loss (including splices and cable margin) in the 1530-1565 nm range, and on an assumption 0.55 dB/km for the 1310 nm single-channel IrDI. From a practical point of view, attenuation spans of 11 dB for 40 km and 22 dB for 80 km at 1550 nm and 11 dB for 20 km and 22 dB for 40 km at 1310 nm are defined, except for very short reach and intra-office applications. It should be noted that this method, which is also used for the definition of other interfaces at the given wavelength, gives a theoretical value. Connector and splice losses, which are present in practical implementations, may lead to other distances.

7.2.3.2 Minimum attenuation

The minimum path attenuation that allows the system in question, operating under worst-case transmit-side conditions, to achieve a BER no worse than 10^{-12} (or as given by the application code).

7.2.3.3 Maximum chromatic dispersion

This parameter defines the maximum value of the optical path chromatic dispersion that the system shall be able to tolerate. The required maximum dispersion tolerance of the systems is set to a value equal to the target distance times 20 ps/nm km for G.652 fibre, and 3.3 ps/nm km for G.653 fibre in the 1550 nm region, as well as for G.652 fibre in the 1310 nm region. This is considered a worst-case dispersion value for the relevant fibre types. The worst-case approach on this parameter is intended to give some margins on a sensitive parameter, as well as making it possible to stretch the transmission distances for low-loss fibre plants.

The allowed optical path penalty considers all deterministic effects due to chromatic dispersion as well as the penalty due to the maximum differential group delay.

7.2.3.4 Minimum optical return loss

Reflections are caused by refractive index discontinuities along the optical path. If not controlled, they can degrade system performance through their disturbing effect on the operation of the optical source or amplifier, or through multiple reflections which lead to interferometric noise at the receiver. Reflections from the optical path are controlled by specifying the:

– minimum optical return loss of the cable plant at the source reference point (e.g. MPI-S_M, S_{M-S}), including any connectors; and
– maximum discrete reflectance between source reference points (e.g. MPI-S_M, S_{M-S}) and receive reference points (e.g. MPI-R_M, R_{S-M}).

Reflectance denotes the reflection from any single discrete reflection point, whereas the optical return loss is the ratio of the incident optical power to the total returned optical power from the entire fibre including both discrete reflections and distributed backscattering such as Rayleigh scattering.

Measurement methods for reflections are described in Appendix I/G.957. For the purpose of reflectance and return loss measurements, points S_{M-S} and R_{S-M} are assumed to coincide with the endface of each connector plug. It is recognized that this does not include the actual reflection performance of the respective connectors in the operational system. These reflections are assumed to have the nominal value of reflection for the specific type of connectors used.

7.2.3.5 Maximum discrete reflectance

See 7.2.7.4 for the definition of maximum reflectance. The maximum number of connectors or other discrete reflection points which may be included in the optical path (e.g. for distribution frames, or WDM components) must be such as to allow the specified overall optical return loss to be achieved. If this cannot be done using connectors meeting the maximum discrete reflections cited in the tables of clause 8, then connectors having better reflection performance must be employed. Alternatively, the number of connectors must be reduced. It also may be necessary to limit the number of connectors or to use connectors having improved reflectance performance in order to avoid unacceptable impairments due to multiple reflections.

In the tables of clause 8, the value –27 dB maximum discrete reflectance between source reference points and receive reference points is intended to minimize the effects of multiple reflections (e.g. interferometric noise). The value for maximum receiver reflectance is chosen to ensure acceptable penalties due to multiple reflections for all likely system configurations involving multiple connectors, etc. Systems employing fewer or higher performance connectors produce fewer multiple reflections and consequently are able to tolerate receivers exhibiting higher reflectance.

7.2.3.6 Maximum differential group delay

Differential group delay (DGD) is the time difference between the fractions of a pulse that are transmitted in the two principal states of polarization of an optical signal. For distances greater than several kilometres, and assuming random (strong) polarization mode coupling, DGD in a fibre can be statistically modelled as having a Maxwellian distribution.

In this Recommendation, the maximum differential group delay is defined to be the value of DGD that the system must tolerate with a maximum sensitivity degradation of 1 dB.

Due to the statistical nature of Polarization Mode Dispersion (PMD), the relationship between maximum DGD and mean DGD can only be defined probabilistically. The probability of the instantaneous DGD exceeding any given value can be inferred from its Maxwellian statistics. Therefore, if we know the maximum DGD that the system can tolerate, we can derive the equivalent mean DGD by dividing by the ratio of maximum to mean that corresponds to an acceptable probability. Some example ratios are given below in Table 7-3.

Table 7-3/G.959.1 – DGD means and probabilities

Ratio of maximum to mean	Probability of exceeding maximum
3.0	4.2×10^{-5}
3.5	7.7×10^{-7}
4.0	7.4×10^{-9}

7.2.4 Interface at point MPI-R_M

7.2.4.1 Maximum mean channel input power

The maximum acceptable value of the average received channel power at point MPI-R_M to achieve the specified maximum BER of the application code.

7.2.4.2 Minimum mean channel input power

The minimum acceptable value of the average received channel power at point MPI-R_M to achieve the specified maximum BER of the application code.

7.2.4.3 Maximum mean total input power

The maximum acceptable total input power at point MPI-R_M.

7.2.4.4 Maximum channel power difference

The difference between the largest value of the mean channel input power and the smallest value of the mean channel input power present at the same time within a given optical resolution bandwidth, independent of the number of channels, within the application.

7.2.4.5 Maximum optical path penalty

The path penalty is the apparent reduction of receiver sensitivity due to distortion of the signal waveform during its transmission over the path. It is manifested as a shift of the system's BER-curves towards higher input power levels. This corresponds to a positive path penalty. Negative path penalties may exist under some circumstances, but should be small. (A negative path penalty indicates that a less than perfect transmitter eye has been partially improved by the path dependent distortions.) Ideally, the BER-curves should be translated only, but shape variations are not uncommon, and may indicate the emergence of BER-floors. Since the path penalty is a change in the receiver's sensitivity, it is measured at a BER-level of 10^{-12}.

A maximum path penalty of 1 dB for low-dispersion systems, and 2 dB for high-dispersion systems is allowed. The path penalties are not made proportional to the target distances to avoid operating systems with high penalties.

In the future, systems employing dispersion accommodation techniques based on pre-distortion of the signal at the transmitter may be introduced. In this case, the path penalty in the above sense can only be defined between points with undistorted signals. These points, however, do not coincide with the main path interfaces, and may thus not even be accessible. The definition of path penalty for this case is for further study.

