PERFORMANCE ANALYSIS OF HYBRID OPTICAL AMPLIFIERS FOR DENSE WAVELENGTH DIVISION MULTIPLEXING

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Abstract
Optical amplifiers are used for transmission of signal over long distance (>100km) to provide larger dynamic range and least bit error rate but there exists some disadvantages such as gain saturation effect and crosstalk. Hybrid amplifiers are being used in order to overcome the same and in this paper the performance of Raman-EDFA hybrid amplifier was analyzed by comparing Q-factor and BER for 64x10Gbps DWDM systems at channel spacing of 100GHz for transmission distance of 100Km. Simulation results show that the position of amplifier between the fiber plays the main role in determining the link performance in terms of Q-factor and BER.
Keywords: DWDM System, Hybrid Optical Amplifiers, BER, Q-factor.

I. INTRODUCTION

In recent years, there has been a strong demand in high capacity signal transmission systems and networks. In order to increase the data transmission capacity, several methods are proposed by adding more number of channels in the wavelength division multiplexing (WDM) system, so that spectral efficiency must be upgraded. Dense wavelength division multiplexing (DWDM) systems are thus used which offer an attractive solution to enhance the bandwidth by utilizing different optical amplifiers with a capacity of several gigabits per second. For long haul system, the loss limitation is conventionally overcome using optoelectronic repeaters in which the optical signal is first converted into electric form and then regenerated. Such regenerators are quite complex and expensive for WDM systems. Optical amplifiers directly amplify the transmitted optical signal without conversion to electric form and reduce the attenuation. Different types of the amplifiers exist such as Erbium Doped Fiber Amplifier (EDFA), Semiconductor Optical Amplifier (SOA), Erbium-Ytterbium Doped Fiber Amplifier (EYDWA) and Raman amplifier. Each of these amplifiers when used individually has some drawbacks. To compensate the drawbacks and to combine the benefits of optical amplifiers, Hybrid configurations are designed for transmission of signals.

II. TYPES OF AMPLIFIER

The Erbium-Doped Fiber Amplifier was the first optical amplifier widely used in optical communications systems. It became a key component in many optical networks because it provides efficient, low-noise amplification of light in the optical fiber low-loss telecommunications window near 1550 nm. EDFAs are used to amplify signal in two bands of wavelengths in the third transmission window. The wavelength ranging from 1525 nm to 1565 nm is known as the C-band or the conventional band and the second band ranging from 1568 nm to 1610 nm is known as the L-band or the long band. It provides in-line amplification of signal without requiring optical to electrical conversion. The amplification is entirely in optical domain. It provides high power transfer efficiency from pump to signal power. The amplification is independent of data rate. The gain is relatively flat so that they can be cascaded for long distance uses. On the debit side, the devices are large and it is limited by gain saturation effects and presence of amplified spontaneous emission (ASE).

A RAMAN amplifier uses Stimulated Raman Scattering (SRS) occurring in silica fibers when an intense pump beam propagates through it. Raman gain arises from the transfer of power from one optical beam (pump) to another (signal) that is downshifted in frequency. The peak amplifications correspond to the signal frequency that is 13.2 THz lower than the pump. This frequency difference is called the Stokes shift. The advantages of RAMAN amplifiers are very broad gain spectrum which can be tailored by varying the number of pumps and their wavelength and relatively low noise figure. The disadvantages of RAMAN amplifiers are the poor pumping efficiency at lower signal power and the requirement of expensive powerful lasers, capable of delivering high powers into single-mode fibers.

In SOAs, amplification is achieved via the stimulated recombination luminescence. To achieve the population inversion, the electrical energy is applied as a pump. The amplifier gain dynamics is determined by the quick carrier recombination lifetime of SOA. Consequently, SOA will respond quickly to the changes in the input optical signal power. This may cause severe signal distortions in multichannel WDM systems. The gain of a specific channel is saturated not only by its own power but also by the power of the neighboring channels, a phenomenon known as cross-gain saturation. It is undesirable in WDM systems. As a result, the amplified signal appears to fluctuate randomly which degrades the effective SNR at the receiver. The main advantages of

SOAs are their broad amplification bandwidth (up to 70 nm), low power consumption and low cost.

