Optical pulse generation by polarisation modulation and fibre dispersion

Fangzheng Zhang, Bindong Gao and Shilong Pan✉

Optical pulse generation based on polarisation modulation and fibre dispersion is proposed that has the ability of generating multiform optical pulse trains by applying a single electro-optic modulator and a low frequency driving signal. In the experiment, using a 10 GHz RF source, the generation of a 20 GHz time and polarisation interleaved optical pulse train, a 10 GHz single-polarisation pulse train and a 20 GHz single-polarisation pulse train is demonstrated. By using differential group delay in a polarisation maintaining fibre to realise time-division-multiplexing, the repetition rate of the pulse train can be further increased. Based on this principle, the generation of a 40 GHz time and polarisation interleaved optical pulse train, and a 40 GHz single-polarisation pulse train is successfully implemented.

Introduction: High-speed optical pulses have wide applications in optical communication and microwave photonics systems [1, 2]. In such systems, optical pulse generation is essential and has been investigated for a long time [3]. A modelocked laser can generate very short optical pulses, but the repetition rate is usually low and hard to be tuned [4]. Another method for optical pulse generation or compression is based on phase modulation followed by fibre dispersion [5]. In this method, a periodic frequency chirp is first introduced to a continuous wave (CW) light through sinusoidal phase modulation at frequency f_m. After proper dispersion, the various frequency components travelling at different group velocities will 'bunch up' to create pulses with a repetition rate of f_m. This method has been proved to be an efficient way to generating optical pulses and has been used in many applications.

In this Letter, we propose a new technique for optical pulse generation based on polarisation modulation and fibre dispersion. The polarisation modulation can be treated as two opposite phase modulations along two orthogonal polarisation directions. Thus, the proposed optical pulse generator can generate multiform optical pulse trains by applying a low frequency driving signal, which brings great flexibility to the traditional pulse generation by phase modulation and fibre dispersion. In the experimental demonstration, the generation of a 20 GHz time and polarisation interleaved optical pulse train, a 10 GHz single-polarisation pulse train and a 20 GHz single-polarisation pulse train is achieved using a polarisation modulator (PolM) and a 10 GHz driving signal. By simple time-division-multiplexing using a polarisation maintaining fibre (PMF), the repetition rate of the pulse train is further increased to 40 GHz.

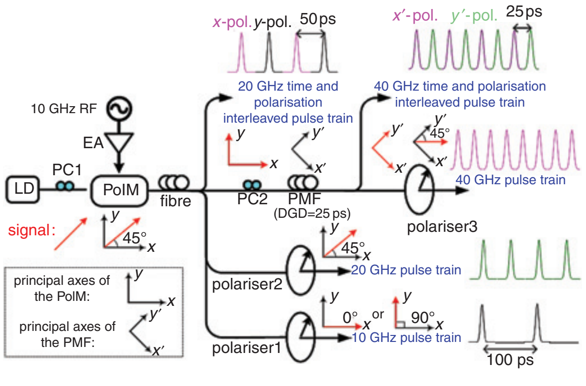

Fig. 1 *Schematic diagram of proposed optical pulse generator*

Principle: Fig. 1 shows the setup of the proposed optical pulse generator. A CW laser generated by a laser diode (LD) is sent to a PolM via a polarisation controller (PC1). By adjusting PC1, the input light can have a 45° angle to one principal axis of the PolM, generating two lightwaves with equal amplitudes along the two principal axes of the PolM (i.e. x and y). The PolM is driven by a 10 GHz RF source of which the power is properly amplified by an electrical amplifier. Since the polarisation modulation realised by the PolM can be treated as two opposite phase modulations along the two principal axes of the PolM [6], a pair of phase modulated signals with the opposite modulation indices are generated along the x and y polarisations. After the PolM, a span of fibre is followed to provide a proper dispersion. Based on the pulse generation theory by phase modulation and fibre dispersion [5], a 10 GHz optical pulse train can be generated along the x and y polarisations, respectively. Considering the opposite phase modulations, there will be a time delay between the two pulse trains along the x and y polarisations, and the time delay equals to half a period of the driving 10 GHz source. Therefore, after the fibre, a 20 GHz time and polarisation interleaved optical pulse train is generated with a time interval of 50 ps between adjacent two pulses. By selecting out the optical pulse in either x or y polarisation using a polariser (polariser 1), a 10 GHz optical pulse train can be generated. If another polariser (polariser 2) with an angle of 45° to the x-axis or the y-axis is used, a 20 GHz single-polarisation optical pulse train is obtained.

