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Optimization of hybrid Raman/erbium-doped fiber amplifier for multi terabits WDM system

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ABSTRACT

In this paper, hybrid optical amplifier (Raman-EDFA) has been optimized using different optimized parameter such as noise figure, output power for fixed output power EDFA and Raman pump, pump power, Raman fiber length for Raman amplifier. It is being shown that when the optimized parameters are used, the hybrid optical amplifier provides better performance. Further we investigate the maximum single span distance using optimized hybrid optical amplifier. It has been shown that using optimized hybrid optical amplifier, the dispersions at 2, 4, 8, 16 ps/nm/km achieves 150, 150, 120 and 70 km of single span distance respectively with the acceptable bit error rate.

1. Introduction

The growing demand for higher transmission capacity in wavelength division multiplexing (WDM) systems can be upgraded by increasing the channel speed, number of channels and spectral efficiency [1]. To overcome these problems optical amplifiers (Raman, EDFA, and SOA) are playing an important role. Raman amplifiers have become essential in overcoming the limitations of the bandwidth, noise figure (NF), and output power of conventional doped fiber amplifiers [2]. The erbium-doped fiber amplifier (EDFA) has been utilized in WDM systems since the 1980s, for every long-haul or ultra-long-haul fiber-optic transmission system [3] and SOA have ultra wide band spectrum, low power consumption and low cost [4]. The overall performance can be enhanced by cascading two amplifiers, this leads to term hybrid optical amplifier. Hybrid amplifiers have many advantages over individual amplifiers, like wide gain bandwidth and more flat gain profile [5,6]. Hybrid amplifier provides high power gain. By appropriately choosing wavelengths and powers of pump signals, Raman fiber amplifiers can provide broader amplification bandwidth and flexible center wavelength compared with pure EDFAs. Hybrid Raman-EDFA is a promising technology for future dense wavelength-division-multiplexing (DWDM) multiterabit systems. Hybrid Raman/erbium-doped fiber amplifiers are designed in order to maximize the span length or to minimize the impairments of fiber nonlinearities and to enhance the bandwidth of erbium-doped fiber amplifiers (EDFAs) [7].

Masum-Thomas et al. [5] designed a hybrid amplifier for short wavelength amplification. It is reported by cascading a Thulium doped fluoride fiber with a discrete Raman amplifier. Gain >20 dB for a bandwidth 1445–1520 nm (75 nm) was achieved and also gain >30 dB and noise figures of between 7 and 8 dB were achieved for 50 nm bandwidth. They achieved a flat gain without the usage of any gain flattening techniques due to the symmetric gain spectra of both amplifiers.

Chung et al. [8] demonstrated a long-haul transmission of 16 channels × 10 Gbit/s over single-mode fiber (span of 80 km) of 1040 km using combined Raman and linear optical amplifiers as inline amplifiers. All the span length used was 80 km (loss of 16 dB), but the span losses varied from 28 to 34 dB according to some additional loss elements. The measured *Q*-factors of the 16 channels after 1040 km (12.7–14.5 dB) were higher than the error-free threshold of the standard forward-error correction, which offers feasibility of the hybrid amplifiers including semiconductor optical amplifiers for the long-haul transmission. In this work EDFA is used as a pre-amplifier.

Chang et al. [9] compared the EDFA and hybrid fiber amplifier (HFA) and reported that HFA can be an alternative to improve the performance of line amplifier instead of EDFA only. They described the configuration of HFA that has low noise figure and high output power. In the transmission experiments with circulating loop, HFA showed better transmission performance than EDFA when it was used as line amplifier. The *Q*-factor and OSNR (optical signal to noise ratio) in the case of HFA was higher by more than 1.0 dB.

Guimaraes et al. [10] investigated the performance of hybrid optical amplifier when it is used as pre-amplifier and described its application on 40 Gb/s systems. In this work it is shown that

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hybrid pre-amplifier provides an improvement in the system power penalty of 3.2 dB when compared with the back-to-back values. The higher performance obtained with the hybrid pre-amplifier is due to the fact that we designed the FOPA to operate in the saturated regime, therefore it is acting as a noise limiter.

Single Raman pump wavelength having advantages over multiple pumps wavelengths are: simpler design and thus possible cost savings and Raman gain shape independent on channel loading. Carena et al. [11] discussed the optimal configuration of hybrid Raman/erbium-doped fiber amplifiers. They have evaluated a maximum reachable distance as a function of the span length and nonlinear weight, given a target optical signal-to-noise ratio. The single pump signal at 1453 nm with pump power of 1000 mw has been used and covered maximum distance with span length of 50 km.

Gest et al. [12] theoretically analysed the dynamic response of amplifier cascades involving combinations of unclamped and gain-clamped discrete fiber Raman amplifiers (DFRAs) in the worst possible case of power transients. In this paper the discrete fiber Raman amplifier is used as a pre-amplifier to increase the system performance. Using the APA technique, they were able to reduce the computation time by at least one order of magnitude compared to the direct Runge–Kutta approach and with a precision within 2%.

