

I n t e r n a t i o n a l T e l e c o m m u n i c a t i o n U n i o n

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.680

(07/2007)

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

Transmission media and optical systems characteristics –
Characteristics of optical systems

Physical transfer functions of optical network elements

ITU-T Recommendation G.680



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ITU-T Recommendation G.680

Physical transfer functions of optical network elements

Summary

ITU-T Recommendation G.680 defines a "degradation function" of optical network elements (ONEs) such as photonic cross-connects (PXC), optical add-drop multiplexers (OADMs), etc. making up an optical network. This is done in terms of a list of parameters which characterize physical impairments such as optical noise, chromatic dispersion, etc., and is intended to be independent from the network architecture that the devices are deployed in. For each kind of ONE considered in this Recommendation, the general functional description and the reference diagram is provided. Principles for calculating the effect of cascading multiple ONEs on the degradation of the optical signal quality are given and example transfer parameter values for OADMs and PXC are also provided.

This version of the Recommendation covers the situation where the optical path between two consecutive electrical regenerators is composed of dense wavelength division multiplexing (DWDM) line segments from a single vendor and OADMs and PXC from other vendors.

Source

ITU-T Recommendation G.680 was approved on 29 July 2007 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

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Introduction

The present optical transport networks (OTN) are evolving towards optical networks with an ever decreasing number of O/E/O conversions within their boundaries. The two main reasons for this evolution are the following:

- i) DWDM systems are becoming capable of transporting light signals for some thousands of kilometres without electrical regeneration;
- ii) Photonic cross-connects (PXC) and optical add/drop multiplexers (OADMs) are becoming available with capacity, space requirements, power consumption, reliability and cost, suitable for their use in the telecommunication networks.

This evolution will lead to the deployment of a domain of optical transparency that can be large enough to ensure that all the potential routes of the backbone network of a medium size country (optical paths up to around 2000 km) could be realized all optically.

Physical transfer functions of optical network elements

1 Scope

The scope of this Recommendation is to define a "degradation function" of the optical network elements (DWDM line segment, PXC, OADM, etc.) between points MPI-S_M and MPI-R_M (Figures 6-1 to 6-3) in terms of ASE, non-linear impairment, chromatic dispersion, PMD, etc., independently from the network architecture/structure/configuration that the system is deployed in.

These degradation functions are the basis for guidelines found in clause 8 for the consequence of the cascading of optical network elements (not including DWDM line segments for Situation 1 as described below) within an optical transmission system in order to assess the degradation of the signal quality due to the optical path between the ingress and egress 3R electrical regenerators.

This version of the Recommendation covers the reference situation:

Situation 1 – The optical path between two consecutive 3R regenerators is composed of DWDM line segments from a single vendor and OADMs and PXC from another vendor as shown in Figure 1-1.

The information in this Recommendation (when taken together with the corresponding parameters from the DWDM line segments including any non-linear effects) enables the evaluation of the impact on line system performance of the combination of transfer parameters related to the cascaded ONEs inserted in the optical route.

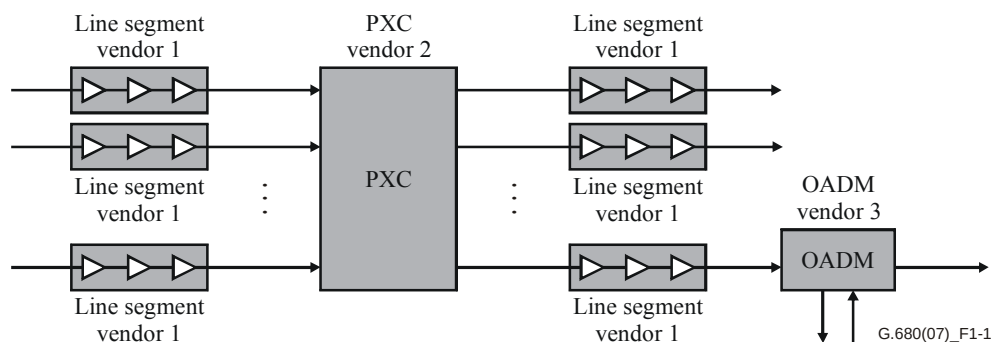


Figure 1-1 – Illustration of Situation 1

A future revision of the Recommendation is expected to cover the reference situation:

Situation 2 – The optical path between two consecutive 3R regenerators is composed of DWDM line segments from different vendors and OADMs and PXC from different vendors as shown in Figure 1-2.

This will enable the degradation of the signal quality due to the optical path for an arbitrary route through an all-optical network (or sub-network) consisting of optical network elements including DWDM line segments to be assessed thereby enabling routing decisions in an all-optical network (or sub-network) to be made.

