# Novel Polarization-assisted Phase Sensitive Optical Signal Processor Requiring Low Nonlinear Phase Shifts

**F. Parmigiani*, G. Hesketh, R. Slavík, P. Horak, P. Petropoulos, D. J. Richardson**
*Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK*
**frp@orc.soton.ac.uk*

**Abstract:** We demonstrate a new scheme to achieve binary step-like phase response and high phase-sensitive extinction ratio at low powers. Phase-sensitive operation is achieved by polarization filtering phase-locked signal/idler in a degenerate dual-pump vector parametric amplifier.
**OCIS codes:** (060.2320) Fiber optics amplifiers and oscillators, (190.4410) Nonlinear optics, parametric processes.

## 1. Introduction

Nonlinear optical processing subsystems exhibiting high phase sensitivity and binary step-like phase response are central in several different applications, such as optical phase regeneration and optical demultiplexing of phase shift keying (PSK) signals [1-3] and analogue-to-digital conversion (ADC) [2]. Phase sensitive amplifiers (PSAs) based on four-wave mixing (FWM) in a highly nonlinear fiber (HNLF) [2] are often used as the basis for such subsystems; a two-level phase response is the result of the coherent addition of the original signal and its first FWM generated complex-conjugated copy (idler). For a binary step-like phase response, the strength of the idler must be comparable to that of the signal allowing for a large phase sensitive extinction ratio, PSER, (defined as the difference between the maximum phase sensitive (PS) gain and the maximum PS de-amplification). Large symmetric (i. e. maximum PSA gain equal to maximum PS de-amplification) PSERs are conventionally achieved only at high pump powers resulting in the generation of other FWM components across a wide spectral bandwidth which, although undesirable in many instances, can be exploited to provide large (asymmetric) PSER. In fact, PSERs of 25dB at a nonlinear phase shift (NPS) of 0.8 rad have been experimentally demonstrated in the scalar degenerate dual-pump PSA [3].

Herein, we propose and experimentally demonstrate a scheme to achieve a high PSER and binary step-like phase response at significantly lower nonlinear phase shifts by generating an idler in the orthogonal polarisation state as compared to the signal via degenerate parametric amplification with two orthogonally aligned pumps. By rotating the angle of a polarizer at the output, it is possible to carefully match the relative strengths of the signal and idler beams even in the instance that the generated idler is significantly weaker than the signal, i.e. at low pump powers. We experimentally demonstrate PSER of around 26dB for a NPS as low as 0.3 rad. The performance of the new scheme is compared to that of both a conventional dual-pump vector PSA as well as a scalar one, showing an increase in the PSER of more than 20dB for a total pump power of less than 20dBm.

## 2. Polarization-assisted dual-pump vector PSA scheme

The operating principle of the polarization-assisted degenerate dual-pump vector PSA scheme is shown in Fig.1. In a conventional degenerate dual-pump vector PSA, the linearly polarized signal is launched at 45° with respect to the two orthogonally polarized pumps [5-6], this generates an idler co- polarised with the signal, allowing for their direct interference. In our proposed implementation the signal is co-polarized with one of the pumps. The signal complex conjugated copy (idler) is generated in the orthogonal polarisation axis and thus no PSA occurs. However, placing a polariser at its output with its polarisation angle carefully adjusted, it is possible to obtain the same projection of the signal and idler along the polarizer axis and to have them interfere; the angle required for optimal interference depends on the overall difference in strength between the idler and the signal, i.e. overall pump power.

In the experiment, an overdriven amplitude modulator (AM) was used to modulate a 17dBm, 1557.4nm continuous wave (CW) laser to produce an optical frequency comb with 50GHz spacing. An example of the generated optical spectrum is shown in Fig.1. The comb was filtered and demultiplexed using a programmable filter (PF) to select the desired phase-locked signal and pumps waves. The signal was passed through a phase modulator (PM) driven at ~1GHz to induce continuous phase variations of over 2π, see corresponding constellation in Fig.1. The waves were then recombined with the desired polarisation, see corresponding spectrum in Fig.1, and launched into the HNLF. The signal and the generated idler at the same frequency, but orthogonal polarisation, were filtered and their polarisation state was adjusted before going into a polarizer. A constellation diagram after the PSA is shown in Fig.1, highlighting the excellent phase squeezing capability of the scheme. Fig.2a shows the simulated and measured PSERs as a function of total pump power for our scheme, conventional vector PSA and scalar PSA (all schemes are based on dual-pump degenerate FWM). It can be seen that for a total pump power as low as 20dBm

(NPS of 0.3 rad), it is possible to achieve a PSER of about 26dB in our scheme, which is mainly limited by the extinction of the polarisation maintaining components used. To achieve comparable PSERs for the other schemes, NPSs of 1rad and 7rad, respectively, are required. Fig.2b contrasts the phase transfer functions of two cases corresponding to values of PSER of 5dB and 26dB, while Fig.2c shows the measured spectral traces after the HNLF for the scalar and vector PSA schemes for the same total pump power of 25dBm at the HNLF input. The FWM components generated solely by the pumps interactions can be reduced by 40dB for the vector case as compared to the scalar one, highlighting the difference in bandwidth occupation between the two schemes. Finally, it is worth pointing out that, by splitting the PSA output signal and passing it through two polarizers at different but correlated angles it would be possible to simultaneously squeeze the signal onto two orthogonal axes, enabling complete QPSK demodulation [4].

