
Time-domain Amplified Spontaneous Emission Noise Model of Semiconductor Optical Amplifiers

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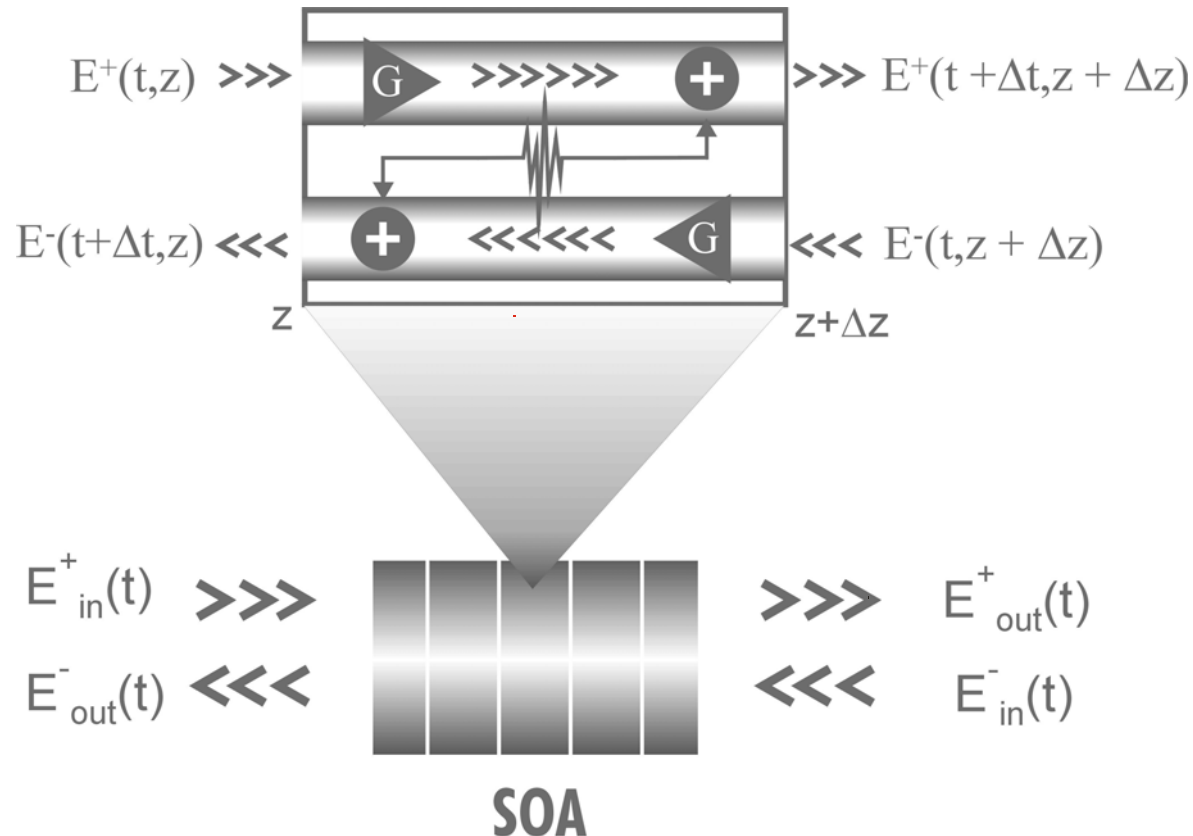
Motivation

- ASE Noise Process in Ultra-Long SOAs:
- Recent applications of long and ultra-long SOAs has shown improved performance in all-optical signal processing operations (ECOC'04 Paper Mo.3.5.1)
- The modeling of such long devices requires the inclusion of the Amplified Spontaneous Emission (ASE) noise
- Computation of Four-Wave Mixing Terms:
- A full time-domain model is advantageous as it computes the FWM beating terms without the inclusion of additional equations

Overview

- Time-domain modelling approach
- Propagation Equation
- Derivation of ASE Noise
- Gain Modeling Approach
- ASE Noise Characteristics: Spectrum and Saturation Properties
- Impact of Random Number Generator on ASE Power
- Verification: Computation of Parametric Amplification in UL SOAs
- Conclusions

Time-domain Model



- Characteristics:

- Spatial and Temporal evolution considered

$$\Delta z = v_g \Delta t$$

- Computational Effort evolves quadratically with the inverse of Δt !
- For example a SOA of 1.5mm length with $\Delta t = 50\text{fs}$ requires 238 segments to be computed
- For $\Delta t = 50\text{fs}$ the computation time is 64s while for a $\Delta t = 25\text{fs}$ the computation time is increases to 280s. Both calculated in a AMD XP2800+ processor.

