Active stabilization of single drive dual-parallel Mach-Zehnder modulator for single sideband signal generation

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We present a study on a single-drive dual-parallel Mach-Zehnder Modulator (DP-MZM) implementation as single side-band suppressed carrier (SSB-SC) generator. High values of both extinction ratio (ER) and side-mode suppression ratio (SMSR) were obtained at different modulation frequencies over the C-band. In addition, a stabilisation loop had been developed to preserve the SSB generation over time.

Introduction: The exploding bandwidth demand in optical networks is favouring technologies that promise a better exploitation of the fibre's available transmission spectrum [1]. In this respect, Single Side-Band modulation (SSB), can be highly attractive as it provides a path to enhance overall spectral efficiency of future optical systems by allowing the transmission of one of the two signal sidebands [2]. At low bitrates, the generation of an SSB signal can be readily achieved by an electronic implementation of the Hilbert transformer. However, at high bitrates electronics cannot follow and all-optical methods are preferred. Fibre Bragg Grating (FBG) and Mach-Zehnder Interferometer based optical filtering schemes have been recently proposed to realize the single side-band suppression [3-6] in the optical domain. However, such schemes are designed to operate at fixed bitrates, and for narrowband signal selection they result in poor ER and SMSR. $LiNb0_3$ optical modulators, on the other hand, have enabled more bit-rate flexible schemes for SSB generation [7,8]. Nevertheless, their practical application in optical transmitter units has been limited by the drifting behaviour of the modulator, as even minor deviations from their optimum operating point degrade heavily their performance.

In this letter we have proposed and implemented a stabilized single sideband signal generation scheme, combining a dual parallel MZM modulator with electronic feedback to obtain high performance merits over a long period of time. Furthermore we have investigated the behaviour of the scheme for different modulation frequencies and across the C-band.

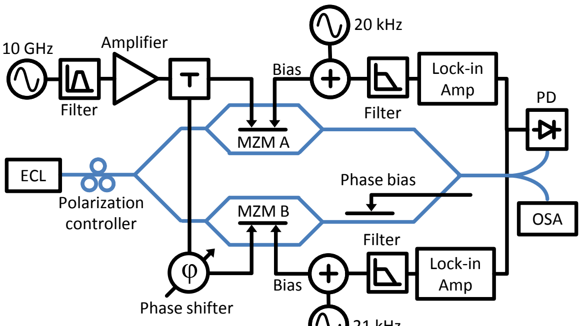

Fig. 1 *Experimental setup of the DP-MZM scheme with the proposed stabilisation for the generation of an SSB-SC optical signal*

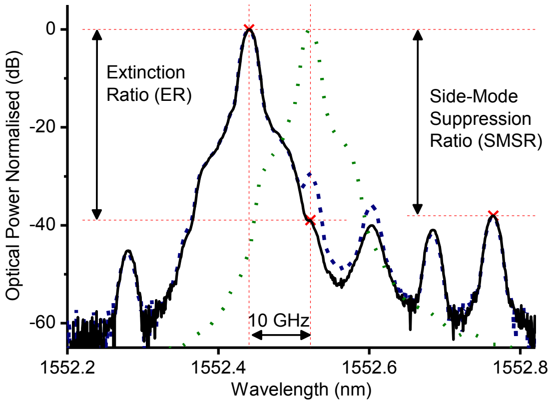

Fig. 2 *Optical spectrum of a 10 GHz SSB-SC generated signal: optimised (solid line), not-optimised (dash) and input optical carrier (dot)*

Experiment: The experimental setup of the DP-MZM with active stabilization for the generation of a high quality optical single sideband suppressed carrier (SSB-SC) signal is illustrated in Fig.1. The DP-MZM was fed by a continuous wave optical signal at λ_{cw}=1552.5 nm emitted by a wavelength tunable external cavity laser (ECL). The two parallel MZMs were driven by an RF clock that originated from a common source. A phase shifter in one of the two RF paths ensured control of the relative phase difference between the two driving signals. Each MZM generated an optical frequency comb with sub-carrier spacing equal to the RF driving frequency. The two combs interfered destructively at the output port of the DP–MZM, creating the SSB-SC modulation when a $\pi/2$ phase difference existed between the two RF driving signals. This required also that the two parallel MZMs operated at the null point, along with an additional $\pi/2$ phase difference introduced in the optical path between the two arms of the DP-MZM. Fig. 2 depicts the optical spectrum of an SSB-SC signal at 10 GHz, along with the spectrum of the input optical carrier, for optimized operating conditions of the DP-MZM. These have been achieved for 16.8 dBm RF driving power applied on each its two parallel MZM, and with corresponding bias voltages of V_{MZM_A}: 3.289 Volts and V_{MZM_B}: 6.213 Volts. A high ER of 38.95dB and a SMSR of 38.13dB were obtained.

