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Tebe Larry Ojukonsin
Department of Electrical/Electronic Engineering, Niger Delta University, Nigeria.

Efiyeseimokumo Sample Ikeremo
Department of Electrical/Electronic Engineering, Niger Delta University, Nigeria.

Ayibapreye Kelvin Benjamin
Department of Electrical/Electronic Engineering, Niger Delta University, Nigeria.

Correspondence:
Tebe Larry Ojukonsin
Department of Electrical/Electronic Engineering, Niger Delta University, Nigeria.

MATLAB Based Simulation of BER Performance of Cascaded Optical Fibre Amplifiers

Tebe Larry Ojukonsin, Efiyeseimokumo Sample Ikeremo, Ayibapreye Kelvin Benjamin

Abstract
In optical fibre communication networks, the bit-error rate (BER) to signal-to-noise (SNR) ratio has been very peculiar to analysing optical fibre communication system performance. Here, we report explicitly, the optical BER performance of a network of cascaded optical amplifiers with respect to the amplifier spontaneous emission noise. The transmission of an on-off keyed non-return to zero (NRZ) optical signal via a network of cascaded optical amplifiers (mainly: erbium doped fibre amplifiers (EDFAs)) were simulated using MATLAB. These EDFAs are separated by optical fibre losses and computations of amplified spontaneous emission noise (ASE), optical signal-to-noise ratio (OSNR), Q-factor and BER at both amplifier input and output was implemented. The BER performance of the system due to OSNR, ASE and BER are reported.

Keywords: Cascaded optical amplifiers, optical fibre, MATLAB, BER performance, simulation.

Introduction
For efficient and effective design of an optical fibre communication network, its germane to optimise the different electrical and optical parameters in other to improve the working conditions of the network. Two separate parts are required for optical network design namely electrical or higher layer design and the optical system design. Nevertheless, in this design a point-to-point optical link is assumed. Here, the optical layer (wavelength division multiplexing (WDM)) is perceived as a baren physical layer that transmit raw bits at high bit-rate with negligible loss [1].
It was reported that majority of conventional network planners failed to take into consideration the heuristics of the optical layer which can be a very costly mistake and problematic. It is of immense concern that the optical parameters are considered with exception to cases where some transmission distance and bit-rate are under bounded constraints [1].
Nonetheless, the transmission length of optical link is directly proportional to the bit-rate and the parameters possess the ability of absenting in the network. It is salient for network planners to take aforementioned relationship between the transmission length and bit-rate into consideration, to build a network that can tolerate impairments and nonlinearities caused by optical parameters [2].
Optical signal attenuates as it travels through a fibre optics network channel which we understand is an inherent property of the medium of propagation. This is often characterized by the signal attenuation content α, which is expressed as the loss $(in\ dB)$ per travelled km [2]. It is expected that if the total attenuation is greater than the launched input signal from the transmitter p_{av}, there will be no signal reception at the receiver. This seems untrue but remains an important factor for determining signal reception at the receiver of an optical communication network. A receiver such as a photodetector, either of the PIN or APD type needs a minimum amount of power to enable separation of the 0s and 1s from the raw optical input signal in other to achieve efficient reception of an optical transmitted signal [2, 3]. The optical receiver sensitivity plays a significant role in ensuring that there is efficient signal reception from an optical transmitter at the receiver. It is the minimum power

requirement of the receiver. Given a quoted optical sensitivity or when a target BER must be met, a threshold BER is set at 10^{-12} unless otherwise stated. In other to guarantee that, the transmitted power is high enough to maintain signal power greater than the receiver sensitivity at the receiver in spite of attenuation along the transmission line. It is worth noting that increase in power transmitted to the higher level doesn't assure that bits can be transmitted through great distances because of induced impairments and nonlinearities by high input power [3].

There exists an upper limit for all receivers (PIN type or APD type) for reception of optical power, this is often given by the dynamic range of the receiver. There is need for optical power at the receiver to always lie within the dynamic range of the receiver. In case, the transmitted power exceeds its maximum value, it damages the receiver. However, the receiver cannot separate between 0s and 1s if the power level is less than the minimum value [4, 5].

In this study, the losses through the cascaded optical amplifiers are reported by the BER performance and amplified spontaneous emission noise (ASE) behaviours as the transmitted input signal travels through the cascaded optical network neglecting polarization mode dispersion (PMD), nonlinearities dependent gain and loss, and related issues of wavelength division multiplexing (WDM) [5].

