Basics of Fiber Propagation
Fiber 1

Interactive learning module

University Program
Photonics Curriculum Version 8.0

Preface

In this introductory module on optical fibers, attenuation and dispersion, the two main characteristics of optical fibers are explored.

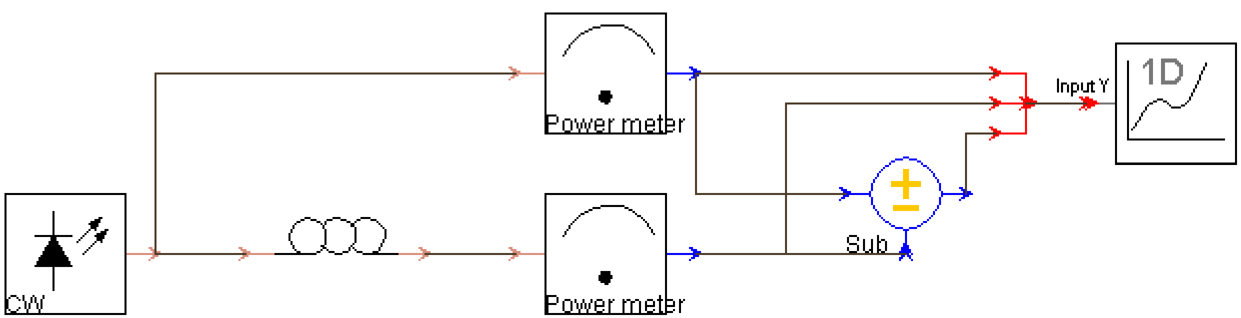
- Attenuation and dispersion both place limits on an optical transmission system's maximum achievable transmission bit rate and distance. Thus, the first step in designing optical transmission links is to consider the effects, and to avoid those aforementioned limitations, of attenuation and dispersion. At the end of the module, the effect of fiber nonlinearity is briefly highlighted.
- The following topics are covered in this module:
  + Fiber attenuation measurement using the "cut-back" method
  + Effect of linear dispersion on optical pulses and pulse chirp
  + Effect of fiber attenuation on the BER performance of a transmission link
  + Effect of fiber (linear) dispersion on the BER performance
  + Combined effects of dispersion and attenuation
  + Effect of fiber nonlinearity on the BER performance

Note:

For details on the handling of VPItransmissionMaker / VPIcomponentMaker please read the *Simulation Guide* before starting this unit.

Fiber Attenuation Measurement

- Open the setup Fiber1_1. The schematic is shown below.
- The set up shown below is used to measure fiber attenuation by the “cut back” method.
- The power of the light from the CW source is measured by a power meter *PowerMeter*. The output unit of the power meter is set to dBm.
- The power at the output of the fiber is also measured. The difference (between the power at the fiber input and output) are calculated by the module *Sub*. The measured quantities and their difference are displayed by a text visualizer module *NumericalAnalyzer1D*.



Fiber Attenuation Measurement

- Run the simulation. (You can change from **Text View** to **Plot View** in the menu **Analysis** of the *VPIphotonicsAnalyzer*).
- The attenuation in the fiber is simply the difference between the power at the input and output of the fiber. The attenuation coefficient of the fiber can be calculated by dividing the attenuation by the fiber length.
- The input power P_{in}, output power P_{out} of fiber and their difference, loss, are listed in a table shown below
- **Exercise 1**: Calculate the attenuation coefficient of the fiber from the result below, and check this against the value stored in the fiber module.
- **Question 1**: Would this setup work for a real measurement? If not, why not? What would need to be different?