The average value of the random dispersion penalties due to PMD is included in the allowed path penalty. In this respect, the transmitter/receiver combination is required to tolerate an actual DGD of 0.3 bit period with a maximum sensitivity degradation of 1 dB (with 50% of optical power in each principal state of polarization). For a well-designed receiver, this corresponds to a penalty of 0.1-0.2 dB for a DGD of 0.1 bit period. The actual DGD that may be encountered in operation is a randomly varying fibre/cable property, and cannot be specified in this Recommendation. This subject is further discussed in Appendix I/G.691.

Note that a signal to noise ratio reduction due to optical amplification is not considered a path penalty.

This definition can be directly applied to single-channel systems. For the multichannel IrDI, this parameter is a single-channel equipment design parameter and is not incorporated in the power budget between MPI-S_M and MPI-R_M. In the case of the multichannel IrDI, two alternative methods can be used.

– Method A can be used when single-channel reference points are accessible at the receive end of the link for verification. For this method the procedures described in ITU-T G.957 and ITU-T G.691 are used. The configuration for this method is contained in Annex A.
– Method B employs a reference optical bandpass filter to isolate the individual transmitted signals, followed by a reference receiver. The characteristics of the reference optical bandpass filter and the reference receiver are contained in Annex B.

NOTE – The optical path penalty observed in the reference receiver may not be the same as actually experienced in the receiving equipment, depending on the design implementation.

7.2.4.6 Maximum reflectance of optical network element

Reflections from the ONE back into the cable plant are specified by the maximum permissible reflectance of the ONE measured at reference point MPI-R_M. Maximum reflectance is defined in 7.2.7.4.

7.2.5 Interface at point S_{M-S}

7.2.5.1 Operating wavelength range

The system operating wavelength range depends on the source characteristics, transmission fibre characteristics (attenuation, chromatic dispersion) and on the gain bandwidth of an optical amplifier (if used).

7.2.5.2 Source type

Depending on attenuation/dispersion characteristics and hierarchical level of each application code, feasible transmitter devices include multi-longitudinal mode (MLM) lasers and single-longitudinal mode (SLM) lasers. For each of the applications, this Recommendation indicates a nominal source type. It is understood that the indication of a nominal source type in this Recommendation is not a requirement and that SLM devices can be substituted for any application showing MLM as the nominal source type without any degradation in system performance.

7.2.5.3 Maximum RMS width

The maximum Root-Mean-Square (RMS) width or the standard deviation σ (in nm) of the spectral distribution of an MLM laser considers all laser modes, which are not more than 20 dB down from the peak mode. Only a system with an MLM laser at 1310 nm requires this specification.

7.2.5.4 Maximum −20 dB width

The maximum −20 dB spectral width (in nm) of an SLM laser is specified by the maximum full width of the central wavelength peak, measured −20 dB down from the maximum amplitude of the central wavelength under standard operating conditions.

7.2.5.5 Minimum side mode suppression ratio

The minimum value of the ratio of the largest peak of the total transmitter spectrum to the second largest peak. The spectral resolution of the measurement shall be better than the maximum spectral width of the peak, as defined in 7.2.5.4. The second largest peak may be next to the main peak, or far removed from it.

7.2.5.6 Maximum mean output power

The maximum value of the average power of a pseudo-random data sequence coupled into fibre by the transmitter.

7.2.5.7 Minimum mean output power

The minimum value of the average power of a pseudo-random data sequence coupled into fibre by the transmitter.

7.2.5.8 Minimum extinction ratio

See 7.2.2.7.

7.2.6 Optical path from point S_{M-S} to R_{S-M}

7.2.6.1 Maximum attenuation

See 7.2.3.1.

7.2.6.2 Minimum attenuation

See 7.2.3.2.

7.2.6.3 Maximum chromatic dispersion

See 7.2.3.3.

7.2.6.4 Minimum optical return loss at S_{M-S}

See 7.2.3.4.

7.2.6.5 Maximum discrete reflectance between S_{M-S} and R_{S-M}

See 7.2.7.4 for a definition of maximum reflectance, and 7.2.3.5 for a discussion of discrete reflectances.

7.2.6.6 Maximum differential group delay

See 7.2.3.6.

7.2.7 Interface at point R_{S-M}

7.2.7.1 Maximum mean input power

The maximum acceptable value of the average received power at point R_{S-M} to achieve the specified maximum BER of the application code.

7.2.7.2 Minimum sensitivity

The minimum value of average received power at point R_{S-M} to achieve the specified maximum BER of the application code. It takes into account power penalties caused by use of a transmitter under standard operating conditions with worst-case values of extinction ratio, pulse rise and fall times, optical return loss at points S_{M-S}, connector degradations, crosstalk, optical amplifier noise, and measurement tolerances. This does not include power penalties associated with dispersion, jitter, or reflections from the optical path; these effects are specified separately in the allocation of maximum optical path penalty. Note, however, the minimum average optical power at the receiver must be higher than the minimum sensitivity by the value of the optical path penalty. Aging effects are not specified separately. Worst-case, end-of-life values are specified.

7.2.7.3 Maximum optical path penalty

See 7.2.4.5.

7.2.7.4 Maximum reflectance

The maximum ratio of the reflected optical power present at the reference point, to the optical power incident to that reference point. Control of reflections is discussed extensively in ITU-T G.957.

8 Parameter values

8.1 Multichannel IrDI

The physical layer parameters and values for multichannel inter-domain interfaces are given in Table 8-1.

A possible method that in some cases may be useful in indicating adherence with the IrDI specifications in Table 8-1 is to measure the control parameter "optical signal-to-noise floor ratio" (OSNFR), described in Appendix V.

