Distortion-Reduced Pulse-Train Propagation with Large Delay in a Triple Gain Media

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Outline

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Motivation

- Slow Light for telecommunication
  - Optical delay-line / buffer
  - Data re-synchronization
  - Jitter correction

- Slow Light based on Stimulated Brillouin Scattering (SBS) effect
  - Wide wavelength range
  - Good dynamic controllability
  - Con: limited by bandwidth and distortion

Principles: single gain line

\[ \tilde{n}(\nu) = 1 + \frac{g_0 \gamma}{2k_0} \frac{1}{\nu + i\gamma} \]

- \( \nu \) -- detuning from the line center
- \( g_0 \) -- amplitude gain coefficient
- \( \gamma \) -- Brillouin gain linewidth

Gain coefficient

Group index
Principles: double gain line

\[ \tilde{n}(\nu) = 1 + \frac{g_0 \gamma}{2k_0} \left\{ \frac{1}{(\nu-\delta)+i\gamma} + \frac{1}{(\nu+\delta)+i\gamma} \right\} \]

Gain coefficient

Group index

Principles: triple gain line

\[ \tilde{n}(\nu) = 1 + \frac{g_0 \gamma}{2k_0} \left\{ \frac{1}{(\nu-\delta)+i\gamma} + \frac{1}{(\nu+\delta)+i\gamma} + \frac{r}{\nu+i\gamma} \right\} \]

Gain coefficient

Group index
Principles: triple gain line

- Free parameters for a triple-gain-line medium:
  - half-separation $\delta$
  - Side line gain peak $A_1$
  - Peak ratio $r = \frac{A_2}{A_1}$
Principles: triple gain line

- Gain line separation and peak ratio are optimized for each bandwidth using the following 3 criteria
  - Maximal amplitude gain
    \[ G_{\text{max}} < 3.5 \]
  - Phase distortion factor
    \[ D_p \equiv (\max\{n_{\text{dev}}\} - \min\{n_{\text{dev}}\})k_0L/2\pi < 0.05 \]
    \[ n_{\text{dev}} \equiv n(\nu) - n(0) - \nu n(1) \]
  - Gain distortion factor
    \[ D_g \equiv (G_{\text{max}} - G_{\text{min}}) / (G_{\text{max}} + G_{\text{min}}) < 0.05 \]
Experimental Setup

Schematic diagram for the multi-gain-line SBS experiment

**TL**: tunable laser; **IS**: isolator; **FPC**: fiber polarization controller; **MZM**: Mach-Zehnder modulator; **AFG**: arbitrary function generator; **SMF**: single mode fiber; **VOA**: variable optical attenuator.
Pump amplitude modulation

\[ E_{\text{out, pump}} = E_0 \cos \alpha \left( -V_{\pi/2} + \frac{r}{2} V_1 + V_1 \cos 2\pi \delta t \right) \]
Experimental Setup

- SBS Gain is controlled by changing the gain of the EDFA

- Delay is measured by comparing signal output with/without pump
Results: Optimum configuration

Half separation

- Optimum value for δ

Peak ratio

- Optimum value for peak ratio r

Graphs show the relationship between Δν/γ and the optimum values for δ and peak ratio r, comparing triple-gain-line and double-gain-line configurations.
Results: Maximum delay

\[ FD \equiv \Delta T 2\pi \Delta \nu \]
Results: Maximum delay

gain distortion limited only (double gain line)

gain limited only

gain distortion limited only (triple gain line)

double gain line

maximal fractional delay

$\Delta v/\gamma$

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
Results: Eye-diagram

\[ \Delta \nu = 1.6 \gamma \]
Summary

- Multiple gain lines can be produced by biased amplitude modulation on the pump field in a SBS slow light system.

- Using a triple-gain-line system, fractional delays up to 1.5 (>30% improvement than a double-gain-line system) can be achieved with very small distortion.

- In this demonstration, $\gamma = 23.5$ MHz. However, it has been shown that $\gamma$ can be increased up to 12 GHz using a spectrally broadened pump\(^1\).

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Thank you for your attention!