

Optimal design of Raman amplifiers for optical fiber communication systems

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The gain and noise figure optimization of Raman amplifier is carried out for single-mode fiber (SMF) and dispersion-shifted fiber (DSF) with simple WDM pumping scheme. For SMF a 16 dB gain with 100 nm bandwidth and for DSF, a 34 dB gain with 95 nm bandwidth is obtained.

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1. Introduction

The dramatic growth of data and internet traffic demanded rapid deployment of the wavelength-division-multiplexed (WDM) systems to increase the channel capacity and transmitting distance. The WDM systems based on EDFAs were used widely because of broad-bandwidth, lower coupling loss, higher saturated power and so on. Even though the entire band of EDFA is fully utilized and very high spectral efficiency was obtained through soliton technologies, the demands from internet associated services still seem to keep on growing. The demand cannot be fulfilled by EDFA based WDM technology because this technology is hitting the upper limit of transmission capacity. It is the Raman amplifier which can enhance the system capability at this juncture because of its potential to offer gain at any wavelength as long as a suitable pump laser can be found at the suitable frequency [1,2].

Fiber Raman amplifier (FRA) can amplify photonic signals of any wavelength if there is a suitable pump source. The wide band and low noise distributed fiber Raman amplifiers (DFRA) are based on stimulated Raman scattering (SRS) [Fig. 1].

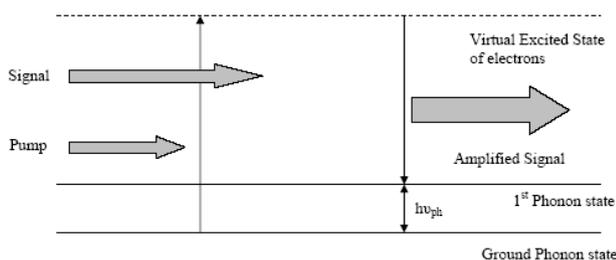


Fig. 1. Quantum mechanical picture of SRS process.

In case of continuous waves, the coupled equations [2] are given as,

$$\frac{dI_S}{dz} = g_R I_P I_S - \alpha_S I_S$$

and

$$\frac{dI_P}{dz} = -\frac{\omega_P}{\omega_S} g_R I_P I_S - \alpha_P I_P \quad (1)$$

Here I_P and I_S are the intensity of pump and signal, g_R is the Raman gain coefficient, α_P and α_S are the fiber loss coefficient at pump and signal wavelength respectively, and ω_P and ω_S are angular frequencies of pump and signal respectively. The light signal is amplified during propagation in fiber because of the stimulated Raman scattering of the pump light. The signal intensity I_S can be written as

$$I_S(L) = I_S(0) \exp[g_R I_P L_{eff} - \alpha_P L] \quad (2)$$

The effective fiber length L_{eff} is defined as

$$L_{eff} = \frac{1 - \exp[-\alpha_P L]}{\alpha_P} \quad (3)$$

$I_S(L)$ and $I_S(0)$ represent stokes wave intensity at $z=L$ and $z=0$ respectively. If there is no pump light then

$$I_P(z) = I_0 \exp[-\alpha_P z]$$

and the gain of amplifier is given by

$$G_R = \exp(g_R I_0 L_{eff}) \quad (4)$$

The noise figure (NF) of Raman amplifier can be defined as

$$NF = P_{ASE} / h\nu B_0 + 1/G \quad (5)$$

where P_{ASE} is the amplified spontaneous emission and B_0 is the bandwidth of amplifier. EDFAs are lumped amplifier in which the gain is lumped at a point of the transmission line. On the other hand, distributed amplifiers such as fiber Raman amplifiers, retain the optical signal level over a long distance along the transmission line. In principal the distributed amplification shows better system performance [Fig. 2].

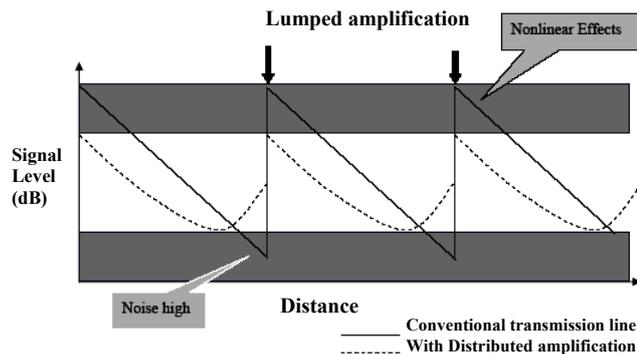


Fig. 2. Schematic diagram to compare a distributed and lumped amplifier.