Propagation Equation

Propagation Equation

$$E_{x,y}^{\pm}(z \pm \Delta z, t + \Delta t) = [c_1 E_{x,y}^{\pm}(z, t) + c_2 E_{x,y}^{\pm}(z, t - \Delta t) \exp(j\Delta\omega_{peak}\Delta t)] \times \exp(j\Delta\phi_{tot}) + E_{SE}(z, t)$$

FIR filter coefficients

$$c_1 = \frac{\sqrt{a} + \sqrt{a - 4b}}{2} \quad c_2 = \frac{b}{c_1}$$

Spontaneous Emission Field

$$E_{SE\,x,y}(z, t) = \sqrt{\hbar\omega g(N(z))n_{sp}(N(z))\Delta z\Delta\nu} \frac{x_1 + jx_2}{\sqrt{2}}$$

$$a = 1 + [\Gamma g_{peak}(N(z)) - \alpha_{int}]\Delta z \quad b = \frac{\Gamma g_{peak}(N(z))\Delta z}{\Delta\omega^2 \Delta t^2}$$

Derivation of SE Complex Field

Spectral width of SE much broader than gain spectrum -> White Gaussian noise assumption

$$\langle E_{SE}(z, t) E_{SE}^*(z, t - t') \rangle = \rho_{SE}(z, t) \delta(t') \quad (1)$$

$$E_{SE}(z, t) = \sqrt{\frac{\rho_{SE}(z, t)}{\Delta t}} x_e \quad \text{D. Marcuse JQE pp.1139 (1984)} \quad (2)$$

$$\rho_{SE}(z, t) = \int_z^{z+\Delta z} \hbar \omega g(N(z')) n_{sp}(N(z')) dz' \quad (3)$$

$$E_{SE\ x,y}(z, t) = \sqrt{\hbar \omega g(N(z)) n_{sp}(N(z)) \Delta z \Delta \nu} \frac{x_1 + jx_2}{\sqrt{2}} \quad (4)$$

A.M. Melo et al, Submitted to IEEE JQE 2005

Gain Modeling: FIR filter approach

$$g_{par}(\omega, N) = g_{peak}(N) \left\{ 1 - \left[\frac{\omega - \omega_{peak}(N)}{\Delta\omega_g(N)} \right]^2 \right\} \quad (1)$$

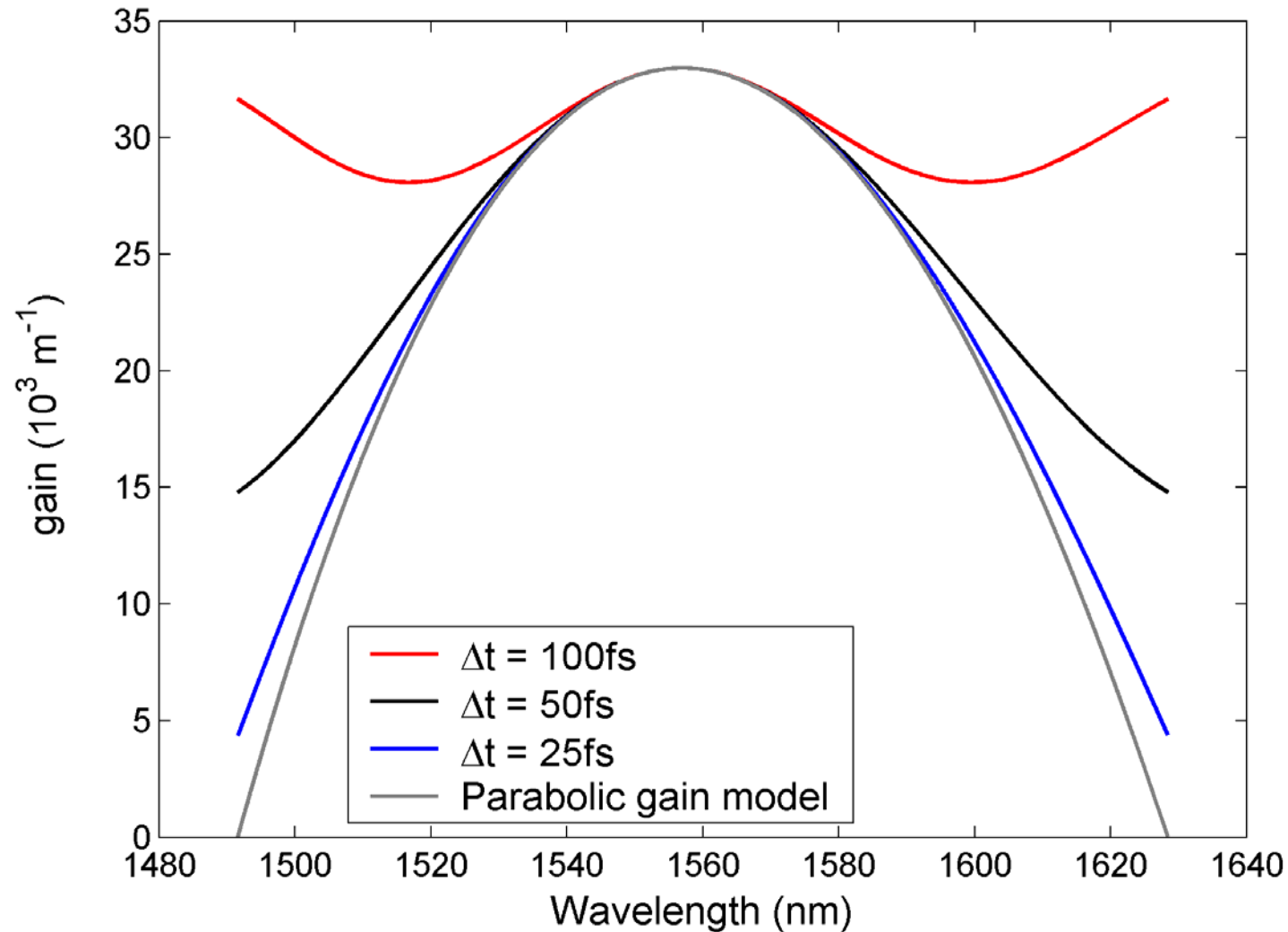
$$G(\omega, N(z)) = c_1^2 + c_2^2 + 2c_1c_2 \cos[(\omega - \omega_{peak}(N(z)))\Delta t] \quad (2)$$

