Reconfigurable Optical Fiber–Based Microwave Dispersive Line for Single-Shot Chirped Microwave Pulse Compression

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Abstract: A fiber-based approach for reconfigurable and single-shot chirped microwave pulse compression is proposed and demonstrated based on a time-spectrum convolution system. Different nanosecond-long, GHz-bandwidth linearly chirped microwave pulses are successfully compressed using the same platform.

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1. Introduction

Recently, chirped microwave pulse generation and processing has been a topic of increased interest as this can find many important applications in modern radar, ultra-fast wired and wireless communications, medical imaging, and modern instrumentation [1]. To overcome the limited sampling rate of the currently available digital electronics, numerous photonic-assisted techniques have been proposed to generate and/or process chirped microwave pulses based on either free-space optics or fiber optics. The frequency and bandwidth of the chirped microwave pulse can be as high as a few tens of gigahertz, typically limited by the bandwidth of the photodetector. A fundamental chirped microwave pulse processing functionality is that of temporal compression at the receiver end, leading to e.g. an improved range resolution in radar systems and increased communication distances through dispersive channels [1]. This operation is usually realized via correlation or matched filtering. Optical techniques have proved very advantageous to implement pulse compression of high-frequency and broadband chirped microwave pulses (see for instance [2] and references therein). However, previously demonstrated photonic-based methods are generally not reconfigurable (i.e. in each case, the system is essentially designed for optimal operation only on a specific, pre-defined input chirped microwave pulse). This drastically limits the range of application of the photonic-based chirped microwave pulse compression approaches proposed to date.

Time-spectrum convolution (TSC) has been previously employed to implement Fourier transformation of microwave signals by ultra-high dispersion [3, 4]. The key feature of the TSC technique is that ultra-high microwave dispersion up to several tens of ns^2 (equivalent to the dispersion introduced by propagation through thousands of km of conventional optical fiber sections) can be achieved over GHz bandwidths [3]. However, due to the need for an incoherent light source, the signal-to-noise ratio (SNR) of the output signal is very poor, typically preventing the use of the processing platform in a single-shot measurement basis [3-5]. This restricts the use of the platform to processing periodic pulse waveforms, which is rarely the case found in practice.

In this paper, an optical fiber-based approach to realizing fully *reconfigurable and single-shot* chirped microwave pulse compression is proposed and experimentally demonstrated based on a TSC system incorporating a programmable spectral shaper. Key to the achieved SNR improvement, enabling single-shot processing, is the use of a suitable multi-wavelength (frequency comb) fiber laser source instead of a broadband incoherent light source. The system is demonstrated by optimal compression of different nanosecond-long, GHz-bandwidth chirped microwave pulses with achieved compression ratios ranging from ~12 to ~22. The outstanding robustness of the compression system against the presence of noise in the input microwave signal is also demonstrated.

2. Experiment

The experimental setup of the proposed single-shot TSC system is shown in Fig. 1. In this TSC system, the optical source is no longer a broadband incoherent source, such as that used in [3], e.g. amplified spontaneous emission (ASE) or a super-luminescent diode (SLD). An all-fiber SLM multi-wavelength laser source with a free-spectral-range (FSR) of 100 GHz and a linewidth lower than 100 KHz, extending over a total bandwidth of ~4 THz, is employed. More details on this laser system can be found in Ref. [6]. The multi-wavelength laser is then shaped by a fiber-pigtailed programmable optical filter (Finisar WaveShaper 4000S). The programmable optical filter has a minimum filter bandwidth of 10 GHz and a maximum filter bandwidth of 5 THz. The spectrum-shaped broadband multi-wavelength laser source is directed into a 20-GHz MZM and modulated by an amplified microwave signal from an arbitrary waveform generator (AWG, AWG7122C, Tektronix Inc.). The modulated optical signal is then launched into a dispersive SMF section (optical dispersion line) and converted to an electrical signal at a 25-GHz PD.

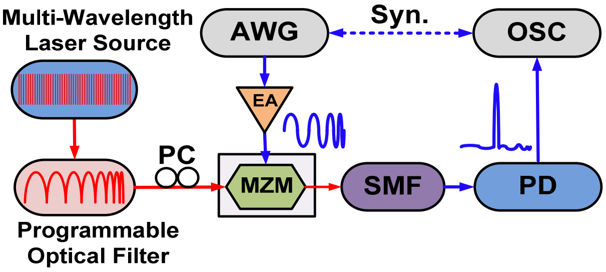

Fig. 1. Experimental setup of a multi-wavelength TSC system for single-shot chirped microwave pulse compression. PC: polarization controller, AWG: arbitrary waveform generator, EA: electric amplifier, MZM: Mach–Zehnder modulator; SMF: single mode fiber; PD: photodetector, OSC: oscilloscope.

