Pulse Propagation in Polarization-sensitive Semiconductor Optical Amplifiers

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Outline

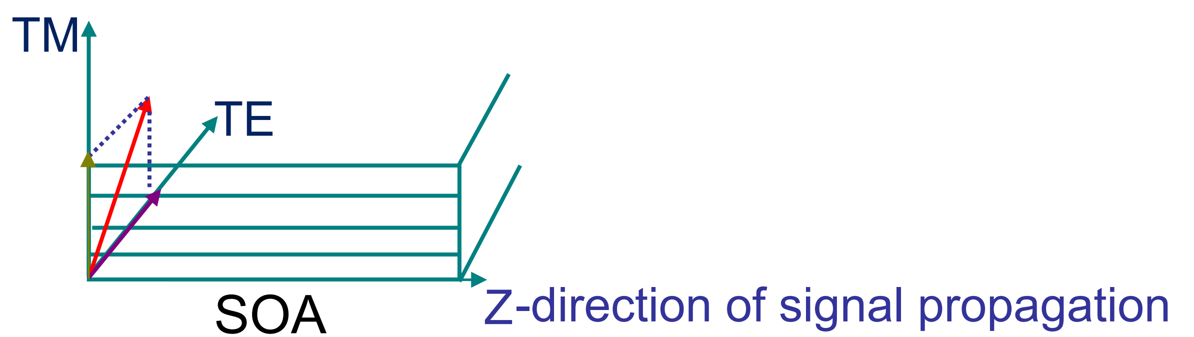
- Introduction to polarization sensitive SOAs
- Methodology and applications
- Experimental results
- Conclusions

Polarization-sensitive SOAs

- Polarization rotation in semiconductor optical amplifiers
  - useful for optical signal processing
  - an interesting area of research!

- What does polarization sensitivity imply?
  - TE and TM components experience different gains
  - TE - signal component parallel to waveguide layers [1]
  - TM - perpendicular component

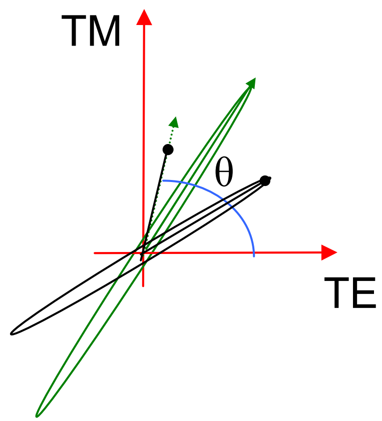
Coordinate frame definition



[1] H. J. S Dorren *et al.*, *Nonlinear polarization rotation in semiconductor optical amplifiers: Theory and application to all-optical flip-flop memories*, IEEE. J. Quantum Electron., Vol.39, pp. 141-148, Jan. 2003.

Polarization-sensitive SOAs

- Input linearly polarized light
  - state of polarization rotates towards amplifier axis with greater gain
- Difference in phase delay of TE and TM components
  - output signal is elliptically polarized
- TE-TM gain ratio higher for low power signal
  - low power signal rotates more than a high power signal



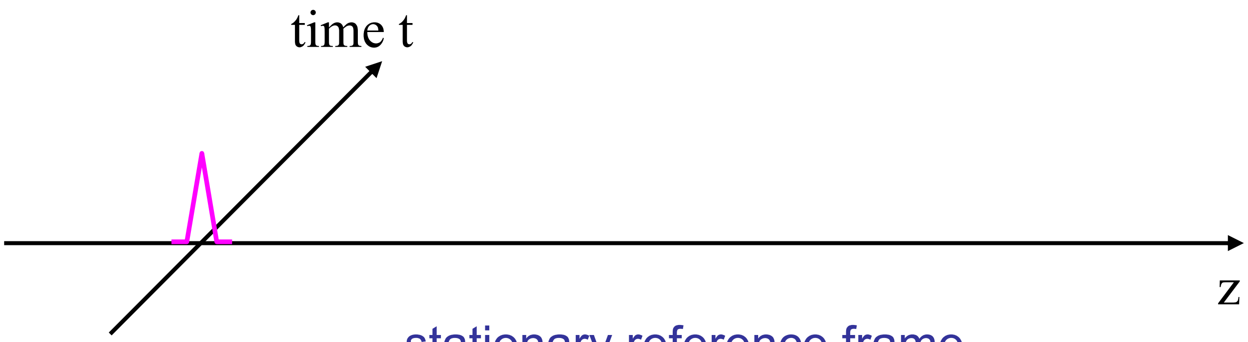
Objective

- Analytical expressions
  - modal gain
  - phase evolution
  - energy gain
  - same approach as in [1]
- Numerical simulations using [2]
  - compare results
- Analytical Model verification - SOA as distance ranger
  - experimental results
  - numerical simulation

[1] M. Premaratne *et al.*, *Analytical Characterization of SOA-Based Optical Pulse Delay Discriminator*, IEEE. J. Lightwave Technol., Vol.23, pp. 2778-2787, Sep. 2005

[2] H. J. S Dorren *et al.*, *Nonlinear polarization rotation in semiconductor optical amplifiers: Theory and application to all-optical flip-flop memories*, IEEE. J. Quantum Electron., Vol.39, pp. 141-148, Jan. 2003.

