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Performance Investigation of L- Band Raman Parametric Amplifier cascade for 96 X 100 Gbps Dense Wavelength Division Multiplexed System

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Abstract

We investigate the use of highly non-linear fibers (HNLF) for Raman amplification in Raman-Fiber optical parametric amplifiers (RA-FOPA) hybrid. We demonstrate gain enhancement of minimum 13.32 dB using RA-FOPA cascade in 96 X100 Gbps high data rate, Dense Wavelength Division Multiplexed system (DWDM) compared to Raman- assisted parametric amplifiers used. The use of HNLF for Raman amplification has been investigated and results compared with use of Single Mode Fibers (SMF). The results show long length SMF interaction to given high gain but HNLF offers more gain uniformity with low peak to peak gain variation and ripple as low as 2.1 dB.

***Keywords**: Parametric amplifiers, Raman amplifier, DWDM*

INTRODUCTION

The increase in demand for larger bandwidth and lower gain-ripple is limiting the spectrum of C+L bands characterized with low transmission loss and high gain. The need for wide bandwidths with high gain has made optical parametric amplifiers and their hybrid amplifiers more attractive than traditional EDFAs, which are limited up to 40 nm bandwidth around 1545 nm for a single amplifier and up to 80 nm bandwidth around 1565 nm for multiple stage amplifier [9].

Availability of high-power compact pump lasers, has given impetus to research in FRAs and FOPAs for achieving flat gain over extended bandwidths. Golovchenko et al [10] examined the phase mismatch parametric gain and have demonstrated that the gain depends strongly on the real part of the complex Raman susceptibility. In conventional RA-FOPAs, most energy from the Raman amplifier is trapped in the parametric pump at the output end of the amplifier. Wang et al [11] proposed a hybrid fiber Raman/parametric amplifier (HFRPA) constructed by cascading a FOPA after the RA-FOPA. Wang numerically demonstrated 70 dB peak small signal gain in 1-km HNLF with 1.5 W and 0.2 W Raman and parametric pump powers, respectively for 8 channel WDM system resulting in gain enhancement of 34 dB compared to a conventional RA-FOPA for same parametric pump powers. Ummy et al [12] demonstrated the extended flat gain of about 15 dB of with gain ripple of 5 dB, using combined Raman and parametric interaction in HNLF. Peiris et al [13] demonstrated hybrid Raman-Optical Parametric amplifier (HROPA) in Tandem configuration for extended bandwidth, with gain more than 20 dB and extended gain bandwidth of 170 nm and gain ripple of less than 4 dB. The tandem configuration used concept of single pump FOPA for two sub-bands and crosstalk of idlers controlled through multiplexer filter transfer function. In [14] improved performance with RA-FOPA for WDM system has been achieved with net gain of 20 dB and gain ripple of 1.9 dB for 10 , 100 GHz spaced DFB lasers. Use of tunable NRZ signals showed reduced susceptibility to saturation of gain in Raman-FOPA hybrid [15].

In all the above discussed FRA-FOPA configurations either same short length HNLF fiber is used as in Raman-assisted parametric amplification or small sections of HNLF are used each for Raman amplification followed by parametric amplification [10-12, 14]. Parametric amplification is generally implemented in short length HNLF whereas Raman gain process requires long interaction lengths, in this paper we investigate the use of varying fiber lengths of HNLF for both Raman as well as parametric amplifiers Vs use of traditional SMF based Raman amplifier in cascaded configuration with HNLF parametric amplifier.

EXPERIMENTAL SET UP:

Experimental set up is shown in figure 1. The transmitter consisted of 96 WDM, 25 GHz equally spaced channels ranging from 187 THz to 189.375 THz. The channels are driven by NRZ, 100 Gbps signal with total input power of 3mW. In proposed system, 100 Gbps [8] signal has been chosen to model future, high data rate DWDM systems. In our model, the state of polarization of the input and pumps is assumed to be aligned, which may not always be true in practical system. The signals are then input to

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Raman-FOPA amplifier. The input power per channel fed to amplifier black box is -18.5 dBm. The Raman-FOPA hybrid comprises of Raman amplifier with 15 pumps ranging from 1460 nm- and 1530 nm equally spaced at spacing of 5 nm.

