Characterization of a Balanced Modulation and Detection Analog Optical Link

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The characterization of a Balanced Modulation and Detection analog optical link is presented. The link consists of a pair of low-biased DFB lasers modulated in a push-pull manner and a balanced photodetector. The measured link noise shows an enhancement of 15 dB around the laser threshold and large intermodulation distortion is observed due to imperfections in the half-wave rectification process. The link noise and distortion can be suppressed up to 10 and 30 dB, respectively, if the RF signal is externally half-wave rectified prior to the optical modulation.

Introduction

In applications such as phased-array antenna remoting, analog optical links are required to have a large spurious-free dynamic range (SFDR) that imposes stringent requirements in links signal-to-noise ratio (SNR) and linearity. A way to increase this SFDR is to reduce the link noise. One can identify that shot noise and relative intensity noise (RIN), two dominant noise terms in such links, are proportional to the average optical power and the square of it, respectively. Hence, limiting this optical power (while maintaining the desired signal power) is crucial in the SFDR enhancement.

One way to limit the DC optical power is to employ low-biased optical links. In such links, a pair of optical modulation devices are pre-biased at positions lower than the conventional bias point (i.e. the linear part of their transfer functions) and modulated in a push-pull manner to create complementary half-wave rectified optical signals. The detection is done in a balanced detector, which subtracts the two signals with a small, or no, DC average [1].

In this paper, we present the first measurement results on the performance of a low biased link called the balanced modulation and detection (BMD) that employs a pair of directly modulated lasers as the modulation devices, as we proposed earlier [2, 3].

BMD Link Realization

Ideally, the transmitter of the BMD link consists of a pair of laser diodes (LDs) with a common RF input. When the modulating signal is positive, one of the LD will conduct and light is launched in one arm of the optical link, while no light is launched in the other arm. The situation is reversed if the signal is negative. The optical signals in both arms comprise complementary half-wave rectified versions of the original modulating signal. Since each arm only carries the half-wave rectified version of the RF signal, both LDs can be biased close to the threshold level, which gives virtually zero DC optical power in modern semiconductor lasers.

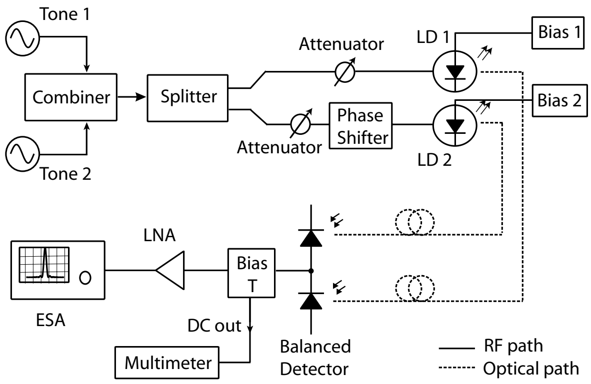
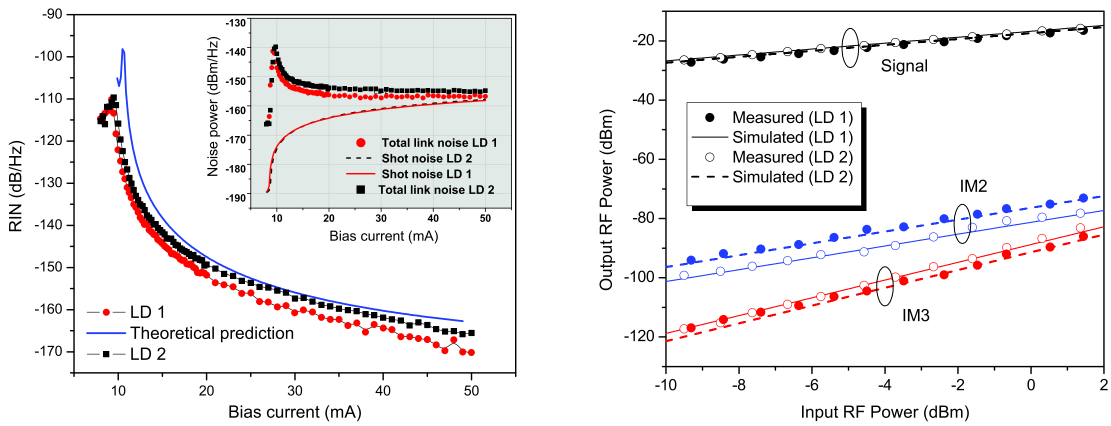


