Theoretical and Experimental Results on Transmission Penalty Due to Fiber Parametric Gain in Normal Dispersion

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Outline

- Introduction.
- The origin of Parametric Gain (PG) and its system impact.
- Description of the Transfer Matrix analytical tool developed for both dispersion regions.
- Sideband Instability, an effect related to Parametric Gain in the presence of periodical links.
- Experimental measurements on a recirculating loop.
- Comparison between experimental, theoretical and simulated results.
- Conclusions.

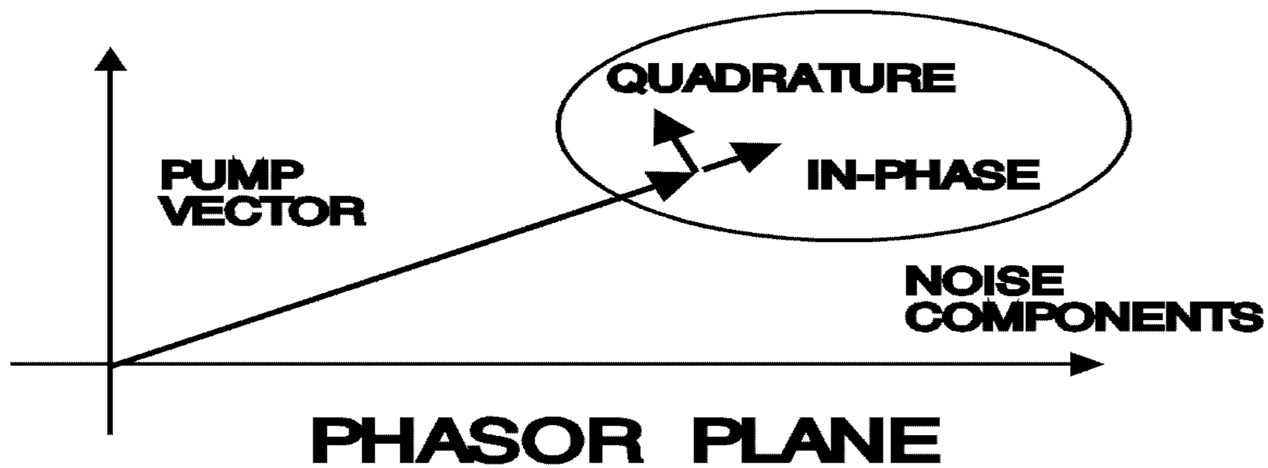
Introduction

- PG is caused by the interaction of fiber nonlinearities with dispersion.
- PG induces a transfer of optical power from the signal to the ASE noise, in both dispersion regions.
- PG effects

  Anomalous dispersion region ⇒ Noise Enhancement
  Modulation Instability

  Normal dispersion region ⇒ Noise Enhancement
- Periodical structures are affected by Sideband Instability too.

Parametric Gain (I)



PG characteristics depend on:

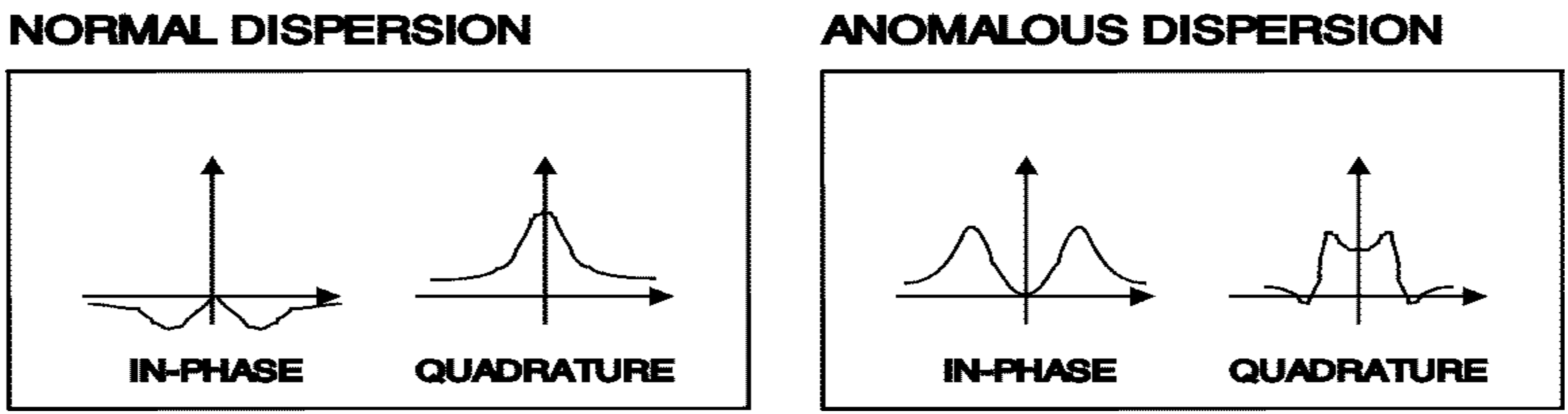
L	Fiber length
D	Dispersion parameter
γ	Nonlinear parameter
P_0	Pump power
α	Attenuation parameter