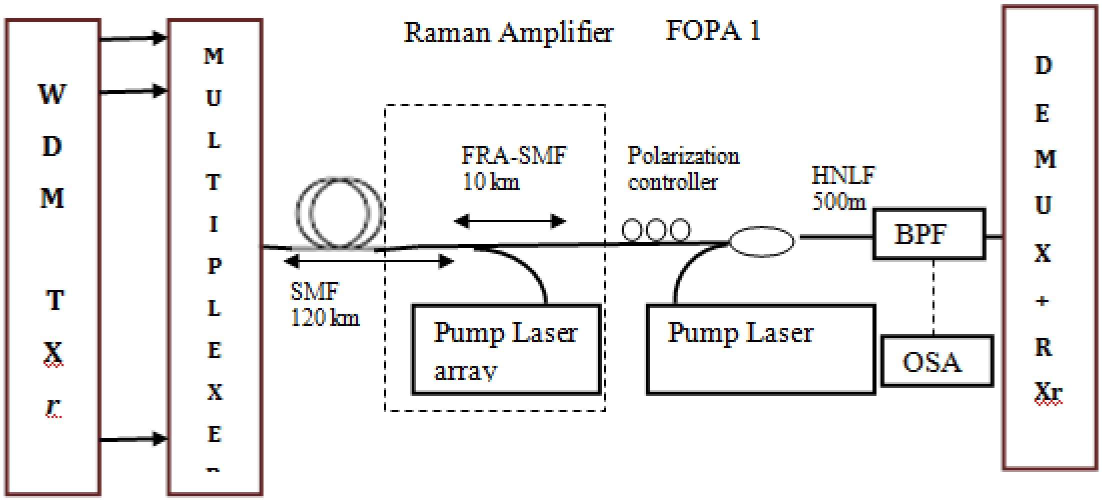

Figure 1: Schematic of Set up implemented

The signal amplified is fed to HNLF section of 500 m with α=0.8 dB/km, ZDWL at 1609 nm, dispersion of 2 ps. nm^{-1}. Km^{-1} and dispersion slope 0.025 ps. nm^{-2}. Km^{-1} and λ_p= 189.325 THz nm with 4 dBm power. The output is filtered through a Band pass Filter (BPF) before being fed to demultiplexer and Receiver section.

The proposed schematic is governed by

$$G_{total}=G_{Raman} * G_{FOPA} \quad (1)$$

Where $G_{Raman} = 10.\log_{10}\left(exp\left(\frac{g_{R.P.L_{eff}}}{A_{eff}} - \alpha L\right)\right)$ and G_{FOPA} is the gain of parametric sections

$$G_{FOPA} = 1 + \left(\frac{\gamma P}{g}\sinh(gL)\right)^2 \quad (2)$$

Where $g=\sqrt{(\gamma P)^2 - \left(\frac{K}{2}\right)^2}$ for single pump FOPA.

RESULTS AND DISCUSSIONS:

The previous work done in RA-FOPA hybrid [2], [4], [6] focuses on Raman assisted parametric pumping configuration in same length of fiber that is short length of HNLF. But Raman susceptibility affects parametric interactions in single pump FOPA as:

$$\frac{\partial A_3}{\partial z} = 2qA_3 + qA_4^* e^{-iKz} \quad (3a)$$

$$\frac{\partial A_4^*}{\partial z} = -2qA_4^* - qA_3 e^{iKz} \quad (3b)$$

for signal and idler, respectively. Here q= (iγ + δ) P_0. 'γ' represents non-linear coefficient of HNLF and 'δ' represents interactions due to Raman susceptibility.

We compare our proposed system with Raman assisted under similar pump and input power. Figure 2 shows result which clear confirms higher gain due to Raman amplifier with long length SMF in cascade instead of short length HNLF Raman assisted pumping. Cascaded Raman uses amplifier 10 km of SMF whereas 1.2 km of HNLF is used in traditional Raman-assisted parametric set up.

