Simulation of a New Method to Generate Gaussian Pulses for UWB Systems

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Abstract

We proposed and demonstrated a novel method to generate Ultra-Wideband (UWB) pulse (monocycle and doublet) using an optically reconfigurable photonic microwave delay-line filter and Optical amplifier (OA) . By using the XGM in the OA, a pair of polarity-reversed optical Gaussian pulses is generated at the output of the OA, to which a Gaussian pulse pump and a continuous-wave probe are applied. The two polarity-reversed optical pulses are then time delayed by two cascaded fiber Bragg gratings to introduce a time delay difference. A UWB monocycle pulse with a full width at half-maximum of 35 ps was achieved. The microwave filter can be reconfigured as a three-tap microwave filter with coefficients of (1, -2, 1). The function of microwave filter is equivalent to an operation of a second-order difference, which can be approximated as a second-order derivative.

الخلاصة

تم اقتراح واثبات إنشاء نبضة بصريه أحاديه وثنائيه من نوع Gaussian لانظمة الحزم فائقة العرض باستخدام معيد التشكيل البصري فلتر التأخير الخطي لإشارة المايكرويه الضوئية والمكبرة البصرية. بواسطة ظاهرة تضمين تقاطع الربح لموجتين داخلتين للمكبرة البصرية تم إنشاء نبضتين متعاكستين بالقطبية عند مخرج المكبرة . ثم تم وضع زمن تأخير بين تلك النبضتين البصريتين لإنشاء نبضه أحادية ذات عرض 35 ps عند FWHM . ولإنشاء موجه ثنائيه ذات عرض 25 ps عند FWHM تم ا استخدام فلتر التأخير الخطي حيث تم تضبيطه على معاملات (1,-2,1) . إن وظيفة فلتر التأخير الخطي هي مكافأة لعمل المشتقة من الدرجة الثانية.

1. Introduction

Ultra wideband (UWB) is a fast emerging technology that has recently attracted considerable interest for its applications in short-range, high-capacity wireless communication systems and sensor networks, thanks to advantages such as a very high data rate, low power consumption, and immunity to multipath fading [Shen ,2006].

Among these techniques, the implementation of the first- or the second-order derivatives of a Gaussian pulse, to generate a Gaussian monocycle or a Gaussian doublet, is considered as a simple and efficient technique for UWB pulse generation [Fontana 2004]. UWB pulses can be generated in the electrical domain using electronic circuitry. Recently; the generation of UWB pulses in the optical domain has been a topic of interest. The generation of UWB pulses in the optical domain provides a higher flexibility, which enables the generation of UWB pulses with switchable pulse shapes and polarities. In addition, the huge bandwidth offered by photonics enables the generation of UWB pulses to fully occupy the spectrum range specified by the FCC. Different approaches have been recently proposed and demonstrated [Yao, 2007]. The major limitation of the approaches in is that each scheme can only generate one type of UWB pulse (Gaussian monocycle or doublet). For some applications, such as pulse shape modulation (PSM), it is desirable that both Gaussian monocycle and doublet can be generated in a single system. In [Zuniga, 2006], different waveforms can be obtained, but the switching speed between the waveforms is limited by the speed of the liquid crystal modulator. Very recently, a design was proposed to generate UWB monocycle and doublet pulses in one system [Fontana, & Richley,2007], in which a fiber Bragg grating (FBG) was used to serve as a frequency discriminator, to perform phase modulation to intensity modulation (PM-IM) conversion. By locating the optical carrier at the linear or the quadrature region of the FBG reflection spectrum, UWB monocycle or doublet pulses were generated [Li, 2007]. The main drawback of this scheme is the requirement for a high-speed tunable laser source (TLS) to realize the waveform switchability. In addition, the high sensitivity of the FBG to environmental changes would affect the stability of the system.

UWB signals are produced by pulsed emissions, where a very wide RF bandwidth is related to a narrow pulse width. Unlike many conventional radio transmitters in which a modulated signal is up converted & amplified, in UWB systems information is encoded in the series of baseband pulses and transmitted without a carrier. Hence, the transmitters require precise pulse shaping to produce the required spectrum and maximise the antenna's emission. Producing emissions with flat & wide PSDs requires extremely accurate pulse designs.

