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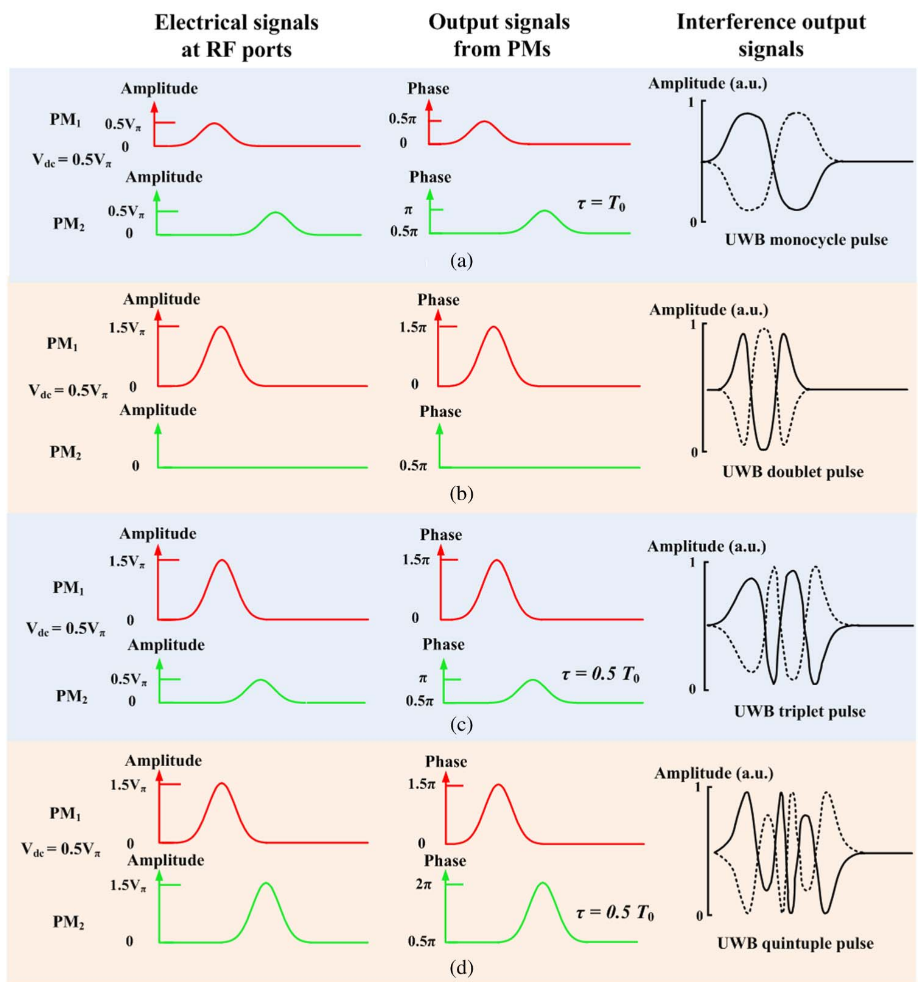


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# Reconfigurable UWB Pulse Generation Based on a Dual-Drive Mach–Zehnder Modulator

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**Abstract:** We propose and experimentally demonstrate a reconfigurable ultrawideband (UWB) pulse generation scheme by using a dual-drive Mach–Zehnder modulator (DDMZM). In the proposed method, two phase modulators of the DDMZM are respectively driven by properly designed electrical signals. By carefully setting the parameters of the two electrical signals and the bias voltage of the DDMZM, different UWB pulses can be achieved at the interference output of the DDMZM. A proof-of-concept experiment verifies the feasibility of the proposed method. Photonic generations of UWB monocycle, doublet, triplet, and quintuple pulses have been successfully demonstrated, with central frequencies of 4.69, 4.69, 5.47, and 6.25 GHz and fractional bandwidths of 150%, 133%, 186%, and 75%, respectively.