Analysis



stationary reference frame

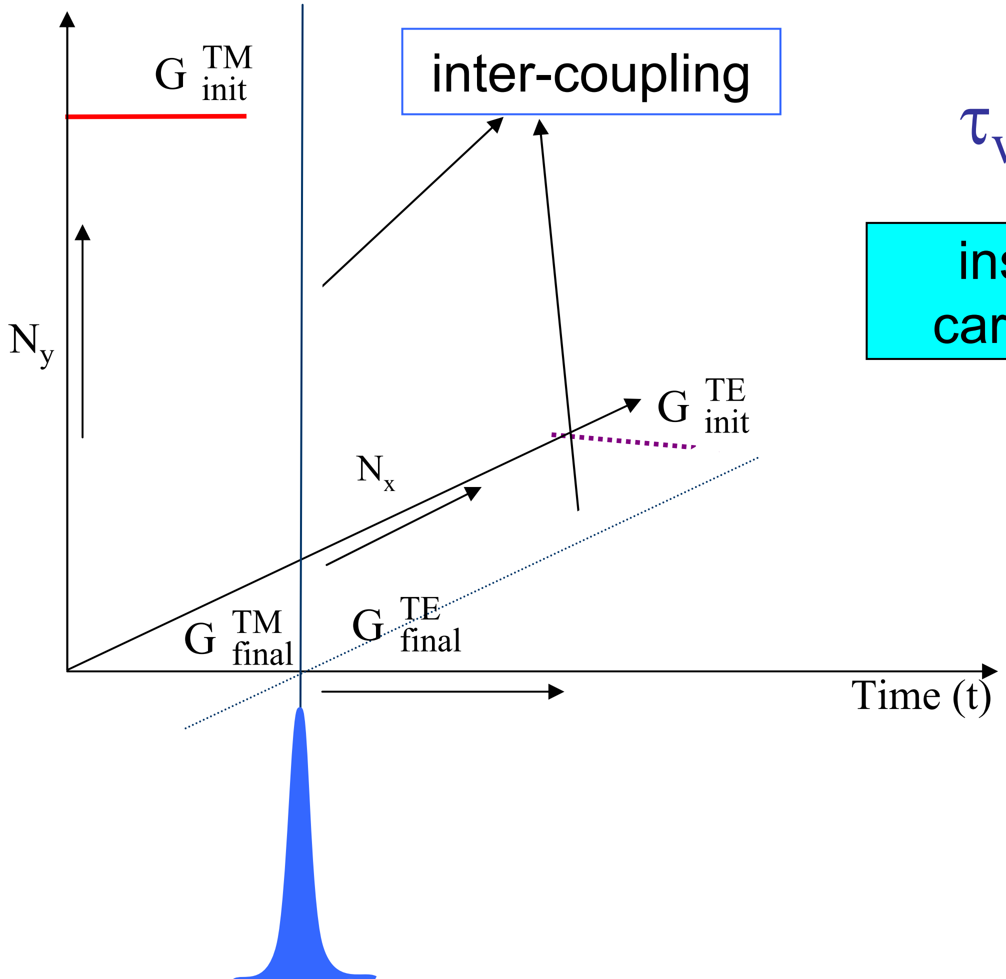
- Reference frame stationary while pulse moves
  - changed to a moving co-ordinate system

Analysis

Lagrangian reference frame

- Reference frame stationary while pulse moves
  - changed to a moving co-ordinate system
- Delayed time-coordinate τ
  - centered on pulse arrival time at each plane ξ along the amplifier
- Transformations for time and spatial derivatives:
  - $\frac{\partial}{\partial z} = \frac{\partial}{\partial \xi} - \frac{1}{v_g}\frac{\partial}{\partial \tau}; \frac{\partial}{\partial t} = \frac{\partial}{\partial \tau}$ v_g-group velocity
- Simpler expressions for SOA dynamic response
  - solved analytically

