Performance Investigation of 64 × 20 Gbps DWDM System using Hybrid Optical Amplification for NRZ, RZ and DPSK Modulation Formats

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Abstract

In this editorial, we investigated the performance of dense WDM system, deployed using hybrid optical amplification (Raman-EDFA) for three data formats like non return to zero (NRZ), return to zero (RZ) and differential phase shift keying (DPSK). We observed that in 64x20 Gbps system RZ format is undesirably affected by nonlinearities and another two formats (NRZ and DPSK) are affected by dispersion, we also find that the RZ offer good quality factor (minimum 14 dB and maximum 24.5 dB), less eye closure (maximum 2.69 dB), tolerable bit error rate (3.875 × 10^8) at individual distance as compared to other formats. We further investigated flat gain performance of hybrid optical amplifier (Raman-EDFA) after each stage (first stage Raman amplifier and second stage EDFA provides gain nearly 5 dB and 17 dB respectively).

Keywords: Hybrid optical amplifier, Modulation formats, Transmission distance, DWDM: Dense Wavelength Division Multiplexing

I. INTRODUCTION

Dense wavelength division multiplexing (DWDM) with hybrid optical amplifiers (HOA) systems is today’s need of high capacity communication networks. In DWDM systems, different wavelengths carry information, are multiplexed organized and are passed over single span optical fiber. Instead of deploying individual fibers for different users, single strand of fiber is used in DWDM systems. By reducing the channel spacing between adjacent channels, given BW can be used effectively. Hence data rate will be increased without any need of more BW. In this technology each user is assigned with unique wavelength, each wavelengths carry different information signal. Typically channel spacing is 1 nm or less.

In DWDM system channels should be narrowly spaced so as to enhance the transmission capacity. This pressurize on optical amplifier (OA) to provide broad band gain and flat gain for these closely spaced channels. The OA can be connected either in parallel or in series and configuration is referred to as Hybrid optical amplifiers (HOA) [1]. HOA are promising technology for long haul DWDM. There is the method of utilizing OA for utilization of available fiber bandwidth i.e. by way of using various combinations of optical amplifiers in different wavelength range.

The HOA has wide gain spectrum. This amplifier increases the link distance and gain flatness, which is limited by fiber loss in an optical communication system. However, the amplifiers also introduce nonlinear effects, which not only limits the bit rate but also the propagation distance in an optical fiber link is reduced. HOAs are available to effectively use the bandwidth and to achieve significant gain up to wide range of BW [2, 3]. There are several combinations of optical amplifiers, such as Raman-Erbium doped fiber amplifier (EDFA), EDFA- Semiconductor optical amplifier (SOA) and so on. Among all Raman-EDFA shows effective gain performance up to C and L band [4]. Recently research has been done on DWDM technology using hybrid optical amplifiers, also effective performance of system is analysed [5]. It is observed that Raman-EDFA has multichannel flat gain [6]. As per the today requirement of high data speeds and high throughput, maintaining the same bandwidth. Further number of channels can be increased by reducing channel spacing. This is done in this paper 64x20 Gbps DWDM. In this paper simulation setup is done for 64 (1531.01 nm to 1601.56 nm) channels are spaced at 100 GHz. The gain spectrum of Raman can be varied by adjusting the pump power and pump wavelength. This property is used to enhance the bandwidth of EDFA. Noise figure of Raman is lower than that of EDFA, Therefore to achieve a higher gain with lower noise figure or wide band amplification, use an EDFA in combination with a distributed Raman amplifier (RA). Dual stage Raman-EDFA amplifier provided wide gain spectra.

Matsu d et al. [8] compared non return to zero (NRZ) and return to zero (RZ) signal formats for single-channel long-distance transmission in an in-line amplifier system with dispersion management providing average zero dispersion and local nonzero dispersion at an interval equal to the in-line amplifier spacing. It is reported that with linear amplified spontaneous emission (ASE) accumulation, signal waveform distortion due to the combined effect of higher order group-velocity dispersion (GVD) and self-phase modulation (SPM) dominates the performance. Hayee et al. [8] compared NRZ with RZ modulation format for wavelength-
division multiplexed systems operating at data rates up to 40 Gb/s. It is reported that in 10–40-Gb/s dispersion-managed systems single mode fiber alternating with dispersion compensating fiber.

Bosko et al. [10] investigated the ultra-dense wavelength division multiplexing (UDWDM) scenario at 40 Gb/s using NRZ, RZ, and carrier suppressed return-to-zero (CSRZ) modulation formats. It is reported that NRZ modulation does not benefit from the introduction of a transmission optical filter, while it takes advantage of the orthogonal polarization launch of adjacent channels, but its performance is still worse than the RZ and CSRZ performance in a UDWDM scenario. Singh et al. [11] investigated the return to-zero (RZ) pulse duty cycle for single-channel standard single mode fiber (SSMF), nonzero dispersion shifted fibers (normal NZDSF and anomalous NZDSF fiber) for 10 Gbps optical fiber communication system.

Malhotra et al. [12] investigated the performance of the optical system consisting of chain of EDFA amplifiers for different data formats such as NRZ, RZ and Manchester. Their effect on the spectral loss variations produced in fiber output is analyzed. It is reported that the NRZ raised cosine modulation format best compensates the spectral loss variations in case of 3 channels WDM system which is amplified by cascaded EDFAs. In this paper, we pursue the same target, but in the context of 64 DWDM system which is amplified by hybrid optical amplifier (Raman-EDFA). Each virtual channel has 20 Gbps data speed. We further investigated the performance comparison of hybrid optical amplifier Raman-EDFA with different modulation formats (RZ, NRZ and DPSK) in the term of Q-factor, bit error rate (BER), output power and eye closure and optimize the maximum single span transmitted distance. The paper is organized into four sections. In Section 2, the optical simulation set-up is described. In Section 3, comparison results have been reported for the different modulation formats and finally in Section 4, conclusions and future work are made.

