

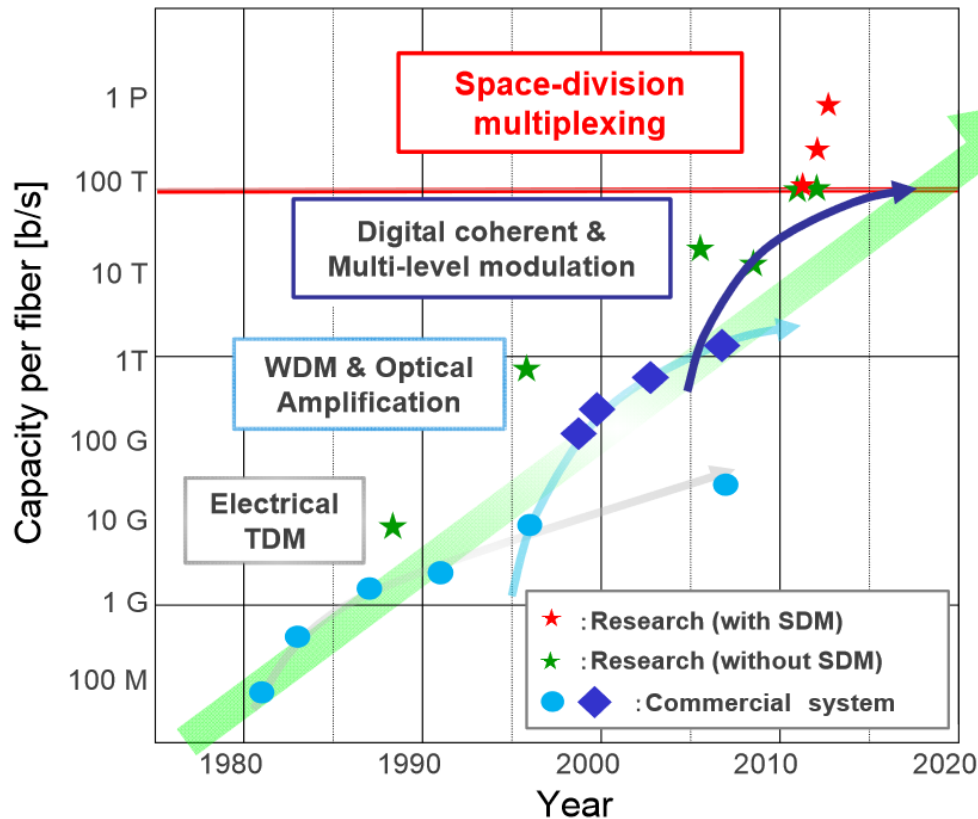
Different Optical Fiber Nonlinear Coefficient Experimental Measurements

Sugan Shakya, Andis Supe, Ingrida Lavrinovica,
Sandis Spolitis and Jurgis Porins

Institute of Telecommunications, Riga Technical University, LV-1048, Riga, Latvia
sandis.spolitis@rtu.lv

- » **Aim and Motivation**
- » **Principle of nonlinear coefficient measurement**
- » **Experimental**
 - » **Setup and fiber parameters**
 - » **Results**
- » **Conclusions**

Motivation (1/2)



$R = 1.05 \text{ Pb/s}$ [1]

[1] Dayou Qian et.al, *1.05Pb/s Transmission with 109b/s/Hz Spectral Efficiency using Hybrid Single- and Few-Mode Cores*, Frontiers in Optics pp. 1-3 (2012)

R. G. H. van Uden et al, *Ultra-high-density spatial division multiplexing with a few-mode multicore fibre*, Nature photonics 8, pp. 865–870 (2014) .

Yutaka Miyamoto *Over one Pbit/s capacity optical transmission based on 400 Gb/s channel and beyond*, NTT Network Innovation Laboratories (2013) .

