IEC TR 62343-6-4

Edition 1.0 2017-01

TECHNICAL REPORT

colour inside

Dynamic modules –
Part 6-4: Design guides – Reconfigurable optical add/drop multiplexer

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CONTENTS

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DYNAMIC MODULES –

Part 6-4: Design guides – Reconfigurable optical add/drop multiplexer

FOREWORD

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IEC TR 62343-6-4, which is a Technical Report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
86C/1400/DTR	86C/1420/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62343 series, published under the general title *Dynamic modules*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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DYNAMIC MODULES –

**Part 6-4: Design guides –
Reconfigurable optical add/drop multiplexer**

1 Scope

This part of IEC 62343, which is a Technical Report on reconfigurable optical add/drop multiplexers (ROADMs), provides a description of the ROADMs in dynamic optical networks and related optical component and module technologies, including wavelength selective switches (WSSs).

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Abbreviated terms

AWG arrayed waveguide grating
CDC colourless, directionless and contentionless
demux demultiplexer
DWDM dense wavelength division multiplexing
DLP digital light processor
EDFA erbium doped fibre amplifier
IPLC integrated planar lightwave circuit
LC liquid crystal
LCD liquid crystal device
LCOS liquid crystal on silicon
LH long haul
MEMS micro-electromechanical systems
MPD monitor photo-diode
mux multiplexer
OA optical amplifier
OEO optical-electrical-optical
OCM optical channel monitor

OADM	optical add drop multiplexer
PDL	polarization dependent loss
PLC	planar lightwave circuit
PMD	polarization mode dispersion
ROADM	reconfigurable optical add/drop multiplexer
TF	tuneable filter
TRx	transceiver
Rx	receiver
3R	regeneration, retiming and reshaping
Tx	transmitter
ULH	ultra long haul
VOA	variable optical attenuator
WSS	wavelength selective switch
WB	wavelength blocker
WDM	wavelength division multiplexing

4 Reconfigurable optical add/drop multiplexer

4.1 Background

Optical networks are evolving to address both the rapid growth in capacity demand and highly efficient and seamless connectivity requirements. While high data rate DWDM channels at 40 Gb/s and 100 Gb/s are being introduced in the network to grow the capacity to multiple Tb/s per fibre, the uncertainty in traffic demand and the emergence of bandwidth-hungry applications like video-on-demand have turned the industry's focus to dynamic, reconfigurable optical networks. Telecommunication carriers and content providers require switching nodes at their central offices in order to route, switch and monitor the optical wavelength channels as they traverse the optical network. These switching nodes, as shown in Figure 1, are called reconfigurable optical add/drop multiplexers (ROADMs), and they are the key nodal sub-systems used in implementing modern optical communication infrastructure.

