OPTICAL AMPLIFIERS THAT BUILD BETTER NETWORKS

White Paper

Integrated Self Managed EDFA / ROADM Subsystem

1 Introduction

It is now widely accepted that Reconfigurable Optical Add Drop Multiplexer (ROADM) Modules are a key component for dynamic flexible optical networks. These components allow network operators to dynamically configure the wavelengths that are added and dropped at each network node, thus increasing network flexibility, and reducing operational complexity and cost. Next generation ROADM solutions are increasingly based on Wavelength Selective Switch (WSS) technology, which allows any wavelength to be dropped at, or added to, any port. WSS technology facilitate full and remote reconfigurability, as well as enabling higher degree network nodes with optical cross connects (OXC's) for all optical mesh networks.

While the benefits of ROADM in general and WSS technology in particular are clear, there are many technical and commercial challenges facing the actual implementation of the technology within optical networks. Many of these challenges can be addressed through tight integration of ROADM modules with optical amplifiers at each node, thus creating integrated ROADM Amplification subsystems. Advanced intelligent optical amplifiers including spectral monitoring capabilities are particularly well suited for such integration.

In this white paper we review the challenges facing ROADM implementation, and describe how these challenges have been addressed by providing an advanced integrated ROADM amplification subsystem. This subsystem includes Capella's advanced WSS module and RED-C's unique self managed amplifier in a fully integrated and network ready pizza-box configuration. The subsystem substantially reduces the development effort and time to market for ROADM enabled systems, while at the same time providing a state-of-the-art technical solution.

RED-C Optical Networking

RED-C Optical Networks, Ltd., Atidim Technology Park, Bldg. 3, P.O. Box 58101 Tel-Aviv 61580, Israel, **sales@red-c.com**

RED-C Optical Networking, Inc., 2600 Philmont Ave. Suite 310, Huntingdon Valley, PA 19006, USA, **ussales@red-c.com**

ww.red-c.com

2 The Challenge of ROADM Implementation

While the basic building blocks necessary for the integration of ROADM technology within WDM systems are gradually becoming available, there remain significant challenges for the actual implementation of this integration. These challenges can roughly be categorized as technical and market related.

2.1 Technical Challenges

The insertion loss of first generation ROADM modules based on wavelength blockers is extremely high, typically above 10dB. While WSS technology such as that developed by Capella significantly reduces insertion loss, it is still high enough to require consideration when designing the accompanying amplification subsystem. The insertion loss and associated OSNR penalty can be mitigated by placing the ROADM module at the mid stage of a standard commercially available two-stage amplifier. While this implementation addresses the insertion loss issue, it suffers from a crucial flaw with respect to network protection and restoration, in that failure of the two stage amplifier leads to failure of the entire Add/Drop network node (single point of failure).

To avoid a single point of failure, current implementations of ROADM do not place the module at amplifier mid stage, but instead utilize an additional separate amplifier to mitigate the ROADM insertion loss, as shown for example in Figure 1. This solution leads to added system complexity and cost, as well as degrading the OSNR performance and transient response of the entire subsystem.

