Chromatic Dispersion and Kerr Nonlinearities
Fiber 2

Interactive learning module

University Program
Photonics Curriculum Version 8.0

Developed in cooperation with
Prof. Klaus Petermann
and his group at
Technische Universität Berlin

Author: J.K. Fischer

Preface

In this module, the nonlinear fiber effects of self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM) are explored in greater detail. Furthermore, the interaction between these effects and chromatic dispersion is highlighted.

- Fiber nonlinearities such as the aforementioned SPM, XPM, and FWM place strict limits on the maximum number of WDM channels and power per channel in optical transmission systems. When designing WDM systems it is therefore essential to understand the nature of these effects and to effectively apply means to mitigate these limitations.
- The following topics are covered in this module:

  + Effects of SPM and XPM on pulse spectra

  + Build-up of FWM products WDM systems

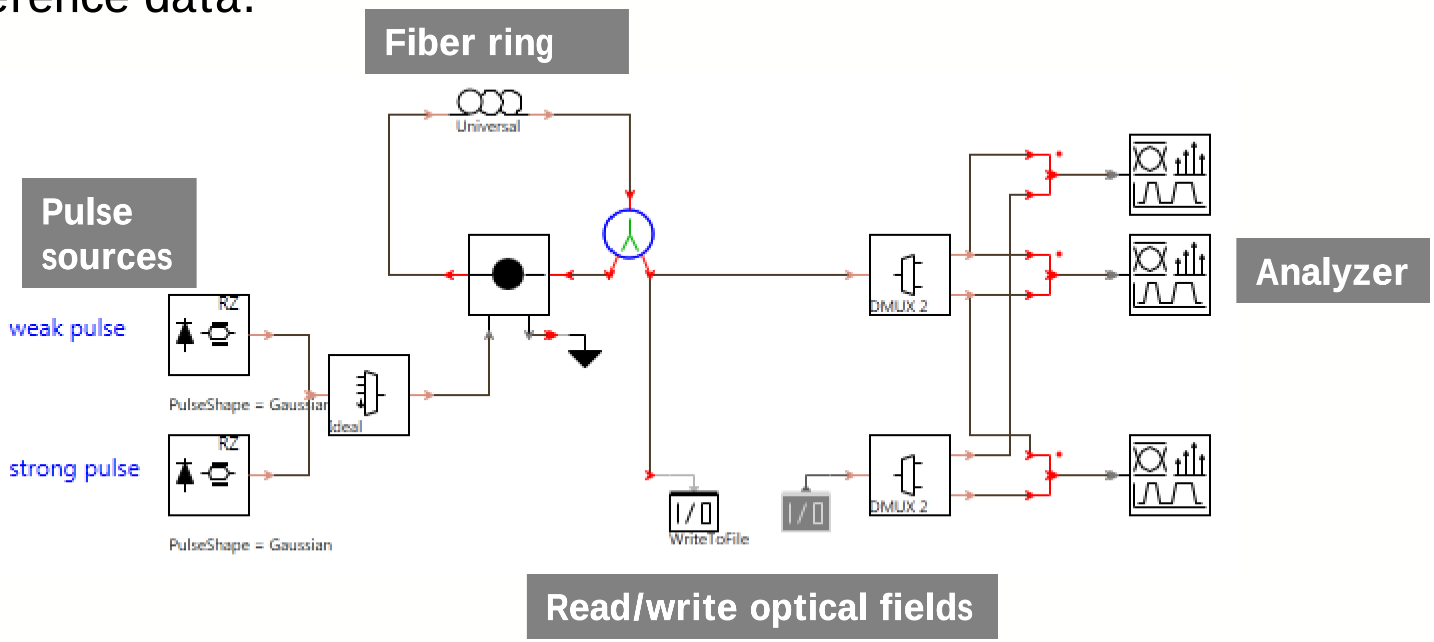
  + Dispersion compensation schemes

Note:

