Simple design method for gain-flattened three-pump Raman amplifiers

J.D.Ania-Castanon (1), S.M.Kobtsev (2), A.A.Pustovskikh (2), and S.K.Turitsyn (1)
(1) Photonics Research Group, Aston University, Birmingham B4 7ET, UK, e-mail: aniacajd@aston.ac.uk
(2) Novosibirsk State University, Pirogova 2, Novosibirsk, 630058, Russia, e-mail: pustovs@lab.nsu.ru

Abstract: A simple and efficient approach to the optimal design of 3-wavelength backward-pumped Raman amplifiers is proposed. Gain flatness of 1.7 dB is demonstrated in a spectral range of 1520-1595 nm using only three pumps with wavelengths within the 1420-1480 nm interval.

Introduction

The use of multi-wavelength-pump silica-fiber Raman amplifiers makes it possible to considerably widen the overall gain-bandwidth while simultaneously reducing its spectral non-uniformity [1]. As a typical example, the amplifying system described in [1] uses 12-wavelength pumps in a 1412.5-1504.5-nm band and provides gain flatness ~0.1 dB over the wavelength range of the C+L-bands (1527–1607 nm) with a counter-propagating pump configuration in 25-km of DSF. Note, however, that gain flatness of about 1 dB over the spectral range of C+L-bands is quite acceptable for some applications of Raman amplifiers. There must be a trade-off between advanced device characteristics and their overall cost and practicality. For many applications, it is of interest to achieve reasonable flatness in a wide spectral range using the minimal number of pump sources.

Implementation of multi-wavelength-pumped Raman amplification in practical transmission links requires a reliable and efficient method to adjust pump powers and wavelengths in order to obtain the desired gain profile. Although a few numerical optimization methods have already been proposed [2,3] with their specific advantages and limitations, development of new approaches is of interest to address the variety of applications and practical boundary conditions and constraints.

Optimization procedure and results

In this work we introduce a simple and efficient approach to the optimal design of 3-wavelength backward-pumped Raman amplifiers. Applying this method, we demonstrate Raman amplifier gain flattening over a wide band, by choosing either an appropriate power or wavelength distribution for a three-wavelength pumping source (3λ-PS) in the 1420-1480-nm band.

Our full numerical model of the Raman amplifier includes all of the most important physical effects affecting the Raman gain [4,5]: stimulated and spontaneous Raman scattering and their temperature dependences, Rayleigh scattering, arbitrary interactions between the pumps and the signal from both directions (signal-signal, pump-pump and signal-pump interactions) and high-order Stokes generation. As a measure of the gain ripple, we use the normalized parameter $\Delta G = (G_{max} - G_{min})/G_{min}$. To demonstrate our method, we consider implementations of a WDM system with 1-nm separated channels, and consider 40 channels within 1525-1565 nm and 75 channels within 1520-1595 nm intervals, with -10 dBm/channel power propagating through 25-km of SMF. We consider a 3λ-PS within the 1420-1480-nm band, with a total power of 1 W. Three optimization procedures are studied:

(a) three pumps equally spaced within a defined band (1420, 1450 and 1480 nm), with the powers of the individual spectral components variable, and;

(b) three pumps with equal power outputs, with the wavelength of the middle component being variable.

(c) three pumps with variable component powers and variable position of the middle component.

Thus, gain flattening is obtained by optimization of the lower and higher wavelength pump power ratios in case (a), by the optimization of the middle pump wavelength in case (b), and by simultaneous optimization of both parameters in case (c).

We note that there are two main applications of the Raman amplifier, for distributed and for discrete (point) amplification, respectively. In the first case, typically, the overall loss/gain balance should be equalized to zero, while in the second case the amplifying medium is required to produce overall gain at the fiber output. In this paper, we focus on flattening of the gain ripples of the module capable of producing output gain in the range 5-10 dB. We point out, however, that our proposed, simple method is generic, and can be used in a wide variety of scenarios.

In case (a), we have defined the relation between the powers of the lower and higher wavelength pumps by the non-dimensional parameter $k1 = (P_3 - P_1)/0.40$, where $P_3 + P_1 = 0.40$ W. The dependence of ΔG on the optimization parameter $k1$ is shown in Fig. 1. It may be seen that there exists a clear minimum at about $k1 = -0.6$, corresponding to $P_1 = 0.32$ W and $P_3 = 0.08$ W. The gain contour for the obtained value of the parameter $k1$ is shown in Fig. 2. The gain

0-7803-7500-9/02/$17.00

difference between ripples in the optimized amplifier is lower than 1.2 dB, and the average value of the small-signal optical gain is 8.1 dB. Two other gain contours are also shown in the same figure for different values of the parameter *k1* in order to make the effect of the gain flatness optimization visible.

