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

Transmission media and optical systems characteristics – Characteristics of optical components and subsystems

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Characteristics of multi-degree reconfigurable optical add/drop multiplexers

Recommendation ITU-T G.672

ITU-T

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Recommendation ITU-T G.672

Characteristics of multi-degree reconfigurable optical add/drop multiplexers

Summary

Recommendation ITU-T G.672 provides a description of the relevant characteristics of multi-degree reconfigurable optical add/drop multiplexer (MD-ROADM) network elements. The MD-ROADM is intended to be used in optical networks based on dense wavelength division multiplexing (DWDM), to enhance network scalability and to support enhanced service provisioning and resilience features. Recommendation ITU-T G.672 also provides classification criteria and a list of optical transfer parameters for MD-ROADMs appropriate for both fixed and flexible DWDM grid applications. In this edition of Recommendation ITU-T G.672, additional optical transfer parameters have been specified.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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DWDM, flexible grid, OADM, ROADM.

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

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Characteristics of multi-degree reconfigurable optical add/drop multiplexers

1 Scope

This Recommendation deals with the classification and the characteristics of multi-degree reconfigurable optical add/drop multiplexers (MD-ROADMs), including two-degree ROADMs. Some examples of MD-ROADM configurations and applications are given in the appendices.

Photonic cross connects (PXCs), which are a special category of MD-ROADM characterized by a unique switching matrix (see Figures 7-4, 7-5, 7-6, 7-7, 9-2 and I.4 of [ITU-T G.680]), lie outside the scope of this Recommendation.

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.661] Recommendation ITU-T G.661 (2007), *Definitions and test methods for the relevant generic parameters of optical amplifier devices and subsystems.*

[ITU-T G.671] Recommendation ITU-T G.671 (2019), *Transmission characteristics of optical components and subsystems.*

[ITU-T G.680] Recommendation ITU-T G.680 (2007), *Physical transfer functions of optical network elements.*

[ITU-T G.694.1] Recommendation ITU-T G.694.1 (2020), *Spectral grids for WDM applications: DWDM frequency grid.*

[ITU-T G.806] Recommendation ITU-T G.806 (2012), *Characteristics of transport equipment – Description methodology and generic functionality.*

[ITU-T G.870] Recommendation ITU-T G.870/Y.1352 (2016), *Terms and definitions for optical transport networks.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 adjacent channel isolation [ITU-T G.671]

3.1.2 channel addition/removal (steady-state) gain response [ITU-T G.661]

3.1.3 channel extinction [ITU-T G.671]

3.1.4 channel frequency range [ITU-T G.671]

3.1.5 channel gain [ITU-T G.661]

3.1.6 channel input power range [ITU-T G.661]

3.1.7 channel insertion loss (WDM devices) [ITU-T G.671]

3.1.8 channel insertion loss deviation (WDM devices) [ITU-T G.671]

3.1.9 channel output power range [ITU-T G.661]

3.1.10 channel polarization dependent loss (PDL) (for OADM type subsystems) [ITU-T G.671]

3.1.11 channel signal-spontaneous noise figure [ITU-T G.661]

3.1.12 channel spacing [ITU-T G.671]

3.1.13 defect [ITU-T G.806]

3.1.14 flexible DWDM grid

NOTE – The term is described in clause 7 of [ITU-T G.694.1]. In this Recommendation, the term is also shortened to "flexible grid".

3.1.15 group delay [ITU-T G.671]

3.1.16 input reflectance [ITU-T G.661]

3.1.17 maximum reflectance tolerable at input [ITU-T G.661]

3.1.18 maximum reflectance tolerable at output [ITU-T G.661]

3.1.19 maximum total output power [ITU-T G.661]

3.1.20 multichannel gain-change difference (inter-channel gain change difference) [ITU-T G.661]

3.1.21 multichannel gain tilt (inter-channel gain-change ratio) [ITU-T G.661]

3.1.22 non-adjacent channel isolation [ITU-T G.671]

3.1.23 polarization mode dispersion (PMD) [ITU-T G.671].

NOTE – This Recommendation uses the equivalent term "channel differential group delay".

3.1.24 reconfigure time (for ROADM) [ITU-T G.680]

3.1.25 reflectance [ITU-T G.671]

3.1.26 ripple [ITU-T G.671]

3.1.27 specified by application (sba) [ITU-T G.671]

3.1.28 optical transport module (OTM n[r].m) [ITU-T G.870]

3.1.29 output reflectance [ITU-T G.661]

3.1.30 transfer matrix (for optical branching and WDM devices) [ITU-T G.671]

3.1.31 transient duration [ITU-T G.661]

3.1.32 transient gain increase [ITU-T G.661]

3.1.33 transient gain reduction [ITU-T G.661]

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 channel asymmetric group delay: Between optical lines, the difference between the group delay from an optical line #n input port to an optical line #m output port and the group delay from an optical line #m input port to an optical line #n output port for the same channel. Between optical line and add/drop port, the difference between the group delay from an optical line #n input port to an optical drop port #m and the group delay from an optical add port #m to an optical line #n output port for the same channel.

3.2.2 cumulative port isolation: Within the operating wavelength range, the minimum value of the ratio of the transfer coefficient from an input port to an output port in the on state to the sum of the transfer coefficients from all other input ports to the same output port in the off state for the same wavelength.

It is given by the following formula:

$$CPI = 10\log_{10}\left(\frac{t_{xow}}{\sum_{s,s\neq x} t_{sow}^{0}}\right)$$

The terms t_{xow} and t_{sow}^{0} are elements of the transfer matrix (defined in clause 3.2.3.13 of [ITU-T G.671]), where *o* is the output port number, *w* is the (channel) wavelength number of the considered channel, *x* is the input port number that is in the on state to the output port for the channel *w*, and *s* represents the input port numbers that are in the off state to the output port for channel *w*. Each input port *s* is in the on state for the wavelength *w* to that output port other than *o*, for which the term t_{sow}^{0} is maximized.

