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# Quality of light path with ASE noise accumulation in nonlinear optical propagation using global performance metrics

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## Abstract

In this paper, we have targeted our investigations to the inclusion in performance evaluation of light path on the effect of amplified spontaneous emission (ASE) noise accumulated in nonlinear optical propagation. Quality of light-path transmission feasibility has been reported by using a global performance metrics, called *Q*-factor, optical signal-to-noise ratio (OSNR), BER, extinction ratio and nonlinear frequency shift, which takes into account the interaction between the parameters aforementioned and returns a unique value corresponding to the performance metrics.


***Keywords:*** ASE noise; EDFA; BER; *Q*-factor; Nonlinear frequency shift

## 1. Introduction

Since erbium-doped fiber amplifiers (EDFAs) were commercially available, more than thousands of kilometer long optical fiber networks have been made possible. EDFAs are an important component in the design of long-haul telecommunication links. In the transmission systems, removing of amplified spontaneous emission (ASE) noises [1], which are essentially generated from EDFAs, are very important problem.

In [2,3], the authors consider independently the impairments due to the effect of polarization mode dispersion (PMD) and accumulated ASE noise. The analysis was done for each light path and they consider that light path performs well if both the requirements in terms of noise accumulation (ASE) and PMD are satisfied. In these works, the effect of fiber nonlinearities is not considered: it implies neglecting the fundamental trade-off between increasing of transmitted power to overcome noise impairments and limiting the power to avoid the impact of nonlinearities. Similarly, in [4,5] the authors considered only the impairments of optical ASE noise introduced by the in-line EDFAs and of electrical noise of the receivers. A different approach to the problem was presented in [6], the authors proposed to completely separate the transmission layer from control layer.

In this paper, we have targeted our investigations to the inclusion in performance evaluation of light path on the effect of ASE noise accumulated in nonlinear optical propagation. Quality of light-path transmission feasibility has been evaluated using a global performance

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metrics, called *Q*-factor, optical signal-to-noise ratio (OSNR), extinction ratio and nonlinear frequency shift. The system modeling and description is mentioned in Section 2 after brief introduction in Section 1. In Section 3 the results are discussed and concluding remarks are reported in Section 4.

## 2. System modeling and description

Here the physical EDFA model is based on a standard set of equations for an EDFA's steady-state atomic manifold population densities and the evolution of optical powers along the length of the device [1,7,8]. Optical signals propagating along the EDFA interact with the local population densities, resulting in power gain or loss via stimulated emission and absorption. Spontaneous emission and its subsequent amplification also occur. The topology layout for an optical transmission system is shown in Fig. 1 below.

There are 10 EDFA fiber spans and the total transmission distance is 500 km. The length of the fiber in each span is 50 km, and the length of the erbium-doped fiber is 14 m. ASE noise from optical amplifiers is added by a nominally fixed amount in each span. ASE noise is often quantified by the OSNR, which is the ratio of the signal power to the ASE noise power in a 0.1-nm optical bandwidth. Fig. 1 illustrates the monitoring situation for ASE noise that utilizes the *OptSim*™ Physical EDFA model. Forward-propagating optical signals are launched into the EDFA via the first input node, while backward-propagating signals (e.g., counter-propagating pumps) enter via the second input node (not shown in Fig. 1). *OptSim*'s multiplexer components can be used to combine signals and pumps at either input. The EDFA output is available at the output node, and includes any signals, pumps and ASE that are exiting in the amplifier.

The optical monitor is used that provides the facility to measure a number of standard properties of an optical signal, specifically *average optical power* (a power meter), *frequency shift and OSNR*. The results are obtained in several forms showing the dependence of the properties on scanned parameters. Moreover, the model is given with an output port and the collected

