Raman, Brillouin and Rayleigh scattering Fiber 4

Interactive learning module

University Program
Photonics Curriculum Version 8.0

Developed in cooperation with Technische Universität Dresden, Communications lab – RF engineering

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Preface

In this module, scattering effects in optical fibers like Rayleigh scattering, Raman scattering and Brillouin scattering are explored in greater detail.

- Scattering effects have various influences in optical transmission systems. For example they can limit the power per optical channel and they can induce crosstalk between different WDM channels.
- Otherwise scattering effects can be used for various sensing applications and to design optical amplifiers.

- The following topics are covered in this module:
  - Rayleigh scattering and double Rayleigh scattering
  - Raman gain and Raman scattering in WDM systems
  - Brillouin scattering threshold and suppression

Note: Please read the *Simulation Guide* of VPItransmissionMaker™/VPIcomponentMaker™ before starting this unit.

Universal fiber module

Rayleigh scattering parameters:

1.) BackscatterDescription

In the **OTDR** mode Rayleigh scattering is described by the following parameters:

a.) EffectiveGroupIndex n_{eff}

b.) OTDRPulseWidth τ

c.) RayleighDescription

RayleighCoefficient: constant value (see RayleighBackscatterCoefficient)

RayleighFile: RayleighBackscatterCoefficient from a File
(can be frequency dependent)

d.) RayleighBackscatterCoefficient: Can be found in the datasheet of a fiber, expressed in dB.

Rayleigh scattering

In the **linear** mode Rayleigh scattering is described by the following parameters:

a.) RayleighDescription

RayleighCoefficient: constant value (see RayleighBackscatterCoefficient)

RayleighFile: RayleighBackscatterCoefficient from a File
(can be frequency dependent)

b.) RayleighBackscatterCoefficient: expressed in 1/m.

The relationship between both RayleighBackscatterCoefficients

(OTDR / linear mode) is defined by equation (1):

$$\eta[1/m] = \frac{n_{eff}}{c\tau} 10^{\frac{\eta[dB]}{10}}$$

with the speed of light in vacuum c.

Rayleigh scattering

The backscattered power PRS for a fiber with the length L can then be calculated by equation (2):

$$P_{RS}[dBm] = P_{in}[dBm] + 10\log_{10}\left(\frac{\eta[1/m]}{2\alpha^{'}}\left(1-e^{-2\alpha^{'}L}\right)\right)$$

