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Performance Evaluation of Hybrid (Raman+EDFA) Optical Amplifiers in Dense Wavelength Division Multiplexed Optical Transmission System

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Abstract— In this paper hybrid optical amplifier is investigated by cascading configuration of distributed fiber Raman amplifier and Erbium doped fiber amplifier for 64 X 10-Gb/s dense wavelength division multiplexing operating at 100-GHz channel spacing. The main idea behind the investigations is to examine the optical link of Wavelength Division Multiplexing system using different types of amplifier like EDFA amplifier, RAMAN amplifier and their Hybrid configuration. At the input power of 3 mW and with the variation in the Raman fiber length (11, 15, 17 and 20 km) of Raman amplifier having two Raman pumps, a flat gain of > 30 dB is obtained in optical signal wavelength range 1540 nm to 1589.28 nm with gain flatness of 4.5 dB and noise figure < 0.8 dB. Also, using four Raman pumps a gain of more than 50 dB and gain bandwidth up to 34 nm are achieved. The gain ripple after length of 80 km and noise ripple after length 100 km of hybrid amplifier is found to be stable.

Keywords—*Wavelength Division Multiplexing (WDM), Hybrid Optical Amplifier (HOA), Erbium Doped Fiber Amplifier (EDFA), RAMAN Amplifier***.**

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I. INTRODUCTION

Hybrid optical amplifiers due to their wider bandwidth are important components of modern high speed dense wavelength division multiplexed (DWDM) optical transmission systems. Basically, it is a combination of different optical amplifiers to obtain the broad transmission bandwidth. Among the various hybrid optical amplifier configurations, Raman/EDFA is most preferred in comparison other, for broad bandwidth and other promised transmission characteristics [1, 6]. Erbium doped fiber amplifier (EDFAs) is very mature technology and its bandwidth is fully utilized for multichannel fiber optic transmissions. Distributed fiber Raman amplifiers (DFRAs) are nowadays essential components of all long haul and ultra long haul DWDM optical communication systems [2]. Moreover, DFRAs having improved noise figure and relatively low nonlinearity impact are preferred in hybrid optical amplification configurations. Broad bandwidth Raman amplifier design involves the considerations of multi pumping parameters such as number of pumps, pump wavelengths and powers [7]. Multi pumping of DFRAs improve gain, gain ripple, noise figure etc. Martini et. al. [3, 8] have compared and analysed of Raman+EDFA and EDFA+Raman hybrid configuration using pump optimizations and recycling.

Performance analysis of Raman/ EDFA hybrid optical amplifier in dense wavelength division multiplexed is a contribution to design of modern high capacity transmission systems. A lot of works have been reported in the literature on this issue but still there is big scope of improvement such as gain bandwidth needs to be addressed. S. Singh [1] had investigated the EDFA/DRFA gain and gain ripple by varying input power in range of 3 to 15 mW with channel spacing of 25 GHz in L band WDM optical communication systems. K, Singh et. al. [7] has solved propagation equations of multi pump fiber Raman amplifier using Runge-Kutta (RK 4th order) numerical method and pump power along with the fiber length. They utilized the pump power evolutions along the fiber to calculate the net gain and gain ripple by varying the input signal powers for different fiber lengths. Their model is very effective in design of distributed Raman amplifier in high capacity transmissions.

Moreover K, Singh et. al. [2, 13] has investigated the effect of counter propagating pumping in fiber Raman amplifier. Pumping options like single, two and seven counter propagating pumps are expressed and their effects on bandwidth and gain ripple are explored. K. Singh et. al. [9, 10] have analyzed dual order backward pumping in fiber Raman amplifiers in terms of on-off Raman gain, noise figure and optical signal-to-noise ratio. The investigations presented that a 50 mW second order pump is beneficial to reduce the noise figure tilt and 5 dB improvement in Q- factors in a multichannel optical fiber transmissions. Huri et. al. [4] use zerbium ion type EDFA in their hybrid configuration with semiconductor optical amplifiers. Shivani et. al. [3] proposed 20 X 50 Gbps Raman/EDFA hybrid configuration using eight pumps for Raman amplifier without connecting optical fiber in the transmission system.

