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

Jianji Dong\textsuperscript{1,2}, Songnian Fu\textsuperscript{1}, P. Shum\textsuperscript{1}, Xinliang Zhang\textsuperscript{2}, Dexiu Huang\textsuperscript{2}

\textsuperscript{(1)} Network Technology Research Centre, Nanyang Technological University, 637553, Singapore.

\textsuperscript{(2)} Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, 430074, China.
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 \cite{1}/80G/160G/320G \cite{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.


Analytical solution derivation

Basic configuration

Modeling:

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

\[ E_{\text{probe}}(t) = E_{\text{in}} g(t) \exp[i(\omega_0 t - \Phi(t))] \]  \hspace{1cm} (1)

the impulse response function of the OBF is obtained by

\[ h(t) = \frac{B_0}{\sqrt{2\pi}} \exp\left[-\frac{1}{2} (B_0 t)^2\right] \exp(i\omega_f t) \] \hspace{1cm} (2)
The output filtered signal is a convolution

\[ E_{\text{out}}(t) = E_{\text{probe}}(t) \otimes h(t) = \int E_{\text{inv}}(\tau)h(t-\tau)d\tau \]  \hspace{1cm} (3)

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

\[ E_{\text{out}}(t) = \lim_{\varepsilon \to 0} \frac{B_0\varepsilon}{\sqrt{2\pi}} \sum_{n=-\infty}^{\infty} E_{\text{in}}(t+n\varepsilon) \exp[i(\omega_0(t+n\varepsilon) - \Phi(t+n\varepsilon))] \exp[-\frac{1}{2}(B_0n\varepsilon)^2] \exp[-i\omega_fn\varepsilon] \]  \hspace{1cm} (4)

\[ E_{\text{out}}(t) = \frac{B_0\varepsilon E_{\text{in}}}{\sqrt{2\pi}} g(t) \exp[i(\omega_0t - \Phi)] \Re(\varepsilon,t) + \frac{B_0\varepsilon E_{\text{in}}}{\sqrt{2\pi}} \frac{dg(t)}{dt} \exp[i(\omega_0t - \Phi)] \Im(\varepsilon,t) \]

\[ \Re(\varepsilon,t) = \lim_{\varepsilon \to 0} [1 + \sum_{n=1}^{N} 2 \exp[-\frac{1}{2}(B_0n\varepsilon)^2] \cos[(\omega_f - \omega_0 + \frac{d\Phi}{dt})n\varepsilon]]\varepsilon \]

\[ \Im(\varepsilon,t) = \lim_{\varepsilon \to 0} [i \sum_{n=1}^{N} 2n\varepsilon \exp[-\frac{1}{2}(B_0n\varepsilon)^2] \sin[(\omega_f - \omega_0 + \frac{d\Phi}{dt})n\varepsilon]]\varepsilon \]

The output optical power can be obtained

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

\[ \Delta \nu(t) = -\frac{1}{2\pi} \frac{d\Phi}{dt} \]  \hspace{1cm} (5)
Error analysis of the formula

Comparison between FFT solution and analytical solution

Detuning=0nm
Detuning=0.8nm
Error analysis of the formula

Comparison between FFT solution and analytical solution
Simulation Results

\[ P_{\text{out}}(t) = |E_{\text{out}}(t)|^2 = P_{\text{in}} \exp\left[-(4\ln 2)\left(\frac{v_f - v_0 - \Delta v(t)}{B_{3dB}}\right)^2\right]\left[g^2(t) + g'(t)^2\left(2\ln 2\frac{v_f - v_0 - \Delta v(t)}{\pi B_{3dB}^2}\right)^2\right] \]

Transient cross phase modulation

Cross gain modulation

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

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

<table>
<thead>
<tr>
<th>polarity</th>
<th>experiment blue shift/nm</th>
<th>calculation blue shift/nm</th>
<th>experiment red shift/nm</th>
<th>calculation red shift/nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>inverted</td>
<td>0.04-0.08</td>
<td>0.04-0.16</td>
<td>0.05-0.08</td>
<td>0.04-0.12</td>
</tr>
<tr>
<td>non-inverted</td>
<td>0.24-0.3</td>
<td>0.28-0.48</td>
<td>0.25-0.34</td>
<td>0.28-0.52</td>
</tr>
</tbody>
</table>

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

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

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

This work is partially supported by the project M47040039 of Agency for Science, Technology and Research, Singapore
Thank you!