Table 8-1/G.959.1 – Physical layer parameters and values for multichannel IrDI applications

Parameter[a)]	Units	P16S1-1D2 P16S1-1D5	P16I1-2D2 P16I1-2D3[c)] P16I1-2D5	P16S1-2B2 P16S1-2B5	P16S1-2C2 P16S1-2C3 P16S1-2C5
General information					
Maximum number of channels	–	16	16	16	16
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G	NRZ 10G	NRZ 10G	NRZ 10G
Maximum bit error ratio	–	10^{-12}	10^{-12}	10^{-12}	10^{-12}
Fibre type	–	G.652, G.655	G.652, G.653, G.655	G.652, G.655	G.652, G.653, G.655
Interface at point MPI-S_M					
Maximum mean channel output power	dBm	–4	–3	+3	–7
Minimum mean channel output power	dBm	–10	–6	0	–11
Maximum mean total output power	dBm	+8	+9	+15	+5
Central frequency	THz	192.1 + 0.2 m, m = 0 to 15	192.1 + 0.2 m, m = 0 to 15	192.1 + 0.2 m, m = 0 to 15	192.1 + 0.2 m, m = 0 to 15
Channel spacing	GHz	200	200	200	200
Maximum central frequency deviation	GHz	40	40	40	40
Minimum channel extinction ratio	dB	8.2	8.2	8.2	8.2
Eye mask	–	STM-16 per G.957	STM-64b per G.691	STM-64b per G.691	STM-64b per G.691
Optical path (single span) from point MPI-S_M to MPI-R_M					
Maximum attenuation	dB	11	6[3]	11	11
Minimum attenuation	dB	2	0	0	0
Maximum chromatic dispersion	ps/nm	800	400	800	800
Minimum optical return loss	dB	24	24	24	24
Maximum discrete reflectance	dB	–27	–27	–27	–27
Maximum differential group delay	ps	120	30	30	30

Table 8-1/G.959.1 – Physical layer parameters and values for multichannel IrDI applications (*concluded*)

Parameter[a)]	Units	P16S1-1D2 P16S1-1D5	P16I1-2D2 P16I1-2D3[c)] P16I1-2D5	P16S1-2B2 P16S1-2B5	P16S1-2C2 P16S1-2C3 P16S1-2C5
Interface at point MPI-R_M					
Maximum mean channel input power	dBm	–6	–3	+3	–7
Minimum mean channel input power	dBm	–21	–12	–11	–22
Maximum mean total input power	dBm	+6	+9	+15	+5
Maximum channel power difference	dB	NA	NA	NA	2
Maximum optical path penalty[b)]	dB	1	2 for G.652, 1 for G.653[c)], 1 for G.655	2 for G.652, 1 for G.655	2 for G.652, 1 for G.653, 1 for G.655
Maximum reflectance of optical network element	dB	–27	–27	–27	–27

a) – The parameter values in this table may not be applicable to future systems that use line amplifiers, or to Intra-Domain Interfaces (IaDIs).

b) – This parameter is a single-channel equipment design parameter, and is not incorporated in the power budget between MPI-S_M and MPI-R_M.

c) – For an optical path penalty of 1 dB, the transmission distance of multichannel intra-office interfaces on G.653 fibres is recommended to be within 2 km due to fibre nonlinearity. If this distance is longer than 2 km, a further penalty (in addition to the 1 dB optical path penalty) may be observed.

8.2 Single-channel IrDI

The physical layer parameters and values for single channel inter-domain interface are given in Tables 8-2 through 8-4.

Table 8-2/G.959.1 – Single-channel IrDI parameters and values for optical tributary signal class NRZ 2.5G

Parameter	Units	P1I1-1D1	P1S1-1D1	P1S1-1D2	P1L1-1D1
General information	–	(Note)	(Note)	(Note)	(Note)
Maximum number of channels	–	1	1	1	1
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G	NRZ 2.5G	NRZ 2.5G	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}	10^{-12}	10^{-12}	10^{-12}
Fibre type	–	G.652	G.652	G.652	G.652
Interface at point S_{M-S}					
Operating wavelength range	nm	1266-1360	1260-1360	1430-1580	1280-1335
Source type		MLM	SLM	SLM	SLM
Maximum RMS width (σ)	nm	4	NA	NA	NA
Maximum −20 dB width	nm	NA	1	<1	1
Minimum side mode suppression ratio	dB	NA	30	30	30
Maximum mean output power	dBm	–3	0	0	+3
Minimum mean output power	dBm	–10	–5	–5	–2
Minimum extinction ratio	dB	8.2	8.2	8.2	8.2
Optical path from point S_{M-S} to R_{S-M}					
Maximum attenuation	dB	6	11	11	22
Minimum attenuation	dB	0	0	0	10
Maximum chromatic dispersion	ps/nm	12	NA	As G.957 "S-16.2"	NA
Minimum optical return loss at S_{M-S}	dB	14	14	14	24
Maximum discrete reflectance between S_{M-S} and R_{S-M}	dB	–27	–27	–27	–27
Maximum differential group delay	ps	120	120	120	120
Interface at point R_{S-M}					
Maximum mean input power	dBm	–3	0	0	–9
Minimum sensitivity	dBm	–17	–17	–17	–25
Maximum optical path penalty	dB	1	1	1	1
Maximum reflectance	dB	–14	–14	–14	–27
NOTE – Parameter values for these application codes are largely based on ITU-T G.957.					

Table 8-3/G.959.1 – Single-channel IrDI parameters and values for optical tributary signal class NRZ 10G

Parameter	Units	P1I1-2D1r	P1I1-2D1	P1I1-2D2r	P1I1-2D2	P1I1-2D3	P1I1-2D5
General information	–	(Note)	(Note)	(Note)	(Note)	(Note)	(Note)
Maximum number of channels	–	1	1	1	1	1	1
Bit rate/line coding of optical tributary signals	–	NRZ 10G	NRZ 10G	NRZ 10G	NRZ 10G	NRZ 10G	NRZ 10G
Maximum bit error ratio	–	10^{-12}	10^{-12}	10^{-12}	10^{-12}	10^{-12}	10^{-12}
Fibre type	–	G.652	G.652	G.652	G.652	G.653	G.655
Interface at point S_{M-S}							
Operating wavelength range	nm	1260- 1360	1290-1330	1500-1580	1500-1580	1500-1580	1500-1580
Source type		MLM	SLM	SLM	SLM with ext. mod.	SLM with ext. mod.	SLM with ext. mod.
Maximum RMS width (σ)	nm	3	NA	NA	NA	NA	NA
Maximum −20 dB width	nm	NA	1	ffs	ffs	ffs	ffs
Minimum side mode suppression ratio	dB	NA	30	30	30	30	30
Maximum mean output power	dBm	–1	–1	–1	–1	–1	–1
Minimum mean output power	dBm	–6	–6	–5	–5	–5	–5
Minimum extinction ratio	dB	6	6	8.2	8.2	8.2	8.2
Optical path from point S_{M-S} to R_{S-M}							
Maximum attenuation	dB	4	4	7	7	7	7
Minimum attenuation	dB	0	0	0	0	0	0
Maximum chromatic dispersion	ps/nm	3.8	NA	40	500	80	ffs
Minimum optical return loss at S_{M-S}	dB	14	14	24	24	24	24
Maximum discrete reflectance between S_{M-S} and R_{S-M}	dB	–27	–27	–27	–27	–27	–27
Maximum differential group delay	ps	30	30	30	30	30	30
Interface at point R_{S-M}							
Maximum mean input power	dBm	–1	–1	–1	–1	–1	–1
Minimum sensitivity	dBm	–11	–11	–14	–14	–13	–13
Maximum optical path penalty	dB	1	1	2	2	1	2
Maximum reflectance	dB	–14	–14	–27	–27	–27	–27
NOTE – Parameter values for these application codes are largely based on ITU-T G.691.							