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

SPM and XPM

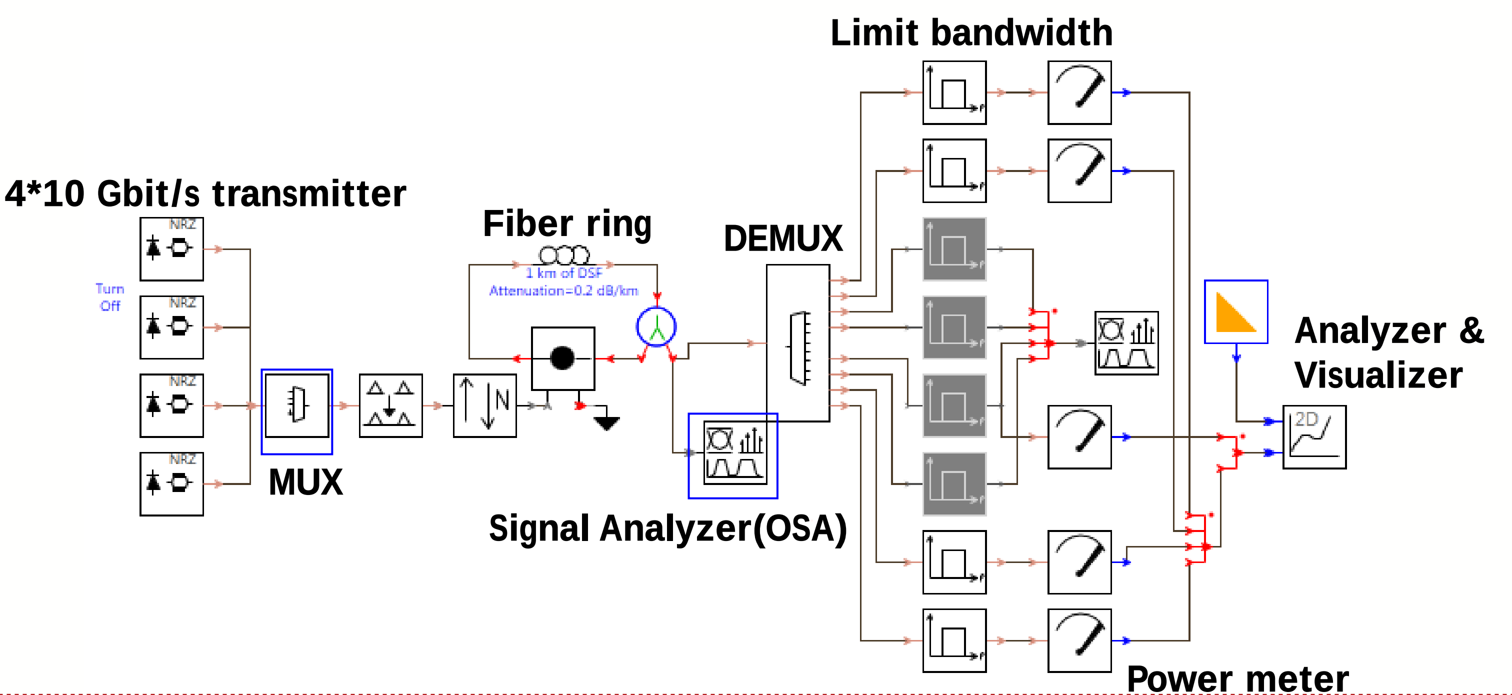
- Open “Fiber2_1”. The schematic is shown below.
- This exercise is used to visualize the effects of SPM and XPM
- Two pulses at different wavelengths co-propagate inside a fiber ring. The fiber length is 5 km. After each round trip the pulses are passed to a WDM de-multiplexer to visualize their spectra with a *SignalAnalyzer* **(OSA)** and their time domain pulse shape also with a *SignalAnalyzer* **(Scope)**.
- The modules *WriteToFile* and *ReadFromFile* are used to store and read reference data.



- Check that the parameters *SPM_EC*, *XPM_EC* of the module *UniversalFiberFwd* are set to ‘No’. Run the simulation to gather reference data on linear transmission. The module *WriteToFile* saves the reference optical fields in a temporary folder in the file ‘data_lin.dat’.
- Change the parameters *SPM_EC*, *XPM_EC* of the module *UniversalFiberFwd* to ‘Yes’ to consider self-phase modulation and cross-phase modulation in the numerical calculations. In order to compare nonlinear transmission with the linear case activate the module *ReadFromFile* (set parameter *Active* to ‘On’). The optical fields of the nonlinear case for later reference are now stored in module *WriteToFile* to ‘data_nonlin.dat’. Run the simulation.
- **Exercise 1**: Analyze the spectra of the weak and the strong pulse. Identify the approximate distance where the spectrum of the weak pulse is maximally red shifted.
- **Question 1**: Explain why there is a distance where the spectrum of the weak pulse is maximally red shifted.
- **Question 2:** Which effect dominates the spectral evolution of the weak and strong pulse, respectively?

Four-wave mixing (FWM)

- Open “Fiber2_2”. The schematic is shown below.
- This setup serves to demonstrate the growth of four-wave mixing products in WDM transmission systems.
- The transmitter generates four 10 Gbit/s WDM channels spaced 50 GHz apart.
- The WDM signal is then transmitted over 50 km of dispersion shifted fiber (DSF) with a dispersion parameter of 0.2 ps/(km nm).
- After each kilometer the optical spectrum, the eye diagrams of the WDM channels, and the signal power as well as the power of FWM products is shown.

