# Descriptions of the Demonstration Setups

## 1.0 Overview

This CD-ROM contains a variety of interactive demonstrations that use the Photonic Transmission Design Suite (PTDS) from Virtual Photonics, Inc. These demonstrations are intended to help the reader understand and extend the concepts presented in this book. The demonstrations are listed in alphabetical order in the menu bar and include the following:

- BER Estimation
- Dispersion Compensation
- Fiber Dispersion
- Fiber Nonlinearities
- Fiber Polarization-Mode Dispersion (PMD)
- Lasers
- Networks (WDM ADM using FBGs and Circulators, Interchannel crosstalk in a ring network)
- Optical Amplifiers (Dynamic EDFA Effects; EDFA Types; Gain Curves; Gain Shaping)
- Soliton Propagation
- Wavelength Converters

Note that since the demonstration setups are listed in alphabetical order, they do not follow the sequence of topics listed in the book. However, it should be fairly clear which of the demonstrations relate to a specific topic in the book. Furthermore, in some cases the demonstrations can relate to more than one specific section of the book. For example, the Fiber Dispersion setup can be used to examine the concepts of fiber dispersion, their effect on system performance, and how to measure this parameter. These topics on dispersion are covered at various levels of detail in Chapters 3, 8, 12, and 13.

The architectures of the setups can be modified and the user can change all parameters of the building blocks (e.g., lasers, modulators, fibers, receivers) in any module, so that an indefinite number of system variations can be realized. This will allow the performance of a setup to be examined over a wide range of component parameter values. The calculated performance values can be stored and printed out. However, the changes to the demo setups cannot be saved, and the parameter values will revert to the original settings when the setup is closed. Note that this feature, the ability to include arbitrary modules from a rich module library and to create new setups and sweeps, is part of the full version of the PTDS software. The PTDS simulation and modeling tool is commercially available from Virtual Photonics, Inc. (see Sec. 1.4.3 and the description of the PTDS tool on the CD-ROM).

# 2.0 What Can Be Learned

This section describes some of the fundamental concepts that can be observed or studied with the various demonstration setups. Before simulating the setups you are strongly recommended to read the sections Quick Start in the VPI Ptolemy Users Manual and the visualizers sections in the Photonic Modules Reference Manual, which can be accessed over the *Help* menu. To each topic of the demonstrations the appending setups and sweps are listed. Open the setups listed in the sections or (if existing) the appending sweeps. Start them using the submit simulation button or by clicking the green guy. Adjust the parameters in the setup and the submit simulation window.

## 2.1 BER Estimation

Setup: *BitErrorRate* (Figure 1), Sweep: *Attenuation_Sweep*

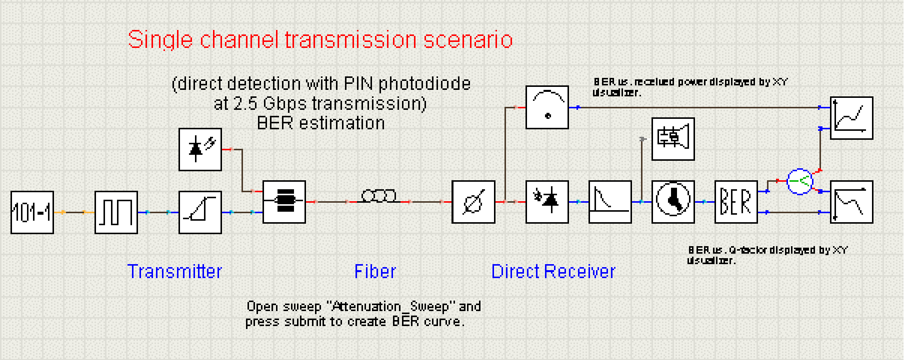


**Figure 1.** *BER estimation demo*

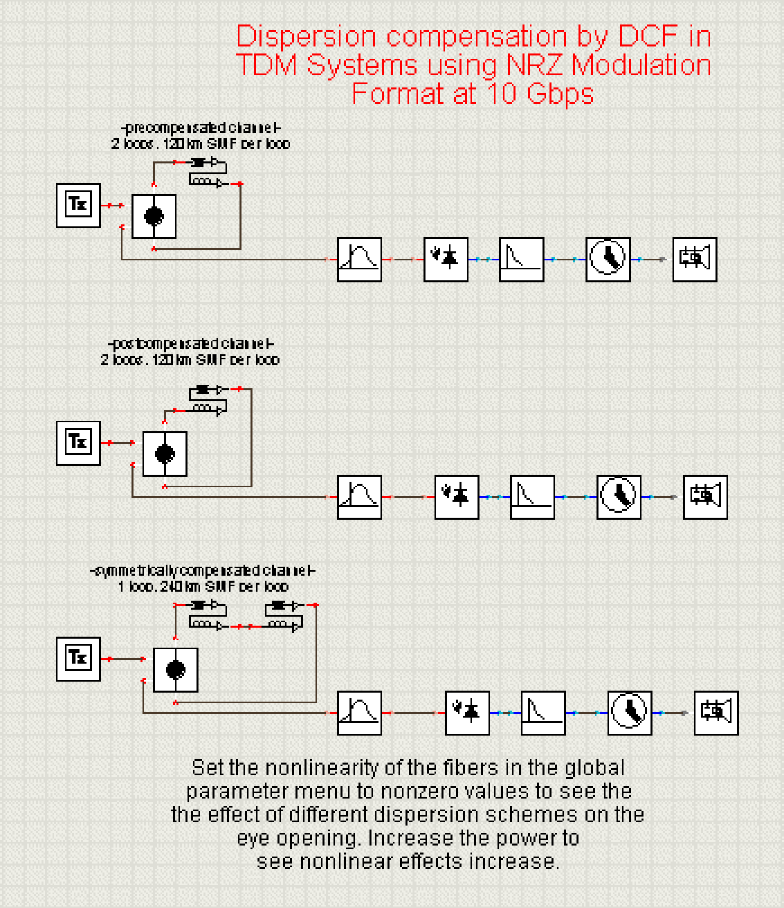
Open the sweep ( by double clicking on it in the icon bar or using the right mouse button) to access schematic and press *Open Schematic* to access sweep. The setup architecture consists of a single-channel transmission link containing an externally modulated laser transmitter, a standard single-mode fiber, and a direct-detection *pin* receiver. The standard data rate is 2.5 Gb/s. By sweeping over a range of 6 dB of attenuations before the receiver, the two visualizers present displays of BER versus received power and BER versus the Q factor. See Figs. 7-8 and 7-7, respectively. An eye diagram is obtained from the time signal data (see Sec.13.6 for a discussion on eye pattern measurements) and displayed in the scope for each sweep point. Note the simulation tool will automatically calculate the BER from the eye diagram when the user places a BER-measurement marker at any desired position of the eye opening and enables the calculate BER function. Because the sweep is performed over the attenuation before the receiver the first sweep point (0) will correspond to the highest power level, the last one (5) to the lowest.

