Modeling of SOA-based high speed all-optical wavelength conversion with optical filter assistance

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Outline

1. Introduction
2. Analytical solution derivation and modeling
3. Simulation Results & Discussion
4. Conclusions

Introduction

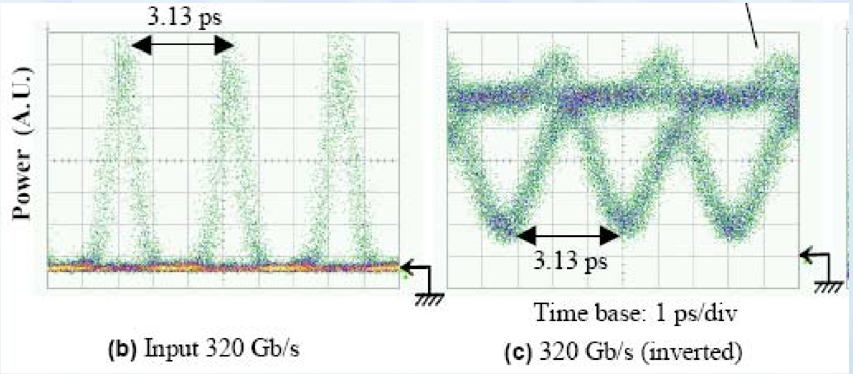
Motivation:

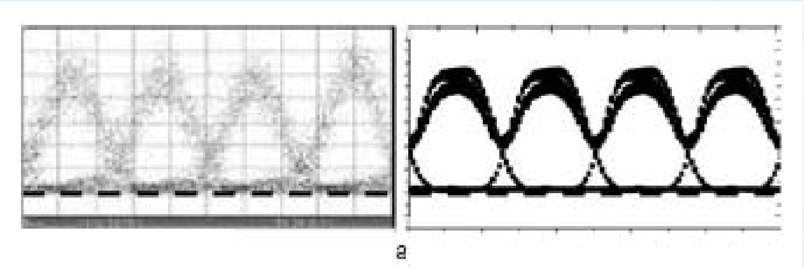
SOA-based wavelength conversion schemes with blue-shifted filter assistance were presented (40G [1] /80G/160G/320G [2]), including inverted WC and non-inverted WC.

The key point is to adjust the central wavelength of the filter with respect to probe carrier.

Objective:

to establish a uniform formula to explain wavelength conversion polarity evolution .





40Gb/s

[1] M. L. Nielsen, *et al*. “Polarity-preserving SOA-based wavelength conversion at 40 Gbit/s using bandpass filtering,” *Electron. Lett.*, vol.39, pp. 1334 - 1335, 2003

[2] Y. Liu, *et al*. “Error-free 320 Gb/s SOA-based Wavelength Conversion using Optical Filtering,” *OFC 2006*, PDP28.

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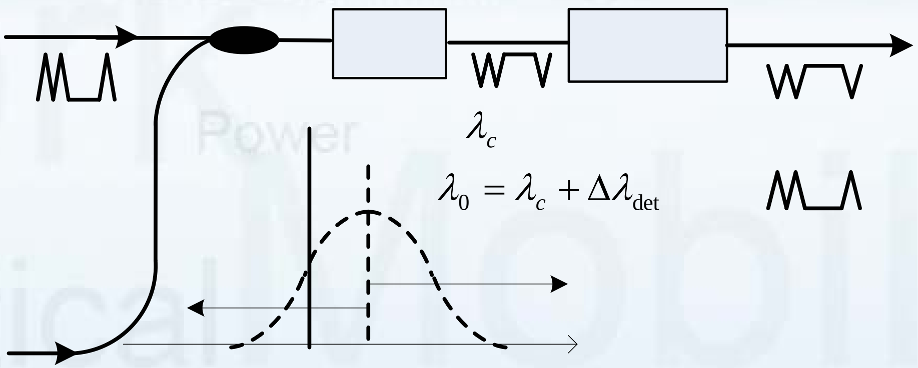
Analytical solution derivation