Motivation (2/2)

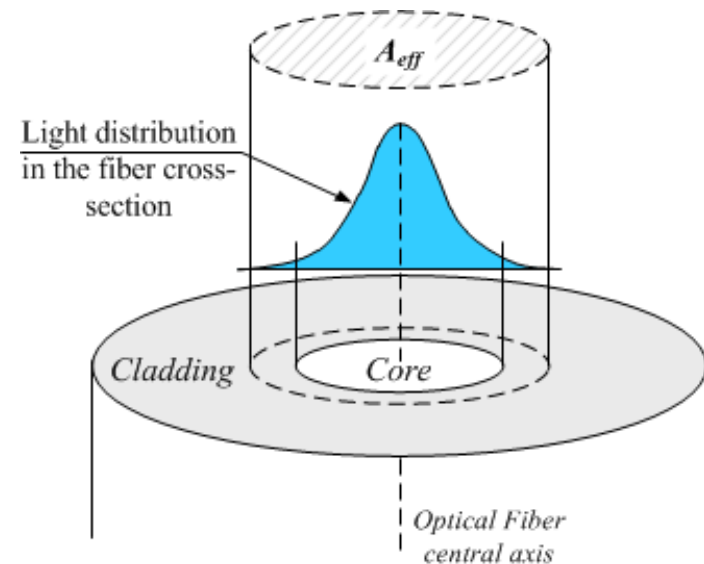
Kerr Effect is a very significant nonlinear optical effect to be seriously considered when it is required to transmit large bandwidth signal through optical fibers over long distances.

The Kerr effect results from the dependence of the refractive index n change on the optical intensity, which brings on self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM).

Nonlinear coefficient is a relation between optical fiber nonlinear refractive index and fibers effective cross section area:

$$\gamma = \frac{n_2 \omega}{c_g A_{eff}}$$

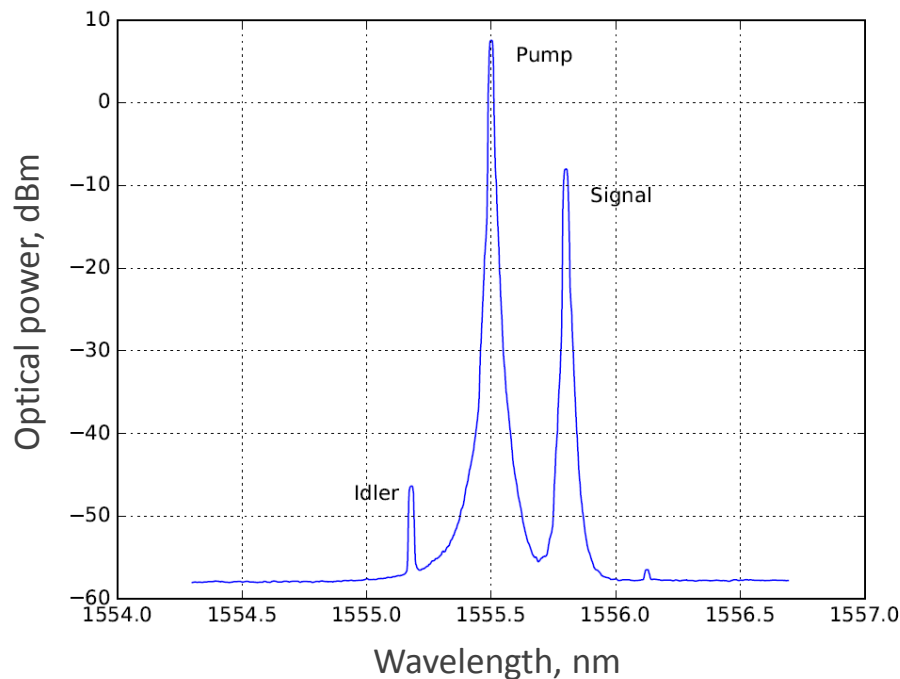
where n_2 nonlinear refractive index and A_{eff} effective area.