Analysis



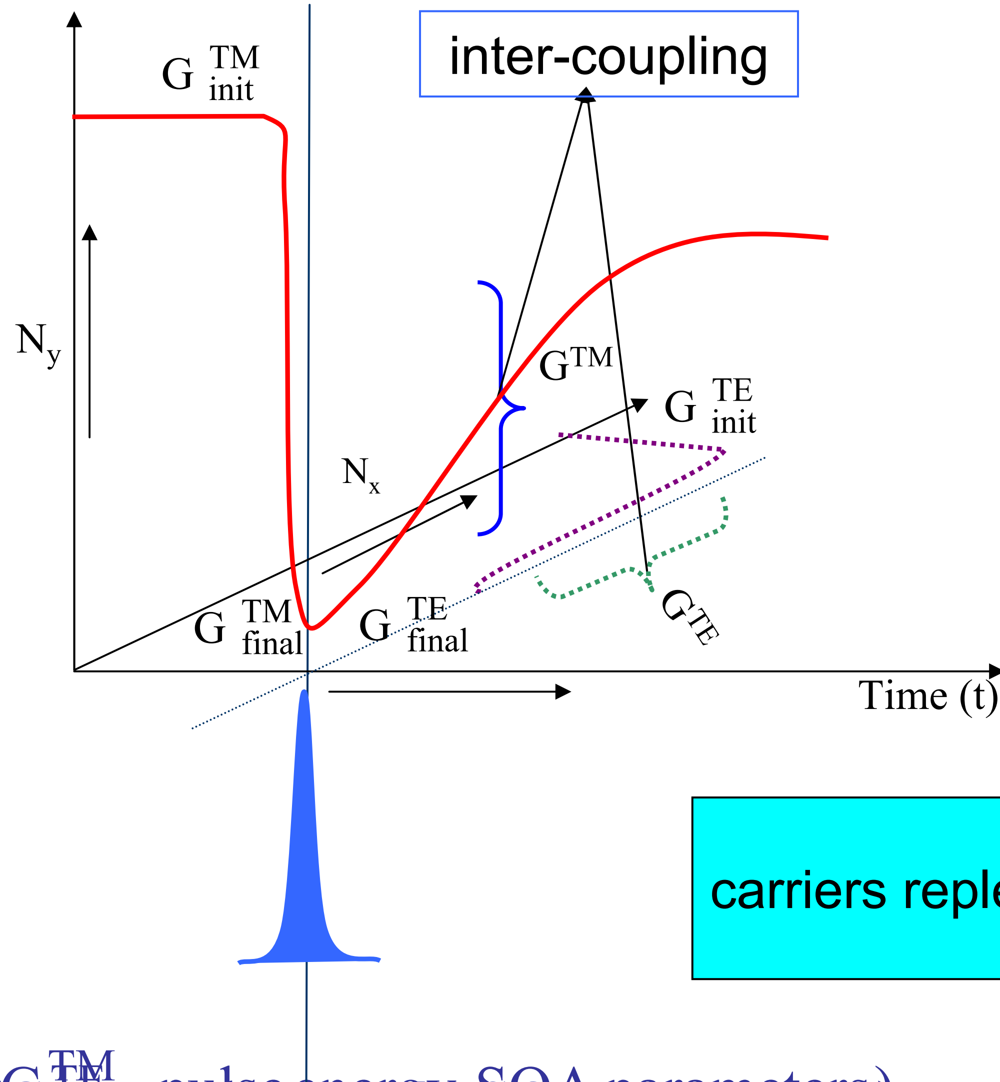
$\tau_w << \tau_e$

instantaneous carrier depletion

$$G_{final}^{TE} = f(G_{init}^{TE}, \text{pulse energy}, \text{SOA parameters})$$

$$G_{final}^{TM} = f(G_{init}^{TM}, \text{pulse energy}, \text{SOA parameters})$$