3.2.3 degree of a multi-degree reconfigurable optical add/drop multiplexer: The number of bidirectional optical lines that can be connected between the multi-degree reconfigurable optical add/drop multiplexer (MD-ROADM) and other optical network elements. It is also the number of reconfigurable wavelength add/drop devices (R-WADDs) that are installed in the MD-ROADM.

3.2.4 hitless operation: An operation performed on an optical network element embedded in an optical network is hitless when, considering the full time period from the start of the operation to its end, the following two conditions are both satisfied:

– no defects are detected on any of the unswitched optical channels managed by that optical network element or their related client signals;

– the bit error ratio measured at the receiver interfaces of those client signals is less than or equal to the maximum bit error ratio allowed for them.

See Figure 1.

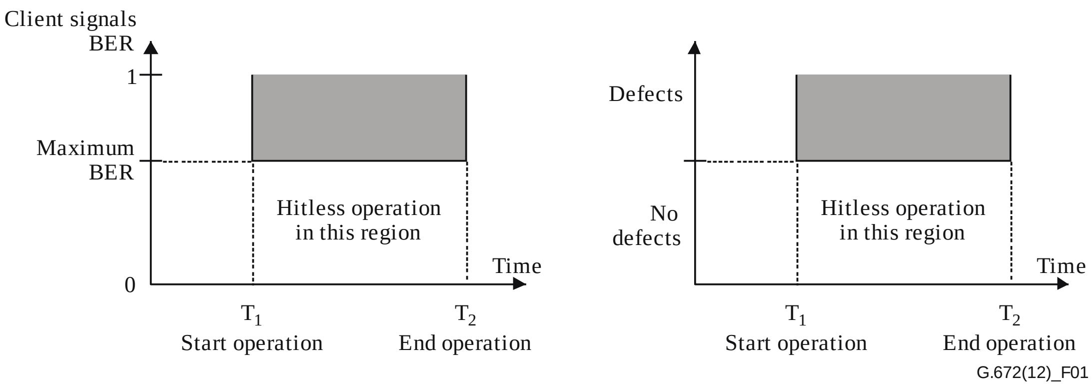

Figure 1 – Illustration of hitless operation conditions

3.2.5 multi-degree reconfigurable optical add/drop multiplexer (MD-ROADM): An element of an optical transport network capable of transferring any wavelength from one optical line to any other optical line, by means of reconfigurable wavelength add/drop devices (R-WADDs), and also to transfer local add/drop wavelengths to/from optical lines, by means of reconfigurable local add/drop devices (R-LADDs). Moreover, for an MD-ROADM, it should be possible to increase or decrease the optical node degree (i.e., to add or remove optical lines) up to the maximum supported, without any impact on live traffic. See Figure 2.

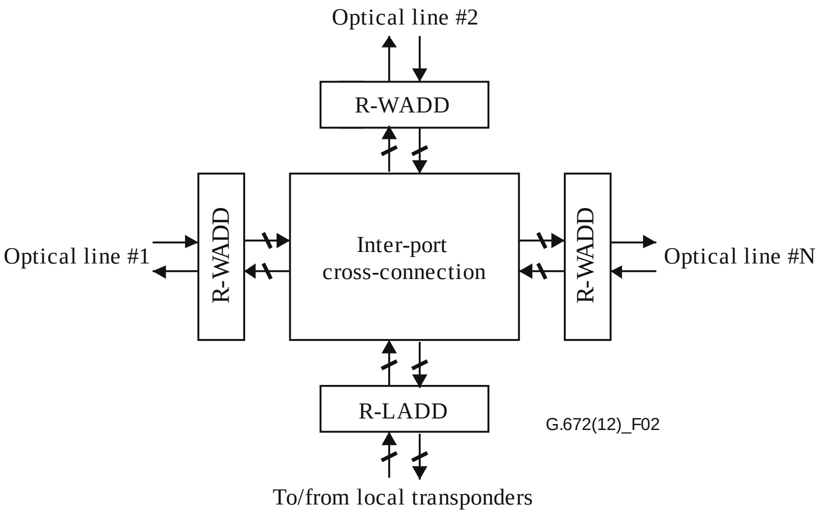

Figure 2 – MD-ROADM reference diagram

3.2.6 reconfigurable local add drop/device (R-LADD) NxM: A wavelength selective branching device which has a reconfigurable "drop" function in which wavelengths coming from any of N optical input ports can be transferred either to one specific port, or to a subset, or to any of M optical drop ports, and also has a reconfigurable "add" function in which wavelengths presented to any of M optical add ports (that are wavelength-compatible) can be transferred either to one specific port, or to a subset, or to any of N optical output ports.

See Figure 3.

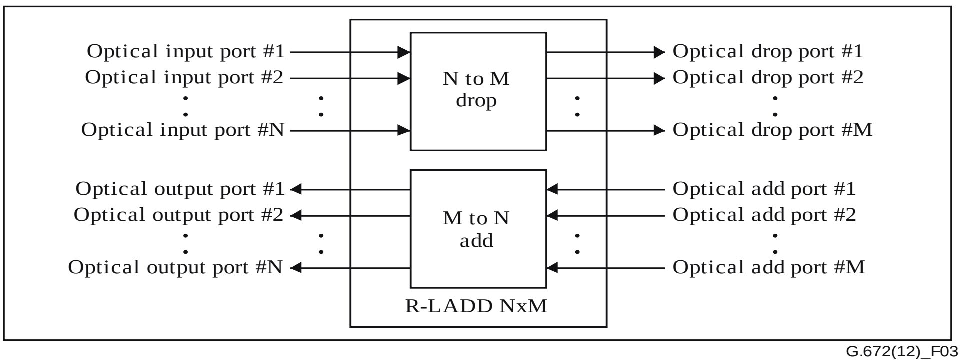

Figure 3 – R-LADD NxM reference diagram

3.2.7 reconfigurable wavelength add/drop device (R-WADD) 1xN: A reconfigurable wavelength selective branching device capable of transferring wavelengths from one optical line input port to any of N optical output ports, and also capable of transferring wavelengths coming from any of N optical input ports to the optical line output port while avoiding transferring the same wavelength from more than one input to the optical line output.