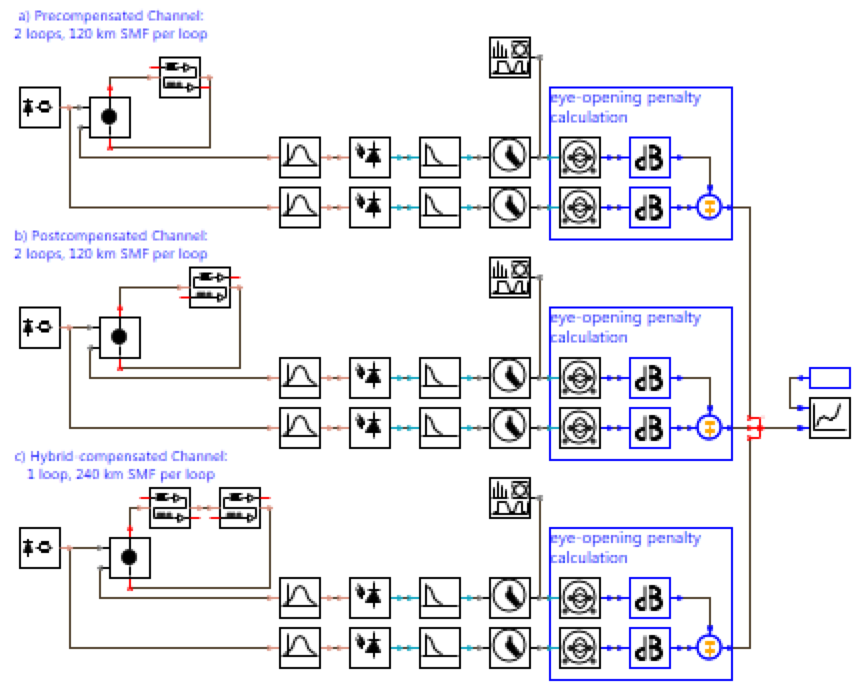


Four-wave mixing (FWM)

- Run the simulation. Note the growth of the four out-of-band FWM products as well as distortions of eye-diagrams through in-band FWM products causing channel crosstalk.
- **Exercise 2:** Turn off the module *TxExtModLaser3* (parameter *Active* ‘Off’). Run the simulation. Measure the power of the in-band FWM product at the center frequency of the turned-off WDM channel (193.125 THz) after 50 km.
- **Exercise 3:** Change the dispersion parameter (*Dispersion*) of module *FiberNLS* to 2 ps/(km nm). Run the simulation. Compare the power of the in-band FWM product at 193.125 THz with the power measured in Exercise 2.
- **Exercise 4:** Change the dispersion parameter (*Dispersion*) of module *FiberNLS* back to 0.2 ps/(km nm). Now change the parameter *ChannelSpacing* in the global parameter window under the ‘General’ tab to 100 GHz. Run the simulation and compare the power of the in-band FWM product at 193.125 THz with the powers measured in Exercise 2 and 3.
- **Question 3**: Name two methods to reduce four-wave mixing efficiency.

Dispersion compensation

- In this lab (Fiber2_3), three dispersion compensation schemes are compared: pre-, post- and hybrid compensation.
- Three 10 Gbit/s NRZ transmitters generate the same bit-sequences. After transmission over 240 km SSMF the signals are received and compared using the eye-opening penalty (EOP).
- The receiver consists of an optical filter (*FilterOpt*), an ideal pin-photodiode (*Photodiode*), an electrical filter (*FilterEl*) and a clock recovery unit (*ClockRecoveryIdeal*).
- The EOP is calculated by comparing the eye-closure (measured with the module *SignalAnalyzerEl*) of the transmitted signal with the eye-closure of the back-to-back (no transmission over fiber) signal.



Dispersion compensation

- First, we consider the in-line amplifiers as noiseless, to assess the transmission performance of the three compensation schemes with respect to the interaction between fiber nonlinearity and dispersion only. Since this setup simulates a single wavelength channel system the only considered nonlinear effect is self-phase modulation.
- **Exercise 5:** Check that the parameter *IncludeNoise* in the global parameter editor under the 'Physical' tab is switched 'Off'. In order to judge the performance of the three compensation schemes in the presence of strong SPM, the pulse peak power is varied. Increase the peak power from 0 to 11 dBm, with steps of 1 dB. Note the increasing distortion of the eye diagrams when the peak power is raised.
- **Exercise 6**: Now switch the parameter *IncludeNoise* to 'On' to include amplifier noise in the simulation. Run the simulation and compare the resulting EOP graphs with the ones obtained in Exercise 5.
- **Question 4:** Identify the two factors limiting system performance for low and high peak powers respectively.
- **Question 5:** Why do the three compensation schemes show different performance when high peak powers are used?

Summary

- In this learning module, the three nonlinear effects self-phase modulation, cross-phase modulation and four-wave mixing are explored as well as dispersion compensation schemes and their performance in the presence of nonlinearities.
- Spectral broadening through SPM and XPM is shown in Fiber2_1.
- Fiber2_2 deals with the growth of four-wave mixing products in a 4x10 Gbit/s WDM transmission system and introduces two simple means to lower FWM efficiency.
- Finally in Fiber2_3, three dispersion compensation schemes (pre-, post- and hybrid compensation) are compared with respect to their performance in the presence of strong self-phase modulation.