Point-To-Point Link OSNR Calculation

Figure 1 shows a physical optical amplifier network link. We considered a long-haul fibre WDM link. Periodically placed amplifiers are repeated at intervals to boost signal power. Hence, a signal can attain more than the maximum allowable accumulated loss due to attenuation across the transmission distance (αL) [6]. This however, causes each amplifier stage to add its own component of amplified spontaneous emission (ASE) noise and degrades the OSNR further. Furthermore, each amplifier increases the inherent noise in it. It is almost impossible to be remove the inherent noise throughout the spectra. Therefore, it is significant to deploy a technique to compute the output OSNR at the terminal of an N stage amplified system and to validate the value of N [6].

We must certify that the OSNR of the last stage is in agreement with the system OSNR and BER requirements in an OSNR based design. To ensure that the system support a particular BER, it is essential to make the OSNR system design compliant [6].

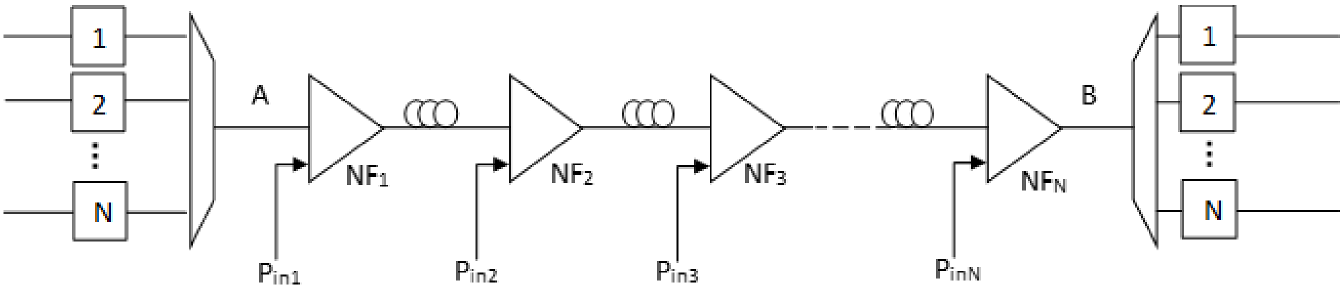

Fig.1: Optical amplifier cascade network.

Cascaded Optical Amplifier Model

In this study, a MATLAB computer program/file is used to describe signal and ASE noise propagation through a cascade of optical amplifiers separated by loss. For simplicity, there was need to neglect the separate loss contributions of VOAs, splices, connectors, multiplexers and de-multiplexers effectively, as their consideration will lead to reduced fibre length and nonlinearities. Nevertheless, these were taken into consideration to a great extent in determining the relationship between the OSNR and the number of amplifiers in cascade. The cascade amplifier model focuses fundamentally on modelling of an OSNR calculator such that the Q-factor and the BER (Bit Error Rate) can be computed, in other to evaluate the performance of the receiver. The frequency of the input signal used is the same as that of the frequency of noise near the input signal. For the purpose of this design, we considered a white (flat) signal with small bandwidth but generally, this should be wide band (30 nm). [7, 8].

Propagation of Input Signal

The signal power at the input and output amplifier was computed both linearly and in dBm. Figure 2 below illustrate plot of output power signal in dB against number of amplifiers in cascade which varies randomly.

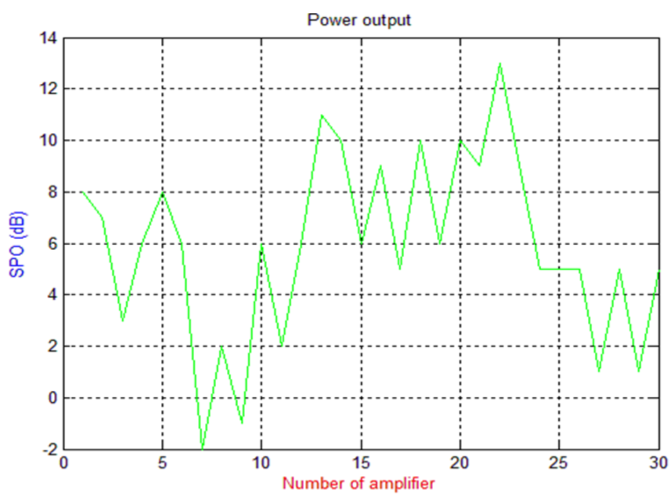

Fig. 2: Power output in dB against Number of amplifiers.

