June 2007

OPTICAL AMPLIFIERS THAT BUILD BETTER NETWORKS

# White Paper

# Operational Issues in the Deployment of Raman Amplifiers

Written By: Dr. David Menashe, VP and Chief Scientist

## 1 Introduction

Distributed Raman Amplification (DRA) is a key technology for modern optical communications systems. Typically, DRA is used in conjunction with conventional EDFA technology to enable many important applications, such as long span masking in multi-span links, single span links up to ~300km, and ultra long haul links.

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 with the Sentior 9000 module product line and the Sentior 19000 Network Interfaced 1RU subsystems, and with extensive field deployment since 2004, RED-C Optical Networks 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 RED-C 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 hybrid Raman/ EDFA configuration is shown schematically in Figure 1.

Raman amplifiers typically contain either two or three pump laser diodes, with different wavelengths and/ or polarizations to achieve flat and polarization independent gain over the transmission band. The pump output power of the amplifiers is usually in the range of 500-800 mW, thus providing a gain of 10-16dB for G652 (SMF) transmission fiber.

RED-C Optical Networking
**RED-C Optical Networks, Ltd.,** Atidim Technology Park, Bldg. 3, P.O. Box 58101 Tel-Aviv 61580, Israel, **sales@red-c.com**
**RED-C Optical Networking, Inc.,** 2600 Philmont Ave. Suite 310, Huntingdon Valley, PA 19006, USA, **ussales@red-c.com**
**ww.red-c.com**

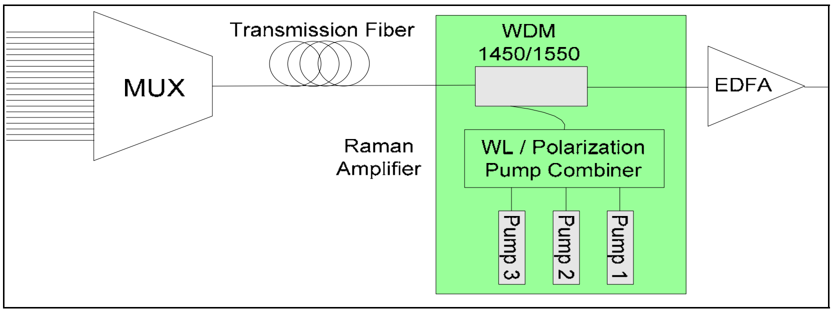


**Figure 1: A simplified block diagram of a Raman amplifier deployed in backward pumping configuration**

# 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.

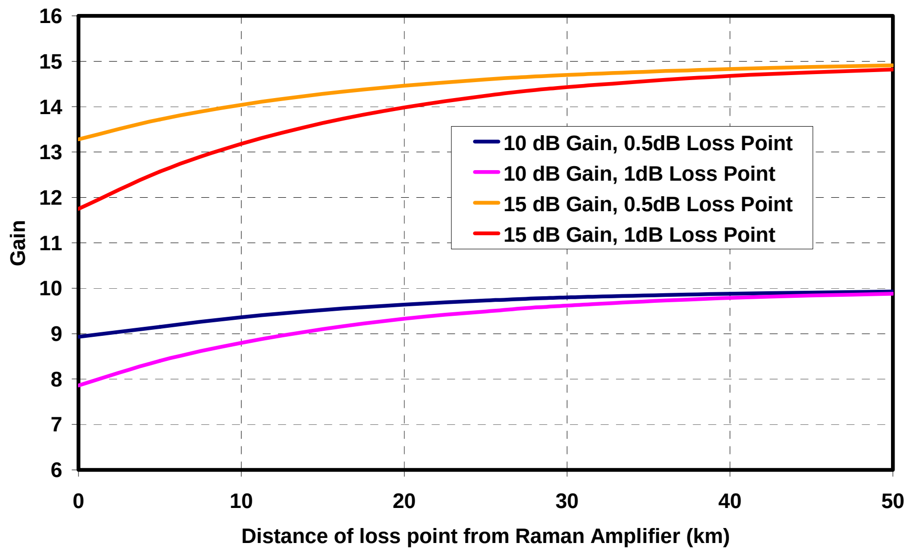


**Figure 2: Effect of discrete loss points on Raman Gain. Results are shown for Raman amplifiers with nominal gain of 10 and 15 dB, and for 0.5 dB and 1dB discrete loss points.**

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 -23 dB.

## 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. Additionally, if the Raman amplifier contains internal connectors, these should be easily replicable at the customer premises.

