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DWDM Transmission using Hybrid Optical Amplifiers

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Abstract: In this paper the transmission performance of 32 × 10 Gbps with 0.8 nm channel spacing dense wavelength division multiplexed system using hybrid optical amplifiers (RAMAN-EDFA, RAMAN-SOA AND EDFA-SOA) has been investigated. The performance has been compared at different distances and has been evaluated on the basis of Quality factor, optical output power, bit error rate and average eye opening. It is observed that maximal transmission distance of 224 Km is achieved in case of RAMAN-EDFA whereas in RAMAN-SOA and EDFA-SOA hybrid amplifiers the signal can travel up to maximum distance of 218 and 211 Km with acceptable Quality Factor and Bit Error Rate respectively. The RAMAN-EDFA hybrid optical amplifier also provides the highest output power of 14.205 dBm and minimum bit error rate of $1.96e^{-10}$ at 224 Km.

Keywords: Dense Wavelength division multiplexing, EDFA-SOA, RAMAN- EDFA, RAMAN-SOA

I. INTRODUCTION

The development of the wavelength division multiplexing (WDM) technique has opened new avenues for all-optical devices, which compensate for signal losses while performing data regeneration (i.e., dispersion compensation) with lower cost than its electronic counterpart [1].Wavelength division multiplexing (WDM) has become the preferred transmission technology in transport network of long distance operators[2]. The advances in the optical communications have been promoted in part by development of efficient and powerful optical amplifiers which eliminate the need of costly conversions from optical to electrical signal and vice versa. Due to the recent advance in wideband optical amplifiers, DWDM systems at terabit per second transmission rates have become a reality [3]. A particular attraction of EDFAs is their large gain bandwidth, which is typically tens of nanometers and thus actually more than enough to amplify data channels with the highest data rates without introducing any effects of gain narrowing [4]. Raman amplifiers improve the noise figure and reduce the nonlinear penalty of fiber systems, this improves the overall system performance thus allows us longer amplifier spans, higher bit rates, closer channel spacing [5]. To cater to the demand for an increasing number of channels, high signal powers are required at the output of each amplifier in the network link. Cascaded/multistage amplifiers can provide such high signal powers, but require extremely severe operating conditions [6]. Hybrid amplifiers have many advantages over individual amplifiers, like wide gain bandwidth and more flat gain profile. Hybrid amplifier provides high power gain [7].

Singh et al. [8] investigated the post, pre and symmetrical power compensation methods for a different position of hybrid optical amplifier RAMAN–EDFA in fiber link. It was found that the post power compensation method is superior to pre and symmetrical power compensation methods. Further, it was observed that RAMAN–EDFA as post power compensation method provides least bit error rate (10^{-40}) and high output power (12 dBm) at −15 dBm signal input power at fiber link.

R.S. Kaler [9] investigated 16 channel WDM systems at 10 Gb/s for the various optical amplifiers and hybrid optical amplifiers and the performance had been compared on the basis of transmission distance and dispersion. The amplifiers EDFA and SOA had been investigated independently and further compared with hybrid optical amplifiers like RAMAN-EDFA and RAMAN-SOA. It was observed that hybrid optical amplifier RAMAN-EDFA provides the highest output power (12.017 and 12.088 dBm) and least bit error rate (10^{-40} and 9.08×10^{-18}) at 100 km for dispersion 2 ps/nm/km and 4 ps/nm/km respectively.

V. Bobrovs et al. [10] investigated the performance improvement in long reach optical access system with hybrid optical amplifiers. The apparent options of optical amplification in wavelength division multiplexing systems included the distributed Raman amplifiers, erbium doped fiber amplifiers, and semiconductor optical amplifiers. It was concluded that hybrid DRA-EDFA and DRA-SOA solutions may be successfully implemented in passive optical networks to extend the achievable transmission distance. In this particular case the usage of RA- SOA helped to enlarge transmission from 69 km to 124 km, and the implementation of the DRA-EDFA hybrid to 126km.

Ju Han Lee et. al [11] demonstrated a novel concept of the dispersion-compensating Raman/erbium-doped fiber amplifier hybrid amplifier recycling residual Raman pump for increase of overall power conversion efficiency. Using the proposed scheme, he achieved the significant enhancement of both signal gain and effective gain-bandwidth by 15 dB (small signal gain) and 20 nm, respectively, compared to the performance of the Raman-only amplifier.

