The Impact of Fiber Effective Area on Systems using Raman Amplification

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Introduction

Large effective area (A_{eff}) fibers are beneficial in reducing the effects of fiber non-linearities when signal power is high. Conversely, when Raman pumping is used, small A_{eff} fibers increase the Raman efficiency and therefore give higher gains for a set pump power. The primary purpose of this paper is to show the significant impact of the noise generated within the Raman amplifier. The second purpose is to demonstrate that fiber attenuation must also be taken into account to assess how the Raman performance of different fiber designs can impact overall transmission performance. To illustrate these points, transmission results from an experiment using Corning® SMF-28® fiber with an A_{eff} of 80 μm^2 are compared to results using Corning® Vascade® L1000 fiber, which has an A_{eff} of 102 μm^2.

The Distributed Nature of Raman Gain

The main benefit of a distributed Raman amplifier (DRA) over a discrete amplifier, such as an erbium doped fiber amplifier (EDFA), lies in the fact that the amplification occurs at a distance from the fiber end where the signal power is higher. This decreases the level that the signal power drops to in the span and consequently increases the overall optical signal-to-noise ratio — improving the system bit error rate (BER).

Figure 1 illustrates the signal levels with and without Raman pumping from the receiver end and shows the Raman gain distributed over approximately the last 40 km of the fiber. In systems using a single fiber type, the exact distribution of the gain is largely independent of the fiber effective area and is related to the fiber loss at the pump wavelength.

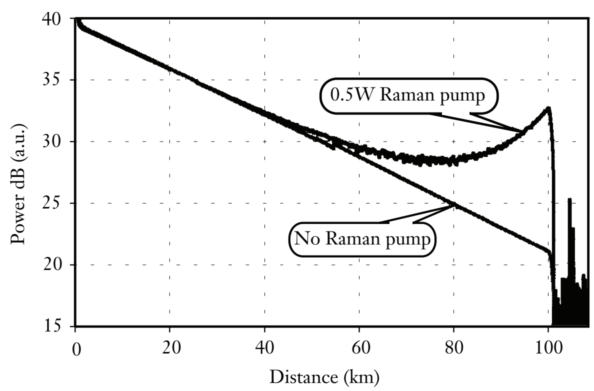

Figure 1. OTDR Traces for 101 km of SMF-28 Fiber With and Without Raman Pumping

Dependence of Raman Gain on Pump Power

The amount of Raman gain for a fiber is calculated in the equation below:

$$\text{gain (dB)} = 10 \log_{10}(e) \cdot \frac{g_r \cdot L_{eff} \cdot P_0}{A_{eff}}$$

Where: g_r is the fiber Raman gain coefficient (approximately the same for the two fibers tested)

P_0 is the Raman pump power input into the fiber

L_{eff} is the effective length for the Raman interaction ($L_{eff} = 10\log_{10}(e)$ / pump attenuation)

A_{eff} is the fiber effective area

This equation predicts that the 80 μm^2 fiber will provide 30% more Raman gain in dBs for the same pump power than the 102 μm^2 fiber. This is indeed found to be the case as shown in Figure 2.

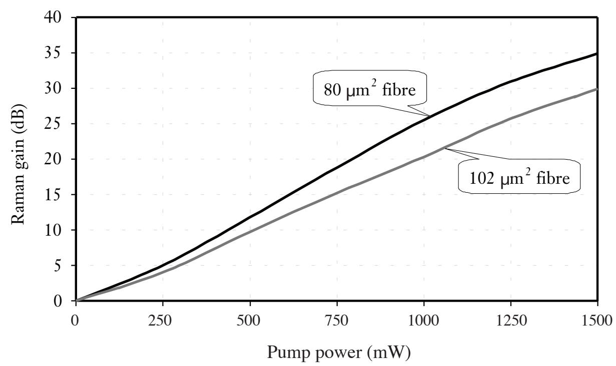

Figure 2. Difference in Raman Gain for Fibers with Different Effective Areas

Stimulated Raman scattering produces amplification in a DRA in a manner analogous to an EDFA. Furthermore, as in an EDFA, this is always accompanied by amplified spontaneous emission (ASE) which manifests itself as noise at the receiver.

The experimental configuration shown in Figure 3 is used to demonstrate the impact of Raman gain and noise on the maximum loss that can be placed between transmitter and receiver. The power launched into the first 100 km span was kept constant and the loss of the attenuator in the middle of the span under test was adjusted until the BER was 1×10^{-8}. The maximum span loss is defined as the loss of this attenuator after adjustment plus the fiber loss. Figure 4 shows this plotted as a function of Raman pump power for the two different effective area fibers.