Figure 1: Measurement setup of the BMD link

The schematic of the realized BMD link is shown in Fig.1. A pair of 1310 nm DFB LDs from Fitel (20 mW optical power, 4 GHz modulation bandwidth) are directly modulated with two RF tones of 1.11 GHz and 1.10 GHz frequencies. Their threshold current was measured to be 9.5 mA. A pair of attenuators is needed to adjust the RF power supplied to the LDs (LD 1 and LD 2) since they have different slope efficiencies (0.32 W/A for LD 1 and 0.37 W/A for LD 2). Since both phase and amplitude matching are crucial, a tunable RF phase shifter is placed in one of the RF paths in order to ensure that the optical signals coming to the balanced detector (Discovery Semiconductor DSC710) are 180^{o} out-of-phase. This condition is indicated by a minimum second-order intermodulation (IM2) power of the output spectrum, displayed on the electrical spectrum analyzer (ESA). The amplitude matching is done by means of varying the LDs bias current, while keeping the detected photocurrent (coupled from the DC port of the bias T) close to zero. For noise measurements purpose, a low noise amplifier (LNA) with a gain of 24 dB and noise figure of 1.2 dB is placed before the ESA to reduce the displayed analyzer noise level (DANL). The LNA is replaced by RF attenuators in the intermodulation distortion measurements to minimize the internal distortion generated at the input mixer of the ESA.

Measurement Results

First, we characterize the LDs in terms of noise and distortions. The noise is measured in a resolution bandwidth (RBW) of 300 Hz and the detected photocurrent was measured for shot noise calculation. Extracting the RF amplifier noise and gain, thermal noise, DANL and the calculated shot noise from the total link noise, the RIN of each LD can be calculated. The measured RIN as a function of the bias current is depicted in Fig.2(a) while the total noise and the shot noise are depicted in the inset.



(a) (b)

Figure 2: Laser characterization. (a) RIN as a function of the bias current. Inset : the measured total link noise as a function of the bias current (b) Intermodulation distortion

A two tone test is performed to measure the LDs nonlinearities. In this measurement, the LDs are biased midway of their P-I curves (50 mA bias current). The results are shown in Fig. 2(b). By means of curve fitting, the second order and third order input intercept points (IIP2 and IIP3, respectively) are determined. The IIP2 values for LD1 and LD2 are 56 dBm and 61 dBm, respectively, while the IIP3 values are 33 dBm and 34 dBm, respectively.
For the BMD link, distortion measurements are performed at a bias point of 10 mA for both LDs. The results are shown in Fig. 3. The measured values of the signal, third-order intermodulation distortion (IM3) and IM2 powers as functions of the input RF power are depicted together the values obtained from simulations. The latter were calculated from a model of the BMD link, taking into account various effects such as amplitude and phase imbalances, a difference in nonlinear behaviors of the LDs, signal clipping as well as limitations in CMRR and the detector bandwidth.

Discussions

The measured total link noise shows a sharp enhancement (of about 15 dB) around the threshold (inset of Fig 2(a)). This enhancement is attributed to the sharp RIN peak in this region (Fig.2(a)). Even though this behaviour was not predicted in our previous investigations [2, 3], it's actually showing a good agreement with the theoretical prediction described in [4]. Some minor discrepancies between the theoretical prediction and the measured values can be attributed to the fact that the theoretical model depends on various physical parameters of the lasers, which most of the time are not directly measurable.
The fact that the noise is enhanced around the threshold is severely hurting the BMD link performance since the expected noise reduction cannot be achieved. Furthermore, intermodulation distortions in this region are too high for practical applications. As seen in Fig.3, the IM2 and IM3 levels of the BMD link rise dramatically compared to the case of a single link (Fig.2(b)). This high distortion is attributed to the highly nonlinear frequency response of the LDs below the threshold. As a result, the part of the modulating RF signal that falls in this region is not clipped as expected, but severely distorted.

