VPIphotonics
DESIGN AUTOMATION

BER and Q-factor
TaM2

Interactive learning module

University Program
Photonics Curriculum Version 8.0

Preface

This module covers bit error ratio (BER) measurements and estimation.

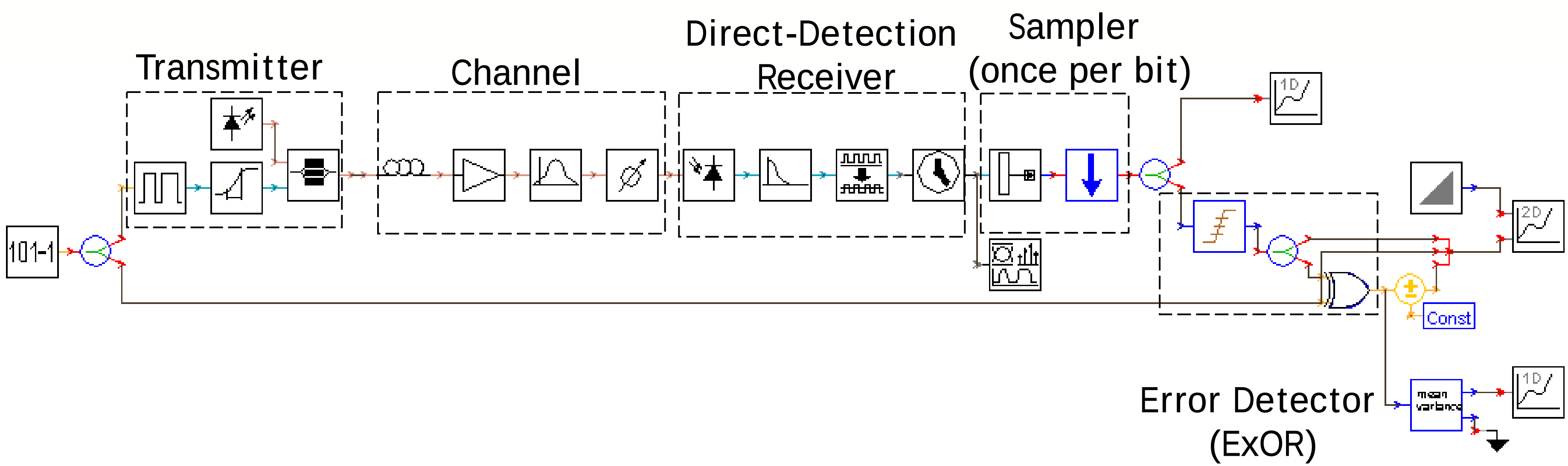
- In practice, BER is measured by counting the number of error bits and dividing by the total number of bits received. As long as a statistically significant number of bits is counted, the ratio of error bits to the total number of bits is, by definition, the BER.
- This module starts with a simulation of how BER is measured in real life. The results obtained are compared with those obtained via statistical estimation.
- Next, the statistical estimation of BER is explored. The number of bits used to estimate the BER has a significant impact on its accuracy. In particular, the fluctuation in the estimated value of the BER depends on the number of bits.
- Then a new device, which estimates the BER of DPSK modulation formats is presented. A comparison is made between ASK and DPSK formats.
- The rest of the module explores various system examples of the BER measurement/estimation. The following examples are covered:
  - Back-to-Back measurement (baseline for comparison with system measurements)
  - System measurement (an unamplified fiber-optic link)
  - BER degradation due to transmitters with poor Extinction Ratio
  - BER floors in optically amplified links
  - BER curves of optically pre-amplified receivers

Note:

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

BER Measurements

- The schematic TaM2_1, shown below, simulates how BER is measured in a real experiment using a BER test set.
- The setup works by counting the number of error bits and received bits. The ratio of the number of error bits to the total number of bits received is by definition the BER.
- The output of a PRBS generator is split into two, with one portion transmitted through a "system under test". The other portion is connected directly to an error detector. The error detector compares the received bits (those that have been transmitted through the system under test) with the ones directly from the PRBS generator. The comparison is done by a logic circuit (an Exclusive OR or EXOR gate), and a mismatch indicates that a bit has been received incorrectly (an error bit).