Singh et al. [4] investigated placement of semiconductor optical amplifier for 10 Gb/s non-return to zero format in single mode and dispersion–compensated fiber link. In this work power, different compensation methods (pre-, post- and symmetrical) for different positions of the SOA in fiber link have been described. The effect of increase in signal input power for these three power compensation methods are compared in terms of eye diagram, bit error rate, eye closure penalty and output received power. It is found that the post-power compensation method is superior to pre- and symmetrical power compensation methods when SOA is used.

In this paper we extended the previous work by increasing the single span distance when the optimized hybrid optical amplifier is used which amplifies 64 channels simultaneously. These results have been checked in the term of Q factor, BER and eye closure by varying the transmission distance and dispersion.

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 dispersion and finally in Section 4, conclusions and future work are made.

2. Simulation setup

Simulation setup for 64 channels pre-amplified by amplified by hybrid optical amplifier is shown in Fig. 1.

As shown in figure, 64 signals from CW laser sources, modulated by NRZ format, are transmitted over a medium hall link. The laser power is set to 0 dB m because at higher power the wavelengths tend to overlap each other causing more dominance of non-linear effects like XPM and FWM [4]. The 64 channels (1531.01–1601.56 nm) are spaced at 100 GHz. The input signal spectrum occupies a bandwidth of 6.4 THz. The signals are transmitted over DS-anomalous fiber at different dispersions and distance. The variation of the dispersion is from 2 to 16 ps/nm/km and distance is from 50 to 160 km. At the receiver section, the performance of one of the 64 channels is evaluated using the optical spectra, eye diagram, BER and Q value measurement.

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. Data source simulates a pseudo-random or a deterministic logical signal generator. The period length of the corresponding pseudo-random sequence is $2^D - 1$ bits, where D is the degree set by the degree parameter. Electrical driver converts

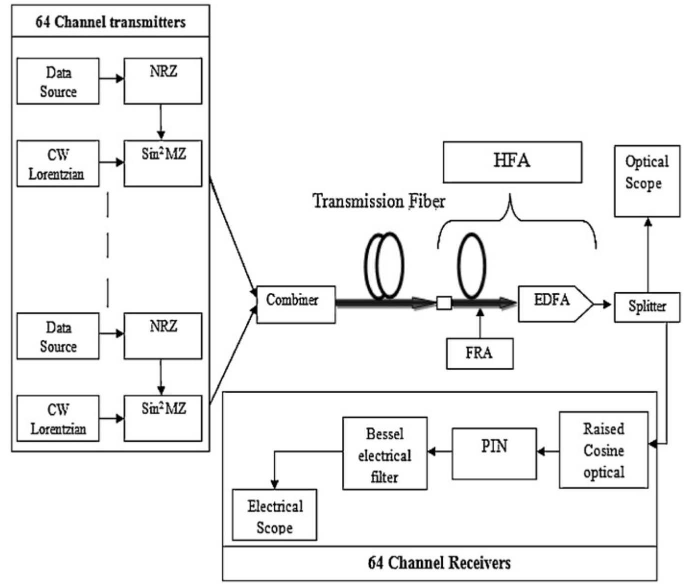

Fig. 1. Simulation setup for 64 WDM channels; FBG: fiber Bragg grating; FRA: fiber Raman amplifier; HFA: hybrid fiber amplifier.

logical input signal, binary sequences of zeros and ones into an electrical signal. Here we are using NRZ electrical drivers. For NRZ rectangular format the fraction of bit duration is set to 1 and signal dynamics low level is −2.5 and high level is 2.5.

FRA consist a DS-anomalous fiber which is counter pumped by optimized pump wavelength and pump power [11] which is 1453 nm at 1000 mW pump power. In this fiber the non linearity, fiber PMD and fiber birefringence are considered. Here we vary the fiber length from 50 to 160 km to check and optimize the single span distance. The Raman amplified signals are further amplified by EDFA.

The fixed output power EDFA with the 20 mW output power and 5 dB noise figure is used to amplify the signals after FRA. The gain shape of EDFA is flat. Maximum small signal gain of the amplifier can give to the signal to ensure the requested output power is 35 dB. These amplifies signals are received by the optical receiver.

PIN photo diodes with quantum efficiency 0.798 are used to detect the amplified signals.

3. Result and discussion

In this paper, the 64 channels are used to transmit the data with the speed of 10 Gb/s which is amplified by hybrid optical amplifier (Raman) after covering the single span distance.

Firstly, we optimized the parameters of EDFA (noise figure and output power) and Raman amplifier (Raman fiber length). The optimization of parameter has been done on the basis of Q factor and jitter. Then, further we covered the maximum single span distance for different dispersions (2, 4, 8, 16 ps/nm/km) using optimized hybrid optical amplifier.

Fig. 2 shows the graphical representation of optimization of noise figure (EDFA parameter) on the basis of Q factor and jitter. This optimization has been done using same setup but without any transmission fiber.

From Fig. 2 it is observed that at 5 dB of noise figure of EDFA, the system provides better results. The results have been observed in the term of Q factor and jitter. At 5 dB of noise figure the system provide high Q factor (29.70 dB) and least amount of jitter (0.01808 ns). Then 5 dB is the optimized noise figure.

Further the output power of EDFA has been optimized on the basis of Q factor and jitter as shown in Fig. 3. It is observed that at