ASE Noise Propagation

The input signal and amplified spontaneous emission noise (ASE) are amplified respectively. The ASE noise or optical noise with power spectral density (PSD) in W/Hz (in a single polarization) is generated by each amplifier. The total ASE power spectral density (PSD) was computed at the input and output of every amplifier. The mathematical description of the ASE generated by each amplifier is modelled as follows.

$$N_{Oself} = \frac{1}{2}(NFG - 1)hv$$

Where h denotes Planck's constant, v denotes frequency of the signal, NF denotes the noise figure of the amplifier and G denotes the amplifier gain. Figure 3 below illustrate plot of the total ASE PSDout against the number of amplifiers in cascade which varies randomly.

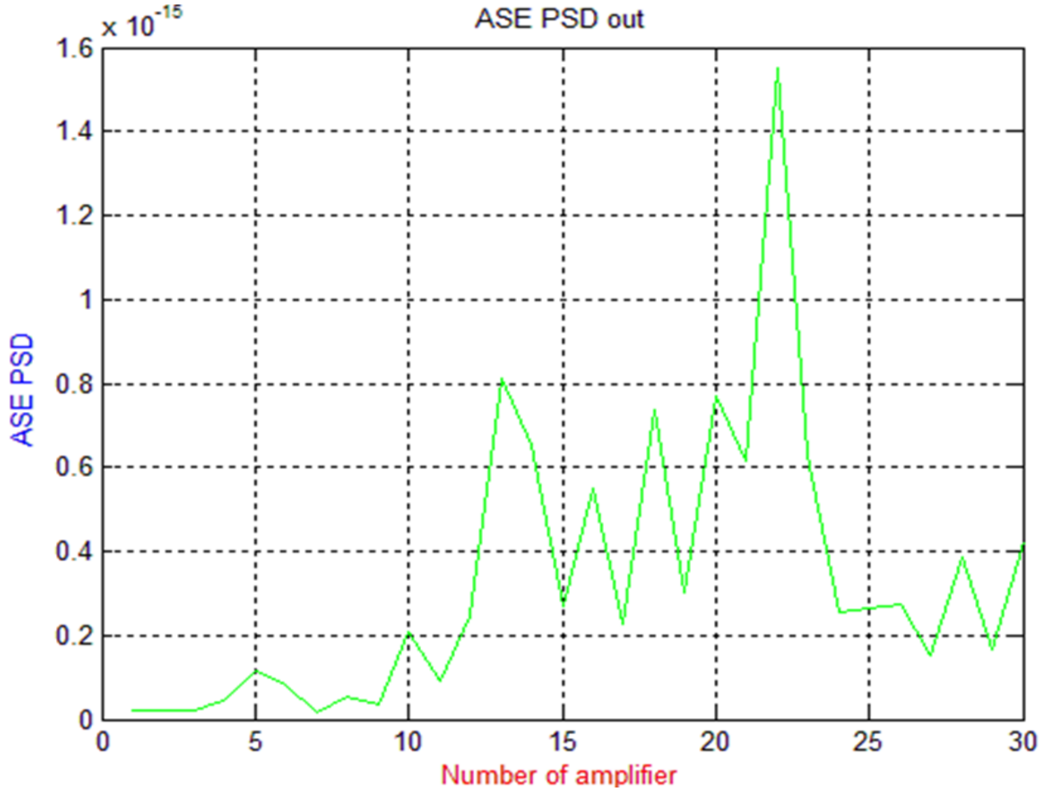

Fig. 3: ASE PSDout against number of amplifiers.

Optical Signal-To-Noise Ratio (OSNR)

Figure 4 below illustrate variation of OSNRout in dB with number of amplifiers. It is obvious that the OSNRout in dB against number of amplifiers cascade is a linear function that decreases with increase in number of amplifier cascade. The OSNR at the input and output of the amplifiers was calculated both linearly and in dB.

