Polarisation dependence and gain tilt of Raman amplifiers for WDM systems

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Abstract: We investigate the polarisation dependence and gain tilt of Raman amplifiers for WDM systems. We find no polarisation dependence of the gain for backward propagating pumps. Results from experiments on commercial 32 –channel WDM system are presented, highlighting the effect of gain tilt and pump depletion.

OCIS codes: (140.4480) Optical amplifiers, (290.5910) Scattering, stimulated Raman, (060.2330) Fiber optics communication

1. Introduction

Due to technological advances in the field of high power lasers, amplifiers based on Raman amplification have once again come into focus [1-5]. That ability of providing broadband gain makes fibre Raman amplifiers an attractive candidate for application in optical communication systems. By pumping at multiple wavelengths bandwidths of approximately 100 nm are possible [2,3,5]. Distributing the gain into the transmission fibre itself reduces the power variation along the fibre which can be used for reducing nonlinear penalties and for increasing the noise margin [4].

In this work we show that pump depletion and gain tilt due to signal-signal interaction are important design issues for Raman amplifiers in DWDM systems and measurements of these two effects in a commercial 32 –channel system are presented. We have also measured the polarisation dependence of the Raman gain and found that for backward propagating pumps there is a strong averaging over polarisation and in this case it is not necessary to depolarise the pump light.

2. Gain efficiency

We have performed measurements in both standard fibres and dispersion compensating fibres (DCFs). The Raman gain efficiency, g_r, of the fibres is shown in Fig 1. The pump light was unpolarised (degree of polarisation < 2%) by polarisation multiplexing two laser diodes. Four different pump wavelengths ware used, 1438 nm, 1452 nm, 1466 nm and 1480 nm, and g_r was calculated from measuring the gain of a tuneable probe source. For the standard fibre g_r is proportional to the frequency of the pump but for the DCF we observe a stronger dependence on the frequency which can be due to wavelength dependence of the effective area of the fibre.

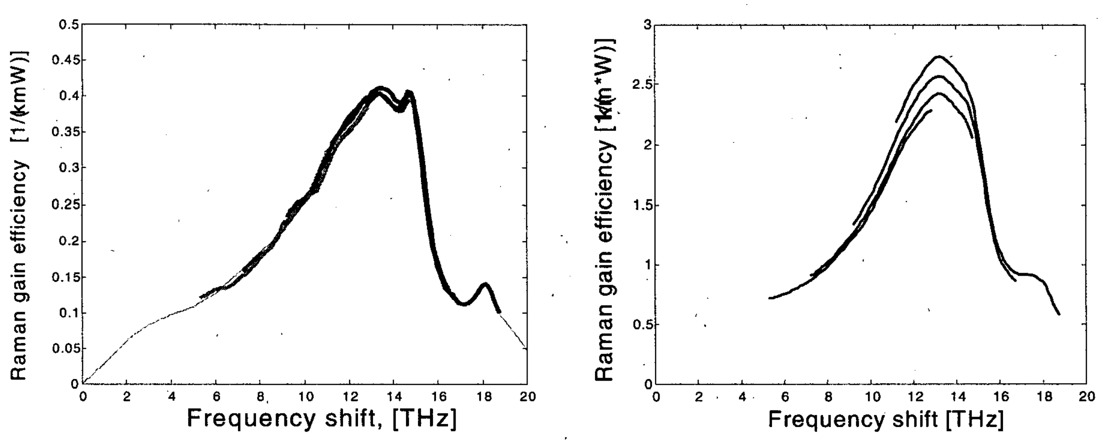

Fig. 1. Raman gain efficiency of the fibres used in this work; the standard fibre (left) and the DCF (right), the four lines are results from using four different pumping wavelengths, 1438 nm, 1452nm, 1466 nm, and 1480 nm. The thin line (left) shows a numerical fit to experimental data.

