SFDR Improvement of a Coherent Receiver Using Feedback

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Abstract: A novel coherent optical receiver is proposed and experimentally demonstrated by using a feedback technique capable of reducing the nonlinear distortion in a traditional receiver while retaining the signal to noise ratio. Up to 15 dB of SFDR improvement is obtained.

OCIS codes: (060.1660) Coherent communications; (120.5060) Phase modulation

1. Introduction

The nonlinear intensity response of optical modulators has been a major limiting factor of intensity modulated analog optical links [1]. In general, the modulation depth has to be restrained and the bias point needs to be properly set in order to achieve higher linearity [2]. System parameters such as noise figure and link gain can be degraded by these requirements. In contrast, optical phase modulators have excellent linearity over a wide modulation range. The modulation depth is not limited by the optical power as in intensity modulation but only by the total modulation capability of the phase modulator. However, the challenge of linearity in a phase-modulated link is shifted to the receiver side. The traditional interferometer-based phase demodulator has a sinusoidal response that limits the spur free dynamic range (SFDR) [3]. To overcome this limitation, a novel feedback technique is proposed in this paper to increase the linearity of an analog optical link. In the proposed approach, the demodulated signal is fed back to the input of the coherent receiver through a local phase modulator, which compensates the phase difference between the signal and the local optical waves. As a result, the phase difference seen by the phase demodulator is reduced and falls in the linear region of the response curve. As a result of the feedback architecture, the signal to noise ratio (SNR) in the receiver remains unchanged, despite the reduced net depth of the detected phase difference. For successful operation, the delay of the feedback must be short compared to the speed of the incoming signal in order to stay in phase. We present experimental verification of this novel approach using discrete components. In practice, an integrated implementation is necessary to achieve the short feedback delays necessary for proper operation at gigahertz frequencies. We successfully demonstrate the increased linearity without penalty in SNR, resulting in an overall SFDR improvement of 14.9 dB. The results are also in line with what is predicted from a time-domain analysis that addresses theoretical predictions and imperfect realizations [4].

2. Experiment and results

The experimental setup is shown in Fig. 1 where the transmitted signals are 160 kHz and 180 kHz. These

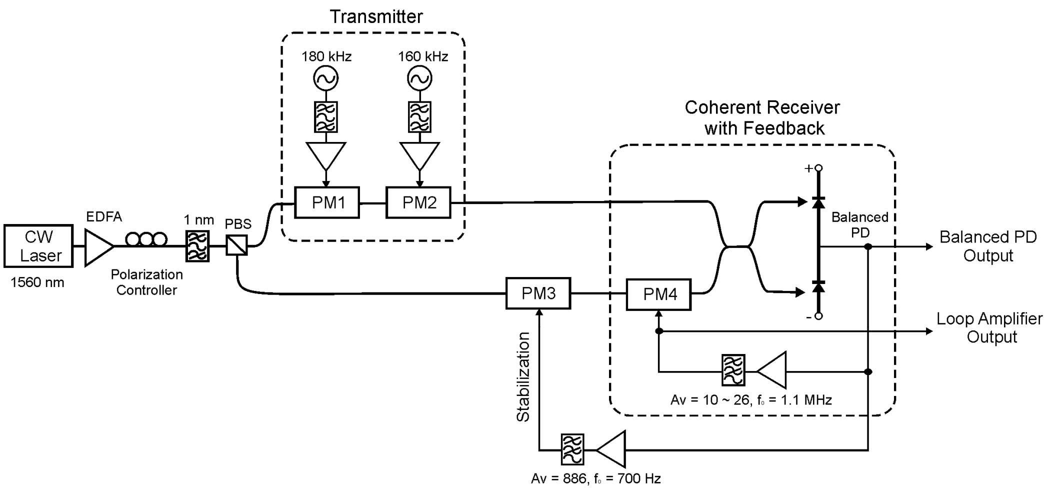

Figure 1 Experimental setup of the optical coherent receiver with feedback technique. PM#: phase modulator, A_v: voltage gain, f_o: 3-dB frequency, PBS: polarization beam splitter.

frequencies are limited by the delays due to the fiber patch cords of the optical components. An external-cavity tunable laser is used as the CW laser source at 1560 nm whose output is amplified by a high-power EDFA. The interferometer-based optical link is constructed with polarization maintaining fibers and components for better stability. The power ratio between the two branches can be adjusted by a polarization controller through polarization dependent splitting of the polarization beam splitter (PBS). The transmitter is composed of two optical phase modulators, PM1 and PM2, used to apply phase modulations at different frequencies. This arrangement decouples the driving electronics at respective tones. The V_π of the phase modulators is around 4.4 V.