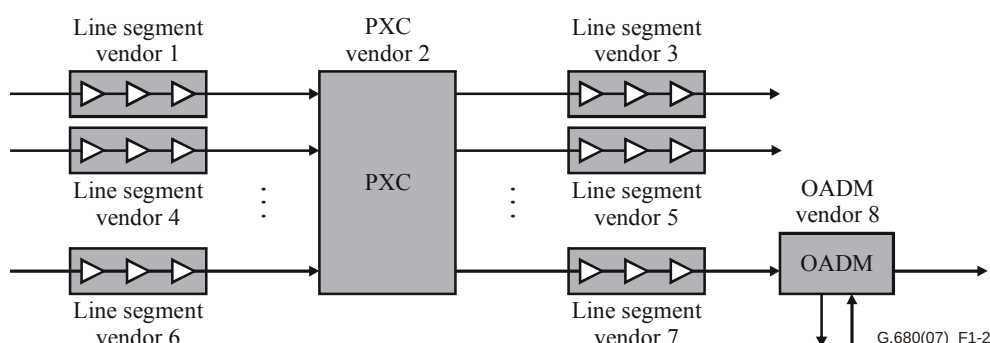


Figure 1-2 – Illustration of situation 2

2 References

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

- [ITU-T G.652] ITU-T Recommendation G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.
- [ITU-T G.661] ITU-T Recommendation G.661 (2007), *Definition and test methods for the relevant generic parameters of optical amplifier devices and subsystems*.
- [ITU-T G.662] ITU-T Recommendation G.662 (2005), *Generic characteristics of optical amplifier devices and subsystems*.
- [ITU-T G.663] ITU-T Recommendation G.663 (2000), *Application related aspects of optical amplifier devices and subsystems*.
- [ITU-T G.665] ITU-T Recommendation G.665 (2005), *Generic characteristics of Raman amplifiers and Raman amplified subsystems*.
- [ITU-T G.666] ITU-T Recommendation G.666 (2005), *Characteristics of PMD compensators and PMD compensating receivers*.
- [ITU-T G.667] ITU-T Recommendation G.667 (2006), *Characteristics of adaptive chromatic dispersion compensators*.
- [ITU-T G.671] ITU-T Recommendation G.671 (2005), *Transmission characteristics of optical components and subsystems*.
- [ITU-T G.694.1] ITU-T Recommendation G.694.1 (2002), *Spectral grids for WDM applications: DWDM frequency grid*.
- [ITU-T G.709] ITU-T Recommendation G.709/Y.1331 (2003), *Interfaces for the Optical Transport Network (OTN)*.
- [ITU-T G.959.1] ITU-T Recommendation G.959.1 (2006), *Optical transport network physical layer interfaces*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined in [ITU-T G.661]:

- channel addition/removal (steady-state) gain response;
- channel gain;
- channel input power range;
- channel output power range;
- channel signal-spontaneous noise figure;
- input (or output) power change;
- input reflectance;
- maximum reflectance tolerable at input;
- maximum reflectance tolerable at output;
- maximum total output power;
- multichannel gain variation (inter-channel gain difference);
- multichannel gain-change difference (inter-channel gain-change difference);
- multichannel gain tilt (inter-channel gain-change ratio);
- optical signal-to-noise ratio (OSNR);
- output reflectance;
- rate of change of power;
- total input power range;
- transient duration;
- transient gain increase;
- transient gain reduction.

This Recommendation uses the following term defined in [ITU-T G.663]:

- amplified spontaneous emission (ASE) (see "noise accumulation").

This Recommendation uses the following terms defined in [ITU-T G.671]:

- adjacent channel isolation;
- channel extinction;
- channel frequency range;
- channel insertion loss;
- channel insertion loss deviation;
- dense WDM (DWDM) device;
- differential group delay (see "polarization mode dispersion (PMD)");
- isolation (see "unidirectional (far-end) isolation");
- non-adjacent channel isolation;
- polarization dependent loss (PDL);
- reflectance;
- ripple;

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- switching time;
- channel uniformity (see "uniformity").

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 reconfigure time (for ROADM): The reconfigure time (of an ROADM) is the elapsed time measured from the earliest point that the actuation energy is applied to reconfigure the ONE to the time when the channel insertion loss for all wanted channels has settled to within 0.5 dB of its final steady state value and all other parameters of the device (e.g., isolation and channel extinction) are within the allowed limits.

Here, channel insertion loss for all wanted channels means:

- from the input port to the drop port for all dropped channels;
- from the add port to the output port for all added channels;
- from the input port to the output port for all through channels.

This is illustrated in Figure 3-1.

