A simplified stimulated Brillouin scattering pulse compression of broadband microwave signal based on differential detection

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***Abstract*—We experimentally demonstrate a simplified scheme of stimulated Brillouin scattering (SBS) pulse compression of broadband microwave signal based on differential detection. The simplified pulse compression without subtraction is implemented by use of a parallel delay line without SBS gain and a balanced photodetector. The experimental results shows a higher performance of pulse compression by eliminating the background noise and decreasing the quantizing noise.**

Keywords—Stimulated Brillouin Scattering; differential detection; pulse compression

I. INTRODUCTION

Pulse compression, a key signal processing technique in radar field, resolves the contradiction between the radar's range resolution and its velocity resolution [1, 2]. However, the existing pulse compression methods often require sufficient analogue bandwidth, ultra-high sampling rate, and great sampling resolution [3], which burdens the pressure of digital storage and digital signal processing. Thanks to the development of microwave photonics [4], it enables broadband microwave signal processing with high phase stability in generation, controlling, and processing [5-11]. Although several kinds of photonic analog-to-digital conversion (ADC) [12, 13], to some extent, have conquered the bandwidth limitation of electronic ADC, the demand for digital storage and signal processing is not satisfied. An all-optical pulse compression of broadband microwave signal based on stimulated Brillouin scattering (SBS) was theoretically and experimentally demonstrated in [10] to fulfill pulse compression in analogue domain before digitalization. Acoustic wave inherits the amplitude and phase information of the pump lightwave. The derivation of SBS coupling equations proves a natural auto-correlated process of pump lightwave with acoustic wave and leads to that an amplified probe lightwave contains the information and auto-correlated formula of pump lightwave. However, to obtain a pure compressed signal from the amplified probe lightwave, an operation of turning on and off the pump lightwave is required. Consequently, a severe amplitude noise exists and the quality of the pulse compression is deteriorated.

In this work, we demonstrate a simplified scheme of SBS pulse compression based on differential detection. To obtain a net SBS probe lightwave gain, a delay line without SBS probe lightwave gain is introduced as a parallel path with the equal optical distance path with respect to the SBS process. Besides, a balanced photodetector (PD) is imported so that the compressed signal can be directly detected from the probe lightwave, avoiding the turning pump lightwave on and off operations and numerical subtraction. Proof-of-concept experiment is carried out to testify the feasibility of the differential detection of pulse compression on a linear frequency modulation (LFM) signal with 3.3 μs duration and different sweep ranges at 10.818GHz carrier frequency. The compressed results and the range resolution show a high signal-to-noise (SNR) and broad bandwidth.

II. EXPERIMENTAL DETAILS

Figure 1 shows the experimental setup. Lightwave at the wavelength of 1550nm is generated from a distributed-feedback laser (DFB-LD, NEL NLK1C6DAAA) and is separated into two paths by a 1:1 fiber coupler. The upper path is set as pump lightwave. To generate the frequency difference between pump lightwave and probe lightwave which is equal to the Brillouin frequency shift (BFS) of fiber, the pump lightwave is modulated by an input microwave signal to be processed through a single sideband modulator (SSBM). And the first higher sideband is selected after the SSBM. The lower path is set as probe lightwave. The probe lightwave is modulated by a radio frequency (RF) signal through an electro-optic modulator (EOM, Eospace, AX-6K5-10PFU-PFUP-R4) and is further split into two parallel branches by a 1:1 coupler. The right branch is used as a typical probe light path in the SBS based pulse compression. The left branch is imported as a delay line without SBS gain. The optical distance of delay line is equal to the SBS fiber. A polarization-insensitive balanced photo-detector (PD) is used to counteract light power of the parallel branches so a compressed signal with a net SBS gain is obtained and converted into an electrical voltage. Polarization controllers (PC1 and PC2) are introduced to optimize the light polarizations before modulators.

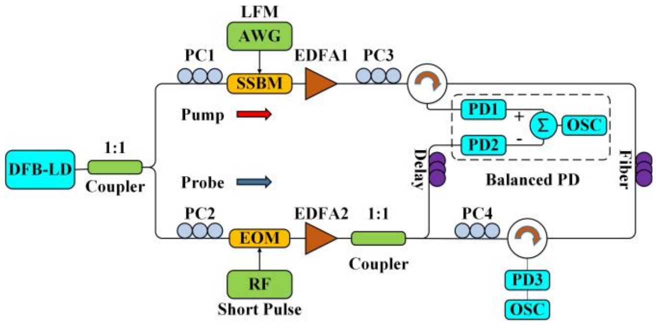

Fig.1. Experimental setup for a simplified all-optical SBS pulse compression of the broadband microwave frequency based on differential detection. DFB-LD: distributed-feedback laser. PC: polarization controller. EOM: electro-optic modular. EDFA: erbium-doped fiber amplifer. ISO: isolator. SSBM: single sideband modulator. PD: photo-detector. AWG: arbitrary waveform generator. OSC: oscilloscope.