On the other arm of the interferometer are the two phase modulators on the receiver side. PM3 is used to compensate environmentally induced slow phase drifts between the two branches and stabilizes the interferometer to the quadrature point. Up to 6π rad of differential phase drift can be compensated. PM4 is the local phase modulator used to apply the feedback signal for compensating the phase difference. The voltage gain is adjustable with a 3-dB bandwidth of 1.1 MHz, set by a first-order RC filter. The two interferometer branches are connected to a polarization maintaining coupler and eventually to a balanced photodetector, as in a traditional phase demodulator.

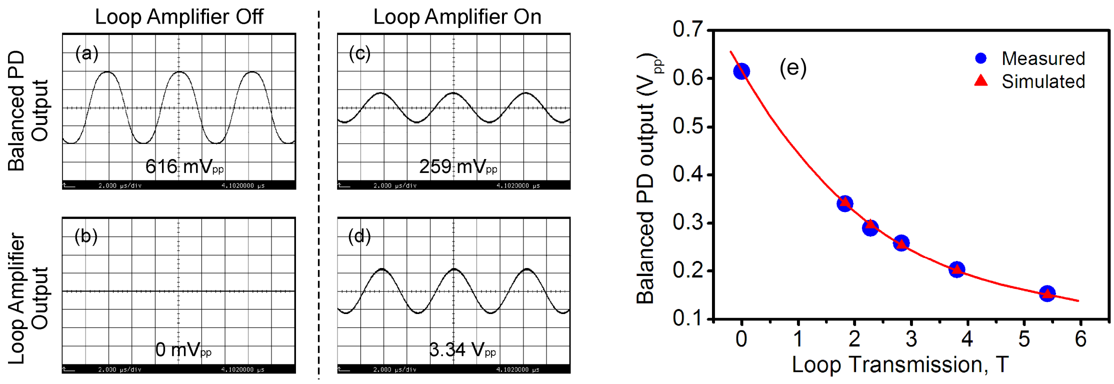

Figure 2 Scope traces in one-tone measurement. The modulation depth is π rad peak-to-peak at 160 kHz. (a) and (b): loop amplifiers off; (c) and (d): loop amplifiers on with loop transmission of 2.8; (e) balanced photodetector output as a function of loop transmission

First, a one-tone measurement is conducted at 160 kHz to demonstrate the successful operation of phase-tracking. The optical power in each interferometer branch before the coupler is 10 mW. The transmitter modulation depth is π rad. As shown in Fig. 2(a), with the loop amplifiers turned off, which corresponds to a traditional phase demodulator, the balanced photodetector output is distorted due to the nonlinear response. However, when the loop amplifiers are turned on, Fig. 2(c) shows that the voltage swing as well as distortion of the balanced photodetector output is reduced. The loop amplifier output that drives PM4 (Fig. 2(d)) is an amplified replica of the balanced photodetector output. Fig. 2(e) shows that when the loop transmission, T, which represents the closed-loop phase gain, is increased, the balanced photodetector output reduces. This would in turn lead to better linearity. Excellent matching with the time-domain numerical simulation [4] is obtained.

More detailed linearity measurements can be obtained by two-tone (160 kHz and 180 kHz) measurements. The (third-order) intermodulation is measured at 140 kHz. The signals are measured after an amplifier with a DC voltage gain of 11.2 and a 3-dB bandwidth of 1.1 MHz. Fig. 3(a) shows the results *without* using the feedback technique (i.e. a traditional phase demodulator). Due to the nonlinear response of the receiver, the output power of the fundamental tone starts to saturate at 17 dBm of output power. The noise level is measured to be -111.9 dBm/Hz with no input signal to PM1 and PM2 but everything else remains active. The SFDR can thus be obtained as 88.6 $dB \cdot Hz^{2/3}$.