$$g_{fir}(\omega, N(z)) = \frac{1}{\Gamma} \left[\left(\frac{G(\omega, N(z)) - 1}{\Delta z} \right) + \alpha_{int} \right] \quad (3)$$

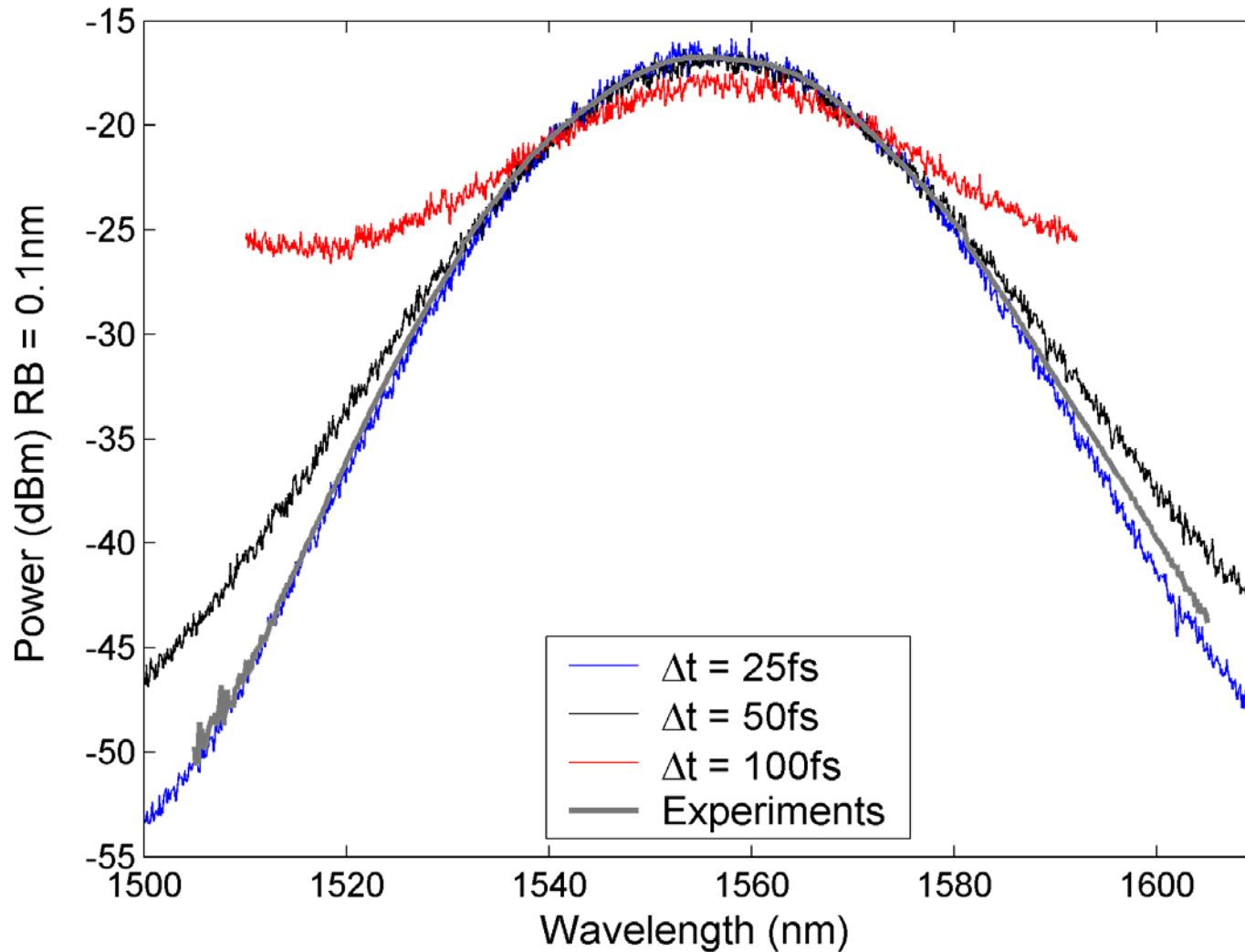
$$c_1 = \frac{\sqrt{a} + \sqrt{a - 4b}}{2} \quad c_2 = \frac{b}{c_1} \quad (4)$$

$$a = 1 + [\Gamma g_{peak}(N(z)) - \alpha_{int}] \Delta z \quad b = \frac{\Gamma g_{peak}(N(z)) \Delta z}{\Delta\omega^2 \Delta t^2} \quad (5)$$