**Index Terms:** Ultra-wideband (UWB), dual-drive Mach–Zehnder modulator (DDMZM), UWB-over-fiber (UWBoF).

## 1. Introduction

Ultra-wideband (UWB) impulse signal provides a promising solution for future wireless communications due to its low power consumption and high bit-rate [1]–[3]. To overcome its limitation of short transmission distance, UWB-over-fiber (UWBoF) technology has been proposed for generations and transmissions of UWB impulse signals in optical domain [4]–[6]. Many approaches to photonic generations of UWB pulses were proposed in recent years [7]–[19]. UWB signal generations based on phase modulation to intensity modulation (PM-IM) conversion have been extensively studied, where the phase-modulated signals were converted to UWB pulse signals by using optical frequency discriminator or other methods [7]–[12]. Moreover, nonlinear effects in semiconductor optical amplifiers (SOAs) [13]–[15] and delayed interference of phase-modulated signals [16]–[19] have been demonstrated to achieve UWB pulse signals. Nevertheless, most of the previous methods can only generate a fixed UWB pulse shape, which may limit potential applications.

Flexible UWB pulse generators have been proposed in optical field, which can obtain different UWB pulse shapes by adjusting the parameters of the electrical signals and the modulators. In Ref. [20], by adjusting the bias voltage of the dual-parallel Mach–Zehnder modulator (DPMZM),

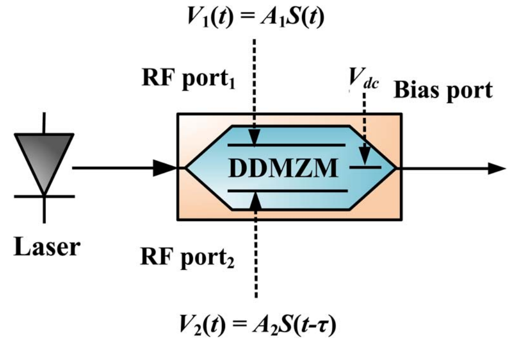


Fig. 1. Basic structure of reconfigurable UWB pulse generation using a single DDMZM.

the amplitude-modulated pulses from the two sub-MZMs are constructively or destructively combined to obtain different UWB impulse shapes at the output of the DPMZM. Three different polarity-switchable UWB pulse shapes have been achieved by utilizing a chirped intensity modulator and an asymmetric Mach-Zehnder interferometer (AMZI) [21]. P. Li *et al.* reported a reconfigurable UWB impulse generator which consists of two optical carriers, two phase modulators, and a frequency discriminator [22]. Moreover, microwave photonics filter [23], [24] and nonlinear effect [25] have been proposed to generate high-order UWB pulses. However, these schemes for UWB impulse generations need a number of optical devices.

Millimeter-wave UWB pulse [26] and three-dimensional (3-D) UWB monocycle pulse [27] have been demonstrated by using dual-drive MZMs (DDMZMs). In this paper, we propose and experimentally demonstrate a cost-effective scheme to generate different UWB pulse shapes by employing one single DDMZM. An integrated DDMZM consists of two phase modulators (PMs) which can be independently modulated. In our proposed method, the two PMs are respectively driven by different low repetition rate signals, and two different phase-modulated signals can be generated on the two optical paths of the DDMZM. By properly setting the signal amplitudes, the time delay between the two signals and the bias voltage of the DDMZM, four different UWB pulse shapes can be obtained through interference between the two phase-modulated signals at the output of the DDMZM. Theoretical analysis and a proof-of-concept experiment verify the feasibility of the proposed method. UWB monocycle, doublet, triplet, and quintuple pulses with central frequencies of 4.69, 4.69, 5.47, and 6.25 GHz, and respective fractional bandwidths of 150%, 133%, 186%, and 75% are experimentally demonstrated.

## 2. Operation Principle

Fig. 1 illustrates the basic structure of reconfigurable UWB pulse generation using a single DDMZM. The two PMs of the DDMZM are driven by different electrical signals. Meanwhile, a direct current (DC) bias voltage is used to adjust the relative phase shift between the two optical paths. The two PMs are driven by $V_1(t)$ and $V_2(t)$ which are $A_1S(t)$ and $A_2S(t-\tau)$, respectively. Here, $S(t)$ is the normalized Gaussian pulse signal, $\tau$ is the relative time delay between the two signals, $A_1$ and $A_2$ are the amplitudes of the two electrical signals. With an input optical field of $E_{in}$, the output signal is expressed as