The fiber Raman optical amplifier is quickly emerging as an important part of long-distance, high capacity and high speed optical communication systems [3,4]. The decreasing cost of high-power semiconductor lasers and increasing need in optical fiber transmission for more gain bandwidth, lower gain-ripple and lower noise figures makes Raman amplification a more attractive technology than the traditional EDFA. Raman amplification can be used for the design of an arbitrary gain contour by combining several pump sources. By a proper choice of the pump power and wavelengths it is possible to reduce the gain-ripple [5] of the corresponding Raman gain contour in a broad wavelength range.

Gain flattening of the broad-band Raman amplifier is one of the most important tasks for the designers. Different pump techniques are being used for Raman gain flattening. The traditional one is “WDM pumping” which employs a set of several 14XX- nm diode laser pumps with optimized wavelengths and/or power.

The optimization procedure has been developed that allows for a choice of pump frequencies and power in order to achieve the best possible gain flatness over a specified signal bandwidth. This procedure chooses not only optimal pump powers but also their wavelengths allowing any possible values within a realistic range of values. The beauty of WDM pumping arises not only from the wide band gain flatness, but also from the fact that the output power necessary for each pump laser may be reasonably small as the total pump power is diversified. Furthermore, WDM pumping allows to realize bandwidth upgradeability and robustness by redundancy as well as better thermal dissipation for higher efficiency of Raman

amplification and helps Raman amplification to be significantly practical [6-8].

An alternative to WDM pumping could be either specially broadened pump sources or a single pump source that is fast tunable in wide wavelength range (“SMART” Raman pumping). However, this pump scheme has not yet been realized [8-11].

In this paper gain and NF is optimized for SMF and DSF with simple WDM pumping scheme. The proposed configuration is cost effective, simple and advantageous. The optimization is done simply by allocating suitable pump powers at suitable wavelengths.

2. Experimental set-up

The schematic diagram of Raman amplifier is shown in Fig. 3. The system for gain and noise figure optimization consists of a multiple signal laser, two isolators, a WDM coupler, a multiple pump laser (in count-12) and an optical spectrum analyzer. The gain and NF are calculated for both 30 km of SMF and DSF. Input isolator prevents ASE and signals from propagating in backward direction. Otherwise it may reduce population inversion which leads to reduction in gain and enhancement in noise figure. Backward pumping is preferred for Raman amplification because it gives better conversion efficiency and noise figure.

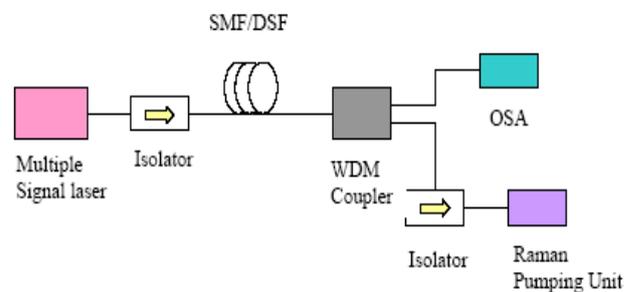


Fig. 3. Schematic diagram for Raman amplification in single-mode fiber/ dispersion shifted fiber.

3. Results and discussion

To evaluate the gain and noise performances, gain and noise figure are measured as function of signal wavelength for both SMF and DSF of length 30 km each. In case of SMF multiple signal laser (each with line-width 0.1 nm) is used with -60 dB power each. Raman pumping unit consists of 12 pump LDs with total power almost 725 mW. By simply adjusting the pump wavelengths and pump powers, a 16 dB gain with gain flatness of 100 nm is obtained. In this case gain ripple of almost ± 0.2 dB is observed. Raman gain in DSF is as high as 34 dB with 95 nm flatness and gain ripple is about ± 0.25 dB. For same signal power and wavelength 630 mW pump power is needed for DSF [Fig. 4, 5].

