BIT ERROR RATE PERFORMANCE OF CASCADED OPTICAL AMPLIFIERS USING MATLAB COMPUTATION SOFTWARE

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Abstract

This paper gives a detailed presentation of the bit error rate (BER) performance of cascaded optical amplifiers with variation of amplified spontaneous emission noise in an optical network using Matlab files that models the transmission of an on-off keyed non-return to zero (NRZ) optical signal through a cascade of optical amplifiers (typically Erbium Doped Fibre Amplifiers (EDFAs) separated by optical loss (i.e. fibre) and calculate the amplified spontaneous emission (ASE) noise, optical-signal-to-noise ratio (OSNR), Q factor and BER at the amplifier input and output, fibre dispersion was accounted for by a penalty on Q. Matlab computer program was used to model the design and calculation of ASE noise, OSNR, Q factor, BER and penalty in Q were made. The performance of the receiver as a function of OSNR and received ASE PSD, BER and other output parameters was investigated.

Keywords: ASE noise, optical-signal-to-noise ratio, cascaded optical amplifiers, bit error rate

Introduction

In network design it is significant that a network planer needs to optimize the various electrical and optical parameters to enhance the smooth operation of the network. Optical system design is inherently of two separate parts irrespective of the network topology: optical system design and electrical or higher layer system design. However, in our design we are considering a point-to-point link. The optical layer (WDM layer) can be viewed as a barren physical layer whose function is to transmit raw bits at a high bit rate with negligible loss. Most conventional network planners do not consider the heuristics of the optical layer but such mistakes can be problematic. It is of great interest to consider the optical parameters except that the bit rate and some transmission distance are under some bounded constraint [1].

However, the transmission length increases with increase in the bit rate and the parameters have the capability of absenting in the network. It is imperative for a network planer to consider the affecting parameters and build a network that can accommodate impairments and nonlinearities caused by optical parameters.

An optical signal propagates through an optical fibre and is subjected to attenuation which is a property of the medium of propagation. Attenuation in a fibre is often characterized by the attenuation content α, which gives the loss (in dB) per travelled km.

It is common to think that if the total attenuation is greater than the input signal launch from the transmitter Pav, a signal will not be received at the receiver. This is not true but is an important issue for determining signal reception at the terminal of a communication channel. For achieving efficient reception of an optical transmitted signal, a receiver (essentially a photo-detector, either a PIN or APD type) needs a minimum amount of power to separate the 0s and 1s from the raw optical input signal [2, 3].

The receiver sensitivity is the minimum power requirement of the receiver. If an optical sensitivity is quoted or when a target BER must be met then the BER should be 10^{-12} unless otherwise stated and this is to ensure that the transmitted power should be high enough so that it can maintain signal power greater than the receiver sensitivity at the receiving end, despite the attenuation along the transmission line. If we increase the transmit power to a higher level it is not a guarantee that we can send bits across great distances because high input power creates impairment and nonlinearities [4, 5].

Also, an upper limit exists for all receivers (APD type or PIN type) for receiving optical power this is usually given by the dynamic range of the receiver, and it sets the maximum and minimum power range of a receiver. The optical power at the receiver must always be within the dynamic range of the receiver. If it exceeds the maximum value it damages the receiver or the receiver cannot distinguish between 1s and 0s if the power level is less than the minimum value.

As regards to this study the following effects and details are neglected: polarization mode dispersion (PMD), nonlinearities dependent gain and loss, issues related to optical dense wavelength division multiplexed (ODWDM) power.

BER calculator

1. Using a Matlab program Figure (1) which shows the plot of BER curves at constant OSNR (with all noise on) has been generated. Table 1 shows the required OSNR for the specified BER floors. On increasing the bit rate to 10 Gb/s and using the same OSNRs for achieving the required BER floors, the new BER floors (i.e. at 10 Gb/s) were higher (See figure 2).