Hybrid amplifier configuration increases the gain but gain flatness is main issue in long haul transmission systems. The channel spacing is another hurdle to obtain a high gain and noise free operation. The EDFA-Raman combination as a hybrid amplifier may a viable configuration as compare to other combinations. To estimate its performance the metrics like gain, noise figure, and bandwidth are required to be critically analyzed. Although gain flattening techniques and useful in achieving desired performance but they are costlier. So there is a scope for reinvestigating the RAMAN+EDFA combination as a Hybrid configuration.

After this introductory part, the simulation setup of hybrid configuration is explained in Section II. Section III describes the results and their explanations and Section IV summarizes the conclusions.

II. SIMULATION SETUP

Fig. 1 shows schematic of the proposed WDM optical fiber transmission system. From the transmitter side, 64 channel NRZ WDM transmitter at 10 Gb/s bit rate with wavelengths range from 1540 to 1589.28 nm, 100 GHz channel spacing is launched for analyzing the hybrid configuration. An ideal WDM MUX is employed to multiplex the channels. These multiplexed channels are launched in 100 km single mode fiber (SMF). To compensate the chromatic dispersion a 17 km dispersion compensating fiber (DCF) is employed at the end of SMF. The SMF and DCF dispersion, attenuation and other parameters selected during simulations are as listed in table 1.

The Raman amplifier with varied different length 11, 15, 17, 20 km is employed with effective interaction area of 75 μm^2 connecting with two/four backward signal pumps. The dispersion of 16 ps/nm/Km is enabled to Raman amplifier. The other parameters Rayleigh scattering coefficient of Raman amplifier, fixed value of gain and noise figure of EDFA are listed in table 2. The wavelength and power selected for pump signal given to Raman amplifier is mentioned in table 3.

An ideal WDM DEMUX is employed to demultiplex the channels. These demultiplexed channels are received by an optical receiver. To investigate parameters of hybrid optical amplifier such as gain, noise figure and OSNR, WDM analyser is connected to the ports of EDFA and Raman amplifier. At the receiver end, BER analyzer is connected to investigate performance parameters of hybrid amplifier. In case of HOAs (Hybrid Optical Amplifier) total gain is the product of separate gains of individual cascade amplifiers as report in [9]. The total gain of proposed DFRA-EDFA is (G_{RE}) and is given by,

$$G_{RE} = G_{Raman} + G_{EDFA}$$

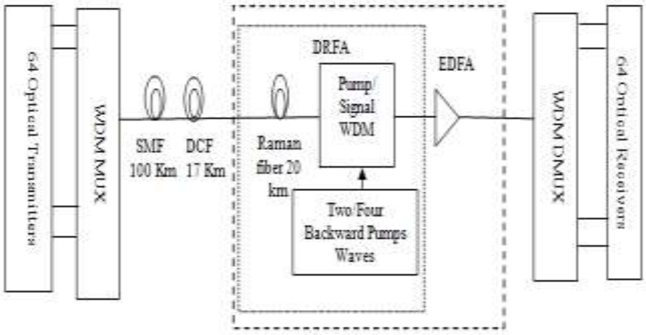


Fig. 1. Block Diagram of proposed Optical Transmission System

TABLE 1 Fiber parameters

Component	Length (Km)	Fiber Attenuation (dB/km)	Dispersion (ps/nm/km)	Dispersion Slope (ps/nm^2/km)
SMF	100	0.2	16	0.075
DCF	17	0.5	-90	0.075

Table 2 Raman and EDFA parameters

S.No	Parameters	Value
RAMAN		
1.	Peak Raman gain Coefficient (g_R)	1×10^{-13} m/W
2.	Effective Raman Fiber Core Area (A_{eff})	75 μ m^2
3.	Rayleigh Back Scattering Coefficient	5×10^{-5} km^{-1}
4.	Fiber attenuation (α)	0.2 dB/km
EDFA		
5.	Gain	25 dB
6.	Noise Figure	4 dB

