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Nonlinear Threshold Decrease with Distance in 112 Gb/s PDM-QPSK Coherent Systems

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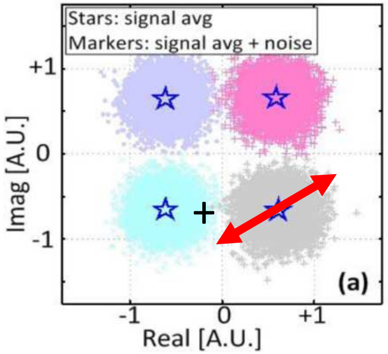
Outline

- Motivation and previous work
- NLT simulations vs. Distance
  - Dispersion Uncompensated (DU)
  - Dispersion Managed (DM)
- Conclusions

Motivation

In Dispersion-Uncomp. (DU) coherent sytems, NL noise is found to be Circular Gaussian [1,2]



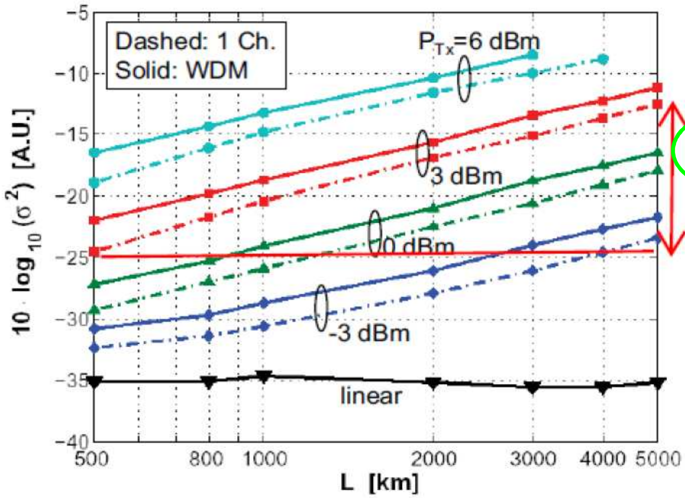
Variance of NL noise

$$\sigma^2 = a_{NL} P^3$$

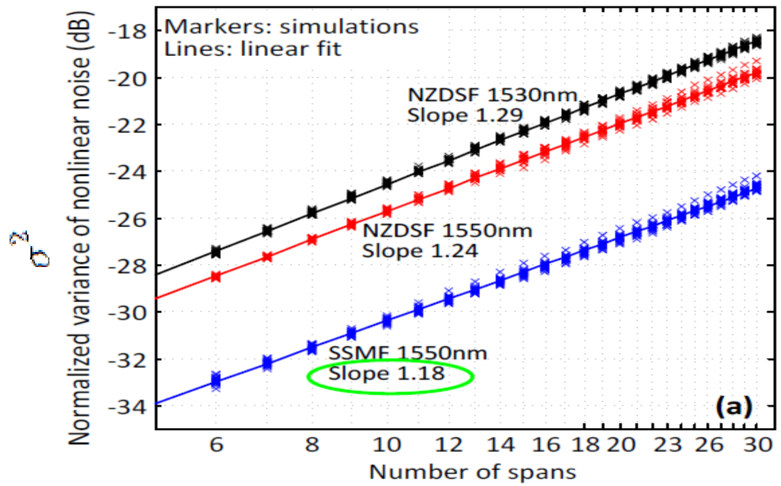
NL accumulation rate

$$a_{NL} = \alpha_{NL} N^{1+\varepsilon}$$

For Nx100km SMF PDM-QPSK @ R=28Gbaud, Δf=50GHz



$$\frac{R}{\Delta f} = 0.56$$



[1] A. Carena et al., ECOC'10, P4.07

[2] F. Vacondio et al, Opt. Exp. **20**, 1022 (2012)

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Motivation

More work on NL accumulation rate:

- [3] O. Rival et al., OFC'12, JW2A.52:
  For Nx100km SMF PDM-QPSK 28Gbaud links:

$$a_{NL} = \alpha_{SPM} N^{1.34} + \alpha_{XPM} N^{1.1} \text{ in the range } 8 < N < 30$$

