**Tunable upconversion photon detector**

R. T. Thew, H. Zbinden, and N. Gisin

*Group of Applied Physics, University of Geneva, 1211 Geneva 4, Switzerland*

(Received 9 June 2008; accepted 18 July 2008; published online 19 August 2008)

We introduce a simple approach for a tunable upconversion detector. This scheme is relevant for both single photon detection or anywhere where low light levels at telecom wavelengths need to be detected with a high degree of temporal resolution or where high count rates are desired. A system combining a periodically poled lithium niobate waveguide for the nonlinear wavelength conversion and a low jitter silicon avalanche photodiode is used in conjunction with a tunable pump source. We report more than a tenfold increase in the detectable bandwidth using this tuning scheme. © 2008 American Institute of Physics. [DOI: 10.1063/1.2969067]

Single photon detection, or indeed, detection of any low light signals at telecommunication wavelengths, has suffered from a variety of performance constraints. The reliance on InGaAs/InP avalanche photodiodes (APDs) has meant, until recently, working with efficiencies of around 10% in a gated or triggered regime with relatively high levels of noise compared to silicon (Si) APDs. Despite this, many seminal experiments in quantum key distribution (QKD), see Ref. 3, have helped push this technology to the level of a commercial viability. The introduction of single photon counting for distributed telecommunication measurements, such as optical time domain reflectometry (OTDR), has also provided significant advantages in terms of sensitivity and precision.

Furthermore, whether it be in telecommunication, where faster and faster communication results in a lower mean number of photons per bit (pulse), or more generally in any low light-level metrology scheme, the role of single photon detection is increasing in importance.

Recently, we have seen the arrival of detectors based on superconduction that hold great promise. These detectors have low efficiencies, for the moment, of less than 10% at 1550 nm, although this is offset by their potential for very low noise, a few hertz, low timing jitter (temporal response) of less than 20 ps, and with improvements in electronics, count rates approaching 1 GHz. Their drawback is, however, the need for cryostatic cooling. An alternative approach that has been pursued by a few groups is to combine nonlinear upconversion, also referred to as sum-frequency generation, to convert the telecom wavelength photons to the visible spectrum where Si APDs can be harness. It should be mentioned that this is not restricted to this regime and some of us have previously shown its operation in the mid-IR at 4.6 μm. These approaches also have the added advantage of bringing a passive detection technique to these regimes. In our particular case we normally use either one of two different types of Si APDs (MPD: PD5CTA, id Quantum: id100–50) that provide for very low timing jitter (<50 ps). This is an order of magnitude improvement over both InGaAs/InP (Ref. 1) and the standard Si APDs (Ref. 2) currently in wide use. We have already used these upconversion detectors to significantly increase transmission rates for QKD (Ref. 10) and, more recently, gain another order of magnitude increase in the two-point, fault-finding, resolution for a single photon OTDR scheme. Due to the narrow acceptance bandwidth, governed by the nonlinear conversion process, these upconversion schemes have been restricted to operate in systems with well defined source wavelengths such as in QKD and OTDR. In this letter we introduce a variation to the upconversion detection scheme that gives over a tenfold increase for the detectable bandwidth. We first introduce the basic principle and operation in the context of recent improvements in device performance, before detailing the process used for tuning the detection wavelength. We finish by elaborating on possible extensions to this idea.

The detection scheme we proposed is illustrated in Fig. 1. The underlying principle involves the nonlinear upconversion of a signal in the telecom band, around 1550 nm, to the visible regime, followed by its subsequent detection with a silicon (Si) APD. In more detail, the signal photons are mixed at a fiber wavelength division multiplexer (WDM) with a strong pump laser at 980 nm. We will describe the tuning mechanism in more detail momentarily. This fiber is pigtailed to a temperature stabilized periodically poled lithium niobate (PPLN) waveguide (W/G) (HC Photonics)

![Experimental scheme](image)

**FIG. 1.** (Color online) Experimental scheme: (single) photons at 1550 nm are combined with a tunable (see text) laser at 980 nm in a fiber WDM before entering a nonlinear PPLN W/G for upconversion to 600 nm. This output is filtered using a prism and an interference filter before detection with a Si APD. Signal and pump intensities and wavelengths are monitored after a fiber beamsplitter.

---

*Electronic mail: robert.thew@physics.unige.ch.*
where the nonlinear wavelength conversion is performed. The W/G is 2.2 cm long and has a poling period of 9 \mu m with a normalized internal efficiency of over 500% \ W^{-1} \ cm^{-2}. After the W/G, the upconverted light is collimated and passed through a filtering system, consisting of a prism and an interference filter, centered at 600 nm to remove any excess pump photons and their second harmonic generation signal that is also present. Finally, we focus the signal onto a free space Si APD (MPD: PD5CTA). Note, that this nonlinear process is equally valid for classical-level light pulses and even down to the level of a single photon.

Since our first attempts at this type of detection, improvements in the fabrication of the PPLN W/Gs, the filtering, as well as optimization of the Si APDs for these schemes have seen overall detection efficiencies greater than 10% obtained. The efficiency-noise characteristics are a function of the pump power and are shown in Fig. 2. This is the efficiency for obtaining an electrical output, a click, when we send in a 1550 nm photon. We see clearly that in this instance that significant noise persists, as was the case for all previous experiments. In the inset, we see a close-up of the pump wavelength and the quasiphase matching condition of the nonlinear PPLN W/G. As previously mentioned, the nonlinear interaction imposes a constraint on the detection bandwidth and hence all previous systems have worked only for very well defined wavelengths. We wish to increase the range of wavelengths that can be used by such a detector to improve the practicality of these devices. As we can see there are several possibilities to tune the detector to a desired detection wavelength. One can change the temperature, thus using the temperature dependence of the refractive indices for the different wavelengths. Different poling periods for the phase matching could also be incorporated or, as we have chosen to do here, one can change the pump wavelength.