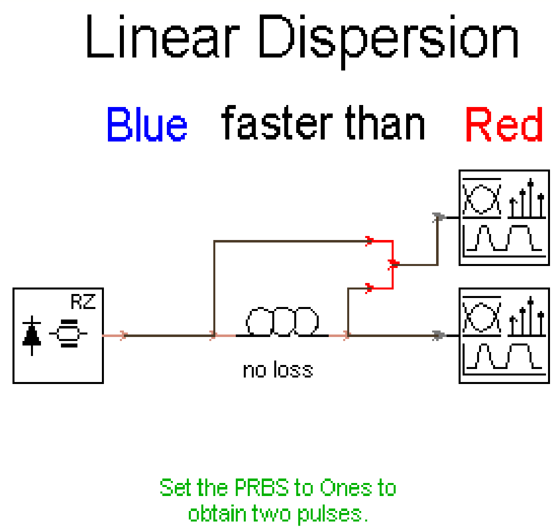
NumericalAnalyzer1D_vtms1

Numerical

	Pin[dBm]	Pout[dBm]	Loss[dB]
	Y(None)	Y(None)	Y(None)
1	3.01	2.81	0.2

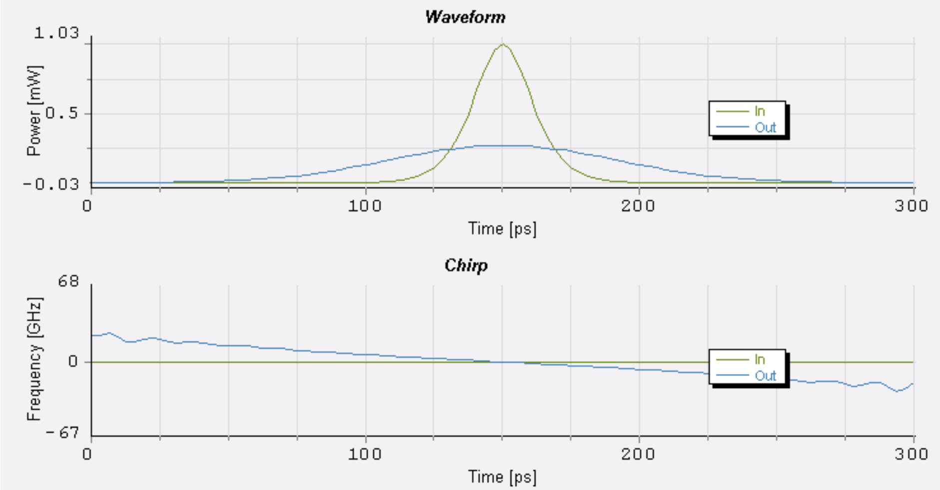
Linear Dispersion and Chirp

- Open the setup Fiber1_2. The schematic is shown below
- In this lab, we will look at the effect of linear dispersion on the transmission of optical pulses.
- A pulse generated by the module *TxPulse* is transmitted through a fiber. The pulse at the input and output of the fiber is displayed by a *SignalAnalyzer* **(Scope)** set to show the waveform. To see the chirp of the pulse, click in the menu on **view**, then on **Control Panel** and label **Chirp**.
- Set the PRBS to *Alternate, and the fiber dispersion to 16e-6 s/m^2*. ***Run the setup for*** increasing values of the fiber length, from 0 km up to 50 km in steps of 10 km.