Most of the approaches proposed for generating UWB signals with characteristic monocycle or doublet waveforms are implemented mainly by using electronic circuits in the electrical domain.[Wang and Yao, 2006] To distribute UWB signals over a longer distance, state-of the- art optical fiber with extremely low loss is considered an excellent candidate for a transmission medium. Therefore the generation and distribution of UWB signals directly in the optical domain has been a topic of interest recently . The generate UWB doublets in the optical domain by using a specially designed frequency-shift keying modulator that consists of four optical phase modulators with three electrodes. In the same way the hybrid system for generating UWB monocycle signals in the gain-switched Fabry– Perot laser diode was used to generate an optical pulse train; a UWB monocycle signal is then produced in the electrical domain by a microwave differentiator [Wang& Zeng, 2006], the generated UWB signals by using an optical phase modulator in combination with a length of single-mode fiber (SMF) was performed In Ref. [D. Wentzloff,2006], instead of a long SMF, a fiber Bragg grating (FBG) is employed as a frequency discriminator to perform PM–IM conversion. UWB monocycle or doublet signals can be generated by altering the location of the optical carrier at the linear or the quadrature slopes of the FBG spectral response.

Recently proposed to generate UWB signals by using photonic microwave delay line as differentiated. Because Gaussian monocycle or doublet pulses can be generated by implementing the first-or the second-order derivative of a Gaussian pulse this was achieved in [Wang & Yao, 2007].

3. Gaussian pulse generation

3.1 Mathematical analysis

Gaussian monocycle or doublet pulse can be generated by implementing the first- or the second-order derivative of a Gaussian pulse where the zero-mean Gauss function is described by Equation (1), where σ is the standard deviation:

$$G(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-x^2/2\sigma^2} \qquad \text{---(1)}$$

Where: G(x) are called Gaussian waveforms because their mathematical definition is similar to the Gauss function.

The basis of these Gaussian waveforms is a *Gaussian pulse* represented by the following Equation

$$y_{g1}(t) = K_1 e^{-(t/\tau)^2} \qquad \text{---(2)}$$

Where: y_{g1} is the basis of the Gaussian pulse, $-\infty < t < \infty$, τ is the time-scaling factor, and K_1 is a constant. More waveforms can be created by a sort of high-pass filtering of this Gaussian pulse. Filtering acts in a manner similar to taking the derivative of Equation (2). For example, a Gaussian monocycle, the first derivative of a Gaussian pulse, has the form:

$$y_{g2}(t) = K_2 \frac{-2t}{\tau^2} e^{-(t/\tau)^2} \qquad \text{---(3)}$$

Where: y_{g2} is the first derivative of a Gaussian pulse, $-\infty < t < \infty$, τ is the time-scaling factor and K_2 is a constant. A Gaussian monocycle has a single zero crossing. Further derivatives yield additional zero crossings, one additional zero crossing for each additional derivative. If the value of τ is fixed, by taking an additional derivative, the fractional bandwidth decreases, while the centre frequency increases. A Gaussian doublet is the second derivative of Equation (3) and is defined by [Shen 2006]

$$y_{g3}(t) = K_3 \frac{-2}{\tau^2}\left(1 - \frac{2t^2}{\tau^2}\right) e^{-(t/\tau)^2} \qquad \text{---(4)}$$

Where: y_{g3} is the second derivative of a Gaussian pulse, $-\infty < t < \infty$, τ is the time-scaling factor and K_3 is a constant.

After generating the optical monocycle pulses by using the optical amplifier the doublet Gaussian pulses can be generated according to equation (4). The second -order derivative of Gaussian pulses can be approximated by the first- or the second-order difference. It is known that the a second-order difference can be realized using a three-tap microwave delay-line filter with coefficients of (1, -2, 1) [Wang and Yao, 2007].

