Integrated Self Managed EDFA / ROADM sub-system

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.

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 Optical Amplifiers with ROADM modules at each node, thus creating integrated Amplification/ROADM subsystems. Advanced intelligent optical amplifiers embedding 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 Amplification / ROADM Subsystem. This subsystem includes RED-C's unique Self-Managed amplifier and Capella's advanced WSS module 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 at much lower cost.

2 The Challenge of ROADM Implementation

While the basic building blocks necessary for the integration of ROADM technology within WDM systems are now available, there remain significant challenges for the actual implementation of this integration. These challenges can roughly be categorized as either technical or 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 recent WSS technology significantly reduces insertion loss, it is still high enough to require consideration when designing the accompanying amplification sub-system. 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 degradation of OSNR performance and transient response of the entire sub-system.

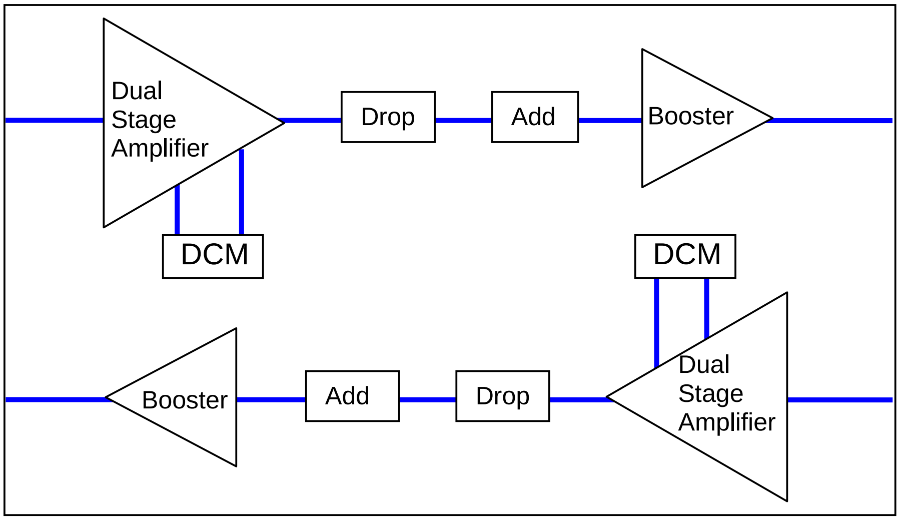

Figure 1: Typical current implementation of ROADM with optical amplifiers

Another important technical issue relating to integration of ROADM modules is that they manipulate the power and spectral properties of WDM signals, as do the EDFAs at the network node. Unless the dynamic responses 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 synchronizing and coordinating dynamic control, there is also a clear need to provide spectral monitoring and control capabilities at the sub-system 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 sub-system using the channel power equalization features incorporated in the ROADM modules.
- For diagnostic and network performance verification, it is necessary to monitor each channel for loss of signal, wavelength drift, OSNR and ROADM configuration verification.

If all the modules are discrete, and most likely from different vendors, it is up to the system integrator to achieve dynamic coordination and synchronization of the elements, and to provide spectral monitoring and control at the sub-system level. This inevitably involves, not only intensive development efforts by the system integrator but, 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 an 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 much as possible, without sacrificing the key ROADM functionality.

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

- Identifying, evaluating and qualifying separate ROADM and EDFA suppliers
- Integrating modules into the system, and addressing the various technical issues outlined above
- Performing necessary modifications to the amplification sub-systems, 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 sub-system.

Figure 2 shows the implementation of the integrated sub-system, 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 a 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 sub-system).

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.