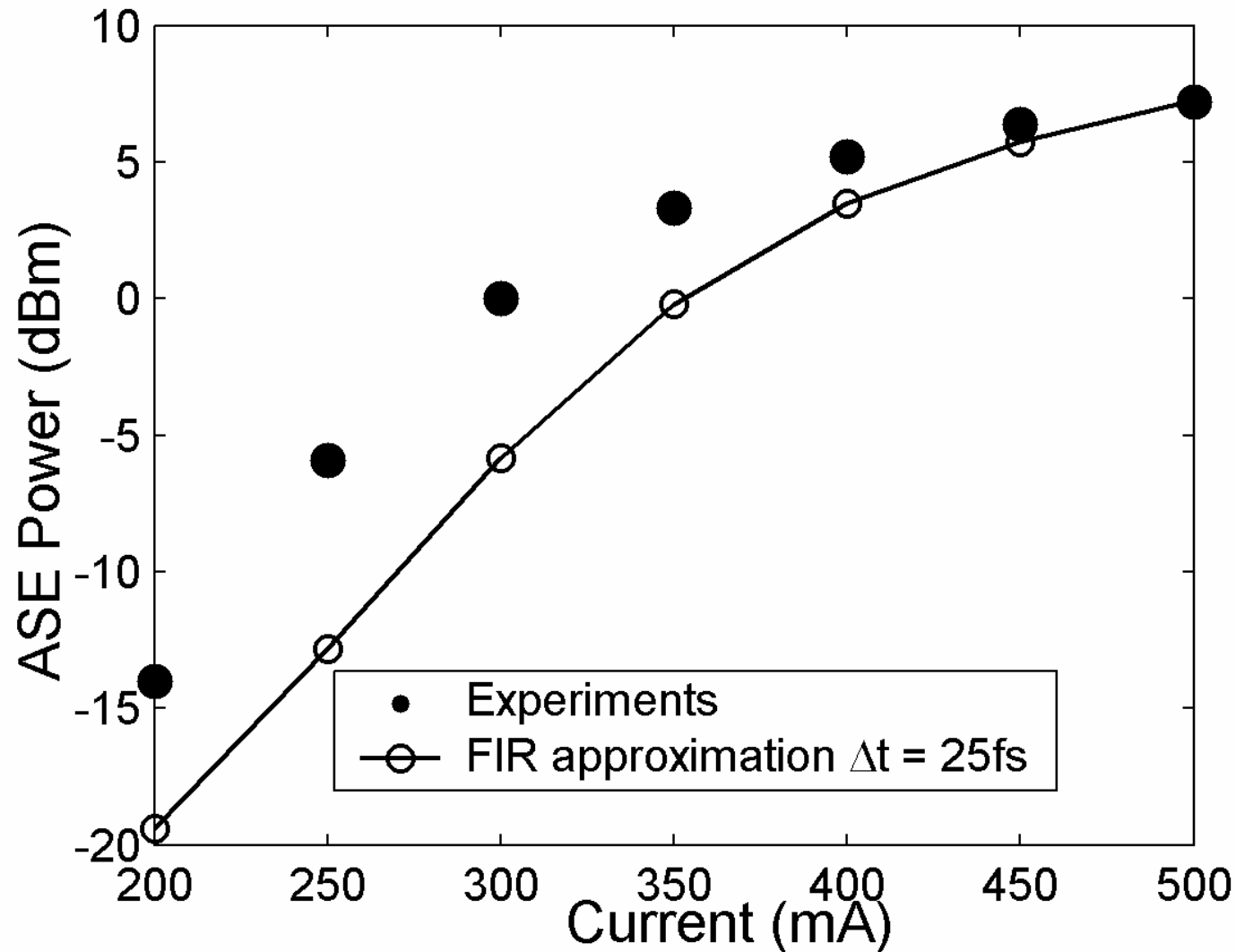
FIR filter approach



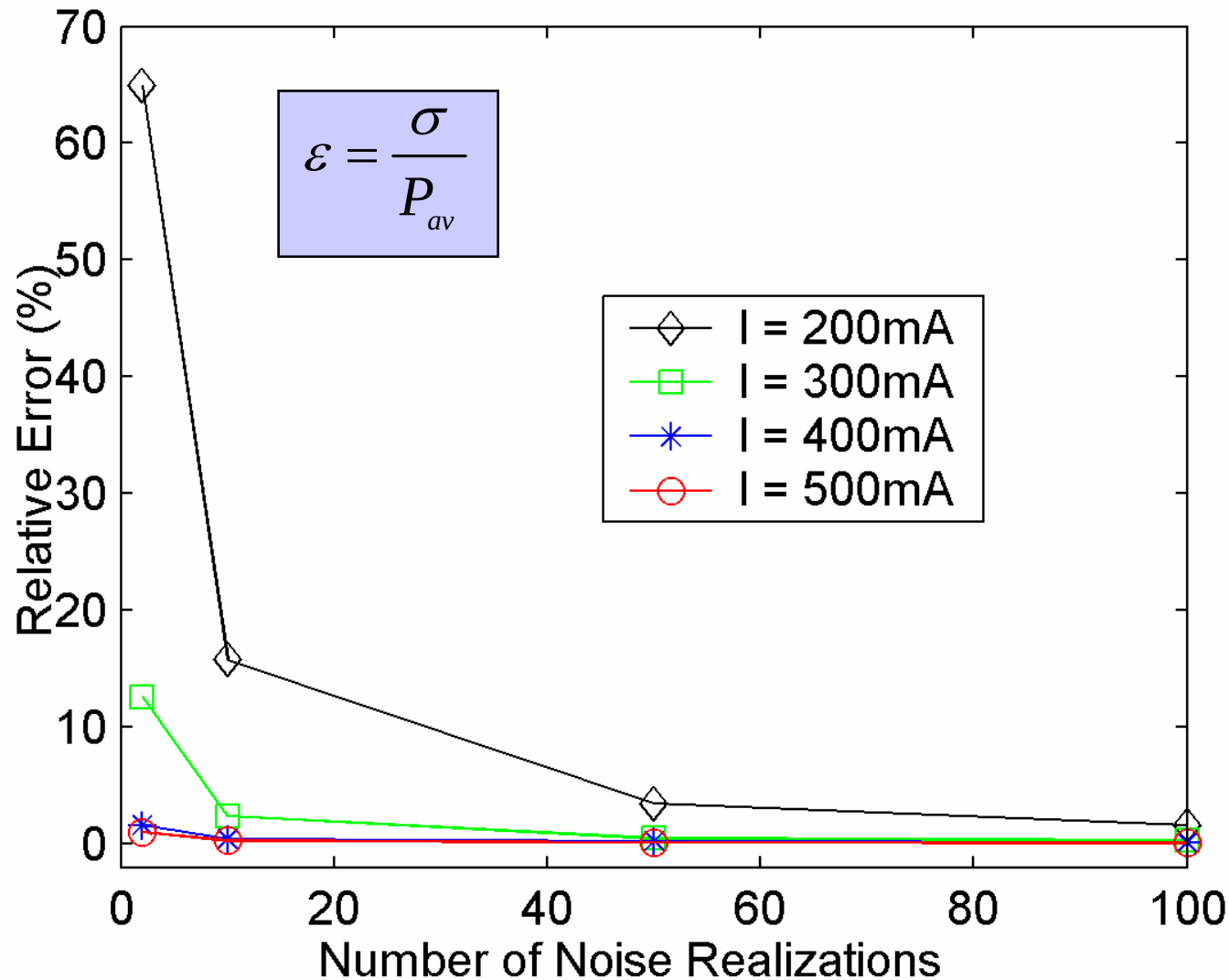
ASE Spectrum ($I = 500\text{mA}$)



