Photonic Systems Laboratory

Photonic Systems and Technologies – Lab 1
Introduction to Fibre Optic Communication Systems

1. Introduction

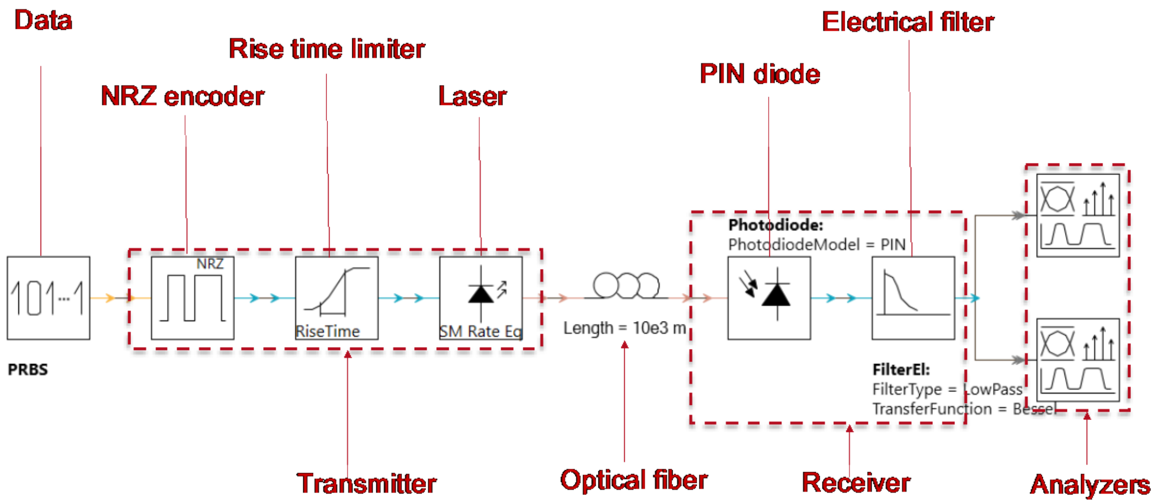
A simple but complete fiber-optic transmission link will be studied. The setup consists of the three basic elements common to all fiber-optic communication systems:

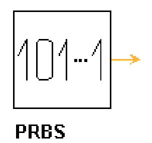
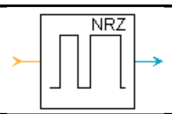
- An optical transmitter*:* converts an electrical signal into optical signal. In the simulation setup, a single longitudinal mode semiconductor laser is directly modulated with a pseudo random bit sequence (PRBS).
- The optical signal is transmitted over the fiber-optic channel, which in this case consists of one section of optical fiber.
- The optical receiver converts the transmitted data back into the electrical domain.

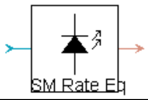
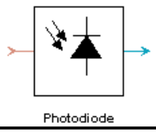
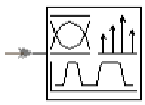
Such system is called intensity modulated direct detection link (IMDD). The details of each element will be covered during the semester in class and in the following labs.

2. Computer model of an IMDD link

2.1. Elements



	Generates a pseudo random bit sequence (PRBS). The output can be: - Fixed mark number (i.e. fixed number of '1's) - Sequences of '0's and '1's, or alternating low and high marks - Programed to other features
	Generates an encoded train of electrical pulses defined by the train of bits at its input: - Pulse waveform at the output of the coder is sampled

	Adjusts the rise time of the electrical pulses: - Realistic electrical pulses do not have sharp edges - Rise time refers to the ratio 10% / 90% of amplitude values - Typical values: (rise time) = 0.25 / (bit rate) but other values may be used
	Lasers are usually modeled using laser rate equations - Time dynamics and other detailed laser characteristics that can distort the pulse and add noise are taken into account
	Optical fiber propagation modeled using the Nonlinear Schrödinger equation. The following are taken into account: - Fiber loss - First and second order group velocity dispersion - Nonlinear effects
	Converts the incident optical filed into an electrical signal: - The electrical signal is a photocurrent which contains the useful signal current, and currents from noise (shot noise, thermal noise and dark current)
	An electrical low pass filter used to remove some of the electrical noise added by the photodiode: - Filter type can be chosen - Main parameters are cut off frequency and filter order
	Analyzer can operate in various modes: - As an optical spectrum analyzer (OSA) to examine the frequency content - As an oscilloscope to examine the time domain - As an electrical spectrum analyzer - As an eye diagram analyzer

2.2. Global parameters for simulations

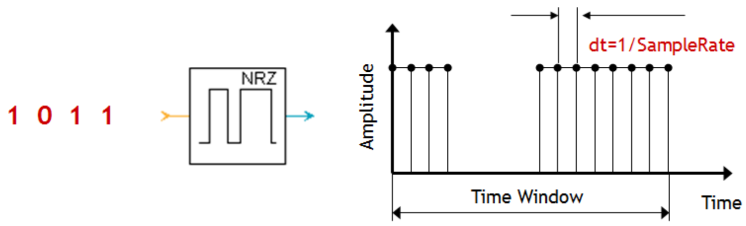
BitRateDefault: defines the bit rate per channel (*B*). This means the number of bits of information sent in one second of time.