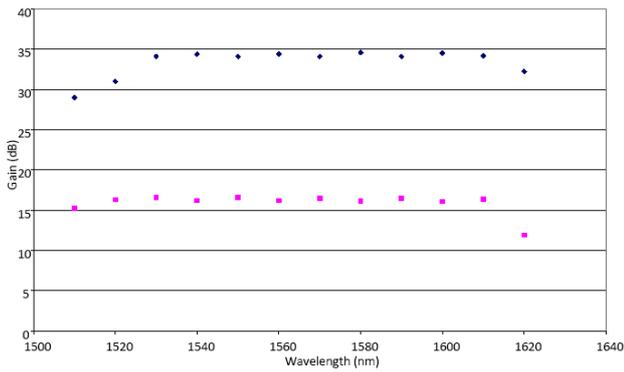


Fig. 4. Raman gain spectrum for single-mode fiber and dispersion-shifted fiber.

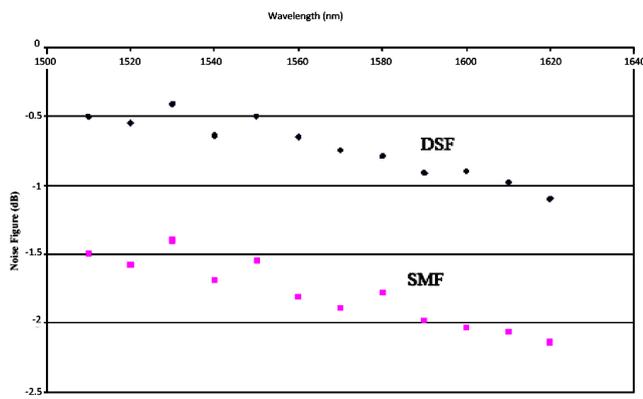


Fig. 5. Noise figure spectrum for single-mode fiber and dispersion-shifted fiber.

In case of DSF gain is high as compared to SMF because of lower effective cross sectional area and higher Raman gain efficiency [Fig. 6]. Noise figure in both cases is slightly high in lower signal wavelength region because of allocation of higher pump energy in this range. Thermal instabilities, pump-to-pump Raman interactions and power fluctuation in pumps result in more NF in lower signal wavelength region. Over entire signal band noise figure is well below the 3 dB quantum limit and mostly negative, indicating the noise improvement due to DRA.

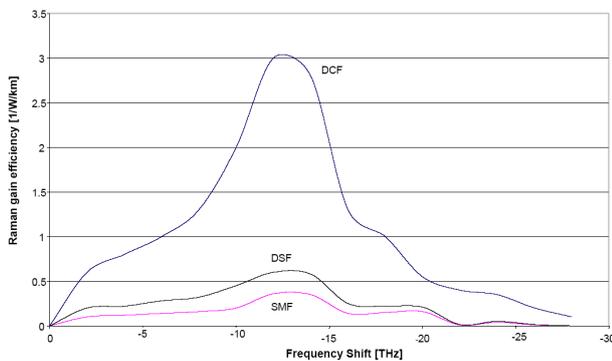


Fig. 6. Raman gain efficiency spectra for SMF, DSF and DCF.

Lumped Raman amplifiers (LRAs) based on dispersion shifted fiber (DSFs) can compensate both fiber dispersion and span loss simultaneously and have been successfully used in many long-haul transmission systems. Therefore an attempt to optimize the gain and noise figure of DSFs is advantageous for LRAs. A distributed Raman amplifier (DRA) having more than 20 dB gain in SMF is challenging because of two reasons: first, pump power necessary to achieve such a high gain in SMF is more than 1W and is still challenging even though we have very powerful state-of-art pump lasers. Second, too much distributed gain results in undesirable effects called double Rayleigh-back scattering (DRB) and this deteriorate the signal quality.

In order to make Raman gain flat, a gain flattening filter could be used just as done in EDFAs. However the use of such components leads to the lower efficiency and higher cost. Indeed, utilizing the feature of gain at any wavelength, a flat Raman gain can be composed by simultaneously launching pumps at different wavelengths. In this way Raman gain are slightly shifted from each other so as to partly overlap each other forming a composite gain. By properly choosing pump wavelengths and pump energy, the composite Raman gain can be very flat over a wide band.

4. Conclusions

The gain and noise figure optimization for Raman amplifier using 30 km SMF and DSF is carried out with simple WDM pumping scheme. A gain of 16dB with 100nm gain flatness is obtained for SMF. In case of DSF gain is 34dB with 95nm flatness. Gain ripple is 0.2dB and 0.25dB for SMF and DSF respectively. Over entire signal band noise figure is below 0.5 dB for DSF and below 1.5 dB for SMF with negative sign.

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