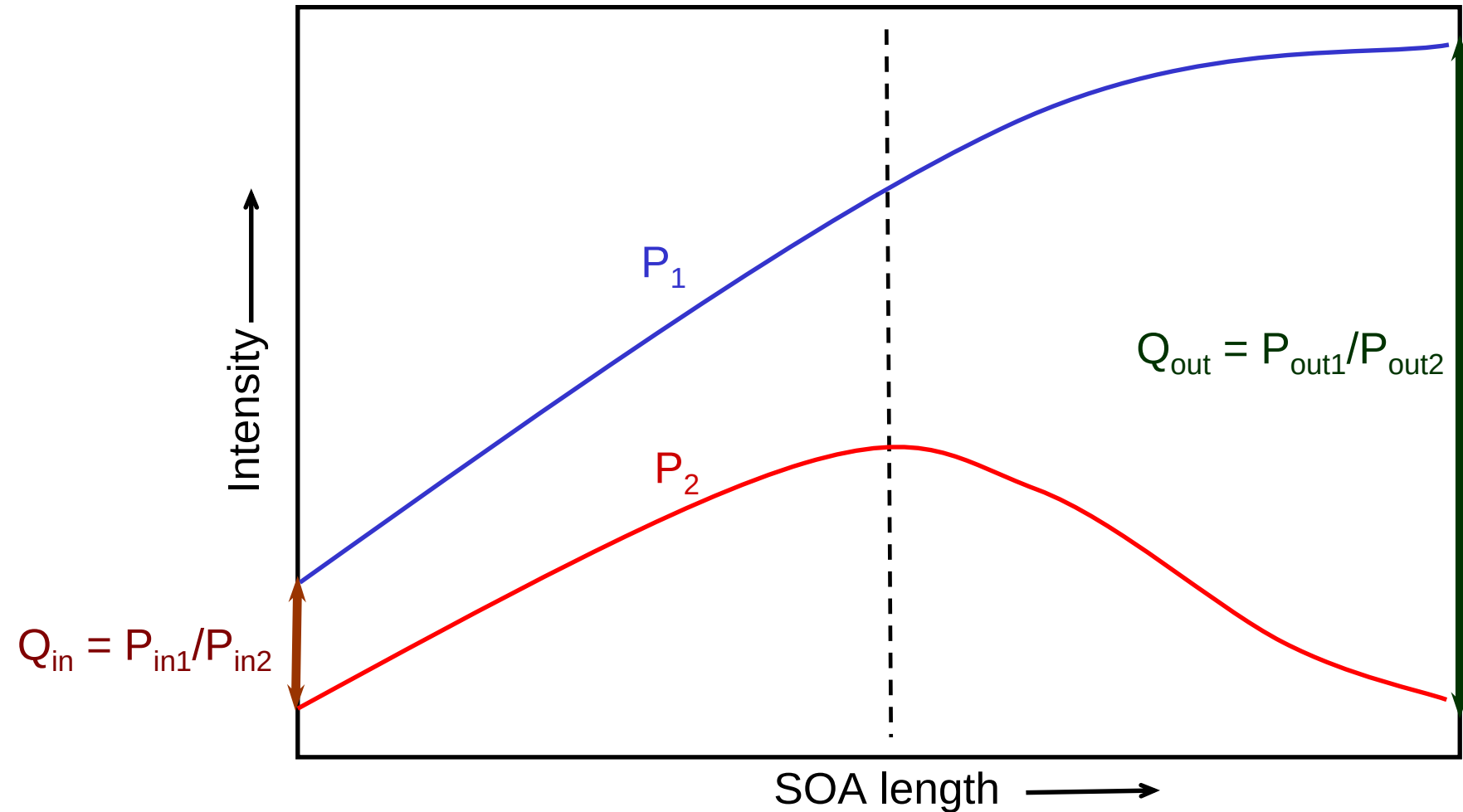
Saturation Properties



