OPTICAL COMMUNICATION COMPONENTS
Lab 2

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Exercise 1

To compute the attenuation coefficient α we use the "cut-back" method, cutting the fiber at various lengths and measuring the relative power. We compute the attenuation coefficient as:

$$\alpha = \frac{P_2 - P_1}{|L_2 - L_1|}$$

Where $P_2 > P_1$. In the following table are reported three measures:

P_{out} [dBm]	Length [m]	α [dB/m]
2.81	$1 \cdot 10^3$	$2 \cdot 10^{-4}$
2.61	$2 \cdot 10^3$	$2 \cdot 10^{-4}$
2.41	$3 \cdot 10^3$	$2 \cdot 10^{-4}$

The value stored in the module fiber is $2 \cdot 10^{-4}$ [dB/m], so the computation of the attenuation coefficient works well.

Question 1

In a real setup this couldn't work because we have launch losses that are unknown. In the simulation, instead, we assume that all the power of the laser is transmitted into the fiber.

Question 2

The difference between the two cases is the inversion of the chirp sign. In Figure 1 is shown the waveform and the corresponding chirp function that travels in the fiber with negative dispersion. In Figure 2 is shown the same signal that travels in a positive dispersion fiber. It is easy to see that the second chirp function is equal to the first one, but with the sign inverted.
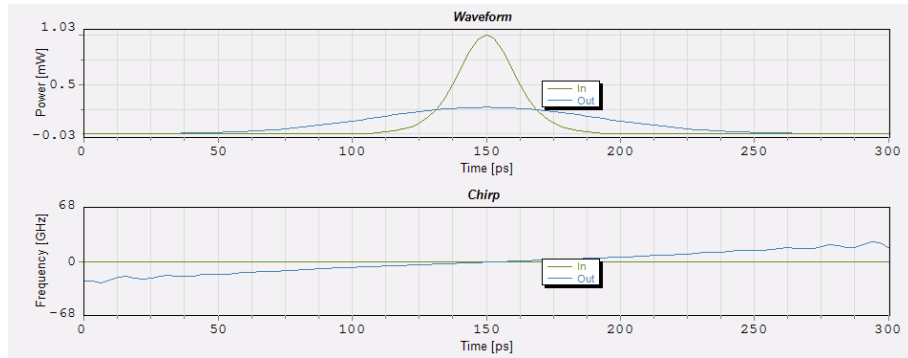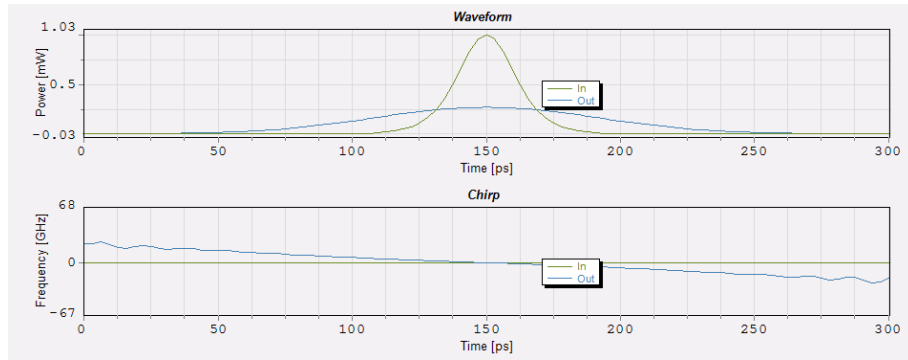

Figure 1: Negative dispersion.

Figure 2: Positive dispersion.

Question 2.a

In Figure 3 is shown the case of two transmitted pulses, separated by a time of 100 ps. The green function represents the signal at the input of the fiber. As we can see it has no chirp. The blue function, instead, represents the signal at the output of the fiber, that is 50 Km long. The dispersion value is equal to $1.6 \cdot 10^{-5}$ $[s/m^2]$. We can notice that the received signal is very different from the transmitted one: it is made of three pulses, where the central one has the highest power. Moreover, the signal is chirped. This happens because of dispersion phenomenon: while travelling, different spectral components of the pulses propagate with different velocities. This causes the widening of the two pulses that interfere one with each other, causing a constructive sum that form the central pulse.
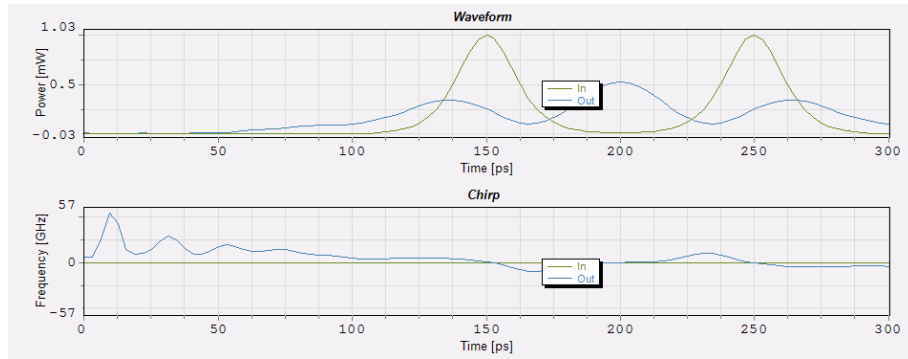