Table 8-4/G.959.1 – Single-channel IrDI parameters and values for optical tributary signal class NRZ 10G

Parameter	Units	P1S1-2D2a	P1S1-2D2b	P1S1-2D3a P1S1-2D5a	P1S1-2D3b P1S1-2D5b	P1L1-2D1
General information	–	(Note 1)	(Note 1)	(Note 1)	(Note 1)	(Note 1)
Maximum number of channels	–	1	1	1	1	1
Bit rate/line coding of optical tributary signals	–	NRZ 10G	NRZ 10G	NRZ 10G	NRZ 10G	NRZ 10G
Maximum bit error ratio	–	10^{-12}	10^{-12}	10^{-12}	10^{-12}	10^{-12}
Fibre type	–	G.652	G.652	G.653, G.655	G.653, G.655	G.652
Interface at point S_{M-S}						
Operating wavelength range	nm	1530-1565	1530-1565	1530-1565	1530-1565	1290-1320
Source type	–	SLM with ext. mod.	SLM with EA modulator	SLM with ext. mod.	SLM with EA modulator	SLM
Maximum RMS width (σ)	nm	NA	NA	NA	NA	NA
Maximum –20 dB width	nm	ffs	ffs	ffs	ffs	ffs
Minimum side mode suppression ratio	dB	30	30	30	30	30
Maximum mean output power	dBm	–1	+2	–1	+2	+7
Minimum mean output power	dBm	–5	–1	–5	–1	+4
Minimum extinction ratio	dB	8.2	8.2	8.2	8.2	6
Optical path from point S_{M-S} to R_{S-M}						
Maximum attenuation	dB	11	11	11	11	22
Minimum attenuation	dB	7	3	7	3	17
Maximum chromatic dispersion	ps/nm	800	800	130	130	130
Minimum optical return loss at S_{M-S}	dB	24	24	24	24	24
Maximum discrete reflectance between S_{M-S} and R_{S-M}	dB	–27	–27	–27	–27	–27
Maximum differential group delay	ps	30	30	30	30	30

Table 8-4/G.959.1 – Single-channel IrDI parameters and values for optical tributary signal class NRZ 10G (*concluded*)

Parameter	Units	P1S1-2D2a	P1S1-2D2b	P1S1-2D3a P1S1-2D5a	P1S1-2D3b P1S1-2D5b	P1L1-2D1
Interface at point $R_{S\text{-}M}$						
Maximum mean input power	dBm	–8	–1	–8	–1	–10
Minimum sensitivity	dBm	–18	–14	–17	–13	–19
Maximum optical path penalty	dB	2	2	1	1	1
Maximum reflectance	dB	–27	–27	–27	–27	–27
NOTE 1 – Parameter values for these application codes are largely based on ITU-T G.691.						
NOTE 2 – Application codes with a suffix "a" have transmitter power levels appropriate to APD receivers; application codes with the suffix "b" have transmitter power levels appropriate to PIN receivers.						

9 Optical safety considerations

See ITU-T G.664 for optical safety considerations.

NOTE – For the optical power levels specified in the current version of this Recommendation, Automatic Power Reduction (APR) is not necessary according to ITU-T G.664 and IEC 60825-1 and IEC 60825–2. Future versions of this Recommendation may, however, contain power levels exceeding the safe levels. In this case, for pre-OTN applications, the ALS procedure defined in ITU-T G.664 shall be applied on individual SDH client signal interfaces only.

10 Power level management

For further study.

ANNEX A

Configuration for Method A for assessment of single channel characteristics in a multichannel IrDI

A.1 Reference configuration

In the case of the multichannel IrDI, single-channel reference points can be used to access the individual transmitted signals for assessing single channel characteristics (extinction ratio, eye mask and optical path penalty).

The extinction ratio and eye mask measurements are performed by submitting the single channel signal at the S_X reference point to the "Measurement set-up for transmitter eye diagram" illustrated in Figure B.1/G.957.

For the optical path penalty two measurements are performed as illustrated in Figure A.1. The first (measurement 1) involves measuring the power required to achieve the reference BER using the signal at S_X, this is then repeated (measurement 2) using the signal at R_X. reference point.