- [4] O. Sinkin et al., OFC'12, OTu1A.2
  For Nx52 km SMF PDM-QPSK 28G and 10G links:

$$\text{if } \frac{R}{\Delta f} \lesssim 0.6 \text{ then } a_{NL} \propto N^{1.2-1.6}\text{ . If } \frac{R}{\Delta f} \text{ close to 1 then } a_{NL} \propto N^{1.05}$$

Alternative Measurement

$$S_0 = \frac{P}{N_A + a_{NL}P^3} = \frac{1}{3a_{NL}P^2}$$

@ optimal power $N_A = 2(a_{NL}P^3)$. So solution is

$(a_{NL} = \alpha_{NL}N^{1+\epsilon})$

$$\hat{P}_{NLT} = \frac{1}{\sqrt{3S_0 a_{NL}}} = \frac{N^{-\frac{1+\epsilon}{2}}}{\sqrt{3S_0\alpha_{NL}}}$$

However, at $\hat{P}_{NLT}$ penalty is known to be $10\mathrm{Log}(3/2) \sim 1.76$ dB.

Normally we calculate the 1dB penalty NLT $\hat{P}_1$ which is lower by 1.04 dB [5]

$$\boxed{\hat{P}_1 = \frac{N^{-\frac{1+\epsilon}{2}}}{1.27\sqrt{3S_0\alpha_{NL}}}}$$

Plan is thus to estimate ε from slope of 1dB NLT vs N in log-log plot

[5] A. Bononi et al, Opt. Exp. **20**, 7777 (2012)

1dB NLT Simulations

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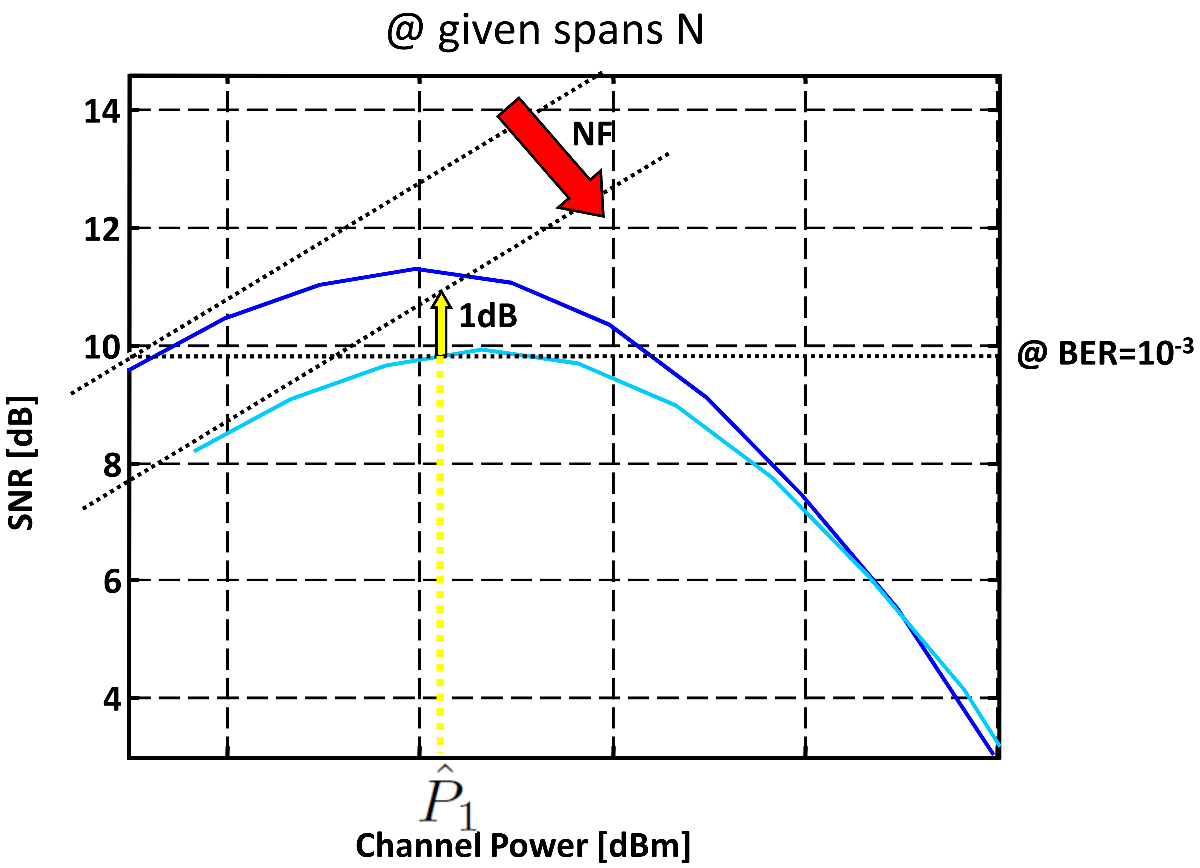

