Numerical simulation of point to point transmission in a 40 channel 40 Gbit/s system with three different modulation formats and two types of gain flattened amplifiers : discrete versus distributed amplification

D. Dahan and G. Eisenstein

Electrical Engineering Department TECHNION
Haifa 32000 ISRAEL
Tel : +972 4 8294694 Fax +972 4 8323941 gad@ee.technion.ac.il

Abstract : We describe numerical simulations of fourty - 40 Gbit/s channel transmission at 100 GHz detuning. Discrete and distributed amplification are compared for three possible modulation formats at different transmission distances.

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Summary

The transmission properties of dense DWM systems are determined by a variety of complicated mutually interacting non-linear phenomena. Understanding and quantifying these systems calls for detailed modeling which in turn require numerical simulations. This paper describes a comprehensive simulation of a multi wavelength point to point transmission system based on the IST - METEOR project specifications which include 40 channels each operating at 40 Gbit/s. The wavelength separation between channels is 100 GHz and the transmission distance ranges from 75 Km to 375 Km. The simulation compares discrete and distributed amplification for three modulation formats NRZ, RZ and CS-RZ. Distributed amplification uses multiwavelength Raman amplification while for the discrete amplifier we assume an ideal gain block with frequency independent gain and noise figure (NF = 4 dB). The distributed Raman gain configuration is found to be superior in all cases. Linear dispersion is assumed compensated while the polarization mode dispersion is considered only to first order with PMD values characteristic of high quality modern fiber, 0.15 ps / $Km^{0.5}$. The mutual interaction of PMD and the Raman gain is included together with all other fiber nonlinearities.
Figure 1 shows schematically the distributed gain link configuration. Each transmission span consists of 75 Km single mode fiber, six backward pump sources at different wavelengths ensuring the broad, flat Raman gain spectrum which is slightly larger than the fiber losses. Linear dispersion is perfectly compensated for by a 15 Km long DCF.

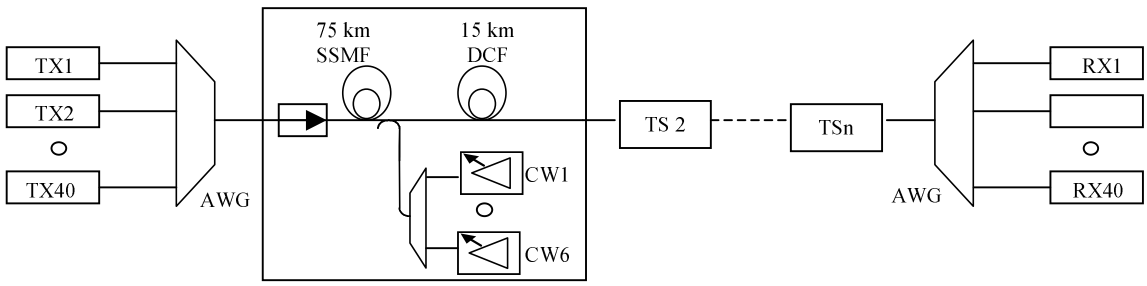

Fig. 1 : Schematic of Transmission link with backwards pumped distributed Raman amplification

For the distributed Raman amplifier we examined both forward and backward pumping. The two possibilities are compared in Fig. 2, which shows for each the evolution along the transmission span of pump power together with signal and noise power at all 40 channels. The forward pumped case exhibits a better optical signal to noise ratio at the output but the signal power close to mid span is higher and therefore the effects of nonlinearities may be more severe. The transmission span with the discrete amplifier comprises a 75 km fiber with an ideal gain block followed by the 15 Km DCF. For each configuration, the total transmission distance comprises one to five identical spans.