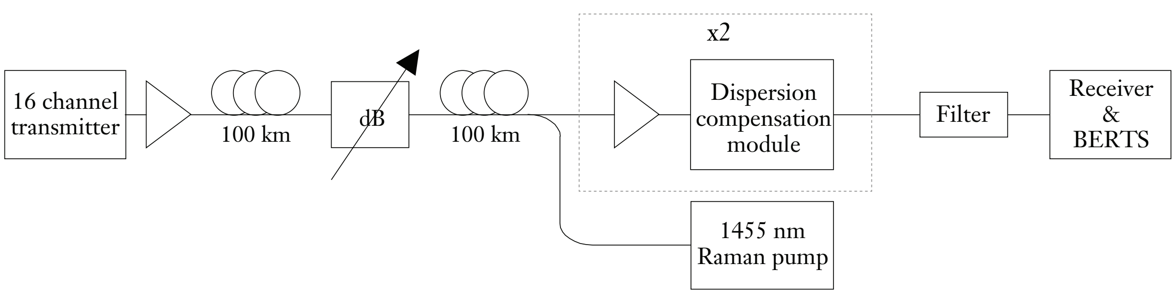

Figure 3. Experimental Configuration for Comparing Fibers with Different Effective Areas

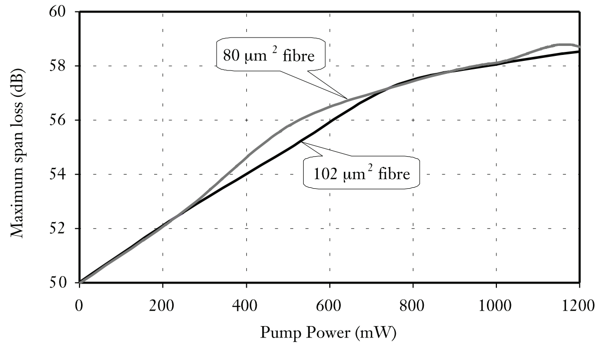

Figure 4. Maximum Span Loss for a BER of 10^{-8} Versus Pump Power

In general, both fibers have similar maximum span losses for a given Raman pump power. A more detailed analysis shows that this is due to two factors. First, the higher Raman gain in the smaller effective area fiber is accompanied by a similar increase in the Raman noise. Secondly, the gain occurs farther from the fiber end for the 102 µm^2 fiber due to its lower loss at the 1455 nm pump wavelength (0.227 dB/km cf. 0.241 dB/km). In this case, the combination of both of these substantially reduces any system benefits potentially gained from Raman pumping by using the lower effective area fiber.

In the experiment described, the 102 µm^2 Vascade L1000 fiber had a loss at 1550 nm of 0.185 dB/km while the loss of the 80 µm^2 SMF-28 fiber was 0.195 dB/km. Using these figures, the maximum span losses shown in Figure 4 can be converted into total system reach as shown in Figure 5. This illustrates that even in systems with Raman amplification, a low fiber loss is still critical in order to maximize the distance over which satisfactory transmission is possible.

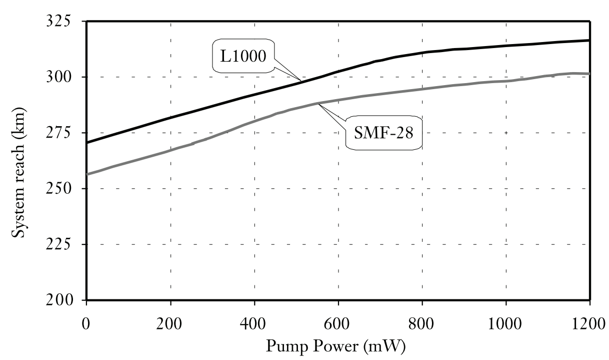

Figure 5. Maximum Span Loss for a BER of 10^{-8} Versus Pump Power

Summary

The major advantage of a DRA over a stand-alone EDFA is that it provides gain a distance away from the fiber end where the signal power is higher. The distribution of this gain is largely set by the fiber attenuation at the pump wavelength. For a given pump power, the Raman gain in dBs is approximately inversely proportional to the fiber effective area. Thus, for a given pump power, the Raman gain in a fiber with an effective area of 80 µm^2 is almost 30% higher than in a 102 µm^2 fiber. This higher Raman gain, however, is also accompanied by more Raman ASE noise which significantly reduces the advantages seen in overall system performance. Therefore, fiber loss at both the pump and signal wavelengths as well as Raman gain efficiency need to be considered when selecting fiber types for Raman amplified systems.

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