Télécom Paris

Deliverable 3 - Group 1

TELECOM205 - Projet de synthèse : système de communications

Mohamed Benyahia
Arthur Gastineau
Ker Chee Tung

19 octobre 2024

1 Impact of chromatic dispersion (CD) on transmitted pulses

The chromatic dispersion is responsible for the temporal broadening of the transmitted pulses.

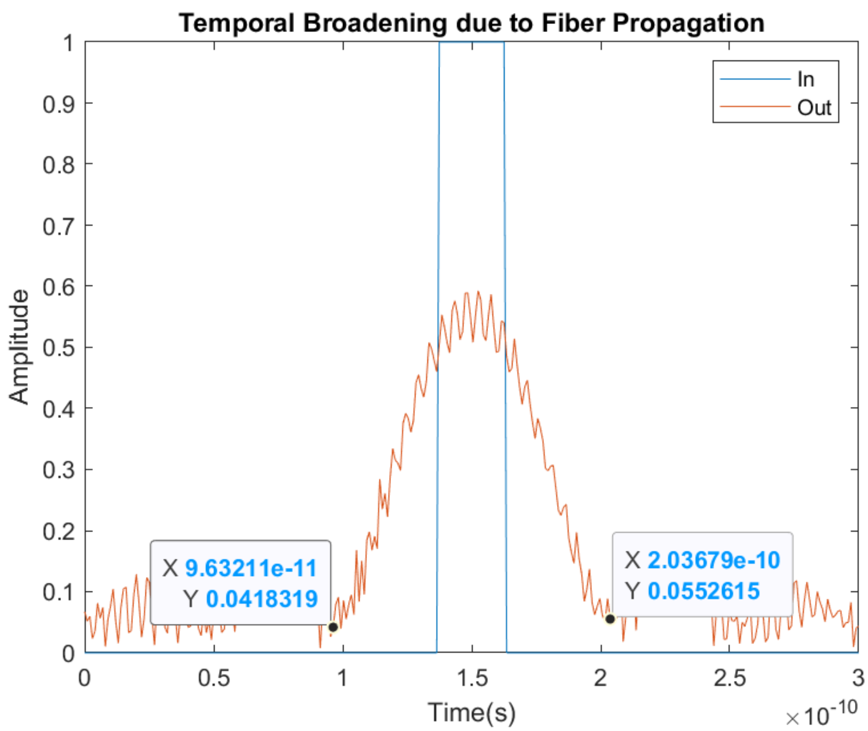

FIGURE 1.1 – Temporal broadening of a rectangular pulse

Let's take for example a rectangular pulse of width T :
The optical fiber is characterized at $\lambda = \lambda_0$ by parameters $\beta_2 = -\frac{D\ \lambda^2}{2\pi c}$ and $\beta_3 = \frac{S\ \lambda^4}{4\pi^2 c^2}$ with D the dispersion coefficient and S the dispersion slope.

The pulse spread due to CD is given by : $\Delta\tau = D * L * \Delta\lambda$ L is the fiber length, D the dispersion coefficient and $\Delta\lambda = \frac{\Delta f\ \lambda^2}{c}$.

If we estimate the spectral occupation Δf as the width of the main spectral lobe of the pulse : $\Delta f = \frac{2}{T_{imp}}$.

For $L = 10km$ and $D = 17ps/nm/km$ and $S = 0.09ps/nm^2/km$ and $T_{imp} = 2.5ns$ and $\lambda = 1550nm$ we find that $\Delta\tau = 10.9ns$. From the plot can be seen, that the output pulse width is approximately equal to $10 * 10^{-10} = 10.8ns$. This is in good accordance to the theory.

