UWB doublet generation employing non-linear effects of a Semiconductor Optical Amplifier Mach-Zehnder inteferometer

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ABSTRACT:

In this article, a novel method to generate an ultra-wideband (UWB) doublet using the cross-phase modulation (XPM) effect is proposed and experimentally demonstrated. The main component of the submitted architecture is a SOA-Mach-Zehnder interferometer (MZI) pumped with a modulated Gaussian pulse. Maximum and minimum conversion points are analyzed through the systems transfer function in order to determinate the most effective operation stage. By tuning different values for the SOAs currents, it is possible to identify a conversion step in which the input pulse is enough large to saturate the SOA-MZI, leading to the generation of a UWB doublet pulse.

Key words: optical pulse generation, non-linear effects, ultra-wideband communications, microwave photonics, conversion process, transfer function.

1.- Introduction

Ultra-wideband (UWB) technologies have been developed in recent years as an interesting solution in the fields of wireless communications, radar systems, imaging applications and sensor networks. The US Federal Communications Commission (FCC) defines UWB as any signal that occupies more than 500 MHz bandwidth or possesses a fractional bandwidth greater than 20%. The FCC has also established the unlicensed use of the band located between 3.1 and 10.6 GHz with a power density lower than -41.3 dBm/MHz.

UWB signals have attracted a lot of interest in the scientific area because of their high data rate, low power consumption, immunity to multipath fading, interference mitigation, low loss, carrier free and especially for their capacity of sharing their corresponding spectrum with other technologies.

At the same time, microwave photonics (MWP) emerges with an aim of carrying equivalent tasks to those of any ordinary microwave filter within an Radio Frequency system or link, in parallel it provides features which are very difficult or even impossible to achieve with traditional technologies, such as fast tunability and reconfigurability [2].

The joint of these two techniques opens the door to interesting possibilities and appeals researchers as an alternative for several current limitations. For instance, the scope for UWB in terms of distance is limited to a few tens of meters due to its low power density. In order to increase the area of coverage, the distribution of such signals using optical fibers has emerged as a useful solution [3]. Nevertheless, distribution is not the only use that can be attributed to MWP for UWB. Also, signal generation is a potential application.

In this context, the employment of photonic technologies to produce UWB signals in the optical domain has shown amazing accomplishments. It is feasible to find bibliography that proposes several methods for UWB generation, based on phase-modulation (PM) to intensity-modulation (IM) [4], photonic microwave filtering [5], and optical spectral shaping and dispersion-induced frequency to-time mapping [6].

Some schemes have been proposed to generate high order pulses that properly fulfill the mask established by the FCC [7]. However, the most common signals employed in Impulse Radio UWB (IR-UWB) communications are monocycle and doublets. In this perspective, we can also find more simple methods to generate doublet pulses based on the use of a biased electro-optic intensity modulator or the non-linear effects of a SOA [8-9].

In the present article, we propose a novel scheme to simply generate UWB doublet pulses based on the non-linear effects in an interferometric structure which integrates Semiconductor Optical Amplifiers (SOAs). The conversion process depends directly of the currents applied to the SOAs that integrate such device. A pump signal is introduced to the system to induce the cross phase modulation (XPM) effect in the SOA-MZI. Due to the non-linear characteristics of its transfer function, we can achieve the generation of UWB doublets at a specific operation point which is established by the saturation of the SOAs.

2.- Principle of Operation

Figure 1 shows the experimental scheme proposed to generate UWB doublets. It is composed of an optical source (labeled as λ_{CW1}), an integrated SOA-MZI that includes two 1-mm length InGaAsP-Inp SOAs with low polarization sensitivity, a pump signal and a photodetector.

Since the SOA-MZI is a non-linear device, both cross-gain modulation (XGM) and cross-phase modulation (XPM) effects could be present. However, the linewidth enhancement factor of the SOAs is enough large to neglect the XGM.

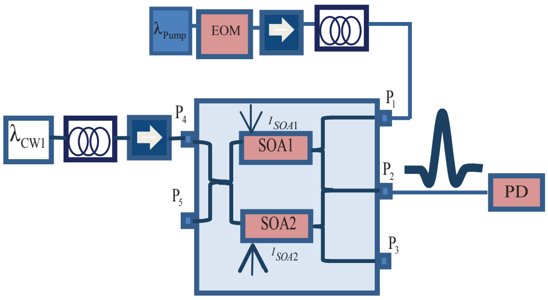

Fig. 1: Experimental setup based on SOA-MZI.

