Synthesis of phase-locked counter-phase modulated pumps for SBS-suppressed fiber parametric amplifiers

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Abstract: We propose and experimentally demonstrate a new all-optical technique for the generation of two optical pumps with oppositely varying carrier phases for mitigating SBS in parametric amplifiers without phase-dither transfer from pumps to signal.

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1. Introduction

The need to suppress stimulated Brillouin scattering (SBS) is currently a major limitation of fiber optic parametric amplifiers (FOPA) [1]. The most common approach to raise the SBS threshold is by dithering the pump phase thereby reducing the power spectral density. However, this is accompanied by detrimental spectral broadening of the idler wave, as well as gain distortions originating from the modulator rise and fall times [2-3]. Theoretically, the idler broadening can be fully suppressed by using a two-pump FOPA (2P FOPA) in which the two pumps are modulated using complementary phase patterns. This was demonstrated in various schemes directly employing a $LiNbO_3$ modulator (with the optical delay between the two pumps precisely calibrated) [4] or two $LiNbO_3$ modulators (driven by opposite electrical drive signals) [5]. These approaches are limited by the need for precise phase and amplitude synchronization of the modulating signals, as well as the finite device rise and fall times [6]. Recently, a customized dual wavelength push-pull style modulator [6] was demonstrated negating the need for the electrical signal synchronization in the previous schemes.

Phase sensitive amplifier (PSA) applications require pumps that are not only oppositely dithered but also have carriers locked in phase. In this paper we demonstrate a new all-optical configuration in which two counter-phased pumps can be automatically phase locked to an incoming signal and can thus be directly used in a two pump FOPA without the need for dynamic pumps-signal phase synchronization. It is based on a cascaded process of second harmonic generation (SHG) followed by difference frequency generation (DFG) in a 30-mm long periodically-poled $LiNbO_3$ (PPLN) waveguide [7]. The use of the PPLN guarantees far greater immunity to the effects of SBS of the pump beams as well as the use of pumps with spectral separations of up to 80 nm.

2. Experimental Setup and Results

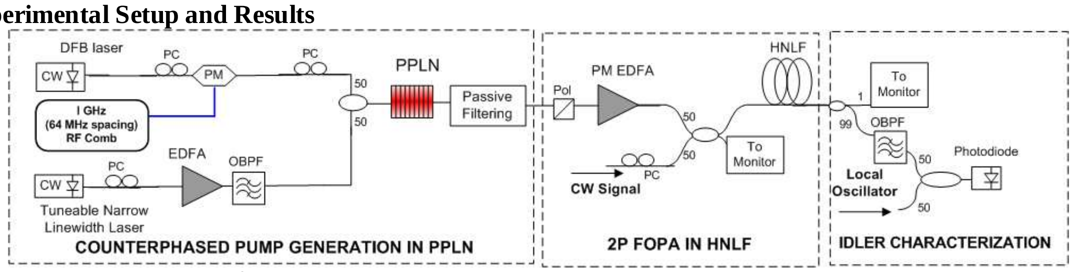

Figure 1: Phase sensitive amplifier setup, CW – continuous wave, PM EDFA – polarisation maintaining erbium doped fibre amplifier, PC – polarisation controller, PM – phase modulator, Pol – Polariser, OBPF – optical band pass filter.

A narrow linewidth (~10 kHz) CW signal at 1539 nm (primary pump) was amplified to 20 dBm and combined with another CW signal at 1545.5 nm (linewidth of ~15 MHz), which was phase modulated using a 64 MHz spaced electrical RF comb to broaden its linewidth to 1 GHz (Secondary Pump). With this setup, the use of a $LiNbO_3$ modulator could in the future be replaced by all-optical techniques such as cross phase modulation (XPM) in a nonlinear medium [8] to modulate the secondary pump. This would prevent the unwanted residual amplitude noise transfer to the modulated waves that is characteristic of $LiNbO_3$ phase modulators, as this can significantly impair the noise performance of the 2P FOPA, more so in the PSA configuration.

