White Paper

Variable Gain EDFAs for Dynamic Mesh 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 96 channels in the C-Band) and higher bit-rates (40/100 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

- 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 level, Finisar has developed a family of Variable Gain EDFAs (VG EDFA) designed to support the requirements above, and to provide future proof functionality for dynamic reconfigurable and Mesh networks. These amplifiers provide

- 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 Finisar in 2004, to support ROADMs with limited or no channel monitoring capability

- Ultra-fast digital/analogue automatic gain control (AGC) loop with smooth transfer function and 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 of advanced reconfigurable optical network layers.

2 Optical Design

The major building blocks of the Finisar 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).

Various packaging options are available, including two gain stages in a single package (100x150mm footprint), or single gain stage packages (70x90mm footprint) designed to allow two packages on a single line card.
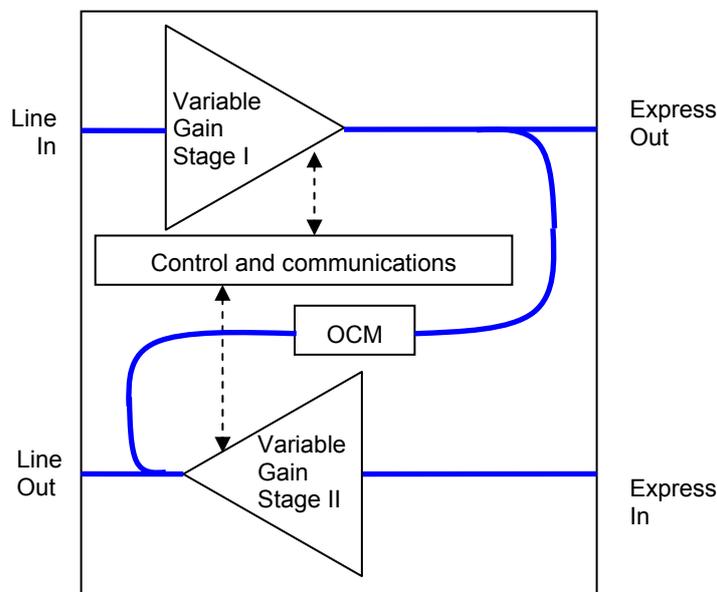

Figure 1: Block diagram of the main Self-Managed EDFA building blocks

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 96 channel). 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 15 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 20.5dBm, in order to take into account suitable safety margins.

For an EDFA to provide output power above 20.5 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 to radiation above the Class 1M hazard level.

The Finisar 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 20.5 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 20.5 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 an 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 Finisar EDFAs 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

Dynamic reconfigurable networks will typically need to include OCMs at each node in order to monitor the channel power for equalization and 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 to 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. Finisar'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.
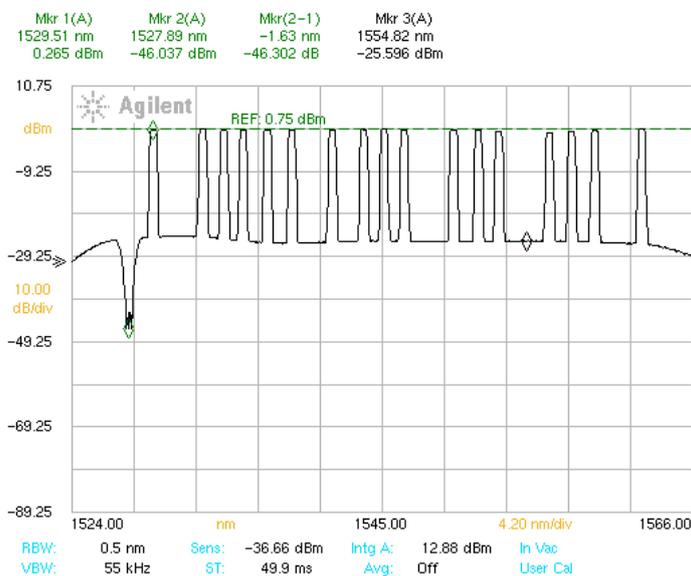

Figure 2: The effect of a notch used for wavelength referencing on the amplifier output spectrum

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, Finisar 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 EDFA Dynamic Response