The user can change settings such as the data rate, optical power emitted from the laser, or receiver sensitivity in the setup to see their effect on the BER and the shape of the eye diagram.

## 2.2 Dispersion Compensation

Setup: *DispersionCompensationSchemes* (Figure 2), Sweep: *NonlinearIndex*

As noted in Sec. 12.5.6, to reduce the effects of FWM (as they would appear using a dispersion shifted fiber), dispersion compensating fibers having a dispersion characteristic that negates the accumulated dispersion can be inserted into a fiber link. These dispersion-compensating fiber loops can be placed either at the transmitter end, the receiver end, or distributed symmetrically at both ends. This demonstration module shows the effects on system performance for these three cases in a time-division multiplexed (TDM) system using a non-return-to-zero (NRZ) modulation format at 10 Gb/s. If the sweep is applied to the setup, the behaviour of the dispersion compensation schemes  for both neglected and applied nonlinearity of the fiber is investigated and displayed in the visualizers (where each sweep point produces a new plot in the scopes). The user can also increase the optical power level to see how the nonlinear effects increase. The measurement is done via an eye diagram (press *EYE* button in scope), where the BER is calculated automatically when the user places a BER-measurement pointer at that position of the eye opening where the data stream will be sampled. Note, that if the nonlinearity of the fiber comes into play, the symmetrically compensating scheme will show its adavantage in comparison to post and precompensation. As can be seen from the time traces and the resulting eye diagrams the using of a post compensation scheme cannot be recommended.



Set the nonlinearity of the fibers in the global parameter menu to nonzero values to see the the effect of different dispersion schemes on the eye opening. Increase the power to see nonlinear effects increase.

**Figure 2.** *Dispersion Compensation schemes: precompensation, postcompensation, symmetrical compensation*

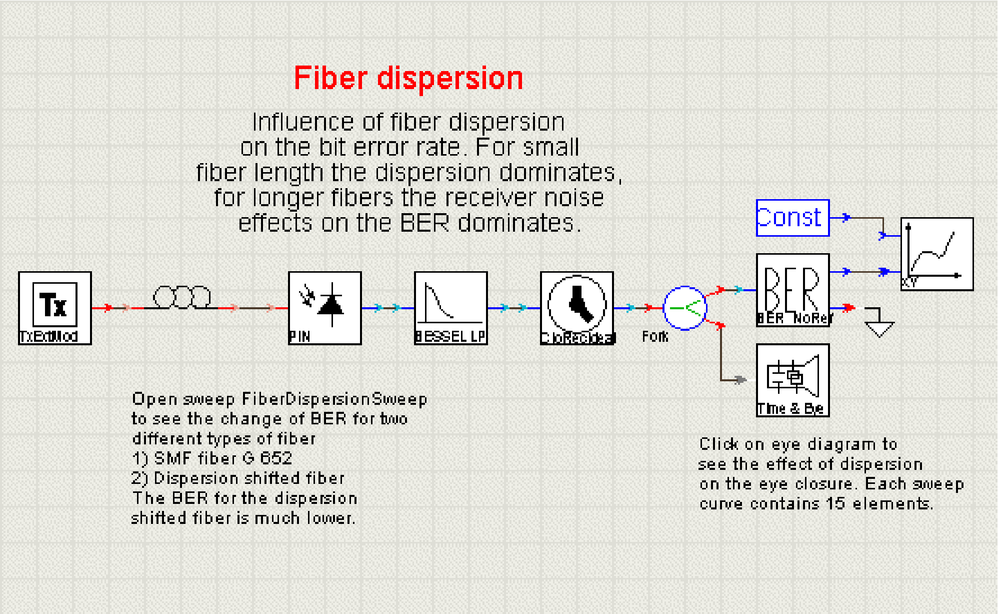
## 2.3 Fiber Dispersion

Setup: FiberDispersionInfluence (Figure 3), Sweep: FiberDispersionSweep

This setup can be used to examine the effects of dispersion on the BER for two types of fiber: single-mode G.652-type fiber and dispersion-shifted fiber (see Sec. 3.5). The demo will show that the BER for the dispersion-shifted fiber is much lower than the BER of the G.652 fiber. Also note which factors dominate the BER for long or short fiber lengths. An eye diagram can be obtained from the BER data in the scope and updated for each sweep point.