3.2 Principle of photonic microwave delay line filter

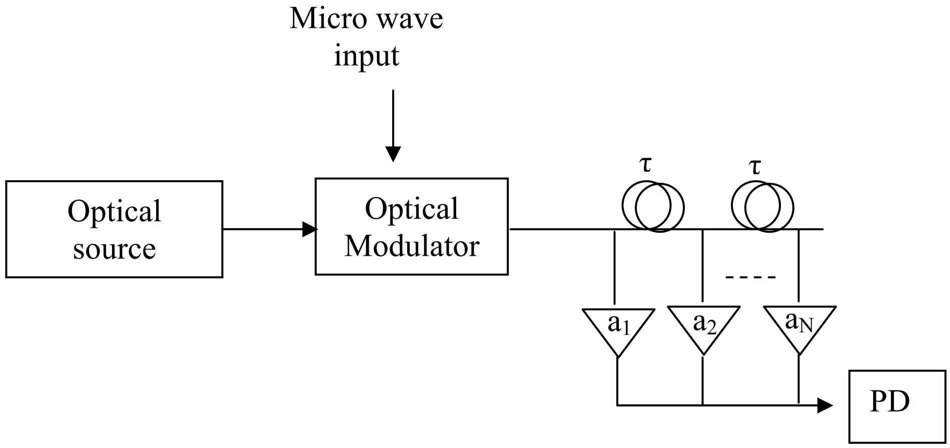

Figure (1) illustrate the principle of photonic microwave delay line filter

The schematic diagram of a general *N*-tap photonic microwave delay-line filter is shown in Fig. 1. It consists of an optical source, an optical modulator, a delay tine device, and a photodetector (PD). The microwave signal to be filtered is modulated onto the lightwave

Generated from the optical source via the optical modulator. The modulated lightwave is then sent to an *N*-tap delay-line device to introduce different time delays with an identical time delay difference between two adjacent taps. The time-delayed signals are then applied to the PD. The time delay difference determines the free spectral range (FSR) and the coefficients determine the shape of the filter response. Mathematically, the frequency response of an *N*-tap microwave delay-line filter is given

$$H_N(\omega) = \sum_{k=0}^{N-1} a_k e^{-jk\omega\tau} \qquad \text{---(5)}$$

Where $H_N(\omega)$ is the frequency response of delay–line filter, τ is the time delay difference and a_k is the coefficient of the *k*th tap. For a two-tap filter with coffecient of (1,-1), the frequency response is given

$$H_2(\omega) = 2j\sin\frac{\omega\tau}{2}e^{-j\omega\tau/2} \qquad \text{---(6)}$$

For a three-tap filter with coefficients of (1, -2, 1), the frequency response is given

$$H_3(\omega) = -4\sin^2\frac{\omega\tau}{2}e^{-j\omega\tau} \qquad \text{---(7)}$$

If $\omega\tau / 2$ is small, Eq. 2 and 3 can be approximated as[Q. Wang , F. Zeng,2006]

$$H_2(\omega) \cong -j\omega\tau e^{-j\omega\tau/2}$$

$$H_3(\omega) \cong -\omega^2 \tau^2 e^{-j\omega\tau} \qquad ---(8)$$

3.3 Generation monocycle Gaussian pulse

We propose and simulate a simple method for generating UWB monocycle pulses based on cross-gain modulation (XGM) in a optical amplifier (OA) as shown in Fig.(2) . In this system an optical Gaussian pulse (pump) and a continuous wave (CW)(probe) are applied to the OA. The XGM in the OA, a pair of polarity-reversed optical Gaussian pulses is generated at the output of the SOA. The two polarity-reversed optical pulses are then time delayed by two cascaded FBGs to introduce a time-delay difference. When the physical spacing between the two FBGs and their reflectivities are properly designed, a monocycle pulse with the required design parameters is generated.