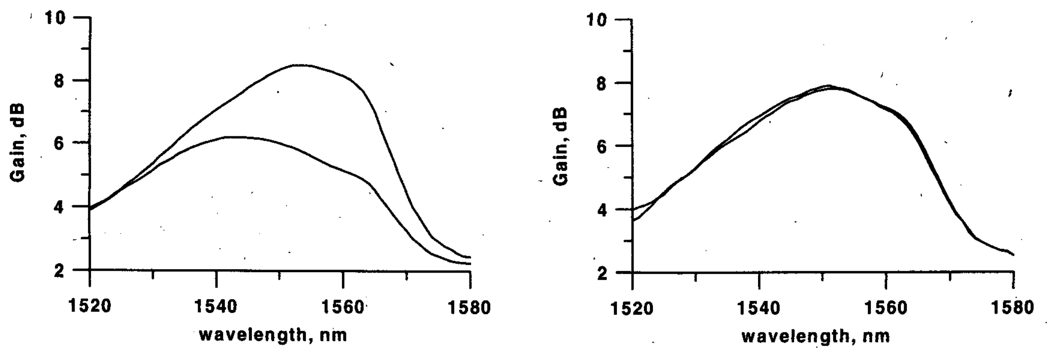

Fig 2. Polarisation dependence of the Raman gain in 15 km DCF for forward propagating pump (left) and backward propagating pump (right) of 137 mW at 1452 nm. The two curves represent orthogonal pump polarisations, the signal polarisation was adjusted to give maximum difference between the two curves at 1552 nm.

In order to measure the polarisation dependence of the Raman gain we performed two different measurements with orthogonal polarisations of the pump. The measurements were made on a DCF since the polarisation dependence is enhanced by higher Raman gain efficiency (x5), higher losses (x3) and slightly lower PMD-value (0.22 ps vs 0.25 ps) compared with the standard fibre. The gain of a probe signal varies, in general, with the input polarisation of the signal. We adjusted the input polarisation to maximise the gain at 1552 nm with one of the pumps active. The gain as function of wavelength for the two orthogonal pumps is shown in Fig 2, both for the forward (pump co-propagates with the signal) and the backward (pump and signal propagates in opposite directions) pump scheme. For the pump propagating forward there is an averaging over polarisation but the variation of the gain with signal polarisation is still large, in this particular case up to 3 dB. The averaging is due to the polarisation-mode dispersion of the fibre which uncorreleates the relative polarisation of pump and the probe. The most interesting result is for backward propagating pumps where no polarisation dependence of the gain could be detected within the resolution of the measurement. This is important since it means that arrangements made for depolarising the pump light are unnecessary for backward propagating pumps.

3. Gain tilt and pump depletion

The computational model for the bi-directionally pumped Raman amplifier is based on the equation presented by Kidorf et al. [5] which accounts for spontaneous Raman scattering and its temperature dependence, Rayleigh scattering, SRS and interaction between an unlimited number of pumps. The forward and backward propagating power, Pf, and Pb, are related by

$$
\begin{aligned}
\frac{dP_f(z,\nu)}{dz} = & -\alpha(\nu)P_f(z,\nu)+\Gamma(\nu)P_b(z,\nu) \\
& +\int_{\xi>\nu}\left\{g_r(\nu-\xi)\left[P_f(z,\xi)+P_b(z,\xi)\right]\left(P_f(z,\nu)+2h\nu\Delta\nu\left[1+\frac{1}{e^{h(\nu-\xi)/kT}-1}\right]\right)\right\}d\xi \\
& -\int_{\xi<\nu}P_f(z,\nu)\left\{g_r(\nu-\xi)\left[P_f(z,\xi)+P_b(z,\xi)\right]+2h\nu\Delta\nu g_r(\nu-\xi)\left[1+\frac{1}{e^{h(\nu-\xi)/kT}-1}\right]\right\}d\xi
\end{aligned}
\quad (1)
$$

where Γ is the Rayleigh scattering coefficient and T is the temperature.

The Raman interaction between signals in at different wavelengths was experimentally measured in a 32-channel WDM system, (signals were between 1534.25 nm and 1558.98 nm). The signals were combined in an AWG and the output power was boosted to 20 dBm. Fig 3 shows the input spectrum and the Raman gain the gain tilt induced by the WDM signal in 15 km of DCF.

The dependence of the Raman gain on the input power is shown in Fig 3 for the case of pumping in the backward direction with 140 mW at 1438 nm and 260 mW at 1452 nm. The effect of pump depletion, or gain saturation, is that the gain decreases with input power. Also present in Fig 3 is the gain tilt due to signal-signal interaction; as the input power increases from 5 dBm to 20 dBm the output spectrum tilts roughly 0.5 dB. In the calculation the signal-signal interaction was modelled as if were the signals unpolarised. As in the case of pump-signal interaction the PMD of the fibre decorrelates the relative state of polarisation but the process is slow for signal-signal interaction since the wavelength separation is smaller. The main reason for modelling the signal-signal interaction as polarisation independent is instead that many waves, each with a random state of polarisation, contributes to the resulting gain.