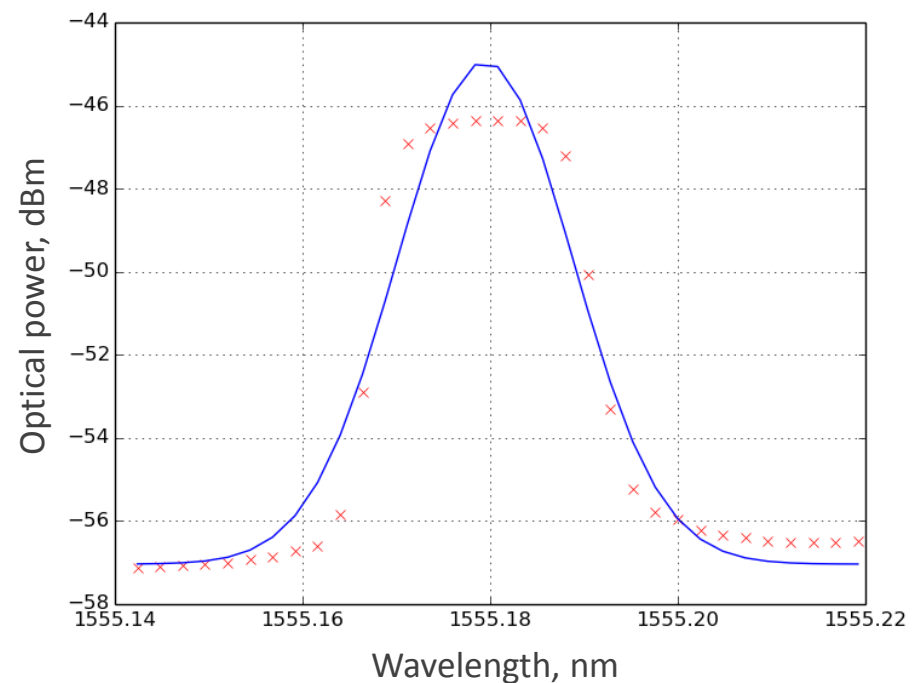
Optical fiber effective area A_{eff}

Nonlinear coefficient measurement method

Degenerate (two component) four wave mixing (FWM) was used in this research to **measure different optical fiber nonlinearity coefficient γ** . So called pump and signal lasers cause FWM generation in a fiber under test and a new idler component appears in the output spectrum.



Output spectrum from optical fiber under test.



Enlarged FWM generated idler component (blue line is Gauss fit to measured values).

Nonlinear coefficient measurement method

Measurements of nonlinearity coefficient by initiating FWM in the fiber under test are so called indirect. In this case actual measurement result is achieved using FWM generated idler component equation:

$$P_3(L) = \eta(\Delta\beta)(\gamma P_1(0)L_{eff})^2 P_2(0)e^{-\alpha L}$$

where

P_1 - pump power

P_2 - signal power

P_3 - idler power

η – FWM efficiency

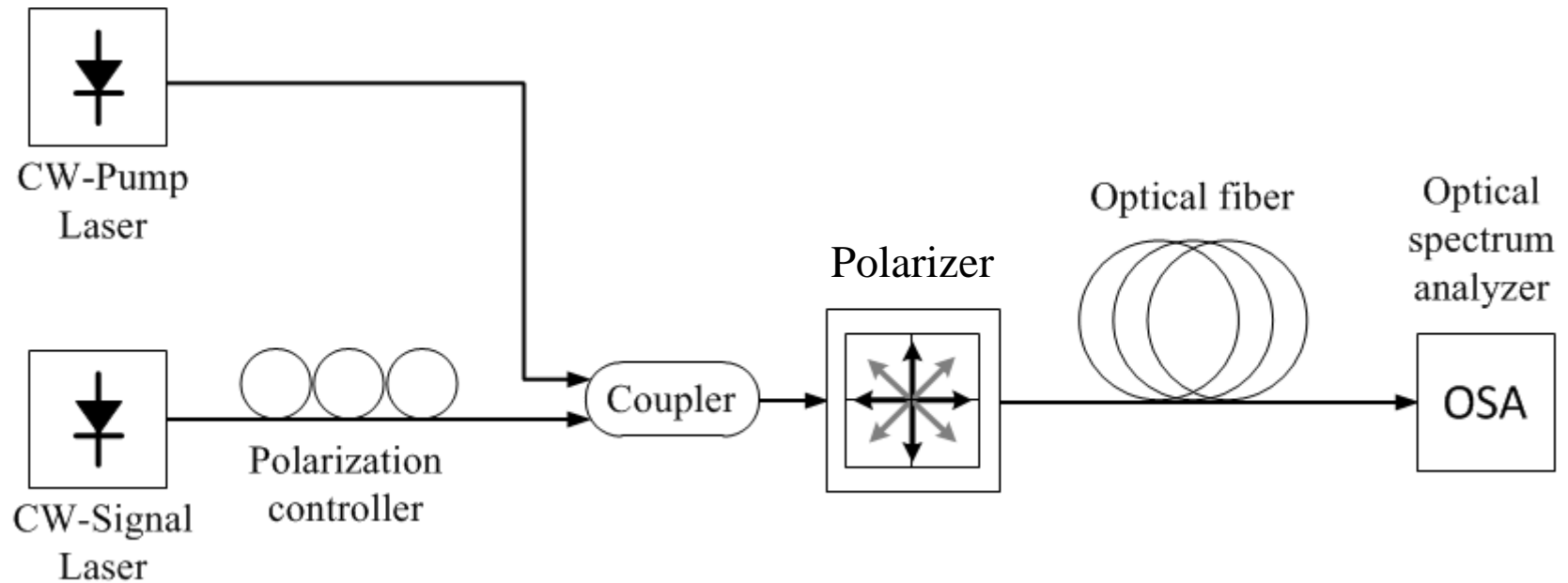
$\Delta\beta$ – phase mismatch

γ – nonlinearity coefficient

L_{eff} – effective length

α – attenuation coefficient

Experimental setup



$$\lambda_{\text{pump}} = 1555.5 \text{ nm}$$

$$P_{\text{pump}} = 7 \text{ dBm}$$

$$P_{\text{signal}} = -8 \text{ dBm}$$

Fiber under test:

- SMF-28
- ESMF (Enhanced SMF)
- HNLF

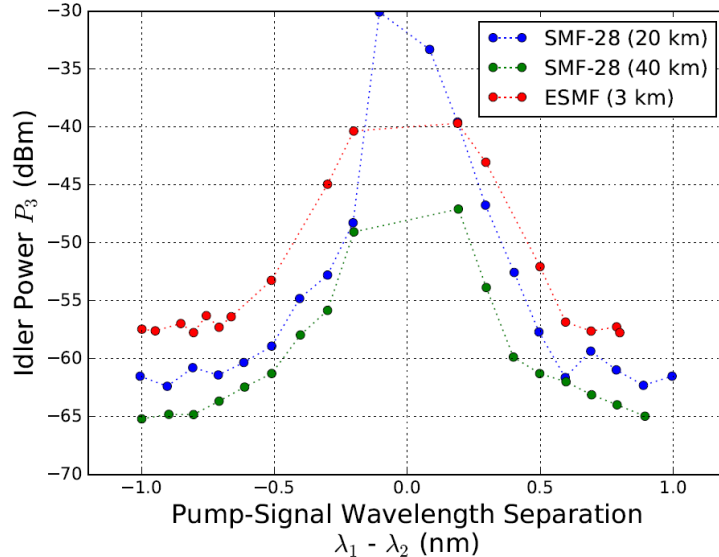
» Experimental setup for nonlinearity coefficient γ measurements using degenerate four wave mixing. Signal laser wavelength is tunable to evaluate FWM dependence on the pump and signal wavelength difference.