$\hat{P}_1$ 1dB NLT:
channel TX power
at 1dB penalty
w.r.t BB at BER=10^{-3}

[6] A. Bononi et al, Opt Fiber Techol. **16**, 73 (2010)

Simulated Links

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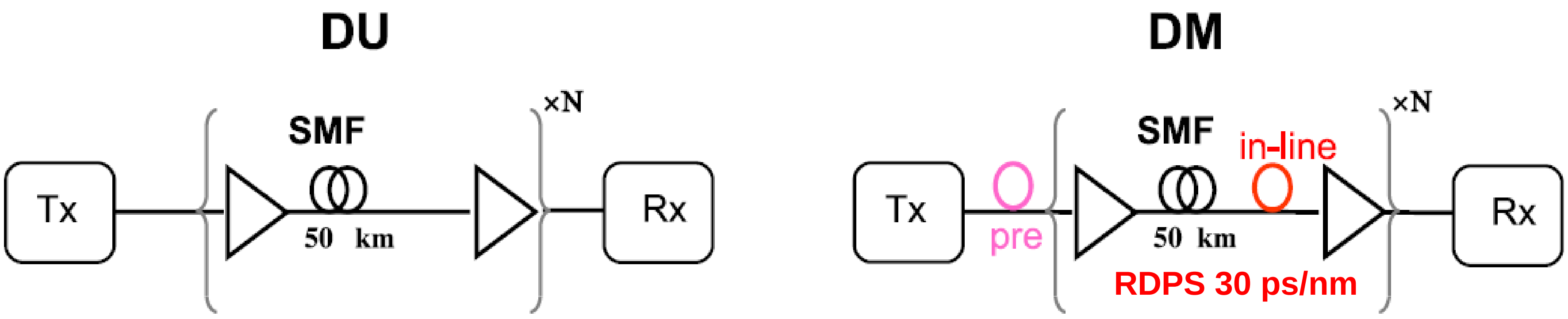

Block diagrams of DU and DM simulated systems. TX block represents 19 WDM channels spaced by $\Delta f = 50\text{GHz}$, and NRZ-PDM-QPSK modulated at $R = 28$ Gbaud. Propagation uses the SSFM with Manakov nonlinear step.

$$\frac{R}{\Delta f} = 0.56$$

NL Decoupling

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[7] A. Bononi et al., ECOC'10, Th.10.E.1

WDM Manakov nonlinear step [*M. Winter et al, JLT 2009, pp. 3739-3751*]:

$$\frac{\partial \vec{A}_n}{\partial z} = -i\gamma\left(\left(\underbrace{||\vec{A}_n||^2}_{\text{SPM}} + \underbrace{\frac{3}{2}\sum_{k\neq n}||\vec{A}_k||^2}_{\text{XPM}}\right)\sigma_0 + \underbrace{\frac{1}{2}\sum_{k\neq n}(\boldsymbol{s}_k\cdot\boldsymbol{\sigma})}_{\text{XPolM}}\right)\vec{A}_n$$

Label	NL Effect
SPM	self-phase modulation
XPM	**avergae scalar** cross-phase modulation
XPolM	cross-polarization modulation
WDM	All effects (SPM,XPM,XPolM,FWM)