III. HYBRID OPTICAL AMPLIFIERS

EDFA-EDFA amplifiers are used as power boosters, optical repeaters as well as inline amplifiers for long distance. It provides better performance for two bands (C & L) but has variation in gain beyond some frequency range. So, there is a need for several gain clamping techniques to achieve gain flatness..

SOA-EDFA hybrid amplifier can be used to widen the gain spectrum of an EDFA. But it generates larger amount of ASE than in the RAMAN-EDFA and RAMAN-SOA. This affects the total performance of nonlinearity-sensitive transmission system, where the limitations on signal amplification is caused by nonlinearity, the received optical power plays a great role as it affects the receiver's sensitivity which is needed for achieving a definite bit error rate (BER). Therefore, it is not applied in long haul DWDM systems.

In RAMAN-SOA, RAMAN amplifier suppresses the nonlinear effects produced by SOA. SOA benefits include compactness and has the ability to facilitate additional functionalities such as wavelength conversion and all-optical regeneration and moreover Raman amplifiers provide broad amplification spectrum, less amplified signal distortions, even negative noise figure values. But this hybrid amplifier requires powerful pumping sources. Therefore, we can achieve higher gain with low noise figure or a wider amplification bandwidth. However this hybrid combination is not preferred due to large signal distortion produced by air.

In RAMAN-EDFA, the gain spectrum of RAMAN can be varied by adjusting the pump powers and pump wavelengths. So these properties are used to increase the amplification bandwidth of EDFA. As Raman amplifiers have less noise figure compared to EDFA, to achieve a high gain with low noise figure or wider amplification band , EDFA along with Raman amplifier is used. This hybrid optical amplifier has been analyzed in a DWDM system with 100 GHz channel spacing. It is observed that as we increase the input power, the gain variation over the bandwidth increases. With an input signal power of 3mW, a least BER and high Q-factor is obtained for the given frequency. In order to compare different system configurations, impact of non-linearities on fiber has been introduced.

We made four designs for comparison by changing the positions of RAMAN-EDFA hybrid pair which are mentioned as follows, Fiber-RAMAN-Fiber-EDFA, Fiber-RAMAN-EDFA-Fiber, Fiber-EDFA-Fiber-RAMAN and EDFA-Fiber-RAMAN-Fiber.

IV.SIMULATION SETUP AND ANALYSIS

The proposed system has been simulated in Opti system software. In this setup, an attempt has been made to improve the performance of 64 channel DWDM system for frequency ranging from 187 THz to 193.3 THz, which is amplified by different hybrid optical amplifiers.

Each channel has 10 Gbps data speed. The DWDM system is simulated with a frequency spacing of 100GHz for 100 Km link distance. In the transmitter side, WDM transmitters are used and the input signals are modulated by NRZ format. Initially input power of 1mW is used for transmission and later we increased the input power to 3mW to obtain better performance at the receiver side. The signals are transmitted with dispersion 2 ps/nm/Km. Hybrid optical amplifiers are used as inline amplifiers. Further, at the receiver side, Q-factor, eye opening and Bit Error Rate (BER) is analyzed in the presence as well as absence of nonlinearities.

. In order to achieve better performance, optimized parameter values are used with hybrid optical amplifiers. For EDFA amplifier length and pumping power are optimized as 5m and 100mW respectively. On considering Raman amplifier pump laser array is used for providing pump power and pump frequency. In this setup, two source pump laser array is used with pump powers of 250mW, 650mW and pump frequencies of 201 THz, 207 THz. The length of the Raman amplifier is optimized to 22 Km. This simulation setup is reconstructed for different hybrid amplifier combinations.

Figure 1 depicts the block diagram of hybrid optical amplifier for DWDM system with a frequency spacing of 100GHz. In receiver side, the blocks 1, 2, 3 represent PIN photo detector, 3R regenerator, BER analyzer respectively.

