Optics and Laser Technology 105 (2018) 135–138

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

Phase-coded microwave signals generation using a dual parallel construction including two phase modulators

Fei Wang [a,*], Qiong Yu [a], Jun Gu [b], Youxi Lu [b]

[a] School of Electrical and Electronic Engineering, Chongqing University of Technology, Chongqing 400054, China
[b] School of Science, Chongqing University of Technology, Chongqing 400054, China

ARTICLE INFO

Article history:
Received 16 September 2017
Received in revised form 1 February 2018
Accepted 23 February 2018

Keywords:
Optical generation of microwave signal
Phase modulator (PM)
Phase coded
Microwave pulse compression

ABSTRACT

A photonic approach to realizing binary phase-coded microwave signal generation using a dual parallel construction including two phase modulators (PMs) was proposed and demonstrated. A beam CW is split into two beams light wave with equal power in the dual parallel construction, one beam is modulated in a PM driven by a radio frequency (RF) microwave signal in the upper arm, and the other beam is modulated by another PM driven by a binary coding electrical pulse sequence in the under arm, then the two phase-modulated beams combine and interfere. When the interference light field is send to a high-speed photodetector (PD) for beating, 2 Gbit/s binary phase-coded 10 GHz and 2.5 Gbit/s phase-coded 20 GHz microwave waveform with a π phase shift was respectively achieved, and corresponding pulse compression ratio is 20 and 16.5, respectively. The obtained phase-coded microwave signals exhibit a good pulse compression performance, which can find potential applications in modern radar systems and wireless communications.

1. Introduction

In radar systems, to increase range resolution of short pulses, a phase-coded pulse compression technique has been widely investigated [1]. Phase-coded microwave signals are generated by using the direct digital synthesizer (DDS) in traditional electrical domain, which are with lower operation frequency, in general, only a few gigahertz. In order to obtain high frequency phase-coded microwave signal, due to excessive distortions of amplitude and phase, the needful expense must be paid out. Fortunately, in optical domain, the phase-coded microwave signal generation is not suffered from the above problems, which have many unique features, including a large operation bandwidth, high frequency, low loss, small size and immunity to electro-magnetic interference, and so on [2–5]. Previously, phase-coded microwave signal generation based on optical pulse shaper by space-to-time mapping (STM) [6] or frequency-to-time mapping (FTM) [7,8] had been realized. Recently, phase-coded microwave signal generation using electro-optical modulator is widely researched due to distinct features of low loss, flexible and compact [9–17]. For example, phase-coded microwave signal was obtained based on directly modulated laser and phase modulator [9]. Phase-coded microwave waveform generation based on the polarization modulator (PolM) also was demonstrated [10–12]. Researchers also presented approaches for phase-coded microwave signal generation using an optoelectronic oscillator (OEO), which generated frequency tunable microwave signal [13,14]. In addition, a phase-coded microwave waveform generation with an ultra-wide frequency tunable range was achieved by using a Mach-Zehnder modulator (MZM) and a phase modulator (PM) [15]. Especially, a simple scheme is presented to generate a phase-coded microwave signal using a single dual parallel MZMs [16].

In this paper, we propose a novel method to generate phase-coded microwave signal based on a dual-parallel construction including two PMs, in which the dual-parallel interferential construction is used to convert phase-modulated microwave signal to intensity-modulated microwave signal. Optical generation of binary phase-coded microwave waveform with a π phase difference at 2-Gbit/s coding rates 10-GHz microwave frequency and 2.5-Gbit/s coding rates 20-GHz microwave frequency was respectively achieved, and corresponding pulse compression ratio is 20 and 16.5, respectively. The proposed scheme has many advantages, such as simple structure, easy integration, good pulse compression performance, without polarization control, which can find potential applications in modern radar systems and wireless communications.

* Corresponding author.
E-mail address: wangf17@cqut.edu.cn (F. Wang).

https://doi.org/10.1016/j.optlastec.2018.02.045

2. Principle

The schematic diagram of the proposed system is shown in Fig. 1. A CW emitted from a tunable laser source (TLS) is split into the two beams with equal power via a 50:50 optical power splitter (OPS), the one beam pass the upper arm of the dual parallel construction, which include a PM1 driven by an injecting RF microwave signal, and the other beam pass the under arm of the dual parallel construction, which include a PM2 driven by a binary coding electrical pulse sequence. The two beams of phase-modulated light waves combine and interfere at a 50:50 optical power combiner (OPC). Then, the interference light field is sent to a high-speed photodetector (PD) for beating, the phase-coded microwave signals are generated.

For simplicity, we start our analysis from a phase-modulated microwave signal how to be converted to intensity-modulated microwave signal by using the dual-parallel construction including a single PM and a single mode fiber, as shown in Fig. 2. A mathematical model is developed to describe this system. We assume that a CW emitted from a TLS is direct sent to the PM1 driven by a RF microwave signal, the output optical field from the PM1 can be expressed as

$$E_{out1}(t) = E_0 e^{j\omega_c t} e^{j\beta\cos\omega_m t} e^{j\theta} \tag{1}$$

where E_0 is the amplitude of the input optical field, β is the phase modulation index of the PM1, ω_c, ω_m is the angular frequency of the optical carrier and RF microwave signal injected to the PM1, respectively, and θ is the phase difference caused by PM1. Since the phase-modulated microwave signal cannot be directly detected by PD [17,18], a dual-parallel construction including a single PM and a SMF was used, as shown in Fig. 2. By means of the interference of the light fields between the two arms of dual-parallel construction, phase-modulated microwave signals are converted to intensity-modulated microwave signals. So, the output optical field of OPC can be expressed as

$$E_{out}(t) = 1/2E_0 e^{j\omega_c t} e^{j\beta\cos\omega_m t} e^{j\varphi} + 1/2E_0 e^{j\omega_c t} \tag{2}$$