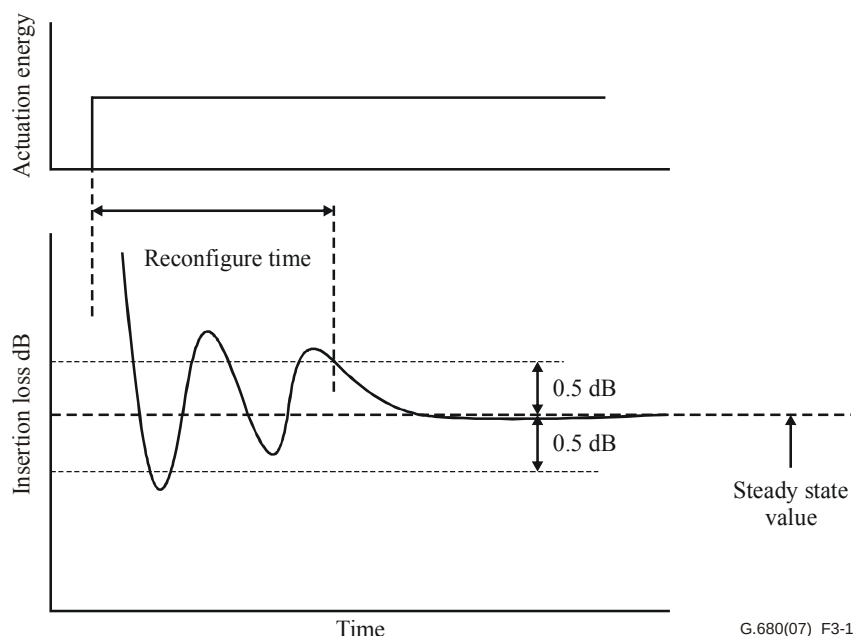


Figure 3-1 – Illustration of reconfigure time

4 Abbreviations

This Recommendation uses the following abbreviations:

2R	Re-amplification and Reshaping
3R	Re-amplification, Reshaping and Retiming
ADC	Adaptive Dispersion Compensator
AGC	Automatic Gain Control
AON	All-Optical Network
AOWC	All-Optical Wavelength Converter
ASE	Amplified Spontaneous Emission

BA	Booster-Amplifier
BER	Bit Error Ratio
CD	Chromatic Dispersion
CU	Channel Uniformity
DCM	Dispersion Compensation Module
DGD	Differential Group Delay
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium-Doped Fibre Amplifier
FEC	Forward Error Correction
MPI-R	Main Path Interface – Single-channel reference point at the at the ONE input
MPI-R _M	Main Path Interface – Multichannel reference point at the ONE input
MPI-S	Main Path Interface – Single-channel reference point at the ONE output
MPI-S _M	Main Path Interface – Multichannel reference point at the ONE output
NA	Not Applicable
NF	Noise Figure
O/E/O	Optical-Electrical-Optical conversion
OA	Optical Amplifier
OADM	Optical Add/Drop Multiplexer
OD	Optical Demultiplexer
OLA	Optical Line Amplifier
OM	Optical Multiplexer
ONE	Optical Network Element
OSNR	Optical Signal-to-Noise Ratio
OTF	Optical Transfer Function
OTN	Optical Transport Network
OTUk	Completely standardized optical channel transport unit – k
PA	Pre-Amplifier
PDG	Polarization-Dependent Gain
PDL	Polarization-Dependent Loss
PMD	Polarization Mode Dispersion
PMDC	Polarization Mode Dispersion Compensation
PXC	Photonic Cross-Connect
RD	Residual Dispersion
RG	Relative Gain
ROADM	Re-configurable OADM
SOP	State of Polarization
SPM	Self-Phase Modulation

STM	Synchronous Transport Module
VOA	Variable Optical Attenuator
WDM	Wavelength Division Multiplexing

5 Classification of optical network elements

A list of the ONEs which are described by the current version of this Recommendation is:

- DWDM line segment;
- OADM (Fixed and re-configurable optical add/drop multiplexer);
- PXC (photonic cross-connect).

In a future revision of this Recommendation, it is expected that the following ONEs may be added:

- OA (optical amplifier) as a separate ONE rather than inside the ONEs above;
- AOWC (All-optical wavelength converters);
- Optical 3R (optical 3R regenerator);
- Optical 2R (optical 2R regenerator).

6 Reference points

The reference points for DWDM line segments, PXC and OADM are illustrated in Figures 6-1 to 6-3, respectively.