II. SIMULATION SETUP

Simulation setup for 64 channels DWDM is shown in Fig. 1. As shown in figure, each transmitter section consists of the data source, electrical driver, laser source and amplitude modulator. The data source is of different modulation formats changed after one another according to the analysis work (NRZ, RZ, and DPSK) at 20 Gb/s bit rate. The output of the modulator is fed to an optical link with the Raman–EDFA. The laser power is set to 0 dBm because at higher power the wavelengths tend to overlap each other causing more dominance of nonlinear effects like cross phase modulation and four wave mixing [1]. 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 pre-amplified by a booster amplifier and transmitted over fiber at different distances from 50 to 200 km. This fiber is pumped by 1480 nm with 280 mW power, amplified by Raman-EDFA. Dispersion is completely compensated using fiber Bragg grating. 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.

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. For RZ rectangular format the duty cycle is set to 0.5. For DPSK the center frequency is set using the condition which is centre frequency < BW/4. For 64 channel system the used band width is 8.625 THz (187.18–195.81 THz). Then selected DPSK centre frequency and real symbol period are 2.1 THz and 1000 ps. The external modulator used is Sin2 Mach-Zehnder type modulator which has 5 dB insertion loss, 30 dB extinction ratio and 0 chirp factor. The modulated optical signals are amplified by fiber Raman amplifier (FRA) after pre-amplified by the booster.

Fig. 1: Simulation Setup 64 × 20 Gbps System for different Modulation Formats.

The CW Lorentzian laser is used in this model. The parameters for CW Lorentzian laser are: center emission wavelength is 1550 nm, CW power is 1 mW and laser phase is random. The amplitude modulator is a sine square with an excess loss of 3 dB. The simulated bit rate is 20 Gb/s with pseudorandom binary sequence. The responsivity of the PIN detector is 0.875 and dark current is 0.1 nA. The frequency domain simulations are performed at the center wavelength of 1550 nm with a bandwidth of 6.4 THz.
The cascade Raman-EDFA (Hybrid optical amplifier) is used to amplify the optical signal. The parameters for Raman fiber are: length is 50-200 km, operating temperature is 100 K, counter-propagating pump wavelength is 1480 nm, and co-propagating pump power is 200 mW. The fixed output power EDFA is used for amplification and its parameters are: output power is 35 mW, gain shape is flat and noise figure is 4.5 dB.

The same setup is repeated for various modulation formats (NRZ, RZ and DPSK).

### III. RESULT AND DISCUSSION

This investigation reveals that the highest level produced at the output with minimum noise and maximum single span distance covered is in the case of RZ rectangular data format for 64 channels DWDM system. The different modulation formats have been compared for 64 × 10 Gbps DWDM system in the term of received maximum Q value (dB), minimum eye closure, minimum BER and maximum output power. To analyse the system, the results of the first channel have been taken.

Fig. 2 shows gain flatness of DWDM system for dual stage HOA. It can be seen that gain after first stage is completely flat not sufficiently large, but after second stage it is acceptable gain of approximately 17 dB. First stage consists of fiber Raman amplifier and second stage is EDFA.

![Gain Flatness of DWDM System](image)

**Fig. 2:** Dual stage hybrid optical amplifier flat gain spectra of Rama-EDFA in DWDM system.

Fig. 3 indicates the eye closure penalty which is high for NRZ and for DPSK because of ASE noise power. We observed that RZ provided the least eye closure also in worst case (2.609 dB). Means as we increase the transmission distance, the eye closure penalty goes on increasing. This shows good agreement with the result [13]. As the eye closure penalty goes on increase, the quality goes on decreasing.

![Eye Closure Penalties](image)

**Fig. 3:** Distance versus eye opening for 64 channels DWDM system.

The graphical representation of Q value is shown in Fig. 4. It is shown as a function of transmission distance. Q value can be seen for all the modulation formats that as the line is vary from 40 km to 180 km then the Q factor is decreased due to the fiber...
nonlinearities. The better Q value is provided by the RZ data format (24.5 dB) and also for the worst case (at 180 km) it becomes 14 dB. The variation in Q-factor for NRZ, RZ and DPSK are 21.31–14.95 dB, 24.42–13.88 dB and 22.25–14.62 dB, respectively. When we compare these data formats RZ rectangular provides the better result as compare to other formats.

![Q-factor versus distance for 64 channels DWDM system.](image1)

![Distance versus output power for 64 channels DWDM system](image2)

Fig. 4: Q-factor versus distance for 64 channels DWDM system.

Fig. 5 reported the power penalty versus transmission distance. RZ data format provide better output power (15.082 and 15.027 dBm for 50 and 180 km). We further investigate the maximum single span distance for different modulation formats. For 64 channels DWDM system the maximum distance is covered by RZ (180 km) with acceptable power level and good quality. In same system both NRZ and DPSK covered 170 km distance.

IV. CONCLUSION

In this paper, we investigated the performance of 64 x20 and Gbps DWDM optical system consisting of hybrid optical amplifier Raman-EDFA for different data format such as NRZ, RZ and differential phase shift keying DPSK. It has been noticed that in link consisting of the Raman-EDFA amplifiers, the RZ raised cosine modulation format has the highest power levels with the minimum loss which is indicated by the reduction of the noisy spikes at the output of the receiver and BER estimator. We further investigated the maximum single span distance for different modulation formats. RZ provided the better results and covered 180 and 175 for 64.
REFERENCES