Experimental Demonstration of Optical Signal Level Swapping and Multi-level Amplitude Noise Mitigation using Three Parametric Gain Regions

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Abstract: An optical signal level swapping function and a multi-level amplitude noise mitigation method are proposed using three parametric gain regions. Experiments demonstrate less than 1% EVM-penalty for swapping and multi-level amplitude noise mitigation is achieved.
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1. Introduction

Optical signal processing has the potential for achieving high-speed operational functions without the need for optoelectronic conversion to avoid the delay [1]. Typically, optical signal processing can be achieved when a certain physical property of an optical element presents an opportunity to enable a specific function. For example, nonlinear processes have given rise to functions like amplification [2], wavelength conversion [3], and phase quantization [4]. Specifically, nonlinear wave mixing can be high speed with little additive noise, and there has been much progress on advances in different types of nonlinear materials and devices [5,6].

One type of nonlinear process using wave mixing is the optical parametric amplifier (OPA) [7,8]. In this case, power from a pump provides gain to an incoming data channel. As with most other amplifiers, a further increase in input power will ultimately saturate the amplifier gain, which is already used for the single-level amplitude noise mitigation [9]. However, with even more input power, a third OPA gain region appears in which the gain falls dramatically since the power of the signal itself is providing gain back to the pump and other idlers.

Given these three different gain regions (i.e., linear gain, saturated gain, and gain inversion), there might be certain interesting optical signal processing functions that can be achieved.

In this paper, we experimentally demonstrate optical signal level swapping and multi-level amplitude noise mitigation using these three different parametric gain regions. We first verify the existence of these three gain regions in the highly nonlinear fiber (HNLF) and use the gain inversion region to swap multi-level signals as 2 amplitude shift keying (2ASK) and 8QAM of 10G/20Gbaud. The error-vector-magnitude (EVM) penalty of less than 1% is observed. Then, we employ all the three gain regions to experimentally achieve the multi-level amplitude noise mitigation for the 8QAM signal.

2. Concept

The concept of three OPA gain regions and signal level swapping are shown in Fig. 1(a-d). Fig. 1(a) shows the OPA gain and power profiles. The regions of linear gain, saturation gain and inversion gain are marked correspondingly. Taking 2ASK signal for example, the input has two types of symbols A and B with different amplitude levels. In the linear gain region as in Fig. 1(b), A and B enjoy the equal amplification and the shapes of constellation and intensity waveform remain the same. In the saturation gain region as in Fig. 1(c), since the output power is saturated, A and B have the same output level. Both the constellation and waveform shrink to one level. More interestingly, if A and B fall into the inversion gain region in Fig. 1(d), the output power becomes inversely proportional to the input power. As the output, the amplitude levels are inverted and symbols A and B are exchanged. In the constellation, the symbol B swaps with symbol A and meanwhile, the intensity waveform is also inverted.

Figure 1(e) is the concept of multi-level amplitude noise mitigation, which uses all three gain regions in Fig. 1(b-d). Let us assume the input 8QAM signal has a scattering constellation due to ASE noise. Before Stage 1, by tuning the signal power, the noisy upper level symbols reach the OPA saturation gain region and noisy lower level symbols fall into the linear gain region. Therefore, the output constellation has less amplitude variation for the outer symbols after Stage 1. Then, by tuning the signal power again before Stage 2, the upper level symbols reach the inversion gain region while the lower lever symbols fall into saturation gain region. In this case, the lower level and

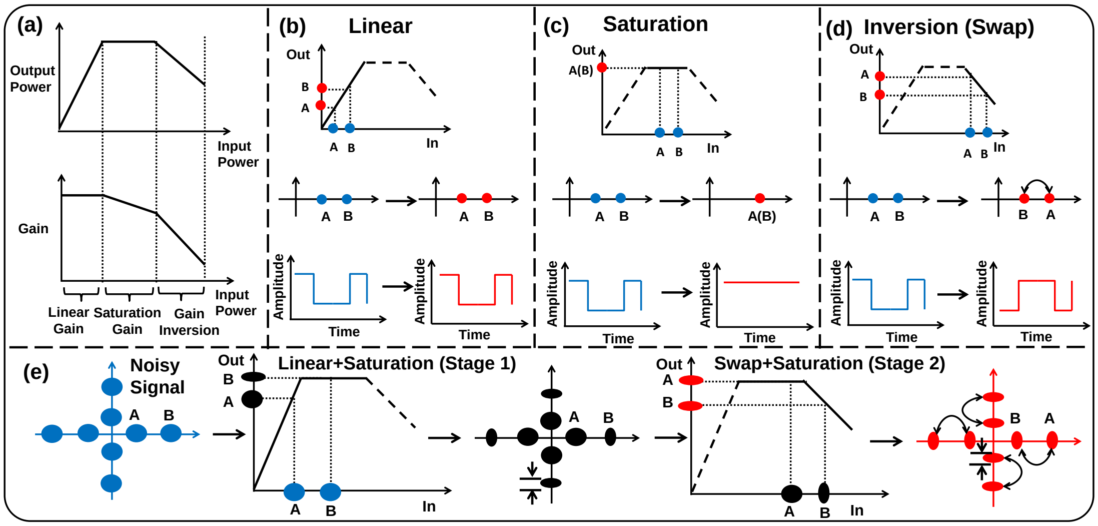

Fig. 1. (a) OPA's three gain regions, (b) linear region, (c) saturation region, (d) swap region, (e) multi-level amplitude noise mitigation.