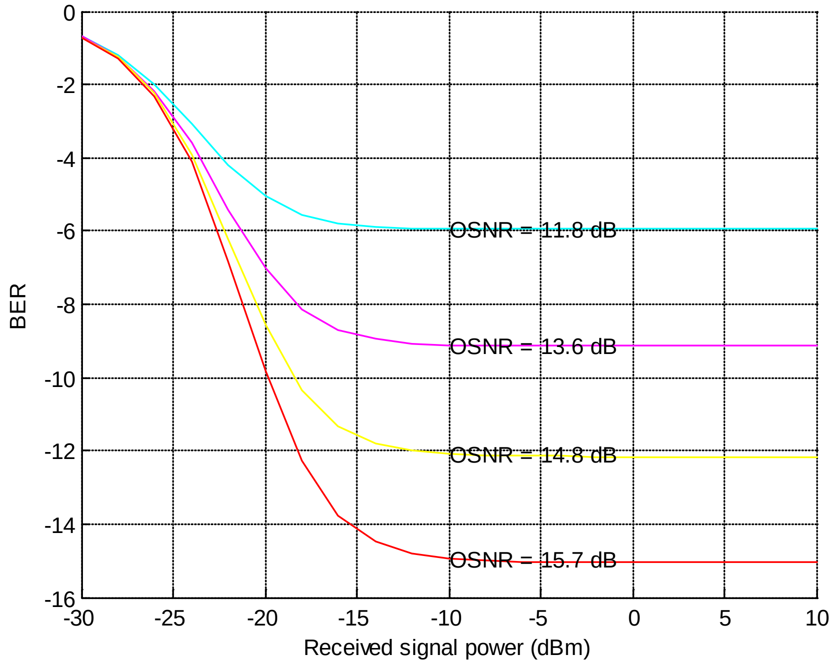


Figure 1: BER curves for constant OSNR (with all noise on)

Table 1: OSNR and corresponding BER floors

BER floors	OSNR [dB]
10^{-6}	11.8
10^{-9}	13.6
10^{-12}	14.8
10^{-15}	15.7

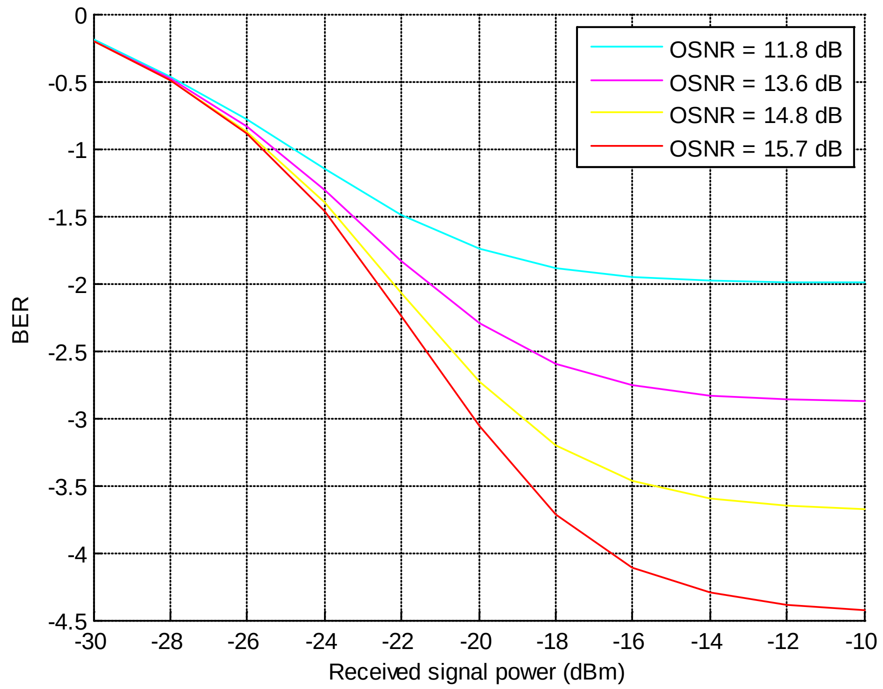


Figure 2: BER curves for constant OSNR at R = 10 Gb/s

2. On plotting the BER curve with only ASE beat noises on, constant BERs were observed for all the received power in each of the OSNRs. These BER values are similar to the BER floors obtained in 1. The curve is shown in Figure 3.

