UWB Doublet Generation in an Integrated Semiconductor Optical Amplifier Mach-Zehnder Interferometer

Manuel Rius , Vanessa Moreno , José Mora , Miguel A. Muriel , José Capmany

ABSTRACT

In this paper, we propose and experimentally demonstrate a novel technique to generate ultrawideband (UWB) doublet pulses by exploiting the cross-phase modulation (XPM) in a semiconductor optical amplifier (SOA). The key component in the proposed system consists on an integrated SOA Mach–Zehnder interferometer (MZI) pumped with a Gaussian pulse modulated optical carrier. The transfer function of the nonlinear conversion process leads to the generation of UWB doublet pulses through the control of the biasing point of the SOA-MZI.

Keywords: optical pulse generation, ultrawideband technology, radio over fiber, microwave photonics.

1. INTRODUCTION

Ultra-wideband (UWB) technology is considered an interesting technology for its application in wireless communications, sensor networks, location and radar systems. The US Federal Communications Commission (FCC) has regulated the definition of UWB signal which has a spectral bandwidth greater than 500 MHz or a fractional bandwidth greater than 20% with a power spectral density lower than -41.3 dBm/MHz within a frequency band form 3.1 GHz to 10 GHz [1].

In the last years, UWB has become in an attractive technology because of its capability to coexist and share the spectrum with other technologies. UWB wireless signals are especially interesting for short-range communications where high data rates are needed. Characteristics such as high data rate, low power consumption, immunity to multipath fading, interference mitigation, carrier free and the facility to overcome obstacles define this successful technology and differentiate it from traditional narrowband technologies [2].

Parallel to the increasing use of UWB technology, there has been a considerable interest in the implementation of photonic solutions in order to profit the benefits of Microwave Photonics (MWP) [3]. For example, wireless transmission for UWB communications is able only to reach a distance of a few tens of meters. At this point, MWP leads to bring an elegant solution to this problem by increasing the coverage area through the distribution of the UWB signals in the optical domain. However, MWP is not only used to UWB signals distribution but also for UWB signal generation. Inherent advantages of the optical domain as low losses, light-weight, high bandwidth, tunability, reconfigurability and immunity to electromagnetic interference are useful in the process of the UWG signal generation.

In this context, the proposal of techniques to generate UWB signals in the optical domain over traditional and pure electronic methods has been productive. We can find methods for UWB generation based on phase-modulation-to-intensity modulation conversion, photonic microwave filtering, and optical spectral shaping and dispersion-induced frequency to-time mapping [5]. Many schemes have been proposed to generate high order pulses in order to fulfil the FCC mask [4], however, the most usual signals that are being used in Impulse Radio UWB (IR-UWB) communications are monocycle and doublet pulses. For example, a simple method to generate UWB doublet pulses was reported based on a nonlinearly biased electro-optic intensity modulator [6].

In this paper, we present a scheme to generate UWB doublet pulses based on the use of nonlinearities present in an active integrated interferometric structure. The performance of the system exploits the properties of a Mach-Zehnder interferometer (MZI) that integrates a semiconductor optical amplifier (SOA) in each branch [7]. An optical pulsed signal is used as pump signal in order to induce cross-phase modulation (XPM) in the SOA-MZI. The nonlinear characteristics of the SOA-MZI transfer function permits the generation of UWB doublet pulses for a given operation point which is determined by the saturation of the SOAs.

2. PRINCIPLE OF OPERATION

Figure 1 shows the experimental scheme implemented by using an integrated SOA-MZI that contains two 1-mm length InGaAsP–InP SOAs with low polarization sensitivity. In principle, cross-gain modulation (XGM) and cross-phase modulation (XPM) processes could be present in the SOAs. However, the linewidth enhancement factor of the SOAs is large enough to neglect the XGM.

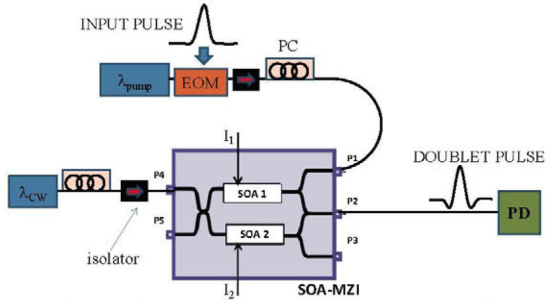

Figure 1. Experimental layout (PC: polarization controller).

The nonlinear SOA-MZI consists on an interferometric structure used in counter-propagation configuration with different input and output ports. In our case, a pulsed pump signal centred at the optical wavelength λ_{PUMP} = 1535 nm is obtained by external electrooptic modulation (EOM) of a CW optical carrier with an electrical signal (Gaussian pulse).