Next, the feedback loop is closed by sending the demodulated signal to PM4. The amplifier voltage gain is adjusted to 23.9 which results in a loop transmission of 6.5. From Fig. 3(b), it is clear that no saturation in the output power of the fundamental tone is observed because of the reduced phase difference due to feedback. Therefore, the intermodulation level is reduced as a result of the reduced swing at the phase demodulator. The resulting SFDR is 103.5 $dB \cdot Hz^{2/3}$, corresponding to an improvement of 14.9 dB over the traditional receiver.

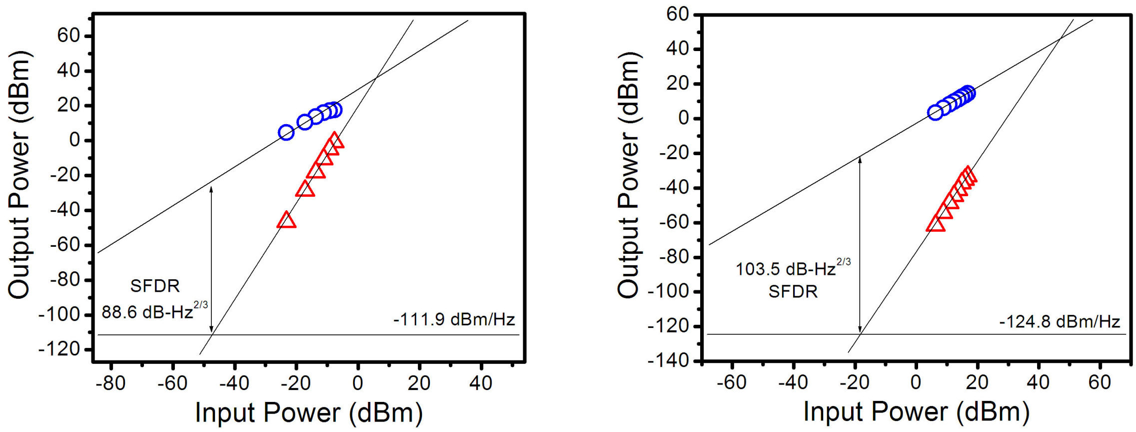

Figure 3 Two-tone SFDR measurements (a) without feedback (traditional phase demodulator); (b) with feedback. The vertical and the horizontal scales of the two plots are exactly the same but shifted for clearer comparison. Circle: signal, triangle: intermodulation.

It is observed from Fig. 3(a) and (b) that the SNR of the two cases are almost identical but the intermodulation level is suppressed by the feedback technique, verifying that the proposed approach can increase linearity without any penalty in SNR. The experimentally observed noise floor of -124.8 dBm/Hz with feedback is 6.4 dB higher than the theoretical shot-noise limited value of -131.2 dBm/Hz. The most likely cause is the finite noise figure of the loop amplifiers. The intermodulation level can be further suppressed by increasing the loop transmission (loop gain). However, it is limited in practice by the loop delay (~ 5 meters) imposed by the fiber patch cords and electronic phase delays. When the loop transmission increases beyond 6.5 in the current setup, oscillations around 8.5 MHz occur. The excessive noise and, in particular, limited loop transmission constrained the experimentally achievable SFDR. Therefore, integration of the local phase modulator, the balanced photodetector, and the loop electronics should improve the performance and is under intensive investigation.

3. Conclusion

A novel coherent optical receiver with feedback is proposed and demonstrated experimentally with up to 15 dB of SFDR improvement compared to the traditional approach. The feedback technique effectively reduces the signal swing at the phase demodulator and achieves a higher level of linearity. The SNR is preserved by this feedback technique. The currently realized SFDR of 103.5 dB·Hz$^{2/3}$ is limited by the excessive noise of the loop amplifiers and the delay due to the fiber patch cords of the optical components. Improved performance at higher operating speeds is promising by using advanced integration technologies.

4. Acknowledgment

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5. References

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