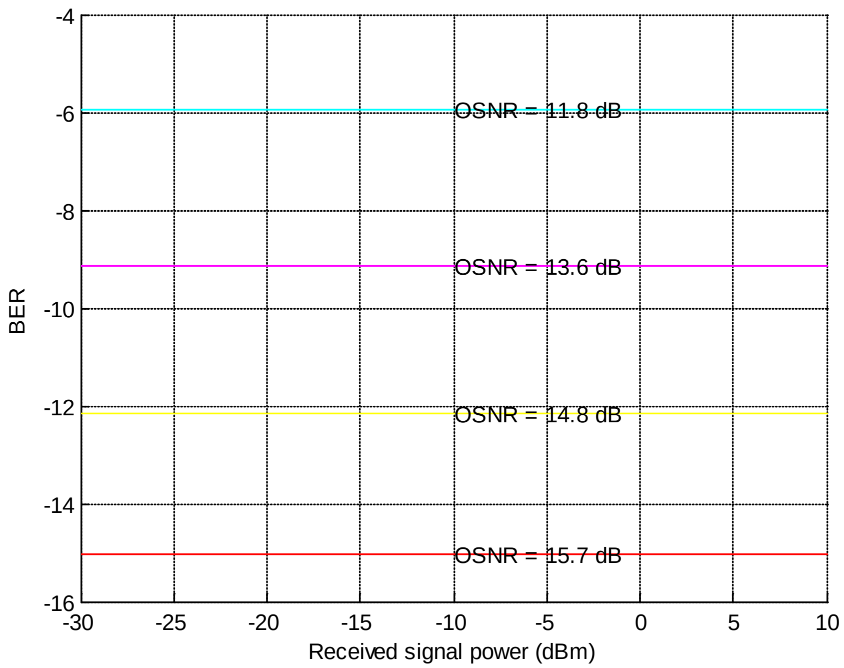


Figure 3: BER curves with fixed OSNRs and no shot noise.

3. At constant and different ASE PSD values with all noise on, it was impossible to arrive at a BER floor. The BER curve is shown in figure 4. .

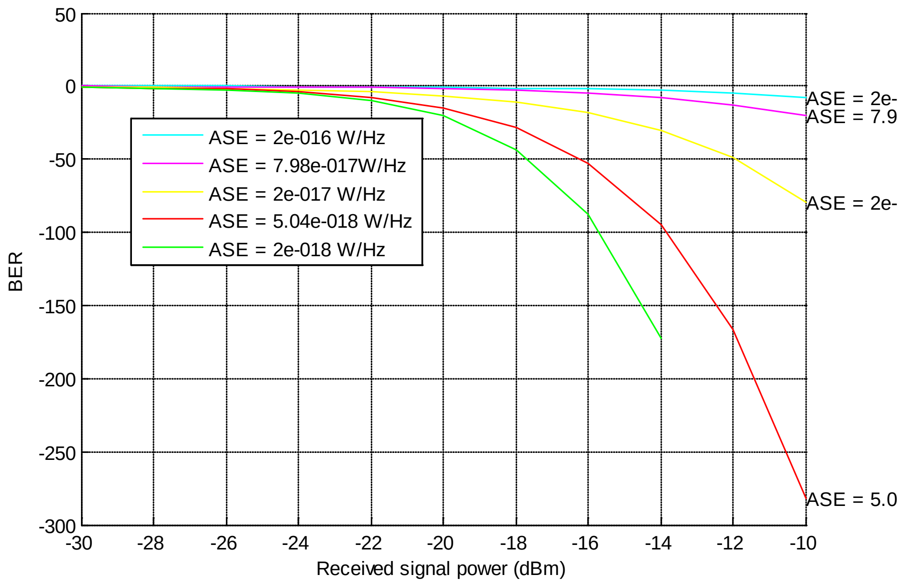


Figure 4: BER curve with fixed ASE PSDs

4. Using G = 20dB and NF= 6, the ASE PSD obtained is 2.5479 E -017 W/Hz. The plot is shown in figure 5. The sensitivity is the received power in dBm required to obtain a target BER value. Here, we assumed a BER value of 10^{-12} which has an amplified received power of approximately 16.8 dBm as obtained from figure 7 in [6]. Since a preamplifier of G = 20dB was used, this implies that the actual sensitivity is 16.8dBm – 20dB = **-3.2dBm**.