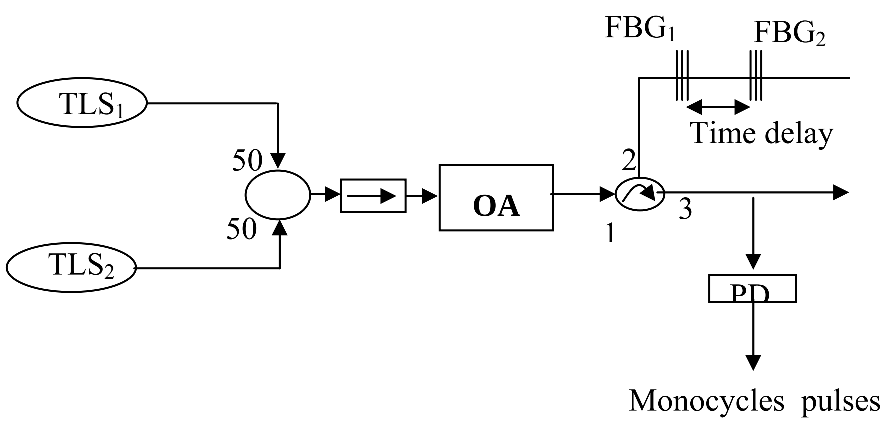

Figure (2) the monocycle pulse generation system

The basic idea of this approach is to generate a pair of polarity-reversed pulses at different wavelengths with an appropriate time delay difference between the pulses. The material gain spectrum of an OA is homogenously broadened therefore the cross gain modulation (XGM) effect in an OA is used to generate the polarity-reversed pulses.

In the proposed approach, when a high-power pulsed pump light is injected into the OA, the variation of the pump power modulates the carrier density of the OA so that the gain of the OA varies inversely with the input laser power. If a CW probe light is injected into the OA with the pump, the power of the probe light will vary inversely with the pump power, and a pair of polarity-reversed pulses is generated, with one pulse at the pump wavelength and the other at the probe wavelength, the non-linear mechanism is (XGM) illustrated in Fig. (3)

Since the polarities of the pump and the probe pulses are reversed, a direct detection of these two pulses would lead to a cancellation of the two pulses. However, if a proper time-delay difference is introduced between the two pulses, a new pulse that has a shape of a monocycle is generated. The pulse width of the monocycle can be controlled by altering the time-delay difference.

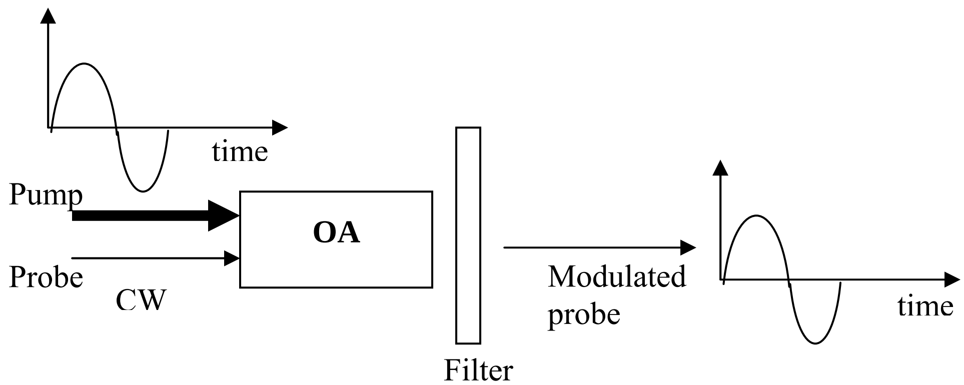

Figure (3) Illustration the XGM mechanism in OA

3.4 Doublet Gaussian pulses

If the input signal to the three-tap microwave delay-line filter is a Gaussian monocycle, a Gaussian doublet can be generated. This will be illustrated in figure (4) where the monocycle pulses was generated and entering to the photonic delay- line filter the output wave (doublet) taken at the BPD.