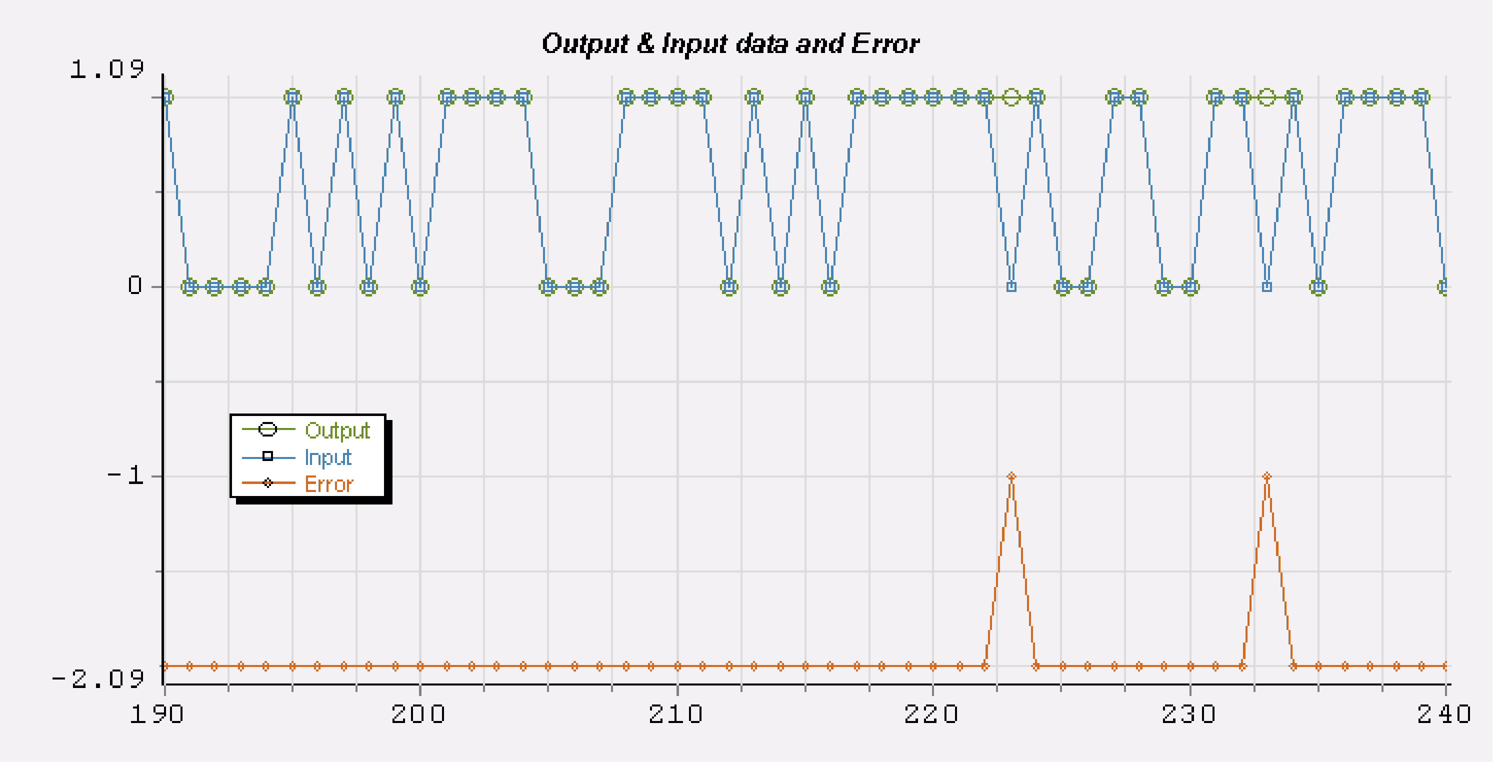


BER Measurements

- The system under test is a typical amplified optical transmission link. The transmitter in the setup is an externally-modulated semiconductor laser, where ***ModulatorMZ*** is the modulator and ***LaserCW*** is the semiconductor laser.
- The optical channel comprises an optical fiber ***FiberNLS***, an optical amplifier ***AmpSysOpt*** and an optical filter ***FilterOpt***.
- The attenuator is used to reduce the performance of the system so that actual errors can be counted in the period of time it takes the simulation to complete.
- The receiver consists of a PIN diode ***Photodiode***, an electrical filter ***FilterEl*** (low pass), a ***DCBlock*** and a clock recovery circuit ***ClockRecoveryIdeal***.