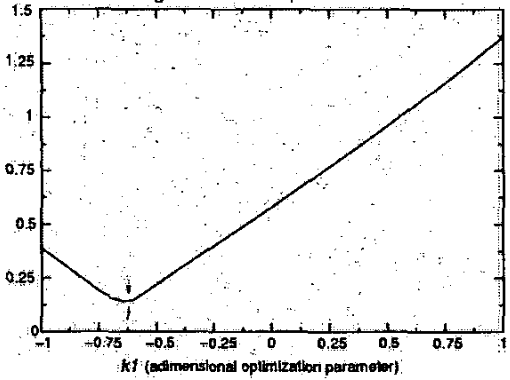

Fig.1. Dependence of the gain flatness ΔG on the optimization parameter k1.

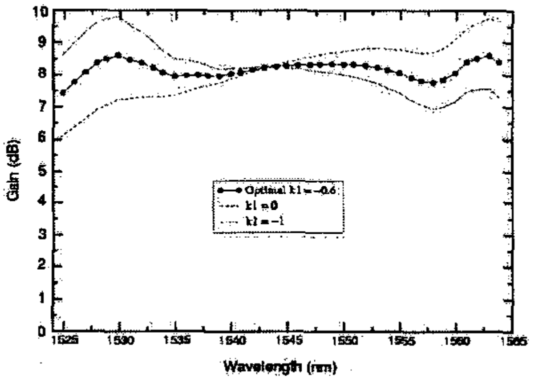

Fig.2. Small-signal optical gain contours for different values of the parameter k1.

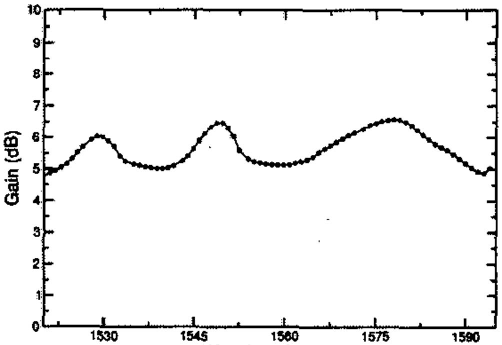

Fig.3. Optimized gain contour for case (c).

As a next step, we have analyzed case (b), in which we keep with equal pump powers. The lowest and highest wavelength pumps, each providing 1/3 of the total power, are fixed at 1420 and 1480 nm, respectively; the spectral location, ν_2, of the middle pump with the same power of 1/3 W was this time optimized, through the adimensional parameter $k2 = (\nu_2 - \nu_1)/(\nu_3 - \nu_1)$, where $\nu_{1,2,3}$ are the frequencies of the corresponding pumps ($\nu_1 > \nu_2 > \nu_3$). As in the previous case, we find here that the gain flatness parameter, ΔG, has a clear minimum, in this case at about $k2 = 0.35$, which corresponds to a wavelength $\lambda_2 = 1437$ nm for the middle pump. The optimized gain profile presented ripples < 1.9 dB over the 75 nm spectral range, with an average gain of about 5.5 dB.

Finally, we have proceeded with case (c), perfoming simultaneous optimization of the pumps power ratio and position of the central pump, using a simple downhill minimization algorithm, focusing on further optimization in the same broad band as in case (b), 75 nm. Using a simple downhill simplex method, we find that the optimal values of k1 and k2 are, respectively, -0.02 and 0.28, corresponding to pump powers of 339 mW, 333 mW and 328 mW, With the central pump positioned at 1437.2 nm. The optimized gain profile obtained is shown in Fig. 3. The average gain obtained is again about 5.5 dB, but the ripples have been reduced now to < 1.7 dB.

Conclusions

We have proposed and demonstrated a simple and efficient direct method to optimize the design of 3-wavelength Raman amplifiers. For a backward-pumped amplifier, we have determined the optimal power ratio of the pumps with regularly spaced spectral components, and the optimal spectral locations for the individual pump components in the case where each delivers an equal power. We finally have demonstrated that marginal further improvement of the gain flatness can be obtained in a broad bandwidth of 75 nm by simultaneous optimization of both the external pumps power ratio and the spectral position of the central pump. The composite Raman gain spectrum from the 3λ-PS with a total pump power of 1W is able to provide an average gain of 8.1 dB with ripples < 1.2 dB to 40 channels spaced 1 nm, and an average gain of 5.5 dB with ripples < 1.7 dB for 75 channels over over a broad bandwidth of 75 nm.

References

1. S.Namiki et al. IEEE J. of Sel. Topics In Quant. Electr., v.7 (2001), pp. 3-16.
2. M. Yan et al. IEEE Photon. Tech. Lett., v.13 (2001), pp. 948-950.
3. V. Perlin and H. G. Winful, OFC'2002, TuJ1, (2002), pp. 57-59.
4. H.Kidorf et al. IEEE Photon. Tech. Lett., v.11 (1999), pp. 530-532.
5. N.Park et al. IEEE Photon. Tech. Lett., v.12 (2000), pp. 486-1488.