Baseband Optical Down-Sampling for High-Performance Analog Links

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Abstract: A baseband optical down-sampling architecture is experimentally demonstrated where both inphase and quadrature channel are directly accessed using two integrated dual mode-locked lasers. A 2-dB conversion penalty is obtained for a 50Mbaud QPSK-modulated 2.5GHz RF signal.

OCIS codes: (070.1170) Analog optical signal processing; (140.4050) Mode-locked lasers

1. Introduction

The development of high-performance analog optical links will simplify the antenna RF front-end. Ideally, such optical link should have gain, low noise figure, dynamic range as good as state-of-the-art RF front-ends and be able to perform direct access to baseband signal. Link gain and low noise figure can be achieved using high performance laser sources and low V-pi optical modulators [1]. Achieving high dynamic range has proven more challenging, as most types of optical modulators have inherently a non-linear response and most efforts to linearize the modulator response have provided incremental improvements at best. Currently, a promising approach to achieve a high dynamic range is the implementation of post-detection digital signal processing (DSP) where the non-linear response of the modulator (and receiver) can be corrected for to the limit given by the knowledge of the modulator transfer function [2]. Due to the resolution / speed constrictions of A/D converters, the highest performance is obtained at low received frequencies. A second promising approach is to use optical phase modulation in combination with a tracking optical phase-lock loop receiver. The performance of this approach is limited by the amount of feedback gain available while maintaining a dynamically stable operation in the phase-locked receiver. This is in turn determined by the feedback phase lag such that the highest performance is again obtained at lower received frequencies.

High performance optical downconversion is a key function for high-performance antenna remoting applications, not only as a mean to overcome the limitations of electrical frequency downconversion, but also to make the analog optical link architectures above available at an extended frequency range. The challenge is to perform the optical downconversion in a manner that does not degrade link performance. Conventionally, an optical frequency-conversion link is realized by applying a secondary sinusoidal modulation to the optical carrier to downconvert the RF-modulation to an intermediate frequency [3]. Unfortunately, this leads to 6dB optical power penalty in a shot-noise limited optical link. This penalty can be reduced by using pulsed optical sampling downconversion for more efficient frequency conversion [4] and baseband downconversion to eliminate the frequency duality. This work demonstrates optical frequency down-conversion directly to baseband with low conversion penalty.

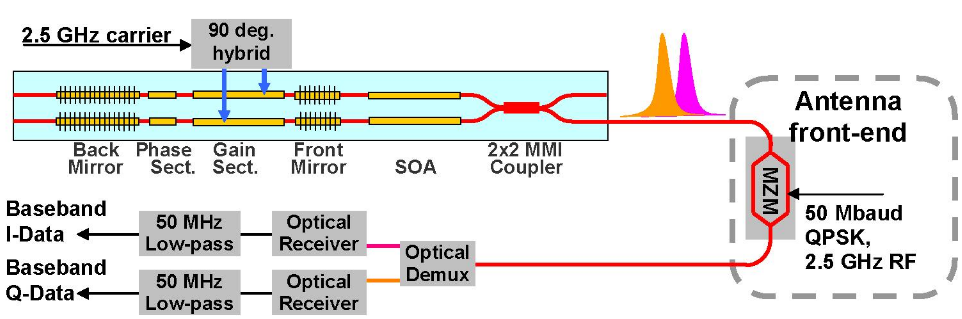

Fig. 1: Schematic of the optical down-sampling arrangement, including the dual mode-locked laser.

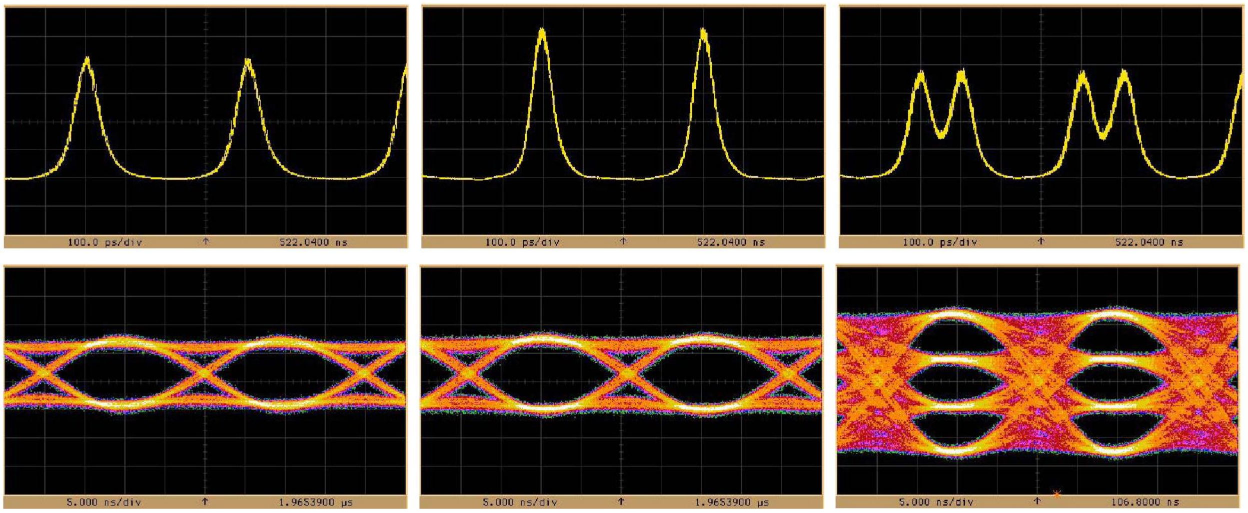

Fig. 2. *Top;* Generated pulsed waveforms from the two mode-locked lasers; I-channel, Q-channels and the combined pulse-train from left to right. Fig. 2. *Bottom* shows the corresponding demodulated baseband eye-diagrams for I-, Q- and combined channels. The lower right eye diagram has been rotated in phase to clearly show all four data levels.

