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OPTICAL AMPLIFIERS THAT BUILD BETTER NETWORKS

White Paper

Gain Switched Variable Gain EDFA
A Unique Ultra-wide Gain Range Variable Gain EDFA

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1 Introduction

Over the last few years Variable Gain Erbium Doped Fiber Amplifiers (VG EDFAs) have become the standard in amplification for metro, regional and long-haul WDM networks. These amplifiers provide gain-flattened output over a dynamic gain range of up to 15 dB, thus allowing:

- Continuous and on-line gain adjustment to changing conditions (e.g. increase in link loss due to line deterioration or maintenance)
- Simplified operation and installation by being able to remotely set the amplifier gain
- Improved inventory and sparing management by providing a single amplifier type that can be used for a wide range of spans

Traditional VG EDFAs use a Variable Optical Attenuator (VOA) embedded between lengths of Erbium Doped Fiber to achieve variable gain operation. Since the VOA is embedded within the EDFA, the deterioration in Noise Figure (NF) over the gain range is much less than if the VOA were to be placed at the amplifier input. However, there is still some deterioration in NF, which restricts the practical dynamic gain range of the amplifier to about 15dB.

Recent trends in optical networking suggest that optical amplifiers need to support an every expanding application range, with very different gain requirements. For example:

- Short spans in access and metro, through medium range spans in regional and long haul, up to special purpose very long single span
- Compensation of discrete loss due to DCMs, ROADMs and other devices
- Support for different bit rates for 2.5 Gb/s up to 40 Gb/s, each with different OSNR and hence repeater spacing requirements.

The wider the gain range of a given amplifier, the more applications it can support. Examples of some applications include:

- Network reconfiguration
- Multi-vendor networks
- Rerouting due to protection and restoration
- Addition of new services and wavelengths.

The RED-C Sentior 2180 Gain Switched VG EDFA addresses these applications by providing up to 32 dB dynamic gain range, with good NF and gain flatness performance over the entire gain range. This unique product is cost effective, is based on patent protected technology, and provides a significant advantage over traditional VG EDFAs. In this paper we describe the concept behind the Gain Switched VG EDFA and discuss its typical performance.

2 The Gain Switched Concept

A typical Fixed Gain EDFA contains a length of Erbium Doped Fiber (EDF), followed by a Gain Flattening Filter (GFF). The amplifier is operated such that the EDF provides a fixed amount of Gain, while the GFF is designed to have a spectral attenuation profile that exactly compensates for the spectral gain profile of the EDF. In this way the spectrum at the output of the EDFA is flattened. If the amplifier is operated at another gain, the GFF will not exactly compensate the gain profile of the EDF, and the output of the amplifier will no longer remain flattened. In principle, one could use an optical switch to switch the signal between different GFFs, each designed for a different gain profile of the EDF, and thus operate the amplifier at different gains while still maintaining a flattened output. However, for a given length of EDF the gain profile can change drastically as a function of gain, introducing as much as 15 dB gain tilt over a 20dB gain range. To compensate for such a high gain tilt the GFF would need to attenuate the higher gain wavelengths by a very large amount, thus making the amplifier very inefficient.

To overcome this issue the gain switched VG EDFA uses lengths of un-pumped EDF fiber placed between optical switches, as shown in Figure 1:. As with a regular Fixed Gain EDFA, the amplifier consists of 1) a primary length of pumped EDF designed to provide the most flattened gain profile when the amplifier is operated at the maximum design gain, and 2) a GFF designed to compensate the gain profile of the primary EDF. In addition to these two regular elements, the amplifier also contains two optical switches with different lengths of secondary un-pumped EDF between them. Since these lengths of EDF are un-pumped, they act as saturable absorbers which transfer energy from higher power wavelengths to lower power wavelengths.

When the amplifier is operated at the maximum design gain, the switches are set so that there is no length of secondary EDF in the optical path. Thus, the GFF exactly compensates for the primary EDF gain profile. When the amplifier is operated at less than the maximum gain, a gain tilt develops at the output of the primary EDF for which the GFF cannot compensate. To compensate for this tilt, the switches are set so that the optical path includes a secondary length of EDF at the appropriate length, which compensates for the tilt by transferring energy from the high power (high gain) wavelengths, to the lower power wavelengths.

