Finisar

White Paper

Operational Issues in the Deployment of Raman Amplifiers

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1 Introduction

Distributed Raman Amplification (DRA) is a key technology for modern optical communications systems, and especially in coherent links and mesh networks. Typically, DRA is used in conjunction with conventional EDFA technology to enable many important applications, such as long spans and “hut skipping” in multi-span links, single span links up to ~300km, and long haul 40/100 Gb/s coherent links beyond >1000km.

While the advantages of DRA technology are clear, there are also many operational issue related to the deployment of the technology. Being a world leader in Raman amplification, and with extensive field deployment since 2004, Finisar has invested significant time and effort in understanding and providing solutions for these operational issues. In this paper we describe some of the main issues, and how the Finisar Raman product line addresses them.

2 Background

DRA refers to the process whereby pump energy propagating along the transmission line causes signal amplification through stimulated Raman scattering. Since amplification occurs along the transmission line, as opposed to lumped amplification at the end of each span, the signal power is prevented from reaching very low levels, thus improving the Optical Signal to Noise Ratio (OSNR) of the system. An additional advantage of DRA is that the gain spectrum of the amplification depends on the pump wavelengths used, allowing to achieve flat gain in any transmission band.

In this white paper we focus on the more common counter propagating, “backward”, DRA configuration, where the pump energy is introduced at the end of each span, and propagates counter to the signal. In this context DRA is most often used in conjunction with conventional EDFA amplifiers, with the Raman amplifiers serving as pre-amplifiers to the EDFA. This Raman/ EDFA configuration is shown schematically in Figure 1. In many cases the Raman and EDFA modules are combined into a single Hybrid Raman/EDFA module, thus providing size and cost benefits, as well as significant performance benefits due to the tight integration of the two modules.

Finisar Raman amplifiers can contain up to six pump laser diodes, providing up to 2W Raman pump power. In the most common application a two or three pump module provides up to 850mW Raman pump power and up to ~18dB Raman on-off gain for G.652 fiber (SMF). For special applications requiring higher pump power, a six pump standalone unit with removable hot-swappable pump laser drawers is available.

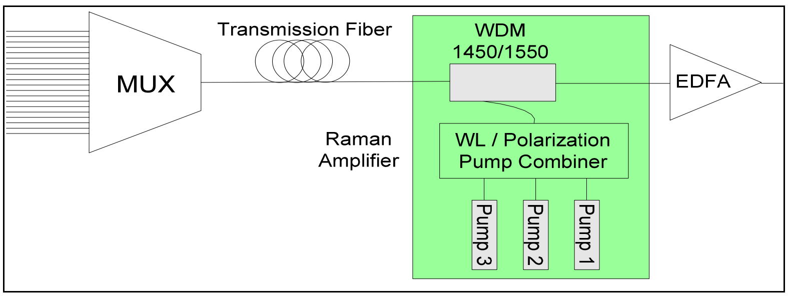

Figure 1: A simplified block diagram of a Raman amplifier deployed in backward pumping configuration

3 Preparing the Transmission Line for DRA

Since DRA occurs within the transmission line itself, the quality of the line can dramatically affect the performance of the Raman amplifier and in particular, the achievable signal gain. In this section we review a number of key issues which should be considered before deploying DRA on a transmission line.

3.1 Losses along the Line

High loss along the transmission line, and in particular discrete loss points occurring close to the Raman amplifier, can severely decrease the available pump power for DRA, and thus the achievable Raman gain. Discrete loss points can occur due to dirty or faulty connectors, or sharp bends and other stress point along the fiber. Figure 2 illustrates the effect on Raman gain of discrete loss points at various distances from the Raman amplifier. For example, if the nominal Raman gain of the amplifier (for a given fiber type) is 15 dB, then a discrete loss point of 0.5 dB occurring at the output of the Raman amplifier will reduce the gain by more than 1.5 dB, whereas a discrete loss point of 1 dB occurring at the same point will reduce the gain by more than 3 dB.