PG linearized equation

$$\frac{\partial a}{\partial z} = \jmath \frac{1}{2}\beta_2 \frac{\partial^2 a}{\partial T^2} - \jmath\gamma P_0 e^{(-2\alpha z)} \left(a + a^*\right)$$

Parametric Gain (II)

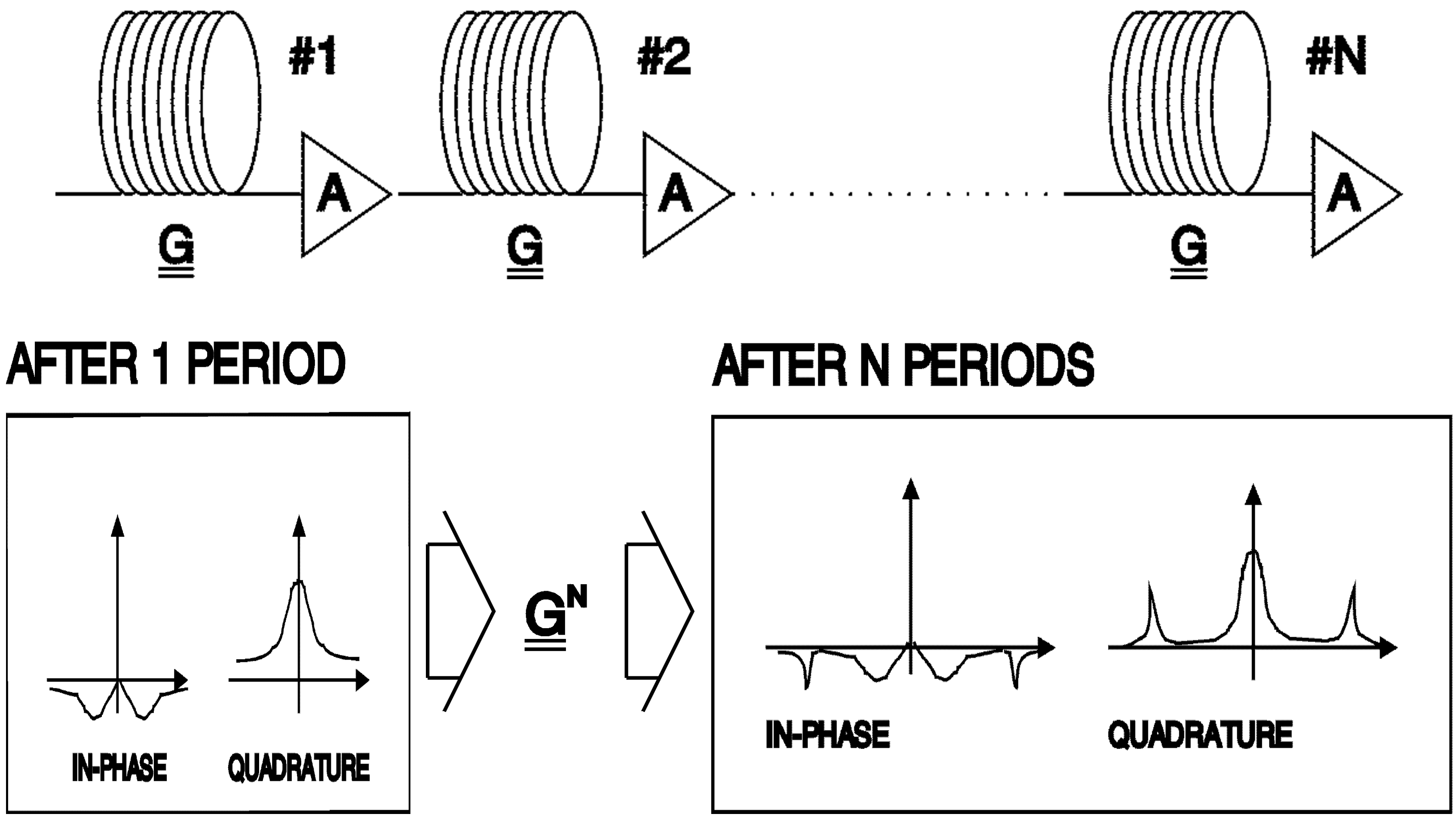
$$\underline{\underline{G}}(z,\Omega) = \begin{bmatrix} G_{pp}(z,\Omega) & G_{pq}(z,\Omega) \\ G_{qp}(z,\Omega) & G_{qq}(z,\Omega) \end{bmatrix}$$



Reference

A. Carena,V. Curri, R. Gaudino, P. Poggiolini *New theoretical result on fiber Parametric Gain and its effects on ASE noise*, IEEE Photonics Technology Letters, vol. 9, n. 4, pp. 535-537, Apr. 1997.