Figure 3: Propagation of two pulses.

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Exercise 2

In Figure 4 are shown three plots of the BER versus the fiber length at three different bitrates: 2.5 Gbit/s (red dots), 5 Gbit/s (blue dots) and 10 Gbit/s (green dots). The distance varies from 80 Km to 140 Km with steps of 10 Km.
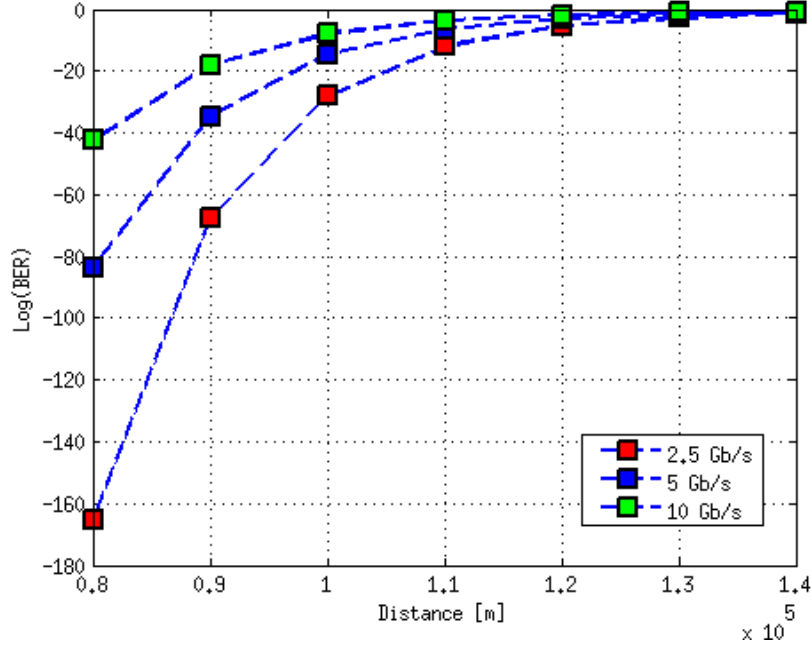

Figure 4: BER plots for 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s.

In order to understand for which values of length we have acceptable BERs, we zoom the graph as shown in Figure 5.

The maximum distances achievable are approximatively:

- 2.5 Gbit/s $\longrightarrow L = 114500$ m

- 5 Gbit/s $\longrightarrow L = 106000$ m

- 10 Gbit/s $\longrightarrow L = 98800$ m

Exercise 3

We fix the rate at 10 Gbit/s, sensitivity of receiver to $1.05 \cdot 10^{-5}$ W and average output power of the transmitter to 10^{-3} W. Dispersion value is set equal to the one of the previous exercise. To compute the maximum distances for various attenuation coefficients we first convert the powers in dB:

