Incoherent-light implementation of the photonic time stretch concept

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Abstract: We propose and experimentally demonstrate photonic time stretch of radio-frequency signals by using a time-gated (pulsed) incoherent light source, with time-stretch factors of 0.83 and 8.66, and a time-bandwidth product of > 340.

OCIS codes: (070.1170) Analog optical signal processing; (350.3950) Micro-optics.

The photonic time stretch concept enables undistorted temporal re-scaling (compression or magnification) of intensity waveforms and it involves temporal modulation of a linearly chirped (dispersed) optical pulse followed by dispersive propagation. This concept has proven particularly useful to realize ultrahigh-speed (or ultrawide-bandwidth) analog-to-digital conversion [1-6], which is widely recognized as a key bottleneck in modern high-performance communication and radar systems [1, 2, 6]. A main limitation of a photonic time-stretch system is the realization of the required linearly chirped optical pulse, which is conventionally obtained by dispersing the output of a coherent ultrafast optical pulsed source, e.g. a femtosecond mode-locked laser [2-7]. However, relatively complex and costly techniques (e.g. mode locking) are needed to be able to produce coherent optical pulses with wavelength bandwidths extending even over a few nanometers. Compared to a coherent light source, it is generally more practical and simpler to produce incoherent light with large wavelength (frequency) bandwidths. In this work, we propose and experimentally demonstrate a new technique to realize photonic time stretch of radio-frequency (RF) signals by using a time-gated (pulsed) incoherent light source. The proposed system provides similar performance specifications (stretch factor, temporal aperture and resolution) to those of a conventional coherent system but using a temporal gating process that is significantly longer than the transform-limited pulse duration of the equivalent coherent configuration. We experimentally demonstrate temporal magnification and compression of high-speed RF signals, with time-stretch factors of 0.83 (temporal compression) and 8.66 (temporal magnification), using a broadband (11.6-nm) incoherent light source temporally gated over ~163 ps. In one of the reported experiments, we achieve a resolution of ~67.5 ps over a temporal aperture of ~23 ns, representing a time-bandwidth product (TBP) > 340.

An illustration of the proposed scheme is shown in Fig. 1. This scheme is obtained by exchanging the dispersive process and temporal pinhole modulation in an incoherent-light temporal pinhole system [8]. This results in the exact equivalent of the coherent photonic time stretch scheme [3-7], except for the key fact that the ultrashort pulse laser source in the coherent case is now implemented through a time-gated incoherent light source. The later is achieved by short temporal gating of a broadband incoherent light source, which is assumed to exhibit a uniform energy spectrum over a broad bandwidth.

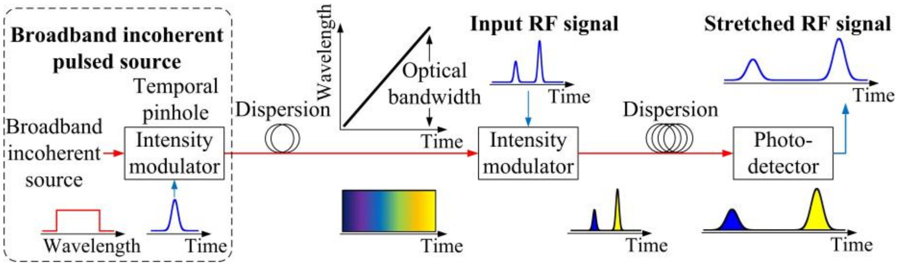

Fig. 1. Diagram of an incoherent-light photonic time-stretch scheme. All waveforms and spectra, and the instantaneous wavelength are averaged profiles.

Temporal stretching of the intensity waveform under test is achieved through a concatenation of time-to-frequency and subsequent frequency-to-time mapping processes. In particular, the broadband incoherent pulse is firstly dispersed by a dispersive element, which provides a group-delay dispersion of $\ddot{\Phi}_1$. As such, an averaged linear frequency chirp is induced in the time domain. This is followed by a second temporal intensity modulation process with the input RF signal to be processed; the RF temporal waveform is mapped along the frequency domain (time-to-frequency mapping) as a result of the optical pulse linear frequency chirp. The resulting modulated light is finally dispersed by the second dispersive element with a group-delay dispersion of $\ddot{\Phi}_2$, effectively mapping the modulated light spectrum along the time domain. This results into the anticipated temporal stretching process of the original RF signal by a magnification factor $M = 1 + \left(\ddot{\Phi}_2 / \ddot{\Phi}_1 \right)$.