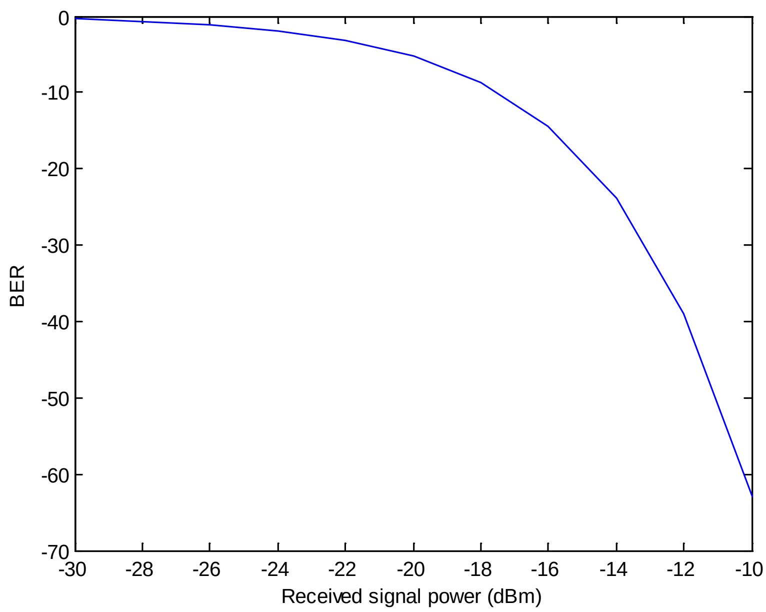


Figure 5: BER curve at G= 20dB and NF =6

5. On increasing the extinction ratio r, the BER floor values decreases. For r = 5, the BER floor was observed at $10^{-5.25}$, for r = 7, the BER floor was observed at $10^{-6.5}$, for r = 10, the BER floor was observed at $10^{-7.9}$, for r = 15, the BER floor was observed at $10^{-9.2}$ and for r = 20, the BER floor was observed at $10^{-9.9}$. The BER curve is shown in figure 6.

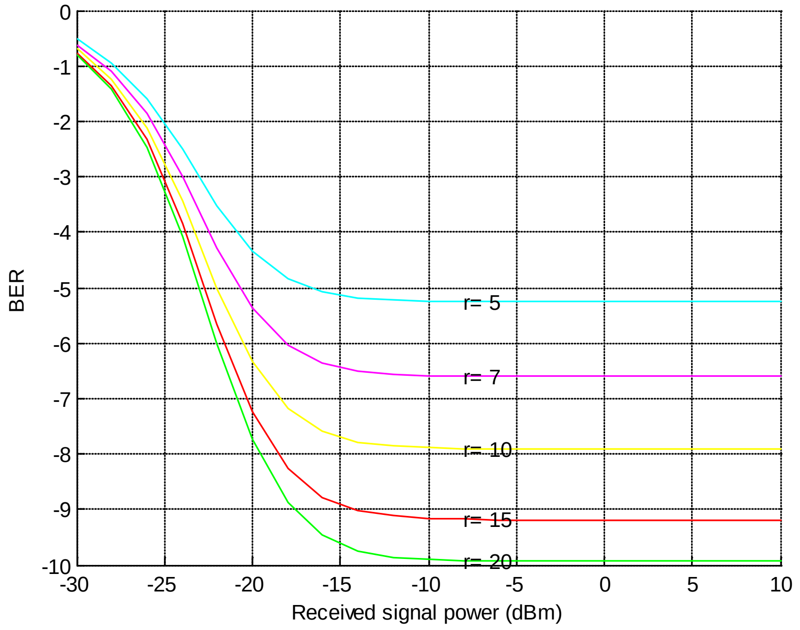
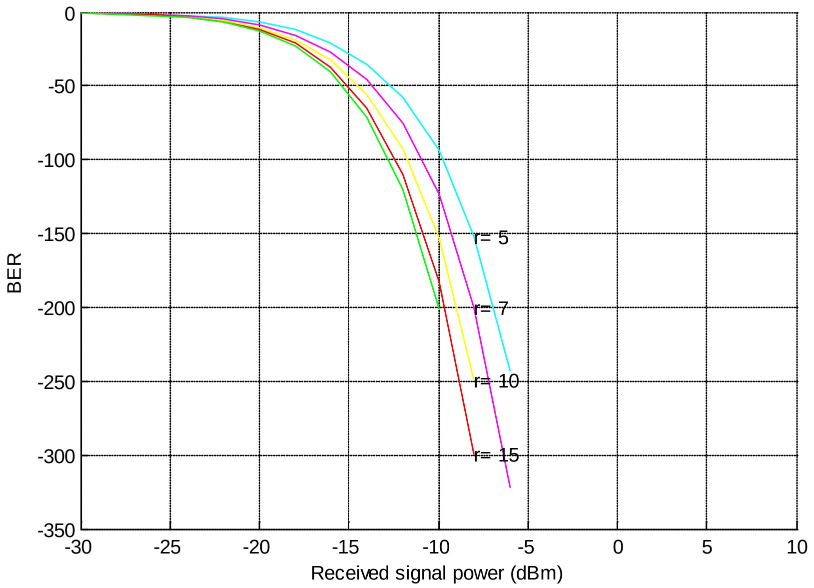