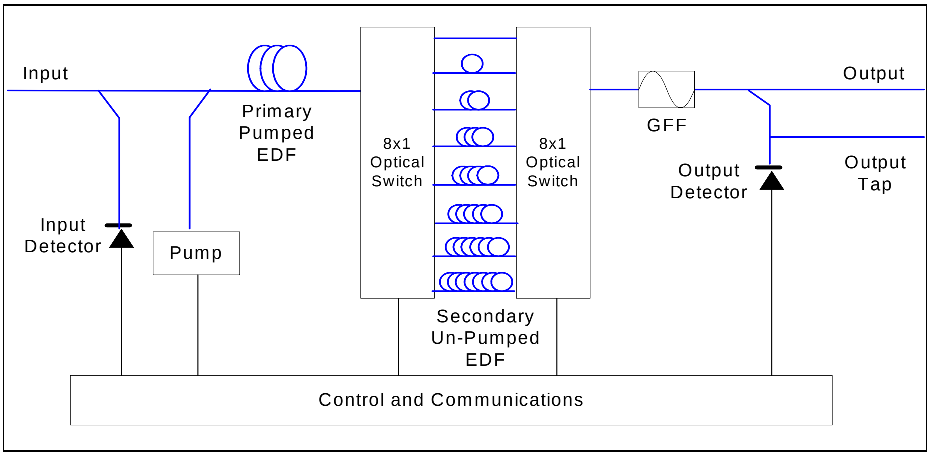

Figure 1: Construction of a 32 Gain range Gain Switched VG EDFA

This is illustrated in Figure 2, which shows the signal spectrum at the output of the primary EDF (left), and the output of the secondary EDF (right). In this case, the amplifier is operated at a gain of 20dB less than the maximum design gain, and as a result the signal spectrum at the output of the primary EDF has a 15 dB tilt over the C-Band. However, this tilt vanishes at the output of the secondary EDF, since energy is transferred from the blue part of the C-Band to the red part. Note that the overall energy of the signal is almost totally conserved (with the exception of the optical switch insertion loss), since the secondary EDF is saturated (i.e. does not absorb energy), and only serves to change the spectral distribution of the signal energy. This fact has important implications with respect to the NF of the Gain Switched VG EDFA, as will be discussed in section 3.2.

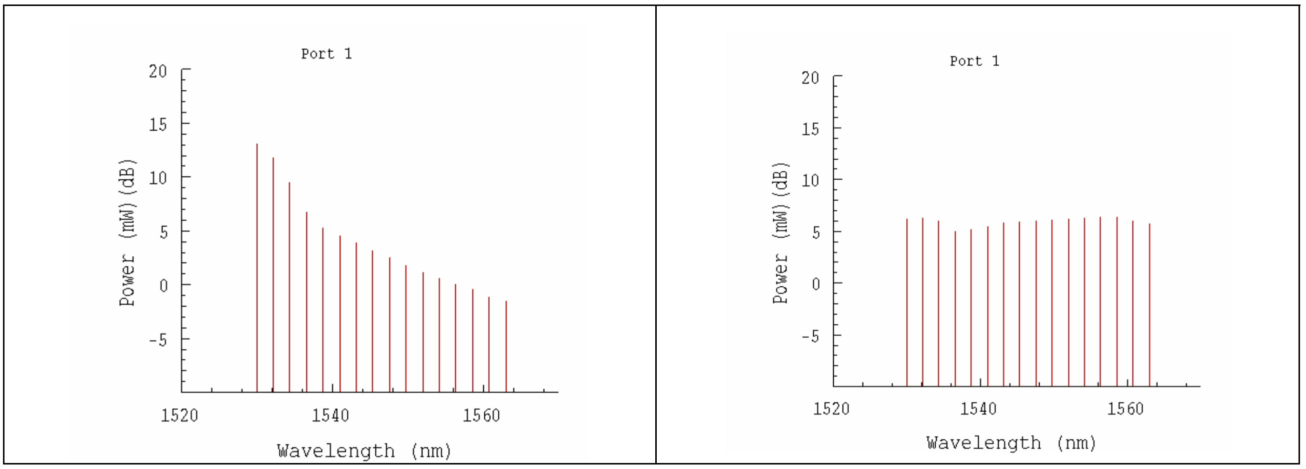

Figure 2: Using the secondary EDF as a saturable absorber to compensate for the tilt of the primary EDF. Left – the signal spectrum at the output of the primary EDF, Right – the signal spectrum at the output of the secondary EDF.

