Photonic generation of linearly-chirped microwave waveform with tunable center frequency and time-bandwidth product

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Abstract: A novel approach is presented to generate linearly-chirped microwave waveforms with tunable center frequency and expandable time-bandwidth product (TBWP). Different types of waveforms are demonstrated and the maximum measured TBWP is up to ~166.4.

OCIS codes: (060.5625) Radio frequency photonics; (140.4050) Mode-locked lasers; (350.4010) Microwaves

1. Introduction

Linearly-chirped microwave waveforms are used to increase range resolution determined by its time-bandwidth product (TBWP) in modern radar systems [1] and optical instruments [2]. Photonic methods are able to substantially improve the bandwidth [3-4]. Most recently, wavelength-to-time mapping method becomes attractive due to its superior tunability [5-6]. However, tuning of the generated signal's center frequency via changing the time delay in the Mach-Zehnder interferometer leads to reduced waveform duration. Also the sweeping bandwidth cannot be flexibly controlled [5]. In [6], the frequency chirped microwave waveform was generated by beating a pre-chirped optical pulse with a CW optical signal. The phase irrelevance of two independent lasers may result in instability.

In this paper, we demonstrate a novel method to generate linearly-chirped microwave waveform with large TBWP based on the unbalanced dispersion introduced by two dispersion compensation fibers (DCFs). Both the center frequency and sweeping bandwidth of generated microwave signal can be independently and flexibly controlled by tuning two tunable optical filters (TOFs).

2. Principle

Figure 1 (a) shows the setup of the proposed method. A mode-locked laser (MLL) with pulse repetition rate of 37 MHz is used as the optical source. A 50:50 optical coupler (OC1) is used to divide the optical pulses into two arms. Then their optical spectra are shaped by TOF1 and TOF2 whose profile is approximately rectangular (Alnair Labs, CVF-220CL). Two sections of DCFs, DCF1 and DCF2 with dispersion of $\ddot{\Phi}_1 = -1915\ \mathrm{ps}^2$ and $\ddot{\Phi}_2 = -1660\ \mathrm{ps}^2$, respectively, are used to introduce different chirps into the optical pulses via wavelength-to-time mapping effect. A variable optical delay line (VODL, General Photonics, MDL-002) is added in the second arm to compensate for time offset between two arms caused by the length difference of two DCFs. After being coupled together by another 50:50 optical coupler (OC2) and amplified by an erbium doped fiber amplifier (EDFA), the optical signal is converted into a linearly-chirped microwave waveform by an ultra-fast 100-GHz photo-detector (Finisar, XPDV4120R).

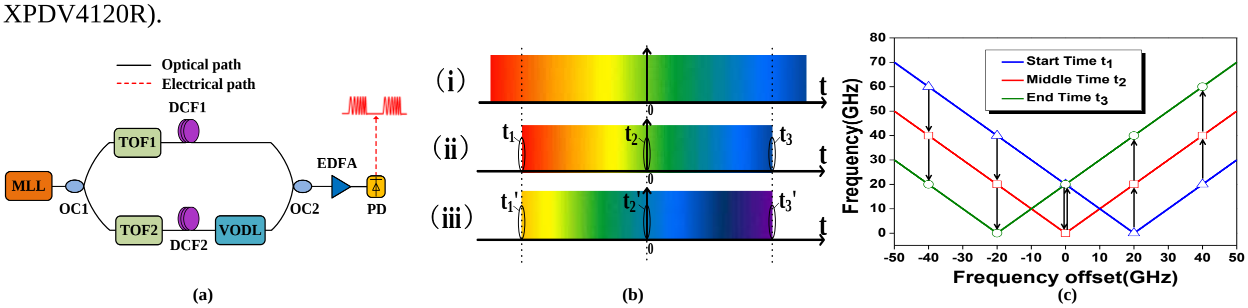

Fig.1. (a) Schematic of the proposed method. MLL, mode locked laser; OC, optical coupler; TOF, tunable optical filter; DCF, dispersion compensation fiber; VODL, variable optical delay line; EDFA, erbium doped fiber amplifier; PD, photo-detector. (b) Principle of the proposed method. (c) Instantaneous frequency at the start, middle, and end time of the microwave waveform when tuning the center wavelength of TOF2.