Figure 6: BER curve with OSNR fixed at13dB for different extinction ratios

6. The BER curve at fixed ASE PSD shows that no BER floors were observed for all the extinctions ratios r. At equal received signal power, the lower r values gave higher BERs. The BER curve is shown in figure 7.



7.

Figure 7: BER curves for different extinction ratios at fixed ASE PSD

8. The BER curve at fixed OSNRs shows that the lower the OBPF bandwidth, the faster the BER floor is attained and the higher the BER floor value. Figure 8 shows the BER curve.

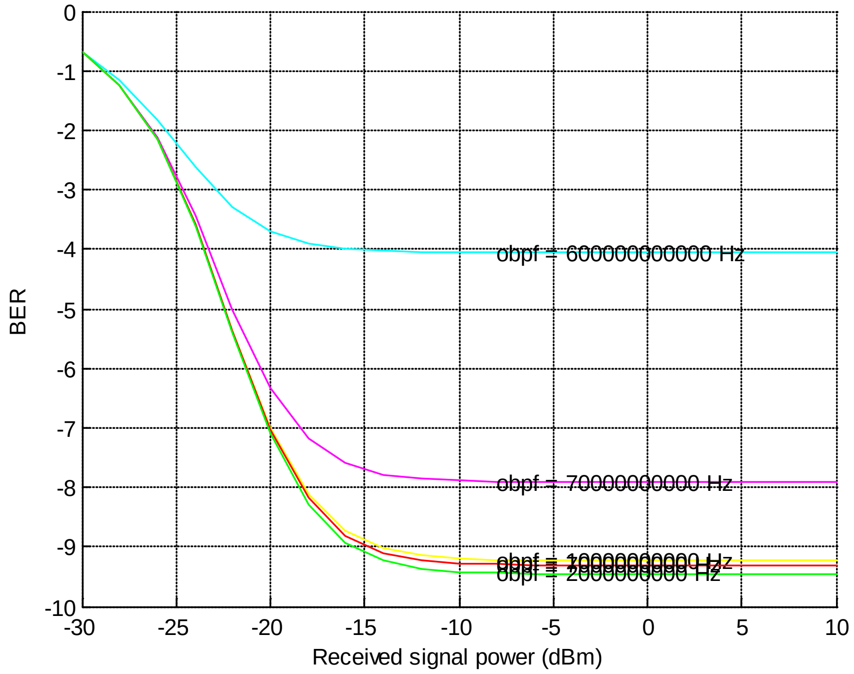


Figure 8: BER curve at fixed OSNR with varying OBPF bandwidths

9. The BER curve at fixed ASE PSD shows the absence of BER floors for different OBPF bandwidths. At a particular received signal power, the BER value decreases with increasing OBPF bandwidths. Figure 9 shows the BER curve at fixed ASE PSD and varying OBPF bandwidths.