PC3 and PC4 adjust the light polarization of pump lightwave and probe lightwave respectively to ensure the maximum SBS interaction in a standard single-mode-fiber (SMF). A circulator in the upper path is used to isolate amplified probe lightwave from pump lightwave. The other circulator in the lower path is used to select the pump lightwave so that the modulation of SSBM can be monitored through another PD. The output power of DFB-LD is about 14.14dBm; the input power of SSBM and EOM are 9.43dBm and 8.88dBm, which are close to the saturation power of modulators. It is unnecessary to use extra Erbium-doped fiber amplifiers (EDFA) before the modulators to amplify the input power. The EDFA1 and EDFA2 are utilized to compensate the power loss after modulation and optimize the optical power of pump lightwave and probe lightwave. The output power of EDFA1 and EDFA2 is 28.57dBm and 13.55dBm, respectively.

To generate an LFM signal, an arbitrary waveform generator (AWG) is used in the first higher sideband of the modulated signal in SSBM. The frequency of LFM signal with different sweep ranges sweeps from 10.818GHz, which equals to the SMF's BFS. The time duration is set to be 3.3μs. In the lower path, a short pulse with 0.5 ns time duration and 5V amplitude is set as the RF signal. Each experimental results is conducted after a 1024-time average by the oscilloscope (OSC).

Figure 2 (a) illustrates the compressed result which was illustrated in [10]. The curve represents the detected probe lightwave power with and without SBS gain by using SMF when the pump lightwave is turned on and off. The compressed result is not apparent, so a numerical calculation is essential to extract the pulse compression result. Moreover, the background noise cannot be effectively eliminated, leading to a low quality of the compressed result. Due to an inconspicuous increase of detected probe lightwave power, the quantizing window is unfilled so that the quantizing noise is also serious. Figure 2 (b) represents the procedure of the simplified scheme based on the differential detection and its pulse compression results. From Fig. 2(b), the optical distance between two parallel paths are precisely even and the power are offset accurately to pick up a net SBS gain after a balance PD. Note that the curve still contains a small bump. As pointed out in [10], the amplification of the detected probe lightwave contains two parts. The one is its own increase induced by SBS; the other is induced by pump lightwave and contains the amplitude and phase information of the pump lightwave. As the amplification caused by pump lightwave is offset, the small bump is produced by its own increase. The comparison among the operation of the substraction between the pump lightwave on and off, differential detection and ideal pulse compression is given in Fig. 2(c). The bandwidth of LFM signal is set to be 0.5 GHz. The trends among three different results are consistent.