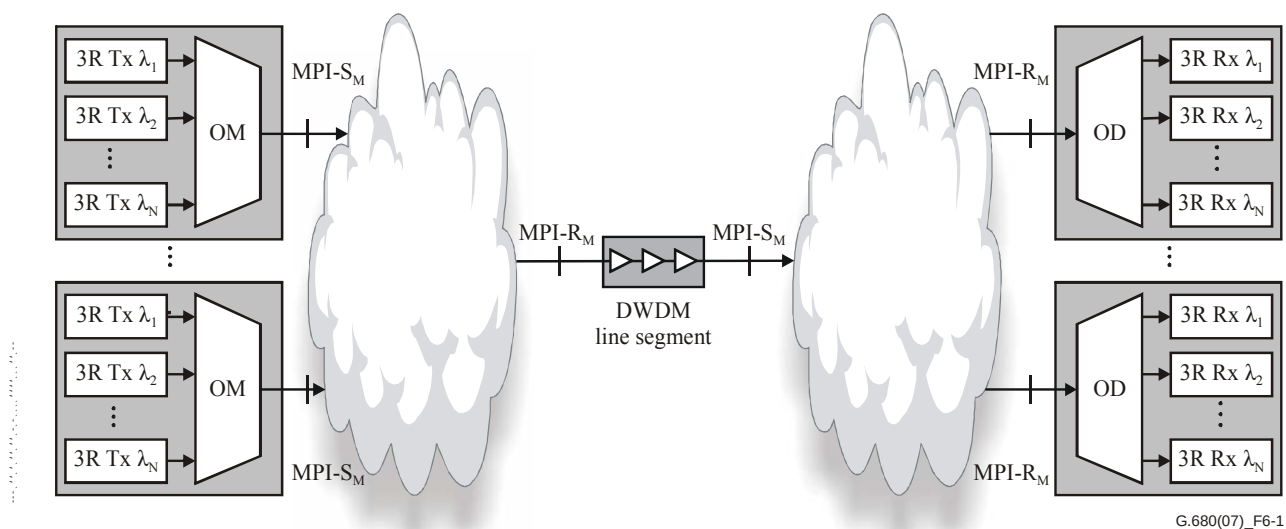


Figure 6-1 – DWDM line segment reference points

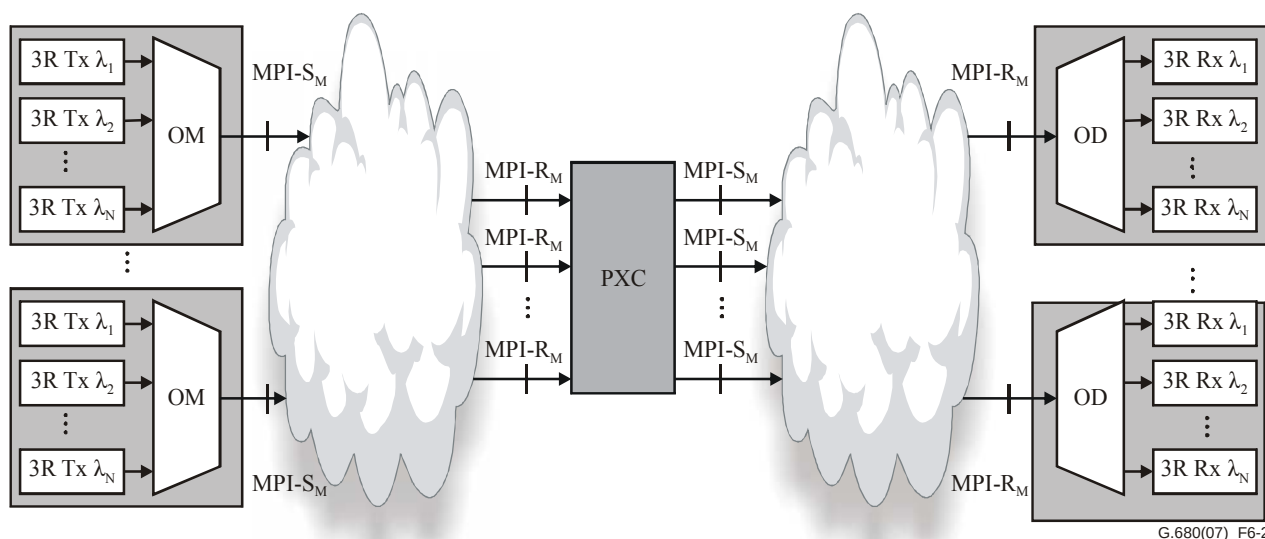


Figure 6-2 – PXC reference points

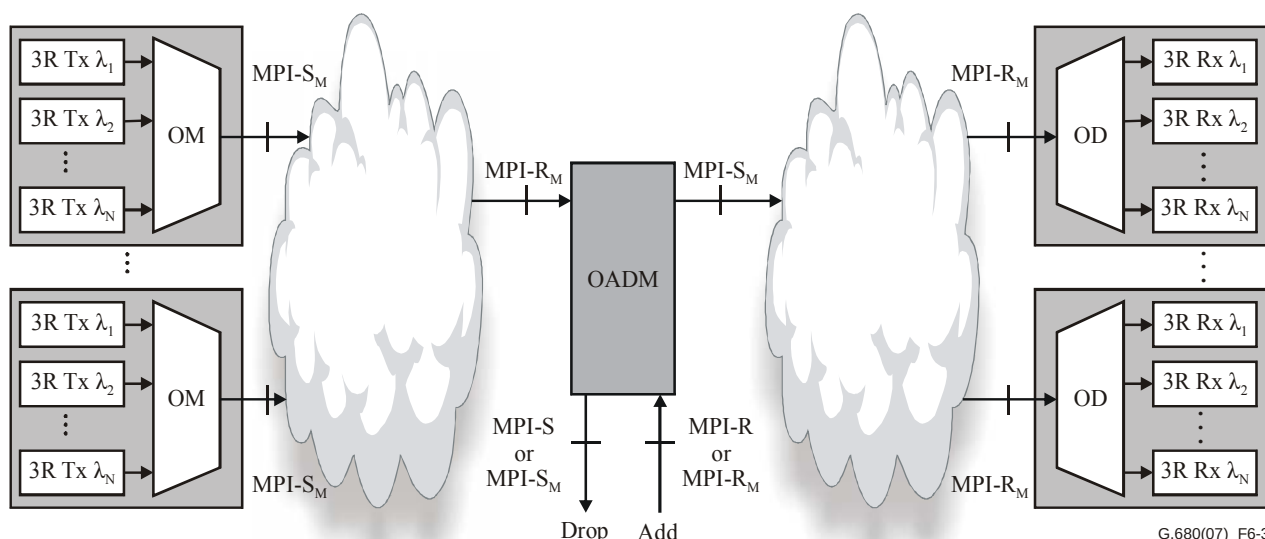


Figure 6-3 – OADM reference points

The reference points in Figures 6-1 to 6-3 are defined as follows:

- 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;
- MPI-S is a single-channel reference point on the optical fibre just after the OADM output optical connector;
- MPI-R is a single-channel reference point on the optical fibre just before the OADM input optical connector.

7 Functional description of the optical network elements (ONEs)

In this clause, the general functional description and reference diagram is provided for each kind of ONE considered in this Recommendation.

7.1 Functional description of a DWDM line segment

A DWDM line segment is a section of optical transmission fibre together with its associated line amplifiers and any embedded dispersion compensation. This is illustrated in Figure 7-1. The actual arrangement of elements within the DWDM line segment (whether there is an amplifier before the first fibre section or an amplifier after the last fibre section or the placement of any embedded dispersion compensation is not defined).

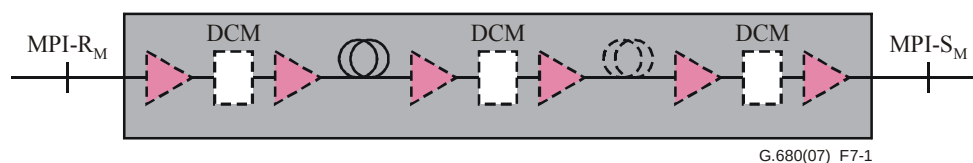


Figure 7-1 – DWDM line segment reference diagram

7.2 Functional description of an OADM (optical add/drop multiplexer)

An OADM is a wavelength selective branching device (used in WDM transmission systems) having a wavelength "drop" function in which one or more signals can be transferred from an input port to either an output port or drop port(s) depending on the wavelength of the signal and also having a wavelength "add" function in which optical signals presented to the add port(s) are also transferred to the output port. The reference diagrams for two variants of OADM are shown in Figures 7-2 and 7-3. For the case illustrated in Figure 7-2, any amplifiers associated with the OADM are considered to be part of the preceding or following line segment, whereas for the case shown in Figure 7-3 they are within the OADM "black-box" and consequently have to be accounted for in the list of transfer parameters.

A re-configurable OADM (ROADM) is an OADM where the wavelengths that are added, dropped and passed through can be dynamically modified (usually remotely).

The arrangement of elements within the OADM black-box shown in Figures 7-2 and 7-3 is not intended to indicate the architecture of the OADM, but simply to define the location of the interfaces. A wide variety of different architectures of OADM are possible and these ONEs may include additional optical functions such as chromatic dispersion compensation (which may be tunable) or PMD compensation, etc.