As shown in Fig. 1, the pump signal is introduced in the system at port P1 and a continuous probe wave (CW) laser source is launched into Port P4 with a central optical wavelength λ_{CW} = 1550 nm. Thus, the conversion process is carried out in counter-propagation configuration, and hence, optical filtering is not needed to separate pump and probe signals. Finally, at the output port P2 the optical processing is performed and the optically processed signal is measured by means of a photodetector (PD) in an oscilloscope or an electrical spectrum analyzer.

The process of XPM in the interferometric structure depends on the average optical power of the pump and probe signals and also it depends on the electrical currents applied to each SOA. Therefore, the optical power of the pump and probe signals have to be controlled in order to optimize the conversion process. In Fig. 2, we represent the conversion transfer function of the proposed system. This experimental characterization has been obtained by modulating the pump signal with an RF tone with a frequency of 10 GHz generated and analyzed by a lightwave component analyzer (LCA). In this way, Fig. 2 plots the conversion amplitude and the relative RF phase between the optical wavelength of the output port P4 and pump signal launched into port P1 depending on the employed current at the SOA2. The SOA1 in the upper branch has a high constant current of 300 mA that determines the speed conversion of the probe continuous signal.

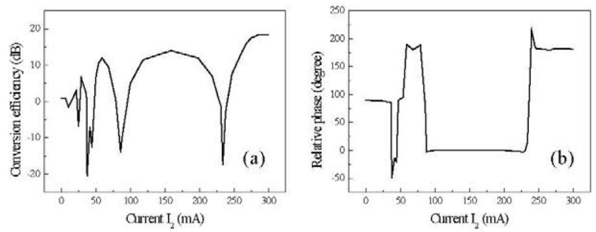

Figure 2. Transfer function of the SOA-MZI. Conversion amplitude (a) and relative phase (b) of the output port P2 respect to input port P1 in function of the current applied to SOA2.

We can observe that different operation current points can be achieved to perform a conventional wavelength conversion. The maximum XPM conversion is found by applying to the SOA2 a current of 300 mA. Since the transfer function is measured by means of a RF tone in low modulation regime, the maximum conversion corresponds to an operation point with a quasi-linear response while the points of minimum conversion correspond to a SOA-MZI transfer function with a quadratic response. In this way, the nonlinear response of the transfer function can be achieved for currents far from maximum operation points in a similar way as in the proposal based on the nonlinear transfer function of an EOM [6]. In this case however, our system achieves higher extinction ratio and modulation efficiency than with conventional EOMs improving the performance of UWB pulse generation. In addition, we can observe also in Fig. 2 different regions where the relative phase between the output and input signal changes from 0° to 180°. This change of sign leads to a control of the UWB pulse polarity in function of the applied current.

3. EXPERIMENTAL RESULTS

In order to demonstrate the UWB generation approach, an experiment has been carried out according to Fig. 1. In this case, the pump laser is modulated with a quasi-Gaussian pulse train. The EOM is fed with an electrical signal coming from an electrical generator with a fixed pattern of 64 bits with one "1" and sixty-three "0" and a bit rate of 12.5 Gb/s. The equivalent signal is a pulse train with a repletion rate of 195 MHz and a pulse width of 80 ps as shown in Fig. 3a. The optical output of the EOM corresponding to the pump signal is represented in Fig. 3b. We can observe that the EOM is biased in a negative region in order to obtain an inverted optical pulse. This is needed to guarantee the saturation of the SOA1 with high level of power coming from the pump signal.

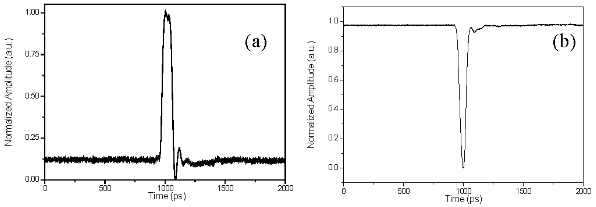

Figure 3: (a) Electrical pulsed signal and (b) optical signal at the output of EOM which is used as pump signal.

As mentioned above, the pump signal is launched into the port P1 and the probe signal into the port P4. The doublet pulse is obtained at the output of the PD (port P2 in Fig. 1). In this case, we set the operation current of SOA1 at 300 mA and adjust the applied current to SOA2, in order to monitor the waveform and RF spectrum of the generated pulse by using a digital communication analyzer (DCA) and an electrical spectrum analyzer (ESA), respectively.

Firstly, a current of 300 mA is applied to SOA2 that corresponds to operation region in the transfer function with negative slope as plotted in Fig. 1. As expected, the output pulse is inverted leading to the generation of a quasi-Gaussian pulse as shown in Fig. 4a. The corresponding spectrum is plotted in Fig. 4b.

