Switchable down-, up- and dual-chirp linearly frequency modulated signal generation utilizing a dual-polarization dual-parallel Mach-Zehnder modulator

Peng Li, Lianshan Yan*, Jia Ye, Xihua Zou, Bin Luo and Wei Pan
Center for Information Photonics & Communications, School of Information Science and Technology, Southwest Jiaotong University, Chengdu 610031, Sichuan, China.

Abstract: A photonic method to generate switchable down-, up- and dual-chirp linearly frequency-modulated (LFM) signals is proposed. Such signals with a carrier frequency of 5 GHz and a chirp rate of 1 GHz/4us are experimentally demonstrated.
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1. Introduction

Linearly frequency-modulated (LFM) waveforms have been widely used in modern radar systems to increase detection range and range resolution, due to their pulse compression capability [1]. Conventionally, LFM signals are implemented by using electrical methods. However, the center frequency and instantaneous bandwidth are limited, due to electrical bottleneck. Compared with electrical methods, photonic ones have attracted great attentions, due to their intrinsic advantages in term of compact size, light weight, low insertion loss, large bandwidth and immunity to electromagnetic interference (EMI) [2, 3]. In the past few years, a series of photonic methods have been proposed to generate **single chirp or dual-chirp** LFM signal, including frequency-to-time mapping [4, 5] and optical heterodyning [6-8]. However, for multi-functional radar systems, **switchable single chirp and dual-chirp** LFM signals are needed to meet different application requirements. Consequently, a single photonic scheme that can generate switchable single chirp and dual-chirp LFM signals is of great importance.

In this paper, we proposed and experimentally demonstrated a photonic method to generate switchable down-chirp, up-chirp, and dual-chirp LFM signals, which consist of a laser diode (LD), a dual-polarization dual-parallel Mach-Zehnder modulator (DP-DPMZM) and a photodetector (PD). A radio frequency (RF) signal and a baseband single chirp LFM signal are directly applied to two RF ports of the x-polarization MZM of the DP-DPMZM, while the phase shifted RF signal and LFM signal are applied to the other two RF ports of the y-polarization MZM of the DP-DPMZM. By controlling the phase shifts, different formats (down-chirp, up-chirp and dual-chirp) LFM signals can be obtained.

2. Principle

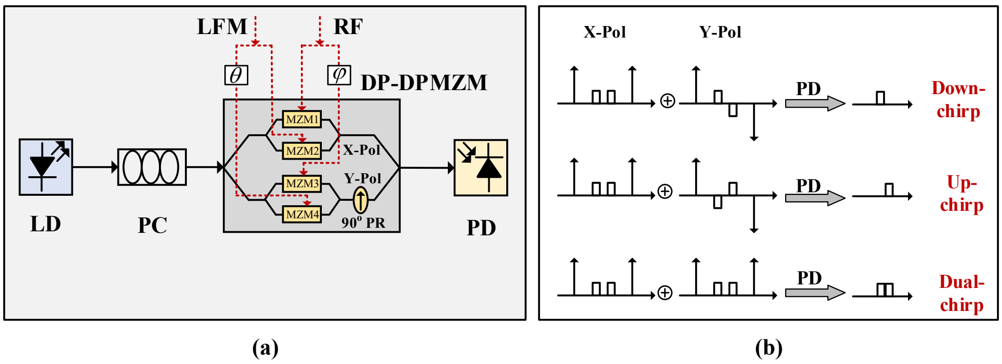

Fig.1. (a) Schematic diagram of the proposed approach for down-chirp, up-chirp and dual-chirp signal generation, LD, laser diode; PC, polarization controller; DP-DPMZM, dual-polarization dual-parallel Mach-Zehnder modulator; RF, radio frequency; LFM, linear frequency-modulated; X-Pol, X-polarization; Y-Pol, Y-polarization; PR, polarization rotator; PD, photodetector. (b) Progress of multi-formats LFM signal generation.