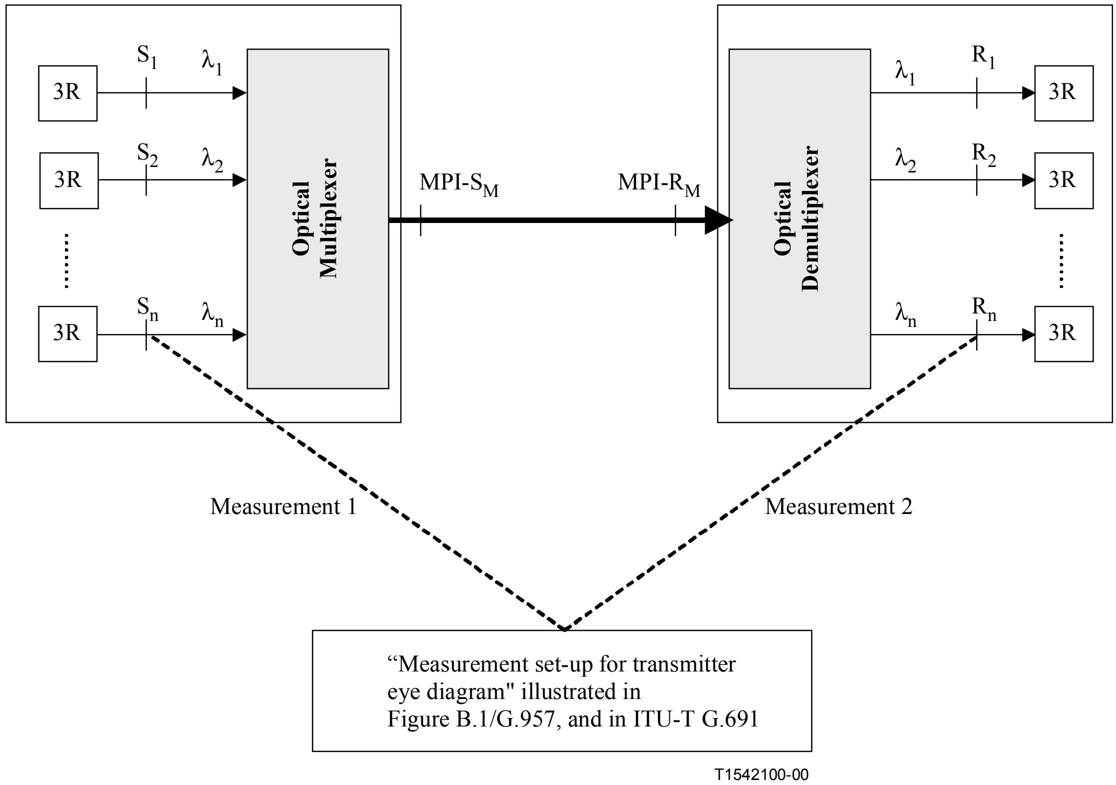

Figure A.1/G.959.1 – Method A configuration

ANNEX B

Reference optical bandpass filter and reference receiver characteristics for Method B, for assessment of single-channel characteristics in a multichannel IrDI

B.1 Reference configuration

In the case of the multichannel IrDI, a reference optical bandpass filter can be used to isolate the individual transmitted signals for assessing single-channel characteristics (extinction ratio, eye mask and optical path penalty) by using a reference receiver.

The extinction ratio and eye mask measurements are performed by submitting the signal at MPI-S_M to the reference optical bandpass filter and taking the output to a reference receiver in accordance with the configuration given in Annex B/G.957.

In the case of the optical path penalty two measurements are performed as illustrated in Figure B.1. The first (measurement 1) involves measuring the power required to achieve the reference BER using the signal at MPI-S_M, this is then repeated (measurement 2) using the signal at MPI-R_M.

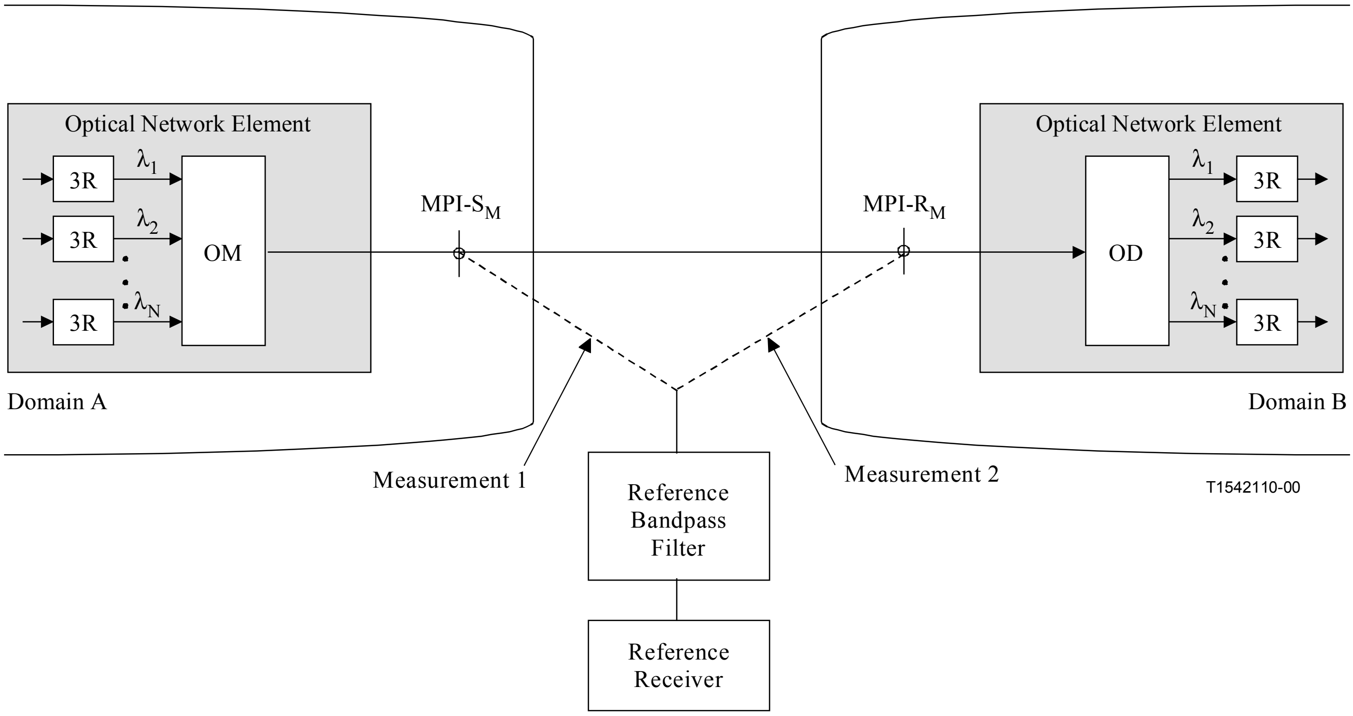

Figure B.1/G.959.1 – Method B configuration

B.2 Reference optical bandpass filter

The purpose of the reference optical bandpass filter is to isolate the individual optical channels from the composite multichannel signal. It should have adequate characteristics to ensure minimal interference from adjacent channels whilst introducing negligible distortion to the signal under test. A minimum set of requirements is given in B.2.1.

There are several technologies available to perform this function, e.g. tuneable filter or a demultiplexer.

B.2.1 Optical filter parameters

The requirements on the reference optical bandpass filter frequency response are illustrated in Figure B.2. The value of Y is chosen such that the ratio of the power in the channel being measured to the sum of the powers of all of the other channels is greater than 20 dB.