For L>>α‘ the simplified equation (3) can be used

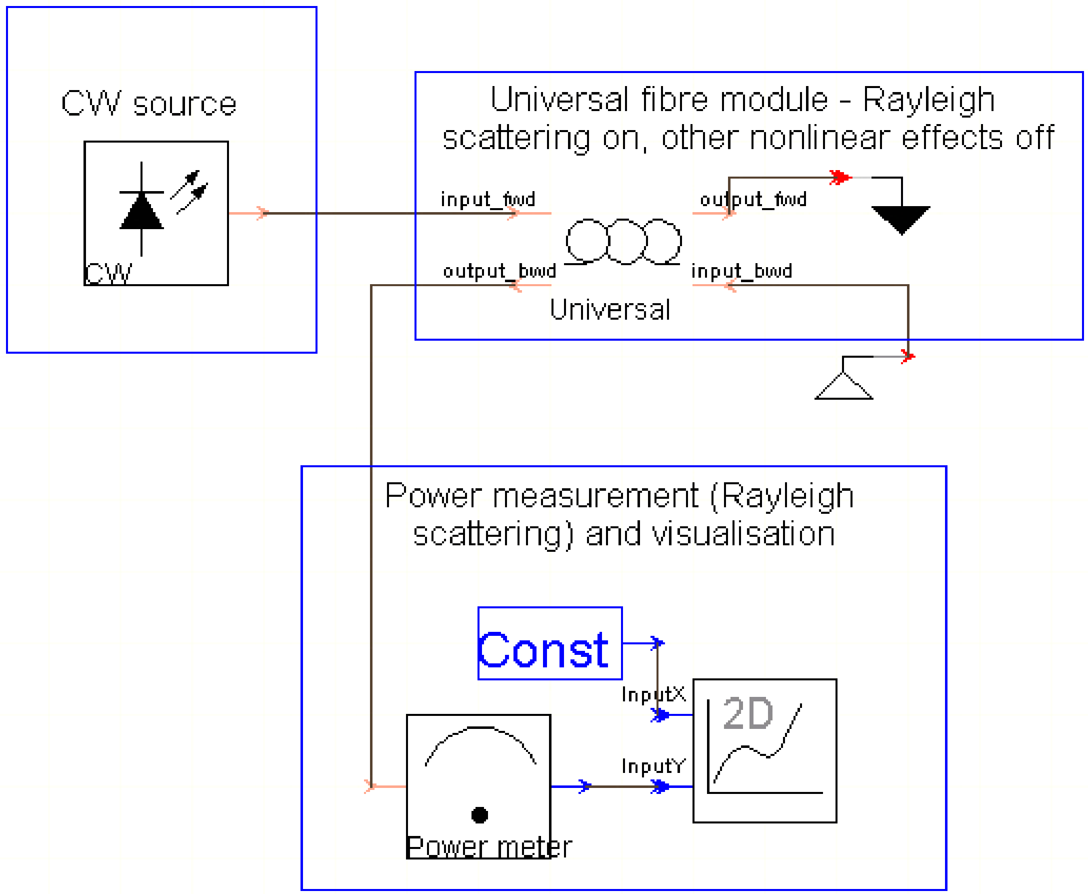
$$P_{RS}[dBm] = P_{in}[dBm] + 10\log_{10}\left(\frac{\eta[1/m]}{2\alpha^{'}}\right)$$

This leads for a SSMF @ 1550 nm (η≈ -80 dB) to a Rayleigh backscattering of approximately 10 log10 (P_{RS}/P_{in}) ≈ -32.7 dB.

Note: In some publications the Rayleigh backscattering is defined by a scattering coefficient (local attenuation coefficient for the scattering process) and a backscatter capture fraction (includes e.g. fiber parameters such as mode field diameter for single mode fibers and numerical aperture for multimode fibers). The product of both defines the power which is scattered back and guided. The VPI parameter η is the product of the local scattering coefficient and the backscatter capture fraction.

Rayleigh scattering

- Open “Rayleigh_1“. The schematic is shown below.



Rayleigh scattering

The setup is used to visualize the Rayleigh scattering effect. A CW laser with a power of 0 dBm transmits power to the optical fiber. Inside the optical fiber a portion of the optical light is scattered back to the transmitter, characterized by the Rayleigh scattering coefficient η[1/m] and η[dB]. This power is measured with an optical power meter (module Powermeter) and visualized for different fiber lengths (module NumericalAnalyzer2D). Increase the fiber length from 1 km up to 100 km with steps of 10 km.

- **Exercise 1:** Calculate the Rayleigh backscattering power for a SSMF and an input power of 1 mW for L>> α' using equation (3).