See Figure 4.

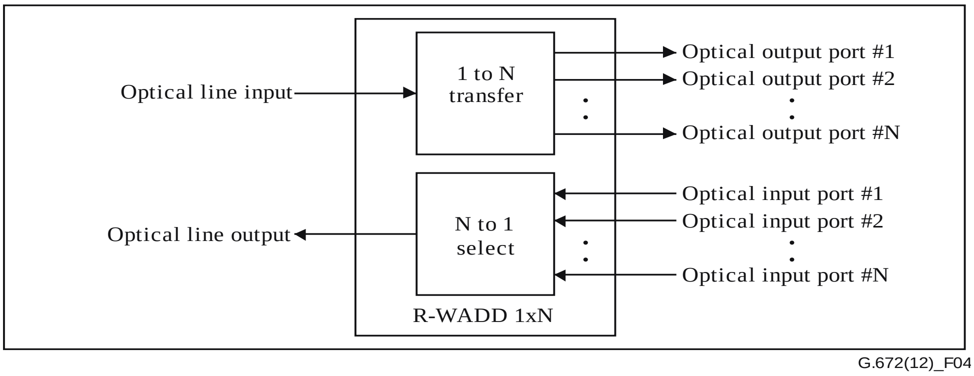

Figure 4 – R-WADD 1xN reference diagram

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

BER	Bit Error Ratio
DGD	Differential Group Delay
DWDM	Dense Wavelength Division Multiplexing
MCS	Multicast Switch
MD-ROADM	Multi-Degree Reconfigurable Optical Add/Drop Multiplexer
NA	Not Applicable
OADM	Optical Add/Drop Multiplexer
OTF	Optical Transfer Function
OTM	Optical Transport Module
PDL	Polarization Dependent Loss
PMD	Polarization Mode Dispersion
PXC	Photonic Cross Connect
R-LADD	Reconfigurable Local Add/Drop Device
R-WADD	Reconfigurable Wavelength Add/Drop Device
sba	specified by application
WSS	Wavelength Selective Switch

5 Classification criteria

In an MD-ROADM it should be possible to increase or decrease the optical node degree (i.e., to add or remove optical lines) up to the maximum supported. Consequently, the total number of wavelengths that can be managed both for node pass-through and also for local add/drop can change dynamically. The following criteria are established.

– **Maximum node degree**: the maximum number of bidirectional optical lines supported by an MD-ROADM.

– **Maximum node channel count**: the total number of channels that can be managed on all of the bidirectional optical lines. It is the maximum number of incoming wavelengths per line multiplied by the maximum node degree.

– **Minimum channel spacing**: the minimum value of the channel spacing as defined in clause 3.1.12.

– **Maximum add/drop ports**: the number of add/drop ports provided by the MD-ROADM at its maximum add/drop capability.

– **Maximum add/drop ratio**: the maximum add/drop ports divided by the maximum node channel count (expressed as a percentage).

In an MD-ROADM, the R-LADD feature should provide both the wavelength-dependent add/drop of optical channels, as well as the wavelength-independent add/drop. Therefore, the following criteria are established.

– **Coloured local add/drop**: an MD-ROADM that features coloured local add/drop ports is able to add/drop an optical channel with a specific wavelength to one of those ports.

– **Colourless and fixed grid local add/drop**: an MD-ROADM that features one or more colourless local add/drop ports is able to add/drop a fixed grid optical channel with any supported wavelength to any of those ports.

– **Colourless and flexible grid local add/drop**: an MD-ROADM that features one or more colourless local add/drop ports is able to add/drop a flexible grid optical channel with any supported wavelength to any of those ports.

In an MD-ROADM, the R-LADD feature should also provide either direction-dependent or direction-independent add/drop of optical channels and allow the reuse of the same wavelength for different directions. Therefore, the following criteria are established.

– **Directional local add/drop**: an MD-ROADM with a directional local add/drop feature is able to add or drop an optical channel to/from a specific optical line port.

– **Directionless local add/drop**: an MD-ROADM with a directionless local add/drop feature is able to add or drop an optical channel to/from any optical line port.

– **Contentionless local add/drop**: an MD-ROADM with a contentionless local add/drop feature is able to add or drop more than one optical channel with the same wavelength to/from different optical line ports.

The above criteria are not mutually exclusive, e.g., an MD-ROADM could provide a local add/drop with coloured, directionless and colourless features, on different local add/drop ports. So, it is useful to establish some criteria about the add/drop capability, to help in categorizing MD-ROADM.

– **Maximum coloured and directional add/drop ratio**: the maximum number of add/drop ports with a coloured and directional local add/drop feature, divided by the maximum node channel count (expressed as a percentage).

– **Maximum coloured and directionless add/drop ratio**: the maximum number of add/drop ports with a coloured and directionless local add/drop feature, divided by the maximum node channel count (expressed as a percentage).

– **Maximum coloured, directionless and contentionless add/drop ratio**: the maximum number of add/drop ports with a coloured, directionless and contentionless local add/drop feature, divided by the maximum node channel count (expressed as a percentage).

– **Maximum colourless and directional add/drop ratio**: the maximum number of add/drop ports with a colourless and directional local add/drop feature, divided by the maximum node channel count (expressed as a percentage).

– **Maximum colourless and directionless add/drop ratio**: the maximum number of add/drop ports with a colourless and directionless local add/drop feature, divided by the maximum node channel count (expressed as a percentage).

– **Maximum colourless, directionless and contentionless add/drop ratio**: the maximum number of add/drop ports with a colourless, directionless and contentionless local add/drop feature, divided by the maximum node channel count (expressed as a percentage).
– **Maximum colourless, directionless and flexible grid add/drop ratio**: the maximum number of add/drop ports with a colourless, directionless and flexible grid local add/drop feature, divided by the maximum node channel count (expressed as a percentage).
– **Maximum colourless, directionless, contentionless and flexible grid add/drop ratio**: the maximum number of add/drop ports with a colourless, directionless, contentionless and flexible grid local add/drop feature, divided by the maximum node channel count (expressed as a percentage).