## 2.4 Fiber Nonlinearities

Setup: *FiberNonlinerities* (Figure 4)



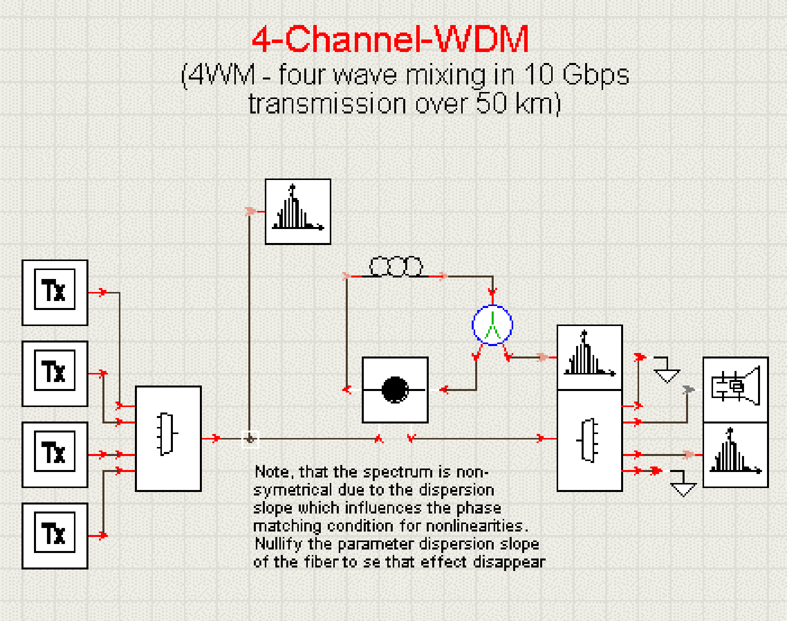
Fiber dispersion

Influence of fiber dispersion
on the bit error rate. For small
fiber length the dispersion dominates,
for longer fibers the receiver noise
effects on the BER dominates.

Open sweep FiberDispersionSweep
to see the change of BER for two
different types of fiber
1) SMF fiber G 652
2) Dispersion shifted fiber
The BER for the dispersion
shifted fiber is much lower.

Click on eye diagram to
see the effect of dispersion
on the eye closure. Each sweep
curve contains 15 elements.

**Figure 3.** *Fiber dispersion influence on BER*



4-Channel-WDM

(4WM - four wave mixing in 10 Gbps
transmission over 50 km)

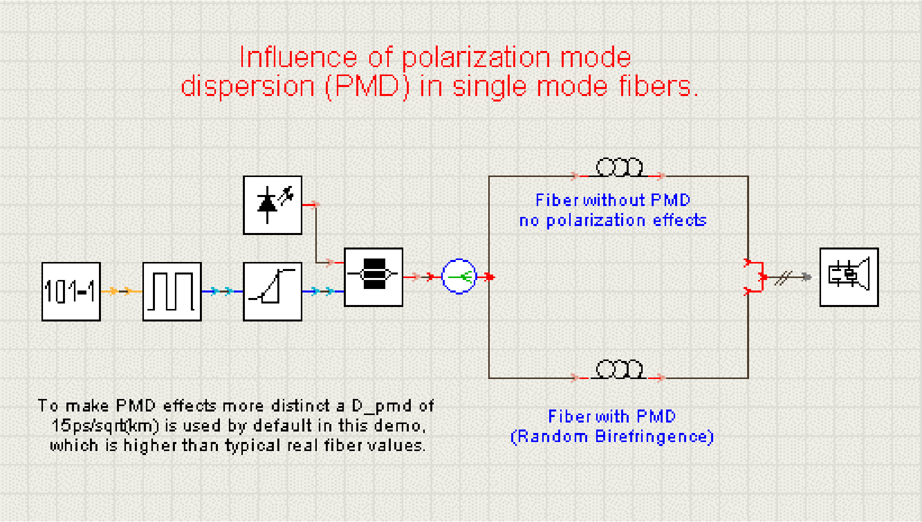
Note, that the spectrum is non-
symetrical due to the dispersion
slope which influences the phase
matching condition for nonlinearities.
Nullify the parameter dispersion slope
of the fiber to se that effect disappear

**Figure 4.** *Four wave mixing effects in a 4 channel WDM system*

Four-wave mixing (FWM) is illustrated by combining several 10-Gb/s WDM channels and sending them over a 50-km link (see Sec. 12.5.5 for a discussion on FWM). In this case, the output spectrum of four WDM channels spaced 100 GHz (0.8 nm) apart is displayed. The appearance of FWM-induced side modes is easily seen on the display of the spectrum, which is updated each 5 km propagation distance in the fiber. Note that the spectrum is asymmetric due to the dispersion slope, which influences the phase-matching condition for the nonlinearities. Nullifying the dispersion slope in the parameter setup results in a symmetric display. The user can also display a single output channel to see the effects of FWM. Note how far (in decibels) the side lobes are below the signal peak. Measure the frequency difference and the difference of power levels using markers in the OSA.

## 2.5 Fiber Polarization-Mode Dispersion (PMD)

Setup: *PolarisationModeDispersion* (Figure 5), Sweep: *BitRate_Sweep*



Influence of polarization mode dispersion (PMD) in single mode fibers.

To make PMD effects more distinct a D_pmd of 15ps/sqrt(km) is used by default in this demo, which is higher than typical real fiber values.