- The error detector consists of a quantifier ***Quant*** and a logic circuit ***Logic***. The number of error bits and received bits are counted here, and from this information, BER is calculated.
- The setup will display the results as an XY plot, an histogram and a text box.

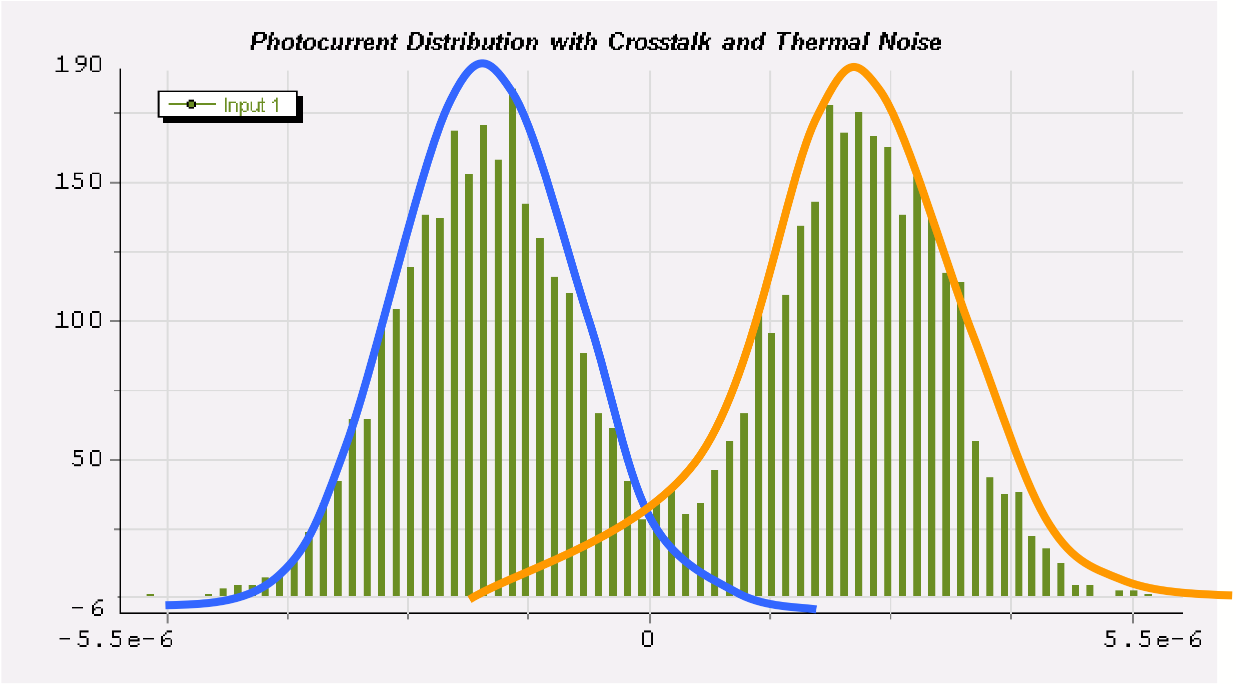
BER Measurements

- Run the simulation.
- The *NumericalAnalyzer2D* (below) shows the input bit stream and the output bit stream. Any error bits that are detected are also displayed, but these are offset from the input and output bit streams so that they be clearly discerned.
- The 1st error bit is a ‘0’ that is detected as ‘1’, while the 2nd error bit is a ‘1’ that is detected as ‘0’.



