

Photonic generation of ultrawideband signals using a delay interferometer

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Abstract We demonstrate a novel scheme to generate ultrawideband (UWB) monocycle and doublet pulses by inputting a dark return-to-zero (RZ) signal into a delay interferometer (DI), which accords with the general features in future applied UWB system, namely, single optical source input, simple configuration and passive device. The two polarized interferential beams have a time delay and a phase difference when they propagate through the DI. By adjusting polarization controllers (PCs), the total phase difference, i.e., the sum of the relative optical-phase difference between two orthogonally polarized components caused by PCs and the optical-phase shift due to birefringence of the polarization-maintaining fiber (PMF), the orientation angle of the polarization beam-splitter (PBS) relative to the two axes of the PMF are able to be changed and controlled. When the appropriate conditions are met, UWB monocycle and doublet pulses are generated conveniently.

Keywords ultrawideband (UWB), delay interferometer (DI), polarization-maintaining fiber (PMF), interference

1 Introduction

Ultrawideband (UWB) photonic generation has attracted considerable research interests because of its use in short-range high-throughput wireless communications and sensor networks. UWB is defined by the Federal Communications Commission (FCC) for indoor UWB systems operating in the frequency range from 3.1 to 10.6 GHz with a power density lower than -41.3 dBm/MHz, and a UWB signal should have a spectral bandwidth that is greater than 500 MHz or a fractional bandwidth that is

greater than 20%. To realize uninterrupted service across different networks and high-data-rate access at any time and from any place, it is highly desirable that the UWB signals can be generated directly in the optical domain without the need for extra electrical-to-optical conversion [1].

Since generating UWB pulses in the optical domain is the key technique for UWB fiber communications, more and more research groups have concentrated their research on this field. Lin et al. proposed a scheme to generate UWB monocycle signals using a gain-switched Fabry-Perot laser diode, a tunable filter and a microwave differentiator [2]. Wang et al. presented an all-optical monocycle generation using cross gain modulation of a semiconductor optical amplifier (SOA) [3]. Zeng et al. presented Gaussian doublet pulse generation using an all-optical microwave bandpass filter constructed by an electro-optic phase modulator (EOPM), an single-mode fiber (SMF) link and a photodetector (PD) [4], and UWB signals generation based on an EOPM followed by a fiber-Bragg-grating-based frequency discriminator [5]. The first demonstration of the frequency-to-time mapping technique for UWB pulse and UWB frequency-hopped code-division multiple access (CDMA) waveform generation was performed by the group of Jalali [6]. Recently, Wang et al. presented UWB monocycle and doublet pulses generation based on spectrum shaping in an all-fiber spectrum shaper and dispersion-induced frequency-to-time conversion in a dispersive fiber [7]. Chen et al. proposed a scheme to generate UWB monocycle pulses using a single phase modulator followed by a polarization-maintaining fiber (PMF) [8,9]. Dong et al. presented all optical UWB monocycle generation utilizing cross phase modulation of the SOA [10] and the gain saturation effect of the SOA [11]. More recently, Dong et al. presented optical UWB doublet and triplet generation from NRZ-DPSK signals based on optical fiber and filter [12]. Torres-Company et al.

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proposed an efficient method to generate UWB pulses based on chirp-to-intensity conversion requiring a single optical source [13]. Li et al. proposed a pair of polarity-reversed monocycle pulses generation by employing a single Mach-Zehnder modulator (MZM) with dual-wavelength injection at around 1310 and 1550 nm [14].

In this paper, we propose and demonstrate a novel scheme to generate UWB monocycle and doublet pulses based on a delay interferometer (DI). When an optical signal with a dark return-to-zero (RZ) format propagates through the DI, the two polarized interferential beams have not only a time delay but also a phase difference. By adjusting polarization controllers (PCs), the total phase difference (i.e., the sum of the relative optical-phase difference between two orthogonally polarized components caused by PCs and the optical-phase shift due to birefringence of the PMF), and the orientation angle of the polarization beam-splitter (PBS) relative to the two axes of the PMF are able to be changed and controlled. For appropriate conditions, UWB monocycle and doublet pulses can be generated conveniently. Our scheme is different from the scheme in Ref. [8], and it is possible to obtain UWB doublet pulses. Our scheme has the advantages of all-optical operation, single optical source input, simple configuration, passive device, and convenient operation.