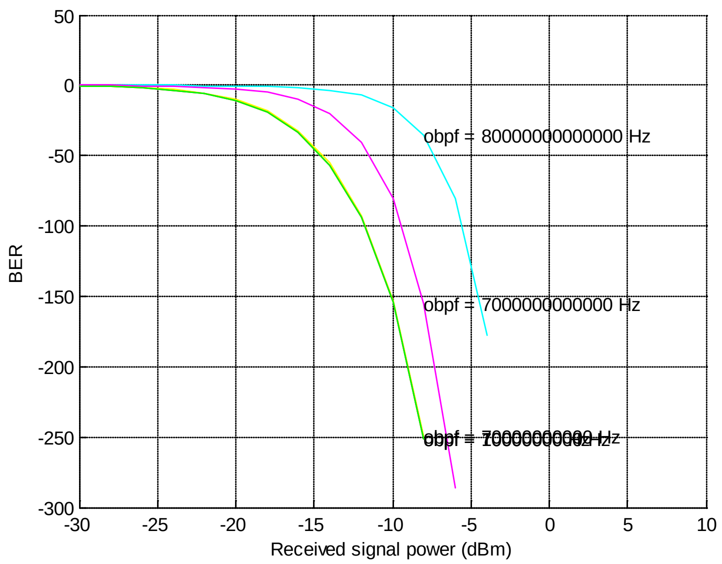


Figure 9: BER curve at fixed ASE PSD for various OBPF bandwidths

10. Repeating 1 and 3 with 10dB extinction ratio for various distances.

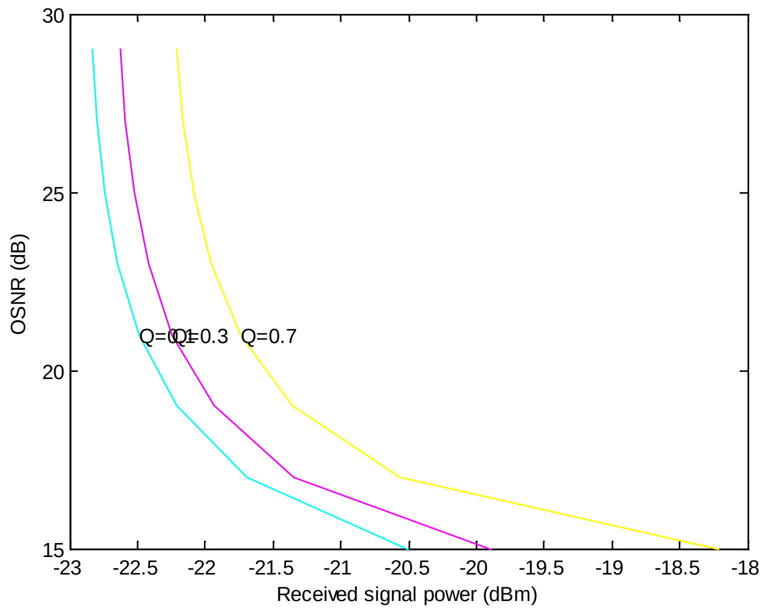


Figure 10: Plot of OSNR vs. Received signal power for r = 10Db

Results and Discussions

1. Using the OSNR calculator from Task1, for a cascade of 30 amplifiers with an inter-amplifier loss of 20dB. Following the Tx-loss-G-Rx approach, for an average transmitted power of 6dBm, the amplifier with a 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 11 shown a plot of OSNR at each amplifier stage for both specified amplifiers.