Basic configuration



Modeling:

The optical field of probe signal after SOA can be expressed as

$$E_{probe}(t) = E_{in} g(t) \exp[i(\omega_0 t - \Phi(t))] \quad (1)$$

the impulse response function of the OBF is obtained by

$$h(t) = \frac{B_0}{\sqrt{2\pi}} \exp[-\frac{1}{2}(B_0 t)^2] \exp(i\omega_f t) \quad (2)$$

The output filtered signal is a convolution

$$E_{out}(t) = E_{probe}(t) \otimes h(t) = \int E_{inv}(\tau) h(t-\tau) d\tau \quad (3)$$

$$= \frac{B_0}{\sqrt{2\pi}} \int_{-\infty}^{\infty} E_{in} g(\tau) \exp[i(\omega_0 \tau - \Phi(\tau))] \exp[-\frac{1}{2}(B_0(t-\tau))^2] \exp[i\omega_f (t-\tau)] d\tau$$

$$E_{out}(t) = \lim_{\varepsilon \to 0} \frac{B_0 \varepsilon}{\sqrt{2\pi}} \sum_{n=-\infty}^{\infty} E_{in} g(t+n\varepsilon) \exp[i(\omega_0 (t+n\varepsilon) - \Phi(t+n\varepsilon))] \exp[-\frac{1}{2}(B_0 n\varepsilon)^2] \exp[-i\omega_f n\varepsilon] \quad (4)$$

$$E_{out}(t) = \frac{B_0 \varepsilon E_{in}}{\sqrt{2\pi}} g(t) \exp[i(\omega_0 t - \Phi)] \mathrm{Re}(\varepsilon, t) + \frac{B_0 \varepsilon E_{in}}{\sqrt{2\pi}} \frac{dg(t)}{dt} \exp[i(\omega_0 t - \Phi)] \mathrm{Im}(\varepsilon, t)$$

$$\mathrm{Re}(\varepsilon, t) = \lim_{\varepsilon \to 0} \{1 + \sum_{n=1}^{N} 2 \cdot \exp[-\frac{1}{2}(B_0 n\varepsilon)^2] \cdot \cos[(\omega_f - \omega_0 + \frac{d\Phi}{dt}) n\varepsilon]\} \varepsilon$$

$$\mathrm{Im}(\varepsilon, t) = \lim_{\varepsilon \to 0} \{i \cdot \sum_{n=1}^{N} 2n\varepsilon \cdot \exp[-\frac{1}{2}(B_0 n\varepsilon)^2] \cdot \sin[(\omega_f - \omega_0 + \frac{d\Phi}{dt}) n\varepsilon]\} \varepsilon$$

the output optical power can be obtained

$$P_{out}(t) = |E_{out}(t)|^2 = P_{in} \exp[-(4\ln 2)(\frac{\nu_f - \nu_0 - \Delta\nu(t)}{B_{3dB}})^2][g^2(t) + g'(t)^2 (2\ln 2 \frac{\nu_f - \nu_0 - \Delta\nu(t)}{\pi B_{3dB}^2})^2]$$