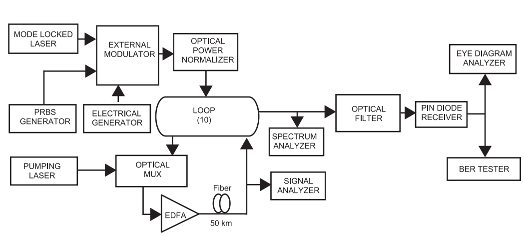



**Fig. 1.** System modeling.

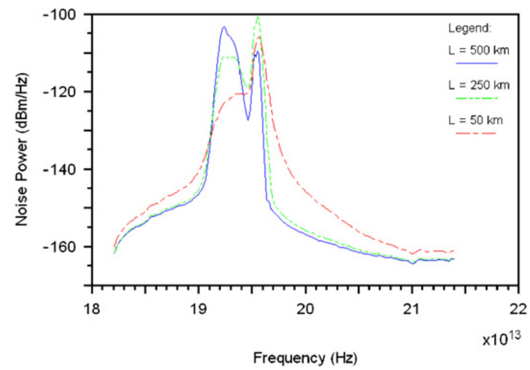
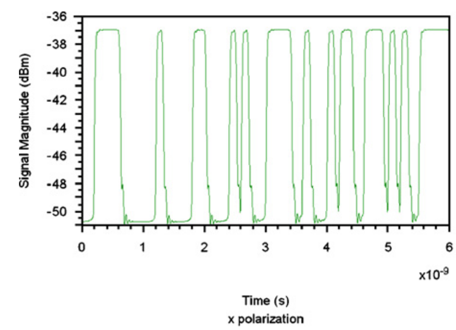
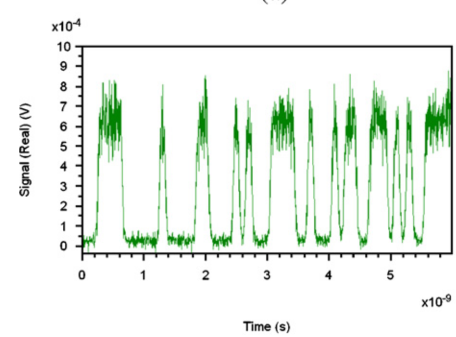


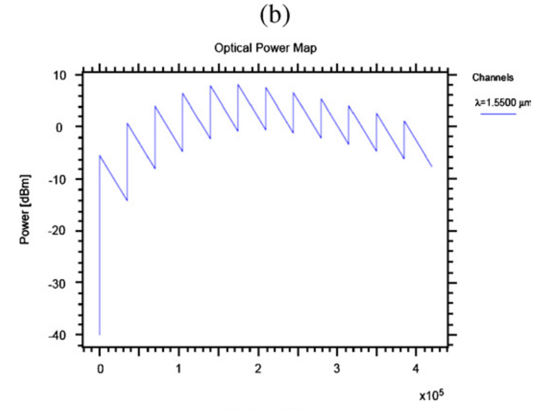

**Fig. 2.** Illustrates the phenomenon where the ASE output spectral peak gradually shifts to shorter frequencies (longer wavelengths).




(a)




(b)




(c)

**Fig. 3.** (a) Input and (b) output at 500 km with ASE and (c) power map.

information is passed to the XY-Plotter model to be combined with data from another point in the topology BERTester data.

## 3. Results and discussion

We target our analysis to the inclusion in performance evaluation of light path effect of accumulated ASE noise, *linear* and *nonlinear* propagation. For physical path, the accumulated ASE noise is evaluated with nonlinear effects and varied chirp. As a result, light path is targeted with the corresponding *OSNR and ASE*. An interesting effect in chains of EDFAs is the peaking of the ASE output spectrum at longer wavelengths has been observed (see Fig. 2). Typically, the ASE spectrum is most strongly peaked near 1530 nm (195.942783 THz), where EDFAs absorption/emission cross-sections are the largest. The results have been reported for the transmission distance of 500 km at 10 Gbps with 10 spans of 50 km each. It has been observed that over a chain of amplifiers the gain tends to saturate, which shifts the gain peak, and hence the ASE output spectra, to longer wavelengths. As can be seen, the spectral peak gradually shifts to shorter frequencies (longer wavelengths), as expected. The input and output signal with ASE and the power map have been reported in Fig. 3.

Further, in order to observe the robustness of system on ASE noise and chirping the performance metrics $Q$-factor, AVE noise ones (V) versus frequency shift at varying chirp has been reported. The initial eye opening, frequency chirp and eye opening at output is mentioned in Fig. 4. It has been observed that there is sufficient eye opening at the receiver after transmission distance of 500 km, which indicate that the signal can be recovered easily in the presence of ASE noise and fiber nonlinearities. The minimum BER observed is of the order of $10^{-9}$.

From Fig. 5a (frequency shift versus AVE noise ones), it has been observed that the frequency shift is