Fiber under test parameters

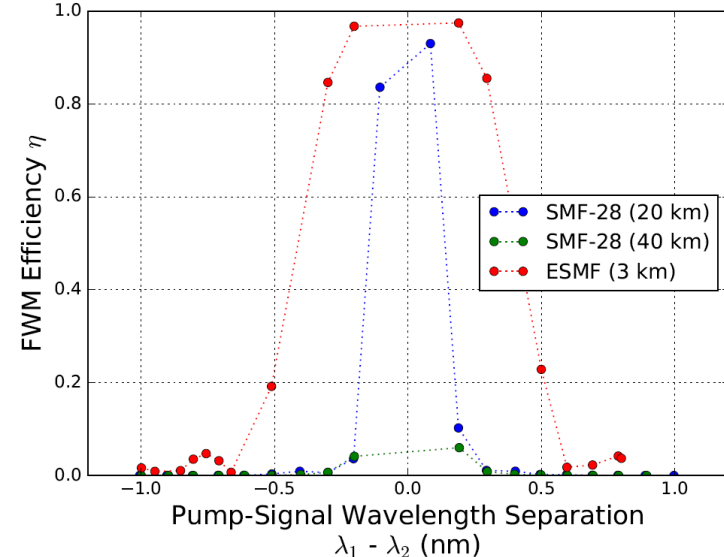
Parameters	SMF-28 Ultra Low Loss Optical Fiber	ESMF	HNLF
Fiber Type	G.652	G.652	HNLF
Length	20 and 40 km	3 km	250 m
Attenuation (α)	0.18 dB/km	0.2 dB/km	0.81 dB/km
Zero Dispersion Wavelength (λ_0)	1319.2 nm	1397.74 nm	1250.75 nm
Dispersion	342.77 ps/nm	49.70 ps/nm	1.51 ps/nm
Dispersion Coefficient	16.82 ps/(nm.km)	16.70 ps/(nm.km)	5.53 ps/(nm.km)
Dispersion Slope (dD/d λ)	0.059 ps/(nm ² .km)	0.088 ps/(nm ² .km)	0.014 ps/(nm ² .km)
Input Pump Power (P_1)	6.7 dBm	8.0 dBm	5.5 dBm
Input Probe/Signal Power (P_2)	0.1 dBm	-7.8 dBm	-6.4 dBm

SMF-28 and ESMF fiber results

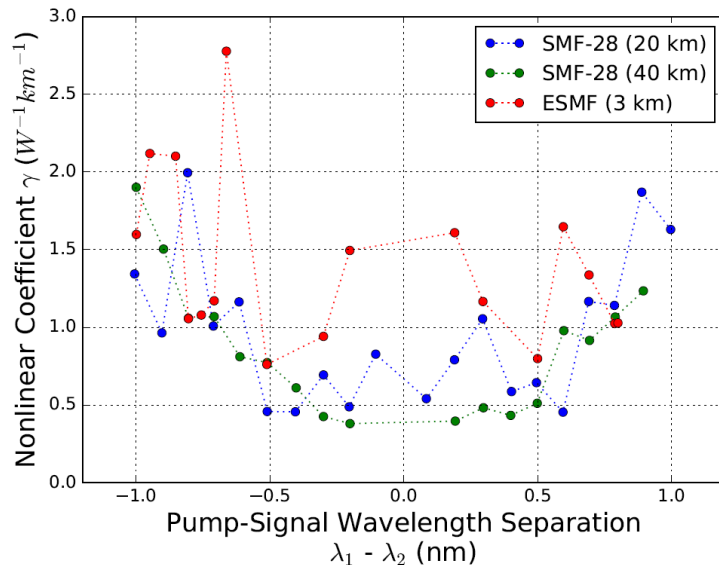
A) Idler dependence on the signal wavelength



B) FWM efficiency



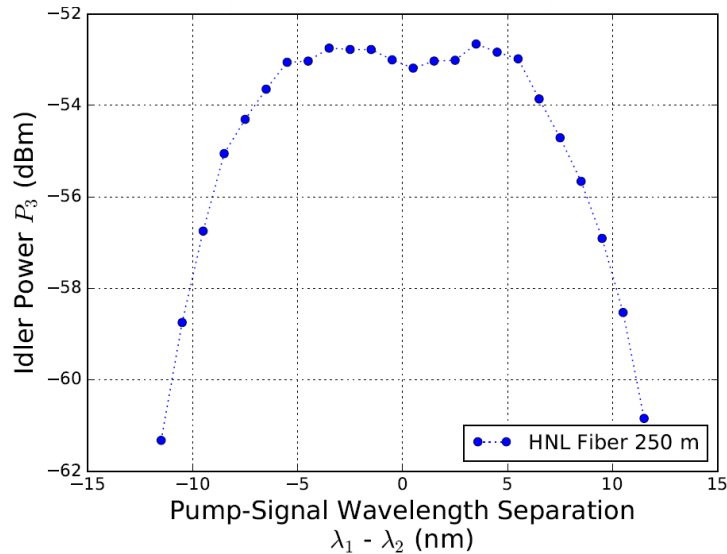
C) γ dependence on the signal wavelength