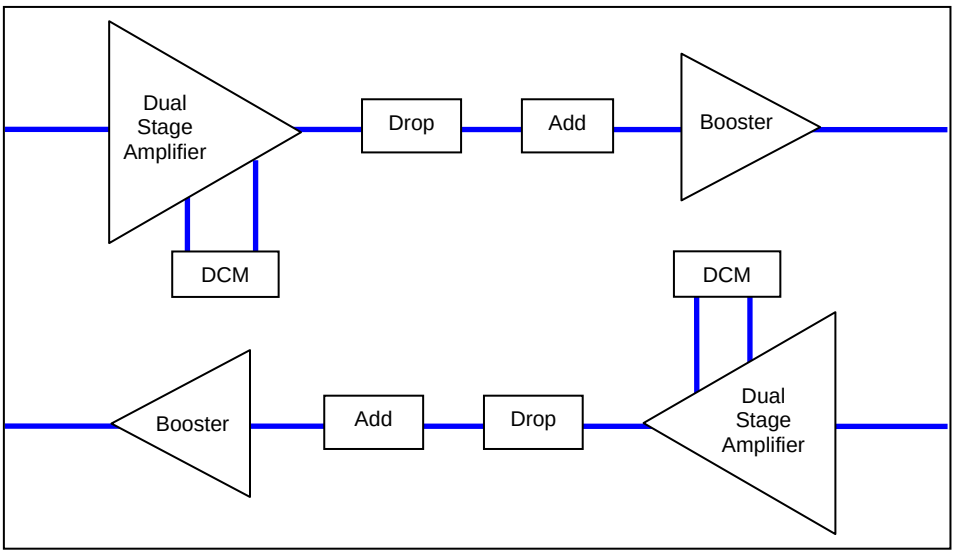

Figure 1: Typical current implementation of ROADM with optical amplifiers

Another important technical issue relating to integration of ROADM modules is that they manipulates the power and spectral properties of WDM signals, as do the EDFAs at the network node. Unless the dynamic response of the ROADM modules and EDFAs are coordinated and synchronized, dynamic events in the system may lead to uncontrolled and independent response of the various modules, eventually leading to system destabilization.

Besides the need for synchronize and coordinate dynamic control, there is also a clear need to provide spectral monitoring and control capabilities at the subsystem level, i.e. above the module level. For example:

- It is necessary to verify that the residual power in a wavelength vacated at the Drop module is small enough before allowing it to be populated with a signal channel at the Add module.
- It is desirable to achieve overall gain flatness of the amplification subsystem using the channel power equalization features incorporated in the ROADM modules.

If all the modules are separate, and most likely from different vendors, it is up to the system integrator to achieve dynamic coordination and synchronization, and to provide spectral monitoring and control at the subsystem level. This inevitably involves intensive customization of the modules themselves, as well as major modifications to system management software.

2.2 Market Challenges

Although the benefits of ROADM technology are clear, as is the potential reduction in Operating Expenditure (OPEX), implementation of ROADM necessitates a significant increase in day-one Capital Expenditure (CAPEX) for the system. The increased CAPEX results from the following main factors:

- The direct cost of the ROADM modules
- The cost of added amplification complexity, as discussed above
- The increased cost and complexity of system management software

In the current cost-sensitive market environment, any day-one CAPEX should be reduced as far as possible, without sacrificing the key functionality provided by ROADM.

An equally important factor relates to the need by system vendors to devote significant R&D and operation resources to ROADM implementation. This includes:

- Identifying, evaluating and qualifying separate ROADM and EDFA suppliers
- Integrating modules into the system, and dealing with the various technical issues outlined above
- Performing necessary modifications to the amplification subsystems, often involving customization of the various modules
- Maintaining a complex and multi-vendor supply chain

In today's competitive market environment, the added effort and increased time to market associated with the above tasks can significantly inhibit the adoption of ROADM technology.

3 Benefits of Amplifier / ROADM Integration

All the above challenges can by addressed to a large extent through tight integration of ROADM, amplification and monitoring modules into a single network ready subsystem.

Error! Reference source not found. shows the implementation of the integrated subsystem, which consists of four major building blocks:

- Stage 1 of the EAST amplifier packaged with stage II of the WEST amplifier
- EAST Drop packaged with WEST Add
- EAST Add packaged with WEST Drop
- Stage II of the EAST amplifier packaged with stage I of the WEST amplifier.

These building blocks are packaged in two identical and separate units as shown in the figure. Each of the units contains additional local control electronics and firmware, a communications module for communicating with system management, and power supply.

Mid-stage access (between stage 1 of the amplifier and the WSS Drop module) is provided for a DCM unit (not included in the subsystem).

The drop module is implemented as a fully functional WSS, while the Add module is implemented as a cost-effective passive star coupler with a VOA array to provide power control for each of the individual Add ports.