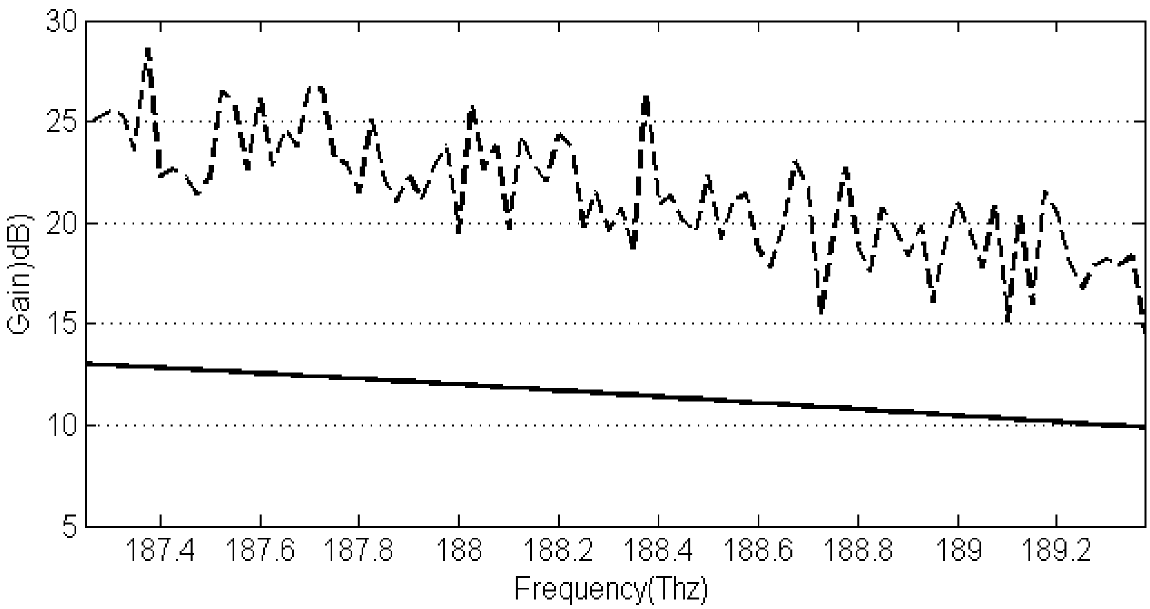

Figure 2: Gain comparison of cascaded Raman-FOPA (dashed curve) vs Raman assisted FOPA (solid Curve)

The given system used proposed Raman-FOPA cascade as inline amplifier after traversing 75 km of distance. To understand the use of HNF vs SMF for Raman amplifiers we test the WDM system with 10km of SMF Vs 1.2km HNLF. The highest gain achieved using cascaded RA-FOPA is 26.6 dB for 96 X 100 Gbps Dense WDM systems with 25 GHz spacing. On the other hand for same system Raman assisted FOPA gives maximum gain of 13.28 dB. The gain ripple for former is 12 dB while latter has ripple of 3.41 dB.

Since much higher gain is achieved using Raman-FOPA cascade we investigate use of HNLF Vs SMF for Raman amplification for cascaded system. Results are shown in Figure 3. In figure 3a it clearly shows high gain is achieved using SMF and even peak to peak gain variation is lesser in SMF based Raman amplifier. Maximum gain for SMF is 18.48 dB and minimum gain is 11.81 dB giving the gain ripple of 6.7 dB which highest gain for L-band amplifiers DWDM system with 25 Ghz spacing. Use of HNLF for Raman amplifier in same system configuration gives highest gain of 17.39 dB and minimum gain of 9.86 increasing the ripple to 7.53 dB.