upper level symbols are swapped and meanwhile, the OPA saturation squeezes the amplitude noise on the lower level symbols. After Stage 2, the amplitude variation of the constellation is mitigated on both levels.

3. Experimental Setup

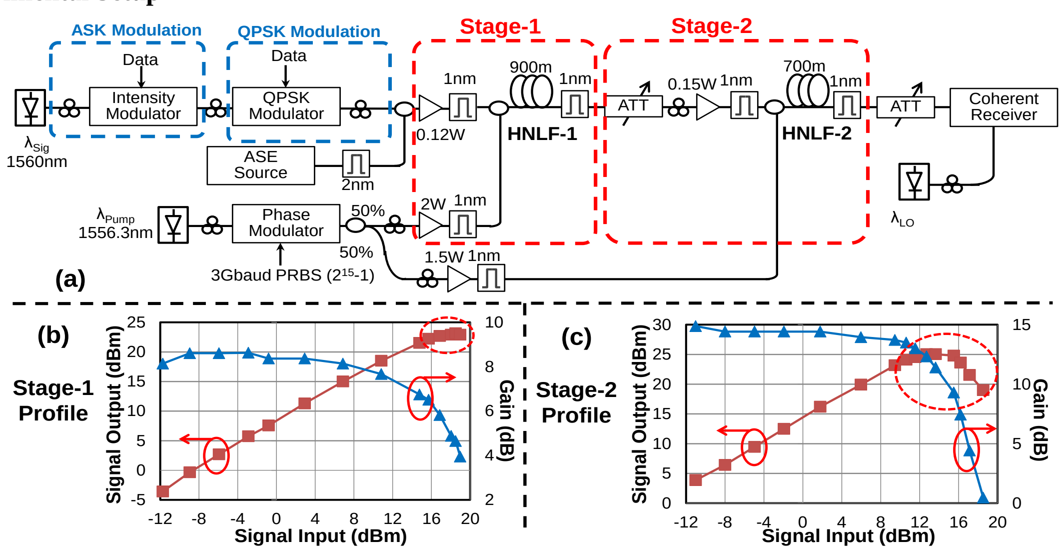

Fig. 2. (a) Experimental setup for signal level swapping (bypassing Stage 1) and multi-level amplitude noise mitigation; (b) measured gain and power profile of Stage 1; (c) measured gain and power profile of Stage 2.

Figure 2(a) illustrates the experimental setup for both signal level swapping and multilevel amplitude noise mitigation (for only signal level swapping, Stage 1 is bypassed). A continuous wave (CW) signal at 1560 nm after getting modulated by a 2ASK modulator cascaded with a QPSK modulator carries the 8QAM constellation. An ASE source at the transmitter adds noise on the original singal. Here, one pump source at 1556.3 nm is equally power divided and used for Stage 1 and Stage 2 shown in Fig. 2(a). To suppress the stimulated Brillouin scattering (SBS) effect, the pump is phase modulated. Stage 1 uses OPA linear and saturation regions for high amplitude level squeezing, which is employed only for the experiment of multi-level amplitude noise mitigation. In this stage, the 8QAM signal with 0.12W couples with 2W pump in a 900m HNLF1 of zero dispersion wavelength (ZDW) around 1556nm and nonlinear coefficient of 9.2W^{-1}•km^{-1}. Fig. 2(b) depicts the measured relationship between the input signal power and output power in Stage 1. The corresponding gain profile is also displayed. It is worth mentioning that for HNLF gain profile measurement, the CW signal bypasses the module of 2ASK modulation and directly goes through QPSK modulation for SBS suppression. In Fig. 2(b), it can be seen that the saturation region appears when the level power reaches above 16dBm. Stage 2 uses OPA saturation and inversion regions for signal level swapping and low level amplitude squeezing. In this stage, 0.15W signal is coupled with 1.5W pump and sent through a 700m dispersion stable HNLF with nonlinear coefficient of 21.4W^{-1}•km^{-1} and ZDW around 1551.5 nm. Fig. 2(c) shows the measured gain and power profile in Stage 2. It is noticeable that there is a region as shown in the dotted circle, if the low input level falls on the flat region (power saturation) and high input level locates on the descending region, amplitude squeezing and signal level swapping can be realized simultaneously.