V.RESULT AND DISCUSSION

The performance of different hybrid optical amplifiers (EDFA-EDFA, EDFA-SOA, RAMAN-EDFA, RAMAN-SOA) has been compared for 64 x 10Gbps DWDM system with NRZ modulation format in terms of Q-factor and BER. Simulation results show that RAMAN-EDFA has better Q-factor and least BER. Use of RAMAN and EDFA amplifier at different positions also has been compared for 64 x 10Gbps with 100GHz spacing in the presence as well as in the absence of nonlinearities in the fiber.

Table-1 and Table-2 show the performance of RAMAN-EDFA hybrid amplifier at different locations in the link in terms of Q-factor and BER in the absence and presence of nonlinearities respectively. It is found that FIBER-RAMAN-FIBER-EDFA gives least bit error rate of 10^{-21} and Q-factor of 8.778 compared to the other combinations in the absence of nonlinearities. Similarly, we introduced nonlinearities into the fiber. In the presence of nonlinearities, it is found that the same setup FIBER-RAMAN-FIBER-EDFA gives least bit error rate of 10^{-13} and Q-factor of 8.667 compared to other combinations such as Fiber-RAMAN-EDFA-Fiber, Fiber-EDFA-Fiber-RAMAN and EDFA-Fiber-RAMAN-Fiber. As EDFA signal to noise ratio decreases with distance from amplifier due to the presence of ASE, using EDFA immediately before the receiver gives better performance compared to other set ups.

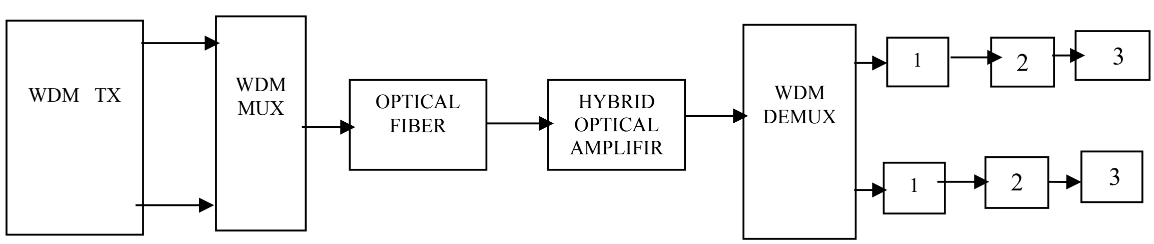

Figure 1 : Simulation setup

Table-1: Comparison of RAMAN-EDFA for 64 channels in the absence of nonlinearities in the fiber.

HYBRID AMPLIFIERS	FIBER-RAMAN-FIBER-EDFA	FIBER-RAMAN-EDFA-FIBER	FIBER-EDFA-FIBER-RAMAN	EDFA-FIBER-RAMAN-FIBER
Q-FACTOR	8.778	5.37	3.88	2.177
BER	6.17e-21	3.7e-13	5.06e-12	0.0122

Table-2: comparison of RAMAN-EDFA for 64 channels in the presence of nonlinearities in the fiber

HYBRID AMPLIFIERS	FIBER-RAMAN-FIBER-EDFA	FIBER-RAMAN-EDFA-FIBER	FIBER-EDFA-FIBER-RAMAN	EDFA-FIBER-RAMAN-FIBER
Q-FACTOR	8.667	6.582	7.345	1.125
BER	3.255e-13	2.7e-9	4.5e-12	0.000124

VI.CONCLUSION

In this manuscript, the performance of different hybrid optical amplifiers has been analyzed for 64 channels with frequency spacing of 100GHz. We observed that RAMAN-EDFA hybrid optical amplifier performs better. Further, we have concentrated on the position of RAMAN and EDFA amplifiers in the link. It is observed that FIBER-RAMAN-FIBER-EDFA gives better results in the presence as well as in the absence of nonlinearities compared to other Setups such as FIBER-RAMAN-EDFA-FIBER, FIBER-EDFA-FIBER-RAMA and EDFA-FIBER-RAMAN-FIBER.

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