Performance Comparison of Two Analog Photonic Links Employing a Pair of Directly Modulated Lasers and a Balanced Photodetector

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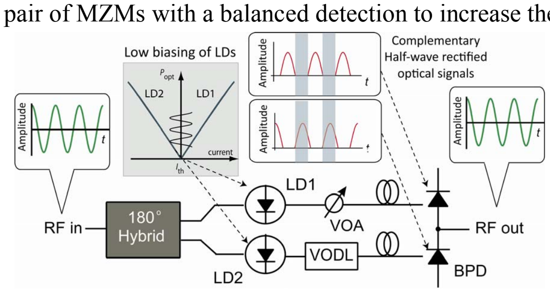
Abstract: We compare the effects of low biasing and push-pull modulation on the spurious-free dynamic range (SFDR) of an analog photonic link (APL) architecture employing a pair of directly-modulated laser diodes and a balanced photodetector.

1. Introduction

Analog photonic links (APLs) for RF/microwave signals distribution have found various applications, including radio-over-fiber, antenna remoting and signal processing, among others [1]. To perform these functions, the APLs must be capable of preserving the fidelity of the signal in terms of linearity and signal-to-noise ratio (SNR). An important indicator of the link performance is the so-called spurious-free dynamic range (SFDR), which is defined as the maximum SNR that can be achieved by the link without any measurable intermodulation distortion (IMD) product [2].

Various techniques have been proposed in the effort to increase the SFDR of APLs. In externally-modulated APLs, the most popular way to do this is to use a dual-output Mach-Zehnder modulator (MZM) in combination with a balanced photodetector (BPD) to suppress the laser relative intensity noise (RIN) and subsequently increasing the SFDR [3]. Another option is to low-bias the modulator, for example a Mach-Zehnder modulator (MZM), to limit the average optical power in the detector which directly contributes to the dominant link noise sources, such as the shot noise or the RIN [3]. Additionally, a technique called the class-AB photonic link which combines the low biasing of a pair of MZMs with a balanced detection to increase the link SFDR has been investigated [4].



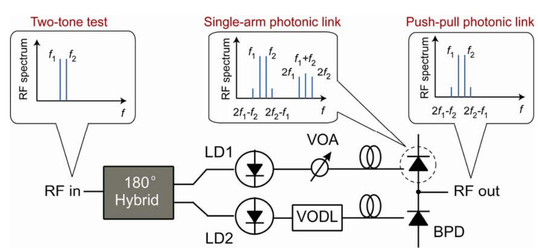


Figure 1. Two photonic link architectures considered in this paper. (a) Low biased link, (b) push-pull modulated link. VOA: variable optical attenuator, VODL: variable optical delay line.

In this paper, we compare the performance of two APL architectures employing a pair of directly-modulated laser diodes (LDs) and a balanced photodetector (BPD). In the first APL, the LDs are low biased (i.e. biased close to their threshold currents) such that the output optical signals resemble the complementary half-wave rectified versions of the modulating RF signal, as shown in Fig. 1(a). In its ideal operation, the link offers high spurious-free dynamic range (SFDR) due to shot noise and the laser relative intensity noise (RIN) reduction [4]. This link can be regarded as the counterpart of the class-AB photonic link [5]. In the second architecture, the LDs are not low biased but biased at the position where the third-order intermodulation distortion (IMD3) terms of individual LDs are minimized. Moreover, the LDs are push-pull modulated with antiphase RF signals coming from the outputs of a 180^o hybrid coupler. In this way, the second-order IMD (IMD2) will be suppressed, leading to a broadband high SFDR [6]. This push-pull link can be regarded as the direct-modulation counterpart of the dual-output MZM link. The main difference is that unlike in the case of the dual-output MZM, the laser RIN is not cancelled [6].

2. Performance of the Low-Biased APL

The low biased APL is realized using a pair of 1310 nm DFB LDs from Fitel (FOL1310) and a 10 GHz BPD from Discovery Semiconductor (DSC-710) . The threshold current of the LDs (dubbed LD1 and LD2) is 9.5 mA and their slope efficiencies are 0.32 and 0.37 W/A, for LD1 and LD2 respectively. The detailed characterization results of these LDs are presented elsewhere [6]. Variable optical attenuator (VOA) and delay line (VODL) have been used