Subsequently, the two waves were launched into the PPLN waveguide (coupling loss 1.4dB , propagation loss 0.3dB/cm, nonlinear SHG coefficient 25 pm/V at 1064 nm) with a total input power of 21 dBm (limited by the device damage threshold). The phase matching wavelength of the PPLN device is 1545.5 nm at 44^{o}C. Due to the cascaded SHG/DFG process [7] an idler at 1552 nm is generated. If φ_p, φ_s and φ_i are the absolute phases of the primary pump, signal, and idler waves, respectively, then $\varphi_i = 2\varphi_p - \varphi_s$, implying that the idler and signal are counter-phased within the narrow limits imposed by the $2\varphi_p$ term. In addition, if the primary pump is obtained from a recovered signal carrier then the $2\varphi_p$ term indicates that the counter-phased pumps are phase locked to the signal, and could be directly used in a PSA. Due to the relatively low input powers, the generated idler power was 17 dB below that of the signal and therefore an intermediate stage, comprising an EDFA and passive filters, was required to reduce the signal-idler pair power difference followed by narrow filtering to remove the residual primary pump signal. The two remaining signals were the generated counter phased pumps that could be directly used in a subsequent FOPA, see Fig.2(a).

To evaluate the phase correlation of the counter-phased pumps and to show its usability in an FOPA, the following characterization was carried out. The pumps were amplified and coupled into a 500m HNLF (zero dispersion wavelength 1550 nm, dispersion slope 0.03 ps/nm^2/km, nonlinearity 20/W/km and loss 0.53 dB/km). They were then combined with a 15-MHz linewidth 1548 nm CW signal to generate an idler at the wavelength of 1542 nm via the four wave mixing (FWM) process, see Fig. 2(b).

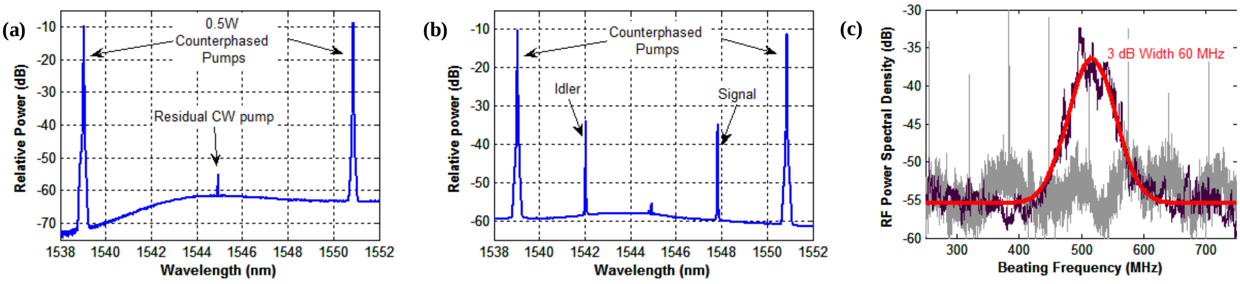

Figure 2(a) -- Counter phased pumps at the 2P FOPA HNLF input amplified in a PM EDFA with OSNRs exceeding 50 dB. 2(b) -- 2P FOPA output spectrum with idler OSNR over 25 dB. 2(c) --Heterodyne signal generated by mixing idler and a local oscillator, thick solid line is 60 MHz fit, dashed grey line shows mixing result with both pumps co-phased in the same $LiNbO_3$ modulator.

The idler, which had an optical signal-to-noise ratio (OSNR) better than 20 dB, was then extracted at the output of the HNLF and subsequently heterodyned with a ~15 MHz linewidth CW laser of a slightly different carrier frequency (about 520 MHz apart). The heterodyne signal is shown in Fig. 2(c) showing beating 3-dB width of 60 MHz, which is within a factor of 2 of the anticipated minimum beating width. As a comparison, the dashed grey line in Fig. 2(c) shows the mixing result when two co-phased pumps are used in the same 2P FOPA (bypassing the PPLN), revealing the transfer of the pump dither including the strong 64 MHz spaced tones to the idler and a linewidth exceeding the 750 MHz measurement bandwidth. In addition, pump powers in excess of 30 dBm were coupled into the 2P FOPA without exceeding the SBS threshold, indicating a threshold increase of at least 13 dB.

4. Conclusions

We used a simple optical technique to generate counter-phased pumps for 2P FOPA applications with optical signal-to-noise ratio >50 dB and thereby drastically reduce the broadening experienced by the idler of a HNLF-based PSA. The use of parametric techniques to perform the counter-phasing allows for pumps that are automatically phase locked to an incoming signal.

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5. References

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