$$P_{out} = 10Log\Big(\frac{10^{-3}}{10^{-3}}\Big) = 0 \ dBm$$

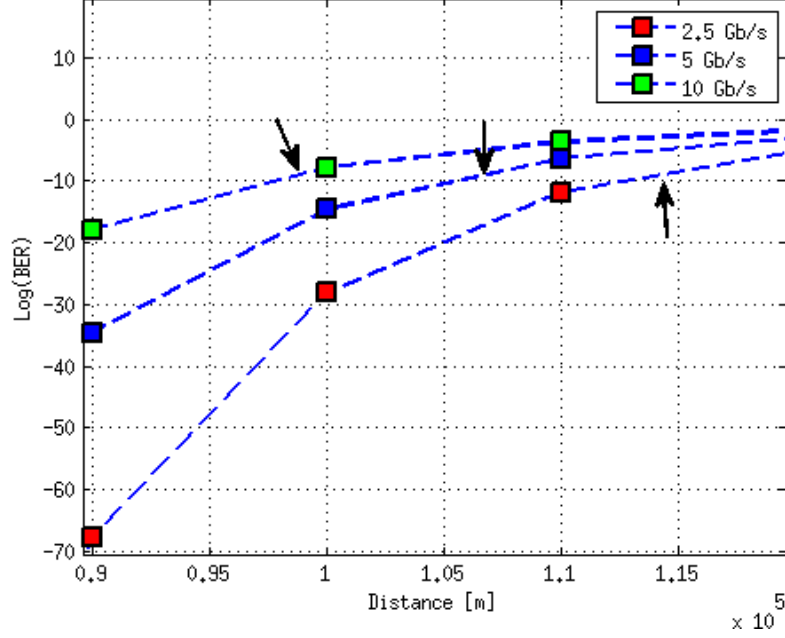$$P_{rx} = 10Log\Big(\frac{1.05 \cdot 10^{-5}}{10^{-3}}\Big) = -19.79 \ dBm$$

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Figure 5: Distance limits.

To compute the maximum lengths we use the equation:

$$L_i = \frac{P_{out} - P_{rx}}{\alpha_i}$$

We obtain the following values:

- $\alpha_1 = 0.4$ dB/Km $\longrightarrow L_1 = 49.47$ Km

- $\alpha_2 = 0.6$ dB/Km $\longrightarrow L_1 = 32.98$ Km

- $\alpha_3 = 0.8$ dB/Km $\longrightarrow L_1 = 24.74$ Km

- $\alpha_4 = 1$ dB/Km $\longrightarrow L_1 = 19.79$ Km

Exercise 4

In Figure 6 are shown the BERs over the distance with no attenuation, a dispersion of $1.6 \cdot 10^{-5}$ $[s/m^2]$, a dispersion slope of 80 $[s/m^3]$ and zero non linear index. The fiber length varies from 100 Km to 1400 Km with steps of 100 Km.

We can observe that, for the bit rate of 2.5 Gbit/s, we can reach almost the whole length of the fiber within an acceptable BER, while with the 5 Gbit/s rate we can travel for 20 Km from the starting point (100 Km) and with the 10 Gbit/s rate the BER is too high even at the starting point.

In Figure 7, 8 and 9 are shown the eye diagrams at the distances: 1400 Km for the rates 2.5, 5 and 10 Gbit/s.

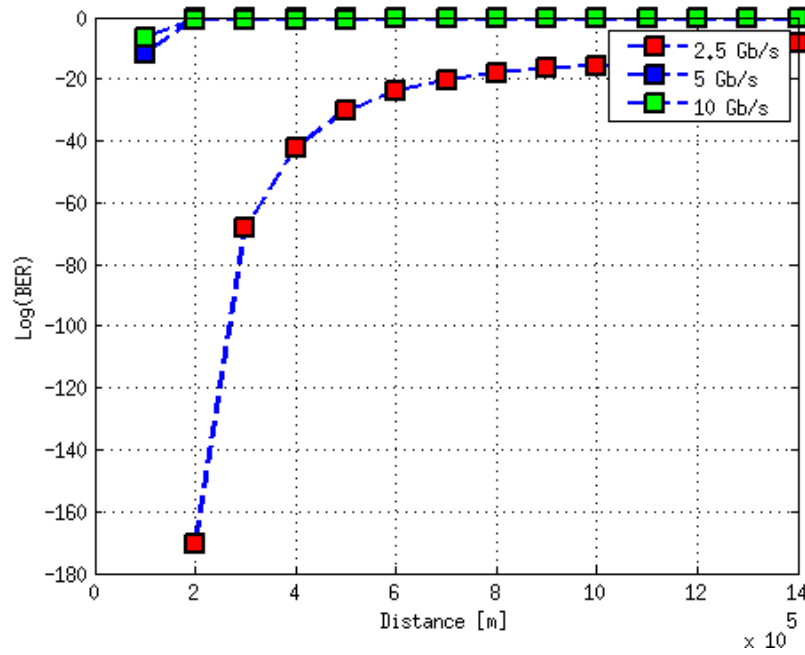The only acceptable is the one corresponding to a rate of 2.5 Gbit/s.

Figure 6: BER plots for 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s.