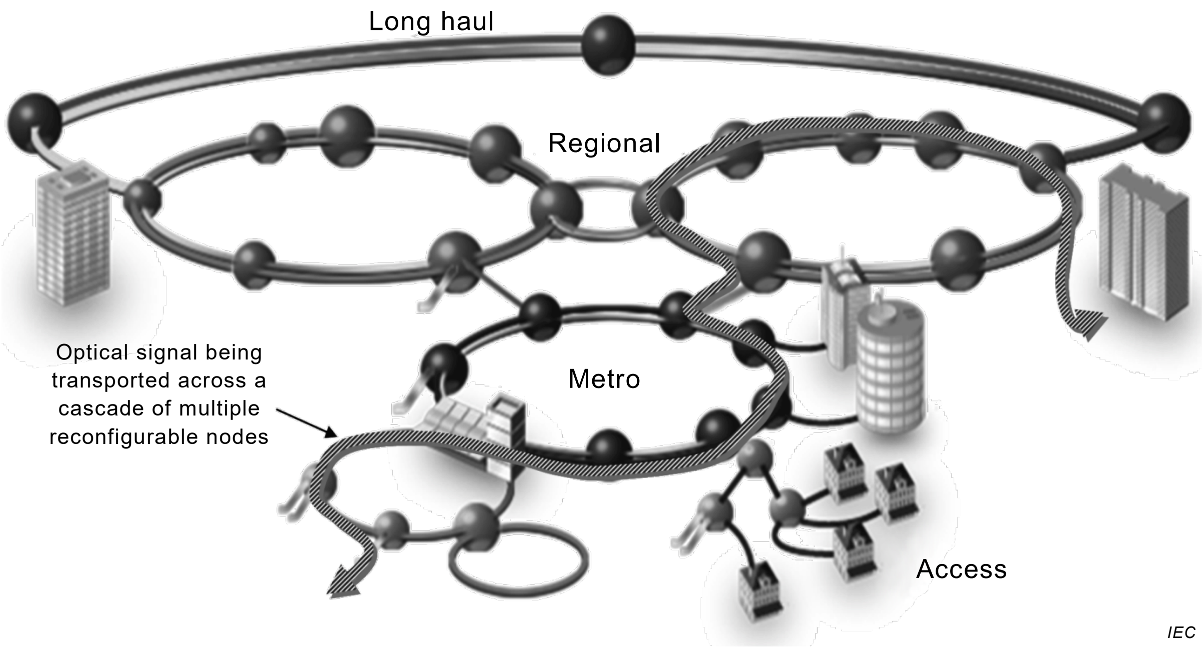


Figure 1 – Reconfigurable optical network

Different segments of the optical network, long haul (LH)/ultra long haul (ULH), regional, metro and access, are schematically shown in Figure 1. Generally, the long haul network is optimized for point-to-point traffic with a predictable traffic pattern. The regional and metro networks are characterized by having the bandwidth scalability of long haul with the service flexibility of the access network. In this segment of the network, the traffic pattern tends to be more dynamic and less predictable, requiring the network to have greater flexibility. While ROADMs were first introduced in the LH/ULH part of the network, it is the metro and regional segment where they offer the highest value proposition.

In addition to ease of service provisioning and network reconfigurability, optically routed networks reduce the need for unnecessary processing of through-traffic by eliminating the signal conversion from the optical to the electronic domain and back to the optical domain for retransmission, thereby significantly reducing cost. Elimination of signal conversion to the electronic domain makes ROADM nodes transparent to traffic data rate and modulation format, enabling easy network capacity upgrade without impacting the live traffic, a key requirement of service providers. They also include the important function of signal monitoring and power balancing. For dynamic optical networks, it is increasingly important to co-optimize different networking aspects, such as optical layer flexibility and signal impairments.

4.2 Optical network evolution

Evolution of wavelength division multiplexing (WDM) transmission networks is illustrated in Figure 2. Networks have evolved from transmission systems consisting of point-to-point WDM links to modern dynamic and reconfigurable networks. As illustrated in part (a) of Figure 2, the earliest WDM systems included point-to-point high capacity links interconnecting terminal equipment. Transmission links consisted of periodic fibre spans and optical amplifiers for compensating link loss. All wavelengths entering the node are terminated via optical-electrical-optical (O-E-O) conversion at the network nodal points, where the optical channels are demultiplexed via an arrayed waveguide grating (AWG) element, for example, and each wavelength is directed to a receiver of a separate transponder that converts the DWDM signals to the electrical domain, and then to a client optical signal at 1 310 nm for short reach interconnect. Similarly, the egress traffic from the node is sent on a fibre link and is originated from multiplexed DWDM wavelengths from transponders connected to 1 310 nm client short reach interfaces.