Analysis

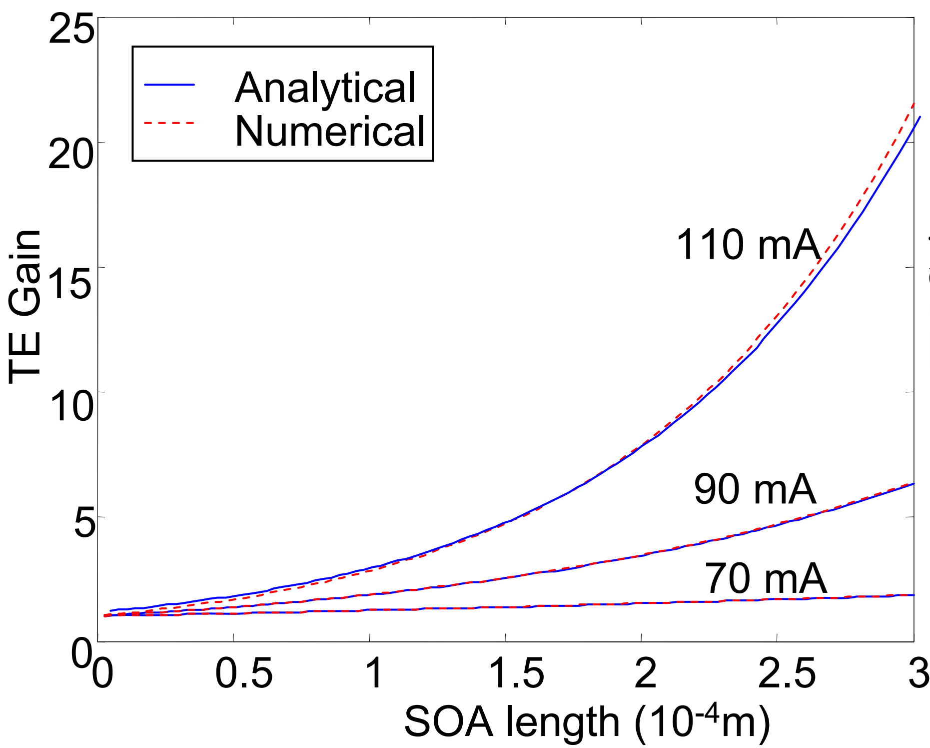


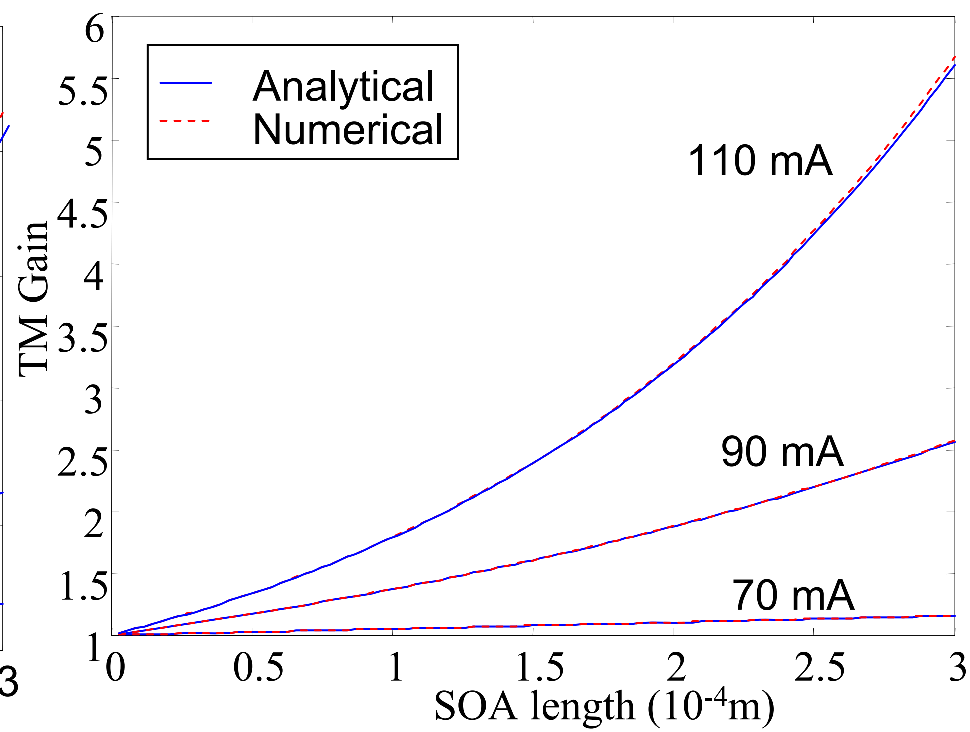
carriers replenish by injection

$$G^{TM} = f(G^{TM}_{final}, \text{pulse energy, SOA parameters})$$

$$G^{TE} = f(G^{TE}_{final}, \text{pulse energy, SOA parameters})$$

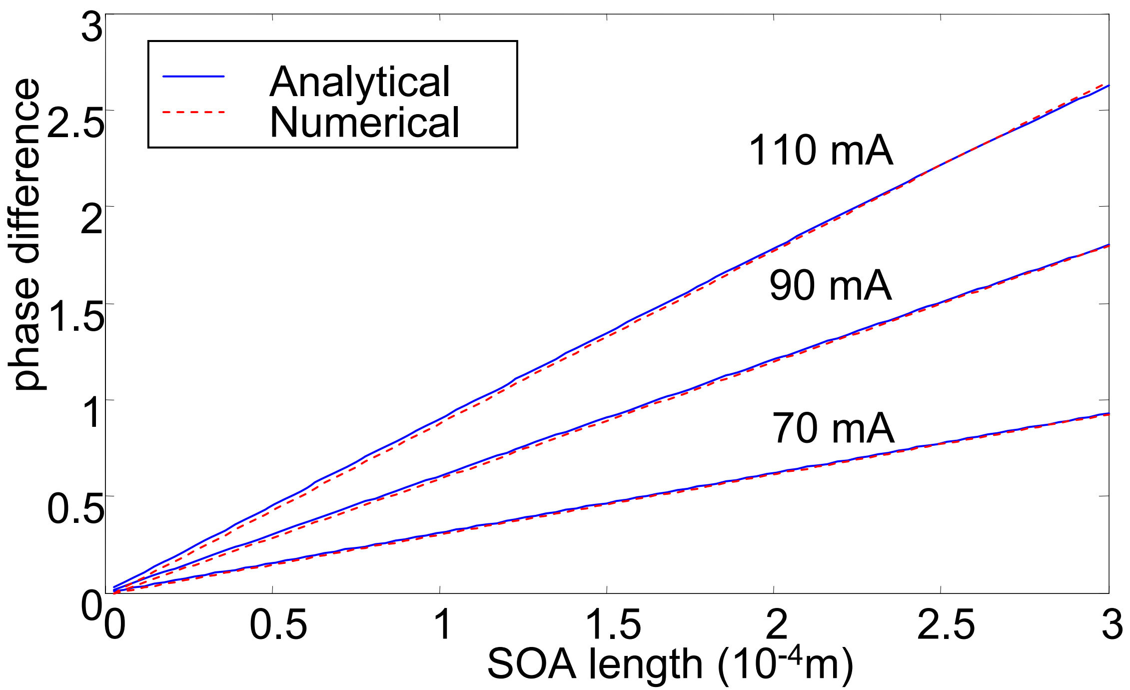