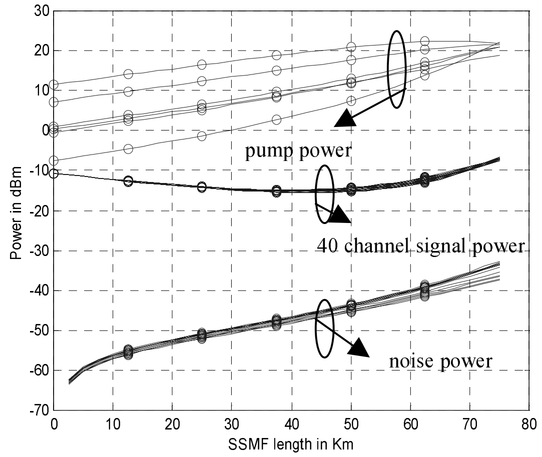

Fig. 2a : Backward pumped configuration

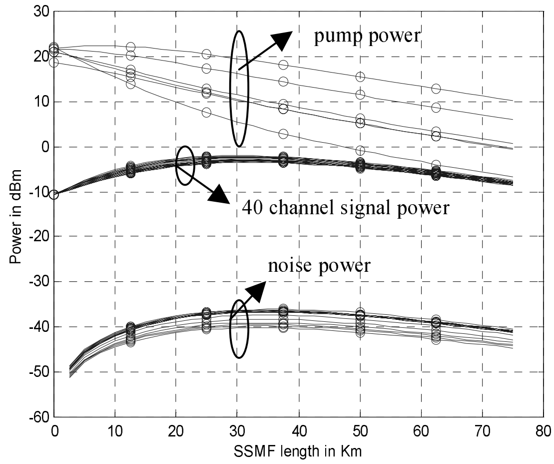

Fig. 2b: Forward pumped configuration

In the transmission simulations we consider NRZ modulation and two types of RZ. Conventional RZ is generated from a 50 % electrical RZ signal driving a modulator fed by a CW signal. The resulting optical RZ signal has a duty cycle of 62.5 %. The carrier suppressed RZ is generated by two cascaded differential Mach Zender modulators the first modulates a CW signal with an NRZ drive at 40 Gbit/s and the second is driven by a 20 GHz sinusoidal signal while the modulator is biased at V_{Π} [1]. The resultant duty cycle is 87.5 %. The average power per channel is kept constant and low so that the total power launched into the fiber following the multiplexer is only 3.4 mW. The multiplexer and demultiplexer are modeled as hyperbolic tapered horn filters with a bandwidth of 78 GHz.

The numerical model uses our own numerical tool for the fiber transmission part. It is developed in Matlab and integrated in the Virtual Photonics software environment. It uses the coarse step method approach to simulate dispersion, nonlinearities and first order PMD, with a special care in resizing the PMD strength to its original value in the statistical sense and in distributing uniformly the optical state of polarization (SOP) on the Poincare sphere [2].The Raman gain factor is assumed to occur for parallel signal and pump polarizations. As the PMD makes the polarization of the signals and pumps rotate with respect to one another over all the possible SOP, we assume that the pumps are unpolarized so that both orthogonal signal polarizations undergo Raman amplification during the transmission.