Kenneth C. et al. [12] demonstrated the cascading of broad-band semiconductor optical amplifier-Raman hybrid

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amplifiers which provided nearly flat gain over 70 nm. A coarse-wavelength-division multiplexing transmission system consisting of three spans of 80 km showed uniform performance and 1dB power penalty. Uniform performance was observed over the entire band with no more than a 1dB power penalty after 240 km and no measurable degradation due to variations in polarization. In this paper we extended the previous work [9] by increasing the number of channels used in the system and also the single span transmission distance .These results have been checked in terms of Quality Factor, Output Power, bit error rate and eye opening by varying transmission distance.

The paper is organized into four sections. In Section 2, the optical simulation setup is described. In Section 3, optimized results have been reported for the different distance and finally in Section 4, conclusions are made.

II. SIMULATION SET UP

To investigate the performance of different hybrid optical amplifiers (RAMAN-EDFA, RAMAN-SOA and EDFA-SOA) a simulation model of a 10 Gbit/s 32 channel dense wavelength division multiplexed transmission system with non-return-to zero encoding technique and 0.8nm channel spacing has been introduced. The simulation set up is shown in Fig. 1.

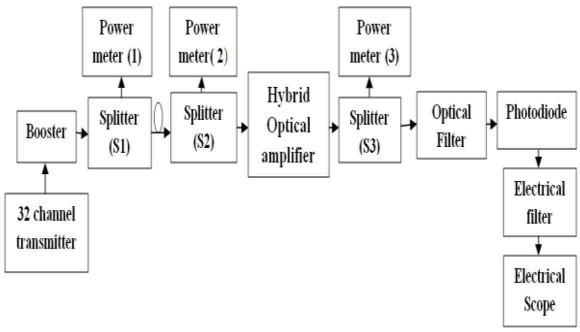

Fig. 1 System setup

The transmitter block consists of 32 channel transmitters, each of them operating at its own frequency in range from 192.35 THz to 195.45 THz. Each transmitter includes a Data Source, NRZ coder, Modulator and a Continuous Wave Laser. The laser power is set to 0 dBm because at higher power the wavelengths tend to overlap each other causing more dominance of non-linear effects like XPM and FWM. Then all of the 32 generated optical signals are pre-amplified by booster and transmitted over DS-anomalous fiber at different distances from 90 to 240 Km. The DS Anomalous fiber has reference frequency of 193.414 THz and 0.2 dB/km of attenuation. After pre-amplification by booster the signal is further amplified by hybrid optical amplifier. Optical power meter (P1, P2, P3) with splitters (S1, S2, S3) are used for measuring the signal power and spectrum at different levels. The parameters of basic attribute sections taken are 10 Gb/s bit rate, number of bit per symbol is 1 and the pseudo-random sequence is selected. The fixed output power EDFA is used for amplification and its parameters are output power is 25mW, gain shape is flat and noise figure is 4.5 dB. The optimized parameters of SOA and Raman fiber are shown in table 1 and table 2.

Table 1. Optimized Parameters of SOA

Parameter	Value	Unit
Bias current	100	mA
Amplifier Length	500	µm
Active layer width	2	µm
Active layer Thickness	0.2	µm
Confinement Factor	0.41	µm
Spontaneous carrier lifetime	0.3	Ns
Transparency carrier density	1.5×10^{18}	cm^{-3}
Material gain constant	2.1×10^{-16}	cm^2
Input and Output Coupling Losses	3	dB

Table 2. Optimized Parameters of Raman Fiber

Parameter	Value
Raman fiber length	10 Km
Operating temperature	300 K
Pump power	500mW
Pump Wavelength	1450 nm
Pump attenuation	0.2dB/km

At the receiver section, the performance of first channel is evaluated using the eye diagram. Single receiver is composed of Optical raised cosine filter, PIN photodiode and Electrical raised cosine filter. PIN photodiode is used to convert the optical signal into electrical signal the responsivity of which is 0.87 and Quantum efficiency is 0.7A/W. Electrical Scope as the measurement component is used to obtain the eye diagram. From the eye diagram, the values of Q factor, average eye opening and BER can be analyzed.

