Experimental Investigation of Quasi-Periodic Power Spectrum in Raman-Assisted Phase Sensitive Amplifier for 10/20/50-Gbaud QPSK and 10-Gbaud 16QAM Signals

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Abstract *Raman-assisted PSA without phase-stabilization-loop is experimentally evaluated by placing signals at different locations in a quasi-periodic PSA power spectrum. With phase adjustment, an 18dB peak-dip gain-extinction-ratio difference is observed. Improved performance is demonstrated using 10/20/50-Gbaud QPSK and 10-Gbaud 16QAM signals.*

Introduction

Phase sensitive amplifier (PSA) has gained great attention in ultra-low noise amplification[1-3] and optical signal regeneration[4,5]. Meanwhile, the quasi-periodic PSA power spectrum, which encompasses periodic peaks and dips, has been discovered in the cascaded PSA configuration[6]. Although there are prior works investigating the quasi-periodic spectrum in terms of noise level, power distribution and gain characteristic[6-8], few have reported on systematic manipulation of the spectrum to study and optimize the system performance with the modulated data transmission.

In this paper, the system performance of a cascaded Raman-assisted PSA without phase stabilization[9] is experimentally evaluated and optimized by placing signal on different positions of the quasi-periodic spectrum. The gain-extinction-ratio (GER) of the signal at the peak is 18dB higher than that at the dip when phases are adjusted at both locations. A system sensitivity difference of 4.5dB is observed by placing the signal at the peak and the dip. With relative phase optimization and signal positioning at the peak, about 3dB and 5dB sensitivity improvements are obtained compared to EDFA and Raman-assisted phase insensitive amplifier (PIA) for a 10-Gbaud QPSK signal. Similar improvements are observed for 20/50-Gbaud QPSK and 10-Gbaud 16QAM signals.

Concept and Experimental Setup

Figure 1 shows the conceptual diagram. At the input, the signal (S) and PSA-pump (P) are sent into a cascaded PSA configuration, which has a quasi-periodic power spectrum. By tuning the wavelength of the PSA-pump, the pair of the signal (S) and the idler (S*) can be shifted to different positions, for example, the dip (Case A) or the peak (Case B). (De-)Amplification can be achieved by tuning the relative phase between S and S*. Different positions would yield different GERs, which could also affect BER performance. Using this adjustment, the optimization of system performance could be realized.

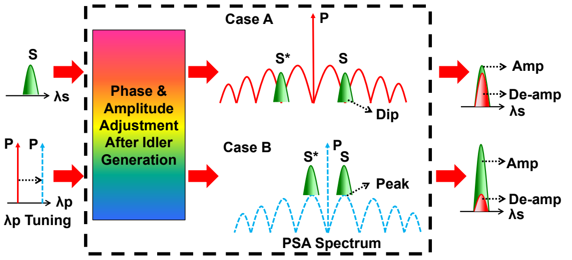

Fig. 1: Concept of the system evaluation with a quasi-periodical PSA power spectrum. The signal can be placed at the dip (Case A) or peak (Case B), which is realized by tuning the wavelength of PSA-pump. Amplification and de-amplification can be achieved by adjusting the relative phase between S and S*. Different gain-extinction-ratios (GERs) and BERs are expected for the signal at different locations.

Figure 2(a) shows the experimental setup. At the transmitter, I/Q data modulates a laser with the wavelength of 1558.4nm. The modulated signal is QPSK or 16QAM depending on the setting of the pattern generator. An attenuator (ATT-1) is placed afterwards to change the input signal power to the system. The signal is then sent through a 300m highly nonlinear fibre (HNLF-1) together with a PSA-pump at the wavelength of 1553.2nm. To suppress the stimulated Brillouin scattering (SBS) effect, the pump is phase modulated by an 800-Mhz pseudorandom binary sequence (PRBS). After HNLF-1, an idler is generated with -10dB conversion efficiency with negligible parametric