Any drift from the optimum biasing points of the two modulators i.e. due to environmentally induced temperature variations, could affect the suppression of the input optical carrier at λ_{cw} and degrade the overall performance of the SSB generation, see also Fig. 2. Long term stability at the optimum operating condition has been achieved, with a feedback loop scheme that applied separate control of each MZM bias. This was enabled by two electrical dithering tones, at 20 kHz and 21 kHz, added on the respective bias voltages. The dither was transferred only on the residual (un-suppressed) portion of the optical carrier, at $\lambda_{cw,}$ and could be extracted from the monitored optical signal, with the help of high gain lock-in amplifiers. The optical output was detected by a low speed photodiode. The two loops were closed with low pass electrical filters of 40 Hz bandwidth, enabling efficient compensation of the occurring slow drift effect. Fig. 3 depicts the results of long term measurements for the ER and SMSR of a 10 GHz SSB-SC generation process. After 24 hours of operation, the stabilization loop maintained, with small variations, a high ER level of ~38 dB and a SMSR level of ~38 dB. The ER and SMSR peak-to-peak variations calculated from the set of data are 0.77 dB and 0.45 dB respectively. Without feedback control the ER and SMSR figures degraded severely to 30 dB.

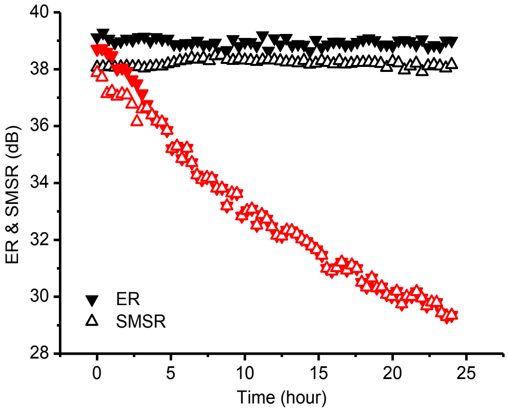

Fig. 3 *SSB modulation stability over time (24h): Stabilisation enabled (black) and disabled (red)*

The potential of the scheme to support SSB generation at different bitrates has been also explored. Fig. 3 depicts the results of the corresponding ER and SMSR measurements as a function of the RF driving frequency with either blue or red shifting of the generated SSB signal with respect to the input optical carrier. ER values above 35 dB were obtained for frequencies higher than 9 GHz approaching even 50 dB at 12 GHz. The limited resolution bandwidth of our optical spectrum analyser (~0.02 nm) didn't allow accurate measurements below 8 GHz. The SMSR performance seems to be more dependent on the characteristics of the DP-MZM as it follows the frequency response of the modulator and decrease with frequencies above 10 GHz. All the measured SMSR values were nonetheless above 20 dB.

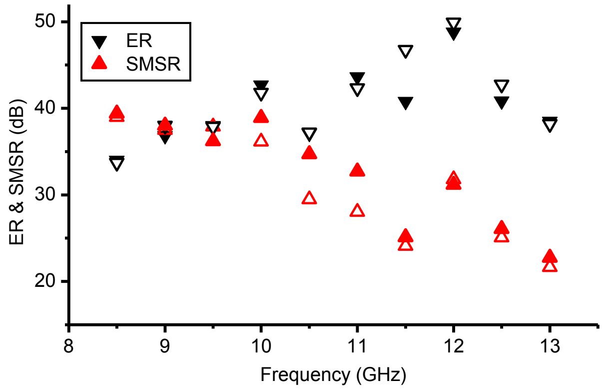

Fig. 4 *SSB generation at different shift frequency: blue shift (fill) and red shift (open)*

The scheme has been also tested through the whole C-band by measuring its ER and SMSR performance every 100 GHz. As the modulator is designed for the whole transmission window, the values were consistent. Nevertheless a drop in the SMSR is noticed in the lower part of the spectrum. Fig. 5 shows that the minimum values are still above 35 dB for the ER and SMSR. A very stable output optical power for the generated SSB tones is also shown.

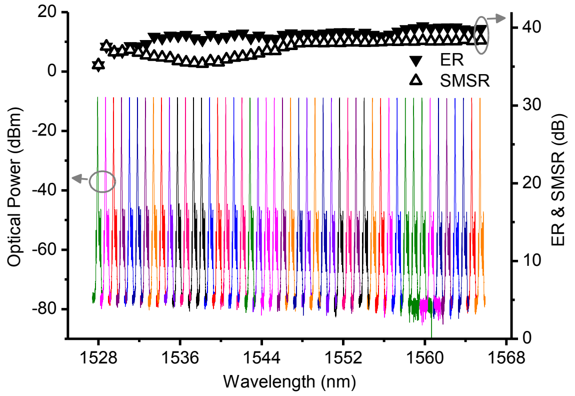

Fig. 5 *SSB-SC generation over the C-band. Optical spectrums and corresponding ER and SMSR values*

Conclusion: In this letter we have presented a stabilized SSB-SC generation scheme based on the use of a single drive DP-MZM and a feedback control loop. The scheme maintained high performance metrics of ER and SMSR over a time long period, different modulation frequencies and operating wavelengths proving its high potential for practical application in future optical transmitter units.

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