$$E_{out} = \frac{E_{in}}{2}\left\{\exp\left[j\pi\frac{V_1(t)+V_{dc}}{V_\pi}\right] + \exp\left[j\pi\frac{V_2(t)}{V_\pi}\right]\right\} \tag{1}$$

where $V_\pi$ and $V_{dc}$ are the half-wave voltage and the bias voltage of the DDMZM, respectively. After photodetection, the alternating current (AC) term of the output signal can be written as

$$i_{AC} \propto \frac{|E_{in}|^2}{2}\left\{\cos\left\{\frac{\pi}{V_\pi}[V_1(t)+V_{dc}-V_2(t)]\right\}\right\} = \frac{|E_{in}|^2}{2}\left\{\cos\left\{\frac{\pi}{V_\pi}[A_1S(t)+V_{dc}-A_2S(t-\tau)]\right\}\right\}. \tag{2}$$

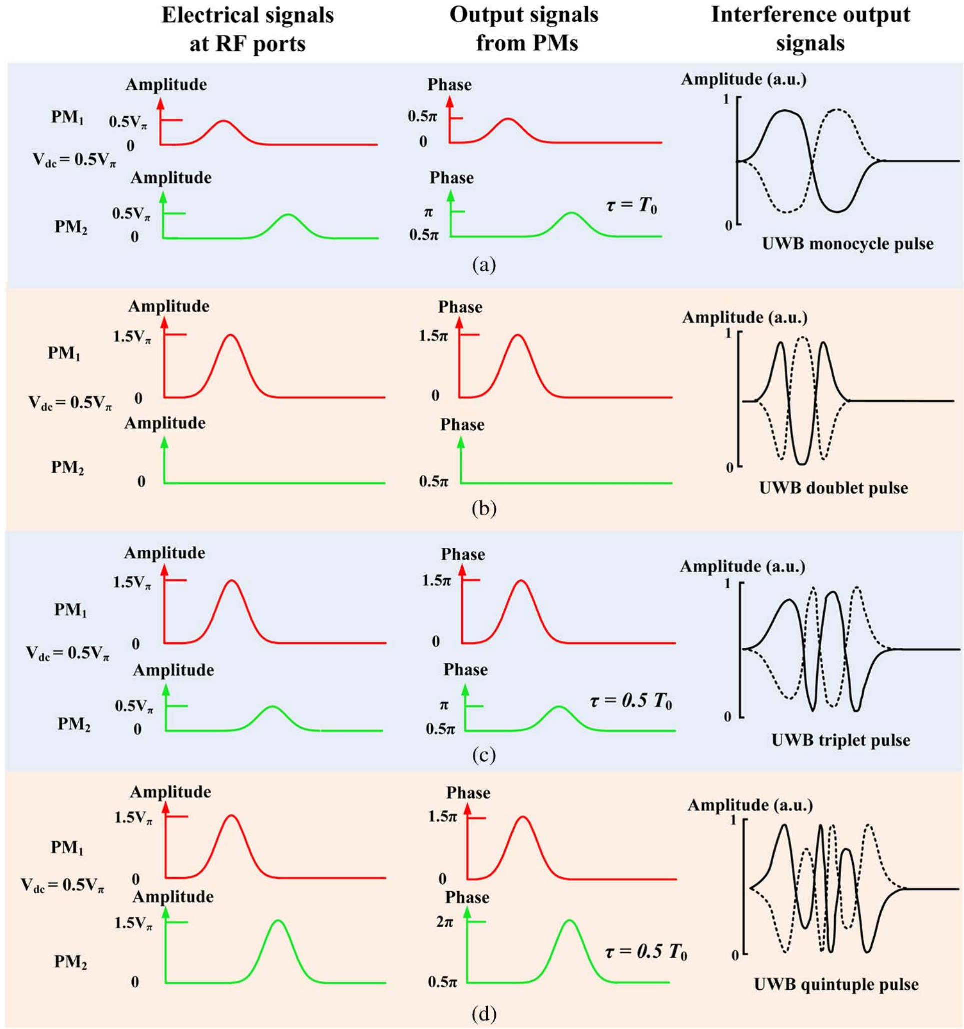


Fig. 2. Simulation results for generations of different UWB impulses. Waveforms of signals at the two RF ports, output signals from PMs, and UWB waveforms for UWB (a) monocycle, (b) doublet, (c) triplet, and (d) quintuple pulses.