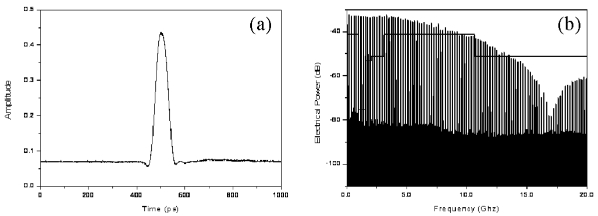

Figure 4: (a) Waveform and (b) electrical spectrum of the optical signal at the output of port P2 when the current applied to SOA 2 is 300 mA.

When the electrical current is tuned to be a value of 270 mA in SOA2, the input pulse is large enough to saturate the SOA-MZI which permits to generate an UWB doublet as shown in the waveform of Fig. 5a. As expected, the corresponding spectrum of Fig. 5b shows a reduction of spectral components close to baseband comparing with Fig. 4b. Also, the polarity of the UWB doublet pulse can be inverted by modifying the current applied to SOA2. When SOA2 current is changed from 270 mA to 176 mA, a UWB doublet with a reversed polarity is obtained. Figure 5c and Fig. 5d represents the corresponding waveform and spectrum, respectively. Note that the amplitude of the UWB doublet obtained in Fig. 5a is much higher than in Fig. 5c. The reason is due to the fact that the conversion efficiency is lower for a current of 176 mA than 270 mA as shown in Fig. 2.

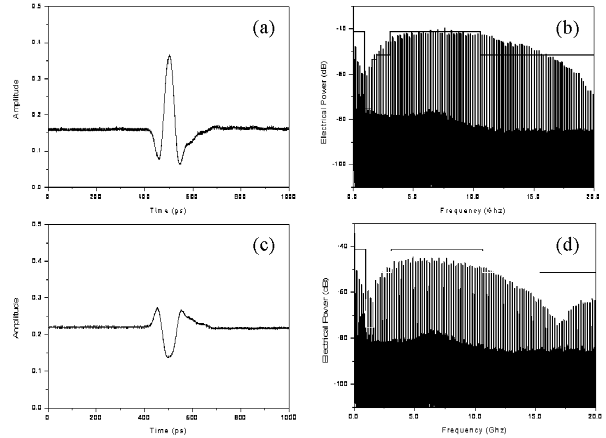

Figure 5: (a) Waveform of the UWB doublet pulse and (b) its corresponding electrical spectrum at the output port P2 for an electrical current applied to SOA2 of 270 mA. (c) Waveform and (d) its corresponding electrical spectrum of a UWB doublet pulse with inverted polarity for an electrical current applied to SOA2 of 176 mA.

4. CONCLUSIONS

A novel approach has been proposed to generate UWB double pulses based on XPM in a SOA. An optical pulse is used as pump signal in order to convert a CW signal by means of XPM in an integrated SOA-MZI. The experimental analysis of the transfer function permits to find an optimum operation point in the conversion process which leads to the generation of UWB doublet pulses by means the electrical current applied to each SOA. Also, we have experimentally demonstrated the generation of UWB doublet pulses. Firstly, the biasing point of the SOA1 where the XPM is realized between the pump and probe signals is set to a maximum value to guarantee an optimum conversion. Then, the current of the SOA2 is changed to find a compromise between the conversion efficiency and the nonlinear response to obtain a UWB doublet pulse. In this way, the polarity of the doublet is controlled by switching the electrical current applied to SOA2.

ACKNOWLEDGEMENTS

The research leading to these results has been funded by the national project TEC2010-21303-C04-02 and TEC2011-26642 funded by the Ministerio de Economía y Competitividad and the projects FEDER UPVOV08-3E-008 and UPVOV10-3E-492.

REFERENCES

[1] D. Porcine, P. Research, W. Hirt, "Ultra-wideband radio technology: Potential and challenges ahead," *IEEE Commum. Mag.* 41, 66-74 (2003).
[2] F. Nekoogar, *Ultra-Wideband Communications: Fundamentals and Applications*, Prentice Hall: United States of America, (2006).
[3] J. Capmany, D. Novak, "Microwave photonics combines two worlds," *Nature Photon.* 1, 319-330 (2007).
[4] J. Yao, F. Zeng, Q. Wang, "Photonic generation of ultrawideband signals," *Journal of Lightwave Technology*, vol. 25, no. 11, pp. 3219-3235, (2007).
[5] M. Bolea, J. Mora, B. Ortega, J. Capmany, "High-order UWB pulse generation based on a microwave photonic filter using incoherent optical sources," *In Proc. International Topical Meeting on Microwave Photonics Conference*, pp. 462-465, (2011).
[6] Q. Wang, J. Yao, "UWB doublet generation using nonlinearly-biased electro-optic intensity modulator," *Electronics Letters* , vol. 42, no. 22, pp. 1304,1305, Oct. 26 2006.
[7] M.D. Manzanedo, Mora, J. Capmany, J. Mora, "Continuously tunable microwave photonic filter with negative coefficients using cross-phase modulation in an SOA-MZ interferometer," *IEEE Photonics Techn. Lett.* 20, 526-528 (2008).