Table 3 Parameters used for 4 backward pumps

S. No.	Parameters	Investigated values	
1	Raman Fiber Length (km)	11, 15, 17, 20	
2	No. of Channels	64	
3	Signal Wavelength (nm)	1540 -1598.28 nm with 0.8 nm channel Spacing	
4	Pump wavelengths (nm)	Two Pumps: 1455, 1477	Four Pumps: 1450, 1465, 1480, 1495
5	Pump Powers (mW)	Two Pumps 200, 300	Four Pumps 500, 400, 300, 300

III. RESULTS AND EXPLANATION

Simulations of hybrid configuration of amplifiers are performed by taking two and four backward pumps of Raman amplifier. Fig. 2 shows the first case of two pumps (1455 and 1477 nm). The On-off Gain versus Signal wavelength is plotted for four cases of Raman amplifier fiber length. The different values of fiber length taken are 11 Km, 15 Km, 17 Km, 20 Km. The graph shows that On-off gain is function two parameters Raman fiber length and signal wavelength. Numerically, on-off gain remains in the range 27-33 dB for the wavelength range 1540-1590 nm. Further, the plot indicates that maxima of On-off gain (33 dB) occur at signal wavelength of 1570 nm. In other words, among the varied length cases 20 km fiber length gives highest gain. In other words, the noise figure is plotted in the same graph, indicates noise figure is below 9 dB at the same wavelength point.

In second case, investigations are performed for Hybrid amplifier configuration by taking four pumps of Raman amplifier (at wavelengths: 1450, 1465, 140, 1495 nm) for the setup shown in Fig. 1. The Gain versus signal wavelength points are plotted for Raman fiber length cases: 11, 15, 17 and 20 km and shown in Fig. 3 (a). The gain remains in the range 37-51 dB for wavelength range 1540-1590 nm. The result shows that the maximum gain is obtained at 1568 nm of signal wavelength. The 20 km of length gives the maximum gain which is more than 50 dB.

Corresponding noise figure of the hybrid configuration is plotted against signal wavelength for the varied Raman fiber length as shown in Fig. 3(b). The noise figure is decreasing as increase of the signal wavelength. It is minimum at signal wavelength of 1568 nm for all the cases of Raman fiber length. The range of noise figure is from 7.2 dB to 8.9 dB. For the case of 11 km of fiber length noise figure is 8 dB and while for the case of 20 km is 8.9 dB. Another observation on comparison of 20 km case with 11 km case is that in overall, increase in Raman fiber length increases noise figure. OSNR is plotted versus signal wavelength for Raman fiber length as shown in Fig. 3(c). OSNR is decreasing as increase in the Raman length and it is minimum at 1540 nm of signal wavelength. The value of OSNR at that signal wavelength is 22.3 dB with 20 km of Raman fiber length.

The maximum gain versus length of the Raman fiber amplifier of the HOA is plotted as shown in Fig. 3(d). The plot indicates that maximum gain increases with increase in Raman length and reaches at maximum value (57 dB) at a length of 60 Km. After this point, the maximum gain start decreasing. The figure shows investigation length up to 200 km. The starting value of gain is 42 dB for length of 10 km while gain reduced to 36 dB at Raman fiber length of 200 km.

The gain ripple versus length of the fiber of Raman amplifier is plotted as shown in Fig. 3(e). The gain ripple is increasing with fiber length but after 80 km of Raman length it is stable. This shows that gain variation is constant after that Raman this fiber length. Similarly, the noise ripple is also plotted versus Raman fiber length as shown in Fig. 3(f). It is less than 2 dB for the cases taken in our previous investigated cases of Fig. 3(b). Further by increasing Raman lengths beyond 50 km, the noise ripple starts increasing drastically with increase of Raman length and at approximately 100 km of Raman length reaches to a value of 9 dB and remain same till the explored length. So it shows that the fiber length exploration should remain the fiber length below 40 km.

The noise figure versus Raman fiber length of the hybrid configuration is plotted as shown in Fig. 3(g). It is increasing with increase of the Raman length but it is smaller for the cases lengths of Raman fiber and remains below 9 dB. Thus it recommends that Raman length should be kept below 25 km to select low noise figure zone of the HOA.