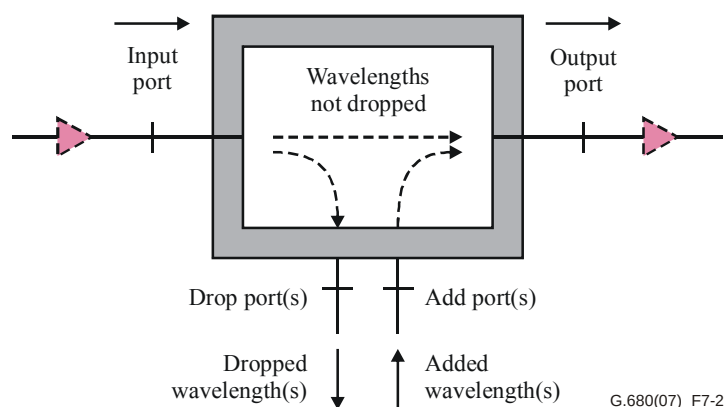


Figure 7-2 – Optical add/drop multiplexer (OADM) reference diagram without amplifiers

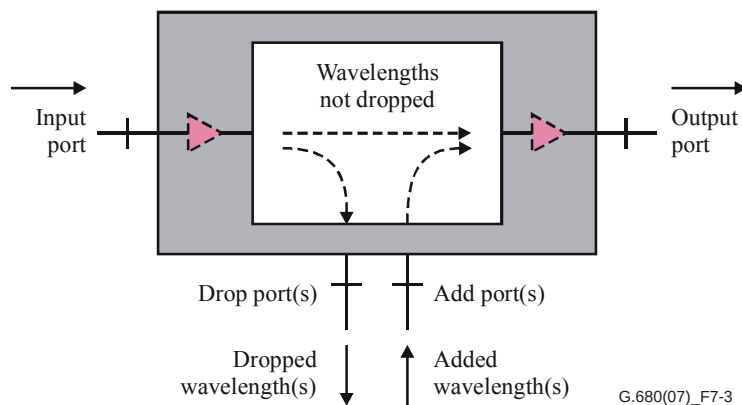


Figure 7-3 – Optical add/drop multiplexer (OADM) reference diagram including amplifiers

7.3 Functional description of a PXC (photonic cross-connect)

The PXC is a (possibly wavelength selective) cross-connect device (used in WDM transmission systems) in which one or more signals can be cross-connected from one of a number of input ports to one of a number of output port(s). The reference diagrams for four variants of PXC are shown in Figures 7-4 to 7-7. Any optical multiplexers or de-multiplexers that are associated with the PXC are considered to be within the PXC "black-box". For the case illustrated in Figure 7-4, any amplifiers associated with the PXC are considered to be part of the preceding or following line segment, whereas for the case shown in Figure 7-5 they are within the PXC "black-box" and consequently have to be accounted for in the list of transfer parameters.

The PXC's illustrated in Figures 7-6 and 7-7 have the additional feature that one or more single channel ports are directly available at the input or output side of the switch, thereby enabling the ONE to additionally perform the function of adding or dropping individual channels.

The arrangement of elements within the PXC black-box shown in Figures 7-4 to 7-7 is not intended to place constraints on the architecture of the PXC, but simply to define the location of the multichannel interfaces. A variety of PXC types are included within this definition such as devices which switch from any input port to any output port:

- any wavelength;
- groups of wavelengths;
- all wavelengths;
- a combination of the above.

Also, these ONEs may include additional optical functions such as chromatic dispersion compensation (which may be tunable) or PMD compensation, etc.