Time evolution of SOA gain



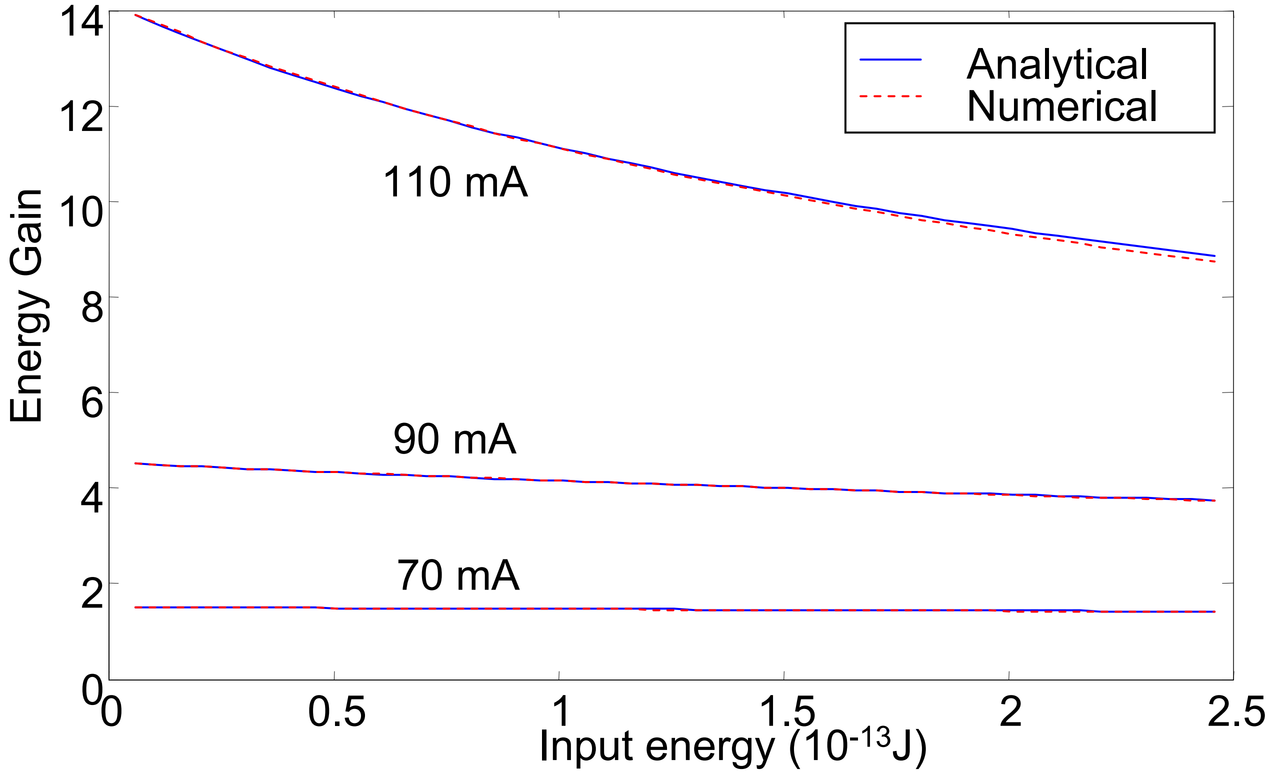


Phase evolution

- Phase difference varies with length
  - output elliptically polarized



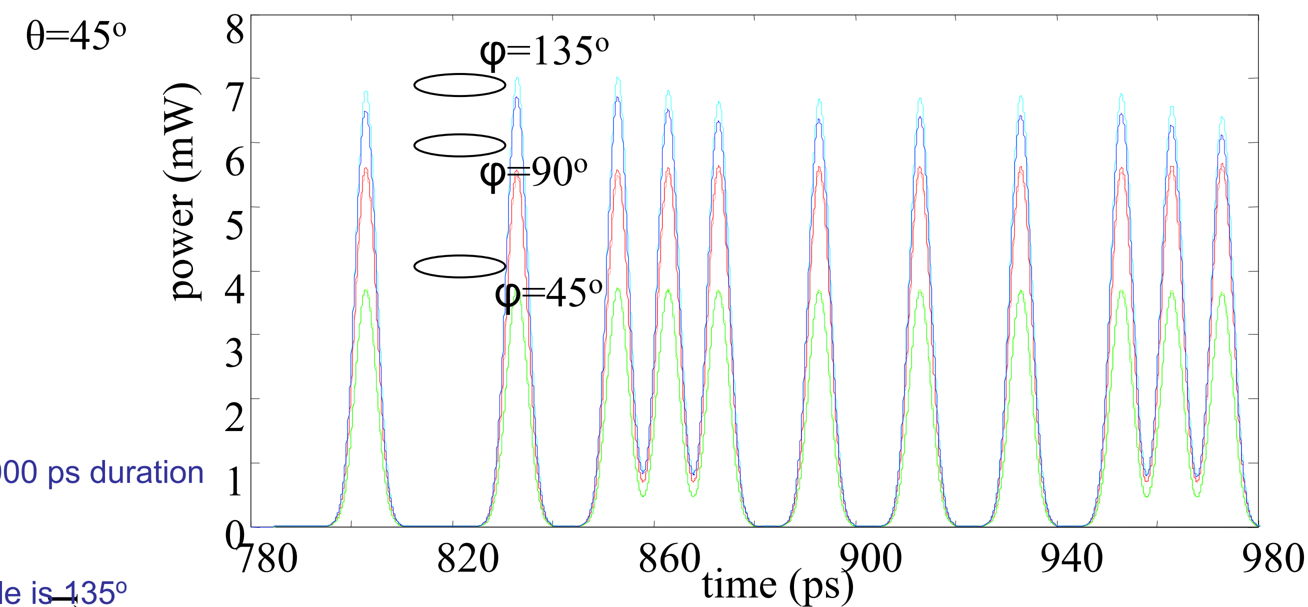
Pulse energy gain



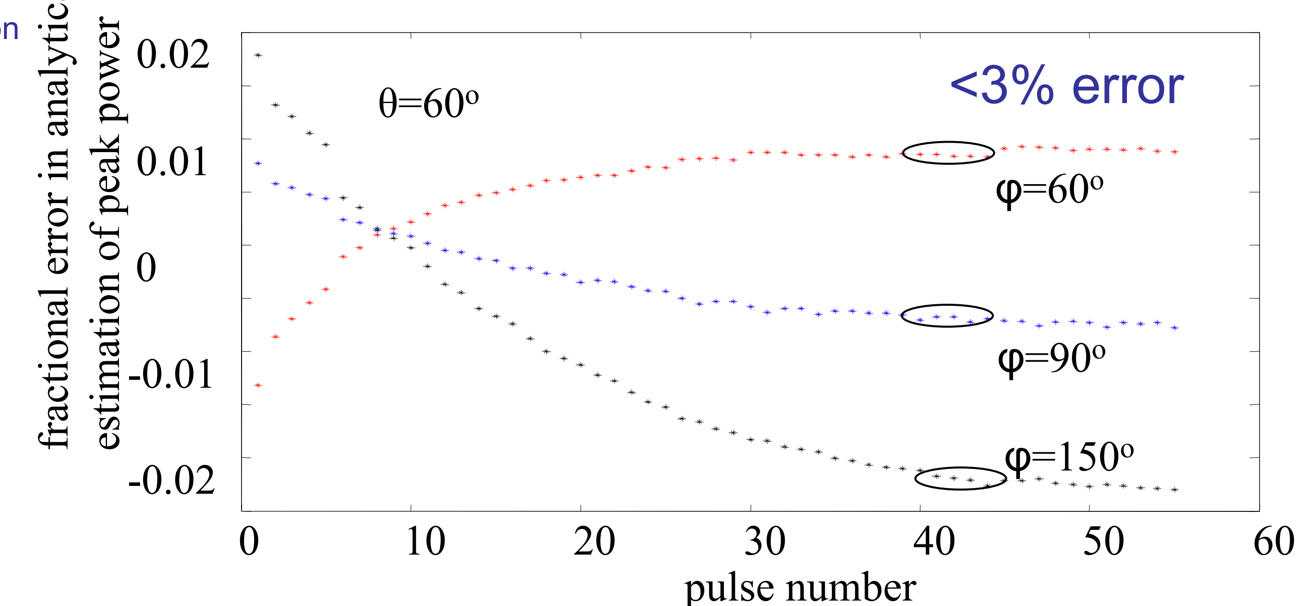