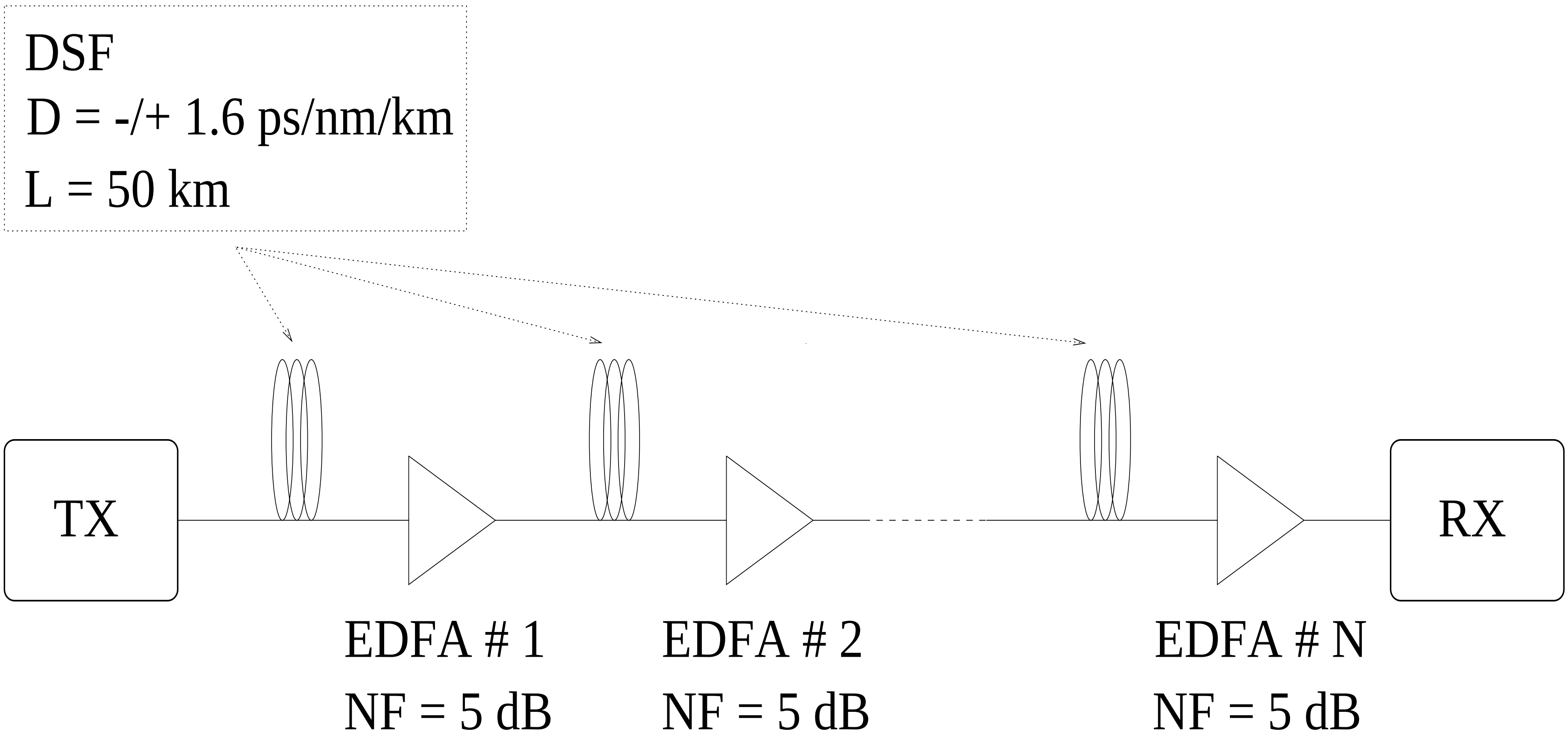
Sideband Instability



OPTSIM - Optical System Simulator

- Time-domain simulator.
- It is based on a split-step algorithm.
- A dual polarization fiber model is considered to include all polarization related phenomena.
- It takes into account attenuation, dispersion, birefringence and PMD.
- Non-linear Kerr effect is considered, too.
- Joint linear-nonlinear effects are accurately evaluated.