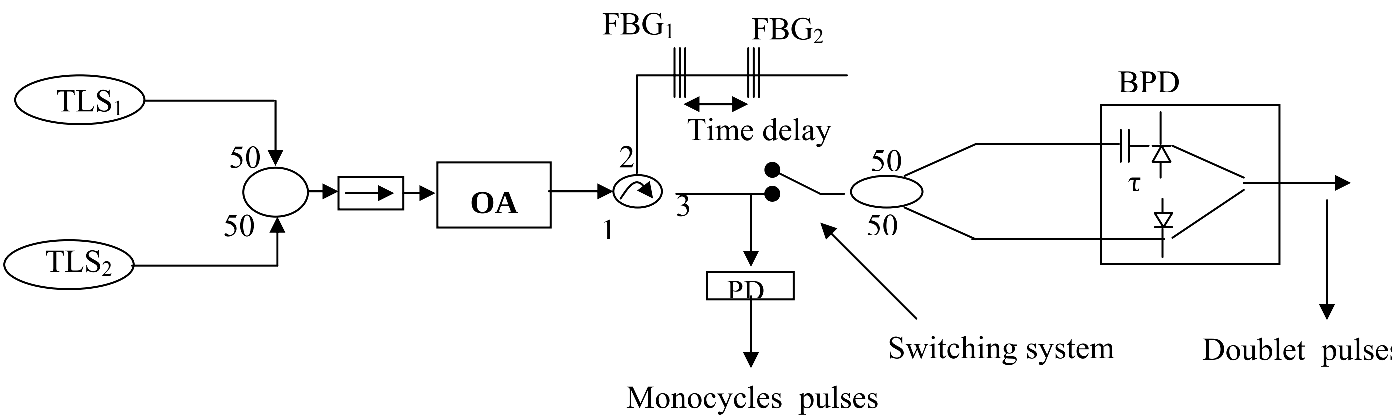

Figure (4) The completed switchable new system to produced the monocycles and doublet Gaussian pulse

4. The simulation Results

A simulation is carried out to verify the proposed approach. The system shown in Fig. 4 was simulated with two parts one for monocycle and for doublet. Two CW tunable laser sources, TLS1 and TLS2, serving, respectively as the pump and the probe, are used in the system. The output of TLS1 is pulsed laser source with Gaussian shape. Then a CW probe from TLS2 and the pulsed optical sequence are applied to the OA via a 3 dB coupler. At the OA, because of the XGM, the intensity of the probe light is modulated by the pump pulse. A pulse with a shape similar to the pump pulse but with a reversed polarity is generated at the probe wavelength are shown in Fig (6). To obtain a UWB monocycle, a time delay difference between the two polarity-reversed pulses needs to be introduced. It is realized in the numerical experimental system by using two uniform FBGs (FBG1 and FBG2). The central wavelengths of the two FBGs are chosen to be identical to the wavelengths of the probe and the pump. The time-delayed pulses are then detected at PD photo detector, a UWB monocycle pulse is thus generated, and the simulation was performed where, the physical spacing between FBG1 and FBG2 is 3.5mm, which corresponds to a time-delay difference of 35 ps. Both FBGs are 1 mm long. The central reflection wavelengths of FBG1 and FBG2 are 1549.21 and 1552.63 nm, with 3 dB bandwidths of 0.55 and 0.87 nm. The FBG bandwidths are wide enough that no considerable distortions to the pump or probe pulses are generated. Fig(5) shows the XGM where a strong pump light will reduction the gain of OA, and causes to modulation of a weak CW probe light .