2 Experimental setup and principle

A schematic diagram of our experimental setup is depicted in Fig. 1. First, a tunable laser diode (LD) emits a continuous wave (CW), which is modulated by an MZM at a bit rate of 10 Gbit/s to form dark RZ pulses driven by the dark RZ coder. The bit sequence of the dark RZ signal is set with a fixed pattern 0111 1111 1111 1111 (one “0” per 16 bits), which is equivalent to a dark RZ pulse train with a repetition rate of 0.625 GHz. The power of the dark RZ signal is controlled via an Er³⁺-doped fiber amplifier (EDFA) and a variable optical attenuator (VOA). Then, the optical pulses with dark RZ format propagate through a DI, which is formed by a segment of 31.5-m-long PMF with a time delay of about 50 ps between its fast axis and slow one, two PCs and a fiber PBS with an extinction ratio (ER) of 20 dB. The total loss of the delay interferometer is 4 dB. Because the PMF is sensitive to environmental temperature, PMF has been encapsulated in a self-made insulated

box. In the experiment, the wavelength and the full width at half maximum (FWHM) of the dark RZ signal are tunable. Finally, the output optical signal is converted to an electrical signal by an optical receiver, and is monitored by a digital communication analyzer and a radio frequency (RF) analyzer.

Input dark RZ signal is coupled into the PMF and is divided into two polarization components that are parallel to the optical axes of the PMF respectively. We denote the fast and slow axes of the PMF as x and y axes, respectively. Therefore, the amplitude envelope of temporal waveform in the fast and slow axes at the output port of the PMF can be expressed as [15]

$$\begin{aligned} E_x &= E_{x0}\cos(\omega t) = E_0(t)\sin\theta\cos(\omega t), \\ E_y &= E_{y0}\cos(\omega t + \varphi + \phi) \\ &= E_0(t-\tau)\cos\theta\cos(\omega t + \varphi + \phi), \end{aligned} \quad (1)$$

where $E_0(t)$ is the amplitude envelope of the input dark RZ pulses, θ is the linearized angle between the polarization of input dark RZ pulses, E_{x0} and E_{y0} are respectively the amplitude of two polarization components at the input port of PMF, τ is the total differential group delay (DGD) of the PMF, φ is relative optical-phase difference between two orthogonally polarized components caused by the PCs and is able to be changed and controlled by adjusting the PCs, ϕ denotes the optical-phase shift due to birefringence of the PMF. When the two polarized interferential beams are combined at PBS, the amplitude envelope of the output from the polarization orientation of PBS may be given by [15]

$$E_{\text{out}} = E_x\cos\Theta + E_y\sin\Theta, \quad (2)$$

where Θ is the orientation angle of the PBS relative to the two axes of the PMF. The principle of UWB signals generation from the dark RZ signals can be seen clearly from Fig. 2. E denotes the resultant-vector amplitude of two polarization components. When the two polarized interferential beams with an invariable time delay that approximate the half of pulse width of dark RZ pulse combine at PBS, by adjusting PCs, the total phase difference $\varphi + \phi$ and Θ are changed and controlled. If the appropriate conditions are acquired, UWB monocycle and doublet pulses will be able to be generated one by one. First, when $\varphi + \phi = \pi$, and $\Theta = \arctan(2E_{x0}/E_{y0})$, UWB monocycle pulses are obtained (as shown in Fig. 2(a)).

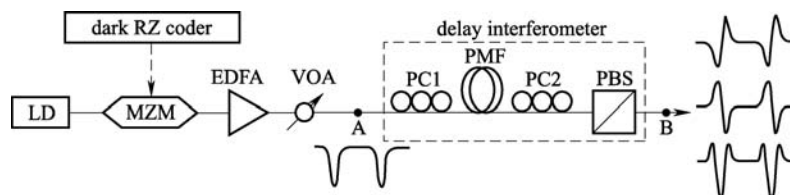


Fig. 1 Experimental setup

Second, when $\varphi + \phi = \pi$, and $\Theta = \arctan(E_{x0}/(2E_{y0}))$, the polarity-reversed UWB monocycle pulses are obtained (as shown in Fig. 2 (b)). Finally, UWB doublet pulses are obtained (as shown in Fig. 2 (c)) when $\varphi + \phi = \arccos\{- (E_{x0}\cos\Theta)^2/3 - (E_{y0}\sin\Theta)^2\}/[E_{x0}E_{y0}\sin(2\Theta)]\}$ (assuming $|E_2|^2 - |E_0|^2 = (|E_2|^2 - |E_3|^2)/3$), and $\Theta = \arctan(E_{x0}/E_{y0})$.