**Figure 5.** *Polarization mode dispersion effects: dependence on bitrate*

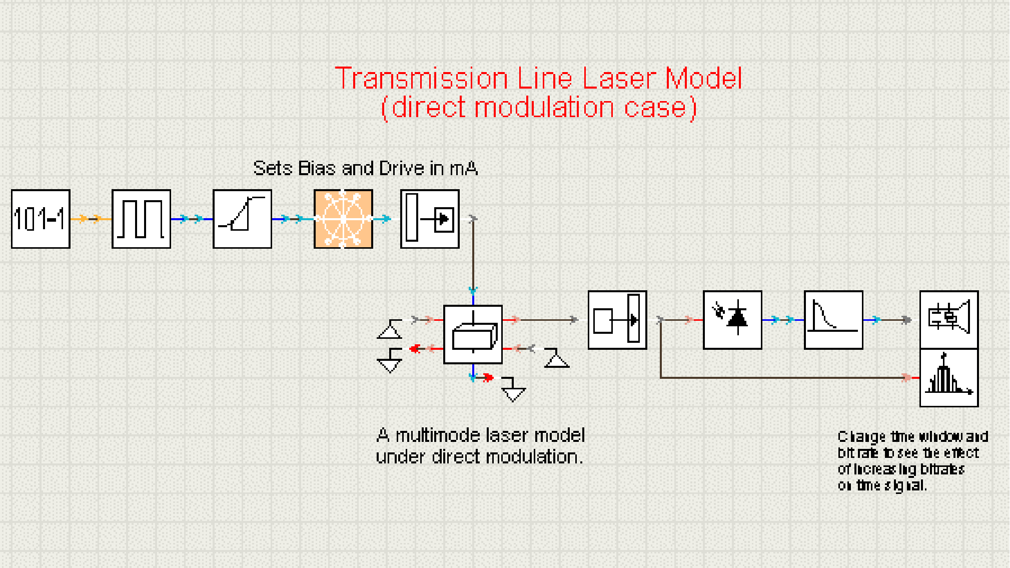
This setup compares the polarization-mode dispersion effects in a PMD-independent fiber with a fiber having a PMD-dispersion coefficient of 15 ps/km$^{1/2}$. This value, which is about 30 times larger than a typical value in real fibers, was chosen to make the PMD effects more distinct (see Sections 3.2.6 and 13.4.5). If the sweep is applied the user can observe how the influence of PMD increases for increasing bitrates. In this case 2 bitrates: 2.5 Gbps and 10 Gbps are compared in their influence. Press PowerX and PowerY buttons in the scope to see the power contributions in the x and y polarization, respectively. As can be seen in the scope the y-power value increases for 10 Gbps.

## 2.6 Lasers

Several different concepts can be studied here.

### (a) Fabry Perot Laser showing sidemodes

Setup: *FP_Laser_with_sidemodes* (Figure 6)



A multimode laser model under direct modulation.

Change the window and bit rate to see the effect of increasing bitrates on the signal.

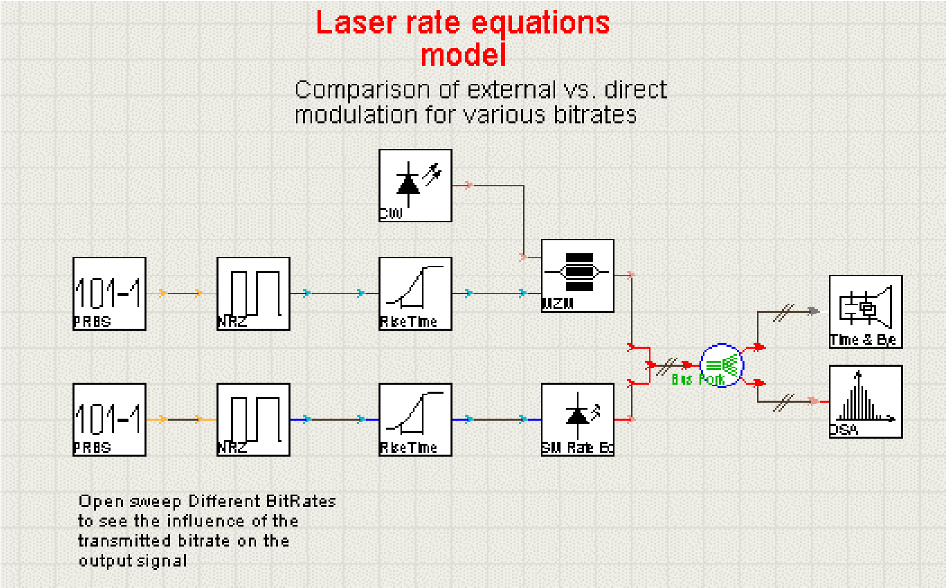
**Figure 6.** *Directly modulated Fabry Perot laser, showing sidemodes*

A multimode Fabry-Perot laser is directly modulated. The user can change the time window and the bit rate to see the temporal effects on the signal when the bit rates are changed. One can also view the laser spectrum of the Fabry-Perot modes (e.g., see Fig. 4-21) in the OSA. To measure the side mode supression ratio of the laser, set a bandwidth resolution in the OSA and apply markers

### (b) Comparison of external and direct modulation for various bitrates

Setup: *External_vs_direct_modulation* (Figure 7), Sweep: *DifferentBitRates*

A comparison is made between external and direct modulation of a laser diode for various bit rates (the following birates are applied to the setup: 1.25 , 2.5 , 5 and 10 Gbps, see also Sec. 4.3.7). The time signal and the spectrum of both modulation schemes are compared in visualizers, where for each sweep point one visualizer plot is generated. To allow the change of bit rates, please open the appending sweep. Note the limitation of direct modulation when the bit rate is increased; for example, the output signal no longer tracks the input waveform at 10 Gb/s.



Open sweep Different BitRates to see the influence of the transmitted bitrate on the output signal

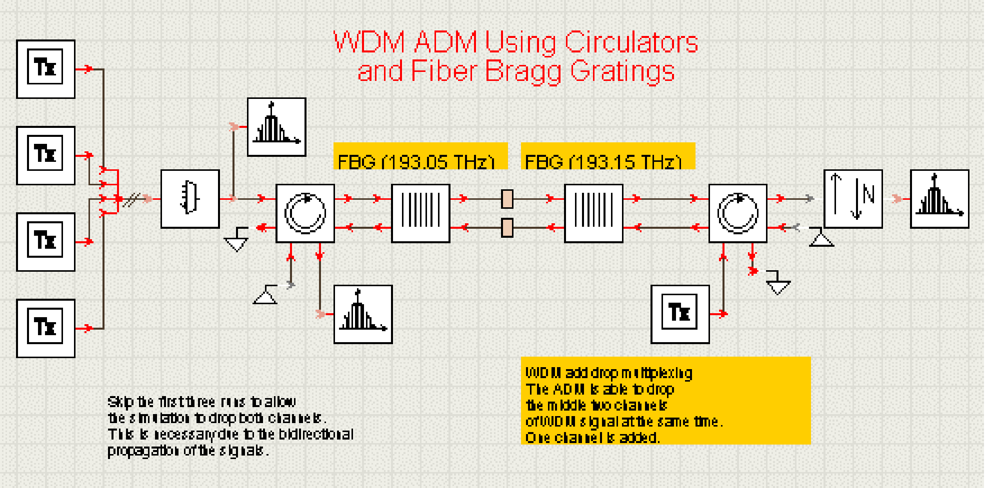
**Figure 7.** *Comparison of direct vs. external modulation for various bitrates*