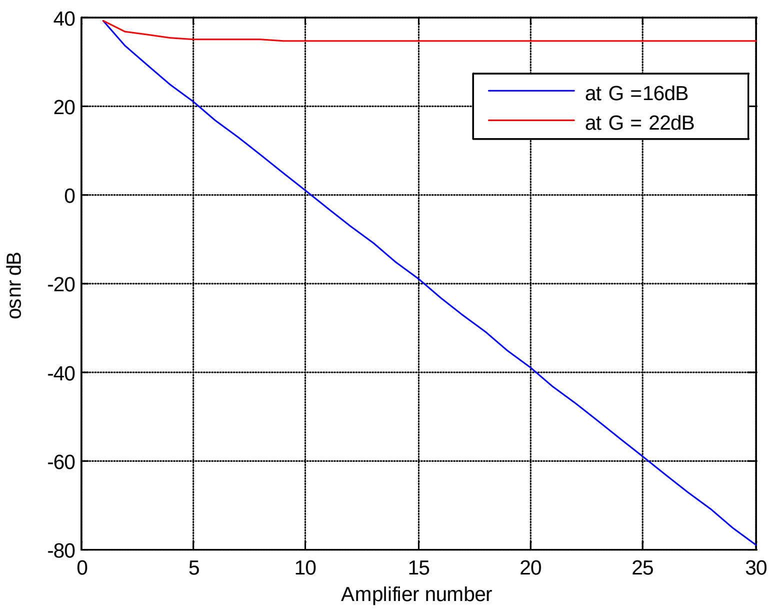


Figure 11: OSNR vs. amplifier number

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

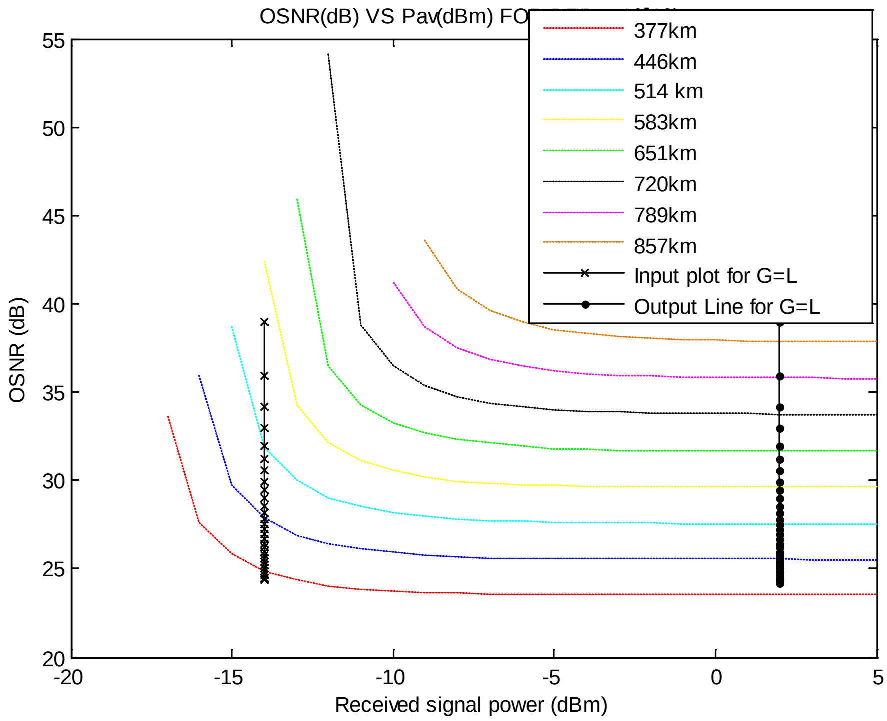


Figure 12: Plot of OSNR Vs P for G=L

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

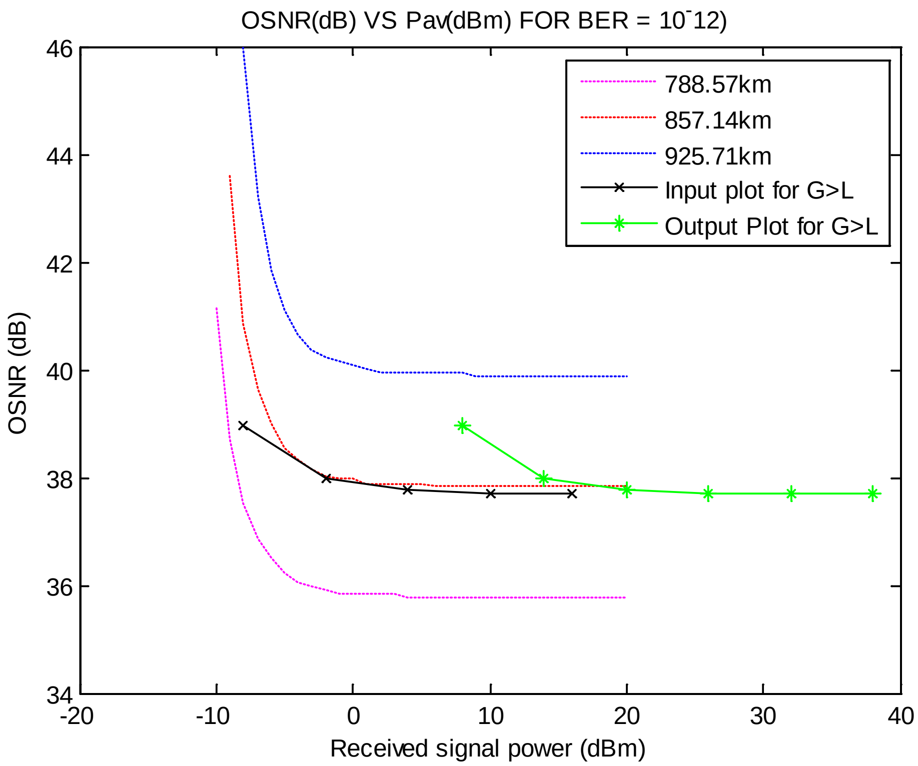


Figure 13: Plot of OSNR Vs P for G>L (only first 6 stages are shown for input and output)