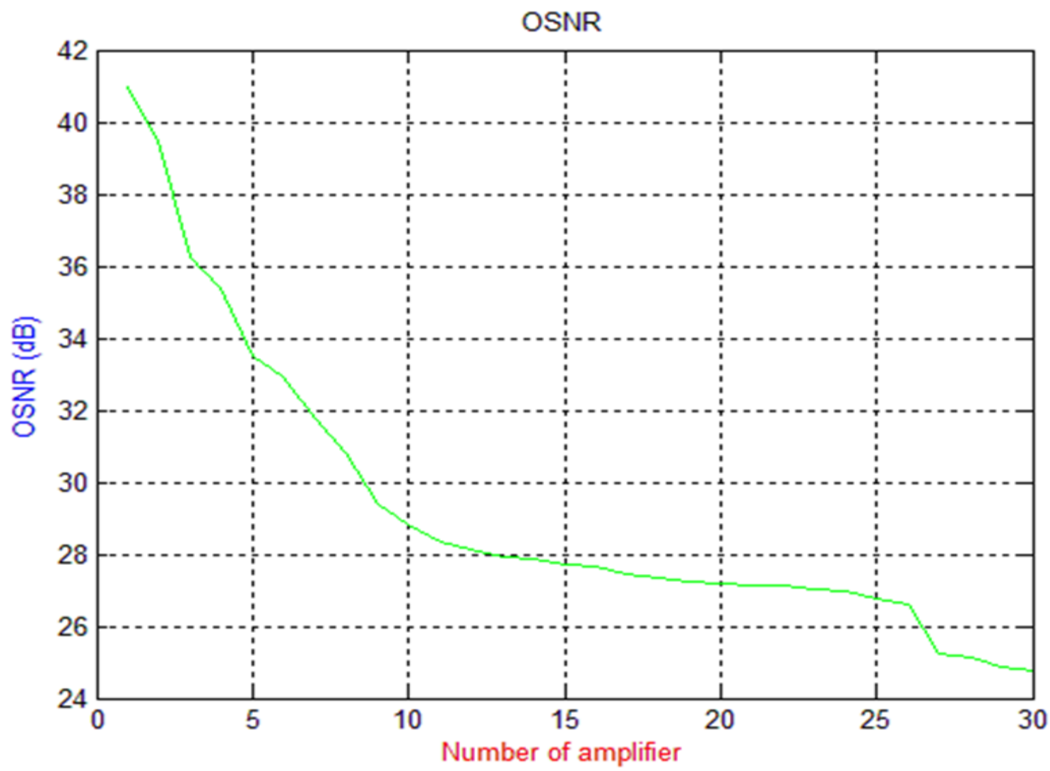

Fig. 4: OSNRout against number of amplifiers.

Cumulative Fibre Loss

The cumulative fibre loss is the total loss (dB) in the optical fibre amplifier cascaded network from transmitter output to any position in the cascade where OSNR can be calculated. Figure 5 below shows plot of cumulative loss against number of amplifiers in cascade. It is a linear function as it increases with increase in number of amplifiers in cascade.

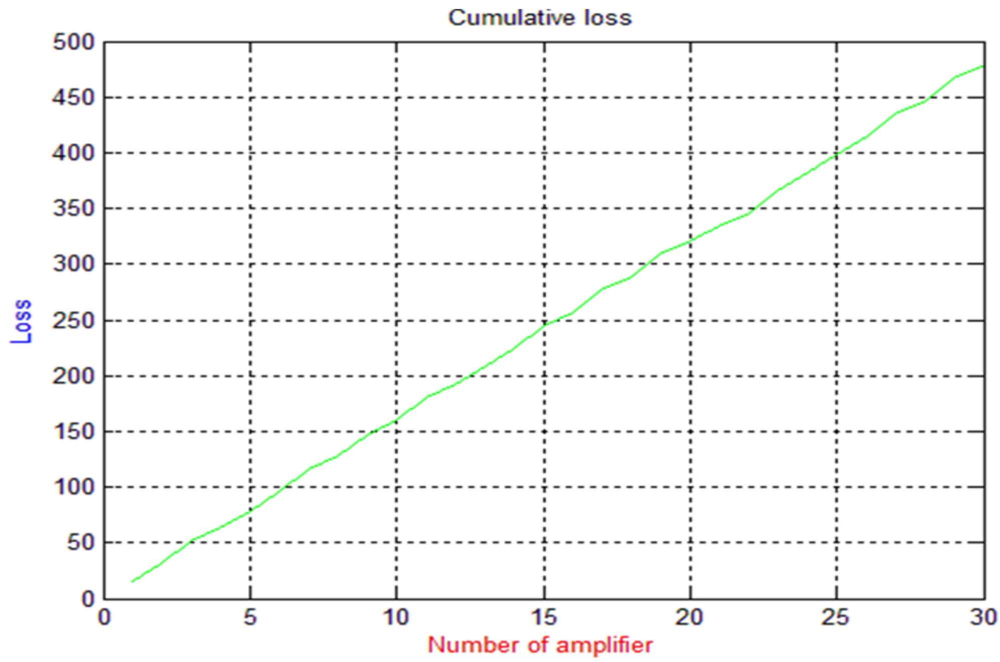

Fig. 5: Cumulative loss against number of amplifiers in cascade.