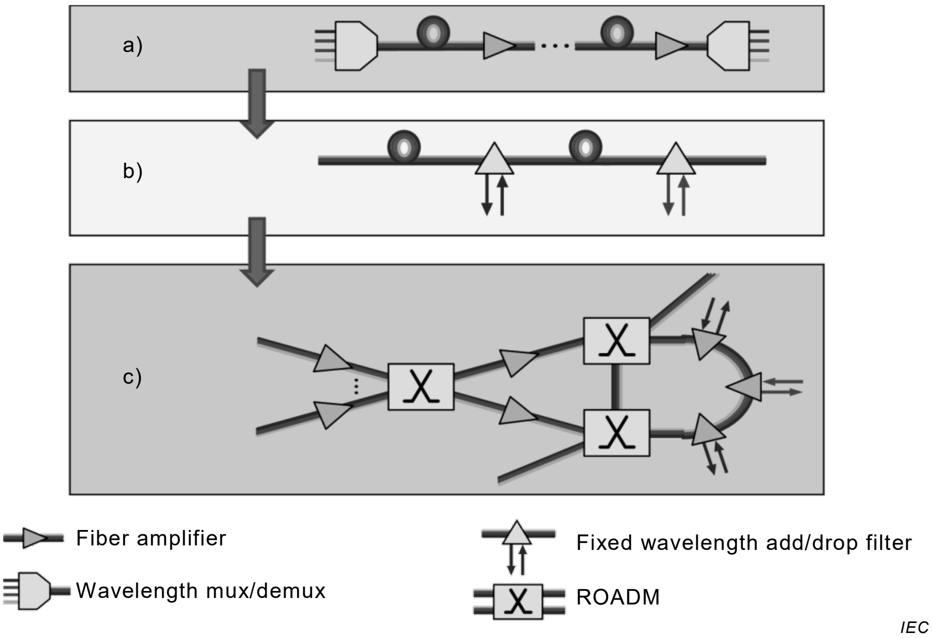
The node is equipped to handle two types of traffic:

a) express traffic, which after passing through the node is directed to its final destination via another WDM link intersecting the node;

b) add/drop traffic, which is either terminated at the node or originates from the node.

As mentioned earlier, all traffic through the node is mediated via 1 310 nm links, and the express and add/drop wavelength channels are predetermined by hard-wired connections. The benefits of this architecture include full 3R (regeneration, retiming and reshaping) regeneration and wavelength conversion of all the optical signals leading to pristine signals from the node, multi-vendor equipment interoperability via a commonly used 1 310 nm client interface, and signal quality monitoring in the electrical domain, for example via overhead bytes.

The main drawback of this architecture is that any reconfiguration of the node will require manual intervention by changing the patch cords. In addition, the architecture is not scalable, since the transponders are data rate specific. The network cannot therefore be upgraded to handle higher data rate traffic without replacing all the transponders. The rapid and unpredictable growth of network traffic from today’s internet requires the network to be dynamic and flexible in supporting new growth areas.



Key

a) point-to-point transport network

b) fixed wavelength add/drop filter based network

c) ROADM networks

Figure 2 – Evolution of optical networks from point-to-point to reconfigurable WDM

In order to increase network flexibility for growing traffic demand in the networks, optical add drop multiplexers (OADMs) were introduced. The initial OADMs that were commercially available in the mid-1990s were not configurable and were achieved via fixed filters. As shown in part (b) of Figure 2, these provided fixed WDM connectivity between multiple nodes. The introduction of fixed OADMs helped reduce the cost of the network by eliminating the need of OEO conversion for the express optical channels. However, the network designer needed to predetermine which wavelengths would be dropped at a node, since the OADM would remain fixed in this configuration. This posed a severe limitation because the service providers could not adapt to unpredictable deviations to network capacity demand. Moreover, provisioning of new channels created the additional complication of adequately balancing the power of all the WDM channels without affecting service on the live channels, through optical amplifier transients, for example. This led to cumbersome controlled and manual turning up of channels, negating the benefits derived from the elimination of transponders at the nodes.

Subsequent availability of fully configurable OADMs (part (c) of Figure 2) enabled network operators to configure any wavelength as transiting or add/drop, without affecting any of the existing traffic on the OADM. OADMs with this flexibility and configurability were termed reconfigurable-OADMs (ROADMs).

The functionality of a ROADM node is illustrated in Figure 3, which shows a two-degree node consisting of a pair of input and output fibres entering a network node, for example east to west. Usually, there is another pair of fibres (not shown in the figure) carrying traffic the other direction (west to east). The wavelength channels entering the node from the east side are shown to have different power levels. The channels are dispersed by the first module and selectively routed either to the express path to continue further or to the local drop ports. The module also includes variable optical attenuators that adjust the power of the channels in conjunction with an optical power monitor shown in the second module. The express channels out of the first module and the locally added channels are combined by the second module. Optical attenuators in the add path are used to adjust the power of these channel so that all the channels egressing from the node have equal power. The ROADM node is thus able to accomplish selective routing of the wavelength channels to the express path, carry out the wavelength drop and add function, and finally monitor and balance the power of optical channels sent on the output fibre.