In operation, the switch configuration of the amplifier is selected to provide optimal compensation for the required gain. Each switch configuration supports a sub-range of the full gain range, with neighboring sub-ranges overlapping to provide for hystheresis operation. Thus, if for example one switch configuration supports gains 14-19 dB, while the next support gains 10-15, then for decreasing gain switching will occur at 14.2 dB, while for increasing gain switching will occur at 14.8 dB. In this way stable operation of the amplifier is guaranteed at all gains.

3 Typical performance

3.1 Gain range and gain flatness

The total gain range supported by the amplifier is a function of the number of switch configurations available and the size of the sub-range that each switch configuration supports. The size of the sub-range depends on the required gain flatness specification of the amplifier, since a wider sub-range will result in sub-optimal tilt compensation for some gains.

To achieve a specified gain flatness of +/- 1dB, we have found that the gain sub-range should be slightly more than 4 dB, which provides a net sub-range of 4dB taking into account overlap between the sub-ranges. This is illustrated in Figure 3, which shows the output gain profile over two sub-ranges (totaling 8dB) covered by two adjacent switch configurations. Switch configuration 1 (sw1) is designed to provide optimum tilt compensation at 17dB gain, whereas switch configuration 2 (sw2) is designed to provide optimal tilt compensation at 13dB. For each of the two configuration the gain can deviate by up to 2 dB from the optimum gain, with a resulting tilt of less than 2 dB (i.e. gain flatness < +/-1 dB).

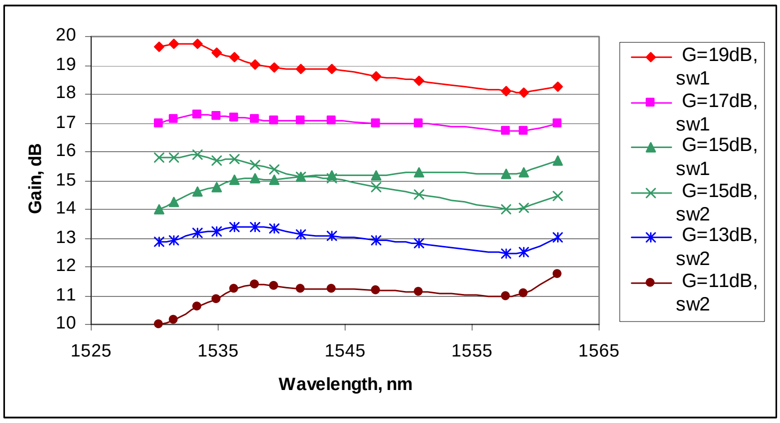

Figure 3: The gain profile exhibited over a range of 8 dB supported by two neighboring switch configurations

Thus, by using two 8x1 switches (i.e. 8 switch configurations) as shown in Figure 1:, a total gain range of 32 dB is achieved with gain flatness +/- 1dB.

3.2 Noise Figure Performance

A major advantage of the Gain Switched VG EDFA over a conventional VOA based VG EDFA is the NF performance. As noted in the introduction, the NF performance of a VOA based VG EDFA deteriorates as the VOA attenuation is increased, which limits the practical gain range of such an amplifier. On the other hand, for a Gain Switched VG EDFA the loss introduced by the switches and lengths of secondary EDF remains small over all configurations, which allows these components to be placed at the amplifier output. This in turn means that there is practically no NF deterioration over the entire gain range of the amplifier.

For a Gain Switched VG EDFA with 32 dB gain range, a NF of better than 6 dB has been achieved for all gains and over all operating conditions.

4 Summary

The RED-C Sentior 2180 Gain Switched VG EDFA is based on a novel patent protected concept utilizing optical switches and lengths of un-pumped EDF which act as saturable absorbers. This design achieves a total gain range of up to 32 dB, with NF better than 6dB for all gains. In comparison, a typical VOA based VG EDFA can only achieve a gain range of up to 15 dB, which is usually accompanied by a few dB deterioration in NF at lower gains.

Thus, the Gain Switched VG EDFA provides an excellent solution for applications requiring a single type of VG EDFA to cover a very wide gain range. This unique advantage comes at a price that is comparable to a traditional VG EDFA.