Question 3

In Figure 10, 11 and 12 are shown the plots of BER versus distance. We use a loop in the fiber, in order to obtain faster plots. The fiber lengths are respectively 10^5, 10^5 and 10^4 meters. The other parameters are the same of the ones used in Exercise 4. The intersection points have been read on the zoom of the graphs in the point corresponding at a BER of 10^{-9}, multiplying these points with the fiber lengths we obtained the maximum distances reachable:

- 2.5 Gbit/s $\longrightarrow L = 1270000$ Km

- 5 Gbit/s $\longrightarrow L = 269800$ Km

- 10 Gbit/s $\longrightarrow L = 81260$ Km
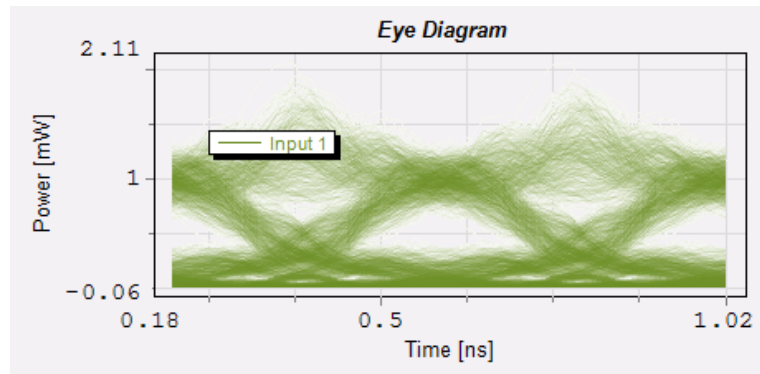
Figure 7: Eye diagram for 2.5 Gbit/s.
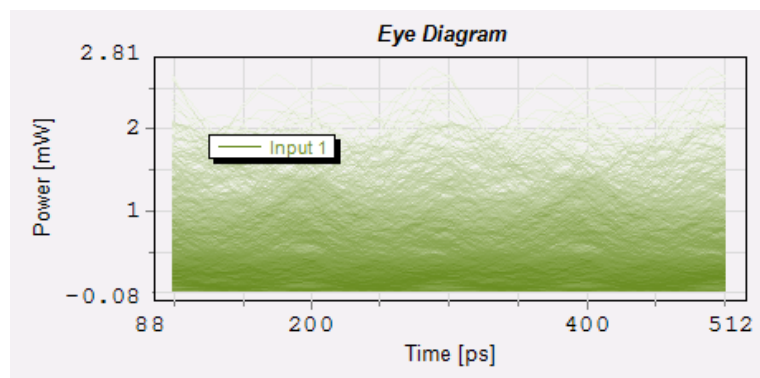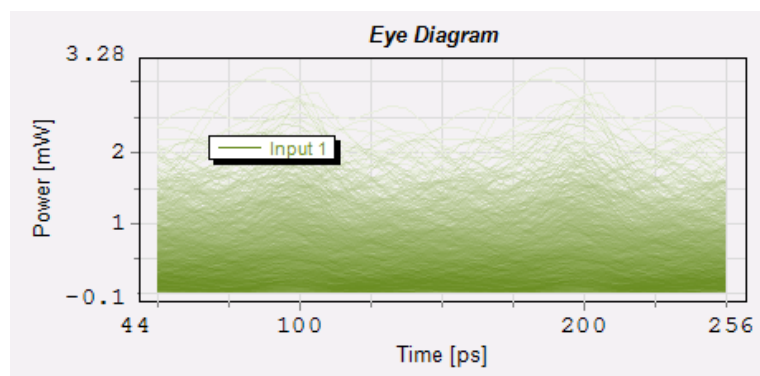

Figure 8: Eye diagram for 5 Gbit/s.

Figure 9: Eye diagram for 10 Gbit/s.