BER Measurements

- The figure below shows the amplitude histogram of the received signal.
- The received signal is quantized into voltage bins (horizontal axis), while the vertical axis shows the % of samples that fall into the respective voltage bin.
- The histogram shows two distinct peaks, corresponding to the distribution of ’0s’ and ‘1s’ (highlighted by the blue/orange curves).
- If the distributions can be modelled as a Gaussian distribution, the BER and Q can be calculated easily.

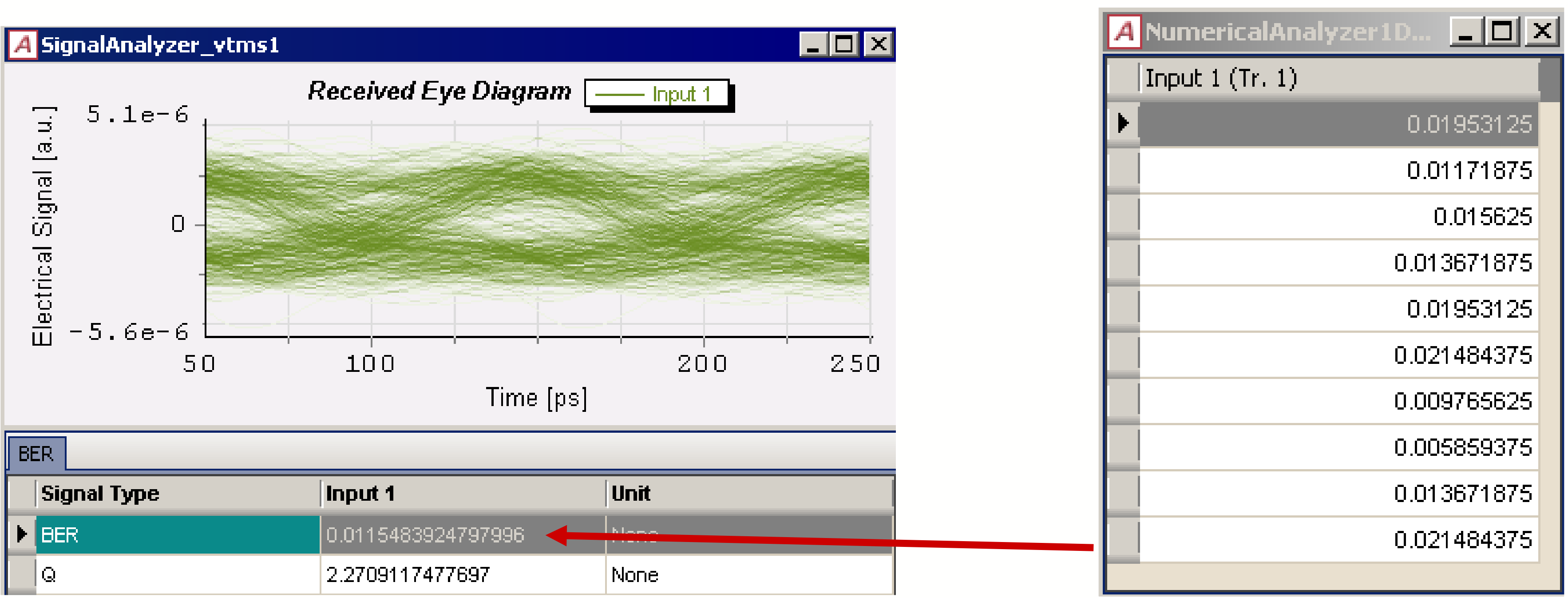


BER Measurements

- The eye diagram of the received signal is shown below. BER can be estimated if you box-mark the BER in the BER Analysis (in the Control Panel).

Question 1: The BER of the tenth iteration obtained from the eye diagram is not exactly the same as the one shown in the text window. Why are the two BER values different? How can the two results be made to converge? Run the simulation to demonstrate it.

Question 2: In a computer simulation, why is BER not obtained by counting the received and error bits (which is how it is obtained in real experiments using real equipment)?