Ber Model in Presence of ASE Noise

The probability that an error may occur in a bit of a pulse train, i.e., a "1" bit turns into a "0" bit or vice versa is the Bit Error Rate (BER). The target BER for a commercial fibre system is 10^{-12}, while it is 10^{-9} for laboratory experiment. Mathematically, under the assumption of Gaussian noise statistics in the electrical domain, BER at optimal threshold is given by

$$BER = \frac{1}{2}\, erfc\left(\frac{Q}{\sqrt{2}}\right)$$

Sometimes the BER can be useful for high Q, BERapp = $\frac{\exp\left(-\frac{Q^2}{2}\right)}{\sqrt{2\pi}Q}$

Where $Q = \frac{i_1 - i_0}{\sigma_1 + \sigma_0}$

Matlab program was used to calculate the Q and BER values, and to generate the BER curves. At constant OSNR of13dB (varying ASE PSD), a BER floor occurred at approximately 10^{-12} and 10^{-9} figure 6. BER floor did not occur when ASE PSD was fixed at 1e-17 (see figure 7).

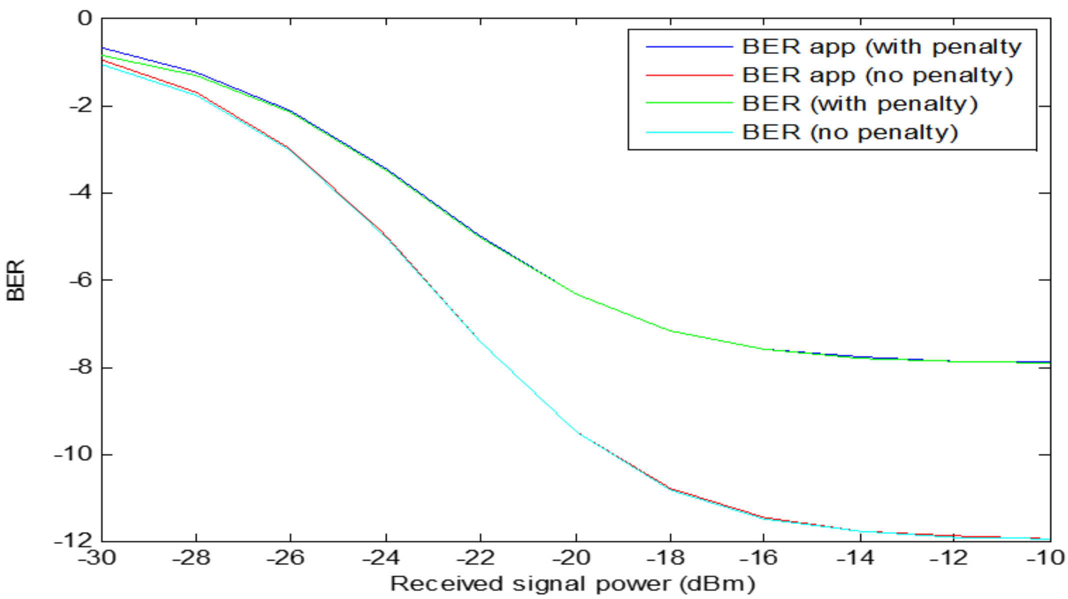

Fig. 6: BER curve at constant OSNR (13 dB).