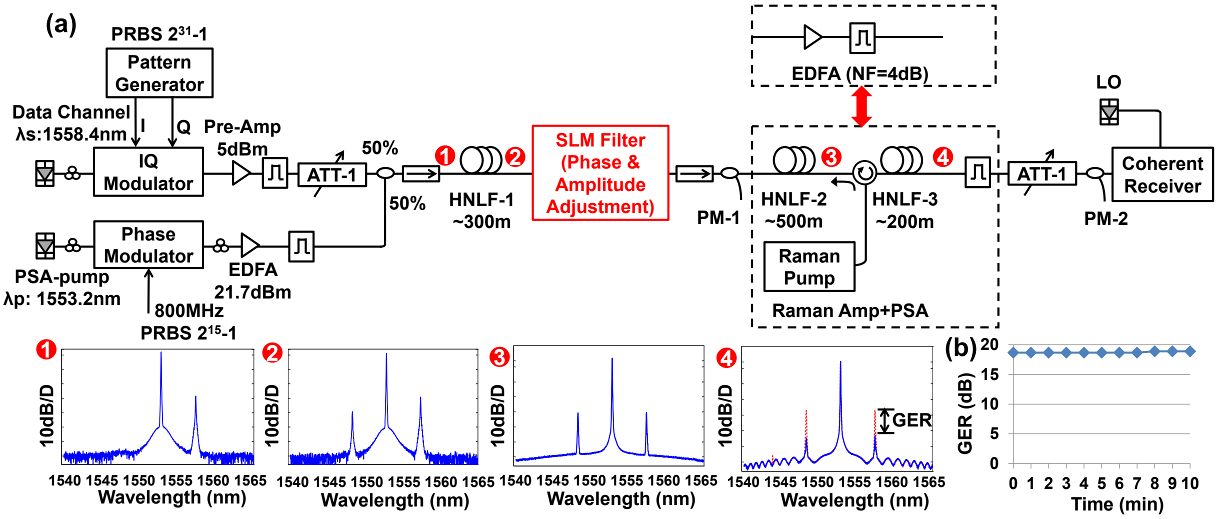

Fig. 2: (a) Experimental setup and the corresponding optical spectra at each node. The wavelength of PSA-pump is tuned to 1553.2nm to locate the data channel at the peak of the PSA power spectrum; (b) temporal variation of gain-extinction-ratio (GER) without phase stabilization feedback loop. PRBS: pseudorandom binary sequence; HNLF: highly nonlinear fibre; ATT: attenuator; SLM: spatial light modulator; PM: power monitoring; LO: local oscillator; NF: noise figure.

gain on the signal. In a spatial light modulator (SLM) filter, the power difference and relative phase between the signal and idler are adjusted. In the next HNLF (HNLF-2), the signal, idler and PSA-pump are amplified by a 28dBm back-propagated Raman-pump at the wavelength of 1455nm. In this stage, although PSA can also occur, the quasi-periodic power spectrum is not observed from the optical spectrum at node-3. After another 200m HNLF (HNLF-3), the quasi-periodic power spectrum appears and the signal can be placed at the peak or the dip on the spectrum by tuning the wavelength of PSA-pump. The optical spectrum at node-4 corresponds to the signal being placed at the peak. By tuning the relative phase between the signal and idler with the SLM filter, both amplification and de-amplification (attenuation) can be achieved, where the power difference corresponds to GER. At the output, the signal is selected by a filter and sent to a coherent receiver, where another attenuator (ATT-2) is used to adjust the receiver input power. The total signal gain in Raman/PSA stage shown in the dotted box of Fig. 2(a) is 25.7dB. Here, all three dispersion stable HNLFs have a nonlinear coefficient of 21.4/W/km and zero dispersion wavelength (ZDW) around 1551.5 nm.

Since there is no path separation, a feedback loop for phase stabilization can be avoided. Figure 2(b) illustrates the stability of the system. In a 10-minute span, once the relative phase is optimized at first, stable 19dB GER is observed.