III. RESULTS AND DISCUSSIONS

To analyze the performance of the system Quality Factor, bit error rate, output power and eye opening is examined at the first channel . Performance of different hybrid optical amplifiers (RAMAN-EDFA/RAMAN-SOA/ EDFA-SOA) is compared by varying the distance from 90 to 240 Km. The maximum achievable transmission distance in case of Raman- Edfa and Raman- Soa in [9] were limited to 180 and 170 Km with acceptable Quality Factor whereas in our paper the maximum transmission distance is extended to 224 Km for Raman-Edfa (with Quality factor of 15.05 dB and bit error rate of $1.96e^{-10}$) and 218 Km (with Quality factor of 15.40 dB and bit error rate of $1.01e^{-09}$) for Raman-Soa and 211 Km (with Quality factor of 16.41 dB and bit error rate of $4.16e^{-11}$) for Edfa-Soa amplifier. After that the signal degradation takes place.

In order to observe the performance of different hybrid optical amplifiers (RAMAN-EDFA, RAMAN-SOA,

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EDFA-SOA), the output power vs. transmission distance graphs are shown in Fig. 2. This graph shows that as the transmission distance increases from 90 to 240 km, the degradation of output power occurs. The variation in output power from different optical amplifiers is 38.874 to 12.509 dBm for RAMAN-EDFA, -14.669 to -41.872 dBm for RAMAN-SOA and 9.758 to -6.236 dBm for EDFA-SOA amplifier. This result shows an improvement in output power of Raman-Edfa at 180 Km over the results reported in [9].

It is observed that maximum output power is obtained from RAMAN-EDFA i.e 14.205 dBm (at 224 Km transmission distance) as compare to RAMAN-SOA and EDFA-SOA which is -37.978 and -4.998 dBm respectively.

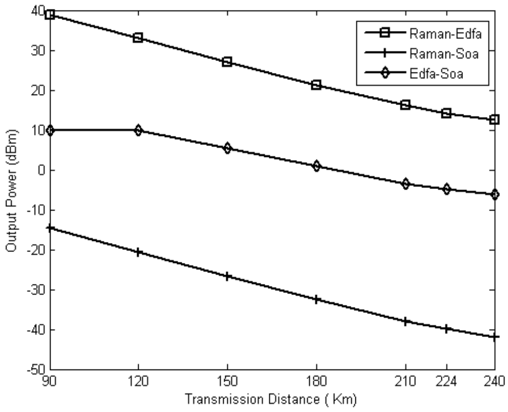

Fig. 2 Output Power vs. Transmission Distance

Figure 3 depicts the transmission distance vs Quality factor graph. It is observed that by increasing the transmission distance from 90 to 240 km, Q factor is decreasing. The variation in Q factor is 26.86 to 12.30 dB for RAMAN-EDFA, 26.21 to 12.60 dB for RAMAN-SOA, and 24.40 to 11.42 dB for EDFA-SOA amplifier. It is observed that maximum Quality factor is shown from RAMAN-EDFA i.e 15.05 dB (at 224 Km transmission distance) as compare to RAMAN-SOA and EDFA-SOA which is 14.82 and 13.80 dB respectively.

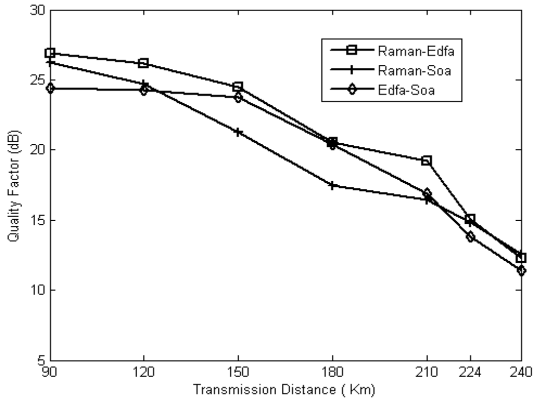

Fig. 3 Quality Factor vs. Transmission Distance

Fig. 4 shows the transmission distance vs Bit error rate graph. The variation in BER from different optical amplifiers is 1e^{-40} to 1.76e^{-05} for RAMAN-EDFA, 1e^{-40} to 9.62e^{-06} for RAMAN-SOA and to 1e^{-40} to 0.00010 for EDFA-SOA. The simulation results shows that at 224 Km transmission distance, the minimum bit error rate value is obtained by RAMAN-EDFA which is 1.96e^{-10} whereas the bit error rate value for RAMAN-SOA and RAMAN–EDFA is 2.32e^{-08} and 4.11e^{-07} respectively.