3 Results and discussion

Figure 3 shows waveforms and radio frequency (RF) spectra of input dark RZ pulses. The wavelength and the FWHM of the input dark RZ signal are set at 1560 nm and 120 ps, respectively. The repetition rate of the input dark RZ signal is 0.625 GHz with an average power of 3 mW and ER of 10 dB (as shown in Fig. 3(a) and point A in Fig. 1). Obviously, the RF spectra of input dark RZ pulses do not conform with the FCC regulations on UWB (as shown in Fig. 3(b)). When dark RZ pulses were launched into the DI, only by adjusting PCs, UWB monocycle and

doublet pulses are achieved one by one (point B in Fig. 1). Waveforms and RF spectra of a pair of polarity-reversed UWB monocycle pulses acquired are shown in Fig. 4. Figure 4(a) depicts the waveform of the generated UWB monocycle. The upper FWHM and lower FWHM are 49 and 75 ps, respectively. The upper and lower amplitudes are 1.36 and 0.20 mV, respectively. Figure 4(b) shows the RF spectrum of the UWB monocycle pulse, which has a central frequency of 6.28 GHz, and a 10 dB bandwidth of about 11.16 GHz (from 1.24 to 12.40 GHz). Thus, the generated UWB monocycle pulse has a fractional bandwidth of 178%. Figures 4(c) and 4(d) show the waveform and RF spectrum of the polarity-reversed UWB monocycle pulse. The upper FWHM and lower FWHM are 50 and 60 ps, respectively. The upper and lower amplitudes are 1.35 and 0.20 mV, respectively. The central frequency is also 6.84 GHz with a 10 dB bandwidth of 11.16 GHz (from 1.24 to 12.40 GHz) and therefore a fractional bandwidth of 163%.

The waveform and RF spectrum of the generated UWB doublet pulses are shown in Figs. 5(a) and 5(b), respectively. The lower FWHM of the doublet pulses is