All of the above criteria can be tabulated: Table 1 relates to the availability of MD-ROADM general characteristics; and Table 2 relates to the MD-ROADM local add/drop ratio.

Table 1 – MD-ROADM general characteristics

Maximum node degree	Number
Maximum node channel count	Number
Minimum channel spacing	GHz
Maximum add/drop ports	Number
Maximum add/drop ratio	%
Coloured local add/drop	Yes/No
Colourless and fixed grid local add/drop	Yes/No
Colourless and flexible grid local add/drop	Yes/No
Directional local add/drop	Yes/No
Directionless local add/drop	Yes/No
Contentionless local add/drop	Yes/No

Table 2 – MD-ROADM local add/drop ratio parameters

Maximum coloured and directional add/drop ratio	%
Maximum coloured and directionless add/drop ratio	%
Maximum coloured, directionless and contentionless add/drop ratio	%
Maximum colourless and directional add/drop ratio	%
Maximum colourless and directionless add/drop ratio	%
Maximum colourless, directionless and contentionless add/drop ratio	%
Maximum colourless, directionless and flexible grid add/drop ratio	%
Maximum colourless, directionless, contentionless and flexible grid add/drop ratio	%

6 Main characteristics

The minimum list of MD-ROADM relevant characteristics is as follows.

– **Degree upgrade capability**: an MD-ROADM should provide the capability to increase the optical node degree (i.e., to install a new R-WADD) up to the maximum supported. The degree upgrade operation should be hitless.
– **Degree downgrade capability**: an MD-ROADM should provide the capability to decrease the optical node degree (i.e., to remove an installed R-WADD) down to the minimum supported. The degree downgrade operation should be hitless.

– **Optical channel set-up capability**: an MD-ROADM should provide the capability to set up an optical channel using any of the wavelength resources managed by the MD-ROADM. The MD-ROADM should be able to set up a new optical channel, as well as to modify an existing one, by switching or detuning the required wavelength-specific resources. If the required wavelength-specific resources are free and available on the related R-WADDs, as well as on the R-LADD, the optical channel set-up operation should be hitless for all channels except for the one being set up or modified.
– **Optical channel tear-down capability**: an MD-ROADM should provide the capability to tear down (remove) an existing optical channel, releasing the related wavelength-specific resources. The optical channel tear-down operation should be hitless for all channels except the one being removed.
– **R-WADD fault partition capability**: in an MD-ROADM, a fault in any of the installed R-WADDs should be hitless for all of the optical channels which are not managed by the faulty R-WADD.

A list of optional MD-ROADM characteristics follows.

– **MD-ROADM fault tolerance**: an MD-ROADM should provide the capability to arrange its R-WADD, R-LADD and inter-port cross-connections so as to support protection against a single failure in any subsystem.

7 MD-ROADM transfer parameters

7.1 Transfer parameters of MD-ROADMs without amplifiers

For the evaluation of the optical transfer function (OTF) of MD-ROADM without amplifiers, a list of optical transfer parameters is given in Table 3. In this edition of this Recommendation, all parameter values are given as specified by application (sba), since the required values are dependent on the application.

Table 3 – Transfer parameters of MD-ROADM without amplifiers

Parameter		Max	Min
Channel frequency range	GHz	sba	sba
Channel insertion loss Line input to line output Line input to drop Add to line output	 dB dB dB	 sba sba sba	 sba sba sba
Channel insertion loss deviation	dB	sba	NA
Ripple	dB	sba	NA
Channel chromatic dispersion	ps/nm	sba	sba
Channel differential group delay (DGD) Line input to line output Line input to drop Add to line output	 ps ps ps	 sba sba sba	 NA NA NA
Channel polarization dependent loss (PDL) Line input to line output Line input to drop Add to line output	 dB dB dB	 sba sba sba	 NA NA NA
Reflectance	dB	sba	NA
Adjacent channel isolation (line input to drop)	dB	NA	sba

Table 3 – Transfer parameters of MD-ROADM without amplifiers

Parameter		Max	Min
Non-adjacent channel isolation (line input to drop)	dB	NA	sba
Channel extinction (line input to line output)	dB	NA	sba
Reconfigure time	ms	sba	sba
Channel uniformity	dB	sba	NA
Channel asymmetric group delay Between optical lines Between optical line and add/drop port	 ps ps	 sba sba	 NA NA
Cumulative port isolation Line input and add to line output Line input to drop	 dB dB	 NA NA	 sba sba

7.2 Transfer parameters of MD-ROADMs with amplifiers

For the evaluation of the OTF of MD-ROADM with amplifiers, a list of optical transfer parameters is given in Table 4. In this edition of this Recommendation, all parameter values are given as specified by application (sba), since the required values are dependent on the application.

Table 4 – Transfer parameters of MD-ROADM with amplifiers

Parameter		Max	Min
Channel frequency range	GHz	sba	sba
Channel gain Line input to line output Line input to drop Add to line output	 dB dB dB	 sba sba sba	 sba sba sba
Channel insertion loss deviation	dB	sba	NA
Ripple	dB	sba	NA
Channel chromatic dispersion	ps/nm	sba	sba
Channel differential group delay (DGD) Line input to line output Line input to drop Add to line output	 ps ps ps	 sba sba sba	 NA NA NA
Channel polarization dependent loss (PDL) Line input to line output Line input to drop Add to line output	 dB dB dB	 sba sba sba	 NA NA NA
Reflectance	dB	sba	NA
Adjacent channel isolation (line input to drop)	dB	NA	sba
Non-adjacent channel isolation (line input to drop)	dB	NA	sba
Channel extinction (line input to line output)	dB	NA	sba
Reconfigure time	Ms	sba	NA
Total input power range (line input)	dBm	sba	sba