2 BER of an optical system back-to-back using on-off-keying (OOK)

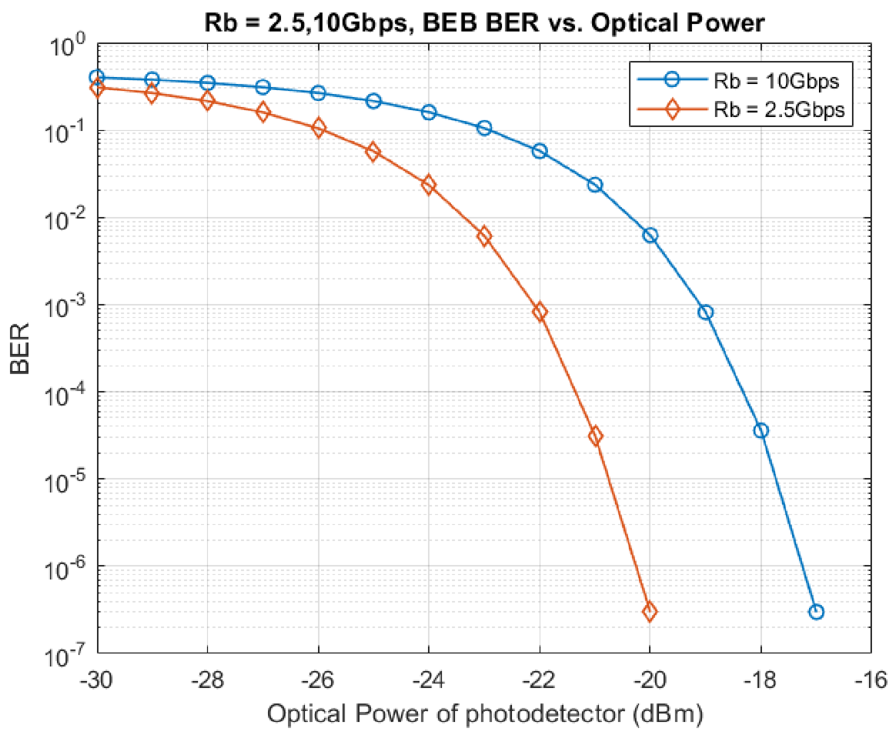

FIGURE 2.1 – BER of an optical system back-to-back using OOK versus laser power

From the plots can be seen that for $R_b = 2.5Gbit/s$, to obtain a BER lower than 10^{-3} we need at least -22 dBm of laser power. For $R_b = 10Gbit/s$, we need at least -19 dBm. In addition, if we want to achieve a BER lower than 10^{-6}, laser power required for $R_b = 2.5Gbit/s$ is approximately -20.4 dBm and laser power required for $R_b = 10Gbit/s$ is around -17.2 dBm.

Based on this observation, we can conclude that with a bit rate of 2.5Gbps, the receiver provides a better performance in term of BER. Since this is a B2B system without applying fiber, thus, the reason comes from the receiver with different photoreceiver bandwidth, which represents Rb. With a greater photoreciever bandwidth, the raised-cosine filter designed has a higher cut-off frequency, hence, more noise will be included after filtering.

Besides, with a greater photoreceiver bandwidth, thermal noise becomes higher as : Thermal noise= $N_{th} * R_b/R_{load}$. These two reasons results in a lower SNR at receiver with a higher photoreceiver bandwidth, R_b.

3 BER of an optical system with optical fiber up to 100km

In this configuration, we want to observe BER with a system up to 100km of fiber for $R_b = 10Gbps$ and $R_b = 2.5Gbps$. By maintaining a constant power at the receive side for each distance and both data rate, we are going to study the impact of chromatic dispersion on signal demodulation.