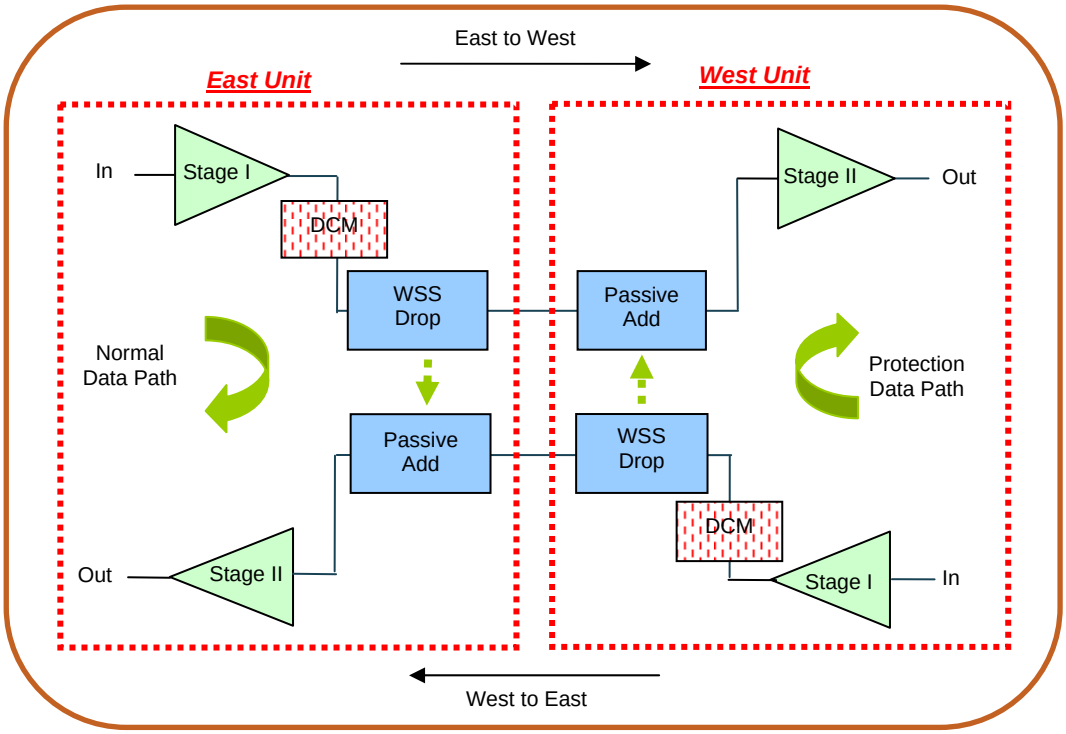

Figure 2: Amplifier-ROADM subsystem implementation. Note that DCMs are not included in the unit, although mid-stage access is provided to support them

The construction of the subsystem in this manner addresses the following technical challenges:

- A single point of failure is avoided, since the normal and protection data paths are completely separated and do not depend on the same building blocks. Failure of one of the two units comprising the subsystems effects with the normal or protection path, but not both.

- The ROADM modules are integrated at the amplifier mid-stage without needing additional external amplification, thus achieving
  - Reduced subsystem cost
  - Improved OSNR
  - Improved transient control.
- The fact that all modules are optimized to work as a single subsystem allows dynamic coordination and synchronization control of the modules, and also allows the optimized spectral monitoring and control of entire subsystem.
- The unified control and system interface allows simple operation and integration of the entire subsystem, without the need to independently control each module

In addition to the technical benefits, the unified Amplifier ROADM subsystem will reduce the day-one CAPEX associated with ROADM. This is due to

- Reduced amplification costs associated with the ROADM being placed at mid-stage, thus eliminating additional amplifiers
- Cost effective integrated passive Add module.
- Tight cost-optimized integration of the two subsystems.
- Reduced cost of system management software due to a high level of local management at the subsystem level.