Table 4 – Transfer parameters of MD-ROADM with amplifiers

Parameter		Max	Min
Channel input power range Line Input Add	 dBm dBm	 sba sba	 sba sba
Channel output power range Line Output Drop	 dBm dBm	 sba sba	 sba sba
Channel signal-spontaneous noise figure Line input to line output Line input to drop Add to line output	 dB dB dB	 sba sba sba	 NA NA NA
Input reflectance	dB	sba	NA
Output reflectance	dB	sba	NA
Maximum reflectance tolerable at input	dB	NA	sba
Maximum reflectance tolerable at output	dB	NA	sba
Maximum total output power (line output)	dBm	sba	NA
Channel addition/removal (steady-state) gain response	dB	sba	sba
Transient duration	Ms	sba	NA
Transient gain increase	dB	sba	NA
Transient gain reduction	dB	sba	NA
Multichannel gain-change difference (inter-channel gain-change difference)	dB	sba	NA
Multichannel gain tilt (inter-channel gain-change ratio)	dB/dB	sba	NA
Channel uniformity	dB	sba	NA
Channel asymmetric group delay Between optical lines Between optical line and add/drop port	 ps ps	 sba sba	 NA NA
Cumulative port isolation Line input and add to line output Line input to drop	 dB dB	 NA NA	 sba sba

Appendix I

MD-ROADM classification examples

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

I.1 Example 1

In Figure I.1, a 2-degree MD-ROADM is depicted on day one (shown as continuous lines). The optical lines can contain up to 80 optical channels (OTM-80r.m, where OTM is optical transport module) with 50 GHz spacing, and each R-WADD can provide up to four multi-channel ports, which can be connected either to another R-WADD or to an R-LADD. A colourless and directional local add/drop feature for 40 channels is provided for each of the two optical lines. A coloured and directionless add/drop feature for 40 channels is also provided: each of these wavelengths can be added/dropped to/from four directions, but it is not possible to reuse the same wavelength, because this device is not wavelength contentionless.

Starting from this day one configuration, it is possible to upgrade the MD-ROADM with one degree more. It is reasonable to have an R-WADD with the same characteristic (OTM-80r.m), providing a colourless and directional add/drop feature as before, and to have the coloured and directionless feature by connecting the new R-WADD to the coloured/directionless device already installed. In Figure I.1, the upgrading is depicted by dashed lines. The maximum number of optical channels that this MD-ROADM is able to add/drop is equal to 160.

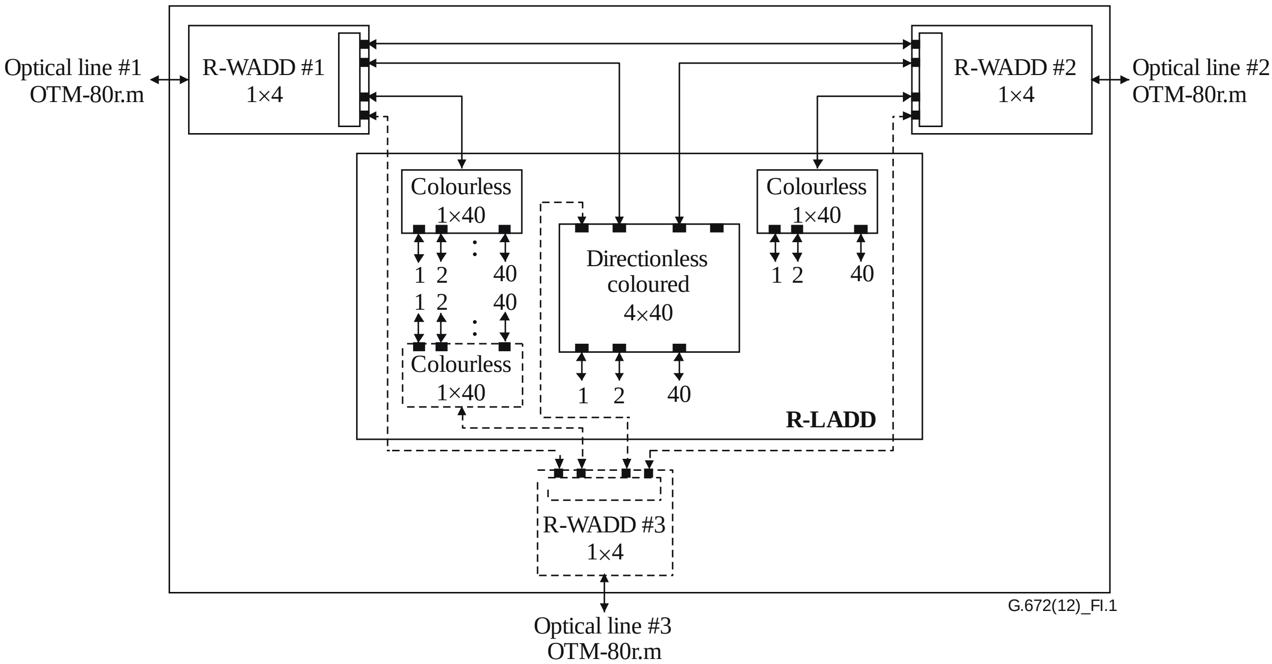

Figure I.1 – MD-ROADM scheme for example 1

The classification according to clause 5 is shown in Tables I.1 and I.2.

Table I.1 – MD-ROADM example 1: general characteristics

Maximum node degree	3
Maximum node channel count	240
Minimum channel spacing	50 GHz
Maximum add/drop ports	160
Maximum add/drop ratio	66%
Coloured local add/drop	Yes
Colourless and fixed grid local add/drop	Yes
Colourless and flexible grid local add/drop	No
Directional local add/drop	Yes
Directionless local add/drop	Yes
Contentionless local add/drop	Yes

Table I.2 – MD-ROADM example 1: local add/drop ratio parameters

Maximum coloured and directional add/drop ratio	0%
Maximum coloured and directionless add/drop ratio	16%
Maximum coloured, directionless and contentionless add/drop ratio	0%
Maximum colourless and directional add/drop ratio	50%
Maximum colourless and directionless add/drop ratio	0%
Maximum colourless, directionless and contentionless add/drop ratio	0%
Maximum colourless, directionless and flexible grid add/drop ratio	0%
Maximum colourless, directionless, contentionless and flexible grid add/drop ratio	0%

I.2 Example 2

In this example, some requirements for an MD-ROADM deployment are given. This MD-ROADM should provide a 3 degree OTM-80r.m, 50 GHz spacing, with a maximum add/drop ratio of 60%, consisting of 50% with a colourless, directionless and contentionless feature, and 10% with a coloured and directional feature, on day one. The MD-ROADM should provide a maximum degree equal to 6. Moreover, it has to provide protection against a single failure in the colourless, directionless and contentionless subsystem.