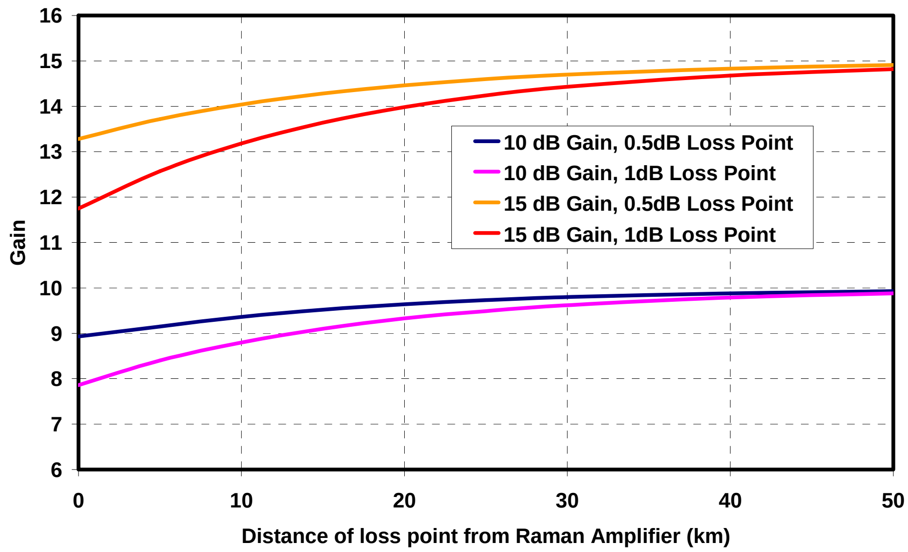

Figure 2: Effect of discrete loss points on Raman Gain. Results are shown for Raman amplifiers with nominal gain of 10 and 15 dB, and for 0.5 dB and 1dB discrete loss points.

In order to minimize discrete loss points, the number of jumper cables between the Raman amplifier and the transmission fiber should be reduced to a minimum. Where possible, splices should be used instead of connectors, and in those cases where connectors are used, care should be taken to clean the connectors and to make sure they are properly closed. Care should also be taken to minimize bend losses and stress in the cable plant between the Raman amplifier and the outside cable plant.

As a rule of thumb, the total loss between the Raman amplifier and the outside cable plant should not exceed 0.5 dB. An OTDR can be useful in analyzing the transmission line and identifying discrete loss points.

3.2 Back Reflection along the Line

Another important issue that should be monitored is back-reflection along the transmission line. High back reflection is often associated with loss, and thus can occur at discrete loss points as described in the previous section. If there is high back-reflection, then part of the pump energy propagating along the line will be back-reflected, and will return to the pump laser diode from which it originated. A high level of back reflection can degrade the performance of the laser diode, and thus decrease the available pump power.

The same measures described in the previous section should also ensure that the transmission line has low back-reflection. As a rule of thumb, the total back-reflection from the line should not exceed a level of -25 dB, and should preferably be in the region of -30dB.

3.3 Connector Quality

As discussed in the previous sections, dirty or faulty connectors may cause loss and / or back-reflection, thus reducing the available Raman pump power. An additional potential problem is that the high Raman pump power passing through the connectors can harm or degrade the connectors with time. To avoid this, the number of connectors close to the Raman amplifier should be minimized, and those that remain should be specially designed to handle high power (such as E2000 connectors). Ideally, the output port of the Raman amplifier should be a high power adaptor, and the other end of the jumper connecting to this adaptor should be directly spliced to the outside cable plant, as shown in Figure 3.