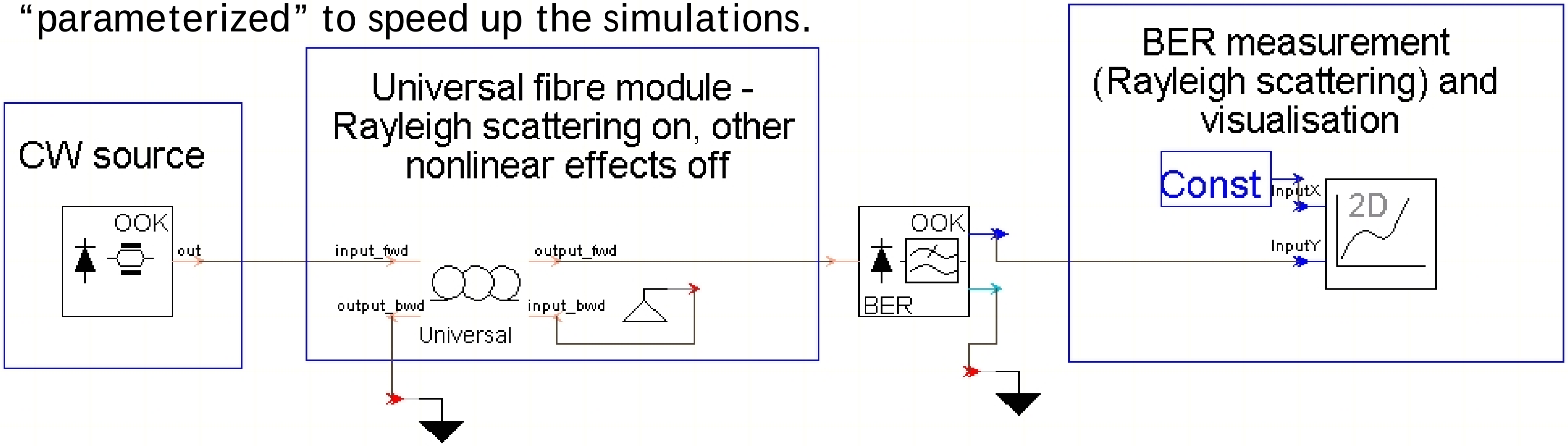
- **Exercise 2:** Run the simulation and compare the result with the calculation. Why does the Rayleigh backscattering power saturate?

- **Exercise 3:** Connect the module SignalAnalyzer to the end of the fiber and evaluate the spectrum. Explain the simulation result.

Rayleigh scattering

Open “Rayleigh_2“. The schematic is shown below.

The CW laser was replaced by an OOK transmitter and the visualizer by an OOK receiver with integrated BER measurement. The output data type was set to “parameterized” to speed up the simulations.



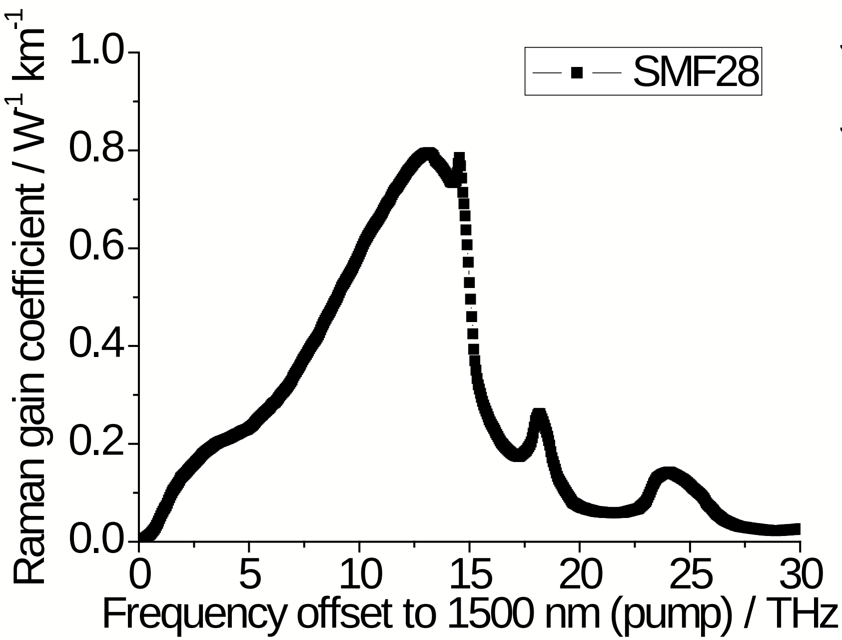
- Set the linear distortion parameters dispersion, dispersion slope, PMD to zero (equivalent to an ideal CD and PMD compensation) for the BER simulation.
- Furthermore, the parameter Rayleigh_Distortions in the module Rx_OOK_BER must be set to “yes” to include Rayleigh scattering in the BER calculation.