The classification according to clause 5 is shown in Tables I.3 and I.4.

Table I.3 – MD-ROADM example 2: general characteristics

Maximum node degree	6
Maximum node channel count	480
Minimum channel spacing	50 GHz
Maximum add/drop ports	288
Maximum add/drop ratio	60%
Coloured local add/drop	Yes
Colourless and fixed grid local add/drop	Yes
Colourless and flexible grid local add/drop	No

Table I.3 – MD-ROADM example 2: general characteristics

Directional local add/drop	Yes
Directionless local add/drop	Yes
Contentionless local add/drop	Yes

Table I.4 – MD-ROADM Example 2: local add/drop ratio parameters

Maximum coloured and directional add/drop ratio	10%
Maximum coloured and directionless add/drop ratio	0%
Maximum coloured, directionless and contentionless add/drop ratio	0%
Maximum colourless and directional add/drop ratio	0%
Maximum colourless and directionless add/drop ratio	0%
Maximum colourless, directionless and contentionless add/drop ratio	50%
Maximum colourless, directionless and flexible grid add/drop ratio	0%
Maximum colourless, directionless, contentionless and flexible grid add/drop ratio	0%

An example of the resulting MD-ROADM scheme on day one is shown in Figure I.2. Optical connections (shown as continuous lines) indicate connections between R-WADDs for wavelength pass-through, while dashed lines indicate connections between the R-WADDs and the R-LADD.

To reach the maximum node degree, three multi-channel ports should still be available on each R-WADD.

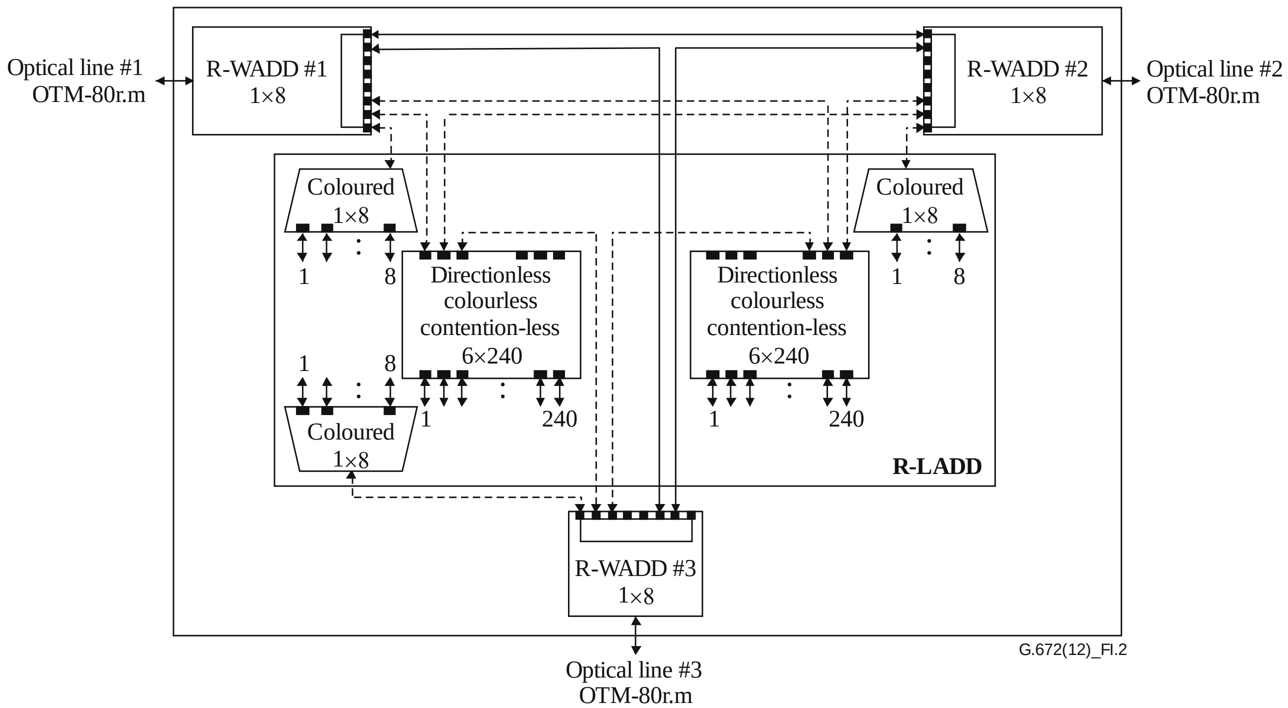

Figure I.2 – MD-ROADM scheme for example 2

I.3 Example 3

In this example, the MD-ROADM should provide a 3 degree OTM-106r.m, 37.5 GHz spacing, with a maximum add/drop ratio of 15%. All the add/drop ports support a colourless, directionless, contentionless and flexible grid feature on day one. The MD-ROADM should provide a maximum degree equal to 7. Moreover, it also provides protection against a single failure in the colourless, directionless and contentionless subsystem.

The classification according to clause 5 is shown in Tables I.5 and I.6.

