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OPTICAL AMPLIFIERS THAT BUILD BETTER NETWORKS

White Paper

Next Generation Adaptable Variable Gain EDFAs for Dynamic Reconfigurable Optical Networks

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1 Introduction

Most new network builds and major upgrades in recent years have been focused on building dynamic reconfigurable optical layers to support the explosive growth in IP traffic. These advanced optical layers include Reconfigurable Optical Add Drop Multiplexer (ROADM) devices allowing network operators to dynamically configure the wavelengths to be added and dropped at each network node, thus increasing network flexibility, improving bandwidth utilization, and reducing operational complexity. Many of the more advanced networks builds also require support for optical mesh layers, utilizing higher degree ROADM based on Wavelength Selective Switch (WSS) technology to provide optical cross connections.

The emergence of these advanced dynamic reconfigurable networks dictates new requirements for the optical components that form the building blocks of the optical layer. In particular, Erbium Doped Fiber Amplifiers (EDFAs), which are a critical component in any optical network, need to address the following:

- Support for higher channel count (up to 80 channels in the C-Band) and higher bit-rates (40 Gb/s) required for high capacity reconfigurable networks
- Support for dynamic traffic routing in optical mesh networks by providing network management with data for optical path calculations
- Providing advanced wavelength and channel monitoring to support the dynamic functionality of the system
- Optimizing the response of the in-line amplifiers to dynamic spectral conditions
- Coordinating and synchronizing the dynamic behavior of various active devices in the system, such as ROADMs, VMUXs, tunable DCMs and EDFAs
- Future proof design – ROADM technology, and especially pertaining to Wavelength Selective Switch (WSS) devices, is a relatively young technology, and still constantly improving. The design of ROADM enabled systems need to support different vendors and changing technologies

Following an intensive research and development effort, at both the device and the system levels, RED-C has developed a family of next generation adaptable Variable Gain EDFAs (VG EDFA) designed to support the requirements above, and to provide future proof functionality for dynamic reconfigurable networks. These next generation amplifiers provide for

- High output power (up to 26 dBm) with class 1M laser safety classification to support high capacity WDM networks
- Access by network management to critical performance data stored in EEPROM (such as spectral noise and power response for various operating conditions), to support advanced optical path calculations

- Enhanced functionality of the optional integrated optical channel monitor (OCM), pioneered by RED-C in 2004, to support ROADMs with limited or no channel monitoring capability
- Multiple communication ports are provided for direct communications between the EDFA and ROADM devices, as well as other future active devices (such as tunable DCMs)
- Ultra-fast digital transient suppression compatible with network dynamics on a microsecond time-scale

In what follows we describe in detail these features, and how they can be used by system integrators to facilitate the design and implementation and advanced reconfigurable optical network layers.

2 Optical Design

The major building blocks of the RED-C VG EDFA product family is shown in Figure 1. The amplifier can support one or two completely independent gain stages, and an optional fully functional Optical Channel Monitor (OCM) that can monitor the output of each stage (via switching).

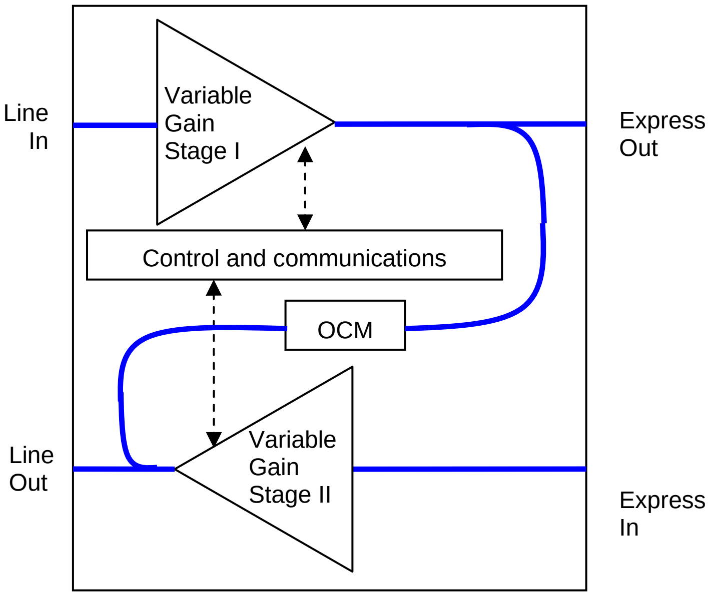

Figure 1: Block diagram of the main Self-Managed EDFA building blocks

Each gain stage can be independently configured to provide:

- Either Variable Gain or Fixed Gain operation
- Saturation output power up to 23dBm to support high capacity networks (up to 80 channel and/or 40Gb/s channels). For an amplifier with a single gain stage, up to 26 dBm output power can be supported.
- For Variable Gain operation – dynamic gain range up to 14 dB
- Sub-stage design for optimized Noise Figure (NF)
- Gain flattening of less than 1dB in all environmental conditions
- Independent control and monitoring

3 High Output Power with Class 1M Laser Safety

High capacity reconfigurable networks require high output power in order to maintain acceptable levels of OSNR. On the other hand, a major requirement for optical networks is that they comply with relevant laser safety standards, such as IEC 60825 parts 1 and 2, ITU-T G.664, and CDRH 21 CFR §1040.10. These standards dictate a maximum safe level of laser radiation, known as the class 1M hazard level, above which exposure to radiation can be potentially harmful to skin and eyes. For EDFA's operating in the C-Band, the Class 1M hazard level corresponds to a maximum theoretical output power of about 21.3 dBm. In practice however, the specified output power of a class 1M EDFA should not exceed 20dBm, in order to take into account suitable safety margins.

For an EDFA to provide output power above 20 dBm, and still retain a class 1M safety classification, it is necessary to provide an Automatic Power Reduction (APR) mechanism that ensures reduction of output power upon occurrence of any event which could potentially lead to exposure of personal to radiation above the class 1M hazard level.

The RED-C VG EDFA class 1M APR scheme is based on two independent detection mechanisms designed to detected any disruption in the output transmission line up to a distance of a few tens of kilometers, sufficiently far to cover that part of the transmission line where the signal power is above 20 dBm. Upon detection of such a disruption, the output power is decreased within 100 ms (in compliance with class 1M requirements) to a level below 20 dBm. The APR hardware supports full redundancy of all critical components, such that there is no single point of failure which could lead to a situation where the EDFA remains operational, while the APR is not in operation.

A complementary feature to the APR mechanism is the Automatic Restart Procedure (ARP). This ensures that when the fiber disruption that caused and APR event is corrected, the EDFA will automatically increase output power to the required level without need for manual operator intervention.

These unique and patent protected mechanisms allow RED-C EDFA's to be classified as class 1M laser products, while at the same time providing up to 26 dBm output power.

4 OCM with Online Calibration and Redundancy Protection

Dynamic reconfigurable networks will typically need to include OCMs at each node in order to monitor the channel power (for equalization) and channel add/drop configuration. Having a low-cost integrated OCM inside the EDFA saves cost and space by relaxing the requirement for a dedicated OCM card, and/or the requirement for the ROADM device to have an internal OCM. Furthermore, an OCM within the EDFA can monitor the output of the node, thus improving equalization, whereas an OCM integrated in a ROADM device can only monitor the mid-stage. Finally, data from an integrated OCM can be used internally by the EDFA optimize it's gain and tilt settings to accommodate different channel loading conditions.

While the benefits of integrating an OCM in the EDFA are clear, there are various technical complexities that need to be addressed. Due to size and cost constraints, an integrated OCM within an EDFA is typically based on a tunable filter. All tunable filters exhibit some wavelength drift over their operating lifetime, which needs to be corrected via calibration. In dedicated OCM modules, this calibration is achieved using an external referencing source, a solution which is expensive and impractical for an OCM integrated in an EDFA. RED-C's patent pending solution to this problem is to implement a sharp notch in the Gain Flattening Filter (GFF) of the EDFA. By placing this notch outside of the transmission band, it only affects the Amplified Spontaneous Emission (ASE) noise generated by the EDFA, creating a notch in the ASE spectrum which can be detected by the OCM, and thus used for referencing. This solution is illustrated in Figure 2.