Results and Discussions

The wavelength of PSA-pump is adjusted to shift the signal to different locations of the quasi-periodic power spectrum. Figure 3(a) demonstrates that if the wavelength of PSA-pump is changed by 1.2nm, the location of the peak becomes to the dip. The variation of signal output power by sweeping the relative phase at different locations is shown in Fig. 3(b). Within a 2π phase range, when the signal is placed at the dip, only a 2dB GER can be observed. In contrast, a 20dB GER is achieved when the signal is located at the peak. It is noted that the maximum gain cannot be achieved without appropriate relative phase tuning in the SLM filter, which is -80 degree for the peak scenario.

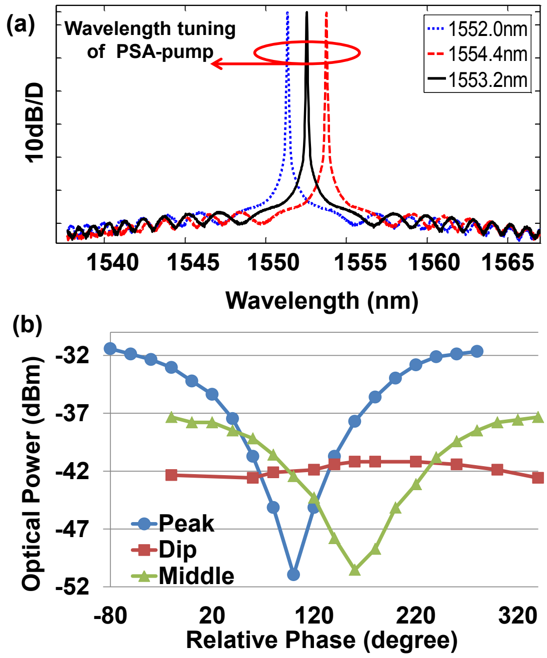

Fig. 3: (a) The PSA power spectrum can be moved by PSA-pump wavelength tuning; (b) variation of output power (1%) by sweeping the relative phase at different locations of a 10-Gbaud signal. The signal input power (blocking PSA-pump) measured at PM-1 in Fig. 2(a) is -27.5dBm.

To relate GER with signal quality, the BER of a 10-Gbaud QPSK signal is measured in the coherent receiver. The signal input power at PM-1 is tuned by ATT-1, while ATT-2 is adjusted to ensure the same output power at PM-2 before the receiver in Fig. 2(a). Figure 4 indicates that the signal at the peak enjoys a 4.5dB sensitivity benefit compared with the signal at the dip. It might be explained that with a low GER, the PSA effect at HNLF-3 can be neglected, resulting in a PIA. It is thus preferable to locate the signal at the peak to yield the strongest PSA.

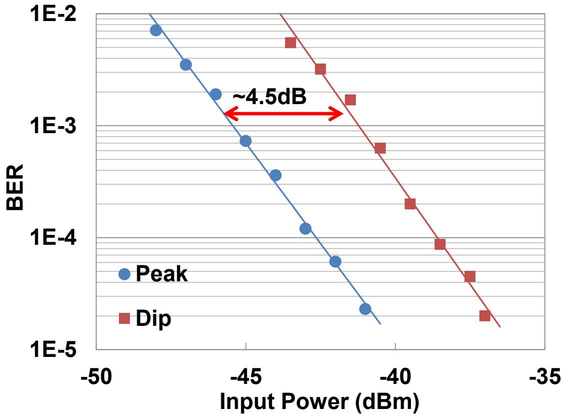

Fig. 4: Measured BER versus the input signal power by locating a 10G-baud QPSK signal at the peak or the dip.