4. Results and Discussions

To demonstrate signal level swapping, 2ASK and 8QAM signal, both of which have two amplitude levels, are employed in the experiment. Figure 3(a) shows the intensity waveform of 10Gbaud 8QAM as the input and output. For the same time period, the waveform is successfully inverted. It also shows the constellations of the 2ASK/8QAM input and output signals. Similar results are obtained for 20Gbaud signals in Fig. 3(b). From EVM measurement, the signal quality is almost preserved with less than 1% degradation. In this experiment, signal level swapping is the premise of the following multi-level amplitude noise mitigation.

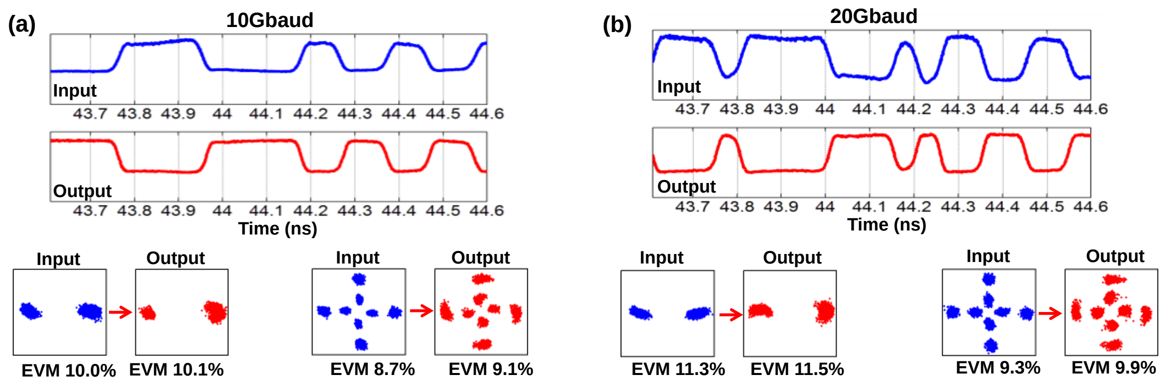

Fig. 3. Demonstrated signal level swapping: (a) intensity waveforms of 10Gbaud 8QAM and constellations of ASK as well as 8QAM as the input and output (b) 20Gbaud 2ASK/8QAM constellations and intensity waveforms.

Figure 4 shows the results of 8QAM amplitude noise mitigation. Fig. 4(a) shows the constellation comparison for both 10G/20Gbaud cases. The upper and lower figures represent the scenarios with adding low and high ASE noise respectively. It can be seen that after Stage 1, the high level constellation points are squeezed due to OPA gain saturation. After Stage 2, signal level swapping happens and the original low level amplitude points are squeezed as well. The performance on amplitude noise mitigation is evaluated by amplitude error in Fig. 4(b) (stage 0 represents the input signal). Here, amplitude error is defined as the root mean square (RMS) of the amplitude difference between the received and the ideal constellations. It can be seen that the amplitude noise decreases after each stage. On the other side, the EVM is degraded as shown in Fig. 4(a) since the nonlinearity between the signal and pump brings extra phase noise. This penalty might be compensated by the other optical phase noise mitigation method [4].

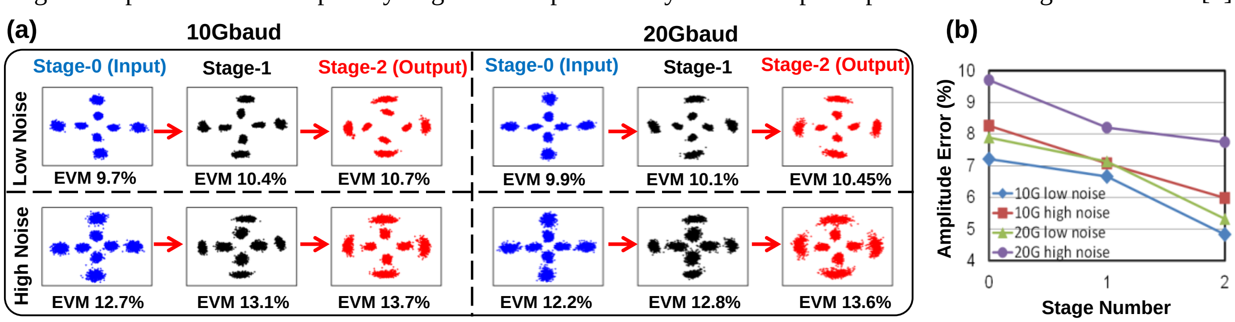

Fig. 4. Experimentally measured (a) 10Gbaud and 20Gbaud 8QAM constellations with corresponding EVMs at different stages for two levels amplitude noise, (c) Amplitude error at different stages.

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