Finally the proposed single unified amplifier ROADM subsystem represents significant value to system vendors through:

- Rapid time to market with a ROADM enabled system.
- Reduced R&D costs associated with solving the various integration issues, and development new system management software modules.
- Reduced operation costs associated with qualifying and managing separate ROADM and amplifier suppliers.

4 Subsystem Description and Operation

As shown in Figure 2, each amplification subsystem will comprise of two separate identical units, an example of which is shown in Figure 3. We will now describe in detail the construction and operation of each unit.

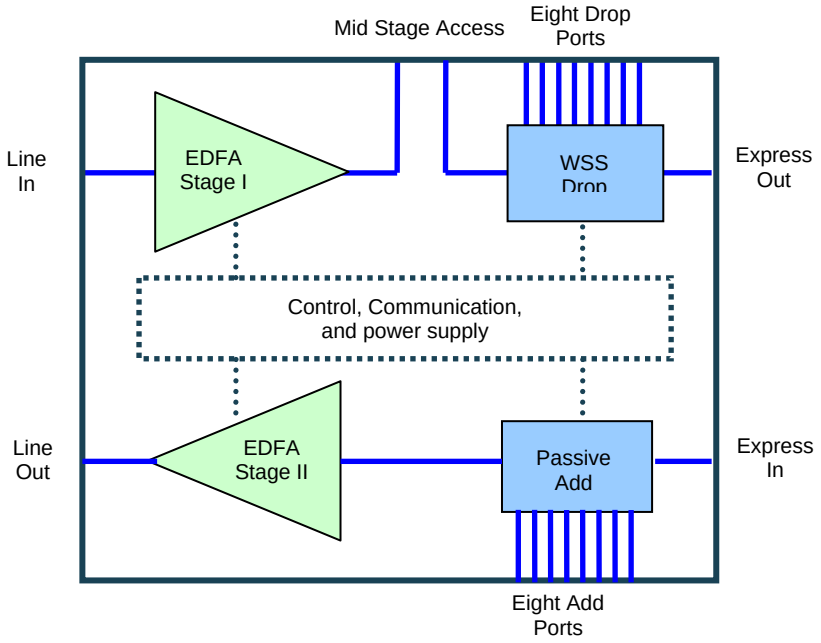

Figure 3: Detailed schematic of an EDFA / ROADM unit

4.1 Components

Each unit contains:

- A RED-C self managed amplifier, comprising a pre-amplifier and booster stage. Each stage operates as a separate variable gain single stage amplifier, with fully controlled gain and gain tilt, allowing for complete east/west separation. In addition, the output of the booster stage includes an integrated Optical channel monitor, allowing full spectral monitoring of the output signal of the system.
- A Capella WSS configured as a Drop module. The WSS allows full wavelength control, with any wavelength dropped to any of the 8 output ports, or passed through the add port. In addition, full power control and monitoring (OCM) is provided for each separate wavelength.
- A “passive” add module comprising 8 input ports. The Add module is constructed using a star coupler, and a VOA array to control the power of each port. The construction of the passive Add module is shown in Figure 4
- Control and communication electronics and firmware, provide control of each module within the unit, as well as external communication to system management.
- 48V DC rack compatible power supply.

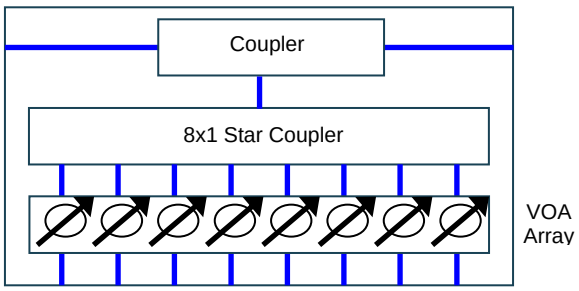

Figure 4: Cost-effective “passive” Add module

4.2 Functionality

Each unit provides the following functionality:

- Two completely independent variable gain EDFA stages
- Fully reconfigurable Drop module based on state-of-the-art WSS technology. Any wavelength can be dropped to any of 8 drop ports.
- Individual channel power control for each Drop and Express channel
- Eight Add ports with Individual power control for each port.
- Mid-stage access for a DCM between the pre-amplifier and the Drop module
- Two fully functional OCMs, one at the output of the drop module (for Drop and Express channels), and one at the output of the Booster EDFA.