Table I.5 – MD-ROADM example 3: general characteristics

Maximum node degree	7
Maximum node channel count	742
Minimum channel spacing	37.5 GHz
Maximum add/drop ports	112
Maximum add/drop ratio	15%
Coloured local add/drop	Yes
Colourless and fixed grid local add/drop	No
Colourless and flexible grid local add/drop	Yes
Directional local add/drop	Yes
Directionless local add/drop	Yes
Contentionless local add/drop	Yes

Table I.6 – MD-ROADM example 3: local add/drop ratio parameters

Maximum coloured and directional add/drop ratio	0%
Maximum coloured and directionless add/drop ratio	0%
Maximum coloured, directionless and contentionless add/drop ratio	0%
Maximum colourless and directional add/drop ratio	0%
Maximum colourless and directionless add/drop ratio	0%
Maximum colourless, directionless and contentionless add/drop ratio	0%
Maximum colourless, directionless and flexible grid add/drop ratio	0%
Maximum colourless, directionless, contentionless and flexible grid add/drop ratio	15%

An example of the resulting MD-ROADM scheme on day one is shown in Figure I.3. Optical connections (shown as continuous lines) indicate connections between R-WADDs for wavelength pass-through, while dashed lines indicate connections between the R-WADDs and R-LADD.

To reach the maximum node degree, four multi-channel ports should still be available on each R-WADD.

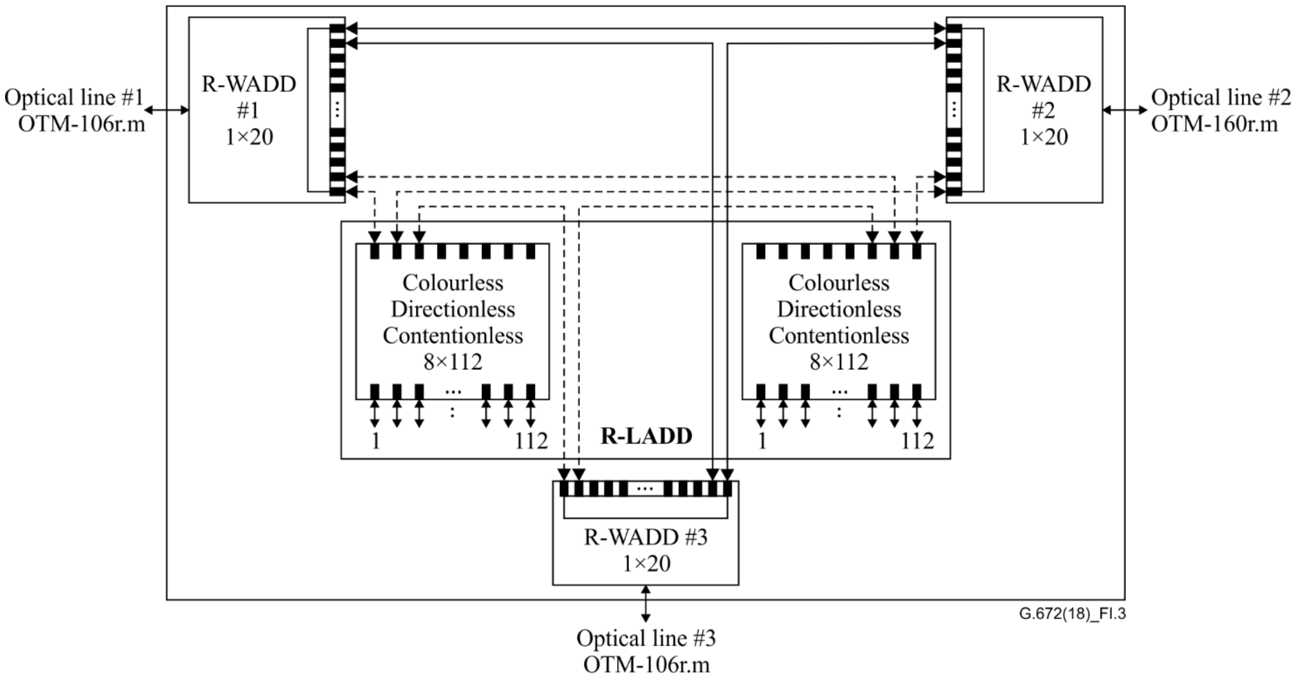

Figure I.3 – MD-ROADM scheme for example 3

Appendix II

Configuration examples of MD-ROADM

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

II.1 Example of direction/degree expansion of MD-ROADM

In order to illustrate the direction/degree expansion of MD-ROADM, an example configuration is shown in Figure II.1. A 2-degree MD-ROADM with optical amplifiers is first constructed by using two multi-port R-WADDs and when expanding to a new direction, another multi-port R-WADD shown with dashed lines is included by connecting with fibre jumpers. The maximum direction/degree is then expanded to three, and consequently, the total number of wavelengths that are locally added/dropped and managed for node pass-through can change dynamically.

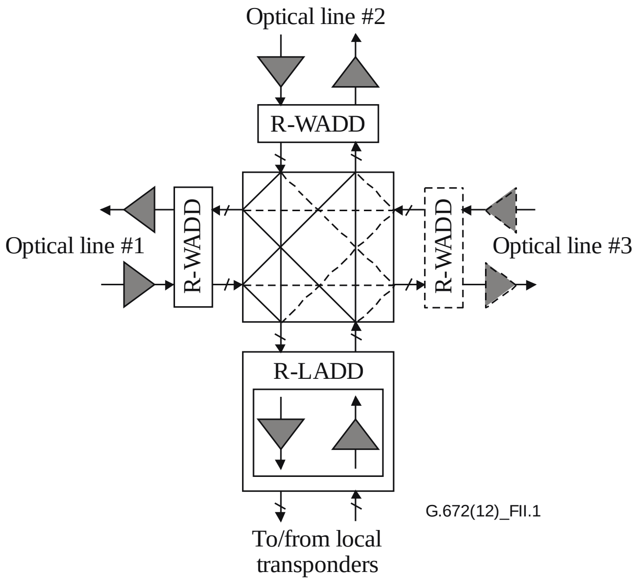

Figure II.1 – Configuration of the direction/degree expansion example

II.2 Example of an MD-ROADM with the directionless, colourless (and flexible grid) feature

An MD-ROADM with the directionless and colourless feature is depicted in Figure II.2 and the L-WADD device is realized by using wavelength selective switches (WSSs) [b-Marom]. In an MD-ROADM, the L-WADD feature should provide both wavelength-independent add/drop of optical channels, as well as direction-independent add/drop. Any wavelength from any direction or originating at that node can then be multicast to all the directions to/from any optical line port.