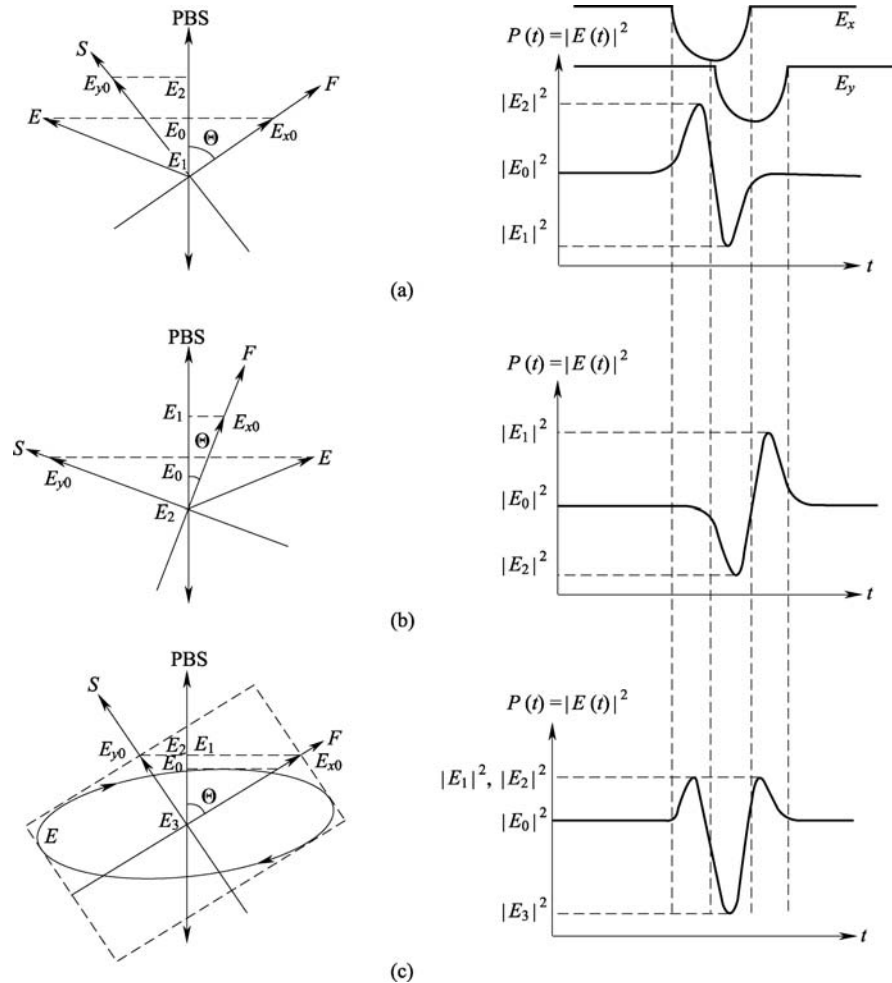


Fig. 2 Principle of UWB signals generation from dark RZ signals based on DI

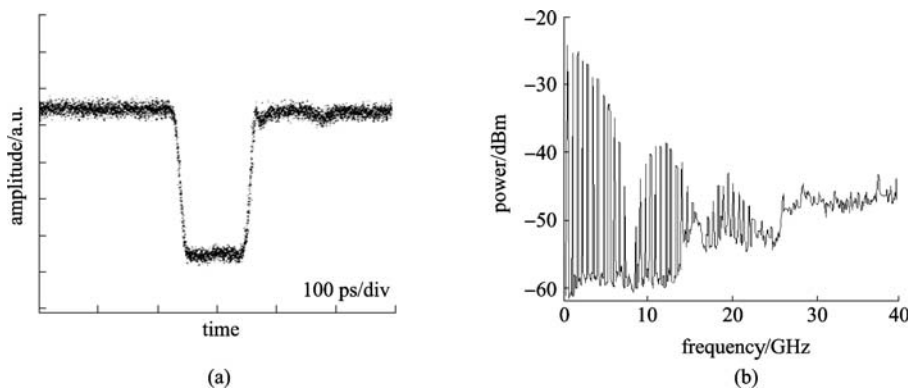


Fig. 3 Input dark RZ pulses. (a) Waveforms; (b) RF spectra

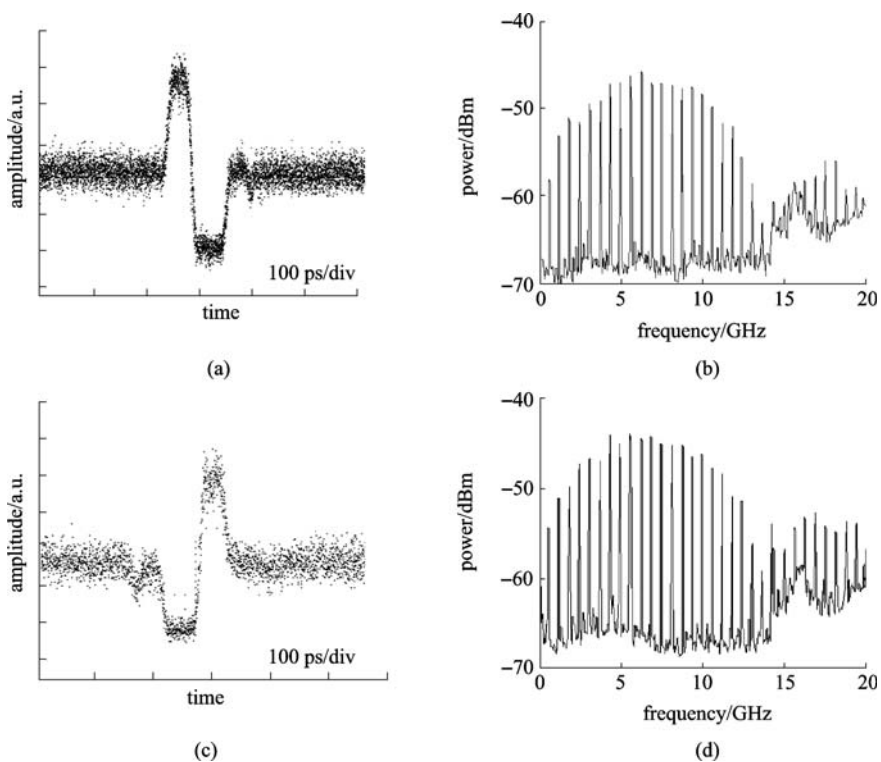


Fig. 4 Pair of polarity-reversed UWB monocycle pulses. (a) Waveforms of generated UWB monocycle; (b) RF spectrum of UWB monocycle pulse; (c) waveforms of polarity-reversed UWB monocycle pulse; (d) RF spectrum of polarity-reversed UWB monocycle pulse