By carefully adjusting the signal amplitudes, the time delay between the two electrical signals and the bias voltage of the DDMZM, different UWB pulse shapes can be obtained at the interference output of the DDMZM. The proposed method can be used to realize pulse-shape modulation and flexible UWB pulse generation.

Fig. 2 shows the schematic diagram for the generation of different UWB impulses. In the theoretical calculation, UWB monocycle pulse is achieved when $A_1 = A_2 = 0.5V_\pi$, $V_{dc} = 0.5V_\pi$, and $\tau = T_0$, with $T_0$ denoting the bit period of the electrical pulse signal. The waveforms of the signals at the two RF ports, the output signals from the PMs and the UWB impulse are depicted in Fig. 2(a). By adjusting the signal amplitudes and the time delay between the two electrical signals, different UWB pulse shapes can be obtained. We set $A_1 = 1.5V_\pi$ and $A_2 = 0$, UWB doublet pulse is realized as presented in Fig. 2(b). UWB triplet pulse can be achieved if $A_1 = 1.5V_\pi$, $A_2 = 0.5V_\pi$ and $\tau = 0.5T_0$, as illustrated in Fig. 2(c). In addition, if $A_1 = A_2 = 1.5V_\pi$ and $\tau = 0.5T_0$, UWB quintuple pulse can be generated as observed in Fig. 2(d). It is worth noting that the polarity of the UWB pulse can be switched by adjusting the bias voltage of the DDMZM, as shown by the dash curves of Fig. 2.

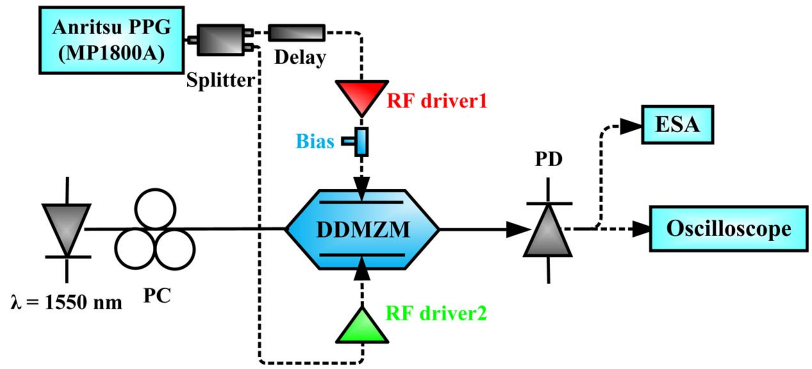


Fig. 3. Experimental setup of the reconfigurable UWB pulse generation using a single DDMZM.

## 3. Experimental Setup and Results

An experiment is performed to verify the feasibility of the switchable UWB pulse generation, and the experimental setup is shown in Fig. 3. A continuous wave (CW) light from a distributed feedback (DFB) laser at 1550 nm is sent to a DDMZM (Fujitsu FTM7921ER), and a polarization controller (PC) is used to ensure the transverse electric (TE) mode input. The Gaussian-like pulse stream with a fixed pattern of “1000 0000 0000 0000” is generated by a pulse pattern generator (PPG, Anritsu MP1800A) operating at 12.5 Gb/s. Thus the repetition rate and the duty cycle of the electrical signal are 781.25 MHz and 1/16, respectively. Then the electrical signal is divided into two parts by a power splitter. One part of the signal is input to RF $port_1$ of the DDMZM through an electrical delay line, an RF amplifier, and a bias-T, which are used to adjust the time delay between the two signals, the signal amplitude, and the bias voltage of the DDMZM, respectively. The other part of the electrical signal is amplified by the other RF amplifier and input to RF $port_2$ of the DDMZM. The generated UWB signals are detected by a 40-GHz photo detector (PD, $U^2T$ XPDV2140R) and the electrical spectra are measured by an electrical spectrum analyzer (ESA, Rohde & Schwarz FSUP50).