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

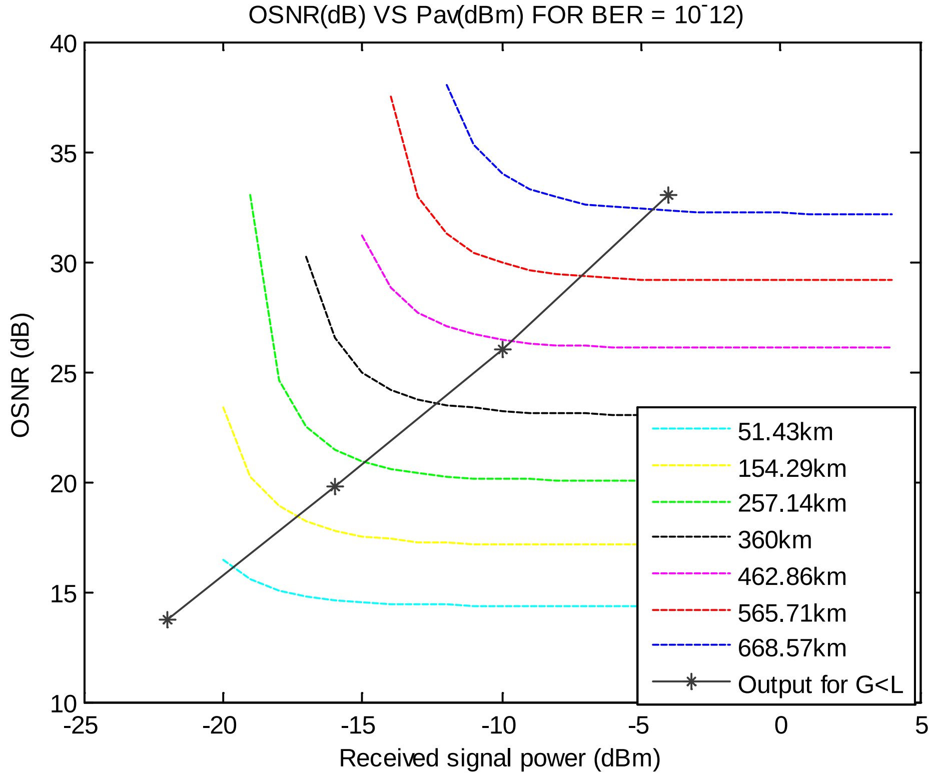


Figure 14: Plot of OSNR Vs P for G<L (only first 4 stages are shown for output)

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

To design a network, it is imperative to compliment the system design with the BER requirement of the network. The Q-factor offers a qualitative description of the receiver performance via the signal-to-noise ratio (OSNR). The Q-factor determines the minimum OSNR required to obtain a particular BER for a given signal. It should be noted that BER is difficult to simulate or calculate. This is because for a given design at BER of 10^{-12} and a line rate of OC-3, or 155Mbps, there is bound to be one error in approximately 10days. Hence, it would take 1000days to read a steady state BER value. Adversely, Q-factor analysis is relatively easy.

There will be better receiver performance if we ensure that the gain of the amplifier cascade exceeds loss. This is because when the amplifier loss exceeds gain the OSNR of the amplifier cascade is far worse than conditions when gain exceeds the loss. Although the signal increases almost linearly, the OSNR does not improve. In a best case scenario, the OSNR would remain constant as the signal progresses down the amplifier cascade.

We can see that when EDFA gain factor G is not considered. That is because OSNR is a ratio, the gain acts equally on signal and noise cancelling the gain factor in the numerator and denominator. In other words, although EDFAs alleviate the upper bound on the transmission length due to attenuation, by cascading EDFAs in series the OSNR is continually degraded with the transmission length and ASE from EDFAs.

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 26dB is good for identifying degradations that affects the BER.

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