SampleRateDefault: the number of samples per bit (*S*) times the bit rate (*B*) - $S*B$

TimeWindow: the number of bits to be simulated (*M*) divided by the bit rate (*B*) – M/B. Typically *M* is chosen to be such that its greatest prime factor is 2, i.e. *M* must be 2^m in order to ensure high speed of the fast Fourier transform.

Note: the time window sets the duration of the blocks in seconds. A long time window leads to greater simulation accuracy (for example increased spectral resolution) but increases computation time.

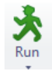
Illustration:



M = 4
S = 4
B = 10 Gb/s
Sample rate = 40 GHz
Time window = 40 ns

3. Simulations

3.1. Part 1 – the transmitter and basic transmission

a. Open the file FOC1_01 and run the program without making any changes (). The SignalAnalyzer will open. The PRBS is currently set to produce a string of '0's: no data is sent therefore there is no information imprinted on the laser (i.e. it is unmodulated). Record the optical spectrum, which represents the distribution of power as a function of wavelength/frequency.

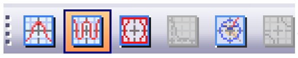
Question: What is the central wavelength of the laser?

Answer:

b. Double click on the icon of the ***PRBS*** and modify its parameter ***PRBS_Type*** from '**Zero**' to '**PRBS**' and run the program. Record the optical spectrum.

Question: What are the differences in the spectrum that you observe between this and the unmodulated laser spectrum ?

Answer:

c. Change the SignalAnalyzer mode to the oscilloscope (top menu ). The optical waveform in the time domain produced by the laser will be displayed. Play around with the various features of the scope (e.g. rescaling the axes, magnifying a portion of the trace, etc). Note the overshoot and fluctuations.

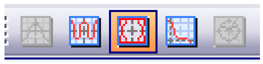
Question: From the time trace, can you estimate the speed of the optical signal in bits/s?

Answer:

d. Close the current setup and open FOC1_03. An optical fiber, a photodiode and electrical filter have been added. Run the program: the time domain and frequency domain will be displayed.

Question: From the electrical spectrum, the radio frequency (RF) component at f_0, $2f_0$, $3f_0$ etc can be seen. They correspond to the fundamental modulation frequency and its harmonics. What is f_0 ? Does it coincide with the bit rate you had estimated from the time domain display?

Answer:

e. Display the eye diagram instead of the waveform (top menu ). Change the length of the fiber: double click on the fiber icon and modify the parameter ***Length*** from 10.0e3 (10 km) to 150.0e3 (150 km) and run again.

Question: Compare the eye diagram for the 10 km and 150 km case. What are the main differences? How do you think the system performance compare?

Answer:

f. While the eye diagram provides a graphical feel for the performance, a more objective measure of performance is the bit error rate (BER). The scope has a built in function to estimate (will be covered in greater details in another lecture). Click in the menu on **Control Panel** in the lower right corner, look for **SER Analysis** and box mark **Enable SER** and **BER**. The estimate BER appears at the bottom of the screen.

Question: What is the BER value? What does it mean?

Answer:

3.2. Part 2 – Limitation in transmission length

a. Open the file FOC2_01. This setup is different than the previous one: the length of the fiber is 150 km and the parameters of the optical fiber have been modified such that fiber *dispersion* and *nonlinearities* are turned OFF. Signal analyzers are placed at the input and output of the fiber and one after the photodiode. Run the program.

   Question: What is the difference between the scope trace at the input of the fiber and directly at the output of the fiber.

   Answer:

b. **Question** : Look at the scope trace after the detector (electrical signal). You can see it is severely distorted. In a following lecture we will see this is due to the low power reaching the detector which leads to domination of the detector thermal noise. . From the eye diagram use the **BER Analysis** to estimate BER. Then change the length of the fiber (parameter ***Length***) to 100 km, rerun and extract the BER. . Repeat the step above increasing the fiber length by 10 km each time until you reach 150 km. Make a plot of BER versus fiber length.

   Answer:

   Question: What happens to the performance as the distance increases? If the maximum acceptable BER is 10^{-9}, what is the maximum distance for this specific link? What do you think limits the reach in this case?

   Answer:

c. Open the file FOC2_03. Change the parameters of the fiber such that the loss is turned OFF(***Attenuation*** parameter). Note that nonlinearities are already turned off but that dispersion is enabled and that the length is set to 1 km. Run the program then change the length of the fiber to 100 km and 200 km. Re-run each time.

Question: Compare the signal at the output of the fiber for these 3 distances. What happens?

Answer:

d. The default bit rate of the simulation can be retrieve from the parameter editor window (double click anywhere – but not on an element – to open the window) under ***System/BitRateDefault***. Change the bit rate from 10 Gb/s to 20 Gb/s and re-run the simulations for the 3 previous distances (1 km, 100 km, 200 km).

Question: Compare the results with the one obtained at 10 Gb/s. What can you conclude?

Answer: