Optik - International Journal for Light and Electron Optics 176 (2019) 549–558

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Analysis of optical arbitrary waveform generation based on time-domain synthesis in a dual-parallel Mach–Zehnder modulator

Jin Yuan, Tigang Ning, Jing Li, Li Pei*, Jingjing Zheng, Yueqin Li

Key Lab. of All Optical Network and Advanced Telecommunication Network of EMC, Beijing Jiaotong University, Beijing, 100044, China

ARTICLE INFO

Keywords:
Microwave photonics
Arbitrary waveform
Time-domain synthesis
Dual-parallel Mach–Zehnder modulator

ABSTRACT

A photonic-assisted microwave arbitrary waveform generator is theoretically analyzed and verified by simulation. The basic principle of the generator is synthesis of optical field envelops. By using a sinusoidal signal to modulate a CW via a dual-parallel Mach–Zehnder (DP-MZM), square-shaped waveforms are directly generated firstly, whose envelops or harmonic power ratios are able to be modified by changing the RF driving voltage. When two identical square-shaped pulses with harmonics power ratio (9:1) between the 1st- and the 3rd-order components suffer a differential envelope phase shift ($\pi/2$), the superposition of these envelops contributes to a triangular-shaped waveform. Similarly, we generate flat-top waveform and Gaussian waveforms by properly setting the bias drifts of DP-MZM, time delay of the tunable time delay line, and modulation index. As DP-MZM is a key component in our proposal, we discuss the influence of the bias drifts on the generated waveforms, which make the scheme more practical.

1. Introduction

Recently versatile microwave waveforms, such as sinusoidal, triangular, square, trapezoid, and sawtooth waveforms have attracted much attention because of their applications in optical communication links [1], all-optical microwave signal processing and manipulation [2,3], wire and wireless communications [4,5]. Conventionally, electric frequency synthesizers or digital-analog converters are used to generate arbitrary waveforms. However, waveform generator based on electronic techniques is bandwidth limited and cannot meet high-frequency and large-bandwidth requirements of future electric systems [4]. In order to break these limitations, photonic approaches are highly expected for generating arbitrary waveforms [6–16]. One basic photonic generation of microwave waveform is Fourier synthesis [6]. An optical comb acts as a coherent broadband source to generate the tailored optical signal by using an optical spectral shaper and the desired waveform can be obtained by detecting the tailored optical signal in a photodetector (PD). Furthermore, microwave waveform can also be generated based on optical spectral shaping incorporating frequency-to-time mapping (FTTM) [7,8]. The desired spectral envelope can be obtained by using a dispersive element, which can be mapped to the temporal waveform via FTTM. However, the flexibility of this method is restricted and the mode-locked laser (MLL) which used as the optical source is high-cost. Besides the approaches mentioned above, microwave waveform can also be generated using external modulation of a continuous wave (CW) optical signal [9,7–16]. Due to the nonlinearity of the external modulator, a series of optical sidebands are generated. By controlling the phase and amplitudes of the optical sidebands, the desired microwave waveform can be obtained. For example, approaches based on stimulated Brillouin scattering (SBS) in optical fiber are proposed [9,10]. However, the SBS effect in sensitive to the environment, which may make the system unstable. Li et al. reported proposals to

* Corresponding author.
E-mail address: lipei@bjtu.edu.cn (L. Pei).

https://doi.org/10.1016/j.ijleo.2018.09.120
Received 19 July 2018; Received in revised form 16 September 2018; Accepted 20 September 2018
0030-4026/ © 2018 Elsevier GmbH. All rights reserved.

generate triangular-shaped waveform by using a Mach–Zehnder modulator (MZM) in conjunction with an optical interleaver [11] or a dispersive element [12]. It is noted that the schemes mentioned above can only generate triangular-shaped waveform and are limited to generate other waveforms. Recently, approaches reported are extended to generate other types of microwave waveform. For example, arbitrary waveform generation using a polarization modulator (PolM) in a Sagnac loop is reported, in which the primary problem is the stability of the system [13]. Dai et al. carried out a versatile waveform generator based on frequency comb generation [14,15]. A photonic approach of microwave waveform generator based on time-domain synthesis is also proposed [16]. Despite of two Mach–Zehnder modulators which decrease the system integration, other optical devices are needed, which increase the complexity of the system.