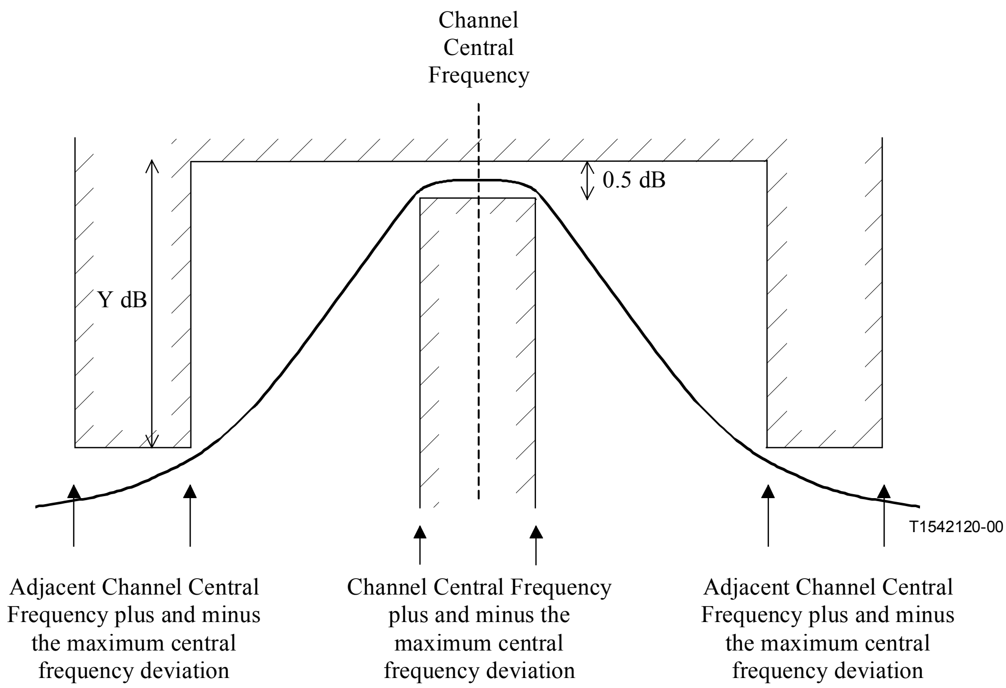

Figure B.2/G.959.1 – Optical bandpass filter frequency response

The design of the filter should be chosen so that a maximum rate signal should undergo no significant distortion due to amplitude and phase ripple.

B.3 Reference receiver

This is a receiver with a frequency response such as is outlined in Annex A/G.691, i.e. a fourth-order Bessel-Thomson filter with a cutoff frequency at 0.75 times the bit rate in question. The tolerance values of this filter are given in Table A.1/G.691.

In the case where the reference receiver is used to measure bit error ratio (BER) for optical path penalty assessment, the decision threshold should be adjusted for the lowest BER for measurement 1 and then reoptimized for measurement 2 in order to accommodate the requirements of different application codes and cover various design implementations meeting those application codes.

In order to perform single channel tests on some application codes it may be necessary to include a pre-amplifier inside the reference receiver.

Different reference receiver characteristics are required for the various per channel signal bit rates as defined in Annex A/G.691.

APPENDIX I

Single-channel client interfaces with 3R regeneration

I.1 Introduction

This appendix describes the use of 3R regeneration at client signal interfaces to pre-OTN optical networks. The use of 3R regeneration will facilitate the interconnection of such optical networks with existing transport networks, e.g., SDH networks, and is expected to accelerate OTN deployment as optical networking technology is maturing.

I.2 Description of client signal interfaces with 3R regeneration

Client signals with optical characteristics that meet the physical layer specifications, e.g. wavelengths and frequency tolerances, of pre-OTN optical networks may appear to be attractive because such networks avoid the cost of optical-to-electrical-to-optical (OEO) processing at network interfaces. However, in order to transport client signals from legacy SONET/SDH equipment, an OEO conversion may be necessary. Additionally, in order to achieve interoperability, the use of physically compliant client signals will require joint engineering until such time as the required physical layer optical interface specifications can be agreed.

If the OEO processing described above includes 3R regeneration plus any other required adaptation, e.g., wavelength conversion, then the specification of physical-layer optical parameters at the client interface can be taken from short-reach applications specified in ITU-T G.957. This short-reach client signal interface based on the use of 3R regeneration on the network side of the interface can be used for legacy client signals, as well as for newer client signal transmitters and receivers. This interface is an example of the non-OTN Inter Domain Interface (non-OTN_IrDI) described in ITU-T G.872, Architecture of Optical Transport Networks. The interface is shown in Figure I.1, where λ_S denotes wavelength used for the short-reach interconnect.

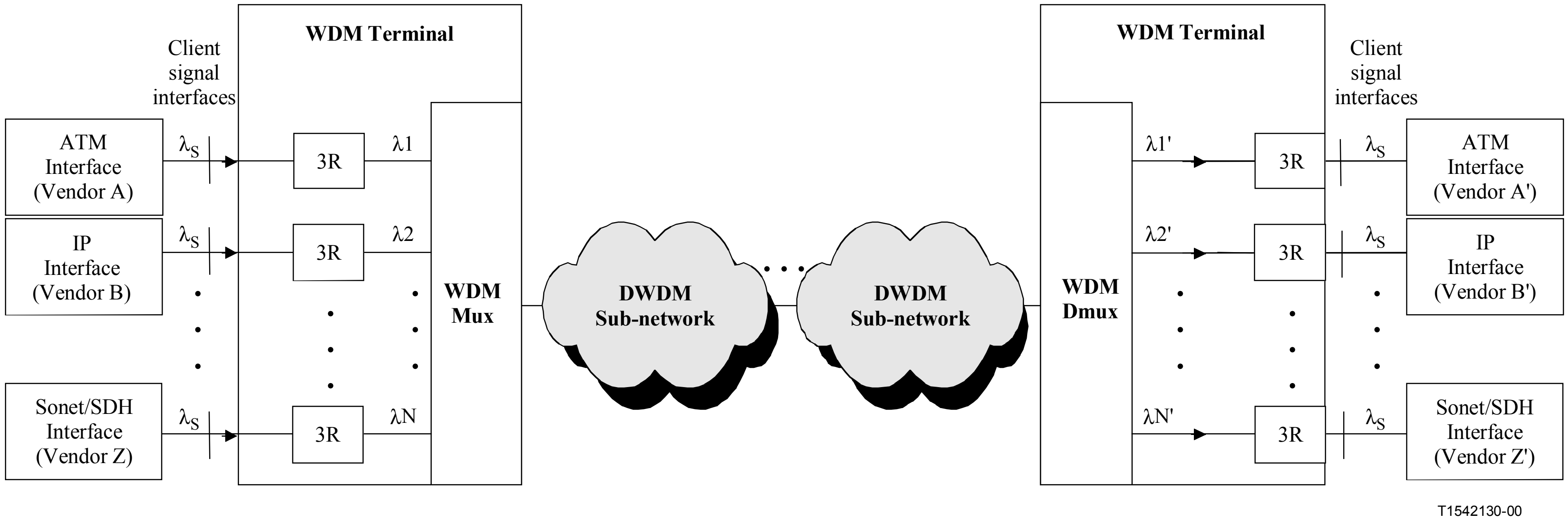

Figure I.1/G.959.1 – Example of client signal interface with 3R regeneration

APPENDIX II

Clarification of use of reference points within IrDI and IaDI

In Figure II.1 a further clarification is given on the application of the generic OTN reference points as specified in 5.2.

