Technical University of Denmark

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Xu, Zhenbo; Rottwitt, Karsten; Jeppesen, Palle

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An investigation of different Raman amplification configurations in 160 Gbit/s transmission

Zhenbo Xu, Karsten Rottwitt, Palle Jeppesen
Research Center COM, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark Email:xuz@com.dtu.dk

Introduction

Distributed Raman amplification become very attracting with various merits such as more flatten gain profile, higher OSNR along the fiber. However, up to now there are few papers that present numerical comparisons between different pumping schemes[1]. In our work, different Raman pumping schemes are numerically simulated with newly developed super large core area fiber (SLA) at 160 Gbit/s single channel for the first time. We find the optimal scheme is middle pump scheme. Transmission distance of 1700 km is predicted and shorter pulse is preferred.

Raman model and span setup

Regarding single channel systems, pump depletion is not taken into account in our model. Spontaneous Raman scattering distributed across the whole Raman gain bandwidth and Rayleigh backscattering act as the main noise sources. Because stimulated Raman scattering generated by the pump is strongly polarization dependent, in order to get a realistic gain, we use half of the maximum gain under condition of aligned polarizations between signal and pump. All the terms with gain coefficient are multiplied by 0.5. Simplified signal, pump and noise power equations for co-propagating pumping are as follows: $\frac{dP_s}{dz} = 0.5\times g_R P_p P_s + \eta P_R - \alpha_s P_s$ $\frac{dP_p}{dz} = -\alpha_p P_p$ $\frac{dP_n}{dz} = -\alpha P_n + \eta P_n + 0.5\times g_R P_p P_n + g_R N P_p$

Here P_s is signal power, P_p pump power, P_n noise power, P_R Rayleigh backscattering power, g_R gain coefficient and η Rayleigh backscattering. Fiber loss α_p, α_s are assumed here as same value. The factor N[2] represents spontaneous Raman scattering factor independent of polarization. SLA with dispersion 20ps/nm/km, disp.slope 0.06ps/km/nm^2, loss 0.2dB/km, A_{eff} 105μm^2, g_R 0.5(W·km)$^{-1}$. Inverse dispersion fiber dispersion(IDF) with dispersion -20ps/nm/km, disp.slope -0.06ps/km/nm^2, loss 0.25dB/km, A_{eff} 30μm^2, g_R 1.5(W·km)$^{-1}$. Here SLA and IDF have same value at η 5.8*10^{-8} (1/m) and N_2 2.6*10^{-20}. Symmetrical dispersion map is used and span length is 100 km. Considering trade off between calculation time and BER calculation accuracy, a 512 bit PRBS sequence is adopted with Gaussian pulse shape, signal and pump wavelength is 1552nm, 1450 nm respective. Figure 1 shows different Raman pumping schemes. For all backward pumping, we assume that SRS effects only take place in the fibers which directly connected to the pumps. However, for the forward pump, we assume it will affect all the fibers cascaded in front of it. A simple receiver is used after an optical filter with bandwidth 480GHz. For all cases, EDFAs launch fixed power signal level at input of span.

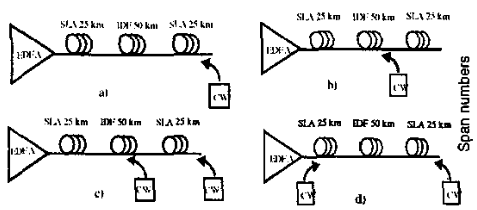

Figure 1. Raman Setup

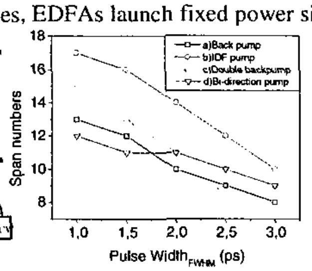

Figure 2. Distance and pulse width

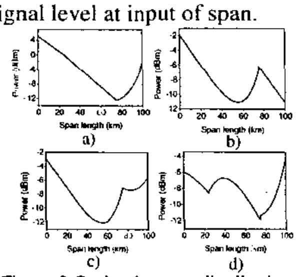

Figure 3 Optimal power distribution inside span

Numerical results

After power calculation along fibers, NLSE equation including dispersion, dispersion slope and nonlinearity is solved numerically and with split-step algorithm[2]. Available transmission distance at BER 1.0e-9 as a function of pulse width for different Raman pump schemes is shown at Fig. 2. It shows that transmission distance increases with shorter pulse width. Middle pumping from IDF is better than other pumping schemes with longest transmission distance 1700km. Optimal power evolution inside spans are shown in Figure 3 with initial pulse width 1ps. It is found that, although optimal pump level changes significantly for different pump configurations, the optimal power distribution range for same pump configuration stays constant regardless of pulse width variation. It can clearly be seen that IDF, double back and bi-directional pumping give smaller power level variation than back pumping around 9 dB, which is important for optimal OSNR. IDF has smallest average power level, which gets least nonlinearity effect compared to other schemes. Included with these Raman noise sources mentioned above in the signal spectrum, which would be the case in reality, the balance between smaller power variation and generated Raman noise should be carefully designed.

Conclusions

Different pump schemes are compared and the optimal pumping scheme found to be IDF pumping with the lowest average power and least nonlinearity. Transmission distance of 1700 km can be obtained with 100 km span length. In all the cases shorter pulses give better performance. Optimal pump range is stable against pulse width variation.

Reference

1. R.H "Comparison of span configurations of Raman amplified dispersion managed fibers" PTL,Vol.14, No.4, 2002
2. VPItransmissionMaker -VPIcomponentMaker, Virtual Photonics Incorporation

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