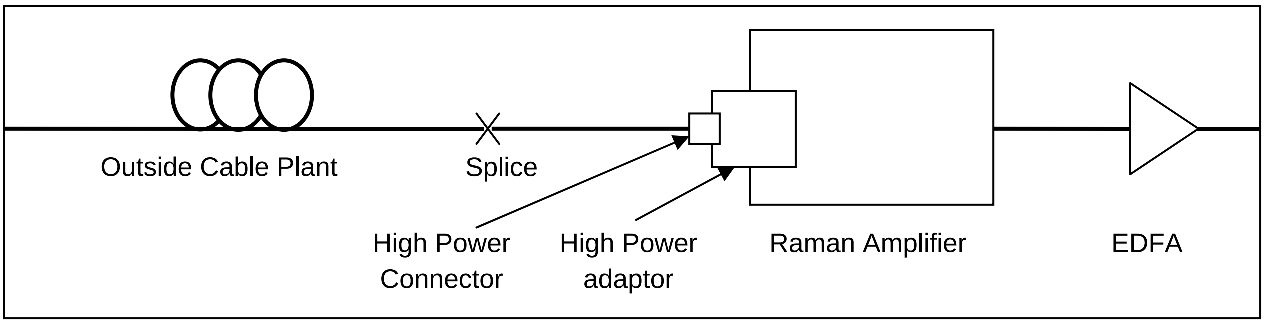

Figure 3: Connecting the Raman Amplifier to the outside cable plant

4 Automatic Gain Control

Even in the case where the transmission line has been prepared as described in section 3, DRA can still be affected by the quality of the transmission fiber itself. It is well known that different types of fibers, such as NZDSF (G.654) and SMF (G.652), have different Raman gain, however, even fibers of the same type but of different batches can exhibit different Raman gain. This is particularly true of older fiber (deployed before 2000), which have high water peaks, leading to relatively high (and varying) attenuation coefficients for the Raman pump wavelengths (1420-1460). This effect can lead to variations of up to 10% in the achievable Raman gain.

To address this and also be able to deal with non-ideal fiber lines and deterioration over time, A Raman amplifier should ideally be operated in automatic gain control (AGC) mode. Operation in AGC mode combines two aspects:

- Accurate measurement of the Raman gain at any given time
- Ability to control the Raman pumps to achieve a required gain while maintaining good gain flatness.

In order to accurately measure Raman gain, Finisar uses amplified spontaneous emission (ASE) measurements in a wavelength band outside the signal band, combined with sophisticated processing algorithms. Figure 4 shows an example of the correlation between the measured ASE and signal gain. If suitably processed and combined with other measurements such as signal power, such a measurement can yield the correct Raman gain in any fiber line, including lossy and low quality lines, with an accuracy of better than +/- 0.5 dB. Once the Raman gain is measured correctly, it is compared to the required gain and then the AGC loop applies corrections to the Raman pump power until the required Raman gain is achieved. The corrections applied to each of the Raman pumps are such that optimal gain flatness is always maintained.

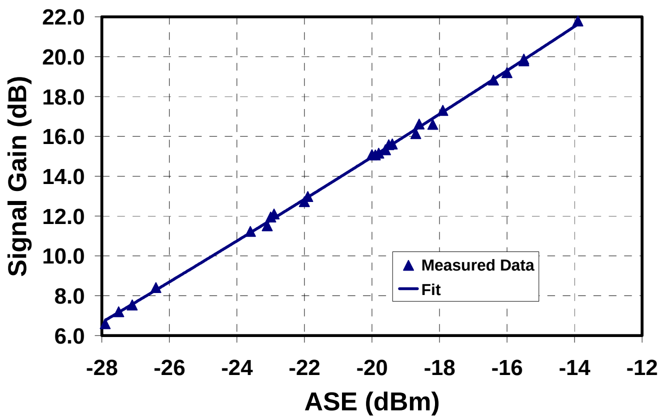

Figure 4: Correlation between ASE and signal gain

4.1 Gain Padding

Even if the Raman amplifier operates correctly in AGC mode, it may not be possible to achieve the required gain if the quality of the transmission line is low, resulting is severe deterioration of the Raman gain. For example, a Raman amplifier may be designed such that for an ideal fiber line it provides a maximum of 15dB gain. In a non-ideal fiber line the maximum gain could deteriorate to, e.g., 13 dB, meaning that it is not possible to achieve a required gain above 13 dB.

To avoid such a scenario, the Raman amplifier should be designed with gain padding. This means that the amplifier should be able to provide more pump power than is required to achieve the maximum planned gain in an ideal fiber line. Thus, even if the transmission line is non-ideal, there will still be sufficient pump power to achieve the maximum planned gain.

Gain padding can also be implemented in a Hybrid Raman/EDFA module, in which case it is not always necessary to provide extra Raman pump power. Since the Raman and EDFA are in the same module, and since the AGC loop includes both the Raman and EDFA gains, any deterioration in the Raman gain can be automatically compensated for by the EDFA. While this requires that the EDFA be designed with sufficient extra gain, this is often preferable cost-wise to providing extra Raman pump power.