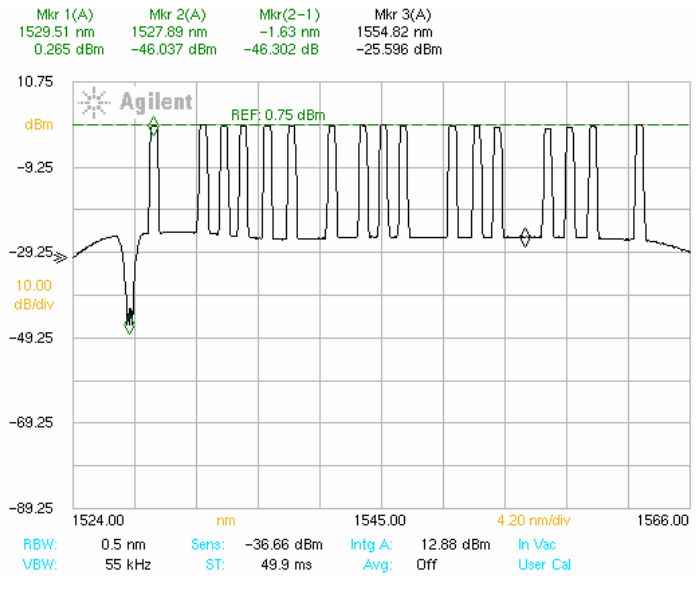

Figure 2: The effect of a notch used for wavelength referencing on the amplifier output spectrum

Another issue that needs to be addressed is the long-term reliability of tunable filters. As dictated by their function, tunable filters used in OCM for telecom applications should be able to continuously scan the transmission band, with a frequency of at least 1 Hz, over at least a 25 year operating lifetime. Being a relatively young technology, with only a few commercial solutions available, the long term reliability of tunable filters is still largely unknown. Since OCM functionality is critical for dynamic systems, RED-C has implemented a protection scheme which allows two amplifiers at the same site to share a single OCM in case of failure. In this manner redundancy is provided for the OCM, which then ceases to be a critical component.

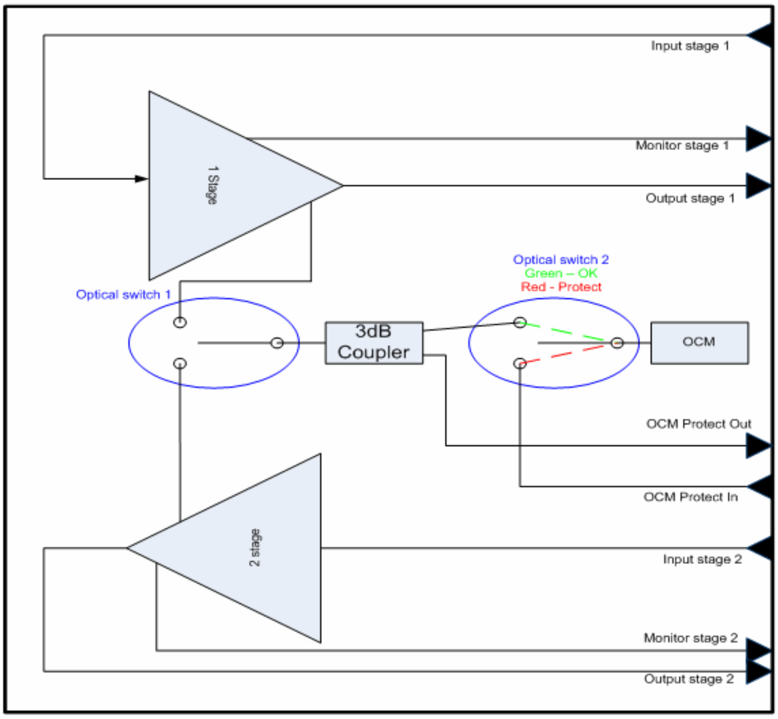

Figure 3: OCM Protection scheme

5 Support for dynamic light path performance calculations

While optical monitoring allows systems management to monitor the optical performance of a system operating in a given configuration, it does not allow management to predict the performance ***before a configuration is selected***.

In ROADM enabled links, a change in the channel loading of different amplifiers can change the spectral noise and power response of the amplifier, thus affecting the overall optical performance of the link. Furthermore, in optical mesh networks, reconfiguration of the network means that signals will take a new light path, traversing a new sequence of amplifiers from transmitter to receiver (in fact, different channels can also have different paths). In both these scenarios, it would be highly beneficial to be able to predict the spectral noise and power response of an amplifier at given operating conditions, in order to predict the optical performance of a light path under different network configurations.