$$\Delta\nu(t) = -\frac{1}{2\pi} \frac{d\Phi}{dt} \quad (5)$$

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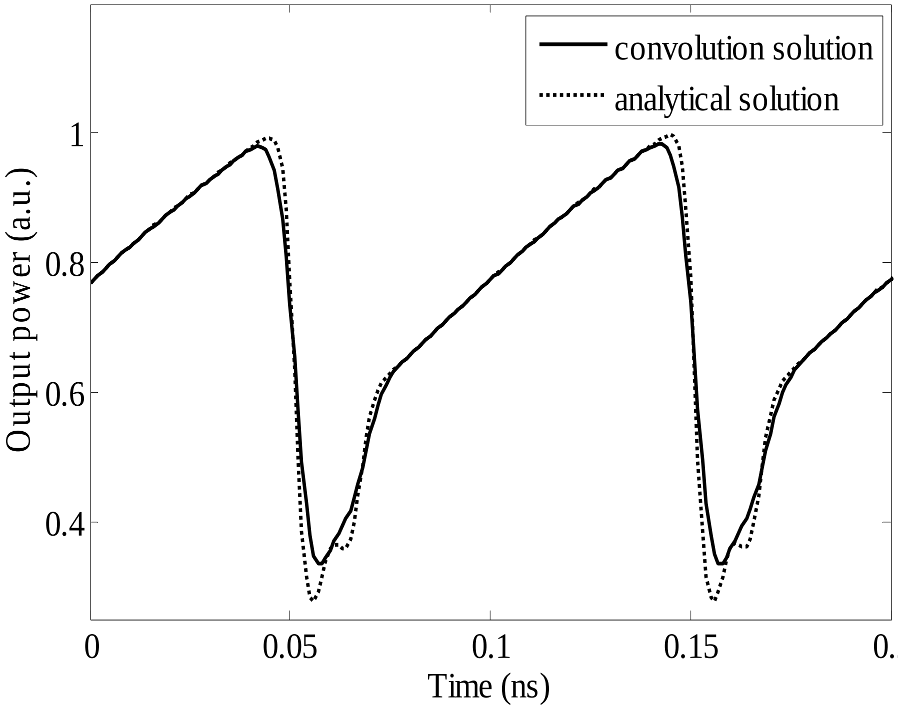
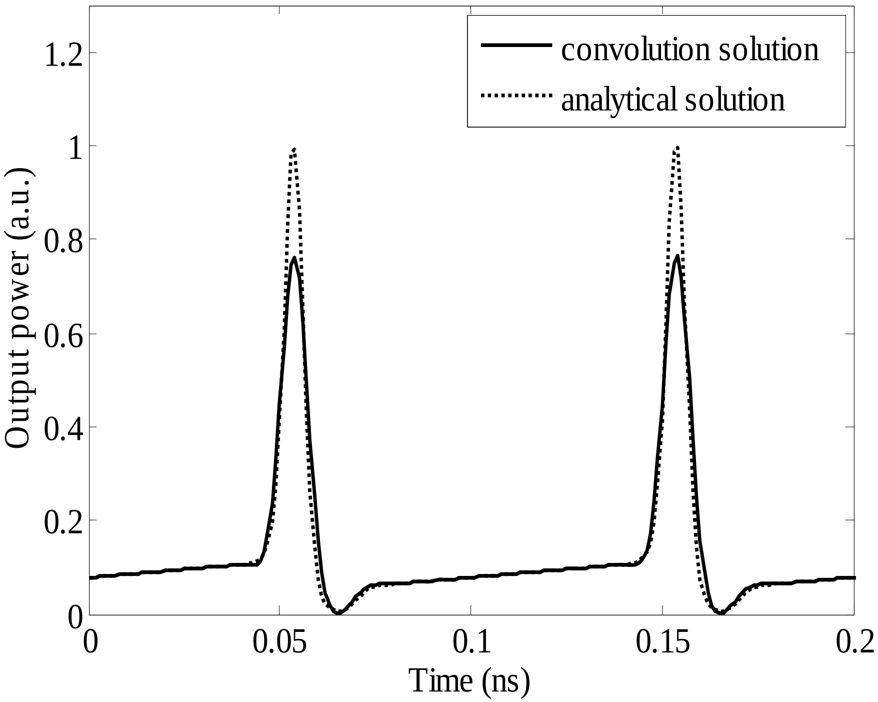
Error analysis of the formula