BER Measurements

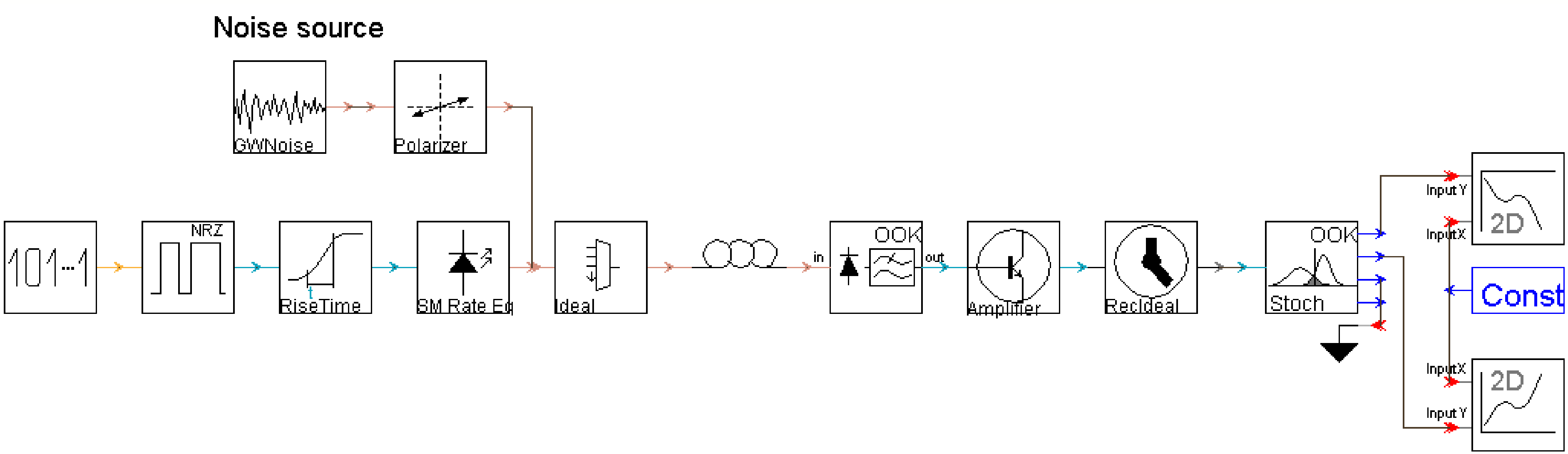
Exercise 1: Re-run the simulation, but this time, decrease the amount of attenuation (in the attenuator of the optical channel). Compare the results (in particular, the histogram) of this run with the results shown in the previous pages. Repeat with different values of attenuation and comment on the effect of varying the attenuation on the distribution of ‘0s’ and ‘1s’ in the histogram.

Exercise 2: Repeat Exercise 1, but vary the bandwidth of the electrical filter after the receiver instead.

Exercise 3: Experiment with the set up by varying other parameters of the system under test (for example, the fiber length, the average output power of the CW laser, the extinction ratio of the external modulator, etc). How are the distributions affected? How is the BER affected?

BER Estimation via Simulation

- In order to obtain a reliable measure of the BER, the number of counted bits should be statistically significant. For example, to ascertain reliably that BER performance of a system is 1e-9, the number of bits counted should be at least 1e10, or more.
- It is generally impractical (or impossible) to simulate so many bits, so statistical methods for estimating BER, based on a far smaller number of simulated bits, are used instead.
- The schematic of TaM2_2 (shown below) is used to investigate various aspects of BER estimation.



BER Estimation via Simulation

- In the schematic, the signal generated from a directly modulated semiconductor laser ***LaserRateEqSM***, is transmitted through an optical fiber ***FiberNLS*** and is detected by an optical receiver ***Rx_OOK.***

- Let us investigate the dependence of the estimated BER on the number of bits used in the estimation. Start with a number of bits (herein referred to as the “sample size”) equal to 32, and double this number until the final value of 2048 is reached.
- For each sample size, the simulation is iterated 10 times. The purpose of the iterations is to reveal the fluctuations in the estimation of Q, and hence BER. Such fluctuations are expected and are due to the randomness of the PRBS sequence as well as the statistical nature of the Q and BER estimation.
- Run the simulation.