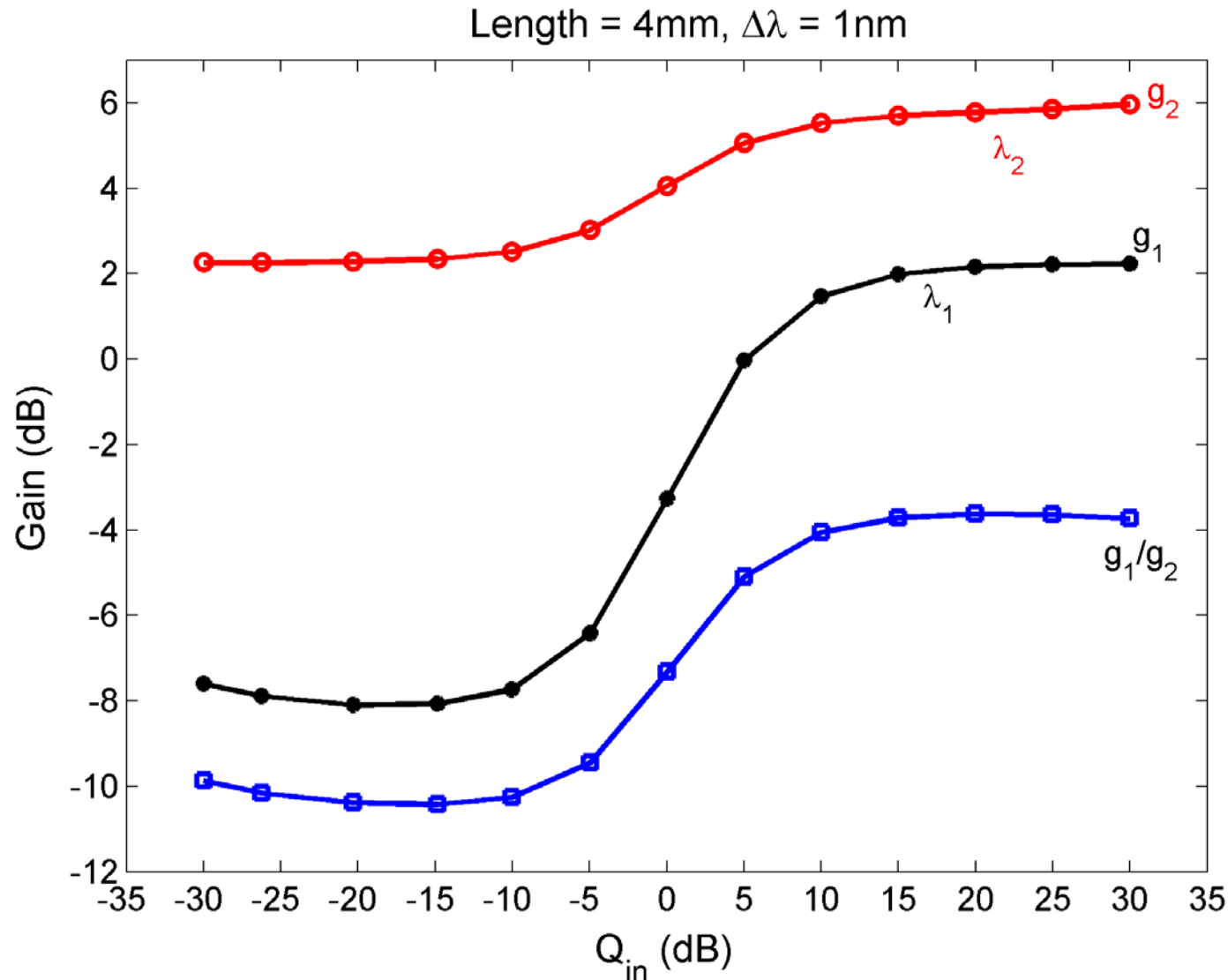
Impact of Random Number Generator on ASE Power