4.3 Control and Monitoring

Each unit contains a local control card, allowing for a range of control options:

- Full “Set and Forget” local control: System management sets basic requirements, such as output power of all Express, Add and Drop channels, and the local control card then provides local management of the subsystem to maintain these requirements. Thus, the local control card sets the optimum gain and tilt of each EDFA gain stage, the attenuation of each Express and Drop channel, and the attenuation of each Add port. These setting are then adjusted throughout operation of the subsystem to maintain system management requirements.
- Hybrid Local / System management control: System management sets basic requirement, and local management sets the various subsystem parameters to meet these requirements. When changes in input conditions occur, local management notifies system management, and waits for requirements to be updated
- Full “Hands on” system management control: System management directly controls all subsystem parameters, such as gain, tilt and channel and port attenuation.

The local control card also provides for a coordinated response of the WSS and EDFA module to dynamic events, using the fast power detectors within the EDFA to detect fast and sharp changes in input power. When such events are detected, the WSS and EDFA are controlled to maintain the pre-existing gain / attenuation of each channel, with maximum transient overshoot / undershoot of 1dB, and transient time less than 0.4 ms.

The two integrated OCMs within each unit, together with the channel and port power control, allow the spectral loop of the entire subsystem to be closed, thus providing features such as:

- Dynamic channel equalization of all express channels
- Equalization of Add channel power to express channel power
- OSNR monitoring at the line out port
- Monitoring of extinction ratio of blocked / dropped channels

4.4 System Interface

Each unit is packaged in a 2RU rack mountable Pizza-box, as shown in Figure 5.

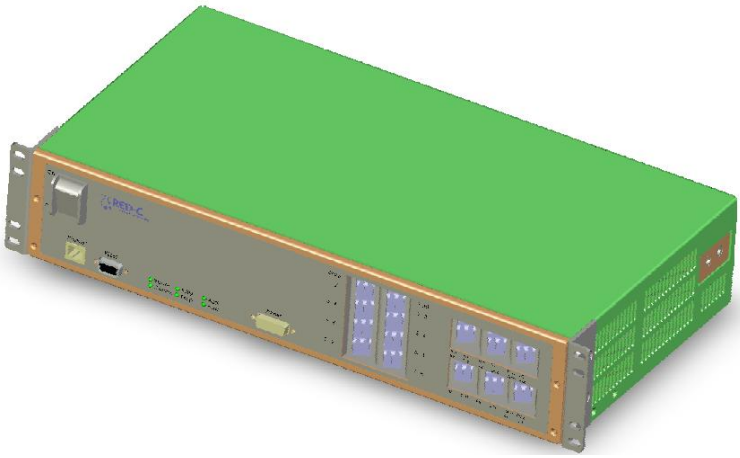

Figure 5: 2RU rack mountable Pizza Box

This package features:

- All optical ports accessible from the front panel
- Front panel connector for 48V DC power supply
- Ethernet connector to support SNMP and TL1 system interfaces
- RS232 interface for testing and debug
- LED indicators signaling correct operation of power supply, cooling fans, communications, EDFA, WSS and Add Module

5 Conclusions

The technical and market challenges related to the introduction of ROADM technology can be largely addressed through tight integration of ROADM modules with amplifiers into a single subsystem. In this white paper we have described such a subsystem in detail, and have shown how it can substantially reduce the development effort and time required for ROADM implementation. This network ready cost-effective solution comprises state of the EDFA and WSS technology, and provides a comprehensive system interface in a space-saving package.