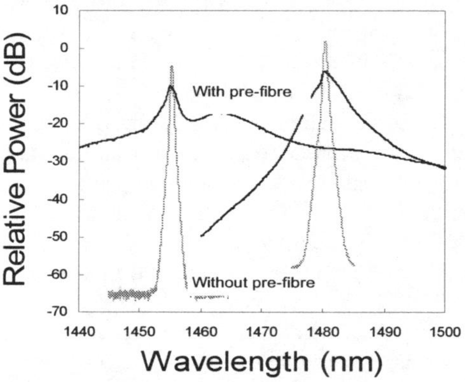
Dual-pump Raman amplification with enhanced flatness using modulation instability

T. J. Ellingham, J. D. Ania-Castañón, S.KTuritsyn
School of Engineering and Applied Science, Aston University, Birmingham B4 7ET, United Kingdom.
A.Pustovskikh, S. Kobtsev
Laser Systems Laboratory, Novosibirsk State University, Russian Academy of Sciences, 630090 Novosibirsk, Russia
M. P. Fedoruk
Institute of Computer Technologies, Russian Academy of Sciences, 630090 Novosibirsk, Russia

The application of distributed Raman amplification in long-haul, broadband transmission using wavelength division multiplexing relies on the ability of the amplifiers to provide a flat gain profile to enable maximum reach of all signal channels. The gain flatness of the amplifier over its operational bandwidth can be improved by using a large number of pumps [1], but this is not always a practical solution, since it increases both the cost and the complexity of the system while reducing its flexibility. Therefore, alternative approaches to gain ripple suppression are of great practical and fundamental interest. A possibility for lowering residual Raman gain fluctuations with a fixed number of pump sources is to apply a nonlinearly-broadened pump as originally demonstrated experimentally for a single pump in [2]. In this work we utilize modulation instability to the broadening of the two CW-pumps of a wideband Raman amplifier, and study the improvement achievable on its gain response.

Two Truewave-RS fibers were used for the broadening of the pumping waves. For the 1455 nm pump, a 10.390 km reel with a zero-dispersion wavelength of 1453.77 nm was used. The 1480 nm pump was broadened in a 5.077 km piece of fiber with zero dispersion wavelength at 1475 nm. Pump powers at the input and the output of the pre-broadening fibers were monitored using a power meter. Figure 1 shows the pump spectra at the input and output of the broadening fibers, in order to obtain broadened pump powers of 391 mW (1455 nm) and 715 mW (1480 nm), from input powers of 690 mW and 1052 mW respectively.



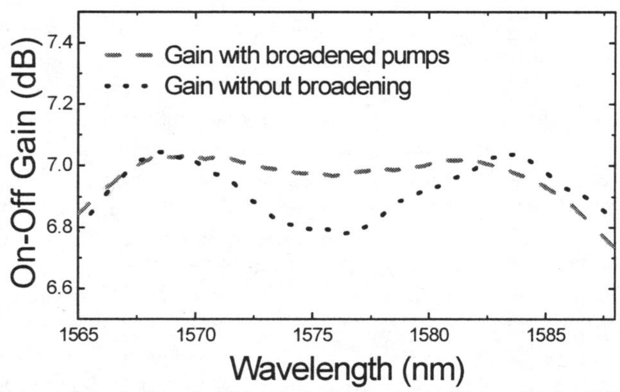


Fig. 1 (left). Pump spectra at the input (grey lines) and output (black lines) of the broadening pre-fibers. Left - 1455 nm. Right - 1480 nm.

Fig.2 (right) Gain spectra of the amplifier with nonlinearly-broadened pumps. The black dashed line - experimental result without pre-fibers, the grey dashed line - the experimental result with pre-fibers.

Figure 2 Compares the experimental result of the with/without pre-fiber cases. Even though the limitations imposed by the available pre-broadening fibers, especially that of the 1480 pump, led to a drop in the gain at about 1590 nm for the broadened pump amplifier, the improvements in gain ripple performance are evident, as shown. In particular, the continuous bandwidth corresponding to a gain ripple of 0.1 dB is increased from 5 nm to 19 nm, and the total gain variation over a 20 nm window is halved from 0.26 dB to 0.13 dB

Applying nonlinear fiber process, we demonstrate a feasibility of a certain control over the broadening process, leading to clear improvements in the flatness of the amplifier gain. In our particular experimental example, we demonstrate an extension of the 0.1 dB continuous gain ripple bandwidth from 5 nm to 19 nm. This work shows that there is a possibility of applying the broadening technique to multi-wavelength design, improvement of the degree of broadening and reduction of loss to the pump power, in the 'pre-fiber' is required to obtain a more viable solution. This might be possible to realize with acquirement of fibers with appropriate nonlinear/dispersive characteristics such as highly nonlinear fiber.

References:

1. Y. Emori, K. Tanaka, S. Namiki, Elec. Lett., 35, 1355-1356, (1999)
2. T.J.Ellingham, L.M.Gleeson, N.J. Doran, Proc. ECOC 2002, 4.1.3, 2002