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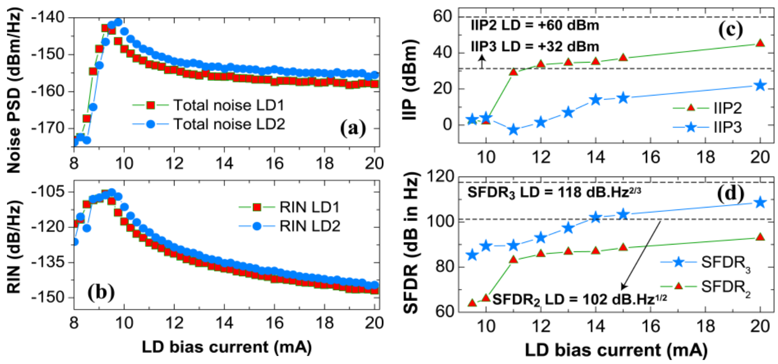

Figure 2. Measurement results on the low biased APL at the frequency of 1 GHz. (a) Noise PSD, (b) RIN, (c) IIP and (d) SFDR as functions of the laser bias currents.

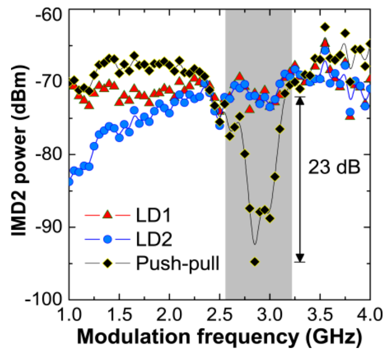

Figure 3. IMD2 suppression in the push-pull APL as a function of the frequency.

to ensure that the amplitudes of the optical signals in the APL arms are equal and their RF modulation phases are opposite. The advantage of a low biased link relies on the noise reduction due to the removal of the DC component. We measure the noise contributions from the individual LD as functions of the bias current. This is shown in Fig. 2(a). From these measurements, the RIN of each LD is determined and plotted against the bias current, as shown in Fig 2(b). From these measurements, it is apparent that low biasing the signal will increase the total APL noise. This is because while shot noise reduces, the RIN is enhanced due to the spontaneous emission. Furthermore, we performed two-tone tests at tone frequencies of 1.0 and 1.01 GHz to determine the SFDR and the input intercept points (IIP). The results are shown in Fig. 2(c) and (d), where the IIP2 and IIP3 as well as the second-order and the third-order SFDRs ($SFDR_2$ and $SFDR_3$, respectively) of the APL are depicted against the bias currents. As benchmarks, the measurements for the individual links, biased at 50 mA (halfway of the laser LI curve), are also indicated. From these results, we can conclude that low biasing is not attractive for enhancing the SFDR of APL. Besides noise enhancement, reduction of link linearity limits the achievable SFDR. To our knowledge, the effects of low biasing on directly modulated APL performance have not previously been reported.

3. Performance of the Push-Pull APL

We realize the push-pull APL with the same components as used in the low biased link. A 180^o hybrid coupler was used to supply antiphase signals to the LDs. A variable optical attenuator (VOA) and a variable optical delay line (VODL) were used to control the amplitude and the RF modulation phase of the optical signals such that the IMD2 components from the LDs arrive at the BPD with the same amplitudes but out-of-phase. In this way, the IMD2 components are suppressed. Fig. 3 shows this suppression as function of the modulation frequency, obtained from a two tone test with 1.5 dBm tone power and 10 MHz frequency spacing. In a frequency band of 600 MHz (2.6 to 3.2 GHz), the IMD2 power of the push-pull APL is suppressed, relative to the individual links containing LD1 and LD2. The suppression results in enhancement of the APL $SFDR_2$ as shown in Fig. 4(a). The APL also shows minor improvements of $SFDR_3$ as depicted in Fig. 4(b). From these results, we can conclude that the push-pull architecture can significantly improve the SFDR of a directly modulated APL.

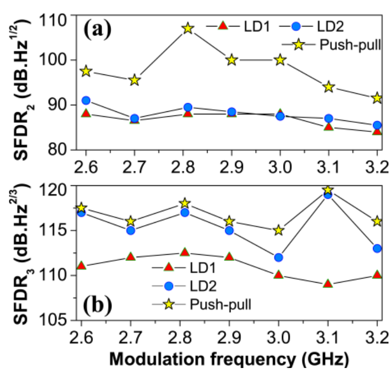

Figure 4. Measured $SFDR_2$ (a) and $SFDR_3$ (b) of the push-pull APL and the individual single arm APLs.

4. Conclusions

We compare the effects of low biasing and push-pull modulation on the performance of an APL with a pair of directly-modulated LDs and a balanced photodetector. Unlike in the case of external modulation, low biasing the LDs is not attractive to increase the link SFDR due to the increase in laser RIN and decrease in the linearity in the region close to the threshold. On the other hand, push-pull modulation is very promising for providing high second-order SFDR.

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