Amplified Link, DS Fiber, L=3,000 km



Parameters: CW power: 0 dBm, Fiber loss: $\alpha = 0.22$ dB/km, Fiber nonlinearity: $\gamma = 2$ W^{-1}km^{-1}.

Noise gain after 3,000 km, D=+1.6 ps/nm/km

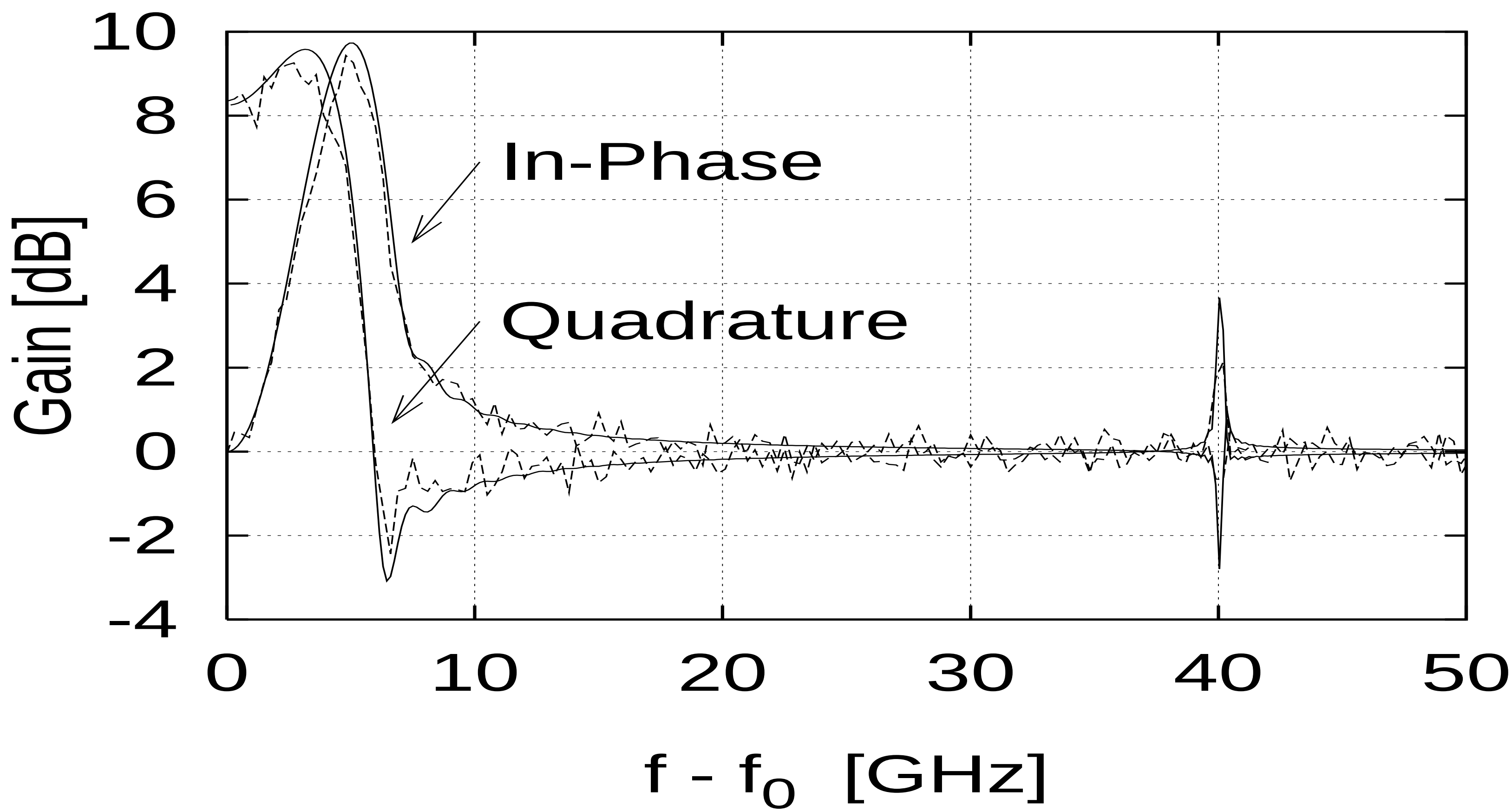


Figure 1: Simulated (dashed) and analytical (solid) in-phase and quadrature ASE noise gain spectra. Anomalous dispersion.