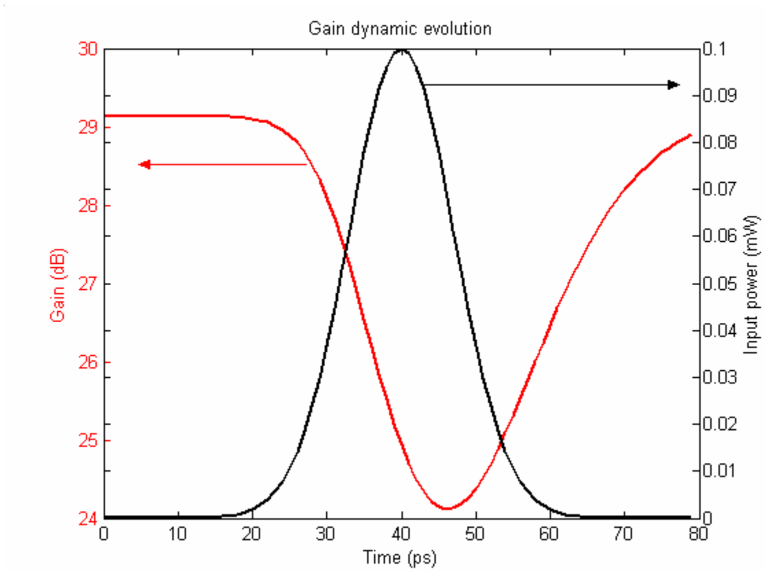

Figure (5) Gain reduction due to Strong pump pulse

Since the pump power is usually higher than the probe power, a certain asymmetry will occur in the generated monocycle as shown in Fig. (6). In addition to the introduction of the time-delay difference, the two FBGs also function as an optical bandpass filter to remove the amplified spontaneous emission generated in the OA. In the simulation, the driving current to the OA is set at 200 mA. The wavelength of TLS1 is tuned to 1549.01 nm, aligned with the central reflection wavelength of FBG1. The output laser power of TLS1 is adjusted to be -20 dBm. The average optical power of the pump pulse at the input of the OA is −10 dBm. The wavelength of TLS2 is set to be 1552.80 nm, aligned with the central reflection wavelength of FBG2.

The output power of TLS2 is adjusted to optimize the amplitude of the probe pulse to make the generated monocycle symmetric at PD as shown in Fig. (7). When the output power of TLS2 is −4.8 dBm .

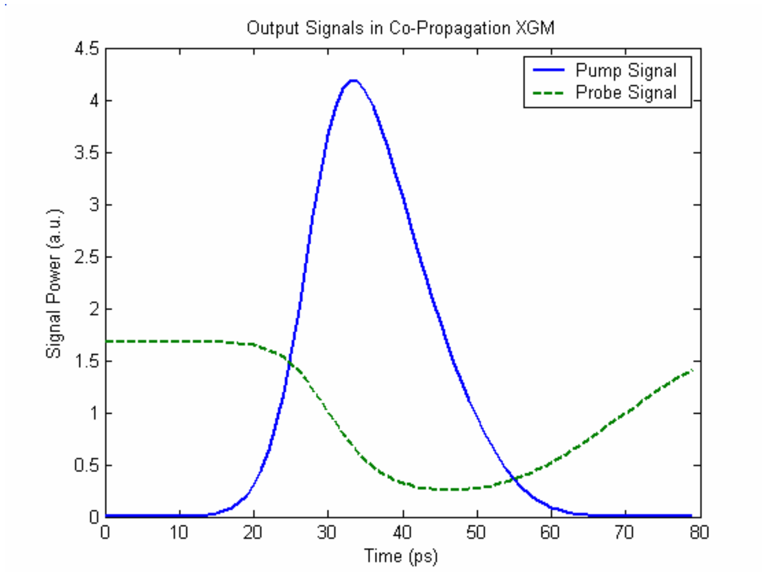

Figure (6) Asymmetry monocycle pulse

Monocycle that has a very good shape is obtained, as shown in Fig.(7). The FWHM of the monocycle pulse is about 35 ps, which is narrower than electronic generated Gaussian pulse. This is because the time-delay difference between the pump and the probe pulse is smaller than the width of the Gaussian pulse.