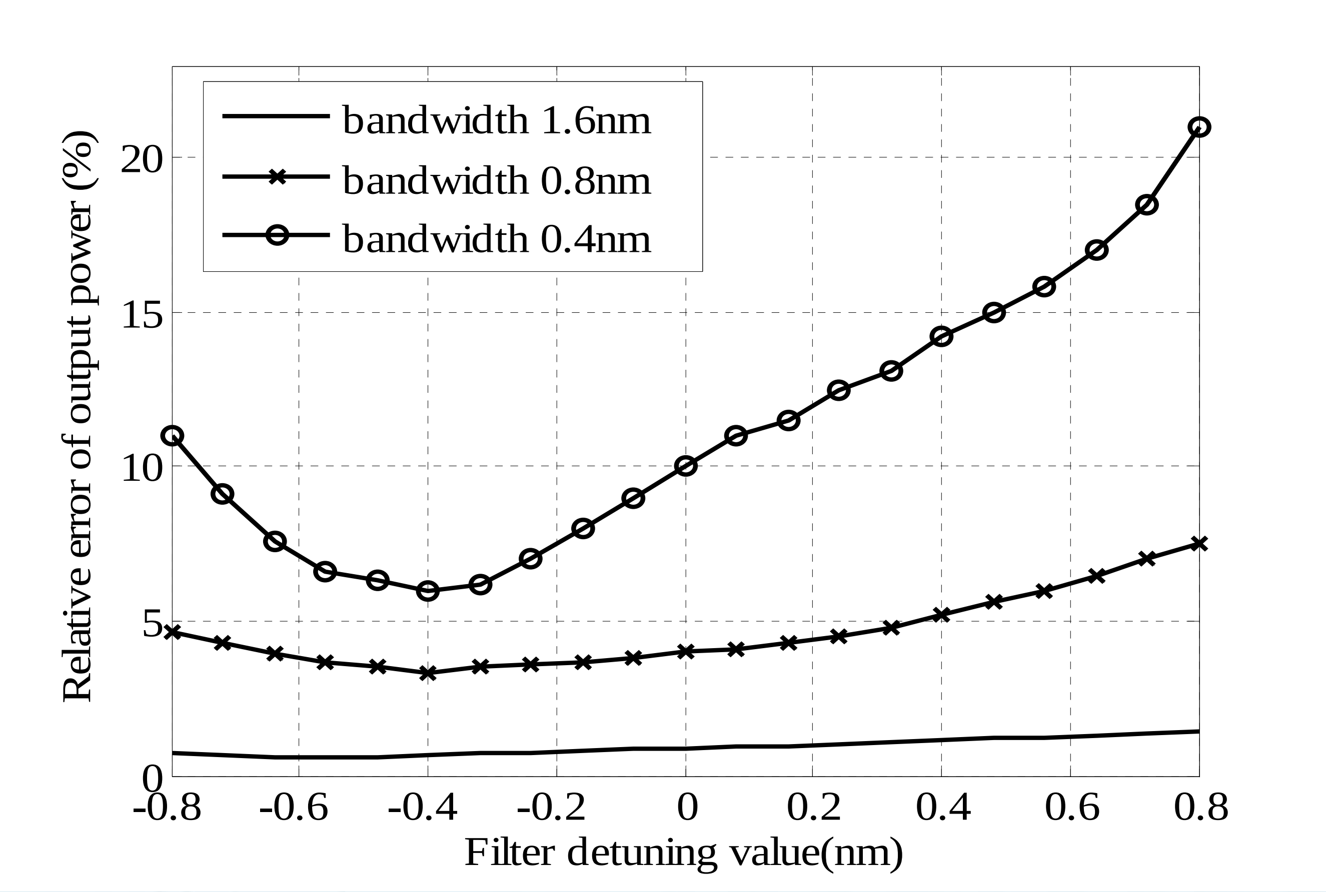


Detuning=0nm

Detuning=0.8nm

Comparison between FFT solution and analytical solution

Error analysis of the formula

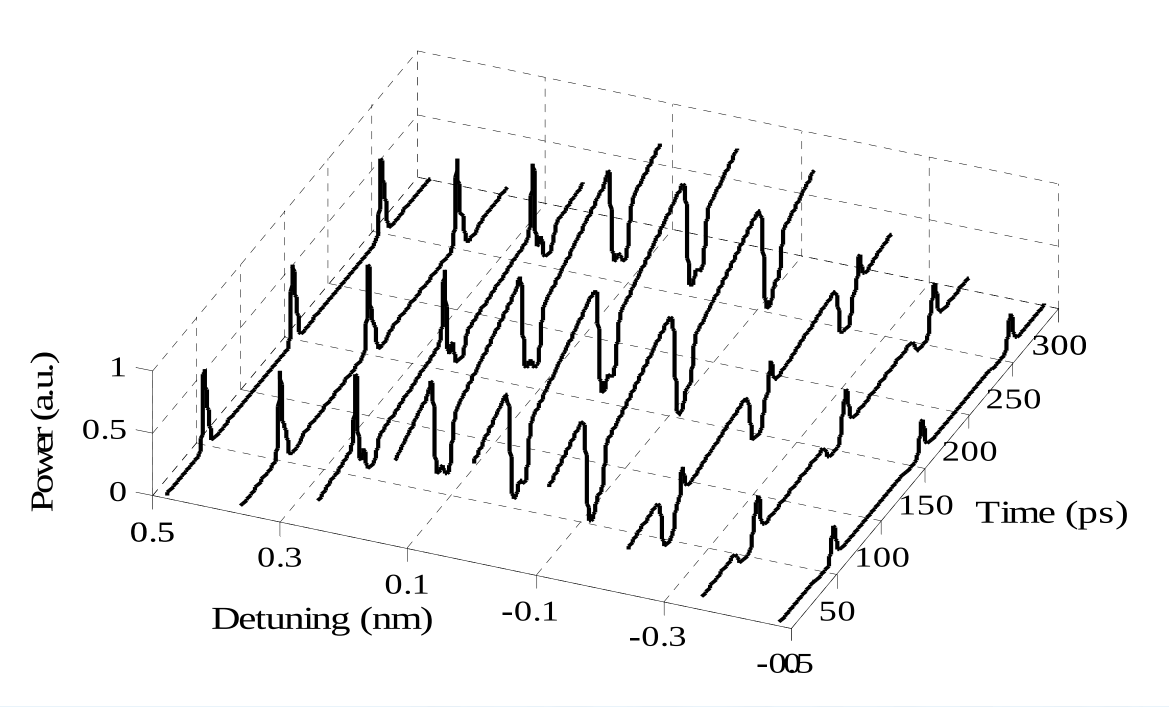


Comparison between FFT solution and analytical solution

Simulation Results

$$P_{out}(t) = |E_{out}(t)|^2 = P_{in}\exp[-(4\ln 2)(\frac{\nu_f - \nu_0 - \Delta\nu(t)}{B_{3dB}})^2][g^2(t) + g^{'}(t)^2(2\ln 2\frac{\nu_f - \nu_0 - \Delta\nu(t)}{\pi B_{3dB}^2})^2]$$

Transient cross phase modulation **Cross gain modulation**



The evolutions of the output filtered waveforms when the filter detuning varies from -60GHz to 60GHz

