Multi-wavelength pumping technique for up-conversion single-photon detectors

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Abstract: We propose a multi-wavelength pumping technique to improve temporal resolution of up-conversion single-photon detectors. By using two-wavelength pumping we doubled the date rate of a quantum system beyond its original limitation.

OCIS codes: (040.5570) Quantum detectors; (190.4410) Nonlinear optics, parametric processes

I. Introduction

An up-conversion detector is based on sum-frequency generation in a non-linear crystal, such as periodically-poled lithium niobate (PPLN) to convert single photons in near-infrared wavelengths to visible by a strong pump. The converted visible photons are then detected by a Si-APD. In such up-conversion detector with a continuous wave (CW) pump, its temporal resolution is determined by the jitter of the Si-APD used in the up-conversion detector. When the up-conversion detector is used in a quantum communication system, the jitter-limited temporal resolution becomes a bottleneck as the data rate increases. A short pulse pump, which is equivalent to optical sampling, may help to improve temporal resolution [1, 2]. However, the sampling rate is still limited by the jitter of the Si-APD used. We propose a multi-wavelength pumping approach, in which multiple spectrally and temporally distinct pump pulses lead to high temporal resolution for the up-conversion detector; therefore, the system can be operated at a data rate beyond the jitter limitation.

II. The approach

Fig. 1 shows the proposed approach. In a conventional up-conversion device, the minimum resolvable time period τ_{det} is determined by the jitter of the Si-APD. Instead of using one pump at a single wavelength, we use *n* short pulse pumps at different wavelengths to interact with the incident single-photons. The *n* pump pulses are synchronized and with a time separation τ_{det}/n. In the up-conversion device the incident signal photons are then up-converted to the visible range, but their wavelengths are slightly different depending on the wavelength of the pump pulse with which it interacted. A subsequent dispersive element, such as a grating, is used to separate and distribute the up-converted signal photons to an array of Si-APDs. Each Si-APD in the array corresponds to a particular pump wavelength, and, therefore, to a particular arrival time in the duration τ_{det}/n. With this approach, the up-conversion detector is able to resolve single-photon signal arrivals to a period as small as τ_{det}/n, representing an improvement in temporal resolution by a factor of *n*.

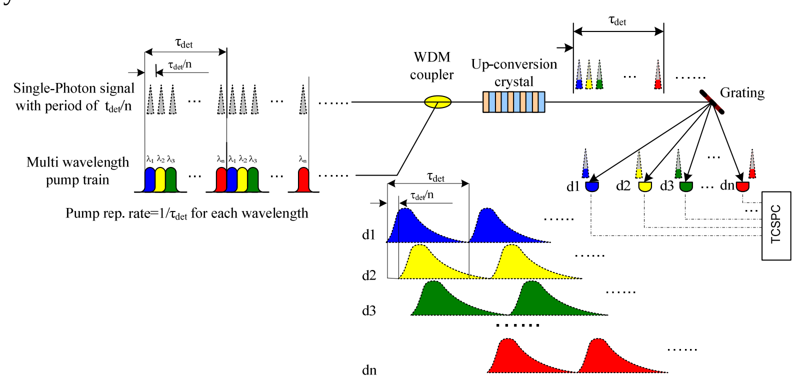

Fig. 1 Schematic diagram of up-conversion single-photon detection with multi-wavelength optical sampling.

III. Experimental Demonstraion

The experimental setup is shown in Fig. 2 (a). A pattern generator drives a pulse-carving system to generate two synchronized up-conversion pumps: Pump 1 at 1549.2 nm and Pump 2 at 1550.0 nm. Each pump source has a period of 1.25 ns. The pulses in Pump 1 and Pump 2 are pre-aligned with the even signal pulses and odd signal pulses, respectively, as shown as in Fig. 2(b). The two pump beams are combined by a 1x2 coupler and then amplified by an erbium-doped fiber amplifier (EDFA). At the output of the EDFA two 1310/1550 WDM couplers are used in series to suppress noise around 1310 nm. The amplified pump light is then combined with the 1310-nm signal by another WDM coupler, and the combined pump and signal are coupled into the up-conversion medium. Up-conversion takes place in a 1-cm PPLN waveguide. The pump pulse width of 400 ps was chosen to be wider than the 220 ps signal pulse width for higher conversion efficiency [3]. When mixed with the slightly different pump wavelengths in the PPLN waveguide, the 1310 nm signal photons are up-converted to output photons at 710.0 nm and 709.8 nm. After removing noise and excess pump light the output photons at 710.0 nm and 708.8 nm are separated by a holographic grating and then directed onto two Si-APDs. In this system an adjustable iris placed in front of each Si-APD, in conjunction with the holographic grating, acts as a 0.4-nm band-pass filter, which greatly reduces the dark count rate. The detected signals are counted by a time correlated single photon counting system.