Fig. 1 shows the schematic diagram of the proposed approach. A light wave from a laser diode (LD) is sent into a DP-DPMZM via a polarization controller (PC). The DP-DPMZM is an integrated device which consists of four MZMs, a 90º polarization rotator (PR) and a polarization beam combiner (PBC). The PC is used to minimize the polarization-dependent loss (PDL). A RF signal is equally divided into two parts: one part is directly applied to MZM1; the other part is applied to MZM3, after introducing a phase shift φ . A LFM signal is also equally divided into two parts: one is directly applied to MZM2, the other part is phase shifted θ and then applied to MZM4. The four MZMs are all biased at the minimum transmission point. Under small signal modulation, the optical field at the output of DP-DPMZM can be expressed as

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} \propto E_0 J_1(m)\exp(j\omega_c t)\begin{bmatrix} \exp(j\omega_R t)+\exp(\text{-}j\omega_R t) \\ +\exp j(\omega_0 t+\frac{1}{2}kt^2)+\exp(\text{-}j(\omega_0 t+\frac{1}{2}kt^2)) \\ \exp(j\omega_R t+\varphi)+\exp(\text{-}j\omega_R t-\varphi) \\ +\exp j(\omega_0 t+\frac{1}{2}kt^2+\theta)+\exp(\text{-}j(\omega_0 t+\frac{1}{2}kt^2+\theta)) \end{bmatrix} \tag{1}$$

where E_0 and ω_c are the amplitude and angular frequency of optical carrier; J_n is the nth-order Bessel function of the first kind; m is the modulation index of the modulator; ω_R is the angular frequency of the RF signal; ω_0 is the initial angular frequency of the LFM signal; k is the sweeping rate (Hz/s). The orthogonally polarized optical signals are sent to a photodetector (PD), and the output electrical signal can be expressed as

$$I \propto I_0 + I_1\begin{pmatrix} \cos(\frac{\varphi+\theta}{2})\cos(\omega_R t+\omega_0 t+\frac{1}{2}kt^2+\frac{\varphi+\theta}{2}) \\ +\cos(\frac{\varphi-\theta}{2})\cos(\omega_R t-\omega_0 t-\frac{1}{2}kt^2+\frac{\varphi-\theta}{2}) \end{pmatrix} + I_2(\ldots) \tag{2}$$

The first term and third term are direct current and higher-order signal which can be filtered out by using an electrical filter. The second term is the generated LFM signal and can be further simplified as

$$I \propto I_1\begin{pmatrix} \cos(\omega_R t-\omega_0 t-\frac{1}{2}kt^2) & \theta=\frac{\pi}{2},\varphi=\frac{\pi}{2} \\ \cos(\omega_R t+\omega_0 t+\frac{1}{2}kt^2) & \theta=\frac{\pi}{2},\varphi=\frac{3\pi}{2} \\ \cos(\omega_R t+\omega_0 t+\frac{1}{2}kt^2)+\cos(\omega_R t-\omega_0 t-\frac{1}{2}kt^2) & \theta=0,\varphi=0 \end{pmatrix} \tag{3}$$

It can be obtained that when $\theta=\varphi=\frac{\pi}{2}$, a down-chirp signal is generated; when $\theta=\frac{\pi}{2}$ *and* $\varphi=\frac{3\pi}{2}$, an up-chirp signal is obtained; when $\theta=\varphi=0$ a dual-chirp signal is obtained, which is shown in Fig. 1(b).

3. Experimental results

To verify the proposed scheme, an experimental setup is built as shown in Fig. 1(a). A light signal from a narrow linewidth laser (PS-TNL, TeraXion) with the center wavelength of 1550.17 nm is sent to a DP-DPMZM (Fujitsu, FTM7977) via a PC. Two RF signals with the same carrier frequency of 5-GHz and two baseband LFM signals with the same sweeping rate of 1GHz/4us are generated by using a four-channel arbitrary waveform generator (AWG, M8195A). The modulated optical signals are detected by a PD (Agilent 11982A) with a 3-dB bandwidth of 15 GHz. The detected electrical signals are captured by using a digital storage oscilloscope (Keysight, DSOZ634A) with the bandwidth of 65 GHz and the sampling rate of 160 GSa/s.

Fig. 2(a1) and Fig. 2(a2) show the input temporal waveforms of the channel 1, 3 and channel 2, 4 for the down-chirp LFM signal generation. The waveform of the channel 3 is delayed 90^o to the one of the channel 1 and the channel 4 is delayed 90^o to the one of the channel 2. Fig. 2(a3) shows the instantaneous frequency-time diagram of the generated down-chirp LFM signal. It can be seen that a down-chirp LFM signal with a carrier frequency of 5 GHz and a sweeping rate of 1 GHz/4us is observed. Fig. 2(b1) and Fig. 2(b2) show the input temporal waveforms of the channel 1, 3 and channel 2, 4 for the up-chirp LFM signal generation. The waveform of the channel 3 is delayed 90^o to the one of the channel 1 and the channel 4 is advanced 90^o to the one of the channel 2. Fig. 2(b3) shows the instantaneous frequency-time diagram of the generated up-chirp LFM signal. It can be seen that an up-chirp LFM signal with a carrier frequency of 5 GHz and a sweeping rate of 1 GHz/4us is observed. Meanwhile, Fig. 2(c1) and Fig. 2(c2) show the input temporal waveforms of the channel 1, 3 and channel 2, 4 for the dual-chirp LFM signal generation. The waveform of the channel 3 is same to the one of the channel 1 and the channel 4 is same to the one of the channel 2. Fig. 2(c3) shows the instantaneous frequency-time diagram of the generated dual-chirp LFM signal.