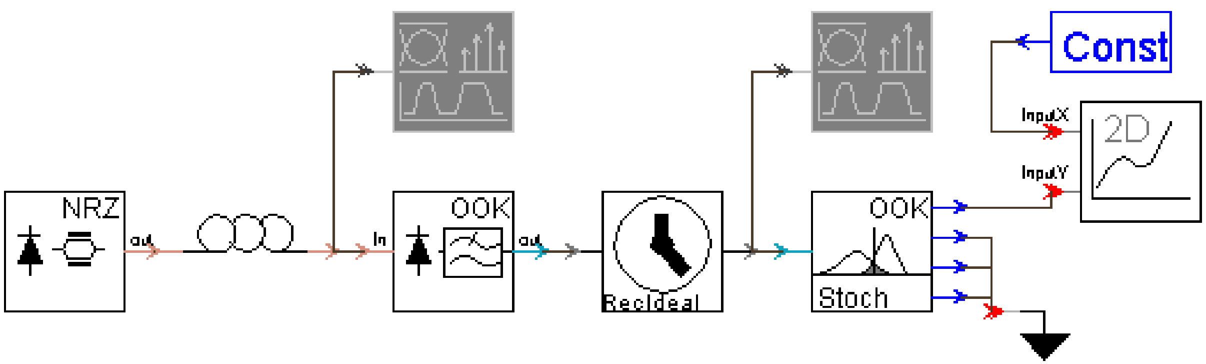
Linear Dispersion and Chirp

- The waveform and chirp of input pulse (In) and the pulse after propagating through the 50 km fiber (Out) are shown below. The results for other fiber lengths may be accessed using the **<<** and **>>** buttons to step through the various results (obtained as a result of the sweep).
- The input pulse has no chirp. After 50 km, the pulse is broadened and chirped. Describe the behaviour of the observed chirp across the pulse duration. How the observed chirp is related to the action of linear dispersion in the fiber?
- **Question 2**: Alter the sign of the fiber dispersion parameter in the fiber module and rerun the simulation sweep. What is the difference now?
- **Question 2.a:** Set the PRBS to *"Ones" to obtain two pulses. With the fiber length set at* 50 km and the dispersion as in the first case, describe what is observed.



BER limited by Fiber Characteristics

- In this lab, we use one channel transmission system to investigate the dependence of the bit error rate (BER) of the system on the characteristics (mainly attenuation and dispersion) of an optical fiber.
- Open the setup Fiber1_3_10G. It is shown below. The schematic consists of a transmitter *TxExtModLaser* (externally modulated laser), a fiber *FiberNLS*, a receiver *Rx_OOK*, clock recovery, BER estimator and *SignalAnalyzers*.
- The estimated BER is displayed in the *NumericalAnalyzer2D*. The eye diagrams can be displayed in the *VPIphotonicsAnalyzer* by clicking in the menu on the "**Turn on Eye**" button (previously, they should be activated by setting the parameter *SignalAnalyzer* ***Active*** = ON).



Fiber Attenuation

- First, we consider the dependence of the BER on fiber attenuation. Dispersion and nonlinear effects will be neglected here. Set the following parameters:

  FiberNLS ***Attenuation*** = 0.2e-3 dB/m

  FiberNLS ***Dispersion*** = 0 s/m^2

  FiberNLS ***DispersionSlope*** = 0 s/m^3

  FiberNLS ***NonLinearIndex*** = 0 m^2/W

- **Exercise 2**: Plot the BER versus the fiber length for the following bit rates: 2.5 Gbit/s, 5 Gbit/s, 10 Gbit/s signal. This can be done by running the files Fiber1_3_2.5G, Fiber1_3_5G, and Fiber1_3_10G, respectively. Vary the distance from 80 to 140 km with steps of 10 km)
- If the BER is required to be below 10^{-9}, at which length the transmission is limited, for transmission rates of 10 Gbit/s , 5 Gbit/s and 2.5 Gbit/s?
- Note that high bit-rate signals suffer from limitation in the maximum transmission distance because of their increased signal bandwidth. In fact, the bandwidth of the electrical noise filter inside the optical receiver is set proportional to the bit rate. Thus, the larger the signal bit rate, the more electrical noise passes through the filter.

Fiber Attenuation

- **Exercise 3**: If the sensitivity of the receiver for a 10 Gbit/s signal is 1.05e-5 W, and the average output power of the transmitter is 1e-3 W, calculate the expected maximum transmission distance for fiber attenuation coefficient of: 0.4e-3 dB/m, 0.6e-3 dB/m, 0.8e-3 dB/m and 1.0e-3 dB/m.
- Run simulations to verify your calculations, i.e. fix the bit rate of the system to 10 Gbit/s and plot the BER versus distance (i.e. fiber length) curves for the following fiber attenuation coefficients: 0.4e-3 dB/m, 0.6e-3 dB/m, 0.8e-3 dB/m, 1.0e-3 dB/m.