We report here results from two experiments with different time stretch factors, including examples of temporal compression and magnification, see results in Fig. 3. In these experiments, two different input temporal waveforms are used. In particular, the values of the first and second dispersion used in the first experiment are 1,981 ps/nm and −692 ps/nm, respectively, whereas the values of the first and second dispersion used in the second experiment are −346 ps/nm and −2,652 ps/nm, respectively. Thus, the time-stretch factors of these two experiments are given by 0.83 and 8.66, respectively. Fig. 3(a) and (b) shows the averaged temporal intensity profile and the averaged spectrum of the incoherent pulse at the output the broadband incoherent pulsed source, respectively. The incoherent pulse has a duration that is nearly 360 times longer than the coherence time of the light source. As shown in Fig. 3(c)-(d), the temporally stretched output waveforms (solid red) in average closely resemble the corresponding scaled input waveforms (dotted blue). Note that the input waveforms are averaged optical temporal intensity profiles measured at the output of the second intensity modulator. The system temporal apertures (processing temporal window) of these two experiments are ~22.98 ns and ~4.02 ns, respectively, whereas the system temporal resolutions of these two experiments are ~67.5 ps and ~122.7 ps, respectively. In particular, the achieved TBP for the first experiment is ~340. To confirm that time-to-frequency mapping is achieved at the output of the second intensity modulator, Fig. 3(e) shows the measured spectrum at the system output (solid black) in the last experiment [which corresponds to Fig. 3(d)]. There is again an excellent agreement between the measured spectrum at the system output and the scaled input temporal waveform (dotted blue).

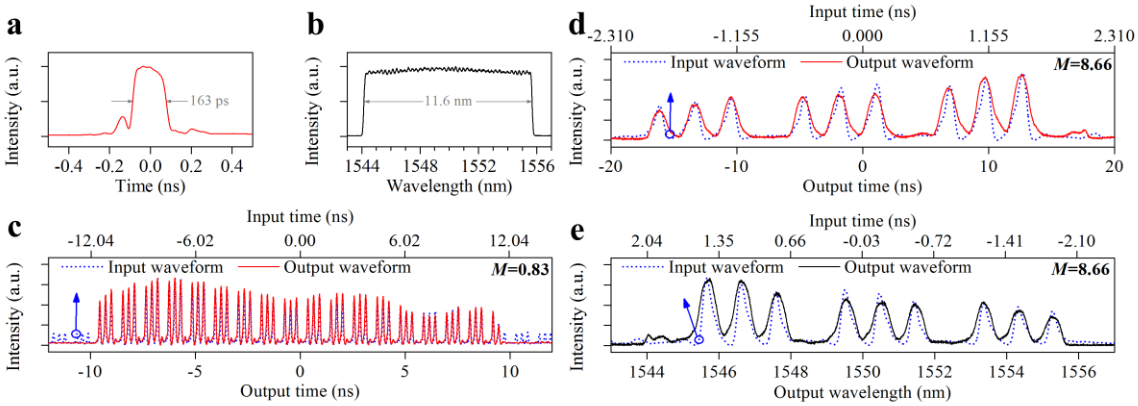

Fig. 2. Experimental demonstration of incoherent time stretch. (a) and (b) shows the averaged temporal intensity profile and the averaged spectrum of the incoherent pulse at the output of the broadband incoherent pulsed source, respectively. Two experiments with different stretch factors *M* are shown in (c) and (d), respectively. In particular, the temporally stretched output waveforms (solid red) are compared with the scaled input waveforms (dotted blue), where the scaling factors in the figures are fixed to match the theoretical time-stretch factors. Additionally, the plots in (e) show the spectrum of the system output (solid black), compared with the scaled input temporal waveform (dotted blue), where the scaling factor in the figure is fixed according to the input dispersion value of −346 ps/nm.

In summary, we have theoretically proposed and experimentally demonstrated a new time-stretch system based on a pulsed incoherent light source. The proposed incoherent scheme can provide similar performance specifications to those of its coherent counterpart but using a temporal gating process significantly longer than the transform-limited pulse duration of the equivalent coherent mode-locked laser system. This novel concept could be potentially useful to improve many of the previous signal processing platforms based on coherent photonic time stretching of RF waveforms.

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