The corresponding OSNR versus fiber length of the HOA is also plotted Raman amplifier as shown in Fig. 3(h). On similar lines, OSNR is more than 20 dB is observed. These plots may be used to have insight of the HOA behavior.

The overall numerical values are shown in a tabulated form as shown in table 4. In this table on-off gain and noise figure is listed at varied length of Raman fiber (11, 15, 17, 20 km). The Gain Bandwidth of HOA by taking four pumps is achieved up to 34 nm or 4.29 THz at 11 km of Raman fiber length and 27 nm at 20 km length. Their comparison of gain, gain flatness, bandwidth with other previous work is done in table 6. Gain is observed more than 30 dB which is the highest and bandwidth is maximum of 4.29 THz. The bandwidth difference with [1] is 0.32 THz.

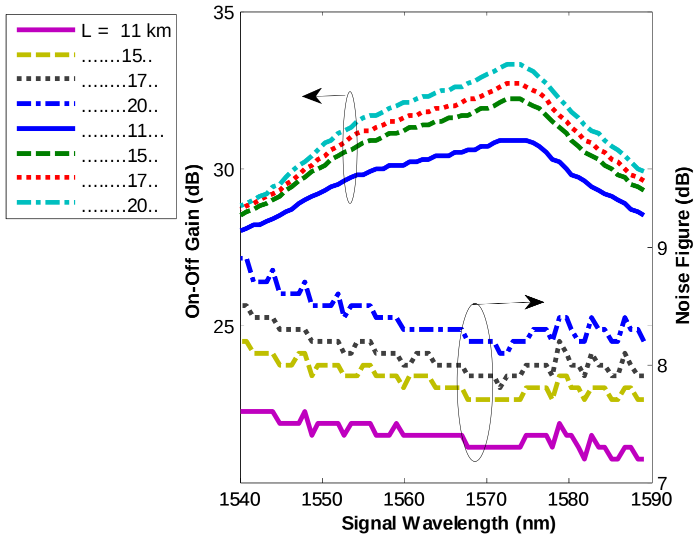
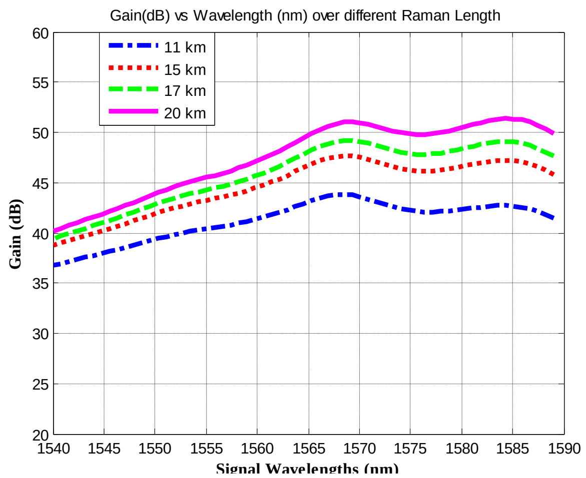
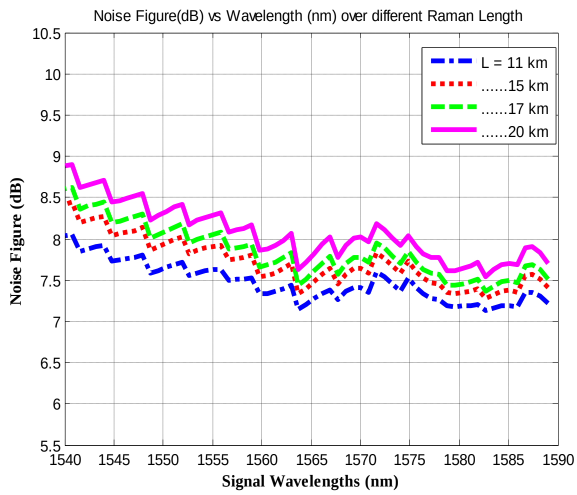


Fig. 2. Gain and Noise Figure versus signal wavelength of HOA taking two Raman Pumps



(a)