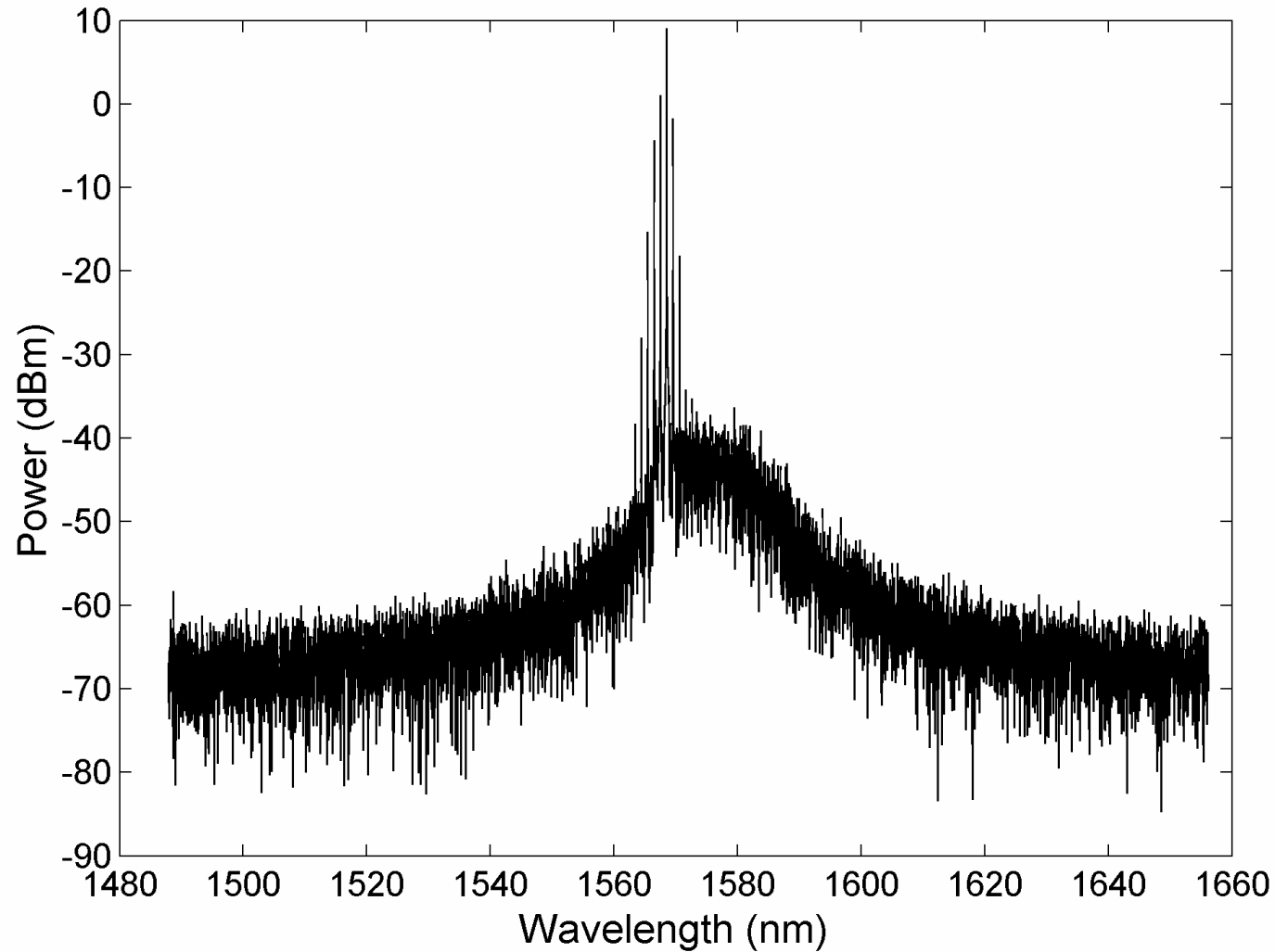
Parametric Amplification in Ultra Long SOAs



