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Background-free microwave pulse generator based on both bright and dark temporal gate and a single photodetector

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ABSTRACT

A novel approach to generating background-free microwave pulse based on both bright and dark temporal gate and a single photodetector is proposed and demonstrated. Incoherent wavelength-to-time conversion (WTTC) using only bright or dark gate renders the generation of positive or negative pulse separately. By using both gates simultaneously, background-free pulse is realized with enhanced amplitude compared with that obtained using only bright or dark gate. A dual-output intensity modulator functions as both the bright and dark gate. Narrow drive pulse is provided by the combination of two polarity-opposite electrical pulses with a relative time-delay, which releases the requirement of expensive narrow-pulse generator. Incoherent WTTC using dark gate is demonstrated experimentally. The system resolution remains the same as that using bright gate. Furthermore, UWB pulse with 10-dB bandwidth of 3.8-GHz is generated based on 1-Gb/s gate driven by 1-Gb/s data sequence. Several other background-free pulses are generated to verify the tunability of central frequency, pulse envelope, duty cycle, and repetition rate. In addition, the effect of gate width on WTTC is explored experimentally. With narrower gate width, higher system solution and maximum achievable frequency can be implemented. 10.4-GHz and 14.5-GHz background-free pulses are generated when using 1-Gb/s and 10-Gb/s gate respectively.

1. Introduction

Pulsed microwave signal has attracted considerable interests in wireless communications, medical imaging systems, pulsed radars, and warfare systems. Traditionally, pulsed microwave signal is generated based on electrical approaches, and yet the frequency and bandwidth of generated signal are restricted by the electronic bottleneck. Photonically assisted approaches have been proposed as a desirable solution to generate and distribute high-frequency and large-bandwidth signals [1,2]. One kind of photonically assisted approach is based on optoelectronic up-conversion, in which a microwave source and a pulse pattern generator (PPG) are required to provide local oscillator signal and rectangular/Gaussian pulse respectively [3–5]. In Ref. [6], frequency-multiplied microwave pulse is obtained based on an unbalanced temporal pulse shaping system. Another kind of photonically assisted approach that is based on optical spectral shaping and wavelength-to-time conversion (WTTC) is widely utilized to generate various microwave pulses [7–17]. As the converted microwave pulse is derived from a pulsed light source, at the output of photodetector (PD), the obtained microwave pulse is always positive due to the square-law detection. Thus there exists a pulse pedestal in the time-domain, which corresponds to the low-frequency components in RF spectrum, called "background". The undesired background becomes a noise source for other narrow-band applications operated at the same frequency band. Several technologies have been reported to achieve background-free microwave pulse based on optical spectral shaping and WTTC. A two-branch structure associated with a balanced photodetector (BPD) is proposed to generate background-free UWB pulse. The target pulse superimposed on a pedestal transmits along one branch, and a copy of the pedestal transmits along the other branch; therefore, at the output of BPD, the pedestal is eliminated, and the energy passing through the lower branch is used to suppress the pedestal [10]. In addition, based on balanced detection of two complementary waveforms, background-free microwave pulse is also achieved, and its spectral power is increased by 6-dB compared with single-end photodetection [11,16].

There exist two kinds of WTTC systems, coherent WTTC [7–11] and incoherent WTTC [12–17]. The major difference lies in the optical pulse source. In a coherent WTTC system, a mode-locked laser or supercontinuum source is employed to provide ultra-short pulse train, while in an

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incoherent WTTC system, a time-gated incoherent source is employed to provide optical pulse train. Compared with the coherent counterpart, the use of incoherent source can reduce system cost, provide a broad frequency bandwidth conveniently, and allow the tunability of pulse repetition rate. As the output of temporal gate is usually bright pulse, after incoherent WTTC, only positive microwave pulse with a pedestal is generated. In this work, we investigate incoherent WTTC technology based on dark gate theoretically and experimentally, which renders the generation of negative microwave pulse. To the best of our knowledge, it is the first experimental demonstration of incoherent WTTC based on dark gate. Since dark pulse can be viewed as inverted bright pulse, and the system configuration is unchanged for WTTC based on bright or dark gate, the temporal resolution remains the same for both cases. In this context, we propose a background-free pulse generator based on both bright and dark gate, and a single PD. Conventionally, an intensity modulator (IM) biased at quadrature functions as the gate, hence the gate width that decides the system resolution is roughly identical to the pulsewidth of drive signal. For good system resolution, expensive high-speed PPG or arbitrary waveform generator is usually used to drive the gate, such as using 20-Gb/s PPG to achieve 50-ps gate width. In order to release the serious requirement of expensive narrow-pulse generator, we propose to generate narrow drive pulse by combining two polarity-opposite electrical pulses with a relative time-delay. By properly biasing a dual-output IM in one of three specific regions, both bright and dark pulse train with narrow pulsewidth are generated. In addition, the use of Sagnac interferometer configuration can avoid the environmental fluctuations. Experimental demonstration of proposed pulse generator is provided. UWB pulse with 10-dB bandwidth of 3.8-GHz is generated based on 1-Gb/s gate driven by 1-Gb/s data sequence. Furthermore, several other background-free microwave pulses are generated to verify the tunability of central frequency, pulse envelope, duty cycle, and repetition rate. 10.4-GHz and 14.5-GHz background-free pulses are generated when using 1-Gb/s and 10-Gb/s gate respectively. With narrower gate width, higher system solution and maximum achievable frequency can be realized. Consequently, the proposed background-free pulse generator provides a cost-effective and flexible solution for practical applications.