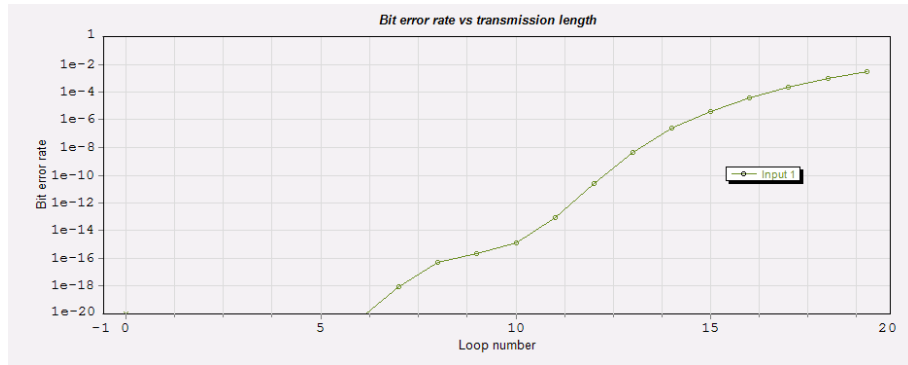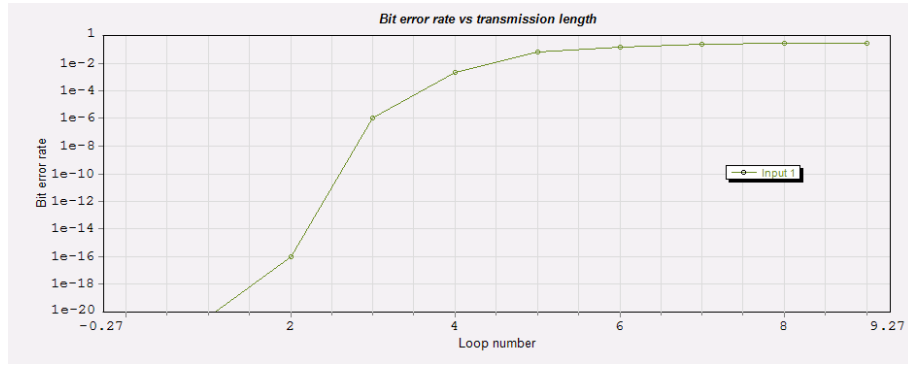Figure 10: BER plot at 2.5 Gbit/s.

Figure 11: BER plot at 5 Gbit/s.

Figure 12: BER plot at 10 Gbit/s.

Exercise 5

We fix the bit rate at 10 Gbit/s and we plot the BER versus the following values of dispersion:

- $D_1 = 10^{-5} \ [s/m^2]$

- $D_2 = 4 \cdot 10^{-6} \ [s/m^2]$

- $D_3 = 2 \cdot 10^{-6} \ [s/m^2]$

- $D_4 = 10^{-6} \ [s/m^2]$

In Figure 13, 14, 15 and 16 are shown the plots. The values of the fiber spans are respectively: 10^4, 10^5, 10^5 and $5 \cdot 10^5$ meters.
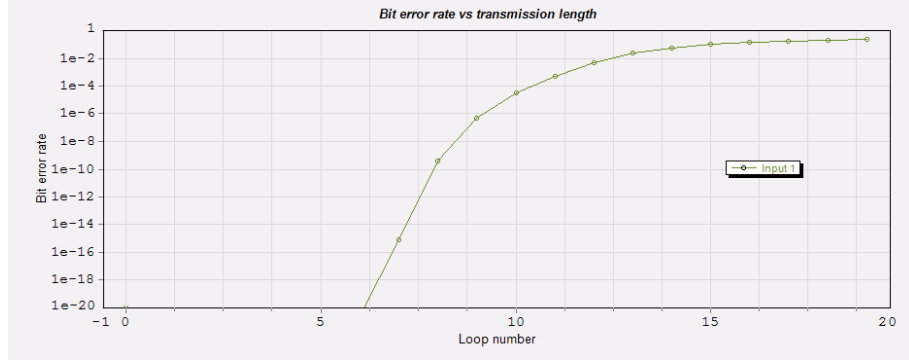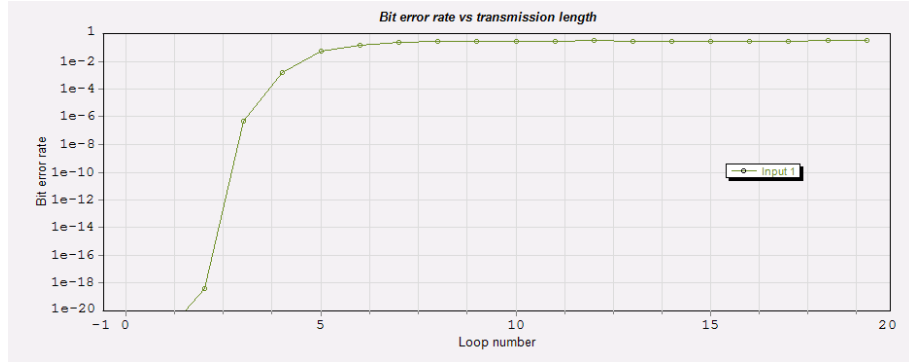