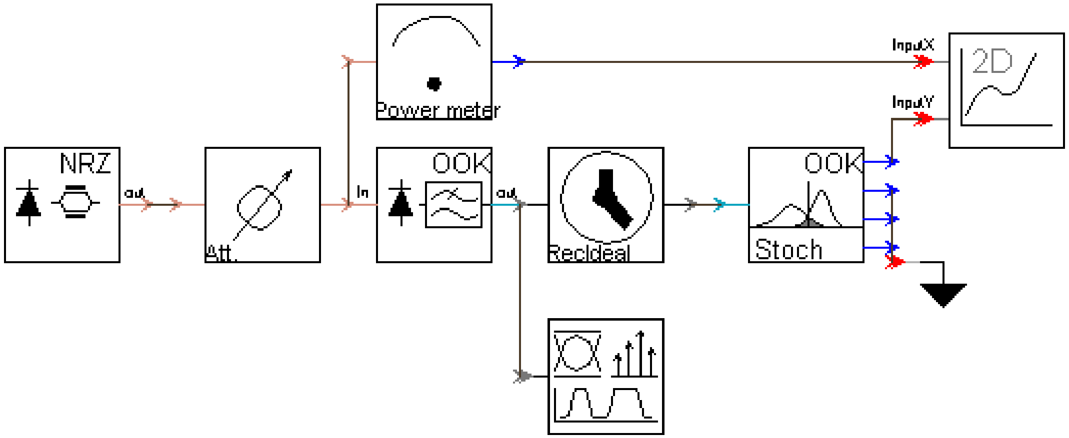
BER Estimation via Simulation

- Plot the BER (left) and the Q factor (right) versus the sample size (the number of bits in the PRBS sequence simulated by the setup). The BER is plotted on a logarithmic scale while the Q is plotted on a normal scale.
- Show that BER and Q factor fluctuations decrease with the number of Bits (related to the number of samples)

Exercise 4: Plot the maximum deviation of BER and Q versus the sample size. The deviation is calculated by taking the difference between the maximum and minimum value.

Back-to-Back Measurement

- The setup TaM2_3 (below) shows a back-to-back measurement.
- The transmitter is a externally modulated Laser ***TxExtModLaser*** and the receiver is a PIN diode ***Rx_OOK***.
- The input power is measured by the power meter ***Powermeter***. It is set to output the power level in dBm.
- The bit error rate of the received signal is measured by clock recovery ***ClockRecoveryIdeal*** and BER measurement module ***BER_Stochastic_NoRef***, which uses a statistical measurement method.



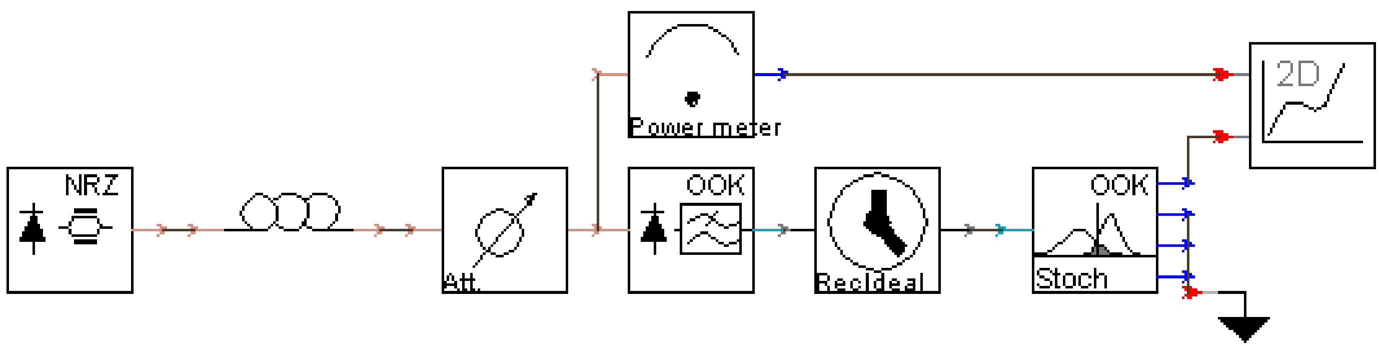
Back-to-Back Measurement

- Increase the attenuator loss from 26 to 35 dB, with steps of 1 dB. Plot the logarithmically scaled BER versus input power of the back-to-back measurement. What type of BER curve is obtained?
- The back-to-back measurement characterizes the receiver. From the BER curve, obtain the receiver sensitivity (for a BER of 10^{-9}).