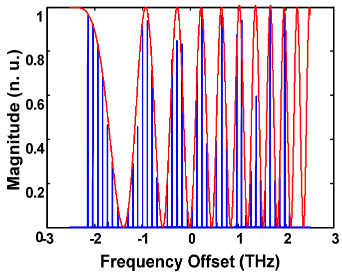

Fig. 2. Measured spectrum of the shaped multi-wavelength laser.

In a TSC system, the time-domain output signal is proportional to the convolution of the spectrum of the broadband source (mapped along the time domain via the optical dispersion) and the temporal intensity of the modulation signal. The spectrum of the shaped multi-wavelength laser source is shown in Fig. 2. A sinusoidal modulation with a quadratic phase variation must be used to emulate the temporal impulse response of a microwave dispersive line [3]. The red line in Fig. 2 shows the chirped envelope of the comb lines. Notice that the dispersion and bandwidth of the implemented microwave dispersive line depends on the shape of this spectral chirped envelope and the optical dispersion value. In the first experiment, a SMF with a length of 2.5 km is employed as the dispersive element. Using this scheme, we demonstrate here a microwave dispersion value approaching 0.16 ns^2 (equivalent to the dispersion induced by a section of standard SMF of ~8,000 km) with an operation bandwidth ranging from 2.23 GHz to 10.36 GHz. As shown in Fig. 3(a), the input microwave signal is a single linearly chirped microwave pulse with a frequency ranging from 2.5 GHz to 8.4 GHz (in intensity). Fig.3 (b) shows the output signal measured in a real-time oscilloscope (DPO70804, Tektronix Inc.) with a bandwidth of 8 GHz and a sampling rate of 25 Gs/s. The temporal width of the compressed microwave signal is 0.1 ns, corresponding to a compression ratio of ~15. The key to the achieved SNR ratio, enabling single-shot microwave signal processing, is on the use of a multi-wavelength laser system with a very narrow spectral linewidth and a FSR higher than the PD bandwidth [7].

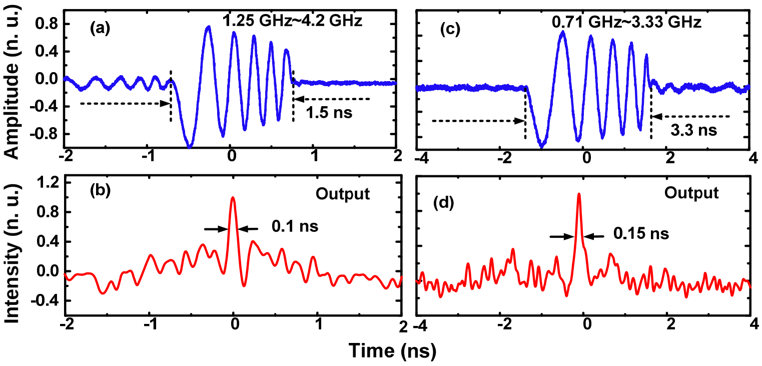

Fig. 3. (a) Input microwave signal with a linearly chirped frequency ranging from 1.25 GHz to 4.20 GHz, and (b) the compressed microwave signal. (c) Input microwave signal with a linearly chirped frequency ranging from 0.71 GHz to 1.90 GHz, and (d) the compressed microwave signal.