Noise gain after 3,000 km, D=-1.6 ps/nm/km

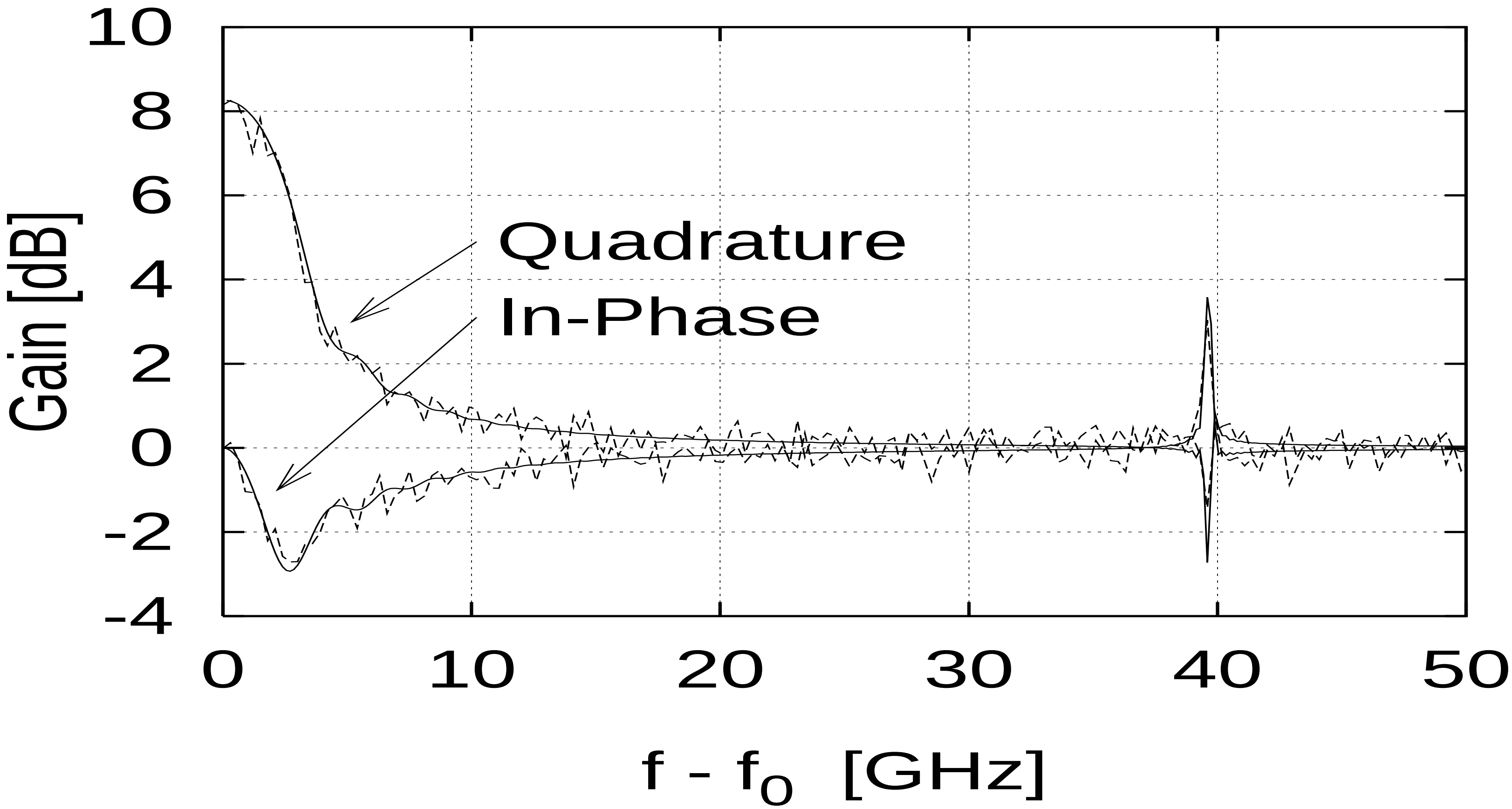
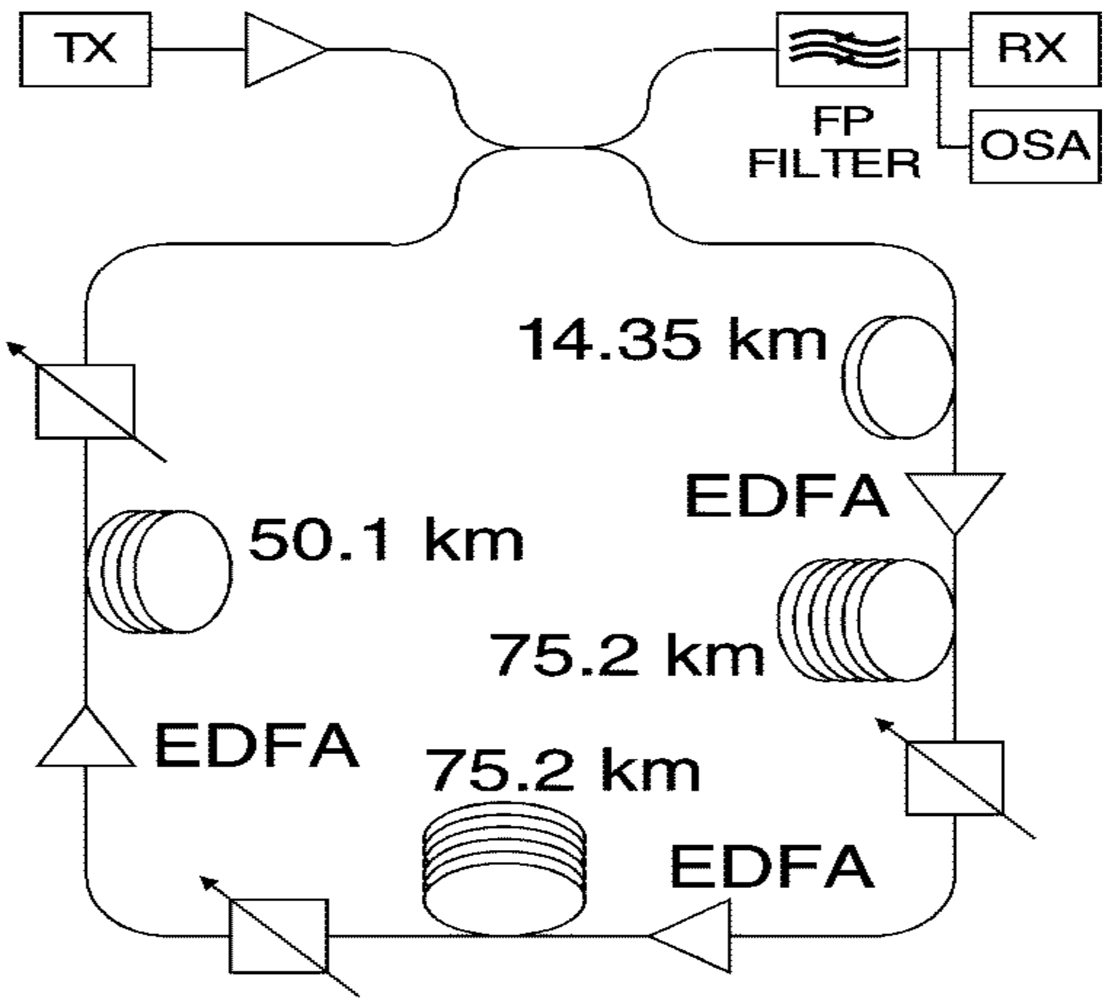


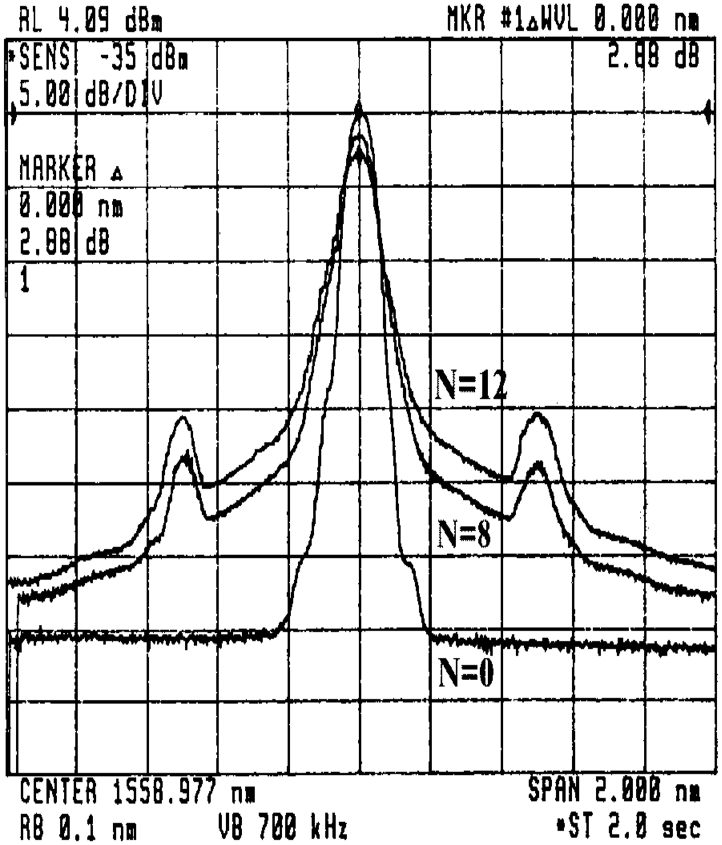
Figure 2: Simulated (dashed) and analytical (solid) in-phase and quadrature ASE noise gain spectra. Normal dispersion.

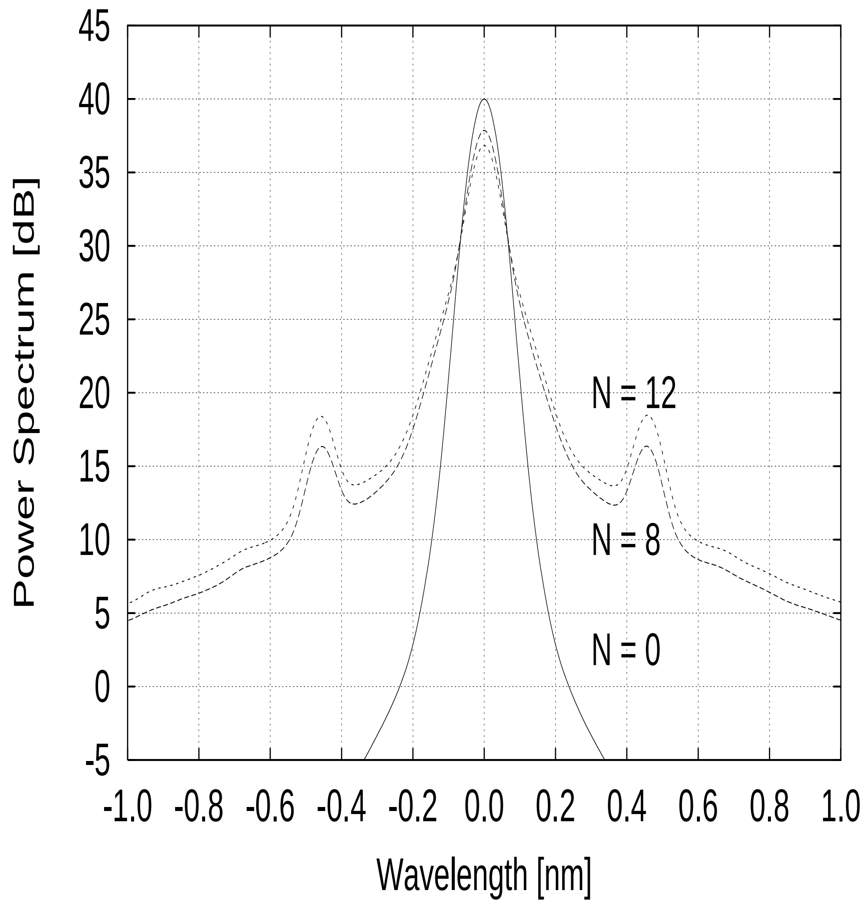
Experimental setup



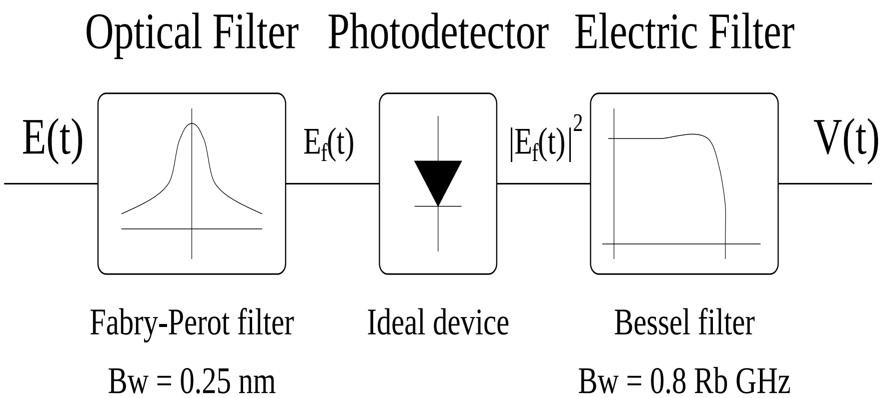
- λ_s = 1539 nm
- B_R = 2.5 Gbit/s
- λ_0 = 1565 nm
- D = -0.48 ps/nm/km
- α = 0.224 dB/km
- EDFA output power P_0= +9 dBm

