Photonic generation of UWB pulses with pulse position modulation

H. Mu and J. Yao

A novel photonic approach to generating ultra-wideband (UWB) signals with pulse position modulation (PPM) is proposed. The proposed system consists of two subsystems, the first subsystem being a two-tap photonic microwave delay-line filter for UWB monocycle pulse generation, the second subsystem being a pulse-position-modulation module to achieve PPM. When a Gaussian pulse train is inputted to the first subsystem, a monocycle pulse train is generated. The PPM is then realised in the second subsystem by modulating the state of polarisation of the monocycle pulse train with a data sequence, which is then sent to a polarisation-dependent device to introduce a time delay difference. An UWB signal with PPM at a bit rate of 625 Mbit/s is experimentally generated.

Introduction: The distribution of ultra-wideband (UWB) signals over optical fibre has been considered a promising solution to extend the area of coverage of an UWB wireless communication system [1, 2]. To fully exploit the advantages offered by optics, it is desirable to generate the UWB signals directly in the optical domain without extra electrical-to-optical conversion. Numerous techniques for the generation of UWB monocycle and doublet pulses have been proposed [3–8]. For example, UWB pulses can be generated based on phase modulation and phase-modulation-to-intensity-modulation conversion using a fibre Bragg grating (FBG) or a Sagnac-loop filter [3, 4]. UWB pulses can also be generated based on cross-gain modulation in a semiconductor optical amplifier [5]. Use of optical pulse shaping and frequency-to-time conversion for UWB pulse generation has also been demonstrated [6–8].

In an UWB communication system, the data information is carried by the UWB pulses with different modulation schemes, such as pulse position modulation (PPM), pulse shape modulation (PSM), pulse polarity modulation (PPoM), on-off keying, or pulse amplitude modulation (PAM). Wang and Yao proposed a scheme to achieve PPoM and PSM using a polarisation modulator (PolM) and an FBG. The polarity or shape of an UWB pulse can be changed by controlling the voltages applied to the two electrically tunable arbitrary waveplates [9]. Recently, a scheme to implement a two- or three-tap photonic microwave delay-line filter with one negative coefficient for polarity- and shape-switchable UWB pulse generation was proposed [10]. In [11], a flexible UWB pulse generator that can be adapted to achieve different pulse modulation formats was reported.

Among the different modulation schemes, PPM has the advantageous features of high power efficiency and constant transmitter power; therefore the generation of UWB signals with PPM is of great interest. In this Letter, we propose a novel photonic approach to generating UWB signals with PPM. The proposed system consists of two subsystems. The first subsystem consists of an optical phase modulator and a polarisation-maintaining fibre (PMF) with a polariser, which performs as a two-tap photonic microwave delay-line filter with one positive and one negative coefficient for UWB pulse generation. The second subsystem consists of a PolM and another PMF, which is used to perform the PPM. When a data sequence is applied to the PolM, the state of polarisation (SOP) of the light wave carrying the UWB pulse train is polarisation modulated, with the polarisation direction aligned with either the slow or the fast axis of the PMF. Owing to the birefringence of the PMF, pulse position modulation is thus achieved.

UWB signal generation with PPM: The schematic diagram of the proposed UWB pulse generator for pulse-position-modulated UWB signal generation is illustrated in Fig. 1. A linearly polarised light wave emitted from a laser diode is modulated at the phase modulator by a Gaussian pulse train, which is generated by a bit error rate tester (BERT, Agilent 4901B) with a fixed pattern of one ‘1’ for every 16 bits at a bit rate of 10 Gbit/s, corresponding to a Gaussian pulse train with a duty cycle of 1/16 and a repetition rate of 625 MHz. The full-width at half-maximum of the Gaussian pulse is about 100 ps. The phase modulated light wave is then launched into the first PMF (PMF1) with an incidence angle of 45° with respect to the fast axis of PMF1 by adjusting the first polarisation controller (PC1). In the PMF1, the light wave is equally decomposed into two orthogonally polarised components and then transmitted at different velocities; thus at the output of the PMF1, a time delay difference τ_1 between the two orthogonally polarised components is introduced.

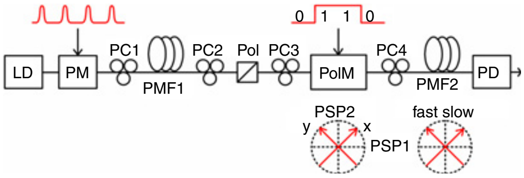

Fig. 1 *Schematic diagram of proposed UWB pulse generator for pulse-position-modulated UWB pulse generation*

LD: laser diode; PM: phase modulator; PC: polarisation controller; PMF: polarisation maintaining fibre; Pol: polariser; PolM: polarisation modulator; PD: photodetector; PSP: principal state of polarisation

The electric field of a phase-modulated optical carrier can be expressed as $E_{PM}(t) = E_0 \exp(j\omega_c t)\exp[j\beta_1 s_1(t)]$, where E_0 and ω_c are the amplitude and angular frequency of the optical carrier, respectively, β_1 is the phase modulation index of the phase modulator, and $s_1(t)$ is the electrical modulation signal applied to the phase modulator. An optical polariser is connected at the output of PMF1. The angle between the fast axis of the PMF1 and the transmission axis of the polariser is adjusted to be 45° by PC2. The corresponding optical field at the output of the polariser is given by

$$\begin{aligned} E_{Pol}(t) = E_0 \exp\,[j\omega_c t + j\beta_1 s_1(t)]/2 \\ + E_0 \exp\,[j\omega_c(t-\tau_1) + j\beta_1 s_1(t-\tau_1)]/2 \end{aligned} \tag{1}$$

If the output signal from the polariser is sent to the photodetector (PD) directly, a Gaussian monocycle pulse is obtained with an invertible polarity depending on the angle between the fast axis of the PMF1 and the transmission axis of the polariser being 45° or −45° [10].