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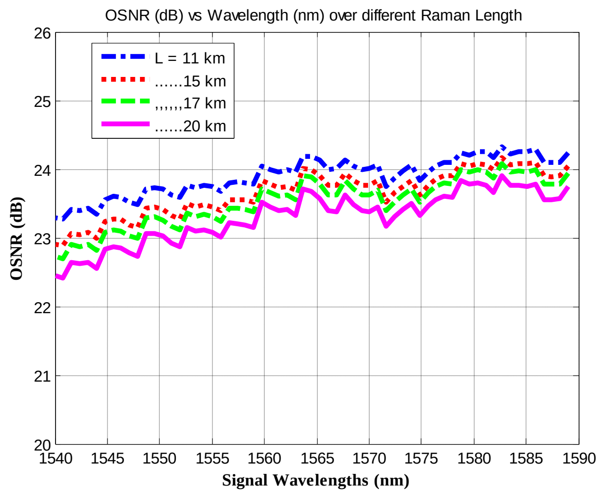
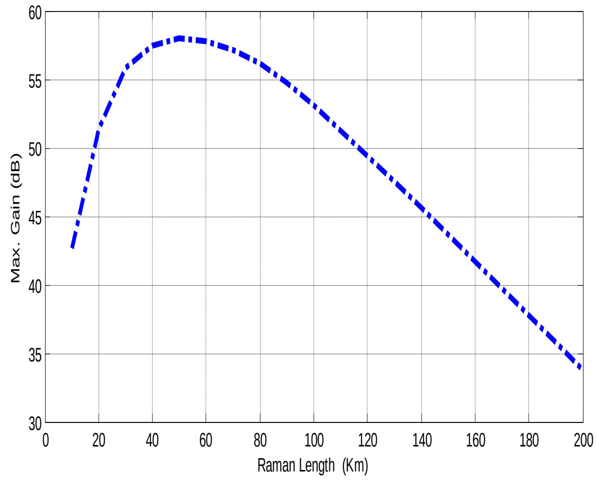


(c)



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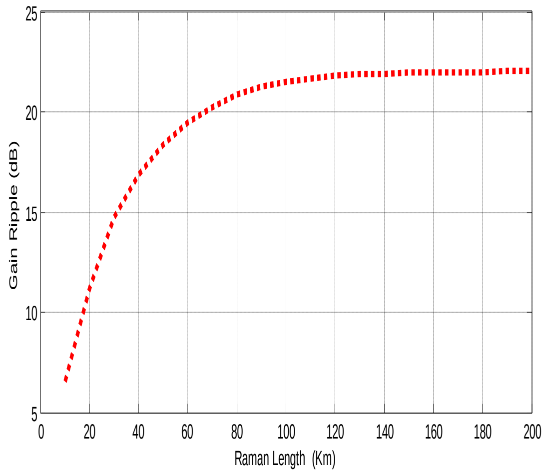
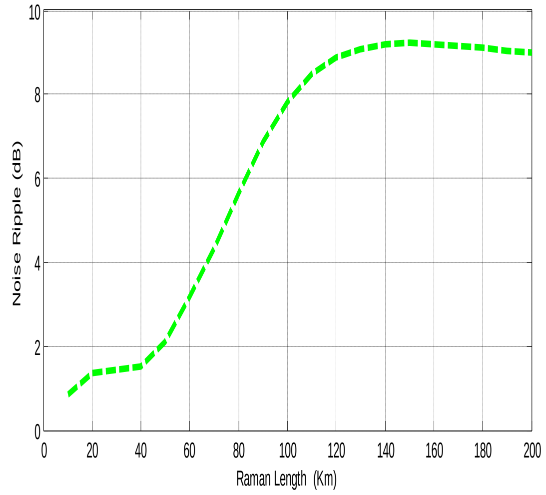
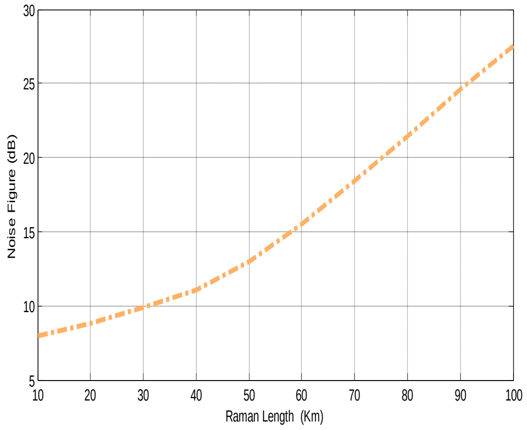