The key component of the architecture is the SOA-MZI which is detailed in [10]. This structure consists on an interferometric device configured with a counter-propagation configuration. It has several input and output ports. For the experimental design submitted the pump signal features an optical wavelength (λ_{PUMP}) of 1535.04 nm. As shown in Fig. 1, the pump signal is launched into the structure through port P_1. In parallel, the continuous wave laser source represented by λ_{CW1} is introduced at port P_4 with a central optical wavelength of 1550.12 nm. Finally, the signal obtained through the XPM process is measured at port P_2 by means of a photodetector (PD) and it is analyzed in an oscilloscope or a spectrum analyzer.

The XPM procedure in the SOA-MZI depends on the average optical power of the pump and probe signals and at the same time on the currents applied to each SOA. For instance, such power values must be controlled to optimize the conversion process. In this case, the values for the optical power of the pump and probe were established in 13 dBm and 5.40 dBm, respectively.

Figure 2 shows the conversion transfer function of the proposed system. The experimental characterization was obtained by modulating the pump signal with an RF tone at a frequency of 10 GHz generated and analyzed by a lightwave component analyzer (LCA). Fig. 2(a) plots the conversion efficiency factor and Fig. 2(b) the relative phase between the optical wavelength of the output (port P_4) and the pump signal launched into Port P_1, in function of the modification of the current applied to SOA2 (I_{SOA2}). The value for the current applied to

SOA1 (I_{SOA1}) remains fixed at 300 mA, which is the value that defines the speed conversion of the probe continuous signal.

The transfer function is measured by means of a RF tone in low modulation regime. Therefore, the maximum conversion point corresponds to an operation stage in which a quasi-linear response appears, while the points of minimum conversion correspond to a SOA-MZI transfer function with a quadratic response.

The nonlinear response of the transfer function can be achieved for current values far from maximum operation points, similar to approaches based on an EOM [8]. In our case, the conversion efficiency reveals noticeable improvements. We can observe in Fig. 2(b) how the relative changes from 0º to 180º phase for different regions between the output and input signal. This change of sign leads to a control of the UWB pulse polarity in function of the applied current.

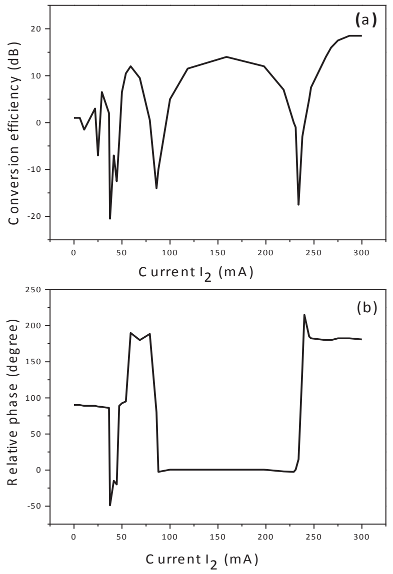

Fig. 2: Transfer function of the SOA-MZI: (a) Conversion amplitude of the output port P2 and (b) the corresponding relative phase.

3.- Experimental Results

In order to experimentally demonstrate the UWB doublet pulses generation, the scheme presented in Fig 1 was carried out. In the case of the pump laser, it was modulated with a quasi-Gaussian pulse train. The electrical signal that feeds the EOM has a fixed pattern of one "1" and sixty-three "0", summing up a total of 64 bits with a bit rate of 12.5 Gb/s. Fig. 3(a) shows the electrical pulsed signal that is launched into the EOM and Fig. 3(b) shows the output of the modulating process which is finally used as pump signal. We notice that the EOM is biased in a negative region so it is plausible to obtain an inverted pulse. Such feature is needed to guarantee the saturation of the SOA1 with high level of power coming from the pump signal.

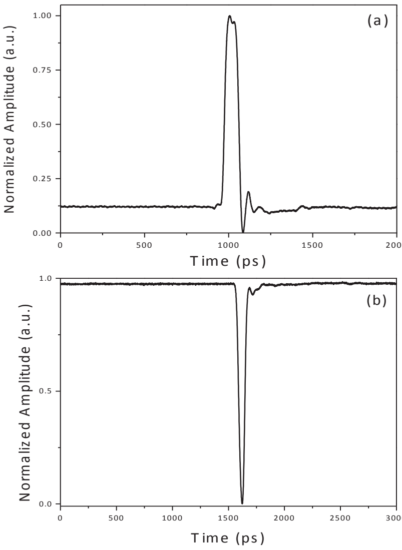

Fig. 3: (a) Electrical pulsed signal used as input and (b) modulated pulse which is used as pump signal of the system.