To increase the repetition rate of the generated pulses, a simple time-division-multiplexing module based on the differential group delay in a PMF can be applied, as shown in Fig. 1. Before the 20 GHz time and polarisation interleaved optical pulse train is fed to the PMF, its polarisations are adjusted by another PC (PC2) to have an angle of 45° with the principal axes of the PMF (i.e. x' and y'). The length of PMF is properly chosen such that a differential group delay of 25 ps is introduced to the 20 GHz pulse trains along the x' and y' axes, respectively. After the PMF, a 40 GHz time and polarisation interleaved optical pulse train is obtained. To generate a 40 GHz single-polarisation optical pulse train, a polariser (polariser 3) with a 45° angle to the x'-axis or the y'-axis should be connected to the PMF. Based on this principle, optical pulse trains with higher repetition rates (80, 160 GHz etc.) can be easily generated.

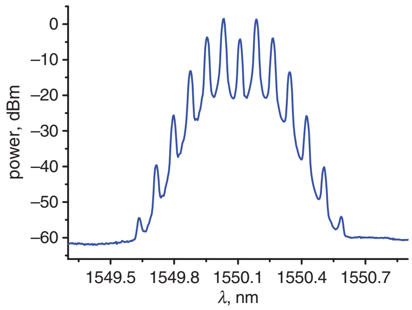

Fig. 2 *Measured optical spectrum of the signal after the PolM*

Experimental demonstration: An experiment has been carried out based on the setup in Fig. 1. A CW light at 1550.51 nm from a LD (TeraXion NLL04) with a power of 15 dBm is used as the light source. The PolM (Versawave Inc.) has a bandwidth of 40 GHz and a halve-wave voltage of ~3.5 V at 10 GHz. A 10 GHz RF signal from a microwave source (Agilent E8257D) is amplified and then applied to drive the PolM. After the PolM, a rack mount dispersion compensation fibre (DCF) is followed to provide a dispersion of −153 ps/nm. To generate optical pulses with a small pulse width, the RF power driving the PolM is optimised to be 20 dBm, resulting in a modulation index of ~1.8π. Fig. 2 shows the optical spectrum of the signal after the PolM, where many sidebands are generated because of the large modulation depth of the PolM. After the DCF, a 20 GHz time and polarisation interleaved optical pulse train is generated. Its waveform is observed through an 80 GHz optical sampling oscilloscope (OSC, Agilent 86100C), as shown in Fig. 3*a*. To obtain a 10 GHz optical pulse train, a polariser is connected to the DCF. In the experiment, the polariser was implemented using a PC followed by a polarisation beam splitter (PBS). By tuning the PC, the optical pulses in x or y polarisation can be exported at the output of the PBS. Figs. 3*b* and *c* show the waveform of the 10 GHz optical pulse train in the x and y polarisations, respectively. In Figs. 3*b* and *c*, each optical pulse has a full-width-at-half-maximum of 16 ps. The small pedestals are caused by the unideal compensation of the chirp induced by phase modulation at the PolM. By adjusting the polariser direction, a 20 GHz single-polarisation optical pulse train is obtained, as shown in Fig. 3*d*. Slight overlap between adjacent pulses appears because the pulse width is not small enough. By increasing the modulation depth and adjusting the fibre dispersion to generate optical pulses with smaller pulse width [5], the overlap between adjacent pulses can be reduced.