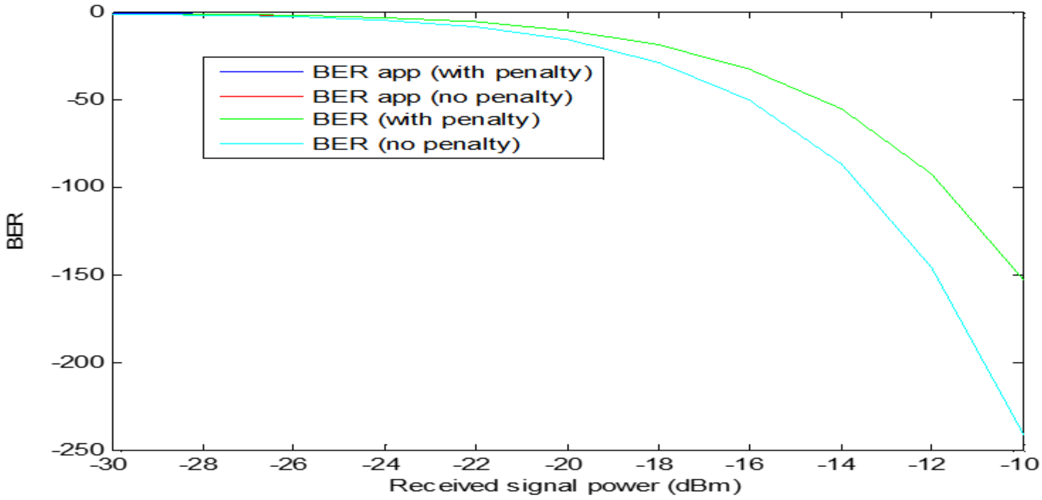

Fig. 7: BER curve at Fixed ASE PSD (1E-17).

Results and Discussions

For a cascade of 30 amplifiers with an inter-amplifier loss of $20\,dB$. Following the Tx-loss-G-Rx approach, for an average transmitted power of $6\,dBm$, the amplifier with $G = 22\,dB$ and $NF = 5dB$ produced a better OSNR input and output, and average signal at each amplifier compared to the amplifier with $G = 16\,dB$ and $NF = 5dB$. Figure 8 shown a plot of OSNR at each amplifier stage for both specified amplifiers.