6.1 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 lead to transmission disruption and in some cases 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 96 channels in the C-Band, meaning that changes in input power can be as high as 20 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 3 shows typical transient performance of Finisar VG EDFAs. In this figure the Magenta curve represents the input power, while the blue curve represents the output power of a single channel (the remaining channel in the case of a drop event, or the existing channel in the case of an add event). 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.
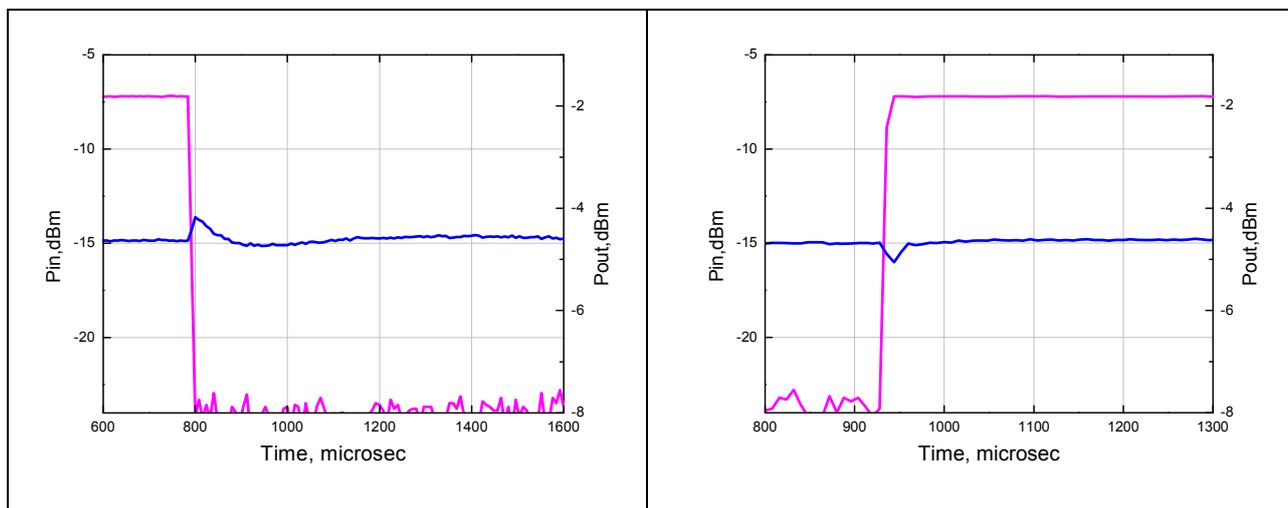
Figure 3: Typical transient suppression of Finisar VG EDFAs. Left: Drop of 19 dB occurring in 1 μs. Right: Add of 19 dB occurring in 1 μs

6.2   Transfer Function

However, add and drop events are not the only concern in dynamic networks. Due to the existence of multiple active devices such as amplifiers and WSS's, complicated dynamics can evolve in long links and mesh networks which also include oscillations in the KHz and MHz frequency ranges, and not just sharp changes in the average optical powers. Such oscillations occurring at the input to an EDFA may cause unpredictable results in the EDFA gain response, especially since the EDFA "natural frequency" (dictated by the Er lifetime and saturation conditions) is often in the same frequency range.

To reduce such effects and ensure a smooth gain response at all input frequencies, the EDFA control loop should be designed accordingly, and in particular be sufficiently fast to suppress deviations from a smooth frequency independent gain response. These effects can be characterized by the transfer function of the EDFA. This is typically generated using a network analyzer, and measures the change in amplitude and phase of the EDFA output as a function of the frequency of a pure sinusoidal input.

In order to ensure stable operation of the network, Finisar's VG-EDFA platform is designed such that the transfer function (both phase and amplitude) is smooth to within specified boundaries.

7   Conclusions

Finisar 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 effort is the M7000 product family of VG EDFAs, which provides, amongst others, the following features:

- Up to 26 dBm output power with Class 1M laser safety classification

- Optional Integrated optical channel monitor (OCM), with self calibration of wavelength measurement

- Spectral noise and power response for different operating conditions stored in amplifier EEPROM, allowing systems management to predict the amplifier performance under different path configurations.

- Optimized dynamic response with fast transient suppression and smooth transfer function

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

For more information please contact sales@finsiar.com.