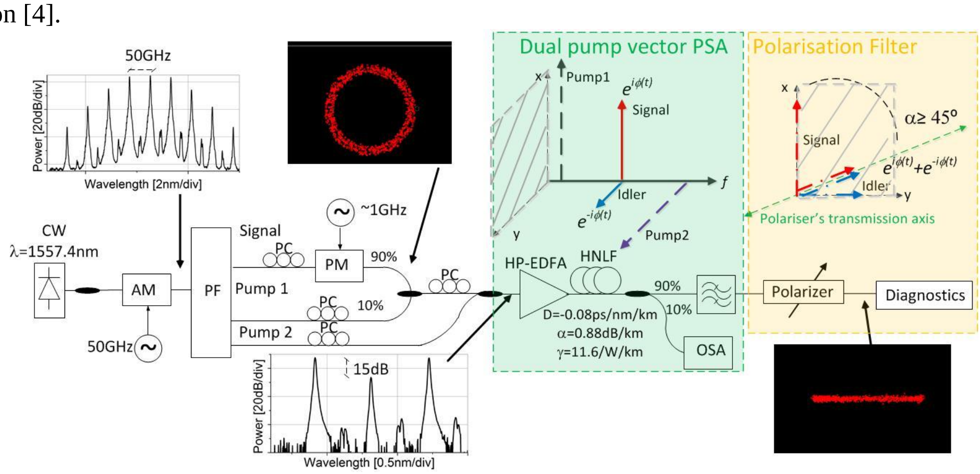


Fig. 1: Experimental set-up of the polarization-assisted dual-pump vector PSA scheme. Inset figures: Operation principle sketch, spectral traces and constellation diagrams at different points in the system.

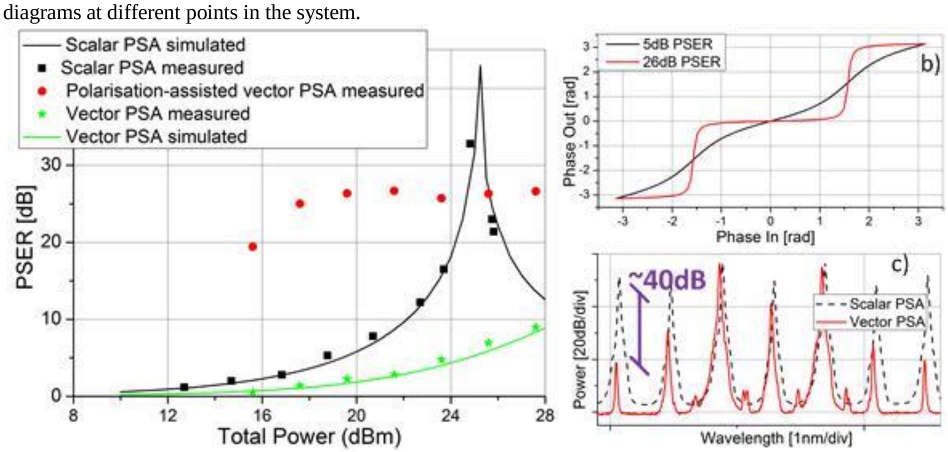


Fig. 2: a) Measured and simulated PSER as a function of total power launched into HNLF for various schemes. b) Simulated phase transfer functions as a function of input phase for two PSERs. c) Measured output optical spectra for vector and scalar PSAs (OSA resolution of 0.01nm).

## 3. Conclusion

We have proposed and experimentally demonstrated a new phase sensitive signal processor based on polarization-assisted degenerate dual-pump vector parametric amplifier, showing a PSER of more than 26dB for a nonlinear phase shift as low as 0.3 rad. The improvement as compared to the more conventional schemes has been highlighted.

## 4. References


[1] R.Slavík et al.,"All-optical phase and amplitude regenerator for next-generation telecommunications systems," Nat. Phot. 4, 690–695 (2010).

[2] J. Kakande et al., "Multilevel quantization of optical phase in a novel coherent parametric mixer architecture", Nat. Phot. 5, 748-752, (2011).

[3] M. Gao et al., Electronics Lett., 39 (2), 140-141 (2013).

[4] M. Gao et al., "Low-penalty Phase De-multiplexing of QPSK Signal by Dual-pump Phase Sensitive Amplifiers", ECOC, We.3.A.5 (2013).

[5] C. J. McKinstrie and S. Radic, "Phase-sensitive amplification in a fiber", Opt. Exp. 12, 4973-4979 (2004).

[6] A. L. Riesgo, et al., "Demonstration of Degenerate Vector Phase-Sensitive Amplification", We.3.A.3, ECOC 2013.