Low gain ripple broadband Raman amplifier with continuous-spectrum pump

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Different pump optimisation techniques are employed to minimise gain ripple of Raman amplifiers in a broad spectral range. Raman amplification smoothing can be achieved using several (or many) narrow-band pump sources with optimised wavelength and/or output power. Another technique uses spectrum-broadened pump sources or pump sources with swept radiation wavelength. One of new approaches to the problem of best smoothing of Raman amplification spectrum may be identification of such contours of continuous-spectrum pump that produce a flat contour of Raman amplification within a wide spectral region. The most prospective method to find such pump contour forms is to solve the inverse problem for low gain ripple of Raman amplification, which results in identification of the optimal contour of the continuous pump spectrum. This approach has allowed [1] within the simplified model of distributed Raman amplification to calculate the contour of continuous-spectrum pump that produces gain ripple at the $2.5\cdot10^{-3}$ dB and 0 dB net gain within the 1540–1590 nm range over a 100-km stretch of TrueWave fibre.

The use of more realistic Raman amplifier models substantially increases complexity of the inverse problem. This is why we applied this model to study different low gain ripple broadband Raman amplifiers while varying/optimising the contour of the continuous pump spectrum, including various dot Raman amplifiers with net gain > 0.

In this report we present the results of numerical modelling of backward-pumped low gain ripple Raman amplifier for C+L band with continuous pump spectrum. A full numerical model [2] was applied for modelling of Raman amplifier, which simulates all of the most important physical phenomena affecting the Raman gain: stimulated and spontaneous Raman scattering and its temperature dependence, Rayleigh scattering, arbitrary interactions between pumps and signal from both directions (signal-signal, pump-pump and signal-pump interactions), high-order Stokes generation. The calculations were carried out for 25-km length of SMF-28 optical fibre in two versions: at integral pump power of 1 W (net gain > 0) and at zero net gain. Continuous pump spectrum was approximated by 31 monochromatic sources within the 1410–1490 nm range, their frequencies being spaced by 14 cm^{-1}. In order to minimize the gain ripple the intensities of individual pump sources were varied.

Identified are the contours of continuous pump spectra that enable a 71-nm amplification band (1528–1599 nm) with the gain ripple less than 0.1 dB at the average amplification of 7.7 dB (total pump power 1 W) and with the gain ripple less than 0.042 dB at net gain = 0 (total pump power 365 mW). In Fig. 1 the identified optimal contours of continuous pump spectra are given together with corresponding gain contours.

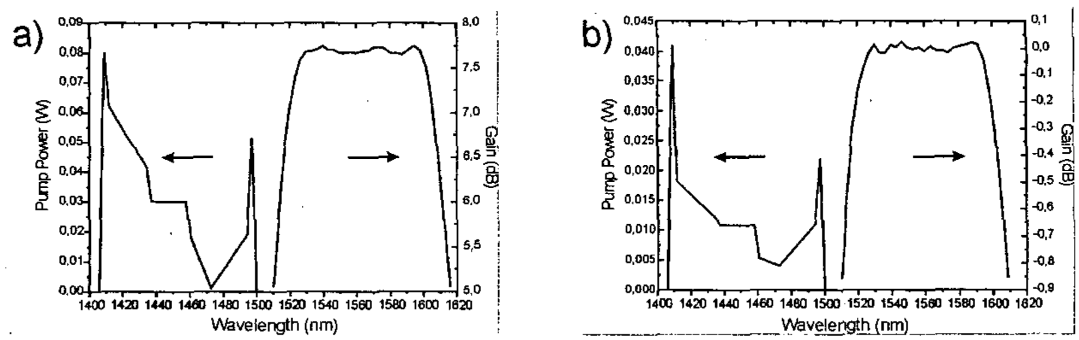

Fig. 1. Optimal contours of continuous pump spectra in case of non-zero average gain (a) and in case of zero average gain (b) with correspoding Raman gain contours.

It is pertinent to note that the identified optimal pump spectra contours exhibit more smooth character than those reported in [1], which can substantially simplify the implementation of pump sources with such spectra in practice. Specifically, this sort of spectra can be formed while using a comparatively small number of monochromatic and spectrally broadened pump sources.

1. A.R.Grant. Calculating the Raman pump distribution to achieve minimum gain ripple. IEEE J. of Quantum Electron., v. 38, N 11, pp. 1503-1509 (2002).
2. J.D.Ania-Castanon, S.M.Kobtsev, A.A.Pustovskikh, S.K.Turitsyn. Simple design method for gain-flattened three-pump Raman amplifiers. LEOS-2002 15th Annual Meeting, 10-14 November 2002, Glasgow, Scotland. Tech. Prog., WQ4.

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