Simple optical networks can be configured using back-to-back connected WDM demultiplexers and multiplexers forming a simple optical add-drop multiplexer (OADM). They are interconnected via single channel interfaces. Figure II.1 shows such an arrangement.

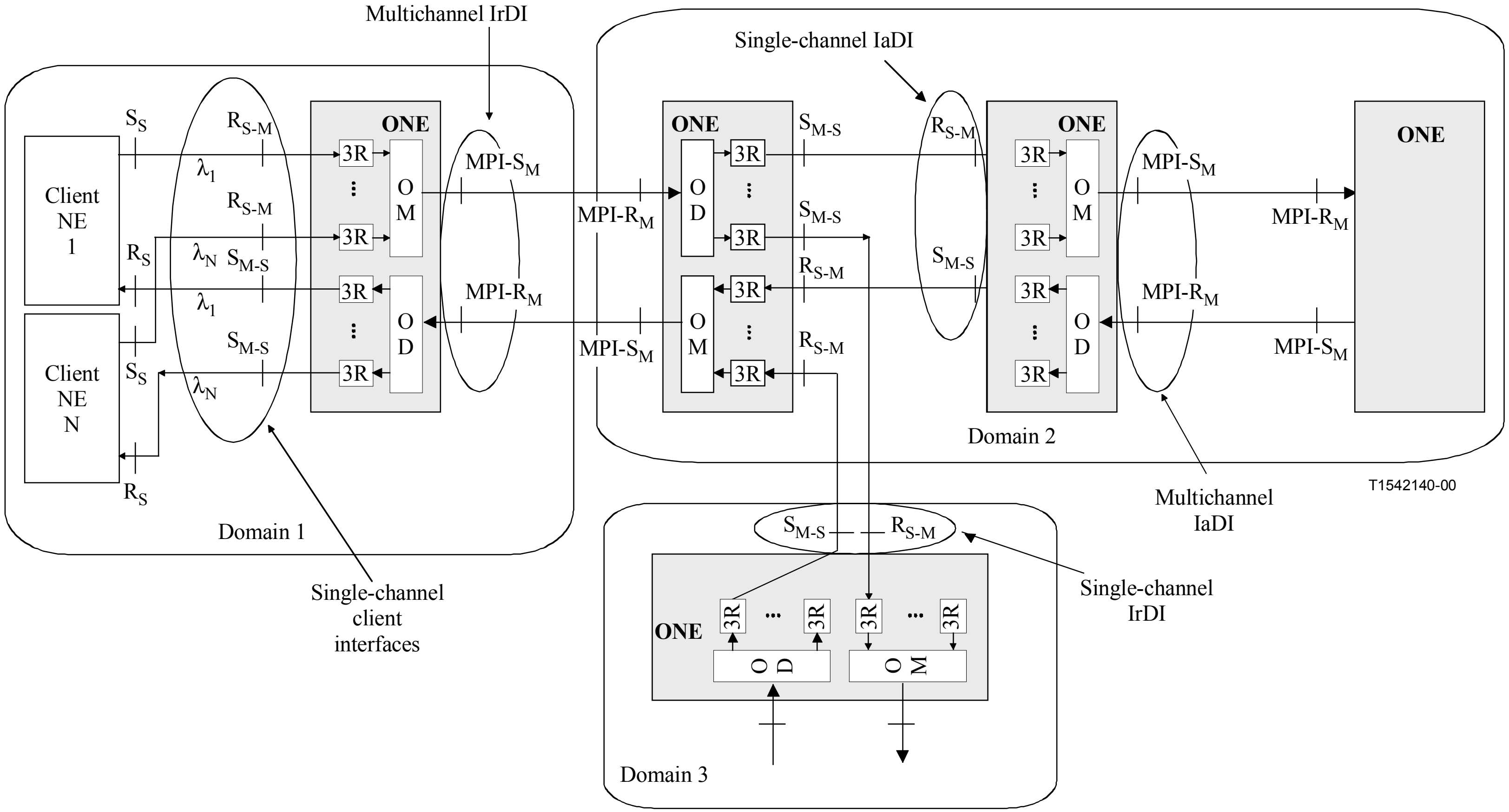

Figure II.1/G.959.1 – Examples of multichannel and single-channel inter-domain and intra-domain interfaces

APPENDIX III

Considerations for management signal implementations

The presence of signals to manage the Optical Channel, Optical Multiplex Section and Optical Transmission Section layers is defined for OTN IaDIs and is foreseen for some future OTN IrDIs. Considerations for physical implementations of such signals are presented below.

III.1 Optical Channel management signal implementation

Both channel-associated and channel-non-associated OCh management signal implementations may be needed.

For channel-associated management signals a "digital wrapper" approach is defined in ITU-T G.709. This method employs a digital frame structure, comprising overhead bytes, payload bytes and bytes for forward error correction. The possibility of relaxation of some parameter values due to the presence of forward error correction has not been incorporated into the present version of this Recommendation.

OCh associated overhead transport by non-digital (optical) mechanisms, e.g. sub-carrier-modulation, may also be appropriate for certain applications, and they are for further study. Further system penalties may be introduced by these techniques.

An Optical Supervisory Channel (OSC) is the approach specified in ITU-T G.709 for implementing channel non-associated signals. This is discussed below in connection with Optical Multiplex Section and Optical Transmission Section management signal implementation.

The OCh overhead information for each optical channel originates and terminates in the OCh layer of optical network elements.

III.2 Optical Multiplex Section and Optical Transmission Section management signal implementation

The OSC is a separate channel, which carries overhead information for network management purposes. Management messages for the OMS and OTS layers, together with management messages for the OCh layer which are transported via a channel-non-associated implementation, share an OSC. For monitoring the multichannel signal in the OTS and OMS layers of optical network elements, an OSC may be provided for each transmission direction. An OSC originates and terminates in each optical network element.

Currently, the preferred wavelength for the OSC is given in ITU-T G.692. Full transverse compatibility and redundancy of application codes should be taken into consideration when specifying the OSC wavelength in the future.

APPENDIX IV

Future IaDI considerations

Some considerations on possible future IaDI specifications are given below. They concentrate on the additional interfaces and parameters that may need to be taken into account.

IV.1 Additional interfaces to consider

In addition to the interfaces and related parameters given in Tables 7-1 and 7-2, the interfaces listed in Table IV.1 may need to be considered.