While the first two choices are feasible they are not particularly practical. Changing the temperature to tune the QPM is possible, where a 10 K shift in temperature changes the accepted QPM signal wavelength by around 3–4 nm. Unfortunately this is a very slow process where the speed and stability for changing wavelengths is governed by the rate at which thermal equilibrium can be recovered. The poling period is something that needs to be determined at the production stage, but samples are commonly fabricated with series of differently poled regions. Hence, one could imagine moving the different W/Gs in and out of the optical beam to choose the desired interaction. This is however, both very slow, and given the difficulty in alignment of these devices, highly impractical.

Our original choice of components was made with a view to simplicity and the pump that we use is a standard fiber coupled 980 nm laser diode as used, for example, in telecom erbium doped amplifiers. The lasing wavelength of these devices is determined by the reflection band from an external cavity consisting of a fiber Bragg grating. Thus, varying the central wavelength reflected by the Bragg grating tunes the wavelength of our pump and hence that of the detected signal. We use a fiber stretcher to physically lengthen the fiber Bragg grating and hence change the grating periodicity and subsequently, the pump laser wavelength.

We see in Fig. 3 the efficiency as a function of the signal wavelength for three different pump wavelengths. The peak efficiency corresponds to a noise level of 50 kHz in each case. We see the normal acceptance bandwidth of <0.5 nm can be extended tenfold to around 5 nm as illustrated by the envelope—this is to guide the eye and is not a fit.
analyzer (OSA) and power meter, and then choosing a pump power that corresponds to around 6% detection efficiency and 50 kHz noise. The signal photons are generated by a cw tunable laser (Exfo: FLS-2600 B) and attenuator (Exfo: FVA-60 B) and the wavelength is scanned to find the optimal conversion efficiency. This efficiency is calculated simply by the number of photons detected at 600 nm with respect to the number at 1550 nm after the variable attenuator shown in Fig. 1.

We also see in Fig. 3 that the acceptance bandwidth for the signal is around 0.5 nm. We have drawn an envelope over the three curves to illustrate the gain in usable detection bandwidth that this scheme provides. In this instance we were quite conservative about tuning the pump wavelength, 2 nm. Realistic limits of around 4–5 nm would result in an overall acceptance bandwidth of >10 nm. If one takes this idea a little further, we could imagine an integrated array of such detectors. This could be realized with a WDM on the input fiber, separating the incoming signal into smaller bands, pigtailed to the same PPLN sample, with multiple W/G zones. Each band would require their own pump and certainly the cost and complexity of the overall system would increase, but four pumps could see the detection bandwidth cover the whole telecom C-band.

In conclusion, we have presented a simple scheme for a compact and tunable single photon telecommunication wavelength detector capable of passive operation and with high count rates and timing resolution.

R.T.T. would like to thank Alexios Bevaratos for useful discussions concerning the original idea and the authors acknowledge financial support from the European projects SECOQC and QAP and the Swiss NCCR “Quantum Photonics.”

1D. Stucki, G. Ribordy, A. Stefanov, H. Zbinden, J. G. Rarity, and T. Wall, J. Mod. Opt. 48, 1967 (2001).
2M. Ghioni, A. Guidice, S. Cova, and F. Zappa, J. Mod. Opt. 50, 2251 (2003).
3N. Gisin, G. Ribordy, W. Tittel, and H. Zbinden, Rev. Mod. Phys. 74, 145 (2002).
4Commercial QKD companies can be found at www.idquantique.com, www.magiqtech.com and www.smartquantum.com.
5F. Scholder, J.-D. Gautier, M. Wegmiller, and N. Gisin, Opt. Commun. 213, 57 (2002).
6A. Korneev, P. Kouminov, V. Matvienko, G. Chulkova, K. Smirnov, B. Voronov, G. N. Gol’tsman, M. Currie, W. Lo, K. Wilsher, J. Zhang, W. Slysz, A. Pearlman, A. Verevkin, and R. Sobolewski, Appl. Phys. Lett. 84, 5338 (2004).
7A. P. VanDevender and P. G. Kwiat, J. Mod. Opt. 51, 1433 (2004).
8M. A. Albota and F. N. C. Wong, Opt. Lett. 29, 1449 (2004).
9R. V. Roussev, C. Langrock, J. R. Kurz, and M. M. Fejer, Opt. Lett. 29, 1518 (2004).
10R. T. Thew, S. Tanzilli, L. Krainer, S. C. Zeller, A. Rochas, I. Rech, S. Cova, H. Zbinden, and N. Gisin, New J. Phys. 8, 32 (2006).
11K. Karstad, A. Stefanov, M. Wegmuller, H. Zbinden, N. Gisin, T. Aellen, M. Beck, and J. Faist, Opt. Lasers Eng. 43, 537 (2005).
12S. Cova, A. Lacaita, M. Ghioni, G. Ripamonti, and T. A. Louis, Rev. Sci. Instrum. 60, 1104 (1989).
13A. Rochas, M. Gani, B. Furrer, P. A. Besse, R. S. Popovic, G. Ribordy, and N. Gisin, Rev. Sci. Instrum. 74, 3263 (2003).
14M. Legre, R. Thew, H. Zbinden, and N. Gisin, Opt. Express 15, 8237 (2007).
15M. P. De Micheli, Quantum Semiclassic. Opt. 9, 155 (1997).