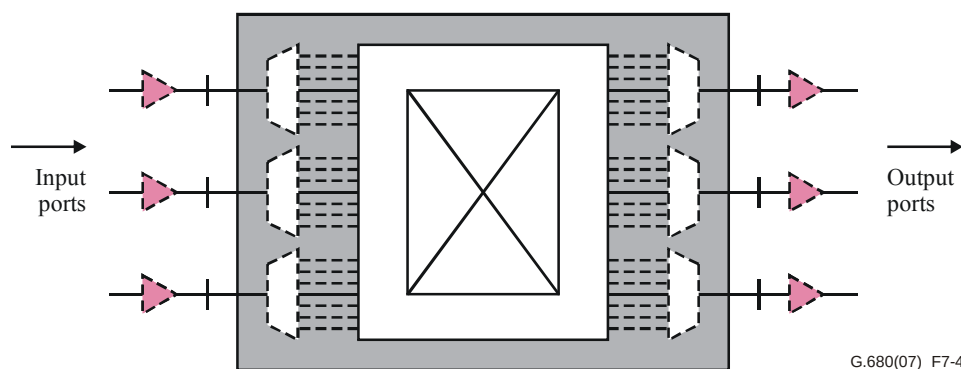


Figure 7-4 – Photonic cross-connect (PXC) reference diagram without amplifiers

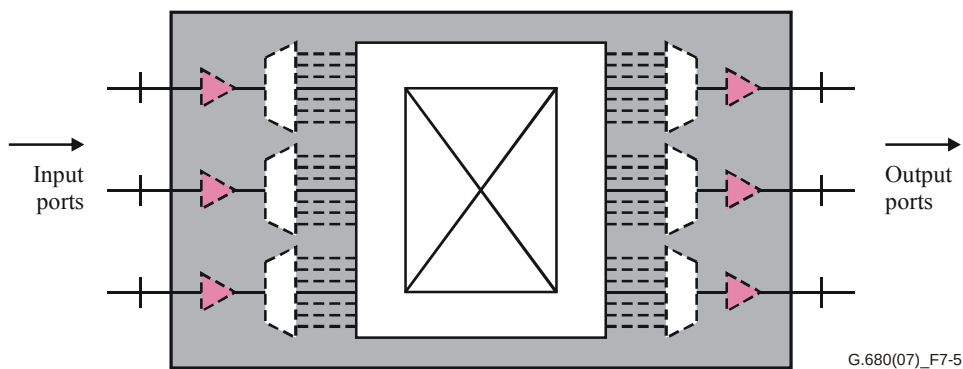


Figure 7-5 – Photonic cross-connect (PXC) reference diagram including amplifiers

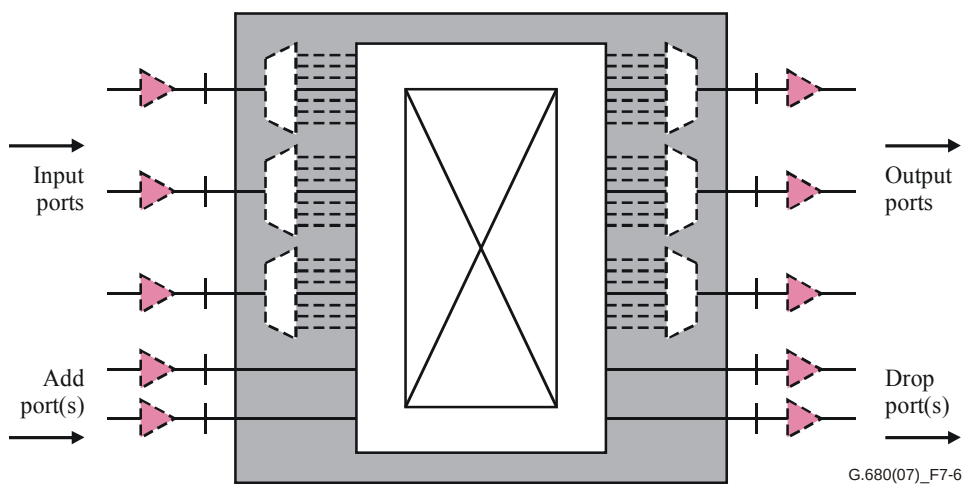


Figure 7-6 – Photonic cross-connect (PXC) with add/drop functions reference diagram without amplifiers

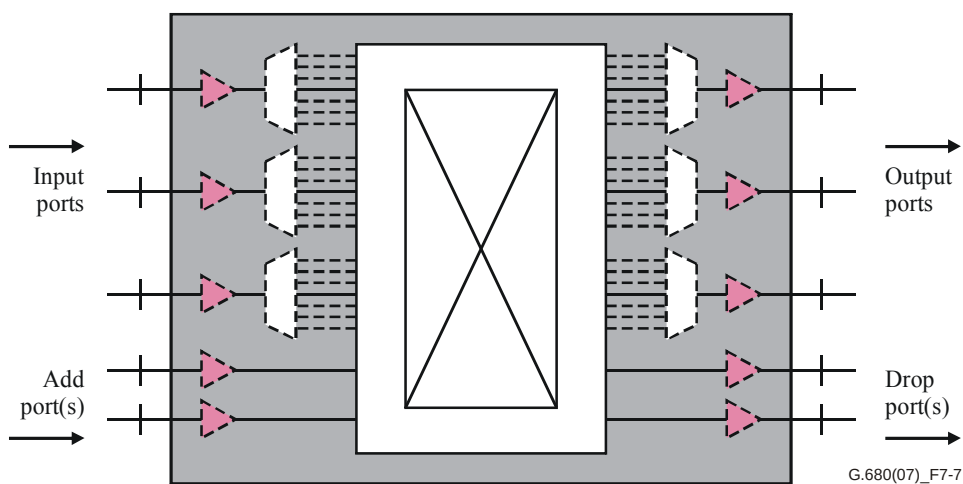


Figure 7-7 – Photonic cross-connect (PXC) with add/drop functions reference diagram including amplifiers

7.4 Functional description of an AOWC (all-optical wavelength converter)

An all-optical wavelength converter (AOWC) is a device that converts the wavelength of an optical channel from one value to another by optical means (i.e., without requiring optical-electrical-optical conversion). Devices that perform this function may operate on multiple channels at once and employ mechanisms such as: cross-gain modulation (XGM), cross-phase modulation (XPM) or four-wave mixing (FWM).