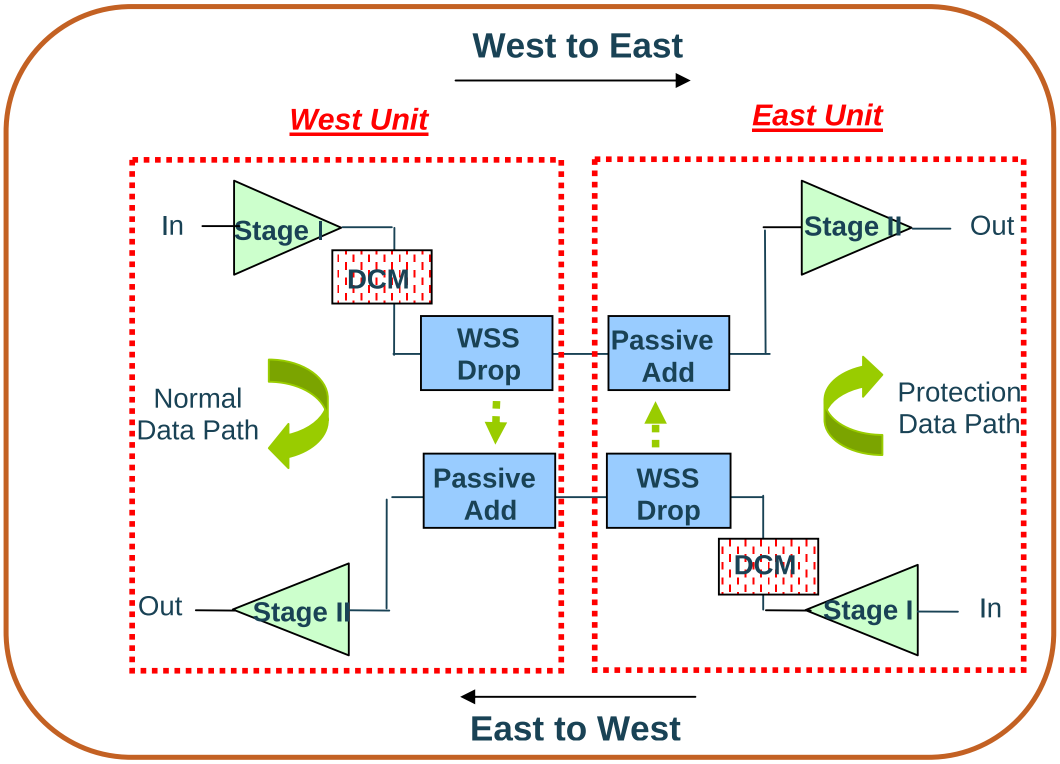

Figure 2: Amplifier-ROADM sub-system implementation. Note that DCMs are not included in the unit, although mid-stage access is provided to support them

The construction of the sub-system in this manner results in the following technical and economic benefits:

- There is no single point of failure 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 sub-systems affects either the normal or protection path, but not both.
- The ROADM modules are integrated at the amplifier mid-stage, eliminating the need for external amplification, thus achieving
  - Reduced sub-system cost
  - Improved OSNR
  - Improved transient control.
- All modules are optimized to work as a single sub-system providing coordinated and synchronized control of the modules during dynamic events, and also allowing for optimized spectral monitoring throughout the entire sub-system.
- The unified control and system interface allows simple operation and integration of the entire sub-system, without the need to independently control each module.

In addition to the technical benefits, the unified Amplifier ROADM sub-system 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 sub-systems.
- Reduced cost of system management software due to a high level of local management at the sub-system level.

Finally the proposed single unified amplifier ROADM sub-system 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 developing new system management software modules.
- Reduced operational costs associated with qualifying and managing separate ROADM and amplifier suppliers.
- Ready to install ROADM subsystem providing a smooth up-grade path for legacy system to replace OEO switching fabric.

4 Sub-system Description and Operation

As shown in Figure 2, each amplification sub-system will be comprised 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.