Figure 1 (b) schematically depicts the principle of the proposed method. According to the real-time Fourier transform introduced by dispersion [7], the temporal signal amplitude at t is proportional to the Fourier transform of input signal at the angular frequency $\omega = t/\ddot{\Phi}$ and the filtered optical spectra in two arms can be mapped to the temporal waveforms through DCFs. The duration time of the optical pulse is proportional to both the filtering bandwidth of TOF and the dispersion of DCF. The rectangular color bars (i) and (ii) represent different wavelength components beating at PD at different time, respectively, when TOF1 and TOF2 have the same filtering bandwidth and center wavelength. Note that (i) experiences more dispersion and hence is longer than (ii). The time axis is the time offset from the middle time in an observation window. For the beating of (i) and (ii), the center frequency at the middle time t_2 is 0 GHz. Color bar (iii) represents the beating wavelength components when the center wavelength of TOF2 is detuned. For the beating between (i) and (iii), the frequency at middle time t_2' changes accordingly. The blue, red and green lines in Fig. 1 (c) represent the instantaneous frequency at the start, middle and end time of the microwave waveform, respectively, when changing the optical frequency offset of two TOFs (suppose total linearly sweeping bandwidth is 40 GHz).

3. Experimental Results

TOF1 and TOF2 are at first set at the same center wavelength of 1555 nm and bandwidth of ~4 nm. Then, the center wavelength of TOF2 is detuned by ~$\pm$0.26 nm, corresponding to the change of the optical frequency offset between two TOFs from ~-32 GHz to ~+32GHz. Note that when the center wavelength of TOF2 changes, VODL needs to be precisely adjusted to tune difference of average time delay in each arm to an integer multiple of pulse period (T = 27 ns). Figure 2 illustrates three types of measured waveforms using an oscilloscope (Agilent, DSAX93204A, 32GHz bandwidth, 80Gsa/s) and their short-time Fourier transform (STFT) analysis. In Fig. 2 (a) (d), the center frequency locates at 0 GHz and the measured bandwidth is ~32 GHz with duration time ~5.2 ns, corresponding to a TBWP of ~166.4. For Fig. 2 (b) (e) or Fig. 2 (c) (f), the instantaneous frequency at middle time locates at ~32 GHz but the linear chirp has opposite signs. Note that only the frequency components within 32 GHz bandwidth are captured due to the limited bandwidth of oscilloscope.

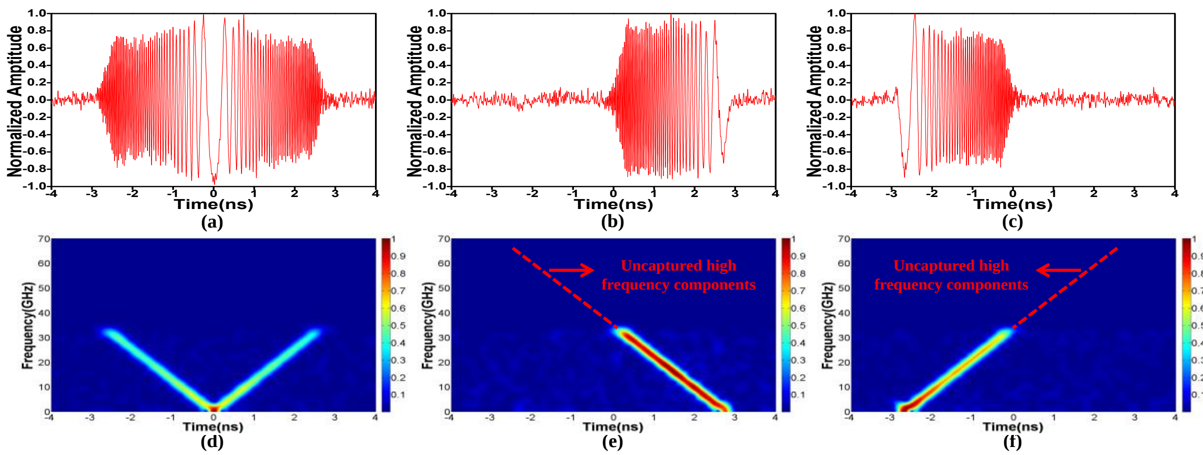

Fig.2. Temporal waveforms (a-c) and STFT analysis (d-f) of the measured microwave waveforms when the center wavelength of the TOF2 is detuned by (a), (d) 0 nm; (b), (e) -0.26 nm; (c), (f) +0.26 nm.

4. Conclusion

We have demonstrated a method to generate linearly-chirped microwave waveform with tunable center frequency and expandable TBWP. TBWP up to ~166.4 is achieved and larger value could be expected if the measurement device is improved.

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