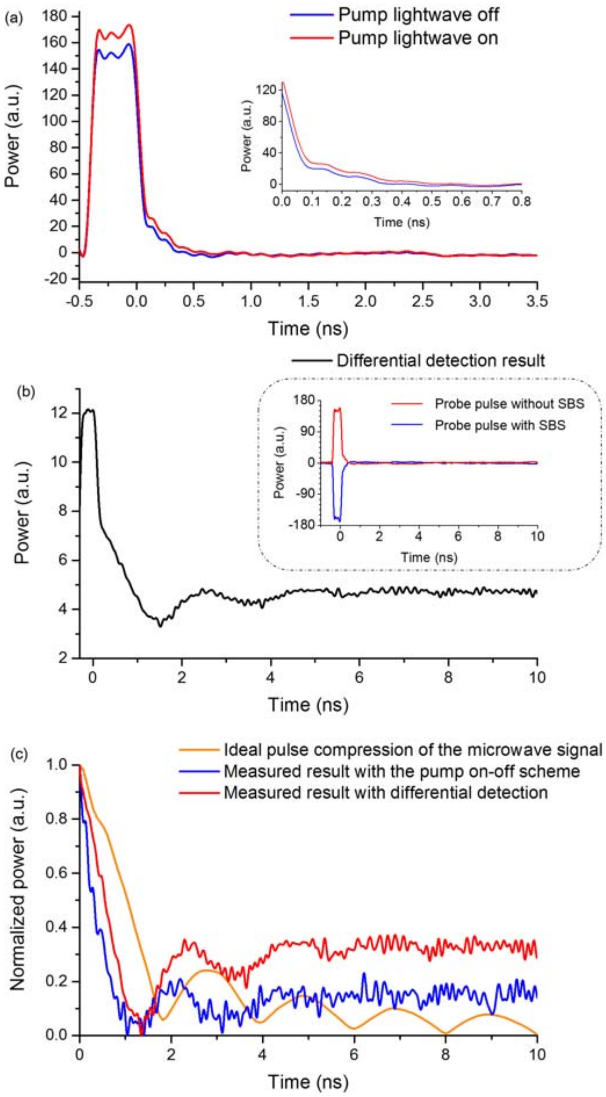

Fig.2 Experimental results for pulse compression based on SBS process with different methods. The bandwidth of LFM signal is set to be the same at 0.5GHz with time duration of 3.3μs. (a) The detected probe lightwave power with and without the pump lightwave injected. (b) The experimental result based on differential detection. (c) Comparison among ideal pulse compression of signal to be proceeded, pump lightwave on and off method, and differential detection.

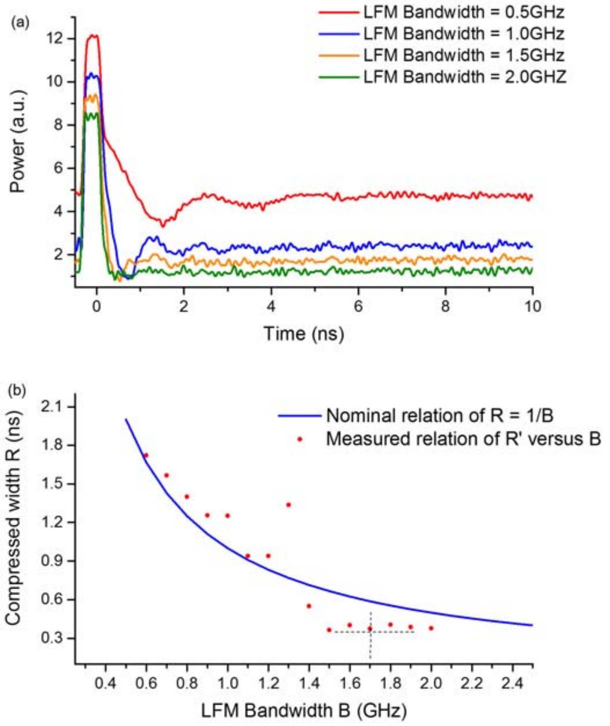

Fig.3. Experimental result of SBS pulse compression based on differential detection. (a) The pulse compression results with different LFM bandwidth. (c) The full width of the compressed mainlobe as function of sweeping bandwidth of the LFM pulse.

The main lobes of both the pump lightwave on-off method and the differential detection are evident and match the ideal curve. However, thanks to the differential detection, a more clear SBS gain can be observed in real time directly by the OSC rather than operating numerical extraction shown in [10]. Therefore, the background noise is effectively eliminated and the quantized window is full, resulting in a smaller quantized noise. Hence, the side lobe of differential detection curve is more evident and in agreement with the ideal pulse compression.

Since the side lobe of differential detection pulse compression result is more distinct than the previous one in [10], it may conclude that the system bandwidth of the simplified scheme can be expanded. To testify the system bandwidth, we measure several typical pulse compression results with different LFM signal bandwidth that are depicted in Fig. 3(a). It is clear that the system bandwidth based on the differential detection can easily reach to 1.7 GHz. However, the system bandwidth of the former scheme based on the pump lightwave on-off is limited to 1 GHz due to severe noise. Besides, the measured relationship between range resolution (R) and LFM signal bandwidth (B) is summarized in Fig. 3 (b). According to [10], resolution range, defined as the width between peak and null, is theoretically equal to the reciprocal of the LFM signal's bandwidth. In this work, we define the sidelobe as the new resolution range R'. The comparison between the ideal R-B curve and the R'-B curve of the differential detection is carried out. The R'-B curve matches well with the ideal R-B curve and shows good inverse relationship. The trend of the differential detection curve tends to 1.7 GHz.

III. CONCLUSION

We have demonstrated a simplified scheme of all-optical SBS pulse compression technique of broadband microwave signal based on differential detection. By adding a delay line without SBS gain as a parallel path, a pure pulse compression result is obtained through a balanced PD. The compressed signal is obtained immediately without the operation of turning on and off the pump lightwave so that the quantized noise is lower and the background noise is eliminated. The comparison of the experimental results proves that the pulse compression of the simplified scheme based on the differential detection is better than the pump lightwave on-off scheme and the system bandwidth is larger.

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