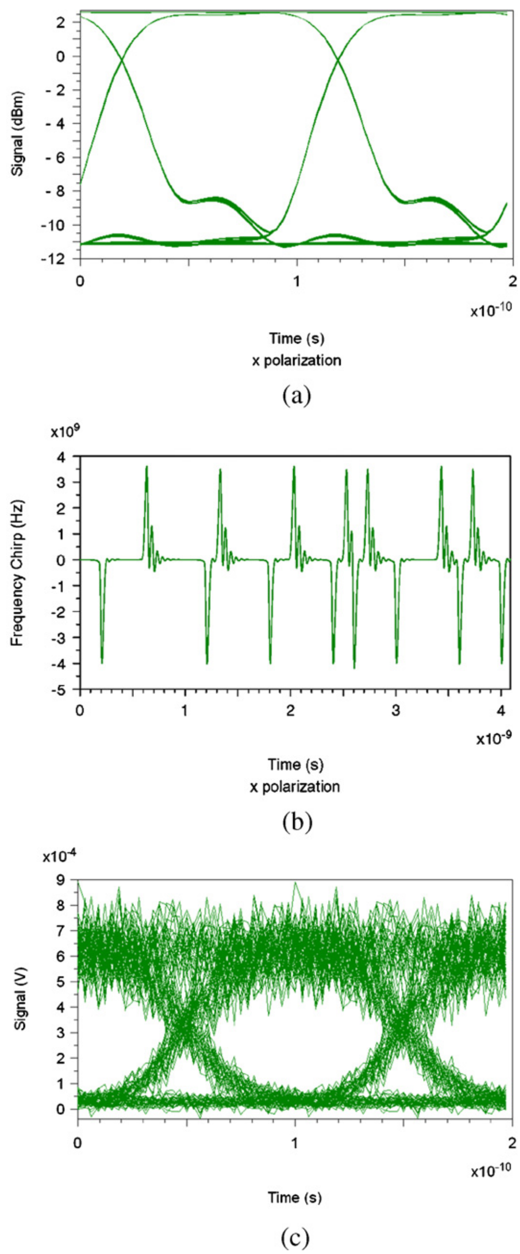



**Fig. 4.** (a) Initial eye opening; (b) frequency chirp signal and (c) eye opening at output.

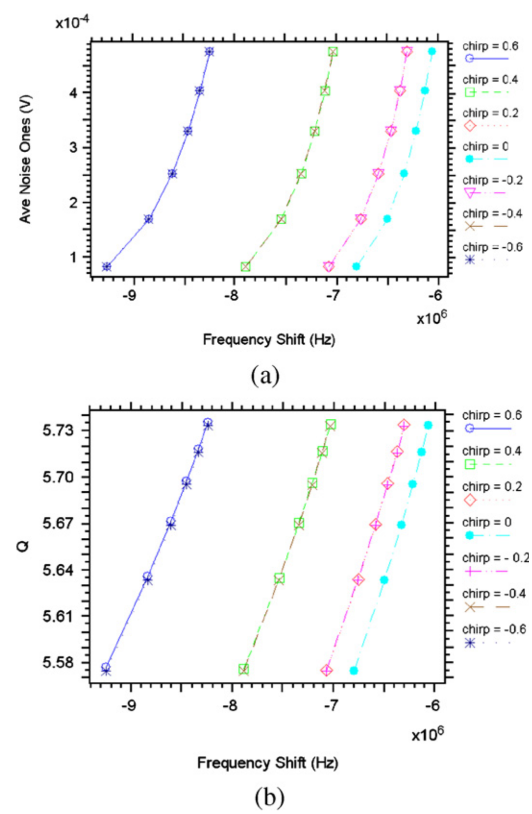
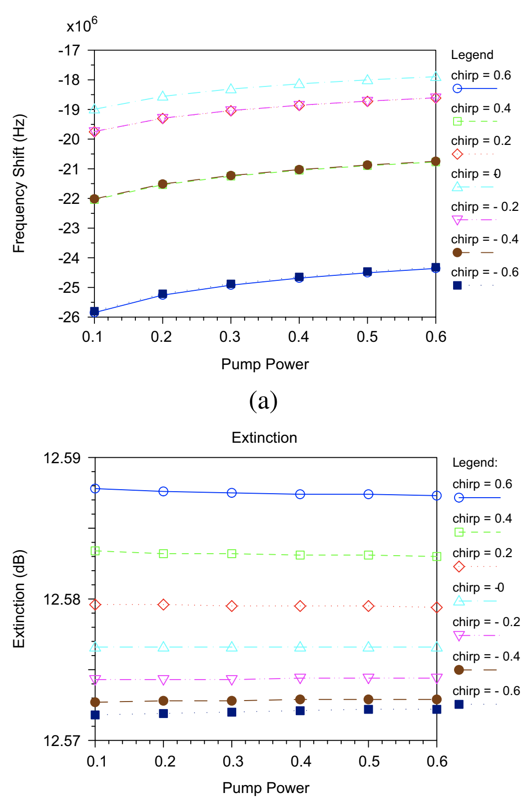



**Fig. 5.** (a) Frequency shift versus average noise ones (V) and (b) frequency shift versus $Q$-factor at varied chirp factor.

maximum at chirp $C = \pm 0.6$ and minimum at $C = 0$. Interesting results have been obtained, indicating that the shift in frequency remains same at equal values of positive and negative chirp. Similar trends have been observed at varying chirp for $Q$-factor versus frequency shift (see Fig. 5b). These investigations ascertain that there is equal shift in frequency both at positive or negative initial chirp with respect to $Q$-factor and AVE noise ones (V) Fig. 6.