2. Optical sampling downconversion scheme

For direct baseband downconversion, inphase and quadrature (I and Q) mixing is required to access the full vector information within the information band. In this work, this is being realized by supplying two sets of pulse-trains at the RF carrier frequency, 90 deg. shifted in phase. The two sets of pulses are supplied at different wavelengths and are being modulated by the input RF signal. A receiver demultiplexer can then separate the two downconverted signals and the I- and Q-channels are recovered separately. A schematic for the baseband down-sampling scheme is shown in Fig. 1 above, where a MZ modulator is modulating the two pulse-trains by the received RF signal to separately produce I- and Q- channel data. The use of two sets of optical pulse-trains at different wavelengths fits well into a local WDM network environment, where separate receivers can digitize the two waveforms and be further routed in digital form, if required.

In this work, the two pulse-trains were generated by using a single-chip source incorporating two widely-tunable Sampled-Grating DBR lasers [5] with an integrated 2x2 MMI coupler, produced by Agility Communications. The two lasers are being actively mode-locked at the carrier frequency using gain switching at 90 deg. relative phase offset. The resulting waveforms are shown top in Fig. 2 below, both separately demultiplexed (top left, top middle) and combined on the detector (top right). The generated optical pulses had between 15% and 20% duty cycle, corresponding to 60 ps to 80 ps FWHM at 2.5 GHz. Under gain-switched operation, the average optical power remained within 1 dB compared to CW operation using the same gain bias current.

By using a practical integrated dual semiconductor laser source, the demonstrated optical downconversion scheme can be applied in an antenna remoting configuration where direct data access is required. By replacing the need for post-detection frequency conversion and demodulation, this arrangement is particularly attractive at higher frequencies, where semiconductor laser sources have been used to demonstrate pulses up to 240 GHz repetition ratio [6]. To reach high performance in terms of link noise figure or available link signal-to-noise ratio, higher performance, low noise mode-locked lasers must be used [4].

3. Experiment

To demonstrate the baseband down-sampling approach, a simple test signal was used to drive a MZ modulator consisting of a 50Mbaud QPSK-modulated 2.5 GHz RF carrier. Selecting wavelength, either the I- or the Q-data stream could be directly accessed in the optical receiver, as shown in Fig. 2, bottom left and bottom middle. Correct operation could be verified by switching to exclusive I or Q modulation, where the second received wavelength remained unmodulated within the receiver passband. Combining both wavelengths on one receiver, a four-level demodulated eye could be generated when the I- and Q- phase has been rotated slightly to clearly show all four data levels.

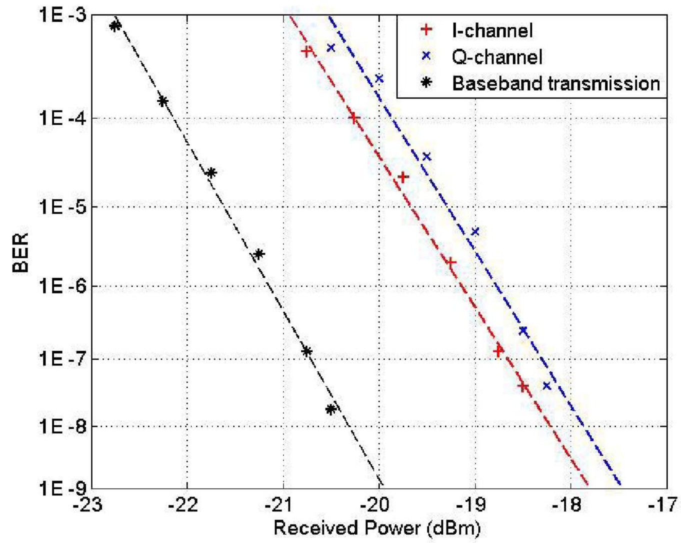

Fig. 3. Measured bit-error-rate as a function of received optical power for both baseband data modulation and downconverted I- and Q-channel data streams.

To evaluate the down-conversion penalty for the demonstrated approach, a 50 Mbps binary NRZ intensity modulated signal was generated and detected. The conversion penalty is then given by the required received power for a given bit error rate. Compared to baseband modulation, the downsampled signal require around 2 dB higher average optical power, lower than the theoretical limit given by sinusoidal carrier modulation. About 1-dB penalty can be attributed to the penalty predicted by the observed pulse-width, and the second 1-dB penalty is due to lower effective modulation index of the RF modulation, than that of the binary modulation that had 12dB extinction ratio. By improving pulse-width and modulation depth, a conversion penalty lower than 1-dB will be available using this technique.

4. Summary

In this paper we have demonstrated baseband optical down-sampling with low conversion penalty. In the demonstrated arrangement, an integrated dual mode-locked SG-DBR laser is used to produce two sets of pulse-trains for separate I- and Q-channel baseband access. Using a 50 Mbaud QPSK-modulated 2.5 GHz RF signal to characterize the sampling approach, a 2-dB power penalty is obtained compared to the baseband-modulated optical signal. With the current source, the downconversion scheme offers an alternative to electrical frequency conversion. However, using higher performance mode-locked lasers, the baseband optical downconversion scheme will play an important role in extending the frequency range of promising linear link technologies, such as the use of high resolution ADC's with digital signal processing, or the use of phase-lock loops in optical phase demodulators.

5. References

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