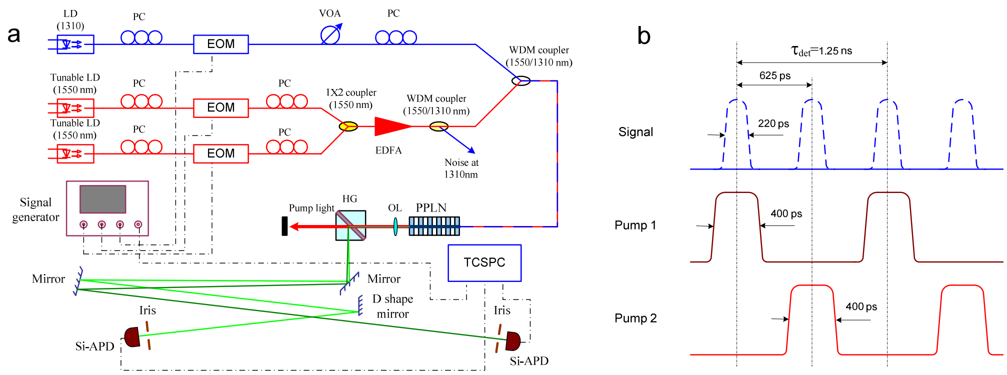

Fig. 2. (a) Experimental setup; (b) Timing diagram of the signal, pump 1 and pump 2.

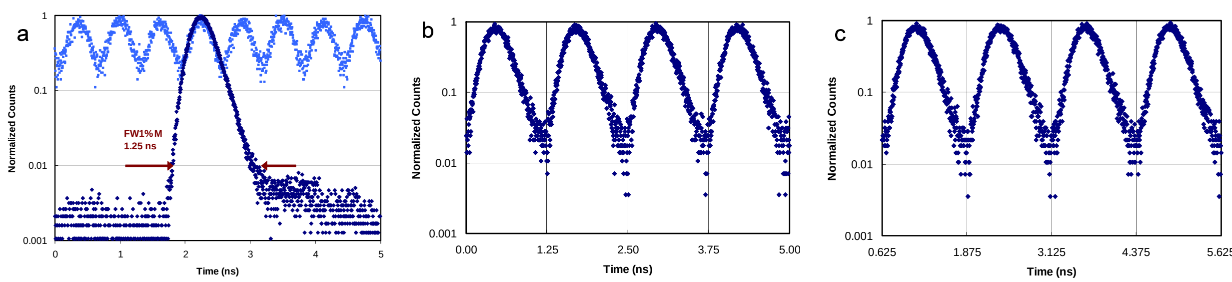

Fig. 3. Response histogram of the up-conversion detector.

For a 220-ps signal pulse train used in this system at a transmission rate of much less than 1.6 GHz, the response histogram of our up-conversion detector with a single wavelength pump is shown in Fig. 3(a) (dark blue). The FW1%M of the histogram is about 1.25 ns. When the signal transmission rate is increased to 1.6 GHz, the insufficient temporal resolution of the detector results in severe inter-symbol interference (ISI), as indicated by the poor pulse resolution shown in Fig. 3(a) (light blue). When we use two spectrally and temporally distinct pulse pumps and a separate Si-APD for each pump wavelength, as described above, we obtained a 1.25-ns FW1%M in each individual pump channel for an overall signal transmission rate of 1.6 GHz with low ISI. Fig. 3 (b) and (c) show the response histogram of each APD in the optical-sampling up-conversion system for a repetitive signal pattern “11111111”. In this system the ISI is below 1%. To measure the ISI in the optical sampling up-conversion system under conditions found in a typical QKD system we also drove the signal with a 1.6 Gb/s pseudo-random data pattern. After comparing the received data to the original data, the error rate was found to be approximately 1.2 %. Subtracting the error rate caused by the imperfect extinction ratio of the modulator and the intrinsic dark counts of APDs, the error rate caused by ISI is less than 1%.

References:

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