For this purpose, RED-C has developed a set of measurements performed for each amplifier during manufacturing, the results of which are stored in the amplifier EEPROM accessible by the system's control plane management. This data allows the prediction of the amplifier spectral noise and power response under different operating conditions, thus allowing system management to assess the impact of the amplifier on overall optical performance (power and OSNR) for any given configuration.

Thus, when a new network configuration is selected, the system's control plane sends the expected channel loading to each amplifier in a given light path, and receives from each amplifier the resulting spectral noise and power response that can be expected due to this channel loading. This information is used by system management to predict the expected optical performance of the light path before the new configuration is actually activated.

In addition to the above described application, the EEPROM data stored in the amplifier can also be useful as a cost effective alternative to OCM and OSNR monitoring, when such monitoring is not available.

6 Communicating with other active devices

In static point to point links the only active devices that manipulate the power and spectrum of the signal along the link are optical amplifiers. In dynamic networks, including ROADM devices, Wavelength blockers, and in the future possibly also Tunable Dispersion Compensators, this is certainly not the case.

In order to provide stable operation of all dynamic devices at a given site, it would be advantageous if the devices could communicate with one another rapidly and directly, without the intervention of system management. Some example applications of such functionality, illustrated in Figure 4, are:

- Direct communication between the integrated OCM within the EDFA and a ROADM device with channel equalization capabilities would allow the spectral loop of the combined EDFA / ROADM subsystem to be closed without system management control.
- The onset of a transient event in the EDFA could be rapidly communicated to a closed loop ROADM device to temporarily deactivate the closed loop until the transient has subsided.
- Communication between two EDFAs at the same site to implement the OCM protection switching discussed in the previous section

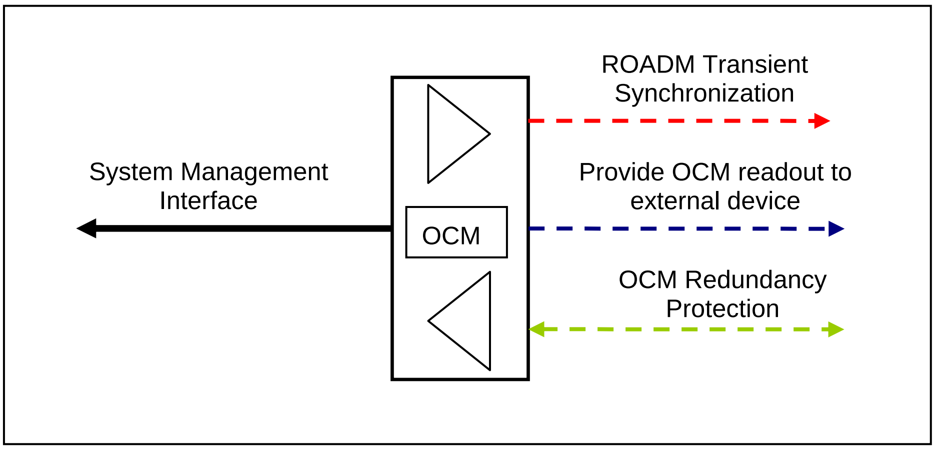

Figure 4: Illustration of direct communication between active devices.

As dynamic system become more complex, more and more functionality will be delegated from the global system management level to the local sub-system level. This will necessarily require some level of direct communication between different active devices at the same site. By providing multiple communication ports, an EDFA can support this trend into the future.

7 Transient Suppression

Fast transient suppression has long been a requirement of EDFAs operating in the deeply saturated regime. In this regime, a sharp change in input power causes the amplifier gain to change for a short period, before settling back to the nominal value. Unless controlled electronically, the gain overshoot / undershoot can be quite large, and can accumulate in a cascade of amplifiers. This can cause short but strong power surges along the link, which can be potentially harmful to equipment.

In previous generation static networks, the main causes for sharp changes in input power were related to protection switching or link disruptions, typically occurring on time scales of milliseconds or longer. This dictated the requirement that transient suppression needed to deal with input power changes up to 15 dB (maximum 32 channels), occurring on a scale of about 1ms. For such conditions, it was usually required that overshoot / undershoot be less than 1 dB per amplifier stage with setting time of the order of 1ms.