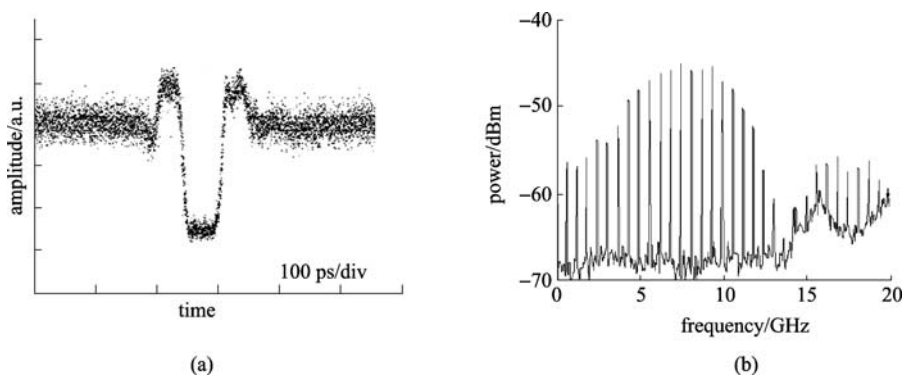


Fig. 5 UWB doublet pulses. (a) Waveforms; (b) RF spectra

70 ps. The central frequency is 7.44 GHz, and the 10 dB bandwidth is 9.32 GHz (from 2.44 to 11.76 GHz). Therefore, the fractional bandwidth is 125%. In other experiment, for example, at the different repetition rate (1.25 GHz) of the input dark RZ signal and the different time delay (25 ps) of PMF, UWB monocycle and doublet pulses are achieved too, and UWB-pulses envelope generated are smoother.

4 Conclusion

We have proposed and demonstrated a simple and compact scheme to generate all-optical UWB monocycle and doublet pulses utilizing a DI. Only a single optical source with dark RZ format is required and UWB monocycle and doublet pulses can be conveniently achieved by only adjusting PCs.

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References

1. Yao J P, Zeng F, Wang Q. Photonic generation of ultrawideband signals. *Journal of Lightwave Technology*, 2007, 25(11): 3219–3235
2. Lin W P, Chen Y C. Design of a new optical impulse radio system for ultra-wideband wireless communications. *IEEE Journal of Selected Topics in Quantum Electronics*, 2006, 12(4): 882–887
3. Wang Q, Zeng F, Blais S, Yao J P. Optical ultrawideband monocycle pulse generation based on cross-gain modulation in a semiconductor optical amplifier. *Optics Letters*, 2006, 31(21): 3083–3085
4. Zeng F, Yao J P. An approach to ultrawideband pulse generation and distribution over optical fiber. *IEEE Photonics Technology Letters*, 2006, 18(7): 823–825
5. Zeng F, Yao J P. Ultrawideband impulse radio signal generation using a high-speed electrooptic phase modulator and a fiber-Bragg-grating-based frequency discriminator. *IEEE Photonics Technology Letters*, 2006, 18(19): 2062–2064
6. Chou J, Han Y, Jalali B. Adaptive RF-photonic arbitrary waveform generator. *IEEE Photonics Technology Letters*, 2003, 15(4): 581–583
7. Wang C, Zeng F, Yao J P. All-fiber ultrawideband pulse generation based on spectral-shaping and dispersion-induced frequency-to-time conversion. *IEEE Photonics Technology Letters*, 2007, 19(3): 137–139
8. Chen H, Chen M, Qiu C, Zhang J, Xie S. UWB monocycle pulse generation by optical polarisation time delay method. *Electronics Letters*, 2007, 43(9): 542–543
9. Chen H, Chen M, Wang T, Li M, Xie S. Methods for ultra-wideband pulse generation based on optical cross-polarization modulation. *Journal of Lightwave Technology*, 2008, 26(15): 2492–2499
10. Dong J J, Zhang X L, Xu J, Huang D X, Fu S N, Shum P. Ultrawideband monocycle generation using cross-phase modulation in a semiconductor optical amplifier. *Optics Letters*, 2007, 32(10): 1223–1225
11. Dong J J, Zhang X L, Xu J, Huang D X. All-optical ultrawideband monocycle generation utilizing gain saturation of a dark return-to-zero signal in a semiconductor optical amplifier. *Optics Letters*, 2007, 32(15): 2158–2160
12. Dong J J, Zhang X L, Xu J, Huang D X, Fu S N, Shum P. High order ultrawideband pulse generation from NRZ-DPSK signals. In: *Proceedings of National Fiber Optic Engineers Conference*. 2008, JThA67
13. Torres-Company V, Prince K, Monroy I T. Fiber transmission and generation of ultrawideband pulses by direct current modulation of semiconductor lasers and chirp-to-intensity conversion. *Optics Letters*, 2008, 33(3): 222–224
14. Li J Q, Fu S N, Xu K, Wu J, Lin J T, Tang M, Shum P. Photonic ultrawideband monocycle pulse generation using a single electro-optic modulator. *Optics Letters*, 2008, 33(3): 288–290
15. García Larrodé M, Koonen A M J, Vegas Olmos J J, Verdurmen E J M. Microwave signal generation and transmission based on optical frequency multiplication with a polarization interferometer. *Journal of Lightwave Technology*, 2007, 25(6): 1372–1378