## 2.7 Networks

Two different network concepts can be studied here.

### (a) 2 channel WDM add drop multiplexer using Fiber Bragg Gratings and Circulators

Setup: *WDM_ADM_2FBG_Add_and_Drop* (Figure 8)



Skip the first three runs to allow the simulation to drop both channels. This is necessary due to the bidirectional propagation of the signals.

WDM add drop multiplexing
The ADM is able to drop the middle two channels of WDM signal at the same time.
One channel is added.

**Figure 8.** *WDM add drop multiplexer using circulators and FBGs*

The first setup in this group exhibits the use of two optical circulators and a pair of fiber Bragg gratings to perform add/drop multiplexing in a 4-channel WDM system (see Fig. 10-27). Input and output WDM signals and the dropped signals are shown by OSAs. Here the Bragg gratings are tuned to 193.05 and 193.15 THz, which correspond to the wavelengths 1552.92 and 1552.12 nm, respectively. The module shows that these two wavelengths are dropped at the first circulator (after being reflected by the Bragg gratings) and the remaining two wavelengths pass through the system. In addition, one of the dropped wavelengths is reinserted at the second circulator. Note, that in the OSAs you have to skip the first three runs to allow the simulation to build up.

### (b) Interchannel crosstalk influences in an unidirectional ring network

Setup: *Interchannel-Crosstalk_In_A_Ring* (Figure 9)

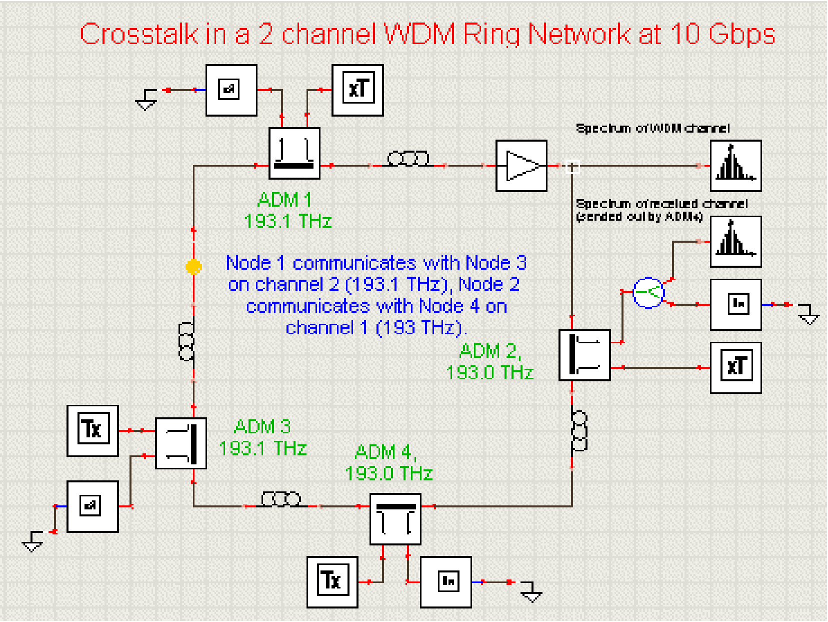


**Figure 9.** *Interchannel crosstalk in an unidirectional ring network*

The demo shows crosstalk effects in a 2-channel WDM ring network operating at 10 Gb/s. The network consists of four nodes. Node 1 communicates with node 3 on channel 2 (193.1 THz), and node 2 communicates with node 4 on channel 1 (193.0 THz). Since channel 1 is fed into the ring at ADM 4 it propagates (clockwise) over three fibers and is amplified only once untill it is taken from the ring at ADM 2. In contrast, channel 2 propagates through only one fiber and is amplified once when it reaches ADM 2. The WDM signal on the ring visualized by an OSA underlines this. The crosstalk channel 2 has a obviously higher power then the signal channel 1. The optical filter bandwidth in the ADM is 100 GHz, so due to the incomplete filtering, there will be some crosstalk from one channel to another (see Sec. 12.6). This can be seen on the output spectrum. The crosstalk level can be measured by the user applying bandwidth resolution and markers.

## 2.8 Optical Amplifiers

Several different concepts relating to Chap. 11 can be studied here.

### (a) Dynamic EDFA effects

Setup: *DynamicEDFAEffects* (Figure 10)