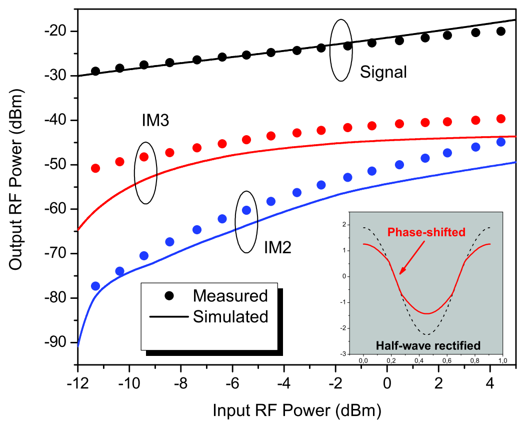
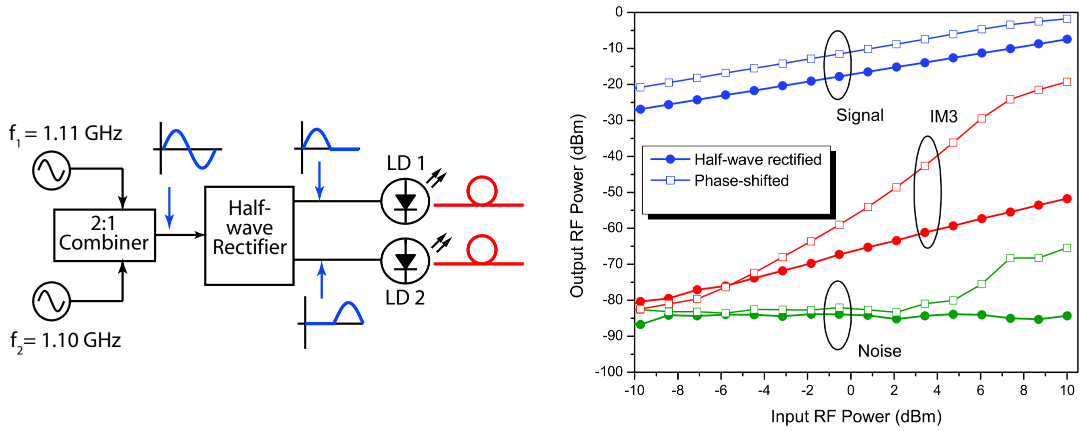


Figure 3: Intermodulation distortion in the BMD link. The lasers are biased at 10 mA.

A way to mitigate this problem is to half-wave rectify the RF signal prior to the modulation. This means the LDs are not modulated by RF signals with a phase difference of 180° but rather modulated directly with complementary half-wave rectified signals. This scheme is shown in Fig 4(a). This complementary half-wave rectification can be done by a dedicated high frequency circuit that will only add relatively small amount of distortion during the process. The advantage of this alternative scheme is that the RF signal need not fall to the region where the noise and distortion are enhanced.
We performed a simulation with VPI TransmissionMaker to compare link performance with phase-shift modulation and external half-wave rectification schemes. In both schemes,



(a) (b)

Figure 4: (a) External half-wave rectification prior to the optical modulations. (b) Comparison of noise and distortion in the BMD link with the phase shift method and with the external half-wave rectification.

the LDs are biased around 20 mA, which is roughly twice the threshold current. With this bias current, the total link noise already rolls-off to a much lower value relative to the noise power around the threshold. The simulation results are shown in Fig 4(b). It is clear that by external half-wave rectification,the IM3 power and the noise power can be reduced up to 30 dB and 10 dB, respectively, and hence, dramatically improves the overall BMD link performance.

Conclusions

The first measurement results regarding the performance of the BMD link have been presented. The RIN enhancement around the laser threshold combined with large signal distortions due to an inefficient push-pull modulation of the lasers have limited the achievable dynamic range of the link. Performance improvement, however, can be expected if the half -wave rectification of the RF modulating signal is done prior to the optical modulation.

Acknowledgements

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