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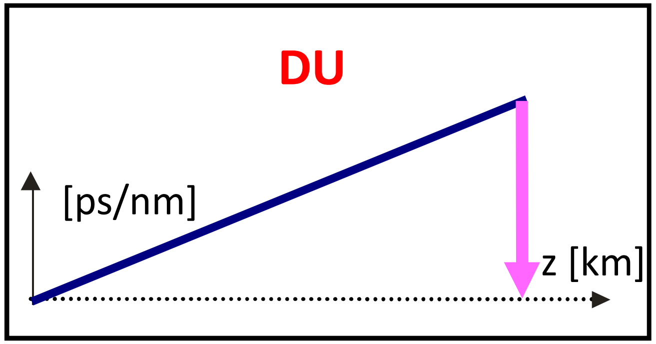
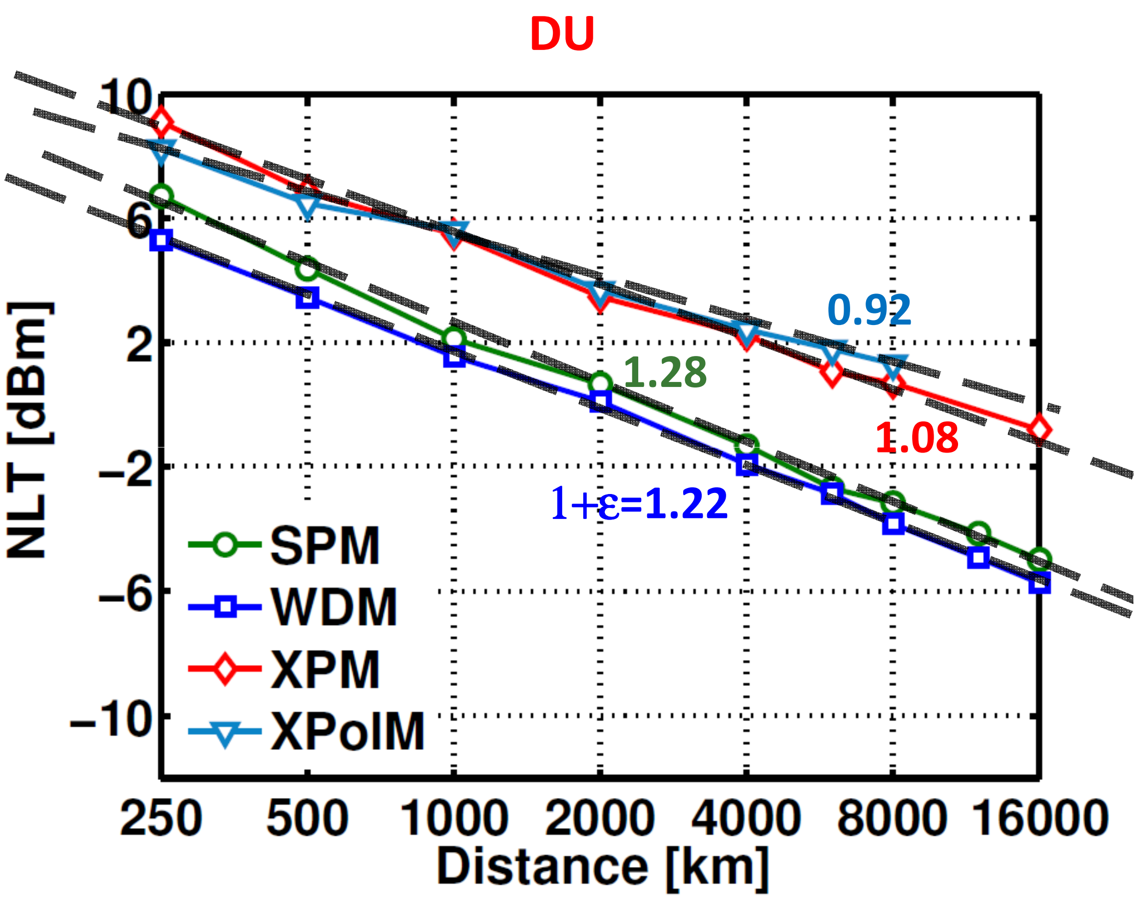
NLT vs. Distance