Fig. 4 depicts the waveforms and the electrical spectra of the UWB monocycle, doublet, triplet, and quintuple pulses. The electrical signals from the PPG with the same amplitude and certain relative time delay are directly fed to the two RF ports of the DDMZM. Then UWB monocycle pulse can be achieved by properly adjusting the amplitudes of the two electrical signals and the bias voltage of the DDMZM. It is worth noting that the bias drifting problem of the DDMZM can affect the waveforms of the generated UWB pulses, which can be overcome by using feedback control [28]. Fig. 4(a) and (b) visualize the waveform and the electrical spectrum of the UWB monocycle pulse, where the central frequency is 4.69 GHz and the 10-dB bandwidth is 7.03 GHz (from 781 MHz to 7.81 GHz). Thus the fractional bandwidth is 150% for the UWB monocycle pulse. Other UWB pulse shapes can be realized by using the aforementioned methods. Here, to obtain amplitude of 1.5 $V_\pi$, the RF signal needs to be boosted by an electrical amplifier, resulting in some distortions for pulsed signal with low repetition rate. Fig. 4(c)–(f) illustrate the waveforms and the electrical spectra of UWB doublet and triplet pulses, where the corresponding central frequencies are 4.69 GHz and 5.47 GHz, respectively. Meanwhile, the 10-dB bandwidths of UWB doublet and triplet pulses are 6.25 GHz and 10.2 GHz, indicating fractional bandwidths of 133% and 186%, respectively. Fig. 4(g) and (h) show the waveform and the electrical spectrum of UWB quintuple pulse, where the central frequency and the 10-dB bandwidth of UWB quintuple pulse are 6.25 GHz and 4.69 GHz, respectively. Thus the fractional bandwidth of UWB quintuple pulse is 75%.

## 4. Conclusion

A simple switchable photonic UWB pulse generator has been experimentally demonstrated by using a single DDMZM. In our proposed method, UWB monocycle, doublet, triplet, and