7.5 Functional description of an OA (optical amplifier)

In the current version of this Recommendation optical amplifiers are not included as a separate ONE because, when deployed, they are included in DWDM line segments, ROADMs and/or PXC.

7.6 Functional description of an optical 3R regenerator

An optical 3R regenerator is a device or sub-system that performs simultaneously in the optical domain the "re-shaping", "re-amplification" and "re-timing" functions on an optical signal. Thus this device or sub-system restores the amplitude of the signal to a level suitable for onward transmission, removes any amplitude noise or distortion present on the waveform and also re-times the signal to remove any timing jitter that may be present.

7.7 Functional description of an optical 2R regenerator

An optical 2R regenerator is a device or sub-system that performs simultaneously in the optical domain the "re-shaping" and "re-amplification" functions on an optical signal. This is generally taken to mean a device that amplifies the optical signal with a non-linear input power to output power transfer curve so as to reduce the amplitude noise or distortion on the optical ones and/or zeros. Any timing jitter on the optical signal, however, is not removed.

8 ONE transfer parameters

A list of ONE optical transfer parameters is given in Table 8-1 for ONEs that do not contain amplifiers. A list of additional parameters that are required for ONEs that do contain amplifiers is given in Table 8-2.

Table 8-1 – ONE transfer parameters for ONEs without amplifiers

Channel frequency range (GHz)
Insertion loss (dB)
Channel insertion loss deviation (dB)
Ripple (dB)
Channel chromatic dispersion (ps/nm)
Differential group delay (ps)
Polarization dependent loss (dB)
Reflectance (dB)
Isolation (dB)
Channel extinction (dB)
Reconfigure time (for ROADM)
Switching time (for PXC)
Channel uniformity
NOTE – Not all parameters apply to all devices.

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An additional parameter that may need to be included is the level of multi-path interference. The definition of this parameter and the penalty that it may introduce in cascaded OEs is left for further study.

Table 8-2 – Additional OE transfer parameters for OEs with amplifiers

Total input power range
Channel input power range
Channel output power range
Channel signal-spontaneous noise figure
Input reflectance
Output reflectance
Maximum reflectance tolerable at input
Maximum reflectance tolerable at output
Maximum total output power
Channel addition/removal (steady-state) gain response
Transient duration
Transient gain increase
Transient gain reduction
Channel gain
Multichannel gain-change difference (inter-channel gain-change difference)
Multichannel gain tilt (inter-channel gain-change ratio)

8.1 DWDM line segment transfer parameters

The transfer parameters of a DWDM line segment apply to reference Situation 2 and are for further study.

8.2 OADM transfer parameters

8.2.1 Transfer parameters of OADMs without amplifiers

For the evaluation of the OTF of fixed and re-configurable OADMs without amplifiers, a list of optical transfer parameters is given in Table 8-3 (fixed OADM without amplifiers) and in Table 8-4 (re-configurable OADM without amplifiers).

Table 8-3 – Transfer parameters of fixed OADM without amplifiers

Parameter		Max	Min
Channel frequency range	GHz		
Channel insertion loss			
Input to output	dB		
Input to drop	dB		
Add to output	dB		
Channel insertion loss deviation	dB		NA
Ripple	dB		NA
Channel chromatic dispersion	ps/nm		
Differential group delay (DGD)	ps		NA
Polarization dependent loss (PDL)	dB		NA

Table 8-3 – Transfer parameters of fixed OADM without amplifiers

Parameter		Max	Min
Reflectance	dB		NA
Adjacent channel isolation input to drop	dB	NA	
Non-adjacent channel isolation input to drop	dB	NA	
Channel extinction input to output	dB	NA	
Channel uniformity	dB		NA

Table 8-4 – Transfer parameters of re-configurable OADM without amplifiers

Parameter		Max	Min
Channel frequency range	GHz		
Channel insertion loss Input to output Input to drop Add to output	dB dB dB		
Channel insertion loss deviation	dB		NA
Ripple	dB		NA
Channel chromatic dispersion	ps/nm		
Differential group delay (DGD)	ps		NA
Polarization dependent loss (PDL)	dB		NA
Reflectance	dB		NA
Adjacent channel isolation input to drop	dB	NA	
Non-adjacent channel isolation input to drop	dB	NA	
Channel extinction input to output	dB	NA	
Reconfigure time	ms		
Channel uniformity	dB		NA

8.2.2 Transfer parameters of OADMs including amplifiers

For the evaluation of the OTF of fixed and re-configurable OADMs with amplifiers, a list of optical transfer parameters is given in Table 8-5 (fixed OADM with amplifiers) and in Table 8-6 (re-configurable OADM with amplifiers).