If the WSSs are of the flexible grid type, this MD-ROADM also has the flexible grid feature.

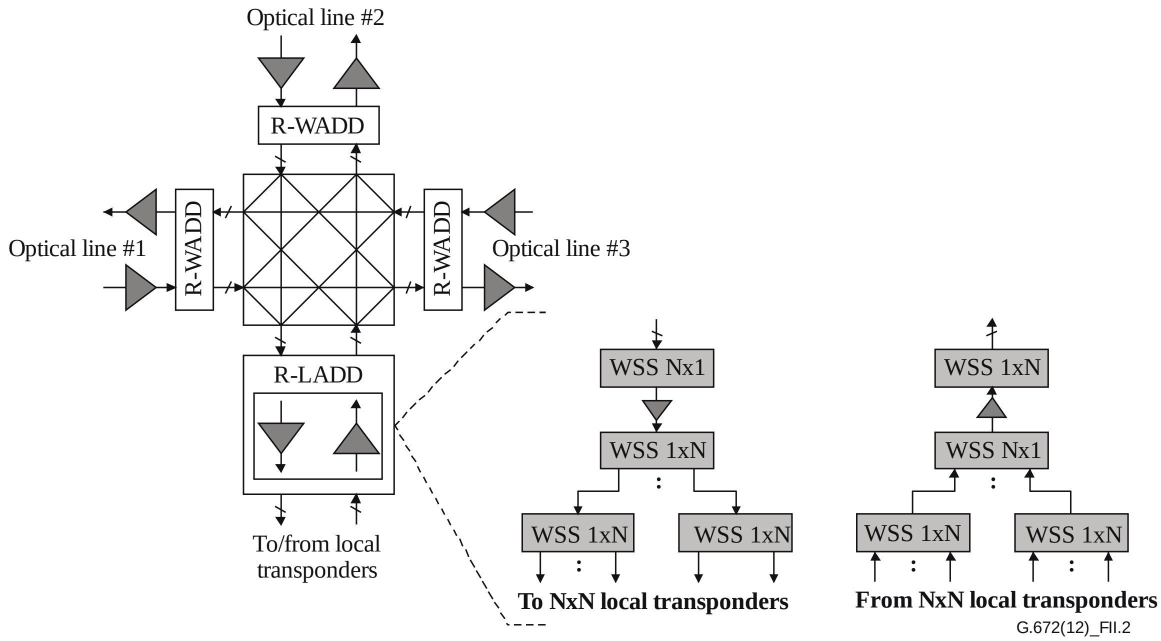

Figure II.2 – Configuration of an MD-ROADM with the directionless and colourless feature

II.3 Example of an MD-ROADM with the colourless, directionless, contentionless (and flexible grid) feature

An MD-ROADM with the colourless, directionless, contentionless feature is depicted in Figure II.3. The R-WADD device is realized by using high-degree 1xL WSS and R-LADD device using MxN WSS [b-Yan], optical cross connect [b-Jensen] or multicast switch (MCS) [b-Way]. If the R-WADD and R-LADD are flexible grid devices, this MD-ROADM also has the flexible grid feature. In such an MD-ROADM, the combination of R-WADD and L-WADD feature should provide a wavelength-independent, direction-independent, contention-independent as well as flexible grid add/drop function. Any flexible grid wavelength from any direction or originating at that node can then be multicast to all the directions to/from any optical line port, while the same wavelength to/from multi optical line ports can be added/dropped to local transponders.

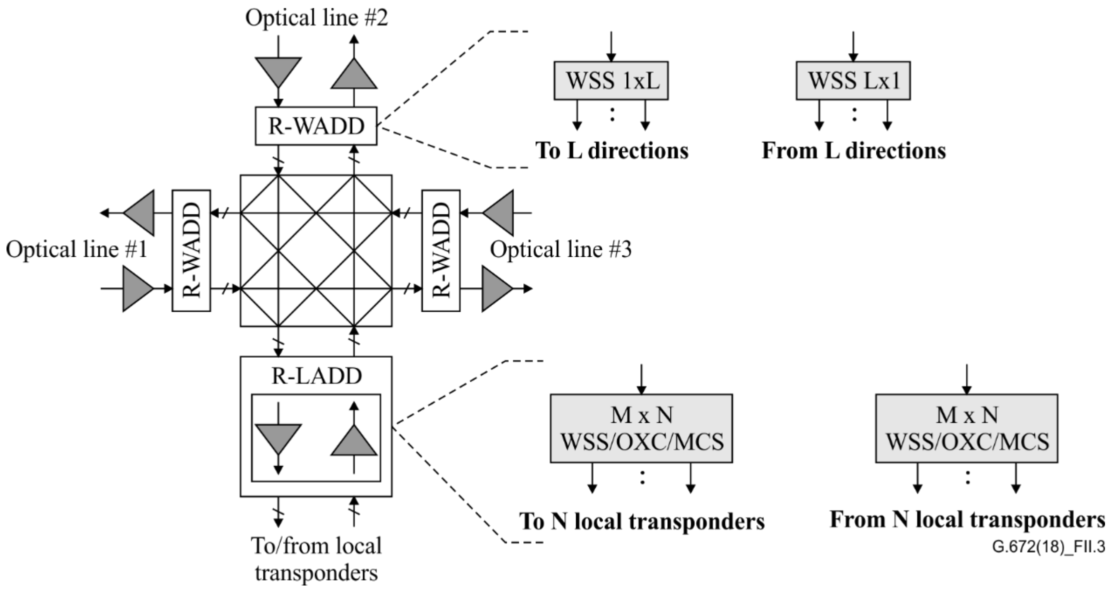

Figure II.3 – Configuration of an MD-ROADM with the colourless, directionless, contentionless (and flexible grid) feature

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