Fiber Dispersion

- Next, we investigate the dependence of BER on fiber dispersion. Here, we neglect the effects of attenuation and nonlinearities. In setup Fiber1_3-XX, set the following parameters to:

  FiberNLS ***Attenuation*** = 0 dB/m

  FiberNLS ***Dispersion*** = 16e-6 s/m^2

  FiberNLS ***DispersionSlope*** = 0.08e3 s/m^3

  FiberNLS ***NonLinearIndex*** = 0 m^2/W

- **Exercise 4**: Plot the BER vs fiber length curves for transmission rates of 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s. Vary the fiber length between 100 and 1400 km in steps of 100 km. You might want to activate the Scope for this sweep. Measure the BER and investigate the eye diagrams of the received data using the signal analyzer.
- **Question 3**: Plot the BER vs fiber length (i.e. transmission distance) for bit rates of 10 Gbit/s, 5 Gbit/s and 2.5 Gbit/s. What is the effect of the bit rate on the signal quality in the presence of fiber dispersion? If the BER is required to be below 10^{-9}, what is the maximum transmission length for bit rates of 10 Gbit/s , 5Gbit/s and 2.5 Gbit/s?
- **Exercise 5**: Fix the bit rate of the simulation to 10 Gbit/s, and plot the BER vs distance for different values of fiber dispersion: 10e-6 s/m^2, 4e-6 s/m^2, 2e-6 s/m^2 and 1.0e-6 s/m^2.

Dispersion & Fiber Attenuation

- Now we consider the bit error rate of a transmission system that is affected by a combination of attenuation and dispersion, but has no nonlinearities. Set:

  FiberNLS ***Attenuation*** = 0.2e-3 dB/m

  FiberNLS ***Dispersion*** = 16e-6 s/m^2

  FiberNLS ***DispersionSlope*** = 0.08e3 s/m^3

  FiberNLS ***NonLinearIndex*** = 0.0 m^2/w

- **Exercise 6**: Again, plot the BER vs fiber length for transmission rates of 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s signal. Use the sweep to vary the fiber length between 80 and 130 km (in steps of 10 km).
- **Exercise 7:** For high bit rate signals (10 Gbit/s), what of the two effects (dispersion, loss) is determining the maximum transmission distance? And for low (2.5 Gbit/s) bit rate signals? If the BER is required to be 10^{-9} or less, what is the maximum transmission distance for bit rates of 10 Gbit/s, 5Gbit/s and 2.5 Gbit/s?

Dispersion & Fiber Attenuation

- **Exercise 8**: Fix the bit rate of the simulation to 5 Gbit/s and plot the BER vs transmission distance for the following values of fiber dispersion: 10e-6 s/m^2, 4e-6 s/m^2, 2e-6 s/m^2 and 1.0e-6 s/m^2. From the plots, deduce the value of dispersion where the limitation on the maximum transmission distance is dominated by fiber attenuation.

Fiber Nonlinearity

- To finish, we consider a more realistic fiber which has attenuation, dispersion and nonlinear effects.
- Make sure the following parameters are set to:

  FiberNLS ***Attenuation*** = 0.2e-3 dB/m

  FiberNLS ***Dispersion*** = 16e-6 s/m^2

  FiberNLS ***DispersionSlope*** = 0.08e3 s/m^3

  FiberNLS ***NonLinearIndex*** = 2.6e-20 m^2/w

- **Exercise 9**: Plot the BER vs Laser Power for bit rates of 2.5 Gbit/s, 5 Gbit/s, and 10 Gbit/s, where the input laser power is increased from 0 dBm up to +20 dBm, with steps of 4 dB. For each bit rate, is there a range of laser powers for which the BER < 10^{-9}? Is the impact of fiber nonlinearities greater or smaller as the bit rate is increased?