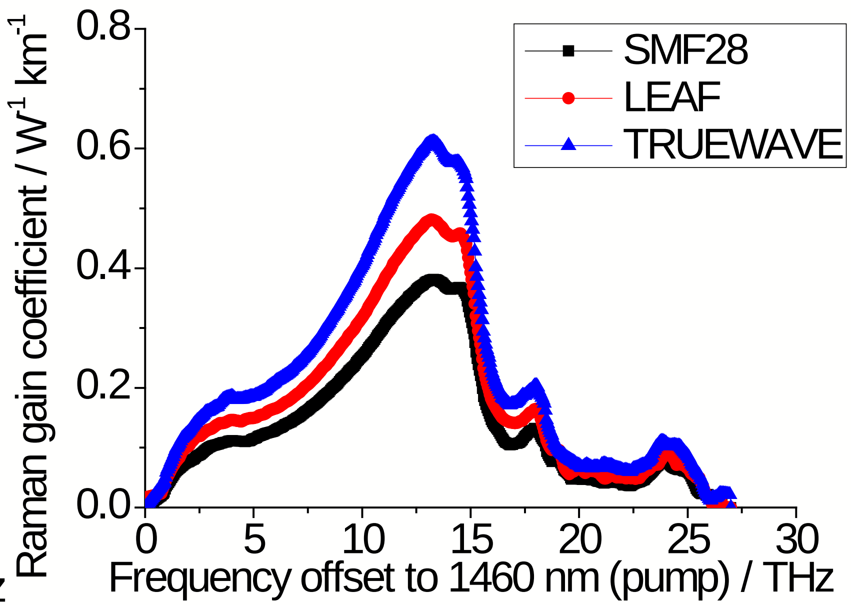
- **Exercise 4:** Scan the Rayleigh scattering coefficient between -80 dB and -52 dB. For which Rayleigh scattering coefficient the BER exceeds 10^{-9} after 80 km of fiber?

Raman Scattering

Raman scattering is included if **RamanScattering** is set to "yes". Noise generated due to spontaneous Raman scattering can be included if **SpontaneousRamanScattering** is set to "yes":

Raman gain profile, pump frequency and frequency offset are defined in a file (**RamanFilename**). Spectra are available for SMF28 for a 1500 nm (**RamanGain.dat**) and a 1460 nm (**RamanGain1.dat**) pump and for LEAF (**RamanGain2.dat**) as well as TRUEWAVE (**RamanGain3.dat**) fiber for a 1460 nm pump.