Exercise 5: Change the ***Rx_OOK*** ***Responsivity*** value and run simulation again. Plot the sensitivity of the receiver versus the responsivity of the receiver

System BER Measurement

- Now we put 50 km fiber ***FiberNLS*** into the system under test
- The set-up is saved as TaM2_3bis (as shown below).



System BER Measurement

- Run the simulation by varying the attenuator loss from 16 to 21 dB, with steps of 1 dB.
- Plot the resulting BER curve. What type of curve is obtained now?
- Compare this BER curve below with the BER curve of the back-to-back measurement: What is the power penalty of the optical fiber?

Exercise 6: Change ***FiberNLS*** ***Length*** and run the simulation again. Plot the power penalty versus the length of fiber.

Extinction Ratio Degradation

- Change the parameter ***ModulatorMZ_ExtinctionRatio***, which represents the extinction ratio of the transmitter, to 10 dB from 30 dB.

- Compare the BER curves when the extinction ratio of laser output is either 30 dB or 10 dB.

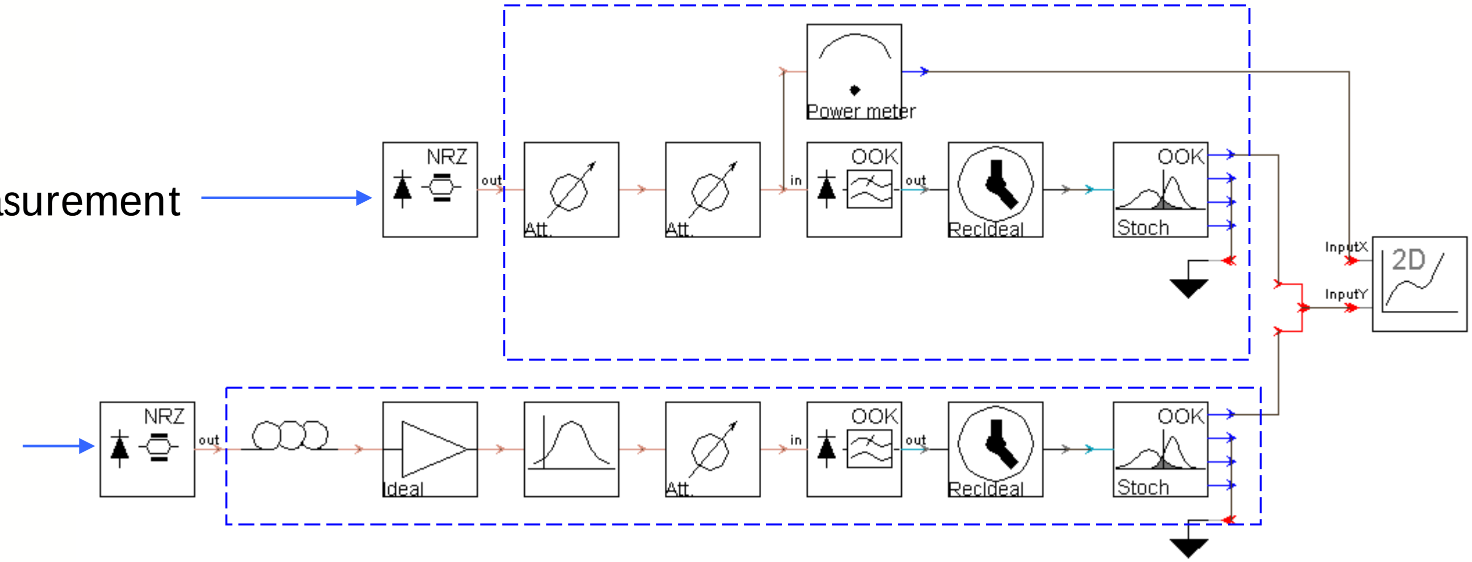
Question 3: Explain why the extinction ratio degradation causes a shift in the BER curve