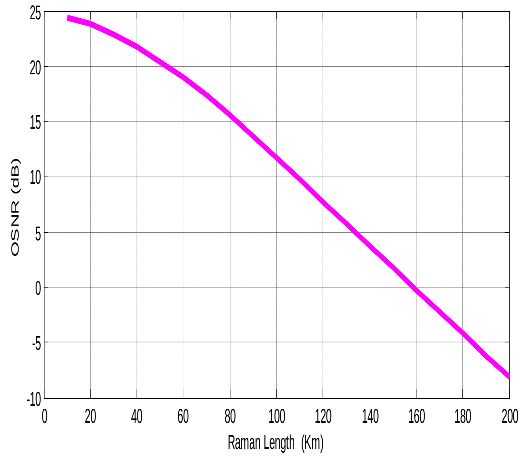
(e)



(f)



(g)



(h)

Fig. 3 Performance of HOA by taking Four pumps of Raman Amplifiers: (a) Gain versus signal wavelength (b) Noise Figure versus signal wavelength (c) OSNR versus signal wavelength (d) Max. Gain at different Raman lengths (e) Gain Ripple at different Raman lengths (f) Noise Ripple at different Raman lengths (g) Noise Figure versus Raman lengths (h) OSNR versus Raman length plot.

Table 4 Calculation of Gain Bandwidth for 4 pump model

S. No.	Raman Length (Km)	On-Off Gain (dB)	Noise Figure (dB)	Bandwidth (nm)
1	11	43.8	8.13	34
2	15	47.7	8.47	32
3	17	49	8.63	29
4	20	51.2	8.91	27

Table 5 Comparison of current investigation with previous work

Parameters	Raman-EDFA (2013) [1]	Raman/EDFA/ FBG/DCF(2011) [11]	L- band EDFA/Raman HOA(2011) [12]	Current Investigation of HOA EDFA+RAMAN
Channels/ Channels Spacing	Channels = 160 Spacing = 25 GHz	Channels = 26 Spacing = ---	Channels = 35 Spacing = 126 GHz	Channels = 64 Spacing = 100 GHz
Gain	> 10 dB	> 4 dB	> 12 dB	> 30 dB
Gain ripple	< 4.5 dB	< 0.5 dB	1.2 dB	< 4.5 dB
Gain Bandwidth	3.97 THz	10.11 THz	2.97 THz	4.29THz

IV. CONCLUSIONS AND FUTURE SCOPE

The hybrid Raman-EDFA amplifier has been investigated to optimize its performance using multiple pump wavelengths and powers of Raman amplifier. The fiber length of Raman amplifier is varied and the parameters such as gain, noise figure, OSNR and gain bandwidth of HOA have been investigated. With the input power of 3 mW and variation in the fiber length (11, 15, 17, 20 km) of Raman amplifier a flat gain of > 30 dB is obtained in signal wavelength range 1540 nm to 1589.28 nm with gain flatness of 4.5 dB and variation in the noise figure is < 0.8 dB with two Raman pumps. Then by taking four Raman pumps, a gain of more than 50 dB and gain bandwidth is achieved 34 nm which indicates improvement in gain parameter. Moreover, the gain ripple and noise ripple of hybrid amplifier are found to be bound at upper fiber length of 80 km and 100 km respectively of Raman amplifier. According to the varied fiber length range of Raman amplifier, the best operating fiber length of Raman Amplifier is observed. The parameters gain, noise figure, and bandwidth with the more flatness can be improved without costly components and without using gain flattening techniques. For future work, one can include more Raman pumps and other wavelength combinations. Moreover, the channel spacing can be varied or even some parameters of Raman or EDFA may also be examined.

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