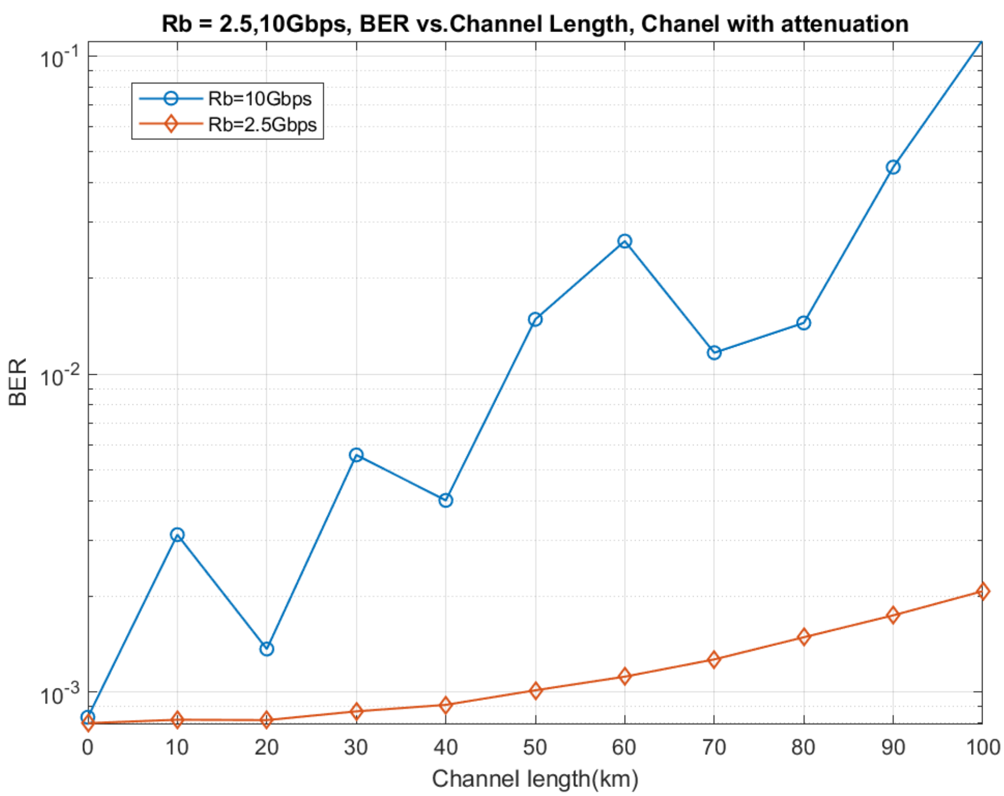

FIGURE 3.1 – BER of an optical system with optical fiber versus channel length

In order to ensure the same received power at the receiver, different laser power needs to be applied for different R_b. Based on Figure 2.1, For $R_b = 2.5Gbit/s$ to obtain a BER lower than 10^{-3} we need at least -22 dBm of laser power. For $R_b = 10Gbit/s$, we need at least -19 dBm. Thus, we apply these two values for laser power. Thus, if it is a back to back system (channel length = 0), both of them should have the same BER of 10^{-3}.

Furthermore, to study solely the impact of chromatic dispersion on two different data rate in which we want to have the same received power for each distance, attenuation need to be removed before sending the signal. Thus, for each channel length, we increase the laser power with a gain value equals to its attenuation value to compensate the attenuation due to propagation in optical fiber. With these two modifications, we are able to compare the impact of chromatic dispersion on BER for $R_b = 2.5Gbit/s$ and $R_b = 10Gbit/s$.

Based on Figure 3.1, we observe that for $R_b = 2.5Gbps$, BER remains low up to 100km of optical fiber. BER increases very slowly until $2 * 10^{-3}$ with channel length of 100km. On the other hand, for $R_b = 10Gbps$, BER increases drastically with channel length. Hence, we can conclude that the system functions up to 100km at $R_b = 2.5Gbps$ but not at 10Gbps.

To explain the difference in BER behavior for different data rates over varying optical fiber lengths, we need to analyse the difference in the effect of chromatic dispersion. If we look at one symbol, with $R_b = 10Gbps$, the width of the main spectral lobe of the pulse, $\Delta f = 2 * R_b$ is 4 times greater than Δf with $R_b = 2.5Gbps$. Besides, we know that the pulse spread is calculated as below :

$$Spectral occupation, \Delta\lambda = \frac{\Delta f \lambda^2}{c}$$
$$Temporal broadening, \Delta\tau = LD\Delta\lambda$$

Thus, with $R_b = 10Gbps$, $\Delta\lambda$ and $\Delta\tau$ are 4 times greater. The temporal broadening is hence 4 times greater which leads to a higher inter-symbol interference. Besides, we can also observe that for $R_b = 2.5Gbps$, it achieves BER of $2 * 10^{-3}$ at 100km, but for $R_b = 10Gbps$ is at 20km. There is also a factor of 4 in BER.

4 Performance of a direct modulation of the laser with back-to-back and over 20 km system

In this configuration, we want to observe the BER for a back-to-back system and one over 20 km of fiber for a direct modulation laser. The laser has a threshold current of 7mA, we decide to observe the influence of the value of I_{DC} to the performance.