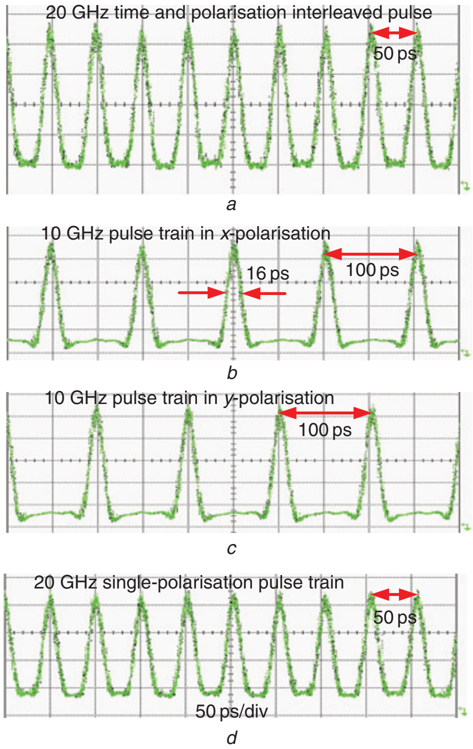

Fig. 3 *Generated 20 GHz time and polarisation interleaved pulse train; 10 GHz pulse train in x-polarisation;10 GHz pulse train in y-polarisation; 20 GHz single-polarisation pulse train*

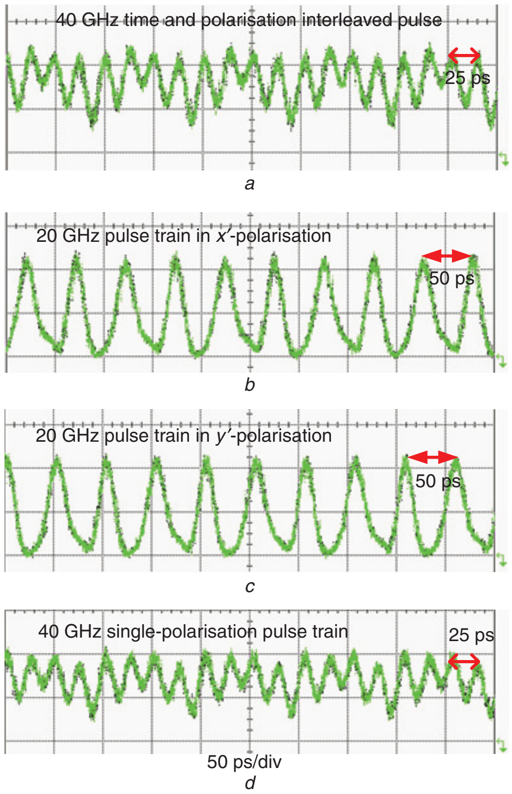

Fig. 4 *Generated 40 GHz time and polarisation interleaved pulse train; 20 GHz pulse train in x'-polarisation; 20 GHz pulse train in y'-polarisation; 40 GHz single-polarisation pulse train*

To increase the repetition rate of the pulse train, a PMF is connected to the DCF via a PC (PC2). The PMF has a length of 12.4 m with a differential group delay of 25 ps. After properly adjusting the polarisation states of the input 20 GHz time and polarisation interleaved pulses, a 40 GHz time and polarisation interleaved pulses train is obtained, as shown in Fig. 4*a*. By using a polariser following the PMF, the 20 GHz pulse trains along the x' and y' polarisations can be exported. The waveforms were measured and are shown in Figs. 4*b* and *c*, respectively. Furthermore, a 40 GHz single-polarisation pulse train is also generated, as shown in Fig. 4*d*. Again, the pulse overlaps in the 40 GHz pulse train can be eliminated by generating short pulses in the first stage.

Conclusion: We have proposed and experimentally demonstrated an optical pulse generation scheme realised by polarisation modulation and fibre dispersion. The main advantage of the proposed method is that multiform optical pulse trains can be generated using a single modulator and a low frequency driving signal, which is rarely achievable in other optical pulse generation schemes. The experimental result confirms the good performance of the proposed optical pulse generator, which can find applications in optical communication and signal processing systems.

Acknowledgments: This work was supported by the NSFC Program (61401201, 61422108), the NSFC Program of Jiangsu Province (BK20140822, BK2012031), the Postdoctoral Science Foundation of China (2015T80549, 2014M550290), and the Fundamental Research Funds for Central Universities.

Submitted: *15 October 2015* E-first: *9 December 2015*
doi: 10.1049/el.2015.3639
One or more of the Figures in this Letter are available in colour online.

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