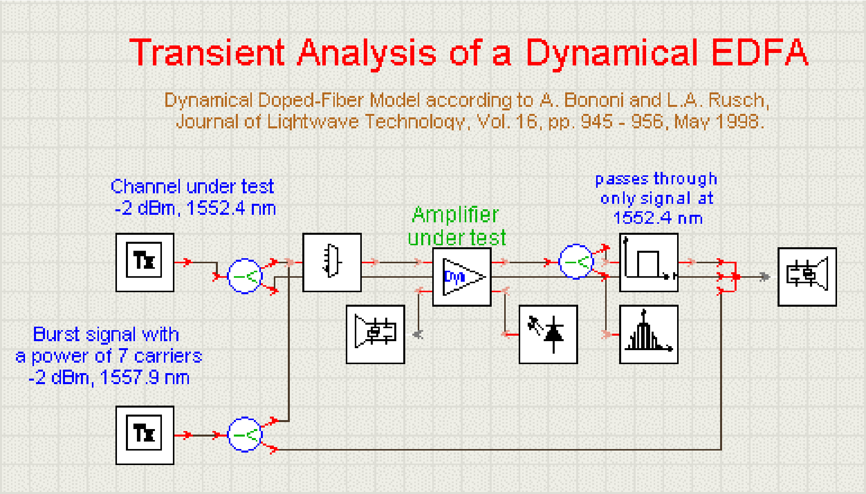


**Figure 10.** *Transient effects in an EDFA*

Since the gain of an optical amplifier gets distributed among the N channels of a WDM system, adding or dropping channels will result in a decrease or increase, respectively, of the amplified power level. To illustrate this, a WDM system has one channel operating at 1552.4 nm with a –2-dBm power level. Along with this, a burst signal with the power of seven carriers is added and dropped at various times to show the dynamic behavior of the EDFA gain. The WDM signal and the dynamically amplifed backward time signal are visualized in an OSA and a Sccope, respectively. At the output a scope visualizer shows the following signals: the burst signal, the input signal of he channel under test, which is fed into the amplifier and the resulting output signal in forward direction. On the display of the output power level versus time, note the change in gain and the recovery and decay times of the signal level when the 7-channel burst turns off and on, respectively.

### (b) Two stage EDFA design

Setup: *TwoStageEDFA* (Figure 11)

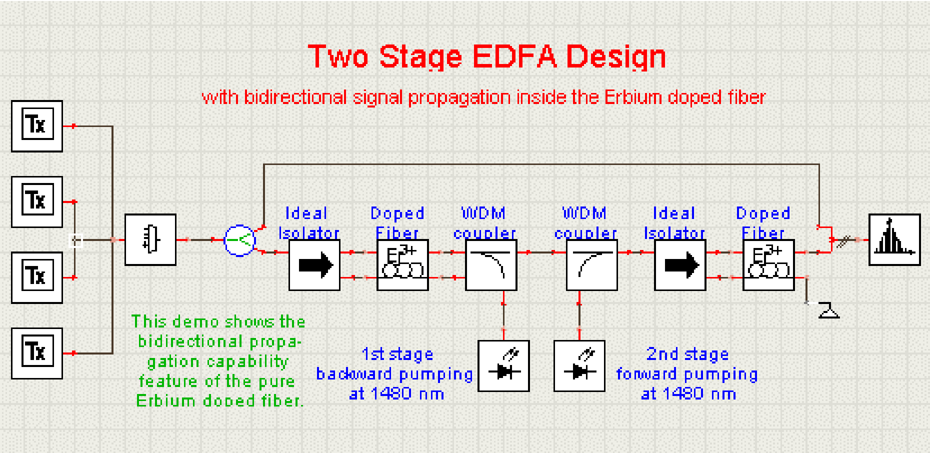


**Figure 11.** *Two stage EDFA: first stage is pumped backward, second stage is pumped forward at 1480 nm*

The two-stage EDFA design setup illustrates the concepts of forward and backward (co-directional and counter-directional) pumping of a two-stage EDFA (see Sec. 11.3.2 and Fig. 11-5 for a single-stage design and pumping concepts). Note, that in the first stage the EDFA is pumped backward, in the second stage it is pumped forward. The pump wavelength can be changed from 1480 nm to 980 nm. Given that there are four input wavelengths, the output display will show the ASE noise, the contribution of the pump, and the slight variation in amplified signal level due to a variation in the gain profile of the EDFA over the spectrum in which the channels are transmitted.

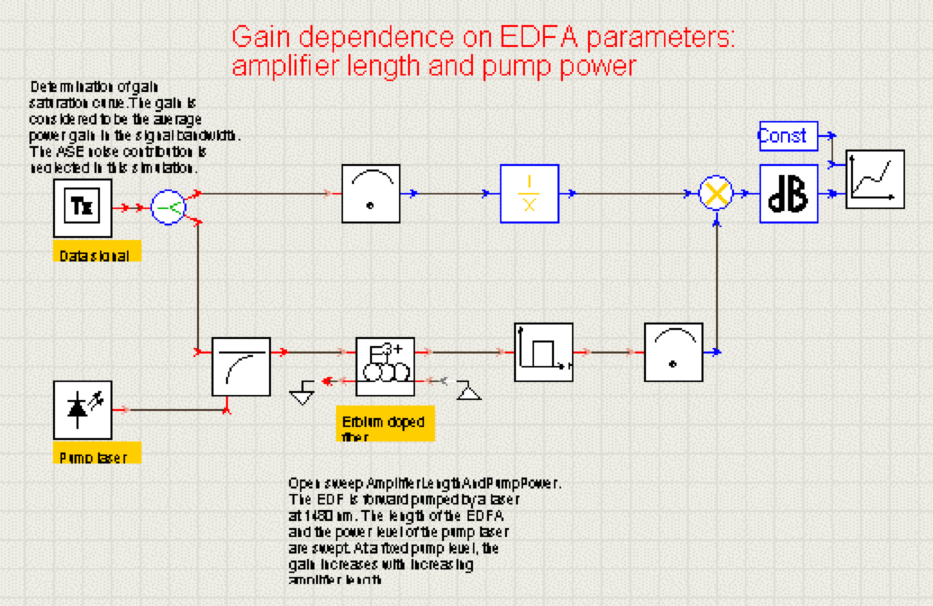
### (c) Gain Curves: Gain saturation vs. amplifier length for different pump levels

Setup: *GainSaturation_vs_Amplifier_length* (Figure 12), Sweep: *AmplifierLengthAndPumpPower*

Gain dependence of EDFA parameters: This module shows the EDFA gain as a function of the erbium-doped fiber (EDF) length for pump powers of 1, 2, 3, 4, and 5 mW. The EDF is forward pumped at 1480 nm. As is illustrated in Fig. 11-6 of the book, the gain drops off with increasing EDF length after an optimum value has been reached. Note, that the ASE noise generation in the EDFA is neglected to point out the gain charateristic in a more clear way..