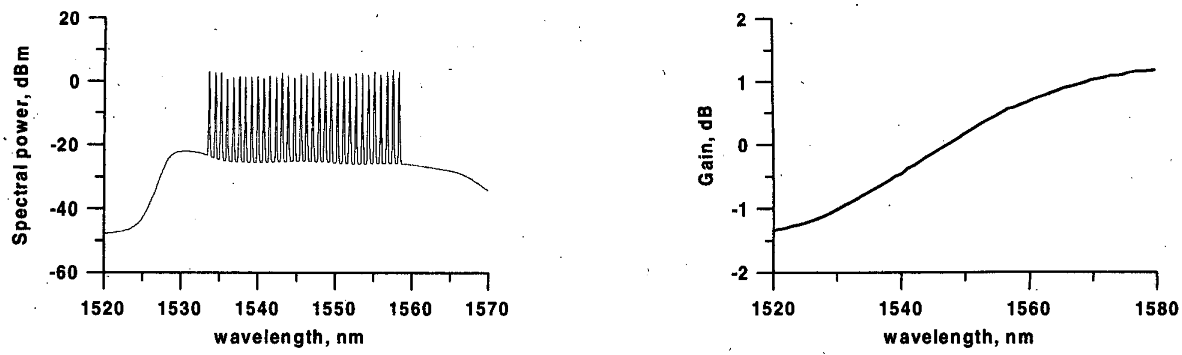

Fig 3. The input 32-channel spectrum (left) having a total power of 20 dBm. Measured gain tilt (right) due to Raman scattering between the signals in a WDM system in 15 km of DCF.

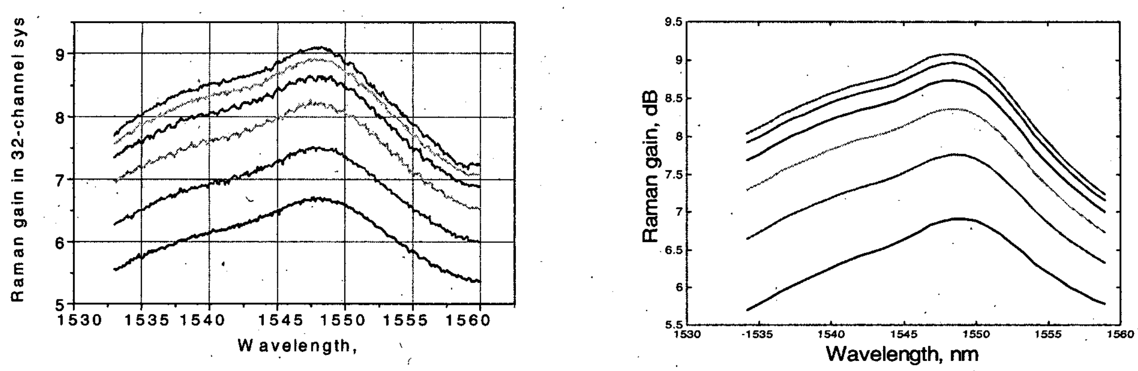

Fig 4. Measured (left) and calculated (right) spectrum of the Raman gain for a 32-channel system in 25 km of standard fibre pumped with 140 mW at 1438 nm and 260 mW at 1452 nm from the reciever end. The different lines correspond to different power of the input signal spectrum, from top to bottom: 5, 8, 11, 14, 17, and 20 dBm.

7. Conclusions

We have investigated the impact of gain tilt due to signal-signal Raman interaction and the effect of gain saturation in multiple pumped Raman amplifiers for WDM systems. Experimental results from measurements on a commercial WDM system with 32 channels are compared with results obtained with by a numerical model. The polarisation dependence of the Raman gain was measured in both the forward and backward pumping scheme. In the forward pumping scheme the gain shows strong polarisation dependence, in the backward direction the no polarisation was detected. This means that for Raman pump units pumping in the backward direction there is no need for depolarisation of the pump light.

7. References

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