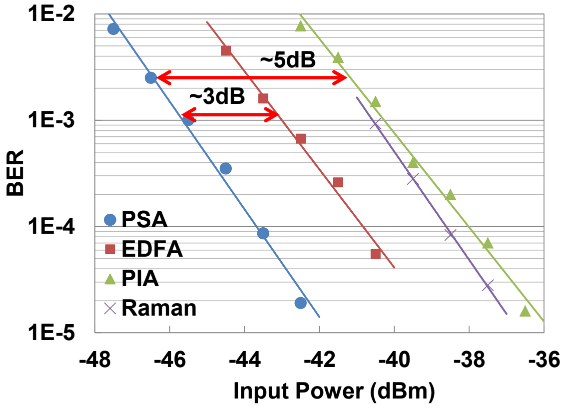

Fig. 5: Measured BER versus input power of a 10-Gbaud QPSK signal for PSA (locating the signal at the peak), EDFA, PIA (w/o idler), and Raman Amplification (w/o PSA-pump).

In the next, an EDFA of 4dB noise figure (NF) in Fig. 2(a) is taken for comparison. The signal is placed at the peak by tuning the wavelength of the PSA-pump; together with the phase adjustment in the SLM filter, optimal PSA is expected. For fair comparison, the same signal gain and input power are ensured. Figure 5 shows that the sensitivity of Raman-assisted PSA is approximately 3dB better than the EDFA. Compared to a less-than-1dB benefit with 9dB GER[9], the additional benefit may result from locating the signal at the peak to yield 10dB extra GER. In addition, PIA can be achieved by blocking the idler in the SLM filter and 5dB sensitivity penalty is observed compared with PSA. The reason of different system benefit by comparing PSA with EDFA (3dB) and PIA (5dB) might attributes to the nosier Raman amplification. By turning off the PSA-pump, the BER curve under pure Raman amplification is depicted in Fig. 5, where about a 2dB sensitivity penalty is observed compared with the EDFA.

In addition, 20-Gbaud and 50-Gbaud QPSK systems are also evaluated as shown in Fig. 6. Both configurations demonstrate noticeable sensitivity improvement compared with EDFA. Finally, a 10-Gbaud 16QAM system is employed. As shown in Fig. 7, about 2dB sensitivity improvement is observed.

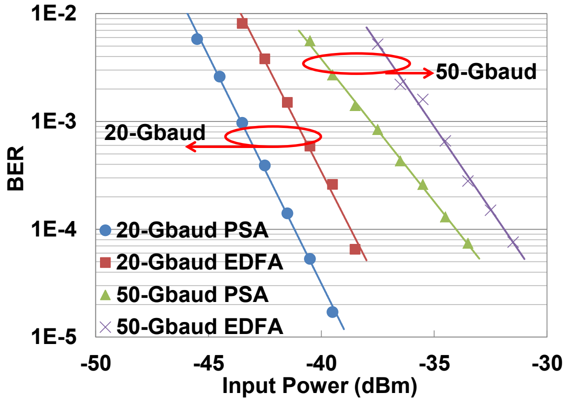

Fig. 6: Comparison of measured BER versus the input power of 20/50-Gbaud QPSK signal between EDFA and PSA by locating the signal at the peak.

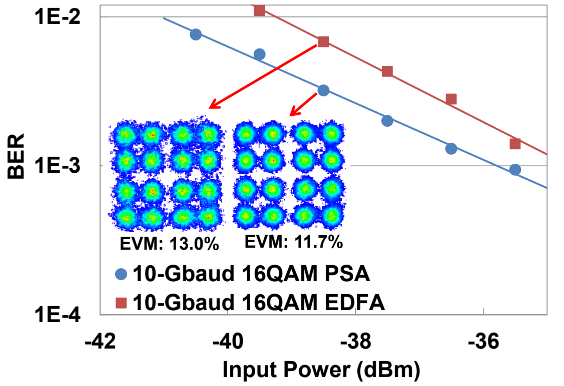

Fig. 7: Comparison of measured BER versus the input power of 10-Gbaud 16QAM signal between EDFA and PSA by locating the signal at the peak.

Acknowledgements

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