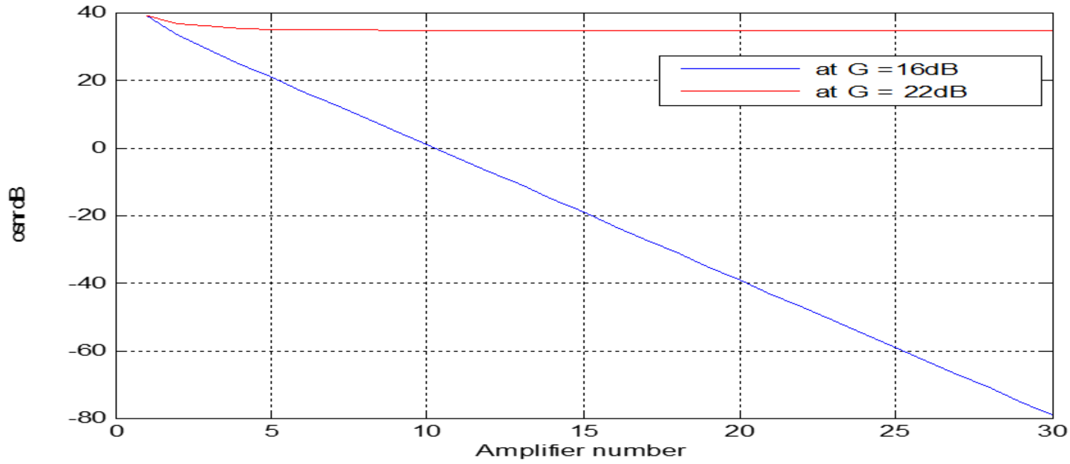

Fig. 8: OSNR vs. amplifier number

2. Below are the OSNR vs. P_{av} Curves for Gain = Total Loss = 16 dB

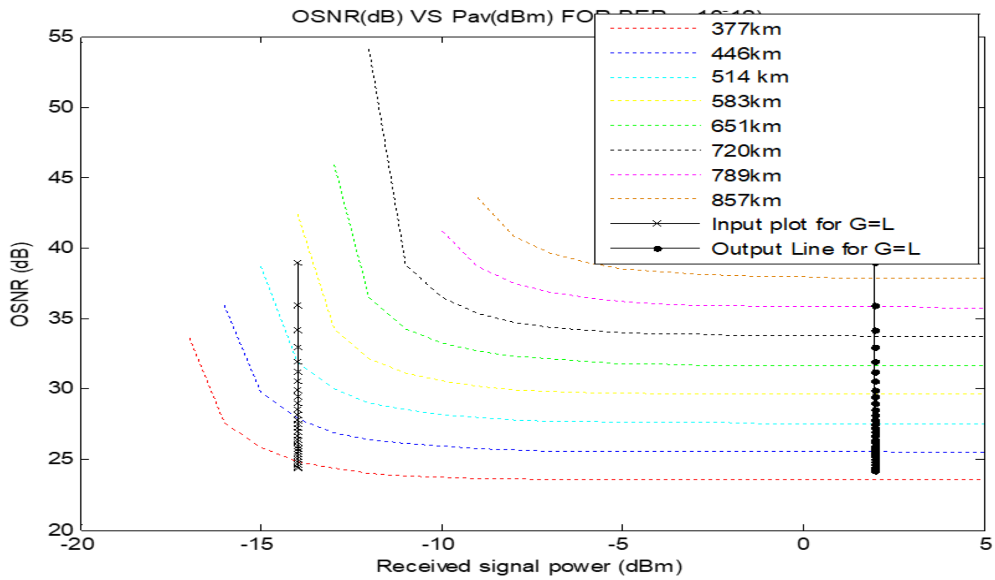

Fig. 9: OSNR against P for G = L

Below are the OSNR vs. Pav plots for Gain = 22dB and Total Loss = 16 dB

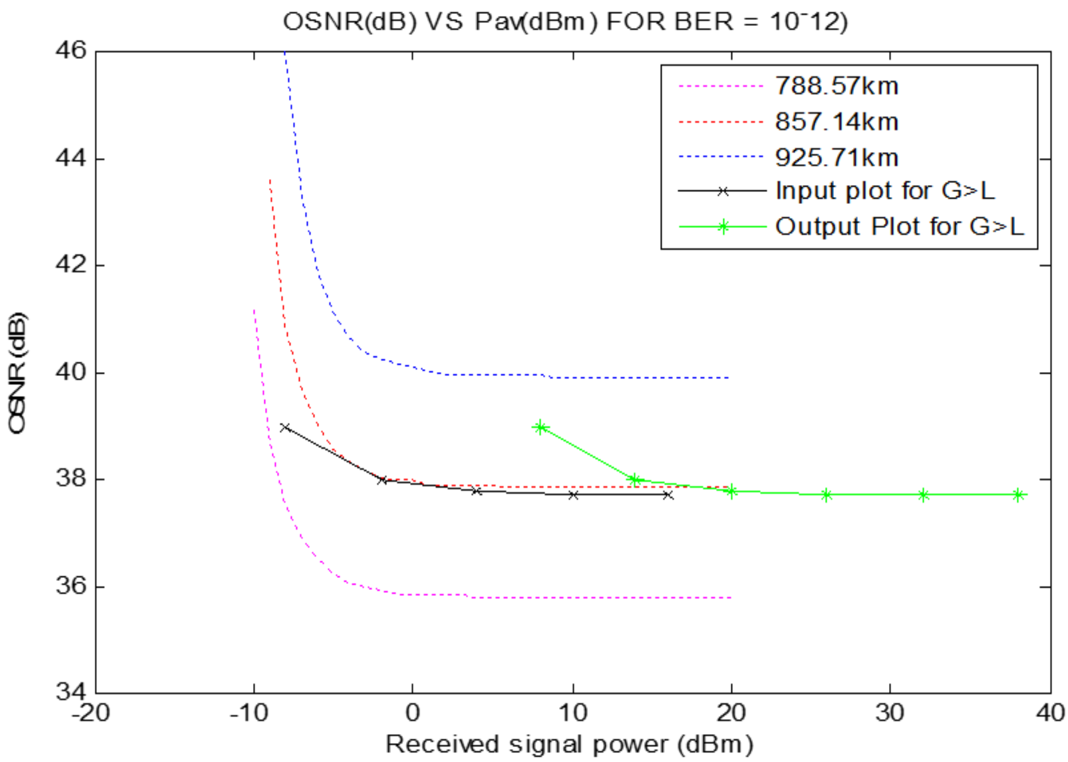

Fig. 10: Plot of OSNR Vs P for G>L (only first 6 stages are shown for input and output)

