Investigation and solution for undesirable counter-propagating effects in Nonlinear Optical Loop Mirrors

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Abstract: Undesirable SPM (Self-Phase Modulation) and XPM (Cross-Phase Modulation) between counter-propagating lights in NOLMs (Nonlinear Optical Loop Mirror) are investigated. A solution to overcome these impairments is also proposed and experimentally validated.

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A fiber NOLM (Nonlinear Optical Loop Mirror) is an attractive device for ultra-fast all-optical processing as pedestal-suppressor, and as wavelength-converter and demultiplexer (Fig. 1) [1,2]. These schemes exploit SPM (Self-Phase Modulation), in the first case, or XPM (Cross Phase Modulation), in the other cases. In a first approximation only one of the two counter-propagating halves of the input signal experiences nonlinear phase shift due to its own power (SPM), or to the co-propagating light power (XPM). Nevertheless, the counter-propagating light experiences SPM/XPM due to nonlinear interaction between counter-propagating signals, depending on the mean power of the light responsible for the effect [3]. If the duty-cycle d of the signal inducing SPM or XPM is low (low-bit rate ultra-short pulsed signal), this effect can be neglected, since the mean power is much smaller than the peak power. But when the duty-cycle gets higher these effects rapidly increase and they can strongly affect the NOLM performance. This is the case of NOLMs used as 160Gbit/s pedestal-suppressors or wavelength-converters.

Here we investigate the SPM/XPM-based NOLMs considering both the implementations that use PM (Polarization Maintaining) or non-PM fiber and we analytically [4] and experimentally demonstrate the advantage of using the second implementation in order to obtain full independence of the transmission characteristic on the duty-cycle value.

Fig. 1. Analytical characteristics of a PM-NOLM based on SPM (left) and XPM (right) for different duty-cycle values of the signal inducing the nonlinearity. The NOLMs based on SPM and XPM are 2.5km long. The input peak powers are 3W in the first case and 3W and 1W for pump and signal respectively in the second case. The considered PM fiber has a nonlinear coefficient of 2 W⁻¹km⁻¹ and the zero dispersion in the signal band.

Fig. 1 shows the analytical variations of SPM/XPM-based PM NOLM characteristic for different duty-cycle values. All signals are polarized along the fiber slow axis. It is clear that the optimum NOLM working point is strictly correlated to the d parameter: the input power required for reaching the full-swing operation (phase shift of π) increases with the duty-cycle, affecting the NOLM performance. This dependence is almost suppressed when the NOLMs are realized with non-PM fibers as DS (Dispersion-Shifted) or HNL (Highly Non-Linear) fibers, and a polarization controller is added into the loop. This feature is experimentally validated as shown in Fig. 2, where the possibility to obtain an inverting XPM-based NOLM using non-PM fiber is also demonstrated. In this case the increased freedom degrees allow to optimize the NOLM working point independently on the duty-cycle. To further
verify this feature of the non-PM NOLMs, we consider the XPM-based NOLM used as optical switch. We define the switching amplitude as the difference between the instantaneous output power for a pump power passing from zero (space level) to its maximum (mark level) and we investigate its behavior as a function of the duty-cycle for a constant peak power. Fig. 3 shows the analytical switching amplitude, normalized to the theoretical optimum value, for both PM and non-PM implementations. While the PM NOLM switching amplitude rapidly decreases with \( d \), an accurate adjustment of the polarization controller parameters makes the non-PM NOLM switching amplitude independent on the duty-cycle. Moreover the analytical study demonstrates that a very high number of optimum working point can be found. This appears as a fundamental feature of the non-PM NOLM for its applications in 160Gbit/s systems.

![Fig. 2 Analytical and experimental characteristics of a DSF NOLM based on SPM (left) and XPM (right) for different duty-cycle values of the signal inducing the nonlinearity. The NOLMs based on SPM and XPM are 2.5 and 26m long. The input peak power are 2.2W in the first case and 0.7W and 0.2W for pump and signal respectively in the second case. By using DSF an inverting XPM-based NOLM can be obtained.](image)

![Fig. 3 Switching amplitude, normalized to the theoretical maximum value, of a XPM-based NOLM implemented by PMF (gray line) and DSF (black line). The NOLM parameters are the same than in the case of the other figures.](image)

7. References