### (d) Gain Curves: Gain dependence on input power

( Setup: *GainSaturationCurve* (Figure 13), Sweep: *DeterminationOfCurve*)

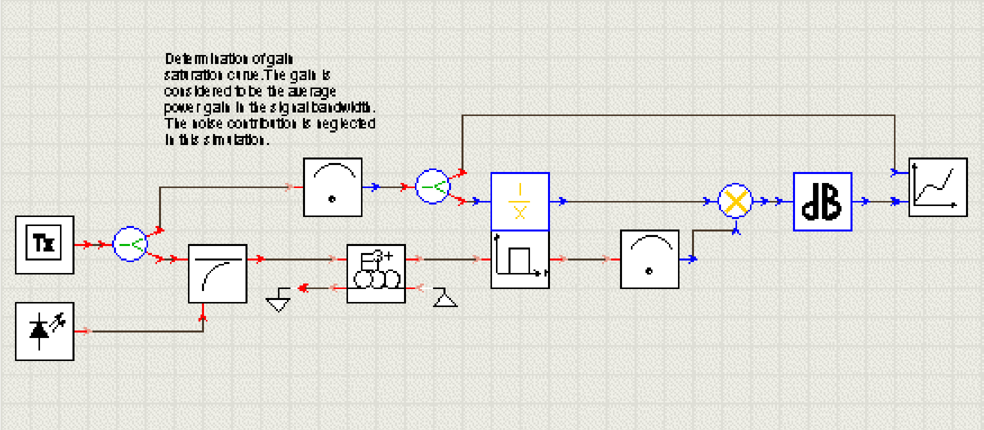


Gain dependence on EDFA parameters: amplifier length and pump power

Determination of gain saturation curve. The gain is considered to be the average power gain in the signal bandwidth. The ASE noise contribution is neglected in this simulation.

Open sweep AmplifierLengthAndPumpPower. The EDF is forward pumped by a laser at 1480 nm. The length of the EDFA and the power level of the pump laser are swept. At a fixed pump level, the gain increases with increasing amplifier length

**Figure 12.** *Dependence of gain on EDFA parameters length and pump power*



Determination of gain saturation curve. The gain is considered to be the average power gain in the signal bandwidth. The noise contribution is neglected in this simulation.

**Figure 13.** *Dependence of gain on input power*

This gain-saturation demo illustrates the gain-versus-input power concept shown in Fig. 11-3 in the book. The curve shows that as the input signal power is increased, the gain first stays near the small-signal level and then starts to decrease as the amplifier saturates. After decreasing linearly in the gain-saturation region, it finally approaches an asymptotic value of 0 dB (a unity gain) for high input powers.

## (e) Gain shaping

Setup: *EDFA_GainShaping* (Figure 14)

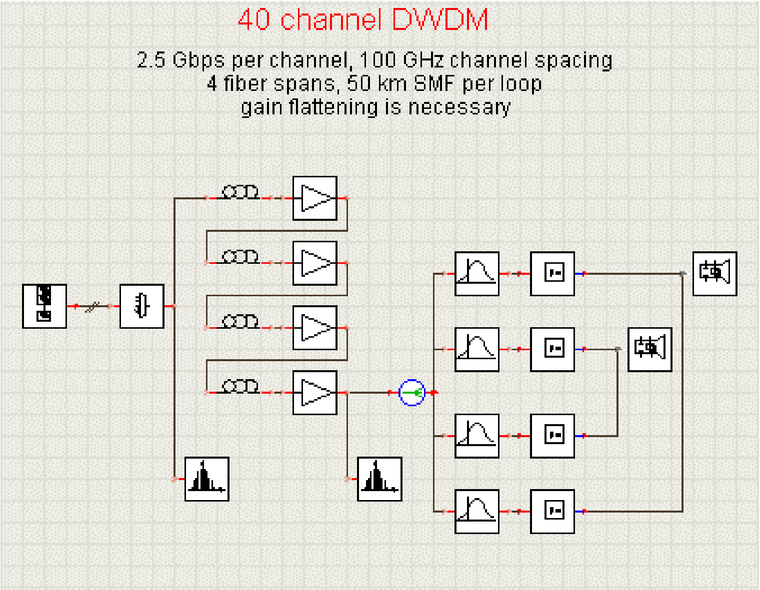


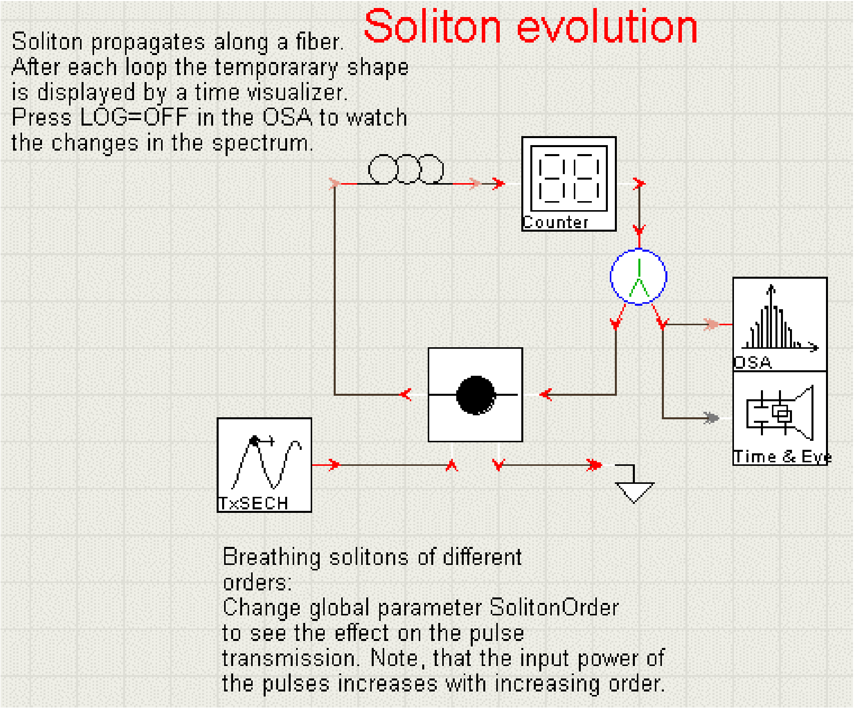
**Figure 14.** *EDFA gain shaping in a 40 channel WDM link*