In this paper, we propose photonic approaches to generate optical arbitrary waveforms based on optical waveform synthesis in time-domain processing. In our scheme, a DP-MZM formed by two sub-MZMs (MZ-a and MZ-b) lying on each arm of a parent MZM (MZ-c) acts as the key component in our scheme. A tunable time delay line (TDL) is applied between the driving signals of two sub-MZMs. Firstly, setting three bias points of DP-MZM at quadrature points and properly tuning the modulation index β of DP-MZM, two square-shaped waveforms can be generated at the output of MZ-a and MZ-b. When the time delay τ of the TDL is 0, square-shaped waveform is obtained at the output of DP-MZM. When τ is tuned to $1/(4f_{RF})$, waveform with triangular-shaped envelopes can be generated by superimposition of two square-shaped waveforms. According to this principle, by properly controlling the bias points of DP-MZM, β, and τ, flat-top and Gaussian waveforms are generated. We also analyzed the impact of the extinction ratio and bias voltage drifts of the DP-MZM on the characteristics of the generated triangular-shaped waveform, which makes the scheme more practical. Moreover, the key significance of our approach is that we use a compact structure of DP-MZM which is expected to be more stable.

2. Model and theory

Fig. 1 shows the schematic diagram of the proposed arbitrary waveform generator. In the setup, a CW light is applied to a DP-MZM which is formed by two sub-MZMs (MZ-a and MZ-b) and a parent MZM (MZ-c). Because of x-cut design, MZ-a and MZ-b are configured for push–pull operation and the two sub-MZMs and the parent MZM have independent DC biases. A radio frequency (RF) signal $V_{RF}(t)$ with a frequency of ω_{RF} and amplitude of V_{RF} is divided into two paths by a RF splitter to drive MZ-a and MZ-b. V_{bias1}, V_{bias2}, and V_{bias3} denote the three bias voltages applied to MZ-a, MZ-b and MZ-c. A TDL is used to set the phase between driving signals of MZ-a and MZ-b. In the system, by properly setting the bias points of the two sub-MZMs and the parent MZM, controlling the powers of the microwave driving signals and tuning the time-delay τ of the TDL, different waveforms can be obtained by overlapping the optical field envelopes at point A and point B. In the following, we will perform the generation of arbitrary waveforms.

2.1. Square-shaped waveform generation

In this case, three bias points of DP-MZM are all biased at quadrature point ($V_{bias1,\ 2,\ 3} = V_\pi/2$, where V_π is the half-wave switching voltage of DP-MZM). The optical field at the output of MZ-a and MZ-b can be expressed as [17]:

$$E_A(t) = \frac{E_{in}(t)}{\sqrt{2}}\cos\left[\frac{\pi}{2V_\pi}(V_{RF}(t) + V_{bias1})\right]\exp\left(j\frac{V_{bias1}}{2V_\pi}\pi\right) \tag{1}$$

$$E_B(t) = \frac{E_{in}(t)}{\sqrt{2}}\cos\left[\frac{\pi}{2V_\pi}(V_{RF}(t+\tau) + V_{bias2})\right]\exp\left(j\frac{V_{bias2}}{2V_\pi}\pi\right) \tag{2}$$

$E_{in}(t) = E_0 exp(j\omega_0 t)$ is the optical field at the input of the DP-MZM. E_0 and ω_0 are the amplitude and angular frequency respectively. The optical field at the output of the DP-MZM can be written as

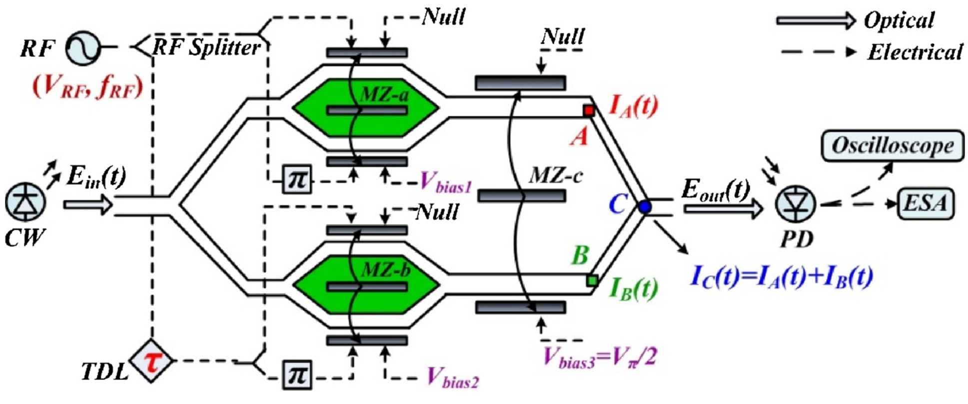

Fig. 1. Schematic setup of the proposed arbitrary waveform generator; (CW, continuous-wave laser; DP-MZM, dual-parallel Mach–Zehnder modulator; TDL, tunable time delay line; PD, photodetector; ESA, electrical spectrum analyzer).

Download English Version:

https://daneshyari.com/en/article/11023507

Download Persian Version:

https://daneshyari.com/article/11023507

Daneshyari.com