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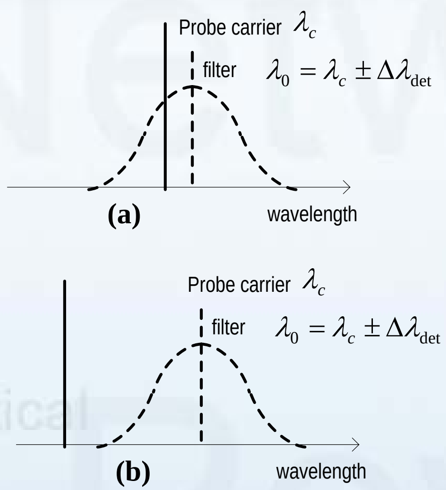
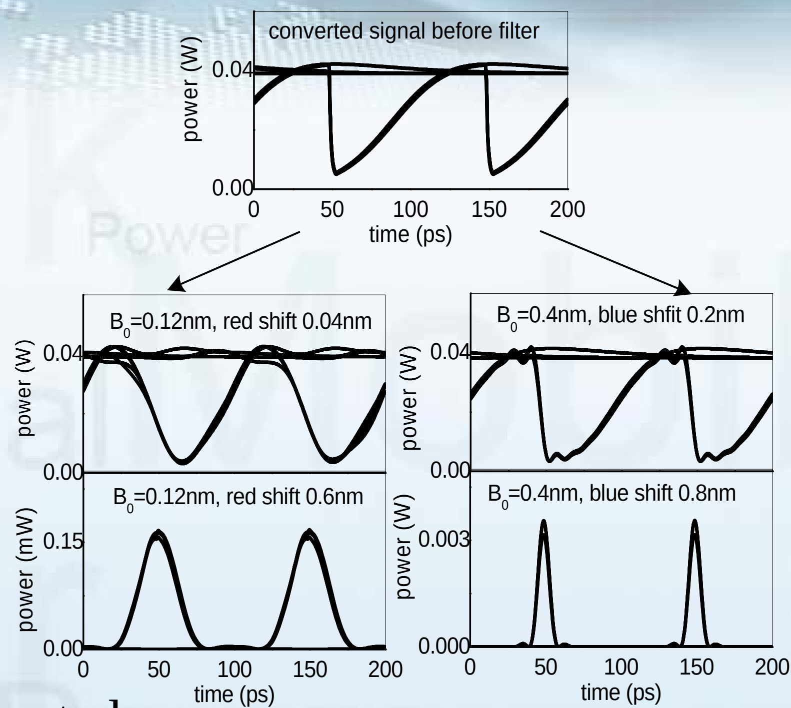
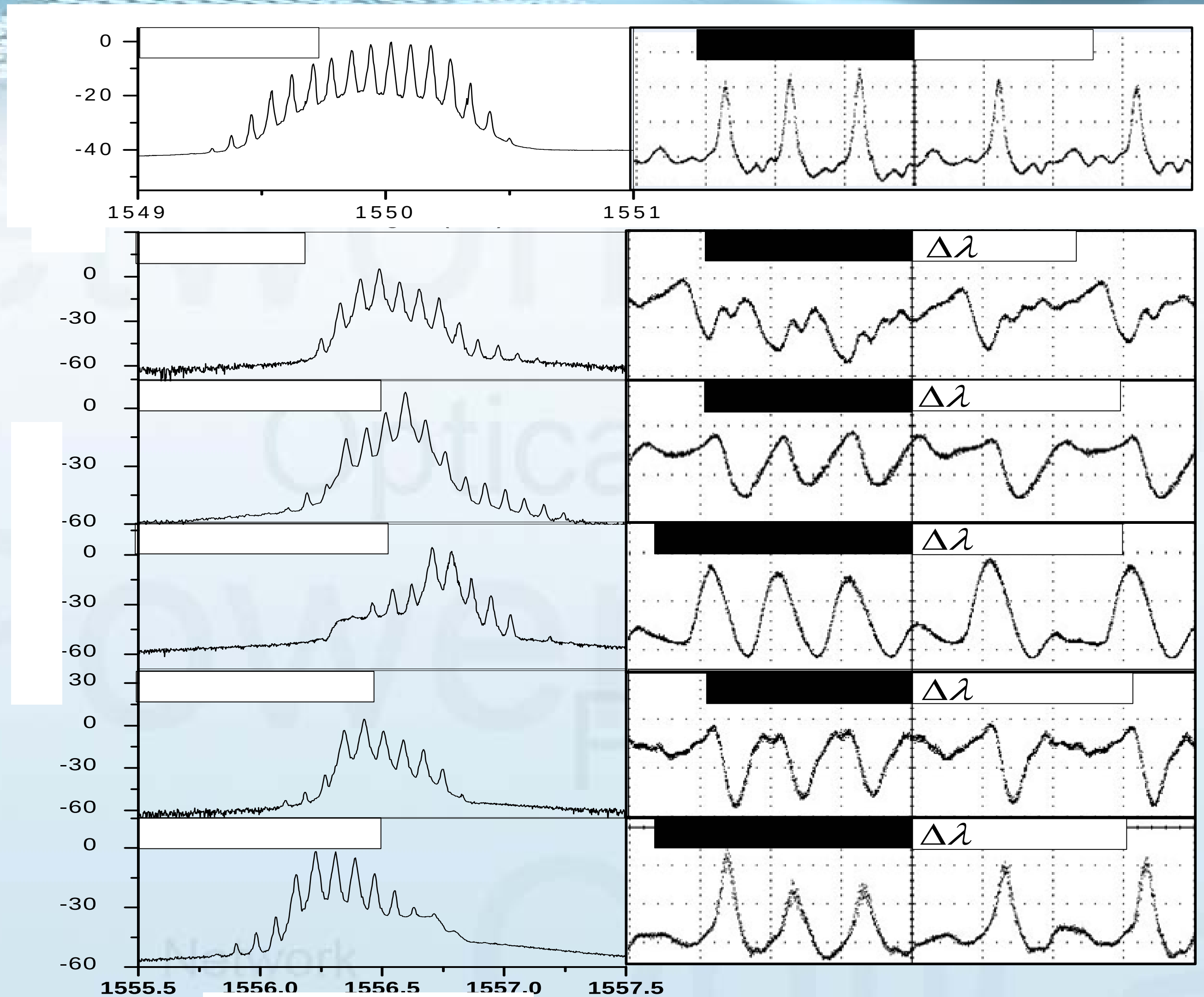
Discussion