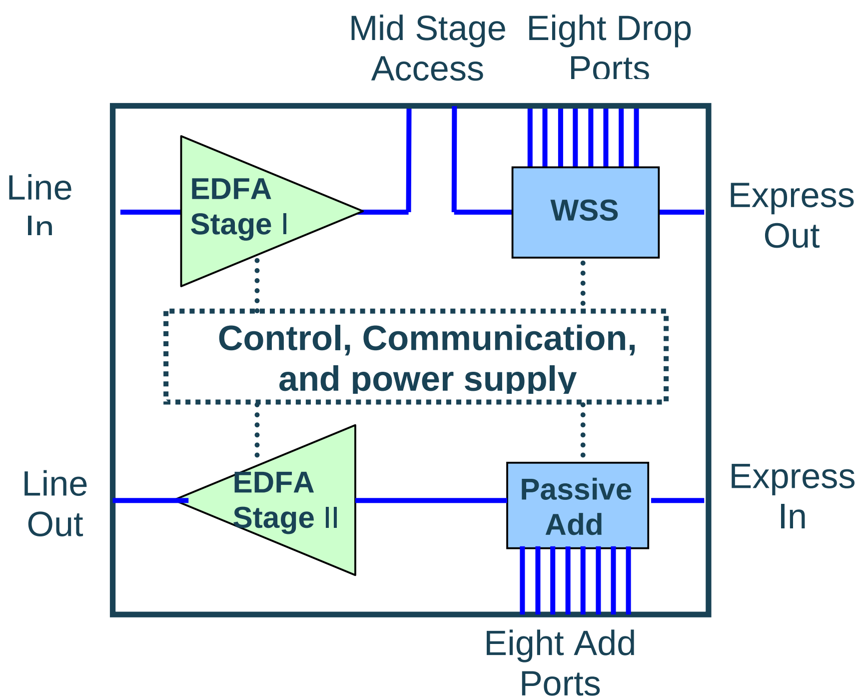

Figure 3: Detailed schematic of an EDFA / ROADM unit

4.1 Components

Each unit contains:

- A Self Managed EDFA (i.e. an EDFA with an embedded OCM), comprising a pre-amplifier and a 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 (OCM), allowing full spectral monitoring of the output signal of the system.
- A WSS configured as a Drop module. The WSS features full wavelength control, allowing any wavelength to be 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.

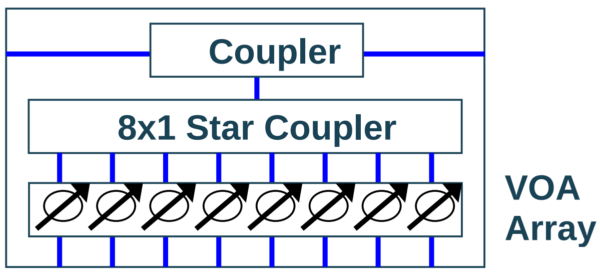

Figure 4: Cost-effective “passive” Add module

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 sub-system 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 sub-system to maintain system management requirements.
- Hybrid Local / System management control: System management sets basic requirements, and local management sets the various sub-system 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 sub-system parameters, such as gain, tilt and channel and port attenuation.

The local control card also provides for a coordinated response of the Self-Managed EDFA and the WSS module to dynamic events, using the fast power detectors within the Self-Managed EDFA to detect fast and sharp changes in input power. When such events are detected, the Self-Managed EDFA and the WSS 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 sub-system 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

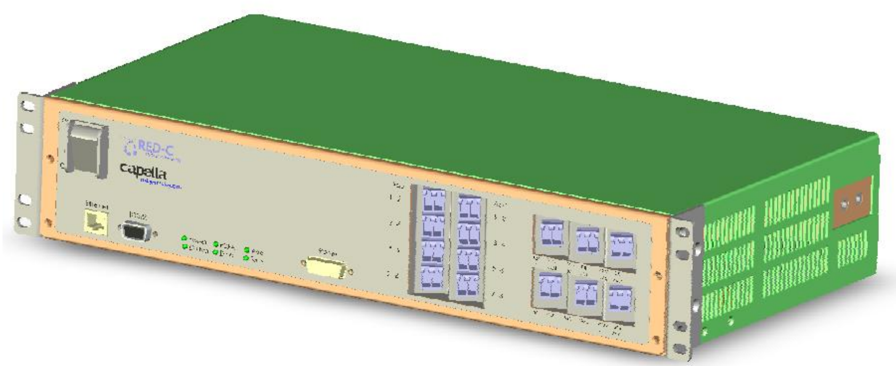

Figure 5: 2RU rack mountable Pizza Box

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, Self-Managed 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 advanced Self-Managed EDFAs with ROADM modules into a single subsystem.

Under the framework of BIRD, the US – Israel Bi-national Industrial R&D Fund, RED-C and Capella have cooperated in pursuing and proving the concept of the Integrated Self Managed EDFA / ROADM Subsystem, showing how it can substantially reduce the development effort and time required for ROADM implementation. The development project, initially launched at the SuperComm 2005 exhibition, has resulted in a fully functional prototype subsystem to be demonstrated during the GlobalComm 2006 exhibition. This network ready cost-effective solution comprises state of the art Self-Managed EDFA and WSS technology and provides a comprehensive system interface in a space-saving package. We believe that this new design concept will play a major roll in future, highly dynamic reconfigurable networks.