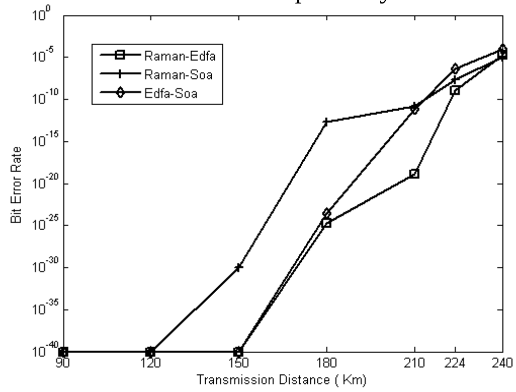

Fig. 4 Bit Error Rate vs. Transmission Distance

The average eye opening from different amplifiers verses transmission distance is shown in Fig. 5 .Large eye opening means less BER and good communication. It is observed that by increasing the transmission distance from 90 to 240 km, average eye opening is also decreasing. The variation in average eye opening from different optical amplifiers at dispersion of 2 ps/nm/Km is 1.6760 to .0016 for RAMAN-EDFA, 7.36e^{-06} to 2.22e^{-08} for RAMAN-SOA and 0.0021 to 1.72e^{-05} for EDFA-SOA amplifier.

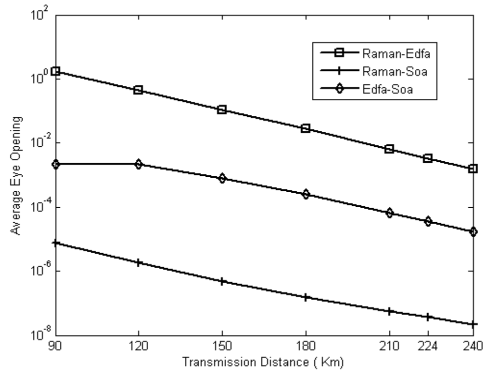

Fig. 5 Average eye opening vs Transmission Distance

It is observed that maximum average eye opening is obtained from RAMAN-EDFA i.e 0.0033 (at 224 Km transmission distance) as compared to RAMAN-SOA and EDFA-SOA which is 3.60e^{-008} and 3.58e^{-05}. The eye diagram of signal after RAMAN-EDFA at 224 Km transmission distances is shown in figure.

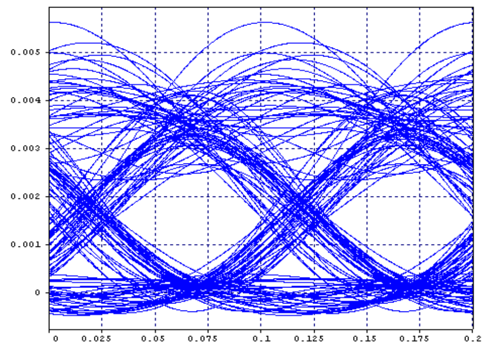

Fig. 6. Eye Diagram of Raman-Edfa at 224 Km

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IV. CONCLUSION

This paper evaluates the comparative performance of hybrid optical amplifiers for 32 × 10 Gbps with 0.8 nm channel spacing dense wavelength division multiplexed system. It is observed that the RAMAN-EDFA hybrid optical amplifier provides the highest output power of 16.086 dBm, maximum average eye opening of 0.0065 and minimum bit error rate of $1.96e^{-10}$ at 224 Km. The RAMAN-EDFA shows better results in terms of transmission distance, optical output power , average eye opening and bit error rate whereas the RAMAN-SOA amplifier provides the worst results among all three combinations at the dispersion of 2 ps/nm/km. So RAMAN-EDFA is a promising alternative to RAMAN-SOA and EDFA-SOA in an optical transmission.

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