As it was previously mentioned, the pump signal is introduced to port P_1, the probe signal is launched into the port P_4 and the resulting doublet is obtained at the output of the PD (port P_2). The operation current for SOA1 (I_{SOA1}) is set at 300 mA, but the value for I_{SOA2} is gradually modified in order to measure the resulting waveform and spectrum through a digital communication analyzer (DCA) and an electrical spectrum analyzed (ESA).

Firstly, we measure the system with a value of $I_{SOA2} \approx 300\text{mA}$, which corresponds to the operation region in the transfer function that holds a negative slope. In Figure. 4(a), we visualized the output pulse which corresponds to the inverted version of the pump signal. The corresponding spectrum is plotted in Figure 4(b).

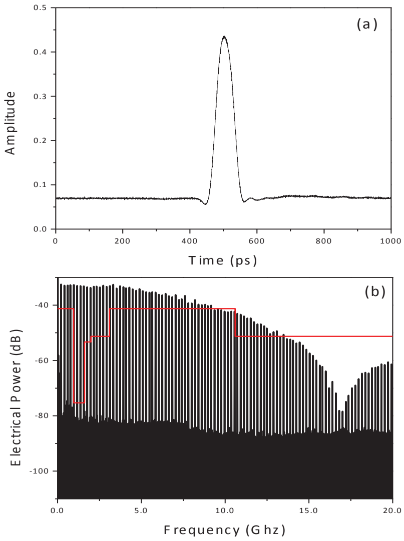

Fig. 4: (a) Waveform and (b) spectrum obtained at Port P_2 with $I_{SOA2} \approx 300mA$.

If we continue tuning different values for I_{SOA2}, we are able to observe interesting waveforms that illustrate the working cycle of the interferometric structure. When we set the current of SOA2 to 270 mA, the input pulse is enough large to saturate the SOA-MZI and generate a doublet pulse. Fig. 5(a) plots the waveform of the obtained UWB doublet and Fig. 5(b) plots the corresponding spectrum, which shows a more proper fit in terms of the values settled by the FCC when compared to Fig. 4(b).

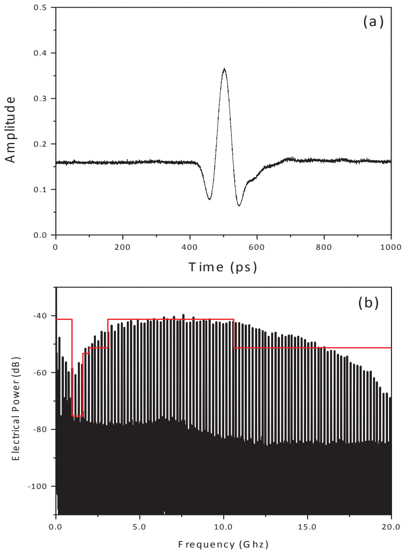

Fig. 5: (a) *Waveform and (b) electrical spectrum of the UWB doublet pulse for an electrical current applied to SOA2 of 270 mA.*

It is feasible to switch the polarity of the obtained doublet pulse by modifying the value of I_{SOA2} by setting it at 176 mA. Fig. 6(a) shows the waveform for the doublet and its visible change of polarity. Fig. 6(b) exhibits the spectrum related to the previous waveform.

By comparing the characteristics of the obtained doublet pulses, we can determinate that the amplitude of the UWB doublet shown in Fig. 5 (a) is much higher than in Fig. 6 (a). 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(a).

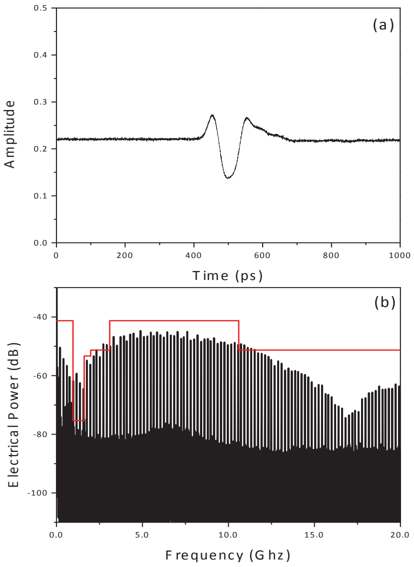

Fig. 6: (a) *Waveform and (b) electrical spectrum of the UWB doublet pulse for an electrical current applied to SOA2 of 176 mA.*

4.- Conclusions

A novel method has been proposed and successfully demonstrated for the generation of a UWB doublet pulse based on the XPM effect present in a SOA-MZI structure. The experimental analysis of the transfer function permits to identify the optimum operation point which leads to the capacity of generating the desired doublet by tuning different values for the current applied to the SOA2. Once the relation between the non linear response and the current value is found, it is also possible to switch the polarity of the obtained pulse.

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