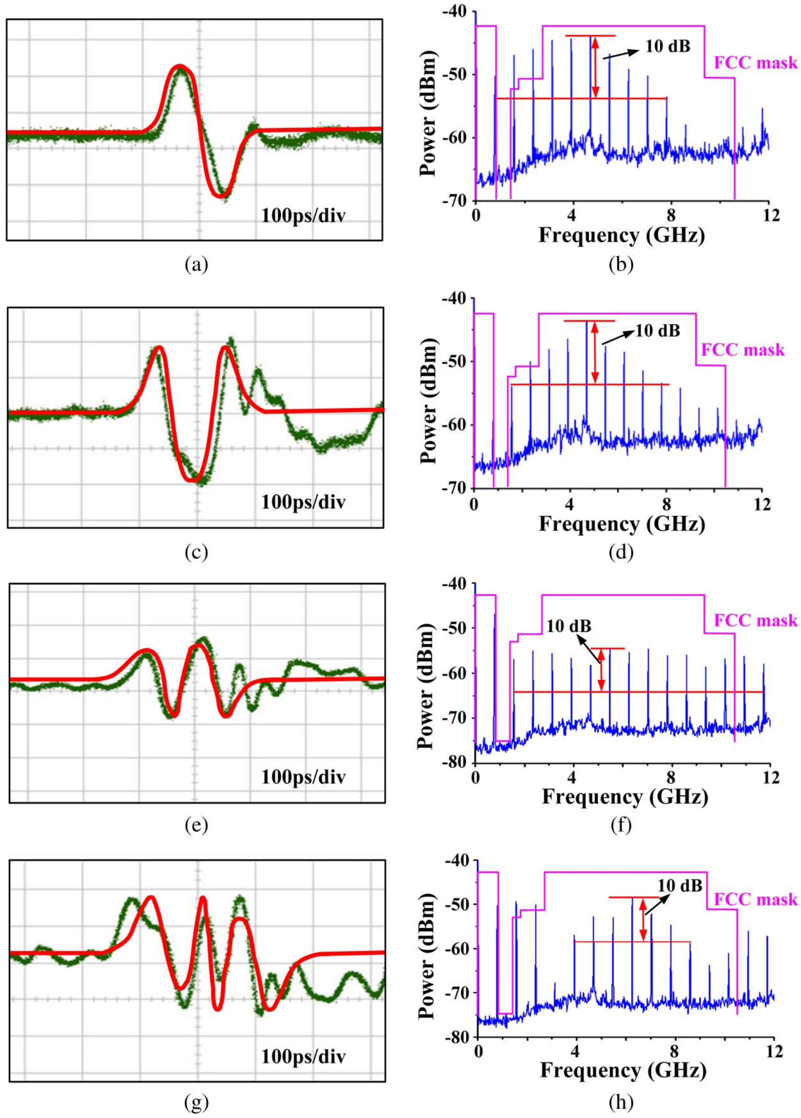


Fig. 4. Waveforms and electrical spectra of the generated UWB pulses. (a) Waveform of UWB monocycle pulse, and (b) the corresponding electrical spectrum, (c) waveform of UWB doublet pulse, and (d) the corresponding electrical spectrum, (e) waveform of UWB triplet pulse, and (f) the corresponding electrical spectrum, (g) waveform of UWB quintuple pulse, and (h) the corresponding electrical spectrum.

quintuple pulses are successfully obtained, whose central frequencies are 4.69, 4.69, 5.47, and 6.25 GHz and fractional bandwidths are 150%, 133%, 186%, and 75%, respectively. The UWB pulse shape can be reconfigured by setting the parameters of the corresponding devices. The proposed scheme could be a promising low-cost candidate to generate switchable UWB pulse shapes in optical domain.

## References


[1] D. Porcino and W. Hirt, "Ultra-wideband radio technology: Potential and challenges ahead," *IEEE Commun. Mag.*, vol. 41, no. 7, pp. 66–74, Jul. 2003.

[2] L. Yang and G. Giannakis, "Ultra-wideband communications: An idea whose time has come," *IEEE Signal Process. Mag.*, vol. 21, no. 6, pp. 26–54, Nov. 2004.