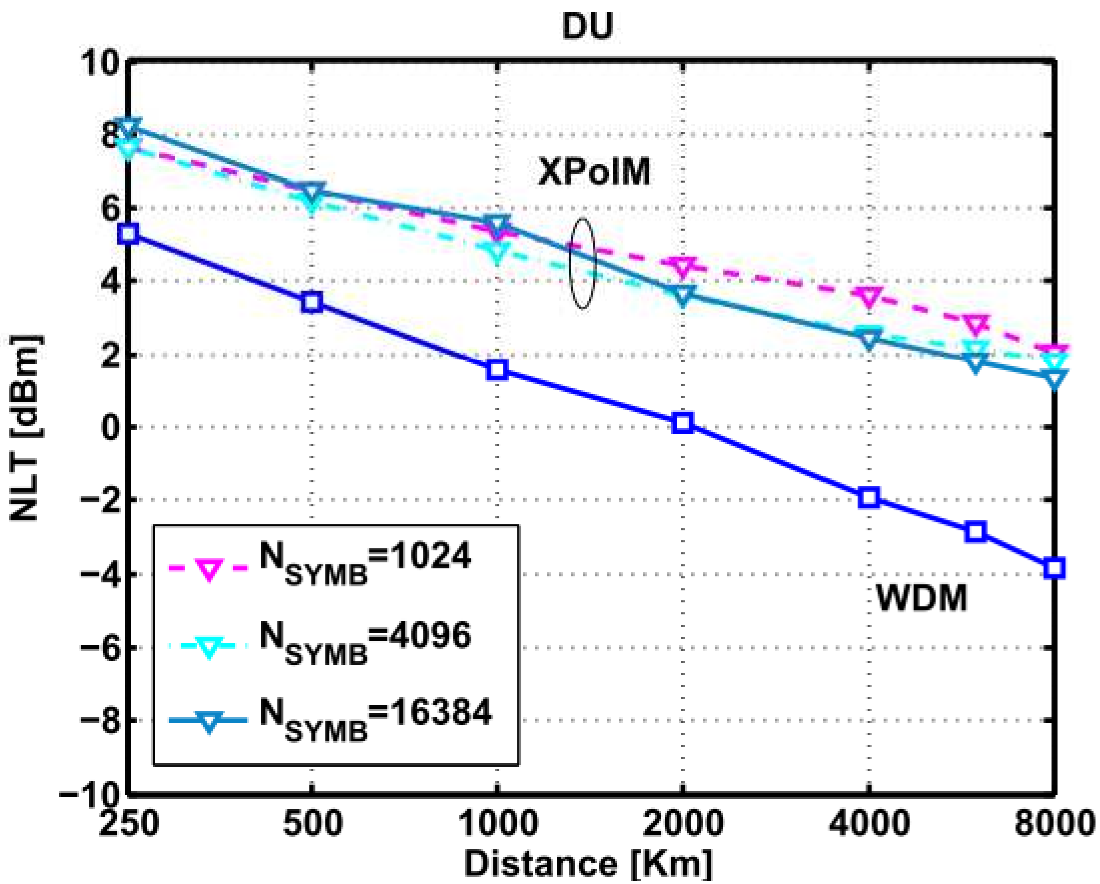


- ✓ SPM dominant
- ✓ XPM, XPolM comparable

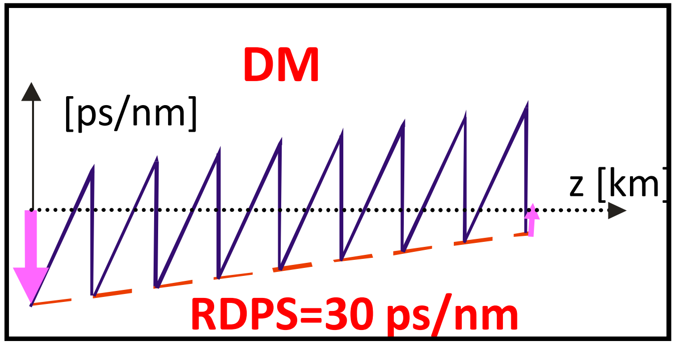


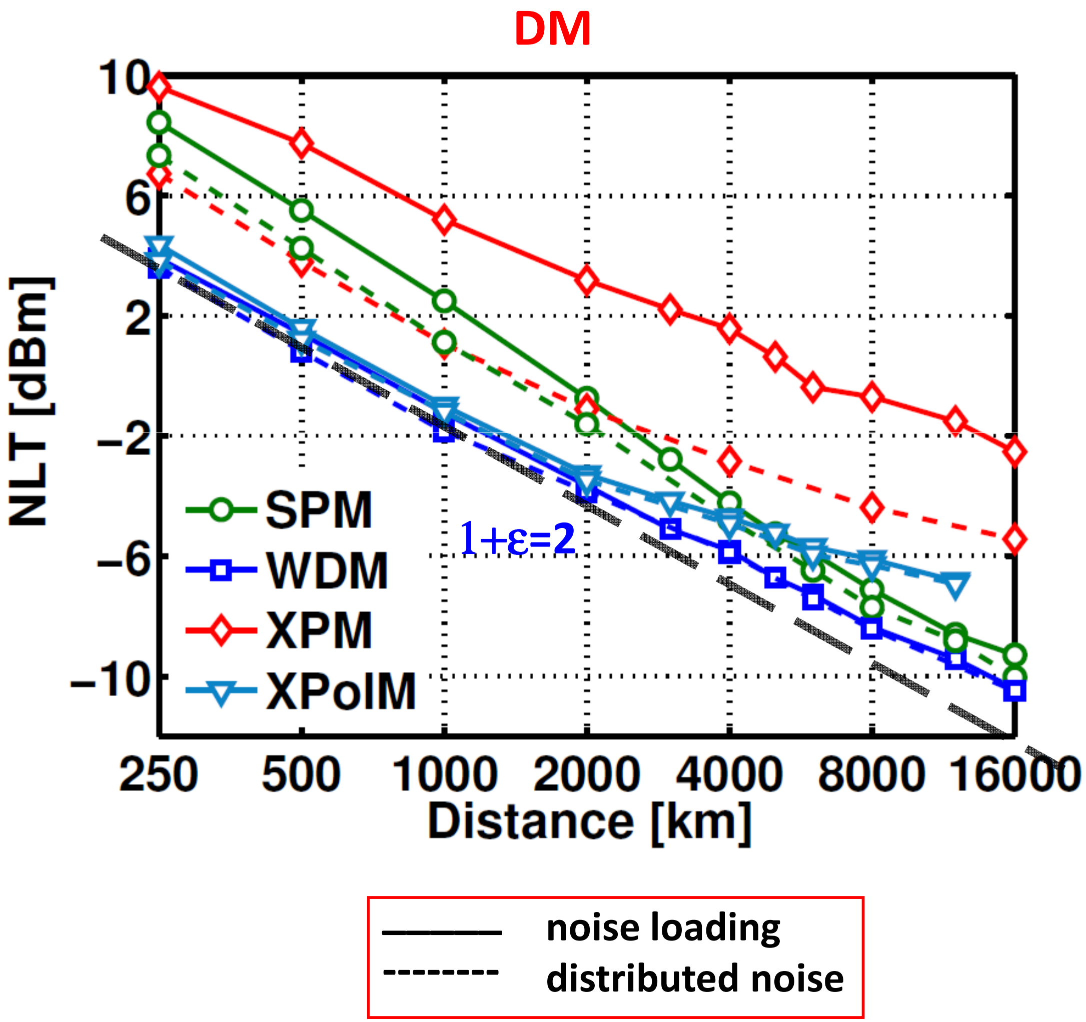
Noise loading

NLT vs. Distance



NLT vs. Distance





✓ XPolM dominant up to 5000km

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Conclusions

- DU: NL accumulation rate from NLT vs Distance
- DU: SPM has largest rate, then XPM, then XpolM
- XPolM NLT needs long patterns