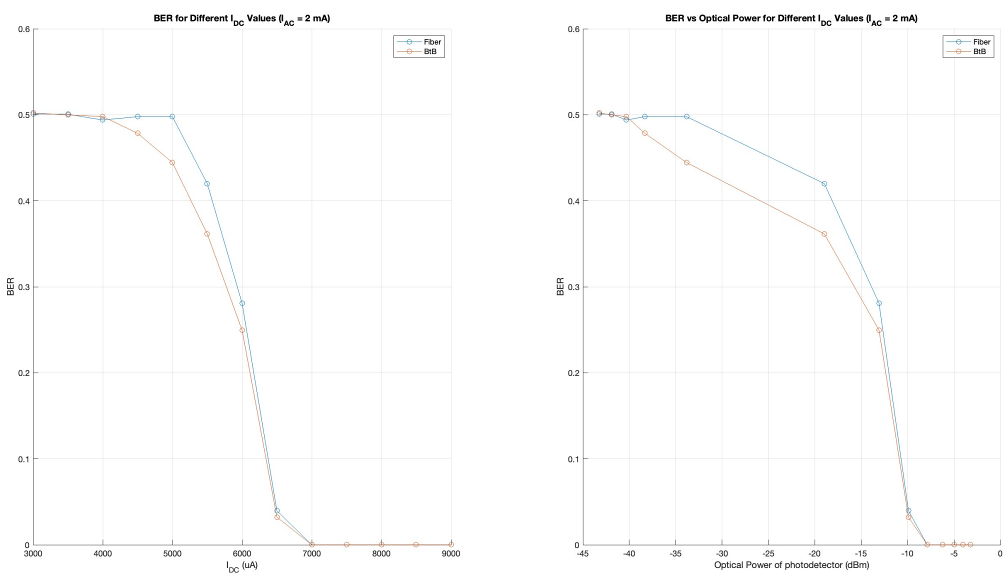

FIGURE 4.1 – BER for a direct modulation versus bias current and optical power

Increasing I_{DC} enhances performance by increasing the average optical power output, which improves the Signal-to-Noise Ratio (SNR) at the receiver. This leads to a lower Bit Error Rate (BER) due to better signal clarity and distinction between '1' and '0' bits. Higher I_{DC} reduces the relative impact of noise, enhancing detection accuracy. We observe quite logically that for a bias current lower than the threshold current plus I_{AC} we get a BER of 0.5 which is logic as we can only identify zeros.

In the back-to-back configuration, the system shows lower BER across all I_{DC} values compared to the 20 km fiber configuration. This is because the back-to-back setup lacks fiber-induced impairments like chromatic dispersion and attenuation. As I_{DC} increases up to the threshold (7 mA), the BER improves steadily, but further increases in I_{DC} yield minimal gains.

The chirp, which is a frequency variation within the signal caused by direct modulation, becomes significant over longer fiber distances. This chirp leads to increased chromatic dispersion effects, spreading the pulse width and causing inter-symbol interference. This interference degrades the signal quality, resulting in higher BER over 20 km of fiber compared to the back-to-back setup.

From the plots, it is evident that for both back-to-back and 20 km fiber configurations, the BER decreases as I_{DC} increases, particularly beyond 5 mA. The back-to-back configuration shows a consistent decrease in BER with increasing optical power, resulting in a smoother curve. The 20 km fiber configuration also shows a decrease in BER with optical power, but less smoothly due to fiber effects and the impact of chirp.

To achieve a BER lower than 10^{-3}, an optical power above -9 dBm is required compared to the -19 dBm needed in external modulation. This highlights the importance of optimizing I_{DC} to manage the trade-offs between noise, chirp, and fiber-induced distortions. Operating the laser above the threshold current is essential for achieving the best performance, especially in back-to-back setups, while carefully managing the challenges of fiber transmission and the effects of chirp.

5 Solutions to reach 100 km at 10 Gbit/s

In order to reach 100km at $R_b = 10Gbps$, there are two solutions to compensate impact of chromatic dispersion :

1. Apply Dispersion Compensation Fiber (DCF) which has a negative dispersion coefficient.

2. Transmit at zero dispersion wavelength ($\lambda = 1300nm$ for Standard Single Mode Fiber)

3. Implement coherent detection to obtain complete received electrical field. Apply inverse fourier transform of deterministic chromatic dispersion to eliminate temporal broadening.

In the section below, we implement the first method to compensate chromatic dispersion.