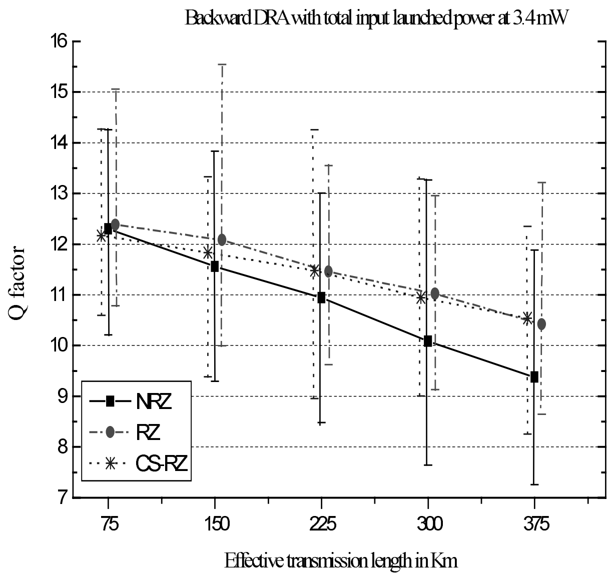

Fig 3a : Q factor for the backward pumped DRA case

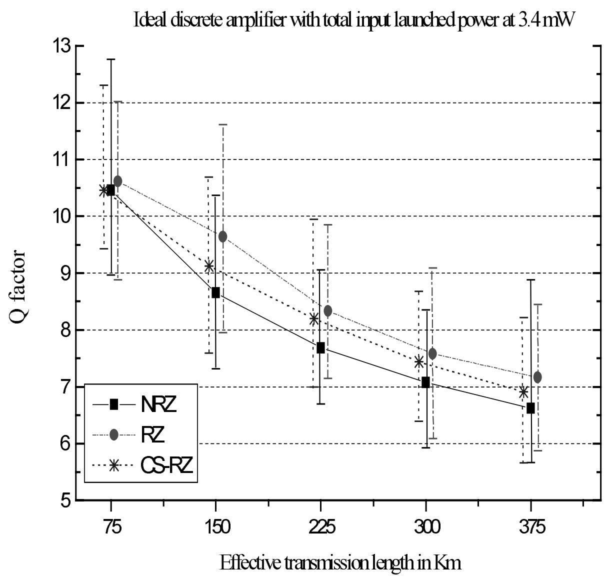

Fig 3b : Q factor for the discrete amplifier case

The simulated transmission results showing the calculated Q factor as a function of distance are described in Fig. 3 where the range of Q factors for the 40 channels is shown separately for each modulation format at the output of each transmission span together with the median value. Figure 3a describes the case of backward pumped Raman amplification where we observe that the worst results are obtained for the NRZ format but even it reaches a Q factor larger than 7 at an effective transmission distance of 375 Km. The RZ format is found to be somewhat better than the CS – RZ.

This is due to the fact that distributed amplification moderates the influence of nonlinear effects in particularly here where relatively low powers are used. Figure 3b shows the results for the discrete amplification case (with ideal gain flattened gain blocks). Here the NRZ gives unacceptable Q factor values at the large distances and again, due to the low power the RZ achieves higher Q factor values than the CS – RZ. At higher powers, when the deterioration due to nonlinearities is much larger, the NRZ format is expected to fail at shorter distances yet and the CS – RZ should be superior to the RZ in either type of gain configuration.

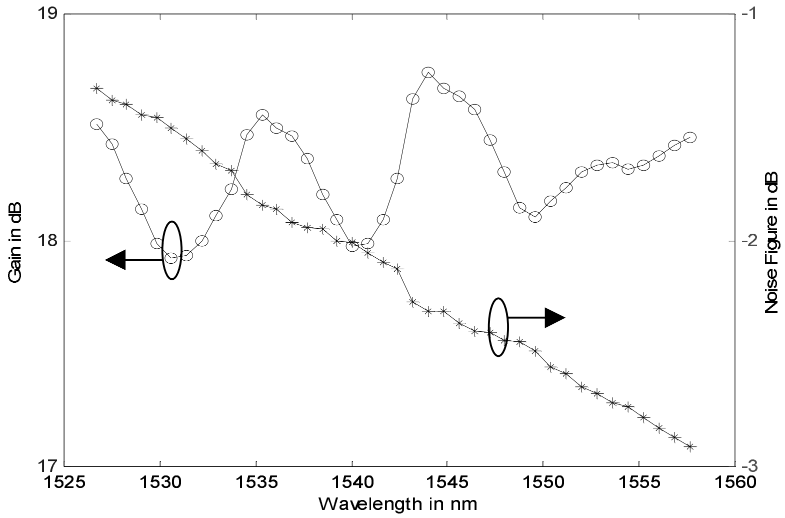

Fig 4 : Gain and Noise figure of the distributed Raman amplifier

The main interest in using the distributed Raman amplification is that the amplification extends over all the transmission length and it is equivalent to placing a string of line amplifiers. Therefore, the signal level is always better than at the end of an unpumped transmission fiber. We define the gain and the noise figure of the distributed Raman amplifier with respect to the signal at a reference unpumped fiber. To make significant comparisons with the discrete amplifier, the Raman gain has to be considered as lumped at the end of the transmission distance, so we have to remove the total loss of the transmission fiber [3]. In such a case, the noise figure of the Raman amplifier becomes negative. The gain and noise figure of the distributed Raman amplification are shown in Fig. 4. With a total pump power less than 800 mW, we achieved a gain flatteness better than 0.8 dB with an average gain of 18.2 dB over 33 nm and very low noise figures.

Conclusion

Using numerical simulations, we have demonstrated the advantages of using distributed Raman amplification for fourty 40Gbit/s channel system for different modulation formats. The DRA allows to reach error free transmission at distances where the most ideal discrete amplifier fails and with low total average power.

Acknowledgement

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References

1 A Hirano, Y. Miyamoto, K. Yonegana, A. Sano and H. Toba "40Gbit/s L-band transmission experiment using SPM tolerant carrier-suppressed RZ format", Electron. Lett. **35**, 2213-2215 (1999).

2 D.Marcuse, C.R. menyuk, P.K.A. Wai "Application of the Manakov-PMD equation to studies of signal propagation in optical fibers with randomly varying birefringence", J. Ligtwave Technol. **9**, 1735-1745 (1997).

3 Characterizations of fiber amplifiers in "*Fiber amplifier user's manual*", VPIcomponentMaker, Virtual Photonics Incorporated