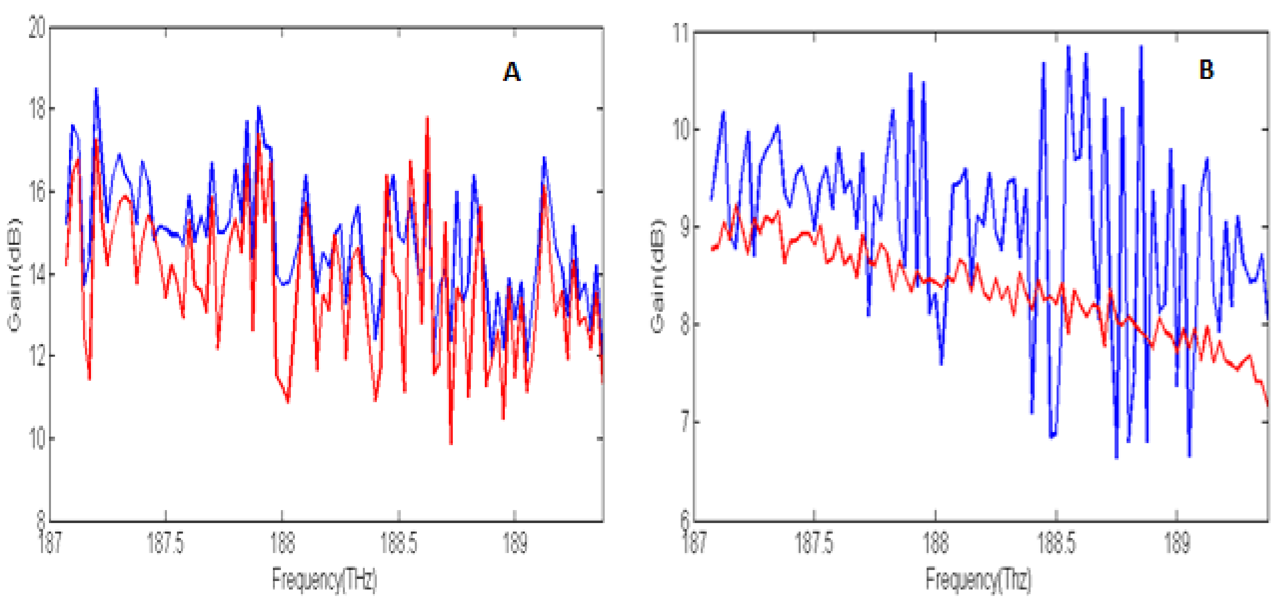

Figure 3a: Comparison for use of 1.2 km HNLF in Raman amplifier (red curve) Vs use of 10 km SMF after 75 km transmission.

Figure 3b: Comparison of HNLF vs SMF for Raman amplifier in 120 km DCF compensated system.

Figure 3b shows the results for dispersion-compensated system where 120 km of transmitting fiber is dispersion compensated by 20 km of DCF. For SMF Raman amplifier highest gain achieved is 10.84 dB while minimum gain is 6.62 dB which gives reduced ripple of 4.22 dB. In contrast HNLF based Raman amplifier in same system gives highest gain of 9.23 dB and minimum gain of 7.16 dB reducing ripple to 2.06 dB. But gain is monotonously falling towards higher frequencies. The gain reduction in figure 3b Raman gain is attributed to increase of transmission fiber length from 75 km uncompensated fiber in 3a to 120 km DCF compensated transmission fiber in 3b.

CONCLUSION:

The Raman-FOPA cascade has been proposed for DWDM system with 25 GHz channel spacing at high data rate of 100 Gbps system. Avery high gain is achieved using the proposed cascade over the previously existing Raman assisted FOPA hybrids. But it has high gain variation and very high ripple of 12 dB. Polarization sensitivity, pump wavelengths and pump powers optimization may lead to decrease in ripple and a Flat gain L band Raman-FOPA hybrid. Results for type of fiber used for Raman-FOPA cascade, clearly indicate use of SMF gives better amplification for Raman amplifiers as expected and confirmed by fact that Raman gain is length dependent and increases with fiber length till gain saturation limits it. So the Raman-FOPA hybrid for future WDM systems should focus on use of SMF based traditional Raman amplifiers in hybrid amplifiers.

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