Further, the investigations have been carried out by changing pump power from 0.1 to 0.6 dBm versus frequency shift and extinction ratio at varied chirp. The observed performance metrics minimum BER, highest $Q$-factor, AV1noise and extinction ratio are of the order of $10^{-9}$, 6, 8.32 V and 12.58, respectively. Fig. 7 reveal that optical SNR vary between 11 and 11.7 dB for $Q$-factor of 5.58–5.73, respectively, and there is negligible impact of chirp on OSNR. Similarly, it has been observed that the chirp variation from 0 to $\pm 0.6$ have negligible effect on the extinction ratio; it remain within the limit of 12.57–12.59 dB. It is indicated that the quality of light path is good even in the presence of ASE noise accumulation and fiber nonlinearities up to the transmission distance of 500 km.




(b)

**Fig. 6.** (a) Pump power (dBm) versus frequency shift and (b) pump power (dBm) versus extinction ratio at varied chirp factor.

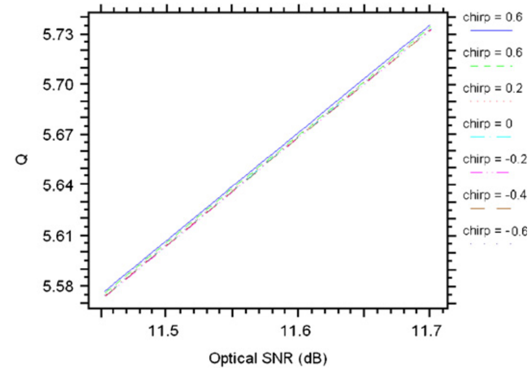



**Fig. 7.** Optical SNR versus $Q$-factor at varied chirp factor.

## 4. Conclusions

In this paper, we have targeted our investigations to the inclusion in performance evaluation of light path on the effect of ASE noise accumulated in nonlinear optical propagation. Quality of light-path transmission feasibility has been reported up to the transmission distance of 500 km. It has been shown that over a chain of amplifiers the gain tends to saturate, which shifts the gain peak, and hence the ASE output spectra, to longer wavelengths. Further, it is indicated that the global performance metrics BER, $Q$-factor, optical signal-to-noise ratio (OSNR), nonlinear frequency shift and extinction ratio is in the range of [$10^{-8}$–$10^{-9}$], [5.58–5.73], [11–11.7] dB, [26–18] GHz and [12.57–12.59] dB, respectively, at chirping factor of 0 to $\pm 0.6$.

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## References

[1] P.C. Becker, N.A. Olsson, J.R. Simpson, Erbium-Doped Fiber Amplifiers: Fundamentals and Technology, Academic Press, San Diego, 1999.

[2] Y. Huang, A. Gencata, J.P. Heritage, B. Mukherjee, Routing and wavelength assignment with quality-of-signal constraints in WDM Networks, in: European Conference on Optical Communications (ECOC '02), Copenhagen, September 2002.

[3] Y. Huang, W. Wen, J.P. Heritage, B. Mukherjee, Signal-quality consideration for dynamic connection provisioning in all-optical wavelength-routed networks, Optical Networking

and Communications Conference (OptiComm), Dallas, TX, October 2003.
[4] B. Ramamurthy, D. Datta, H. Feng, J.P. Heritage, B. Mukherjee, Impact of transmission impairments on the teletraffic performance of wavelength-routed optical networks, IEEE/OSA J. Lightwave Technol. 17 (10) (1999) 1713–1723.
[5] R. Sabella, E. Iannone, M. Listanti, M. Berdusco, S. Binetti, Impact of transmission performance on path routing in all-optical transport networks, IEEE/OSA J. Lightwave Technol. 16 (1998) 1965–1971.
[6] B. Peeters, D. Forbes, R. Friskney, J. Shields, Optimal routing in hybrid networks by decoupling the route calculation from the assessment of optical route viability, in: Ninth European Conference on Networks & Optical Communications (NOC 2004) Proceedings, Eindhoven, The Netherlands, June 29–July 1, 2004, pp. 359–366.
[7] E. Desurvire, Erbium-Doped Fiber Amplifiers, Wiley, New York, 1994.
[8] C.R. Giles, E. Desurvire, Modeling erbium-doped fiber amplifiers, J. Lightwave Technol. 9 (1991) 271–283.