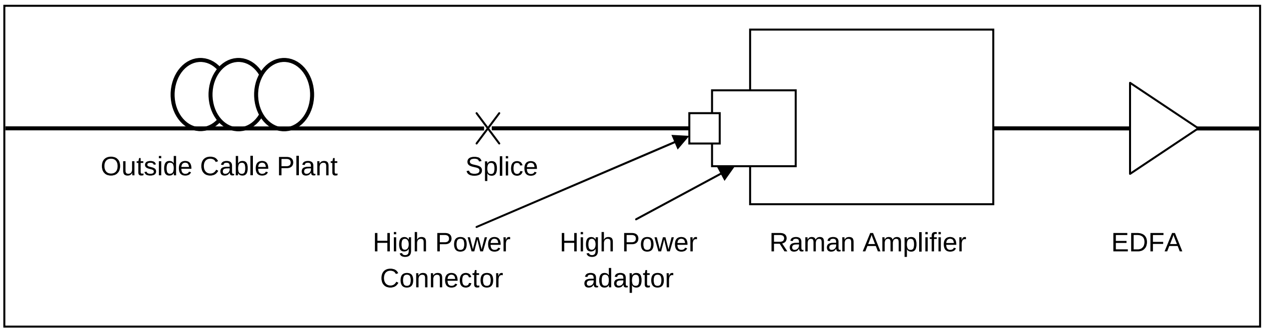


**Figure 3: Connecting the Raman Amplifier to the outside cable plant**

## 3.4 Fiber Quality

DRA can also be affected by the quality of the transmission fiber itself, even if all other issues discussed above are in order. 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 20% in the achievable Raman gain, which in turn complicates system planning and deployment.

To avoid this, the Raman gain of a particular transmission line should be measured as accurately as possible before deployment. Ideally, the measurement should require access to only a single end of the transmission line (the end at which the Raman amplifier is to be deployed), and should not require additional signals to be transmitted along the line. One method for performing such a measurement is to use a Raman amplifier to input pump power into the line, and measure the Amplified Spontaneous Emission (ASE) propagating back along the line towards the Raman amplifier. Figure 4 shows an example of the correlation between the measured ASE and signal gain. If suitably processed, such a measurement can provide a reliable estimate of the achievable Raman gain for that particular transmission line.

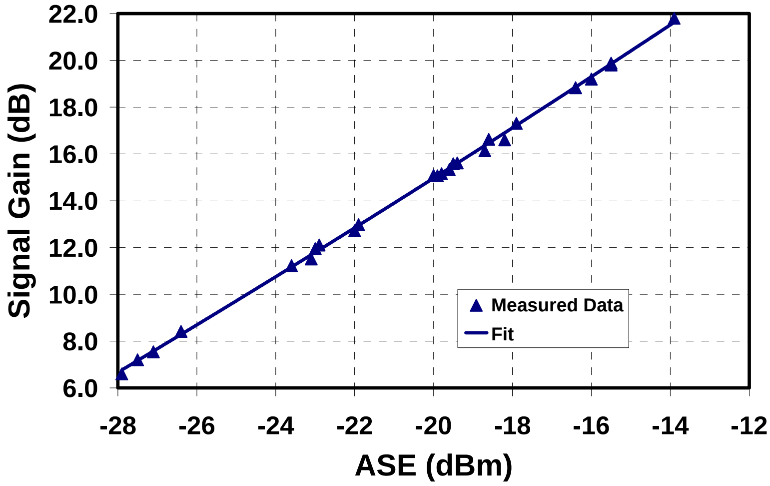


**Figure 4: Correlation between ASE and signal gain**

# 4 Laser Safety and Automatic Shut-down and Start-up

Once the transmission line has been checked and found suitable for DRA, the next issue to consider 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, Raman amplifiers should support additional independent mechanisms for detecting a fiber break or open connector, allowing automatic shut-down of the Raman pump module. Such mechanisms may include:

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

These mechanisms also provide important diagnostic information and alarms regarding the integrity of the transmission line, and the efficiency of the Raman amplification.

## 4.1 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.

- Within a short eye-safe time, check for regular condition relating to automatic shut-down.
- 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.

# 5 Monitoring Performance during Installation and Operation

During the installation procedure of Raman amplifiers, it is extremely useful to be able to monitor various parameters in order to trouble-shoot the installation, and to asses the actual level of performance of the amplifier. For example, monitoring the pump back-reflection can help detect high back-reflection points along the transmission line, which can then be taken care of before operation. Similarly, monitoring the ASE generated by the Raman amplifier, and comparing it to the expected value, can help identify discrete loss points along the line.

After installation has been successfully completed, it is important to continue monitoring performance throughout the operational lifetime of the system. The main parameters that should be monitored are:

- Output pump power
- Back-reflected pump power
- Back-reflected ASE
- Input C-band signal

Suitable alarms should be generated if any of the parameters indicate degradation in the line quality or the Raman gain.

# 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; Measuring the achievable Raman gain prior to deployment.
- Laser safety - Activate multiple safety mechanisms to shut down the Raman pump unit upon detection of a break in the transmission line
- Monitoring - Monitor various parameters to identify degradation in the line quality or the Raman gain.

Leveraging our extensive experience in developing Raman amplifiers and supporting our customers in various deployment scenarios, RED-C 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 RED-C Raman product line includes both modules (Sentior 9000 family) and stand-alone rack-mountable 1RU network interfaced units (Sentior 19000). The Network Interfaced Raman (NIR) functions as a separate network element, with direct hardware and software interfaces to the host network. The NIR supports SNMP communications over Ethernet, and provides a simple and intuitive GUI for control and monitoring purposes. It is ideally suited for rapid integration within the system vendors' product, and provides a comprehensive ready-to-deploy Raman solution.