Below is the OSNR vs P_{av} plot for Gain = 16 dB and Total Loss = 22 dB

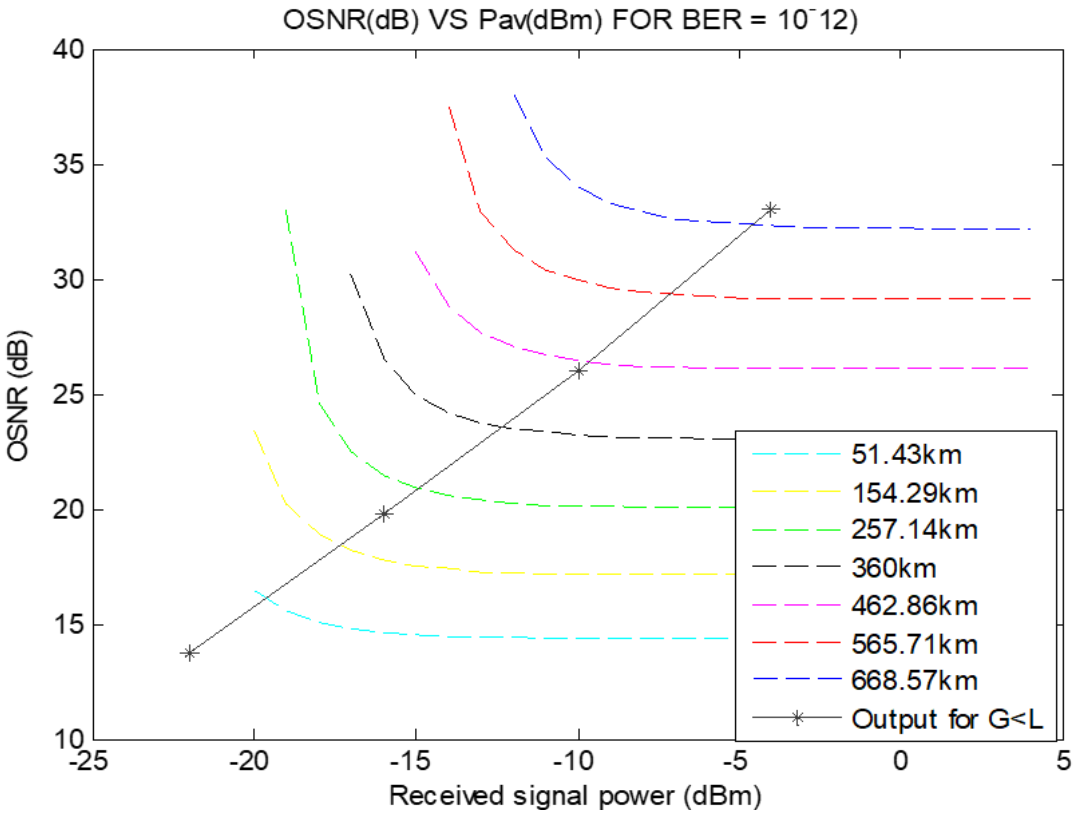

Fig. 11: Plot of OSNR Vs P for G<L (only first 4 stages are shown for output)

3. For a transmitter power of 2dBm,

Maximum Possible distance obtained for Gain =Loss=16dB is 942.86km
Maximum Possible distance obtained for Gain =22dB and Loss=16dB is 942.86km
Maximum Possible distance obtained for Gain =16dB and Loss=22dB is 1457km

4.

Condition for Transmitter Power=2dBm	Maximum Distance (Loss)(Km)	Maximum Distance (Dispersion) (Km)	Length of Cascade for min (max $dist_{Loss}$,max $dist_{disp}$)
G = L =16dB	942.86	550	17
G=22dB, L=16dB (G>L)	942.86	857.14	27
G=16dB, L=22dB(G<L)	1457	<< 32	

Conclusion

We can improve the OSNR by Raman amplification. This degradation can be lessened somewhat by distributed Raman amplifiers. Raman amplification is inherently a result of stimulated Raman Scattering of a high intensity pump signal at a different frequency (compared to the signal frequency). This produces a gain because of creation of stoke wave which in turn produces a gain feeding wave of a wide bandwidth.

Finally, the design was carried out neglecting polarization mode dispersion (PMD), nonlinearities, polarization dependent loss and gain, optical amplifier saturation, gain dynamics and crosstalk as the presence of the effects leads to spectral broadening, impairments and nonlinearities which further reduces the maximum length of the propagation path. The dynamic range of the receiver sets the maximum and minimum power range of the receiver. For optical power above 3dBm propagating through the fibre will incur further nonlinearity penalties.

The addition of amplifier noise across the cascade will cause the noise monitoring sensitivity requirement to evolve through the network.

We established a threshold for BER degradation of 10^{-9} (target bit error rate), by using a root finding method to calculate the signal power needed for the target BER. Thus, if the signal is free from error, then a given impairment must degrade the BER to 10^{-9} before it can be declared significant.

Optical performance can be monitored within the amplifier cascade network by measuring the optical signal-to noise ratio (OSNR) and bit error rate (BER) for the investigation of performance degradation due to amplified spontaneous emission noise.

Measurements on 10-Gb/s signals unveil that performance monitoring sensitivity to OSNR levels of about 26 dB is good for identifying degradations that affects the BER.

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