An Optically-Amplified Link

- Now we test an optically amplified link. The schematic TaM2_5 is shown below.
- The upper part is a back-to-back measurement
- The lower part is an optically-amplified link measurement, which consists of an optical fiber ***FiberNLS***, an optical amplifier ***AmpSysOpt*** and an optical filter ***FilterOpt*.**

Back-to-back measurement

Optically-Amplified link measurement



An Optically-Amplified Link

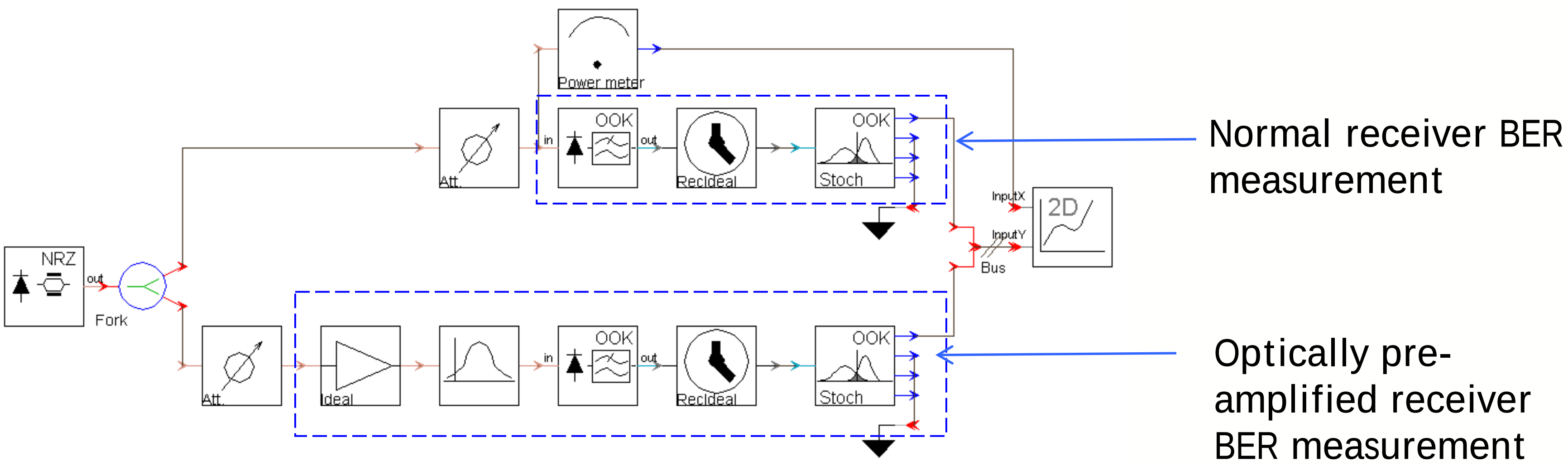
- Increase the attenuators' loss from 0 up to 15 dB, with steps of 1 dB.
- Plot the resulting BER curves of back-to-back measurement and of the optically-amplified link.

Exercise 7: Measure the power penalty. Change the fiber length and run the simulation again. Plot the relationship of power penalty and fiber length.

Exercise 8: Change the gain of the optical amplifier and run the simulation again. Plot the relationship of power penalty and gain.

Optically-Preamplified Receiver

- In this part of lab, we will compare the sensitivity of a PIN diode receiver and optically preamplified PIN diode receiver
- The schematic TaM2_6 is shown below
- The upper part is a BER measurement using a normal PIN diode receiver ***Rx_OOK***
- The lower part is a BER measurement using an optically pre-amplified receiver which includes an optical amplifier ***AmpSysOpt***, an optical filter ***FilterOpt*** and a PIN diode receiver ***Rx_OOK*.**



Optically-Preamplified Receiver

- Run the simulation by increasing the attenuator loss from 28 dB to 52 dB (with steps of 6 dB)
- Plot and compare the BER curves for a normal PIN diode receiver and for an optically preamplified receiver.

Question 4: Why is the *gradient* of the two curves different?