- Inverted WC:
  - the gain recovery can be accelerated.
  - the filter central wavelength is close to probe wavelength.
- Non-inverted WC:
  - the filter central wavelength is detuned far to the probe wavelength.
  - some applications in all-optical logic gates, optical adders

Experimental verification



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S. Fu, J. Dong, *et al*, "Experimental demonstration of both inverted and non-inverted wavelength conversion based on transient cross phase modulation of SOA," Opt. Express 14, 7587-7593 (2006)

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Table 1. The comparison between experiments and calculations based on Eq. (5).

polarity	blue shift/nm		red shift/nm	
	experiment	**calculation**	experiment	**calculation**
inverted	0.04-0.08	**0.04-0.16**	0.05-0.08	**0.04-0.12**
non-inverted	0.24-0.3	**0.28-0.48**	0.25-0.34	**0.28-0.52**

Table 2. The parameters in experimental reports of high speed all-optical WC.

Ref Number	Bit rate /GHz	polarity	Pulsewidth /ps	Bandwidth /nm	Detuning/nm experiment	Detuning/nm simulation
[3]	40	non-inverted	7	0.22	0.5	0.48-0.64
[1]	160	inverted	1.9	1.4	1.23	1.04-1.52
[2]	320	inverted	1	2.7	2.5	2.08-2.88

[1] Y. Liu, E. Tangdiongga, Z. Li, IEEE J.Lightwave.Technol., 24, 230-236, 2006.
[2] Y. Liu, E. Tangdiongga, Z. Li, et al. OFC 2006, PDP28, 2006
[3] M. L. Nielsen, B. Lavigne, B. Dagens, et al. Electron. Lett., Vol.39, pp. 1334 - 1335, 2003.

Conclusions

1. An analytical formula is deduced to investigate the TXPM-based WC evolution.
2. Both inverted and non-inverted WCs can be realized when the central wavelength of the optical bandpass filter is either blue-shifted or red-shifted with respect to the wavelength of the probe signal.
3. The simulation detuning values are in good agreement with those experimental results.

Acknowledgements

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Thank you !