Forty WDM channels centered at 193.1 THz with 100-GHz spacings are sent over 4 fiber spans consisting of 50-km single-mode fiber loops. A standard EDFA is used after each 50-km span. Each channel operates at 2.5 Gb/s. The display of the power output after 200 km clearly shows that gain flattening of the EDFA is needed, since there is about a 30-dB difference in the gain of the inner and outer channels. See Figures 11-8 and 11-12 in the book for the effects of ASE on amplifier gain and the concept of gain flattening. In addition, from the eye diagrams of the inner and outer channels, one can see the large difference in the eye openings at the output.

## 2.9 Soliton Propagation

Setup: *SolitonEvolution* (Figure 15)

In this module, an optical sech pulse shape representing a soliton is launched into a fiber and its temporal evolution over the fiber length is observed (see Sec. 12.7). The pulse passes a number of **Steps** through a loop containing a fiber segment of length `soliton-period/Steps` and after each loop a time visualizer displays the temporal shape. Of interest here are the second and third order soliton pulses, which periodically change their shape as they propagate along the fiber. To change the soliton order please edit global parameters and set parameter **SolitonOrder**. Note, that the spectral shape of the soliton pulses changes too. To observe this behaviour more clearly, please switch the logarithmic scale in the OSA visualizer to `OFF`.



Soliton propagates along a fiber. After each loop the temporarary shape is displayed by a time visualizer. Press LOG=OFF in the OSA to watch the changes in the spectrum.

Breathing solitons of different orders: Change global parameter SolitonOrder to see the effect on the pulse transmission. Note, that the input power of the pulses increases with increasing order.

**Figure 15.** *Soliton evolution over a nonlinear, dispersive fiber*

## 2.10 Wavelength Converters

Two different concepts related to Sec. 11.6 of the book can be studied here.

### (a) Wavelength Converter using crossphase modulation effects in a Semicondutor Optical Amplifier

Setup: *WavelenghtConversion_XPM* (Figure 16)

Using a semiconductor optical amplifier (SOA), an optical frequency converter can be made based on cross-phase modulation (XPM) in a Mach-Zehnder interferometer (MZI) structure. This is described in Sec. 11.6.1.

### (b) Wavelength Conversion Using cross gain modulation effects in a semiconductor optical amplifier

Setup: *WavelengthConversion_XGM* (Figure 17)

Using a semiconductor optical amplifier (SOA), an optical frequency converter can be made based on cross-gain modulation. This concept is additional information to

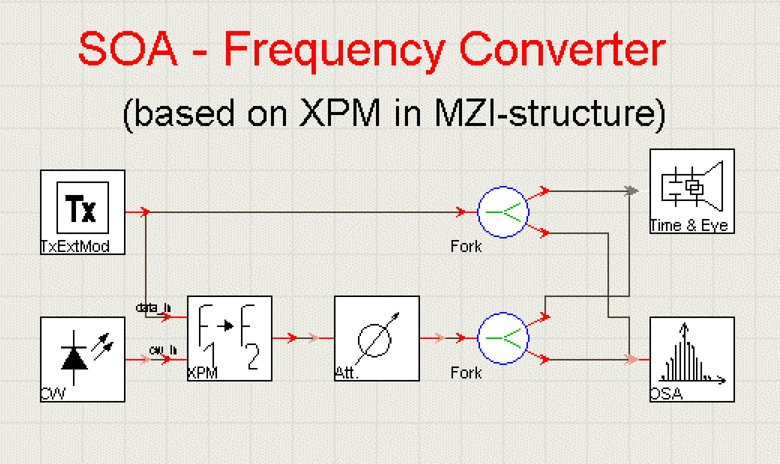


**Figure 16.** *Wavelength conversion using XPM effects in a SOA*

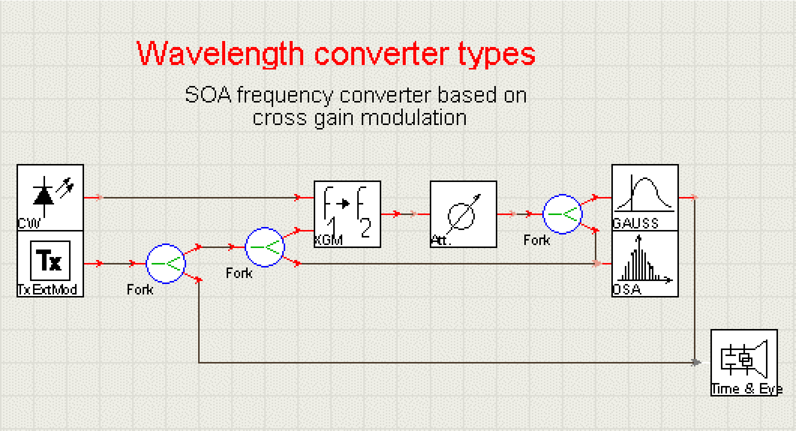


**Figure 17.** *Wavelength conversion using XGM effects in a SOA*

the treatment in the book. Note, that the output signal is inverted with respect to the input signal.