Table IV.1/G.959.1 – Additional interfaces for IaDI considerations

Interface at point S_M
Optical path (multiple spans) from point MPI-S_M to R_M, S_M to R_M, or S_M to MPI-R_M
Interface at point R_M
Optical network element from point MPI-R_M to S_{M-S}
Optical network element from point MPI-R_M to MPI-S_M
Optical network element (optical amplifier) from point R_M to S_M
Optical network element from point R_{S-M} to MPI-S_M
Optical network element from point R_{S-M} to S_{M-S}

IV.2 ONE transfer parameters

ONE transfer parameters apply to signals as they traverse the ONE from the receive to the send interface. There are three types of receive interfaces, namely, MPI-R_M, R_{S-M}, and R_M and three types of send interfaces, MPI-S_M, S_{M-S} and S_M on an ONE as depicted in Figure 5-1. Five signal paths are possible from the ONE receive interfaces to the ONE send interfaces. These are:

– MPI-R_M to S_{M-S};

– MPI-R_M to MPI-S_M;

– R_{S-M} to MPI-S_M;

– R_{S-M} to S_{M-S};

– R_M to S_M.

The first three of these paths are frequently referred to as the "drop-path", "pass-through path" and the "add-path." ONE transfer parameters apply to signals as they traverse these five paths from the receive to the send interface. ONE transfer parameters might have utility in future OTN applications. Table IV.2 contains some transfer parameters that might be applicable in future OTN applications.

Table IV.2/G.959.1 – ONE transfer parameters

Optical Signal-to-Noise Ratio Degradation (dB)
Optical Crosstalk Related Parameters such as: – In-band Crosstalk Ratio (dB) – Out-of-band Crosstalk Ratio (dB)
Frequency response-related parameters such as: – Ripple (dB) – Insertion loss (dB) – Channel Width (GHz)
Polarization related parameters such as: – Differential Group Delay (ps) – Polarization Dependent Loss (dB) – Chromatic Dispersion (ps/nm)

Out of the parameters in Tables 7-1 and 7-2 and Table IV.2, only those parameters applicable to a given situation or ONE are to be specified. Specification and definition of these parameters is for further study. Application of the parameter specifications, e.g., for design purposes or for in-service monitoring or out-of-service verification is for further study.

APPENDIX V

Application of the optical signal-to-noise floor ratio, OSNFR

V.1 Definition of the optical signal-to-noise floor ratio

Referring to Figure V.1, from the optical spectrum, the OSNFR is defined as follows:

$$OSNFR = \text{minimum value of OSNR} \quad \text{dB} \tag{1}$$

for all populated channels.

OSNR is the optical signal to noise ratio of each channel defined as:

$$\mathrm{OSNR} = 10\log\frac{\mathrm{P_i}}{\mathrm{N_i}} + 10\log\frac{\mathrm{B_m}}{\mathrm{B_r}} \ \mathrm{dB} \tag{2}$$

where:

P_i is the optical signal power in watts at the *i*-th channel.

N_i is the interpolated value of noise power in watts measured in noise equivalent bandwidth, B_m, at the *i*-th channel:

$$N_i = \left(\frac{N(\nu_i - \Delta\nu) + N(\nu_i + \Delta\nu)}{2}\right) \tag{3}$$

$\Delta\nu$ is the interpolation offset equal to one-half the channel spacing (for the case of 200 GHz channel spacing, $\Delta\nu$ = 100 GHz).

B_r is the reference optical bandwidth. (The units for B_m and B_r may be in frequency or wavelength but must be consistent.) Typically, the reference optical bandwidth is 0.1 nm.

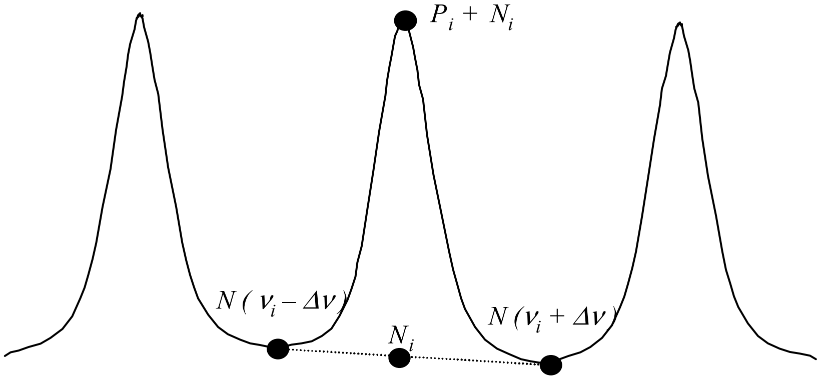

Figure V.1/G.959.1 – OSNFR for each populated channel is derived from direct measurements of the optical spectrum

V.2 Validity of the parameter

The Optical signal-to-noise floor ratio parameter is *not* a design parameter; it is a possible control parameter – though by itself not necessarily sufficient – that may be used to indicate that a connecting operator is complying with the IrDI specifications. More specifically, the parameter is related to the generation of noise in optical amplifiers, and it can give information about proper use of optical amplifiers in the system. Observe that even though the OSNFR is obeyed for a given Optical Channel, the accumulation of various signal impairments (as, e.g., nonlinear effects) could mean that the signal quality is unsatisfactory. In order to assure satisfactory signal quality, the BER is the appropriate parameter to address.

V.3 Non-compliance with the IrDI specifications

The OSNFR can in some cases indicate whether or not the IrDI specifications have been met by a connecting operator. This will typically be an issue for the booster amplifier case, since the connecting operator should not be using an amplifier at the transmitter side for the non-amplified or pre-amplified cases.

The following violations of the IrDI may be detected by the OSNFR:

Booster solution:

– The optical input powers to the booster are too low.
– An extra optical amplifier has been added at the transmitter side.
– The pump laser is degrading while the signal is still within the optical input power dynamic range.

Pre-amplifier or no amplifier solutions:

– An amplifier has been added at the transmitter side.

It is possible that a violation has appeared without this being reflected by the OSNFR as exemplified below.

– By proper filtering of the WDM signal (or the individual channels), a connecting operator can mask the inclusion of an illegal amplifier at the transmitter side.
– A channel with a history of transmission can be added at the transmitting network element in parallel with "freshly" generated channels. This channel can have been distorted from nonlinear effects and it can suffer from dispersion to a degree where the signal quality is unacceptable without any trace of this on the OSNFR.

V.4 Alternative control methods

The OSNFR is not a perfect solution to verify the part of the IrDI belonging to the connecting operator, but it is the best known practical solution today. If a better solution appears, it should replace this method.

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Geneva, 2002