In dynamic networks an additional major cause of transients is related to the actual add and drop event of channels. The time-scale of these events depend on the type of switching technology used and the equalization control loops of the Add channels. Therefore, transient suppression should be able to deal with events on a microsecond time-scale, ensuring compatibility with future switching technologies and applications. Furthermore, dynamic network are usually designed to cater for higher channel counts, up to 80 channels in the C-Band, meaning that changes in input power can be as high as 19 dB. Finally, to allow longer links and longer cascades of EDFA, the transient suppression time needs to be shorter, typically less than 200 µs.

Figure 5 shows typical transient performance of RED-C VG EDFAs. The results apply to dual stage amplifiers, and demonstrate maximum overshoot below 1dB for both stages, with setting time less than 200 µs. This performance is achieved using a proprietary digital feed-back control loop, in conjunction with a fast analogue and digital feed-forward mechanism.

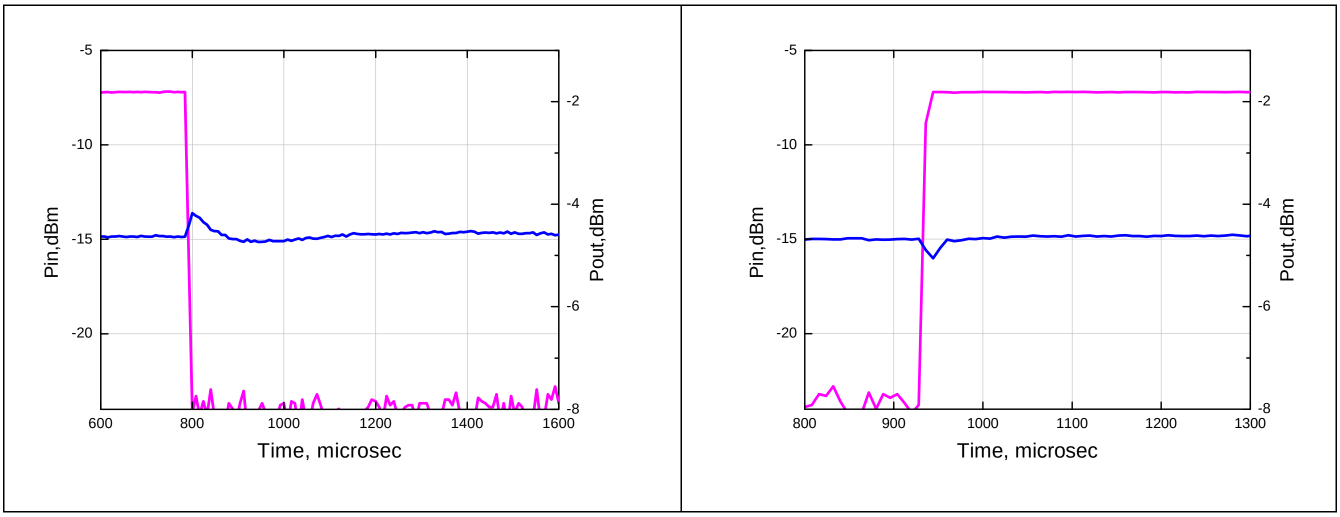

Figure 5: Typical transient suppression of RED-C VG EDFAs. Left: Drop of 19 dB occurring in 1 µs. Right: Add of 19 dB occurring in 1 µs

8 Conclusions

RED-C has invested significant R&D resources in understanding and implementing the requirements placed on EDFA's by advanced dynamic reconfigurable optical networks. The result of this intensive effort is the Sentior 57000 family, the next generation of RED-C's leading VG EDFA product family, which provides, amongst others, the following features:

- Up to 26 dBm output power with class 1M laser safety classification
- Integrated Optical Channel Monitor (OCM), with self calibration and redundancy protection
- Spectral noise an power response for different operating conditions stored in amplifier EEPROM, allowing systems management to predict the amplifier performance under different network scenarios.
- Multiple communication ports for direct and rapid communication with other active devices, such as ROADM modules
- Ultra-fast transient suppression

These advanced features enable system integrators to rapidly and efficiently integrate the amplifiers into their systems, thus reducing time to market for next-generation systems supporting dynamic reconfigurable optical layers.

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