2. Principle

The proposed pulse generator consists of a spectrally sliced incoherent source, a dual-output temporal gate, a dual-input spectral shaper, a dispersion device, and a single PD, as shown in Fig. 1(a). The incoherent broadband source with a coherence time of τ_c is sliced by an optical bandpass filter with 3-dB bandwidth of $\Delta\omega$ (or denoted by $\Delta\lambda$). Provided the spectrum of incoherent source is flat within a relatively narrow passband, the resulting spectrum $G(\omega)$ is determined by the transfer function of bandpass filter. Temporal gate is a key component of incoherent WTTC system, since the gate width determines system resolution. We devise a dual-output gate using a dual-output IM, two output ports of which function as the bright gate and dark gate separately. The complementary transfer functions are expressed by,

$$H(t) = 1 \pm \cos[\Delta\phi(t) + \phi_b] \quad (1)$$

where $\Delta\phi(t)$ and ϕ_b are the phase shift induced by drive signal and DC bias respectively. When a data sequence $s(t)$ and inverted data sequence $-s(t)$ provided by a PPG are combined with a relative time-delay τ, the induced phase shift is expressed by

$$\Delta\phi(t) = \frac{\pi}{V_\pi}[s(t) - s(t-\tau)] \quad (2)$$

where V_π is the half-wave voltage of the IM. As shown on the left-hand side of Fig. 1(b), two polarity-opposite electrical pulses derived from $s(t) - s(t-\tau)$ are employed as the drive signal of IM, the pulsewidth of which is determined by the pulse edge of $s(t)$. As the pulse edge is quite narrow (i.e. usually smaller than 100-ps, or even 50-ps), the drive signal

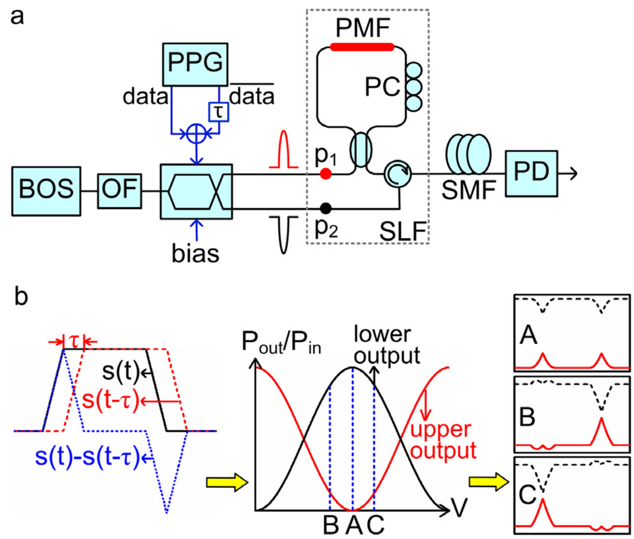

Fig. 1. (a) Schematic diagram of the proposed pulse generator; BOS: broadband optical source; OF: optical filter; PPG: pulse pattern generator; SLF: Sagnac loop filter; PMF: polarization maintaining fiber; PC: polarization controller; SMF: single-mode fiber; PD: photodetector. (b) The operation principle of devised dual-output gate.

has small pulsewidth. Hence, a high-speed PPG or arbitrary waveform generator is not necessary to provide narrow drive pulse. While a dual-drive dual-output IM can also be operated as the dual-output gate, the same phase shift $\Delta\phi(t)$ can be implemented based on only the data sequence $s(t)$, which is equally divided into two parts with a relative time-delay τ, and applied to the two RF ports separately.

Subsequently, we set the DC bias at three specific regions, the maximum (or minimum) transmission point (such as A), and the nonlinear region on the left and right of A (such as B and C), and explore the optical output of the gate. When the IM is biased at point A and driven by an X-Gb/s data sequence with bit pattern “1010…”, two electrical pulses derived from $s(t) - s(t-\tau)$ can both pass through the gate, leading to an optical pulse train with X-GHz repetition rate. In order to keep the same pulse duration, the bit pattern of data sequence ought to be fixed at “1010…”. In this case, the repetition rate of obtained optical pulse is only controlled by the bit rate of data sequence. When the IM is biased at point B or C and driven by an X-Gb/s data sequence with the bit pattern of one “1” for every n bits, one of the two electrical pulses derived from $s(t) - s(t-\tau)$ passes through the gate, while the other one is suppressed, leading to an optical pulse train with X/n-GHz repetition rate. In this case, the repetition rate of obtained optical pulse is controlled by both the bit rate and bit pattern of data sequence. Consequently, when biased at one of the three specific regions, the devised dual-output gate can provide a pair of optical pulses with opposite polarities, as illustrated on the right-hand side of Fig. 1(b). In addition, the polarity of obtained optical pulse can be inverted by simply changing the static phase shift from ϕ_b to $\phi_b + \pi$. This feature makes the pulse polarity modulation possible.

The dual-output temporal gate is connected with the dual-input spectral shaper that is implemented by a Sagnac loop filter (SLF) with complementary spectral response and free spectral range (FSR) denoted by $1/\Delta\tau$, where $\Delta\tau$ is the differential group delay (DGD) of polarization maintaining fiber (PMF). Two input ports of SLF are denoted by p_1 and p_2. The lightwave that enters the SLF from p_1 or p_2 is either transmitted or reflected to the output port. The corresponding output spectra are given by $G(\omega)[1 + \cos(\omega \cdot \Delta\tau)]$ and $G(\omega)[1 - \cos(\omega \cdot \Delta\tau)]$. The spectrally shaped lightwave is then dispersed through a section of single-mode fiber (SMF), the length and group velocity dispersion of which are