In the second experiment, a new SMF section with a length of 5.45 km is employed as the optical dispersive element. The microwave dispersion value is then changed to 0.99 ns^2 (equivalent to the dispersion induced by a section of standard SMF of ~49,000 km) over an operation bandwidth ranging from 1.02 GHz to 4.75 GHz. As shown in Fig. 3(c), the input microwave signal is a single linearly chirped microwave pulse with a frequency ranging from 0.71 GHz to 1.9 GHz. Fig. 3(d) shows the output signal measured in our real-time oscilloscope. The chirped microwave signal is also successfully compressed with a compression ratio of ~22. To further show the robustness of the pulse compression, white Gaussian noise is experimentally added to the generated signal to make the SNR as low as 0 dB, as shown in Fig. 4(a). Fig. 4(b) shows the successfully compressed microwave signal. It can be concluded that the target chirped microwave signal can be recognized and compressed even though it is largely distorted by the introduced white noise. Finally, to demonstrate the significance of using a multi-wavelength laser as the optical source instead of an incoherent optical source in the TSC system, a SLD is employed as the optical source in the experimental setup. Fig. 4(c) shows the output signal without any average measured by using a sampling oscilloscope (CSA8000, Tektronix Inc.). Chirped microwave pulses such as that shown in Fig. 4(c), repeating at a rate of 200 MHz, are employed as the modulation signals. The compressed signal is too noisy to be recognized, which confirms that the TSC system cannot implement chirped microwave pulse compression in a single-shot, in agreement with previous observations [2]. Finally, by employing 50 times average, the compressed pulse is detected but with a small compression ratio of 11 and a notably deteriorated SNR, as shown in Fig. 5(d).

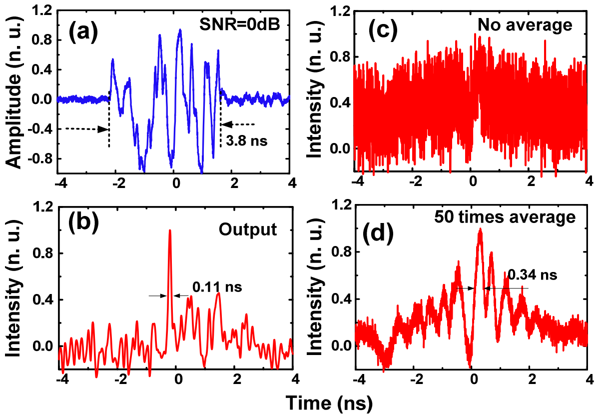

Fig. 4. (a) Chirped microwave signal shown in Fig. 4(c) with an additive white Gaussian noise to make the SNR as low as 0 dB and (b) the compressed microwave signal. The measured output signal (c) without average and (d) with 50 times average from the TSC system in which a SLD is employed as the light source instead of the frequency comb laser.

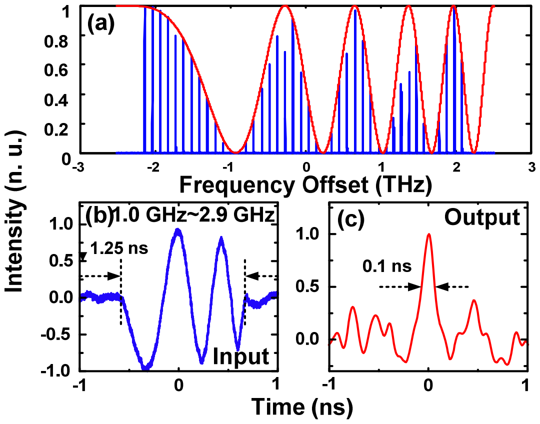

Fig.5. (a) Measured spectrum of the shaped multi-wavelength laser with a half chirp rate of the spectrum shown in Fig. 3. (b). Input microwave signal with a linearly chirped frequency ranging from 1.0 GHz to 2.9 GHz, and (c) the compressed microwave signal.

Finally, by programming the optical spectral shaper, the spectrum of the multi-wavelength laser is re-shaped as shown in Fig. 5(a) with a half chirp rate of the envelope shown in Fig. 3. When the dispersive element is a 2.5 km SMF section, it can be seen from Figs. 5(b)-(c) that a different input microwave signal with a linearly chirped frequency ranging from 1.0 GHz to 2.9 GHz is compressed with a compression ratio of 12.5. The experimental results verify that the system can be programmed for optimal compression of different (arbitrary) chirped microwave signals by suitably shaping the spectral envelope of the multi-wavelength laser and/or tuning the optical dispersion.

4. Conclusion

A fiber-optics approach to implementing reconfigurable and single-shot chirped microwave pulse compression has been proposed and experimentally demonstrated based on a TSC system. Significant improvements in the system SNR, enabling single-shot measurements, are achieved through the use of an all-fiber frequency comb laser system. Different nanosecond-long, GHz-bandwidth chirped microwave pulses are optimally compressed using the same platform, even when the input signal SNR is strongly deteriorated.

5. Reference

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