It can be seen that a dual-chirp LFM signal with a carrier frequency of 5 GHz and a sweeping rate of 1 GHz/4us is obtained. The experimental results agree well with above theoretical analysis.

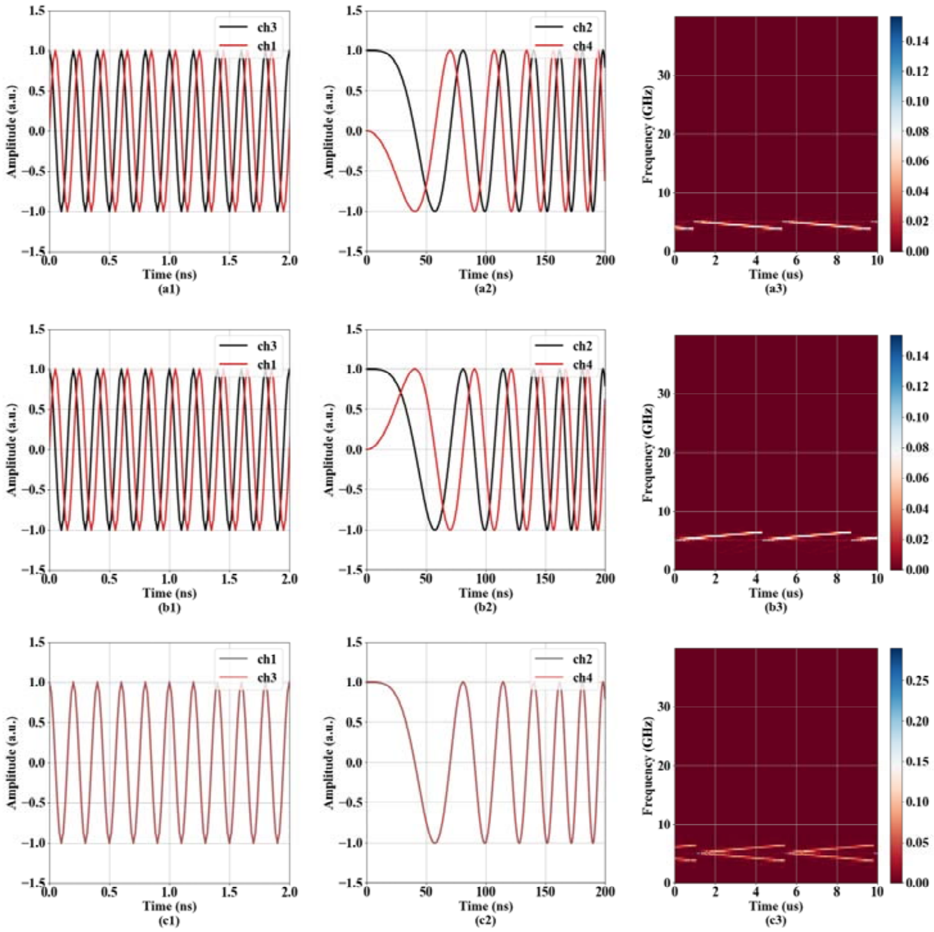

Fig. 2. Input temporal waveforms of (a1) channel 1 and 3, and (a2) channel 2 and 4 for down-chirp LFM signal generation, (a3) the instantaneous frequency-time diagram of the generated down-chirp LFM signal; input temporal waveforms of (b1) channel 1 and 3, and (b2) channel 2 and 4 for up-chirp LFM signal generation, (b3) the instantaneous frequency-time diagram of the generated up-chirp LFM signal; input temporal waveforms of (c1) channel 1 and 3, and (c2) channel 2 and 4 for dual-chirp LFM signal generation, (c3) the instantaneous frequency-time diagram of the generated dual-chirp LFM signal.

4. Conclusion

In this paper, we proposed and experimentally demonstrated a photonic method to generate switchable down-chirp, up-chirp, and dual-chirp LFM signal. The proposed method has a compact structure, which may be used in modern multi-functional radar system.

4. References

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