where φ is the phase difference of the optical field in the two arms. As can be seen from Eq. (3), E_{out} is inputted into the PD with responsivity of α, due to square-law detection, the generated electrical signal can be written as

$$\begin{aligned} i_{out}(t) &\propto \alpha E_{out}(t) E_{out}(t)^* = 1/4\alpha E_0^2 e^{2j\omega_c t}[e^{j\phi}+1][e^{-j\phi}+1] \\ &= 1/2\alpha E_0^2 e^{2j\omega_c t}[1+1\cos\phi] \end{aligned} \tag{3}$$

where is $\phi = \beta\cos\omega_m t + \varphi$, α is a constant of photoelectric conversion ratio, the generated intensity-modulated microwave signals via the PD include DC signal and the alternating current (AC) signal. So, the AC pattern of an intensity-modulated microwave signal can

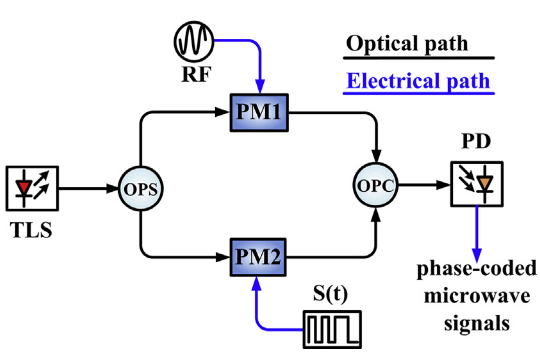

Fig. 1. Schematic diagram of the proposed photonic phase-coded microwave signal generator. TLS, tunable laser source; OPS, optical power splitter; PM, phase modulator; OPC, optical power combiner; PD, photodetector.

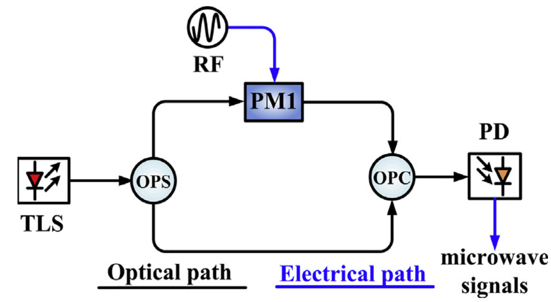

Fig. 2. Schematic diagram of converting phase-modulated signal to intensity-modulated signal.

be detected by the PD. So, by using this structure, phase-modulated microwave signal can be converted to intensity-modulated microwave signal.

When the RF microwave signal and the binary coding electrical signal $s(t)$ is injected to the RF ports of PM1 and PM2 shown in Fig. 1, respectively, the two beams of phase-modulated light waves combine and interfere at a 50:50 OPC, so, the phase-coded microwave waveform output optical field can be written as

$$E(t) = 1/2E_0 e^{j\omega_c t}[e^{j\beta\cos\omega_m t} e^{j\varphi} + e^{j\gamma s(t)}] \tag{4}$$

where γ is the modulation index of PM2, using the Jacobi-Anger expansions and considering a small-signal phase modulation, the Eq. (4) can be expanded to be

$$\begin{aligned} E(t) = 1/2E_0\big[&J_0(\beta)e^{j\omega_c t}e^{j\varphi} + jJ_1(\beta)e^{j\varphi}e^{j(\omega_c-\omega_m)t} \\ &+jJ_1(\beta)e^{j\varphi}e^{j(\omega_c+\omega_m)t} + e^{j\omega_c t}e^{j\gamma s(t)}\big] \end{aligned} \tag{5}$$

where J_n is the n-th order Bessel function of the first kind. As can be seen from Eq. (5), the beating microwave signal is detected at PD. The AC pattern of the microwave signal can be expressed as

$$\begin{aligned} i_{AC} \propto 1/2E_0\{&J_1(\beta)\sin[\omega_m t + \gamma s(t) - \varphi] \\ &-J_1(\beta)\sin[\omega_m t - \gamma s(t) + \varphi] + J_0(\beta)\cos[\gamma s(t) - \varphi]\} \end{aligned} \tag{6}$$

Through adjusting to let $\varphi = \pi/2$, Eq. (6) can be switched as

$$i_{AC} = 1/2E_0\{-2J_1\cos(\omega_m t)\cos[\gamma s(t)] + J_0(\beta)\sin[\gamma s(t)]\} \tag{7}$$

It can be seen from Eq. (7), by controlling the $s(t)$ amplitude, make $\gamma = \pi$, a signal will be obtained as follow,

$$i_{AC} = \begin{cases} E_0 J_1(\beta)\cos(\omega_m t) & for\ s(t) = 1 \\ E_0 J_1(\beta)\cos(\omega_m t + \pi) & for\ s(t) = 0 \end{cases} \tag{8}$$

As can be seen from Eq. (8), a π phase difference of a phase-coded microwave signal is implemented due to change between bit “1” and “0” of the binary coding signal.

3. Results and discussion

First of all, an experiment of the conversion from phase-modulated microwave signal to intensity-modulated microwave signal is performed, using the dual parallel construction including a PM1 and a SMF shown in Fig. 2. A CW light wave at 1550.1 nm emitted from the TL (Yenista Optical, YO14130239) is split into two light beams, one beam passes the upper arm of the dual parallel construction, which includes a PM1 (Photine, MPZ-LN-20) modulated by an injecting 10-GHz RF microwave signal generated by a vector network analyzer (VNA, CETC, AV3629D), and the other beam passes a SMF. The two beams light waves interfere at a 50:50 OPC, then beat at a 50-GHz PD (u^{2}t, XPDV2120R). An intensity-modulated microwave signal is successfully generated.