Experimental and simulated results: spectra





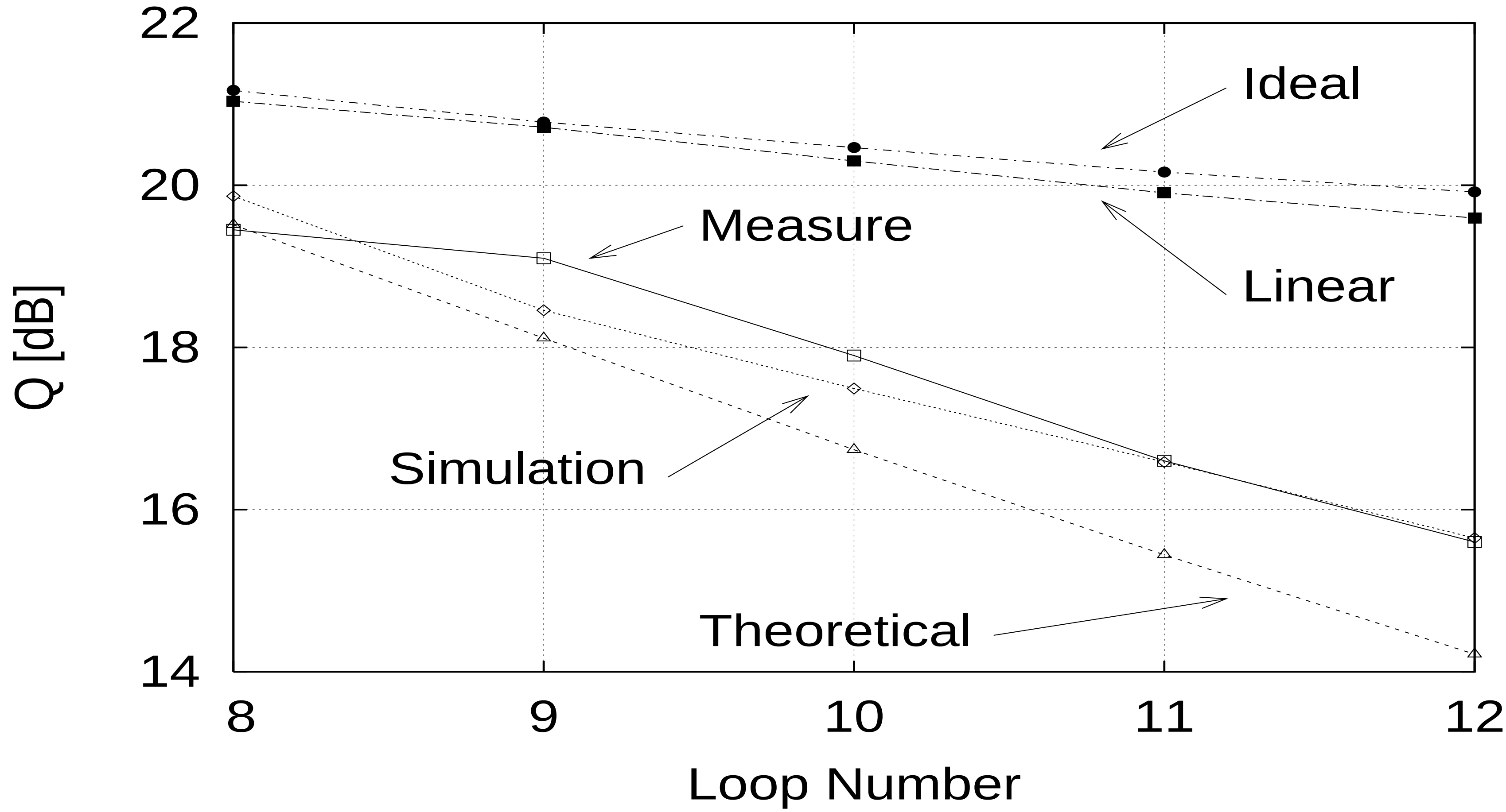
Analitycal Evaluation of Q-parameter



$$Q = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0}$$

- For transmitted "1"'s PG effects on ASE noise are analytically evaluated.
- For transmitted "0"'s linear propagation of ASE noise is assumed.
- Distorsion of the signal is neglected.

Q parameter comparison



Conclusions

- Parametric Gain occurs in normal dispersion as well.
- In long-haul systems PG can be one of the most important limiting phenomena.
- PG characteristics are determined by signal intensity and fiber dispersion.
- A new analytical tool for the evaluation of the impact of PG has been derived.
- Good agreement between experiments, simulation and theory has been obtained.