- Ratio of pulse energy output to pulse energy input
- Efficiency of energy extraction
- Energy gain independent of pulse shape

random pulse streams

FWHM=5 ps
E_g=12.5 fJ



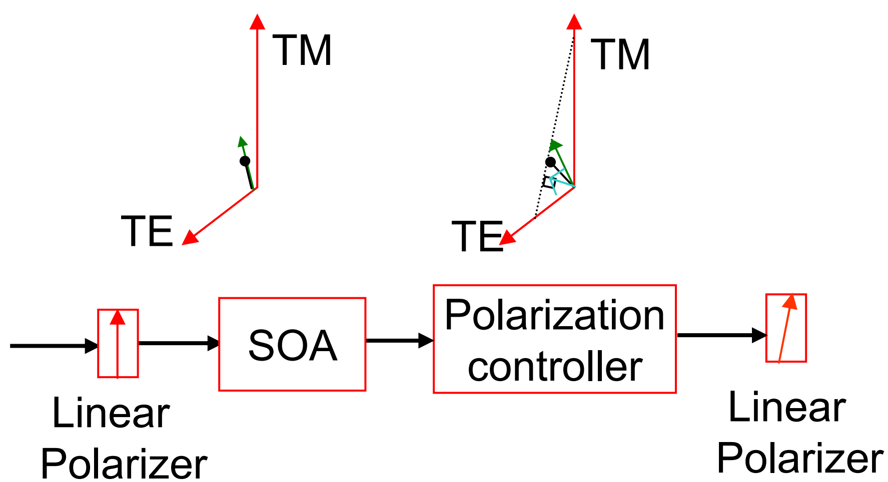
- Random pulse stream incident for 1000 ps duration
  - plot of pulses for last 200 ps