[3] R. Qiu, H. Liu, and X. Shen, "Ultra-wideband for multiple access communications," *IEEE Commun. Mag.*, vol. 43, no. 2, pp. 80–87, Feb. 2005.
[4] Y. L. Guennec and R. Gary, "Optical frequency conversion for millimeter-wave ultra-wideband-over-fiber systems," *IEEE Photon. Technol. Lett.*, vol. 19, no. 13, pp. 996–998, Jul. 2007.
[5] J. Yao, F. Zeng, and Q. Wang, "Photonic generation of ultra wideband signals," *J. Lightw. Technol.*, vol. 25, no. 11, pp. 3219–3235, Nov. 2007.
[6] S. Pan and J. Yao, "UWB-over-fiber communications: Modulation and transmission," *J. Lightw. Technol.*, vol. 28, no. 16, pp. 2445–2455, Aug. 2010.
[7] F. Zeng and J. Yao, "All-optical band pass microwave filter based on an electro-optic phase modulator," *Opt. Exp.*, vol. 12, no. 16, pp. 3814–3819, Aug. 2004.
[8] F. Zeng and J. Yao, "Investigation of phase modulator based all optical bandpass microwave filter," *J. Lightw. Technol.*, vol. 23, no. 4, pp. 1721–1728, Apr. 2005.
[9] J. Wang, F. Zeng, and J. Yao, "All-optical microwave bandpass filters implemented in a radio-over-fiber link," *IEEE Photon. Technol. Lett.*, vol. 17, no. 8, pp. 1737–1739, Aug. 2005.
[10] F. Zeng, Q. Wang, and J. Yao, "All-optical UWB impulse generation based on cross phase modulation and frequency discrimination," *Electron. Lett.*, vol. 43, no. 2, pp. 3092–3094, Jan. 2007.
[11] J. Zheng, N. Zhu, L. Wang, J. Liu, and H. Liang, "Photonic generation of ultrawideband (UWB) pulse with tunable notch-band behavior," *IEEE Photon. J.*, vol. 4, no. 3, pp. 657–663, Jun. 2012.
[12] J. Zheng *et al.*, "Photonic-assisted ultra-wideband pulse generator with tunable notch filtering based on polarization-to-intensity conversion," *IEEE Photon. J.*, vol. 5, no. 3, Jun. 2013, Art. ID. 7900909.
[13] J. Dong *et al.*, "Ultra wideband monocycle generation using cross-phase modulation in a semiconductor optical amplifier," *Opt. Lett.*, vol. 32, no. 10, pp. 1223–1225, Apr. 2007.
[14] Q. Wang, F. Zeng, S. Blais, and J. Yao, "Optical UWB monocycle pulse generation based on cross-gain modulation in a semiconductor optical amplifier," *Opt. Lett.*, vol. 31, no. 21, pp. 3083–3085, Oct. 2006.
[15] F. Wang, J. Dong, E. Xu, and X. Zhang, "All-optical UWB generation and modulation using SOA-XPM effect and DWDM-based multi-channel frequency discrimination," *Opt. Exp.* , vol. 18, no. 24, pp. 24588–24594, Nov. 2010.
[16] H. Chen, M. Chen, C. Qiu, J. Zhang, and S. Xie, "UWB monocycle pulse generation by optical polarisation time delay method," *Electron. Lett.*, vol. 43, no. 9, pp. 542–543, Apr. 2007.
[17] J. Li *et al.*, "Photonic polarity-switchable ultra-wideband pulse generation using a tunable Sagnac interferometer comb filter," *IEEE Photon. Technol. Lett.*, vol. 20, no. 15, pp. 1320–1322, Aug. 2008.
[18] S. Pan and J. Yao, "Switchable UWB pulse generation using a phase modulator and a reconfigurable asymmetric Mach–Zehnder interferometer," *Opt. Lett.*, vol. 34, no. 2, pp. 160–162, Jan. 2009.
[19] Y. Dai, J. Du, X. Fu, G. K. P. Lei, and C. Shu, "Ultrawideband monocycle pulse generation based on delayed interference of $\pi/2$ phase-shift keying signal," *Opt. Lett.*, vol. 36, no. 14, pp. 2695–2697, Jul. 2011.
[20] Q. Chang, Y. Tian, T. Ye, J. Gao, and Y. Su, "A 24-GHz ultra-wideband over fiber system using photonic generation and frequency up-conversion," *IEEE Photon. Technol. Lett.*, vol. 20, no. 19, pp. 1651–1653, Oct. 2008.
[21] S. Pan and J. Yao, "Optical generation of polarity- and shape-switchable ultra-wideband pulses using a chirped intensity modulator and a first-order asymmetric Mach–Zehnder interferometer," *Opt. Lett.*, vol. 34, no. 9, pp. 1312–1314, Apr. 2009.
[22] P. Li, H. Chen, M. Chen, and S. Xie, "Gigabit/s photonic generation, modulation, and transmission for a reconfigurable impulse radio UWB over fiber system," *IEEE Photon. J.*, vol. 4, no. 3, pp. 805–816, Jun. 2012.
[23] M. Bolea, J. Mora, B. Ortega, and J. Capmany, "High-order UWB pulses scheme to generate multilevel modulation formats based on incoherent optical sources," *Opt. Exp.*, vol. 21, no 23, pp. 28914–28921, Nov. 2013.
[24] H. Feng *et al.*, "A reconfigurable high-order UWB signal generation scheme using RSOA-MZI structure," *IEEE Photon. J.*, vol. 6, no. 2, pp. 7900307, Apr. 2014.
[25] W. Li, L. X. Wang, W. Hofmann, N. H. Zhu, and D. Bimberg, "Generation of ultra-wideband triplet pulses based on four-wave mixing and phase-to-intensity modulation conversion," *Opt. Exp.*, vol. 20, no. 18, pp. 20222–20227, Aug. 2012.
[26] W. Li, W. T. Wang, W. H. Sun, L. X. Wang, and N. H. Zhu, "Photonic generation of background-free millimeter-wave ultra-wideband pulses based on a single dual-drive Mach-Zehnder modulator," *Opt. Lett.*, vol. 39, no. 5, pp. 1201–1203, Mar. 2014.
[27] P. Cao, "Photonic generation of 3-D UWB signal using a dual-drive Mach–Zehnder modulator," *IEEE Photon. Technol. Lett.*, vol. 26, no. 14, pp. 1434–1437, Jul. 2014.
[28] L. L. Wang and T. Kowalcyzk, "A versatile bias control technique for any-point locking in lithium niobate Mach–Zehnder modulators," *J. Lightw. Technol.*, vol. 28, no 11, pp. 1703–1706, Jun. 2010.