Figure 13: BER plot with dispersion D_1.
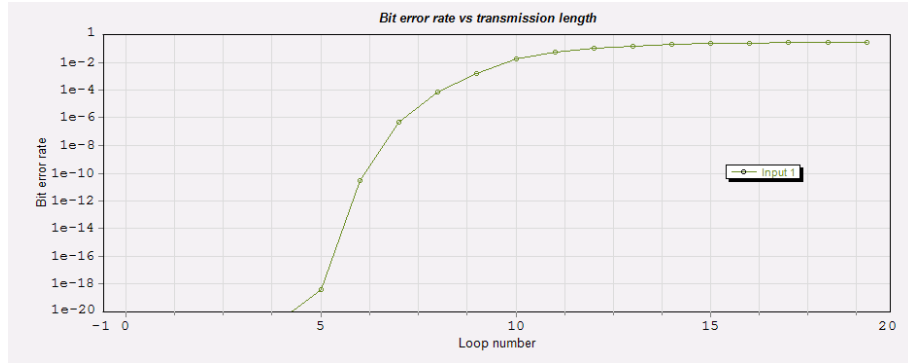

Figure 14: BER plot with dispersion D_2.

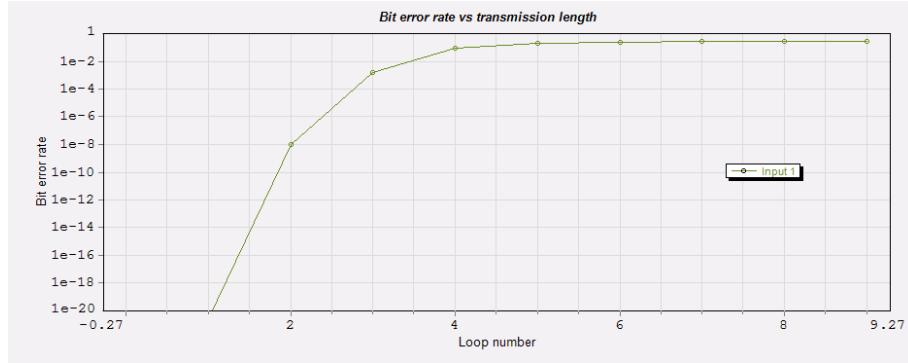Figure 15: BER plot with dispersion D_3.

Figure 16: BER plot with dispersion D_4.

Exercise 6

In Figure 17 is are shown the BERs versus distance for the bit rates 2.5, 5 and 10 Gbit/s. The length of the fiber varies from 80 Km to 130 Km in steps of 10 Km. The attenuation is set to $2 \cdot 10^{-4}$ $[dB/m]$, dispersion to $1.6 \cdot 10^{-5}$ $[s/m^2]$, dispersion slope to 80 $[s/m^3]$ and non linear index to zero.

Exercise 7

Comparing the results with the ones in the Exercise 3 (in which we considered only attenuation), we can conclude that, for the 10 Gbit/s signal, is the dispersion that determines the maximum transmission distance, while for the 2.5 Gbit/s is the attenuation. To find the maximum distances for a ber less or equal than 10^{-9}, we zoom the plot of Figure 17, and we obtain the following values:

- 2.5 Gbit/s $\longrightarrow$ 96700 m

- 5 Gbit/s $\longrightarrow$ 86300 m

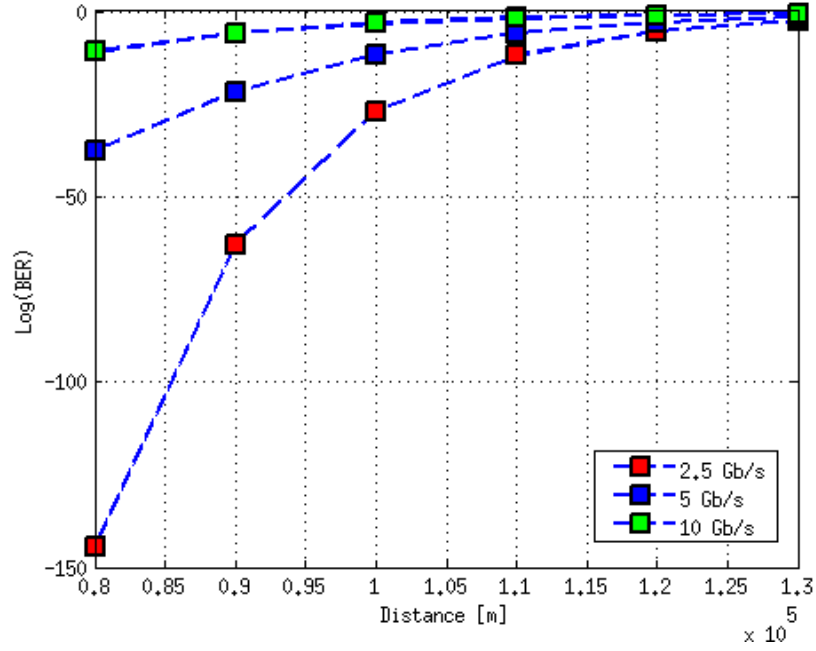- 10 Gbit/s $\longrightarrow$ 64420 m

Figure 17: BER plots for 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s.

Exercise 8

We fix the bit rate to 5 Gbit/s and we plot the BER versus distance for the following values of dispersion:

- $D_1 = 10^{-5} \ [s/m^2]$

- $D_2 = 4 \cdot 10^{-6} \ [s/m^2]$

- $D_3 = 2 \cdot 10^{-6} \ [s/m^2]$

- $D_4 = 10^{-6} \ [s/m^2]$

In the Figures 18, 19, 20 and 21 are shown the relative plots. The computed maximum length values are:

- $L_1 = 88470 \ m$

- $L_2 = 89490 \ m$

- $L_3 = 89530 \ m$

- $L_4 = 89470 \ m$

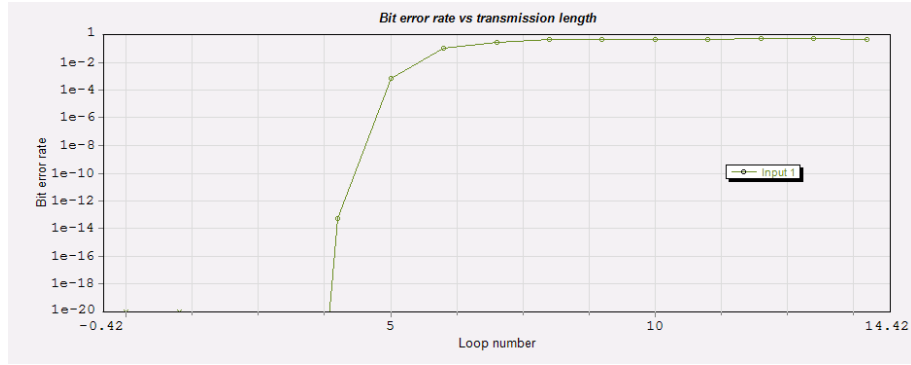Smaller the dispersion more is the distance that can be reached.
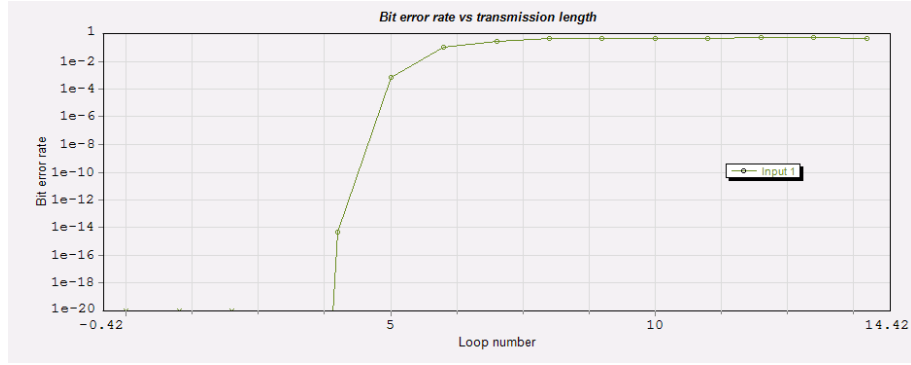
Figure 18: BER plot with dispersion D_1.
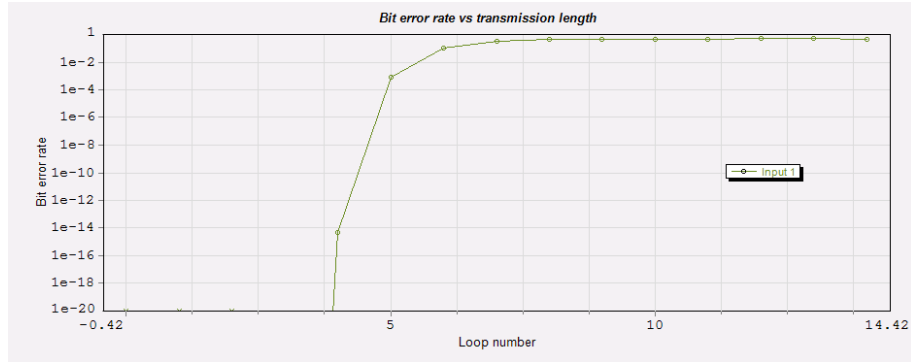

Figure 19: BER plot with dispersion D_2.