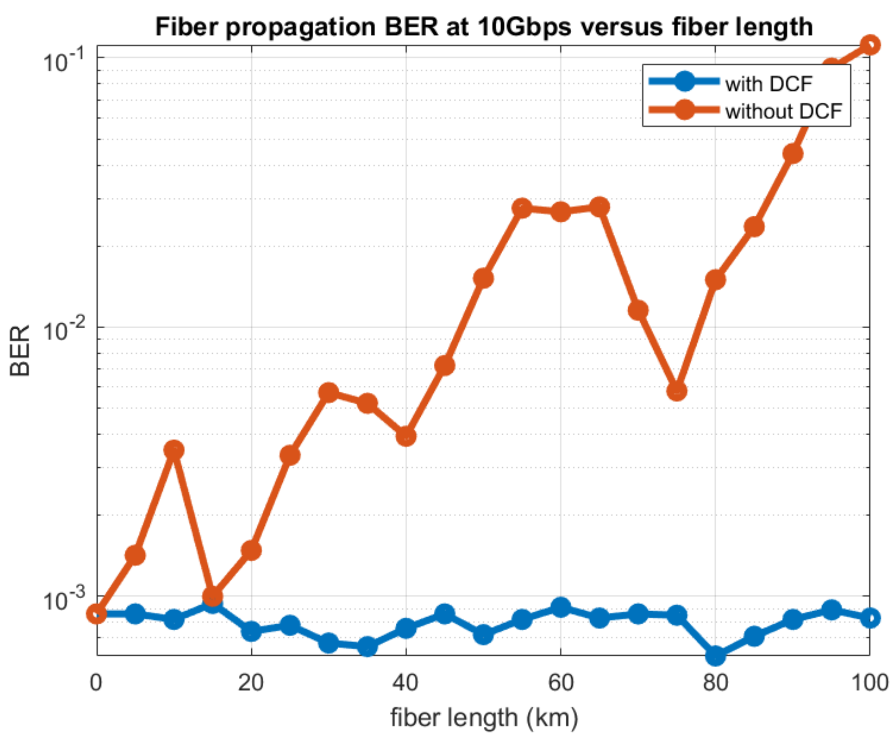

FIGURE 5.1 – BER of an optical system with optical fiber and DCF using OOK versus fiber length at 10Gbps

We have chosen a DCF that has a dispersion coefficient $D_{DCF} = -80ps/nm/km$ and an attenuation factor $\alpha = 0.5dB/km$. We need to reach $L = 100km$ with 10Gbps ; therefore we need a DCF fiber length of $L_{DCF} = -\frac{D}{D_{DCF}} * L = 21.25km$. From the plot can be seen that we managed to have in average values of BER lower than those of the plots before.

In the section below, we implement the second method to compensate chromatic dispersion.

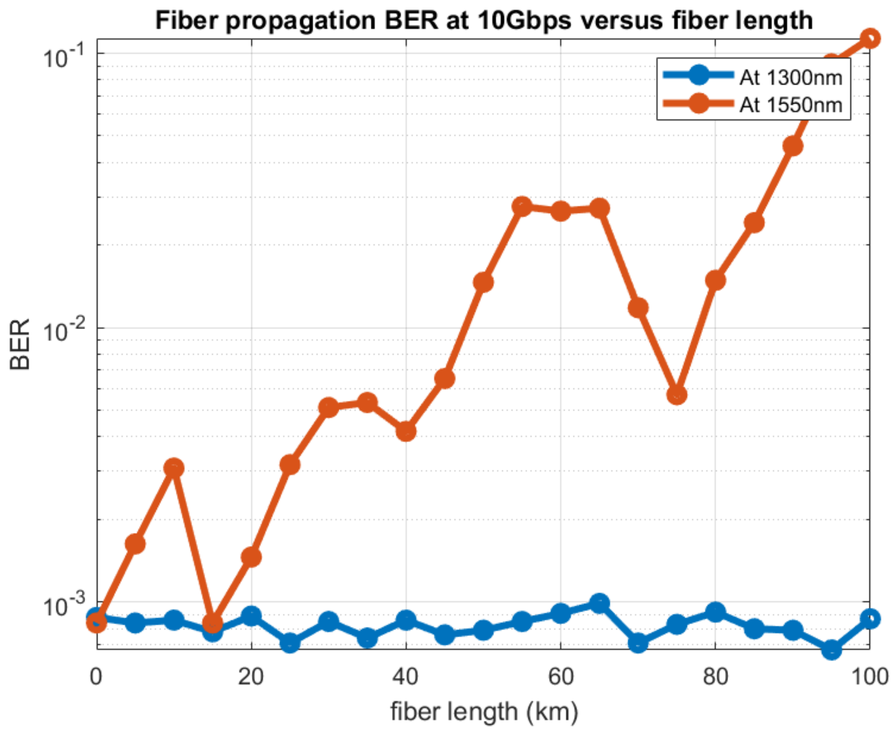

FIGURE 5.2 – BER of an optical system with optical fiber at zero Dispersion Wavelength using OOK versus fiber length at 10Gbps

We have chosen a Standard Single Mode Fiber at $\lambda = 1300nm$ with attenuation factor of $\alpha = 0.35dB/km$. From the plots can be seen that we can achieve a BER of 10^{-3} up to 100km which is a satisfying BER.