VPIphotonics DESIGN AUTOMATION

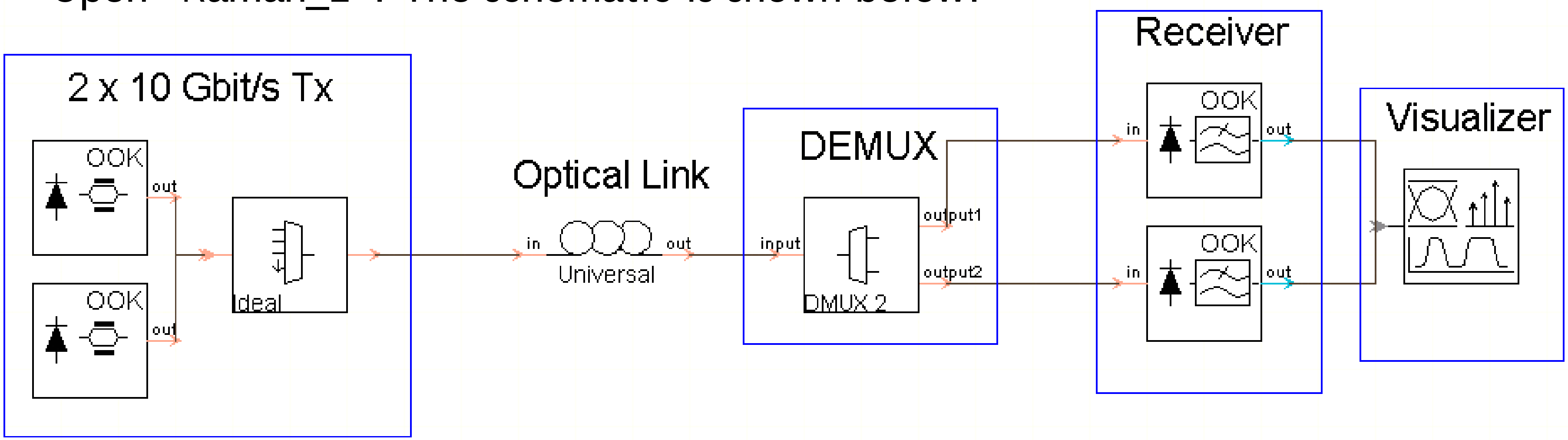
Raman Scattering

LEAF and TRUEWAVE are NZ-DSF fibers with a relatively high effective area of approximately 70 µm² compared to about 50 µm² of a typical NZ-DSF.

The polarization dependency of the Raman gain can be addressed with the **RamanAdjustmentFactors**. If **PolarizationAnalysis** is set to **VectorPMD** the **RamanAdjustmentFactors** are set automatically.

Raman scattering in WDM systems

Open “Raman_1“. The schematic is shown below.



Raman Scattering

The setup is used to visualize the effect of Raman gain in the time domain. Two optical OOK transmitters separated by 13 THz transmit different bit sequences (signal power 10 mW each) to the optical fiber. After the fiber, the signals are separated by a DEMUX, received and compared in the visualizer (module *SignalAnalyzer*).

The PolarарizationAnalysis parameter was set to “VectorPMD”.

- **Exercise 5:** Run the simulation and switch to the scope mode. Explain the simulation result.

- **Exercise 6:** Change the polarization of transmitter 2 to an orthogonal polarization of transmitter 1. Compare this simulation to the one before. Explain the changes.

Brillouin scattering

Brillouin scattering is included if **BrillouinScattering** is set to “yes”:

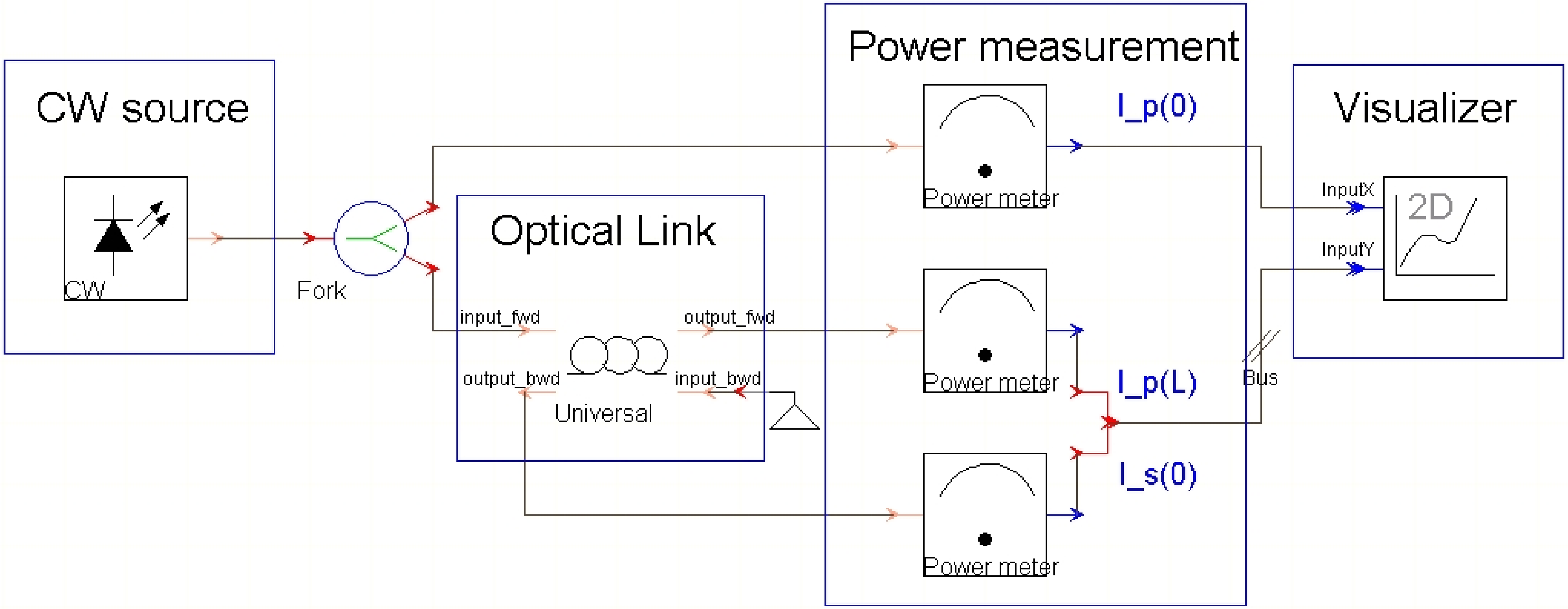
SBS bandwidth and SBS Stokes shift can be set by the parameters **SBSBandwidth** and **SBSStokesShift**.

The SBS gain can be set as a constant value (**SBSDescription:SBSGainParameter**) or a frequency dependent value in a file (**SBSDescription:SBSGainFile**). The SBS gain is polarization dependent. This dependency can be set by the SBSAdjustmentFactor if **PolarizationAnalysis** is set to scalar.

The Noise value due to spontaneous Brillouin scattering and spontaneous Raman scattering is temperature dependent and can be set by the parameter **Temperature**.

Brillouin scattering

Open „Brillouin_1“. The schematic is shown below.



The setup is used to visualize the effect of Brillouin scattering. A CW source is coupled into an optical fiber. The input power, the transmitted power and the reflected power were measured by optical power meters.

Brillouin scattering

- **Exercise 7:** Calculate the Brillouin threshold for a CW signal in a standard single mode fiber of 15 km length. Run the simulation by scanning the input power between -20 dBm and +20 dBm and compare the results.

- **Exercise 8:** Open „Brillouin_2“. Modulate the CW signal with a phase modulator (f=2 GHz and $\Delta\phi$=180°). Set therefore the output data type to “block”. What value has the Brillouin threshold and why it changed?

- **Exercise 9:** Open „Brillouin_3“. A maximal Brillouin scattering power of -10 dBm shall be allowed for a CW signal of 10 dBm. What parameter of the phase modulator has to be changed and to what value?

Summary

- In this learning module, the three scattering effects Rayleigh scattering, Raman scattering and Brillouin scattering are explored.

- The backscattered power due to Rayleigh scattering is shown in Rayleigh_1 and the influence of double Rayleigh scattering on the BER is studied in Rayleigh_2.

- Raman_1 deals with the amplification of bits transmitted on higher wavelength at the expense of the power of bits transmitted on lower wavelength in the same time slot in a WDM system.

- Finally, in Brillouin_1 the Brillouin threshold for a CW signal that can be adjusted by a phase modulated pump is shown.

Constraints

- Rayleigh scattering: Signals were handled as parameterized signals (the bandwidth of the signals will be neglected, no time dependency and phase issues) ghost pulses e.g. can’t be simulated.

- Brillouin scattering also will be handled as a parameterized signal (no interaction between forward and counter-propagating pulses amplification and filtering of light due to Brillouin scattering can’t be simulated).