Figure 20: BER plot with dispersion D_3.

Exercise 9

We consider a case in which we have the following parameters: attenuation $2 \cdot 10^{-4}$ $[dB/m]$, dispersion $1.6 \cdot 10^{-5}$ $[s/m^2]$, dispersion slope 80 $[s/m^3]$, non linear index $2.6 \cdot 10^{-2}$ $[m^2/W]$. The fiber length is fixed to 10^5 m and we increase the transmission power from 0 dBm up to 20 dBm with steps of 4 dB.
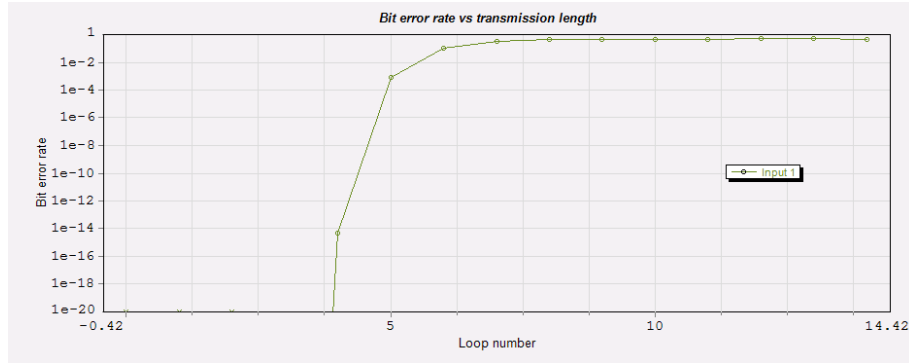
Figure 21: BER plot with dispersion D_4.

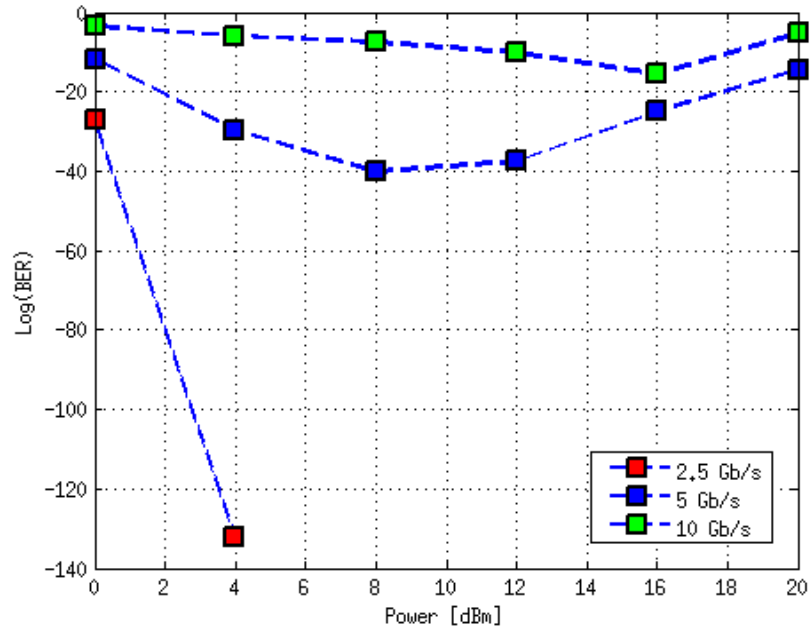In Figure 22 are shown the plots of BER versus power, for 2.5, 5 and 10 Gbit/s rates.

Figure 22: BER plots for 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s.

At this fiber length the only rate which BER is not always acceptable (it is higher than 10^{-9}) is the 10 Gbit/s one. It is good starting from a power of 10.2 dBm, it decreases but then increases again when the power is more than 16 dBm. The 5 Gbit/s BER is always acceptable: it decreases until a power of 8 dBm and then increases, while the 10 Gbit/s BER always decreases. Non linearities increase with the increasing of the bit rate.