5 Laser Safety and Automatic Shut-down and Start-up

Another important issue to consider with respect to DRA is Laser safety. This is a key issue in optical transmission systems, which are typically required to comply with class 1M hazard requirements according to IEC standard 60825 Part 2. This means that in the case of an accidental connector opening or a fiber break, all lasers and transmitters along the system are required to reduce power to a safe level, in many cases within 1s of the occurrence of the hazardous event. Additional information on laser safety in system deploying DRA can be found in ITU-T standard G.664.

Systems deploying DRA differ from conventional EDFA systems in two critical respects:

- The output power of Raman pump modules is much higher than typical power levels in EDFA-based systems, and in all cases is well above the designated safe level of radiation - In many applications the pump power propagating along the fiber is at a level that it is hazardous not only to the eye but also to the skin.
- DRA generates ASE along the transmission line - This means that even in the case of a fiber break, ASE power within the C-band can still propagate along the system. This disrupts the conventional shut-down method based on Loss of Input Signal, which is commonly used to shut down EDFAs in a system.

In order to address this issue, Finisar Raman amplifiers support additional and independent mechanisms for detecting a fiber break or open connector, allowing automatic shut-down of the Raman pump module. These include:

- Detection of an Optical Supervisory Channel (OSC signal)
- Detection of pump back-reflection energy
- Detection of ASE outside the transmission band

These mechanisms, based on unique and patented IP, can also provide important diagnostic information and alarms regarding the integrity of the transmission line, such as the existence of high back-reflection or discrete loss points.

5.1 Automatic Restart Procedure (ARP)

A complementary issue related to laser safety and shut-down procedures is the Automatic Restart Procedure (ARP). If a disruption occurs along the transmission line that causes the Raman amplifier to shut-down (e.g. a fiber break), the amplifier should be able to automatically restart once the disruption has been corrected. This allows automatic operation of the Raman amplifier, without manual intervention of maintenance personal.

Typically, automatic restart will be based on detection of the OSC signal or the C-band data signal. Since the Raman amplifier is off when these signals are to be detected, meaning there is no Raman gain along the transmission line, the signal powers to be detected are usually quite low, which can complicate the detection mechanism. For additional safety, the following procedure should be followed:

- If the OSC and/ or C-band signal has been detected - turn on the pump power at a low eye-safe level
- Check back reflection from the fiber line. If the back reflection is high, turn pumps off. If it is sufficiently high, increase pump power to the required level.
- Within a short eye-safe time, check for any conditions that may still indicate a disruption in the fiber line. If all is OK, then resume normal operation.
- If a shut-down condition still exists, shut-down the amplifier within an eye-safe time. Wait for a specified time (the ARP time), before attempting to restart.

6 Summary

The use of DRA significantly increases the design options for optical networks, often enabling applications which are not feasible or practical with conventional EDFA technology. However, it is necessary to be aware of and address the various operational issues that arise with the deployment of DRA. These include:

- Preparation of the transmission line - Avoiding losses and high back-reflection along the line; Ensuring clean and properly closed connectors; Minimizing connector use near the Raman amplifier; Using high power connectors where possible.
- Operating the Raman amplifier in automatic gain control (AGC) mode, including accurate measurement of the actual Raman gain, and providing gain padding to compensate for possible Raman gain deterioration.
- Laser safety - Using multiple safety mechanisms to shut down the Raman pumps upon detection of a break in the transmission line, and providing an automatic restart procedure to restart the Raman pumps following a shut-down event.

Leveraging our extensive experience in developing Raman amplifiers and supporting our customers in various deployment scenarios, Finisar has developed a unique and comprehensive set of features which make the actual real world deployment of DRA technology as smooth and simple as possible.

The Finisar Raman product line includes Raman and Hybrid Raman/EDFA modules designed for integration within system vendor equipment, as well as the UtlraSpan family of stand-alone rack-mountable network interfaced units. The module products are ideal for systems that address application requiring wide-spread and frequent Raman amplification, such as 100Gb/s links. On the other hand, the UltraSpan product family can provide a simple and easily implemented solution for systems that address applications which less frequency require Raman amplification, or require only small quantities of Raman amplifiers.

For more information please contact sales@finsiar.com.