The PolM (Versawave Technologies, 40 Gbit/s polarisation modulator with a half-wave voltage of 5.3 V) is a special phase modulator that supports both transverse electric mode and transverse magnetic mode but with opposite modulation indexes along the two principal axes (PSP1 and PSP2) [12]. The SOP of the incident light wave is oriented at an angle of 45° with respect to PSP1 by PC3, shown as the x-direction in Fig. 1. The optical field at the output of the PolM along the PSP1 and PSP2 directions is given by

$$\vec{E}_{PolM} = \begin{bmatrix} E_{PSP1} \\ E_{PSP2} \end{bmatrix} = \frac{E_{Pol}(t)}{\sqrt{2}} \begin{bmatrix} \exp\,[-j\beta_2 s_2(t)/2] \\ \exp\,[j\beta_2 s_2(t)/2] \end{bmatrix} \tag{2}$$

where β_2 is the phase modulation index of the PolM and $s_2(t)$ is the electrical modulation signal applied to the PolM. Depending on the drive voltage that is 0 or V_π (the half-wave voltage of the PolM), the SOP of the output light wave of the PolM will be aligned with the x- or y-direction. A second PMF (PMF2) is placed after the PolM with the slow and fast axes aligned with the x- and y-directions, respectively, by adjusting PC4. The PolM is driven by a binary data sequence of voltages of 0 and V_π, which is generated by a second BERT (Anritsu ME522A) at a bit rate of 625 Mbit/s that is synchronised with the Gaussian pulse train generated by the first BERT. In the PMF2, for data bits ‘0’ and ‘1’, the light wave with the SOP along the slow or fast axis will travel at different velocities; thus a time delay difference τ_2 is introduced.

Under small signal modulation condition, neglecting the DC terms we have the photocurrent at the output of the PD:

$$I(t) = \begin{cases} -\Re\beta_1 E_0^2(\sin\omega_c\tau_1)[s_1(t-\tau_2) - s_1(t-\tau_1-\tau_2)]/2 & \text{(for data bits ‘0’)} \\ -\Re\beta_1 E_0^2(\sin\omega_c\tau_1)[s_1(t) - s_1(t-\tau_1)]/2 & \text{(for data bits ‘1’)} \end{cases} \tag{3}$$

where $\Re$ is the responsivity of the PD. As can be seen from (3), if τ_1 is small enough, when the input modulation signal is a Gaussian pulse, a Gaussian monocycle pulse is generated. There is a relative time delay of τ_2 between the generated UWB Gaussian monocycle pulse for data bits ‘0’ and for data bits ‘1’ in a data bit period, which results from the differential group delay (DGD) of PMF2; thus PPM can be implemented. In the experiment, PMF1 is 29.1 m long with a DGD of about 40.1 ps, and the relative time delay for data bits ‘0’ and for data bits ‘1’ is about 0.33 ns.

The generated pulse-position-modulated UWB monocycle pulses at the output of the PD are observed by a high-speed sampling oscilloscope

(Agilent 86116A). Fig. 2 shows the experimentally generated UWB monocycle pulses for data bits '1' and '0' in a data bit period of 1.6 ns. The relative position of the generated UWB monocycle pulse in a data bit period for data bits '1' and '0' can be adjusted by tuning the length of PMF2. The waveform shown in Fig. 3 is an experimentally measured pulse-position-modulated UWB signal with a data sequence of '10010110'.

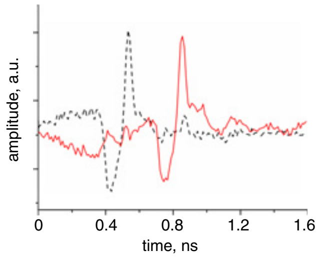

Fig. 2 *Experimentally generated UWB monocycle pulses for data bits '1' (dashed line) and '0' (solid line) in bit period for PPM scheme*

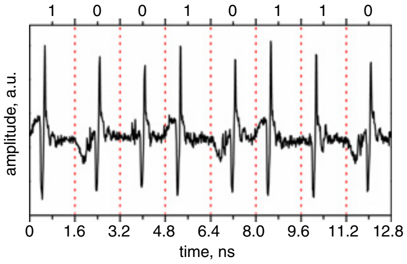

Fig. 3 *Waveform of experimentally generated pulse-position-modulated UWB signal with data sequence of '10010110'*

Discussion and conclusion: A novel photonic UWB signal generator for pulse-position-modulated UWB signal generation is proposed and experimentally demonstrated. The proposed system was implemented using two subsystems, the first subsystem for UWB monocycle pulse generation and the second subsystem for the implementation of PPM. The speed of the system is determined by the phase modulator, the PolM and the PD. Since all three components can operate at 40 Gbit/s, the proposed system can generate pulse-position-modulated UWB signals at a data rate as high as 40 Gbit/s, which is suitable for applications in very high throughput wireless access networks. The total loss of the experimental system is about 10 dB. In a practical system, PMF1, the polariser, the PolM, and PMF2 in Fig. 1 can be fused with the polarisation axes properly oriented during the fusing process, thus the three PCs (PC2, PC3, PC4) are no longer needed, by which the system can be greatly simplified and the major loss in the system would result from the insertion losses of the phase modulator and the PolM, which are 4.5 and 3.5 dB, respectively.

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One or more of the Figures in this Letter are available in colour online.

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