The above example as shown in Figure 3 refers to a two-degree node. ROADMs enable wavelength routing in higher degree nodes consisting of fibre connections in other directions. A four-degree node, for example, will have fibres connecting east, west, north and south directions. ROADMs can interconnect wavelengths coming from different directions in the optical domain. This enables mesh networking at the optical node, which can be managed cost effectively and is agnostic to data rate and modulation format. ROADMs are a key enabler of the modern 100 Gbit/s and 400 Gbit/s coherent transport networks, which use different modulation formats such as QPSK and 16QAM.

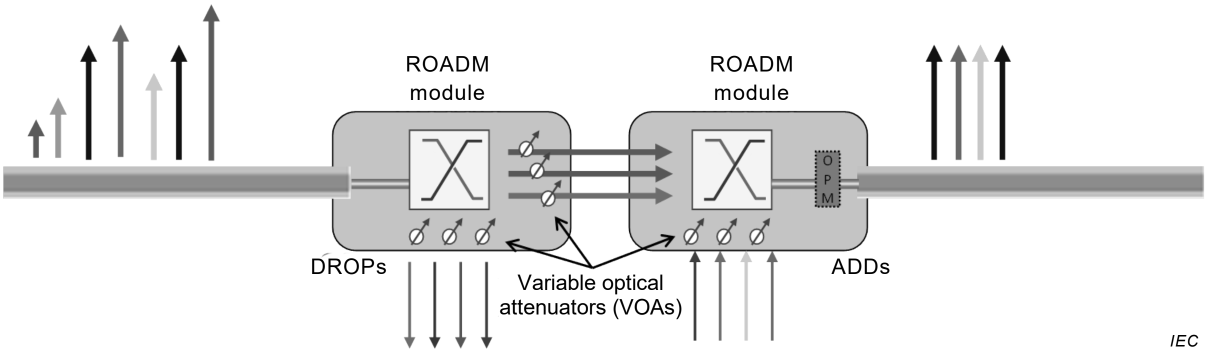


Figure 3 – Schematic of a ROADM node showing functions of wavelength pass-through, add or drop, channel power equalization, and optical channel monitoring (OCM)

ROADM networks are architected with the goal of having a dynamic photonic layer capable of rapid wavelength routing. ROADMs have been widely deployed in intercity and metro core networks in the last decade. Optical bypass and remote configurability in ROADM networks led to fewer router interfaces and reduction in manual fibre patching, thereby lowering the overall cost per bit compared to static networks. When a new wavelength connection is needed in a static network, the transponders and regenerators are individually wired into the network manually via a laborious process. Some of the barriers and limitations to ROADM introduction in the network include the inflexible introduction of interconnections on the client side between the transponders and subtending electronic equipment such as the routers and switches. Another barrier has been the network control software, which is designed without the concept of a dynamic wavelength and can be very difficult to change and update. The third major barrier is related to the business model for ROADM based networks: at present, monetizing these dynamic networks to pay for the additional cost remains a challenge.

Deployment of ROADMs has increased rapidly in recent years. Essentially all new metro, regional and long haul WDM systems developed by equipment manufacturers and new deployments offer ROADM-based wavelength agility as a key feature. The deployments planned by Tier-1 carriers globally require reconfigurable wavelength agility to reduce operational expenses and increase service flexibility. In order to avoid failures due to signal degradation, the optical amplifiers (OAs) for these networks need to be “agile” by incorporating fast gain control and ability to adjust the OA operating conditions quickly in response to changes in the network and number of wavelength channels. It was noted in an industry report that deployment of ROADMs and agile EDFAs is correlated and has enabled the transition from fixed to dynamic optical networks. Since 2010, ROADM and EDFA module deployments were predominantly (over 85 %) dynamic and agile, and only a small number (~15 %) had fixed characteristics.