- Significant power when output pol angle is 135°
  - this is due to polarization rotation



Application eg: SOA based power equalizer

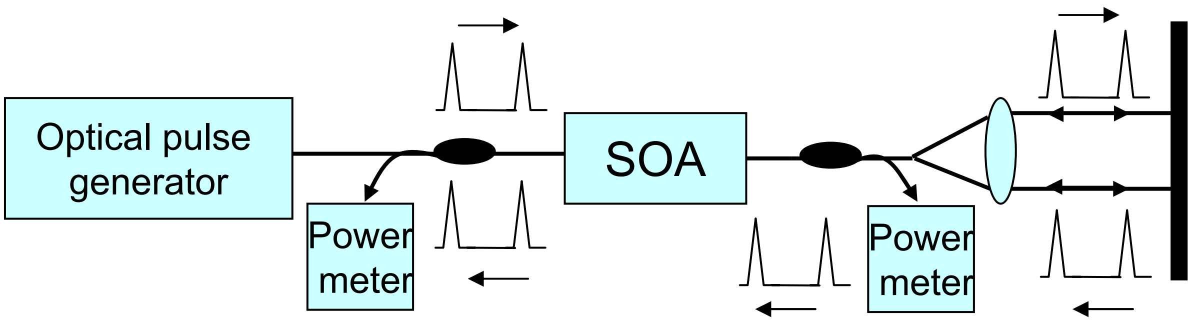
- Consists of
  - input linear polarizer
  - polarization sensitive SOA
  - polarization controller
  - output linear polarizer

- Power equalization
  - adjust linear polarizer orientation
  - ensure output high & low power signals have same projections on the output linear polarizer



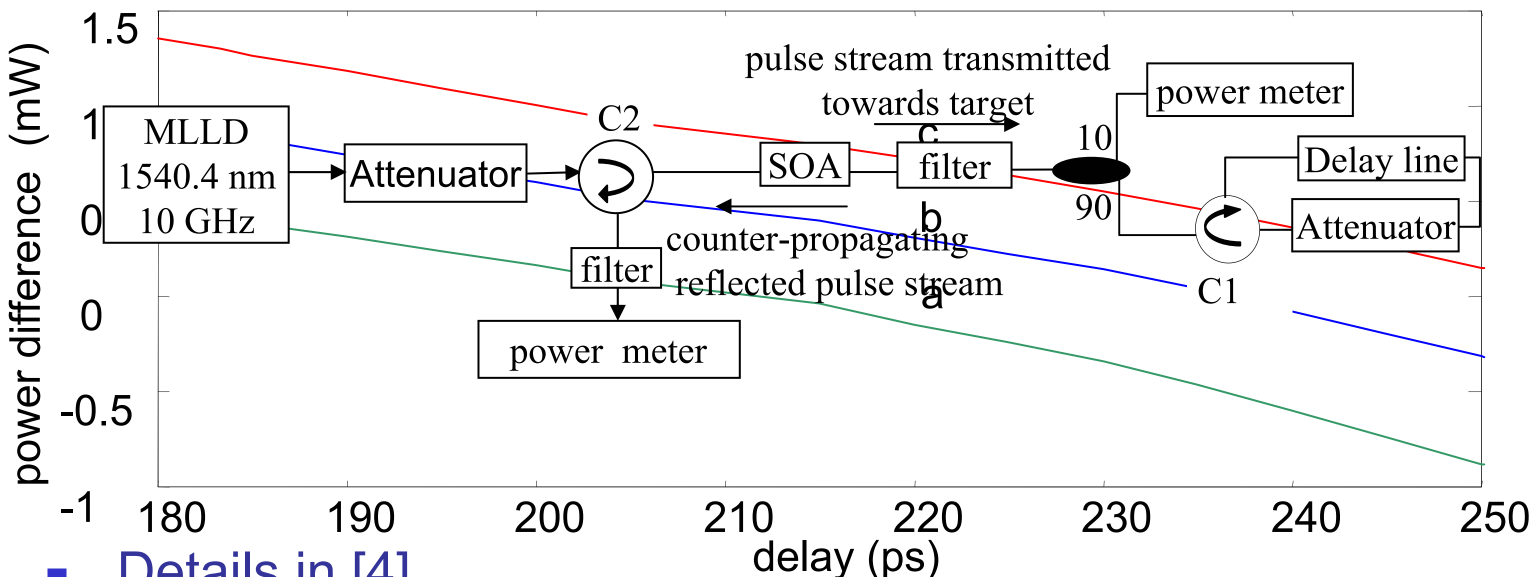
Application-SOA-based Distance Ranger [3]

- Semiconductor optical amplifier - the sensing head
- Two counter-propagating pulse streams travel through SOA simultaneously
  - cross-gain modulation between the pulse streams
- Low-speed photodiodes
  - measurement used to estimate target distance



[3] A. J. Lowery et. al, “Design and simulation of a simple laser rangefinder using a semiconductor optical amplifier-detector”, Opt. Express **13**, 3647-3652 (2005)

Experimental Results



- Details in [4]
- Reflected pulse-stream power
  - a- -13.0 dBm, b- -14.8 dBm, c- -16.6 dBm
  - input pulse power- -14.4 dBm
  - T_w- 2 ps, Pulse repetition rate-9.96 GHz
- power difference $\propto$ delay $\propto$ distance
  - Result agrees with analytical calculations

[4] B. S. Gopalakrishna Pillai *et al.*, *Experimental Demonstration of a Simple Time-of-flight Rangefinder Based on a Semiconductor Optical Amplifier*, OFC 2006, paper OTuL5

Conclusions

- Derived expressions for
  - modal gain
  - phase evolution
  - energy gain
- Assumptions
  - pulses are much shorter than SOA carrier-recovery lifetime
  - no ultra-fast phenomenon
  - pulses do not have very high energy
  - SOA does not have very high gain
- Analyzed SOA response to counter-propagating pulse streams
- Difference in energy gain $\propto$ delay difference
  - measure of delay difference
  - application in distance measurement, synchronization
- Theoretical results agree with
  - numerical integration results
  - experimental results