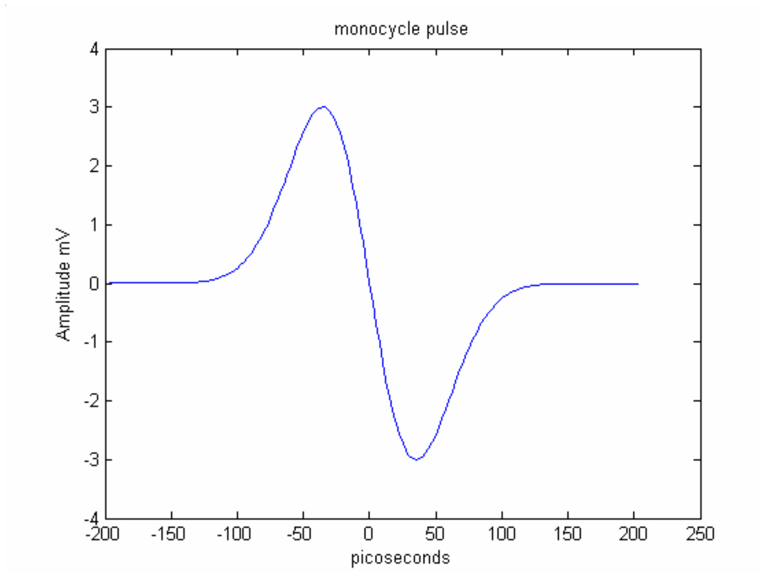

Figure (7) output monocycles Gaussian pulse

Now after the monocycles was generated the system in Fig.(4) can used to generate the doublet Gaussian pulses if it's configured as a three-tap microwave delay-line filter with coefficients of (1, -2, 1). This configuration was achieved by connected the two arm of the coupler to the input port of the BPD, with an additional time-delay difference τ introduced between the two branches by adjusting the internal optical delay line in the BPD the doublet pulses with FWHM =25 ps are shown in figure (8).All parameter used in the simulation shown in table 1.

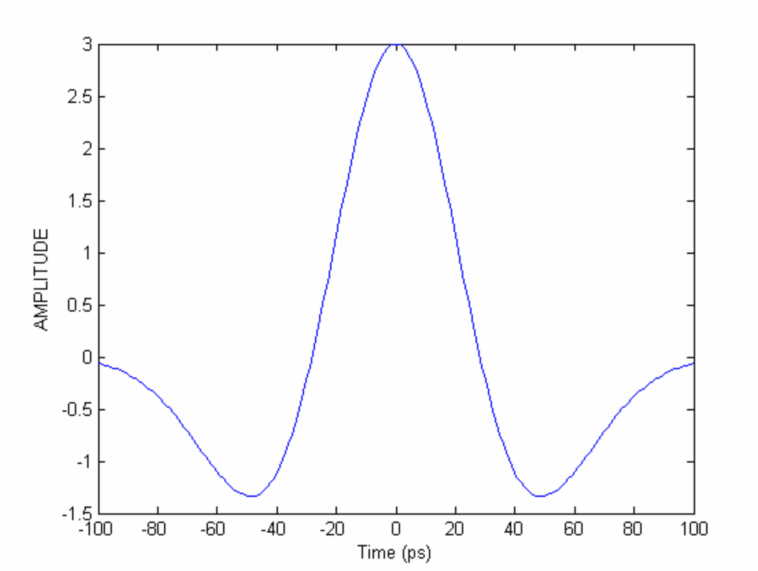

Figure (8) the doublets Gaussian pulse at the output of system

Table 1 simulated parameter

parameter	Value
Pump wavelength	1549.2 µm
Probe wavelength	1552.63 µm
Fibers Bragg Grating length (1, 2)	2mm
Driving current to the OP	300 mA
output power of TLS2 (probe)	- 4.8 dbm
output laser power of TLS1 (pump)	-7.18 dbm
Spacing between FBG1 and FBG2	2.5 mm
Input Pulse shape	Gaussian
Length of OA	100 µm
Carrier density	10^24 m^{-3}
t_{FWHM}	30 ps
Volume of OA	90 μm^3
Width o OA	100 µm

Conclusions

We have proposed and mathematically demonstrated a simple flexible method for generating UWB pulses based on delay-line filter and the XGM in an OA. Using as input Gaussian pulses with 30 ps FWHM and probe power (-20) dBm at pump power (-10) dBm. The generated monocycles have 35 ps at FWHM. When the Gaussian monocycle pulses were generated. the filter was configured as a three-tap delay-line filter with coefficients of (1,-2, 1), to generate a gaussian doublet pulses with 25 ps at FWHM.

The reconfigurability of the system could be easily realized by using an optical ON-OFF switch, which enables the system to operate at a very high speed. Therefore, the proposed system can be used to achieve high-speed pulse shape modulation (PSM).

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