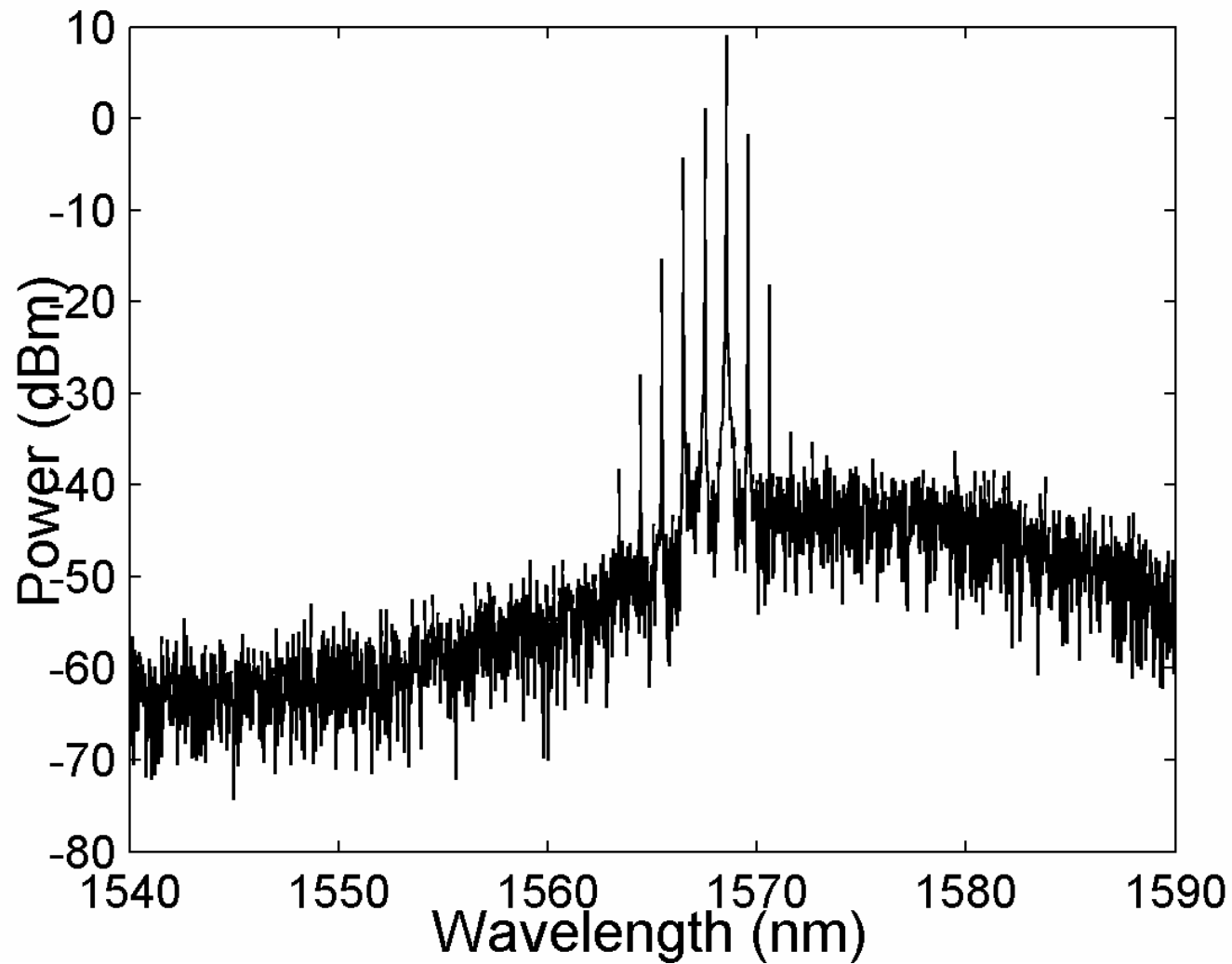
Wave Competition



Output Spectrum



Output Spectrum



Conclusions

- A full time-domain ASE noise model is proposed which implements the material gain as a FIR filter function
- It has shown good agreement with experimental results regarding the ASE spectrum and ASE power per facet. However the inclusion of parameter dependence on pump current may be necessary for current modulation purposes.
- The oscillations on the ASE power caused by the statistical generation of the spontaneous emission through independent and identically distributed Gaussian random numbers are strongly reduced in the saturation regime
- The model is suitable to simulate multiple FWM behavior between signals and signals and noise. This was verified by simulating parametric amplification process in UL SOAs