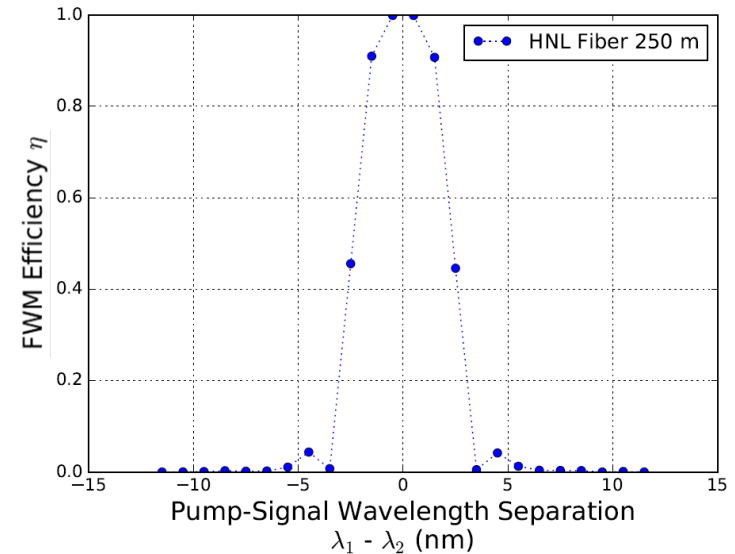
- » Obtained experimental measurements for SMF-28 (20 and 40 km spans) and ESMF fiber.
- » All graphs show dependence on the wavelength interval between pump and signal components.

HNLF fiber results

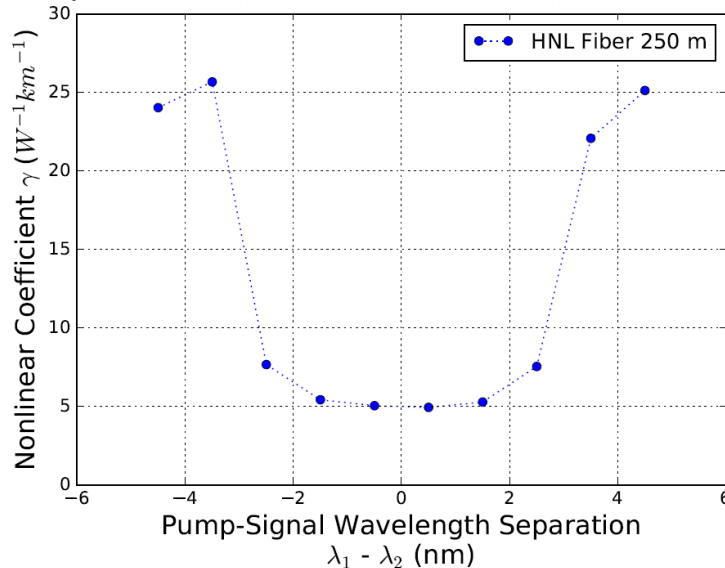
A) Idler dependence on the signal wavelength



B) FWM efficiency



C) γ dependence on the signal wavelength



- » Obtained experimental measurements for HNLF fiber.
- » All graphs show dependence on the wavelength interval between pump and signal components.

» Nonlinearity coefficient γ results for fiber under test

- » SMF-28 $\gamma = 0.74 \text{ W}^{-1}\text{km}^{-1}$
- » ESMF $\gamma = 1.45 \text{ W}^{-1}\text{km}^{-1}$
- » HNLF $\gamma = 10.68 \text{ W}^{-1}\text{km}^{-1}$

» FWM measurement method

- » FWM measurement method is very sensitive to mutual (joint) pump and signal state of polarization. That is the main reason for observable fluctuations in the obtained results.
- » In the case of HNLF fiber idler was observed for larger pump and signal wavelength intervals that is due to much larger nonlinear coefficient γ .
- » Different fibers show slightly different idler power and phase mismatch dependence on the wavelength interval between pump and signal components. It could be related to fiber dispersion (PMD) parameters, but should be further studied.

Thank you for your attention!

- » This work is supported by the Latvian National research program **SOPHIS** under grant agreement Nr.10-4/VPP-4/11

